METHODS TO INTEGRATE OVERLAND, EPHEMERAL GULLY AND STREAMBANK EROSION MODELS

by

NAGA RAGHUVEER MODALA

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Approved by:

Major Professor
Dr. Kyle R. Douglas-Mankin

Abstract

Sediment is considered as one of the important pollutant of concern in the U.S. In order to develop watershed management plans that address sediment pollution, it is essential to identify all sources of sediment in a watershed. The overall goal of this research is to quantify the total sediment from a watershed by integrating the outputs of three types of sediment sources: sheet and rill erosion, ephemeral gully erosion, and streambank erosion, that each operates at different spatial and temporal scales. This approach will be demonstrated in Black Vermillion River Watershed using AnnAGNPS (overland flow/erosion model), REGEM (ephemeral gully erosion model) and field measured values of streambank erosion. The study area includes three subwatersheds (Irish Creek, the Black Vermillion River Main Stem, and North Fork of the Black Vermillion), each monitored for continuous stream flow, base flow and event-based suspended sediment subwatershed export, annual streambank erosion, for 2 years. NASS land use, SSURGO soils data, 30-m DEMs, and local weather data were used to generate input data needed by the models. Stream monitoring data were used to calibrate the models. This paper will present results from independently calibrated and validated combinations of AnnAGNPS, REGEM, and filed measured streambank erosion. Our hypothesis is that use of separate models to simulate sediment load contributions for each sediment source will improve model agreement with measured watershed sediment yield data.

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CHAPTER 1 - Introduction

1.1. General Background

1.1.1. Sediment issues in U.S., globally

Sediment is one of the principal pollutants of surface waters in the United States. Nationally, sediment has been identified as the most important contaminant of concern by the U.S Environmental Protection Agency. Streambank erosion and sedimentation are critical environmental, social and economical problems in U.S. and throughout the world (Borah and Bera, 2003). About 75 billion Mg of fertile soil is lost from world agricultural systems each year (Pimentel, 2006). The amount of soil lost in the U.S. is estimated to be about 3 billion Mg per year (Pimentel, 2006). Erosion reduces soil productivity and causes a range of downstream impacts (Cruse et al., 2006).Sediment is a concern for both physical and chemical reasons.

Physical problems include degraded water quality, degraded aquatic habitat, increased water treatment costs, decrease in flood control, decrease channel capacity, clogged water intakes and loss of water storage capacity in reservoirs. The U.S. Department of Agriculture (USDA, 1989) reports that 60% of water-eroded soil ends up in U.S. streams. In Kansas, there is a 33% loss of lake's original water-storage capacity of 425,000 acre-ft at conservation pool in Tuttle Creek Lake since the dam was closed in 1962 (Juracek and Mau, 2002). The U.S. Geological Survey (USGS), in cooperation with Federal, State, and local agencies, has completed a number of reservoir sediment studies in Kansas using a combination of bathymetric surveying, sediment coring, chemical analysis, and statistical analysis (table 1.1).

Table 1.1 Estimated sediment deposition and yield for several reservoirs in Kansas (http://ks.water.usgs.gov/studies/ressed/).

Reservoir	Drainage area (mi^2)	Years since dam closure	Total deposition (ac-ft)	Mean annual net yield [ac ft/mi^2)/yr]	Decrease in storage capacity (percent)
Mound City	5.8	21	248	2.04	14
Crystal Lake	0.6	121	125	1.72	55
Perry Lake	1,117.0	32	56,700	1.59	23
Mission Lake	8.6	76	926	1.42	50
Hillsdale Lake	144.0	15	2,100	0.97	3
Cedar Lake	6.14	62	338	0.89	50
Gardner City	5.5	60	281	0.85	12
Otis Creek Res.	14.0	31	310	0.71	6
Lake Afton	10.4	41	283	0.66	9
Lake Olathe	16.6	45	317	0.42	10
Tuttle Creek	9,628.0	37	142,000	0.40	33
Cheney Res.	933.0	33	7,100	0.22	4
Webster Res.	1,150.0	40	1,267	0.03	2

Heavy sedimentation leads to rivers and lake flooding. For example, Pimentel (2006) suggests that the floods that occurred in midwestern U.S. were due to the sediment deposited in Mississippi and Missouri rivers.

Sediment serves as a carrier for various contaminants and, under certain conditions, as a source of contaminants to water and biota. Sediment-associated contaminants include nutrients (nitrogen, phosphorus), trace elements, and pesticides. USGS reservoir sediment studies in Kansas shows that sedimentation affects both the useful life of a reservoir for such important purposes as flood control and water supply as well as its aesthetic quality (USGS, 2009).

Sediment quality is an important environmental concern because sediment may act as a sink for water-quality constituents and as a source of constituents to the overlying water column and biota. Once in the food chain, sediment-derived constituents may pose an even greater concern due to bioaccumulation. Soil erosion also adds to global warming, because carbon dioxide is released to the atmosphere when enormous amounts of biomass carbon in the soil are oxidized.

There are many economic losses and costs due to soil erosion. The most costly off-site damages occur when soil particles enter lake and river systems (Pimentel, 2006). Yearly erosion costs in the U.S. are in billions of dollars, with annual off-site costs estimated at $17 billion and onsite costs of about $27 billion (Cruse et al., 2006). Other estimates conclude soil erosion in U.S. costs the nation about $37.6 billion each year in loss of productivity (Uri, 2001).

In order to develop watershed management plans that address sediment pollution, it is essential to identify all sources of sediment in a watershed and consider all sources of sediment while quantitatively determining total sediment from a watershed. Then risk areas can be identified and best management practices or conservation techniques can be implemented to minimize soil erosion rates.

1.1.2. Problems with sediment source identification

Effective management strategies to reduce watershed sediment loads require an understanding of the sources of sediment for a given stream or reservoir (Walling, 2005). Because the relative contribution of sediment from different sources can vary within and between basins and over time, basin-specific information on sediment sources is needed. Erosion and sediment yield in any stream basin are rarely in steady state (Trimble, 1999). Trimble's studies in the agricultural Coon Creek Basin for the period 1975-93 showed that sediment efflux remained relatively constant despite large stream and valley changes within the basin. Trimble's observations demonstrated that the sediment sources, sinks and fluxes vary widely over time and space although improved soil conservation measures have decreased soil erosion.

The proper identification of sediment source could potentially assist with attempts to mitigate output from watersheds and to prolong the usable life of reservoirs. Efforts to limit excessive sediment from reaching a reservoir must target the correct sources. After identifying the sources of sediment, it is essential to quantify the amount of sediment coming from each source. Computer simulation models can help quantify sediment sources.

1.1.3. Sediment simulation models

Computer-based simulation models perform longterm simulation of the effects of watershed processes and management activities on water quality, water quantity, and soil quality. These models also facilitate the simulation of various conservation program effects and aid policy design to mitigate water and soil quality degradation by determining suitable conservation programs for particular watersheds and agronomic settings (Moriasi et al., 2007). Computer models for simulating sediment erosion can be divided functionally by watershed source area into two general categories: (1) overland erosion models and (2) fluvial erosion models.

Many of the overland erosion models do not include algorithms for estimating sediment generated by fluvial processes within a given watershed. Sediment produced via fluvial processes can be quite significant, especially in watersheds that are highly urbanized, have steep slopes, or have large grazing populations with unimpeded access to streams (Dietrich and Dunne, 1978). Fluvial erosion models typically emphasize streambank erosion processes and generally fall into three categories based on their complexity: (1) simplified models, based primarily on land-use designations and imperviousness, (2) moderately detailed simulations, based on empirical loading functions, and (3) highly detailed simulations, which require detailed site-specific data such as management operations, management schedule data. These categories of models differ primarily in the amount of location-specific data required to specify the parameters and on the complexity of computation required to produce results. The accuracy of these models depends on the underlying mathematical equations (McGarity and Horna, 2005).

Simplified models are often based on statistical methods, such as linear regression, to relate loadings to a few parameters that are fairly easy to obtain. They often ignore characteristics such as topography and distribution of precipitation events, and are frequently applied using parameters that are aggregated across a wide area. These simple models typically can be used to support an assessment of the relative significance of different pollutant sources. They can guide decisions for watershed management plans and provide direction for continuous monitoring efforts. Examples of simplified models include STEPL (U.S. EPA, 2006) which models annual watershed pollutant loads and allows users to input an additional sediment load from channel sources (Nejadashemi and Mankin, 2007).

Models in the moderately detailed simulations have mathematical formulas with little consideration given to exact location of specific sites in the watershed. These models can be used to evaluate pollution sources and impacts over broad geographic scales and therefore assist in defining target areas for pollution mitigation programs on large scale basis. Data of this type can be obtained using GIS layers. Examples of moderately simulated models are Fluvial-12 (Chang, 1998), AVGWLF (McGarity and Horna, 2005).

The highly detailed simulations employ the most advanced theory available on mechanisms of pollutant generation (sediment, nitrogen, phosphorous) and transport, and require highly site specific data to characterize these mechanisms. If the proper data are not available or can not be obtained at a reasonable cost, then the output of such models can be highly inaccurate. Complex models most accurately represent the current understanding of watershed processes affecting pollution generation. Complex models are used to identify sources of problems rather than simply describing all conditions. Examples of complex models include Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) (Langendoen, 2000).

1.1.4. Model selection considerations

Selecting the appropriate model is crucial in developing feasible, defensible and equitable TMDLs and load locations (Shoemaker et al., 2005). The following factors must be taken into consideration while selecting a model:

- Stakeholder issues
- Model characteristics
- Water body types
- Pollutant types
- Management practices
- Temporal scale (Climate data)
- Spatial scale
- Calibration needs

- Time and money available
- Project time line

The standard practice in modeling is to identify the dominant processes and identify the simplest models sufficient to meet the needs of the project (Shoemaker et al., 2005).

1.1.5. Limitations of current modeling approach

Understanding and evaluating natural processes in a watershed leading to impairments and problems are continuous challenges for scientists and engineers. Most current erosion and runoff modeling is typically limited in spatial and/or temporal resolution and accuracy. Although watershed models have become increasingly more sophisticated, there is a long way to go before they become household tools. The most ubiquitous deficiencies of the models are their lack of user friendliness, large data requirements, lack of quantitative measures of their reliability (Singh and Frevert, 2006). Models cannot be embedded with social, political and environmental systems (Singh and Frevert, 2006). Developing reliable watershed simulation models and validating them for real-world watersheds with measured and monitored data are also challenging (Borah and Bera, 2003).

1.2. Research Goals and Objectives

Watershed sediment sources include overland (inter-rill and rill), ephemeral gully, streambank, and stream bed. The overall goal of this research was to develop methods that quantify the total sediment from a watershed by integrating estimates from three sources: sheet and rill erosion, ephemeral gully erosion, and streambank erosion, that each operates at different spatial and temporal scales. This approach was demonstrated in Irish Creek, Main Stem, and North Fork Subwatersheds of Black Vermillion Watershed using Annualized Agricultural Non Point Source Pollution Model (AnnAGNPS) (overland flow/erosion model) (Bingner and Theurer, 2003), Revised Ephemeral Gully Erosion Model (REGEM) (ephemeral gully erosion model) (Gordon et al., 2006), and a number of modeling approaches to dissagragate annual field-based measurements of stream-bank erosion to the daily scale. The study area included three subwatersheds (Irish Creek, the Black Vermillion River Main Stem, and North Fork of the Black Vermillion), each monitored for continuous stream flow and event-based suspended sediment subwatershed export, annual streambank erosion for 2 years. The following specific objectives guided this study:

1. Develop and demonstrate a modeling approach that integrates the outputs from overland erosion model, ephemeral gully erosion model, and field measured streambank erosion values, each operating at different spatial and temporal scales.
2. Develop a method to compare integrated watershed-level sediment discharge model estimates to stream suspended-sediment discharge measurements.
3. Quantify the differences in accuracy that result from different levels of integration of AnnAGNPS, REGEM and field measured streambank erosion values in Irish Creek, Main Stem and North Fork Subwatersheds.

CHAPTER 2 - Literature Review

2.1. Introduction

In order to develop watershed management plans that address sediment pollution, it is essential to identify all sources of sediment in a watershed. Total sediment from a watershed includes sediment coming from overland (inter-rill and rill), ephemeral gullies, gullies, streambanks, and stream beds. It is necessary to consider the sediment coming from all these sources when developing plans and prioritizing specific actions to address each source.

Sediment transport in streams includes suspended sediment and bedload. Suspended sediment is typically represented using a measure of total suspended solids (TSS) in the water sample drawn from the stream water column. The procedure used in this study to measure the total suspended solids parameter is described the Standard Methods for the Examination of Water and Wastewater Method 209C (Clesceri et al., 1998). Water with TSS concentrations less than 20 mg/L are considered to be clear, concentrations between 20 and 80 mg/L tend to appear cloudy, while TSS concentrations greater than 150 mg/L appear to be dirty and are considered impaired (Barnes, 2005).

Nonpoint sources of TSS are typically associated with soil erosion in surface runoff and streambank erosion. As levels of TSS increase, a stream begins to lose its ability to support a diversity of aquatic life. Suspended solids absorb heat from sunlight, which increases water temperature and subsequently decreases levels of dissolved oxygen. TSS can also destroy fish habitat because suspended solids settle to the bottom and can eventually blanket the riverbed. Suspended solids can smother the eggs of fish and aquatic insects, and can suffocate newly hatched insect larvae. Suspended solids can also harm fish directly by clogging gills, reducing growth rates, and lowering resistance to disease. Changes to the aquatic environment may result in diminished food sources, and increased difficulties in finding food. Natural movements and migrations of aquatic populations may be disrupted.

Einstein (1950), Colby (1963), Bagnold (1966), and Van Rijn (1984), all defined bed load sediment in terms of material of which the bed is composed and transported by rolling and sliding, and by hopping or jumping or saltating. Bagnold called bed load the movement of particles whose successive contacts with the bed are limited by the effects of gravity. That means that the particles do not go into suspension. The suspended bed-load material is then defined as that in which the excess weight of the particles is supported by the upward impulses of turbulence. Van Rijn chose a similar definition (Abraham and Pratt, 2002). Two methods are being developed to estimate bedload by the U.S. Army Corps of Engineers. One method would be based on the celerity of traveling sand waves and the other is based on the difference of surfaces (Abraham and Pratt, 2002). To date, most methods are only marginally successful (Abraham and Pratt, 2002). Accurate sampling of bedload is difficult due to the movement of sediments in bars, ripples and dunes (for sand), changes in sediment supply, 'the stop and start' nature of sediment movement and the problem of efficiently sampling sediments over a range of sizes.

Streambank erosion and associated sedimentation and land loss hazards are a problem of global significance. Sediment produced via streambank erosion can be a major watershed contributor, especially in watersheds that are highly urbanized, have steep slopes, and have large grazing animal populations with unimpeded access to streams (Evans et al., 2003). Streambank erosion is a dominant source of sediment in many river systems. Wilkin and Hebel (1982) estimate streambanks contribute 50% of total watershed sediment loads in Midwestern U.S. streams. The adverse consequences of streambank erosion results not only in accelerated sediment yields but also in destabilizing the stream channel, leading to associated stream type changes. These instabilities and consequential shifts in stream type can degrade physical and biological function of rivers. Therefore it is essential to include sediment coming from streambank erosion while estimating the total sediment from a watershed.

Soil conservationists have recently noted that an important source of sediment erosion within fields is being overlooked. Among other terms, it has been called ephemeral gully erosion, concentrated flow erosion, and mega rill erosion. The topography of most fields causes runoff to collect and concentrate in a few major waterways within the field. The erosion that occurs in these channels is called ephemeral gully erosion (Foster, 1986). Ephemeral gully erosion is an important soil degradation process affecting environments worldwide (Gordon et al., 2007) and can significantly contribute to total soil losses in agricultural areas. Ephemeral gullies serve as connecting links transferring sediment and associated agrochemicals from upland areas to stream channels. About 20% to 100% of the total agricultural soil loss likely is due to ephemeral gully erosion (Gordon et al., 2007). Because of this significant contribution and their wide spread occurrence, USDA-NRCS stressed the importance of including ephemeral gully erosion processes within the soil loss prediction technology (USDA-NRCS, 1996; Gordon et al., 2007). Hargrove et al. (2010) also identified the critical need for quantifying the contribution of ephemeral gully erosion to upland erosion

Sediment can be quantitatively determined from each source by using watershed models. Watershed models are computer based models that can predict sediment loads. Each source has specific models in predicting sediment load from that source. Models operate at different spatial and temporal scales.

The goal of this study was to quantify the total sediment from a watershed by integrating the outputs of three types of watershed models: an overland erosion model, an ephemeral gully erosion model, and a streambank erosion model, that operate at different spatial and temporal scales. A brief description about the three different watershed models (overland flow model, ephemeral gully erosion, and streambank erosion model) is given below.

2.2. Overland Flow Model

Selecting a suitable watershed/hydrologic model for a particular application and for a certain watershed is a difficult task (Polyakav et al., 2007). Some of the commonly used overland flow models are Annualized Agricultural Non-Point Source model (AnnAGNPS), Soil and Water Assessment Tool (SWAT), L-THIA, and Hydrological Simulation Model (HSPF) (Borah and Bera, 2003). Some of the models are based on simple empirical relations and some are based on empirical equations that have computationally intensive numerical solutions. Sometimes simple models are incapable of producing desired results, yet the detailed models could be inefficient and prohibitive for large watersheds (Borah and Bera, 2003). Therefore selecting a suitable model for a particular application is a difficult task.

In this study, our overall objective was to assess sheet/rill erosion, ephemeral gully erosion, and streambank erosion contributions to stream sediment loads at the watershed scale. The only watershed model that included an ephemeral gully submodel was AnnAGNPS (Borah and Bera, 2003). Therefore, AnnAGNPS was selected for this study. AnnAGNPS provided the following advantages.

First, AnnAGNPS has demonstrated reasonable accuracy in simulating stream flow and sediment yields in a number of watershed settings. This will be discussed further in the following section.

Second, AnnAGNPS has an integrated ephemeral gully erosion model, REGEM, that has been integrated as an additional tool within the Annualized Agricultural Non-point Source (AnnAGNPS) model (Bingner and Theurer, 2001). This allows explicit accounting of the contribution of ephemeral gullies in watershed-scale erosion at the sub-cell scale (Gordon et al., 2006) with a minimum of additional input data. The REGEM model will be discussed in detail in a later section.

Third, AnnAGNPS disaggregates eroded sediment yields by particle size. In AnnAGNPS model the sediment is subdivided into five particle size classes (clay, silt, sand, small aggregate and large aggregate), and these particle sizes are routed separately in the stream reaches in AnnAGNPS. Other models, such as SWAT and HSPF, do not route sediment particle sizes separately. This feature was not fully utilized in the present study, but offers an opportunity for further method development to separate sediment size fractions that are transported by the stream under different flow regimes.

2.2.1. Application of AnnAGNPS model

AnnAGNPS model was selected to simulate overland erosion in this study. AnnAGNPS has demonstrated reasonable accuracy in simulating stream flow and sediment yields in a number of watershed settings. AnnAGNPS predicted the runoff volume within a range of acceptable accuracy and sediment in the range of moderate accuracy (Shrestha et al., 2006). AnnAGNPS simulated and observed runoff values were well matched (100% for runoff and 106% for sediment) at the outlet of Little River watershed in south central Georgia (Suttles et al., 2003; Yuan et al., 2008).

Baginska et al. (2003) evaluated AnnAGNPS performance and produced satisfactory results when simulating event flows. In tests carried out by Yuan et al. (2001), the simulated and observed runoff from individual events resulted in similar coefficient of determination (R^2) of 0.90 for daily stream flow discharge and 0.50 for daily sediment loss. Licciardelo et al. (2007) implemented AnnAGNPS in a small Mediterranean watershed which was mainly of pastureland, and found satisfactory results and a good model efficiency (E_f = 0.55) and a very high coefficient of determination (R^2 > 0.90) were also found for the suspended sediment yields.

AnnAGNPS model was used to study several best management practices for the Chesapeake Bay Basin by Hession et al. (1989). An Arc/Info geographic information system was used to generate input data for this model. As reported satisfactory results were obtained when simulated runoff, peak runoff rate, total nitrogen, total phosphorous, and total suspended solids were compared with recorded data.

2.2.2. Model description

AnnAGNPS version 5.0 is a continuous simulating model jointly developed by USDA Agricultural Research Service (USDA-ARS) and USDA Natural Resources Conservation Service (USDA-NRCS) to predict nonpoint source pollutant loadings in a watershed dominated by agriculture and to facilitate assessment of watershed and landscape processes affecting agricultural areas (Bingner and Theurer, 2002; Gordon et al., 2007). This program was developed based on single-event model AGNPS. It is batch process, daily time step, pollutant loading model developed to simulate runoff and transport of sediment and chemicals as a result of precipitation, irrigation, and snow melt from agricultural watersheds (Cronshey and Theurer, 1998; Bingner and Theurer, 2003; Parajuli et al., 2009). AnnAGNPS divides the watershed into homogenous drainage areas, which are then integrated together by simulated rivers and streams, routing the runoff and pollutants from each area downstream (Parajuli et al., 2009). The hydrology of this model is based on a water balance approach. Daily surface runoff is calculated by using the NRCS Curve Number (CN) method (USDA- SCS, 1985). The CN method can be written as:

$$Q_D = (P - Ia)^2 /(P + S - Ia) \tag{2.1}$$

$$Ia = 0.2S \tag{2.2}$$

$$S = [(1000 / CN) - 10] \tag{2.3}$$

where:

Q_D = surface runoff (mm),

P = storm precipitation (mm),

S = potential maximum retention (mm),

Ia = initial abstraction (mm), and

CN = Curve Number.

The model uses the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) to calculate daily sheet and rill erosion. A delivery ratio, which quantifies the amount of sediment deposited in the field and the amount of sediment delivered to the stream, is calculated using the Hydrogeomorphic Universal Soil Loss Equation (HUSLE) (Yuan et al., 2008). AnnAGNPS uses Bagnold Equation to determine the sediment transport capacity of the stream, and a modified Einstein equation is used to determine the sediment transport in the stream system (Yuan et al., 2008).

The input data that is required for this model includes daily climate data, watershed physical information and land management operations. Additional input requirements, which include crop operations, management practices, defining channel hydraulic characteristics can be organized by the AnnAGNPS input editor, a graphical user interface which is used in selecting appropriate input parameters (Yuan et al., 2007). Much of this information can be obtained from USDA-NRCS sources or from the nine reference databases developed within AnnAGNPS. Runoff, sediment, nutrient and pesticide loads are obtained at various temporal scales ranging from daily to yearly at desired locations as an output.

2.3. Ephemeral Gully Erosion Model

The only tool which was available for field practitioners to simulate ephemeral gully erosion on agricultural fields was the Ephemeral Gully Erosion Model (EGEM; Merkel et al., 1988; USDA-SCS, 1992). EGEM simulates a single, non-bifurcating ephemeral gully on a planar surface. Hydrologic components are based on USDA-NRCS methods (USDA-SCS, 1986) to estimate peak discharge and runoff volume, and erosion components are based on those developed for CREAMS (USDA-ARS, 1980) to estimate gully width and soil loss (Gordon et al., 2007). However the applicability of this model is limited because the exact topographical position (i.e., the length) of the ephemeral gully must be known before a model can be applied.

The length of gully is a key parameter used to determine the volume of gully erosion for EGEM (Nachtergaele et al., 2001b). As there is a strong correlation between the length and volume of the gully (Cheng et al., 2007), it is suggested that gully length is a significant and useful index to estimate the volume of gully erosion. While topographic indices may be used to identify locations of potential gully erosion, there is no method currently available to predict gully length (Gordon et al., 2007). Additional limitations of ephemeral gully erosion routines in EGEM involve the use of diameter and specific gravity of a representative particle to calculate sediment transport capacity. There are two specific limitations to this approach:

1. for any material to be detached, the amount of sediment carried by the water must be below transport capacity, thus deposition cannot be simulated; and
2. because soil particle diameter and specific gravity are simplified to some representative or dominant value, the soil material delivered to the mouth of the ephemeral gully contains the same ratios of clay, silt, sand and aggregates as the soil *in situ* (Gordon et al., 2006).

These limitations limit the usage of these models.

REGEM model was selected for this study for the following reasons:

1. REGEM model has been integrated as an additional tool within the Annualized Agricultural Nonpoint Source (AnnAGNPS) model (Bingner and Theurer, 2001), allowing it to explicitly account for ephemeral gullies in its erosion routines at the sub-cell scale (Gordon et al., 2006, 2007) with a minimum of additional input data. REGEM has been designed specifically to comply with the computational framework of the AnnAGNPS suite of watershed modeling tools (Gordon et al., 2006, 2007).

2. Defining gully length through extending the gully by the upstream migration of the head cut. (Gordon et al., 2007).
3. Its sediment routing calculations address five particle size classes, accounting for differences between the ephemeral gully sediment flux and the *in situ* soil material.
4. It determines channel width from discharge, allowing channel dimensions to be explicitly predicted at any point in time and space (Gordon et al., 2006, 2007).

2.3.1. Model description

The integration of REGEM technology into AnnAGNPS led to other additions to simulate tillage-induced ephemeral gully erosion including: the capability to repair gullies through tillage that defines when an ephemeral gully can again initially form; the influence of prior land use as defined from RUSLE technology; utilization of HUSLE (Theurer and Clarke, 1991) components for sediment transport determination; enhanced gully width calculations; and the determination of the amount of scour-hole erosion. These enhancements and the inclusion of REGEM technology have led to the Tillage-Induced Ephemeral Gully Erosion Model (TIEGEM) within AnnAGNPS to provide a watershed-scale assessment of management practice effects on sediment production from ephemeral gully erosion within croplands (Bingner et al., 2009).

This study used REGEM model in its currently available version (as of July 2010). REGEM is only concerned with the dynamics of channel geometry, unsteady, spatially varied flow, and sediment transport and may be used only to predict sediment delivered to the mouth or outlet of an ephemeral gully. This sediment is combined with overland erosion and routed through the remainder of the watershed using the

AnnAGNPS model channelized flow algorithms. Within AnnAGNPS, REGEM requires no additional information beyond that required by AnnAGNPS itself. REGEM will account for the processes of ephemeral gully erosion at the sub-cell scale, and will become a part of the continuous simulation of runoff and erosion on agricultural lands (Gordon, 2005).

REGEM has four categories of input information: 1) hydrologic; 2) field scale; 3) soil; and 4) management operations. All input to REGEM will eventually be passed from routines in AnnAGNPS, some of which may allow user input while others are calculated internally in other routines (Gordon, 2005). Table 2.1 represents the input parameters required by the REGEM model.

REGEM involves two steps to prepare an ephemeral gully dataset:

- generate potential ephemeral gully and digitize gully mouth, and
- create potential ephemeral gully dataset and export ephemeral gully INP file.

Table 2.1 Input parameters required by REGEM model

Categories	Input variable	Notation	Units
Hydrology	Event peak discharge	Q_p	$m^3\ sec^{-1}$
Hydrology	Event runoff volume	V_r	m^3
Field	Average thalweg slope	S	$m\ m^{-1}$
Field	Manning's roughness	n	
Field	Tillage depth	D_t	m
Field	Drainage area to gully mouth	A_d	ha
Soil	Clay ratio in surface soil	R_{clay}	
Soil	Silt ratio in surface soil	R_{silt}	
Soil	Sand ratio in surface soil	R_{sand}	
Soil	Small aggregate ratio in surface soil	R_{sagg}	
Soil	Large aggregate ratio in surface soil	R_{lagg}	
Soil	Soil bulk density	B_d	$Mg\ m^{-3}$
Soil	Critical shear stress of surface soil	T_c	$N\ m^{-2}$
Soil	Head cut erodibility co efficient	K_d	$cm^3\ N^{-1}\ sec^{-1}$
Management Operations	Integer value classifying current soil condition.	C_{soil}	1= no till, 2= freshly cultivated, 3= established crop

The “generate potential ephemeral gully” tool helps the user to identify the flow network where ephemeral gullies have the potential to form and is based on flow direction and accumulation occurring in landscape. The tool to digitize the gully mouth helps the user to identify gully mouth points in the study area and also to edit the gully mouth dataset. For detailed information about REGEM, refer the REGEM technical documentation (Gordon et al., 2006, 2007).

2.3.2. Model limitations

REGEM within AnnAGNPS has identified several model limitations because little is known about several critical components. Some of the more important limiting components are the identification of and relationships to quantify (1) ephemeral gully width, (2) soil resistance to gully erosion, including a definition for non-erosive layers, (3) the effect of root mass and above-ground vegetation on erosion resistance, (4) ephemeral gully networks, and (5) the effect of subsurface flow on ephemeral gullies (Bingner et al., 2009).

2.4. StreamBank Erosion Models

FLUVIAL-12 (Chang, 1998) and CONCEPTS (Langendoen, 2000) are two streambank erosion models that are currently being used. The CONCEPTS model is particularly complex, requires extensive user inputs, and is time consuming to use. Table 2.2 describes and differentiates key features of FLUVIAL-12 and CONCEPTS and shows the complex nature of streambank erosion models.

Table 2.2 Comparative study of FLUVIAL-12 and CONCEPTS

	FLUVIAL–12	**CONCEPTS**
Full Model Name		Conservational Channel Evolution and Pollutant Transport System
Source	San Diego State University	USDA-ARS
Level of Complexity	One-dimensional, unsteady flow	One-dimensional unsteady flow
Channel form	Considers its natural form.	Assumes the channel is straight
Type of model	Erodible boundary model (considers channel curvature)	Erodible bed model (Does not consider channel curvature), unsteady state model
Simulations (Type, Level of Complexity, Time step, Hydrology, Water quality)	Simulates channel bed scour, fill, width variation and changes caused by curvature effect	Simulates transport of cohesive and cohesion less sediments both in suspension and on bed, open channel hydraulics, and channel morphology.
Governing equations	Continuity and Momentum equations	Saint Venant Equations, Manning equation,
Simulation of channel width	By incorporating bed scour and fill	By incorporating fluvial erosion by flow and mass bank failure.
Model Inputs	Run control data, Discharge data at upstream boundary, an input file for each cross section, grain size distributions of bed sediment, channel curvature, bank erodibility, and hydrology.	Topographic maps of the river, digitized data for cross sections, flow hydrographs and size distributions of sediment samples
Model Strengths	• Formulated and Developed for Sediment and water routing in natural and man made lakes. • Is capable of modeling changes over time in the following physical parameters: • Changes in river curvature. • Changes in Manning's n • Changes in cross section caused by bank erosion. • Changes in water surface and bed elevation profiles. • Can be used for evaluation of general scour at bridge crossings, sediment delivery, channel responses to sand and gravel mining, channelization etc. • Applicable to ephemeral rivers as well as rivers with long term flow. • Adjusts the channel width based on considerations of minimizing stream power expenditure.	• Can predict the dynamic response of flow sediment transport to in stream hydraulic structures. • Computes channel evolution by tracking bed changes. • Simulates transport of both cohesive and cohesion less sediments both in suspension and on bed. • Used to evaluate the efficiency, location and sizing alternatives of in stream grade control structures to reduce sediment yield. • Used to evaluate the design of stream corridor.
Model Limitations	• Does not consider storage effects due to unsteady flow	• Uses 13 predefined sediment particle size classes. • Linear erosion rate of cohesive bed material. • Homogenous cohesive bank material • Only four types of in stream structures are used • Metric system of units.

Due to their complex nature, our lack of the site-specific data required to run these models, and reasonable time constraints associated with completion of this M.S. Thesis project, this study did not apply these models. Instead, this study developed and demonstrated several methods to apply measured annual streambank sediment erosion values to the daily scale in an integrated modeling approach.

2.5. Streams in Black Vermillion Watershed

Streams in Black Vermillion Watershed are highly channelized. Channelization is an engineering process in which attempts are made to physically realign a channel in order to shorten or straighten that channel through dredging, excavation, etc. (Brookes, 1985). Channelization causes rapid morphological changes that have numerous negative effects to the fluvial systems, like lowering of streambed through dredging, increased channel capacity, increased channel gradient and increased velocity; the resulting changes include unstable banks, upstream degradation and downstream aggradation (Simon and Rinaldi, 2006). Stream channelization causes changes in nearly all hydrogeomorphic processes (Hupp, 1992).

The primary reason for channelization of streams in Black Vermillion Watershed was to keep flood flows from impacting crops and to improve water drainage from fields. A secondary benefit of channelization was that the newly-straightened stream channels allowed for increased amounts of land to be put under cultivation (Peterson, 1991). Channelization practices have not been completed consistently – temporally or spatially – in the Black Vermillion Watershed. In fact, channelization has been completed in piecemeal fashion throughout the watershed (fig. 2.1) (Meade, 2009). Overall, channelization has shortened the channel lengths by about 23% on the North Fork, 26%

on the Main Stem above Vliets, and 12% on the Main Stem from Vliets to Frankfort (ACOE, 1998). Today channelized stream reaches are readily visible in the Black Vermillion Watershed (fig. 2.2).

