U.S. Army Corps of Engineers
Detroit District

GRAND RIVER
SEDIMENT TRANSPORT MODELING STUDY

Prepared by:

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Grand River Sediment Transport Modeling Study

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1.0 INTRODUCTION

1.1 Purpose of Study

The U.S. Army Corps of Engineers is directed to develop sediment transport models for tributaries to the Great Lakes that discharge to federal navigation channels or Areas of Concern (AOCs) under Section 516(e) of the 1996 Water Resources Development Act. The models are being developed to assist State and local resource agencies in evaluating alternatives for soil conservation and non-point source pollution prevention in the tributary watersheds. The goal of this initiative is to support State and local measures that will reduce the loading of sediments to navigation channels and AOCs, and thereby reduce the costs for navigation maintenance and sediment remediation. This report includes a description of the Grand River Watershed and the modeling tools that were developed and tested as part of this study.

1.2 Watershed Description

The Grand River Watershed is the second largest drainage system in the State of Michigan and comprises 13% of the entire Lake Michigan drainage basin. With a drainage area of 5,572 square miles (14,431 km²), the Grand River Basin encompasses all or part of nineteen counties. The elevation of the watershed ranges from 1,260 feet (384 meters) in the uplands to 577 feet (176 meters) at its mouth. The river basin is approximately 135 miles (217 km) long and 70 miles (113 km) wide (see Figure 1.1).

The Grand River is the longest river in the State of Michigan. It has several major tributaries, the Thornapple, the Maple, and the Flat Rivers, and many minor tributaries, including the Looking Glass, the Rogue, and the Red Cedar Rivers. The main stream rises in Hillsdale County and flows through Ionia to Grand Rapids and to its outlet at Grand Haven on Lake Michigan. The major tributaries enter the Grand River near Ionia in the relatively flat area west of Grand Rapids. From the confluences to Lake Michigan the stream falls only 50 feet (15 m) in a distance of 80 miles (129 km). In contrast, in some tributaries, there are falls of up to 350 feet (107 m) in fewer miles. The relatively flat slope of the lower watershed compared to the tributaries has a distinct effect on the sediment transport regime of the river.
Figure 1.1 Grand River Watershed
1.3 Hydrologic & Sediment Analyses

In order to understand the processes affecting the movement of water and sediment in the Grand River Watershed, several hydrologic and sediment transport analyses were performed and are presented in Section Three. These analyses include:

- Evaluations of historic land use change and current land use conditions within the watershed;
- Determining the existence of and need for riparian buffer zones along the Grand River and its tributaries; and
- Analysis of changes in hydrologic regime, sediment yields and sediment delivery based on empirical relationships.

1.4 Grand River Watershed Modeling System

To assess sediment erosion and transport issues within the watershed, the SWAT (Soil & Water Assessment Tool, Neitsch, et al., 2005a) model was developed to allow watershed managers to evaluate watershed hydrology, net erosion, sediment delivery, river channel hydrodynamics and sediment transport. This model can be used to gain a general understanding of the hydrologic and geomorphic behavior of the watershed and to predict the effects of changing land use and the effectiveness of different best management practice (BMP) strategies on subwatershed scale erosion and sediment delivery. The model was calibrated to river flow and sediment transport records.

The objective of SWAT is to predict the impact of management decisions on water and sediment yields in large complex watersheds. Variation in land use and management conditions over long periods of time can be represented. SWAT is particularly good at modeling non-point source (NPS) pollution loads from agricultural practices, and routines for urban sediment loads are currently being improved. SWAT also has a good interface with GIS software (ArcView), making it suitable for end-user applications. It is physically based and needs basin-specific data on weather, soil properties, topography, vegetation and land management practices.

Due to project limitations, the SWAT model was set up and calibrated only for the Lower Grand River Watershed (including the Thornapple basin) and uses the United States Geological Survey (USGS) Gage # 04116000 as an upstream inflow boundary (See Figure 4.1). In addition to the base (existing) conditions model, other versions of the model were set up to allow users to simulate various watershed changes and BMPs, including simulating the effects of conservation practices, dams/reservoirs, and agriculture field filter strips on sediment yield.
1.5 Report Outline

The subsequent sections in this report provide an overview of the major activities and findings of the Grand River Watershed Sediment Modeling Study. While this report is intended to be a stand-alone document, the GIS and model data DVD-ROMs and the User Manual accompanying this report provide additional project information and should be referred to where appropriate.

Section Two of this report describes the data used in this study. This includes a summary of a Stakeholders’ Meeting at the start of the project, previous studies and data sources for precipitation, discharge and sediment data, GIS data and information collected in the field.

Section Three presents preliminary analyses of watershed characteristics, including land use history, land use broken down by subbasin, and riparian buffer analysis. It also discusses spatial and temporal alteration to the hydrologic characteristics of the watershed, and presents an overview of sediment delivery in the watershed.

Section Four describes the SWAT model used to evaluate watershed hydrology, sediment yield and sediment delivery. This section outlines model development, calibration and validation.

Section Five illustrates the various BMPs that can be modeled using the customized SWAT models developed for this project.

Section Six provides a summary of the study and provides recommendations for potential future evaluation of management activities using the models provided.
### 2.0 DATA COLLECTION

#### 2.1 Introduction

Several datasets from a variety of sources were located and used throughout the course of this study. These sources included local stakeholders, previous studies, and a diversity of digital data.

#### 2.2 Summary of Stakeholders’ Meeting

The hydrologic, water quality, biological habitat and geomorphologic conditions of the Grand River Watershed were discussed at the Sediment Transport Modeling Workshop for the Grand River Basin, sponsored by the Detroit District USACE and facilitated by Great Lakes Commission. The workshop was held at P.J. Hoffmaster State Park in Muskegon, Michigan on September 18, 2003. These issues and observations were recorded at the meeting:

- Dams and other sediment traps in the upper watershed;
- Data limitations (e.g. Total Suspended Solids data not readily available);
- Harbor structures may interrupt natural littoral drift;
- No lakes acting as sediment traps in downstream end of watershed;
- Agricultural land as a potential source of sediments (worst when land is frozen or no crops);
- Some tributaries and the main channel of the Grand River may be flashy at times;
- Bank erosion and downcutting in urban areas vs. agricultural erosion;
- Thornapple River, Maple River, and Deer Creek – more turbulent and darker in color;
- Drainage in upper watershed as a significant contributor of flow and sediments;
- Development and increased impervious surfaces in lower Grand (urban sprawl issues);
- Lack of construction site BMPs – may be a significant contributor;
- Gravel mining; sites along river with lots of gravel extraction;
- Some counties provide incentives for permanent agricultural BMPs (e.g. Clinton Co.);
- Overall lack of incentives or economic benefit for implementation of BMPs;
- Ottawa County greenway project – sediment reduction (http://www.co.ottawa.mi.us/parks/projects.htm - grg);
- Varying accumulation of sediments based on river water levels and storm events;
- Implications of backwater from Lake Michigan;
- Ice flow in river – transports sediments;
- Blakeslee Creek, Maple River, Thornapple River, Deer Creek, and Sand Creek identified as having the most sedimentation problems;
• Dams exist at Deer Creek, Sand Creek, Blakeslee Creek, Coldwater River, Maple River, Thornapple River;
• Leakage associated with Lyons’ dam (junction of upper and lower Grand);
• Different issues and resources may exist in the upper Grand (agricultural vs. urban issues), less coordination;
• Storage issues – water from agricultural drains in upper watershed impacting the lower Grand;
• Deer Creek, Sand Creek, large sand bedload in creeks;
• Lyons Dam – (confluence of Upper and Lower Grand) repaired fish ladder, talk of possible removal of dam;
• Dry dams located near Hudsonville;
• Loss of fish habitat, especially in coldwater streams;
• Recreation and other uses of river (important to watershed community); and
• Sediment loadings for the Grand River and its tributaries.

2.3 Previous Studies

Due to the size of the Grand River Watershed and the presence of two universities with water resources research institutions in the area, there are many significant watershed studies of the Grand River that are either completed or under way. These studies have included the efforts of (in no particular order):

• The Annis Water Resources Institute of Grand Valley State University;
• The Institute of Water Research at Michigan State University (IWR);
• The United States Geological Survey (USGS);
• The State of Michigan Departments of Environmental Quality (MDEQ) and Natural Resources (MDNR), and
• Many consulting firms and watershed councils.

Although it is not possible to list all the studies that have been performed, the descriptions of the some studies have been compiled as a basis for this project and are included in Appendix A.

2.4 Data Sources

Data sources relevant to this project were identified at the stakeholder meeting. These data included:

• GIS data (land use, soils, topography, digital orthophotos, hydrography);
• Hydrologic data (precipitation, river stage or flow data, historic flood levels);
• Water quality data (suspended sediment) and sediment data;
• Anecdotal flood data (photos, location of debris jams);
• Additional topographic and geologic data (stream cross-sections, soils).
The sources of data included several organizations/agencies:

- Michigan Department of Environmental Quality – total suspended solids (TSS) data;
- Lake Michigan College – TSS and other physical/chemical parameters;
- Michigan DNR – possible source of bedload data;
- Michiana Area Council of Governments (MACOG) – has planning information;
- United States Geological Survey (USGS) – sedimentation study and data for watershed, river flow data from gages;
- EPA has water-quality data available through their STORET database, which includes 33 National Sediment Inventory sites;
- The USDA – NRCS has soils data contained in their STATSGO and SSURGO databases.

2.4.1 Precipitation Data

Precipitation data for this study were obtained from the National Oceanic and Atmospheric Administration / National Weather Service (NOAA/NWS). The NOAA/NWS gage network includes 40 gages in and around the watershed, including daily and hourly gage values (Figure 2.1). The website for the NOAA/NWS data is http://dipper.nws.noaa.gov/hdsb/data/archived/legacy/stainv.html.

2.4.2 Discharge Data

Discharge data for this study were obtained from the USGS through their streamflow data portal at http://nwis.waterdata.usgs.gov/mi/nwis/discharge. A summary of the stream gage location is shown in Figure 2.2, and Table 2.1 summarizes available gage data.

2.4.3 Suspended Sediment Data

Suspended sediment data is invaluable for this type of modeling study, though there are very few sites that collect this information. There are five USGS gaging stations (#04112500, #04113000, #04114000, #04116000, #04119300) in the watershed with some suspended sediment data though only 53 samples were collected from these gages from the years 1975-1982.
Figure 2.1 Location and Data Availability of Precipitation Gages
Figure 2.2  USGS Streamflow Gages
Table 2.1 USGS Flow Gage Stations Within the Grand River Watershed

<table>
<thead>
<tr>
<th>Gage #</th>
<th>Site Name</th>
<th>Area (km²)</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
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<tr>
<td>4109000</td>
<td>GRAND RIVER AT JACKSON, MI</td>
<td>451</td>
<td>4/1/1935</td>
<td>9/30/2003</td>
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<tr>
<td>4109500</td>
<td>PORTAGE RIVER AT PORTAGE LAKE RD NEAR MUNITH</td>
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<td>9/30/1956</td>
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<td>4110000</td>
<td>ORCHARD CREEK AT STATE HWY-106 NEAR MUNITH, MI</td>
<td>127</td>
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<td>9/30/1956</td>
</tr>
<tr>
<td>4111000</td>
<td>GRAND RIVER NEAR EATON RAPIDS, MI</td>
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<td>10/1/1950</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4111379</td>
<td>RED CEDAR RIVER NEAR WILLIAMSTON, MI</td>
<td>422</td>
<td>7/10/1975</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4111500</td>
<td>DEER CREEK NEAR DANSVILLE, MI</td>
<td>42</td>
<td>5/1/1954</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4112000</td>
<td>SLOAN CREEK NEAR WILLIAMSTON, MI</td>
<td>24</td>
<td>6/1/1954</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4112500</td>
<td>RED CEDAR RIVER AT EAST LANSING, MI</td>
<td>919</td>
<td>8/31/1902</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4112850</td>
<td>Sycamore Creek at Holt Road near Holt, MI</td>
<td>209</td>
<td>4/1/1975</td>
<td>10/31/1997</td>
</tr>
<tr>
<td>4112904</td>
<td>Mud Lake Drain at Lansing, MI</td>
<td>11</td>
<td>1/1/1975</td>
<td>10/14/1976</td>
</tr>
<tr>
<td>4113000</td>
<td>GRAND RIVER AT LANSING, MI</td>
<td>3186</td>
<td>3/1/1901</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4113097</td>
<td>CARRIER CREEK NEAR LANSING, MI</td>
<td>31</td>
<td>1/1/1975</td>
<td>10/7/1980</td>
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<td>4114000</td>
<td>GRAND RIVER AT PORTLAND, MI</td>
<td>3587</td>
<td>8/20/1952</td>
<td>9/30/2003</td>
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<tr>
<td>4114498</td>
<td>LOOKING GLASS RIVER NEAR EAGLE, MI</td>
<td>725</td>
<td>8/1/1944</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4114500</td>
<td>LOOKING GLASS RIVER AT HINMAN RD</td>
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<td>4115000</td>
<td>MAPLE RIVER AT MAPLE RAPIDS, MI</td>
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<tr>
<td>4115265</td>
<td>FISH CREEK NEAR CRYSTAL, MI</td>
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<td>10/1/1987</td>
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<td>4116000</td>
<td>GRAND RIVER AT IONIA, MI</td>
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<td>9/30/2003</td>
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<td>9/30/1986</td>
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<td>2/1/1952</td>
<td>9/30/2003</td>
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<tr>
<td>4119000</td>
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<td>3/1/1901</td>
<td>9/30/2003</td>
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<tr>
<td>4119300</td>
<td>GRAND RIVER AT EASTMANVILLE, MI</td>
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<td>3/1/1976</td>
<td>10/6/1977</td>
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<tr>
<td>4120250</td>
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<td>4/1/1994</td>
<td>10/31/1995</td>
</tr>
<tr>
<td>4117000</td>
<td>QUAKER BROOK NEAR NASHVILLE, MI</td>
<td>20</td>
<td>8/1/1954</td>
<td>9/30/2003</td>
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<tr>
<td>4117500</td>
<td>THORNAPPLE RIVER NEAR HASTINGS, MI</td>
<td>997</td>
<td>10/1/1944</td>
<td>9/30/2003</td>
</tr>
<tr>
<td>4118000</td>
<td>THORNAPPLE RIVER NEAR CALEDONIA, MI</td>
<td>2002</td>
<td>10/1/1951</td>
<td>9/30/1994</td>
</tr>
</tbody>
</table>
2.5 GIS Data

GIS data layers from numerous sources were used for basemap analysis as well as for input into watershed numerical models. One source of base GIS data for the Grand River Watershed was the BASINS dataset developed by the EPA. The EPA BASINS dataset is freely available for download from the BASINS website: http://www.epa.gov/docs/ostwater/BASINS/. The GIS layers included in this dataset are categorized into: spatially distributed data, environmental monitoring data and point source data. A listing of these datasets can be found in Appendix B.

