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November 3, 2009

Mr. John Knisley
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Dear Mr. Knisley:

Subject: Final Report Entitled "Development of the Soil and Water Assessment Tool (SWAT) to Evaluate Beneficial Management Practices (BMPs) in the Silver Creek Watershed"
EERC Fund 14456

Enclosed is the subject Energy & Environmental Research Center (EERC) final report. If you have any questions or require clarification of any point, please contact me by phone at (701) 777-5050 or by e-mail at bkurz@undeerc.org.

Best regards,

Bethany Kurz

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BAK/hmv

Enclosure

c/enc: Kathy Rasch, Clearwater Soil & Water Conservation District

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DEVELOPMENT OF THE SOIL AND WATER ASSESSMENT TOOL (SWAT) TO EVALUATE BENEFICIAL MANAGEMENT PRACTICES (BMPs) IN THE SILVER CREEK WATERSHED

Final Report

(for the period February 23, 2008, through October 15, 2009)

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DEVELOPMENT OF THE SOIL AND WATER ASSESSMENT TOOL (SWAT) TO EVALUATE BENEFICIAL MANAGEMENT PRACTICES (BMPs) IN THE SILVER CREEK WATERSHED

1.0 INTRODUCTION

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

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

The goal of this project was to assess the factors that contribute to the water quality impairments identified within the Silver Creek Watershed (SCW) and to evaluate the effectiveness of several BMPs using hydrologic models. The SCW is impaired for fecal coliform that affects the designated use of aquatic recreation. The focus of this project was to evaluate the effectiveness of various BMP scenarios in order to decide which practices will provide the most benefit to water quality.

To better understand the source of fecal coliform impairments within this watershed, a hydrologic model developed with SWAT was utilized. A SWAT model was previously developed and calibrated for the Clearwater River Watershed by the Energy & Environmental Research Center (EERC). However, a more detailed study of the SCW, found within the Clearwater River Watershed was needed to analyze the water quality at a more detailed scale.

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

The modeling conducted for this project focused on long-term (i.e., 15- to 30-year) simulations of water and sediment loading at multiple points of interest within the watershed. The modeling results will be used to gain a better understanding of water quality issues within the watershed and to aid the Clearwater Soil and Water Conservation District (CSWCD) in implementing BMPs for the impaired reaches.

2.0 BACKGROUND

The SCW is a 36-square-mile subbasin within the Clearwater River Watershed, which is located within the RRB. Silver Creek is a stream that feeds into the Lost River, and Silver Creek is fed by the adjacent Clearbrook Creek Watershed (CCW) to the east. For this project, the CSWCD selected the lower portion of the SCW and the CCW (Figure 2) to be included in the SWAT model. The reason for selecting these two subbasins is to investigate the effects of the CCW on Silver Creek.

As defined by the U.S. Geological Survey, the lower portion of the SCW and CCW include an area of approximately 20.1 square miles. However, the SWAT-generated watershed drainage was approximately 16.44 square miles (Figure 3). According to the 2008 303d list, Silver Creek has a fecal coliform impairment.

The SCW lies in the humid continental climate zone, with average monthly temperatures ranging from 66.1°F in July to 2.9°F in January. The average annual precipitation is 23.52 in. The continental climate produces extreme annual temperature swings with very cold winters and warm to hot summers.

The SCW lies within four different ecological regions: North-Central Hardwood Forests, Lake Agassiz Plain, Northern Minnesota Wetlands, and Northern Lakes and Forests (Figure 4). An ecological region—or ecoregion—can be defined as a region that is characterized by a unique combination of geology, landforms, soils, vegetation, climate, wildlife, hydrology, and human factors (Commission for Environmental Cooperation [CEC], 1997).

Approximately 20% of the watershed is contained within the Lake Agassiz Plain, which is characterized by thick beds of clay and silt which made up the floor of former glacial Lake Agassiz approximately 10,000 years ago (U.S. Environmental Protection Agency, 2008). Because of the environment in which it was formed, the Lake Agassiz Plain is extremely flat and, historically, poorly drained. The native tallgrass prairie of the region has been replaced by intensive row crop agriculture. The North-Central Hardwood Forest ecoregion comprises approximately 20% of the watershed. This ecoregion is characterized as a transition zone between the predominantly forested Northern Lakes and Forests to the north and the agricultural ecoregions to the south and contains a patchwork of vegetation and land use, including forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations (U.S. Environmental Protection Agency, 2008). Another 52% of the watershed is characterized by the Northern Lakes

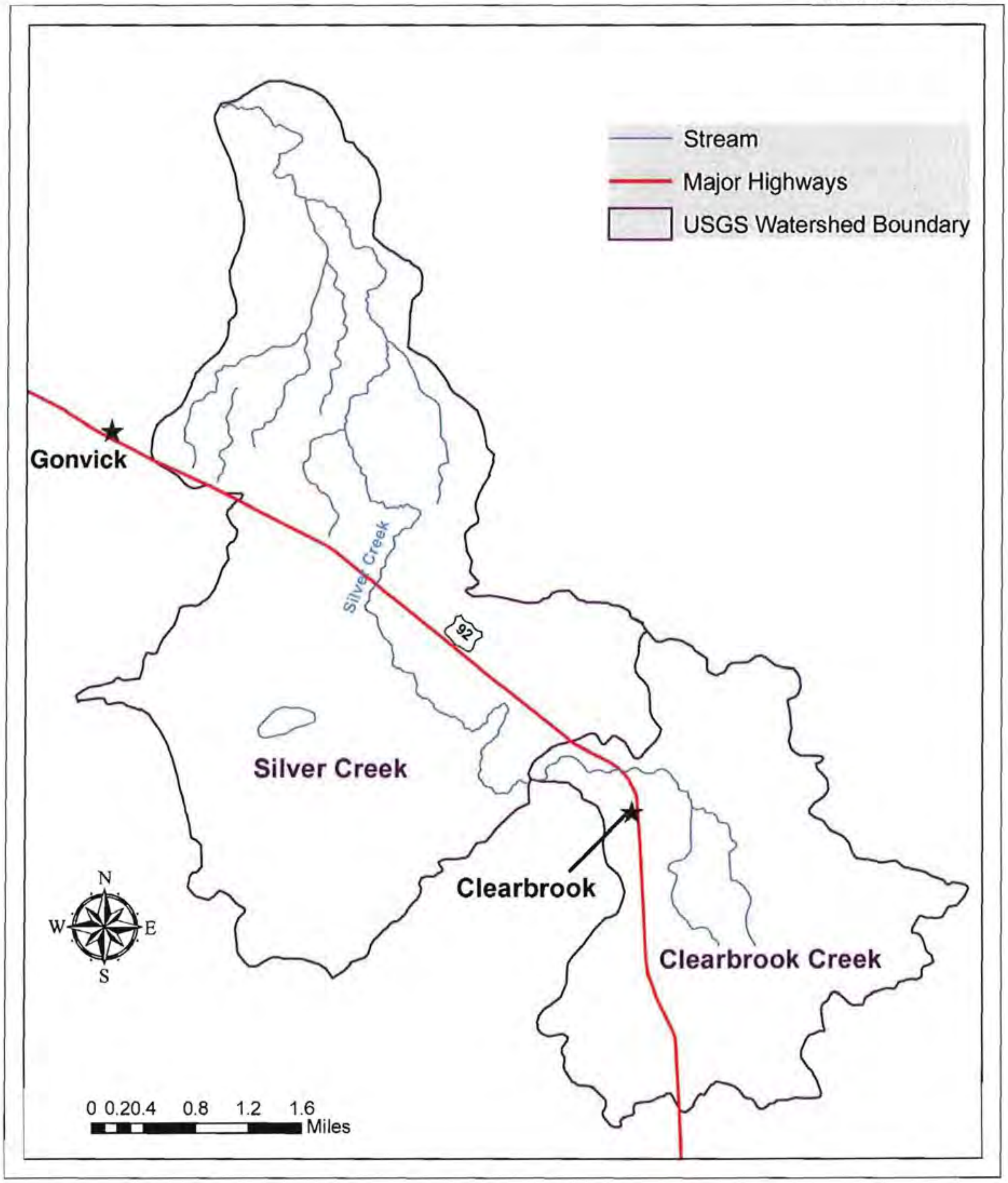

Figure 2. SCW and CCW.

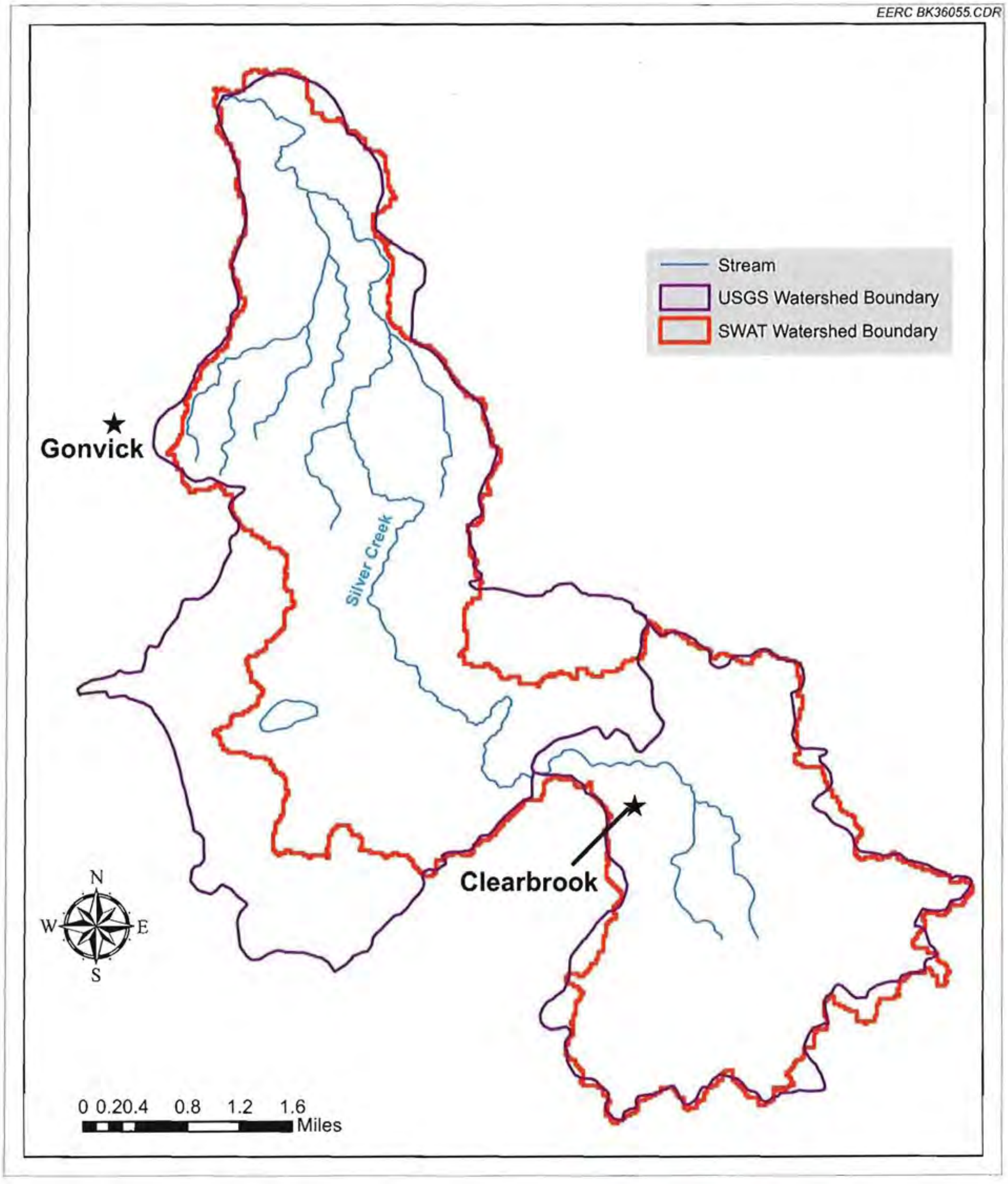

Figure 3. Comparison of USGS and SWAT watershed boundaries.

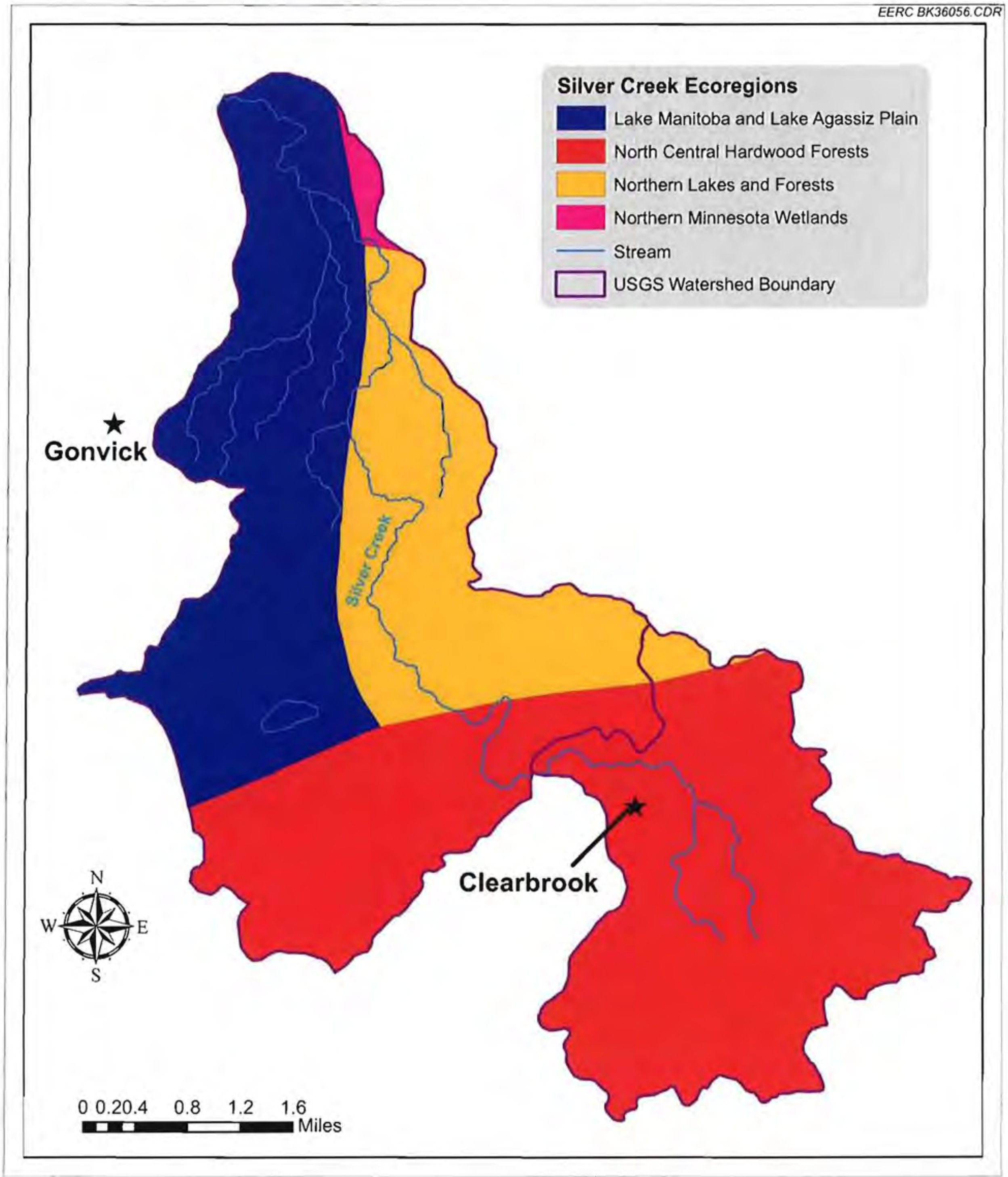

Figure 4. Ecoregions located within SCW.

and Forests ecoregion. This ecoregion comprises glacial soils, coniferous and northern hardwood forests, numerous ponds and potholes, and a variety of hummocky features formed by glaciers (U.S. Environmental Protection Agency, 2008). While the soils in the region are generally thicker than those to the north, they typically lack the arability of soils in adjacent ecoregions to the south (U.S. Environmental Protection Agency, 2008). The remaining 8% of the watershed is contained within the Northern Minnesota Wetlands ecoregion. This region is characterized by boreal forests and numerous marshes and swamps that reside in what were previously glacial lakes. Most of these areas are sparsely inhabited by humans (U.S. Environmental Protection Agency, 2008).

3.0 MATERIALS AND METHODS

3.1 Description of SWAT

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

1. How much runoff can be generated from a precipitation event

2. What is the loading of constituents at a particular location within a watershed

3. Where are the major contributors to sediment and nutrient loading located

4. What changes in flow or loading can be expected from adopting alternative land uses and watershed practices

5. How climate conditions affect loading

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

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

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

The hydrologic cycle is the driving force in model simulations. The weather data input to the model (including precipitation, air temperature, wind speed, and humidity) is used to predict the interaction of precipitation (snowfall or rainfall) with the landscape and estimate the amount of runoff, infiltration, evaporation, transpiration, etc. (Figure 5), that occur in each subbasin. Based on the estimated runoff and the physical characteristics of the landscape (such as soils, topography, and land use), SWAT calculates the amount of sediment, nutrient, and pesticide loading to the main channel in each subbasin. The model then predicts the movement of water, sediment, nutrients, and other water quality components through the channel network of the watershed to the outlet (Figure 6).

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

3.1.1 Rainfall Runoff Estimation

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

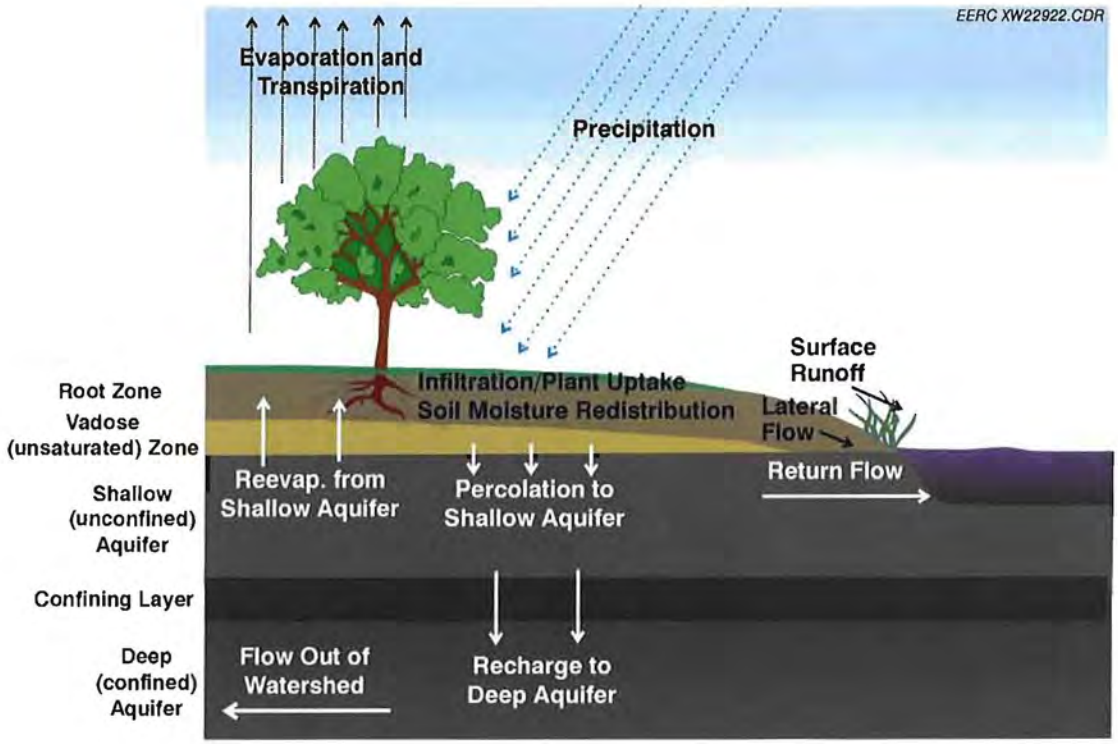

Figure 5. Hydrologic factors modeled within SWAT (modified from Neitsch et al., 2002, http://ftp.brc.tamus.edu/pub/swat/doc/swat2000theory.pdf).