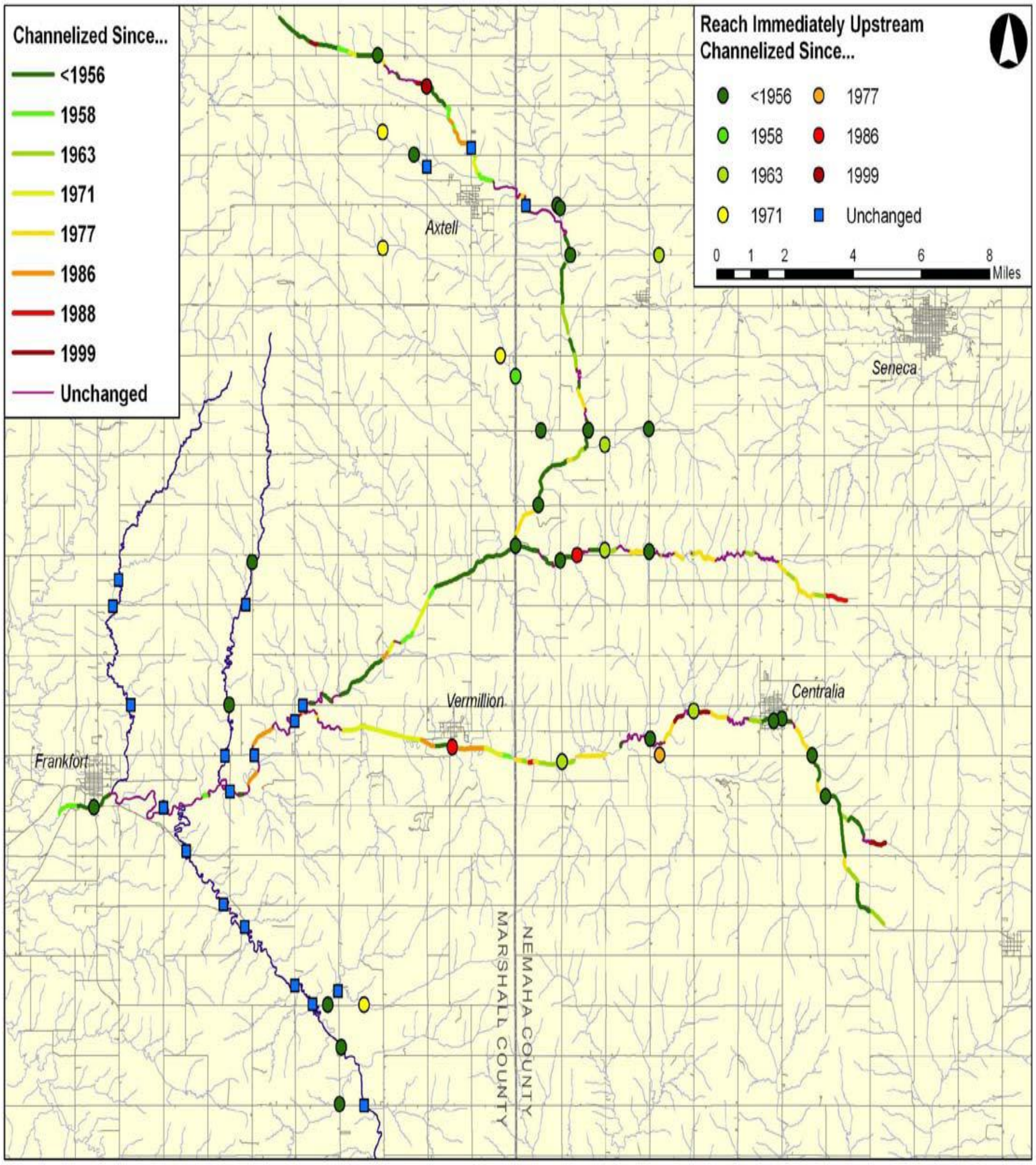


Figure 2.1 Map of timing of channelization in the Black Vermillion watershed. Created by Rob Daniels, 2008. (Meade, 2009).

Figure 2.2 Channelization on Main Stem of Black Vermillion River near Vermillion, Kansas. (Source: Erik Peterson, Jan, 1987)

2.6. Streambank Erosion

Streambank erosion is a natural process. Streambank erosion occurs for two reasons. First, lateral erosion of the bank toe occurs because of the fluvial entrainment of in situ bank materials. This process is known as hydraulic erosion. Second, gravity can cause mass failure of the upper part of the bank (Langendoen and Simon, 2008). Both of these processes can be triggered by channel incision which is in turn triggered by landuse activities. Acceleration of this natural process leads to stream channel instability, landloss, disproportionate sediment supply and other effects. Simon and Rinaldi (2006) stated that channel incision contributes to the generation of higher and steeper streambanks. Channel incision contributes to channel widening due to bank erosion and subsequent channel-width adjustment. Simon (1992) stated that channel widening and bank erosion are important processes in helping the incised channel to recover over time because these processes can effectively reduce flow depth, shear stress, and therefore reduce the sediment transport capacity of the fluvial system. Zaimes et al. (2006) found that bank erosion can contribute up to 50-90% of the sediment transported in stream bed load. Simon and Rinaldi (2006) stated that streambanks can contribute up to 80% of a stream's total suspended load. The streambanks in the Black Vermillion Watershed are highly unstable (fig. 2.3).

Figure 2.3 Bank erosion on the North Fork of the Black Vermillion River. (Source: Chris Sass, June, 2008)

2.7. Stream Channel Aggradation and Degradation

Aggradation involves the raising of the streambed elevation, an increase in width to depth ratio, and a corresponding decrease in channel capacity (Rosgen, 2006). Aggradation often results from an increase in upstream sediment load and/ or sediment size that exceeds the transport capacity of the channel. Aggradation may also result from instability caused by over-widening of the channel, with a resulting decrease in stream power and shear stress. Excess sediment deposition in the stream channel and coarse particle deposits on flood plains are characteristics of an aggrading river. This characterstic is observed in most of the streams in Black Vermillion River watershed. Common adverse consequences include increased flood risk, land loss, the decline of fish habitats, elevated stream temperatures and loss of biological functions (Rosgen, 2006).

Degradation involves the lowering of the bed levels of rivers through the process of excess bed scour and channel incision. The process of channel degradation will generally migrate upstream as a series of knickpoints or knickzones, depending on the bed substrate material and their cohesiveness and erosion resistance. The upstream progression of degradation will occur especially when bed-material mining or channelization has occurred because of the extreme disturbance to stream channels that has occurred (Simon and Rinaldi, 2006).

CHAPTER 3 - Materials and Methods

3.1. Watershed Description

The Black Vermillion River Watershed (Hydrologic Unit Code 10270205; USGS, 2010) selected for this study is located in the north east of Kansas within the Great Plains region of United States. The watershed, located in the parts of Marshall, Nemaha and Pottawatomie counties (fig. 3.1), is dominated by agricultural land uses. Within this watershed, the streams are highly disturbed due to extensive channelization of the stream network (Philip Barnes, personal communication, 17 March 2009). Most of the watershed is rural with the largest towns (fig. 3.2) being Frankfort (population 776) and Centralia (population 486) (U.S. Census Data, 2008). Irish Creek, Main Stem and North Fork are the three subwatersheds (fig. 3.3) that were chosen for this study because of they each have highly unstable streambanks and represent a range of land use distributions representative of the region.

3.1.1. Irish Creek

Irish Creek (fig. 3.4), also known as South Fork of the Black Vermillion River, has a drainage area of 33.55 km^2 (12.95 mi^2), enters the Black Vermillion to the east of Frankfort, Kansas, from the south, and flows primarily through Flint Hill uplands (Sass, 2008). The western banks resemble Flint Hills more than the east bank. The Irish Creek subwatershed has many flow-through water impoundments affecting the watershed drainage area and stream flow characteristics (Sass, 2008). Most of the subwatershed (58.26%) is behind watershed structures (drainage area of 19.52 km^2 [7.54 mi^2] behind watershed structures) (fig. 3.5).

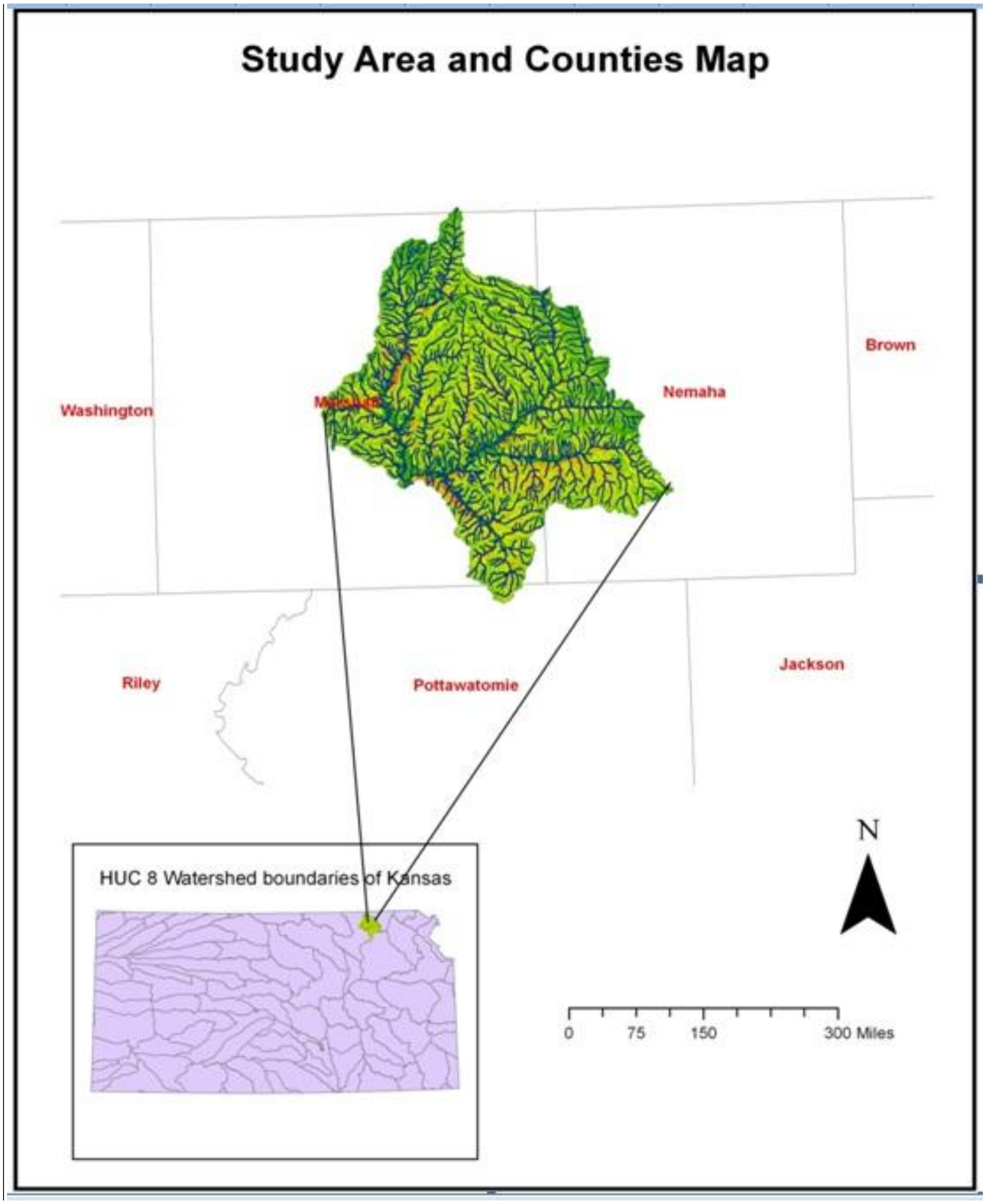


Figure 3.1 Black Vermillion Watershed study area.

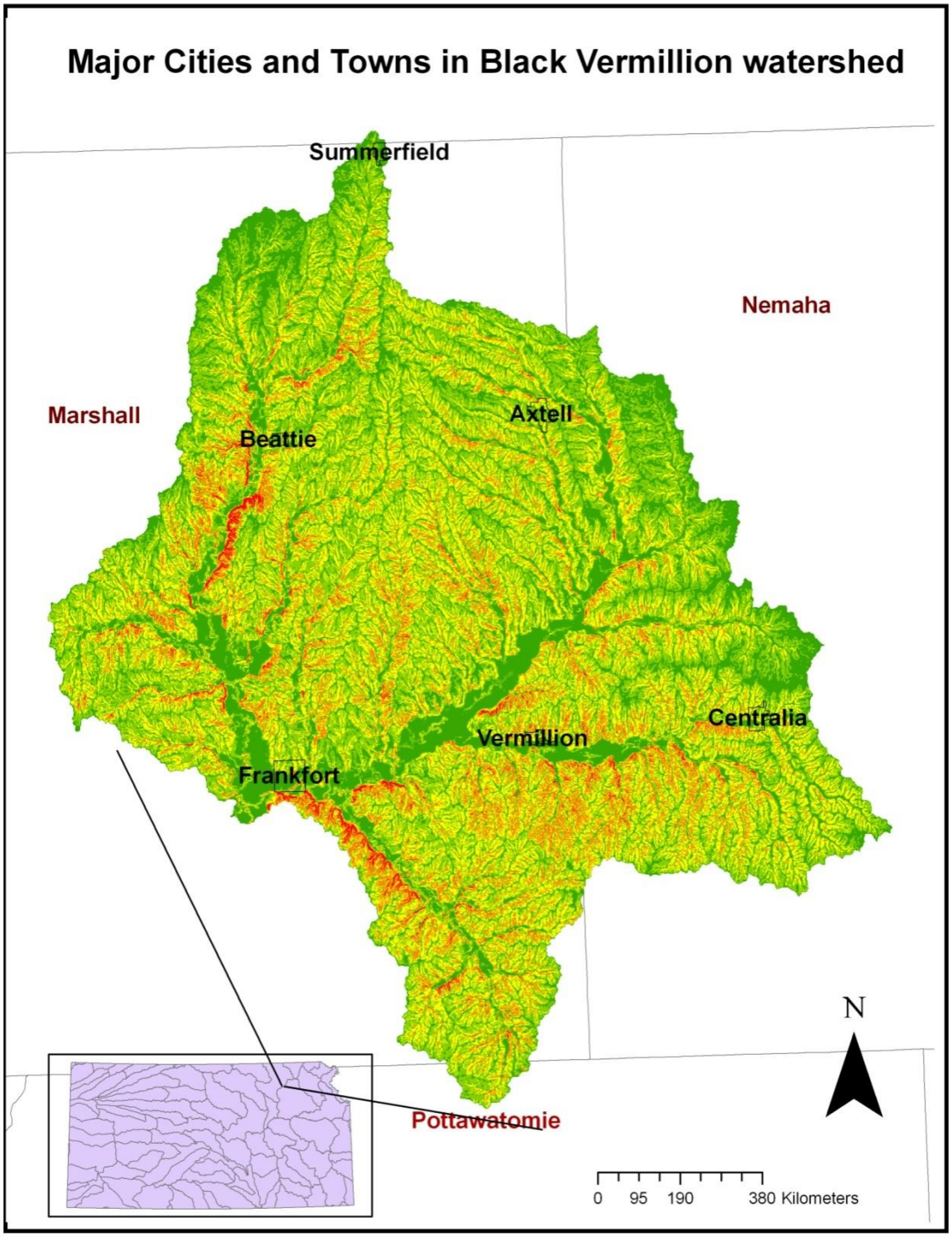


Figure 3.2 Major towns and cities within Black Vermillion Watershed study area.

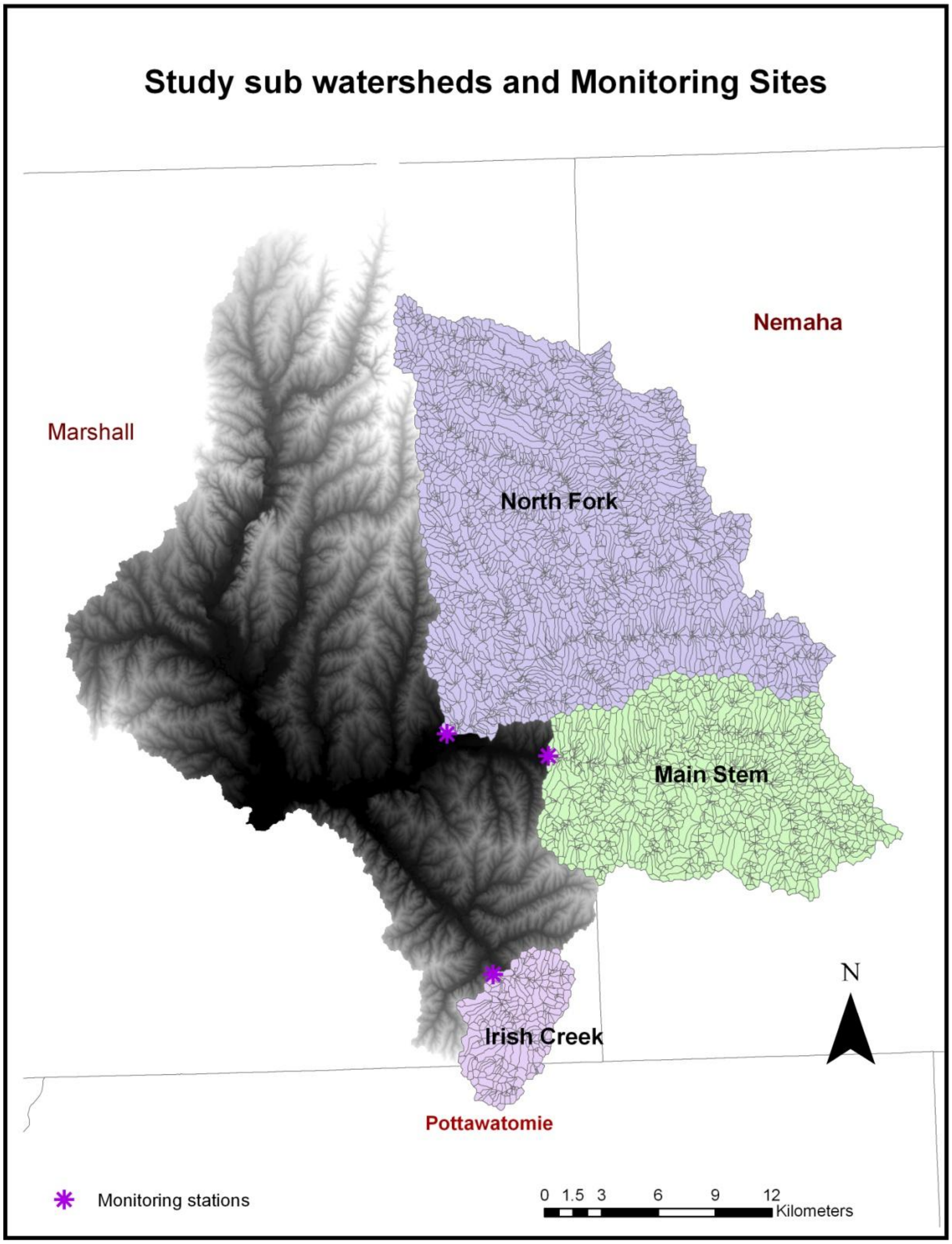


Figure 3.3 Study subwatersheds and stream flow monitoring sites within the Black Vermillion Watershed.

(a)

(b)

Figure 3.4 Irish Creek a) reach 1, and b) reach 2 (Sass, 2008).

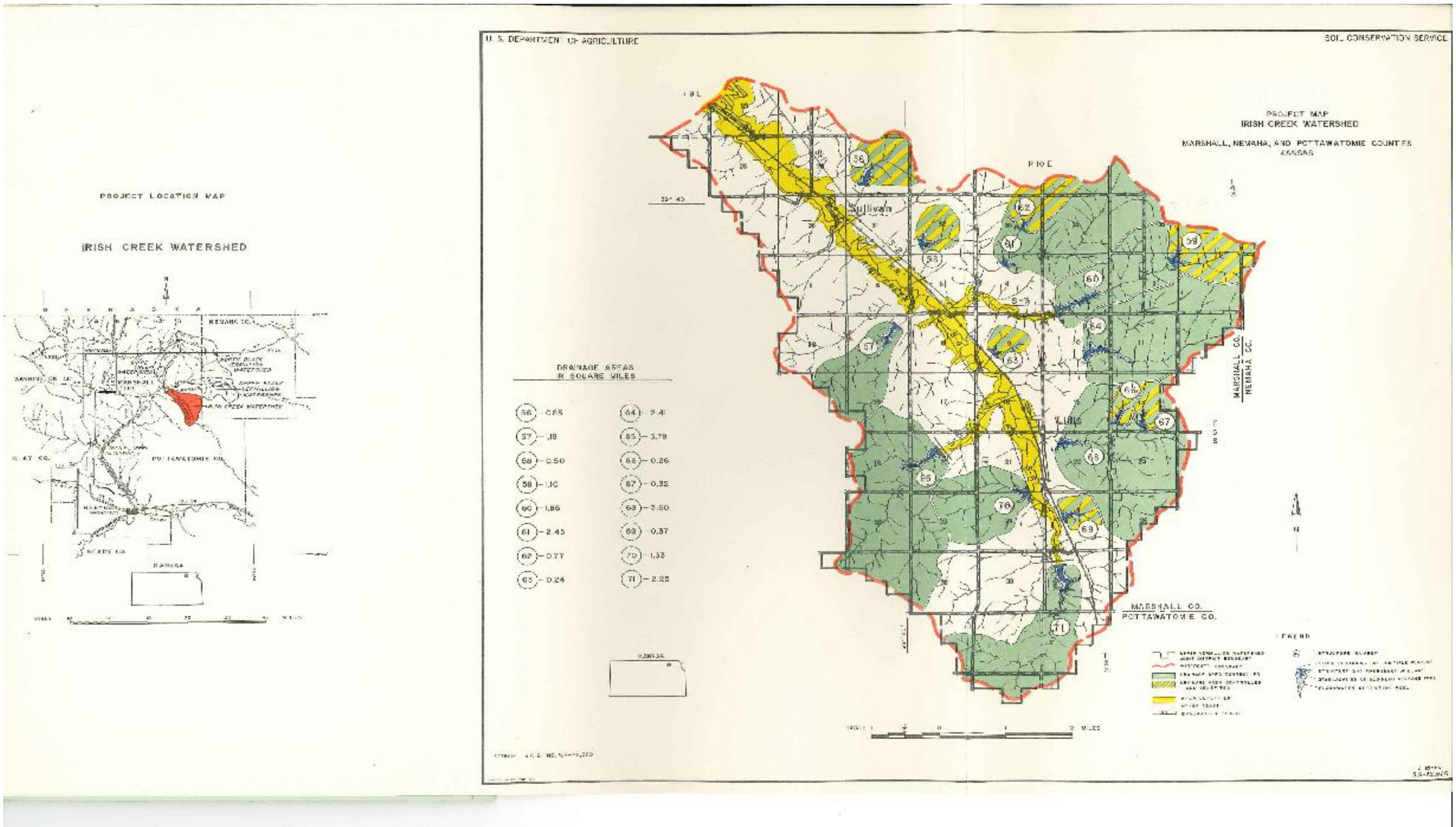


Figure 3.5 Watershed structures and drainage areas in Irish Creek subwatershed. (Source: Developed by State Conservation Commission and the Kansas Water Office, S. C. S. No. 5, R-22, 320).

3.1.2. Main Stem

The Main Stem of Black Vermillion River (fig. 3.6) flows through alluvial and glacial deposits and has a drainage area of approximately 154.37 km^2 (62 mi^2). Main Stem also contains many small flow-through water impoundments, with Centralia Lake as the largest impoundment (approximately 161.6 ha [400 ac] impoundment) (Sass, 2008). Most of the subwatershed (57%) is behind watershed structures (drainage area of subwatershed behind watershed structures is 91.35 km^2 [35.27 mi^2]), and in the future an additional 25.90 km^2 (10 mi^2) of the subwatershed may drain to watershed structures (73% of the total subwatershed) (fig. 3.7).

(a)

(b)

(c)

Figure 3.6 Main Stem a) reach 1, b) reach 2, and c) reach 3 (Sass,2008).

STRUCTURES BUILT

NO.	D.A., Sq.Mi.
10	0.28
11	0.38
13	0.28
23	0.34
24	0.21
25	0.79
26	0.76
27	1.43
28	0.41
29	0.60
30	1.12
31	0.43
32	4.45
35	0.20
36	0.37
37	0.27
38	0.60
39	0.54
40	0.24
42	2.98
43	0.67
45	0.35
46	1.84
47	0.49
50	12.65
52	1.26
53	1.47

STRUCTURES PLANNED

NO.	D.A., Sq.Mi.
12	0.76
14	0.31
49	1.77
51	4.39
54	1.11
227	0.54
231	0.36
232	0.65

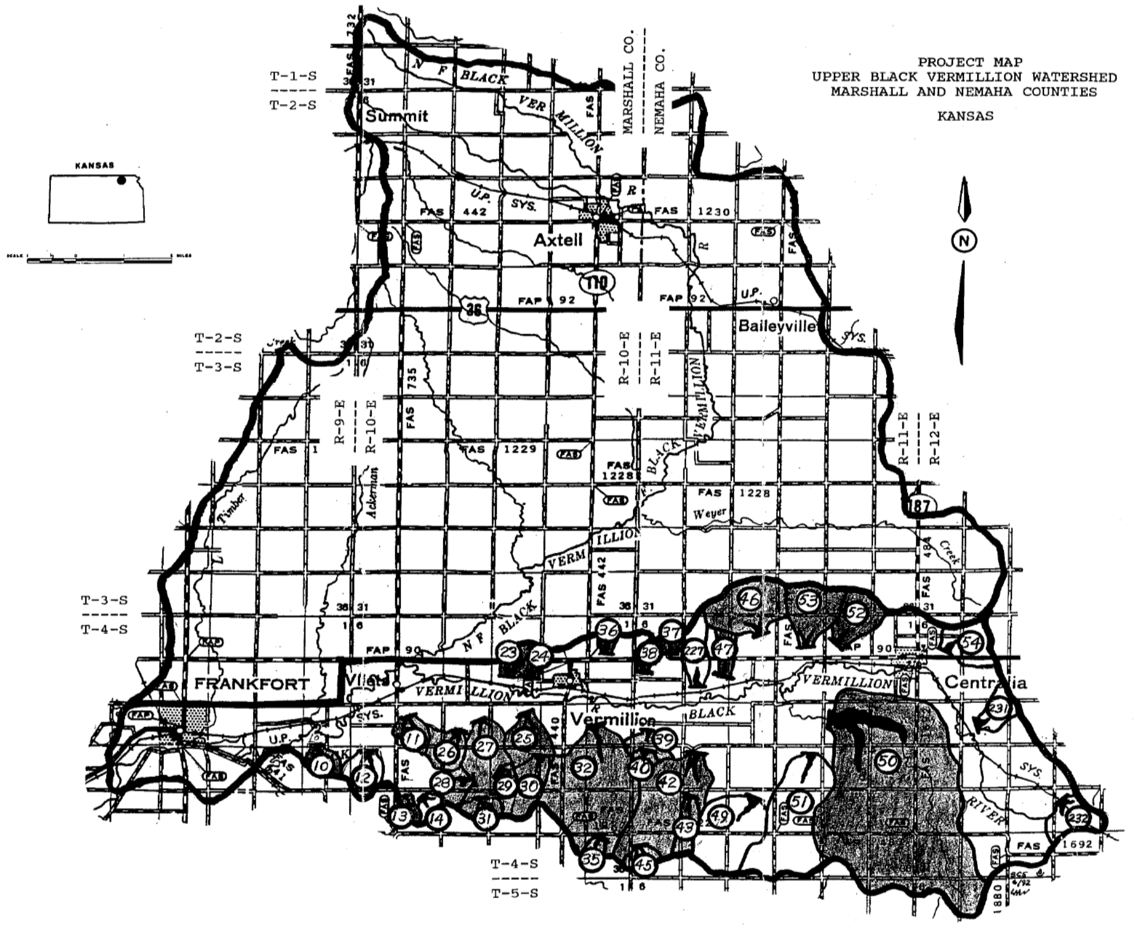


Figure 3.7 Watershed structures and drainage areas in Main Stem subwatershed. (Source: Developed by State Conservation Commission and the Kansas Water Office, S. C. S. No. 5, R-22, 320)

3.1.3. North Fork

North Fork (fig. 3.8), the largest subwatershed of the Black Vermillion Watershed, flows through alluvial and glacial deposits. Topography is rolling with deeply dissected and entrenched streams (Sass, 2008). A portion of the subwatershed (21%) drains to watershed structures (drainage area of 67.23 km^2 [25.96 mi^2] behind watershed structures) and in future an additional 104.58 km^2 [42 mi^2] of the watershed drainage area is planned to be detained by watershed structures (55% of total subwatershed) (fig. 3.9).

(a)

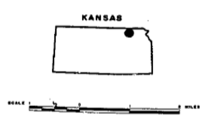
(b)

(c)

Figure 3.8 North Fork a) reach 1, b) reach 2, and c) reach 3 (Sass, 2008).

STRUCTURES PLANNED	
NO.	D.A., Sq.Mi.
4	4.65
19	0.63
72	0.39
76	3.21
77	0.77
79	2.20
92	0.28
93	0.28
94	0.31
96	2.70
107	11.90
109	1.00
110	1.30
111	0.31
200	0.22
201	0.64
202	1.89
203	0.28
204	0.30
205	1.01
206	0.70
209	0.35
212	0.36
213	0.36
214	0.34
215	0.47
217	0.94
218	0.51
219	0.32
220	0.43
221	0.79
223	0.46
224	0.41
226	0.33
229	0.36
230	0.77

STRUCTURES BUILT	
NO.	D.A., SQ.MI.
1	1.08
2	0.69
7	0.45
8	0.50
9	0.45
15	0.70
16	1.55
17	0.84
21	0.27
22	0.42
73	1.58
74	1.24
75	2.38
78	0.95
81	0.22
82	0.81
83	0.31
84	0.28
86	0.39
87	0.40
89	0.50
95	0.34
97	6.25
99	0.25
101	1.34
103	0.43
108	0.39



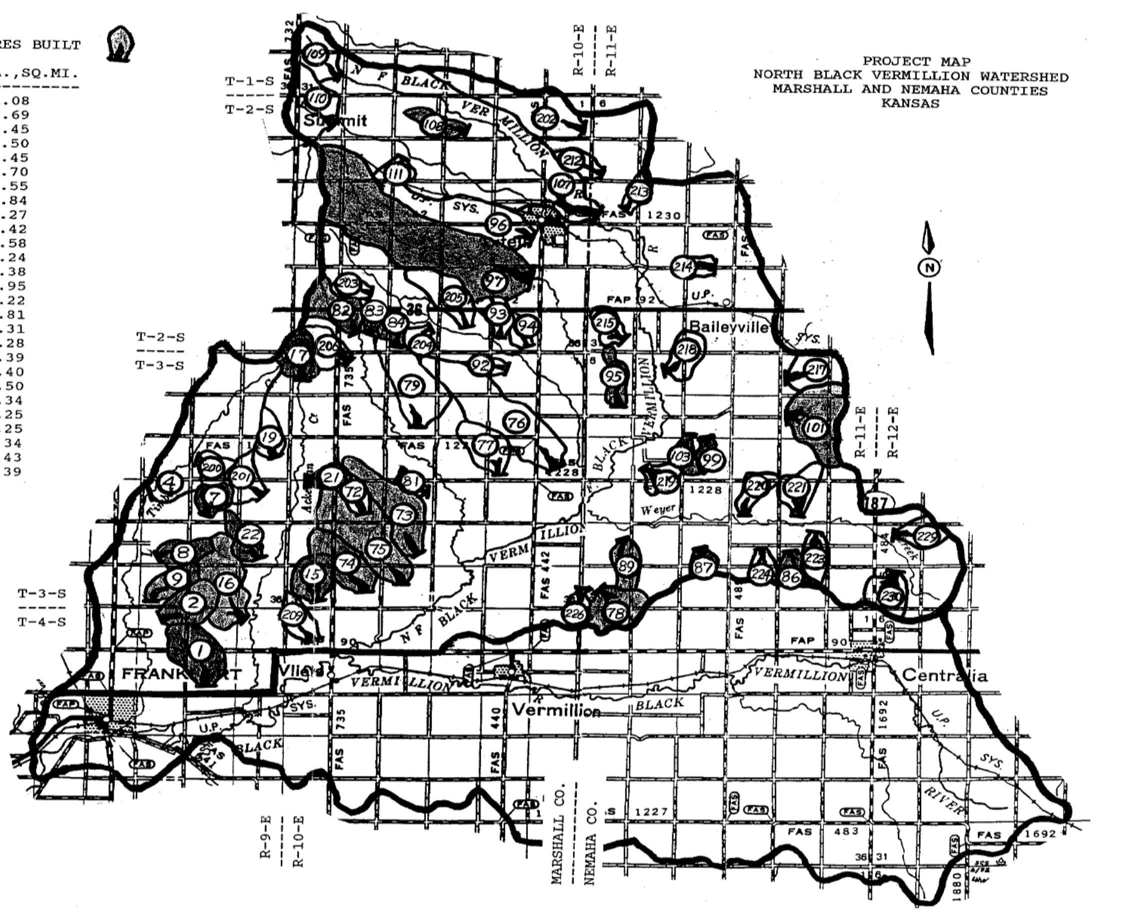


Figure 3.9 Watershed structures and drainage areas in North Fork subwatershed. (Source: Developed by State Conservation Commission and the Kansas Water Office, S. C. S. No. 5, R-22, 320).

3.1.4. Climate

Black Vermillion Watershed in winters (November to February) has average temperature of -1.4 °C (29.4 °F) and average daily minimum temperature of -7.0 °C (19.4 °F). In summer (May to August), the average temperature is 25.8 °C (78.5 °F) and the average daily maximum temperature is 30.7 °C (87.3 °F) (Abel, 2005). The average annual precipitation is 87.8 cm. The sun shines 76% of the time in summer and 63% in winter. Average wind speed is 5.8 m/s (13 mi/h) (Abel, 2005). Precipitation in Kansas increases from west to east. Annual average precipitation is 79.5 cm in Marshall County and 87.5 cm in Nemaha County (Meade, 2009).

