ESTIMATING SEDIMENT LOADING USING SWAT AND IDENTIFYING HABITAT DIFFERENCES IN REFERENCE AND IMPAIRED STREAMS

BY

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

Chapter 1

Introduction

Background

The main thrust of pollution control over the last 25 years under the Clean Water Act (CWA) has been on point sources of pollution through the National Pollutant Discharge Elimination System (NPDES) permitting process. Although the quality of water has improved under the aforementioned system, the goals of the CWA have not been attained in a number of streams and lakes (Sohngen and Yeh, 1999, Bosch, 2003). Data from the U.S. EPA indicate that nonpoint sources of pollution are now the major cause of water quality impairment of water bodies (U.S. EPA, 1998). In light of this, the Total Maximum Daily Load (TMDL) program has shifted the focus of water quality management from an effluent-based to an ambient-based system, where the critical issue is whether or not the waterbody is meeting its intended uses (Bosch, 2003). Section 303(d) of the 1972 Clean Water Act requires every state to identify surface waters that do not, or tend to not, meet their specified ambient water quality standards even with the implementation of the minimum prescribed point source pollution control (Jin et al., 2005a, Bosch, 2003). For each listed water body, a state must establish a plan to attain a TMDL (Total Maximum Daily Load) - the maximum allowable loadings of pollutants that can be delivered to the water without impairing the intended uses (Jin et al., 2005a, Bosch, 2003).

The reference stream method as recommended by the Environmental Protection Agency (U.S. EPA, 1999a), is certainly the most widely used TMDL method (Jin et al., 2005a). Under this method, the target sediment load of an impaired stream is the load of its reference stream that is defined as a non-disturbed stable stream that has a natural sediment transport, similar physiographical properties, and same Rosgen's stream type (Rosgen, 1994) as the impaired stream.

Knowing the amount of sediment load that enters both the reference and impaired streams is very important in the implementation of sediment TMDL (Jin et al., 2005a). Different methods have been used by researchers to quantify the sediment load in streams with either little or no observed data. In Georgia, for example, Keyes and Radckiffe (2002) recommended a 20-30 mg/l sediment concentration in restoring impacted or impaired streams. The aforementioned value was based on data gathered from various reference streams in baseflow conditions.

Among the basin wide hydrological models, the Soil and Water Assessment Tool (SWAT) is probably the most widely used model in estimating flow and sediment loading in the watershed (Jin et al., 2005b; Di Luzio et al., 2002; Duda et al., 2001; Mayers et al., 2001). SWAT was developed to predict the effects of different agricultural management scenarios on water quality, sediment and pollutant loadings in watersheds with different soil types, land use and management conditions over long periods of time (Neitsch et al., 2002). It is a long term yield model that computes the major hydrologic cycle parameters on a daily time step.

While many studies have been focused on sediment loadings as the target in reverting impaired streams, less has been done on the differences in habitat between the reference and impaired streams (Jin et al., 2005c).

Overview of the SWAT Model

The Soil and Water Assessment Tool (SWAT) is a distributed hydrologic model developed by the United States Department of Agriculture – Agricultural Research Service (USDA-ARS) (Neitsch, et al., 2002). It results from the merging of the two models - the SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990) and ROTO (Routing Outputs to Outlets) (Arnold, et al., 1995). SWAT was developed to overcome the limitations of the SWRRB in terms of area coverage and watershed subdivisions. SWRRB can only be utilized for watersheds up to a few hundred square kilometers in size and is limited to ten sub-basins (Neitsch, et al., 2002). With SWAT large watersheds can be modeled. The HUMUS (Hydrologic Unit Model for the United States) project used SWAT to model 350 USGS 6-digit watersheds in the 18 major river basins in the US (Srinivasan, et al., 1993). Other models that contribute to the development of SWAT are CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard, et al., 1987), and EPIC (Erosion-Productivity and Impact Calculator) (Williams et al., 1984).

SWAT is highly capable of simulating watershed hydrologic response, erosion, sediment and nutrient loading in the watershed. The surface runoff is computed by either the SCS runoff curve number method (Soil Conservation Service, 1972, 1985) or by

Green-Ampt infiltration equation (Green and Ampt, 1911) and the sediment transport is calculated using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). For modeling purposes, SWAT approaches a watershed by partitioning it into several subwatersheds or subbasins (Neitsch et al., 2002). The subbasins are further subdivided into hydrologic response units (HRUs) – lumped land areas within the subbasin that are comprised of unique land cover, soil and management combinations (Neitsch et al., 2002). Processes within a HRU are computed independently, and the total yield for a subbasin is the sum of all the HRUs it contains (White, 1999).

Overview of the Yang's Unit Stream Power Formula

Stream power theory by Yang (1972) can be used to calculate soil detachment and transport by flowing water. Water on the soil surface has potential energy by virtue of its elevation above some arbitrary datum. This energy becomes available to detach and transport soil particles as the water moves downslope. When flow goes from upstream to downstream there is a loss of potential energy. This loss in potential energy (gravitational head) may be converted to kinetic energy (increased velocity head), increased pressure head or can be used to do work against friction. If the velocity and pressure heads do not change, this means the change in potential energy is used to overcome friction. The friction force is the shear force or drag used to transport sediment. Yang (1972) defined the unit stream power as the channel velocity-slope product. The rate of energy per unit weight of water available for transporting water and sediment in an open channel with reach length x and total drop of Y (Yang, 2003):

$$\frac{dY}{dt} = \frac{dx}{dt}\frac{dY}{dx} = VS \tag{1}$$

where *VS* (velocity-slope product) = unit stream power.

Overview of Reference and Impaired Streams

A reference stream is regarded as a non-disturbed, stable stream that has “natural” sediment transport rates and amounts (Jin et al., 2005c) (Simon, et al., 2002), while an impaired stream is viewed as a disturbed stream where erosion and sediment transport rates and amounts are high enough to affect the biological communities and other designated uses of the stream (Simon et al., 1999). Sediment loads in reference streams are taken as the target load for restoration of the impaired streams (U.S. EPA, 1999a; Kuhnle and Simon, 2000; Hawkins, 2003). As soon as the sediment load in an impaired stream is reduced to the target level, it is hoped that the impaired stream will regain its natural condition through time and the instream sedimentation processes in the impaired streams will no longer be a problem (Jin et al., 2005c).

In implementing the reference stream method, the impaired streams are required to be the same in physiographical properties, and should be situated in the same ecological region (eco-region) as their reference streams (Jin et al., 2005c). Rosgen’s system (Rosgen, 1994) is one of the most widely used stream classifications and recommended by the EPA in finding the reference stream for the impaired stream. However, in the Rosgen’s classification some of the stream types are, by definition, unstable as argued by Kuhnle and Simon (2000). These are stream types D, F, and G (Rosgen, 1996) which would be expected to produce and transport enhanced amounts of sediment and represent “impacted”, if not “impaired” conditions. The channel evolution concept, an alternative scheme for sediment TMDL was first proposed by Schumm (1984) (later modified by Simon and Hupp, 1986 and Simon, 1989). The process of channel evolution is divided into six stages. The stage I (pre-modified) and stage VI (re-stabilized) represent the stable stage, while the stages II through V correspond to unstable stages. In sediment TMDL analysis, only stages I and VI can be used to represent the true “reference” stream conditions to analyze the background or natural transport rates (Simon et al., 2002).

Study Areas

Two streams located in the Central Oklahoma/Texas Plains (COTP) Ecoregion of Oklahoma State were studied. Upper Black Bear Creek was classified as the reference stream, while Quapaw Creek was considered as the impaired stream. The relative location of each stream is shown in Figure 1.1. The stream channel main characteristics and land use land cover along with soil type in each watershed are presented in Tables 1.1 and 1.2 respectively. All Topo Maps software at a scale of 1:24,000 was used to measure the channel slope with less than 3 cm (0.1 ft) error of measured elevation (Jin et al., 2005a). Other measurements were taken on a 400-m stream reach equally divided into twenty 20-m segments. The Oklahoma Conservation Commission (OCC) did all the measurements according to the EPA Rapid Bioassessment Protocol V (U.S. EPA, 1999b). All the information in each category shown in Table 1.1 is the average value of the twenty measurements. Measurement of water depth was taken at the baseflow condition. Channel bank slope and depth are the average values of the left and right banks. Visual measurement was used to determine bed materials. It might be inaccurate, but considering the fact that this is the standard survey procedure used by engineers in stream channel survey (Jin et al., 1995a), the data are being used with the expectation that Yang’s equation will work for any river with similar data. The surveyed bed material was categorized into five classes: silt and clay (Si&C) (diameter less than 0.1mm), sand (SND (0.1~2.0mm), gravel (GVL) (2~50 mm), cobble (CBL) (50~250 mm), and boulders (BLD) (greater than 250mm). Information about land use and soil type for each watershed was identified using SWAT from USGS Land Use Land Cover and STATSGO soil databases respectively.

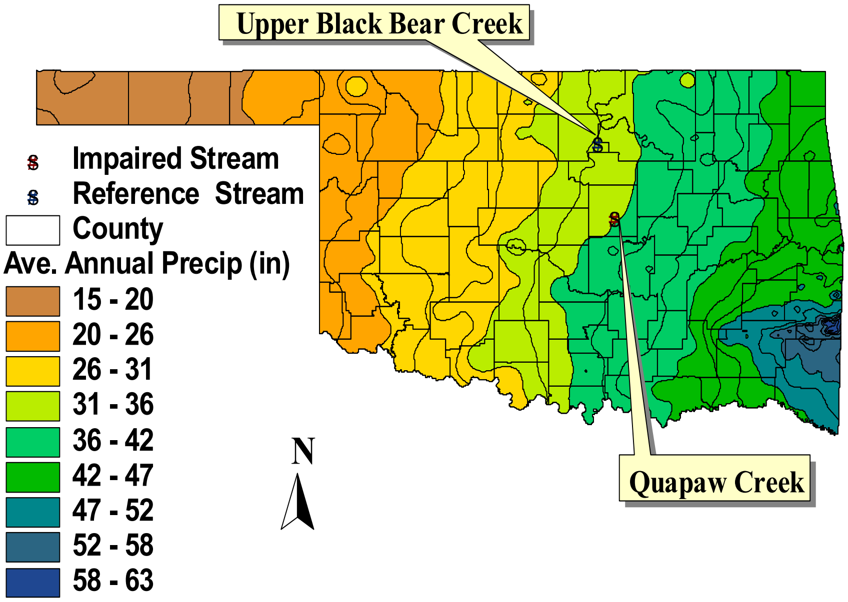

Figure 1.1. The relative location of the studied streams

Table 1.1. Stream Channel Main Characteristics

Name	County	Channel Slope (m/m)	Water Width (m)	Bank Slope $(^{o})$	Water Depth (m)[a]	D_{50} mm (%)				Manning's n
						0.1< (Si&C)	0.1~2.0 (SND)	2~50 (GVL)	50~250 (CBL)	
Upper Black Bear Creek	Noble	0.0003	10.9	58.9	1.0	36.6	2.6	11.1	49.7	0.04
Quapaw Creek	Lincoln	0.0001	10.4	79.6	0.1	5.5	90.2	0	4.3	0.03

[a] Average water depth in baseflow condition

Table 1.2. Land Use Land Cover (%) and Soil Composition (%)

Name	Area (km^2)	Agri – cultural	Range	Pasture	Forest	Urban	Soil Composition
Upper Black Bear Creek	1400	43.8	42.4	9.8	3.8	0.2	Renfrow, 61.4; Grainola, 9.7; Port, 9.7; Bethany, 8.3; Norge, 7.9; Niotaze, 1.9; Shidler, 0.7; Agra, 0.4
Quapaw Creek	1370	1.7	48.1	3.2	38.0	9.0	Darnell, 81.2; Kirkland, 7.0; Zaneis, 4.8; Keokuk, 3.5; Renfrow, 1.8; Eufaula, 1.7

Research Objectives

This paper is aimed at achieving the following objectives:

1. Estimate the sediment loading from the watershed to the reference and impaired streams using the SWAT model. The computed sediment loadings will be compared to the sediment transport capacity of the two streams. Yang's unit stream power formula will be used to calculate the sediment transport capacity in both streams.

2. Compare the differences between the impaired and reference streams in terms of parameters on the micro-scale habitats (such as substrate, cover, and flow condition), macro-scale habitats (such as channel geometry and sediment deposition), and parameters evaluating riparian conditions and bank structure (such as bank stability, vegetation, and streamside cover).

Chapter 2

Literature Review

The Use of SWAT Model in Sediment Estimation

SWAT has been used in various studies involving total maximum daily loads (TMDLs) because of its capability to estimate nonpoint source pollutants like sediment. (Santhi et al., 2001; Kirsch et al., 2002; Storm et al., 2003; Tolson and Shoemaker, 2004). In Texas, SWAT was used for the development of the total maximum daily load (TMDL) program in North Bosque river watershed where point and nonpoint sources of pollution are of a problem. The watershed is 4,277 km^2 wherein land use is rangeland and pasture for the most part with some cropland in the southern portion. A total of nearly 40,500 dairy cattle are in this watershed and the dairy manure from these animals is applied to fields that cover about 94.5 km^2. Although, the main focus of the study is phosphorous as a main pollutant and not sediment, it showed that SWAT could be an important tool for studying the impacts of different management scenarios for pollution control from both point and nonpoint sources in large watersheds (Santhi et al., 2001).

The Rock River Basin which lies within the glaciated portion of south central and eastern Wisconsin was studied using SWAT by Kirsch et al. (2002) to predict the sediment and phosphorous loads. This watershed covers about 9,708 km^2 and has nearly 6,265 total river kilometers, 3,089 km of which are considered as perennial. Agriculture is found to be the dominant land use which accounts for 62%, followed by 11% grassland

and pasture, and 10% forest. The agricultural portion of the watershed is characterized by a continuous corn and corn-soybean rotations in the south to a mixed dairy, feeder operations, cash cropping and muck farming towards the north. The results of this study show that under the existing conditions, 764,000 kg of phosphorous (of which 59% comes from nonpoint sources) goes into the Rock River and its tributaries, while approximately 160,000 tons of sediment enters the streams and surface water bodies on an average annual basis.

Storm et al. (2003) used SWAT along with Water Erosion Prediction Project (WEPP) to estimate the nonpoint pollution source component of the Fort Cobb Basin TMDL. Fort Cobb Basin is located in southwestern Oklahoma. It covers an area of about 804 km^2 and encompasses three counties: Caddo, Washita and Custer. In the 1998 Oklahoma 303(d) list Fort Cobb reservoir, together with the six stream segments in its basin, was identified as impaired due to nutrients, pesticides, siltation, suspended solids and unknown toxicity. Roads and bar-ditch erosion, which accounted for 2.1%, was estimated by WEPP, while sediment loads from upland areas (which are dominated by agricultural land use) was predicted using SWAT. The combined sediment loads calculated by the two models is 292,000 metric tons annually (Storm et al., 2003). The results of this study based on SWAT simulation indicate that sediment loads would be reduced by as much as 55% if no-till practices were adopted, and if all crop land (row crop and small grains) would be converted to pasture the sediment loads would be lowered by 68%.

In the study of the Cannonsville Basin located in Upstate New York, SWAT was used to identify and quantitatively evaluate the long term effects of numerous sediment and nutrient management options for mitigating loading into the reservoir (Tolson and Shoemaker, 2004). The Cannonsville reservoir – a major water supply reservoir for New York City has historically experienced water quality problems brought about by sediment and nutrient loading, especially phosphorous. The Cannonsville Basin covers an area of 1178 km^2 and is predominantly agriculture and forest while less than 0.5% of the basin is urban. The average slope of the lands within the watershed is approximately 19% with an elevation of 285 m and 995 m above mean sea level in the lowland areas and hilltops respectively. The results of the study show that the SWAT model can reasonably represent the temporal and spatial nature of the measured flow and water quality data at multiple locations in the basin, which implies that the model in its present form could be used to evaluate potential management strategies for reducing sediment and nutrient loading in the Cannonsville Basin.

Differences in Reference and Impaired Streams Habitat Characteristics

While the differences between the reference and impaired streams are usually quantified based on their sediment loading and transport capacity; several studies have shown that both streams also exhibit significant differences in river morphology and aquatic habitat characteristics. In the State of Oklahoma, eight reference streams and ten impaired streams west of I-35 were studied by Jin et al. (2005c). The study was conducted by comparing parameters on the micro-scale habitats (such as bottom substrate, cover, and flow condition), macro-scale habitats (such as channel geometry and sediment deposition) as well as parameters defining the riparian conditions and bank structure (such as bank stability, vegetation, and streamside cover).

They found that reference streams usually have a considerable baseflow depth that provides the aquatic life a greater chance to thrive during the dry season. Moreover, the bank slopes of the reference streams in general are steeper (over 65 degrees) compared to those of the impaired streams (less than 50 degrees). The reference streams' substrates are generally comprised of all size particles ranging from loose silt and clay to boulders. The aforementioned combination of substrate materials creates a greater diversity of conditions compared to the predominant run habitat and sandy bed in the impaired streams, and consequently supports more aquatic life by providing a wide range of riffle/pool habitats. More woody debris and undercut banks are observed in reference streams than in impaired streams which are positive signs of ample living space and food availability for aquatic life. Impaired streams manifest an active bank and bed because they have more recently formed point bars than the impaired streams.

DeWalt (2002) conducted a study on ten reference and ten randomly chosen streams in Illinois. The study was done by comparing the reference and randomly chosen streams in terms of EPT (Ephemeroptera, Plecoptera, and Tricopthera) taxa richness and habitat quality scores. Significant differences were found in habitat quality between the two stream reaches. They found out that for the most part (6 out of 10) randomly selected streams were channelized, had narrow treed riparian zones, and had considerable bank erosion.

Stranger Creek of Leavenworth County, Kansas was investigated by the Central Plains Center for Bioassessment (CPCB) Kansas Biological Survey (2002) with regards to ecological integrity. Data on a variety of physical, chemical, and biological attributes in the spring, summer and fall of 2001 were collected from three sites along the main stem of the Stranger Creek. The abovementioned parameters were then compared to the data collected from three reference streams (located in the Western Corn Belt Plains eco-regions) which had been identified previously to have high habitat, water quality and biological conditions.

The habitat analysis showed that the three reference streams scored higher than Stranger Creek in a number of near-stream and in-stream variables. One important near-stream variable is the riparian forest, which is measured in terms of stream shading, riparian width and riparian condition. As a whole, the Stranger Creek riparian condition appeared to be poorer compared to the reference streams; although, they were similar with regards to stream shading and riparian width. This finding was derived from low riparian condition values for Stranger Creek, which demonstrate that the existing riparian forest at that time was composed of thin and broken canopy and had low species diversity. This study also revealed that the amount of active erosion at Stranger Creek was slightly higher than the reference streams. This assessment was conducted by measuring the length and average height of all areas of active bank erosion and by calculating the total area of bank erosion in each of the three sites along the Stranger Creek.

Sentoff (2004) conducted research to determine stream restoration techniques and collect pertinent data for restoration of Fairfield Run – a stream identified as impaired in the University of Delaware Experimental Watershed. The researcher selected a reference stream for Fairfield Run located in the same ecoregion and investigated the data on water quality, habitat and geomorphology. The reference stream received a very good rating in the habitat survey while the three sites selected along the main stem of Fairfield Run received a moderate, good and very good. One of the main reasons for the high rating of reference stream was the composition of its stream bank vegetation. It had well vegetated stream banks with native plants and trees as compared to the Fairfield Run sites which had a number of bare, eroded banks with a higher percentage of scrub and non-native vegetation.

The Use of Yang's Equation in Estimating Sediment Transport Capacity

In Oklahoma, a total of eight streams with drainage areas ranging from 50 km^2 to 400 km^2 were investigated in terms of transport capacity using Yang's unit stream power formula (Jin et al., 2005a). This study was done for the purpose of developing a sediment TMDL endpoint. Three of the streams were identified as reference, while five were considered as impaired or impacted. The sediment transport capacity of each of the streams was calculated using the formula. The results were then compared to the sediment yield from the drainage area using SWAT.