Figure 2.3 shows two of the BASINS datasets that were important for the numerical modeling portion of this project. The dam locations and their associated attribute data were used as input for the SWAT model, and the USGS gage station locations were used for the SWAT model calibration.

Digital elevation data and land use (Figures 2.4-2.5) were also used for the development of the numerical models. These in addition to soils data are the primary datasets used to create the SWAT model.

Soils data are also required for the hydrologic and sediment delivery model. The USDA-NRCS publishes soils data at two different scales. The STATSGO soils dataset has a mapping scale of 1:250,000 and the SSURGO soils dataset has a mapping scale of 1:12,000. The coarser scale STATSGO dataset was used for the SWAT model because the SSURGO dataset does not completely cover the watershed at present.

Additional GIS data used for mapping and modeling purposes include USGS HUC11 (Figure 2.6) and HUC14 (Figure 2.7) watershed boundaries. The Grand River Watershed SWAT model was delineated into subbasins equal to or smaller than the HUC11 subbasin areas (see Section 4).

Various digital imagery datasets are also available for the Grand River Watershed. Digital orthophoto quads (DOQs) with one-meter resolution are available for all counties in the watershed for 1998. This dataset was used in the buffer analysis portion of this project. In addition, digital quad maps and satellite imagery are available for most of the watershed.

A detailed listing of all GIS data layers can be found in the Grand River Watershed Model Users Manual.
Figure 2.3 Dam and USGS Gage Locations for the Grand River Watershed from the BASINS Dataset
Figure 2.4 DEM From the National Elevation Dataset (NED) for the Grand River Watershed
Figure 2.5 1992 National Land Cover Dataset (NLCD) for the Grand River Watershed
Figure 2.6 HUC11 Watershed Boundaries
Figure 2.7 HUC14 Watershed Boundaries
2.6 Field Data Collection Summary

A customized approach was implemented to characterizing the watershed and creating an inventory of geomorphic features in the watershed. This is based upon a wide range of analytical techniques, including watershed geomorphic baseline surveys and analysis of aerial photographs. The methodology for reach-based geomorphic assessment of river systems that has been applied to the Grand River was developed by the Environment Agency (UK) and several universities. The survey is reach-based, and has undergone many revisions to ensure accurate representation of the geomorphic characteristics of rivers channels and riparian zones. This method has been refined for North American rivers and specifically for creeks discharging into the Great Lakes, for different agricultural management scenarios, and for modified channel systems in urban areas. A previous generation of this system has been applied to Fish Creek (WI), and more recent versions have been used on the Dead River (MI) and the Roanoke River (VA).

The baseline survey uses a standardized methodology to determine the geomorphological features of a watershed. These features include channel dimensions; bank materials; profiles and erosion characteristics; bar, pool and riffle formation; sediment sources; storage and transfer mechanisms; vegetation, management, enhancement and mitigation potential. The baseline survey also provides all the necessary information to develop a detailed qualitative sediment budget for the entire watershed. The survey is repeatable, and allows for updating the dataset in the future and the monitoring of geomorphological change. The survey has the following main components:

- Survey reach using the Geomorphological Baseline Survey Sheet Set;
- Photograph representative areas of the reach and key channel features; and
- GPS locations of surveys and photographs.

The following features are evaluated through the baseline survey:

- Catchment context, floodplain morphology, channel planform, channel gradient, bankfull stream power;
- Channel dimensions, river bank profiles, river bank materials;
- Point bars, pools, riffles;
- Stability of bed, evidence of bed-load transport;
- Impacts of channel management, potential catchment influences on flow and sediment transport, recovery from previous channel impacts; and
- Ecological importance, recommendations for protection, recommendations for maintenance, recommendations for mitigation/enhancement.

An example of the baseline survey sheet can be found in Appendix C.
2.6.1  Grand River Baseline Survey

The baseline survey of the Grand River Watershed was conducted in November 2004. One hundred and thirty-two sites (Figure 2.10) around the watershed were visited and evaluated according to the survey methodology. The locations of these sites, together with site photographs and digital field data sheets, are accessible via the GIS accompanying this report. The master database containing all field data, which is searchable by site, is also accessible via the GIS. Examples of photos taken at two different field sites are shown in Figures 2.8 and 2.9.

![Figure 2.8 Road Sediment Washing Into River from Bridge](image)

![Figure 2.9 Urban Creek with Failing Bank Protection](image)
Figure 2.10  Field Visit Locations

Spatial Reference: NAD 1983 Michigan Geodetic System
3.0 PRELIMINARY ANALYSES AND WATERSHED CHARACTERIZATION

3.1 Introduction

This section presents the background data and initial watershed analyses undertaken at the onset of this study. Information regarding the current state of sediment production in the watershed can be determined using existing data and various analyses including GIS analysis. Historic land use change and present land use conditions are evaluated in Section 3.2. Several analyses related to riparian buffer zones are presented in Section 3.3. An analysis of available flow records for indicators of flashiness and changes in baseflow is presented in Section 3.4. Section 3.5 provides information on the geology of the watershed. Section 3.6 discusses sediment yield and sediment delivery.

3.2 Land Use History and Analysis

The Grand River Watershed has undergone significant changes in land use since the early 19th Century and along with that a significant change in sediment delivery regime. To gain an understanding of land use and its effects on sediment delivery, the following sections will explain some of the major land use shifts of the last couple hundred years, as well as present the current land use conditions.

3.2.1 Historic Land Use Change

A review of the notes of the General Land Office section surveyors (Dickmann and Leefers, 2003), a Michigan land use coverage map based on original surveyors’ tree data, and descriptions of the vegetation and land between 1816 and 1856 (http://www.dnr.state.mi.us/spatialdatalibrary/metadata/lu1800.htm), indicates the Grand River Watershed was heavily forested with meadows, lakes and wetlands around the early part of the 19th Century (Figure 3.1). This type of land use/cover would have resulted in very little sediment delivered to the river and harbor area.

The first major human impact on land use was the large scale logging activities through the latter half of the 1800’s (Dickmann and Leefers, 2003). With the removal of large areas of tree cover, runoff would have reached the tributaries and Grand River much more quickly increasing the intensity of flood flows. Therefore, this elimination of large areas of tree cover would have resulted in increased overland, riverbank and bed erosion and an associated significant increase in sediment eroded from the watershed. However, the construction of many dams throughout the watershed especially in the early and mid 1900’s (Figure 3.2) has likely caused much of the eroded sediment generated in the upper portions of the watershed to be intercepted and trapped before it reaches Lake Michigan.

The onset of agricultural development taking advantage of land cleared through logging or through clearing new lands would have followed the large scale logging activities.
When agriculture reached its peak in the early 1900’s, the river sediment load would also have achieved its maximum. This is because the greatest intensity of soil erosion in the watershed generally takes place on cultivated lands, and without modern conservation measures, much of this eroded sediment is delivered to the river channel system.

Figure 3.3 shows the ratio of agricultural land for each county in the Grand River Watershed. The U.S. Bureau of the Census and related agencies inventoried a county cropland series from 1850 to the present. "Improved farmland" acres were counted from 1850 to 1920 for every decade. Starting in 1925, cropland acres were counted. These data were assembled by the USGS into the dataset shown in Figure 3.3. This demonstrates that the amount of land under agricultural production was at a peak during the early 1900’s, declined until the late 1970’s and has been relatively steady since.
Figure 3.1 Landuse circa 1800

Source: http://www.dnr.state.mi.us/spatialdatalibrary/metadata/lu1800.htm
Figure 3.2 Number of Dams Built from 1840 – 1990 in the Grand River Watershed

Source: Based on BASINS National Inventory of Dams database
Figure 3.3  Ratio of Improved Farmland to Total County Area
3.2.2 Land Use Breakdown by Subbasin

While the number of cropland acres has decreased since its peak in the early 1900’s, the Grand River Watershed is still heavily agricultural. A land use analysis of the 1992 National Land Cover Dataset (NLCD) was undertaken to understand the agricultural and other land use distribution within the Grand River Watershed. While this dataset is over 10 years old, the more recent 2001 NLCD dataset was not yet available. This land use dataset has 21 categories. To simplify the interpretation of the analysis, the 21 categories were combined into 6 broader categories (Table 3.1).

The gridded land use data was intersected with the HUC14 subbasins in ArcView to determine the percentage of each land use in each subbasin. Figures of selected results are shown in Figures 3.4-3.7.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td>Water</td>
</tr>
<tr>
<td>Perennial Ice/Snow</td>
<td>Water</td>
</tr>
<tr>
<td>Low Intensity Residential</td>
<td>Developed</td>
</tr>
<tr>
<td>High Intensity Residential</td>
<td>Developed</td>
</tr>
<tr>
<td>Commercial/Industrial/Transportation</td>
<td>Developed</td>
</tr>
<tr>
<td>Bare Rock/Sand/Clay</td>
<td>Barren</td>
</tr>
<tr>
<td>Quarries/Strip Mines/Gravel Pits</td>
<td>Barren</td>
</tr>
<tr>
<td>Transitional</td>
<td>Barren</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>Forest</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>Forest</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>Forest</td>
</tr>
<tr>
<td>Shrubland</td>
<td>Grassland</td>
</tr>
<tr>
<td>Orchards/Vineyards/Other</td>
<td>Cropland</td>
</tr>
<tr>
<td>Grasslands/Herbaceous</td>
<td>Grassland</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>Cropland</td>
</tr>
<tr>
<td>Row Crops</td>
<td>Cropland</td>
</tr>
<tr>
<td>Small Grains</td>
<td>Cropland</td>
</tr>
<tr>
<td>Fallow</td>
<td>Cropland</td>
</tr>
<tr>
<td>Urban/Recreational Grasses</td>
<td>Developed</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>Wetland</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetlands</td>
<td>Wetland</td>
</tr>
</tbody>
</table>

Agriculture dominates watershed land use, with the highest percentage of agricultural land in the Maple River Watershed. These areas also tend to have the least amount of forest and wetlands. This combination is likely to have significant sediment delivery impacts within the watershed, with sediment levels highly elevated over predevelopment conditions. While agricultural land is widespread, there are some highly urban areas. The percent imperviousness for the watershed is shown in Figure 3.8.
Figure 3.4 Cropland Percentage for Each HUC14 Watershed
Figure 3.5  Developed Land Percentage for Each HUC14 Watershed
Figure 3.6 Forestland Percentage for Each HUC14 Watershed
Figure 3.7 Wetland Percentage for Each HUC14 Watershed
Figure 3.8 Impervious Surfaces in the Grand River Watershed
3.3 Riparian Buffer Analysis

The use of riparian buffers to reduce the amount of eroded sediment entering waterways and being transported downstream is becoming an effective, economical and widely accepted BMP in agricultural watersheds as demonstrated by programs such as the Farm Service Agency’s Continuous Conservation Reserve Program. This section presents an introduction to buffers, an analysis of subbasin land use as it relates to land use in the buffer zone, a watershed-wide GIS-based calculation of the required buffer width for effective sediment removal, and an analysis of actual buffered area within several of the subwatersheds using aerial photos.

3.3.1 Introduction to Buffer

Buffers are perennial vegetated areas or strips adjacent to a water body. Various types of buffers include riparian buffers, grassed waterways, filter strips and field borders. Wetlands can even be used as buffers. Often buffers are located between sources of pollutants, such as farm fields or construction sites, and the receiving body of water.