3.1.5. Topography

Kansas Geological Survey shows that the northern portion of Black Vermillion River Watershed is topographically till plains and the southern portion has chiefly a rock-controlled type of topography similar to that of the Flint Hills region. In areas more remote from major streams, the rock-controlled topography is mantled by glacial drift and loess. Black Vermillion River is a large, westward-flowing tributary of Big Blue River and joins it about 1.6 km north of the Pottawatomie County line. Vermillion Creek, a major southward-flowing tributary of Black Vermillion River, joins the Black Vermillion River near the city of Frankfort. A small area in the northeast corner of Marshall County is drained by Nemaha River and another in the southeast corner by a tributary of Vermillion River. Elevations range from approximately 300 to 450 m above mean sea level through out the watershed, with the lowest elevations being found near Frankfort, Kansas, within the valley of the lower reaches of the Black Vermillion River.

The highest elevations are found in the northern portions of the watershed, near the Nebraska-Kansas state line (Meade, 2009).

3.1.6. Soils

The soils in the Nemaha County are deep and gently sloping to moderately steep and have clayey or loamy sub soils, from 0.6 m to 1.0 m deep, and are particularly noted for the manner in which it withstands drought, dry weather seldom affecting it (Abel, 2005). The watershed has a wide variety of soils (table 3.1), and most of the soils in the three study subwatersheds have hydrological soil group D (table 3.2). Figure 3.10 shows the hydrological soil group distribution in the study subwatersheds.

Table 3.1 Soil properties in Black Vermillion Watershed (SSURGO Soils; USDA-NRCS, 2005).

Soil Name	Soil Texture	Hydrologic Soil Group	K-Factor	Albedo
Hobbs	Silt Loam	B	0.32	0.23
Crete	Silty Clay Loam	C	0.37	0.09
Geary	Silt Loam	B	0.32	0.16
Lady Smith	Silty Clay Loam	D	0.37	0.16
Ortello	Sandy Loam	B	0.20	0.16
Tully	Silty Clay Loam	C	0.28	0.09
Eudora	Loam	B	0.32	0.16
Mayberry	Clay loam	D	0.37	0.16
Morrill	Loam	B	0.28	0.16
Wymore	Silty clay loam	D	0.28	0.16
Nodaway	Silt loam	B	0.37	0.23
Kipson	Silty clay loam	D	0.32	0.16
Calco	Silty clay loam	D	0.28	0.09
Wabash	Silty clay loam	D	0.37	0.16
Reading	Silt loam	B	0.32	0.16
Aksarben	Silty clay loam	C	0.32	0.16
Burchard	Clay loam	B	0.28	0.16
Elmont	Silt loam	B	0.32	0.16
Martin	Silty clay loam	C	0.37	0.16
Padonia	Silty clay loam	C	0.37	0.09
Sibleyville	Loam	B	0.28	0.23
Vinland Variant	Loam	B	0.32	0.09
Judson	Silt loam	B	0.28	0.09
Wann	Fine sand loam	B	0.20	0.16
Muir	Silt loam	B	0.32	0.16
Carr	Fine sandy loam	B	0.24	0.30
Chase	Silty clay loam	C	0.37	0.16
Ivan	Silt loam	B	0.32	0.16
Ben field	Silty clay loam	C	0.28	0.09
Clime	Silty clay loam	C	0.32	0.16
Tuttle	Channery silty clay loam	C	0.20	0.09
Wamego	Silt loam	C	0.32	0.16
Bourbonais	Silt loam	C	0.32	0.16
Bismarckgrove	Silt loam	B	0.32	0.23
Belvue	Silt loam	B	0.32	0.30
Zeandale	Silt loam	B	0.32	0.36
Kennebec	Silt loam	B	0.28	0.09
Kimo	Silty clay loam	C	0.37	0.23
Stone house	Loamy fine sand	A	0.15	0.30
Muscotah	Silty clay loam	D	0.37	0.09
Paxico	Silt loam	B	0.37	0.30
Sarpy	Loamy sand	A	0.17	0.23
Zook	Silty clay loam	D	0.37	0.09
Rossville	Silt loam	B	0.28	0.16
Gymer	Silt loam	C	0.32	0.09
Olmitz	Loam	B	0.24	0.23
Pawnee	Clay loam	D	0.37	0.16
Sharpsburg	Silt loam	C	0.32	0.16
Shelby	Clay loam	B	0.28	0.16
Steinauer	Clay loam	B	0.32	0.23
Thurman	Loamy fine sand	A	0.17	0.16
Wymore variant	Fine sandy loam	C	0.28	0.16
Monona	Silt loam	B	0.32	0.09

Table 3.2 Percent soil group distribution in study areas

Watershed	Percent Soil Group A	Percent Soil Group B	Percent Soil Group C	Percent Soil Group D
Irish Creek	0.0	9.7	1.8	88.5
Main Stem	0.0	30.6	0.3	69.1
North Fork	0.0	24.2	1.1	74.7

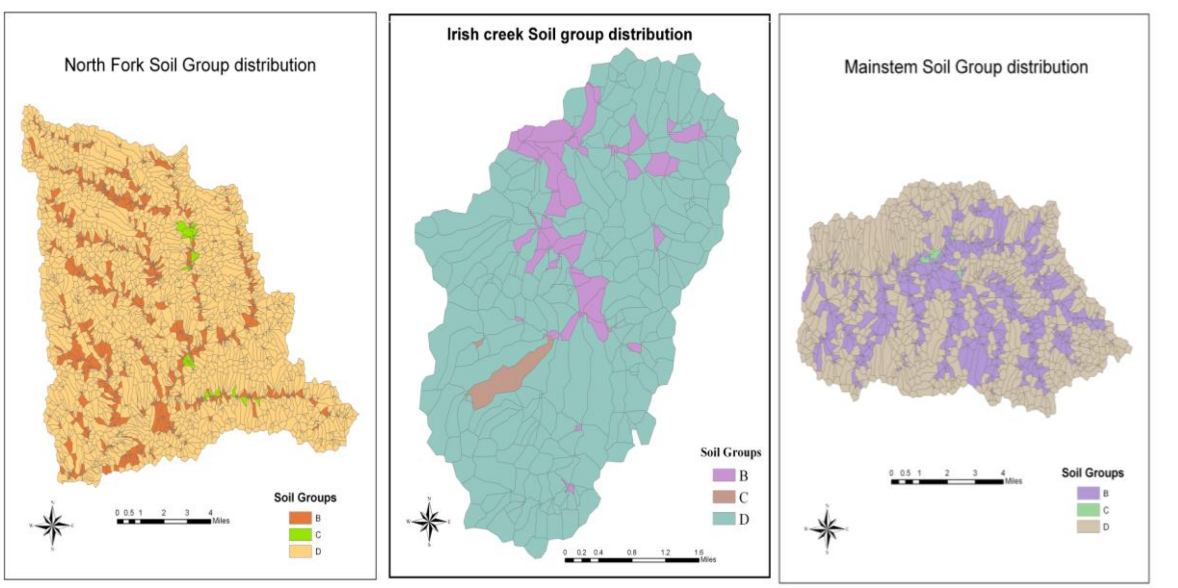


Figure 3.10 Soil group distributions for each study subwatersheds

3.1.7. Land use

In Black Vermillion Watershed, farming was initially concentrated in the river valleys until about 1880 because of flat topography, deep fertile soils found adjacent to the rivers (USDA-SCS-KAES, 1951). After 1880 farming efforts spread on to surrounding hillslopes away from riparian areas (USDA-SCS-KAES, 1951). Most of the land use in the Black Vermilion Watershed is agriculture (table 3.3, fig. 3.11). Most of land north of Frankfort is row crops and tilled cultivated lands; most of the land south of Frankfort is pasture. Corn (*Zea mays)*, wheat (*Triticum aestivum*), grain sorghum (*Sorghum* sp.), soybeans (*Glycine max*), alfalfa (*Medicago sativa*) are the principal crops. About one-third of the acreage of Marshall County is grazing land; a large part of this is in the southwest quarter of the county where the soil is less suitable for tilling. The percentage of land use in agriculture varies slightly by county and by time period. Between 1967 and 1977, 71% of the total land area of Nemaha County was in crops (USDA-SCS, 1982) while in 1967, 60% of the Marshall County was in crops (USDA-SCS, 1980). Sorghum, corn, soybeans, alfalfa and wheat are the main crops that are grown (USDA-SCS, 1982). The acreage planted to sorghum and soybeans increased over the previous 10-year period (USDA-SCS, 1982). Row crops are common in the sub watersheds of North Fork (table 3.3, fig. 3.14) and Main Stem (table 3.3, fig. 3.13), while Irish Creek (table 3.3, fig. 3.12) contains higher levels of grazing land and woodland. Soil erosion is the major hazard on about 90 percent of the cropland in Nemaha County (USDA-SCS, 1982) and 75 percent crop land in Marshall County (USDA-SCS, 1980). The Irish Creek of Black Vermillion flows out of hilly terrain similar to Flint Hills topography to the south. Thinner soils and more bed rock exposure inhibit crop growth and therefore promote rangeland as a land use. The North Fork and Main Stem flow out of flat terrain that is covered with thick deposits of glacial till and loess (Meade, 2009). These areas are more appropriate for row crops. Native grasses such as big bluestem, little bluestem and Indian grass exist in this watershed.

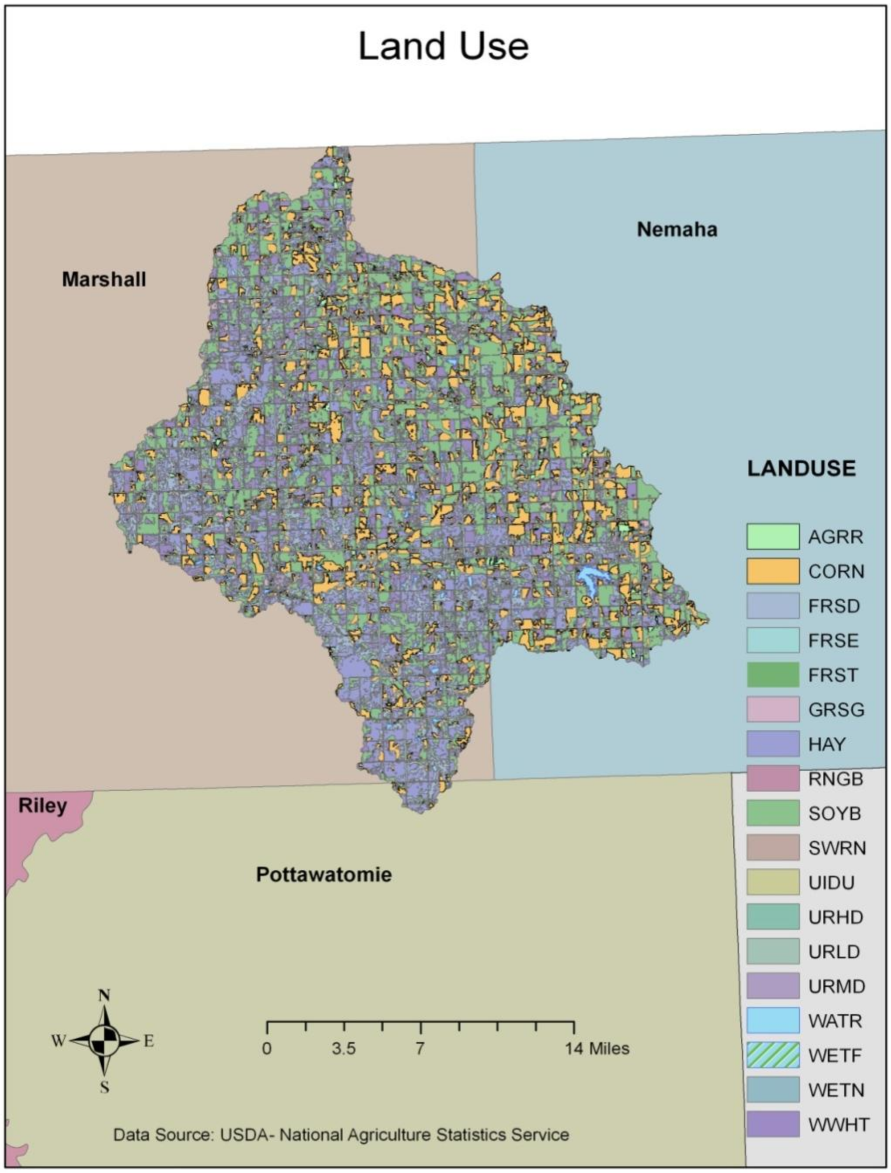


Figure 3.11 Land use map of Black Vermillion Watershed (USDA-NASS, 2008)

According to 2008 NASS land use data (USDA-NASS, 2008), Soybeans, corn, sorghum, winter wheat are the most commonly grown crops.

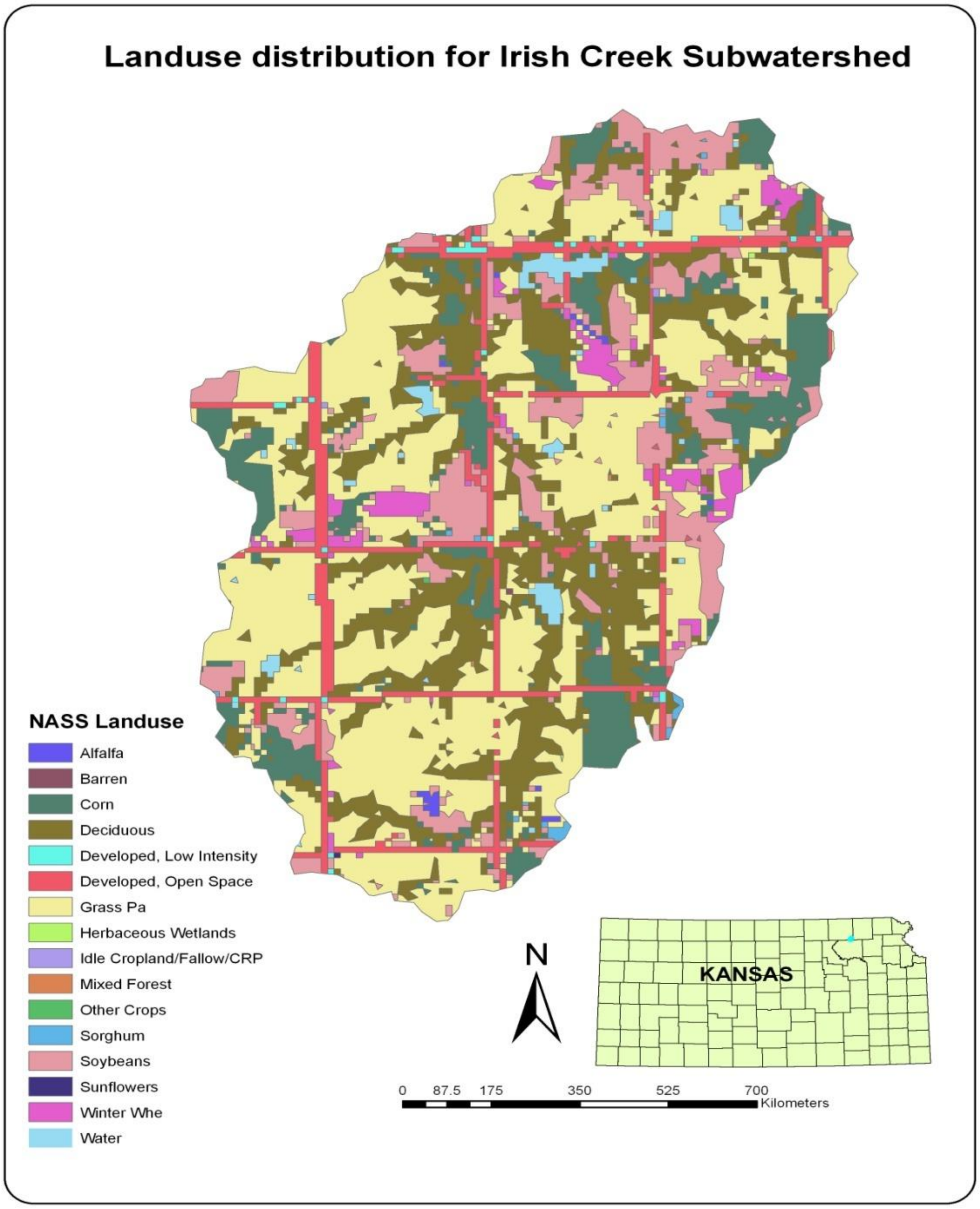


Figure 3.12 Land use map of Irish Creek subwatershed (USDA-NASS, 2008)

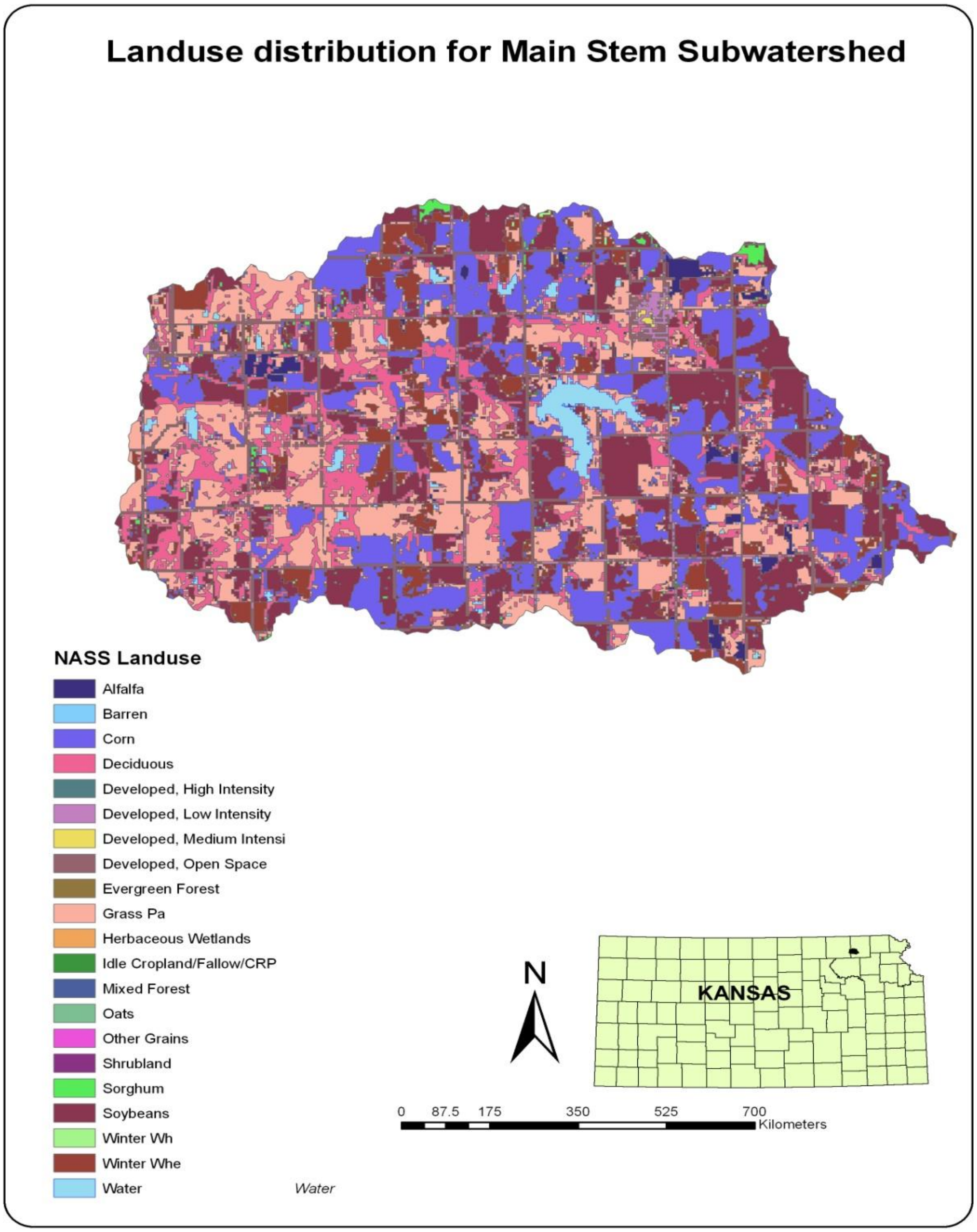


Figure 3.13 Land use map of Main Stem subwatershed (USDA-NASS, 2008)

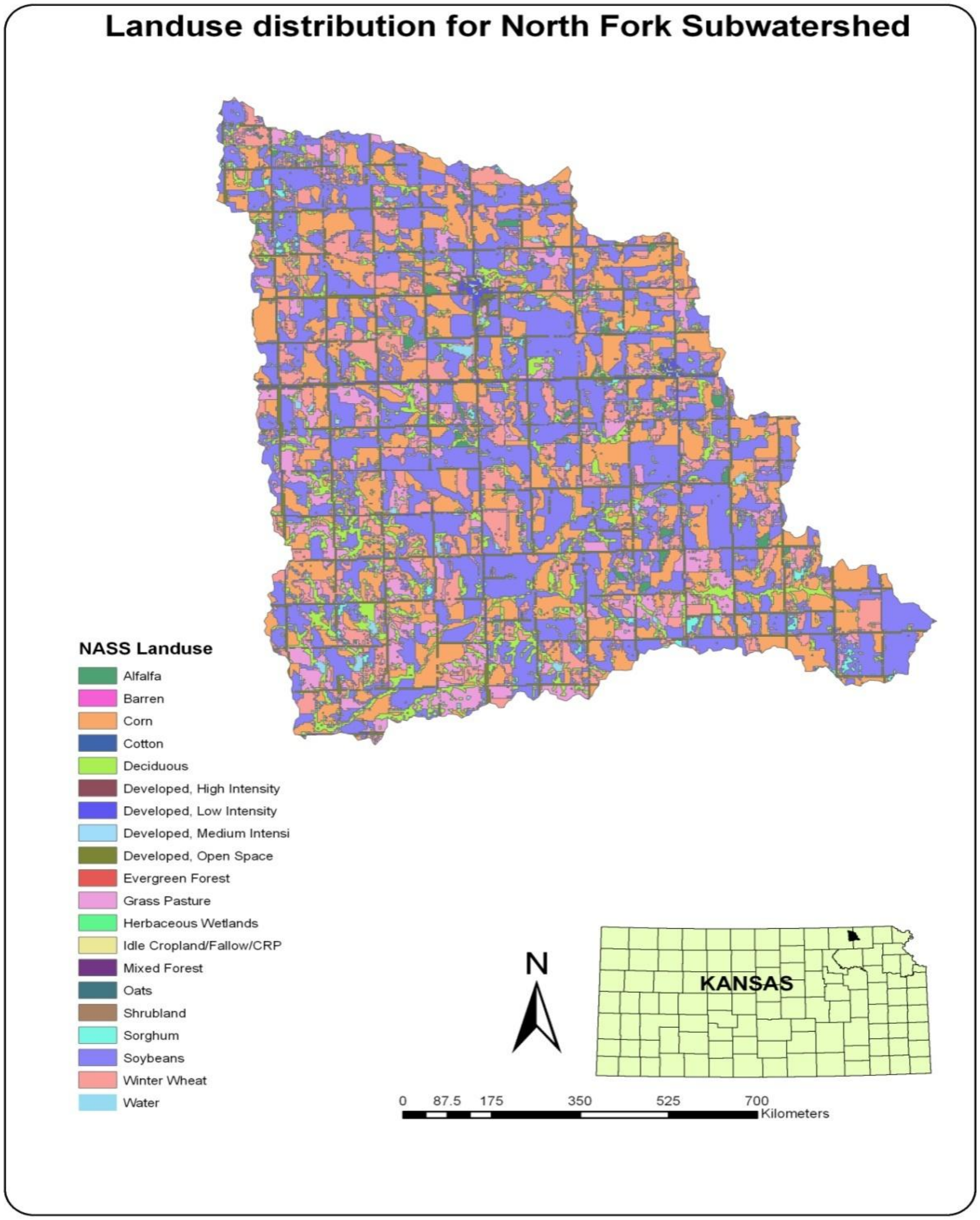


Figure 3.14 Land use map of North Fork subwatershed (USDA-NASS, 2008)

Table 3.3 2008 USDA- NASS Land use distribution for study subwatersheds and total Black Vermillion watershed

Subwatershed	Total Cropland (% of watershed)	Total Grassland (% of watershed)	Total Other (% of watershed)
Irish Creek	24.88	31.62	43.50
Main Stem	35.47	22.06	42.47
North Fork	49.21	20.92	29.87
Total Black Vermillion	40.01	21.58	38.41

The other landuse in the table 3.3 represents urbanland, forestland, residential, water, etc.

3.2. Input Data Requirements for Models

Input data sources for the AnnAGNPS and REGEM model include USGS 30 m Digital Elevation Model for topography (USGS-NED, 2008), USDA-NRCS spatial SSURGO soils data (USDA-NRCS, 2005) at a scale of 1:24000, and the USDA-NASS cropland data layer (USDA-NASS, 2008). This land use was used because of its classification accuracy, which is between 85% to 95% correct for agriculture related land cover categories (USDA-NASS, 2008).

The precipitation data were obtained from Lillis weather station located at Latitude 39°36'N and Longitude 96°20'W, and the rest of the weather data was obtained from Manhattan airport located at Latitude 39°08'N and Longitude 96°40'W (fig. 3.15), which is about 60 km south of the outlet of the Black Vermillion Watershed. This weather station was selected because it is the nearest weather station in that area having all the other climate data required by AnnAGNPS and has atleast 12 years of weather records. Twelve years of climate data were used (01/01/1997 to 12/31/2009). The 24-hour total precipitation depths, maximum and minimum temperatures, average dew-point temperature, total solar radiation, and average wind speed were used. This weather data was used for both AnnAGNPS and REGEM models. All the weather information was obtained from State Climatologist, Mary Knapp.

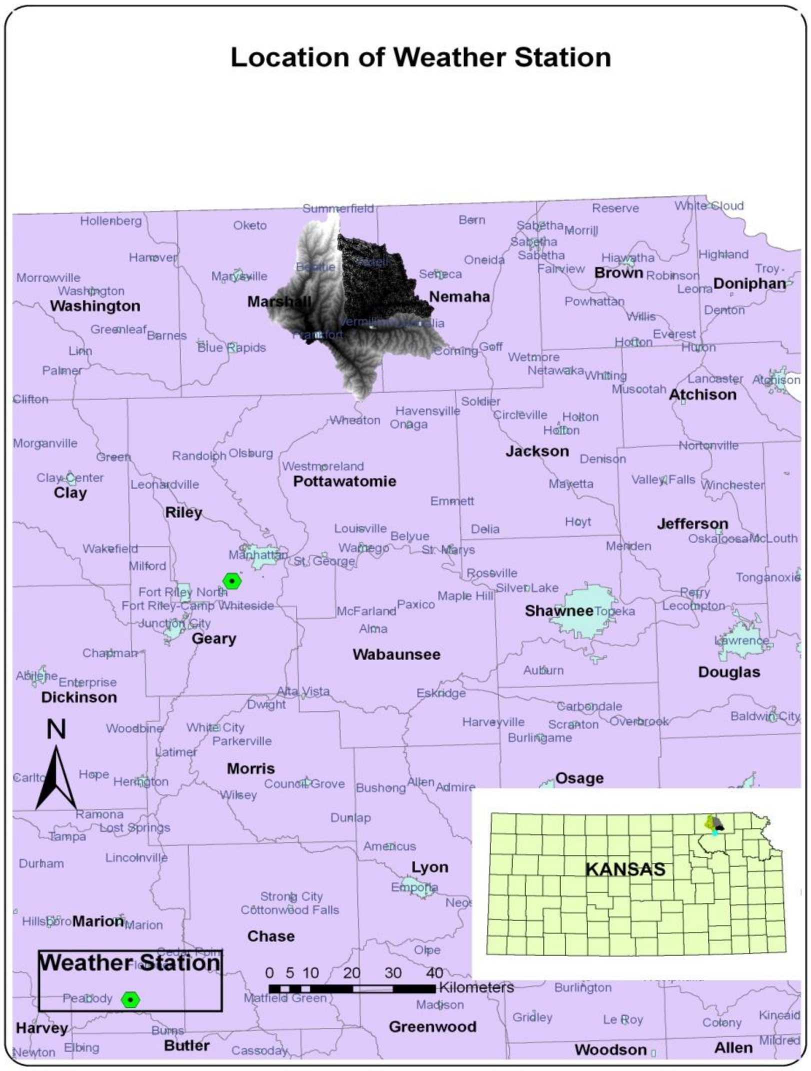


Figure 3.15 Location of Manhattan Airport Weather Station

3.2.1. User-supplied input data

Once the model was populated with the watershed and climate data, a limited amount of additional data were supplied. Some of these data were automatically entered using information from watershed and climate data.

3.2.1.1. Cell data

All CELL DATA used in the AGNPS Input Editor was imported from the AnnAGNPS/ ArcView interface described in Step 9 of the users guide.

3.2.1.2. Crop data

Crop data can be imported from either RULSE 1.06 or RUSLE2.

3.2.1.3. Management field data

The Management field data section includes data for categories of land use (e.g., sorghum, winter wheat, corn, soybeans) and land management (e.g., terraces, contour tillage, strip cropping on the contour) including such information as terrace horizontal distance and terrace grade. Whenever cultivation is done on slopes, the system has to be protected from erosive rains by land management practices that will slow the runoff water and thus reduce the amount of soil it can carry.

Terraces reduce interrill and rill erosion on the terrace interval by breaking the hillslope into shorter hillslope lengths. Also, deposition along the terrace may trap much of the sediment eroded from the inter-terrace surface above, particularly if the terraces are level, of very low gradient, or have closed outlets. Properly designed terraces and outlet channels intercept surface runoff and convey it from the hillslopes at non-erosive velocities (Toy and Foster, 1998).

Terraces were found to be present on a large portion of the croplands within the study subwatersheds (table 3.4). Terraces were identified using 12/09/2008 aerial imagery developed by Farm Services Agency available at Kansas geospatial community website (http://www.kansasgis.org/catalog/catalog.cfm). Boundaries of each field observed to contain a terrace were digitized by hand, and a management field data identification number was assigned to each terraced cell using the Arc View interface. Terrace locations were confirmed by field reconnaissance in Irish Creek on 2 June 2010. Field reconnaissance of agricultural fields identified to have terraces from aerial imagery confirmed terraces on 99% of these fields. To include these terraces the P factor value for the cells having terraces was reduced to 0.1 (Wischmeier and Smith, 1978) and Curve Number was reduced by 6.

Table 3.4 Percentage of watersheds having terraces (aerial imagery, 2008)

Subwatershed	% watershed having terraces	% cropland having terraces
Irish Creek	24%	95%
Main Stem	37%	65%
North Fork	30%	62%

3.2.1.4. Management operation data

The management field ID and the management schedule ID used are the same ID characters for each land use/management scenario. The naming convention used for the land use and land management is the same ID used in the GIS coverage. Table 3.5 and 3.6 show the management operations and management properties used for this research (Lyle Frees, personal communication, 27 October 2009).

Table 3.5 Management Schedule and Management Operations data (Lyle Frees, personal communication, 2009).

Land use	Management Schedule Event data (month- date-year)	Management Operation ID
Corn	3-15-1	Chisel;_st._pt._0
	4-14-1	Cultivator;_field_0
	4-15-1	Planter;_double_di0
	10-15-1	Harvest;_grain;_gr0
Winter Wheat	4-15-1	Disk;_tandem_light0
	4-20-1	Cultivator;_field_0
	5-1-1	Planter;_double_di0
	10-1-1	Harvest;_grain;_gr0
	10-15-1	Cultivator;_field_0
	10-25-1	Drill_or_air_seede0
	7-1-2	Harvest;_grain;_gr0
	11-1-2	Chisel;_st._pt._0
	4-1-3	Cultivator;_field_0
	5-10-3	Planter;_double_di0
	10-5-3	Harvest;_grain;_gr0
	11-1-3	Chisel;_st._pt._0
Soy Beans	4-15-1	Disk;_tandem_light0
	4-20-1	Cultivator;_field_0
	5-1-1	Planter;_double_di0
	10-1-1	Harvest;_grain;_gr0
	11-1-1	Chisel;_st._pt._0
	4-1-2	Disk;_tandem_light0
	5-1-2	Cultivator;_field_0
	5-10-2	Planter;_double_di0
	10-5-2	Harvest;_grain;_gr0
	11-1-2	Chisel;_st._pt._0
Sorghum	4-15-1	Disk;_tandem_heavy0
	5-5-1	Disk;_tandem_secon0
	5-10-1	Fert_applic._anhyd0
	5-15-1	Cultivator;_field_0
	5-20-1	Planter;_double_di0
	10-20-1	Harvest;_grain;_gr0

Table 3.6 Properties of Management Operations

Management Operation ID	Mixing efficiency	Surface Roughness	Tillage Depth
Disk;_tandem_light0	0.5	18	100
Cultivator;_field_0	0.35	17	40
Planter;_double_di0	0.15	10	60
Chisel;_st._pt._0	0.35	15	200
Drill_or_air_seede0	0.25	12	50

3.2.1.5. Management schedule data

Management schedule data can be imported from RUSLE2 by the input editor. Table 3.5 gives the information about the management schedule data (Lyle Frees, personnel communication, 27 October 2009).

3.2.1.6. Non-crop data

Data for non-crop land uses were derived from RUSLE 1.06 *croplist.dat* file import within the AGNPS Input Editor.

3.2.1.7. Run off curve number data

NRCS runoff curve numbers or AnnAGNPS default runoff curve number values provided by TR55 (NRCS Technical Release 55–Urban Hydrology for Small Watersheds, Chapter 2) were used (table 3.7). Curve numbers were used to calibrate the model results to measured runoff data.