They found that the reference streams had a larger transport capacity than their delivered sediment load, while impaired or impacted streams had transport capacities that were less than or approximately equal to the sediment load coming from the watershed.

Chapter 3

Methods

Application of the SWAT Model

Data Input

The SWAT model requires three GIS data layers, namely digital elevation model (DEM), soils, and Land Use Land Cover, as well as weather data as input.

Digital Elevation Model (DEM)

A 30-m seamless Digital Elevation Model (DEM) was used to define the topography of each watershed. United States DEM and related information can be found from several sources on-line. The DEM used in this study was taken from (http://seamless.usgs.gov/website/seamless/viewer.php), one of the sites that offers a seamless DEM coverage of the entire watershed.

The calculation of sub-basin parameters such as slope and slope length as well as the definition of stream network were done using the DEM. The resulting stream network was used to delineate the entire watershed into a reasonable number of sub-basins. Important stream characteristics like width, length and slope were all derived from the DEM (Figures 3.1 and 3.2).

Four points must be known to get the seamless DEM coverage of the entire watershed. These are the extreme north and south latitudes, and the extreme east and west longitudes. These coordinates were obtained from another website (www.mapmart.com) using a known pair of coordinates that defines where the habitat survey was done. Before the DEM was used for modeling, it was projected to Universal Transverse Mercator (UTM) under appropriate zones. Oklahoma belongs to three UTM zones (Chang, 2004). Zone 14 covers most of the state, zone 13 covers a small portion in the western part of the panhandle and zone 15 covers some portion of the state near Arkansas.

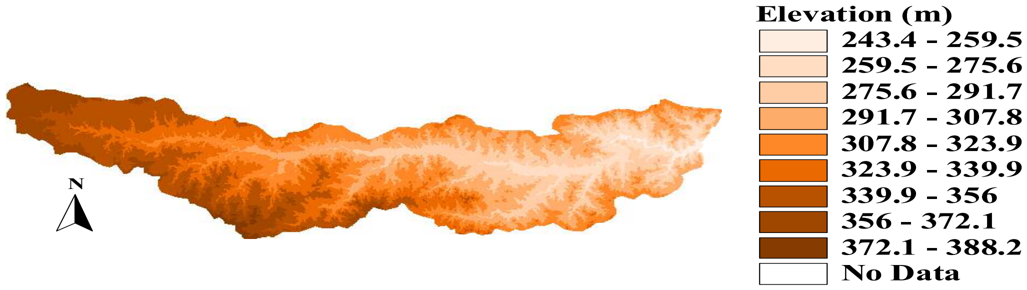

Figure 3.1. Seamless digital elevation model (DEM) of the Upper Black Bear Creek watershed

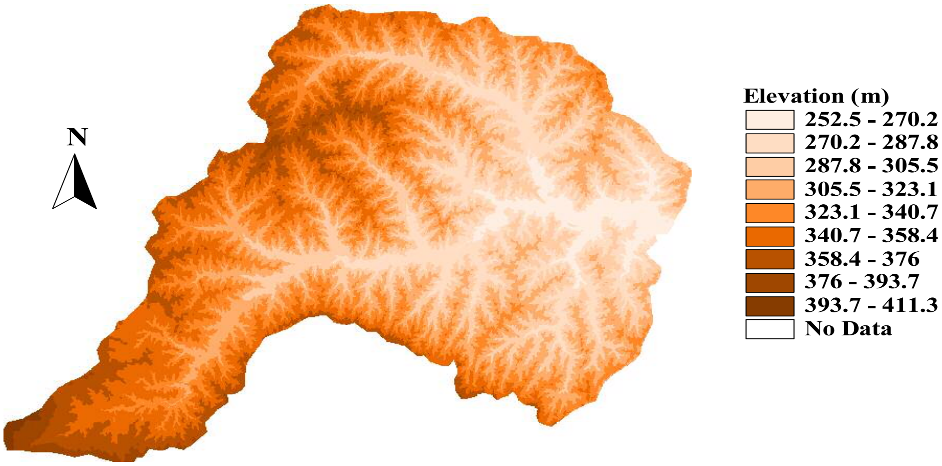

Figure 3.2. Seamless digital elevation model (DEM) of the Quapaw Creek watershed

Soils

Soils data are necessary for SWAT modeling to identify soil types and composition in the entire watershed. SWAT uses the STATSGO (State Soil Geographic) data to define soil attributes for any given soil. The GIS soil data must have either S5ID (Soils5id for USDA soil series) or STMUID (State STATSGO polygon number) to link an area anywhere in the watershed to the STATSGO database. In this study, the STMUID was used.

The soil layer (Figures 3.3 and 3.4) was obtained from the Oklahoma Natural Resources Conservation Service (NRCS) database which is available from (http://www.ncgc.nrcs.usda.gov). A 200-m resolution Map Information and Display System (MIADS) data was used. Basic properties of the soil data used in this study can be found in Appendix A.

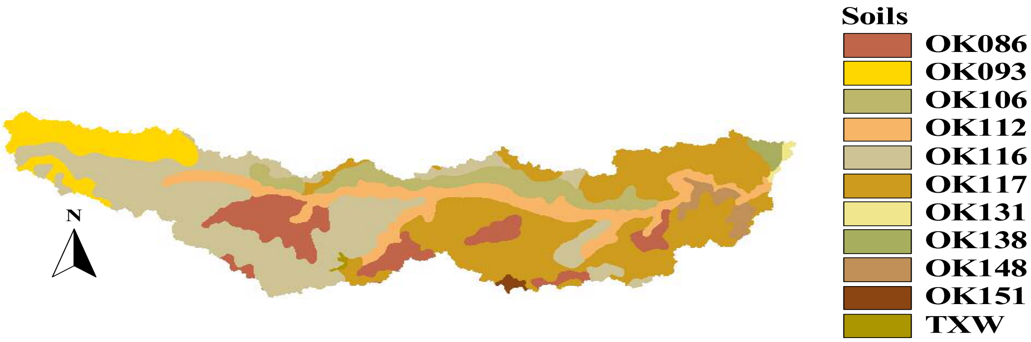

Figure 3.3. Soils of the Upper Black Bear Creek watershed by five digit identification

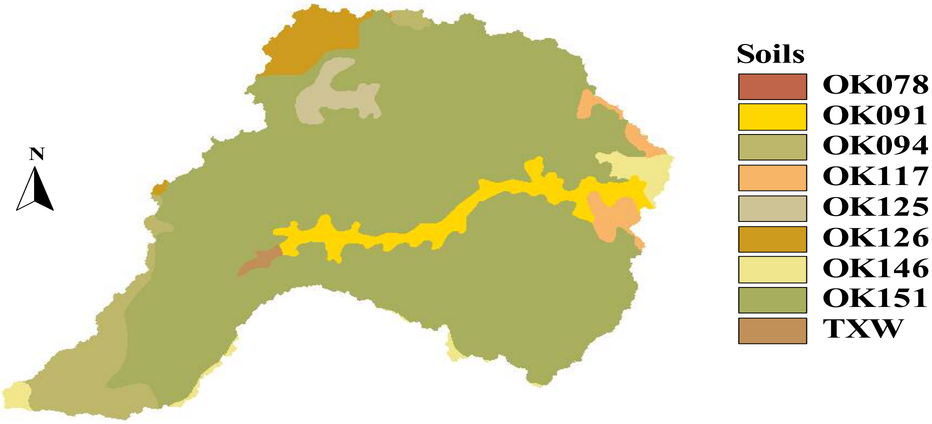

Figure 3.4. Soils of the Quapaw Creek watershed by five digit identification

Land Cover

Considering factors such as slope, slope length and others as being similar; land cover is the most important factor that affects the amount of sediment yield in a given area. Any given rainfall that falls on a completely bare surface will undoubtedly result in a higher amount of erosion than a rainfall of the same magnitude and duration that falls on a grass-covered surface.

The land cover layer was derived from the 1992 National Land Cover Dataset (NLCD) - a 21-class land cover classification scheme applied consistently over the United States. It is derived from the early to mid-1990s Landsat Thematic Mapper satellite data (http://seamless.usgs.gov). The processes involved in obtaining the land cover data layer to make them compatible with SWAT are the same as the DEM. In this study, there are six (6) major types of land cover namely: water, urban, agricultural, range, pasture, and forest (Figures 3.5 and 3.6). Table 1.2 presents the percent coverage of each of these land cover types.

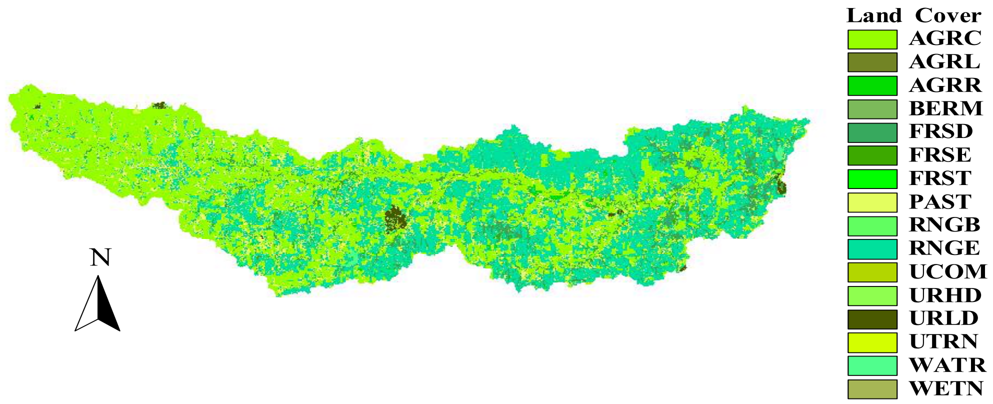

Figure 3.5. Land cover of the Upper Black Bear Creek watershed derived from U.S. Geographic Survey

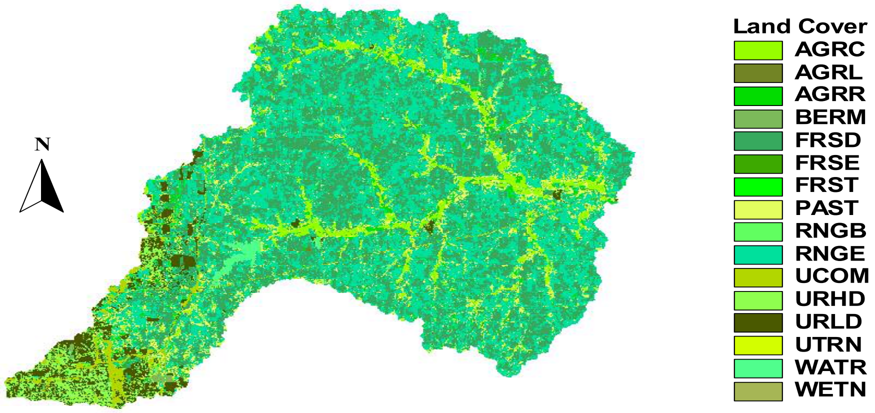

Figure 3.6. Land cover of the Quapaw Creek watershed derived from U.S. Geographic Survey

Weather

SWAT requires daily values of weather data as an input. These data are precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. To run SWAT one can either prepare a file that contains observed data or use values generated by the model from monthly average data summarized over a number of years (Neitsch et al., 2002).

A combination of both observed and simulated weather data were used in this study. Observed weather values from USGS Cooperative Observer Program (COOP) were utilized to create files for daily precipitation, minimum and maximum daily temperatures. The rest of the weather parameters such as solar radiation, wind speed and relative humidity were generated by the SWAT model. COOP weather data can be found on National Oceanic and Atmospheric Administration (NOAA) website (http://cdo.ncdc.noaa.gov/CDO/cdo). The location and other related information about the weather stations used in this study are shown in Appendix B.

Sub-basin Delineation

SWAT defined the sub-basin layout of each watershed using the DEM, stream burn-in layer and an outlet table (in dBase format). The stream burn-in theme which is comprised of digitized streams helps the model to define the right stream locations in flat topography. Each watershed in this study has different values of stream threshold area. The stream threshold area, also known as critical source area, defines the minimum drainage area to form the origin of a single stream (Di Luzio et al., 2002). Threshold areas of 750 and 765 ha were used for Upper Black Bear Creek and Quapaw Creek, respectively. The smaller the specified number of hectares, the more detailed the drainage network delineated by the SWAT interface (Di Luzio, et al., 2002).

The results of the sub-basin delineation are shown below (Figures 3.7 and 3.8). Since this study is focused on getting data on a daily time step, fewer sub-basins were desired to simplify the modeling process. It does not mean, however, that the detail of the drainage network was being sacrificed. In fact, the stream threshold areas mentioned above are at least 50% lower than the recommended model values.

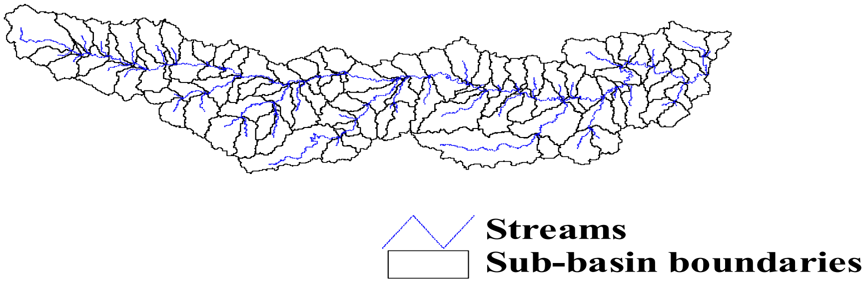

Figure 3.7. The Upper Black Bear Creek watershed subdivided into 111 sub-basins

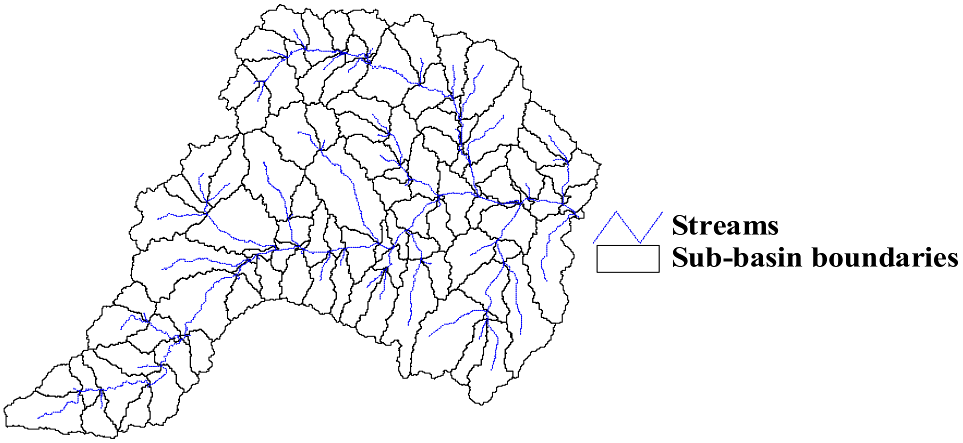

Figure 3.8. The Quapaw Creek watershed subdivided into 107 sub-basins

HRU Distribution

Each sub-basin in the entire watershed was subdivided into Hydrologic Response Units (HRUs) by SWAT. The land use [%] over sub-basin area threshold was reset to 9% from a default value of 20%. This number specifies the minimum percentage of any land cover in a sub-basin that will become an HRU (Di Luzio, et al., 2002). Also, the soil class [%] over sub-basin area was set to a value of 9% from a default value of 20%. By lowering these thresholds, the number of HRUs within a sub-basin was increased allowing more spatial detail to be incorporated in the SWAT model.

Observed Data

Observed Stream flow

Recorded stream flow from USGS stream gage stations (Figures 3.9 and 3.10). were used to calibrate the hydrologic portion of the model. This set of information can be found on-line (http://cfpub.epa.gov/surf/locate/index.cfm). The gage stations have different periods of record (Table 3.1).

Table 3.1. U.S. Geographic Survey Stream Gage Stations Used to Calibrate the Model

Gage Station	Location		Start Date	End Date
	Latitude	Longitude		
USGS 07153000	36.343611	-96.79917	10/1/1944	Current
USGS 07242380	35.680896	-97.00836	10/1/1983	Current

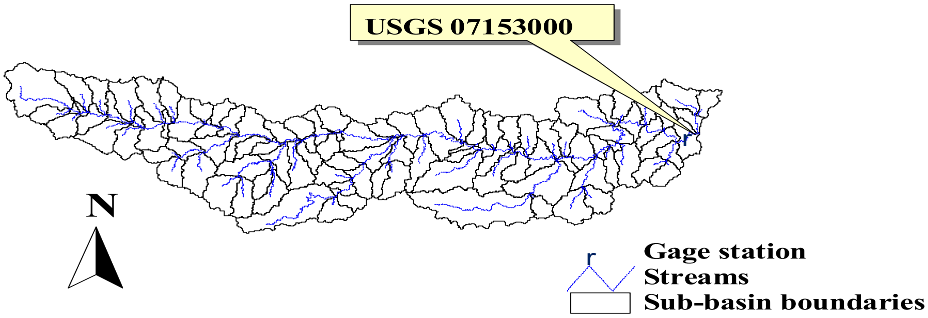

Figure 3.9. Active U.S. Geographic Survey stream gage station used to calibrate the model for Upper Black Bear Creek

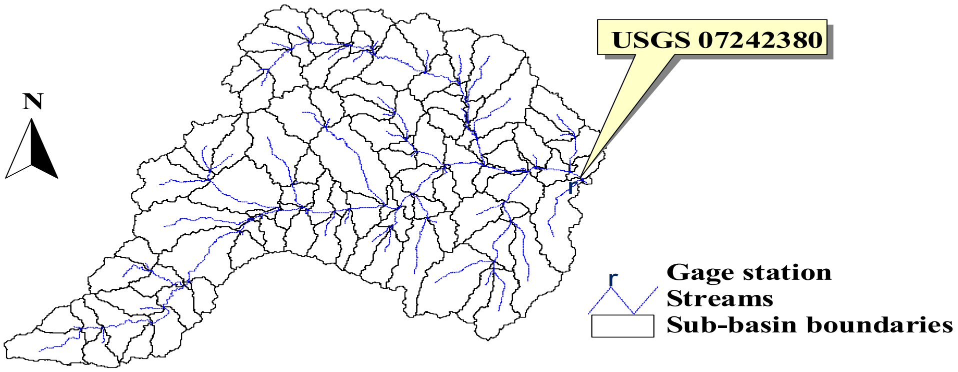

Figure 3.10. Active U.S. Geographic Survey stream gage station used to calibrate the model for Quapaw Creek

Flow Calibration

Surface runoff and baseflow are the two primary sources that contribute to stream flow. Baseflow is the flow that comes from ground water contributions (White, 1999). Before calibrating the model, the total observed stream flow was split into surface runoff and baseflow using the USGS HYSEP sliding interval method. Surface runoff duration was computed using the empirical formula:

$$N = A^{0.2} \tag{2}$$

where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval 2N* used for hydrograph separation is the odd integer between 3 and 11 nearest to 2N. The sliding interval method finds the lowest discharge in one half the interval minus one day [0.5(2N-1) days] (White, 1999) before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated (Figures 3.11 and 3.12).