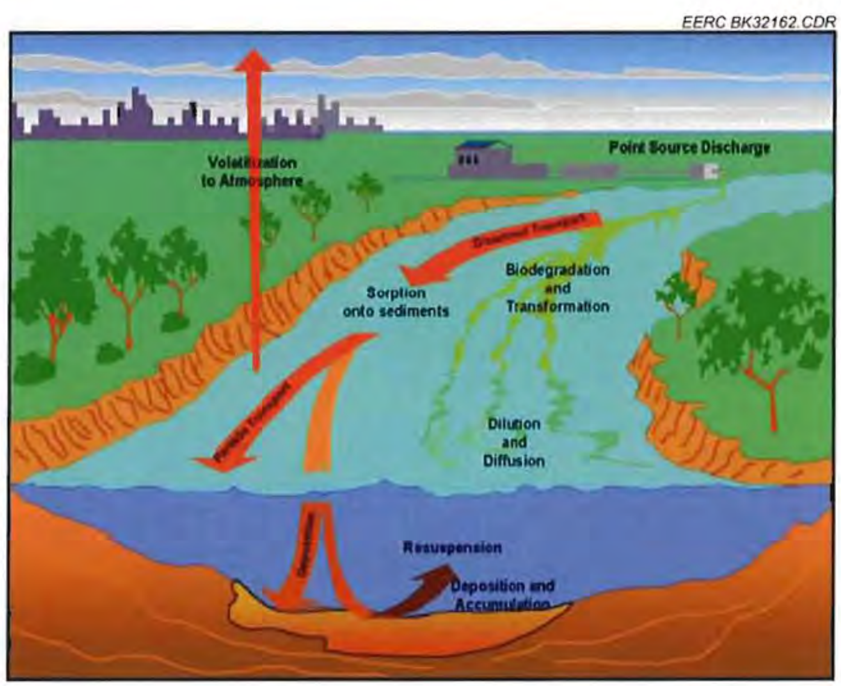

Figure 6. Routing phase of the SWAT model (Neitsch et al., 2002).

as model input as well. Further, SWAT uses a modified rational method to convert estimated surface runoff into corresponding flow rates.

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

3.1.2 Rainfall and Snowmelt

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

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

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

3.1.3 Flow Routing

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

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

3.1.4 Erosion and Sediment Transport

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

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

3.1.5 Simulation of Other Parameters

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

3.1.6 Simulating Effects of Watershed Management Practices

SWAT can simulate the effects of various agricultural and watershed management practices. These practices include the following:

- Land use changes
- Agricultural conservation practices (e.g., no-till, reduced-till, and field buffers)

- Tile drainage
- Nutrient management
- Wetland restoration
- Stream restoration
- Riparian buffering (note: depending on the desired level of detail needed to evaluate this option, SWAT may need to be run in conjunction with the Riparian Ecosystem Management Model).

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

3.2 Data Inputs

The following describes the primary data sets used to develop and calibrate the Silver Creek SWAT model.

Topographic Data: The 30-meter USGS National Elevation Dataset (NED) was used to represent the topography of both subbasins. NED is a raster product assembled and designed to provide national elevation data in a seamless form with a consistent datum, elevation unit, and projection (U.S. Geological Survey, 2006).

Stream Location Data: The USGS National Hydrography Dataset (NHD) is a comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs, and wells. This data set was used as the reference surface water drainage network to delineate the subbasins within the watershed.

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

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

Soil Data: Soil data for the watershed was incorporated using SSURGO (Soil SURvey GeOgraphic) data, a data set compiled and distributed by the USDA Natural Resources

Conservation Service (NRCS). SSURGO is the most detailed geographic soil database available, containing digital data developed from detailed soil survey maps that are generally at scales of 1:12,000, 1:15,840, 1:20,000, 1:24,000, or 1:31,680.

Stream Flow Data: Typically, USGS daily flow data are used for model calibration and validation. The SCW does not have flow data available within its watershed boundaries. However, EERC has completed a SWAT model for the Clearwater River watershed, and these data were incorporated into the Silver Creek project and used for calibration.

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

Non-Point-Source Inputs: While SWAT automatically estimates the amount of sediment and nutrient transport from the land as a result of agricultural practices or natural land use, it does not automatically estimate the contribution of non-point sources of pollution from grazing or feedlot operations. In order to account for these operations in the model, data on the location and size of registered feedlots were obtained from the MPCA and the CSWCD (Figure 7). These data contained information on the number and type of animal units within Clearwater County. The assumptions made with the cattle operations will be discussed later in this document.

4.0 DEVELOPMENT AND CALIBRATION OF THE SCW MODEL

The previously described data sets were used to develop and calibrate the SCW SWAT model. This entailed delineation of the watershed into smaller subbasins and HRUs, incorporation of point-source data, import of the climate data from the weather station used, adjustment of various model parameters to best represent the physical characteristics of the region modeled, and model calibration using observed data. The following sections describe each of the steps taken to develop and calibrate the model.

4.1 Model Development

4.1.1 Watershed Delineation

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

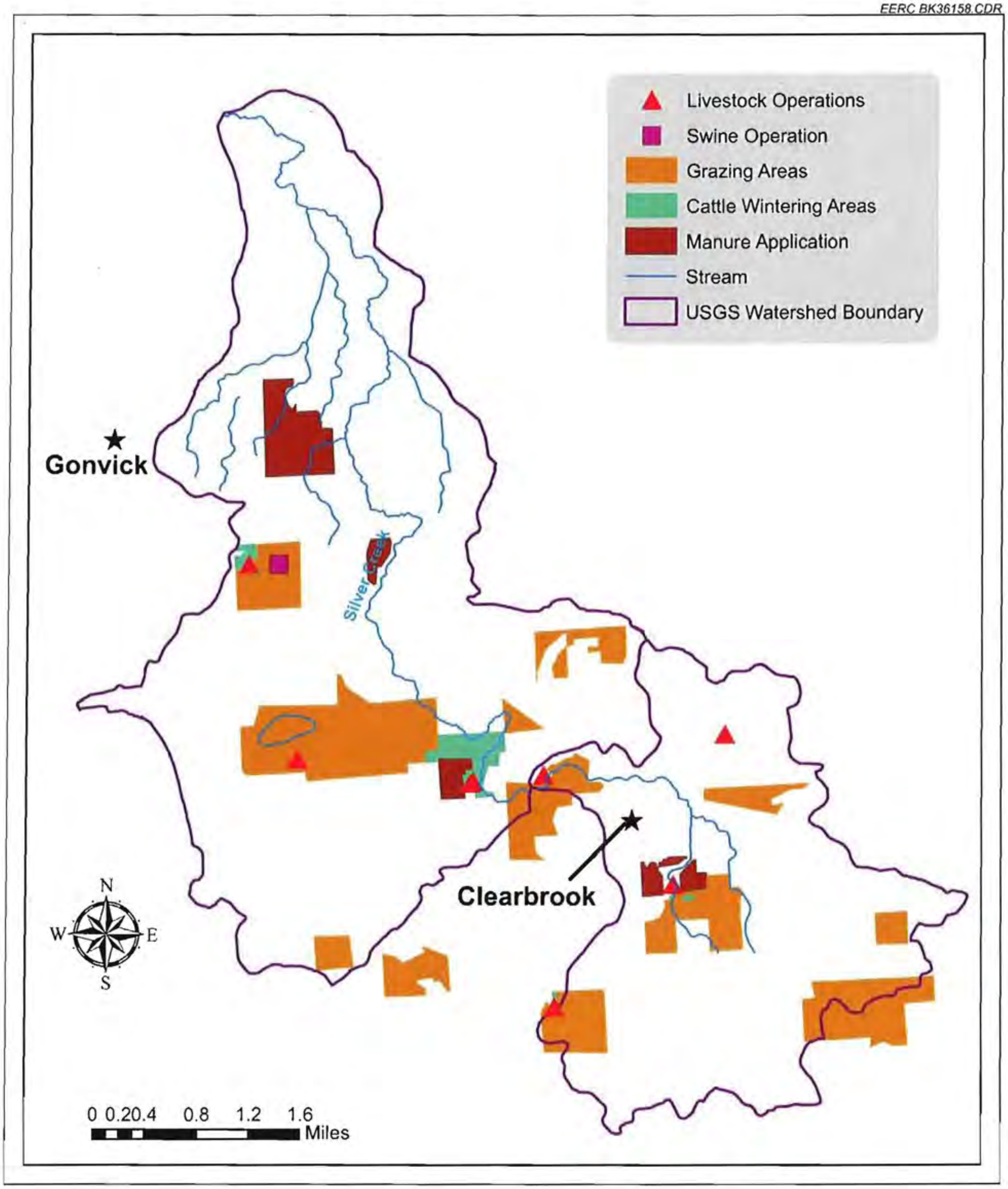

Figure 7. Locations of cattle-related and swine-related activities.

Subbasins were defined based on the topographic information contained within the NED and based on the stream locations defined by the NHD. A trial-and-error approach was used during this step to ensure that the subbasins were relatively similar in size and to ensure that the subbasin outlets were correlated to the USGS gage stations and most of the MPCA water quality station locations. A total of 62 subbasins with an average area of 9.76 km^2 (3.77 mi^2) were defined within the watershed. The location and number of each subbasin are shown in Figure 8.

4.1.2 HRU Delineation

As previously described, a HRU is a smaller unit defined within each subbasin that is a unique combination of land use, soil type, and slope. Figures 9–11 show the distribution of land use, soils, and slopes used to define the HRUs within the SCW. Table 1 shows the percentage of land use within the watershed. Table 1 lists the soil types that comprise more than 0.5% of the total watershed area (out of a total of 24 soils types located within the watershed), and Table 2 lists the land uses found in the SCW.

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

Within the SCW model, the following threshold values were used for each of the three categories:

- Land use: 15%
- Soil type: 20%
- Slope: 18%

This resulted in the formation of 653 HRUs throughout the entire watershed or an average of 10.53 HRUs per subbasin.

4.1.3 Climate Data

One weather station was used to provide precipitation and temperature data input to the model. The National Weather Service station (213206) is located southeast of Gonvick and is shown in Figure 12. Based on the data set, the period of record of climate data incorporated into the model ranges from January 1, 1986, to July 31, 2008. Given the long record of data available from this station, a significantly longer time period of data could have been incorporated into the model; however, a time period of 22 years seemed more than sufficient for the intended use of the model.

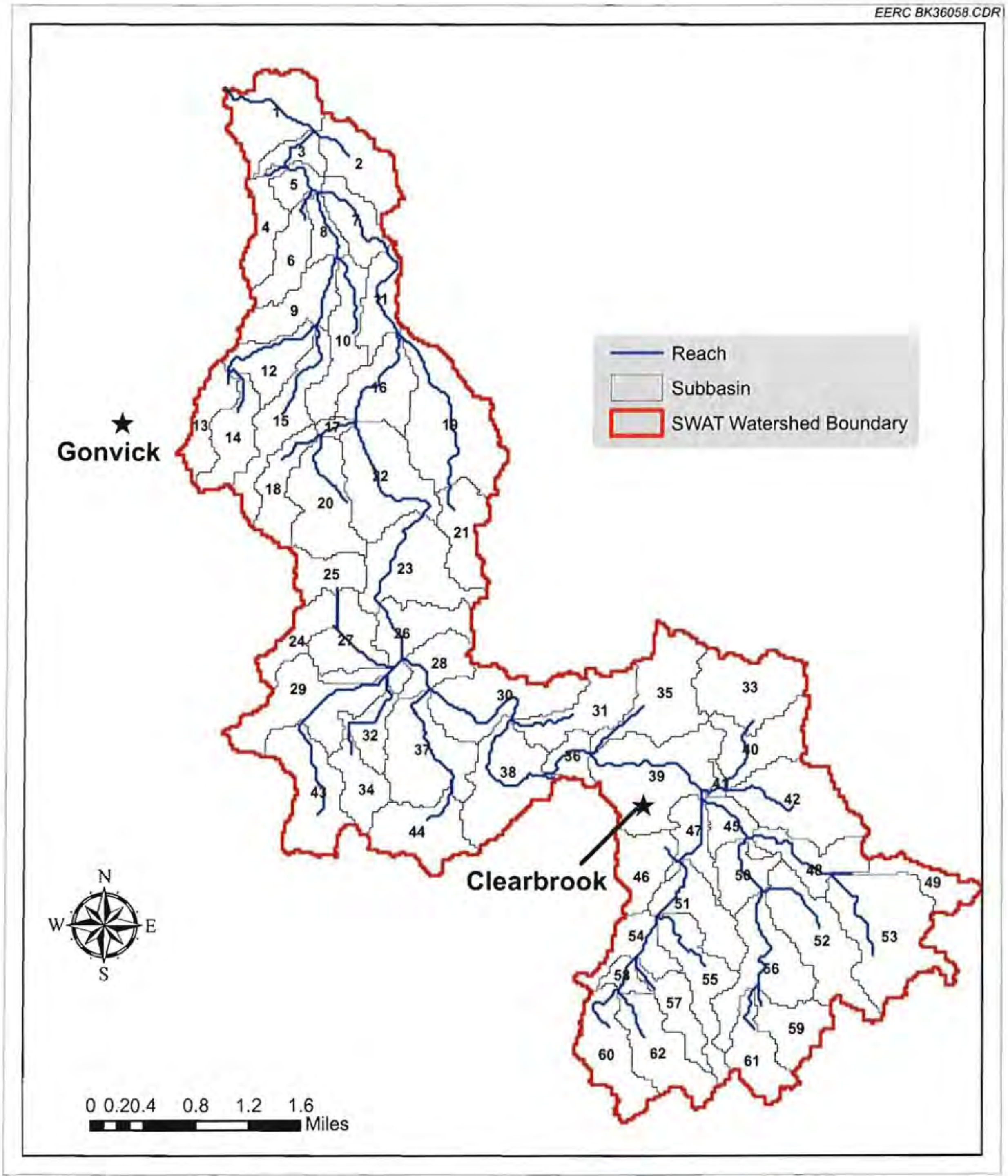

Figure 8. Silver Creek SWAT-delineated watershed and subbasin boundaries.

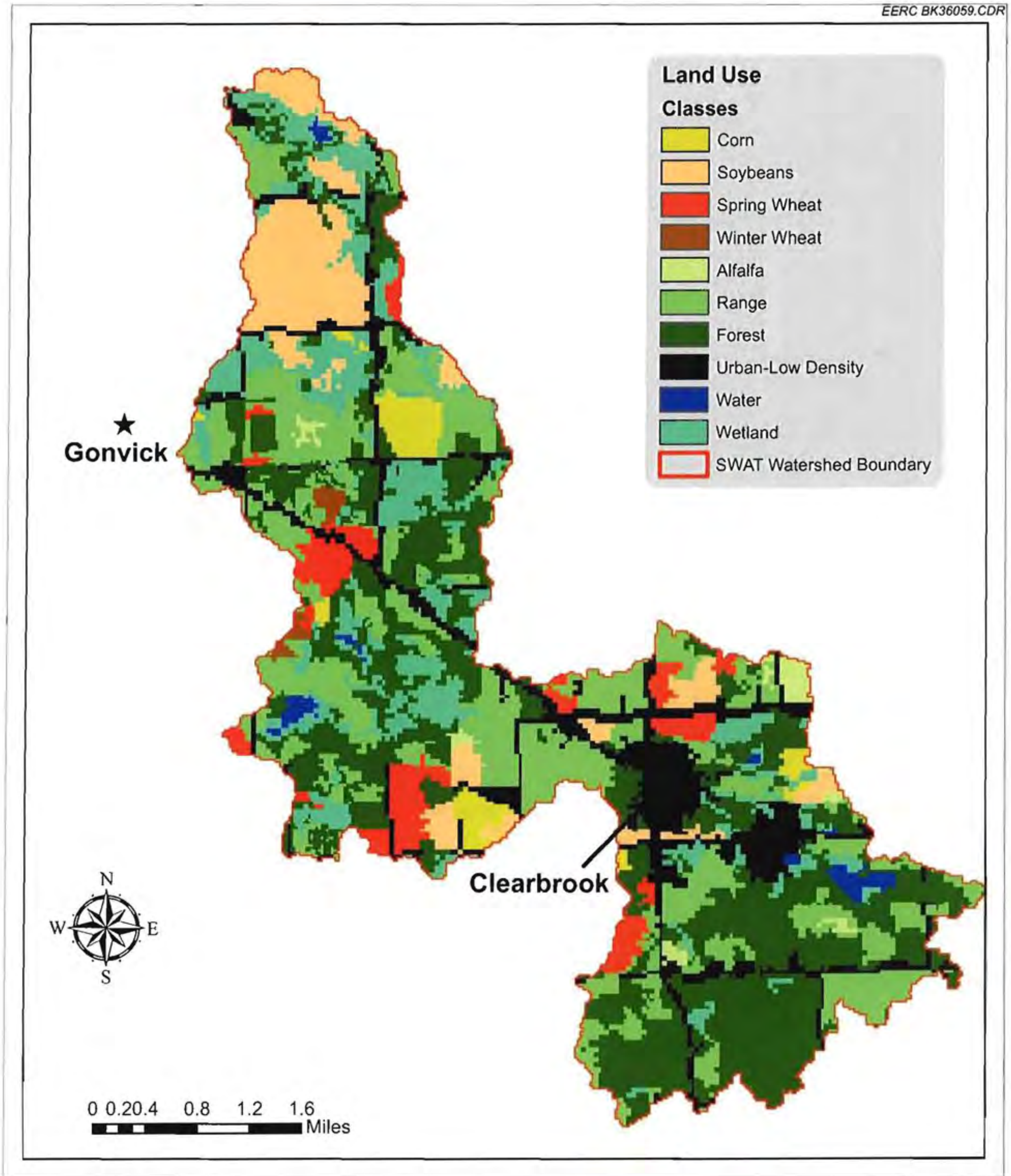

Figure 9. Land use distribution within SCW.

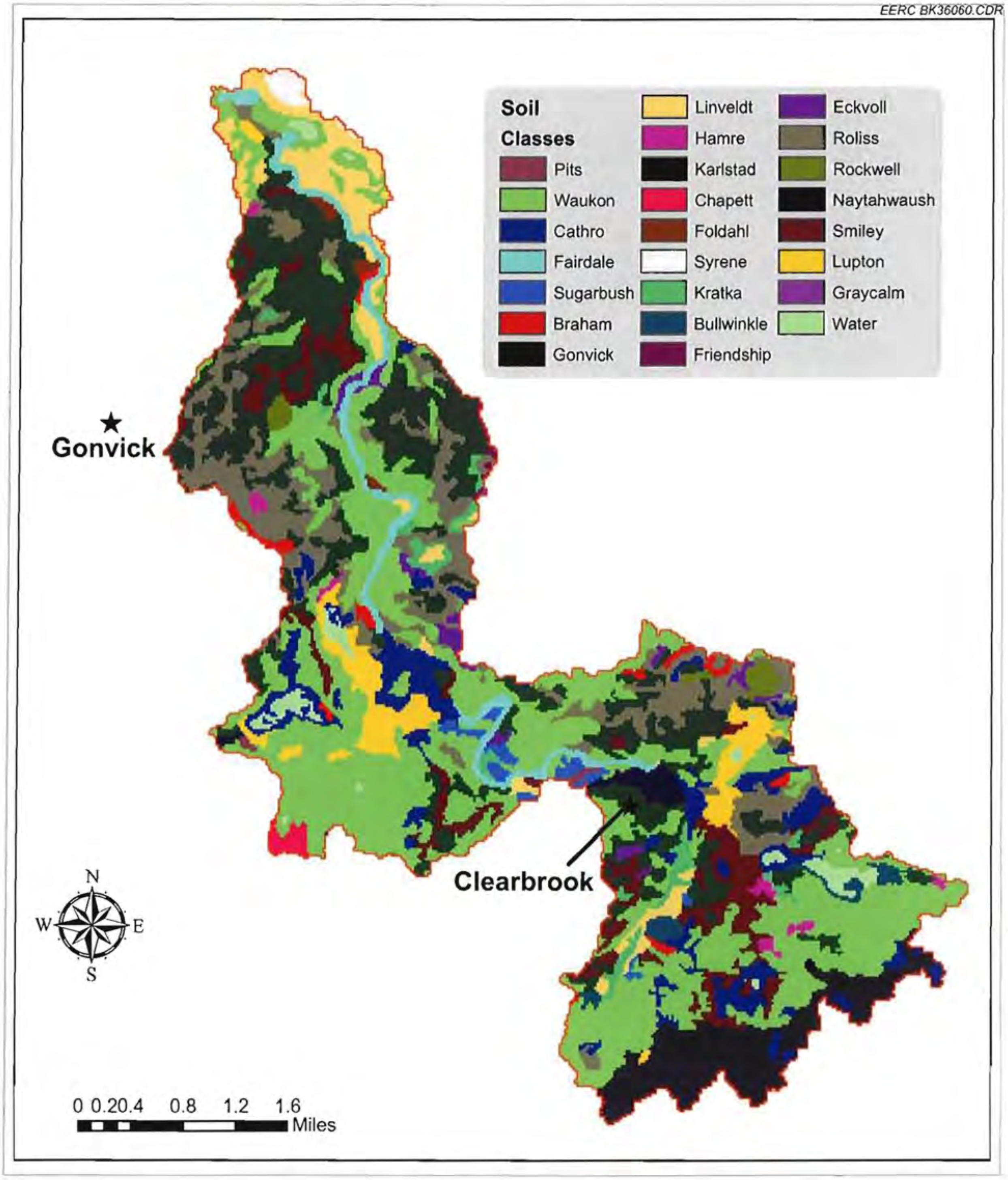

Figure 10. Soil distribution within SCW.