Table 3.7 Run off curve number data

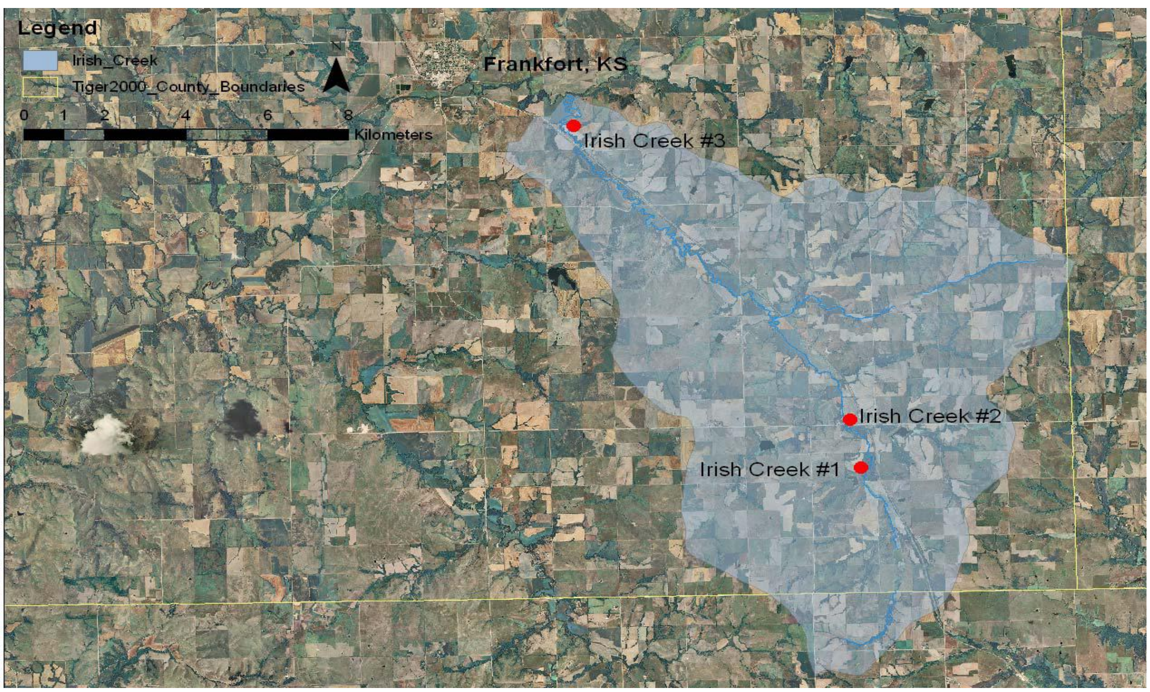
Land use	Runoff Curve Number			
	Soil A	Soil B	Soil C	Soil D
Corn	66	74	80	82
Winter Wheat	66	74	80	82
Soy Beans	66	74	80	82
Idle Crop	39	61	74	80
Grass Pasture	39	61	74	80
Deciduous	30	58	71	78
Alfalfa	39	61	74	80
Developed	46	65	77	82
Sorghum	66	74	80	82

3.3. Stream Process Measurement and Stream Characterization

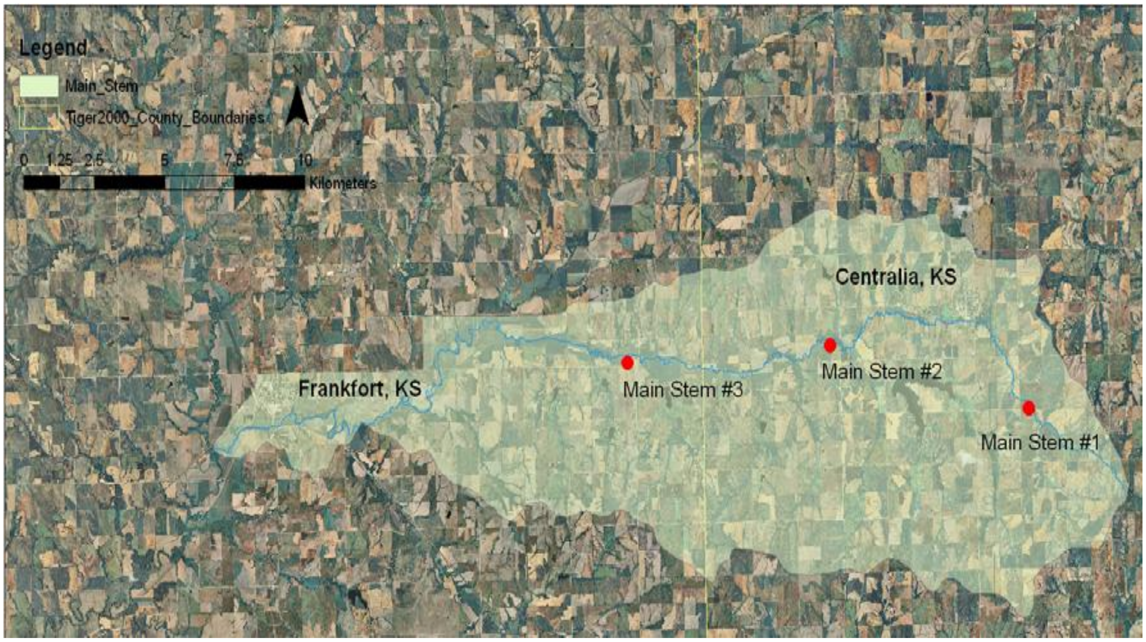
The sections of Irish Creek, Main Stem and North Fork that were surveyed were located near to Frankfort, Kansas. In June 2007 nine monitored sites were established in the three main branches of the Black Vermillion River: Irish Creek, Main Stem, North

Fork (fig 3.16). All the branches experienced different levels of channel modification since the date of territory survey of 1857, including but not limited to water impoundments, channelization, vegetation removal, stabilization structures and levees (Sass, 2008). Three reaches per branch were selected, one each in the upper, middle and lower portions of each river branch. The nine sites were chosen to include varied geology, geomorphology, differing adjacent land cover/ landuse with in the subwatersheds (Sass, 2008). The adjacent land cover ranged from plowed field to established riparian forest. Drainage areas and the surveyed reach lengths of Irish Creek, Main Stem and North Fork are summarized in table 3.8.

(a)



(b)



(c)

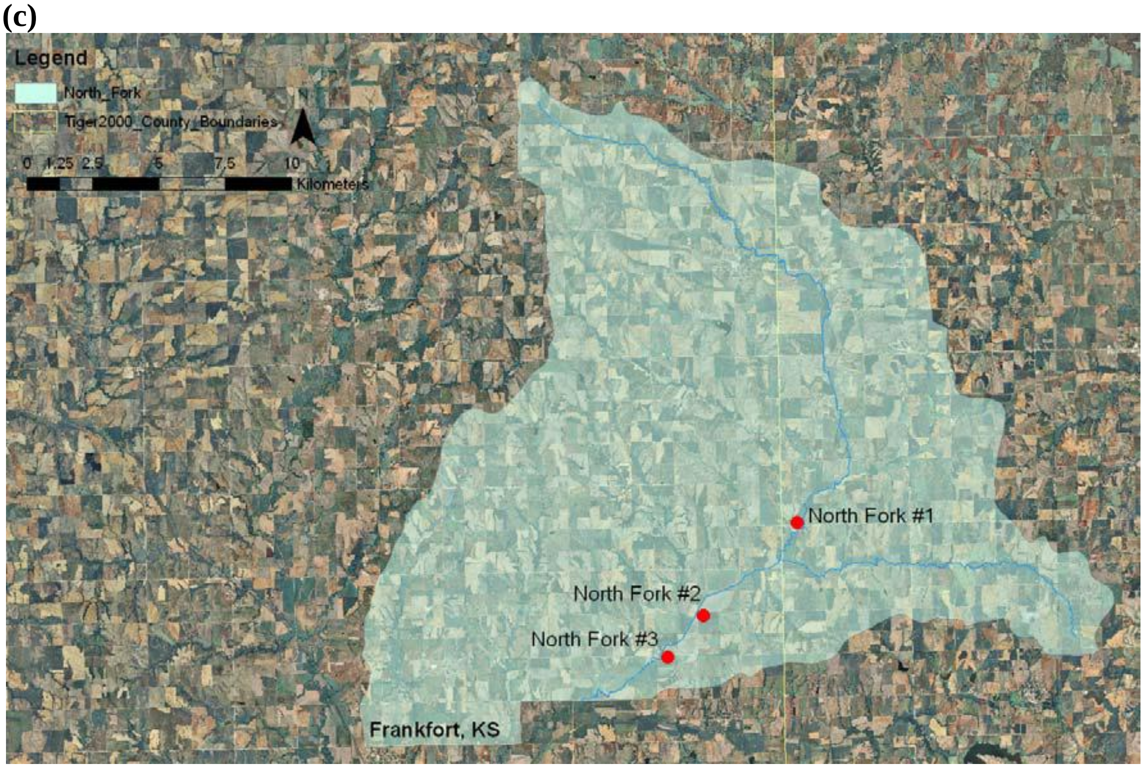


Figure 3.16 Study reach locations within each branch: a) Irish Creek, b) Main Stem, and c) North Fork. (Source: Sass, 2008)

Table 3.8 Survey lengths and drainage areas of each study reach.

Stream	Reach	Drainage Area (km^2)	Reach Length (m)
Irish Creek	Upper: IC-1	22.01	376.43
	Middle: IC-2	59.56	510.23
	Lower: IC-3	117.32	524.86
Main Stem	Upper: BV-1	16.31	316.99
	Middle: BV-2	89.61	472.74
	Lower: BV- 3	159.28	414.53
North Fork	Upper: NF-1	177.67	510.84
	Middle: NF-2	252.26	696.77
	Lower: NF-3	299.92	622.09

3.3.1. Methods to characterize stream

Stream data collection in the Irish Creek, Main Stem and North Fork subwatersheds included analyses of the longitudinal profile of each study reach and cross-sectional profiles of multiple locations within each reach. These procedures are explained below.

3.3.1.1. Longitudinal profile

The longitudinal profile defines the extent of the stream reach in the survey. It is commonly defined as a length that is 20 times the channel bank full width. In order to survey the longitudinal profile three steps were followed:

- Benchmark definition.
- Level setting such that the benchmark and most of the site is visible.
- Stations selection (record elevations). A riffle head was identified in order to start the longitudinal survey. Elevation of the channel bottom, water surface and bank-full discharge was recorded through reach lengths that are mentioned above in the table 3.8. The starting point was at head of a riffle (i.e., 0 + 00). The next station and consecutive stations were defined based on feature presence and visual

changes in elevation. Distances were measured with a tape measure in the downstream direction. Elevations, stations, and important features were recorded in the field book.

3.3.1.2. Cross sectional profile

Survey data were taken of stream bank and bed elevations once each year and used to estimate annual bank erosion in each study reach. The cross-sectional profile was surveyed for Irish Creek at stations (1+56), (11+34) and (0+00) feet of the longitudinal survey, for Main Stem at stations (5+41), (3+82), and (3+90), and for North Fork at stations (12+53) and (15+30). Elevation was recorded, at a minimum, at the water surface and at each location of noticeable change in slope along the cross section. Detailed procedure for measuring cross-sectional profile can be found in Stream Channel Reference Sites: An Illustrated Guide to Field Technique developed by USDA. (Available at: http://www.stream.fs.fed.us/publications/PDFs/RM245E.PDF).

3.3.2. Estimating streambank erosion and bed scour

The following procedures were used to estimate the streambank erosion and to measure bed scour.

3.3.2.1. Bank Profile

Bank profiles were done at permanent cross section to get the most detailed measure of bank erosion rate. A toe pin was installed off-set from the bank. An elevation rod was set on the toe pin with corresponding horizontal measurements taken to intercept the bank (fig. 3.17). A resurvey at the toe pin location allowed a comparison of a detailed computation of a change in bank profiles, yielding lateral erosion rate. The bank profile was resurveyed at least once per year to obtain annual erosion and contribution to sediment supply.

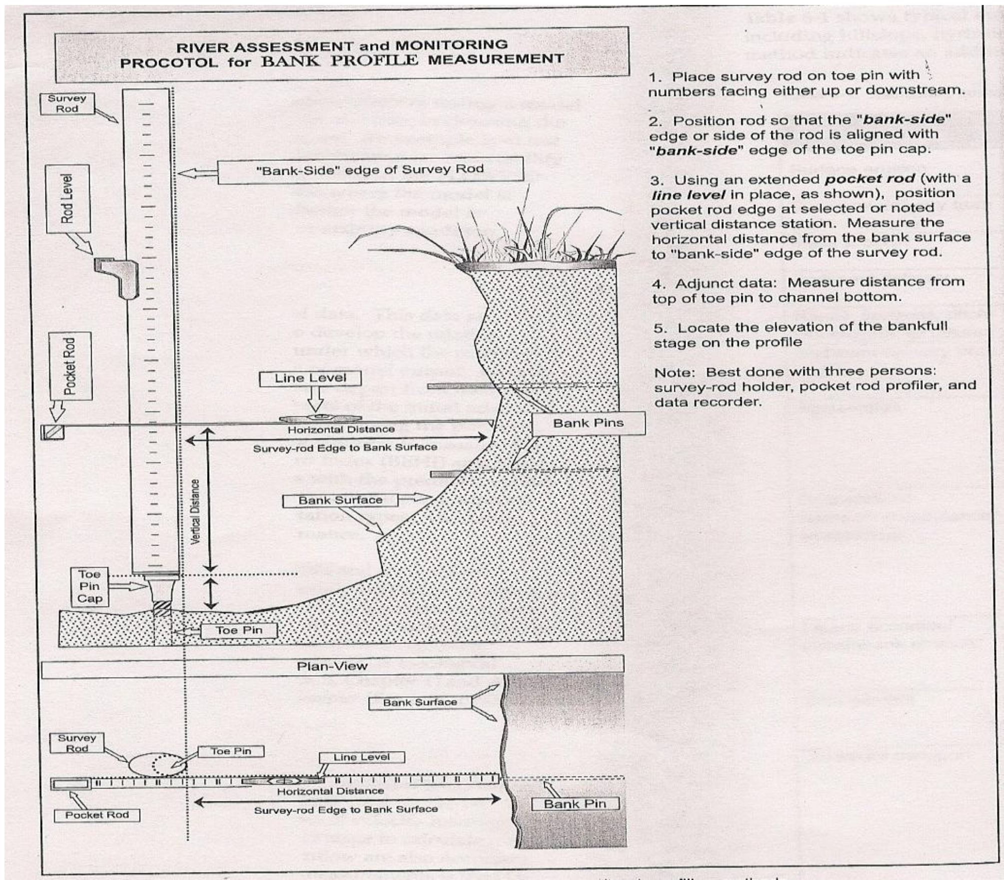


Figure 3.17 River Assessment and Monitoring protocol for bank profile measurement. (Source: Rosgen, 2006)

3.3.2.2. Scour chains

Scour chains were installed in glides and riffles to indicate the depth of scour and particle sizes entrained on an annual basis for various stream types and bed material gradations. These chains were small diameter chains that were attached to a small duck-bill anchor and driven vertically into bed at a specific location until the tip of the chain was flush with the bed surface. These scour chains were installed at surveyed cross section. The chain was left flush with the surface and was resurveyed annually or after a long flow event to determine scour depth, entrainment sizes of bed material and/or deposition and size of particle in the deposition (fig. 3.18).

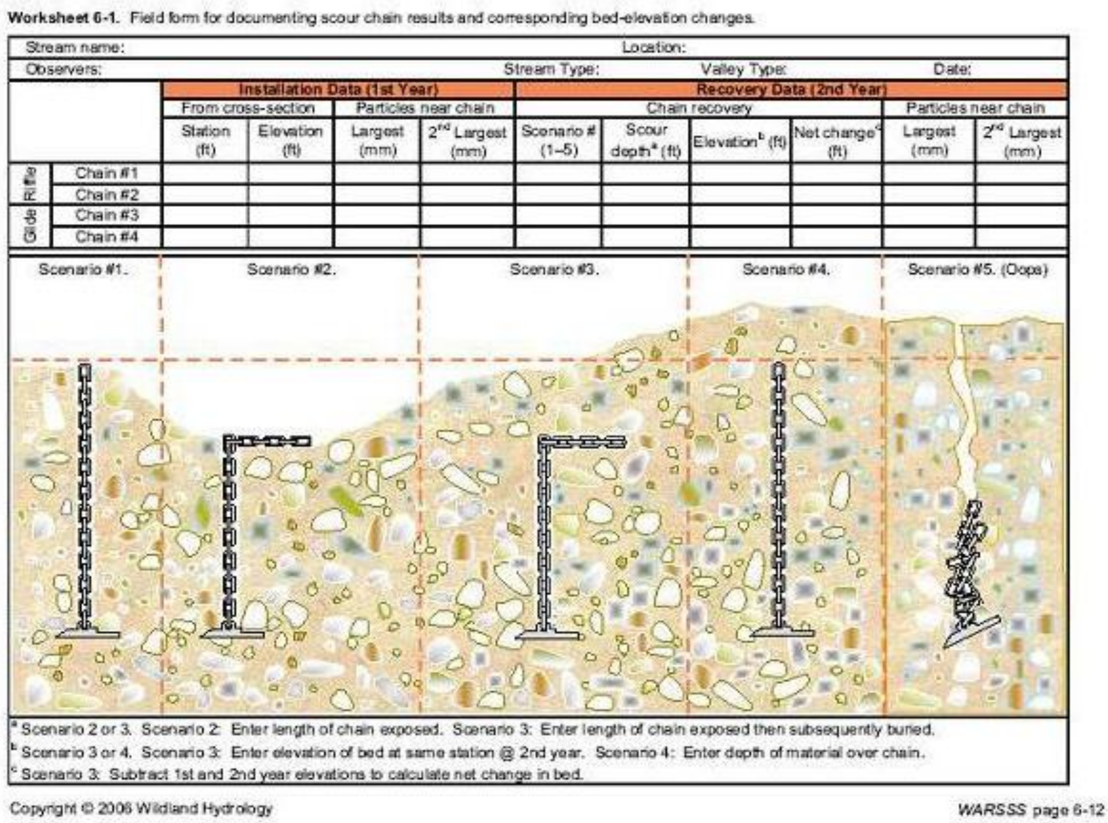


Figure 3.18 Field form for documenting scour chain results. (Source: Rosgen, 2006)

3.3.3. Mass balance of total suspended sediment

Balanced sediment input and output at the subwatershed outlet (mass balance approach) is the central idea in this research (fig. 3.19). It was assumed that there was no net change to sediment mass in the stream bed over the 2-year study period (ds=0). This was supported by scour chain measurements, which showed aggradation during 2007-2008 and degradation during 2008-2009 (Appendix- 3). The scour chain measured values in Appendix 3 shows that the degree of aggradation in year 2007-2008 was offset upto 30 – 40% by the degree of degradation in year 2008-2009. We did not consider stream bed load exported from the subwatershed in the mass balance approach as we don't have stream bed load measurements. The time interval of dt=2 years represents the time period over which the streambank erosion and streamflow measurements were collected. AnnAGNPS simulates sediment only on the days when there is rainfall; that is, all the sediment simulated on a given day is routed through the outlet on the same day. So the sheet, rill and gully sediment is represented as daily with sediment loads only occurring during events. The daily total simulated sediment at the outlet is compared to the measured TSS value at the outlet (efficiencies of the models were estimated for only the days that have measured TSS values at the watershed outlets).

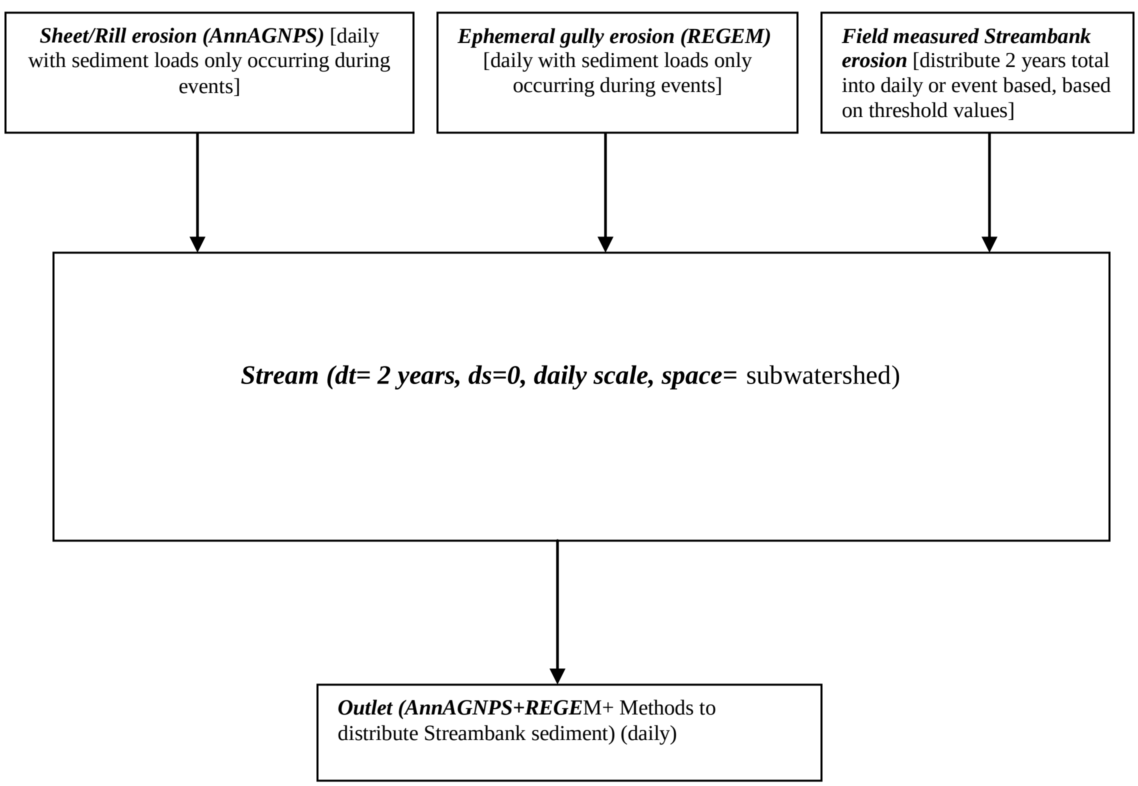


Figure 3.19 Mass Balance approach

3.3.3. Methods to estimate streambank sediment loads

Table 3.9 gives the estimates of the streambank erosion values for each of the nine sites. Total sediment for each year is calculated as average erosion rates per year times the density of soil composition times stream length (only third order streamlengths were considered and were measured using GIS). In many watersheds, erosion occurs from only one of the two streambanks at a given location within a reach. In this watershed, however, erosion in many locations appears to be occurring on both banks, thus a factor of 1.3 was considered appropriate to account for the extra bank erosion (Tim Keane, personnel communication, 18 May 2010). In this study, this bank erosion factor was varied and the calibration process was used to adjust measured stream-bank erosion to match measured stream sediment export rates.

Table 3.9 Measured annual streambank sediment erosion values for 3 reaches segments in each study watershed (Keane et al., 2010)

Site	Annual bank erosion (lb/ft/yr)
Irish Creek 1	503
Irish Creek 2	469
Irish Creek 3	521
Main Stem 1	685
Main Stem 2	574
Main Stem 3	64
North Fork 1	936
North Fork 2	752
North Fork 3	1719

3.4. Stream Flow Monitoring

3.4.1. Stream flow

Flow in a stream is a function of many factors, including precipitation, surface runoff, interflow; the cross sectional geometry and bed slope of the channel, the bed and side slope roughness; meandering, obstructions, and changes in shape; hydraulic control structures and impoundments; and sediment transport and channel stability (Ward and

Elliot, 1995). Generally, flow in streams and impoundments are classified as open-channel flow because the surface of the flow is open to the atmosphere. Stream flow can be classified several ways. For example, it can be turbulent in steep rocky areas or following severe storm events. Typically, stream flow is more tranquil and is considered to be a steady uniform flow (Barnes, 2005). The calculated stream flows for this study assumed this condition in which the stream depth does not change during the flow measurement.

The continuity equation provides basic relationship for calculating stream flow:

$$q = va \tag{3.1}$$

where:

q = stream flow (ft^3/sec),

v = average stream velocity (ft/sec), and

a = cross-sectional area of flow (ft^2).

For uniform flow in a stream, the average stream velocity, v, can be estimated by Manning's equation.

$$v = \frac{1.5}{n} R^{2/3} S^{1/2} \tag{3.2}$$

where:

v = average stream velocity (ft/sec),

n = Manning's roughness coefficient of the stream channel,

R = hydraulic radius (a/p, p = wetted perimeter), and

S = channel bed slope (ft/ft).

3.4.2. Stream flow measurements

Flow measurement and water quality samples were collected at the outlets of the Irish Creek, Main Stem, North Fork subwatersheds (table 3.10, fig. 3.6) and the outlet of the Black Vermillion River at the USGS gage (USGS 06885500) southwest of Frankfort, Kansas (table 3.10). Flow measurement and sample collection for the three subwatersheds were made at road crossings (bridges or culverts) using an automated sampler (ISCO Inc., Lincoln, Nebraska, Model #6700) and bubbler-module stage recorder (ISCO Inc., Lincoln, Nebraska, Model #670).

Stream flow stage data were collected near the bridge cross sections near the bank, with the bubbler outflow point 0.051 m (2 in) above the bottom of the stream (Barnes, P. L., personal communication, 2010). Stream depth was recorded at 5 min intervals throughout the year except when the line was frozen. Depth was converted to velocity using surveyed stream cross-sectional area data, surveyed stream slope, and estimated Manning's roughness along with equation 3.2 (Barnes, P. L., personal communication, 2010). Manning's roughness for the stream bed was estimated to be 0.008 (Barnes, P. L., personal communication, 2010). Velocity and stream cross-sectional area data were used with equation 3.1 to calculate stream flow. Slope of the water surface is determined from accurate measurements of stage at the upstream and downstream ends of the reach referenced to a common fixed point (Barnes, P. L., personal communication, 2010). These data were summarized for each annual period of the study and included in the appendix.

Table 3.10 Monitoring site location descriptions

Site Number	Site Location	Latitude	Longitude
1	Black Vermillion River USGS Gage	N39.68199	W96.4425
2	Black Vermillion Irish Creek	N39.60974	W96.30456
3	Black Vermillion Main Stem	N39.71379	W96.26647
4	Black Vermillion North Fork	N39.72594	W96.32856

3.4.3. Suspended sediment measurements

Grab samples were collected using one litre wide-mouth polypropylene bottles near the bridge cross sections at the centroid of stream flow, 0.051 m (2 in) above the bottom of the stream monthly in the winter months of March, October, November and December. During the rest of the year (April through September), water grab samples were collected weekly and after most runoff events. During runoff events, samples were collected using an automated sampler. The inlet tube for automated samples was located 10 cm off the bottom of the stream and somewhere near bank of the stream. Sampling was initiated when the water level was 0.25 ft above the sampling point. During the events, 340-mL samples were collected every three hours until the water level fell below the sampling point (10 cms from the bottom of the stream) and 1000-mL composite samples (300 mL of each sample is mixed to get composite sample) were made and used for total suspended solids (TSS) analysis.

Total suspended solids include all particles suspended in the water column that will not pass through a 0.45 μm filter. When the TSS concentration (mg/L) was multiplied by the flow volume (L/day), the load of a TSS (mg/day) was determined. The procedure used in this study to measure the TSS parameter is described the Standard Methods for the Examination of Water and Wastewater Method 209C (Clesceri et al., 1998).

3.5. Methods to Disaggregate Bank Erosion from Annual Loads to Daily or Event Loads

3.5.1. Literature review

Streambanks in agricultural areas may erode in response to a variety of water flow processes, including stream flow (shear processes), changes in stream flow (mass wasting processes after flow recession), and water flowing over or through the streambank (fingering erosion processes). Most of the streams are subjected to wide fluctuations in both flow depth and velocity over a period of time, due to seasonal changes in rainfall and due to land use changes. Streambank erosion occurs when the flow depths and velocities increase, rain falling on streambanks, or runoff from adjacent fields.

Streambank erosion involves the detachment of soil aggregates and grains from the bed and banks followed by fluvial entrainment (Allen et al., 1999). Fluvial entrainment or removal of bank material occurs as flow contacts streambank and mass movement of material due to gravity (Harmel et al., 1999). This complex process is influenced by climatic processes (rainfall, microclimate, temperature) (Luppi et al., 2008), fluvial processes (stream power, bends, vegetation, secondary currents) and mass failure (bank height, composition, moisture conditions) (Thorne et al., 1997; Allen et al., 1999). In attempts to understand the complex nature of riverbank erosion, numerous studies have examined fluvial processes (e.g., Rose et al., 1983; Moore et al., 1986; Nearing et al., 1998; Allen et al., 1999), and a few studies have investigated mass failure (Harmel et al., 1999; Simon et al., 2000). However, no study has been able to establish the predominant control on the amount of hydraulic erosion in response to variable flow conditions.

This study attempts to relate sediment loads measured at a point in the stream into event or daily based loads from appropriate watershed sources, including overland (inter-rill and rill), ephemeral gully, and stream bed and bank sources. A key aspect of this research is the disaggregation of annual stream source estimates to daily source contributions. The goal is to determine what fraction of the annual stream sediment loads are transported to the watershed outlet associated with flows that occur on each day. The energy available to transport stream sediments is related to the combination of climatic, land, and stream factors.

Rain fall → Runoff → Streambank fluvial processes

Figure 3.20 Conceptual representation of methods

Major rainfall events can induce sediment yield through slope failure, incision, and surface and channel bank erosion (Lamoureux, 2002). The channel geometry can be altered by the deposited sediments in the channel during these events, depending on the channel conditions.

The following sections will describe the theoretical bases for several methods that will be used in this study to disaggregate annual streambank sediment source loads to event-based loads. Specific methods based on these theoretical concepts will be presented in the methods section of this chapter.

The process of soil detachment from the land by water occurs first via the process of splash from raindrop impact followed by runoff and then by fluvial processes. Renard et al. (1997), in the Agriculture Handbook Number 703, proposed that the soil losses from cultivated fields are directly proportional to a rainstorm parameter: the total storm energy times the maximum 30-min intensity. Raindrop (splash) erosion increases with EI, the I component reflects the prolonged peak rates of detachment and runoff. EI technically indicates how particle detachment is combined with transport capacity. The relation of soil loss to the EI parameter is assumed to be linear. The sum of the storm EI values for a given period is a numerical measure of erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular locality is the rainfall erosion index for the locality.

Rainfall showers of less than 12 mm (0.5 in.) were omitted while developing the initial R-factor map (Renard et al., 1997). Analyses showed that erosion from these light rains is usually too small for practical significance. Xie et al. (2002), in their work on practical thresholds for separating erosive and non erosive storms, showed that a rainfall event less than 12 mm had no significant soil erosion. They also suggested that rainfall erosivity can be over-estimated if non-erosive events are counted, or it can be under-estimated if erosive rainfalls are omitted. The results of Lamoureux (2002) showed that rainfall events totaling approximately 13 mm or more resulted in increased sediment yield. Field observations by Lamoureux also indicated that rainfall-induced flood peaks may have subsequent impacts on sediment yields. The threshold value of 12.7 mm total rainfall suggested by Wischmeier and Smith (1978) is often used in making isoerodent maps in many countries (Renard and Freimund, 1994; Yu and Rosewell, 1996).

Williams (1974) replaced the rainfall factor from RUSLE with a runoff factor and got more accurate results. Runoff is highly affected by antecedent soil moisture. If the soil moisture is low, large rain-storms may produce little or no runoff. Without runoff there is no sediment yield. The runoff rates and volumes were substituted for the rain fall energy factor in the universal soil loss equation (USLE).

$$S = 95(Q \times q_p)^{0.56} \times K \times LS \times C \times P \quad (3.3)$$

where:

S = sediment yield (tons),

Q = volume of runoff (ac ft), and

q_p = peak flow rate (ft^3/s).

The USLE overpredicted sediment production for years with low rainfall factors and underpredicted production for years with high rainfall factors (Williams, 1974). The same concept of peak flow rate has been applied in my research.

Various equations were proposed for describing stream sediment transport capacity in terms of single determinant: flow velocity, slope, shear stress, discharge (Moore et al., 1986). Most of the studies described sediment transport in terms of water discharge or effective discharge (Williams, 1975; Meyer et al., 1975) or in terms of effective shear stress (Foster and Meyer, 1972; Foster, 1982). Many studies also concluded that unit stream power is the dominant factor in determining the total sediment concentration of streams with alluvial and gravel beds (Yang, 1973; Bagnold, 1977; Rose et al., 1983a). Many sediment formulas evaluated by Alonso et al. (1981) showed that unit stream power gave reliable predictions of sediment transport in shallow flows and stream flows, particularly for fine to coarse sands. The concept of stream power was first introduced by Bagnold, who defined stream power in terms of the power per unit area of stream bed (shear stress times flow velocity). Yang (1973) defined unit stream power in terms of power per unit weight of water (Moore and Burch. 1986).

$$P = Vs \qquad (3.4)$$

where:

P = unit stream power (m/s),

V = velocity of flow in longitudinal direction (m/s), and

s = slope (m/m).

Bagnold (1966) defined stream power as the kinetic energy available for erosion and transport:

$$\Omega = \gamma QS \qquad (3.5)$$

where,

Ω = stream power per unit length of channel [(Nm/ms) or (W/m)],

γ = specific weight of water (N/m^3),

Q = stream discharge (m^3/s), and

S = energy gradient or slope (m/m).

Rose et al. (1983a, 1983b) used Bagnold's stream power in their erosion-deposition model to characterize the entrainment of sediment of over land flow. Moss (1979) stated that the basic mechanics of erosion, transportation and deposition varies little from rivers to overland flow. This stream power concept must be applied to the entire river system otherwise the local effects such as armoring or secondary flow from upstream make validation difficult (Moore and Burch. 1986).