Buffers have several purposes. One main purpose is to protect the water body from pollutants (sediments, nutrients, contaminants, etc.) by slowing and spreading out the flow of water, allowing the pollutants to settle out in the buffer zone before they reach the stream or lake. Additionally, the buffer vegetation can help to stabilize the banks while also providing shade, leaf litter and woody debris, all of which are essential to sustain certain habitats. Beyond the environmental benefits, buffer areas can also provide the landowners with a source of income if they choose to selectively harvest and sell lumber, hay, fruit or berries. The following analyses focus on buffer zones adjacent to the streams of the Grand River Watershed.

3.3.2 Comparison of LU Breakdown in Subbasins with Buffer Zones

In a previous study of the St. Joseph River Watershed in Michigan and Indiana (USACE, 2005), a strong correlation was found between subbasins with high cropland percentages and the high cropland percentages in the riparian buffer zones of those subbasins. A similar, more comprehensive, analysis was undertaken for each HUC14 subwatershed of the Grand River Basin, yielding similar results.

Using the Grand River GIS, the percentage of cropland in each HUC14 subwatershed was determined using the 1992 National Landcover Dataset. The land use classes grouped as “cropland” are listed in Table 3.1. Land use in each subbasin was analyzed in a 200 ft (61 m) buffer zone around the 100K DLG stream hydrography linework. A 200 ft buffer was chosen to give a buffer that was at least two 30m land use grid cells wide. The percentage of each land use type in the 200 ft buffer area of each subbasin was then calculated. The following figures show the results of this analysis.

Figure 3.9 shows a strong correlation between percentage cropland in the subbasin and percentage cropland in the 200 ft buffer zone. This analysis shows that by performing a
simple analysis of subbasin land use, watershed managers can determine which subbasins are likely in most need of riparian buffer re-establishment. Due to the relatively coarse resolution of the land use dataset (30 meter), existing buffer zones less than 30 meters wide are not resolved in the NLCD dataset. Therefore, the results from this coarse analysis can be used to focus a more detailed buffer analysis on those subbasins within the Grand River Watershed with the greatest percentage of cropland described in Section 3.3.4.

Figure 3.9  Percent of Cropland Within 200-ft Stream Buffer vs. Percentage in Subbasin
3.3.3 GIS Calculation of Required Buffer Widths by Subbasin for Entire Watershed for Effective Sediment Removal

To determine the effectiveness of existing buffers in the watershed, all buffer areas would have to be digitized and measured. Another way to approach this issue is to use a GIS analysis to determine what buffer width would be necessary for effective sediment removal. A report by USACE – New England District (USACE, 1991) provides a review of buffer research and presents several simplified models to calculate required buffer width based on factors such as slope, soil erodibility, field areas and travel time:

\[ B_w = \frac{S^{\frac{1}{2}}}{E} \]  

(Brown et al., 1987)

where:  
\( B_w \) = width of buffer in feet  
\( S \) = average slope of land in feet per 100 ft  
\( E \) = erodibility factor related to SCS erosion factor (K) as follows:  
- K=0.1, E=4;  
- K=0.15, E=3;  
- K=0.17, E=2;  
- K>0.17, E=1.

Comparison of this equation and Figure 3.10 shows that a factor of 100 missing in the original equation. Thus the equation should be:

\[ B_w = \frac{S^{\frac{1}{2}}}{E} \times 100 \]

Figure 3.10 Graphic Representation of the Sediment Retention Model
Source: Dept. of the Army, New England Division, Corps of Engineers. Buffer Strips for Riparian Zone Management. VT: January 1991
In order to apply this model to the entire Grand River Watershed, 30 m buffers were created around the hydrography linework, then the DEM was analyzed for slope and clipped to the buffer areas. The STATSGO soils layer was also clipped to the buffer area and the K Factor value was used to calculate erodibility. Sequence number 1 and layer 1 values were used. Then all values in the slope grid were raised to the $\frac{1}{2}$ power, divided by the E grid, multiplied by 100 and finally multiplied by 0.3048 to convert from feet to meters. This resulted in a grid containing buffer width values all along the streams. To summarize the data, average widths were calculated for each HUC14 subbasin and are shown in Figure 3.11. There is variation of the widths within the subbasins, as the average standard deviation of the calculated widths is about 20 meters.

In general, the widest buffer widths are required in the Thornapple Basin. This is due to the erodibility of the soils in that area in combination with the steeper slopes within the buffer zone.

Using the information obtained from the analysis of land use in the buffer zone and the required buffer width, a more detailed aerial photo buffer analysis was performed on the subbasins with the highest cropland percentage in the buffer and those that required the widest buffer.

### 3.3.4 Aerial Photo Analysis of Riparian Buffer Extent for Selected Subbasins

#### Subbasins with High Cropland Percentage

A detailed buffer analysis using aerial photos was completed on the fifteen HUC14 subbasins with the highest cropland percentages (see Figure 3.9). First, the NHD hydrography linework was overlaid on 2004 color aerial photos. The hydrography lines were adjusted, where necessary, to more closely follow the visible channels in the aerial photos. Next, a 100 ft (30 m) buffer zone was created on each side of the channel linework. A 100 ft buffer was chosen because this is a typical suggested buffer zone width and the high resolution of the aerial photos allowed for a more detailed analysis. Where the river was wide enough to be represented by right and left bank lines, the buffer was created on each side of the line with the inside (water) portion of the buffer designated as Not Applicable (NA) to the buffer analysis. The buffer zone polygons on each side of the channel were digitized, using the aerial photos, according to the following designations:

- **NONE**: no riparian vegetation visible (0% - 25%) in the 100-ft buffer zone;
- **FULL**: riparian vegetation completely filling (75% - 100%) the 100-ft buffer zone;
- **PARTIAL**: riparian vegetation visible in some (25% - 75%) of the 100-ft buffer zone;
- **NA**: area not applicable to buffer analysis (i.e. water).

This analysis was executed within a GIS and an example of the designations is shown in Figure 3.12.
Figure 3.11 Average Needed Riparian Buffer Width by HUC14 for the Grand River Watershed
Once this was done in GIS, the hydrography linework was segmented to correspond to breaks in buffer type. The percentage of channel length bordered by each buffer type was then calculated.

Figure 3.13 shows the relationship between the percentage of cropland in the buffer zone and the percentage of stream length having no riparian buffer (None) and the percentage of stream length having a full riparian buffer (Full). Despite a relatively small change in % cropland in buffer (~10%) there is a significant upwards trend in the non-buffered stream length and a significant downward trend in the fully-buffer length of stream.
These results show that subbasins with the most cropland (determined by analyzing the land use dataset) also have more channel length with no riparian buffer zone. Thus, the subbasins with the most cropland are the most in need of riparian buffer zone BMP implementation.

Because the same conclusion was reached doing the detailed orthophoto analysis and the quick subbasin land use analysis, the results from the quick analysis can be used to focus more detailed analysis of the subbasins in most need of riparian buffer restoration.

**Subbasins with High Required Buffer Width**

A similar detailed analysis was done with the fifteen subbasins having the highest calculated required buffer width. In contrast to the previous analysis, there was no correlation between the calculated required buffer width and the existing buffer type (Figure 3.14). Therefore, the results from the buffer width calculation cannot be used as an indication of areas in need of riparian buffer restoration.
3.4 Analysis of Watershed Hydrologic Alteration

A preliminary assessment of the Grand River Watershed was performed to determine if there have been any significant alterations to the hydrologic processes over the last 35 years. Substantial portions of the watershed have undergone transformations during this period. These changes involve agricultural practices, such as the installation of tile drainage and irrigation systems. Other changes include the conversion of land from agricultural or fallow to urban land use. These changed land cover and land uses have been shown to produce a change to the hydrologic response of the watershed.

Urbanization generally increases runoff, and at a faster rate, than natural conditions. A watershed with increased tile drainage or irrigation could demonstrate changes in more complex ways. Tile drains are designed to lower the water table of agricultural fields in order to optimize the moisture level in the root zone of the crop. The same function could also produce a faster delivery of water to the drainage systems (and hence the streams and rivers) than a field without tile drains. Increased irrigation could also produce increased runoff, if the soil moisture conditions were maintained at a relatively high level. A rainstorm occurring on a field with high moisture levels would produce more runoff than a non-irrigated field of the same type.

Although channels undergo continual changes due to the erosive forces of the streamflow, an increase in the frequency of higher flows and velocities may accelerate the channel degradation process. This is an important consideration in determining if the
observable channel erosion is progressing at a “natural” rate as it is an objective quantification of the basin response over a long period of time. Since it is common to associate channel degradation processes with perceived changes to the watershed, objective measures must be used to determine if changes to the hydrology are actually occurring.

3.4.1 Flashiness Analysis

One common metric used to characterize the change in basin response is a stream flashiness index. In this analysis, the flashiness index used was based on a method as described in Baker, et al. (2004). The term “flashiness” refers to the temporal response of a river to a rainfall event. A high degree of flashiness indicates that a river is quick to respond, usually both on the rising and falling limbs of the flow vs. time curve. Highly flashy rivers are typified by basins with steeper or rolling topography, and often with lower permeable soils, or basins with significant impervious areas. Conversely, rivers that are lower in flashiness typically have flatter terrain, and often have highly permeable soils with a high degree of shallow groundwater contribution to the base streamflow. As is the case for the characterization for hydrologic and climatologic trends, long-term records are required for meaningful analysis.

The flashiness index used in this analysis was the following equation:

\[
\text{Flashiness Index} = \frac{\sum_{t=1}^{n} |q_{t} - 1 - q_{t}|}{\sum_{t=1}^{n} q_{t}}
\]

This index is a ratio of the absolute value of the sum of the daily flow changes to the sum of the total daily flows. Although this index may vary spatially for a particular year, the long-term temporal trend of this index is a good indicator of hydrologic changes in the watershed.

The flashiness index was computed for all streamgage records in the Grand River Watershed that had a minimum of 10 years of record.

3.4.2 Baseflow Analysis

A baseflow analysis was also performed on the flow gage records in the Grand River Watershed. Baseflow and direct runoff are the two general components that comprise streamflow. Direct runoff is the portion of streamflow that immediately follows a rainfall event, while baseflow is the component that sustains streamflow between rainfall events and is generated by shallow groundwater flowing through the soil into the stream. To quantify the degree of baseflow produced by a watershed, a graphical technique is usually employed. The most common methods compute the inflection points in the runoff hydrographs, in which the streamgage records indicate that the flow is changing from baseflow to direct runoff at the onset of a rainfall-runoff event, and a second inflection point at which the baseflow mechanisms predominate after the runoff has ceased.
Although the actual baseflow percentage value is not as significant itself, it is a good indicator as to which streams are more susceptible to adverse hydrologic changes. Streams with historically high baseflow percentages are generally less prone to sedimentation issues for two reasons. One reason is that streams with higher baseflow tend to have a lower proportion of runoff, and hence less upland erosion. The other reason is that the streams tend to have smaller velocity fluctuations, which is one of the causes of streambank erosion.

3.4.3 Results and Discussion

The results indicate that several of the gages in the watershed have shown slight increases in flashiness since 1970. Others have remained steady or show minor decreases with time. The gages with the most noticeable decreases include locations on the lower Grand River that are influenced greatly by the operation of the hydropower dams. The flashiness values in most cases were not extreme, but the trends shown at some gage locations indicate that the hydrologic processes are changing in a manner that could negatively affect these catchments.

The baseflow analysis indicated that the Grand River Watershed is moderately to highly controlled by baseflow, which is generally a “healthy” sign of a watershed. However, this may reflect the influence of dams on hydrologic regime in this watershed, attenuating river flow to provide a false ‘baseflow’ signal from surface runoff, rather than appropriate land use or appropriate application of BMPs. The trends of baseflow for each gage location over time showed a similar trend as the flashiness – that being a minor shift toward more direct runoff. Although the computational procedure to determine the trend in baseflow is different than for flashiness, there was a strong relationship between these two parameters.

A few examples of the flashiness change over time are shown in Figures 3.15-3.17. The spatial distribution of the gage sites analyzed in this study is shown in Figure 3.18. The summary of the analysis is shown Table 3.2.