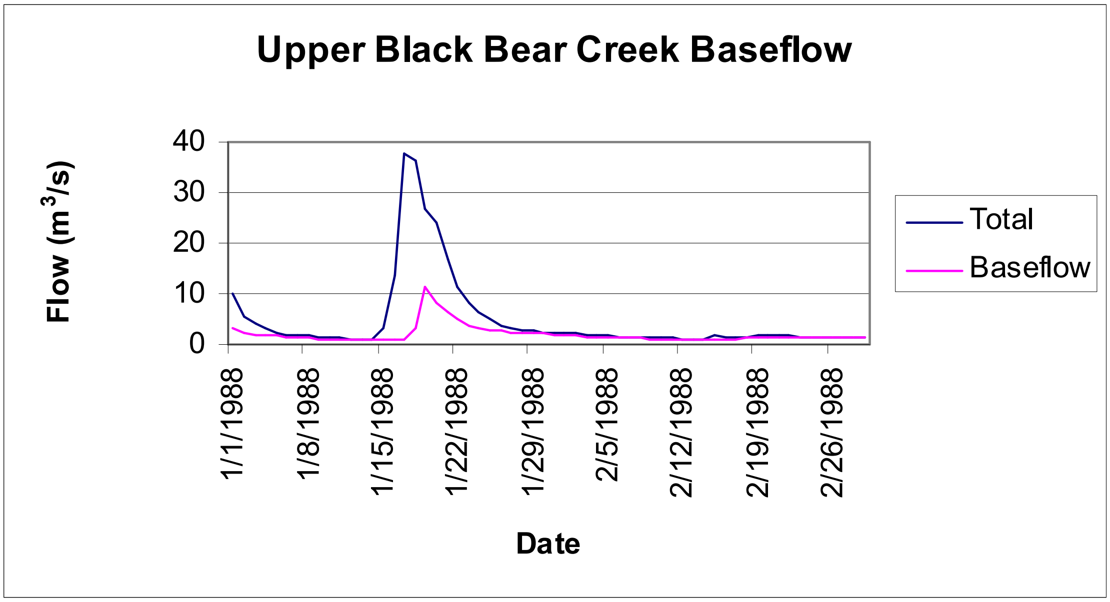

Figure 3.11. Upper Black Bear Creek observed baseflow separation example

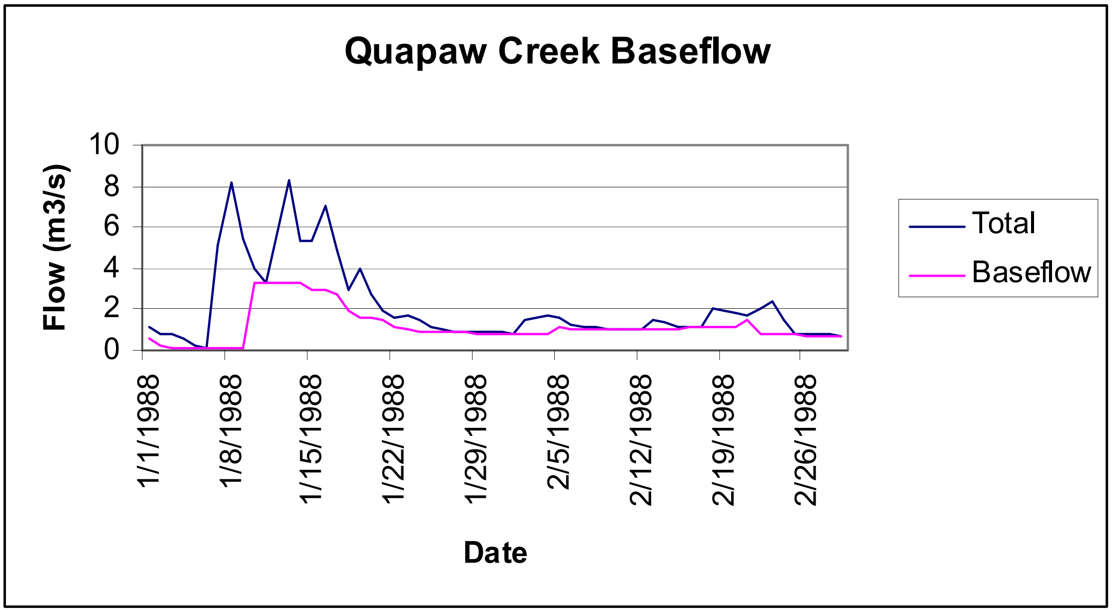

Figure 3.12. Quapaw Creek observed baseflow separation example

Table 3.2. Monthly observed average flow, baseflow and surface runoff fractions as determined by the HYSEP sliding interval

Gage Station	Period	Average Flow (m^3/s)	Baseflow	Surface Runoff
USGS 07153000	1/88 to 12/02	8.2	30%	70%
USGS 07242380	1/88 to 12/02	8.1	43%	57%

The stream flow calibration process was done on a monthly basis. Parameters that affect the amount of surface runoff such as Available Water Content (AWC), Soil Evaporation Compensation Factor (ESCO); and those that influence the volume of baseflow such as Groundwater "revap" Coefficient (GW_REVAP), Threshold Depth of Water in the Aquifer for "revap to occur" (REVAPMN), as well as Threshold Depth in Shallow Aquifer for baseflow to occur (GWQMN) were adjusted. Values for the adjustment of the abovementioned parameters are found in Appendix C at the end of the observed and simulated stream flow tables for each stream.

USGS gage stream flow data from January 1988 to December 2002 were used to calibrate both the Upper Black Bear Creek and Quapaw Creek. To compare the simulated data to the observed data and to guide the whole calibration process relative error was used.

Relative Error (%) = (Observed – Simulated)/Observed * 100 (3)

Nash-Sutcliffe coefficient of efficiency (NSE) (Nash and Sutcliffe, 1970) was used to evaluate the calibration on this study. NSE determines the model efficiency as a fraction of the measured stream flow variance that is reproduced by the model:

$$NSE = 1 - \frac{\Sigma(Qo - Qs)^2}{\Sigma(Qo - \overline{Qo})^2} \tag{4}$$

where Qo is the observed stream flow, Qs is the simulated stream flow and $\overline{Qo}$ is the observed mean stream flow.

The closer the NSE value to 1.0 the better is the estimation of the stream flow by the model. A NSE ≥ 0.75 is considered to be an excellent estimate, and a NSE between 0.75 and 0.36, is generally regarded to be satisfactory (Motovilov et al., 1999).

Application of the Yang's Formula

Yang (1972) related the total sediment concentration to unit stream power and came up with the following sediment transport equation for sand (less than 2 mm in diameter) (Yang, 1973):

$$\begin{aligned} \log C_{ts} &= 5.435 - 0.286\log\frac{\omega d}{v} - 0.457\log\frac{U_*}{\omega} + \\ &\left(1.799 - 0.409\log\frac{\omega d}{v} - 0.314\log\frac{U_*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \end{aligned} \tag{5}$$

where C_{ts} is the total sand concentration in ppm by weight; ω is the sediment fall velocity; d is the sediment particle diameter; v is the kinematic viscosity of water; $U_*(=\sqrt{gDS}\,)$ is shear velocity; V is average flow velocity; S is water surface energy slope; D is depth of flow; g is gravitational acceleration; and V_{cr} is critical average flow velocity at incipient motion. The critical velocity V_{cr}/ω, a dimensionless quantity is calculated using the expression:

$$\frac{Vcr}{\omega} = \frac{2.5}{\log(U * d / v) - 0.06} + 0.66, \quad \textit{if } 1.2 < U^*d/v < 70 \tag{6}$$

$$\frac{Vcr}{\omega} = 2.05, \quad \text{if } 70 \le U^*d/\nu \tag{7}$$

Rubey's formula (Rubey, 1933) is used to compute the sediment fall velocity ω:

$$\omega = F\sqrt{dg(G-1)} \tag{8}$$

where,

$$F = \left[\frac{2}{3} + \frac{36\nu^2}{gd^3(G-1)}\right]^{1/2} - \left[\frac{36\nu^2}{gd^3(G-1)}\right]^{1/2} \tag{9}$$

for $0.0625 < d < 1.0$ mm or $F = 0.79$, for $1 \le d \le 2$ mm; G is the specific gravity of sediment which is equal to 2.65. The kinematic viscosity of water, ν, is a function of water temperature and is calculated using the formula:

$$\nu = \frac{1.792x10^{-6}}{1.0 + 0.0337T + 0.000221T^2} \tag{10}$$

The water temperature, T, in this study is assumed to be at 10^{o}C.

When the concentration of the bed material exceeds 100 ppm, equation (1) takes the form:

$$\log C_{ts} = 5.165 - 0.153\log\frac{\omega d}{\nu} - 0.297\log\frac{U_*}{\omega} + \left(1.780 - 0.360\log\frac{\omega d}{\nu} - 0.480\log\frac{U_*}{\omega}\right)\log\frac{VS}{\omega} \tag{11}$$

with the same degree of accuracy (Yang, 1979).

The unit stream power formula can also be used to estimate the concentration of gravel with a particle diameter greater than or equal to 2mm (Yang, 1984):

$$\log C_{tg} = 6.681 - 0.633\log\frac{\omega d}{\nu} - 4.816\log\frac{U^*}{\omega} + \left(2.784 - 0.305\log\frac{\omega d}{\nu} - 0.282\log\frac{U^*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \tag{12}$$

where C_{tg} is the total gravel concentration in ppm by weight. All the other parameters are the same as in eq.(5). Equations describing the incipient motion eqs.(6) and (7), and kinematic viscosity eq.(10) are still valid for eq.(12). The gravel fall velocity however, takes the form:

$$\omega = 3.32 d^{1/2} \tag{13}$$

Equation (12) was developed for gravel with diameter between 2 and 10 mm, but various studies pointed out it may be applied to materials with size coarser than 100 mm (Yang and Simoes, 2000).

When using the Yang's equation, the channel cross-section is assumed to be trapezoidal in shape (Jin et al., 2005a). In a given stream, the flow velocity and depth can be computed using Manning's equation (Haan et al., 1994):

$$V = \frac{1}{n} R^{2/3} S^{1/2} \tag{14}$$

and the continuity equation:

$$Q = VA = VD(W + D(\tan \beta)) \tag{15}$$

where Q is the stream flow, V is the flow velocity, D is the depth of flow, S is the channel slope, W is the width of water in baseflow, n is Manning's roughness coefficient, and β is the bank slope in degrees.

Cowan (1956) presented a method of calculating the Manning's roughness as shown below:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m \tag{16}$$

where n_b represents the base value for a straight, uniform, and smooth channel; n_1, n_2, n_3 and n_4 are the correction factors that account for the effects of surface irregularity, variation in shape and size of cross section, obstruction, as well as vegetation and flow conditions respectively; while m accounts for the effect of channel meandering.

The value of each factor used in this study was based on the work done by Arcement and Schneider (1989).

Yang's sediment transport equations such as equations (5), (11) and (12) were derived for uniform bed materials. In natural rivers whose bed materials are not uniform with particle sizes ranging from sand to gravel, equations (5) and (12) or (11) and (12) should be combined together using the relationship by Yang (1996):

$$C_t = \sum_{i=1}^{N} p_i C_i \tag{17}$$

where C_t is the total carrying capacity for a particular river section; p_i is the percentage of material size fraction i available in the bed; C_i is carrying capacity for each size fraction computed using equations (5), (11) or (12); and N is the number of size fractions.

For size fractions that have minimum and maximum particle size diameters d_{min} and d_{max}, the mean diameter d_{mean} or d_{50} is calculated by the formula used by Jin, et al., 2005(a) in their study:

$$d_{mean} = \sqrt{d_{\min} * d_{\max}} \tag{18}$$

The daily sediment load or transport capacity of each stream was computed by the formula:

$$Q_s = Q_w * C_{ppm} * 60 * 60 * 24 * 10^{-6} \tag{19}$$

where Q_s is the sediment load in metric tons/day, Q_w is the flow discharge in m^3/s, C_{ppm} is the sediment concentration in parts per million by weight.

Habitat Characteristics Comparison

The physical characteristics of the streams used in this study were all obtained from the results of the Oklahoma Conservation Commission survey. A 400-m reach in each surveyed stream divided into twenty 20-m segments was evaluated. The parameters of interest include:

- Cross-section Geometry – this encompasses water width and depth as well as bank in every cross section during low flow season. Water depth measurement was done at the left ¼, right ¼, and at the cross section center. Measurement of the bank width was taken at the normal high waterline where well-established perennial vegetation is found just above it.
- Instream Cover Area – this is expressed in percent which comprises undercut banks, woody debris (includes large and small, and submerged tree rootwads), stone (gravel, cobble and boulder), and vegetation.
- Habitat Type – this is represented by four categories: riffle, pool, run, and dry habitat.
- Substrate Material – this is expressed in percent and includes eight (8) subcategories. These are: loose silt and clay, sand or rock (0.1~2.0 mm in diameter), gravel (2~50 mm), cobble (50~250 mm), boulder (>250 mm), bedrock, particulate organic matter (rotten leaves and fragments of sticks and logs), and hardpan clay.
- Embeddedness – as the term implies, this refers to the extent by which fine sediment surrounds gravel, cobble and boulders. This is indicative of the suitability of the stream substrate as habitat. This is rated from 0% (no fine

material surrounding the gravel, cobble and boulders) to 100% (gravel, cobble and boulders well surrounded by fine material).

- Canopy Cover – this describes the density of trees that are growing over the channel. This is expressed in percent, in which 0% denotes no canopy cover over the stream segment of interest, while 100% signifies full cover.
- Point Bars – this refers to the currently formed bars which have little or no vegetation at all.
- Bank Vegetative Cover and Dominant Vegetation Type – this includes the estimate of area of the bank on both sides of the stream that is covered by well-established, perennial vegetation. Dominant vegetation type is categorized as tree, shrub, grass, or a combination of the three.
- Bank Erosion Status – this accounts for the average percentage that is actively eroding on both left and right banks of the stream segment, and the height of erosion, as well. Left bank and right bank are the left side and right of the stream banks when looking in the direction of flow.
- Bank Slope – this refers to the average bank slope expressed in degrees.
- Cattle Management – this term indicates whether or not cattle are excluded from entering the stream channel.

The descriptions of the stream parameters shown above were adapted from the research done by Jin et al. (2005c).

Chapter 4

Results and Discussion

Calibration

With the calibration, relative errors for the total flow, surface and baseflow were reduced to less than 10% (Tables 4.1 and 4.2). Simulated total stream flow matched the observed total stream flow fairly well as shown by the scatter plots (Figures 4.1 and 4.3) and by the total flow time series (Figures 4.2 and 4.4).

Table 4.1. Calibration average monthly flow (units are m^3/s) and relative differences of Upper Black Bear Creek (USGS 07153000)

	Observed			Simulated		
	Total	Surface	Baseflow	Total	Surface	Baseflow
Average	8.25	5.74	2.50	8.51	6.09	2.42
Relative Error (R.E.)	-3.19%	-6.04%	3.34%			

$$R.E. = \frac{Observed - Simulated}{Observed} * 100$$

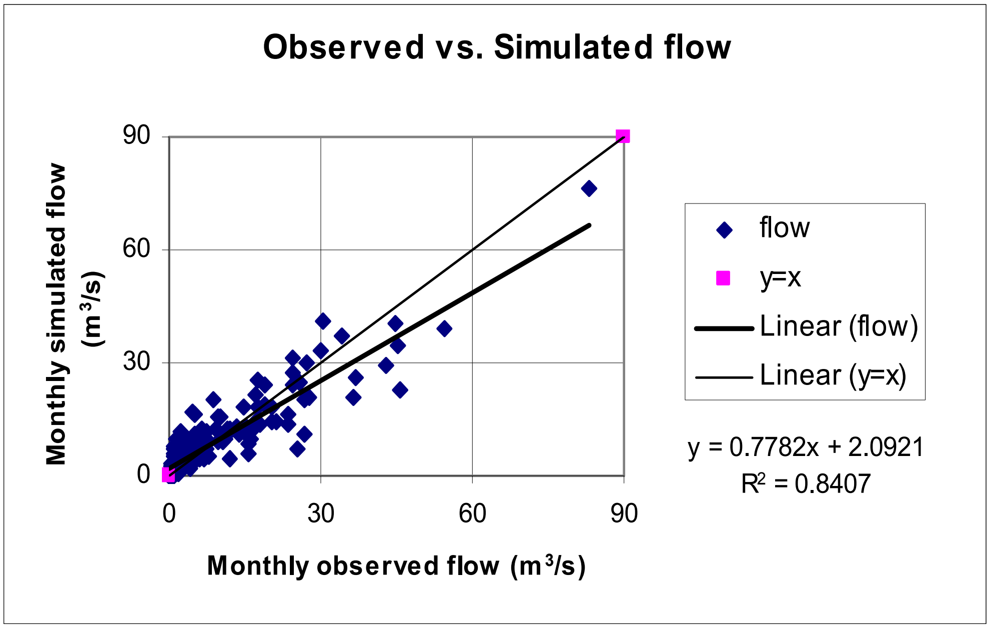

Figure 4.1. Monthly observed stream flow (USGS 07153000) vs. simulated of Upper Black Bear Creek (1988 to 2002)

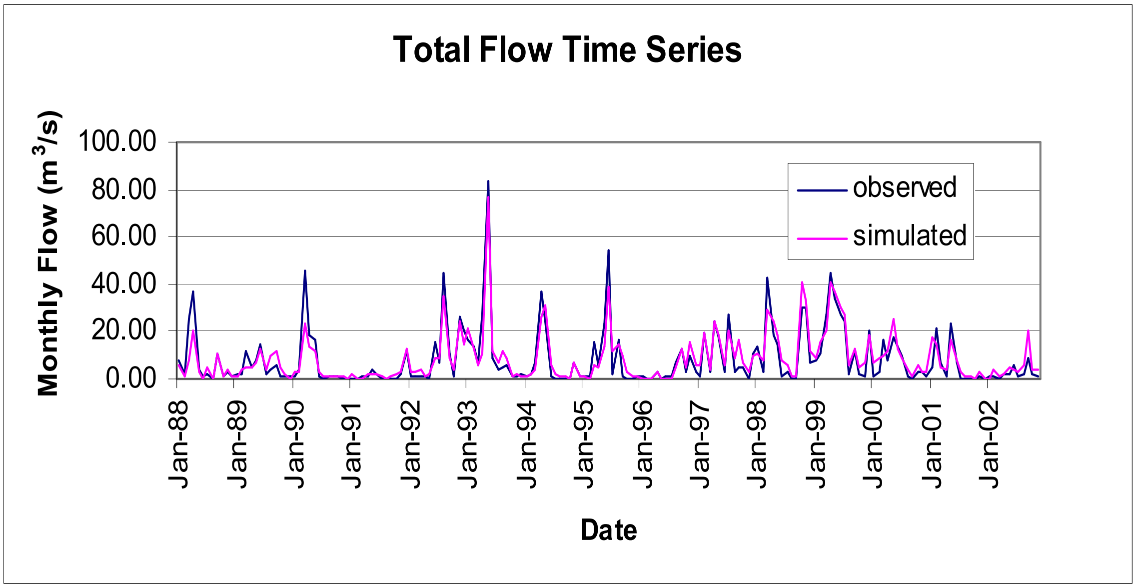

Figure 4.2. Upper Black Bear Creek monthly total flow time series (USGS 07153000)

Table 4.2. Calibration average monthly flow (units are m^3/s) and relative differences of Quapaw Creek (USGS 07242380)

	Observed			Simulated		
	Total	Surface	Baseflow	Total	Surface	Baseflow
Average	8.13	4.61	3.52	8.68	4.89	3.79
Relative Error	-6.78%	-5.94%	-7.89%			

$$R.E. = \frac{Observed - Simulated}{Observed} * 100$$

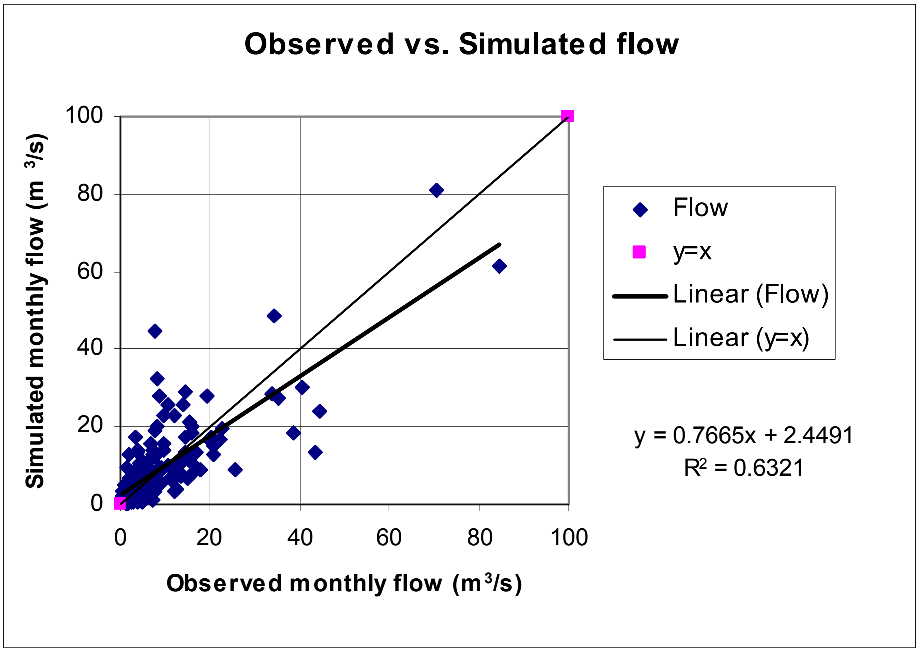

Figure 4.3. Monthly observed stream flow (USGS 07242380) vs. simulated of Quapaw Creek (1988 to 2002)