Bank erosion rates or rate of soil detachment from the channel perimeter is a function of shear stress induced by flow (Nearing et al., 1998; Allen et al., 1999). As flow is increased, shear stress increases until it eventually crosses critical shear stress that is required to detach the particle. The widely used equation for modeling channel erosion is

$$Er = K(Te - Tc) \tag{3.6}$$

where:

Er = the erosion rate (ft/s),

K = erodibility coefficient (ft^3/lb-s),

Te = effective stress (Pa) (lb/ft^2), and

Tc = critical stress (Pa) (lb/ft^2).

Fluvial entrainment depends on the relationship between the flows shear force acting on the bank and the bank's capacity to resist this force (Thorne, 1982; Harmel et al., 1999). The flow shear stress is a function of flows velocity gradient along the channel bank and bed. If the shear stress exceeds the internal resistance of material, bank or bed particles may be dislodged and become entrained in the flow (Thorne, 1982). The rate of bank erosion due to mass failure depends on the relationships among gravitational forces acting on the bank material, the hydro static pressure on the bank material, and the banks resistance to mass failure, referred to as internal shear strength (Thorne, 1981; Harmel et al., 1999).

Engineers design channels based on empirical studies of the erosion thresholds (Allen et al., 1999). Channel geometry is therefore adjusted so that the shear stress, stream power or channel velocities are kept below the critical value. The approach used in this study to integrate all the three sources of sediment is based on these critical values. Using AnnAGNPS (RUSLE) and REGEM as soil and gully erosion methods, a model to disaggregate annual streambank erosion to daily values was formulated based on key terms in the streambank erosion detachment criteria assessed above, such as stream power or discharge. These flow parameters were presumed to be related to streambank erosion through an erosion rate coefficient, which should include such effects as soil erodibility and bank cover (e.g., vegetation), but also the controlling bank erosion mode (fluvial erosion or bank failure).

3.5.2. Methods

3.5.2.1. Use of rainfall (Method 1)

This method distributes total annual streambank erosion according to daily rainfall depths for storms exceeding an established threshold value. The average CN of the watersheds were determined (Irish Creek = 74, Main Stem = 78, North Fork = 76). (Ia/S) values ranging from 0.1 to 0.5 were tested as threshold values.

$$Ia = 0.2S \tag{3.7}$$

$$S = (1000/CN - 10) \tag{3.8}$$

where:

Ia = Initial abstraction (in),

CN = curve number, and

S = potential maximum soil moisture retention after runoff begins (in).

Method 1:

1. Identify all the rainfall events that are above the Ia/S threshold (R*).
2. Days with rain showers less than Ia/S were assumed to contribute no streambank erosion from those events.
3. Sum all the R* values for the study period (SR*).
4. Calculate the ratio of event R* to SR* (RSR)
5. Assign the fraction of total (2-year) study-period streambank erosion based on the RSR for that event.

6. Sum up the daily streambank erosion values with the daily values of AnnAGNPS and REGEM to give the total sediment for each day.
7. Compare the predicted sediment values with the measured TSS values for days having stream TSS measurements.
8. Repeat the above mentioned steps for each Ia/S threshold value.

3.5.2.2. Use of total stream flow (Method 2)

This method will distribute measured streambank erosion based on percentage of the event stream flow / total stream flow of simulation period. This method is similar to that used currently by the STEAD model. STEAD is a stand alone tool for AnnAGNPS. It was written to allow the user to request, extract and summarize specific information from the gauging station output file generated by AnnAGNPS. It allows the user to enter the annual average streambank erosion contribution to the measure total sediment load and assign a daily streambank erosion amount based on percentage of the event stream flow / total stream flow of the simulation period. (Bingner R. L., personnel communication, 1 Feb, 2010).

Method 2 with no threshold stream flow value

1. Calculate total stream flow (runoff + baseflow) for each day of the study period using AnnAGNPS.
2. Assign the measured streambank erosion for the study period to each event based on the ratio of event total stream flow (runoff + base flow) to the sum of daily total stream flow for the study period.

$$event\_percent = event\_streamflow / total\_streamflow$$

$$event\_load = total\_load \times event\_percent$$

3. Sum the streambank erosion value with the daily value of AnnAGNPS and REGEM to give the total sediment for each day.
4. Compare the predicted sediment values with the measured watershed outlet TSS values for days having stream TSS measurements.

Method 2 with a threshold stream flow value

1. Calculate total stream flow (runoff + baseflow) for each day of the study period using AnnAGNPS.
2. Identify all the events that are above a threshold value (thresholds are defined as a given percentage of bank-full flow). (B*)
3. Days which had flow less then the threshold value were assumed to contribute no streambank erosion from those events.
4. Sum all the B* values for the study period (SB*).
5. Calculate the ratio of event B* to SB* (BSB)
6. Sum the streambank erosion value with the daily value of AnnAGNPS and REGEM to give the total sediment for each day.
7. Compare the predicted sediment values with the measured watershed outlet TSS values for days having stream TSS measurements.
8. The above steps are repeated for various threshold values (e.g., 1%, 5%, 10%, 15%, 20%, 25%, 30%) of bank full.

Table 3.11 Bank full depths and discharges of the subwatersheds at bank full depth

Subwatershed	Bank full depth (ft)	Stream flow (cfs)
Irish Creek	4.53	359
Main Stem	8.33	1,833
North Fork	5.87	712

3.5.2.3. Use of stream power (Method 3)

This method will distribute measured streambank erosion based on percentage of the daily stream power / total stream power of simulation period.

Detachment rates are a function of stream power, which is the energy of flow dissipated to the flow boundary (Bagnold, 1977; Rose et al., 1983a; Nearing et al., 1991a). Most of the models assume linear relationships for soil detachment and hydraulic variable like shear stress (Nearing et al., 1998), stream power (Rose et al., 1983a; Nearing et al., 1991a). Stream power is a better hydraulic predictor variable for detachment and sediment yield (Nearing et al., 1991a; Nearing et al., 1997).

Stream power is the energy expended by the flow in doing work on sediment particles to initiate and maintain sediment motion (Cunningham and Armitage, 2006). Stream power is the power available to transport sediment load and critical power is the power needed to transport sediment load. Bagnold (1966) defined stream power as the kinetic energy available for erosion and transport.

$$\Omega = \gamma QS \tag{3.9}$$

where,

Ω = stream power per unit length of channel [(Nm/ms) or (W/m)],

γ = specific weight of water (N/m^3),

Q = stream discharge (m^3/s), and

S = energy gradient or slope (m/m).

Bull (1979) explained the term "critical power" as a short hand expression through a continuity equation, (Q= wdv) for variables such as width (w), depth (d), and velocity (v) that affect hydraulic roughness and channel morphology. All of these variables interact to determine the capacity and competence of the stream to transport sediment.

Method 3 with no threshold stream power

1. Calculate unit stream power (eq. 3.9) for each day of the study period based on measured stream flow and measured stream slope.
2. Assign the measured streambank erosion for the study period to each event based on the ratio of event stream power to the sum of daily stream power for the study period.

$$event\_percent = event\_streampower / total\_streampower$$

$$event\_load = total\_load \times event\_percent$$

3. Sum the streambank erosion value with the daily value of AnnAGNPS and REGEM to give the total sediment for each day.
4. Compare the predicted sediment values with the measured watershed outlet TSS values for days having stream TSS measurements.

Method 3 with a threshold stream power value

1. Calculate unit stream power (eq. 3.9) for each day of the study period based on measured stream flow and measured stream slope.
2. Identify all the events that are above threshold value of stream power. (P*)

3. Days which had stream power less then the threshold value were assumed to contribute no streambank erosion from those events.
4. Sum all the P* values for the study period (SP*).
5. Calculate the ratio of event P* to SP* (PSP)
6. Sum the streambank erosion value with the daily value of AnnAGNPS and REGEM to give the total sediment for each day.
7. Compare the predicted sediment values with the measured watershed outlet TSS values for days having stream TSS measurements.

The above steps are repeated for various threshold values.

Some other methods that are based on shear stress and threshold velocities are explained in Appendix 1.

For several events, the peak daily flow and sediment yield modeled by AGNPS and measured at the streamflow as the precipitation gage location did not align on the same day. This could have occurred due to (1) differences in watershed lag time caused by ponds and other detention structures that were not modeled by AGNPS, (2) differences in lag time caused by a storm crossing the precipitation gage location before (or after) reaching the modeled watershed, since AGNPS applies the precipitation according to recorded timing at the precipitation gage (storms tend to move from west to east in this watershed, and the precipitation gage is west of the study subwatersheds (fig. 3.15) , so the typical case is for the storm to reach the precipitation gage before the subwatershed), or (3) different reporting periods for the precipitation gage (7:00 am to 7:00 am, with the 24-hour rainfall amount attributed to the date of collection), versus streamflow (midnight to midnight). All three factors tend to cause streamflow to lag after recorded precipitation, though to a different degree depending upon how the three factors align for a given event. A substantial temporal deviation was observed to occur on four occasions for Irish Creek (8/2/07, 8/8/07, 9/14/08, and 4/29/09), four occasions for Main Stem (09/13/08, 4/27/09, 6/2/09, and 6/21/09, and seven occasions for North Fork (8/2/07, 8/8/07, 8/24/07, 9/14/08, 4/29/09, 6/3/09, 6/22/09). In these cases, modeled and measured watershed sediment yields were summed for the entire event period (up to 4 days), using the minimum number of days to capture the peak discharge day for both modeled and measured yields, rather than for a single day.

3.6. Model Calibration Procedure

Model calibration is the process of varying uncertain input parameters over a range of likely values until a satisfactory match between measured data and simulated data is achieved. In most of the watershed modeling projects, model output is compared to corresponding measured data with the assumption that all the error variance is contained within the predicted values and the measured values are error free. But recent findings by Harmel et al. (2005; 2006) showed that uncertainty exists in measured stream flow and water quality data, and this uncertainty has to be considered when calibrating, validating and evaluating watershed models because of differences in inherent uncertainty between measured flow, sediment, and nutrient data (Moriasi et al., 2007). Both the hydrological and erosion components of AnnAGNPS and REGEM models were calibrated.

3.6.1. Stream flow calibration

Stream flow is the total water flowing in the stream at a specified location. The sources for this stream flow are the groundwater-fed baseflow and runoff. Two years

(Summer 2007 to Summer 2009) of daily stream flow data collected in Irish Creek, Main Stem and North Fork Subwatersheds were used to calibrate and validate AnnAGNPS and REGEM models. Flow calibration was performed for the simulation periods shown in table 3.13 by adjusting the CN parameter (tables 3.14, 3.15). CN is a key factor in obtaining accurate prediction of runoff and sediment yield (Yuan et al., 2001; Shrestha et al., 2006; Licciardello et al., 2007). CN is a soil moisture balance parameter that allows the model to modify the soil moisture condition of the soil to estimate surface runoff. Many studies suggested CN as the most sensitive parameter (Liccardelo et al., 2007; Parajuli et al., 2009).

Table 3.12 Monitoring site location coordinates

Site Number	Site Location	Latitude	Longitude
1	Black Vermillion River USGS Gage	N39.68199	W96.4425
2	Black Vermillion Irish Creek	N39.60974	W96.30456
3	Black Vermillion Main Stem	N39.71379	W96.26647
4	Black Vermillion North Fork	N39.72594	W96.32856

Table 3.13 Simulation periods used for calibration

Subwatershed	Simulation period (yr)
Irish Creek	6/6/2007- 6/18/2009
Main Stem	8/1/2007- 6/30/2009
North Fork	7/1/2007- 6/30/2009

Table 3.14 Default Curve Number associated with each hydrologic soil group for each land use

	Hydrologic Soil Group			
Land use	A	B	C	D
Residential	46	65	77	82
Cropland	66	74	80	82
Pasture	39	61	74	80
Meadows	30	58	71	78

Table 3.15 Parameters adjusted during flow calibration of subwatersheds Irish Creek, Main Stem, North Fork, and watershed Black Vermillion

Watershed	Parameter[1]	Default Value	Testing Range	Final Value
Irish Creek	CN	Table 3.14	Default CN ± 6	Default CN + 6
	Initial Soil Moisture	0.5	0.3 – 0.8	0.8
Main Stem	CN	Table 3.14	Default CN ± 5	Default CN -5
	Initial Soil Moisture	0.5	0.3 – 0.8	0.4
North Fork	CN	Table 3.14	Default CN ± 7	Default CN -7
	Initial Soil Moisture	0.5	0.3 – 0.8	0.7

[1]CN = Runoff Curve Number

In each calibration step simulation results were compared to daily discharge values using multiple statistical criteria. First, a range of physically acceptable values was selected for each calibrated parameter, and then the procedure was performed by adjusting the input parameters within the range until the simulation results were close to the observed values on daily scale (fig. 4.1).

3.6.2. Sediment load calibration

Models were calibrated for sediment yield for Irish Creek and Main Stem by adjusting the various input parameters (table 3.16) until a match was established between observed and simulated values. The calibrated parameter values for each subwatershed (Irish Creek and Main Stem) were used separately, along with a number of other values, to validate and further test the AGNPS + REGEM model for the North Fork Subwatershed

Table 3.16 Parameters adjusted during sediment calibration for AnnAGNPS and REGEM

Watershed	Parameters	Default value	Test range value	Final value
Irish Creek	USLE P factor	1.0	0.2-1.0	0.4
	REGEM SGF		0.1-0.5	0.2
Main Stem	USLE P factor	1.0	0.2-1.0	0.6
	REGEM SGF		0.1-10.0	0.1

The default values of USLE C for each land-use type were used for calibration. The USLE P factor, defined as the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture, was used for calibration in the range from 0.1 to 1.0 in this study. P values for watershed areas (76% of Irish Creek, 63% of Main Stem, 70% of North Fork) without terraces were adjusted during calibration.

A REGEM Sediment Gully Factor (SGF) found in the PL calibration data of the AnnAGNPS input editor was adjusted over the range of 0.1 to 20.0 until the best model efficiency was achieved.

3.7. Model Evaluation Statistics

Correlation coefficient (R^2), Nash- Sutcliffe efficiency index (E_f) and percent bias (PBIAS) model evaluation statistical techniques were used to measure the relationship between measured and predicted flow, and E_f and PBIAS for measured and predicted sediment yield.

3.7.1. Coefficient of determination (R^2)

Coefficient of determination describes the degree of colinearity between simulated and measured data. R^2 ranges from 0 to 1, with higher values indicating less error variance. An R^2 of 1.0 indicates that the regression line perfectly fits the data.

3.7.2. Nash-Sutcliffe efficiency (E_f)

Nash-Sutcliffe efficiency index indicates the degree of agreement between observed and simulated data. Nash-Sutcliffe efficiency is computed as follows:

$$E_f = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \tag{3.12}$$

where:

E_f: = Nash-Sutcliffe efficiency index,

P_i: = predicted daily value (stream flow, m^3/s),

O_i = observed daily value (stream flow, m^3/s),

$\overline{O}$ = mean of observed daily values (stream flow, m^3/s), and

n = number of observations on observed and predicted values.

Nash-Sutcliffe efficiency indices in assessment of flow modeling were considered “Very Good” for a monthly coefficient of 0.75 to 1.00, “Good” for a coefficient of 0.75 to 0.65, “Satisfactory” for a coefficient of 0.65 to 0.50, and “Unsatisfactory” for a coefficient of less than 0.50 (Moriasi et al., 2007).

3.7.3. Percent bias (PBIAS)

PBIAS measures the average tendency of simulated data to be larger or smaller than observed counterparts (Gupta et al., 1999). PBIAS is calculated:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim}) \mathrm{X}(100)}{\sum_{i=1}^{n} Y_i^{obs}} \right] \tag{3.13}$$

where,

PBIAS = percentage bias (%),

Y_i^{obs} = observed value for event i, and

Y_i^{sim} = predicted value for event i.

The optimal value of PBIAS is 0.0, with low magnitude values indicating accurate model simulation. Positive values indicate model under estimation bias and negative values indicate model over estimation bias (Moriasi et al., 2007). PBIAS for streamflow model performance was considered very good for <±15 for sediment and <±10 for streamflow, good for ±15 ≤ PBIAS <±30 for sediment and ±10 ≤ PBIAS < ±15 for streamflow, satisfactory for ±30 ≤ PBIAS <±55 for sediment and ±15 ≤ PBIAS <±25 for streamflow, and unsatisfactory for PBIAS ≥±55 for sediment and PBIAS ≥±25 for streamflow (Moriasi et al., 2007).

CHAPTER 4 - Results and Discussions

4.1. Flow

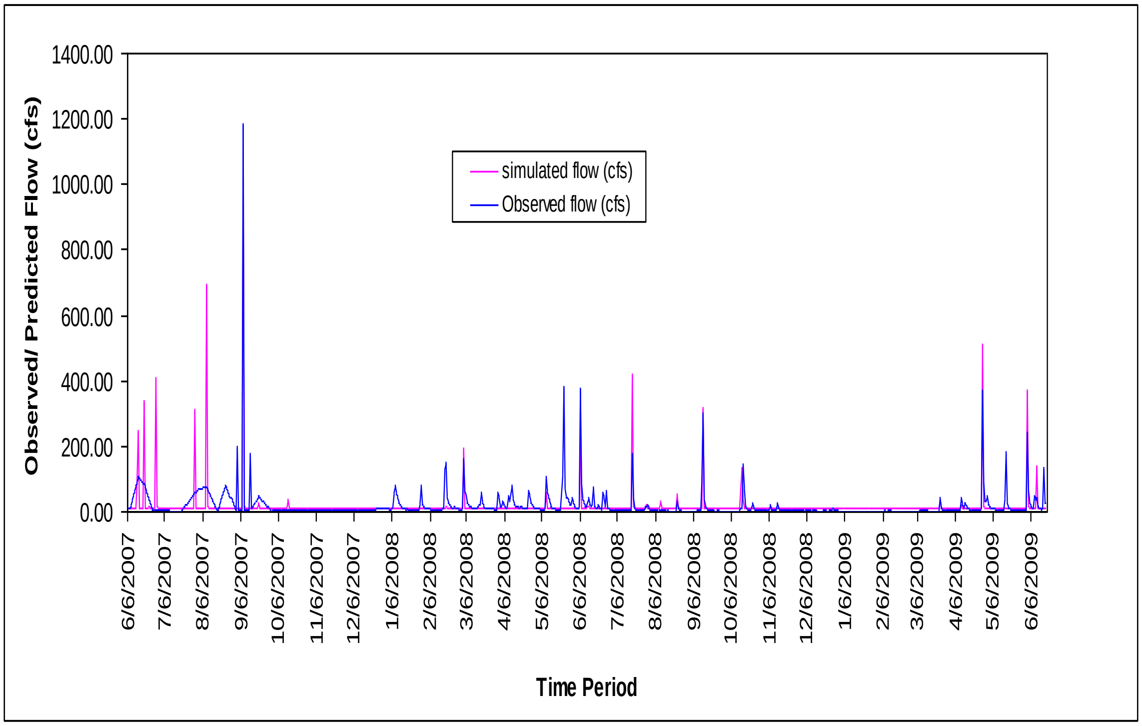
The AnnAGNPS model was calibrated for streamflow using measured data collected at the outlet to each of three subwatersheds (table 3.11). Each of the three subwatersheds was calibrated independently resulting in different flow calibration parameters (table 3.14). Calibrated model results for Irish Creek, Main Stem and North Fork Subwatersheds predicted daily flow of watersheds with satisfactory performance for R^2 (> 0.50) in all three subwatersheds and for E_f (> 0.50) in two of the three subwatersheds, using general performance ratings proposed by Moriasi et al. (2007). The calculated PBIAS values (table 4.1, fig. 4.1) for Irish Creek and Main Stem were satisfactory (< ±25%) for all three subwatershed and very good (< ±10%) for two of the three subwatersheds.

Table 4.1 Statistical parameters[1] of model performance for calibration of daily streamflow for three study subwatersheds and overall watershed for 2-year study period.

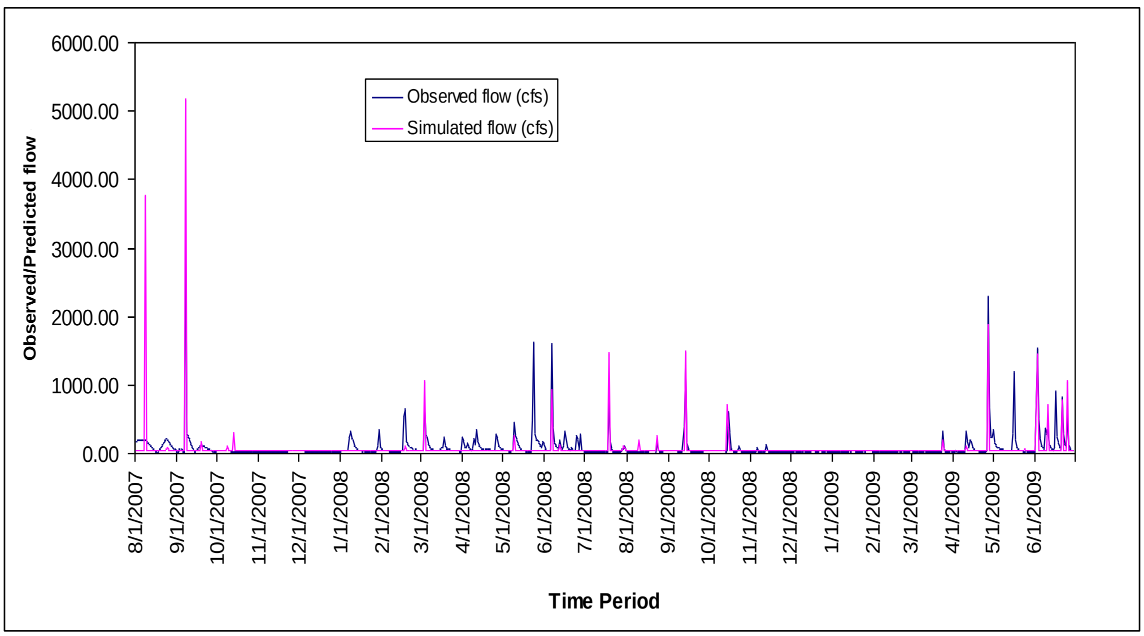
Subwatershed	E_f	PBIAS (%)	R^2
Irish Creek	0.43	6.3	0.50
Main Stem	0.50	8.8	0.49
North Fork	0.49	18.2	0.51

[1]E_f = Nash-Sutcliffe efficiency index, PBIAS = Percent bias,
R^2 = Coefficient of determination

(a)


1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Observed/ Predicted Flow (cfs)
simulated flow (cfs)
Observed flow (cfs)
6/6/2007
7/6/2007
8/6/2007
9/6/2007
10/6/2007
11/6/2007
12/6/2007
1/6/2008
2/6/2008
3/6/2008
4/6/2008
5/6/2008
6/6/2008
7/6/2008
8/6/2008
9/6/2008
10/6/2008
11/6/2008
12/6/2008
1/6/2009
2/6/2009
3/6/2009
4/6/2009
5/6/2009
6/6/2009
Time Period

(b)


6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Observed/Predicted flow
Observed flow (cfs)
Simulated flow (cfs)
8/1/2007
9/1/2007
10/1/2007
11/1/2007
12/1/2007
1/1/2008
2/1/2008
3/1/2008
4/1/2008
5/1/2008
6/1/2008
7/1/2008
8/1/2008
9/1/2008
10/1/2008
11/1/2008
12/1/2008
1/1/2009
2/1/2009
3/1/2009
4/1/2009
5/1/2009
6/1/2009
Time Period

(C)

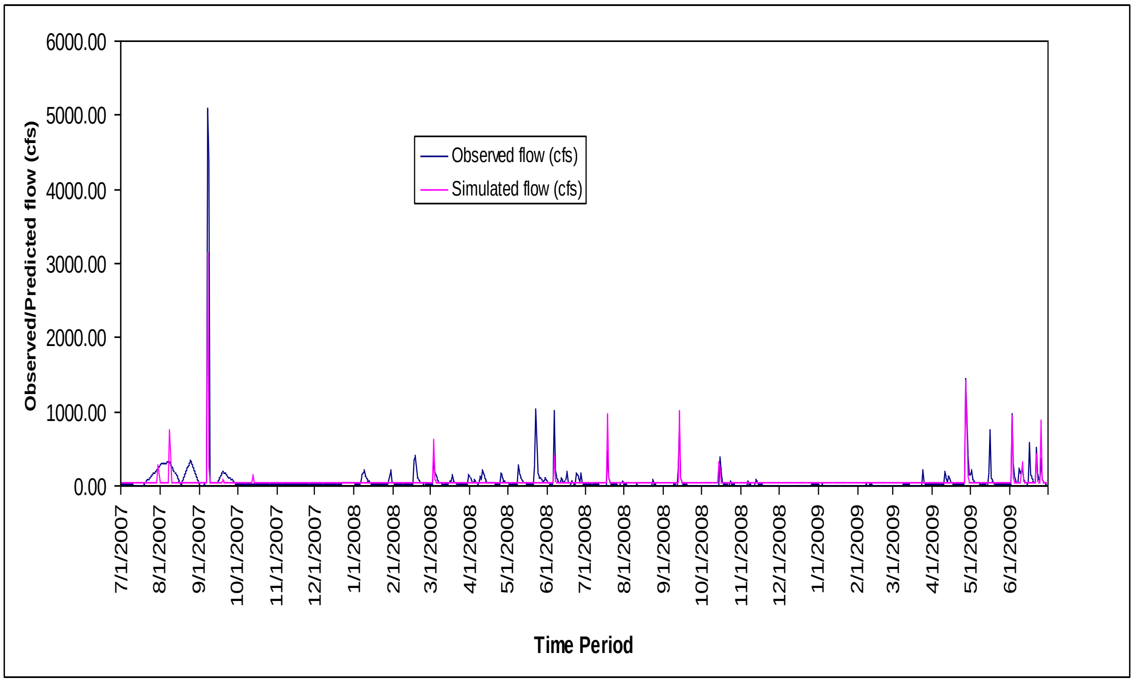


Figure 4.1 Time series of measured and AnnAGNPS simulated daily flow for (a) Irish Creek, (b) Main Stem, and (c) North Fork over 2-year study period.

4.2. Sediment

Sediment calibration was conducted for the Irish Creek and Main Stem Subwatersheds independently. A limited number of parameters were used to calibrate each method: P factor for AnnAGNPS, SGF for REGEM, and a SB multiplier and various thresholds (Ia/S for Method 1, SFT for Method 2, and SPT for Method 3) for each method of disaggregating streambank sediment yields. For each method, parameters were adjusted until an optimal model performance (local maximum E_f and local minimum PBIAS) was found.

Model results for sediment loads from the watershed were interpreted using general performance ratings for sediment calibration proposed by Moriasi et al. (2007): monthly time-step model performance was rated very good for $E_f > 0.75$ and PBIAS <

±15%, good for $E_f > 0.65$ and PBIAS < ±30%, satisfactory for $E_f > 0.5$ and PBIAS < ±55%, and unsatisfactory for $E_f \leq 0.5$ and PBIAS > ±55%. Model results in this study were assessed on an event basis, which tend to produce lower model statistics than a monthly time step (Moriasi et al., 2007), so these monthly performance ratings might qualitatively underestimate event-based performance ratings (i.e., these ratings might be overly-critical in rating the performance of the event-based statistical values in this study).

4.2.1. Overland erosion

The first calibration of sediment yield was for the AnnAGNPS model alone (without the REGEM component) for the Irish Creek and Main Stem subwatersheds. AnnAGNPS was calibrated by adjusting the P factor for model cells that did not have terraces, which accounted for 5% of cropland area in Irish Creek and 35% of cropland area in Main Stem (table 3.4).

The calibrated AnnAGNPS model for Irish Creek and Main Stem predicted daily-based sediment yield with an unsatisfactory model performance (table 4.2) compared to measured sediment yield data. For Irish Creek Subwatershed, the best calibration results were found using a P = 0.8, resulting in the highest E_f (0.30) and the lowest PBIAS (48.4%) (table 4.2). For the Main Stem Subwatershed, the best calibration was considered to be for P = 1.0, with near-optimal E_f (0.25) and the lowest PBIAS (58.0%) (table 4.2).

Optimal calibrated P factors for the model cells that did not have terraces were high for both subwatersheds (0.8 and 1.0). This indicated that the typical recommended P factor of 1.0 for fields without terraces or contouring is a reasonable assumption when using AnnAGNPS alone.

The calibrated parameter values for each subwatershed were used separately, along with a number of other values, to validate and further test the AnnGNPS model for the North Fork Subwatershed (table 1.4). Positive PBIAS value (71.4%) indicated that the model underestimated the sediment yields. The model efficiency values were low with optimal value for P = 0.8 (E_f = 0.01).

The low E_f and high PBIAS values of the AnnAGNPS model for three subwatersheds indicate the need to consider other sediment sources and processes (ephemeral gully erosion, streambank erosion).

4.2.2. Overland + Ephemeral gully erosion

The second calibration of sediment yield was for the AnnAGNPS model combined with the REGEM component for the Irish Creek and Main Stem Subwatersheds. The REGEM Sediment Gully Factor (SGF) found in the PL Calibration Data of the AnnGNPS Input Editor was adjusted together with the P factor until the best set of calibration statistics was achieved.

A heuristic approach was used to arrive at the calibration factor for ephemeral gully erosion for both Irish Creek and Main Stem Subwatersheds. Several model simulations were performed with different parameter combinations of P factor and SGF in order to determine an optimal E_f and PBIAS (table 4.2).

For a constant P factor value, as SGF was increased, the PBIAS value decreased slightly (less than 10% for Irish Creek and less than 1% for Main Stem). Increasing SGF leads to greater sediment contribution from ephemeral gullies, which slightly improved the agreement with measured subwatershed outlet values. At the same time, model efficiency improved as SGF value was increased.

With a constant SGF value, an increase in P factor increased the total sediment load from overland erosion. This resulted in decreasing PBIAS values and increasing model efficiency to optimal values near a P between 0.7 and 0.8 for Irish Creek and 1.0 for Main Stem. Further increase in P factor beyond these values led to poorer model statistics.

The optimal combination of model statistics for Irish Creek was found for a P factor of 0.8 and SGF of 0.8 (E_f = 0.37, PBIAS = 21.1%). For Main Stem, the optimal combination was for P factor of 1.0 and SGF of 14 (E_f = 0.34, PBIAS = 50.7%). For the calibration using AnnAGNPS alone, the optimal P factor values were same for Irish Creek (0.8) and same for Main Stem (1.0). As more sediment was added from ephemeral gullies, the P factor value for Irish Creek and Main Stem remained the same.

The calibrated parameter values for each subwatershed (Irish Creek and Main Stem) were used separately, along with a number of other values, to validate and further test the AGNPS + REGEM model for the North Fork Subwatershed (table 1.4). Positive PBIAS value (64.6%) indicated that the model underestimated the sediment yields. The model efficiency values were low with optimal value for P = 0.8 (E_f = 0.06).

The same trend was observed in the three subwatersheds for both AnnAGNPS alone and in combination with REGEM. The higher PBIAS and lower E_f values indicate the need to consider sediment coming from streambanks.

Table 4.2 Calibration model parameters[1] and event-based (n=62) model performance[2] for five methods to simulate Irish Creek Subwatershed outlet total suspended sediment yield.