![Figure 3.15 Yearly Flashiness Index for USGS Gage at Thornapple River Near Caledonia, MI](image-url)
Figure 3.16 Yearly Flashiness Index for USGS Gage at Grand River at Ionia, MI

Figure 3.17 Yearly Flashiness Index for USGS Gage at Grand River at Jackson, MI

Table 3.2 Trends in River Flashiness in the Grand River Watershed (No. corresponds to Figure 3.17)

<table>
<thead>
<tr>
<th>No.</th>
<th>Gage Name</th>
<th>Gage Number</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>THORNAPPLE RIVER NEAR CALEDONIA, MI</td>
<td>4118000</td>
<td>increasing</td>
</tr>
<tr>
<td>2</td>
<td>MAPLE RIVER AT MAPLE RAPIDS, MI</td>
<td>4115000</td>
<td>increasing</td>
</tr>
<tr>
<td>3</td>
<td>LOOKING GLASS RIVER AT HINMAN RD NEAR EAGLE, MI</td>
<td>4114500</td>
<td>mild increase</td>
</tr>
<tr>
<td>4</td>
<td>THORNAPPLE RIVER NEAR HASTINGS, MI</td>
<td>4117500</td>
<td>mild increase</td>
</tr>
<tr>
<td>5</td>
<td>LOOKING GLASS RIVER NEAR EAGLE, MI</td>
<td>4114498</td>
<td>mild increase</td>
</tr>
<tr>
<td>6</td>
<td>ROGUE RIVER NEAR ROCKFORD, MI</td>
<td>4118500</td>
<td>mild increase</td>
</tr>
<tr>
<td>7</td>
<td>GRAND RIVER AT LANSING, MI</td>
<td>4113000</td>
<td>mild increase</td>
</tr>
<tr>
<td>8</td>
<td>GRAND RIVER AT IONIA, MI</td>
<td>4116000</td>
<td>mild decrease</td>
</tr>
<tr>
<td>9</td>
<td>SLOAN CREEK NEAR WILLIAMSTON, MI</td>
<td>4112000</td>
<td>mild decrease</td>
</tr>
<tr>
<td>10</td>
<td>DEER CREEK NEAR DANSVILLE, MI</td>
<td>4111500</td>
<td>mild decrease</td>
</tr>
<tr>
<td>11</td>
<td>GRAND RIVER AT JACKSON, MI</td>
<td>4109000</td>
<td>decreasing</td>
</tr>
</tbody>
</table>
Figure 3.17 Flashiness Trends in the Grand River Watershed
3.5 Watershed Geology

The geology of the Grand River Watershed was described in a report by the U.S. Army Corps of Engineers (USACE) in 1972. The topography of the basin is a result of Pleistocene glaciating with moraines and outwash plains dissected by streams (see Figure 2.4). Kettle holes appear sporadically on outwash plains and usually are filled with water making them swamps or lakes. Till plains, moraines, kames, and eskers of the Port Huron system are the predominant surface features with relief of 50 to 60 feet (15–18 m).

Surficial geology of the Grand River Basin is dominated by glacial tills overlying bedrock (Figure 3.18). Glacial deposits are a mixture of rock material from many different sources. This rock material was picked up, transported and deposited by glaciers or by waters flowing from the glaciers. The principal glacial deposits in the Grand River Basin are till, moraines, outwash, and glacial lakebeds. The bedrock that underlies the glacial deposits was deposited in large inland seas that covered most of the area of the Great Lakes States. Bedrock formations are comprised primarily of sandstone, limestone, dolomite and shale, but include thick beds of salt, gypsum, and anhydrite (Figure 3.19). After deposition, the bedrock formations in the Great Lakes were warped into geologic structures that resemble a gigantic set of shallow bowls. The Grand River Basin overlies the south and southwestern part of this structure. The bedrock that underlies this basin generally dips gently to the north and east toward the center of the basin structure causing individual formations to be progressively deeper in a northerly and easterly direction.

The Grand River Basin evolved during the retreat of the last of the great continental glaciers. Most of the present surface features of the basin resulted from deposition of the rock materials from glaciers and subsequent erosion. The basin is underlain by sediments deposited from glacial lobes that advanced over the basin from Saginaw Bay and from Lake Michigan. The two lobes coalesced along a north-south line near the center of Kent County. The area of coalescence is one of rolling topography. The lower part of the Grand River Basin is formed on the sediments of former glacial Lake Chicago.

The major portion of the basin is rather flat and featureless. The maximum local relief in the areas upstream from Maple Rapids, Portland, and Hastings generally ranges from 50 to 75 feet (15 - 23 m). The areas of minimal relief contain very poorly drained soil. Swamps and marshes make up a significant part of the Maple, Looking Glass, and Cedar River Basins.
Figure 3.18  Grand River Watershed Quaternary Geology

Grand River Watershed Quaternary Geology

Spatial Reference: NAD 1983 Michigan Geodetic

0 10 20 30 40 Miles
0 10 20 30 40 Kilometers

Watershed Boundary
Quaternary Geology
- Coarse-textured glacial till
- Dune sand
- End moraines of coarse-textured till
- End moraines of fine-textured till
- End moraines of medium-textured till
- Fine-textured glacial till
- Glacial outwash sand, gravel & postglacial alluvium
- Ice-contact outwash sand & gravel
- Lacustrine clay & silt
- Lacustrine sand & gravel
- Medium-textured glacial till
- Water
Figure 3.19 Grand River Watershed Bedrock Geology
The upper reaches of the Flat and Rogue River Basins include extensive and numerous swamps, marshes, and many lakes, as does the middle part of the Thornapple River Basin and the upper part of the Grand River Basin. The upper part of the Maple River Basin includes flatlands formed on the sediments of ancient glacial lakes. The total relief between Lake Michigan, which has an altitude of about 580 feet (177 m), and the highest point in the basin, which is at the altitude of about 1170 feet (357 m) in southern Jackson County, is about 600 feet (183 m). The maximum local relief within the basin ranges from 200 to 275 feet (61 – 84 m) between the banks of the Grand River and the adjacent highlands. Areas with 200 or more feet of local relief, most of which are along the Grand River, constitute less than 5 percent of the total basin area.

3.6 Grand River Watershed Sediment Delivery

3.6.1 Introduction

The purpose of constructing a sediment budget is to understand the sources, pathways and sinks (deposits) of sediment within a watershed system. The transport of sediment out of the watershed can then be seen as a culmination of the various processes mobilizing, transporting and storing sediment within the hillslope and channel system. Of the total sediment mobilized within a watershed, often only a small amount reaches the watershed outlet. The remainder is usually deposited in temporary storage to be remobilized in subsequent events. The active processes in the watershed may then be thought of in two categories: those associated with sediment mobilization (soil erosion; river channel erosion) and those associated with sediment delivery.

Sediment transport by water through a watershed is generally associated with either hillslope or fluvial processes. Sediment in a river can be transported by two processes: suspension and bedload transport. Suspended sediment load in the watershed is usually dominated by clay- and silt-sized particles, whereas coarser particles are transported as bedload. Typical natural processes involved in the erosion and delivery of suspended sediment are:

- Rain drop impact;
- Overland flow;
- Sheet and rill erosion;
- Gully erosion;
- Riverbed erosion;
- River bank erosion, particularly shearing of fine material by river flow, and bank collapse.

These processes are generally distinguished into channel and non-channel sources and also into point and non-point sources. They may be accelerated by human activity in the watershed, as agriculture, industry and construction tend to mobilize and supply additional sediment to the watershed. In agricultural regions, soil loss from cultivated areas may dominate watershed suspended sediment delivery.
The relative contributions of the above processes vary with location in the watershed. Headwaters of the watershed have steeper slopes without floodplains, and these areas are strongly coupled to channels (i.e. there are few sediment sinks between the source areas and the channel). Non-point sources therefore tend to dominate these areas and sediment is largely from non-channel sources. This may have implications for other watershed management issues, such as non-point source contaminant movement in upper watershed zones. Further downstream, wider floodplains reflect temporary sediment storage and the channel becomes increasingly decoupled from the surrounding hillslopes. In these areas, in-channel sediment sources dominate.

Various sediment sinks also exist in the watershed. These may be either natural or anthropogenic, and they are often classified into temporary or permanent sinks. An example of the former would be channel storage of sediment in bar deposits, as sediment may be stored for a period of time before being remobilized by a high magnitude event. An example of a permanent sink would be the abstraction of sand or gravel from the channel for use as construction material. Natural sediment sources and sinks are listed in Table 3.3, and anthropogenic sources and sinks are listed in Table 3.4. The natural processes listed in Table 3.3 are likely to be heavily modified by human activity, which may lead to acceleration or reduction of erosion and delivery rates, depending on the type and extent of the modification.

### Table 3.3  Examples of Natural Sources and Sinks of Sediment

<table>
<thead>
<tr>
<th>Sources</th>
<th>Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland sheet and rill erosion</td>
<td>Colluvial deposition</td>
</tr>
<tr>
<td>Upland gully erosion</td>
<td>Redistribution on upland valley slopes</td>
</tr>
<tr>
<td>Channel bank erosion (several mechanisms)</td>
<td>Floodplain storage</td>
</tr>
<tr>
<td>Channel bed scour</td>
<td>Channel storage</td>
</tr>
<tr>
<td>Animal action (e.g. burrowing)</td>
<td>Lakes</td>
</tr>
<tr>
<td>Landslides</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3.4  Examples of Anthropogenic Sources and Sinks of Sediment

<table>
<thead>
<tr>
<th>Sources</th>
<th>Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivated land</td>
<td>Dams and reservoirs</td>
</tr>
<tr>
<td>Managed Forests</td>
<td>Sand and gravel extraction</td>
</tr>
<tr>
<td>Forest roads</td>
<td>Hedgerow planting</td>
</tr>
<tr>
<td>Urban areas – including drainage systems</td>
<td>Vegetation management</td>
</tr>
<tr>
<td>Removal of vegetation for construction</td>
<td>Conservation activities</td>
</tr>
<tr>
<td>Roads and road drainage systems</td>
<td>Agricultural management (e.g. agroforestry, contour cultivation, etc.)</td>
</tr>
<tr>
<td>Construction sites</td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td></td>
</tr>
<tr>
<td>Mining – Indirect (e.g. land devegetated by smelter fumes)</td>
<td></td>
</tr>
<tr>
<td>Spoil Heaps</td>
<td></td>
</tr>
<tr>
<td>Vegetation fires</td>
<td></td>
</tr>
<tr>
<td>Channel modification</td>
<td></td>
</tr>
<tr>
<td>Mismanagement</td>
<td></td>
</tr>
<tr>
<td>Indirect effects (e.g. devegetation through climate change)</td>
<td></td>
</tr>
</tbody>
</table>

USACE - Detroit District  
Great Lakes Hydraulics and Hydrology Office  
Sediment Transport Modeling Study
3.6.2 **Known Sediment Sources, Scour and Deposition Areas**

The sediment delivery characteristics of the rivers and creeks of the watershed were discussed at the stakeholders meeting. Maple and Thornapple Rivers were mentioned as significant sediment contributors, as well as a number of smaller subwatersheds, such as Blakeslee, Deer and Sand Creeks. The moving sand bedload on Deer and Sand Creeks was specifically mentioned. Evidence of sand bedload in Sand Creek was discovered during the field visit.

The number of dams within the three upper subwatersheds of the Grand River (Upper Grand, Maple and Thornapple Rivers) is significantly greater than in the Lower Grand River (Figure 3.20). There are many dams on small tributaries of the Lower Grand, but only one dam on the Grand River itself, which is located in Grand Rapids.
Figure 3.20  Dams in the Grand River Basin
3.6.3 **Sediment Yield and Sediment Delivery in the Grand River Watershed**

There are no direct measurements of net erosion, sediment yield and sediment delivery within the Grand River Watershed. However, it is possible to estimate likely sediment yield and sediment delivery ratios using basic relationships found in general watershed geomorphology literature. These estimates are intended as background information for the study, and are to be used for comparison to rating curve analysis and model output.

Suspended sediment is normally the dominant component of sediment yield, with the exception of very extreme storm events. Langbein and Schumm (1958) developed a general relationship between effective precipitation and sediment yield for group-averaged data from the United States (Figure 3.21). Effective precipitation is that part of the total hydrograph which constitutes ‘quickflow’, as in the definition of the Unit Hydrograph (see Dunne & Leopold, 1978 for a review). Effective precipitation is also called ‘quickflow’, or ‘precipitation excess’, and is a notion of Hortonian Overland Flow: i.e. it is the proportion of precipitation that is ‘effective’ in producing rapid response streamflow (stormflow).

![Figure 3.21](image)

**Figure 3.21** Relationship of Sediment Yield to Effective Precipitation (Langbein and Schumm, 1958; Knighton, 1998)

The mean annual precipitation in the Grand River Watershed for 1988-2000 was 35.4 inches (900 mm). 65% of this was assumed to be effective precipitation. This was a conservative estimation, based loosely on the SCS method (SCS, 1972; See Hong et al, 2006 for a discussion). Hydrograph separation was outside the scope of this study and would not have improved confidence in the estimates in this section, given the high degree of approximation involved. The effective precipitation was therefore estimated to be approximately 24 in (600 mm), giving an estimated yield of around 518-1425 t mi\(^{-2}\) yr\(^{-1}\) (200-550 t km\(^{-2}\) yr\(^{-1}\)). There is a broad range in this estimate due to the large difference in sediment load estimates, depending on whether reservoir or river sediment load data are used to evaluate the relationship. This difference is methodological, and...
may depend on many issues (such as how reservoirs trap sediment, underestimating channel transport, etc.). The reservoir data give very high yields as they are derived from small reservoirs efficiently trapping sediment at the hillslope scale, and were not meant to be applied to catchments the size of the Grand River Watershed. In this case, the method greatly over-estimates sediment yield as it was derived from data on smaller watersheds, which would have much higher sediment delivery ratios than a watershed the size of the Grand River Watershed. Walling and Kleo (1979) reviewed the validity of the Langbein relationship for a broader range of climatic regimes. For the relationship established by Walling and Kleo (Figure 3.22), the estimated sediment yield for the Grand River Watershed would be approximately 518-777 t mi$^{-2}$ yr$^{-1}$ (200-300 t km$^{-2}$ yr$^{-1}$). While the two relationships are similar in the lower range of precipitation values, Walling and Kleo suggest there is another peak in yield at 1500 mm mean annual precipitation. This is due to vegetation dynamics changing with climate (1300-1500 mm precipitation = Mediterranean and 2500mm = tropical monsoon). Walling and Kleo’s analysis may apply more to climates with strong seasonality, and Langbein and Schumm’s may be more continental, but both give similar predictions of yield for the Grand River Watershed. Both methods lead to over-predictions due to the much smaller watersheds used to derive the relationships.