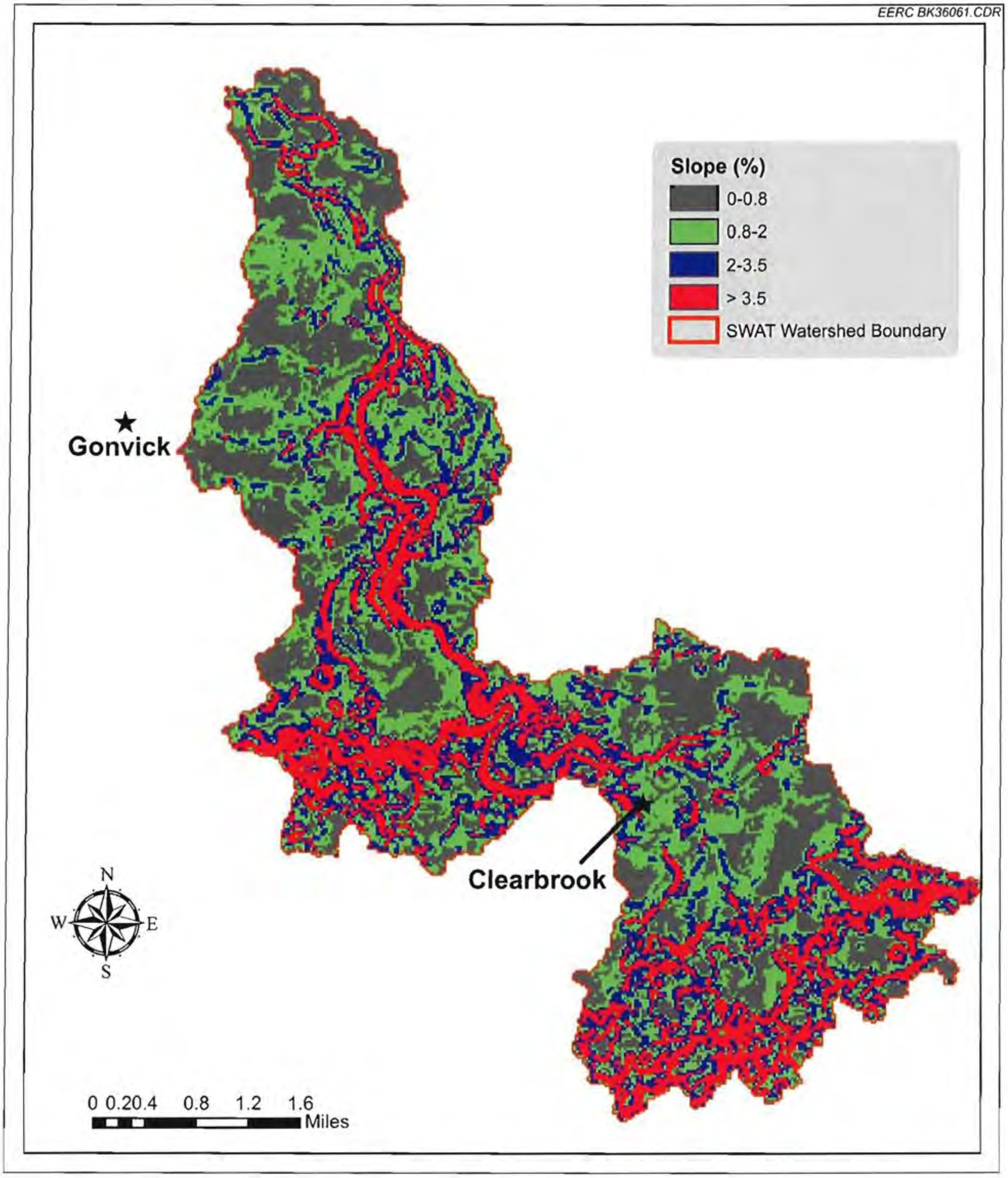

Figure 11. Slope distribution within SCW.

Table 1. Soil Types in SCW

Soil Type	Area, acres	% of Watershed Area
Waukon	3356.2	31.9
Gonvick	1977.9	18.8
Roliss	1220.4	11.6
Smiley	631.3	6.0
Cathro	631.2	6.0
Naytahwaush	568.1	5.4
Linveldt	420.8	4.0
Lupton	378.8	3.6
Fairdale	305.1	2.9
Kratka	168.3	1.6
Eckvoll	105.2	1.0
Sugarbrush	94.7	0.9
Braham	84.2	0.8
Bullwinkle	84.1	0.8
Karlstad	84.1	0.8
Rockwell	73.6	0.7
Hamre	52.6	0.5

Table 2. Land Use in SCW

Land Use	Area, acres	% of Watershed Area
Forest	3293.1	31.3
Rangeland	2535.6	24.1
Wetland	1357.2	12.9
Urban-Low Density	1315.1	12.5
Soybean	936.4	8.9
Spring Wheat	526.1	5.0
Corn	284.1	2.7
Alfalfa	119.9	1.1
Water	114.7	1.1
Winter Wheat	63.1	0.6

For the purposes of this project, a 4-year warm-up period was used at the beginning of the model simulation. This allows the model to equilibrate and estimate the initial value of certain parameter, such as soil moisture, before it starts generating results. Thus the total simulation period of the model is January 1986 to July 2008.

4.2 Flow Calibration

4.2.1 Calibration Parameters

The SCW model was calibrated using the simulated flows from the Clearwater River Watershed SWAT project previously conducted by the EERC. Flow data were compared at the

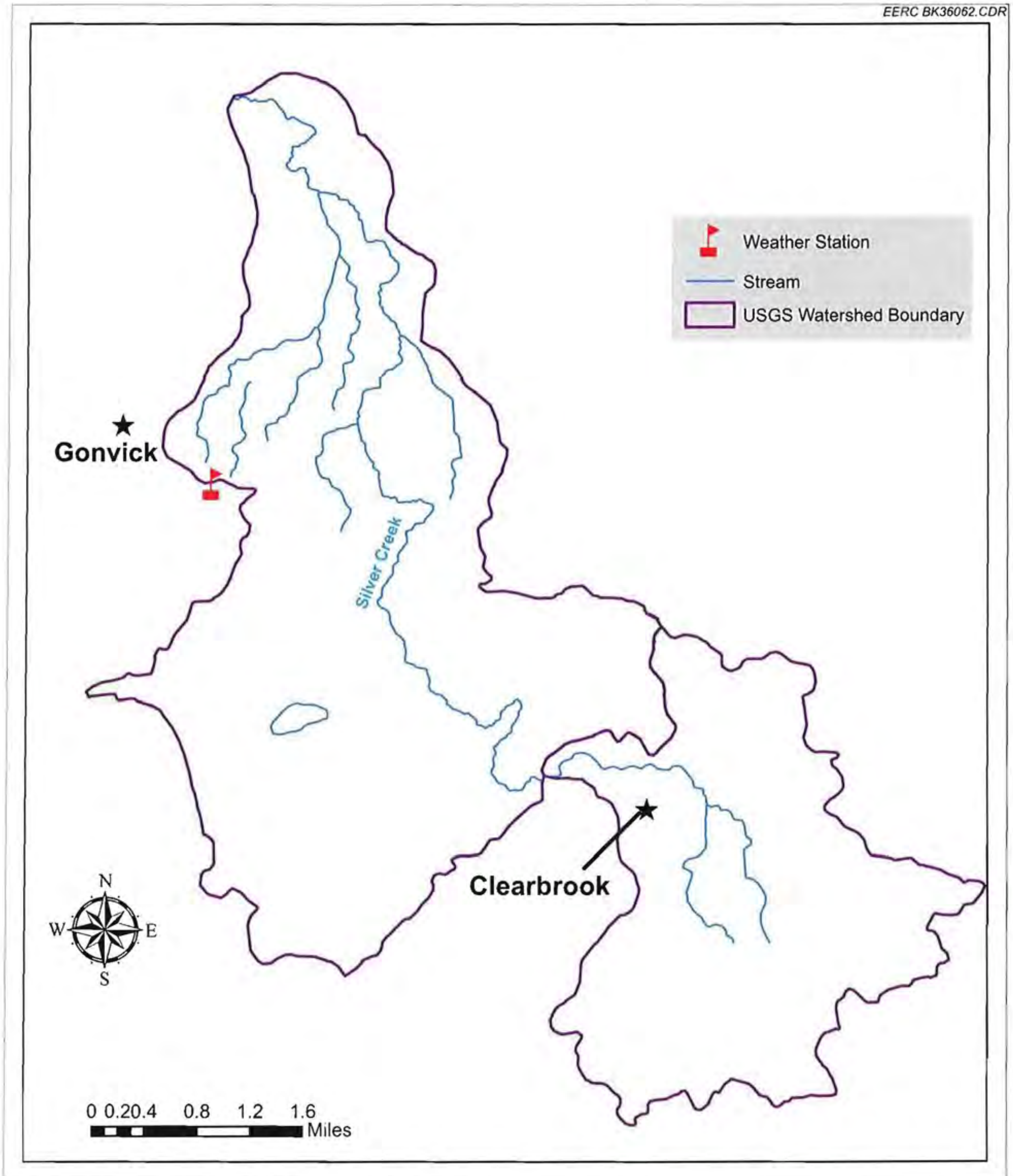

Figure 12. Location of climate station.

watershed outlet. The model was calibrated from January 1997 to July 2008 and validated from January 1990 to December 1996.

Table 3 lists the various model parameters that were adjusted to calibrate the model, including the default and calibrated parameter values. The calibration parameters were adjusted to reflect conditions most appropriate for the RRB and the SCW. Appropriate ranges for most of the sensitive SWAT model parameters had been previously determined through extensive SWAT modeling work conducted by the EERC (Kurz et al., 2007; Wang et al., 2006; Wang and Melesse, 2006; Wang and Melesse, 2005). More information on each parameter, such as the assumptions and equations used to determine the parameter, can be found in the SWAT Input/Output File Documentation (Neitsch et al., 2005), available online at www.brc.tamus.edu/swat/doc.html.

4.2.2 Measures of Model Performance

Because of the lack of available flow data within the SCW, the Silver Creek SWAT model was calibrated by utilizing flow information from the Clearwater River watershed SWAT model. The flow at the SCW outlet was compared to flow from the Clearwater SWAT model (Figure 13). The predicted baseflows matched extremely well throughout the calibration period. The timing of predicted peaks also matched consistently. The magnitude of the higher peak flows tended to be underpredicted in the model. However, most of the smaller peak flows did match very well within the calibration period. The underpredicted peaks are not a great concern because this is a comparison of flows from another model. The Clearwater River SWAT model did have peak flows that were overestimated, so the Silver Creek SWAT model may be accurately representing those peak flows that appear to be underestimated.

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

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

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

Table 3. Parameters Adjusted to Calibrate the Silver Creek SWAT Model

Parameter	Default Value	Calibration Value	Description
SFTMP	1	1.5	Snowfall temperature, °C
SMTMP	0.5	0.8	Snowmelt base temperature , °C
SMFMX	4.5	1.5	Melt factor for snow on June 21 (mmH_2O/°C-day)
SMFMN	4.5	3.5	Melt factor for snow on December 21 (mmH_2O/°C-day)
TIMP	1	0.25	Snowpack temperature lag factor
SNOCOVMX	1	25	Minimum snow water content that corresponds to 100% snow cover (mmH_2O)
SNO50COV	0.5	0.3	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover
IPET	1	0	Potential evapotranspiration (PET) method: 0 – Priestley–Taylor method; 1 – Penman–Monteith method 2 – Hargreaves method; 3 – manually input PET values
ESCO	0.95	1	Soil evaporation compensation factor
EPCO	1	0.1	Plant uptake compensation factor.
SURLAG	4	1	Surface runoff lag coefficient
IRTE	0	1	Channel water-routing method: 0 = variable storage method; 1 = Muskingum routing method
MSK_CO1	0	0.5	Muskingum calibration coefficient used for normal flow
MSK_CO2	3.5	1.1	Muskingum calibration coefficient used for low flow
MSK_X	0.2	0.2	Muskingum weighting factor used to control the relative importance of inflow and outflow in determining the storage in a reach
ALPHA_BF	0.048	0.009	Baseflow alpha factor (days)
GWQMIN	0	500	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH_2O)
GW_REVAP	0.02	0.09	Groundwater reevaporation coefficient
REVAPMN	1	100	Threshold depth of water in the shallow aquifer for reevaporation or percolation to the deep aquifer to occur (mmH_2O)
RCHRG_DP	0.05	0.25	Deep aquifer percolation fraction
CN2	Varies	+5%	Initial SCS runoff curve number for moisture condition II
CH_K1	0.5	16	Effective hydraulic conductivity in tributary channel alluvium (mm/hr)
CH_N1	0.014	0.02	Manning's "n" value for the subbasin tributary channels
CH_K2	0	15	Effective hydraulic conductivity in main channel alluvium (mm/hr)
CH_N2	0.014	0.02	Manning's "n" value for the main channel in each subbasin
CH_EROD	0	0.15	Channel erodibility factor
CH_COV	0	0.3	Channel cover factor
ALPHA_BNK	0	0.2	Base flow alpha factor for bank storage, days

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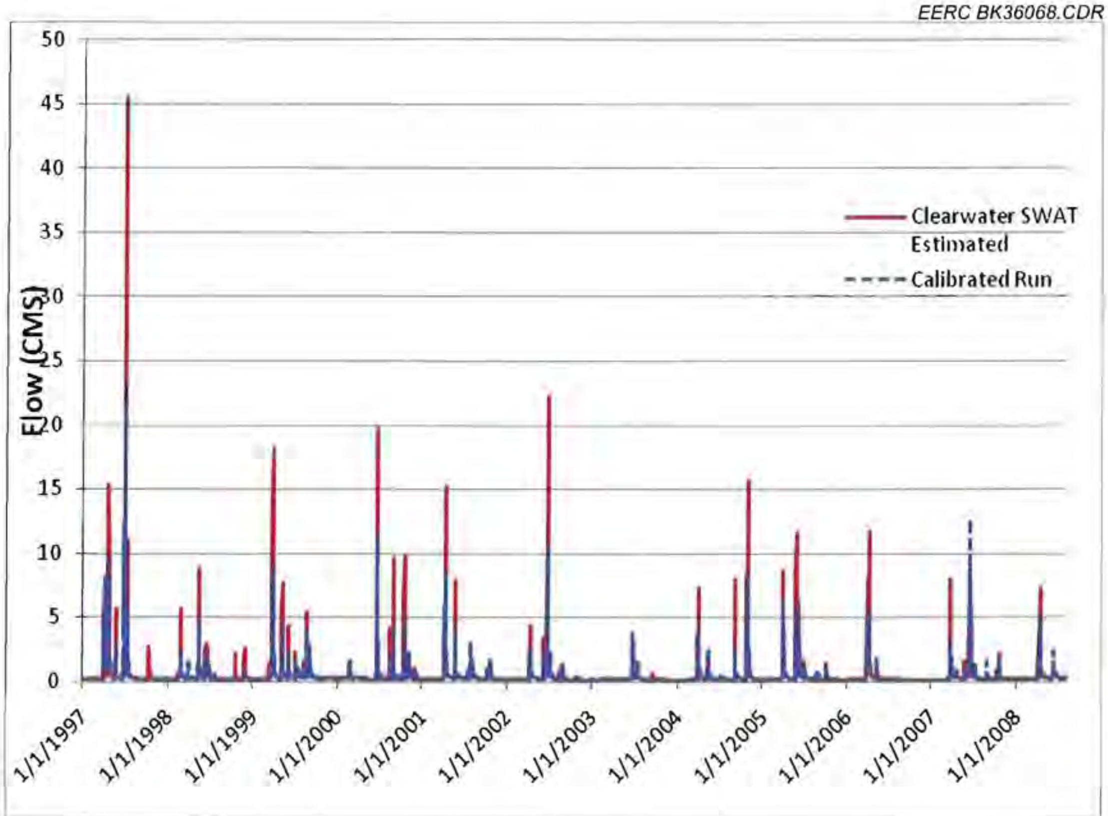

Figure 13. Comparison of Clearwater River SWAT-estimated flow versus model-predicted flow for calibration period at SCW outlet.

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

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

The D_{vj} is a measure of how the predicted annual discharge differs from the measured annual discharge. It is computed as:

$$D_{vj} = \frac{\sum_{i=1}^{n_j} Q_{simi}^{j} - \sum_{i=1}^{n_j} Q_{obsi}^{j}}{\sum_{i=1}^{n_j} Q_{obsi}^{j}} \times 100\%$$

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

As seen in Table 4, the NSE values for the calibration period of the SCW model range from 0.45 to 0.72, with an average of 0.64 at the SCW's outlet. The average annual volume deviation for the calibration period of the SCW is 15.9%. Calibration gave the best and most accurate results possible.

The predicted versus observed flows for the validation period of the model for the Silver Creek outlet are shown in Figure 14. The model-predicted flows match fairly well with the observed flows. The model has a tendency to underpredict the peak flows; however, the statistical parameters calculated for the validation period of the model still look good (Table 5). As mentioned previously, underestimating the peak flows is not a concern in this case because the comparison is being done with another model that did overpredict some peak flows. The average NSE for the validation period was 0.60. The average deviation in volume was 20.29%.

Table 4. Statistical Parameters Used to Evaluate the Silver Creek SWAT Model During Calibration Period

Subbasin 1 – Watershed Outlet		
Year	Volume Deviation, %	Nash–Sutcliffe
1997	19.61	0.66
1998	25.77	0.54
1999	23.82	0.68
2000	27.20	0.65
2001	7.88	0.67
2002	15.86	0.60
2003	13.81	0.67
2004	20.56	0.65
2005	11.28	0.66
2006	14.24	0.71
2007	–25.27	0.45
2008	16.50	0.72
Average	15.90	0.64

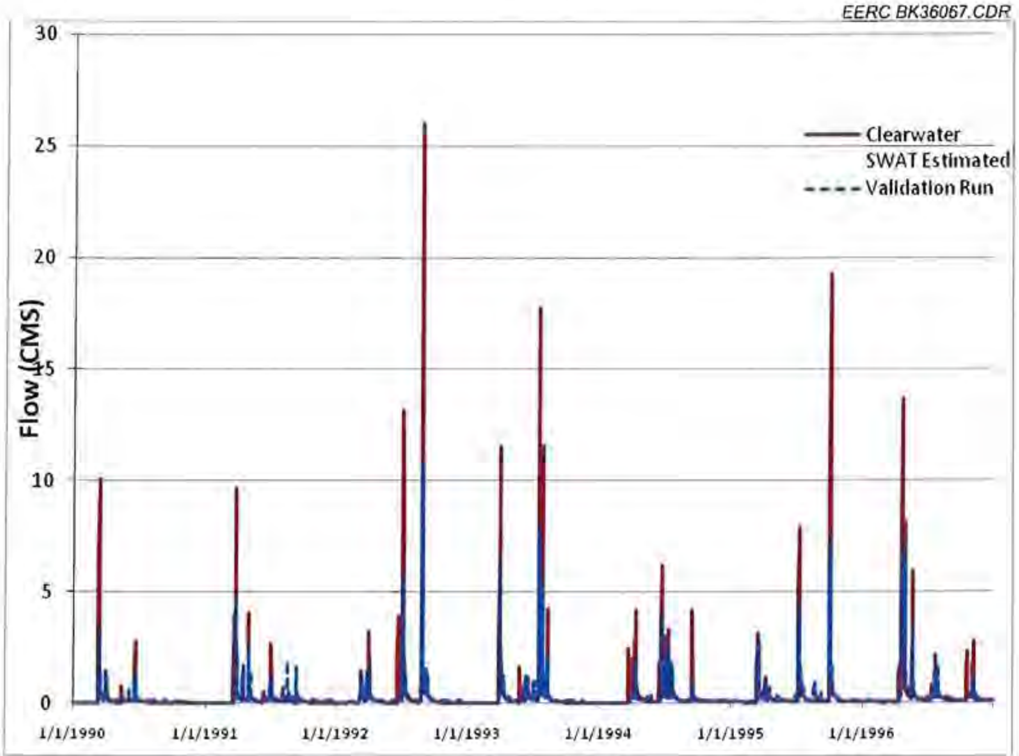

Figure 14. Comparison of Clearwater River SWAT model-estimated flow versus model-predicted flow for validation period at SCW outlet.