Multiplier	Threshold	P factor	SGF	E_f	PBIAS (%)	Total Sediment (Mg)
AnnAGNPS						
SB=0	--	0.5	0	0.26	66.5	352
		0.6	0	0.28	60.5	416
		0.7	0	0.29	54.5	479
		0.8	0	0.30	48.4	542
		0.9	0	0.28	42.4	605
		1.0	0	0.27	36.4	668
AnnAGNPS + REGEM						
SB=0	--	0.5	0.7	0.36	49.1	603
		0.5	0.8	0.37	45.7	641
		0.5	0.9	0.37	42.7	677
		0.6	0.7	0.37	36.7	666
		0.6	0.8	0.38	33.1	704
		0.7	0.8	0.38	27.1	767
		0.7	0.9	0.37	23.6	803
		0.7	1.0	0.36	21.1	830
		0.8	0.8	0.37	21.1	830
		0.8	0.9	0.36	17.6	867
AnnAGNPS + REGEM + Method 1 (Based on Rainfall)						
SB=0.1	Ia/S=0	0.6	0.6	0.45	1.4	1,037
		0.6	0.7	0.45	-1.6	1,069
		0.5	0.8	0.46	0.8	1,043
		0.4	0.8	0.46	6.8	980
		0.4	0.9	0.44	3.4	1,016
		0.4	1.0	0.42	0.8	1,043
	Ia/S=0.1	0.5	0.4	0.51	0.6	1,046
		0.4	0.5	0.52	2.6	1,024
		0.4	0.6	0.51	-0.8	1,060
	Ia/S=0.2	0.5	0.1	0.56	1.5	1,036
		0.5	0.2	0.55	-2.4	1,077
		0.4	0.2	0.56	3.6	1,014
		0.4	0.3	0.55	-0.3	1,055
		0.3	0.4	0.55	2.1	1,030
		0.3	0.5	0.56	-1.9	1,072
	Ia/S=0.3	0.4	0	0.61	-1.1	1,063
		0.3	0.1	0.61	3.0	1,020
		0.3	0.2	0.61	-0.9	1,061
	Ia/S=0.4	0.2	0.1	0.68	0.2	1,050
	Ia/S=0.5	0.2	0	0.76	-7.3	1,129
		0.1	0	0.75	-1.2	1,065
SB=0.2	Ia/S=0	0.3	0.1	0.49	0.1	1,051
	Ia/S=0.1	0.1	0	0.54	-14.2	1,202
	Ia/S=0.2	0.1	0	0.54	-35.4	1,424
	Ia/S=0.3	0.1	0	0.48	-56.4	1,646
SB=0.3	Ia/S=0	0.1	0	0.47	24.0	1,305

AnnAGNPS+REGEM+Method 2 (Based on streamflow)						
SB=0.1	SFT=0%	0.6	0.7	0.53	0.8	1,044
		0.5	0.7	0.54	6.8	980
		0.5	0.8	0.53	3.2	1,018
		0.5	0.9	0.52	-0.2	1,055
		0.4	1.0	0.50	3.2	1,018
	SFT=10%	0.3	0	0.67	-0.5	1,057
		0.2	0.1	0.66	3.6	1,013
		0.2	0.2	0.65	-0.2	1,054
		0.1	0.3	0.63	1.9	1,031
		0.1	0.4	0.63	-1.7	1,070
	SFT=20%	0.3	0	0.67	-2.0	1,073
		0.2	0.1	0.66	2.2	1,029
		0.2	0.2	0.66	-1.7	1,070
		0.1	0.3	0.64	0.4	1,047
		0.1	0.4	0.63	-3.2	1,086
	SFT=30%	0.3	0	0.67	-3.4	1,087
		0.2	0.1	0.66	0.8	1,044
		0.2	0.2	0.66	-3.1	1,084
		0.1	0.2	0.64	3.0	1,020
		0.1	0.3	0.64	-0.9	1,062
SB=0.2	SFT=0%	0.4	0	0.62	0.8	1,044
		0.4	0.1	0.63	-1.2	1,064
		0.3	0.2	0.62	1.0	1,042
	SFT=10%	0.1	0	0.41	-67.3	1,760
SB=0.3	SFT=0%	0.1	0	0.65	-16.9	1,229
	SFT=10%	0.1	0	-0.62	-146.3	2,591
SB=0.4	SFT=0%	0.1	0	0.61	-52.8	1,607
SB=0.5	SFT=0%	0.1	0	0.46	-88.6	1,984

AnnAGNPS+REGEM+Method 3 (Based on stream power)						
SB=0.1	SPT=0	0.6	0.7	0.53	0.3	1,040
		0.5	0.8	0.53	2.7	1,015
		0.5	0.9	0.52	-0.8	1,051
		0.4	1.0	0.50	2.7	1,015
	SPT=0.1	0.3	0	0.66	0.9	1,034
		0.3	0.1	0.66	-1.1	1,055
		0.2	0.2	0.65	1.2	1,031
		0.1	0.3	0.62	3.3	1,009
		0.1	0.4	0.62	-0.3	1,047
	SPT=0.5	0.3	0	0.67	-4.2	1,087
		0.2	0	0.66	2.0	1,023
		0.2	0.1	0.66	-0.03	1,044
		0.1	0.2	0.64	2.2	1,020
		0.1	0.3	0.64	-1.8	1,062
	SPT=1.0	0.2	0	0.67	-0.04	1,044
		0.1	0.1	0.65	4.1	1,000
		0.1	0.2	0.64	0.2	1,041
SB=0.2	SPT=0	0.4	0	0.62	0.6	1,038
		0.4	0.1	0.63	-1.4	1,058
		0.3	0.2	0.62	-0.8	1,035
	SPT=0.1	0.1	0	0.45	-64.3	1,714
SB=0.3	SPT=0	0.1	0	0.65	-16.9	1,220
	SPT=0.1	0.1	0	-0.48	-141.7	2,523
SB=0.4	SPT=0	0.1	0	0.61	-52.8	1,594

SB=0.5	SPT=0	0.1	0	0.46	-88.6	1,969

[1]P factor = USLE P factor for non-terraced cells, SGF = REGEM sediment gully factor, Ia/S = Ratio of initial abstraction (Ia) to total watershed storage (S), SPT = Stream power threshold, SFT = Streamflow threshold
[2]E_f = Nash-Sutcliffe efficiency, PBIAS = Percent bias, Total sediment = Sediment from combined AnnAGNPS, REGEM, and streambank distribution methods (2-yr total),

Table 4.3 Calibration model parameters[1] and event-based (n=60) model performance[2] for five methods to simulate Main Stem Subwatershed outlet total suspended sediment yield.

Multiplier	Threshold	P factor	SGF	E_f	PBIAS (%)	Total Sediment (Mg)
			AnnAGNPS			
SB=0		0.5	0	0.16	77.3	2,827
		0.6	0	0.19	73.4	3,311
		0.7	0	0.21	69.5	3,794
		0.8	0	0.23	65.7	4,276
		0.9	0	0.24	61.8	4,757
		1.0	0	0.25	57.9	5,238
			AnnAGNPS + REGEM			
SB=0		0.9	5	0.29	59.4	5,052
		0.9	10	0.32	56.7	5,388
		0.9	14	0.33	54.5	5,662
		1.0	1	0.26	57.5	5,299
		1.0	5	0.29	55.6	5,532
		1.0	10	0.33	52.9	5,868
		1.0	14	0.34	50.7	6,143
			AnnAGNPS + REGEM + Method 1 (Based on Rainfall)			
SB=1.0	Ia/S=0	0.9	14	0.50	8.5	11,393
		0.8	14	0.51	12.4	10,912
SB=1.3	Ia/S=0	0.9	10	0.52	-3.1	12,838
		0.8	10	0.53	0.8	12,357
		0.8	11	0.53	0.3	12,417
		0.8	12	0.53	-0.2	12,488
		0.8	13	0.53	-0.8	12,559
		0.7	14	0.54	2.5	12,149
	Ia/S=0.1	0.3	10	0.60	-2.3	12,749
		0.2	12	0.60	0.5	12,392
		0.2	13	0.60	-0.1	12,463
	Ia/S=0.2	0.1	0	0.622	-5.5	13,145
	Ia/S=0.3	0.1	0	0.58	-20.9	15,071

AnnAGNPS+REGEM+Method 2 (Based on streamflow)						
SB=1.0	SFT=0	0.9	12	0.59	9.20	11,312
		0.9	14	0.58	8.0	11,455
		0.8	14	0.59	11.9	10,974
		0.7	12	0.60	16.9	10,349
	SFT=10%	0.1	0	0.63	0.3	12,423
	SFT=20%	0.1	0	0.61	-5.2	13,099
SB=1.3	SFT=0	0.9	0	0.61	1.3	12,288
		0.8	10	0.62	0.26	12,438
		0.8	11	0.62	-0.3	12,498
		0.7	11	0.63	3.5	12,016
		0.7	14	0.62	1.8	12,230
	SFT=10%	0.2	0	0.46	-31.5	16,378
SB=1.5	SFT=0	0.7	0	0.64	-0.2	12,483
		0.6	0	0.65	3.7	12,000
	SFT=10%	0.1	0	0.29	-46.1	18,196
AnnAGNPS+REGEM+Method 3 (Based on stream power)						
SB=1.0	SPT=0	1.0	11	0.56	17.1	10,329
		1.0	14	0.55	15.4	10,543
		0.9	14	0.56	18.5	10,149
	SPT=0.1	0.8	10	0.57	23.9	9,479
	SPT=0.5	0.4	0	0.61	1.9	12,217
		0.3	0	0.62	5.1	11,817
SB=1.3	SPT=0	1.0	10	0.58	4.7	11,868
		1.0	14	0.56	2.5	12,143
		0.9	10	0.59	7.9	11,473
		0.9	14	0.58	5.7	11,748
		0.8	11	0.60	10.6	11,139
		0.7	10	0.61	14.2	10,682
		0.6	11	0.61	16.9	10,346
	SPT=0.5	0.1	0	0.49	-1.2	14,098
	SPT=1.0	0.1	0	0.47	-15.4	14,378
SB=1.5	SPT=0	0.8	12	0.60	1.5	12,275
		0.7	0.0	0.62	10.7	11,118
	SPT=0.5	0.1	0.0	0.37	-29.7	16,155

[1]P factor = USLE P factor for non-terraced cells, SGF = REGEM sediment gully factor, Ia/S = Ratio of initial abstraction (Ia) to total watershed storage (S), SPT = Stream power threshold, SFT = Streamflow threshold

[2]E_f = Nash-Sutcliffe efficiency, PBIAS = Percent bias, Total sediment = Sediment from combined AnnAGNPS, REGEM, and streambank distribution methods (2-yr total),

Table 4.4 Validation model parameters[1] and event-based (n=63) model performance[2] for five methods to simulate North Fork Subwatershed outlet total suspended sediment yield.

Multiplier	Threshold	P factor	SGF	E_f	PBIAS (%)	Total Sediment (Mg)
			AnnAGNPS			
SB=0	--	0.2	0	-0.012	91.7	1,781
		0.4	0	0.004	84.8	3,252
		0.8	0	0.01	71.4	6,116
		1.0	0	0.004	64.8	7,523
			AnnAGNPS + REGEM			
SB=0	--	0.8	1	0.02	70.9	6,213
		0.8	10	0.06	64.6	7,561
		1.0	1	0.01	64.3	7,621
		1.0	10	0.05	58.0	8,967
			AnnAGNPS + REGEM + Method 1 (Based on Rainfall)			
SB=0.05	Ia/S=0	0.2	0	0.11	66.8	7,083
		0.2	10	0.15	60.1	8,535
		0.4	0	0.12	60.0	8,554
		0.4	10	0.16	53.2	10,003
		0.8	0	0.11	46.6	11,417
		0.8	10	0.14	39.8	12,863
	Ia/S=0.1	0.2	0	0.18	58.7	8,823
		0.2	10	0.21	51.9	10,275
		0.4	0	0.18	51.8	10,294
		0.4	10	0.21	45.0	11,743
	Ia/S=0.4	0.2	0	0.36	43.2	12,132
		0.2	10	0.37	36.4	13,585
		0.4	0	0.35	36.3	13,604
SB=0.1	Ia/S=0.1	0.2	0	0.31	25.8	15,865
		0.2	10	0.33	19.0	17,317
		0.4	0	0.30	18.9	17,336
		0.4	10	0.32	12.1	18,785
	Ia/S=0.6	0.2	0	0.68	-24.5	26,601
		0.2	10	0.64	-31.3	28,053
		0.4	0	0.64	-31.5	28,072
SB=0.2	Ia/S=0	0.2	0	0.33	-7.6	22,989
		0.2	10	0.34	-14.4	24,441
		0.4	0	0.30	-14.4	24,460

AnnAGNPS+REGEM+Method 2 (Based on streamflow)						
SB=0.05	SFT=0%	0.2	0	0.13	67.4	6,960
		0.2	10	0.16	60.4	8,412
		0.4	0	0.14	60.7	8,404
		0.4	10	0.16	53.9	9,854
		0.8	0	0.13	47.5	11,215
	SFT=10%	0.2	0	0.24	43.3	12,116
		0.2	10	0.24	36.5	13,568
		0.4	0	0.23	36.5	13,561
	SFT=20%	0.2	0	0.24	42.9	12,198
		0.2	10	0.24	36.1	13,650
		0.4	0	0.23	36.2	13,642
SB=0.1	SFT=0%	0.2	0	0.22	43.0	12,172
		0.2	10	0.23	36.2	13,624
		0.4	0	0.22	36.3	13,616
		0.4	10	0.22	29.5	15,065
		0.8	0	0.19	23.1	16,426
	SFT=10%	0.2	0	0.20	-5.2	22,485
		0.2	10	0.14	-12.0	23,937
AnnAGNPS+REGEM+Method 3 (Based on stream power)						
SB=0.05	SPT=0	0.2	0	0.13	67.4	6,960
		0.2	10	0.16	60.3	8,412
		0.4	0	0.14	60.7	8,404
		0.4	10	0.16	53.9	9,854
		0.8	0	0.13	47.5	11,215
	SPT=0.5	0.2	0	0.24	43.2	12,146
		0.2	10	0.24	36.4	13,598
		0.4	0	0.23	36.4	13,590
SB=0.1	SPT=0	0.2	0	0.22	43.0	12,172
		0.2	10	0.23	36.2	13,624
		0.4	0	0.22	36.3	13,616
		0.4	10	0.22	29.5	15,066
		0.8	0	0.19	23.1	16,426
	SPT=0.5	0.2	0	0.20	-5.5	22,543

[1]P factor = USLE P factor for non-terraced cells, SGF = REGEM sediment gully factor, Ia/S = Ratio of initial abstraction (Ia) to total watershed storage (S), SPT = Stream power threshold, SFT = Streamflow threshold

[2]E_f = Nash-Sutcliffe efficiency, PBIAS = Percent bias, Total sediment = Sediment from combined AnnAGNPS, REGEM, and streambank distribution methods (2-yr total),

4.2.3. Overland + Ephemeral gully + Streambank erosion

The field-measured 2-year total annual streambank erosion values were disaggregated to the daily scale using three methods, as described in Section 3.5.

4.2.3.1. AnnAGNPS + REGEM + Streambank Erosion: Method 1

This method distributes the total 2-year streambank erosion, after applying a multiplier (SB), to the daily scale according to the percentage of the daily rainfall depths for storms exceeding an established Ia/S threshold value to the 2-year sum of daily rainfall depths that exceed the Ia/S threshold value.

Results (tables 4.2 and 4.3; also see tables in Appendix 2) suggest that for a constant SGF factor and constant Ia/S threshold, an increase in P factor increased the total sediment load and decreased PBIAS value, but the efficiency of the method increased to a certain P factor value and then decreased. For a constant P factor value and SGF value, an increase in Ia/S threshold value decreased PBIAS values, indicating that more sediment was routed through fewer major events, and the E_f values increased up to an optimum threshold value and then decreased. For a constant P factor and Ia/S threshold, an increase in SGF value increased the total sediment load and decreased PBIAS, but the E_f remained the same.

Field assessments determined that streambank erosion may be originating from both banks, thus a streambank (SB) multiplier of 1.3 might be warranted (Keane et al., 2010). Various SB multipliers were tested in this study (0.1, 0.2, 0.3, 0.4, 0.5 and 1.3 for Irish Creek and 1.0, 1.3 and 1.5 for Main Stem). When no threshold was applied, as the SB multiplier was increased, the efficiency of the method increased up to an optimum SB value and then decreased, but the PBIAS values decreased. As the SB multiplier increased good efficiencies and satisfactory PBIAS values were achieved at lower P factor values and lower SGF values. For Irish Creek using a SB multiplier of 0.1, satisfactory performance was achieved for P factor = 0.5 and SGF factor = 0.8 (E_f = 0.46 and PBIAS = 0.8%). For SB value of 0.2, satisfactory performance was achieved at P factor = 0.3 and SGF factor = 0.1 (E_f = 0.49 and PBIAS = 0.08%) (table 4.2). For Main Stem using a SB value of 1.0, satisfactory performance was achieved for P factor = 0.9 and SGF = 14 (E_f = 0.50 and PBIAS = 8.5%). Based on the statistical parameters in table 4.2 and table 4.3, for Irish Creek the SB multiplier factors of 0.1 and 0.2 gave nearly satisfactory model efficiencies (E_f = 0.46 and E_f = 0.49) and very good PBIAS values (0.8% and 0.08%), and for Main Stem the SB multiplier factor of 1.3 gave satisfactory efficiency (E_f = 0.53) and very good PBIAS values (0.3%) for no threshold conditions.

As more sediment was added from streambanks, the P factor and SGF values decreased, indicating that less sediment was routed from the overland and ephemeral gullies to the outlet. Since 58.3% of the Irish Creek Subwatershed and 57.0% of the Main Stem Subwatershed drained into watershed structures, there was a possibility of the sediment from overland and ephemeral gullies to settle in the watershed structures, particularly for small events. More sediment from overland and ephemeral gullies might be routed to the outlet during bigger events, when detention times in these structures are relatively short. So most of the sediment that was measured at outlet might have been sediment from streambanks.

Threshold conditions of Ia/S = 0 mean that each event contributed to routing the sediment from streambanks to the outlet. As the Ia/S threshold value increased, only a few events (events greater than the threshold value) contributed to routing the total streambank sediment, and the efficiency of the method increased to an optimum threshold value and then decreased. Maximum efficiencies and low PBIAS were achieved at low P factors and low SGF. As the Ia/S threshold value increased, maximum efficiency and low PBIAS values were achieved at lower P factor and SGF values. For Irish Creek, the optimal combinations of statistics were

- Ia/S = 0 at P = 0.5 and SGF = 0.8 (E_f = 0.46 and PBIAS = 0.8%),
- Ia/S = 0.1 at P = 0.5 and SGF = 0.4 (E_f = 0.51 and PBIAS = 0.6%),
- Ia/S = 0.2 at P = 0.5 and SGF = 0.1 (E_f = 0.56 and PBIAS= 1.5%),
- Ia/S = 0.3 at P = 0.3 and SGF = 0.2 (E_f = 0.61 and PBIAS = -0.9%),
- Ia/S = 0.4 at P = 0.2 and SGF = 0.1 (E_f = 0.68 and PBIAS = 0.2%),
- Ia/S = 0.5 at P = 0.1 and SGF = 0.0 (E_f = 0.75 and PBIAS = -1.2%), and
- Ia/S =0.6 at P = 0.1 and SGF = 0.0 (E_f = 0.68 and PBIAS = -11.8%).

For Main Stem the same trend was observed, but the optimal threshold value observed was Ia/S = 0.2 at P = 0.1 and SGF = 0.0 (E_f = 0.62 and PBIAS = -5.5%), and For North Fork the same trend was observed, but the optimal threshold value observed was Ia/S = 0.7 at P= 0.2 and SGF=0.0 (E_f = 0.65 and PBIAS = -30.1%).

The results suggested that the model did not perform well for small events, but it did perform well for large events. In a study of 72 small basins in 17 states, Piest (1965) found that large storms (with a return period of 1 year or more) contributed an average of 31 percent of the total sediment yield from their respective basins (Guy, 1970). The difference in the optimum threshold values for Irish Creek (Ia/S = 0.5) and Main Stem (Ia/S = 0.2) might be attributed to the spatial variability of precipitation. In this study, precipitation was assumed to be spatially uniform, due to the limitation of measured precipitation. Negligence in considering the spatial variability could result in serious errors in model outputs (Chang et al., 2007). The spatial rainfall variability could result in the uncertainty of runoff predictions (Chang et al., 2007). The input errors of precipitation can result in the uncertainty on modeling outputs of flow hydrographs, representing flow volume, peak flow, arrival time of peak flow, and other hydrograph characteristics (Chaubey et al., 1999; Chang et al., 2007). The uncertainty on hydrologic responses would translate to uncertainty in pollutant exports, and even be expanded (Chang et al., 2007). Young et al. (1992) and Luzio and Lenzi (1995) studies demonstrated that the sediment yield, total nitrogen and total phosphorous predictions are sensitive to the spatial variability of rainfall (Chaubey et al., 1999). Chaubey et al. (1999) demonstrated the need to capture the spatial variability of rainfall in order to accurately predict the hydrologic and water quality responses of watersheds. Since rainfall is a driving force behind many kinds of pollutant release and subsequent transport and spread mechanisms, ignoring this property of rainfall in the application of watershed models limits the accuracy of model results (Chaubey et al., 1999). Rainfall spatial patterns can be better captured using a network of rain gauges and radar rainfall data (Gali, 2010).

4.2.3.2. AnnAGNPS + REGEM + Streambank Erosion: Method 2

This method distributed the 2-year total measured streambank erosion, after applying a multiplier (SB), to the daily scale based on the percentage of the daily streamflow that exceeds a threshold (SFT) value to the 2-year sum of streamflows that exceed the SFT threshold value.

Results (tables 4.2 and 4.3; also see tables in Appendix 2) suggest that for a constant SGF factor and constant SFT, an increase in P factor increased the total sediment load and decreased PBIAS values, but the efficiency of the method increased to a certain P factor value and then decreased. For a constant P factor value and SGF value, an increase in SFT threshold value increased the efficiency of the method up to optimum threshold value and then decreased and the PBIAS values decreased. For a constant P factor and SFT threshold an increase in SGF value increased the total sediment load and a decrease in PBIAS value.

Field assessments determined that streambank erosion may be originating from both banks, thus a streambank (SB) multiplier of 1.3 might be warranted (Keane et al., 2010). Various SB multipliers were tested in this study (0.1, 0.2, 0.3, 0.4, 0.5 and 1.3 for Irish Creek and 1.0, 1.3 and 1.5 for Main Stem). At SFT threshold = 0%, as the SB multiplier was increased, the efficiency of the method increased up to an optimum SB value and then decreased, and the PBIAS values decreased. As the SB multiplier increased good efficiencies and satisfactory PBIAS values were achieved at lower P factor values and lower SGF values. For Irish Creek, SB value of 0.1, a satisfactory E_f (0.53) and very good PBIAS (0.8%) was achieved for P factor = 0.6 and SGF factor = 0.7, and for SB value of 0.2, similar performance was achieved at P factor = 0.4 and SGF factor = 0.1 (E_f = 0.63 and PBIAS = -1.2%) (table 1.2). For Main Stem, for SB value of 1.0, satisfactory E_f (0.59) and very good PBIAS (9.2%) was achieved for P factor = 0.9 and SGF = 12, and for SB factor of 1.3, similar performance was achieved for P = 0.8 and SGF = 10 (E_f = 0.62 and PBIAS = 0.2%). For North Fork, for SB value of 0.2, low efficiency E_f (0.23) and very good PBIAS (-5.7%) was achieved for P factor = 0.1 and SGF = 0.

As more sediment was contributed from streambanks, the P factor and SGF values decreased, indicating that less sediment was routed from the overland and ephemeral gullies to the outlet. Since 58.3% approx of the Irish Creek Subwatershed, 57.0% approx of the Main Stem Subwatershed and 21% approx of the North Fork drained into watershed structures, there was a possibility of the sediment from overland and ephemeral gullies to settle in the watershed structures for small events, as discussed above.

Threshold conditions of SFT = 0% means that each event contributed to routing the sediment from streambanks to the outlet. As the SFT threshold increased, fewer events (events greater than the threshold value) contributed to routing the total streambank sediment, and the efficiency of the method increased to an optimum threshold value and then decreased. Maximum E_f and low PBIAS were achieved at low P factors and low SGF. As the SFT threshold increased, maximum E_f and low PBIAS values were achieved at lower P factor and SGF values. For Irish Creek, the optimal combinations of statistics were:

- SFT = 0% at P = 0.6 and SGF = 0.7 (E_f = 0.53 and PBIAS = 0.8%),
- SFT = 10% at P = 0.3 and SGF = 0.0 (E_f = 0.67 and PBIAS = -0.5%),
- SFT = 20% at P = 0.2 and SGF = 0.2 (E_f = 0.66 and PBIAS = -1.7%), and
- SFT = 30% at P = 0.2 and SGF = 0.1 (E_f = 0.66 and PBIAS = 0.8%).

For Main Stem the same trend was observed for SB factor of 1.0 but the optimum threshold value observed was SFT = 10% at P = 0.1 and SGF = 0.0 (E_f = 0.63 and PBIAS = 0.3%), but for the SB factor of 1.3, the method gave optimal model performance with no threshold (SFT = 0%) conditions (E_f = 0.62 and PBIAS = 0.2%). For North Fork, the same trend was observed for SB factor of 0.05 but the optimum threshold value observed was SFT = 20% at P = 0.2 and SGF = 0.0 (E_f = 0.24 and PBIAS = 36.1%), but for the SB factor of 0.1, the method gave optimal model performance with no threshold (SFT = 10%) conditions (E_f = 0.20 and PBIAS = -5.2%).

4.2.3.3. AnnAGNPS + REGEM + Streambank Erosion: Method 3

This method distributes the 2-year total annual streambank erosion, after applying a multiplier (SB), among the events according to the ratio of daily stream power to the 2-year sum of stream power for events in which the stream power exceeds the threshold stream power (SPT).

Results (tables 4.2 and 4.3; also see tables in Appendix 2) shows that for a constant SGF factor and constant SPT threshold, an increase in P factor increased the total sediment load and decreased PBIAS value, but the efficiency of the method increased to a certain P factor value and then decreased. For a constant P factor value and SGF value, an increase in threshold value increased the efficiency of the method up to optimum threshold value and then decreased and the PBIAS values got decreased. For a constant P factor and SPT, increase in SGF value increased the total sediment load and a decrease in PBIAS value.

Field assessments determined that streambank erosion may be originating from both banks, thus a streambank (SB) multiplier of 1.3 might be warranted (Keane et al., 2010). Various SB multipliers were tested in this study (0.1, 0.2, 0.3, 0.4, 0.5 and 1.3 for Irish Creek and 1.0, 1.3 and 1.5 for Main Stem). At SPT threshold = 0, as the SB multiplier increased, the efficiency of the method increased up to a optimum SB value and then decreased, and the PBIAS values decreased. As the SB multiplier increased good efficiencies and satisfactory PBIAS values were achieved at lower P factor values and lower SGF values. For Irish Creek, SB multiplier of 0.1, the best performance was achieved for P = 0.6 and SGF =0.7 (E_f = 0.53 and PBIAS = 0.3%), and for SB multiplier of 0.2, the best performance was achieved at P = 0.4 and SGF = 0.1 (E_f = 0.63 and PBIAS = -1.4%) (table 1.2). For Main Stem, for SB multiplier of 1.0, the best performance was achieved for P = 1.0 and SGF = 11 (E_f = 0.56 and PBIAS = 17.1%), and for SB multiplier of 1.3, the best performance was achieved for P = 0.7 and SGF = 10 (E_f = 0.61 and PBIAS = 14.2%). Based on the statistical parameters in table 1.2 and table 1.3, for Irish Creek the SB multiplier of 0.2 gave satisfactory E_f (0.63) and very good PBIAS (-1.4%), and for Main Stem the SB multiplier of 1.3 gave satisfactory E_f (0.61) and very good PBIAS (14.2%) for SPT threshold of 0.

As more sediment was contributed from streambanks, the P factor and SGF values decreased, indicating that less sediment was routed from the overland and ephemeral gullies to the outlet. Since 58.3% of the Irish Creek Subwatershed and 57.0% of the Main Stem Subwatershed drained into watershed structures, there was a possibility of the sediment from overland and ephemeral gullies to settle in the watershed structures for small events, as discussed above.

Threshold conditions of SPT = 0 means that each event contributed to routing the sediment from streambanks to the outlet. As SPT increased, fewer events (events greater than the threshold value) contributed to routing the total streambank sediment, and the efficiency of the method increased to an optimum threshold value and then decreased. Maximum E_f and low PBIAS were achieved at low P factors and low SGF. As the SPT increased, maximum E_f and low PBIAS values were achieved at low P factor and SGF values. For Irish Creek, for SB factor of 0.1, the optimal combinations of statistics were:

- SPT = 0 at P = 0.6 and SGF = 0.7 (E_f = 0.53 and PBIAS = 0.3%),
- SPT = 0.1 at P = 0.3 and SGF = 0.0 (E_f = 0.66 and PBIAS = -0.9%),
- SPT = 0.5 at P = 0.2 and SGF = 0.2 (E_f = 0.66 and PBIAS = -0.03%), and
- SPT = 1.0 at P = 0.2 and SGF = 0.0 (E_f = 0.67 and PBIAS = -0.04%).

For Main Stem the same trend was observed for SB factor of 1.0 but the optimum threshold value observed was SPT = 0.5 at P = 0.4 and SGF = 0.0 (E_f = 0.61 and PBIAS = 1.9%), but for the SB factor of 1.3, the method gave good agreement with no threshold (SPT = 0) conditions for P = 0.7 and SGF = 10 (E_f = 0.61 and PBIAS = 14.2%). For North Fork, the same trend was observed for SB factor of 0.05 but the optimum threshold value observed was SPT = 0.5 at P = 0.2 and SGF = 10.0 (E_f = 0.24 and PBIAS = 36.4%).

4.2.4. Overall Discussion

From results summarized in tables 4.2, 4.3, and 4.4 (and from tables in Appendix 2), we can say that all the methods followed the same trend as explained above but with different threshold values and SB multipliers for Irish Creek, Main Stem, and North Fork. These differences in threshold values can be attributed to the differences in the three subwatersheds, in terms of landuse activities, management operations, condition of terraces, stream and riparian geomorphologic condition, watershed size, percentage of watershed that drains into watershed structures, and spatial variability of precipitation (differences in the distance of watershed from the weather station). The lower efficiency values were due to the model limitations which are explained later in this chapter.

Satisfactory efficiencies at low P factors and lower SGF factors (for Irish Creek: Ia/S = 0.5 at P = 0.1 and SGF = 0.0 [E_f = 0.75 and PBIAS = -1.2%]; for Main Stem: Ia/S = 0.2 at P = 0.1 and SGF = 0.0 [E_f = 0.62 and PBIAS = -5.5%]; for North Fork: Ia/S = 0.6 at P = 0.2 and SGF = 0.0 [E_f = 0.68 and PBIAS = -24.5%]) indicate that only a fraction, and often a rather small fraction, of the sediment eroded within a drainage basin reached the basin outlet and was represented in the sediment yield. Deposition and temporary or permanent storage of sediment may occur on the slopes, at the base of the slope, in watershed structures (58.3% of Irish Creek, 57.0% of Main Stem, and 21.0% of the North Fork drains into watershed structures), in swales, on the flood plain, and in the channel itself. The relative magnitude of this loss tended to increase with increasing basin size. A study of 105 agricultural production areas in the U.S by Wade and Heady (1978) documented a range of sediment output between 0.1% and 37.8% of gross erosion. In this study, calibrated model results ranged from about 46% to 49% for the two subwatersheds.

Also, a temporal discontinuity may exist between the downstream sediment yield and the upstream erosion rates. Sediment eroded at one location may be stored temporarily and subsequently remobilized several times over a period of time before reaching the drainage basin outlet (Walling, 1994; Gordon et al., 2004).

Low P factor values might be due to: Most of the terraced fields have grass waterways which drain directly into the ponds that are located in the rangelands (impounded terraces) (field observations on June 2, 2010). Impoundment terraces are designed to reduce sediment loss from croplands. They function by collecting and detaining runoff from an upslope area for a period of time to allow sediment deposition.

The impoundment drains via an underground conduit which connects to the bottom of the impoundment so it drains completely between each storm (Nearing et al., 1998).

Reservoir impoundments are designed to collect and store surface runoff for later use. These include stock tanks and farm ponds. As with impoundment terraces, deposition is the main sedimentation process. Runoff from a reservoir impoundment is produced only when it is full and more runoff is introduced. When the pond becomes full, extra runoff is routed over spillways. Estimation of the discharge rates requires a rating table for the spillway. Detailed information about the impoundments is required in order to include in the models (like area, depth, seepage rate, sediment delivery ratio, drain time, release rate, sediment delivery ratio).

In this study, precipitation was assumed to be spatially uniform, due to the limitation of measured precipitation. Failure to include rainfall spatial variability could result in the uncertainty of runoff predictions, as discussed above. There is no allowance for spatially variable rainfall in these models, which is a major limitation.

As the size of the watershed increased, the efficiency of the models decreased. For Irish Creek (33.55 km^2), performance for AnnAGNPS was $E_f = 0.30$ and AnnAGNPS+REGEM was $E_f = 0.38$. For Main Stem (154.37 km^2), performance for AnnAGNPS ($E_f = 0.25$) and AnnAGNPS+REGEM was ($E_f = 0.34$). Finally, for the largest subwatershed, North Fork (320.16 km^2), performance for both AnnAGNPS was $E_f = 0.01$ and AnnAGNPS+REGEM was $E_f = 0.06$. The effect of drainage area on sediment movement is explained in simple terms by Gottschalk and Jones (1995, p.138). The ratio of the amount of sediment carried out of a basin to the gross erosion within the basin is known as the delivery ratio. The delivery ratio of a drainage basin depends on the areial distribution and intensity of runoff, the size and topographic characteristics of the basin including the degree of channelization, and other soil and land use factors, all of which determine the ability of the drainage system to pick up and transport sediment (Guy, 1970). As the size of the drainage basin increases, there are more sites for permanent or temporary storage of sediments, and the sediment yield per unit area decreases (Schumm, 1977). As the size of the watershed increased, the time the runoff and sediment reaching the watershed outlet increased (increase in lag time) and this is further increased by the watershed structures. The model failed to capture the delay time caused by the watershed structures. All runoff and associated sediment, nutrient, and pesticide loads for a single day are routed to the watershed outlet before the next day simulation begins (regardless of how many days this may actually take). This is a major limitation of the AnnAGNPS model.

As the size of the watershed increased, an addition of streambank sediment increased the efficiency of each method for no threshold conditions for two subwatersheds increased. For Irish Creek (33.55 km^2), performance for Method 1 at no threshold conditions was E_f = 0.45. For Main Stem (154.37 km^2), performance for Method 1 at no threshold conditions was E_f = 0.54 but the validation results for North Fork (320.16 km^2) gave an E_f = 0.33.

The overall work did not identify the processes responsible for streambank erosion, but evaluated simple methods to disaggregate annual streambank erosion into daily erosion based on easily available or measureable data (like streamflow, precipitation, etc.). The over all research helped in identifying the different sediment sources and sediment sinks in the subwatersheds.