![Figure 3.22: Relationship of Sediment Yield to Mean Annual Precipitation (Walling and Kleo, 1979)](image)

The yields suggested by empirical relationships are markedly higher than the yields generated by analysis of model output, sediment rating curves and river gage data from other Great Lakes watersheds (Table 3.5). These figures differ due to the large variation in the number of dams in these systems, which will reduce yields significantly below natural basins of similar size and the problem of extrapolating empirical relationships from small to large watersheds.
Table 3.5: Summary of Sediment Yields from Other Studies

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Drainage Area (km²)</th>
<th>Mean Annual Sediment Yield (t km⁻² yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saginaw River (MI)</td>
<td>22,360</td>
<td>20</td>
</tr>
<tr>
<td>St. Joseph River (MI/IN)</td>
<td>12,134</td>
<td>106&lt;sup&gt;a&lt;/sup&gt;; 4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Clinton River (MI)</td>
<td>1,968</td>
<td>200&lt;sup&gt;c&lt;/sup&gt;; 270&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sandusky River (OH)</td>
<td>3,250</td>
<td>75</td>
</tr>
<tr>
<td>Black River (OH)</td>
<td>1,200</td>
<td>100</td>
</tr>
<tr>
<td>Nemadji River (MN/WI)</td>
<td>1,125</td>
<td>25</td>
</tr>
<tr>
<td>Menomonee River (WI)</td>
<td>350</td>
<td>40</td>
</tr>
</tbody>
</table>

<sup>a</sup>SWAT mean annual soil erosion; <sup>b</sup>SWAT mean annual sediment delivery at the Harbor
<sup>c</sup>Estimated from Walling and Kleo; <sup>d</sup>SWAT annual sediment delivery at mouth of river
4.0 WATERSHED-SCALE HYDROLOGY AND SEDIMENT DELIVERY SIMULATION USING SWAT

4.1 Introduction

The Grand River, its tributaries and watershed deliver significant quantities of sediment to the river mouth each year. The rate at which sediment has been delivered to the river mouth has been significantly modified through time by human impacts. Numerical models can provide a cost-effective tool for the analysis of changes to these complex processes over large areas and long time periods. The SWAT model was chosen because it is specifically designed to simulate water and sediment runoff in large agricultural watersheds. This section discusses the application of numerical modeling tools for the understanding and quantification of hydrologic and sediment transport processes occurring in the Grand River Watershed.

4.2 SWAT Model Description

The Soil and Water Assessment Tool (SWAT) is a watershed-scale numerical model for the simulation of water, sediment, nutrient and pesticide movement in surface and subsurface systems. SWAT aids in prediction of the impacts of climate and vegetative changes, reservoir management, groundwater withdrawals, water transfer, land use change and watershed management practices on water, sediment and chemical dynamics in complex watershed systems. Land use and management conditions can be varied over long time periods, making the model a particularly useful tool to aid in the evaluation of BMPs. SWAT is a continuous-time model, intended for the prediction of long-term water and sediment yields from a watershed.

SWAT is a physically-based numerical model requiring input of climatic, soil property, topographic, vegetation, land use and land management data. SWAT uses these data to predict water, nutrient and sediment movement through the watershed, along with vegetation growth. SWAT uses a daily time step, continuous for one to hundreds of years. There are several advantages of this approach over regression-based approaches:

- SWAT may be used to quantitatively predict the long-term effects of land use, climate or vegetation changes on watershed sediment delivery and water quality. It is therefore highly useful in the analysis of certain BMPs;
- The use of Hydrologic Response Units (HRUs) is computationally efficient, allowing for large watersheds to be simulated over long periods of time;
- Most data inputs are available free-of-charge from government agencies.
4.2.1 SWAT Model Background

SWAT was developed at the USDA-Agricultural Research Service (ARS) by Dr. Jeff Arnold. This model is based on the SWRRB (Simulator for Water Resources in Rural Basins; Arnold et al., 1990) model for application to large, complex rural basins. SWRRB is a distributed version of CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems; Knisel, 1980), which can be applied to a basin with a maximum of ten subbasins. SWAT is an extended and improved version of SWRRB, running simultaneously in several hundred subbasins. SWAT also includes elements of GLEAMS (Groundwater Loading Effects on Agricultural Management Systems; Leonard et al., 1987), and EPIC (Erosion-Productivity Impact Calculator; Williams et al., 1984).

The ArcView pre- and post-processor interface for SWAT, AVSWAT, has been developed by Blackland Research Center, a Texas Agricultural Experiment Station part of Texas A&M University System in Temple, Texas, in collaboration with Grassland Soil and Water Research Lab, a USDA-ARS laboratory in Temple, Texas (Di Luzio, et al., 2004).

4.2.2 Characterization of Processes Using SWAT

SWAT allows a wide range of different physical processes to be simulated in a watershed. These processes are briefly summarized in this section. A detailed discussion of each procedure is contained in the Grand River Watershed Model User Manual.

SWAT divides a watershed into subbasins. The use of subbasins in a simulation is beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. Input data for each subbasin are grouped into the following categories:

- Climate;
- Hydrologic response units (HRUs);
- Ponds and wetlands;
- Groundwater;
- Main channel draining the subbasin;
- Soils;
- Vegetation (land cover); and
- Land use and land management.

Hydrologic response units are areas within each subbasin that have been lumped together to comprise a single land cover, soil and management combination.

The water balance equation is the driving force behind all the processes accounted for in the watershed simulation. In order to accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle simulated by the model must conform to
what is happening in the watershed. SWAT simulates the hydrology of a watershed in
two distinct phases:

- Land Phase - The land phase of the hydrologic cycle controls the amount of water,
sediment, nutrient and pesticide loadings to the main channel in each subbasin;
- Water Phase - The water or routing phase of the hydrologic cycle, which can be
defined as the movement of water, sediments, etc. through the channel network of
the watershed to the outlet.

A distributed SCS curve number is generated for the computation of overland flow runoff
volume, given by the standard SCS runoff equation (USDA, 1986). A soil database is
used to obtain information on soil type, texture, depth and hydrologic classification. In
SWAT, soil profiles can be divided into ten layers. Infiltration is defined in SWAT as
precipitation minus runoff and evaporation. Infiltration moves into the soil profile where
it is routed through the soil layers. A storage routing flow coefficient is used to predict
flow through each soil layer, with flow occurring when a layer exceeds field capacity.
When water percolates past the bottom layer, it enters the shallow aquifer zone (Arnold et
al., 1993).

Channel transmission loss and pond/reservoir seepage replenishes the shallow aquifer
while the shallow aquifer interacts directly with the stream. Flow to the deep aquifer
system is effectively lost and cannot return to the stream (Arnold et al., 1993). Based on
surface runoff calculated using the SCS runoff equation, excess surface runoff not lost to
other functions makes its way to the channels where it is routed downstream. Sediment
yield used for instream transport is determined from the Modified Universal Soil Loss
Equation (MUSLE) (Arnold, 1992). For sediment routing in SWAT, deposition
calculations are based on fall velocities of various sediment sizes. Rates of channel
degradation are determined from Bagnold's (1977) stream power equation. Sediment size
is estimated from the primary particle size distribution (Foster et al., 1981) the SWAT
model obtains from the STATSGO (USDA, 1992) database. Stream power also is
accounted for in the sediment routing routine, and is used for calculation of re-
entrainment of loose and deposited material in the system until all of the material has
been removed.

4.2.3 ArcView SWAT Interface - AVSWAT

AVSWAT (ArcView SWAT) is a complete preprocessor, interface and postprocessor of
the hydrological model SWAT (Di Luzio, 2004). The current version of AVSWAT runs
in conjunction with ArcView 3.x. The user is provided with a set of numerical routines
for watershed delineation, definition and editing of the hydrological and agricultural
management inputs, running and calibration of the model. The extension and the model
are user-friendly tools for the watershed scale assessment and control of the agricultural
and urban sources of water pollution.
AVSWAT is organized in several linked tools grouped in the following categories:

- Watershed delineation;
- Land use and soil definition;
- Editing of model databases;
- Definition of weather stations;
- Input parameterization and editing;
- Model run;
- Read and map-chart results; and
- Calibration tool.

A more detailed description of these tools is provided in the SWAT users manual.

### 4.3 Grand River SWAT Model

The purpose of the Grand River Watershed SWAT model is to enable the evaluation of different water and sediment-related watershed management practices at the watershed scale. The following section describes the input requirements of the SWAT model, model outputs and their interpretation, and results of the model calibration and validation.

#### 4.3.1 Model Development

The base condition Lower Grand River (LGR) SWAT model was developed using the AVSWAT interface with readily available inputs; this is one major advantage of using the SWAT model. The domain of the model is the Lower Grand River basin from the USGS Gage #04116000 to the mouth (Figure 4.1). The model domain is limited to the lower portion of the basin due to limited project funding and greater stakeholder interest.

The GIS data layers necessary to create the SWAT input files are a DEM, land use coverage and soils coverage. A 30-meter resolution National Elevation Dataset (NED) DEM was downloaded from the USGS Seamless data server and was preprocessed using ArcHydro Tools which is a non-proprietary package. The land use utilized for the base condition model was the 1992 National Land Cover Dataset (NLCD). The 1992 data was used because the 2001 data was not yet available from the USGS. Each NLCD land use category was assigned a SWAT land cover/plant type. AVSWAT has several land cover/plant types built-in, each having a pre-defined set of model parameters. A table of NLCD land use and corresponding SWAT land cover/plant type is given in the Grand River Watershed Model User Manual. The land cover/plant type AGRR (Agriculture – Row Crop) was modeled in more detail than the other types. Using information from the National Agriculture Statistics Service, this type was broken into Corn and Soybeans which were the two predominant crops grown in the watershed. The corn and soybean categories were broken down further to reflect various tillage practices as described in Section Five. Because of the scale of this model and some data availability limitations, the STATSGO soils data was used instead of the more detailed SSURGO soils data.
In addition to the GIS layers, the SWAT model also requires climate data for the simulation period. AVSWAT has a built-in national climate database that contains statistics for over 11,000 stations within the US that can be used to generate the SWAT model climate data requirements, which include rainfall, temperature, solar radiation, wind speed, and relative humidity. In order to calibrate the SWAT model to measured values, measured local climate data for precipitation and temperature are necessary. For the LGR SWAT model, local precipitation and temperature measurements were supplemented with solar radiation, wind speed, and relative humidity data generated by the national climate database. Daily rainfall and temperature information was obtained from NOAA for several locations within the watershed. Figure 4.2 shows the precipitation and temperature data gage locations utilized for this simulation.

The precipitation data used in the simulations were developed using an Inverse-Distance-Squared weighted average technique for each SWAT model subbasin. This process involves the computation of a synthesized precipitation record using all available NOAA precipitation records in and around the subbasin. The resulting record is derived by taking all of the nearby gage records and weighting the values proportionately to the inverse of the squared distance from the centroid of the subbasin to the location of the rain gage. This process ensures each subbasin has a complete precipitation record, as missing data is supplemented with values from other nearby gages.

The USGS Gage #04116000 was used as the upstream boundary condition for flow and sediment to the model. A sediment rating curve was determined by combining measurements from several Grand River USGS gages (#04113000, #04114000, #04116000, #04119300) due to the limited number of measurements at a single gage. The suspended sediment inflow to the LGR SWAT model was calculated using this sediment rating curve.

An important feature of the Grand River Watershed is that there are several dams and reservoirs along the main branch and tributaries. These features affect flow and sediment transport through the watershed, so it was necessary to incorporate them into the LGR SWAT model. The information needed to incorporate reservoirs associated with dams into SWAT includes volume, surface area of the reservoir, and initial and equilibrium sediment concentrations. Most of this information was taken from the BASINS dam shapefile and associated attributes, which were derived from the National Inventory of Dams Database. Figure 4.3 shows the locations of the reservoirs simulated in the LGR SWAT model. Only those reservoirs with significant impact on flow and sediment transport were included in the LGR SWAT model.
Figure 4.1 Lower Grand River SWAT Model Domain
Figure 4.2 Temperature and Precipitation Stations Used for SWAT Simulations
Figure 4.3 Location of Dam Impoundments Modeled as SWAT Reservoirs
4.3.2 Model Calibration

Calibration is the process of model testing against known input and output data: the results of which may then be used to adjust or estimate model parameters. Validation is the process of testing the performance of the calibrated model against a known dataset that was not used during the calibration process. The SWAT model is physically based and was developed for simulating ungaged watersheds, so model calibration is possible without adjustment of every parameter. This is a great advantage of the SWAT model over more parameter-dependent models.

The years chosen for calibration were 1990-1995 and the 1996-2000 period was used for validation. The model was calibrated for flow and sediment transport against measured flow and sediment from USGS gages. The calibration process required that flow prediction be calibrated prior to calibration of sediment discharge.