Table 5. Statistical Parameters Used to Evaluate the Silver Creek SWAT Model During Validation Period

Year	Volume Deviation, %	Nash–Sutcliffe
1992	29.10	0.65
1993	26.77	0.64
1994	24.70	0.58
1995	4.77	0.59
1996	20.75	0.76
Average	20.29	0.60

4.3 Fecal Coliform Comparison

Fecal coliform prediction by SWAT is an important component of this project because of the aquatic recreation impairment listed by MPCA due to fecal coliform. Minnesota state standards dictate fecal coliform concentrations are not to exceed 200 colony farming units (CFU) per 100 milliliters for more than 10% of samples collected. Extra time was spent carefully looking at the possible causes of the impairment. Cattle grazing areas, manure application fields, and livestock operation (i.e., feedlot) locations were gathered by the CSWCD and MPCA. This information was incorporated into the model.

Cattle located at the livestock operation locations were assumed to have access to waterways. In order to account for this in the model, they were treated as a "point" source. While not typically considered a point source, in order to accurately account for direct manure inputs into the streams, they were modeled as such. This approach has been successfully utilized in other hydrologic modeling studies (Baffaut and Benson, 2003; Yagow et al., 1999). It was assumed that 5% of the total manure generated by the cattle was directly input into the respective stream reach. While in actuality this number may be larger or smaller, or vary temporally, without detailed information on the amount of manure directly input into the streams, it seemed to be a reasonable estimate.

Grazing operations were included in the model in land areas as designated by the CSWCD. Cattle that were grazing on the landscape were assumed not to have direct access to stream reaches. This was done because the manure for these cattle had already been directly input from the cattles' feedlot locations, and to avoid overloading the streams, some manure had been applied to the landscape only on the grazing land. This landscape-applied manure would only contribute to streams if a significant rainfall event generated runoff. It was assumed that the cattle grazed from April to September and then moved to a different holding area during the winter months. Within the model, the summer grazing operations account for the amount of manure produced, biomass consumed, and biomass trampled per animal unit. During the winter months, manure was applied to the landscape, but no biomass consumption or biomass trampling was accounted for. The following assumptions were used in estimating the amount of manure applied within the model to simulate cattle operations:

- Assumed two animals per acre, or 4.94 animal units (AUs) per hectare (based on input from the Clearwater River TMDL stakeholder advisory group).

- MPCA defines one beef AU as 1000 pounds or 454 kilograms.

- Based on manure production and characteristic data published by the American Society of Agricultural Engineers (ASAE, 2003), the amount of wet manure produced per 1000 kg of beef is 58 kg. This translates to 26.3 kg of wet manure per beef AU (or 3.68 kg of dry manure per AU based on ASAE manure moisture content data).

- The fecal coliform content of 1 g (dry weight) of manure was estimated at 4.10×10^7 colonies (based on ASAE data).

The CSWCD also provided a list of updated septic systems. The assumption is that these septic systems would not be adding fecal material to the watershed. However, no known data were available that would indicate the contributions coming from older septic systems in the area. If this information were available, this could be added to the SWAT model. Failed septic systems are known to contribute to water quality issues and should be considered when addressing the fecal coliform impairment.

There are a few locations where producers are known to apply manure to their agricultural fields at the end of the growing season. However, exact manure application rates were unknown. Manure was applied to the landscape at the given locations in the model based on estimated manure application rates obtained from Penn State University Extension (2009). A couple of the locations of manure application coincided with rangeland areas. In this case, the manure was not applied to the landscape.

Several MPCA water quality stations are located throughout the SCW (Figure 15). One station was selected for model fecal coliform calibration because of its location and its relatively long data record. This station is the Silver Creek on CR-111 Bridge, 2 miles northeast of Gonvick (MNPCA1-S002-082).

After calibration of the bacteria-related parameters in SWAT, the model-predicted fecal coliform concentrations seem to match reasonably well with measured values (Figure 16). Some of the concentrations during higher flow events may be overestimated; however, it is difficult to determine when comparing with limited observed data.

4.4 Sediment Comparison

As previously described, the SWAT model predicts the amount of sediment eroded from the landscape into the waterways of each subbasin, and it also predicts the amount of sediment transported within each subbasin reach. The sediment transported within each subbasin reach is reported by SWAT as the amount of sediment into and out of the reach (in metric tons), as well as the sediment concentration. Because the SCW model was run on a daily time step, these values are reported for every day of the simulation period for each of the 62 stream reaches and can be used for comparison with measured water quality data.

Silver Creek Station was selected for model sediment calibration because of its location and its relatively long data record. There was one caveat with using the data from this station for model calibration. The site was sampled for TSS, while the SWAT model predicts suspended sediment. TSS accounts for any physical material entrained in the water column such as sediment, bits of detritus (i.e., leaves, vegetation), and algae, while SWAT is only able to predict sediment. Thus the sediment values predicted by SWAT may be lower than the TSS values, particularly during the later summer months when algae content in the waterways may be elevated.

The suspended sediment concentrations predicted by SWAT versus the measured TSS concentrations for the evaluation location are shown in Figure 17. SWAT values compared well to the measured TSS values consistently throughout the time period. While it is difficult to compare a limited number of sample measurements, the model sediment concentrations matched up well with the measurements. It is important to keep in mind that since the sediment concentrations are highly correlated with stream flow, any inaccuracies in prediction of the peak flow magnitude or timing will also affect sediment concentrations. Thus if the timing of peak flows from a storm event are predicted 3 or 4 days late, the highest sediment concentrations may occur 3 or 4 days later. For this reason, when observed versus measured sediment data are compared, it is acceptable to compare the predicted sediment values from within 3 days before and after the observed date (Raghavan Srinivasan, personal communication, January 2008).

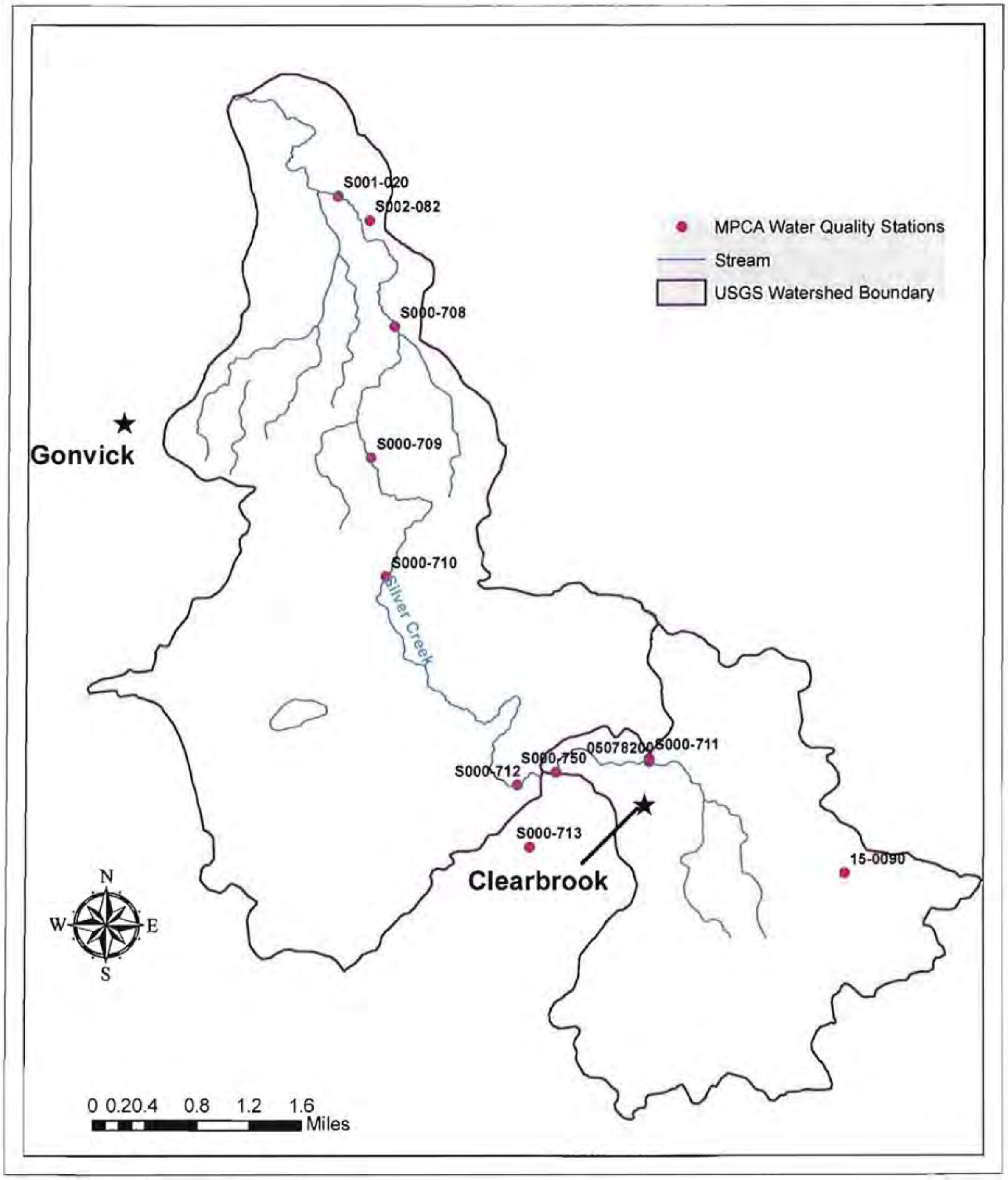

Figure 15. MPCA water quality sampling site locations.

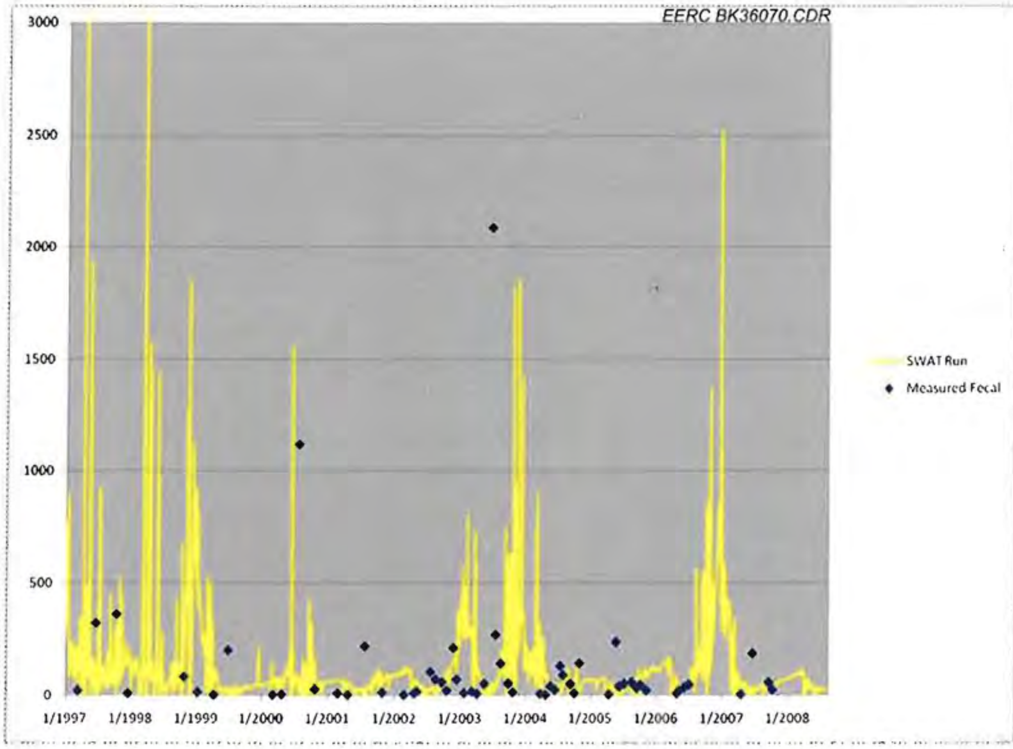

Figure 16. Comparison of measured fecal coliform and SWAT-predicted bacteria concentrations at MPCA station northeast of Gonvick.

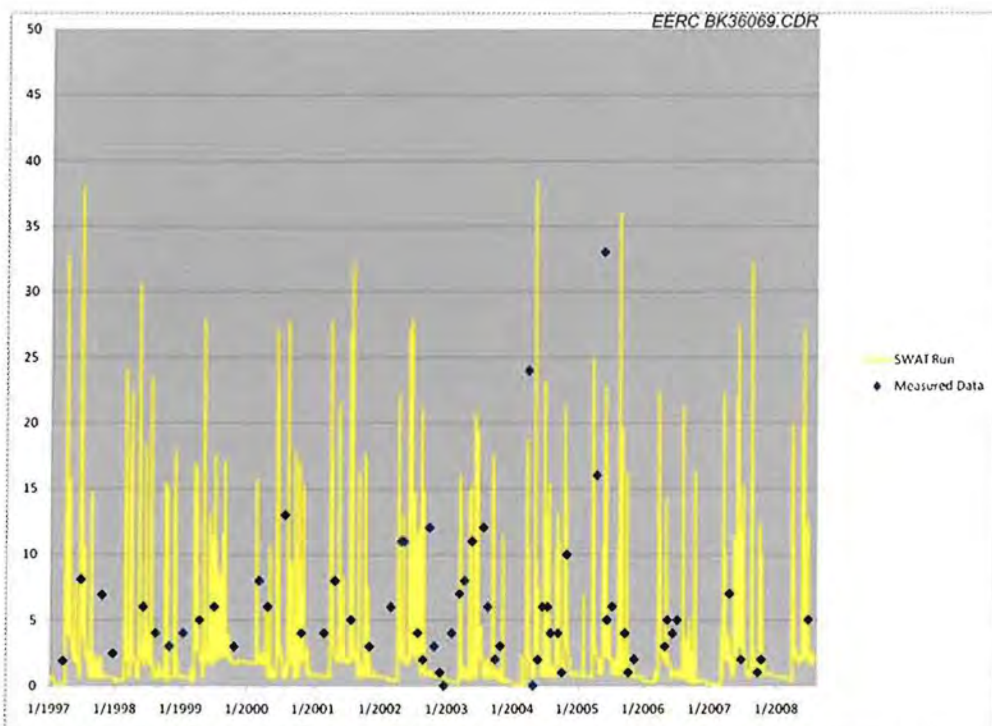

Figure 17. MPCA TSS measurements versus SWAT-estimated sediment values.

5.0 WATER QUALITY EVALUATION AND IMPLEMENTATION OF HYPOTHETICAL BMPS

The following section describes the predicted distribution of fecal coliform and sediment loading within the watershed and presents the results of several BMP scenarios. For reporting purposes, the impacts of the various BMP implementation scenarios were assessed at the outlet of the watershed; however, the data generated by the project allow for evaluation of the results within any subbasin or subbasin reach.

5.1 Fecal Coliform Loading Results

The predicted average annual fecal coliform concentrations for each stream reach are shown in Figure 18. The average annual concentration at the watershed outlet is predicted as 99.25 colony forming unit (cfu)/100 mL. The higher concentrations predicted by the model tend to be along the main channel area, especially in the CCW located north and east of the town of Clearbrook. While some reaches downstream of areas with livestock operations have elevated fecal coliform concentrations, other reaches downstream of livestock operations do not appear to be as severely impacted.

5.2 Sediment Erosion and Loading Results

The predicted average annual sediment erosion from the subbasins and the predicted sediment output, or loading, from the respective stream reaches within the SCW are shown in Figure 19. It is important to note that the subbasins with the highest overland sediment-erosion rates do not necessarily contain stream reaches with the highest sediment-loading rates. This indicates that not all of the sediment that is eroded from the landscape and into the subbasin reaches is transported out of the subbasin. Figure 20 shows the predicted annual net sediment output within each of the subbasin reaches. This was calculated by subtracting the overland sediment erosion and upstream inputs within each subbasin from the total estimated sediment being transported out of the subbasin reach. Negative values indicate that less sediment is leaving the stream reach than is coming in, indicating sediment deposition within the stream reach. Positive values indicate that, on average, more sediment is leaving a particular stream reach than is coming in from upstream loading or from overland erosion within the subbasin. This suggests that stream bank and/or bed erosion is occurring within the reach. Because sediment transport or deposition within the stream reaches is controlled by flow volume and velocity, during major flood events much of the deposited sediment can be transported out of the stream reaches and eventually out of the watershed.

5.3 BMP Implementation

To evaluate how improvements in fecal coliform and sediment loading might be achieved within the SCW, several BMP implementation scenarios were evaluated, including the following:

- Buffer strips
- Exclusion of cattle from streams and waterways

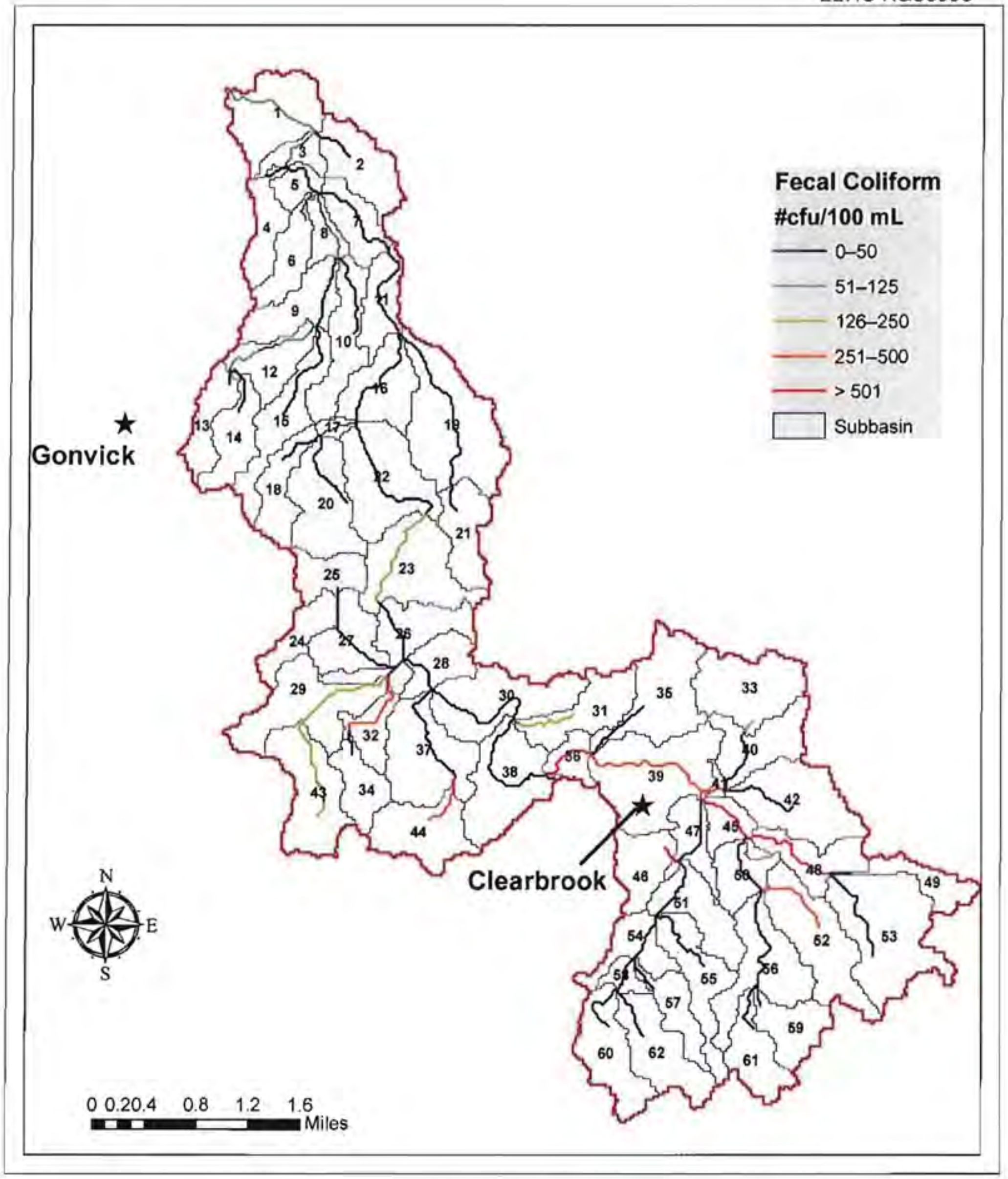

Figure 18. Fecal coliform concentrations.