A different way of defining and investigating the sediment delivery characteristics might be by developing the sediment budget concept, which was advocated by Dietrich and Dunne (1978) and developed by Lehr (1981). In this approach, various sediment sources within a watershed are defined, and the sediment mobilized from these sources is routed to and through the channel system by considering various sinks (Walling, 1994). Based on data represented by Trimble (1981) from Coon Creek (Wisconsin), Lehre (1982) from Long Tree Creek (California), and Zaslavsky (1979), from Oka River Basin (Central Europe), the proportion of soil delivered to the basin outlet can be relatively small, ranging from 53% to 5.5%. But substantial differences exist between the catchments represented in the precise form of budget and in location and importance of the various sinks (Walling, 1994). In this study, the final calibrated models resulted in 22% to 12% delivery in Irish Creek, 62% to 14% delivery in Main Stem, and 24% delivery in North Fork. All these calculations were based on following assumptions. First, it is assumed that the calibrated AGNPS+REGEM results represent actual overland + ephemeral gully erosion. Second, it is assumed that the final model results for each Method are the most accurate estimates of the amount of exported sediment from stream bank sources. Thus, the final model results for each Method also tell you how much of the exported sediment was from overland sources. The DIFFERENCE between this overland source amount and the original calibrated AGNPS+REGEM amount is the amount that was retained by the watershed somewhere (and not exported from the watershed past the stream gage). The ratio of that DIFFERENCE to the original AGNPS+REGEM amount is the retained fraction, and 1 minus this fraction is the delivery ratio. The above results were based on the values of the highest Ef and PBIAS values for all the three methods.

The techniques for quantifying the various sediment sources and sinks involved in sediment budget are rather limited and require considerble effort (Walling, 1994).

CHAPTER 5 - Conclusions and Recommendations

5.1 Conclusions

This study was the first of its kind to develop methods to integrate the three sources of sediment (sheet and rill, ephemeral gully, and streambank erosion). Sediment transport processes can be modeled at the watershed scale by using computer models. This study developed and demonstrated methods to characterize sediment source loads and to assess the sensitivity of model parameters.

Calibration results of AnnAGNPS and REGEM models in two subwatersheds of Irish Creek and Main Stem of the Black Vermillion Watershed using about two years of daily measured data (June 2007- June 2009) for flow ($R^2 > 0.5$ and $E_f > 0.5$) and event measured sediment (E_f values up to 0.38 and PBIAS values up to 58%) and Validation results of AnnAGNPS and REGEM models in North Fork for flow was($R^2 > 0.5$ and $E_f > 0.5$) and for sediment (E_f values up to 0.06 and PBIAS values up to 65%). The model-predicted results varied spatially with the size of the watersheds, landuse, topography, management operations, condition of terraces, watershed size, percentage of watershed that drains into watershed structures, and spatial variability of precipitation (differences in the distance of watershed from the weather station).

The lower efficiencies and higher PBIAS values of both the models for the three subwatersheds indicated the need to consider sediment from streambanks. Various methods (based on rainfall, total streamflow, and stream power) have been developed to disaggregrate annually measured streambank erosion values into event based that are in turn based on some threshold values. All these methods gave satisfactory Efficiencies (E_f

values up to 0.75 and PBIAS values > + 5 %.) for the three subwatersheds, but with different threshold values for three subwatersheds.

The differences in the threshold values is due to the differences in the watershed sizes, stream lengths, differences in stream channelization, spatial variability of precipitation, differences in landuse activities, stream and riparian geomorphologic conditions.

The overall study demonstrated the need to consider sediment sinks along with all sediment sources in order to accurately estimate the total sediment yield from the watershed. In order to better understand about the various sediment sources, sediment sinks, and sediment delivery characteristics in a watershed, it is better to develop sediment budget for that watershed (Dietrich and Dunne, 1978).

5.2 Recommendations for Future Research

Watershed models are useful in developing watershed sediment budgets and are used as educational tools for the watershed and source characterization process for both stakeholders and watershed modelers. Variability in model output caused by inaccurate input estimates can be reduced by decreasing the uncertainty in the inputs through increasing the number of measurements of the parameter and improving methods used to measure the parameter.

The research considered three sediment sources in modeling. Uncertainty in both model and measurements resulted in fair simulation of all sources, but poor agreement was found with individual sources, due to added uncertainty in climate data and uncertainty in watershed structures. However, future studies may focus on the following recommended studies.

5.2.1 Sources and rates of sedimentation

One of the biggest research need is to identify and quantify all the significant sediment sources (uplands, riparian areas, streambanks, stream channels, ephemeral gullies) and their delivery ratios to the reservoirs for a range a climatic zones and ecosystem types. There is also a need to develop simulation models that account for all the sources of sediment and that can predict the impacts of management practices.

5.2.2 Effects of small Impoundments or watershed structures

There is a need to conduct a more complete assessment of watershed structures in order to better quantify the degree of sedimentation and current rates of sedimentation. There is also need to develop models that can simulate small impoundments and their effects on geomorphology and hydrology of watershed.

5.2.3 Developing watershed sediment budgets

It is a more rigorous approach to define and investigate the sediment delivery characteristics of a drainage basin. In this approach various sediment sources are defined, and the sediment mobilized from these sources is routed to and through the channel system by considering the various sinks. An attempt can be made to define source-yield linkages and development of such sediment budgets represents an important research need.

CHAPTER 6 - References

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Appendix -1 Other Methods that can be used to disaggregate annually measured streambank sediment yield to event based

Method 1 : Use of stream velocity

This method distributes the measured average annual streambank erosion values among the events in which the velocity of the stream exceeds the critical particle velocities of the material being transported.

Erosion begins with the detachment of the particle from surrounding material. Entrainment is the process of particle lifting by the agent of erosion. The main force responsible for entrainment is fluid drag. Fluid drag causes the particle to move because of horizontal force and vertical lift. Within a medium both these forces are controlled by velocity. Horizontal force occurs from the push of the medium against the particle. If this push is sufficient to overcome the friction, the particle moves horizontally and the turbulence or eddies produce a vertical lift and pushes the particle upwards. Once the particle is lifted, the only force resisting its transport is gravity, as the forces of friction, slope angle, and cohesion are now non-existent. The particle can also be transported at velocities lower than the entrainment velocities because of the reduction in forces acting on it. The Hjulstrom diagram (Pidwirny, 2008) describes the relationship between stream flow velocity, and particle erosion, transport, and deposition. The critical entrainment velocity curve suggests that particles below a certain size are just as resistant to entrainment as particles with larger sizes and masses (Pidwirny, 2008).

In this method the critical mean flow velocities of the particles (average size of sand) which are required to initiate movement on a flat, uniform bed, for a flow depth of one meter were determined from the Hjulstrom diagram and the days in which the stream flow velocities are greater than these critical mean flow velocities were identified.

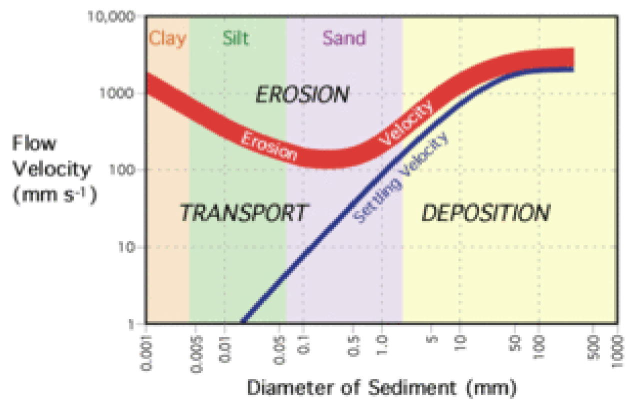

Figure 6.1 Hjulstrom curve (Pidwirny, 2008)

The Hjulstrom curve is used to determine whether a river will erode, transport or deposit sediment. Based on figure 6, consider the velocities (both erosion+ transport velocity and only erosion velocity) of the particle size (average size of sand) that is mostly present in the stream as the threshold velocities.

Method A:

- Identify the days or events (with bank full width) in which the velocity of the stream is greater than the threshold velocity of erosion and transport.
- Assign the measured streambank erosion values based on the fraction of event stream flow (only events with greater velocities greater than threshold velocity) / total stream flow.

  Repeat the above method at various depths (quarter bank full depth, half bank full depth)
- Calibrate and validate the method at various depths.

Method B:

Repeat the above method with velocities greater than threshold velocity of erosion.

These methods were considered to be a refinement of the flow-based methods. Based on consideration of the time constraints of this thesis and preliminary results from the flow-based method, which did not appear to warrant the further refinements offered by the velocity-based methods, these methods were not assessed.

Method 2: Use of stream flow shear stress

This method distributes total annual streambank erosion among the events in which the flow shear stress exceeds the critical shear stress.

Bank erosion rates or rate of soil detachment from the channel perimeter is primarily a function of shear stress induced by flow (Nearing et al., 1998; Allen et al., 1999). As flow is increased, shear stress increases until it eventually crosses critical shear stress that is required to detach the particle. The widely used equation for modeling channel erosion is

$$Er = K(Te - Tc) \tag{3.9}$$

where:

Er = the erosion rate (depth per unit time),

K = erodibility coefficient,

Te = effective stress, and

Tc = critical stress.

Boundary shear stress of one dimensional flow in channels

$$\tau = \gamma RS \tag{3.10}$$

where:

γ = unit weight water (units),

R = hydraulic radius (units), and

S = slope (units).

The stress causing detachment of soil at the soil water interface is called the effective shear stress. Hanson (1990a, 1990b) and Allen et al. (1999) have shown that the critical shear stress encountered is as low relative to effective stress as to be negligible. There fore equation 1 is reduced to

$$Er = K(Te) \tag{3.11}$$

As effective stress increases in the channel, the rate of erosion increases by a factor of K. Effective shear stress is a product of channel dimensions and slope. USLE K factor can replace the soil erodibilty factor in equation 1. Few studies (Knisel, 1980; Allen et al., 1999) suggest that this coefficient can be used in channel erosion. Fewer studies (Laflen, 1991) have showed that rill erodibilties and critical hydraulic shear stress values were either correlated or poorly correlated with USLE K factor.

Method

- Calculate the shear stress for all events
- Identify those flows that have shear stress greater then critical shear stress.
- Assign the measured streambank erosion values based on the fraction of event stream flow (only events above critical shear stress) / total stream flow.

Based on consideration of the time constraints of this thesis and preliminary results from the flow-based and power-based methods, which did not appear to warrant the further refinements offered by the sheer-stress-based methods, these methods were not assessed.

Appendix-2 Calibration model parameters[1] and event-based model performance[2] for five methods to simulate Irish Creek Subwatershed outlet total suspended sediment yield.

Only AnnAGNPS

Subwatershed	Statistical Parameters	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
Irish Creek	E_f	0.26	0.28	0.29	0.30	0.28	0.27
	PBIAS (%)	66.49	60.47	54.46	48.45	42.45	36.40
	A (ton)	352	416	479	542	605.3	668
Main Stem	E_f	0.16	0.19	0.21	0.23	0.24	0.25
	PBIAS (%)	77.30	73.42	69.54	65.67	61.81	57.95
	A (ton)	2827	3311	3794	4276	4757	5238

AnnAGNPS+REGEM

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9
0.0	E_f	0.18	0.22	0.26	0.28	0.29	0.30	0.28
	PBIAS (%)	78.56	72.52	66.49	60.47	54.46	48.45	42.45
	A+R (ton)	225	289	352	416	479	542	605.3
0.1	E_f	0.19	0.24	0.27	0.29	0.30	0.31	0.30
	PBIAS (%)	76.60	70.56	64.55	58.52	52.51	46.50	40.50
	A+R (ton)	246	310	373	436	500	563	626
0.2	E_f	0.21	0.26	0.29	0.31	0.32	0.32	0.30
	PBIAS (%)	72.73	66.69	60.67	54.66	48.65	42.64	36.64
	A+R (ton)	287	350	414	477	540	603	666.45
0.3	E_f	0.24	0.28	0.31	0.32	0.33	0.33	0.32
	PBIAS (%)	68.79	62.75	56.72	50.71	44.70	38.70	32.70
	A+R (ton)	328	392	455	518	581.7	645	707
0.4	E_f	0.26	0.30	0.32	0.34	0.34	0.34	0.32
	PBIAS (%)	65.15	59.10	53.08	47.07	41.06	35.06	29.06
	A+R (ton)	367	430	494	557	620	683	746
0.5	E_f	0.29	0.32	0.35	0.36	0.36	0.35	0.34
	PBIAS (%)	61.19	55.15	49.13	43.12	37.11	31.10	25.11
	A+R (ton)	408	472	535	598	662	725	788
0.6	E_f	---	0.33	0.35	0.37	0.37	0.36	--
	PBIAS (%)		51.72	45.70	39.70	33.68	27.68	
	A+R (ton)		508	571	634	698	761	
0.7	E_f	---	0.34	0.36	0.37	0.37	0.36	--
	PBIAS (%)		48.70	42.67	36.66	30.66	24.65	
	A+R (ton)		540	603	666	729	793	
0.8	E_f	---	0.35	0.37	0.38	0.38	0.37	--
	PBIAS (%)		45.11	39.09	33.08	27.08	21.08	
	A+R (ton)		577	641	704	767	830	
0.9	E_f	---	0.35	0.37	0.37	0.37	0.36	--
	PBIAS (%)		41.65	35.62	29.62	23.61	17.61	
	A+R (ton)		614	677	740	803	867	
1.0	E_f	---	0.33	0.35	0.36	0.36	0.34	--
	PBIAS (%)		39.09	33.07	27.07	21.06	15.06	
	A+R (ton)		641	704	767	830	893	

AnnAGNPS+REGEM+SB (0.1): Method 1 (No threshold)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9
0.0	E_f	0.38	0.41	0.43	0.43	0.42	0.41	0.38
	PBIAS (%)	40.3	34.26	28.23	22.21	16.20	10.19	4.20
	A+R+S (ton)	628	691	755	818	881	945	1008
0.1	E_f	0.39	0.42	0.43	0.44	0.43	0.41	0.38
	PBIAS (%)	38.34	32.30	26.27	20.26	14.25	8.24	2.24
	A+R+S (ton)	649	712	776	839	902	965	1028
0.2	E_f	0.40	0.43	0.44	0.44	0.43	0.41	0.38
	PBIAS (%)	34.48	28.44	22.41	16.40	10.40	4.38	-1.61
	A+R+S (ton)	689	753	816	879	943	1006	1069
0.3	E_f	0.41	0.43	0.45	0.44	0.43	0.41	0.38
	PBIAS (%)	30.53	24.49	18.46	12.45	6.44	0.437	-5.56
	A+R+S (ton)	731	794	858	921	984	1047	1110
0.4	E_f	0.42	0.44	0.45	0.45	0.43	0.41	0.38
	PBIAS (%)	26.88	20.84	14.82	8.81	2.80	-3.2	-9.19
	A+R+S (ton)	769	833	896	959	1022	1086	1149
0.5	E_f	0.44	0.46	0.46	0.46	0.44	0.41	0.37
	PBIAS (%)	22.93	16.89	10.87	4.86	-1.15	-7.15	-13.14
	A+R+S (ton)	811	874	938	1001	1064	1127	1190
0.6	E_f	---	0.46	0.46	0.45	0.44	0.40	--
	PBIAS (%)		13.46	7.44	1.43	-4.54	-10.575	
	A+R+S (ton)		910	974	1037	1100	1163	
0.7	E_f	---	0.46	0.46	0.45	0.43	0.40	--
	PBIAS (%)		10.44	4.41	-1.59	-7.06	-13.6	
	A+R+S (ton)		942	1005	1069	1132	1195	
0.8	E_f	---	0.46	0.46	0.45	0.43	0.40	--
	PBIAS (%)		6.8	0.83	-5.17	-11.17	-17.17	
	A+R+S (ton)		980	1043	1106	1169	1233	
0.9	E_f	---	0.44	0.44	0.43	0.41	0.38	--
	PBIAS (%)		3.38	-2.63	-8.64	-14.67	-20.64	
	A+R+S (ton)		1016	1080	1143	1206	1269	
1.0	E_f	---	0.42	0.42	----	----	----	--
	PBIAS (%)		0.84	-5.18				
	A+R+S (ton)		1043	1106				

AnnAGNPS+REGEM+SB (0.1): Method 1 (Ia/S= 0.1)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.48	0.50	0.50	0.50	0.48
	PBIAS (%)	26.06	20.02	13.99	7.98	1.96
	A+R+S (ton)	778	841	905	968	1031
0.1	E_f	0.49	0.50	0.51	0.50	0.48
	PBIAS (%)	24.10	18.06	12.03	6.02	0.01
	A+R+S (ton)	798	862	925	989	1052
0.2	E_f	0.49	0.51	0.51	0.50	0.48
	PBIAS (%)	20.24	14.20	8.17	2.16	-3.85
	A+R+S (ton)	839	903	966	1029	1092
0.3	E_f	0.50	0.51	0.51	0.50	--
	PBIAS (%)	16.29	10.25	4.22	-1.79	
	A+R+S (ton)	881	944	1007	1071	
0.4	E_f	0.50	0.51	0.51	0.49	---
	PBIAS (%)	12.64	6.60	0.58	-5.43	
	A+R+S (ton)	919	982	1046	1109	
0.5	E_f	0.51	0.52	0.51	0.49	---
	PBIAS (%)	8.69	2.65	-3.37	-9.38	
	A+R+S (ton)	960	1024	1087	1151	
0.6	E_f	---	0.51	0.51	--	--
	PBIAS (%)		-0.77	-6.80		
	A+R+S (ton)		1060	1123		
0.7	E_f	---	0.51	0.50	---	--
	PBIAS (%)		-3.80	-9.82		
	A+R+S (ton)		1092	1155		

AnnAGNPS+REGEM+SB (0.1): Method 1 (Ia/S= 0.2)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.55	0.56	0.55	0.53	0.51
	PBIAS (%)	15.50	9.46	3.43	-2.58	-8.59
	A+R+S (ton)	889	952	1016	1079	1142
0.1	E_f	0.56	0.56	0.56	0.54	--
	PBIAS (%)	13.54	7.50	1.47	-4.54	
	A+R+S (ton)	909	973	1036	1100	
0.2	E_f	0.55	0.56	0.55	0.53	---
	PBIAS (%)	9.68	3.64	-2.39	-8.39	
	A+R+S (ton)	950	1014	1077	1140	
0.3	E_f	0.55	0.55	0.54	--	--
	PBIAS (%)	5.73	-0.31	-6.33		
	A+R+S (ton)	992	1055	1119		
0.4	E_f	0.55	0.55	0.54	---	---
	PBIAS (%)	2.10	-3.95	-9.97		
	A+R+S (ton)	1030	1093	1157		
0.5	E_f	0.56	0.55	0.54	---	---
	PBIAS (%)	-1.86	-7.90	-13.93		
	A+R+S (ton)	1072	1135	1198		
0.6	E_f	---	0.54	---	--	--
	PBIAS (%)		-11.33			
	A+R+S (ton)		1171			
0.7	E_f	---	--	---	---	--
	PBIAS (%)					
	A+R+S (ton)					

AnnAGNPS+REGEM+SB (0.1): Method 1 (Ia/S= 0.3)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R+S (ton)	0.61 4.95 1000	0.61 -1.09 1063	0.60 -7.12 1127	0.57 -13.13 1190	--
0.1	E_f PBIAS (%) A+R+S (ton)	0.61 2.99 1020	0.61 -3.05 1084	0.60 -9.08 1147	--	--
0.2	E_f PBIAS (%) A+R+S (ton)	0.61 -0.87 1061	0.60 -6.91 1125	0.59 -12.94 1188	--	---
0.3	E_f PBIAS (%) A+R+S (ton)	0.60 -4.82 1103	0.59 -14.50 1205	--	--	--
0.4	E_f PBIAS (%) A+R+S (ton)	0.60 -8.46 1141	--	---	---	---
0.5	E_f PBIAS (%) A+R+S (ton)	0.60 -12.42 1183	---	---	---	---
0.6	E_f PBIAS (%) A+R+S (ton)	---	--	---	--	--
0.7	E_f PBIAS (%) A+R+S (ton)	---	--	---	---	--

AnnAGNPS+REGEM+SB (0.1): Method 1 (Ia/S= 0.4)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5
0.0	E_f PBIAS (%) A+R+S (ton)	0.67 8.26 965	0.68 2.15 1029	0.68 -3.93 1093	0.67 -9.98 1157	0.65 -16.00 1220
0.1	E_f PBIAS (%) A+R+S (ton)	0.67 6.29 986	0.68 0.19 1050	0.68 -5.89 1114	0.67 -11.94 1177	--
0.2	E_f PBIAS (%) A+R+S (ton)	0.66 2.43 1026	0.67 -3.67 1091	0.67 -9.76 1155	0.66 -15.80 1218	---
0.3	E_f PBIAS (%) A+R+S (ton)	0.66 -1.52 1068	0.66 -7.62 1132	0.66 -13.71 1196	--	--
0.4	E_f PBIAS (%) A+R+S (ton)	0.66 -5.17 1106	0.66 -11.27 1170	0.65 -17.35 1234	---	---
0.5	E_f PBIAS (%) A+R+S (ton)	0.656 -9.12 1148	0.66 -15.22 1212	0.65 -21.30 1276	---	---
0.6	E_f PBIAS (%) A+R+S (ton)	---	--	---	--	--
0.7	E_f PBIAS (%) A+R+S (ton)	---	--	---	---	--

AnnAGNPS+REGEM+SB (0.1): Method 1 (Ia/S= 0.5)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=1.0
0.0	E_f	0.75	0.76	0.75	0.73	0.70	0.40
	PBIAS (%)	-1.21	-7.3	-13.41	-19.36	-25.48	-55.52
	A+R+S (ton)	1065	1129	1193	1257	1320	1636
0.1	E_f	0.75	0.75	0.74	--	--	
	PBIAS (%)	-3.18	-9.29	-15.38			
	A+R+S (ton)	1085	1150	1214			
0.2	E_f	0.74	0.74	0.73	--	---	
	PBIAS (%)	-7.05	-13.15	-19.24			
	A+R+S (ton)	1126	1190	1254			
0.3	E_f	--	--	--	--	--	--
	PBIAS (%)						
	A+R+S (ton)						
0.4	E_f	--	--	--	---	---	--
	PBIAS (%)						
	A+R+S (ton)						
0.5	E_f	0.73	0.72	--	0.68	---	--
	PBIAS (%)	-18.60	-24.70		-36.82		
	A+R+S (ton)	1248	1312		1439		
0.6	E_f	---	--	---	--	--	---
	PBIAS (%)						
	A+R+S (ton)						
1.0	E_f	---	--	---	0.59	--	---
	PBIAS (%)				-52.88		
	A+R+S (ton)				1608		

AnnAGNPS+REGEM+SB (0.2): Method 1 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.44	0.47	0.49	0.49	0.49	0.47	
	PBIAS (%)	14.24	8.14	2.08	-4.00	-10.03	-16.04	
	A+R+S (ton)	902	966	1030	1094	1157	1221	
0.1	E_f	0.44	0.47	0.49	0.50	0.49		
	PBIAS (%)	12.27	6.17	0.08	-5.96	-11.98		
	A+R+S (ton)	923	987	1051	1115	1178		
0.2	E_f	0.45	0.47	0.49	0.49	0.48		
	PBIAS (%)	8.40	2.31	-3.78	-9.82	-15.84		
	A+R+S (ton)	963	1028	1092	1155	1219		
0.3	E_f	0.45	0.47	0.48	0.49			
	PBIAS (%)	4.46	-1.64	-7.73	-13.77			
	A+R+S (ton)	1005	1069	1133	1197			
0.4	E_f	0.45	0.47					
	PBIAS (%)	0.813	-5.28					
	A+R+S (ton)	1043	1108					
0.5	E_f	0.46	0.48					
	PBIAS (%)	-3.14	-9.24					
	A+R+S (ton)	1085	1149					
0.6	E_f	0.46	0.48					
	PBIAS (%)	-6.57	-12.67					
	A+R+S (ton)	1121	1185					

AnnAGNPS+REGEM+SB (0.2): Method 1 (Ia/S=0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.54	0.55	0.55	0.53
	PBIAS (%)	-14.23	-20.34	-26.43	-32.48
	A+R+S (ton)	1202	1266	1330	1394
0.1	E_f	0.54	0.55	0.54	0.53
	PBIAS (%)	-16.21	-22.31	-28.40	-34.44
	A+R+S (ton)	1222		1351	1414
0.2	E_f	0.53	0.54	0.53	
	PBIAS (%)	-20.07	-26.17	-32.26	
	A+R+S (ton)	1263	1327	1391	
0.3	E_f	0.52			
	PBIAS (%)	-24.02			
	A+R+S (ton)	1305			

AnnAGNPS+REGEM+SB (0.2): Method 1 (Ia/S=0.2)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3
0.0	E_f	0.54	0.53	0.51
	PBIAS (%)	-35.35	-41.46	-47.55
	A+R+S (ton)	1424	1488	1552
0.1	E_f	0.54	0.52	0.50
	PBIAS (%)	-37.32	-43.43	-49.51
	A+R+S (ton)	1445	1509	1573
0.2	E_f	0.52	0.50	
	PBIAS (%)	-41.19	-47.29	
	A+R+S (ton)	1485	1549	

AnnAGNPS+REGEM+SB (0.2): Method 1 (Ia/S=0.3)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	0.48	0.45
	PBIAS (%)	-56.45	-62.57
	A+R+S (ton)	1646	1710
0.1	E_f	0.47	
	PBIAS (%)	-58.43	
	A+R+S (ton)	1667	

AnnAGNPS+REGEM+SB (0.3): Method 1 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	0.47	0.48
	PBIAS (%)	-24.03	-30.12
	A+R+S (ton)	1305	1369
0.1	E_f	0.47	0.48
	PBIAS (%)	-26.00	-32.10
	A+R+S (ton)	1325	1390

AnnAGNPS+REGEM+SB (0.1): Method 2 (No threshold)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9
0.0	E_f	0.45	0.48	0.50	0.50	0.50	0.48	0.45
	PBIAS (%)	42.70	36.64	30.61	24.60	18.58	12.57	6.57
	A+R+S (ton)	603	666	730	793	856	920	983
0.1	E_f	0.46	0.49	0.51	0.51	0.50	0.49	0.46
	PBIAS (%)	40.72	34.68	28.65	22.64	16.63	10.62	4.62
	A+R+S (ton)	624	687	750	814	877	940	1003
0.2	E_f	0.47	0.50	0.51	0.51	0.50	0.49	0.46
	PBIAS (%)	36.86	30.82	24.80	18.78	12.77	6.76	0.76
	A+R+S (ton)	664	728	791	854	918	981	1044
0.3	E_f	0.48	0.51	0.52	0.52	0.51	0.49	0.45
	PBIAS (%)	32.90	26.87	20.84	14.83	8.82	2.81	-3.18
	A+R+S (ton)	706	769	833	896	959	1022	1085
0.4	E_f	0.50	0.51	0.52	0.52	0.51	0.49	---
	PBIAS (%)	29.26	23.22	17.20	11.18	5.18	-0.83	
	A+R+S (ton)	744	808	871	934	997	1061	
0.5	E_f	0.51	0.53	0.53	0.53	0.51	0.49	---
	PBIAS (%)	25.31	19.27	13.24	7.24	1.23	-4.77	
	A+R+S (ton)	786	849	913	976	1039	1102	
0.6	E_f	---	0.53	0.53	0.53	0.51	0.48	--
	PBIAS (%)		15.84	9.82	3.81	-2.20	-8.12	
	A+R+S (ton)		885	949	1012	1075	1138	
0.7	E_f	---	0.53	0.54	0.53	0.51	0.48	--
	PBIAS (%)		12.81	6.79	0.78	-5.22	-11.2	
	A+R+S (ton)		917	980	1044	1107	1170	
0.8	E_f	---	0.53	0.53	0.52	0.50	0.47	--
	PBIAS (%)		9.24	3.21	-2.79	-8.80	-14.80	
	A+R+S (ton)		955	1018	1081	1144	1208	
0.9	E_f	---	0.52	0.52	0.50	0.49	---	--
	PBIAS (%)		5.76	-0.25	-6.26	-12.27		
	A+R+S (ton)		991	1055	1118	1181		
1.0	E_f	---	0.50	0.50	----	----	----	--
	PBIAS (%)		3.21	-2.80				
	A+R+S (ton)		1018	1081				

AnnAGNPS+REGEM+SB (0.1): Method 2 (threshold= 0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R+S (ton)	0.64 11.73 928	0.66 5.62 993	0.67 -0.47 1057	0.67 -6.51 1120	0.65 -12.54 1184	0.63 -18.55 1247	0.60 -24.57 1310
0.1	E_f PBIAS (%) A+R+S (ton)	0.65 9.76 949	0.66 3.65 1013	0.67 -2.43 1077	0.67 -8.47 1141	0.65 -14.50 1204	0.63 -20.51 1268	0.59 -26.52 1331
0.2	E_f PBIAS (%) A+R+S (ton)	0.64 5.89 990	0.65 -0.21 1054	0.66 -6.29 1118	0.66 -12.33 1182	0.64 -18.36 1245	0.61 -24.37 1308	0.58 -30.39 1371
0.3	E_f PBIAS (%) A+R+S (ton)	0.63 1.94 1031	0.65 -4.16 1096	0.65 -10.24 1160	0.65 -16.28 1223	0.63 -22.31 1287	0.60 -28.32 1349.8	
0.4	E_f PBIAS (%) A+R+S (ton)	0.63 -1.70 1070	0.64 -7.8 1134	0.64 -13.88 1198	0.64 -19.93 1261	0.62 -26.0 1325	0.59 -32.0 1388	---
0.5	E_f PBIAS (%) A+R+S (ton)	0.63 -5.66 1111	0.64 -11.76 1176	0.64 -17.84 1240	0.63 -23.88 1303	0.60 -29.90 1366		---
0.6	E_f PBIAS (%) A+R+S (ton)	0.62 -9.08 1147	0.63 -15.18 1212	--	0.62 -27.30 1339	0.59 -33.32 1402.5		--
0.7	E_f PBIAS (%) A+R+S (ton)	---	--	-----	---	---		--
0.8	E_f PBIAS (%) A+R+S (ton)	---	---	--	---	--		--
0.9	E_f PBIAS (%) A+R+S (ton)	---	---	---	---	---	---	--
1.0	E_f PBIAS (%) A+R+S (ton)	---	---	---	----	----	----	--

AnnAGNPS+REGEM+SB (0.1): Method 2 (threshold= 0.2)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.64	0.66	0.67	0.67	0.65	0.63	0.59
	PBIAS (%)	10.23	4.11	-1.97	-8.01	-14.05	-20.06	-26.07
	A+R+S (ton)	944	1009	1073	1136	1200	1263	1326
0.1	E_f	0.64	0.66	0.67	0.67	0.65	0.63	0.59
	PBIAS (%)	8.25	2.15	-3.94	-9.98	-16.00	-22.02	-28.03
	A+R+S (ton)	965	1029	1093	1157	1220	1284	1347
0.2	E_f	0.64	0.66	0.66	0.66	0.64	0.61	0.57
	PBIAS (%)	4.39	-1.71	-7.80	-13.84	-19.87	-25.88	-31.89
	A+R+S (ton)	1006	1070	1134	1197	1261	1324	1387
0.3	E_f	0.64	0.65	0.65	0.64	0.63	0.60	
	PBIAS (%)	0.44	-5.66	-11.75	-17.79	-23.81	-29.82	
	A+R+S (ton)	1047	1111	1175	1239	1302	1366	
0.4	E_f	0.63	0.65	0.65	0.64	--	---	---
	PBIAS (%)	-3.21	-9.30	-15.39	-21.43			
	A+R+S (ton)	1086	1150	1214	1277			
0.5	E_f	0.63	0.64	0.64	0.63	---	---	---
	PBIAS (%)	-7.16	-13.26	-19.35	-25.39			
	A+R+S (ton)	1127	1191	1255	1319			
0.6	E_f	0.62	0.63	--	0.61	---	---	--
	PBIAS (%)	-10.59	-16.69		-28.81			
	A+R+S (ton)	1163	1227		1355			

AnnAGNPS+REGEM+SB (0.1 Multiple): Method 2 (threshold= 0.3)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.65	0.66	0.67	0.67	0.65	0.63	0.59
	PBIAS (%)	8.85	2.74	-3.35	-9.39	-15.42	-21.44	-27.45
	A+R+S (ton)	959	1023	1087	1151	1214	1277	1341
0.1	E_f	0.65	0.66	0.67	0.67	0.65	0.63	0.59
	PBIAS (%)	6.87	0.77	-5.31	-11.36	-17.38	-23.39	-29.41
	A+R+S (ton)	980	1044	1108	1171	1235	1298	1361
0.2	E_f	0.64	0.66	0.66	0.66	0.64	0.61	0.57
	PBIAS (%)	3.01	-3.09	-9.18	-15.22	-21.24	-27.25	-33.27
	A+R+S (ton)	1020	1084	1148	1212	1275	1339	1401
0.3	E_f	0.64	0.65	0.65	0.64	0.62	0.59	
	PBIAS (%)	-0.94	-7.04	-13.12	-19.17	-25.19	-31.20	
	A+R+S (ton)	1062	1126	1190	1254	1317	1380	
0.4	E_f	0.63	0.65	0.65	0.63	--	---	---
	PBIAS (%)	-4.58	-10.68	-16.77	-22.81			
	A+R+S (ton)	1100	1164	1228	1292			
0.5	E_f	0.63	0.64	0.64	0.63	---	---	---
	PBIAS (%)	-8.54	-14.64	-20.72	-26.76			
	A+R+S (ton)	1142	1206	1270	1333			
0.6	E_f	0.62	0.63	--	0.61	---	---	--
	PBIAS (%)	-11.97	-18.07		-30.19			
	A+R+S (ton)	1178	1242		1369			