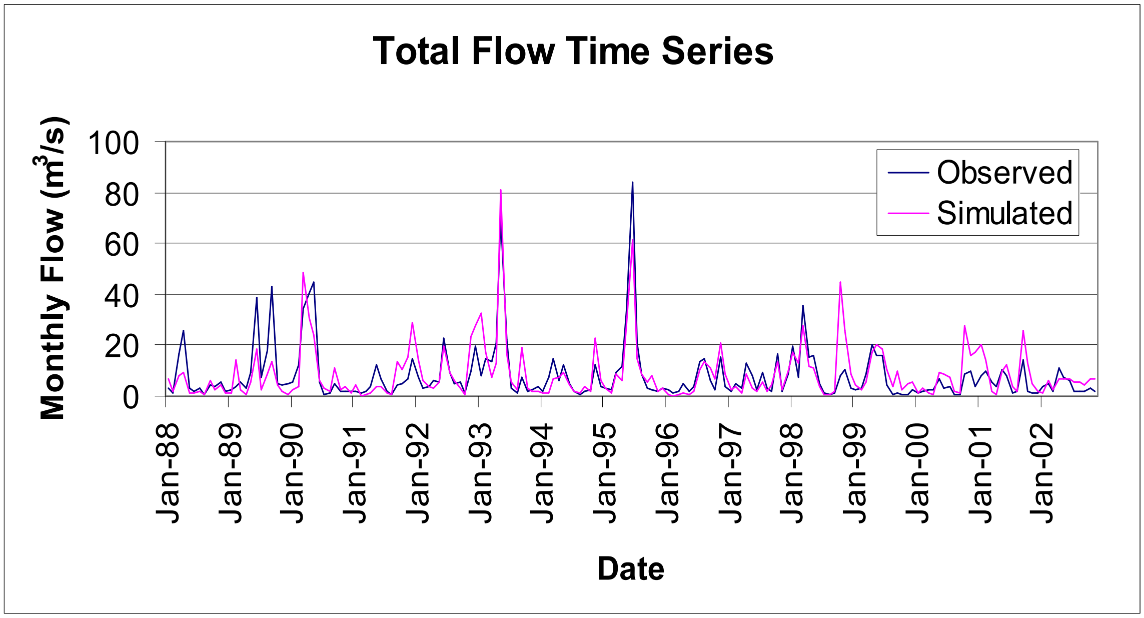

Figure 4.4. Quapaw Creek monthly total flow time series (USGS 07242380)

The flow simulation for the reference stream is considered to be excellent with a Nash-Sutcliffe coefficient of Efficiency (NSE) value of 0.84 (Table 4.3). With a NSE value of 0.60, flow simulation for the impaired stream is considered to be satisfactory.

Surface runoff simulations for the watersheds are considered to be excellent and satisfactory with NSE value of 0.81 and 0.38 for reference and impaired streams respectively. However, for baseflow simulations, only the impaired stream exhibits a satisfactory result with a NSE of 0.39, while the reference stream is considered to be below satisfactory with a NSE of 0.21. But, at any rate, since the NSE results are all positive, this is an indication that the model performance is acceptable as far as flow estimation is concerned. The observed annual precipitation and stream flow variation for the reference is shown in Figures 4.5 a and b, while the annual precipitation and stream flow variation for the impaired stream is shown if Figures 4.6 a and b. In Upper Black

Bear Creek, the average observed precipitation is 973.7 mm, while in Quapaw Creek, the average observed annual precipitation is 1009.4 mm.

Table 4.3. Values of Nash-Sutcliffe coefficient of efficiency (NSE) for the two streams

	Nash-Sutcliffe Coefficient of Efficiency (NSE)		
	Total	Surface	Baseflow
Black Bear Creek: Upper	0.84	0.81	0.21
Quapaw Creek	0.60	0.38	0.39

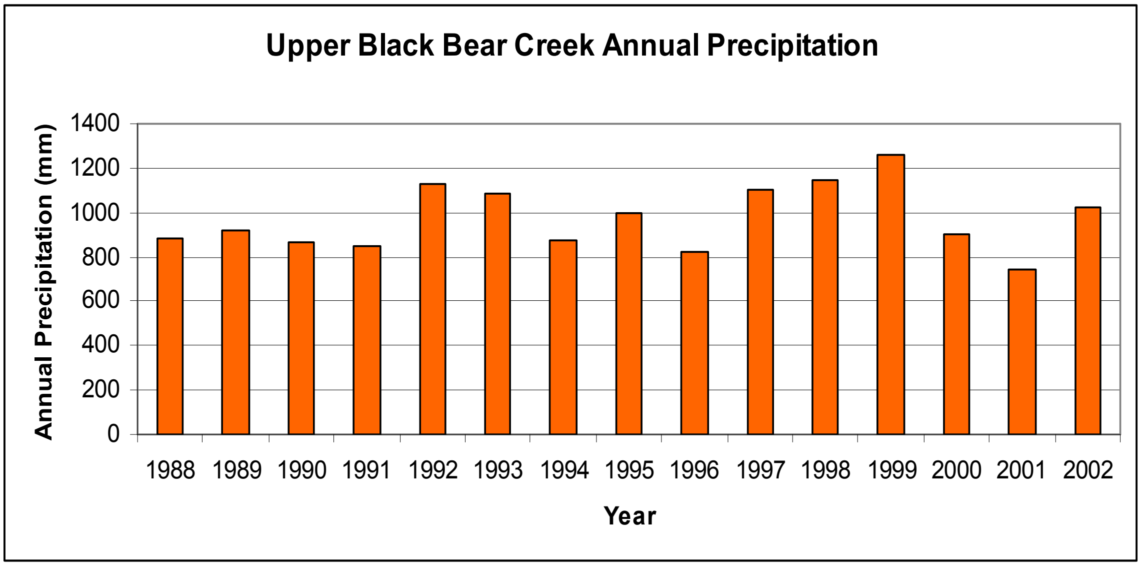

Figure 4.5 a. Observed annual precipitation variation in Upper Black Bear Creek (1988-2002)

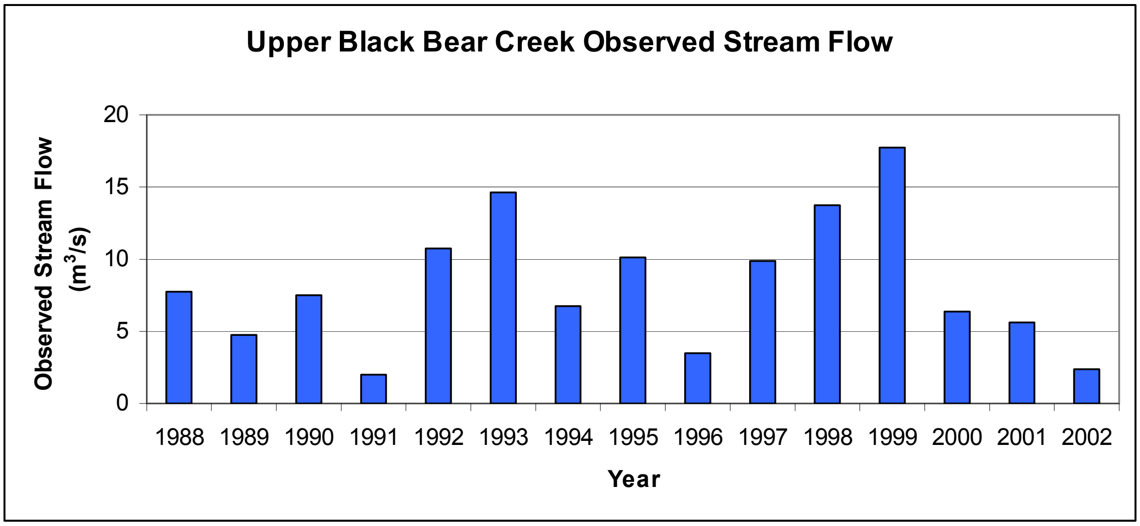

Figure 4.5 b. Observed annual stream flow variation in Upper Black Bear Creek (1988-2002)

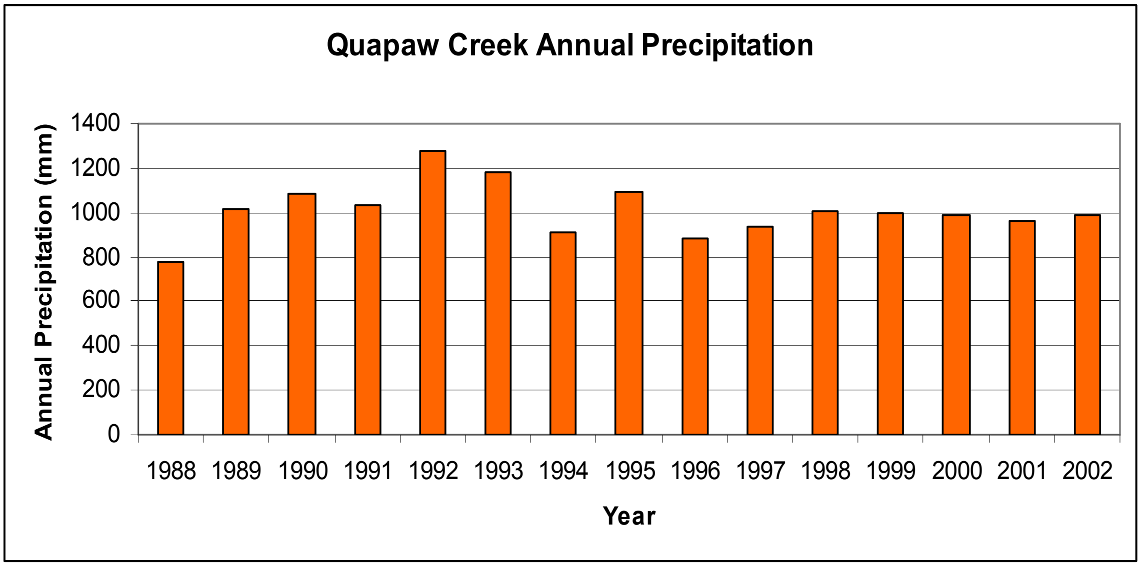

Figure 4.6 a. Observed annual precipitation variation in Quapaw Creek (1988-2002)

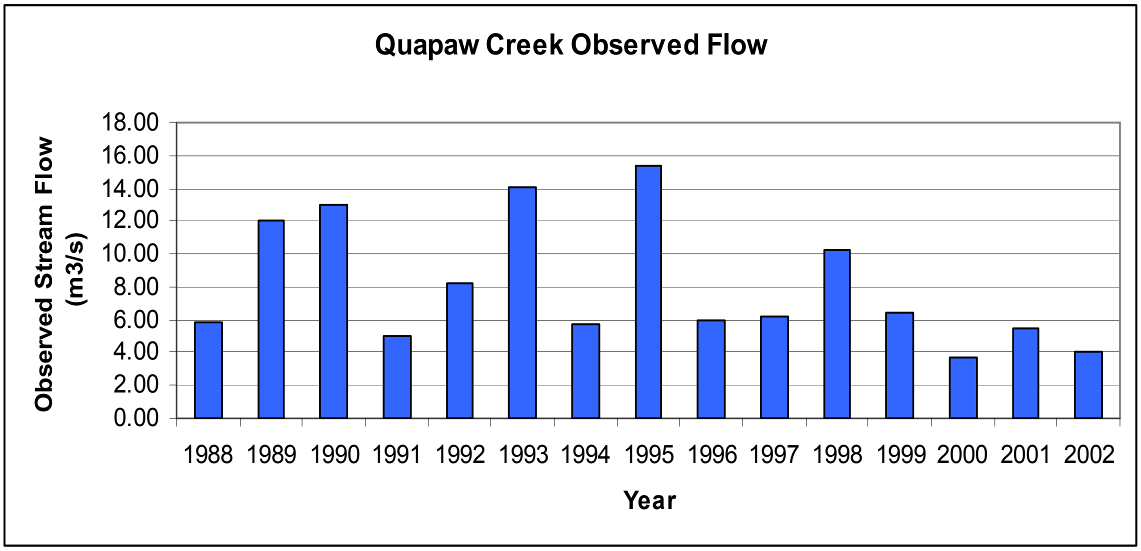

Figure 4.6 b. Observed annual stream flow variation in Quapaw Creek (1988-2002)

Sediment Load and Transport Capacity Comparison

Sediment concentration in Upper Black Bear Creek (reference stream) is higher than in Quapaw Creek (impaired stream) (Figure 4.7). Since slope plays an important role in sediment transport, it is not surprising that the reference stream has a higher concentration, because it is steeper (0.027% slope) than the impaired stream (0.011% slope).

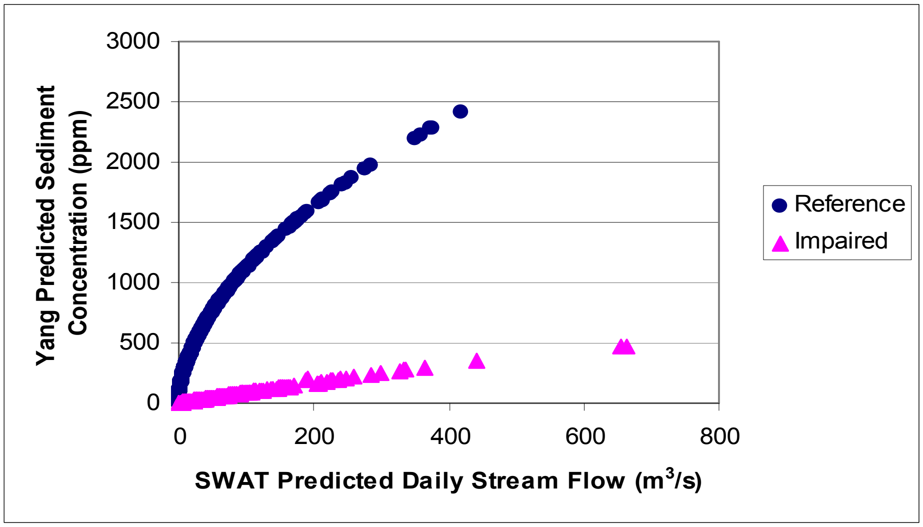

Figure 4.7. Sediment transport capacity based on Yang's Equation versus SWAT predicted daily stream flow

Calculated stream sediment transport capacity and sediment loading from the watersheds for each stream are presented in Figures 4.8 and 4.9. The reference stream has higher transport capacity (Figure 4.8) than the impaired stream (Figure 4.9).

At low stream flow (less than 15.3 x 10^6 m^3/day) in Upper Black Bear Creek (reference stream), there are no significant differences between the sediment load and transport capacity (Figure 4.8). In this case, the stream bed may undergo an alternative process of erosion and deposition (Jin et al., 2005a). When the daily flow exceeds 15.3 x 10^6 m^3, sediment transport capacity becomes higher than the sediment yield from the watershed. At this point, the total amount of sediment (delivered from the watershed plus that deposited during lower flows) is transported out of the stream.

In terms of drainage area, Quapaw Creek (impaired stream) is 30 km^2 less than Upper Black Bear Creek. But, its transport capacity is lower than the amount of sediment coming from the basin (Figure 4.9). Deposition is expected to be the main process that happens in the stream. In this case, the channel bed would have more sand bars than the reference stream (Jin et al., 2005c).

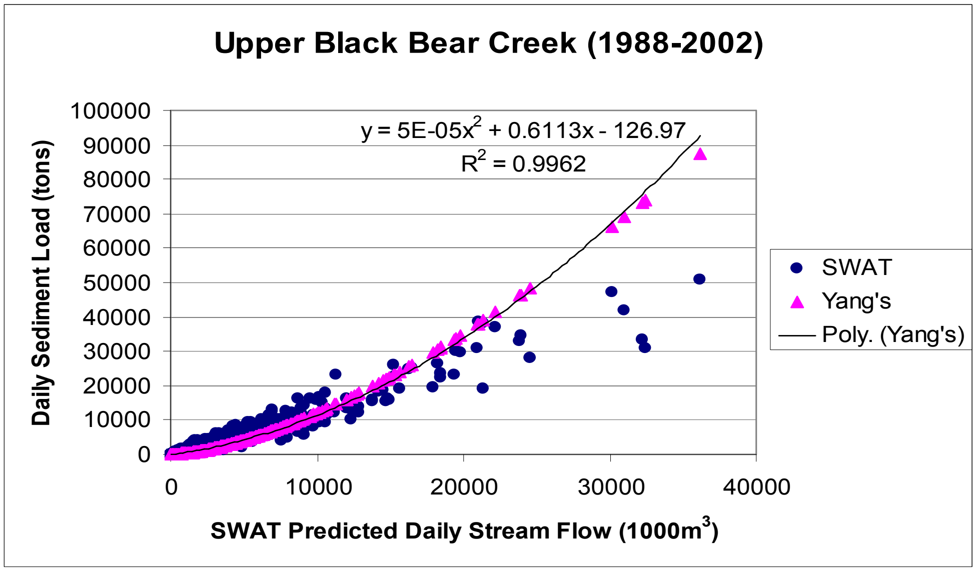

Figure 4.8. Comparison between watershed sediment loading estimated by SWAT and the stream sediment transport capacity computed by Yang's Equation in Upper Black Bear Creek (1988-2002).

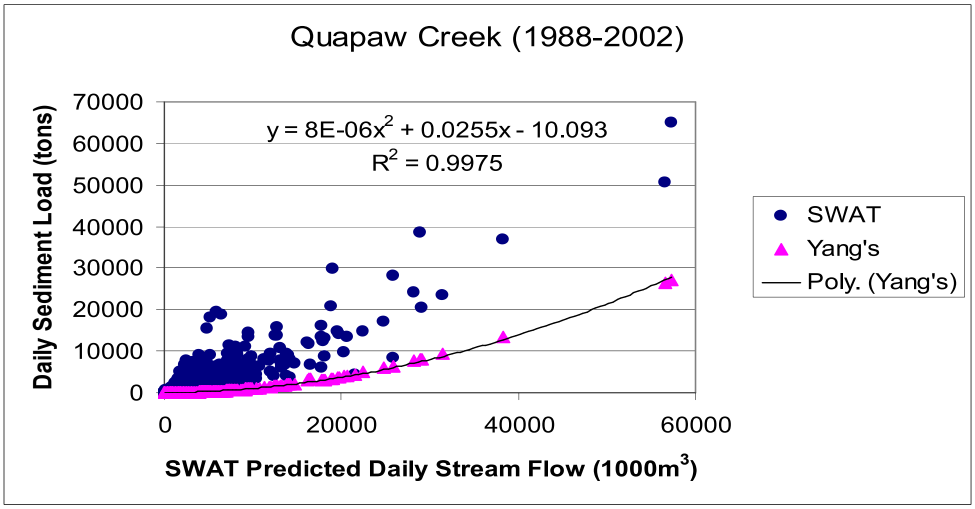

Figure 4.9. Comparison between watershed sediment loading estimated by SWAT and the stream sediment transport capacity computed by Yang's Equation in Quapaw Creek (1988-2002).