The model parameters that were adjusted during the calibration process to best simulate surface and groundwater flows were: SURLAG, GW_DELAY, ALPHA_BF, ESCO, CN2, SPCON, RES_SED, RES_NSED. Parameter adjustments were made to obtain the correct ratio of surface flow to baseflow, baseflow recession, hydrograph shape and overall runoff volume.

Flow measurements from several USGS gaging stations throughout the watershed were available for the calibration period. Figure 4.6 shows the locations of the gages used to calibrate the Grand River SWAT model. Since upstream portions of the model domain supply inputs to the subbasins downstream, it is necessary to calibrate the upper portions of the watershed before the lower portions. Thus, the watershed was split up according to gage location and calibration parameters were determined for the portion of the watershed upstream each of the USGS gages. This process revealed that the parameter adjustments for each separate calibration area were quite similar, so a general set of calibration parameters was derived and used for the overall watershed simulations.

The USGS gage closest to the river mouth with a length of discharge record sufficient for model calibration was Gage # 04119000 on the Grand River at Grand Rapids. The quality of model calibration was evaluated by comparing the mean, standard deviation, R² and Nash-Sutcliffe efficiency (ENS) for each model run against the observed data. The most important of these comparisons was efficiency, which measures how well the simulated vs. measured results fit a 1:1 line. The efficiency value can range from –∞ to 1, with 1 meaning the simulated results are equal to the measured values. When comparing monthly results an efficiency value of 0.5 or greater is considered satisfactory (Van Liew & Garbrecht, 2003). The calibration results for monthly totals for this location are shown in Figure 4.4 and Table 4.1.
The monthly calibration results for flow at the Grand Rapids gage location are good. Visual comparison of daily values (hydrographs) also shows that the model does a good job reproducing flow in the watershed.

Few data points were available for calibration of the sediment yield and delivery routines in SWAT. However, SWAT estimates of sediment yield and delivery are heavily based on the predictions from the Hydrology module, so sediment load predictions are capable of being realistic once the hydrologic model has been satisfactorily calibrated. Figure 4.7 shows sediment load vs. flow for data from several Grand River USGS gages and the simulated results.

**4.3.3 Model Validation**

Model validation is the process of comparing model results with measured values without making any parameter adjustments for a time period other than that used for calibration. This step is used to confirm that the calibrated model is a reasonable representation of
watershed processes. Figure 4.5 and Table 4.2 show the results of model validation for the 1996-2000 flow record at the USGS Grand Rapids gage site.

**Figure 4.5 Monthly Calibration vs. USGS Results**

![Graph of Monthly Flow Validation Results]

**Table 4.2 Monthly Validation Results at Grand Rapids Gage (04119000) for 1996-2000**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (ave. daily, cms)</td>
<td>103</td>
<td>63</td>
</tr>
<tr>
<td>Observed</td>
<td>103</td>
<td>Simulated</td>
</tr>
<tr>
<td>R²</td>
<td>0.89</td>
<td>E_NS</td>
</tr>
</tbody>
</table>

Often validation results are not as good as the calibration results, as in this case, but the results for the validation period are still very reasonable. A chart of both the calibration and validation results for average daily flow is shown in Figure 4.8.
Figure 4.6 USGS Gage Locations Used for SWAT Flow Calibration
Figure 4.7 Sediment Load Comparison between USGS Data and SWAT Simulation
Figure 4.8 SWAT Monthly Flow Calibration and Validation Results at Grand Rapids Gage (04119000)
4.3.4  Model Output Description

Every SWAT simulation generates a number of output files including:

- The summary output file (output.std);
- The HRU output file (.hru);
- The subbasin output file (.sub); and
- The main channel or reach output file (.rch).

These ASCII text files can be viewed using any text editor such as Notepad or Wordpad or they can be imported into Excel using the Text Import Wizard. These files (excluding output.std) can also be imported as tables into ArcView.

Descriptions of the most relevant output variables for the Grand River SWAT model are described below.

**Subbasin Output File (output.sub)**

This file contains summary information for each subbasin in the watershed.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRECIP</td>
<td>Total amount of precipitation falling on the subbasin during a time step (mm H$_2$O).</td>
</tr>
<tr>
<td>SURQ</td>
<td>Surface runoff contribution to streamflow during a time step (mm H$_2$O).</td>
</tr>
<tr>
<td>GW_Q</td>
<td>Groundwater contribution to streamflow (mm H$_2$O). Water from the shallow aquifer that returns to the reach during a time step.</td>
</tr>
<tr>
<td>WYLD</td>
<td>Water yield (mm H$_2$O). The net amount of water that leaves the subbasin and contributes to streamflow in the reach during a time step.</td>
</tr>
<tr>
<td>SYLD</td>
<td>Sediment yield (metric tons/ha). Sediment from the subbasin that is transported into the reach during a time step.</td>
</tr>
</tbody>
</table>
**Main Channel Output File (output.rch)**

This file contains summary information for each routing reach in the watershed.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW_IN</td>
<td>Average daily streamflow into reach during a time step (m$^3$/s).</td>
</tr>
<tr>
<td>FLOW_OUT</td>
<td>Average daily streamflow out of reach during a time step (m$^3$/s).</td>
</tr>
<tr>
<td>SED_IN</td>
<td>Sediment transported with water into reach during a time step (metric tons).</td>
</tr>
<tr>
<td>SED_OUT</td>
<td>Sediment transported with water out of reach during a time step (metric tons).</td>
</tr>
<tr>
<td>SEDCONC</td>
<td>Concentration of sediment in reach during a time step (mg/L).</td>
</tr>
</tbody>
</table>

The variable used to compare SWAT output to measured values (such as USGS gage records) is FLOW_OUT, and the variable used to determine sediment loading is SED_OUT.

**4.3.5 Model Results**

The existing conditions calibrated model was run for the years 1990 – 2000. Average yearly sediment yield from the subbasins (sediment eroded from the subbasin that reaches the channel) is shown in Figure 4.9. The subbasins contributing the most sediment to the Grand River system are generally located near the Grand River main stem. The total average yearly sediment yield for this portion of the watershed for 1990 – 2000 is 163 tons/acre/yr according to the SWAT model.
Figure 4.9 SWAT Average Yearly Sediment Yield Results

Average Sediment Yield
tons/acre

- 0.02 - 0.32
- 0.33 - 0.62
- 0.63 - 1.06
- 1.07 - 1.44
- 1.45 - 2.26

Grand River Watershed SWAT Model
Sediment Loading Results

Spatial Reference: NAD 1983 Michigan OecdRefMeters

1:1,291,988
4.3.6 Model Limitations

While a calibrated model can provide useful insight into watershed processes, it is important to remember the limitations inherent in this type of modeling as listed below:

- The SWAT model is designed to simulate long term processes, and thus it is not designed to provide event-based results;
- Due to the large scale of the model and limited calibration information, detailed subbasin results (especially in areas away from the calibration gages) should be treated as preliminary until additional data is collected to verify their accuracy;
- Certain model parameters were not changed from their default values due to a lack of specific data; this can lead to a certain degree of uncertainty in model results;
- Even though the LGR SWAT model simulates nutrient cycles, neither the input parameters nor the results have been verified.

4.3.7 Future SWAT Developments

A new tool for SWAT output analysis and visualization is currently under development through a joint effort by Baird and Texas Agricultural Experiment Station (TAES). This new tool will incorporate several custom SWAT analysis tools with Baird’s SDA model visualization tool to provide users with a means to easily and quickly view SWAT results (even very large files), perform various analyses on the output datasets, and view results in a GIS environment.

In addition, an ArcGIS 9.x interface for SWAT is currently under development at Texas A&M University. It is compatible with the ArcHydro data model, a standard data model for spatial and temporal hydrologic data, thus enabling more integration with other hydrologic and hydraulic models that use the same type of input data. Since ESRI (the developer of the ArcView software) is no longer updating the ArcView 3.x software, there is a general trend away from ArcView 3.x and towards ArcGIS 9.x.
5.0 ILLUSTRATION OF BEST MANAGEMENT PRACTICES

5.1 Introduction to BMP Modeling

Once areas with high erosion rates (or other sediment management problems) have been identified, mitigation can be implemented with best management practices (BMPs). BMPs in this case are activities used to prevent non-point sources of sediment from impacting downstream areas of the watershed. BMPs can be structural, vegetative or managerial, and their implementation is vital to protecting surface and groundwater quality.

Although there are BMPs for many different kinds of environmental impacts, BMPs for addressing the environmental impacts of sediments are most relevant to the Section 516(e) Program. Sediment BMPs can be divided into two categories: those that prevent erosion and those that control sediment loads (i.e. sediment already in transport by water). Erosion prevention BMPs include: vegetation, bank erosion and hydrologic controls, and modification to agricultural practices in a watershed. Sediment load control BMPs include: use of silt fences, sediment traps, wetland generation and restoration, and filter strips. Both sets of sediment BMPs may be applied in urban and rural settings.

BMPs used in rural settings address sediment problems characteristic of those areas, such as streambank erosion, agricultural runoff and forest floor and hillslope erosion due to poor logging practices. BMPs that can be used to mitigate these problems (depending on land use) are streambank protection/stabilization through the use of vegetation, bioengineering or riprap, conservation tillage practices and the protection or creation of buffer/filter zones.

Urban areas typically have different sediment problems to those in rural areas. These problems include erosion from construction sites, urban runoff from parking lots and roads, and changes in hydrology that cause increased flow peaks and frequency. Some BMPs used to reduce sediment load in these situations are construction barriers, sedimentation basins and on-site infiltration practices that allow stormwater to infiltrate into the ground instead of flowing directly into storm drains and river channels.

In general, many BMP options exist, addressing most pollution problems. A thorough site investigation must be completed prior to the implementation of any type of BMP. Care must be taken to ensure proper design and construction, and ongoing maintenance is often required for a BMP to be successful. While sediment control BMPs, if properly designed and constructed, will reduce sediment loads, no single practice is 100% effective.

Many federal and state agencies have developed guidelines for the design and implementation of BMPs. The NRCS and EPA (along with ASCE and WERF) have websites (listed below) with a great deal of relevant information on BMPs. In addition,
the Michigan DEQ has published a guidebook of BMPs for Michigan watersheds. The BMPs described in that publication have been developed specifically for Michigan watersheds and are under continual development.

Web Links for BMP Information

NRCS Urban BMP Website

EPA/ASCE/WERF International Stormwater BMP Database
http://www.bmpdatabase.org/

BMP Guidebook for Michigan Watersheds

5.2 SWAT BMP Modeling

The Grand River Watershed SWAT model can be used to evaluate the effects of various agricultural BMPs on soil erosion and sediment loads. Since this watershed is mainly agricultural, urban BMPs that are available for sediment management in developed areas are not considered in this study.

While the model has been designed to give realistic sediment yield results for the various land use and management options, there was very little measured sediment data available for comparison with the SWAT model scenario output. Thus, the sediment yield values presented in this section should be considered as relative changes rather than as a prediction of actual yields from the watershed.

5.2.1 Dams & Reservoirs as Sediment Traps

There are 89 dams in the Grand River Watershed represented in the National Inventory of Dams, EPA BASINS database (http://www.epa.gov/docs/ostwater/BASINS/). In general, the dams are spread throughout the watershed, with some notable exceptions. The most downstream dam on the Grand River main stem is at Grand Rapids. This dam has a drainage area of almost 90% of the total Grand River Watershed area. The dam and the accompanying impoundment trap a significant amount of sediment from the watershed. Two other areas where dams trap a considerable amount of sediment are the Thornapple and Flat Rivers. Both these main tributaries have several dams on their main branch. In addition to trapping sediment, these dams also alter the flow downstream, smoothing out flood peaks and reducing velocities, often resulting in less streambank erosion.

The SWAT model can be used to evaluate the effect of dams on sediment movement through the watershed. The following example will show the impact the dams along the Thornapple River have on sediment delivery to the main branch of the Grand River.
Two different SWAT models were set up for the Lower Grand River Watershed, one with and one without dams. Each model is run with the same climatic inputs and results at the mouth of the Thornapple Watershed are compared. Table 5.1 summarizes the results showing the impacts of dams on sediment delivery in the Thornapple Watershed.

Table 5.1 Summary Results for Dam Impacts Scenario for Thornapple Watershed

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Annual Sediment Yield (tons/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Dams</td>
<td>13,674</td>
</tr>
<tr>
<td>Without Dams</td>
<td>95,995</td>
</tr>
</tbody>
</table>

The results show that the dams (as they are modeled in SWAT) on the Thornapple collectively trap 86% of sediment (the model does not indicate whether this is bed load or suspended load). A similar analysis could be repeated for other areas of the watershed without rerunning the models.

While dams and reservoirs can reduce sediment loads and downstream erosion, they also can significantly alter the flow regime in the river and consequently, the habitat. Thus, care must be taken when considering dams/reservoirs as a BMP.

5.2.2 Conservation Tillage

Tillage practices on agricultural land have a profound effect on sediment erosion rates from fields. The LGR Watershed SWAT model simulates the various tillage practices that are in use within the watershed. Information on tillage practices by county was available from the National Crop Residue Management Database distributed by the Conservation Technology Information Center (http://www.ctic.purdue.edu). Tillage practice statistics for the years 1989, 1994 and 1998 were obtained, and the average of those three years was used for model input. The types of conservation practices considered in the model were conventional till, reduced till, mulch till and no till, and these were applied to corn and soybean crops (Table 5.2).