- Streambank stabilization
- Conservation tillage
- Grassed waterways
- Rotational grazing
- Residue management
- Wetland restoration
- Biofuel crops
- Cover crops

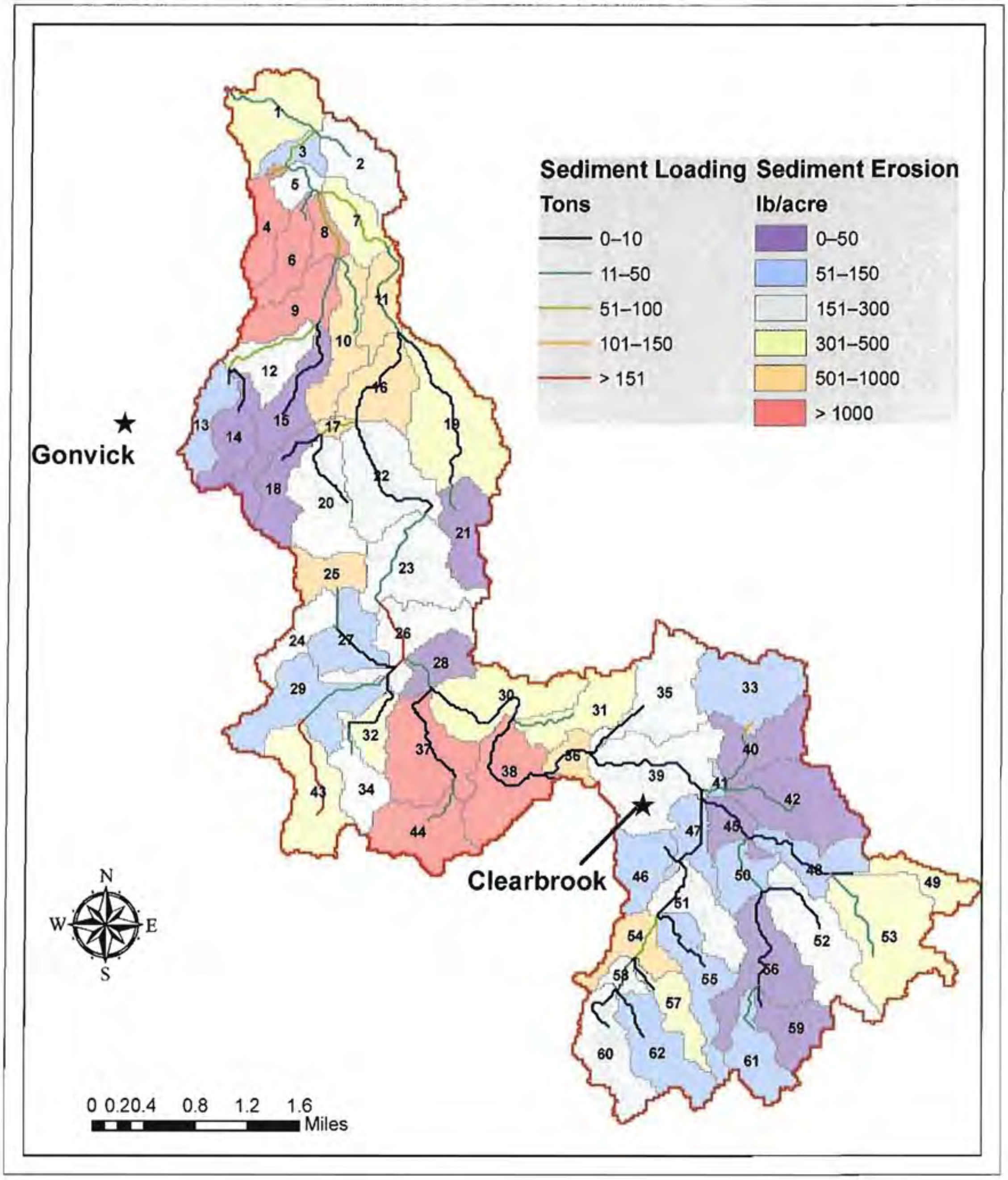

Figure 19. The estimated average annual sediment erosion from each subbasin and sediment loading within the waterways of the SCW.

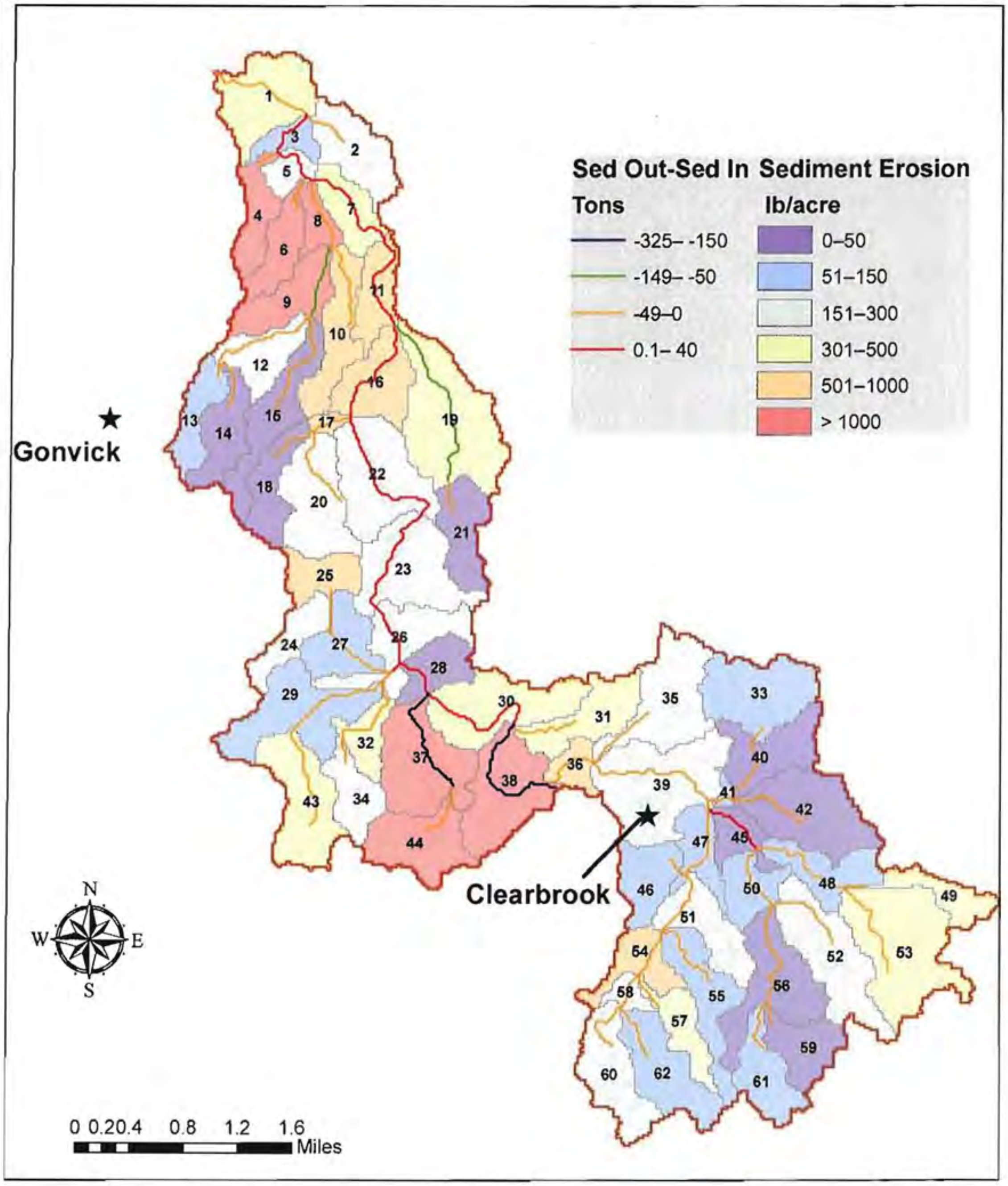

Figure 20. The estimated average annual sediment erosion from each subbasin and net sediment deposition (output minus input) within the waterways of the SCW.

For reporting purposes, the effectiveness of each measure was evaluated at the outlet of the watershed. A brief description of how each of these practices was implemented in the model is described below. Table 6 indicates the location (subbasin) and size of each BMP implemented.

Buffer Strips: Field buffers typically range in width from 30 to 120 feet (Natural Resources Conservation Service, personal communication, 2008). To simulate the implementation of buffer strips within the SWAT model, 50-, 80-, and 120-foot buffers were applied to randomly selected agricultural crops in 25%, 50%, and 75% of the subbasins. At the request of the CSWCD, buffers were also applied to high-slope crop fields, which was defined as fields with a slope greater than 2%. Because of the limited number of fields fitting this criteria, there was minimal impact.

Cattle Exclusion: As discussed previously, the cattle operations, both feedlot and grazing, were considered as sources of direct fecal coliform loading. To simulate cattle exclusion practices, 40% and 100% of these direct inputs were removed. In the 40% scenario, livestock operation contributions in Subbasins 43 and 51 were removed.

Streambank Stabilization: To simulate this practice, the setting for channel erodibility was adjusted so as to limit the amount of erosion in the respective reach to negligible. This was implemented based on input from CSWCD staff indicating two possible project sites. The model is limited to installing on the subbasin level; thus length of BMP is longer than average BMP.

Conservation Tillage: The default setting of the model includes a generic spring and fall tillage practice. These practices were removed, and a generic conservation tillage operation was added in place. The conservation tillage practice includes a more shallow tillage depth as well as a lower mixing ratio. Conservation tillage was implemented on all crop fields. The results indicated that conservation tillage reduced overland sediment erosion. However, the sediment concentration reduction at the outlet was minimal. This was due to the small percentage of cropland in the watershed combined with relatively modest overland sediment erosion reduction.

Grassed Waterways: The settings for channel cover and channel roughness were adjusted to simulate this practice using values found in the literature. This practice was implemented at ten randomly selected locations in the watershed. Like streambank stabilization, the model is limited to installing on the subbasin level; thus length of BMP is longer than average BMP.

Rotational Grazing: This practice was simulated for all of the current grazing operations based on direction given by CSWCD staff. This was accomplished by rotating the cattle through two additional fields. The additional fields selected for grazing were chosen based on similar land use, area, and relatively close proximity. Biomass consumption, biomass trampled, manure rates, number of grazing days, and grazing dates were adjusted accordingly.

Residue Management: This practice was simulated by changing the harvest efficiency and eliminating the fall tillage. Harvest efficiency results in additional biomass being left on the ground. Manning's roughness coefficient was adjusted to the respective fields to a value representative of residue management. This practice was applied to all agricultural crop fields.

Table 6. Subbasin Locations and Areas for BMP Implementation Scenarios

Subbasin	Subbasin Acres	Conservation Tillage	Cons. Tillage Acres	Wetland Restoration	Wetland Area, acres	Streambank Stabilization	Channel Length, feet	Cover Crop – Soybean and Spring Wheat	Cover Crop Acres	Grassed Waterway	Grassed Waterway, total feet	Biofuel – 75% Implementation	Biofuel Acres	Buffers – 75% Implementation	Acres Protected by Buffers	Cattle Exclusion (two sites)	Cattle Exclusion (all)	Residue Management	Residue Management Acres
1	234.33	Y	122.68					Y	122.68			Y	122.68	Y	109.67			Y	122.68
2	176.81	Y	46.31					Y	46.31					Y	46.31			Y	46.31
4	117.64	Y	92.91	Y	3.94			Y	92.91			Y	92.91	Y	63.55			Y	92.91
5	59.64	Y	10.02			Y	2160	Y	10.02			Y	8.74	Y	3.08			Y	10.02
6	118.34	Y	118.34					Y	118.34			Y	118.34	Y	107.42			Y	118.34
7	122.35	Y	27.82					Y	27.82			Y	21.33	Y	27.82			Y	27.82
8	63.18	Y	63.18					Y	63.18			Y	63.18	Y	63.18			Y	63.18
9	162.19	Y	162.19					Y	162.19			Y	93.05	Y	162.19			Y	162.19
10	178.93	Y	92.88					Y	92.88			Y	92.88	Y	92.88			Y	92.88
11	120.70	Y	28.42					Y	28.42	Y	4528	Y	25.8	Y	24.68			Y	28.42
12	135.32	Y	36.66	Y	1.74			Y	36.66			Y	13.33	Y	26.32			Y	36.66
16	181.52	Y	54.27							Y	4658	Y	48.76	Y	21.66			Y	54.27

Continued . . .

Table 6. Subbasin Locations and Areas for BMP Implementation Scenarios (continued)

Subbasin	Subbasin Acres	Conservation Tillage	Cons. Tillage Acres	Wetland Restoration	Wetland Area, acres	Streambank Stabilization	Channel Length, feet	Cover Crop – Soybean and Spring Wheat	Cover Crop Acres	Grassed Waterway	Grassed Waterway, total feet	Biofuel – 75% Implementation	Biofuel Acres	Buffers – 75% Implementation	Acres Protected by Buffers	Cattle Exclusion (two sites)	Cattle Exclusion (all)	Residue Management	Residue Management Acres
19	384.03	Y	77.52	Y	4.62					Y	7612	Y	30.97	Y	61.95			Y	77.52
20	237.16	Y	67.02					Y	67.02	Y	3478	Y	67.02	Y	44.91			Y	67.02
24	104.20											Y	28.94						
25	107.74	Y	63.52					Y	63.52	Y	1640	Y	32.8	Y	63.52			Y	63.52
33	244.94																Y		
35	262.15	Y	87.88	Y	5			Y	87.88			Y	87.88	Y	45.88			Y	87.88
36	66.72																Y		
37	274.41	Y	118.85					Y	118.85	Y	4954	Y	88.02	Y	85.03			Y	118.85
38	260.74	Y	72.48			Y	5840			Y	5840	Y	72.48	Y	62.58		Y	Y	72.48
43	247.77															Y	Y		
44	199.68	Y	154.28					Y	154.28	Y	2296	Y	73.25	Y	121.42			Y	154.28
51	164.79															Y	Y		
54	118.58	Y	66.31					Y	66.31	Y	2099	Y	41.63	Y	41.63			Y	66.31
58	40.78	Y	7.53					Y	7.53	Y	1640	Y	4.26	Y	6.67			Y	7.53
Total	4,384.65		1,571.07		15.30		8,000.00		1,366.80		38,745.00		1,228.25		1,282.35				1,571.07

Wetland Restoration: A wetland was added to the landscape at four sites that were selected based on aerial imagery of the watershed. These four sites were selected randomly based on the appearance of low lying areas that may be subject to wet conditions. These sites were meant to be random and not based on the "optimum" location. No further feasibility assessment was done for these locations. The size of the possible wetland and fraction of subbasin flow through the wetland were estimated based on the aerial imagery.

Biofuel Crop: After discussion with CSWCD staff, switchgrass was selected as a biofuel crop that would be incorporated into the crop rotation. 25%, 50%, and 75% of the agricultural crop fields were randomly selected, and switchgrass was incorporated into Year 3 of each crop's rotation (each crop had 3-year rotations). Additionally, fields with greater than 2% slopes were also used as a scenario. Although the variety of switchgrass was Alamo switchgrass that would not normally be grown in the area, it was determined that the model would still simulate an appropriate growth cycle for the crop to used in this BMP scenario.

Cover Crop: Winter wheat was selected as the cover crop for this study. Winter wheat was then utilized in two scenarios: soybean fields only and soybean and spring wheat fields. Tillage and harvest practices were altered appropriately to accommodate the additional crop being planted in these fields.

5.4 BMP Implementation Results

The results of the BMP implementation scenarios are shown in Table 7 and Figures 21–34. All of the reductions shown are for the SCW outlet located in Subbasin 1. In the rotational grazing scenario, there was an increase in fecal coliform concentration. This is most likely the result of cattle being rotated into new fields that were smaller than the original grazing field. The smaller area results in higher concentrations of manure applied to the landscape, which would result in the model indicating higher fecal coliform concentrations at the outlet. In the case of cattle exclusion, by eliminating all of the livestock operation (feedlot) location contributions, reductions in fecal material were just under 100%. One should not assume this is a guarantee that fecal coliform would be completely eliminated under this scenario; however, it is clear that cattle exclusion would significantly reduce fecal coliform concentrations to meet water quality standards. The data input into the model were based on the assumption that cattle had access to the streams at these operation locations. Field verification of these operations would be important when considering actual BMP implementation on the ground. Additional fecal coliform sources should also be considered.

In the Clearwater River SWAT model, wildlife was considered within the model. Assumptions were made that waterfowl was contributing, particularly near wild rice paddies. Waterfowl were not considered in this particular study since wild rice paddies were not in this watershed. Deer population was also considered, although the calculated contributions of deer were too small for the model to consider.

Table 7. The Effectiveness of the Various BMP Implementation Scenarios as Measured at the SCW Outlet

BMP Scenario	Sediment Concentration Reduction, %	Sediment Loading Reduction, %	Fecal Coliform Concentration Reduction, %
Rotational Grazing	0.04	0.04	−1.22
Conservation Tillage	4.19	3.66	0.07
Wetland Restoration	0.18	0.28	4.08
Streambank Stabilization	9.12	1.99	0.68
Cover Crop – Soybean Only	9.80	9.78	0.49
Cover Crop – Soybean and Spring Wheat	9.50	9.15	0.91
Grassed Waterways	6.64	5.35	13.45
Biofuel – 25% Implementation	9.05	1.85	0.90
Biofuel – 50% Implementation	9.07	1.91	0.86
Biofuel – 75% Implementation	9.12	1.98	0.73
Buffer 50 ft – High Slope	0.00	0.00	0.00
Buffer 80 ft – High Slope	0.00	0.00	0.00
Buffer 120 ft – High Slope	0.00	0.00	0.00
Buffer 50 ft – 25% Implementation	8.58	10.74	0.08
Buffer 50 ft – 50% Implementation	23.08	28.33	0.08
Buffer 50 ft – 75% Implementation	23.15	28.44	0.08
Buffer 80 ft – 25% Implementation	10.14	12.52	0.08
Buffer 80 ft – 50% Implementation	28.66	34.02	0.08
Buffer 80 ft – 75% Implementation	28.78	34.18	0.08
Buffer 120 ft – 25% Implementation	10.83	13.31	0.08
Buffer 120 ft – 50% Implementation	31.47	36.68	0.08
Buffer 120 ft – 75% Implementation	31.66	36.90	0.08
Cattle Exclusion (two sites)	0.00	0.00	30.84
Cattle Exclusion (eliminate all)	0.00	0.00	100.00
Residue Management	3.87	5.36	0.47

This model was based on possible known fecal coliform contributions; however, other possible fecal coliform sources, such as failing septic systems, were not included in the model but are important to reducing fecal coliform in Silver Creek. Unknown sources from the town of Clearbrook could also be investigated.