The Land Use Land Cover (LULC) of the Quapaw Creek is dominated by 48% rangeland and 38% forest, while Upper Black Bear Creek is dominated by 44% agriculture and 42% range. Considering all other factors being equal, the amount of sediment yield from rangeland is expected to be lower than that from agriculture. In fact, the study done by Storm et al. (2003) to estimate the nonpoint pollution source component of the Fort Cobb Basin TMDL shows that the sediment loads will be lowered by as much as 68% if all crop land (row crop and small grains) would be converted to pasture.

The abovementioned information suggests the idea that excessive sediment yield coming from the watershed is not the reason why the transport capacity of Quapaw Creek (impaired stream) is much lower than its sediment loading (Figure 4.9), but because its (Quapaw Creek) riparian zone by itself is unstable and disturbed. One important fact that would support this claim is bank erosion status presented in Figures 4.22 a and b. Although, there are no data about the cattle being excluded from entering the stream as far as the OCC survey results are concerned, it is highly possible that cattle have been allowed to enter into the stream which contributes to bank erosion. Bank erosion and widened streambed could lead to the stream’s shallow depth which has significantly reduced its transport capacity.

Also, while LULC gives the extent of land use areas, it does not make any qualitative assessment of the condition of the land cover. A seriously overgrazed rangeland area on a sandy loam soil can experience significant soil detachment and delivery to a stream channel by overland flow.

Habitat Characteristics Comparison

Water depth in baseflow conditions in Upper Black Bear Creek (reference stream) is greater than in Quapaw Creek (impaired stream) (Figure 4.10). Over the twenty 20-m segments, the observed water depth in the reference stream on the average, ranges from 0.50 to 1.47 m as compared to a depth of 0.10 to 0.30 m in the impaired stream. This shows that the reference stream has the capacity to support more aquatic life than the impaired one. The deeper the water in the stream, the greater the chance for the fish and other aquatic organisms to survive especially during prolonged periods of drought (Jin et al., 2005c).

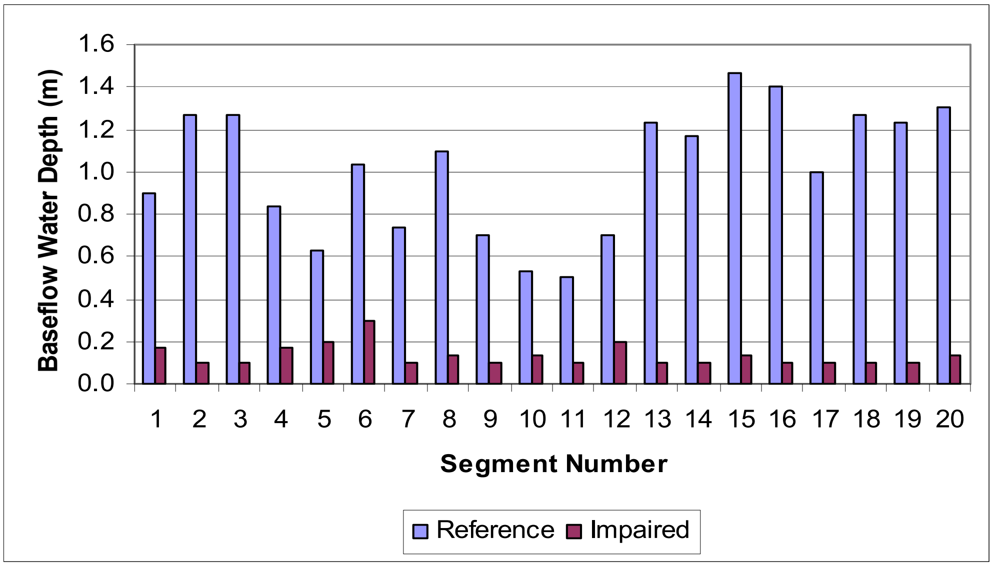

Figure 4.10. Baseflow water depth in the reference and impaired streams

In both baseflow and bankfull flow conditions, the reference stream has a smaller width to depth ratio (Figures 4.11 and 4.12). It has a value of less than twenty in all the stream segments. On the other hand, the impaired stream has larger width to depth ratio in both flow conditions with values as high as 150.

The above information shows that the reference stream is more stable than the impaired one. A high ratio of width to depth is indicative of high bank erosion which would eventually cause the stream to be over-widened and gradually lose its capacity to transport sediment (Jin et al., 2005c).

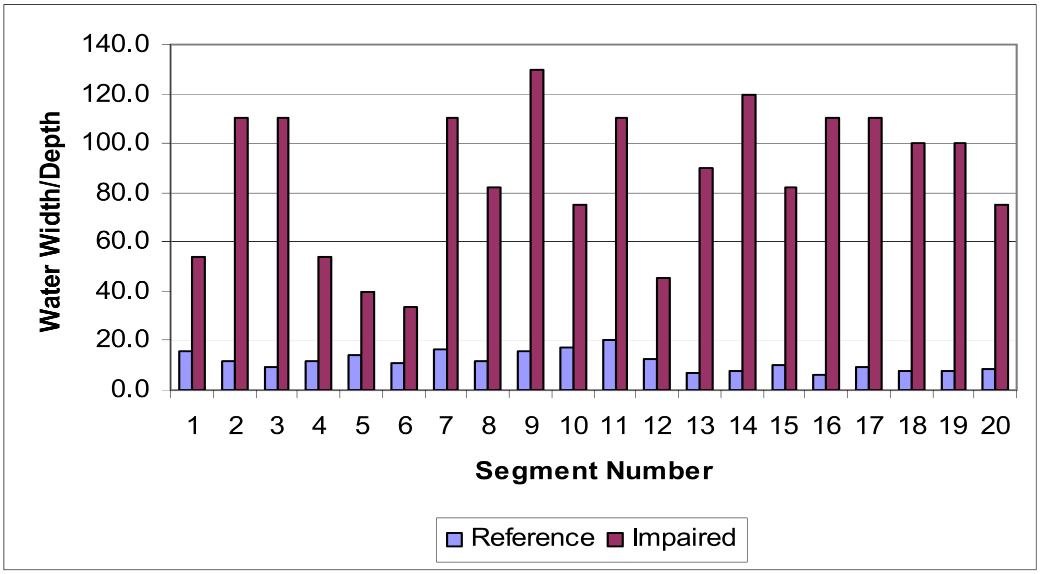

Figure 4.11. Ratio of water width to depth in baseflow conditions

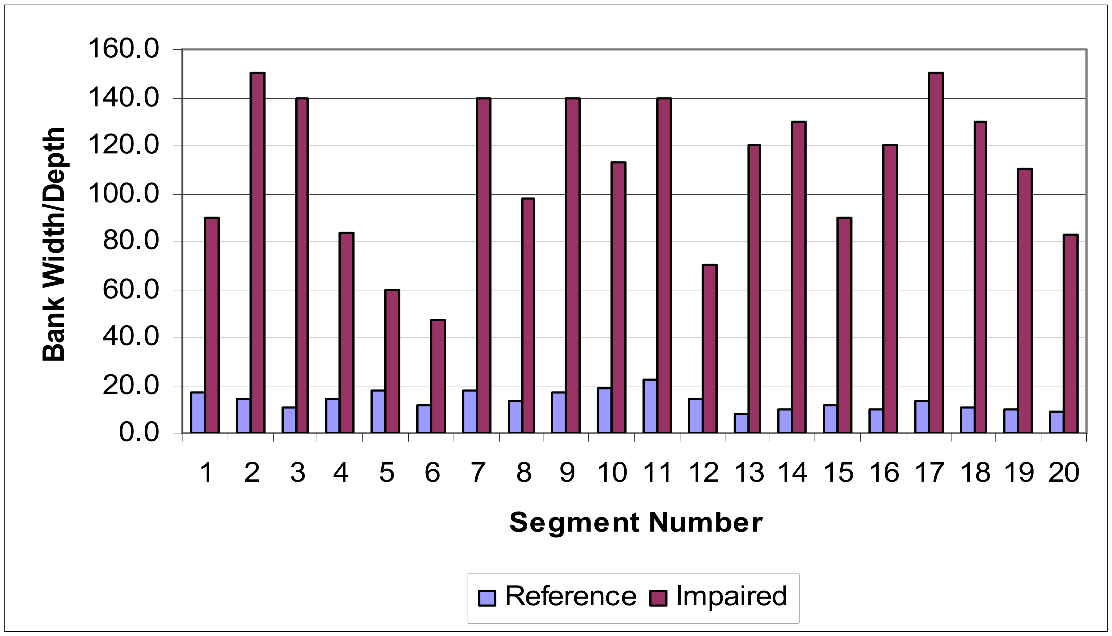

Figure 4.12. Ratio of bank width to water depth

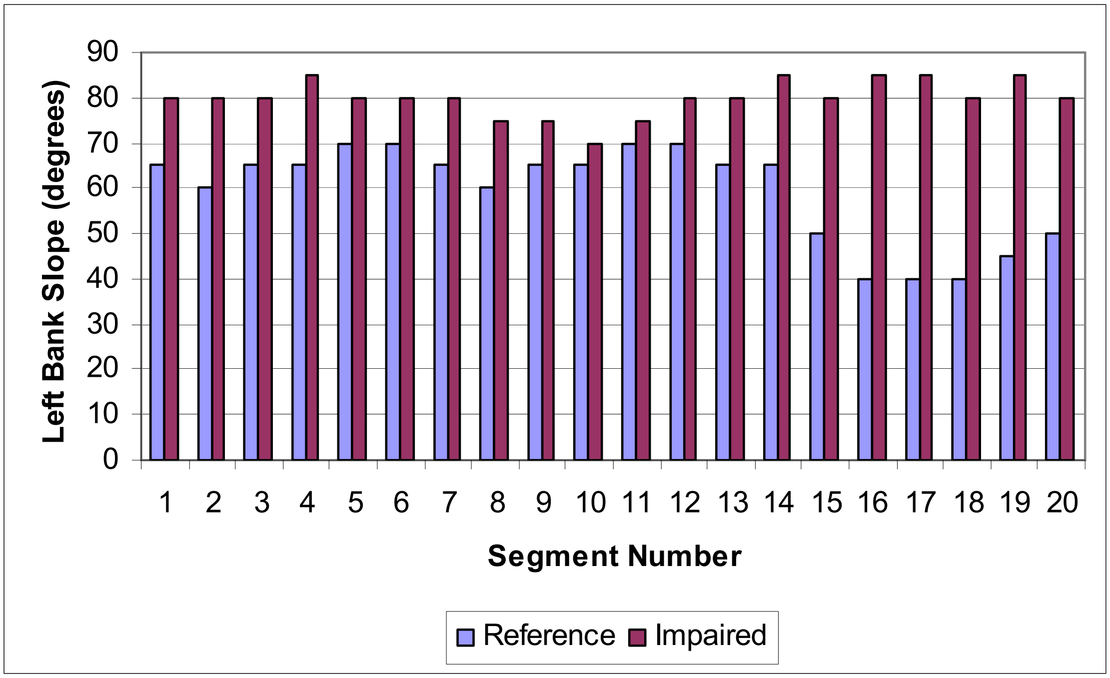

Figure 4.13. Left side bank slope

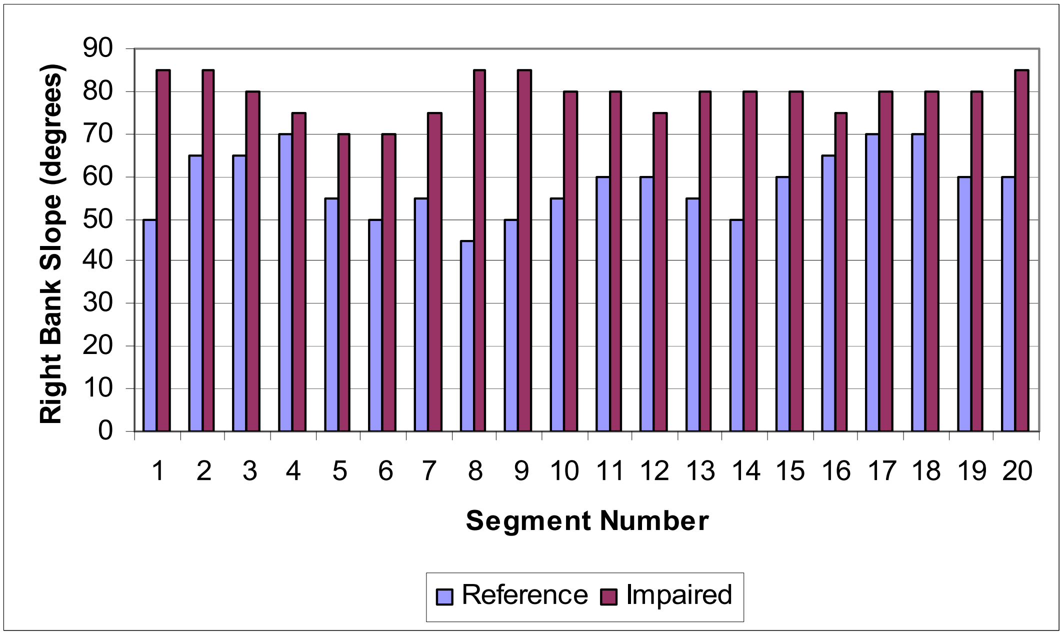

Figure 4.14. Right side bank slope

Research done by Jin et al. (2005c) shows that the reference streams generally have steeper bank slopes than the impaired streams. Reference streams have bank slopes of over 65^o, while the impaired ones have less than 50^o. In this study, however, the result is different. The impaired stream has steeper bank slope compared to the reference stream (Figures 4.13 and 4.14). On the average the impaired stream has 80^o and 79^o left and right side and left side bank slopes respectively, while the reference stream has only a 59^o slope on both sides.

Substrate materials of the reference stream are composed of 37% of loose silt and clay, 3% sand, 11% gravel, 1/2% cobble, 14% bedrock, 1% particulate organic matter, and 35% hardpan clay (Figure 4.15). On the other hand, the impaired stream substrate material composition is dominated by 90% sand and the rest are comprised of 6% loose silt and clay, 1/2% particulate organic matter, and 4% hardpan clay.

Based on the aforementioned information, the reference stream should support more aquatic life. This is due to the fact that large particles such as gravel, cobbles and boulders form more pools which are beneficial to the aquatic organisms (Jin et al., 2005c).

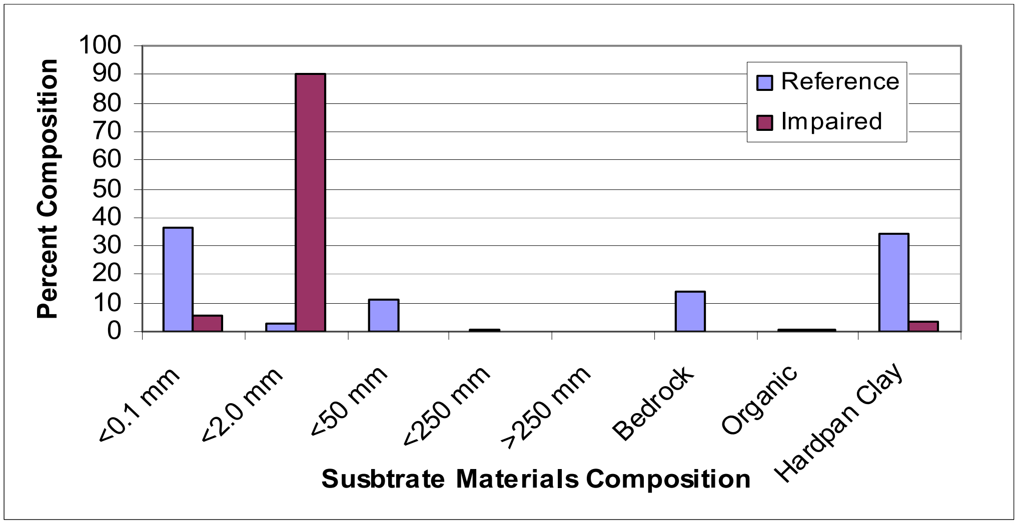

Figure 4.15. Stream substrate materials composition

The observed habitat types in reference and impaired streams are quite different (Figure 4.16). Throughout the twenty segments in the reference stream, seventeen pool and four run habitat types are observed. On the other hand, the impaired stream is dominated by sixteen run and only six pool habitat types.

The riffle habitat type supports more aquatic life than either pools or runs. Its bottom is comprised primarily of larger particles (gravel and rocks) that provide a wide range of living spaces, stable conditions, and large surface areas for the attachment of aquatic organisms. Moreover, it serves as storage for food that is carried in by flowing water (Jin et al, 2005c). For these reasons, riffles are more capable of supporting a wide variety of benthic invertebrates and are thus important food-producing areas for fish (Gordon et al., 1992).

Neither of the streams have the riffle habitat type. The reference stream is dominated by pools, while the impaired stream is dominated by the run habitat (Figure 4.16). The pool habitat serves as an important living space for fish, since it is usually located under overhanging banks or vegetation which not only provide protection from aerial predators but also maintain a cooler environment (Torgersen et al., 1995). It is also an important food-producing area for fish, because it often has large number of burrowing worms and dipteran (true flies) larvae in the substrate (Jin et al., 2005c). Unlike riffles and pools, runs do not provide the same living conditions for aquatic organisms and are not stable. There is a greater chance that they (the runs) will be moved downstream along with organisms living in them by higher flows in the spring and after storm events.

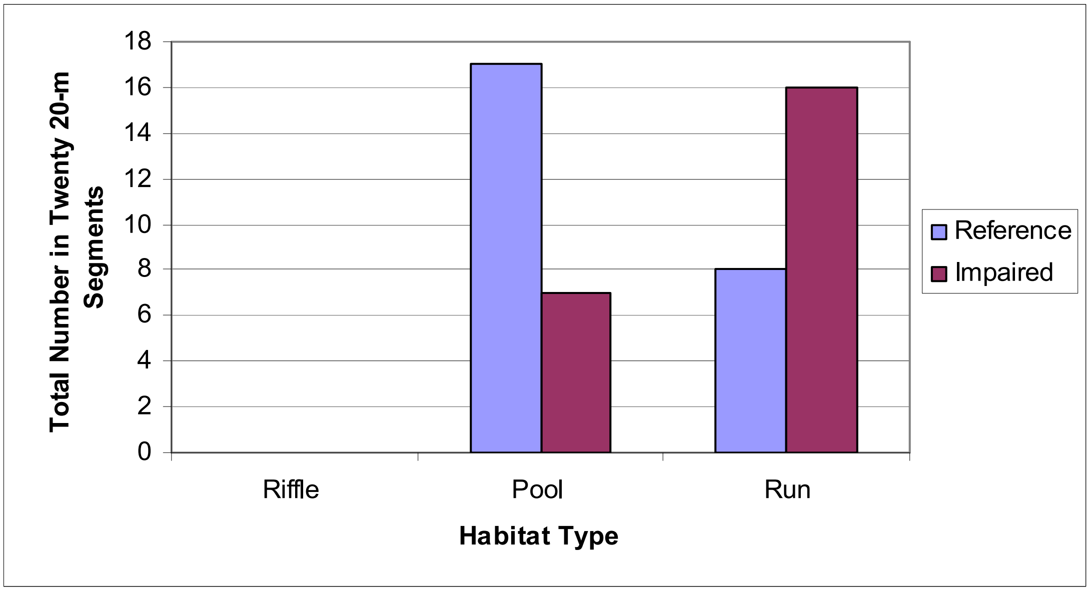

Figure 4.16. Habitat type

There are more woody debris, undercut banks, and the combination of gravel, cobble and boulder in the reference stream than in the impaired stream (Figure 4.17 a, b, c, and d).