Conventional till, also called intensive till, is a full width tillage that disturbs the soil surface. Tillage is performed prior to and/or during planting and generally leaves less than 15% residue cover after planting. A common tillage implement for this type of system is a moldboard plow. This type of tillage is being replaced more and more by conservation and no-till practices.

Reduced till is also a full width tillage that disturbs all of the soil surface, though 15-30% residue cover remains after planting.
Mulch till, considered a conservation tillage type, disturbs the entire soil surface but leaves 30% or more crop residue after planting. Tillage implements for this type of practice include chisels, field cultivators, disks, sweeps or blades.

No-till systems leave the soil undisturbed from harvest to planting. Residue coverage is at least 30%, if not greater. This system allows for strips up to 1/3 of the row width to be tilled, but this may only involve residue disturbance or some soil disturbance.

Table 5.2 Agricultural – Row Crop (AGRR) land use breakdown by crop and management practice

<table>
<thead>
<tr>
<th>County</th>
<th>Corn</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conv.</td>
<td>Reduced</td>
</tr>
<tr>
<td>BARRY</td>
<td>19%</td>
<td>13%</td>
</tr>
<tr>
<td>EATON</td>
<td>4%</td>
<td>5%</td>
</tr>
<tr>
<td>IONIA</td>
<td>11%</td>
<td>17%</td>
</tr>
<tr>
<td>KENT</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>MONTCALM</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>MUSKEGON</td>
<td>5%</td>
<td>11%</td>
</tr>
<tr>
<td>OTTAWA</td>
<td>10%</td>
<td>9%</td>
</tr>
</tbody>
</table>

Table 5.3 shows the average sediment eroded from each crop/management type in the LGR SWAT model.

<table>
<thead>
<tr>
<th>Sediment Erosion (tons/ac)</th>
<th>Corn</th>
<th>Mulch</th>
<th>No</th>
<th>Soybean</th>
<th>Reduced</th>
<th>Mulch</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv.</td>
<td>3.6</td>
<td>2.0</td>
<td>1.5</td>
<td>0.2</td>
<td>6.0</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Reduced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mulch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Even though conservation tillage (mulch till and no till) is widely used within the watershed, the sediment erosion model results illustrate the importance of increasing this participation even further because there is such a significant reduction in sediment eroded when using these practices.

5.2.3 Filter Strips

Edge-of-field filter strips are grassy strips along field boundaries that trap nutrients and sediment before they can enter waterways. These can be simulated in SWAT using an equation that relates strip width to sediment trapping efficiency. While this is only a simple model of filter strip trapping, work is in progress to upgrade this capability within SWAT to include riparian buffer trapping.
To show the effects of edge-of-field filter strips, a 10-meter filter strip was added to all Conventional Till Corn areas in the model. The change in sediment yield from the conventional till corn areas and at the mouth of the watershed are shown in Tables 5.4 and 5.5.

### Table 5.4  Average annual sediment delivered from Conventional Till Corn

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Annual Sediment Yield (tons/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Filter Strips</td>
<td>3.6</td>
</tr>
<tr>
<td>With Filter Strips</td>
<td>1.0</td>
</tr>
</tbody>
</table>

### Table 5.5  Average annual sediment delivery to river mouth

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average Annual Sediment Yield (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Filter Strips</td>
<td>278,704</td>
</tr>
<tr>
<td>With Filter Strips</td>
<td>265,998</td>
</tr>
</tbody>
</table>

The results show that filter strips can have a great effect on how much sediment is transported from agricultural fields. Average annual sediment yield at the river mouth was not affected nearly as much due to the fact that conventional till corn only covers about 3% of the watershed. It is interesting to note that by reducing the sediment yield by 72% on 3% of the watershed decreases the sediment delivered to the river mouth by 5%.
5.3 Discussion

BMPs can be very beneficial in reducing non-point source sediment pollution. While many BMP options exist, a thorough site investigation must be completed prior to the implementation of any type of BMP and care must be taken to ensure proper design, construction and maintenance.

The effects of dams, conservation tillage and filter strips are only a few of the various BMPs that can be simulated within the SWAT model. These practices can be applied basin-wide or within a particular subwatershed of interest. Care must be exercised when looking at results from a single subbasin due to the calibration data limitations (See Section 4.3.5). Additional BMPs available in SWAT are outlined in the accompanying User Manual.
6.0 SUMMARY

The purpose of this study was to review the characteristics of the Grand River Watershed as they relate to sediment erosion and transport and to use that information to develop a hydrologic and sediment transport model of the watershed. State and local watershed managers can use this model to evaluate alternatives for soil conservation and non-point source pollution prevention in tributary watersheds.

6.1 Existing Conditions

The Grand River Watershed is the second largest drainage basin in the State of Michigan and comprises 13% of the entire Lake Michigan Basin. This watershed is comprised of four large basins: Upper Grand, Maple, Thornapple and Lower Grand. The relatively flat slope of the lower Grand River and the presence of a large dam at Grand Rapids result in significant sediment deposition in the channel and dam backwater area.

A field survey was performed in November of 2004 and included data collection and photographs of 132 sites along the Grand River and major tributaries. The data gathered at those sites included channel and bank characteristics, geomorphic sensitivity, land use adjacent to the site, erosion issues and recommendations for protection and maintenance. This data as well as the photographs are incorporated into the Grand River GIS that accompanies this report.

Historic land use change in the watershed has likely led to increased sediment delivery and transport in the Grand River. Pre-development land use/cover conditions were mainly forest with meadows and wetlands. Logging activities in the later half of the 1800’s removed large areas of tree cover resulting in increased runoff and sediment transport. Agriculture in the watershed peaked in the early 1900’s following the clearing of land for logging and declined until about the late 1970’s. Since then land cover has been relatively steady, with about 40% of the watershed devoted to agriculture.

Analyses of the buffer zones in the watershed exposed some interesting trends. First, an analysis of land use in each HUC14 subwatershed and in the buffer zones of those watersheds showed a strong relationship between the percentage of cropland in a subwatershed and the percentage of the buffer zone that was cropland. An additional detailed analysis using 2004 aerial photography confirmed that subbasins with a high percentage of cropland tend to have less riparian vegetation in the buffer zone. A vegetated buffer is important because it slows down runoff and facilitates deposition of sediments, nutrients and other contaminants, thus preventing these constituents from entering the channel.

The flashiness index is used to determine if there has been significant hydrologic alteration in a watershed over time. Several USGS discharge gage records were used to
determine the flashiness index. The results showed that several gages in the watershed had a slight increasing trend in flashiness since 1970, others have remained steady or have decreased for various reasons. Operations at hydropower dams can affect the results of this analysis, generally showing a decrease in flashiness. Locations of increasing flashiness are cause for concern as this means there is a quicker temporal response of the watershed to rainfall. This can lead to higher velocities and peak flows and thus increased sediment erosion and transport.

The baseflow analysis indicated that the Grand River Watershed is moderately to highly controlled by baseflow. This is generally a sign of a “healthy” watershed. However, the influence of dams may have affected the results of this analysis as they tend to slow down the streamflow response, thus providing a “baseflow” signal from surface runoff. A decrease in baseflow would indicate a shift to more surface runoff in a watershed and perhaps an increase in sediment erosion and transport.

Empirical estimates of sediment yield from the Grand River Watershed are markedly higher than yields in other Great Lakes Watersheds. This may be due to the influence dams have on sediment delivery to the mouth of the Grand River and the problem of extrapolating empirical relationships derived from small watersheds to large ones like the Grand River Watershed.

6.2 SWAT Model

The Soil and Water Assessment Tool (SWAT) is a watershed-scale numerical model for the simulation of water, sediment, nutrient and pesticide movement in surface and subsurface systems. SWAT aids in prediction of the impacts of climate and vegetative changes, reservoir management, groundwater withdrawals, water transfer, land use change and watershed management practices on water, sediment and chemical dynamics in complex watershed systems. Land use and management conditions can be varied over long time periods, making the model a particularly useful tool to aid in the evaluation of BMPs. SWAT is a continuous-time model, intended for the prediction of long-term water and sediment yields from a watershed.

The purpose of the Grand River Watershed SWAT model is to enable the evaluation of different water and sediment-related watershed management practices at the watershed scale. The domain of the model is the Lower Grand River Basin (including the Thornapple Watershed) from the USGS Gage #04116000 to the mouth. The model domain was limited to the lower portion of the basin due to limited project funding.

The Lower Grand River SWAT model was calibrated to measured data at four locations in the watershed where sufficient measured discharge data was available. Measured vs. simulated discharge values for the calibration and validation periods were quite good. Due to the limited amount of suspended sediment data available, calibration of the model sediment loads was limited. Since the parameters determined for each calibration basin
were similar, a general set of parameters was chosen for the full LGR SWAT model in order to make user changes to the model easier.

While a calibrated model can provide useful insight into watershed processes, it is important to remember the limitations inherent in this type of modeling as listed below:

- The SWAT model is designed to simulate long term processes, and thus it is not designed to provide event-based results;
- Due to the large scale of the model and limited calibration information, detailed subbasin results (especially in areas away from the calibration gages) should be treated as preliminary until additional data is collected to verify their accuracy;
- Certain model parameters were not changed from their default values due to a lack of specific data; this can lead to a certain degree of uncertainty in model results;
- Even though the LGR SWAT model simulates nutrient cycles, neither the input parameters nor the results have been verified.

Despite the limitations, SWAT is a very useful tool for long-term, large-scale watershed modeling. The input data for SWAT are readily available and the model can be calibrated to measured data with a reasonable amount of effort. The ability of SWAT to simulate nutrients and contaminants makes it a valuable tool for comprehensive watershed management in the future.

6.3 BMPs

The LGR SWAT model can be used to evaluate the effects of various agricultural BMPs on soil erosion and sediment loads. Since this watershed is mainly agricultural, urban BMPs that are available for sediment management in developed areas were not considered in this study.

Examples of the types of BMPs available with the SWAT model include effects of dams and other sediment traps, crop management practices such as conservation tillage, and the use of edge-of-field filter strips.

BMPs can be very beneficial in reducing non-point source sediment pollution. While many BMP options exist, a thorough site investigation must be completed prior to the implementation of any type of BMP and care must be taken to ensure proper design and construction.

The effects of dams, conservation tillage and filter strips are only a few of the various BMPs that can be simulated within the SWAT model. These practices can be applied basin-wide or within a particular subwatershed of interest. Care must be exercised when looking at results from a single subbasin due to model and data limitations. Additional BMPs available in SWAT are outlined in the accompanying User Manual.
While the model has been designed to give realistic sediment yield results for the various land use and management options, there was very little measured sediment data available for comparison with the SWAT model scenario output. Thus, the sediment yield values presented in this study should be considered as relative changes rather than as a prediction of actual yields from the watershed.
7.0 REFERENCES


APPENDIX A

Sycamore Creek Watershed Section 319 National Monitoring Program Project

The USDA Sycamore Creek Watershed Hydrologic Unit Area (HUA) Project is a cooperative effort among the following:

- Michigan State University Extension - Ingham County;
- USDA Natural Resources Conservation Service-National, Michigan;
- USDA CSREES;
- USDA Farm Service Agency;
- Michigan State University;
- MSU Institute of Water Research;
- United States Geological Survey-National, Michigan;
- Ingham County Health Department-Environmental Health;
- Ingham County Drain Commission;
- Michigan Department of Agriculture Groundwater Stewardship Program;
- Ingham County Master Gardeners;
- Tri-County Regional Planning;
- Lansing Board of Water and Light;
- Michigan Department of Environmental Quality;
- AmeriCorps;
- Consolidated Farm Service Agency;
- Landowners within the Sycamore Creek Watershed; and
- Michigan Department of Environmental Quality.

The effort is directed toward assisting local agricultural producers in reducing the potential for nonpoint source water pollution. This project is located in Ingham County in South Central Lower Michigan.

The Sycamore Creek U.S. Environmental Protection Agency (USEPA) Section 319 National Monitoring Program Project is nested within the Sycamore Creek HUA Project. The nonpoint source control strategy includes:

- Identification and prioritization of significant nonpoint sources of water quality contamination in the watershed; and
- Promotion of the adoption of BMPs that significantly reduce the affects of agriculture on surface water and groundwater quality.

Agricultural conservation practices and their effect on water quality has been tracked using the database ADSWQ (Automatic Data System for Water Quality). The EPIC model (Erosion Productivity Index Calculator) was used to estimate changes in edge-of-
field delivery of sediment, nutrients, and bottom of root zone delivery of nutrients resulting from BMP implementation.

Preliminary exploratory analysis includes a linear regression of control values versus target values for storm loads, storm event mean concentrations, storm rainfall amounts, storm runoff volume, and storm runoff coefficients. Storm loads were also compared to the AGNPS model for the first two years of data. Land use and cover data are recorded each year on a ten-acre grid scale.

Information source website: http://h2osparc.wq.ncsu.edu/97rept319/mi-97.htm

**Lower Grand River 319 Project**

A Section 319 Watershed Management Planning Grant was awarded by the MDEQ to facilitate the development of a watershed management plan for the Lower Grand River Watershed (LGRW). The grant was awarded to the Grand Valley Metro Council. The Grand Valley Metro Council has contracted with the Annis Water Resources Institute and Fishbeck, Thompson, Carr & Huber, Inc. to complete the management plan. Many communities are participating in the development of this plan. Counties, cities, and townships are currently involved by matching funds or in kind services. Several of the following projects are part of the overall Lower Grand River Project.