AnnAGNPS+REGEM+SB (0.2): Method 2 (No threshold)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6
0.0	E_f	0.61	0.62	0.62	0.61
	PBIAS (%)	6.80	0.76	-5.27	-11.28
	A+R+S (ton)	980	1044	1107	1171
0.1	E_f	0.62	0.63	0.62	0.61
	PBIAS (%)	4.84	-1.20	-7.723	-13.24
	A+R+S (ton)	1001	1064	1128	1191
0.2	E_f	0.62	0.62	0.62	
	PBIAS (%)	0.98	-5.06	-11.09	
	A+R+S (ton)	1042	1105	1168	
0.3	E_f	0.62	0.62	0.61	
	PBIAS (%)	-2.97	-9.012	-15.04	
	A+R+S (ton)	1083	1147	1210	
0.4	E_f	0.62			
	PBIAS (%)	-6.61			
	A+R+S (ton)	1121			
0.5	E_f	0.62			
	PBIAS (%)	-10.57			
	A+R+S (ton)	1163			

AnnAGNPS+REGEM+SB (0.2): Method 2 (threshold=0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.41	0.39	0.35	0.30
	PBIAS (%)	-67.30	-73.41	-79.5	-85.54
	A+R+S (ton)	1760	1824	1888	1951.7
0.1	E_f	0.40	0.37	0.33	
	PBIAS (%)	-69.28	-75.38	-81.46	
	A+R+S (ton)	1781	1845	1909	

AnnAGNPS+REGEM+SB (0.2): Method 2 (threshold=0.3)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5
0.0	E_f	0.37	0.34	0.29	0.24	0.18
	PBIAS (%)	-73.06	-79.17	-85.26	-91.31	-97.34
	A+R+S (ton)	1820	1885	1949	2012	2076
0.1	E_f	0.35	0.32	0.28	0.22	0.16
	PBIAS (%)	-75.04	-81.14	-87.23	-93.27	-99.30
	A+R+S (ton)	1841	1905	1969	2033	2096
0.2	E_f			0.24	0.18	0.12
	PBIAS (%)			-91.09	-97.13	-103.16
	A+R+S (ton)			2010	2074	2137

AnnAGNPS+REGEM+SB (0.3): Method 2 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.65	0.66	0.66	0.65
	PBIAS (%)	-16.87	-22.98	-29.07	-35.12
	A+R+S (ton)	1229	1294	1357	1421
0.1	E_f	0.64	0.66	0.66	0.65
	PBIAS (%)	-18.85	-24.95	-31.04	-37.08
	A+R+S (ton)	1250	1314	1378	1442
0.2	E_f	0.64	0.65	0.64	0.63
	PBIAS (%)	-22.71	-28.81	-34.90	-40.94
	A+R+S (ton)	1291	1355	1419	1483
0.3	E_f	0.63			
	PBIAS (%)	-26.67			
	A+R+S (ton)	1332			

AnnAGNPS+REGEM+SB (0.3): Method 2 (threshold = 0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	-0.62	-0.67		
	PBIAS (%)	-146.33	-152.44		
	A+R+S (ton)	2591.14	2655		
0.1	E_f	-0.65			
	PBIAS (%)	-148.31			
	A+R+S (ton)	2612			

AnnAGNPS+REGEM+SB (0.4): Method 2 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.611	0.60	0.59	
	PBIAS (%)	-52.76	-58.86	-64.95	
	A+R+S (ton)	1607	1671	1735	
0.1	E_f	0.60	0.60		
	PBIAS (%)	-54.73	-60.83		
	A+R+S (ton)	1628	1692		

AnnAGNPS+REGEM+SB (0.5): Method 2 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.46	0.43		
	PBIAS (%)	-88.63	-94.74		
	A+R+S (ton)	1984	2048		
0.1	E_f	0.45	0.42		
	PBIAS (%)	-90.61	-96.71		
	A+R+S (ton)	2005	2069		

AnnAGNPS+REGEM+SB (0.6) Method 2 (No threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.19	0.15		
	PBIAS (%)	-124.51	-130.62		
	A+R+S (ton)	2362	2426		
0.1	E_f	0.17	0.13		
	PBIAS (%)	-126.49	-132.59		
	A+R+S (ton)	2382	2447		

AnnAGNPS+REGEM+SB (0.1): Method 4 (No threshold)

SGF	Statistical parameters	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9
0.0	E_f	0.45	0.48	0.50	0.50	0.50	0.48	0.45
	PBIAS (%)	42.52	36.43	30.35	24.29	18.22	12.16	6.11
	A+R+S (ton)	600	663	727	790	853	917	980
0.1	E_f	0.46	0.49	0.51	0.51	0.50	0.49	0.46
	PBIAS (%)	40.54	34.45	28.37	22.31	16.25	10.19	4.15
	A+R+S (ton)	620	683	747	811	874	937	1000
0.2	E_f	0.47	0.50	0.51	0.51	0.50	0.49	0.46
	PBIAS (%)	36.65	30.56	24.48	18.42	12.36	6.30	0.26
	A+R+S (ton)	661	725	788	851	914	978	1041
0.3	E_f	0.48	0.51	0.52	0.52	0.51	0.49	0.45
	PBIAS (%)	32.66	26.58	20.50	14.44	8.38	2.32	-3.71
	A+R+S (ton)	703	766	830	893	956	1019	1082
0.4	E_f	0.50	0.51	0.52	0.52	0.51	0.49	---
	PBIAS (%)	28.99	22.90	16.83	10.77	4.71	-1.34	
	A+R+S (ton)	741	804	868	931	994	1057	
0.5	E_f	0.51	0.53	0.53	0.53	0.51	0.49	---
	PBIAS (%)	25.00	18.92	12.84	6.79	0.73	-5.32	
	A+R+S (ton)	783	846	909	973	1036	1099	
0.6	E_f	---	0.53	0.53	0.53	0.51	0.48	--
	PBIAS (%)		15.46	9.39	3.33	-2.72	-8.77	
	A+R+S (ton)		882	945	1009	1072	1135	
0.7	E_f	---	0.53	0.53	0.53	0.51	0.48	--
	PBIAS (%)		12.41	6.34	0.28	-5.77	-11.82	
	A+R+S (ton)		914	977	1040	1104	1167	
0.8	E_f	---	0.53	0.53	0.52	0.50	0.47	--
	PBIAS (%)		8.80	2.73	-3.32	-9.38	-15.43	
	A+R+S (ton)		952	1015	1078	1141	1204	
0.9	E_f	---	0.52	0.52	0.50	0.49	---	--
	PBIAS (%)		5.30	-0.76	-6.82	-12.89		
	A+R+S (ton)		988	1051	1115	1178		
1.0	E_f	---	0.50	0.50	----	----	----	--
	PBIAS (%)		2.73	-3.34				
	A+R+S (ton)		1015	1078				

AnnAGNPS+REGEM+SB (0.1): Method 4 (Threshold =0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.63	0.65	0.66	0.66	0.65	0.63	--
	PBIAS (%)	13.21	7.05	0.91	-5.18	-11.26	-17.32	
	A+R+S (ton)	906	970	1034	1098	1161	1224	
0.1	E_f	0.63	0.65	0.66	0.66	0.65	0.63	--
	PBIAS (%)	11.22	5.07	-1.07	-7.16	-13.23	-19.30	
	A+R+S (ton)	926	991	1055	1118	1182	1245	
0.2	E_f	0.63	0.65	0.65	0.65	0.64	--	--
	PBIAS (%)	7.32	1.17	-4.96	-11.05	-17.13		
	A+R+S (ton)	967	1031	1095	1159	1222		
0.3	E_f	0.62	0.64	0.65	0.64	--	--	--
	PBIAS (%)	3.34	-2.81	-8.94	-15.03			
	A+R+S (ton)	1009	1073	1137	1200			
0.4	E_f	0.62	0.64	0.64	0.63	--	--	---
	PBIAS (%)	-0.33	-6.48	-12.61	-18.70			
	A+R+S (ton)	1047	1111	1175	1239			
0.5	E_f	0.62	0.64	0.64	--	--	--	---
	PBIAS (%)	-4.32	-10.47	-16.60				
	A+R+S (ton)	1089	1153	1217				
0.6	E_f	0.62	0.63	--	--	--	--	--
	PBIAS (%)	-7.77	-13.93					
	A+R+S (ton)	1125	1189					

AnnAGNPS+REGEM+SB (0.1): Method 4 (Threshold =0.5)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.65	0.66	0.67	0.67	0.65	0.63	--
	PBIAS (%)	8.11	1.95	-4.18	-10.28	-16.36	-22.42	
	A+R+S (ton)	959	1023	1087	1151	1214	1277	
0.1	E_f	0.65	0.66	0.67	0.67	0.65	0.63	--
	PBIAS (%)	6.12	-0.03	-6.17	-12.25	-18.33	-24.39	
	A+R+S (ton)	980	1044	1108	1171	1235	1298	
0.2	E_f	0.64	0.66	0.66	0.66	0.64	--	--
	PBIAS (%)	2.23	-3.92	-10.06	-16.15	-22.22		
	A+R+S (ton)	1020	1084	1148	1212	1275		
0.3	E_f	0.64	0.65	0.65	0.64	--	--	--
	PBIAS (%)	-1.75	-7.91	-14.04	-20.13			
	A+R+S (ton)	1062	1126	1190	1253			
0.4	E_f	0.63	0.65	0.65	0.63	--	--	---
	PBIAS (%)	-5.43	-11.58	-17.71	-23.80			
	A+R+S (ton)	1100	1164	1228	1292			
0.5	E_f	0.63	0.64	0.64	--	--	--	---
	PBIAS (%)	-9.42	-15.57	-21.70				
	A+R+S (ton)	1142	1206	1270				
0.6	E_f	0.62	0.63	--	--	--	--	--
	PBIAS (%)	-12.87	-19.02					
	A+R+S (ton)	1178	1242					

AnnAGNPS+REGEM+SB (0.1): Method 4 (Threshold =1.0)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.65	0.67	0.67	0.67	0.65	0.63	--
	PBIAS (%)	6.12	-0.04	-6.18	-12.27	-18.35	-24.41	
	A+R+S (ton)	980	1044	1108	1172	1235	1298	
0.1	E_f	0.65	0.67	0.67	0.67	0.65	0.62	--
	PBIAS (%)	4.13	-2.02	-8.16	-14.25	-20.32	-26.39	
	A+R+S (ton)	1000	1065	1129	1192	1256	1319	
0.2	E_f	0.64	0.66	0.66	0.65	0.64	--	--
	PBIAS (%)	0.23	-5.92	-12.05	-18.14	-24.22		
	A+R+S (ton)	1041	1105	1169	1233	1296		
0.3	E_f	0.64	0.65	0.65	0.64	--	--	--
	PBIAS (%)	-3.75	-9.90	-16.03	-22.12			
	A+R+S (ton)	1083	1147	1211	1274			
0.4	E_f	0.64	0.65	0.64	0.63	--	--	---
	PBIAS (%)	-7.42	-13.57	-17.70	-29.80			
	A+R+S (ton)	1121	1185	1249	1313			
0.5	E_f	0.63	0.64	0.64	--	--	--	---
	PBIAS (%)	-11.41	-17.56	-23.69				
	A+R+S (ton)	1162	1227	1291				
0.6	E_f	---	0.63	--	--	--	--	--
	PBIAS (%)		-21.01					
	A+R+S (ton)		1263					

AnnAGNPS+REGEM+SB (0.2): Method 4 (No Threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.56	0.60	0.61	0.62	0.62	0.61	
	PBIAS (%)	18.94	12.79	6.65	0.56	-5.52	-11.58	
	A+R+S (ton)	846	910	974	1038	1102	1164	
0.1	E_f	0.57	0.60	0.62	0.63	0.62	0.61	
	PBIAS (%)	16.95	10.80	4.67	-1.42	-7.5	-13.56	
	A+R+S (ton)	866	931	995	1058	1122	1185	
0.2	E_f	0.57	0.60	0.62	0.62	0.62		
	PBIAS (%)	13.06	6.91	0.77	-5.31	-11.39		
	A+R+S (ton)	907	971	1035	1099	1162		
0.3	E_f	0.58	0.60	0.62		0.61		
	PBIAS (%)	9.08	2.93	-3.20		-15.37		
	A+R+S (ton)	949	1013	1077		1204		
0.4	E_f	0.58	0.60	0.62				
	PBIAS (%)	5.40	-0.74	-6.87				
	A+R+S (ton)	987	1051	1115				
0.5	E_f	0.59	0.61	0.62				
	PBIAS (%)	1.42	-4.73	-10.86				
	A+R+S (ton)	1029	1093	1157				
0.6	E_f	0.58	0.60					
	PBIAS (%)	-2.04	-8.18					
	A+R+S (ton)	1065	1129					

AnnAGNPS+REGEM+SB (0.2): Method 4 (Threshold =0.1)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	0.45	0.42
	PBIAS (%)	-64.27	-70.43
	A+R+S (ton)	1714	1778
0.1	E_f	0.43	0.41
	PBIAS (%)	-66.26	-72.41
	A+R+S (ton)	1735	1799

AnnAGNPS+REGEM+SB (0.3): Method 4 (No Threshold)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4
0.0	E_f	0.65	0.66	0.66	0.65
	PBIAS (%)	-16.92	-23.08	-29.22	-35.31
	A+R+S (ton)	1220	1284	1348	1412
0.1	E_f	0.64	0.66	0.66	0.65
	PBIAS (%)	-18.91	-25.06	-31.20	-37.29
	A+R+S (ton)	1241	1305	1369	1433
0.2	E_f	0.64	0.65	0.64	
	PBIAS (%)	-22.80	-28.96	-35.09	
	A+R+S (ton)	1281	1346	1410	
0.3	E_f		0.64		
	PBIAS (%)		-32.94		
	A+R+S (ton)		1387		

AnnAGNPS+REGEM+SB (0.3): Method 4 (Threshold=0.1)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	-0.48	-0.55
	PBIAS (%)	-141.75	-147.91
	A+R+S (ton)	2523	2587
0.1	E_f	-0.51	-0.58
	PBIAS (%)	-143.77	-149.89
	A+R+S (ton)	2543	2608

AnnAGNPS+REGEM+SB (0.4): Method 4 (No Threshold)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	0.61	0.60
	PBIAS (%)	-52.79	-58.95
	A+R+S (ton)	1594	1659
0.1	E_f	0.60	0.60
	PBIAS (%)	-54.78	-60.93
	A+R+S (ton)	1615	1679
0.2	E_f	0.58	0.57
	PBIAS (%)	-58.67	-64.83
	A+R+S (ton)	1656	1720

AnnAGNPS+REGEM+SB (0.5): Method 4 (No Threshold)

SGF	Statistical parameters	P=0.1	P=0.2
0.0	E_f	0.46	0.43
	PBIAS (%)	-88.60	-94.81
	A+R+S (ton)	1969	2033
0.1	E_f	0.45	0.42
	PBIAS (%)	-90.65	-96.80
	A+R+S (ton)	1989	2054

Appendix-2 Calibration model parameters[1] and event-based model performance[2] for five methods to simulate Main Stem Subwatershed outlet total suspended sediment yield.

Only AGNPS

Subwatershed	Statistical Parameters	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
Irish Creek	E_f	0.26	0.28	0.29	0.30	0.28	0.27
	PBIAS (%)	66.49	60.47	54.46	48.45	42.45	36.40
	A (ton)	352	416	479	542	605.3	668
Main Stem	E_f	0.16	0.19	0.21	0.23	0.24	0.25
	PBIAS (%)	77.30	73.42	69.54	65.67	61.81	57.95
	A (ton)	2827	3311	3794	4276	4757	5238

AGNPS+REGEM

SGF	Statistical parameters	P=0.8	P=0.9	P=1.0
0.0	E_f	0.23	0.24	0.25
	PBIAS (%)	65.67	61.81	57.95
	A+R (ton)	4276	4757	5238
10	E_f	0.31	0.32	0.33
	PBIAS (%)	60.61	56.75	52.89
	A+R (ton)	4907	5388	5868
11	E_f	0.31	0.32	0.33
	PBIAS (%)	60.13	56.26	52.41
	A+R (ton)	4967	5448	5928
12	E_f	0.31	0.33	0.33
	PBIAS (%)	59.56	55.70	51.84
	A+R (ton)	5038	5519	5999
13	E_f	0.32	0.33	0.34
	PBIAS (%)	58.99	55.12	51.27
	A+R (ton)	5109	5590	6071
14	E_f	0.32	0.33	0.34
	PBIAS (%)	58.41	54.54	50.69
	A+R (ton)	5181	5662	6143
15	E_f	--	--	0.23
	PBIAS (%)			53.58
	A+R (ton)			5304

AnnAGNPS+REGEM + SB (1.0) (Method 1) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	--	0.45 31.30 8558	0.46 27.41 9042	0.46 23.54 9525	0.46 19.67 10007	0.46 15.81 10488	0.45 11.95 10968
10	E_f PBIAS (%) A+R (ton)	--	0.50 26.23 9189	0.51 22.35 9673	0.51 23.28 9556	0.51 14.61 10637	0.50 10.74 11119	0.49 6.88 11599
11	E_f PBIAS (%) A+R (ton)	--	--	0.51 21.87 9733	0.51 17.99 10216	0.51 14.12 10698	0.50 10.26 11179	0.49 6.40 11659
12	E_f PBIAS (%) A+R (ton)	--	--	0.51 21.30 9804	0.51 17.42 10287	0.51 13.55 10768	0.50 9.69 11250	0.49 5.84 11730
13	E_f PBIAS (%) A+R (ton)	--	--	--	0.51 16.85 10358	0.51 12.98 10840	0.50 9.12 11321	0.49 5.26 11801
14	E_f PBIAS (%) A+R (ton)	--	--	--	0.51 16.27 10430	0.51 12.40 10912	0.50 8.54 11393	0.49 4.68 11873
15	E_f PBIAS (%) A+R (ton)	--	--	--	---	--	--	0.40 7.57 11513

AnnAGNPS+REGEM + SB (1.3) (Method 1) No threshold

SGF	Statistical Parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	0.49 21.39 9792	0.50 17.50 10277	0.50 13.61 10761	0.50 9.79 11244	0.50 5.87 11726	0.48 2.00 12207	0.47 -1.85 12688
10	E_f PBIAS (%) A+R (ton)		0.54 12.433 10908	0.54 8.55 11392	0.54 4.67 11875	0.53 0.80 12357	0.52 -3.06 12838	0.50 -6.93 13318
11	E_f PBIAS (%) A+R (ton)		0.54 11.95 10969	0.54 8.06 11452	0.54 4.2 11935	0.53 0.32 12417	0.52 -3.54 12898	--
12	E_f PBIAS (%) A+R (ton)		0.54 11.38 11039	0.54 7.50 11523	0.54 3.62 12006	0.53 -0.25 12488	0.52 -4.11 12969	--
13	E_f PBIAS (%) A+R (ton)		0.54 10.80 11111	0.54 6.92 11594	0.54 3.05 12077	0.53 -0.82 12559	--	--
14	E_f PBIAS (%) A+R (ton)		0.54 10.23 11183	0.54 6.34 11667	0.54 2.47 12149	0.53 -1.40 12631	--	--
15	E_f PBIAS (%) A+R (ton)				0.45 5.36 11789	--	--	--

AnnAGNPS+REGEM+SB (1.3): (Method 1) (Ia/s =0.1)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.58	0.59	0.59	0.58	0.58	0.56	0.55
	PBIAS (%)	10.59	6.65	2.73	-1.17	-5.07	-8.95	-12.83
	A+R (ton)	11138	11628	12177	12603	13088	13572	14055
10	E_f	0.60	0.60	0.60	0.60	0.59	0.57	0.55
	PBIAS (%)	5.51	1.57	-2.34	-6.24	-10.13	-14.01	-17.89
	A+R (ton)	11771	12261	12749	13235	13720	14203	14686
11	E_f	0.60	0.60	0.60	0.59	0.58	0.57	0.55
	PBIAS (%)	5.03	1.09	-2.83	-6.73	-10.62	-14.50	-18.38
	A+R (ton)	11831	12321	12809	13295	13780	14264	14746
12	E_f	0.60	0.60	0.60	0.59	0.58	0.57	0.55
	PBIAS (%)	4.46	0.52	-3.39	-7.29	-11.18	-15.07	-18.95
	A+R (ton)	11902	12392	12880	13366	13850	14334	14817
13	E_f	0.59	0.60	0.59	0.59	0.58	0.56	0.55
	PBIAS (%)	3.30	-0.05	-3.97	-8.45	-11.76	-15.64	-19.52
	A+R (ton)	12045	12463	12951	13509	13922	14406	14889
14	E_f	0.59	0.59			---	0.56	0.54
	PBIAS (%)	3.88	-0.63				-16.22	-20.10
	A+R (ton)	11973	12536				14478	14961

AnnAGNPS+REGEM+SB (1.3): (Method 1) (Ia/s =0.2)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.622	0.61	0.60	0.58	0.56	0.54	0.51
	PBIAS (%)	-5.53	-9.47	-13.38	-17.29	-21.18	-25.07	-28.95
	A+R (ton)	13145	13636	14125	14611	15096	15580	16063
10	E_f		0.60	0.59	0.57	0.55	0.52	0.49
	PBIAS (%)		-14.45	-18.46	-22.37	-26.25	-30.14	-34.01
	A+R (ton)		14269	14757	15243	15727	16211	16694
11	E_f				--	0.54	0.52	--
	PBIAS (%)					-26.74	-30.62	
	A+R (ton)					15788	1627	

AnnAGNPS+REGEM+SB (1.3): (Method 1) (Ia/s =0.3)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.58	0.56					
	PBIAS (%)	-20.98	-24.92					
	A+R (ton)	15071	15562					
10	E_f	0.55						
	PBIAS (%)	-26.06						
	A+R (ton)	15704						

AnnAGNPS+REGEM + SB (1.0): (Method 2) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	--	0.57 30.80 8620	0.57 26.92 9104	0.58 23.04 9587	0.58 19.17 10068	0.57 15.30 10550	0.56 11.45 11030
10	E_f PBIAS (%) A+R (ton)	--	0.59 25.73 9251	0.60 21.85 9735	0.60 17.97 10218	0.60 14.10 10700	0.59 10.24 11180	0.58 6.38 11661
11	E_f PBIAS (%) A+R (ton)	--	0.59 25.25 9312	0.60 21.37 9795	0.60 17.49 10278	0.59 13.62 10698	0.59 9.76 11179	0.58 5.90 11722
12	E_f PBIAS (%) A+R (ton)	--	--	0.59 20.80 9866	0.60 16.92 10349	0.59 13.05 10831	0.59 9.19 11312	0.57 5.34 11792
13	E_f PBIAS (%) A+R (ton)	--	--	0.59 20.23 9938	0.59 16.35 10420	0.59 12.48 10902	0.58 8.62 11383	0.57 4.76 11801
14	E_f PBIAS (%) A+R (ton)	--	--	--	0.59 15.77 10492	0.59 11.90 10974	0.58 8.04 11455	0.57 4.18 11936
15	E_f PBIAS (%) A+R (ton)	--	--	--	---	--	--	0.49 7.07 11575

AnnAGNPS+REGEM + SB (1.0): (Method 2) (threshold=10%)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R (ton)	0.63 0.27 12423	0.63 -3.67 12914	0.63 -7.59 13402	0.62 -11.49 13888	0.60 -15.38 14373	0.59 -19.27 14857	0.57 -23.15 15340
10	E_f PBIAS (%) A+R (ton)	0.59 -4.80 13056	0.59 -8.74 13546	0.58 -12.66 14034	0.57 -16.56 14520	0.56 -20.45 15005	0.54 -24.34 15489	0.51 -28.21 15971

AnnAGNPS+REGEM + SB (1.0): (Method 2) (threshold=20%)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R (ton)	0.61 -5.16 13099	0.61 -9.10 13590	0.60 -13.02 14079				
10	E_f PBIAS (%) A+R (ton)	0.56 -10.24 13733	0.56 -14.17 14223	0.55 -18.09 14711				

AnnAGNPS+REGEM + SB (1.3): (Method 2) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	0.62 20.74 9873	0.62 16.85 10358	0.63 12.96 10842	0.62 9.08 11325	0.62 5.22 11807	0.61 1.35 12288	0.60 -2.50 12769
10	E_f PBIAS (%) A+R (ton)		0.63 11.78 10989	0.63 7.90 11473	0.63 4.02 11956	0.62 0.16 12438	0.61 -3.71 12919	0.59 -7.56 13399
11	E_f PBIAS (%) A+R (ton)		0.63 11.30 11049	0.63 7.41 11533	0.63 3.54 12016	0.62 -0.33 12498	0.61 -4.19 12980	--
12	E_f PBIAS (%) A+R (ton)		0.63 10.73 11120	0.63 6.84 11604	0.62 2.97 12087	0.61 -0.89 12569	0.60 -4.76 13050	--
13	E_f PBIAS (%) A+R (ton)		0.62 10.15 11191	0.62 6.27 11675	0.62 2.34 12158	0.61 -1.47 12640	--	--
14	E_f PBIAS (%) A+R (ton)		0.62 9.57 11264	0.62 5.69 11748	0.62 1.82 12230	0.61 -2.05 12712	--	--
15	E_f PBIAS (%) A+R (ton)				0.55 4.71 11870	--	--	--

AnnAGNPS+REGEM+SB (1.3) (Method 2) (Threshold = 10%)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R (ton)	0.24 -44.48 17998	0.46 -31.47 16378	0.45 -39.35 16866	0.42 -39.30 17352	0.40 -43.19 17837	0.37 -47.07 18321	
10	E_f PBIAS (%) A+R (ton)		0.38 -36.55 17010					

AnnAGNPS+REGEM + SB (1.5) (Method 2) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	0.65 11.44 11031	0.65 7.55 11516	0.65 3.66 12000	0.64 -0.21 12483	0.63 -4.08 12965	0.61 -7.94 13447	0.59 -11.80 13927
10	E_f PBIAS (%) A+R (ton)	0.64 6.37 11663	0.65 2.48 12148	0.64 -1.40 12632	0.63 -5.28 13114	0.62 -9.14 13596	0.61 -13.00 14077	0.58 -16.86 14558
11	E_f PBIAS (%) A+R (ton)		0.64 2.00 12208					0.58 -17.35 14618

AnnAGNPS+REGEM + SB (1.5): (Method 2) threshold=10%

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.29	0.27	0.24	0.21	0.17	0.13	0.09
	PBIAS (%)	-46.07	-50.01	-53.93	-57.84	-61.73	-65.62	-69.49
	A+R (ton)	18196	18487	19175	19662	20147	20631	21114
10	E_f	0.18				0.06		-0.03
	PBIAS (%)	-51.15				-66.80		-74.56
	A+R (ton)	18829				20778		21745

AnnAGNPS+REGEM + SB (1.0): (Method 4) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f		0.54	0.55	0.55	0.55	0.55	0.54
	PBIAS (%)		38.53	35.33	32.15	28.98	25.79	22.62
	A+R (ton)		7658	8055	8452	8848	9244	9639
10	E_f		0.56	0.57	0.57	0.57	0.57	0.56
	PBIAS (%)		33.46	30.27	27.08	23.90	20.73	17.56
	A+R (ton)		8289	8687	9083	9479	9874	10269
11	E_f			0.57	0.57	0.57	0.57	0.56
	PBIAS (%)			29.78	26.60	23.42	20.24	17.08
	A+R (ton)			8747	9144	9540	9935	10329
12	E_f			0.57	0.57	0.57	0.56	0.55
	PBIAS (%)			29.21	26.03	22.85	19.68	16.51
	A+R (ton)			8818	9214	9610	10005	10400
13	E_f			0.57	0.57	0.57	0.56	0.55
	PBIAS (%)			28.64	25.45	22.28	19.10	15.94
	A+R (ton)			8889	9286	9682	10077	10471
14	E_f			0.56	0.57	0.56	0.56	0.55
	PBIAS (%)			28.06	24.88	21.70	18.53	15.36
	A+R (ton)			8961	9358	9754	10149	10543
15	E_f						--	0.47
	PBIAS (%)							18.25
	A+R (ton)							10184

AnnAGNPS+REGEM + SB (1.0): (Method 4) (threshold=0.1)

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f	--	0.54	0.55	0.55	0.55	0.55	0.54
	PBIAS (%)		38.53	35.33	32.15	28.97	25.79	22.62
	A+R (ton)		7658	8056	8452	8848	9244	9639
10	E_f		0.56	0.57	0.57	0.57	0.57	0.56
	PBIAS (%)		33.45	30.27	27.08	23.90	20.73	17.56
	A+R (ton)		8289	8687	9083	9479	9874	10269
11	E_f				0.57			0.56
	PBIAS (%)				26.59			17.08
	A+R (ton)				9144			10329
12	E_f							0.55
	PBIAS (%)							16.51
	A+R (ton)							10400
13	E_f							0.55
	PBIAS (%)							15.94
	A+R (ton)							10471

AnnAGNPS+REGEM + SB (1.0): (Method 4) (threshold=0.5)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6
0.0	E_f	0.61	0.62	0.62	0.61	0.60	0.59
	PBIAS (%)	11.60	8.36	5.14	1.93	-1.27	-4.46
	A+R (ton)	11012	11415	11817	12217	12615	13013
10	E_f	0.57	0.58	0.57	0.57	0.56	0.54
	PBIAS (%)	6.52	3.29	0.07	-3.14	-6.34	-9.53
	A+R (ton)	11645	12048	12449	12848	13247	13644
11	E_f	0.57	0.57	0.57	0.56	0.55	
	PBIAS (%)	6.03	2.80	-0.42	-3.62	-6.82	
	A+R (ton)	11705	12108	12509	12909	13306	
12	E_f	0.56	0.56				
	PBIAS (%)	5.47	2.23				
	A+R (ton)	11776	12179				
13	E_f	0.55					
	PBIAS (%)	4.90					
	A+R (ton)	11847					

AnnAGNPS+REGEM + SB (1.3): (Method 4) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f		0.60	0.60	0.60	0.60	0.59	0.58
	PBIAS (%)		25.69	22.50	19.31	16.13	12.96	9.88
	A+R (ton)		9257	9655	10052	10448	10843	11238
10	E_f		0.61	0.61	0.61	0.60	0.59	0.58
	PBIAS (%)		20.62	17.43	14.24	11.07	7.89	4.73
	A+R (ton)		9888	10286	10682	11078	11473	11868
11	E_f			0.61		0.60	0.59	0.57
	PBIAS (%)			16.94		10.58	7.41	4.24
	A+R (ton)			10346		11139	11534	11928
12	E_f					0.59	0.58	0.57
	PBIAS (%)					10.02	6.84	3.67
	A+R (ton)					11209	11605	11999
13	E_f						0.58	0.57
	PBIAS (%)						6.27	3.10
	A+R (ton)						11676	12071
14	E_f						0.58	0.56
	PBIAS (%)						5.69	2.52
	A+R (ton)						11748	12143

AnnAGNPS+REGEM+SB (1.3): (Method 4) (Threshold = 0.5)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f	0.49	0.48					
	PBIAS (%)	-13.17	-16.41					
	A+R (ton)	14098	14502					
10	E_f	0.42	0.41					
	PBIAS (%)	-18.25	-21.49					
	A+R (ton)	14731	15134					

AnnAGNPS+REGEM+SB (1.3): (Method 4) (Threshold = 1.0)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R (ton)	0.47 -15.42 14378	0.46 -18.66 14782					
10	E_f PBIAS (%) A+R (ton)	0.39 -20.50 15011	0.38 -23.74 15415					

AnnAGNPS+REGEM + SB (1.5): (Method 4) No threshold

SGF	Statistical parameters	P=0.4	P=0.5	P=0.6	P=0.7	P=0.8	P=0.9	P=1.0
0.0	E_f PBIAS (%) A+R (ton)	0.62 20.33 9924	0.62 17.13 10323	0.62 13.94 10721	0.62 10.75 11118	0.61 7.57 11514	0.60 4.40 11909	0.58 1.23 12304
10	E_f PBIAS (%) A+R (ton)	0.62 15.26 10556	0.62 12.06 10954	0.62 8.87 11352	0.61 5.68 11749	0.60 2.51 12144	0.59 -0.66 12540	0.57 -3.83 12934
11	E_f PBIAS (%) A+R (ton)			0.62 8.38 11412	0.61 5.20 11808	0.60 2.02 12205	0.59 -1.14 12600	0.57 -4.31 12995
12	E_f PBIAS (%) A+R (ton)					0.60 1.46 12275		
13	E_f PBIAS (%) A+R (ton)					0.59 0.88 12347		
14	E_f PBIAS (%) A+R (ton)					0.59 0.31 12418		

AnnAGNPS+REGEM + SB (1.5) (Method 4) threshold (0.5)

SGF	Statistical parameters	P=0.1	P=0.2	P=0.3	P=0.4	P=0.5	P=0.6	P=0.7
0.0	E_f PBIAS (%) A+R (ton)	0.37 -29.69 16155	0.32 -32.93 16559					
10	E_f PBIAS (%) A+R (ton)	0.23 -34.77 16788	0.21 -38.01 17192					
11	E_f PBIAS (%) A+R (ton)	0.22 -35.26						

Appendix -3 Scour Chain Measurements

This data is figured from both 2007-2008 and 2008-2009.

Stream	Area (sqft)				
	2007	2008	2009	2007-2008	2008-2009
Irish Creek 1	5209.229	4620.541	4339.276	-588.688	-281.265
IC-2	10195.452	9153.621	9388.207	-1041.831	234.586
IC-3	19205.005	19460.449	19435.058	255.444	-25.391
North Fork 1	21872.142	20228.49	18757.388	-1643.652	-1471.102
NF-2	28757.716	28625.883	28283.477	-131.833	-342.406
NF-3	8239.032	8138.842	8501.875	-100.19	363.033
Main stem 1	1661.28	1693.755	1995.121	32.475	301.366
MS-2	8348.119	7369.529	7811.914	-978.59	442.385
MS-3	17380.696	16940.497	17024.562	-440.199	84.065

Note: Negative (-) numbers signify loss of area using bankfull, or aggradation. Possitive numbers signify degradation.