Research over the past 20 years indicated that woody debris plays an important role in the healthy functioning of rivers (see Managing Woody Debris in Rivers). In active river channels, large woody debris (LWD) can help to reduce bank and bed erosion by slowing down the flow during major flood events. According to the fact sheet Managing Woody Debris in Rivers, a number of high-energy streams have suffered from major erosion events with incision of beds and subsequent collapse of banks due to extensive de-snagging. Woody debris helps in creating pools in the channel bed system which is very essential for aquatic life during periods of low flow. Water flowing over and around debris becomes aerated and has wide range of flow rates (slow in deep pools, fast around obstructing wood) which is essential for the plant and animal life required for healthy rivers. Woody debris also has many important ecological benefits. It provides surfaces on which microscopic plants (algae) can grow, and ample living space and conditions for aquatic invertebrates such as insect larvae and snails. It also plays an important role in the survival and growth of many fish species. It gives them refuge from predators, while hollow logs serve as an important spawning habitat. The fact sheet Managing Woody Debris Rivers stresses the special importance of large woody debris (LWD) in sandy rivers which do not provide a good aquatic life habitat in light of their constantly-moving bed material. Research has shown that in situations like this, the presence of the LWD is the most important determining factor for the occurrence and diversity of invertebrates and fish populations.

Undercuts, also known as vertical banks because of their overhanging nature, are considered to be an important feature of a healthy stream because they generally provide good shelter for macroinvertebrates and fish (Horan et al., 2000; U.S. EPA, 1997). It is also resistant to erosion, although, if seriously undercut, they might become vulnerable to collapse.

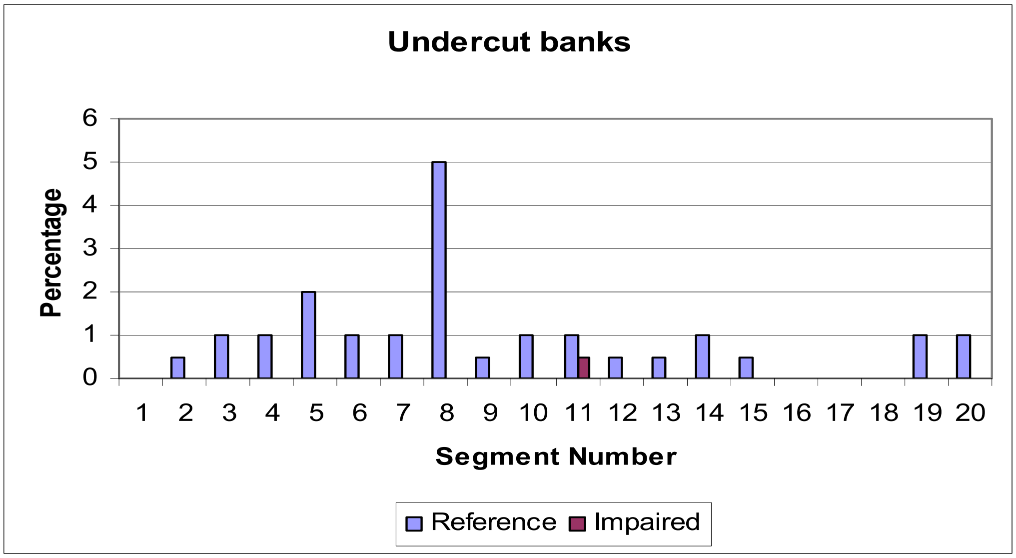

Figure 4.17 a. Instream cover: Undercut banks

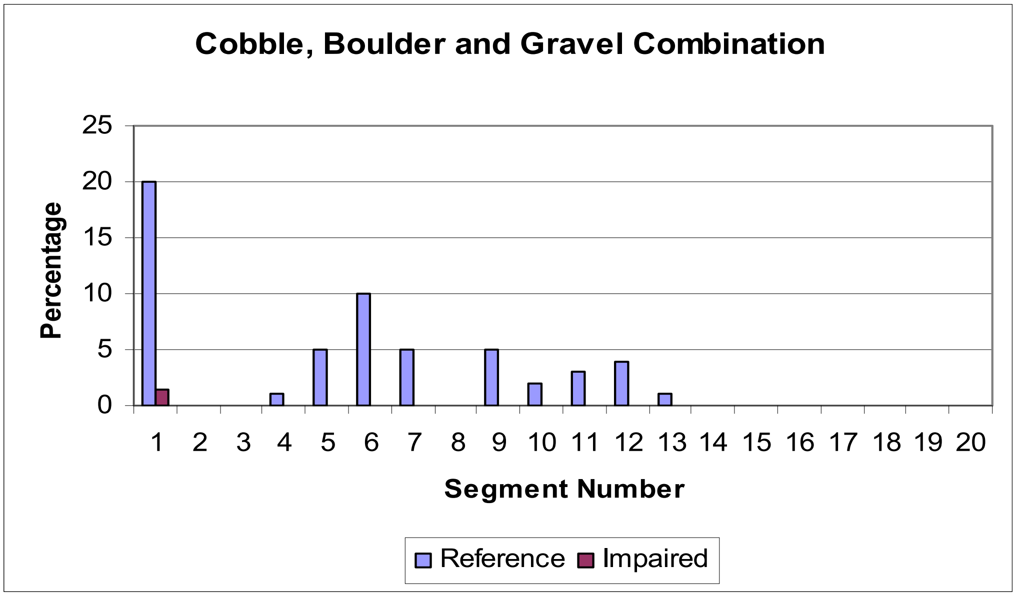

Figure 4.17 b. Instream cover: Cobble, boulder and gravel combination

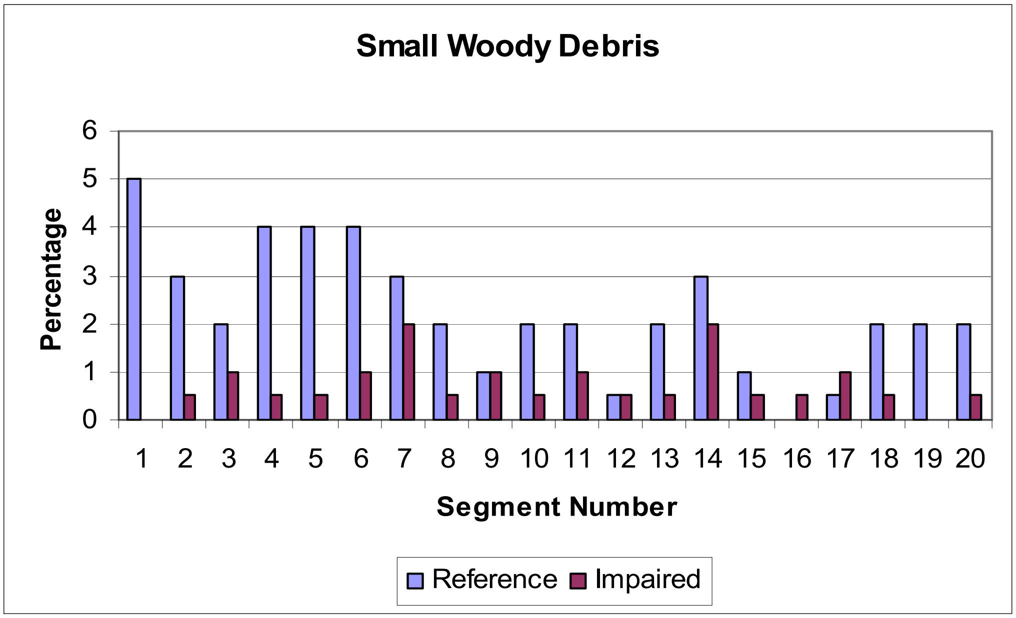

Figure 4.17 c. Instream cover: Small woody debris

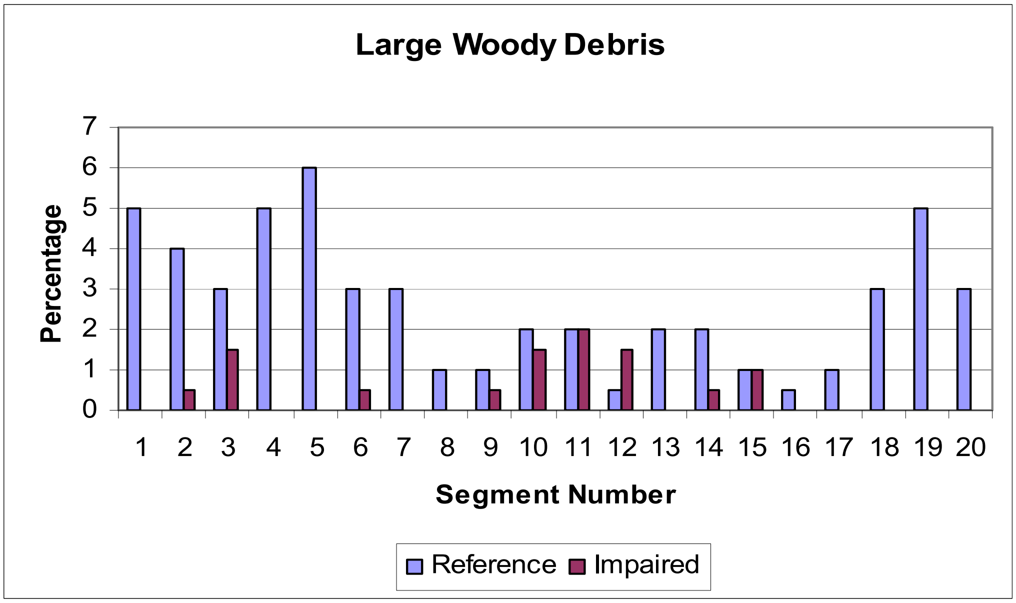

Figure 4.17 d. Instream Cover: Large woody debris

The canopy cover in the reference stream is as high as 40% and only one segment out of twenty that has no canopy cover (Figure 4.18). On the other hand, the impaired stream has 20% canopy cover as its highest with nine out of twenty segments that have no canopy cover at all.

Canopy cover is a measurement of the quality and extent of the riparian zone vegetation (Jin et al., 2005c; U.S. EPA, 1997). Good canopy cover such as trees, bushes and tall grass provides shade and cover for fish and other stream wildlife, which keeps the water temperature at a comfortable level. It also provides the stream with the needed organic input such as leaves and twigs.

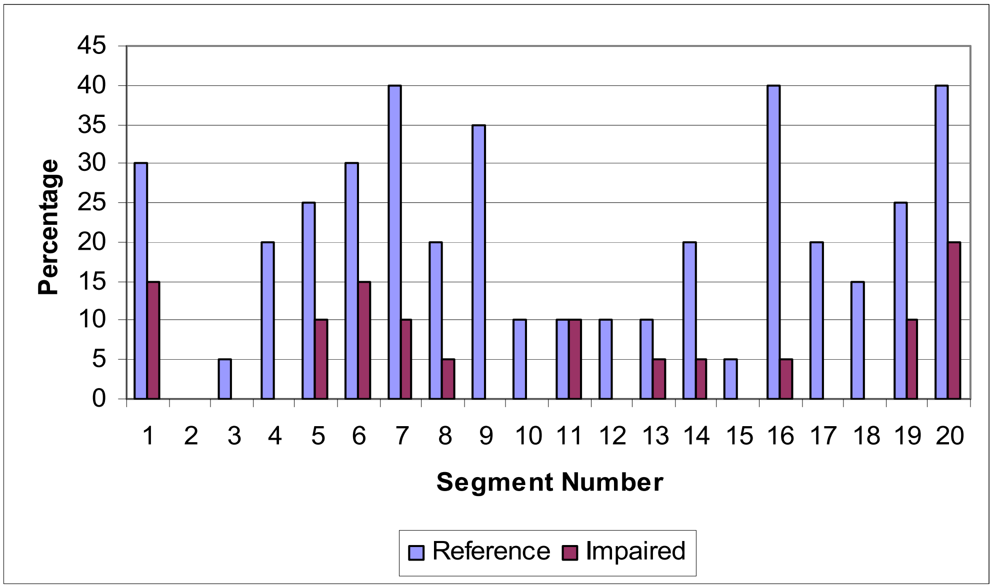

Figure 4.18. Canopy Cover

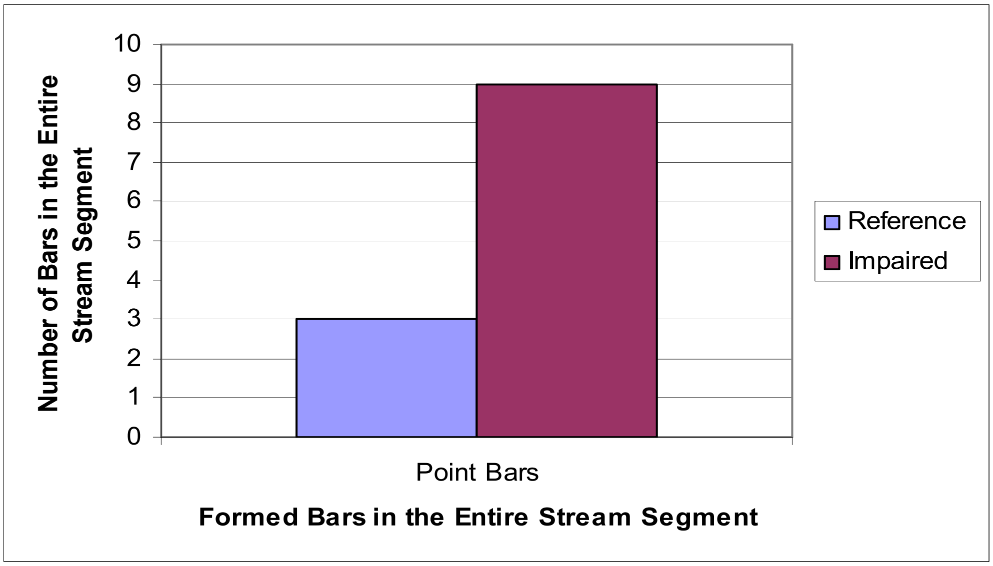

Figure 4.19. Recently Formed Point Bars

The impaired stream has nine recently formed bars, while the reference stream has only three (Figure 4.19).

Point bars are a function of flashy flow and large width-depth ratios. They are formed by sediment deposition generally at bends of meandering rivers. This is because during high flow, a large mass of sediment is emplaced in the channel bend where flow expansion causes deposition. Further deposition takes place by vertical accretion as flows continue to overtop the bar. Subsequent low flows cause erosion of the bar by thalweg meandering and chute channel development, and deposition of fine material takes place in chute channels and on the bar margin. The number of recently formed point bars is an indication of active meandering and bank erosion. (Goodwin and Steidtmann, 1981; Jin et al., 2005c).

The impaired stream has a greater bank vegetation cover rate (Figure 4.20) with a uniform cover of mixed vegetation all throughout, while the reference stream is dominated by mixed vegetation (75%), grass (20%), and tree and shrub (5%) (Figure 4.21).

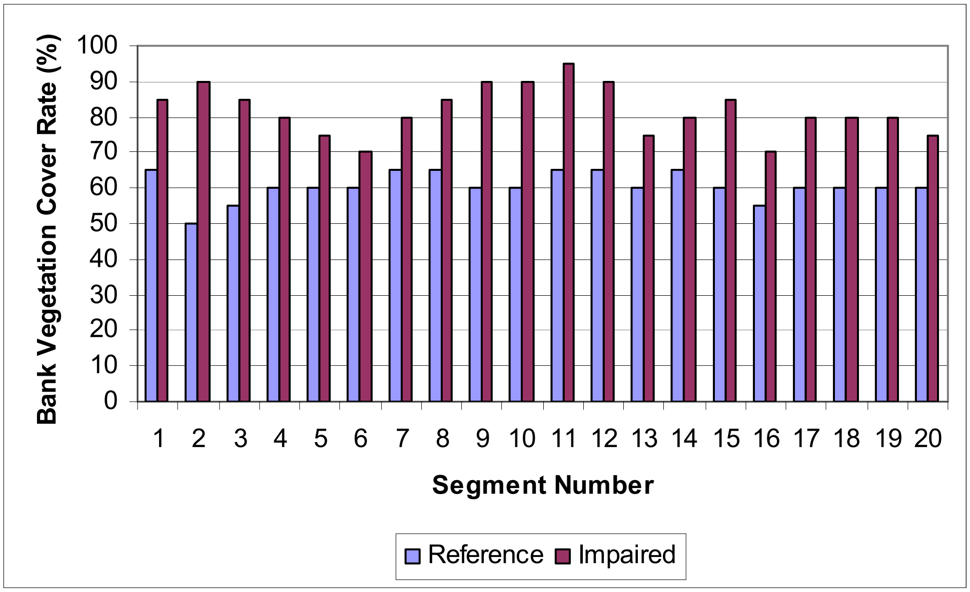

Figure 4.20. Percentage of bank vegetation cover

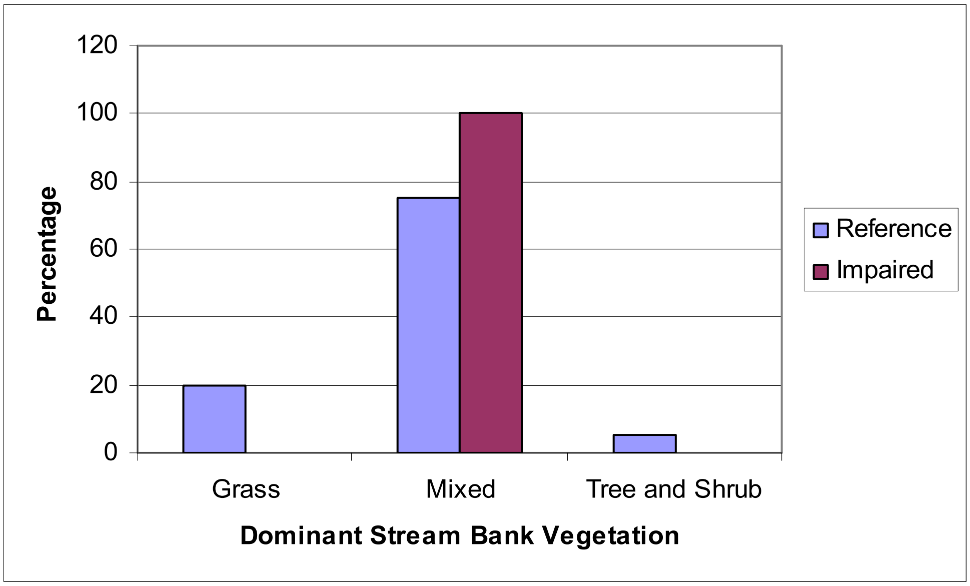

Figure 4.21. Dominant stream bank vegetation

Streambank vegetation is a good indication of stream bank stability which has an indirect influence on the type of habitats available within a stream (Jin et al., 2005c). Vegetation protects the bank from excessive erosion by absorbing the energy of falling raindrops, binding soil particles together, and by slowing overland flow. The mixture of grass, shrubs and trees provides a triple layer of bank protection against raindrop splash, more so, than any of the three alone. Trees and shrubs bind soil particles together better than grass. Trees and shrubs grow on stable stream banks, while grass thrives on frequently moving banks.