6.0 DISCUSSION

BMP implementation costs are an important factor to consider during the planning process. When analyzing the results of the SWAT model, it is clear that certain practices provide the most benefit to water quality. Cattle exclusion, grassed waterways, and wetland restoration provided the most benefit in terms of reduction of fecal coliform at the watershed outlet. Buffer strips, streambank stabilization, cover crops, biofuels, and grassed waterways provided the most benefit

EERC BK36144.CDR

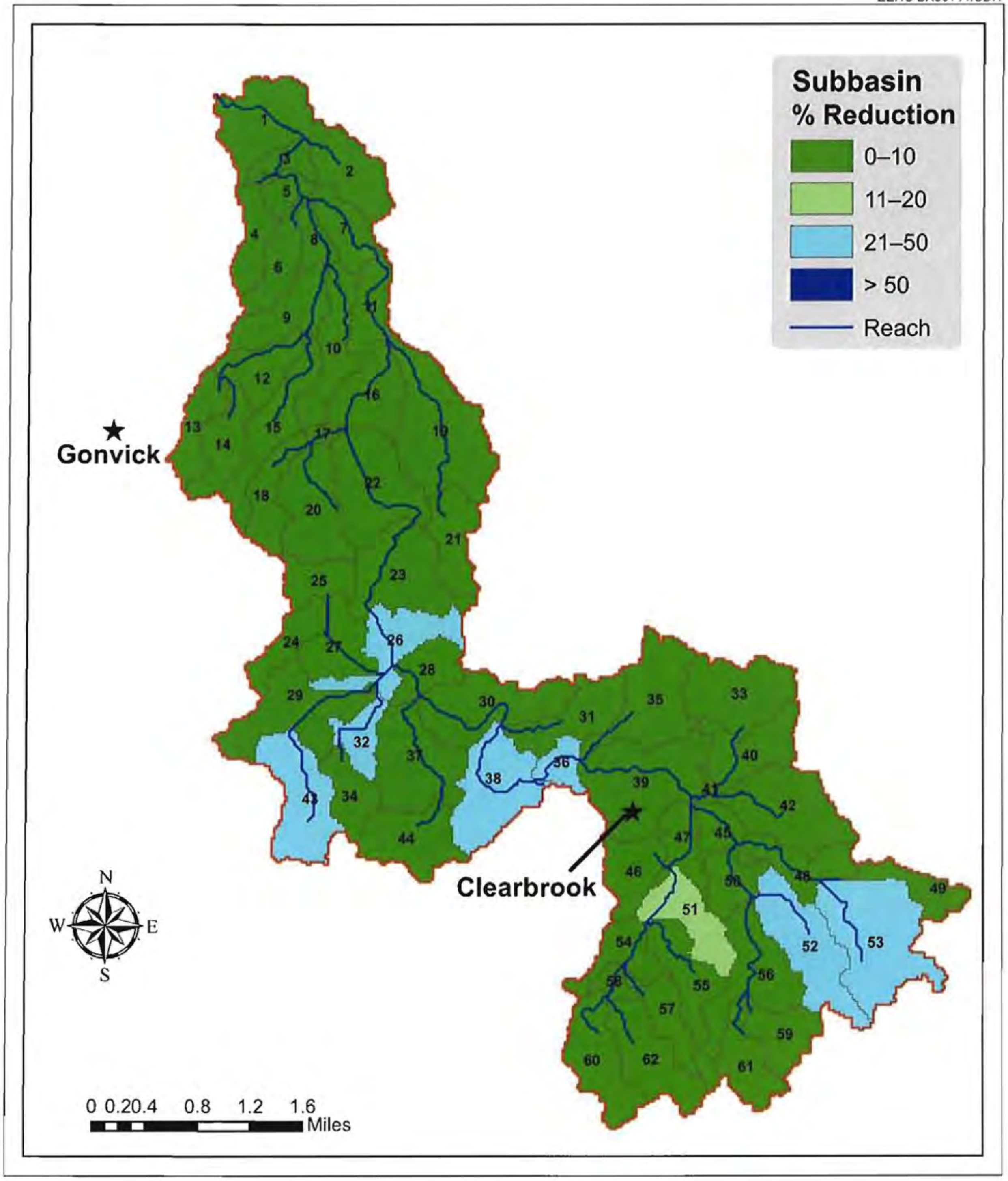

Figure 21. Predicted overland sediment erosion reductions for rotational grazing BMP implementation.

EERC BK36145.CDR

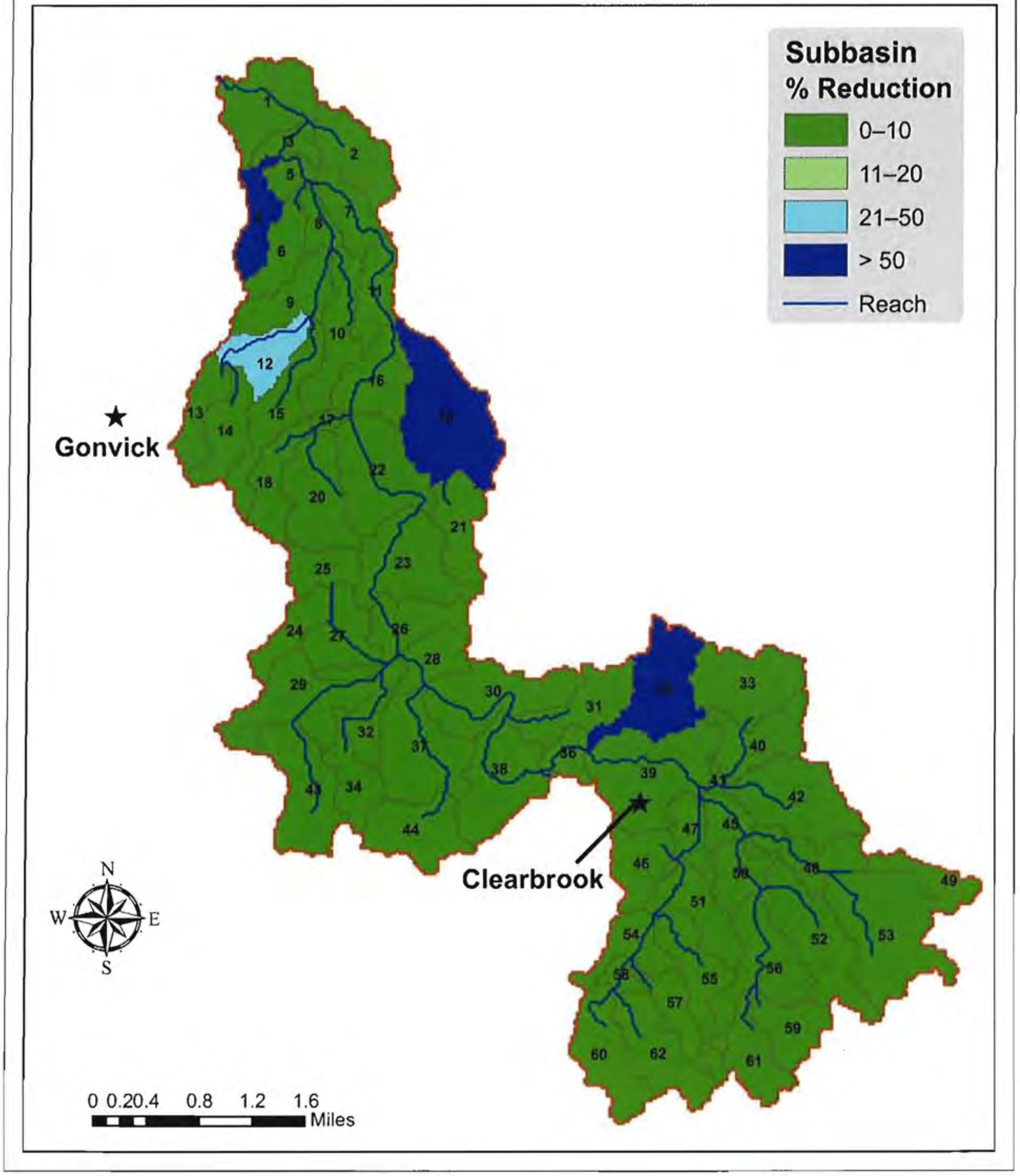

Figure 22. Predicted overland sediment erosion reductions for wetland restoration BMP implementation.

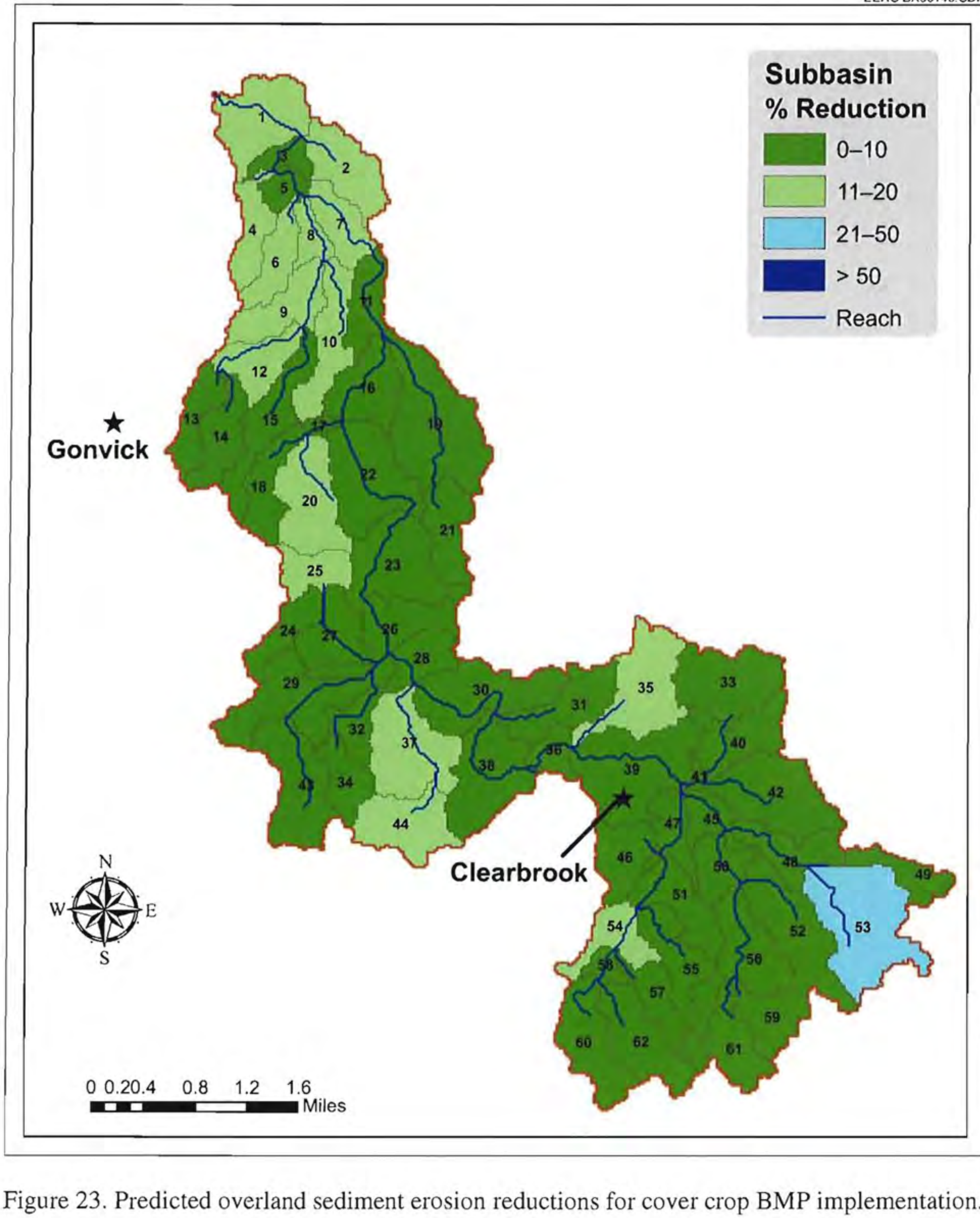

Figure 23. Predicted overland sediment erosion reductions for cover crop BMP implementation.

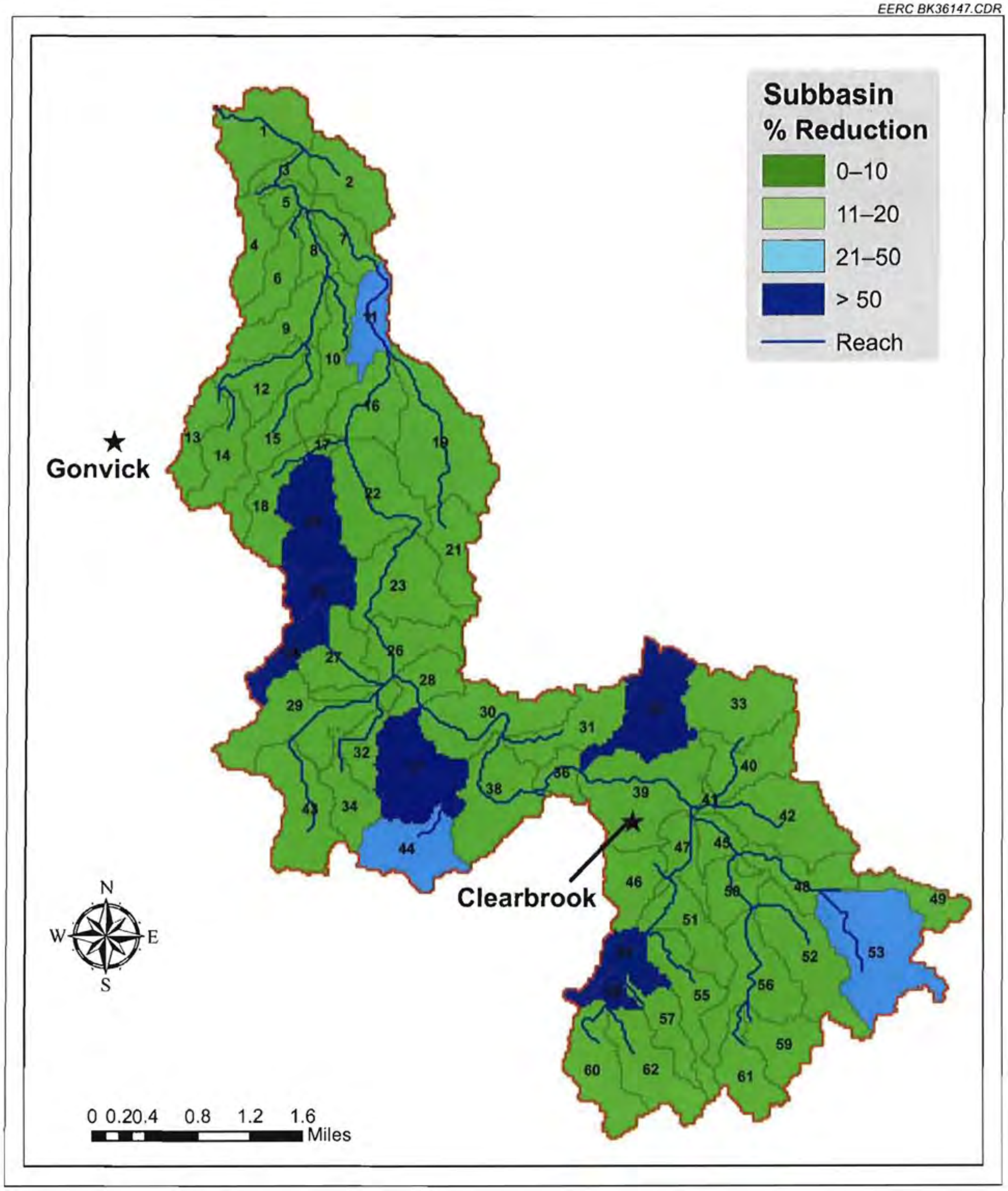

Figure 24. Predicted overland sediment erosion reductions for biofuel BMP implementation.

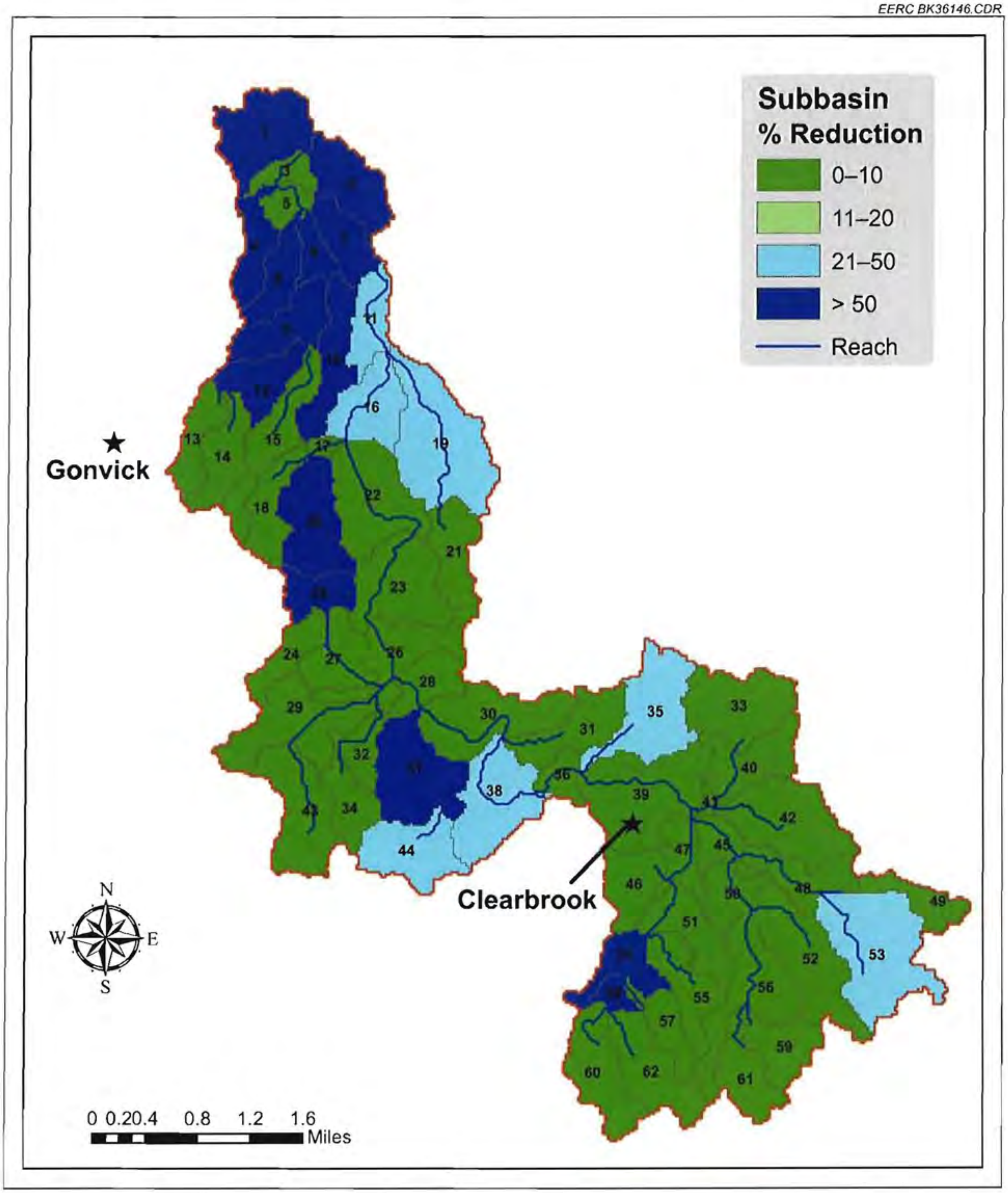

Figure 25. Predicted overland sediment erosion reductions for 50-foot buffer strip BMP implementation on 75% of crop fields.

EERC BK36150.CDR

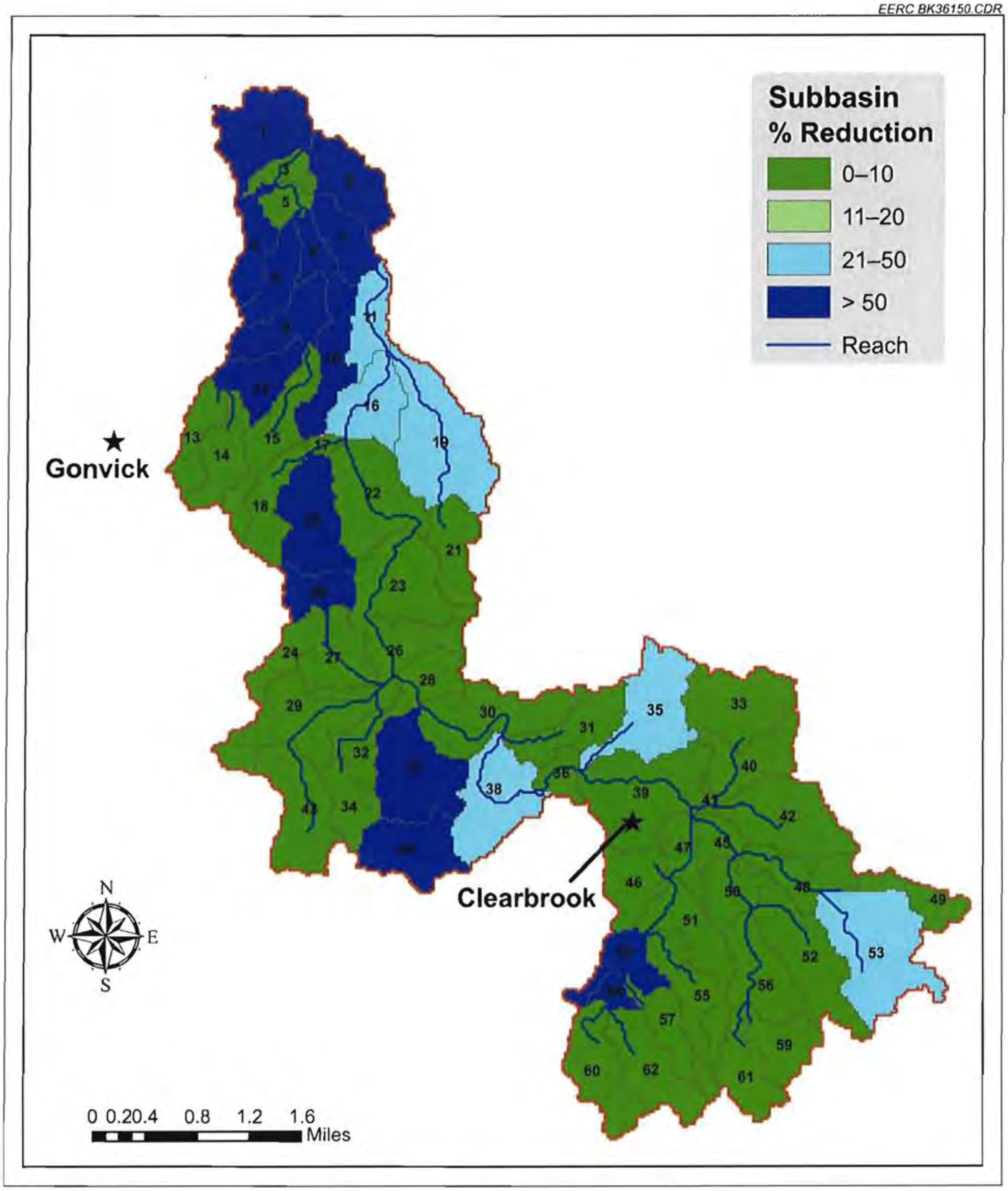

Figure 26. Predicted overland sediment erosion reductions for 80-foot buffer strip BMP implementation on 75% of crop fields.