The approved WMPs in the LGRW are:

- Rogue River;
- Plaster Creek;
- Bear Creek;
- Coldwater River;
- Stegman Creek;
- York Creek;
- Crockery Creek; and
- Spring Lake.

Information source website: http://www.gvsu.edu/wri/isc/lowgrand/

**Blakeslee Creek Hydrologic Study**

This study is being performed by the Hydrologic Studies Unit (HSU) of the Land and Water Management Division (LWMD) of the Michigan DEQ. LWMD have completed the calibration of the Blakeslee Creek hydrologic model. This analysis was requested in support of a Section 319 grant that is intended to develop a design to rehabilitate the tributary through a Clean Michigan Initiative (CMI) grant. This study demonstrated that the transition from predominately forest and meadow to residential in the middle third of
the watershed caused widespread streambank erosion and threatens to degrade a wetland that the stream flows through, even though the development complied with the existing stormwater ordinances.

This watershed study was initiated because of the large volume of sediment moving through the stream into the Rogue River, a designated trout stream. The sediment was caused by poor erosion control practices during the development of a subdivision in the middle portion of the watershed and by streambank and streambed erosion of the stream channel. The channel may have become morphologically unstable because of increased runoff from the subdivision. Morphologic instability is characterized by extensive, accelerated channel erosion.

The goal of this study is to better understand the watershed's hydrology so that:

- A suitable, long-term rehabilitation BMPs can be selected and designed;
- The impact of the rehabilitation designs can be predicted; and
- Further changes in the flow regime of Blakeslee Creek due to future hydrologic changes within the watershed can be predicted and controlled appropriately

This project involves the use of HEC-HMS on a 3-subbasin watershed of approximately 200 acres.

Information source website:  http://www.michigan.gov/deq/0,1607,7-135-3313_3682_3714-57034--,00.html

*Bear Creek Projects*

The goal of the Bear Creek Watershed Project was to protect Bear Creek from environmental impacts associated with urbanization. This project was a partnership between Cannon Township (Kent County, Michigan) and the Robert B. Annis Water Resource Institute of Grand Valley State University. The project was funded by the U.S. Environmental Protection Agency through Section 319 of the Clean Water Act, and administered by the Michigan Department of Environmental Quality. One objective of the project was to demonstrate that protection of a watershed through education and improved land use management was a less expensive method than restoration of a degraded watershed, where a much stronger emphasis is placed on the installation of structural BMPs. The project recently finished its third year of implementation to minimize the impacts of nonpoint source (NPS) pollutants to Bear Creek and its tributaries. The Bear Creek Watershed Project continues as Cannon Township assumes direct responsibility for day-to-day activities. Cannon Township has created a new position, Watershed Administrator, within the township.
An earlier study on Bear Creek included the development of a calibrated, 37-subbasin HEC-1 model for this 29.0 square mile watershed.

Information source website: http://www.gvsu.edu/wri/isc/bear/about.htm

**Buck Creek Project**

Buck Creek is a subwatershed within the LGRW and encompasses portions of Byron Township, Gaines Township, and the Cities of Kentwood, Wyoming, and Grandville. It is one of the three urban areas selected as pilot project areas for the LGRW Project. The LGRW Project is halfway through a two-year project to develop a comprehensive watershed protection plan for the LGRW. This watershed was selected because of its diverse land uses, which provide for innovative solutions to urban and rural stormwater issues. The Buck Creek WMP will provide detailed information about the sources and causes of the pollutants that are impairing the uses of Buck Creek and recommendations of the management measures needed to address the impairments. The Buck Creek WMP will be a model for other subwatersheds within the LGRW on which to base their planning efforts for improving water quality.

**York Creek Project**

This project is a cooperative effort between Grand Valley State University's Water Resources Institute and Alpine Charter Township. It is funded through Section 319 of the Clean Water Act and administered by the Michigan Department of Natural Resources. The goal of the one-year study was to determine the current conditions and recommend restoration measures for the creek.

The Grand Valley State University Water Resources Institute (WRI) and the MDNR Water Quality Studies Unit conducted a series of hydrologic and surface runoff modeling events and evaluated nonpoint source pollution contributions to York Creek. This was accomplished through the use of a variety of Geographic Information Systems (GIS) and an extensive database. Alpine Charter Township officials will be provided with a computer software package adapted specifically for the York Creek Watershed. With the actual and simulated information provided, planning officials can reasonably predict impacts of future land use changes on water quality before the commencement of land disturbing activities. In addition to the development of predictive capabilities regarding future impacts, the York Creek Watershed Project intends to implement numerous soil erosion and sediment control BMPs in order to decrease the NPS pollutant contributions currently impacting the water quality of York Creek.

Information source website: http://www.gvsu.edu/wri/isc/york/index.htm
Dissolved Oxygen TMDL for the Grand River, Jackson County

This project involved the development of a TMDL to identify the sources of dissolved oxygen (DO) standard nonattainment in the Grand, north branch Grand, and Portage Rivers near Jackson, and to quantify reductions in these sources necessary for attainment of the standard. This study was performed by the Water Division of the Michigan DEQ.

Red Cedar River

The goal of this study was to develop a framework to quantify the effects of land use on water quality of the Red Cedar River. This involved the development of hydrodynamic and transport models for the river itself. During Summer 2002, researchers at MSU conducted a series of dye dispersion studies using fluorescein as a tracer, measured water velocities, discharges and river stages to better understand hydrodynamics and transport in the river.

USEPA models DYNHYD and WASP were used to predict flow and transport of both conservative and reactive components. Other modeling included finite-element models of the river based on two-dimensional, vertically integrated St. Venant equations using SMS, RMA-2 and RMA-4 packages. To understand the role of longitudinal dispersion in a natural stream such as the Red Cedar River, a storage zone model was used in which tracer mass is assumed to reside in the main channel as well as in storage or dead zones along the banks. The model parameters were estimated using non-linear gradient-based parameter estimation methods.

The tracer transport model was the first step in developing reactive transport models that include a number of processes such as sorption and degradation. Future studies will integrate the river models with GIS to understand fluxes at the watershed scale.

Information source website: http://www.msu-water.msu.edu/asp/baselineinfo.asp?st_id=3

Portage River Restoration

The Portage River Restoration is a 180-acre wetland restoration located in Jackson County, Michigan. The Portage River Restoration property was one of the first easements to be enrolled in the Wetlands Reserve Program in Michigan (1995). This project has become one of the largest and most successful wetland restorations in southern Michigan.

The wetland restoration has resulted in approximately 80 acres of restored emergent marsh and 100 acres of restored grassy wetlands and upland. This wetland restoration effort provides an important fall migratory staging area and nesting habitat for Sandhill Cranes (Grus canadensis), as well as other species of migratory waterfowl. The restored
wetland is located in an area that has the highest nesting densities of Sandhill Cranes (0.8 cranes per sq. km.) found anywhere in North America. The land remains in private ownership, with a permanent easement to protect it in perpetuity.

Through the Wetlands Reserve Program, private landowners can restore and preserve wetlands that have been previously drained for agricultural land. NRCS purchases a conservation easement and reimburses the cost of construction and seeding to make it affordable for the landowner to retire the wetland from crop production.

This wetland site was previously planted to vegetable "truck crops" such as potatoes, carrots and radishes. Prior to production of vegetables, the site was used for the production of mint. The remnants of a mint oil processing facility can still be found about 1/2 mile north of the restored wetland. In the late 1800's the area was completely tiled, ditched, diked and pumped to control water levels. Restoration included removing the pumping plant, installing culverts and dikes, and removing tile to restore wetland hydrology. Because of the soils, a dike along one side of the restoration had to be cored with a 60 ml, high-density polyethylene membrane to prevent seepage onto adjacent cropland.

In the spring, floodwaters from the Portage River will flow into the wetland and provide an excellent resting and mating site for migratory waterfowl. This restoration will also reduce flooding downstream in the Portage River System. The restored wetland will also provide much needed sediment retention and groundwater recharge in an area of Michigan that is under increasing development pressure.

Information source website:

**Sand Creek Watershed Management Plan**

The development of the Sand Creek WMP was facilitated through the LGRW Project, funded by the USEPA through Section 319 of the Clean Water Act. This 319 grant was administered by the MDEQ. The Grand Valley Metro Council (GVMC) was awarded the grant and consequently contracted with the Annis Water Resources Institute (AWRI) and Fishbeck, Thompson, Carr, & Huber Inc. (FTC&H).

The Sand Creek Watershed was chosen for detailed study through the LGRW Project as a pilot project area. Due to the large size of the LGRW, pilot project areas were selected to represent the urban and rural issues of the area. The Buck Creek Watershed, Millennium Park Watershed, and Grand City Watershed were chosen as the urban pilot project areas while the Sand Creek Watershed was selected as a rural/developing pilot project area. The Sand Creek Watershed was chosen because of its strong local support, rural nature, and changing land uses due to urban development. It is expected that the rural subwatersheds in the LGRW will eventually face changing land uses due to growth and
development. The Sand Creek Watershed will serve as a model on how to effectively accommodate urban land uses while preserving rural land uses. The product of this pilot project, the Sand Creek WMP, will provide detailed information regarding the sources, causes, and impacts of NPS pollutants that typically affect the designated uses of a rural watershed. The management plan will also include recommendations to treat, prevent, or reduce NPS pollution for rural areas.

Nine nonpoint source pollutants have been identified as impairments or threats to the designated uses of the Sand Creek Watershed. Impacted designated uses include the cold water fishery, other aquatic life and wildlife, partial body contact recreation, and total body contact recreation. NPS pollutants were identified using past and current studies performed in the watershed. Sediment, nutrients, thermal pollution, changes in hydrology, hydrocarbons, and invasive/exotic plant species have been identified as known watershed pollutants. These pollutants are impairing the designated use of cold water fishery and threatening the other aquatic life and wildlife use. In addition, pathogens, hydrocarbons, and trash are known pollutants threatening the designated uses of total and partial body contact recreation. Toxic substances, such as Inorganic Contaminants, Synthetic Organic Contaminants (SOCs), and Volatile Organic Contaminants, are suspected of impacting all four designated uses.

Information source website:

**Rogue River**

Annis Water Resource Institute is currently working on two implementation projects in the Rogue River Watershed. MDEQ and USEPA support these projects through funds from Section 319 of the Federal Clean Water Act and the Clean Michigan Initiative. These two implementation projects, an Information and Education Program and a Physical Improvements Project, were the result of a two-year planning phase for the Rogue River Watershed.

Information source website:  http://www.gvsu.edu/wri/isc/rogue/
APPENDIX B

Spatially Distributed Data

- Land use/land cover;
- Urbanized areas;
- Populated place locations;
- Reach File Version 1 (RF1);
- Soils (STATSGO);
- Elevation (DEM);
- National Elevation Dataset (NED);
- Major roads;
- USGS hydrologic unit boundaries (accounting unit, cataloging unit);
- Dam sites;
- EPA regional boundaries;
- State boundaries;
- County boundaries.

Environmental Monitoring Data

- Water quality monitoring station summaries;
- Water quality observation data;
- Bacteria monitoring station summaries;
- Weather station sites;
- USGS gaging stations;
- Fish Consumption advisories;
- National sediment inventory (NSI);
- Shellfish classified areas;
- Clean Water Needs Survey.

Point Source Data

- Industrial Facilities Discharge (IFD) sites;
- BASINS 3 Permit Compliance System (PCS) sites and loadings;
- Toxic Release Inventory (TRI) sites;
- CERCLIS-Superfund National Priority List (NPL) sites;
- Resource Conservation and Recovery Information System (RCRIS) sites;
- Mineral Industry Locations.
## APPENDIX C

<table>
<thead>
<tr>
<th>I</th>
<th>Date</th>
<th>11/11/04</th>
<th>Surveyor</th>
<th>Alex Branson</th>
<th>Catchment</th>
<th>Grand River</th>
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### II Description of Catchment Context:

- Cultivated/Grazed
- Description of Floodplain: Flat
- Description of Channel Platforms: Low
- Estimate of Channel Gradient: Low

### III Measurement type (Pool-Riffle/Uniform/Art)

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<td>Estimated Bankfull Depth:</td>
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<td>Runoff: Debris Line?</td>
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### IV River Bank Profiles:

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<th>L.B.</th>
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<th>E.B.</th>
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<td>Left Bank</td>
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<th>Sediment Sources</th>
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<td>Bed</td>
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<td>Urban Runoff</td>
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<td>Field Drains</td>
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<td>Ditches</td>
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<th>Structures Inspected</th>
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<tr>
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<td>(CV, FAS, ADS, LK, BP, RA)</td>
<td>Realign</td>
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### XI Presence of Channel Debris:

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**Estimated Likely Ecological Importance:** Low

### XII Recommendations for Protection:

Low

**Recommendations for Maintenance:** None

**Recommendations for Mitigation/Enhancement:** Remeandering

### XIII Photograph #:

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### XIV Notes/Additional Comments:

*Prairies by goats, woodland cleared*

### XV Sketches