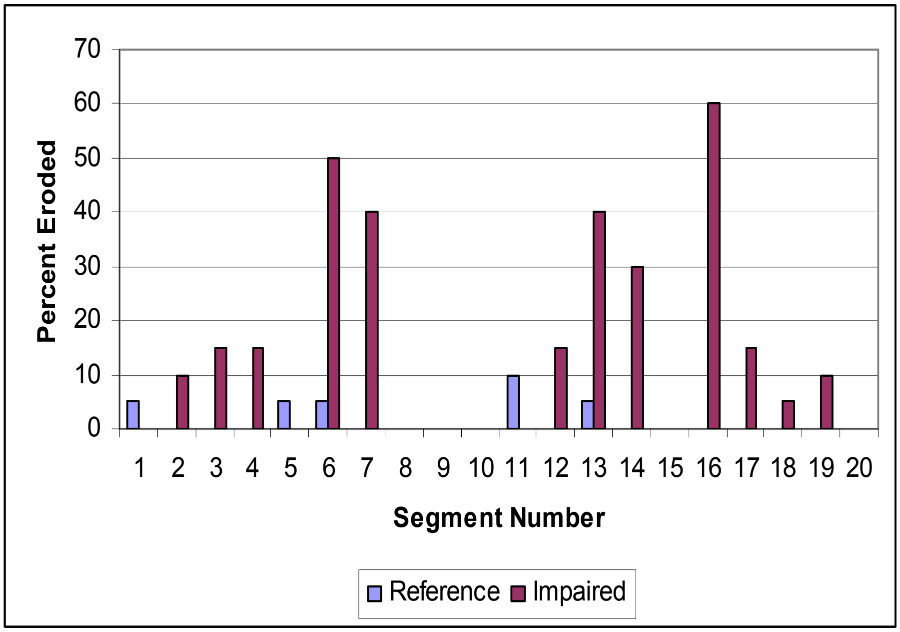

Figure 4.22 a. Percent of bank eroded: Right bank

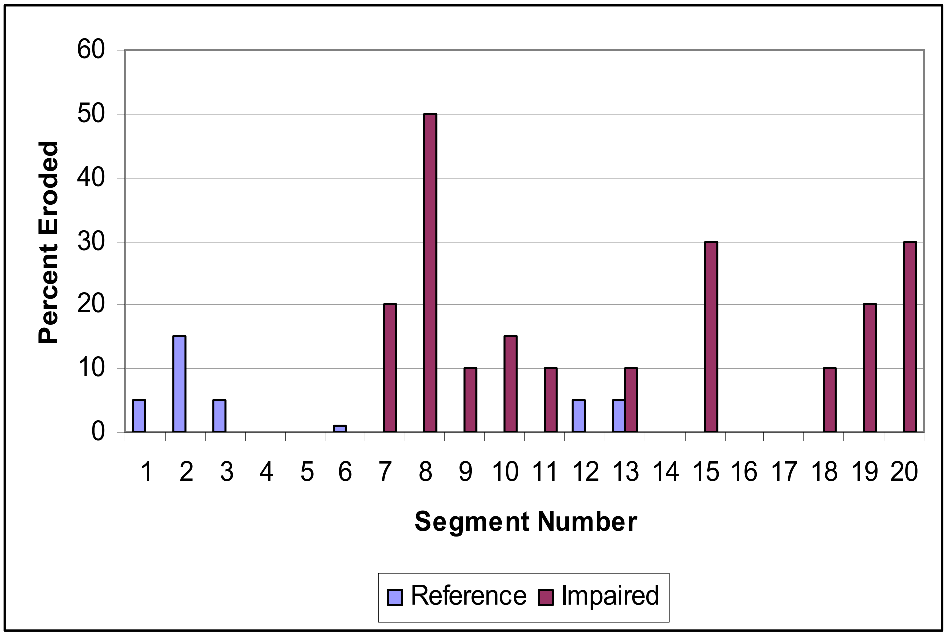

Figure 4.22 b. Percent of bank eroded: Left bank

Bank erosion is a stream's natural way of dissipating the energy of flowing water (see River Dynamics and Erosion). However, excessive erosion can have a detrimental effect on the stream's habitat. When banks erode, pore spaces within gravel and cobble streambeds will be filled by sediment, reducing the living and feeding area of macroinvertebrates such as insect larvae. Stream bank erosion can be accelerated by three major factors: land use change, building of dams, and straightening of streams (see Protecting Streambanks from Erosion).

Both the left and right sides of the impaired streambank have a higher percentage of bank erosion than the reference stream (Figures 4.22 a and b). On the average, the impaired stream has a bank erosion of 25% and 21% on the left and right sides respectively, while the reference stream has only 6% on both sides.

CHAPTER 5

Conclusion

Comparing the sediment loading from the watersheds estimated by SWAT and the stream sediment transport capacity as predicted by Yang's Equation shows that:

1. The reference stream is able to transport the amount of sediment entering in the channel because its transport capacity is equal to or greater than the sediment load. In short, sediment transport is supply limited.

2. The impaired stream is unable to transport the amount of sediment entering in the channel because its transport capacity is less than the sediment load. In short, sediment transport is capacity limited. Deposition becomes the dominant process in the stream channel. Due to over-supply of sediment caused by deposition, the stream channel widens and become shallower.

A number of differences were found by comparing the habitat characteristics, bank vegetation, and channel geometry of the reference and impaired streams:

1. The reference stream has greater water depth and smaller width/depth ratio in both baseflow and bankfull flow conditions. These features indicate that the reference stream provides more favorable conditions for the aquatic life to thrive, especially during dry season.

2. The reference stream's substrate materials composition is comprised of all sizes of particles: loose sand and silt, clay, gravel, and boulders; while the impaired stream is

dominated by sand. The substrates of the reference stream provide more riffle/pool habitats, and allow a wider range of diversity than the predominantly run habitat and sandy bed of the impaired stream.

3. The reference stream has more woody debris and undercut banks which are good signs of ample living space and food supply.

4. The impaired stream contains more recently-formed point bars, which is an indication of active bank erosion.

5. The impaired stream has a higher percentage of bank erosion.

There are two findings in this study that are worthy of comment in terms of the habitat characteristics comparison:

1. The bank slope of the impaired stream is steeper than the bank slope of the reference stream. Jin et al. (2005c) report that the opposite is true.

2) The bank vegetation cover of the impaired stream is higher than the reference stream.

The impaired stream substrate materials are predominantly sand, while the reference stream has 35% clay, 37% loose silt and clay. However, while these materials are eroded from the stream channel, they may not have necessarily come from the habitat assessment zone. The combination of clay and sandy soil materials would make a more stable bank. The alternate cutting/collapse of sandy banks may account for the steeper bank slopes in the impaired stream.

Though the percentage of vegetation cover is greater in the impaired stream, neither habitat assessment indicated the presence or exclusion of cattle in the riparian area. Even with good riparian vegetation in the assessment area, cattle movement into the stream bed maybe a contributing factor to the impaired stream condition.

Suggestions for Future Work

In any modeling work, the quality of the input data is considered to be extremely important because of its tremendous impact on the results. The quality of land use data in SWAT plays a very significant role as far as watershed sediment estimation is concerned. Among the input data, land use is perhaps the most important to consider because it changes dramatically with time, unlike soils and topography. In this study, the land cover data used were taken from 1992 USGS National Land Cover Dataset. This land use information was used because this was the only available data that worked during the time the study was conducted and of the inability of the author to generate more recent data using other means. In future studies related to this work, substantial effort must be taken to incorporate the most recent information about the land use land cover.

Land use land cover data layer does not indicate the quality of land cover. By default agricultural land use would yield more sediment than rangeland/pasture under any given rainfall considering all other factors the same. However, a severely overgrazed rangeland/pasture in a highly erodible soil could also yield a considerable amount of sediment. A visual assessment of the study area to get an idea of the quality of land cover may help draw a better conclusion on sediment yield estimation.

Despite a higher percentage of bank vegetation cover in Quapaw Creek (impaired stream), its percentage of bank erosion is significantly higher than the Upper Black Bear Creek (reference stream). In this case, identifying the soil type and composition of the bank and information on whether or not cattle are excluded from entering the stream, especially in areas which are predominantly pasture and rangeland, would allow more accurate conclusions regarding bank erosion.

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APPENDICES

Appendix A: Basic Soil Properties of the Watersheds

Table A1.1. Some Basic Soil Properties for Upper Black Bear Creek watershed (Excerpt from SWAT database file "sol.dbf")

SNAM	STMUID	HYDGRP	USLEK	Z1	BD1	AWC1	K1	CLAY1	SILT1	SAND1	ROCK1
GRAINOLA	OK086	D	0.37	203.2	1.45	0.17	10.00	31.00	33.55	35.45	10.00
BETHANY	OK093	C	0.43	355.6	1.40	0.21	8.70	17.5	53.35	29.15	0.00
NORGE	OK106	B	0.37	304.8	1.40	0.25	1.9	20.5	68.14	11.36	0.00
RENFROW	OK116	D	0.49	228.6	1.42	0.22	6.10	22.00	52.07	25.93	0.00
AGRA	OK131	D	0.49	279.4	1.42	0.23	3.30	18.00	54.74	27.26	0.00
SHIDLER	OK138	D	0.32	177.8	1.45	0.20	1.60	31.00	49.00	20.00	14.35
NIOTAZE	OK148	C	0.37	254.0	1.35	0.16	18.00	18.5	38.54	42.96	13.49

Table A1.2. Some Basic Soil Properties for Quapaw Creek watershed (Excerpt from SWAT database file "sol.dbf")

SNAM	STMUID	HYDGRP	USLEK	Z1	BD1	AWC1	K1	CLAY1	SILT1	SAND1	ROCK1
KEOKUK	OK091	B	0.37	304.8	1.42	0.24	3.30	14.00	71.84	14.16	0.00
KIRKLAND	OK094	B	0.49	254.0	1.40	0.22	6.7	19.5	53.74	26.76	0.00
RENFROW	OK116	D	0.49	228.6	1.42	0.22	6.10	22.00	52.07	25.93	0.00
ZANEIS	OK125	B	0.37	279.4	1.45	0.19	21.00	20.50	37.59	41.91	0.55
EUFAULA	0K146	A	0.15	1016.0	1.42	0.11	280.00	5.00	0.61	94.39	0.54
DARNELL	OK151	C	0.20	127.0	1.48	0.14	58.00	15.00	19.67	65.53	7.71

Appendix B: Weather Stations Used in the Study

Table B1.1. Information on Cooperative Observations (COOP) Stations from the National Oceanic and Atmospheric Administration (NOAA) for the Upper Black Bear Creek watershed.

ID	NAME	X COORDINATE	Y-COORDINATE	ELEVATION
1	OK6940_P	697420	4024815	255
2	OK7012_P	652678	4016477	313
3	OK7390_P	703042	4041596	252
4	OK8501_P	671003	3998396	273
5	OK7505_P	664236	4037108	262
6	OK0755_P	638760	4043984	305
7	OK5540_P	708187	4013966	288

Projection: UTM Zone 14
Units: Meters

Table B1.2. Information on Cooperative Observations (COOP) Stations from the National Oceanic and Atmospheric Administration (NOAA) for the Quapaw Creek watershed

ID	NAME	X COORDINATE	Y-COORDINATE	ELEVATION
1	OK3821_P	644547	3964596	314
2	OK1684_P	691539	3952541	291
3	OK5779_P	682945	3930165	282
4	OK6661_P	627161	3916219	390
5	OK8501_P	671004	3998360	273
6	OK2318_P	701345	3984202	290
7	OK7003_P	677344	3981343	274

Projection: UTM Zone 14
Units: Meters

Appendix C: Stream flow data

Table C1.1. Monthly observed and simulated flow (m^3/s) at Upper Black Bear Creek (USGS 07153000)

Date	Observed			Simulated		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Jan-88	7.86	5.24	2.62	5.94	5.43	0.50
Feb-88	1.48	0.23	1.25	0.96	0.58	0.38
Mar-88	25.19	18.65	6.54	7.98	7.19	0.79
Apr-88	36.43	27.43	9.00	23.19	21.09	2.10
May-88	3.45	1.68	1.77	5.14	2.58	2.56
Jun-88	0.77	0.10	0.67	1.89	0.40	1.48
Jul-88	2.33	1.58	0.75	5.97	4.88	1.09
Aug-88	0.23	0.05	0.18	0.46	0.00	0.45
Sep-88	11.06	8.79	2.27	10.17	9.78	0.39
Oct-88	0.91	0.39	0.52	1.24	0.39	0.84
Nov-88	2.50	1.74	0.76	4.21	3.34	0.86
Dec-88	0.56	0.10	0.46	0.78	0.03	0.75
Jan-89	1.69	1.17	0.53	0.74	0.31	0.43
Feb-89	1.76	1.06	0.69	3.84	3.52	0.33
Mar-89	11.81	10.18	1.62	4.26	4.05	0.21
Apr-89	4.78	2.58	2.21	4.43	0.30	4.14
May-89	7.49	5.67	1.81	6.72	6.22	0.50
Jun-89	15.02	11.47	3.55	12.15	11.17	0.98
Jul-89	1.80	0.57	1.22	4.61	3.06	1.55
Aug-89	3.83	2.64	1.19	9.40	8.36	1.03
Sep-89	5.92	4.91	1.01	11.77	10.66	1.11
Oct-89	1.04	0.66	0.38	4.82	4.00	0.81
Nov-89	0.75	0.24	0.51	2.05	0.04	2.01
Dec-89	0.51	0.09	0.41	0.54	0.27	0.28
Jan-90	1.01	0.45	0.56	3.17	2.99	0.17
Feb-90	4.23	3.13	1.11	2.58	2.50	0.08
Mar-90	45.50	32.05	13.45	23.14	21.31	1.83
Apr-90	18.13	11.43	6.70	15.91	10.02	5.89
May-90	16.26	10.55	5.71	15.04	7.98	7.06
Jun-90	1.26	0.47	0.79	6.32	0.24	6.08
Jul-90	0.22	0.05	0.17	3.05	0.06	2.99
Aug-90	0.60	0.33	0.27	1.79	0.49	1.31
Sep-90	1.09	0.99	0.10	2.25	1.69	0.56
Oct-90	0.58	0.45	0.13	1.28	0.75	0.53
Nov-90	0.23	0.07	0.16	1.05	0.63	0.42
Dec-90	0.25	0.07	0.19	0.25	0.01	0.23
Jan-91	0.39	0.07	0.32	1.95	1.81	0.14
Feb-91	0.37	0.02	0.34	0.02	0.00	0.02
Mar-91	0.49	0.09	0.40	0.04	0.02	0.02
Apr-91	1.11	0.73	0.38	1.63	1.58	0.05

Table C1.1. Monthly observed and simulated flow (m^3/s) at Upper Black Bear Creek (USGS 07153000) (continued)

Date	Observed			Simulated		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
May-91	3.99	3.27	0.72	1.81	1.71	0.10
Jun-91	2.41	1.68	0.73	2.38	2.10	0.29
Jul-91	0.18	0.11	0.06	0.71	0.51	0.20
Aug-91	0.00	0.00	0.00	0.03	0.00	0.03
Sep-91	0.14	0.11	0.03	0.95	0.86	0.10
Oct-91	0.20	0.15	0.05	1.35	1.27	0.08
Nov-91	2.03	1.68	0.34	2.62	2.14	0.48
Dec-91	12.09	10.45	1.63	10.91	9.47	1.44
Jan-92	0.85	0.17	0.69	2.67	0.02	2.65
Feb-92	0.59	0.18	0.42	2.03	0.05	1.98
Mar-92	1.37	0.94	0.43	3.62	2.63	0.99
Apr-92	0.78	0.40	0.38	0.90	0.66	0.23
May-92	0.45	0.20	0.25	1.33	0.91	0.42
Jun-92	15.84	11.46	4.37	7.01	6.83	0.17
Jul-92	6.37	5.02	1.35	7.16	6.42	0.73
Aug-92	45.08	33.20	11.88	33.61	31.65	1.96
Sep-92	10.66	6.14	4.52	8.32	5.28	3.04
Oct-92	0.72	0.18	0.54	2.68	0.64	2.03
Nov-92	25.85	18.44	7.41	25.54	23.90	1.64
Dec-92	20.24	12.32	7.91	15.25	7.78	7.47
Jan-93	16.85	10.42	6.42	23.70	13.15	10.55
Feb-93	13.43	6.71	6.73	14.87	6.75	8.12
Mar-93	7.13	2.77	4.36	8.03	1.99	6.05
Apr-93	26.99	21.12	5.87	12.69	10.62	2.07
May-93	83.06	46.80	36.26	78.47	67.92	10.55
Jun-93	9.12	4.48	4.64	15.82	1.54	14.28
Jul-93	4.06	1.82	2.24	11.43	2.48	8.95
Aug-93	5.19	4.35	0.84	14.38	10.29	4.09
Sep-93	5.67	4.61	1.06	9.71	7.55	2.17
Oct-93	0.53	0.07	0.46	1.14	0.04	1.10
Nov-93	1.37	0.63	0.74	1.81	1.22	0.59
Dec-93	1.62	0.63	0.99	0.72	0.18	0.54
Jan-94	0.74	0.10	0.64	0.48	0.05	0.43
Feb-94	1.70	0.93	0.77	1.91	1.67	0.24
Mar-94	7.02	4.89	2.13	4.06	3.15	0.91
Apr-94	37.01	29.78	7.23	25.30	24.23	1.07
May-94	24.24	14.55	9.68	30.09	20.27	9.82
Jun-94	1.27	0.56	0.71	5.33	0.58	4.75
Jul-94	0.44	0.22	0.22	2.56	0.28	2.28
Aug-94	0.27	0.13	0.14	1.99	1.09	0.90
Sep-94	0.22	0.10	0.12	0.79	0.20	0.58
Oct-94	0.37	0.14	0.23	0.15	0.01	0.14
Nov-94	6.60	5.28	1.32	6.23	6.01	0.22

Table C1.1. Monthly observed and simulated flow (m^3/s) at Upper Black Bear Creek (USGS 07153000) (continued)

Date	**Observed**			**Simulated**		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Dec-94	0.69	0.09	0.60	0.44	0.00	0.43
Jan-95	0.61	0.07	0.54	0.72	0.38	0.33
Feb-95	0.71	0.23	0.48	0.12	0.01	0.11
Mar-95	15.77	13.54	2.23	5.21	4.90	0.31
Apr-95	5.61	3.87	1.74	3.71	3.03	0.69
May-95	23.37	17.72	5.65	11.52	9.63	1.89
Jun-95	54.29	29.55	24.74	36.55	31.29	5.26
Jul-95	2.42	1.25	1.16	11.47	3.72	7.75
Aug-95	16.94	11.55	5.38	13.61	9.49	4.12
Sep-95	1.19	0.61	0.58	9.29	6.77	2.52
Oct-95	0.32	0.05	0.26	2.26	0.33	1.93
Nov-95	0.33	0.03	0.30	1.12	0.00	1.12
Dec-95	0.64	0.17	0.47	0.98	0.44	0.54
Jan-96	0.50	0.10	0.40	0.20	0.00	0.19
Feb-96	0.42	0.11	0.31	0.35	0.25	0.10
Mar-96	0.37	0.06	0.31	0.03	0.01	0.02
Apr-96	2.84	2.37	0.47	2.97	2.93	0.04
May-96	0.41	0.11	0.30	0.07	0.05	0.02
Jun-96	0.56	0.38	0.19	0.15	0.13	0.02
Jul-96	0.70	0.56	0.14	0.35	0.34	0.02
Aug-96	7.28	5.40	1.87	4.45	4.35	0.10
Sep-96	12.87	11.58	1.30	10.89	10.59	0.30
Oct-96	2.80	1.68	1.12	3.93	2.51	1.42
Nov-96	9.81	8.11	1.70	14.03	11.68	2.35
Dec-96	2.92	1.47	1.45	5.41	0.53	4.88
Jan-97	0.76	0.09	0.67	5.46	1.97	3.49
Feb-97	19.04	15.44	3.60	18.96	17.10	1.86
Mar-97	3.06	0.97	2.09	3.48	0.40	3.09
Apr-97	24.46	18.16	6.30	23.34	20.01	3.33
May-97	17.52	13.36	4.17	17.42	12.56	4.86
Jun-97	3.08	2.05	1.03	5.61	3.23	2.38
Jul-97	26.90	22.22	4.68	20.63	17.84	2.79
Aug-97	3.24	1.97	1.28	8.74	6.63	2.10
Sep-97	5.02	4.39	0.63	15.99	14.23	1.76
Oct-97	4.49	3.64	0.84	6.18	4.03	2.15
Nov-97	0.49	0.07	0.42	2.34	0.05	2.28
Dec-97	11.03	8.45	2.58	9.40	7.80	1.61
Jan-98	13.84	10.13	3.71	10.54	5.71	4.83
Feb-98	2.93	0.67	2.25	7.21	1.35	5.86
Mar-98	42.87	31.12	11.75	29.28	24.96	4.32
Apr-98	18.70	15.34	3.35	23.40	17.17	6.23
May-98	14.89	8.85	6.04	18.48	7.77	10.71
Jun-98	1.02	0.40	0.62	8.03	0.54	7.49

Table C1.1. Monthly observed and simulated flow (m^3/s) at Upper Black Bear Creek (USGS 07153000) (continued)