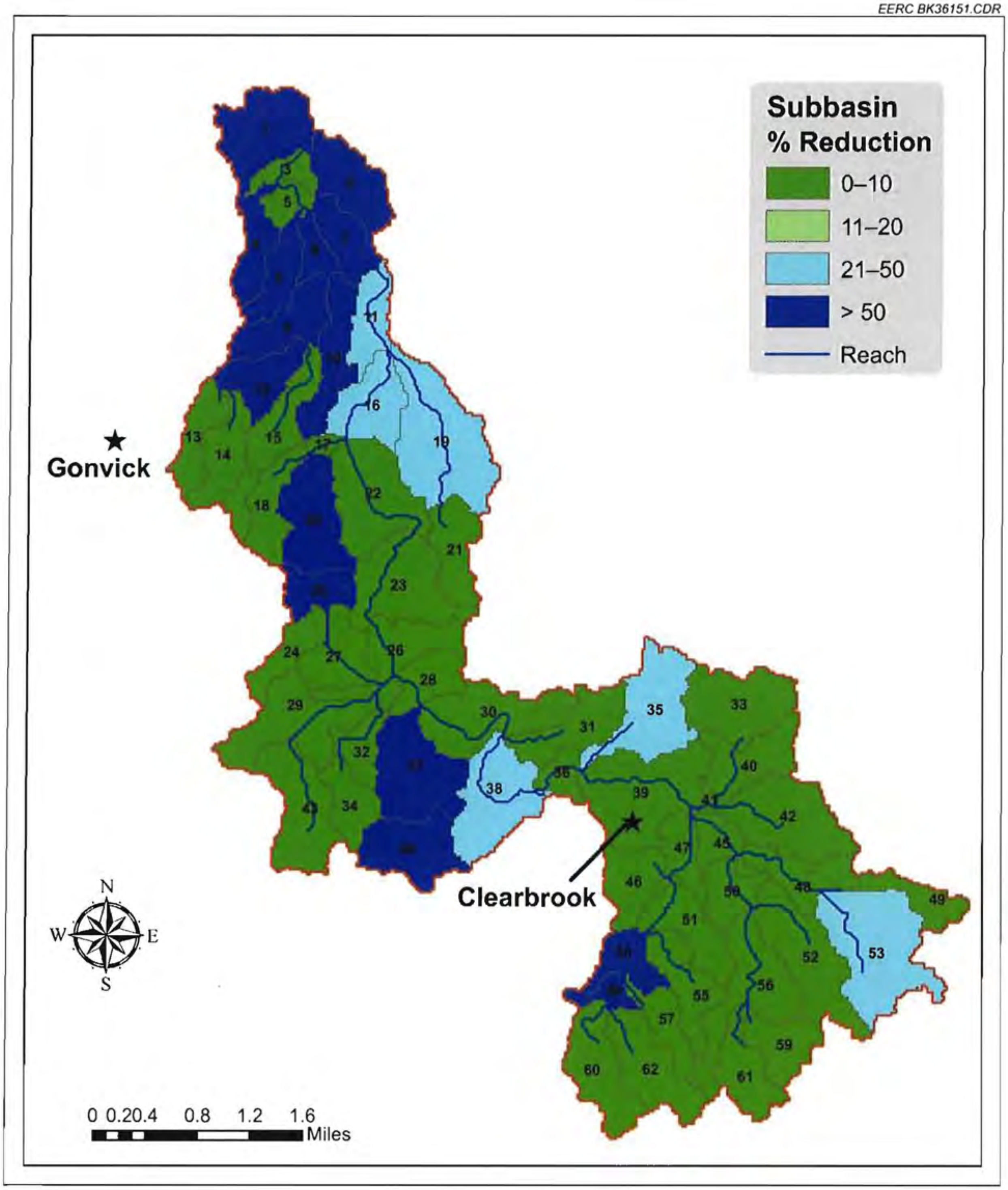

Figure 27. Predicted overland sediment erosion reductions for 120-foot buffer strip BMP implementation on 75% of crop fields.

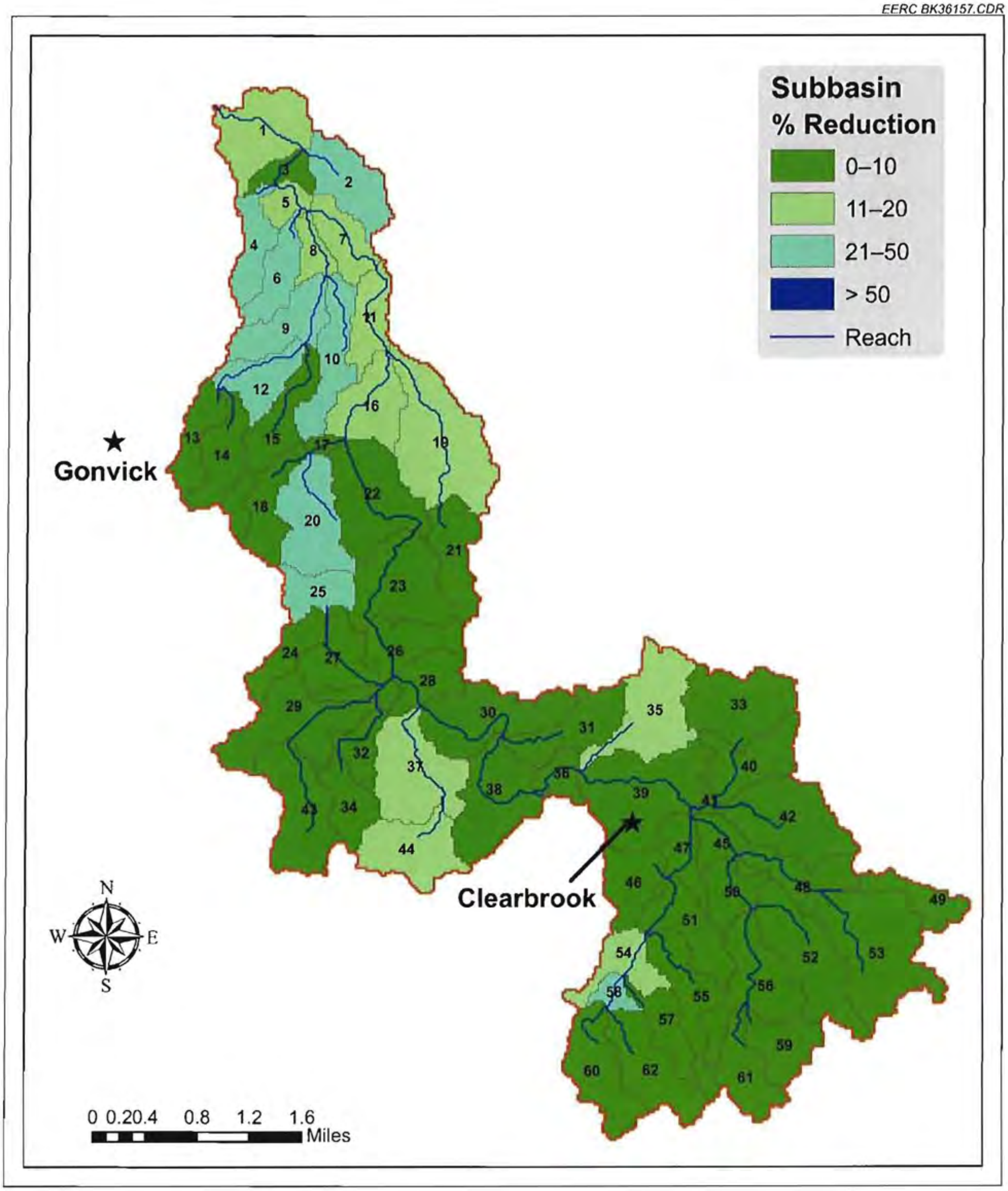

Figure 28. Predicted overland sediment erosion reductions for residue management BMP implementation.

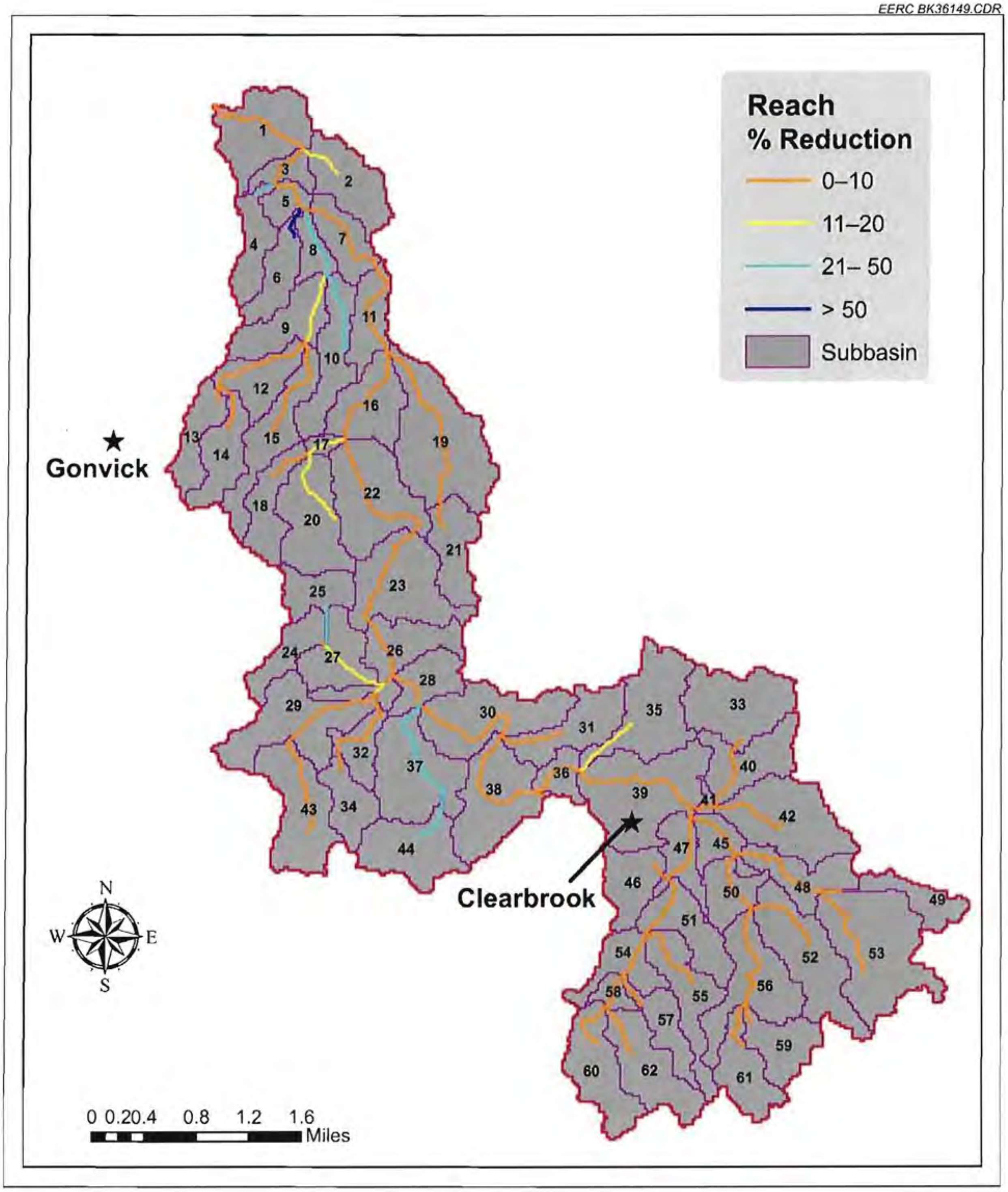

Figure 29. Predicted fecal coliform bacteria concentration reductions for 50-foot buffer strip BMP implementation on 75% of crop fields.

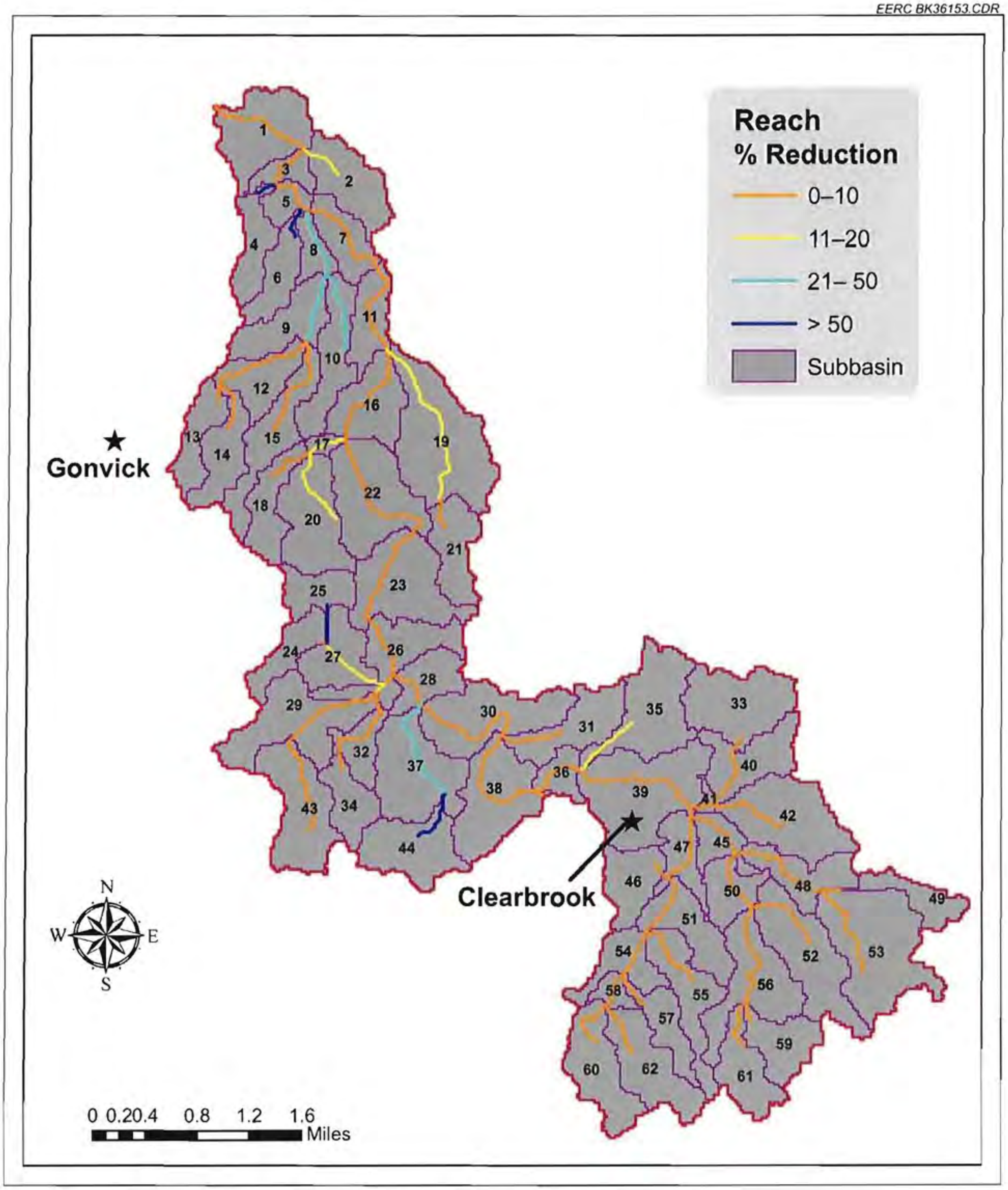

Figure 30. Predicted fecal coliform bacteria concentration reductions for 80-foot buffer strip BMP implementation on 75% of crop fields.

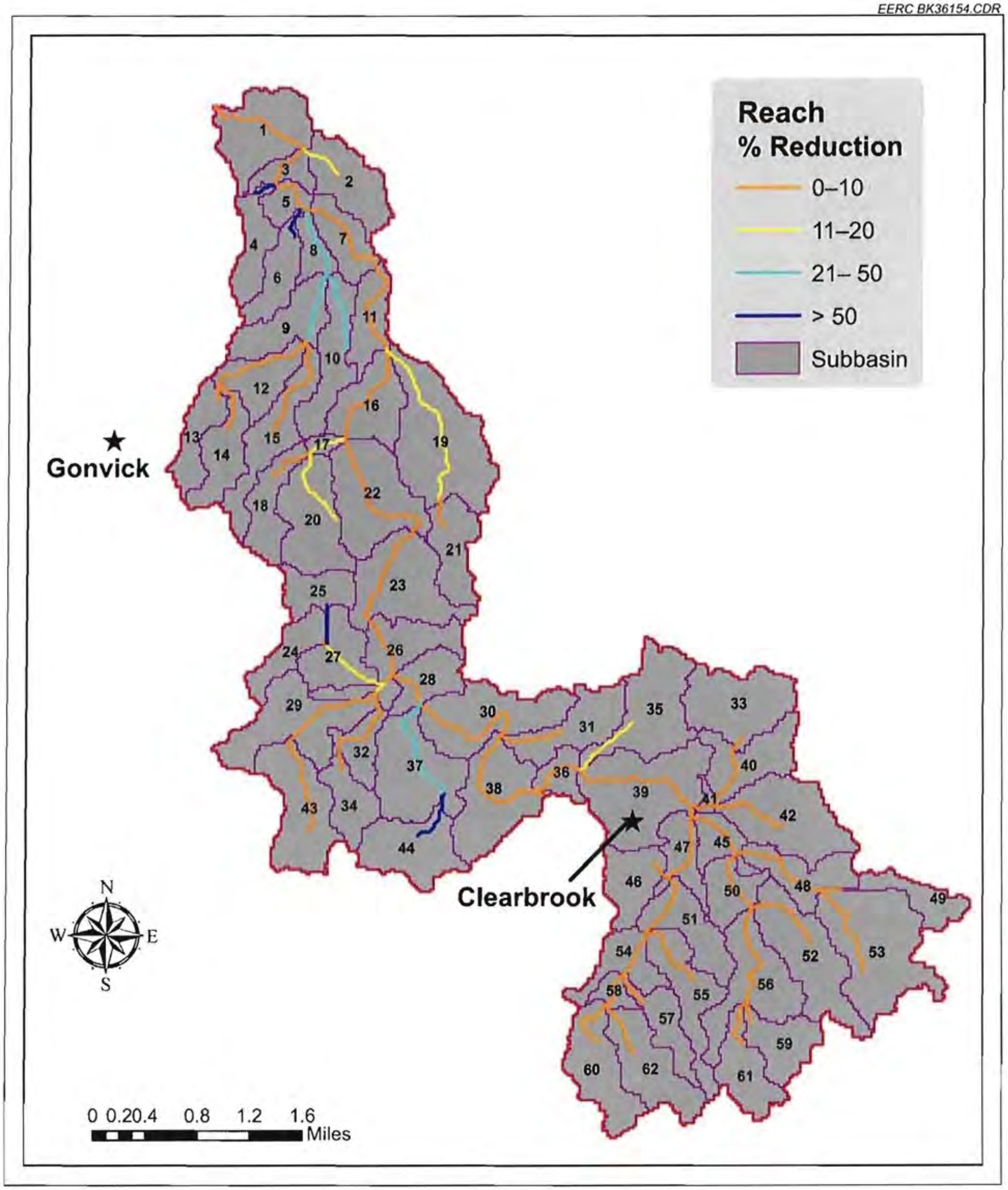

Figure 31. Predicted fecal coliform bacteria concentration reductions for 120-foot buffer strip BMP implementation on 75% of crop fields.

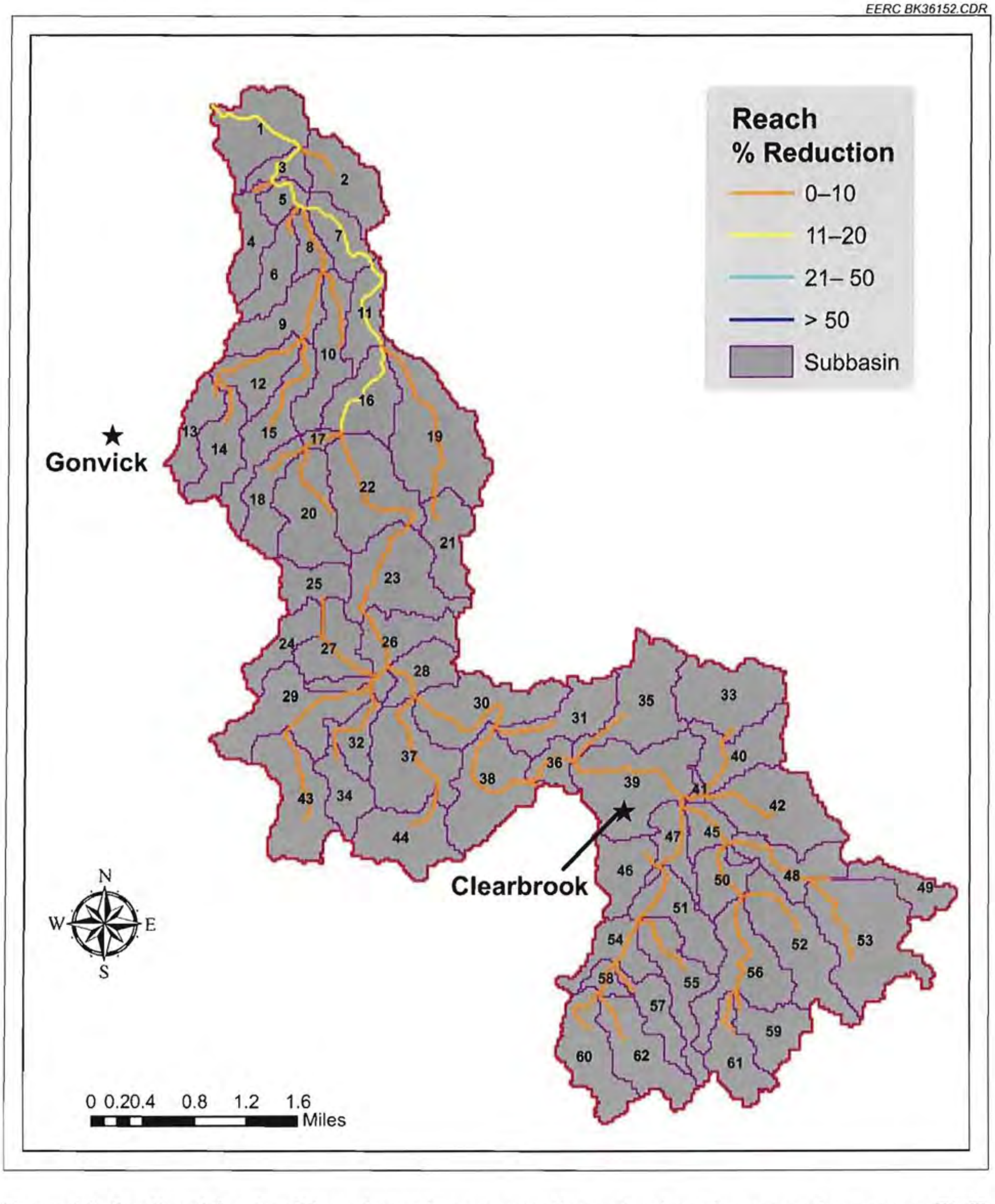

Figure 32. Predicted fecal coliform bacteria concentration reductions for grassed waterway BMP implementation.

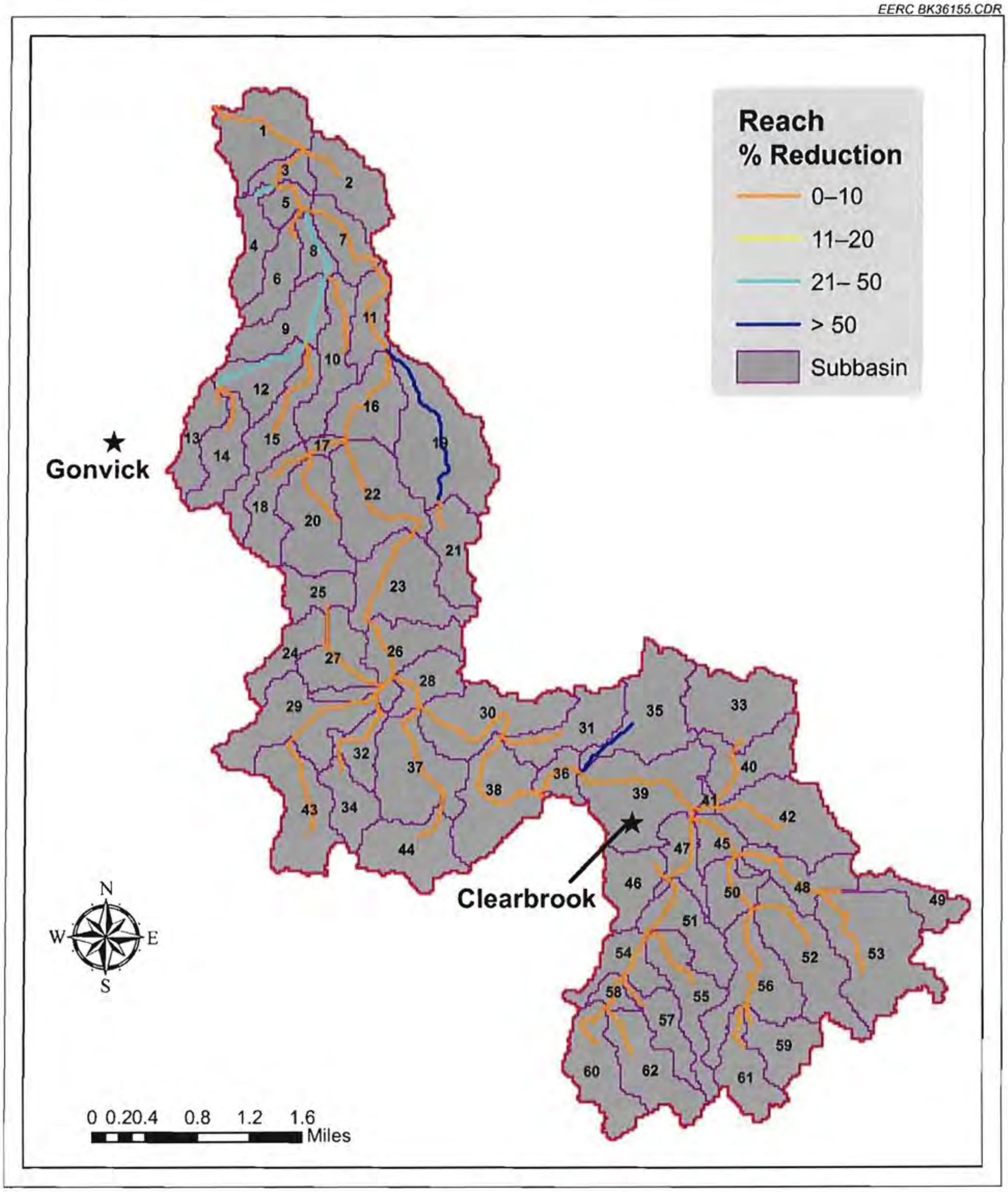

Figure 33. Predicted fecal coliform bacteria concentration reductions for wetland restoration BMP implementation.

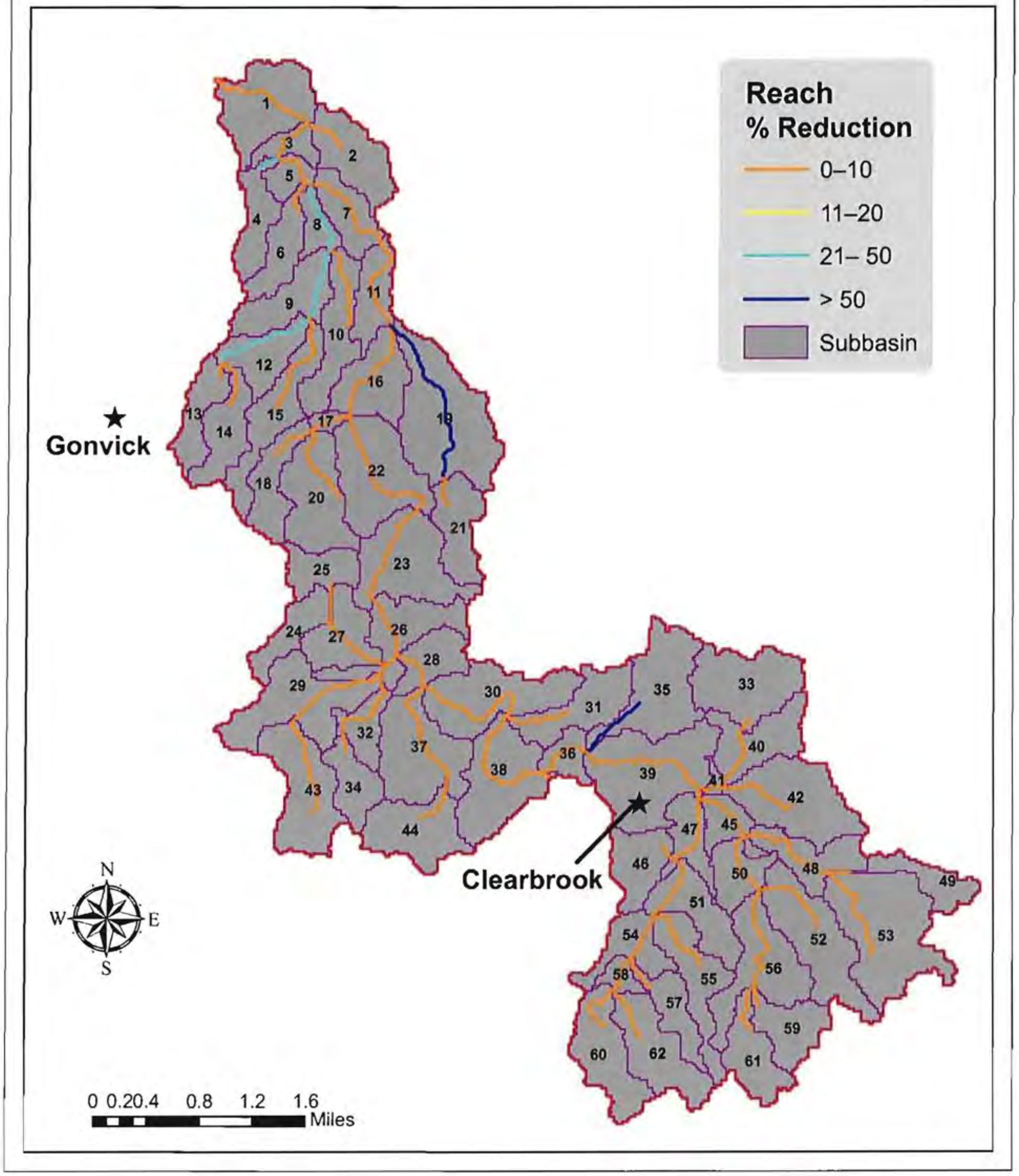

Figure 34. Predicted fecal coliform bacteria concentration reductions for 100% livestock operation point-source elimination.

to sediment reduction. However, project costs are an important consideration when focused BMP implementation efforts are chosen. While it is impossible to determine the exact cost analysis for each BMP scenario, a general estimation of project costs may provide some useful insight.

The cost for implementing BMPs is highly variable and will need to be calculated on a case-by-case basis. Every situation will be unique, so exact costs will be impossible to determine. Based on project cost information provided by the CSWCD, the following BMP practice costs were estimated based on the modeled scenario and following assumptions:

- Wetland restoration
  - Four wetlands installed at Subbasins 4, 12, 19, and 35
  - Excavation cost of $3000/acre
  - Assumed one water control structure ($1250/ea) on each wetland
  - Assumed $2000 to cover extra cost of ditch plugs, tile breaks, and embankments

- Streambank stabilization
  - Two sites selected by CSWCD at Subbasins 5 and 38
  - Based on three sample projects, average cost assumed to be $93.07/ft
  - Assumed both sites needed 200 feet of stabilization work

- Buffer strips
  - 50-, 80-, and 120-foot buffers
  - Each width implemented randomly along crop fields at implementation rates of 25%, 50%, and 75%
  - Crop fields averaged 230.4 acres in the model
  - Total of 82 crop fields in the model
  - Based on average field size, estimated acres needed for each buffer strip width
    - 50-foot buffers would equal 3.23 acres/field
    - 80-foot buffers would equal 4.84 acres/field
    - 120-foot buffers would equal 7.41 acres/field
  - Calculated cost for native grass planting at $524/acre, introduced grass and legumes at $468/acre, and trees/shrubs and grass planting at $750/acre

Additional BMP scenario costs were not calculated because of one or more of the following:

- Lack of cost information
- Highly variable project costs
- Lack of impact on fecal coliform or sediment reductions

The cost-benefit analysis in Table 8 shows that the most cost-effective BMP to reduce fecal coliform is wetland restoration.. However, this analysis does not include cattle exclusion. Cattle exclusion costs are very difficult to determine without going through each livestock operation on a case-by-case basis. Each cattle exclusion BMP scenario will have to include the cost of several different elements including, but not limited to, fencing, items for new freshwater

Table 8. Cost–Benefit Analysis for Selected BMP Scenarios

BMP Scenario	Cost, $	Fecal Coliform Reduction, %	Cost/% Reduction, $	Sediment Load Reduction, %	Cost/% Reduction, $	Sediment Concentration Reduction, %	Cost/% Reduction, $
Wetland Restoration	126,460.00	4.08	30,995.10	0.28	451,642.86	0.18	702,555.56
Streambank Stabilization	37,228.00	0.68	54,747.06	1.99	18,707.54	9.12	4082.02
Buffer (50 ft, 25%, natural grass)	35,542.92	0.08	444,286.50	10.74	3309.40	8.58	4142.53
Buffer (50 ft, 25%, grass/legume)	31,744.44	0.08	396,805.50	10.74	2955.72	8.58	3699.82
Buffer (50 ft, 50%, natural grass)	71,085.84	0.08	888,573.00	28.33	2509.21	23.08	3079.98
Buffer (50 ft, 50%, grass/legume)	63,488.88	0.08	793,611.00	28.33	2241.05	23.08	2750.82
Buffer (50 ft, 75%, natural grass)	106,628.76	0.08	1,332,859.50	28.44	3749.25	23.15	4605.99
Buffer (50 ft, 75%, grass/legume)	95,233.32	0.08	1,190,416.50	28.44	3348.57	23.15	4113.75
Buffer (80 ft, 25%, natural grass)	53,259.36	0.08	665,742.00	12.52	4253.94	10.14	5252.40
Buffer (80 ft, 25%, grass/legume)	47,567.52	0.08	594,594.00	12.52	3799.32	10.14	4691.08
Buffer (80 ft, 50%, natural grass)	106,518.72	0.08	1,331,484.00	34.02	3131.06	28.66	3716.63
Buffer (80 ft, 50%, grass/legume)	95,135.04	0.08	1,189,188.00	34.02	2796.44	28.66	3319.44
Buffer (80 ft, 75%, natural grass)	159,778.08	0.08	1,997,226.00	34.18	4674.61	28.78	5551.71
Buffer (80 ft, 75%, grass/legume)	142,702.56	0.08	1,783,782.00	34.18	4175.03	28.78	4958.39
Buffer (120 ft, 25%, natural grass)	81,539.64	0.08	1,019,245.50	13.31	6126.19	10.83	7529.05
Buffer (120 ft, 25%, grass/legume)	72,825.48	0.08	910,318.50	13.31	5471.49	10.83	6724.42
Buffer (120 ft, 50%, natural grass)	163,079.28	0.08	2,038,491.00	36.68	4446.00	31.47	5182.06
Buffer (120 ft, 50%, grass/legume)	145,650.96	0.08	1,820,637.00	36.68	3970.85	31.47	4628.25
Buffer (120 ft, 75%, natural grass)	244,618.92	0.08	3,057,736.50	36.9	6629.24	31.66	7726.43
Buffer (120 ft, 75%, grass/legume)	218,476.44	0.08	2,730,955.50	36.9	5920.77	31.66	6900.71
Buffer (50 ft, 25%, trees/shrubs)	50,872.50	0.08	635,906.25	10.74	4736.73	8.58	5929.20
Buffer (50 ft, 50%, trees/shrubs)	101,745.00	0.08	1,271,812.50	28.33	3591.42	23.08	4408.36
Buffer (50 ft, 75%, trees/shrubs)	152,617.50	0.08	1,907,718.75	28.44	5366.30	23.15	6592.55
Buffer (80 ft, 25%, trees/shrubs	76,230.00	0.08	952,875.00	12.52	6088.66	10.14	7517.75
Buffer (80 ft, 50%, trees/shrubs)	152,460.00	0.08	1,905,750.00	34.02	4481.48	28.66	5319.61
Buffer (80 ft, 75%, trees/shrubs)	228,690.00	0.08	2,858,625.00	34.18	6690.75	28.78	7946.14
Buffer (120 ft, 25%, trees/shrubs)	116,707.50	0.08	1,458,843.75	13.31	8768.41	10.83	10,776.32
Buffer (120 ft, 50%, trees/shrubs)	233,415.00	0.08	2,917,687.50	36.68	6363.55	31.47	7417.06
Buffer (120 ft, 75%, trees/shrubs)	350,122.50	0.08	4,376,531.25	36.9	9488.41	31.66	11,058.83

source (i.e., tanks, pipes, pumps, wells, etc.), and native plantings or other restoration activities to restore previously trampled areas. Other BMP practices that are difficult to model but should be considered are manure management plans, manure spreader calibration, and correct timing of manure application. These additional BMPs are known to be effective at reducing the amount of fecal material that reaches the waterways.

Sediment reduction cost-benefit analysis clearly indicates that buffer strips are the most economic solution to reducing sediment in the waterways. When looking at the cost between buffer strip widths, 50- or 80-foot buffers would yield the most benefit per dollar spent. The added cost of 120-foot buffers does not amount to enough of a reduction in sediment to make up for the added expense. The native grass planting and introduced grass and legume plantings were shown simply to give a range for the costs of implementing the practice. The SWAT model does not differentiate between the two types of plantings, so there is no difference in reduction of sediment.

7.0 CONCLUSIONS

Through this project, a water quality model of the SCW was developed and calibrated using the best available data. The model was calibrated from January 1997 to July 2008 and validated from January 1990 to December 1996. An evaluation of efficiency statistics for the calibration and validation periods of the model indicate that the predicted versus measured discharge match well.

According to the results of this study, significant reductions in fecal coliform and sediment loading can be achieved through implementation of the BMPs evaluated. The optimum scenario to significantly reduce fecal coliform concentrations and meet water quality standards would be achieved through cattle exclusion from streams and waterways.

Grassed waterways and wetland restoration also showed potential to reduce fecal coliform concentrations. Given that these two BMPs were implemented at random locations, it is likely that the benefits would be even greater if a targeted approach were taken with respect to the implementation of these practices. Other BMPs that were not modeled should also be considered for fecal coliform reductions. Manure management plans, manure spreader calibration, and correct timing of manure application and other such BMPs are known to be effective fecal-coliform-reducing practices and should be considered for Silver Creek.

Buffer strip implementation resulted in significant reductions in sediment concentrations in the watershed. Given that buffer strips were randomly selected around agricultural crop fields, a targeted approach would likely result in higher sediment reductions. Buffer strips located around grazing areas would also result in reductions of fecal coliform concentrations, particularly if implemented between livestock operation locations and waterways.

To better improve the accuracy of the SWAT model developed through this project, additional data are needed to better document the sources of fecal coliform. Field observations of livestock operation practices including the number and locations of direct cattle access to streams would help to determine the total fecal coliform contributions. Additional information on failing septic systems and potential wildlife contributions could also be added to the SWAT model to determine their concentrations.

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

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