Date	**Observed**			**Simulated**		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Jul-98	3.16	2.79	0.38	7.55	3.51	4.04
Aug-98	0.15	0.02	0.13	1.83	0.03	1.80
Sep-98	0.11	0.03	0.08	1.68	0.92	0.76
Oct-98	30.37	25.22	5.15	39.66	38.63	1.03
Nov-98	29.98	22.22	7.75	32.15	26.94	5.21
Dec-98	6.62	3.41	3.20	11.78	3.23	8.55
Jan-99	7.80	6.50	1.29	9.16	5.81	3.35
Feb-99	10.38	6.20	4.17	16.63	4.87	11.76
Mar-99	27.47	18.46	9.00	20.47	13.42	7.05
Apr-99	44.82	35.30	9.53	39.99	31.37	8.62
May-99	34.36	19.16	15.20	36.16	24.26	11.90
Jun-99	27.26	19.50	7.76	29.47	19.06	10.41
Jul-99	24.62	18.76	5.86	27.57	11.87	15.70
Aug-99	1.84	1.12	0.72	8.47	1.95	6.52
Sep-99	11.48	8.38	3.09	13.61	10.38	3.23
Oct-99	1.67	1.21	0.46	4.70	3.72	0.98
Nov-99	0.95	0.35	0.61	6.69	0.36	6.33
Dec-99	20.38	15.60	4.78	17.99	15.19	2.80
Jan-00	1.20	0.10	1.10	5.62	0.91	4.72
Feb-00	3.31	1.74	1.57	8.53	4.73	3.80
Mar-00	16.06	10.37	5.69	9.78	6.66	3.12
Apr-00	7.58	4.49	3.09	10.76	3.88	6.88
May-00	17.36	14.70	2.67	24.96	18.45	6.51
Jun-00	13.45	8.03	5.42	12.59	7.50	5.09
Jul-00	9.81	7.46	2.35	9.37	6.03	3.34
Aug-00	1.20	0.55	0.65	3.91	0.05	3.86
Sep-00	0.11	0.01	0.10	1.05	0.00	1.05
Oct-00	2.51	2.15	0.36	6.00	5.47	0.53
Nov-00	3.09	2.21	0.88	2.27	1.71	0.56
Dec-00	0.65	0.11	0.54	2.30	1.74	0.56
Jan-01	4.62	3.35	1.27	15.79	15.50	0.29
Feb-01	21.03	16.73	4.30	13.74	13.35	0.39
Mar-01	7.06	2.19	4.87	4.18	1.01	3.18
Apr-01	1.40	0.22	1.17	2.60	0.19	2.41
May-01	23.54	20.77	2.77	16.11	15.10	1.01
Jun-01	7.19	4.23	2.96	7.75	2.47	5.28
Jul-01	0.37	0.13	0.24	2.65	0.88	1.78
Aug-01	0.12	0.02	0.10	1.24	0.29	0.95
Sep-01	0.26	0.15	0.11	1.04	0.59	0.45
Oct-01	0.06	0.01	0.05	0.07	0.00	0.07
Nov-01	0.92	0.76	0.16	3.63	3.46	0.16
Dec-01	0.20	0.03	0.17	0.07	0.00	0.07
Jan-02	0.81	0.66	0.15	0.16	0.10	0.06

Table C1.1. Monthly observed and simulated flow (m^3/s) at Upper Black Bear Creek (USGS 07153000) (continued)

Date	**Observed**			**Simulated**		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Feb-02	0.86	0.50	0.36	3.31	3.02	0.28
Mar-02	0.29	0.05	0.23	0.77	0.43	0.34
Apr-02	1.58	1.12	0.46	1.88	1.61	0.27
May-02	2.19	1.61	0.58	4.16	3.60	0.56
Jun-02	6.05	5.03	1.02	3.07	2.43	0.63
Jul-02	0.61	0.35	0.27	1.79	1.43	0.36
Aug-02	1.78	1.46	0.32	4.84	4.51	0.33
Sep-02	8.71	7.29	1.42	17.66	17.19	0.47
Oct-02	2.40	1.43	0.97	2.89	1.96	0.92
Nov-02	1.16	0.40	0.76	1.93	0.01	1.93
Average	**8.25**	**5.74**	**2.50**	**8.51**	**6.09**	**2.40**

Calibration parameter adjustments for the Black Bear Creek: Upper area:

ESCO = 0.98
Curve Number = -5.4
Available Water Content = +0.035
Revap Coefficient = 0.05
Minimum Depth of Water in Shallow Aquifer for Revap to Occur = 310
Minimum Depth of Water in Shallow Aquifer for Baseflow to occur = 305

Table C1.2. Monthly observed and simulated flow (m^3/s) at Quapaw Creek (USGS 07242380)

Date	Observed			Simulated		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Jan-88	2.88	1.51	1.37	6.78	6.71	0.07
Feb-88	1.33	0.36	0.97	1.56	1.47	0.09
Mar-88	16.53	12.79	3.74	8.18	6.06	2.11
Apr-88	25.69	15.80	9.90	9.12	6.01	3.12
May-88	3.25	0.96	2.29	1.06	0.14	0.92
Jun-88	2.00	0.96	1.03	1.17	0.86	0.31
Jul-88	3.12	1.71	1.42	1.56	0.72	0.84
Aug-88	0.88	0.41	0.47	0.63	0.38	0.25
Sep-88	4.01	2.32	1.69	6.15	4.58	1.56
Oct-88	3.66	1.60	2.06	2.30	1.20	1.10
Nov-88	5.32	2.75	2.57	4.10	3.15	0.95
Dec-88	1.72	0.15	1.57	1.05	0.56	0.49
Jan-89	2.21	0.62	1.58	1.01	0.57	0.44
Feb-89	3.95	1.50	2.45	14.09	13.55	0.54
Mar-89	5.26	3.05	2.21	2.58	1.76	0.82
Apr-89	2.86	0.88	1.98	0.34	0.00	0.34
May-89	9.27	6.10	3.17	5.61	4.28	1.33
Jun-89	38.79	25.53	13.26	18.61	14.39	4.22
Jul-89	7.39	3.10	4.29	2.72	0.36	2.36
Aug-89	17.85	12.86	5.00	8.77	6.18	2.59
Sep-89	43.24	32.42	10.82	13.59	10.88	2.71
Oct-89	4.78	2.95	1.84	4.19	3.02	1.17
Nov-89	4.00	0.63	3.38	2.02	0.01	2.00
Dec-89	4.73	1.26	3.47	0.40	0.17	0.23
Jan-90	5.42	1.69	3.73	2.69	2.22	0.47
Feb-90	12.49	7.12	5.37	3.83	3.14	0.69
Mar-90	34.53	22.12	12.40	48.60	36.38	12.22
Apr-90	40.64	24.88	15.76	30.43	12.77	17.66
May-90	44.65	24.47	20.17	24.03	10.68	13.35
Jun-90	5.65	1.77	3.88	6.38	0.26	6.12
Jul-90	0.88	0.08	0.81	2.81	0.49	2.32
Aug-90	1.40	0.72	0.68	2.12	0.88	1.23
Sep-90	4.84	3.78	1.06	11.15	9.57	1.58
Oct-90	2.13	0.75	1.38	2.28	0.44	1.83
Nov-90	1.93	0.72	1.21	3.82	1.95	1.87
Dec-90	2.06	0.75	1.32	1.36	0.32	1.04
Jan-91	2.03	0.49	1.55	4.08	3.77	0.31
Feb-91	1.49	0.26	1.23	0.09	0.00	0.08
Mar-91	1.68	0.43	1.25	0.63	0.39	0.24
Apr-91	3.39	2.28	1.11	1.08	0.53	0.54
May-91	12.05	8.41	3.63	3.48	2.28	1.20
Jun-91	6.90	2.34	4.56	3.53	1.86	1.66
Jul-91	1.91	0.90	1.02	1.45	0.47	0.98
Aug-91	0.70	0.12	0.57	0.85	0.52	0.32
Sep-91	4.07	2.33	1.73	13.48	9.97	3.51

Table C1.2. Monthly observed and simulated flow (m^3/s) at Quapaw Creek (USGS 07242380) (continued)

Date	Observed			Simulated		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Oct-91	4.73	3.88	0.85	10.16	5.73	4.43
Nov-91	6.92	4.86	2.06	15.58	6.58	9.00
Dec-91	14.70	10.09	4.61	28.95	16.61	12.34
Jan-92	7.23	2.28	4.95	14.00	0.57	13.43
Feb-92	3.15	0.29	2.85	6.02	0.37	5.65
Mar-92	3.48	0.80	2.68	3.84	0.73	3.11
Apr-92	6.22	3.32	2.90	3.22	1.43	1.79
May-92	5.69	1.98	3.71	5.43	3.13	2.31
Jun-92	22.75	15.30	7.44	19.74	11.36	8.38
Jul-92	9.29	5.41	3.89	9.39	1.01	8.38
Aug-92	4.84	3.73	1.11	6.26	2.39	3.88
Sep-92	5.73	3.34	2.39	2.81	1.06	1.75
Oct-92	1.32	0.07	1.25	0.72	0.21	0.51
Nov-92	9.83	6.22	3.61	23.11	17.08	6.03
Dec-92	19.34	11.26	8.09	27.85	9.25	18.60
Jan-93	8.16	1.88	6.29	32.26	13.70	18.56
Feb-93	14.62	6.20	8.42	17.25	6.17	11.08
Mar-93	13.62	5.76	7.86	7.51	2.17	5.34
Apr-93	20.78	12.82	7.96	12.66	8.59	4.07
May-93	70.64	36.11	34.52	81.07	61.01	20.06
Jun-93	22.32	6.39	15.92	16.79	1.33	15.46
Jul-93	2.86	0.83	2.02	5.46	0.19	5.27
Aug-93	1.21	0.41	0.80	2.57	0.57	2.00
Sep-93	7.65	4.61	3.04	19.13	15.01	4.12
Oct-93	1.54	0.19	1.36	3.18	0.05	3.13
Nov-93	2.26	0.51	1.75	1.81	0.31	1.49
Dec-93	3.43	0.97	2.46	1.98	0.39	1.59
Jan-94	1.86	0.29	1.58	0.93	0.00	0.93
Feb-94	7.27	3.92	3.35	1.36	0.74	0.62
Mar-94	14.74	9.07	5.67	6.50	3.31	3.19
Apr-94	5.97	3.29	2.68	7.23	3.94	3.29
May-94	11.99	7.72	4.28	9.38	5.30	4.09
Jun-94	4.60	1.80	2.80	4.32	2.34	1.98
Jul-94	1.88	1.10	0.79	2.12	0.85	1.27
Aug-94	0.70	0.22	0.48	1.20	0.55	0.65
Sep-94	1.89	1.08	0.80	3.42	2.17	1.25
Oct-94	2.42	1.21	1.20	1.81	0.98	0.83
Nov-94	12.27	7.08	5.19	22.96	17.70	5.26
Dec-94	3.75	1.37	2.38	6.31	0.06	6.25
Jan-95	2.79	0.77	2.02	2.85	0.45	2.39
Feb-95	2.47	1.03	1.44	1.47	0.48	0.99
Mar-95	9.12	6.23	2.89	8.81	5.72	3.08
Apr-95	11.57	6.86	4.71	6.25	2.65	3.59
May-95	34.04	22.31	11.72	28.29	20.40	7.89
Jun-95	84.35	46.62	37.73	61.55	40.06	21.49

Table C1.2. Monthly observed and simulated flow (m^3/s) at Quapaw Creek (USGS 07242380) (continued)

Date	Observed			Simulated		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Jul-95	20.91	6.36	14.55	14.88	0.45	14.43
Aug-95	8.56	5.62	2.94	8.30	2.42	5.88
Sep-95	2.82	0.64	2.17	5.33	1.46	3.87
Oct-95	2.57	1.14	1.43	8.26	3.57	4.69
Nov-95	1.84	0.09	1.75	2.02	0.01	2.02
Dec-95	2.97	1.15	1.82	2.85	1.78	1.07
Jan-96	2.31	0.71	1.60	0.33	0.00	0.33
Feb-96	1.33	0.06	1.27	0.08	0.00	0.08
Mar-96	1.80	0.55	1.25	0.33	0.19	0.14
Apr-96	5.18	3.79	1.39	1.06	0.72	0.34
May-96	1.60	0.36	1.23	0.80	0.64	0.16
Jun-96	3.81	2.09	1.72	2.11	1.44	0.67
Jul-96	13.48	9.97	3.51	10.71	8.85	1.86
Aug-96	14.52	6.90	7.62	13.66	9.09	4.57
Sep-96	6.13	2.86	3.27	11.29	6.51	4.78
Oct-96	2.50	1.18	1.31	6.99	0.73	6.25
Nov-96	15.26	8.87	6.39	21.12	15.44	5.68
Dec-96	3.41	1.13	2.28	8.36	0.00	8.36
Jan-97	1.58	0.24	1.34	2.48	0.23	2.25
Feb-97	4.97	3.53	1.44	3.53	2.06	1.47
Mar-97	3.07	1.02	2.05	1.02	0.25	0.76
Apr-97	13.01	6.77	6.24	8.55	6.32	2.23
May-97	7.91	4.30	3.60	3.12	1.29	1.84
Jun-97	2.42	0.99	1.43	1.66	0.78	0.88
Jul-97	9.21	7.47	1.74	5.65	4.14	1.50
Aug-97	3.19	1.55	1.64	2.13	1.00	1.12
Sep-97	1.55	1.18	0.37	4.07	3.12	0.95
Oct-97	16.74	11.66	5.07	13.31	10.76	2.55
Nov-97	1.88	0.71	1.17	2.70	0.25	2.44
Dec-97	8.77	6.07	2.70	9.57	7.16	2.40
Jan-98	19.79	10.92	8.87	16.97	8.57	8.40
Feb-98	7.37	4.06	3.31	12.67	5.40	7.27
Mar-98	35.36	21.86	13.50	27.42	22.95	4.47
Apr-98	15.53	10.62	4.91	11.92	6.68	5.24
May-98	15.77	6.43	9.34	10.78	5.95	4.83
Jun-98	4.94	3.07	1.86	3.87	1.03	2.85
Jul-98	0.98	0.10	0.89	0.87	0.01	0.86
Aug-98	0.64	0.06	0.58	0.32	0.03	0.29
Sep-98	1.12	0.59	0.53	2.14	1.48	0.66
Oct-98	7.91	6.39	1.52	44.75	39.61	5.14
Nov-98	10.62	6.43	4.20	25.72	7.22	18.50
Dec-98	3.33	1.03	2.30	8.83	1.21	7.62
Jan-99	2.57	0.68	1.89	4.19	2.12	2.07
Feb-99	3.07	1.23	1.84	2.53	0.90	1.63
Mar-99	8.77	5.40	3.37	5.43	3.12	2.32

Table C1.2. Monthly observed and simulated flow (m^3/s) at Quapaw Creek (USGS 07242380) (continued)

Date	**Observed**			**Simulated**		
	Total Flow	Surface	Baseflow	Total flow	Surface	Baseflow
Apr-99	20.08	17.22	2.86	17.24	13.11	4.13
May-99	15.84	10.59	5.25	20.36	9.18	11.18
Jun-99	16.01	12.01	4.00	18.56	9.81	8.75
Jul-99	4.16	2.09	2.07	10.44	1.05	9.39
Aug-99	0.71	0.02	0.69	3.54	0.28	3.26
Sep-99	1.31	0.60	0.71	9.62	6.18	3.43
Oct-99	0.73	0.10	0.63	2.36	1.00	1.36
Nov-99	0.90	0.07	0.83	4.91	2.24	2.67
Dec-99	2.54	1.48	1.07	5.65	3.18	2.47
Jan-00	1.04	0.09	0.95	1.36	0.12	1.24
Feb-00	1.65	0.73	0.92	3.24	2.57	0.66
Mar-00	2.21	1.13	1.08	1.37	0.68	0.69
Apr-00	2.50	1.79	0.71	0.77	0.66	0.11
May-00	6.98	5.07	1.91	9.15	6.98	2.17
Jun-00	3.33	2.07	1.26	8.30	5.51	2.78
Jul-00	3.40	2.51	0.89	7.47	2.82	4.65
Aug-00	0.47	0.05	0.42	1.96	0.00	1.96
Sep-00	0.33	0.04	0.29	1.41	0.58	0.84
Oct-00	8.78	7.23	1.55	27.76	23.89	3.87
Nov-00	9.67	4.96	4.70	15.90	1.91	13.99
Dec-00	3.49	1.44	2.04	17.13	4.69	12.44
Jan-01	8.00	4.68	3.32	20.02	16.01	4.01
Feb-01	9.71	5.11	4.60	13.89	11.85	2.04
Mar-01	5.25	1.64	3.61	1.56	0.28	1.29
Apr-01	3.80	1.70	2.09	0.83	0.18	0.64
May-01	10.40	8.44	1.96	10.09	9.06	1.03
Jun-01	7.94	4.72	3.22	12.25	1.39	10.86
Jul-01	0.99	0.29	0.70	3.74	1.08	2.66
Aug-01	1.63	0.98	0.65	1.97	0.60	1.38
Sep-01	13.97	10.54	3.43	25.67	20.77	4.90
Oct-01	1.85	0.88	0.97	12.77	4.22	8.55
Nov-01	0.93	0.08	0.85	5.07	0.36	4.70
Dec-01	1.40	0.39	1.00	2.11	0.15	1.96
Jan-02	3.92	2.84	1.07	1.25	0.59	0.66
Feb-02	4.91	1.67	3.24	6.43	5.75	0.68
Mar-02	2.10	0.96	1.14	2.73	2.13	0.60
Apr-02	11.18	6.33	4.85	6.79	4.71	2.08
May-02	7.24	5.14	2.11	6.67	4.46	2.21
Jun-02	5.98	4.19	1.79	6.61	3.76	2.85
Jul-02	2.09	1.03	1.05	5.46	3.15	2.31
Aug-02	2.12	1.42	0.71	5.39	3.35	2.04
Sep-02	1.92	1.08	0.84	4.21	2.10	2.11
Oct-02	3.14	1.74	1.40	6.97	4.60	2.37
Nov-02	1.79	0.59	1.21	6.81	0.17	6.64
Average	**8.13**	**4.61**	**3.52**	**8.68**	**4.89**	**3.79**

Calibration parameter adjustments for the Quapaw Creek area:

ESCO = 0.68
Curve Number = -5.6
Available Water Content = +0.042
Revap Coefficient = 0.054
Minimum Depth of Water in Shallow Aquifer for Revap to Occur = 307
Minimum Depth of Water in Shallow Aquifer for Baseflow to occur = 307

VITA

Julian F. Cacho

Candidate for the Degree of

Master of Science

Thesis: ESTIMATING SEDIMENT LOADING USING SWAT AND IDENTIFYING HABITAT DIFFERENCES IN REFERENCE AND IMPAIRED STREAMS

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Name: Julian Fernandez Cacho Date of Degree: December 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Thesis: ESTIMATING SEDIMENT LOADING USING SWAT AND IDENTIFYING HABITAT DIFFERENCES IN REFERENCE AND IMPAIRED STREAMS

Pages: 81 Candidate for the Degree of Master of Science

Major Field: Biosystems and Agricultural Engineering

Scope and Method of Study: Soil and Water Assessment Tool (SWAT) was used to estimate the sediment loading in reference and impaired streams of Oklahoma. Two streams east of I35 were studied, of which one was reference and the other was impaired. The results were compared to the transport capacity of the streams computed using Yang's Equation. Parameters on the micro-scale habitats (substrate, instream cover, and flow condition), macro-scale habitats (channel geometry and sediment deposition), and parameters evaluating the riparian and bank structure (such as bank stability, vegetation, and streamside cover) between the reference and impaired streams were also compared.

Finding and Conclusion: The comparison revealed that in the reference stream the sediment loading from the watershed is lower than the transport capacity, while in the impaired stream the sediment loading is higher than the transport capacity. Significant differences in the compared habitat parameters were also found.

ADVISER'S APPROVAL: Dr. Michael A. Kizer