MODELING LEAST COST SELECTION OF BEST MANAGEMENT PRACTICES TO REDUCE SOIL EROSION IN THE FORT COBB WATERSHED USING SWAT

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Title of Study: MODELLING LEAST COST SELECTION OF BEST MANAGEMENT PRACTICES TO REDUCE SOIL EROSION IN THE FORT COBB WATERSHED USING SWAT

Major Field: Agricultural Economics

Abstract: The main cause of water quality impairment in the United States is due to Non-Point Source (NPS) pollution caused by human activities like agriculture and urbanization. An example is the Fort Cobb Watershed which has limited capability due to soil erosion and phosphorus load. Soil and water conservation practices can be used to mitigate soil erosion, nitrogen and phosphorus inflow from agricultural lands. Some conservation practices have been implemented in the Fort Cobb Reservoir watershed but their cost effectiveness has not yet been assessed.

The objective of this study is to determine the most cost effective selection and location of Best Management Practices (BMPs) on farmland to reduce soil erosion and the delivery of sediment and phosphorus to the reservoir. Detailed conservation practices were simulated with the SWAT (Soil and Water Assessment Tool) to determine yields, erosion, and phosphorus loss for each practice by each HRU (a soil type-land use unit) and location in the watershed. Linear Programming was used to determine the cost minimizing choice of BMP(s) for each HRU (hydrologic response unit) that meets sediment and phosphorus targets for the watershed.

Of the conservation practices simulated, conservation tillage plus contour farming (66%), conservation tillage plus strip cropping (83%) and conservation tillage plus parallel terrace (95%) are the most effective in reducing sediment loads as compared to the baseline (conservation tillage only). The results of the linear programming maximization of net profit indicate that a combination of management practices is the best option for reducing soil erosion while maintaining a substantial income for the farmers.

Key words: Watershed, management practices, optimal choice, SWAT, linear programming.

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CHAPTER I

I. INTRODUCTION, OBJECTIVES AND BACKGROUND

Introduction

The main cause of water quality impairment in the United States is due to Non-Point Source (NPS) pollution caused by human activities such as agriculture and urbanization (Muleta, 2010). It causes a decline in water quality and harms the creatures that live in and around the water body. Contamination of surface water and groundwater also puts drinking water resources at risk. Unfortunately, these pollutants enter the Fort Cobb watershed system with considerable ease. Oklahoma Water Quality Standards lists Fort Cobb Reservoir as a Nutrient Limited Watershed (due to high primary productivity) and a sensitive public and private water supply (OCC, 2009). Fort Cobb Lake is impaired by turbidity and phosphorus, as indicated on the state's "Comprehensive Water body Assessment" (ODEQ, 2006).

The Fort Cobb watershed is also exposed to erosion which contributes a majority of the total sediment loads. In addition, Cobb Creek, Willow Creek, and Five mile Creek, which are Fort Cobb watershed sub-basins are impaired by bacteria, and ammonia. In fact, too much sediment in municipal surface water supply may result in taste and odor problems and can shield pathogens from the action of disinfectants during treatment. Sediment deposition on streambeds and lake bottoms reduces spawning areas, aquatic organism food resources, and habitat complexity, as well as increasing dredging costs on larger rivers and reservoirs.

To address these problems, substantial efforts have been made by various government agencies to minimize NPS pollution. For example, section 303(d) of the Clean Water Act requires state and local agencies to develop and implement Total Maximum Daily Loads (TMDLs) for impaired waters (Muleta, 2010). The Oklahoma Conservation Commission (OCC), in cooperation with the Environmental Protection Agency (EPA), the Office of the Secretary of the Environment (OSE), local conservation districts, and the Oklahoma Department of Agriculture, Food, and Forestry (ODAFF), initiated a watershed project in 2001. Through this cost-share project, local landowners began to demonstrate Best Management Practices (BMPs). Several conservation practices have been implemented in the Fort Cobb Reservoir watershed including adoption of no-tillage management, conversion of cropland to grassland, crop rotation, strip cropping, contour and terrace farming, cattle exclusion from streams, and various structural and water management practices (Becker and Steiner, 2011).

The cost of implementing some of these BMPs can be high while others may not carry apparent cost. Therefore, the implementation of the BMPs could increase or decrease the total income and cost to farmers. The greatest environmental improvements do not necessarily result in higher economic profits. The question then arises as to what conservation practices can efficiently reduce sediment loads in the Fort Cobb watershed. Is there any optimal number, size, and location of best management practices such as strip cropping or contour cropping to install in the watershed to most cost effectively reduce erosion?

Identifying the most-effective in-stream, streambank, and riparian conservation practices will help build an educational program. This program will include educating farmers, landowners, natural resource managers, policy-makers and youth in and around the Fort Cobb watershed about watershed tools that improve water quality while maintaining a sufficient income to farmers. Enhanced knowledge regarding the efficient management practices should lead to greater farmer adoption of specific conservation measures.

The purpose of this research is to run a watershed simulation model that will be integrated with systems analysis tools such as optimization models to determine an optimal set of best management practices that reduce soil erosion and meet regulations such as TMDLs with least cost.

Objectives

The overall purpose of this study is to determine the optimal set of BMPs to install in the Fort Cobb watershed to reduce sedimentation on land surfaces.

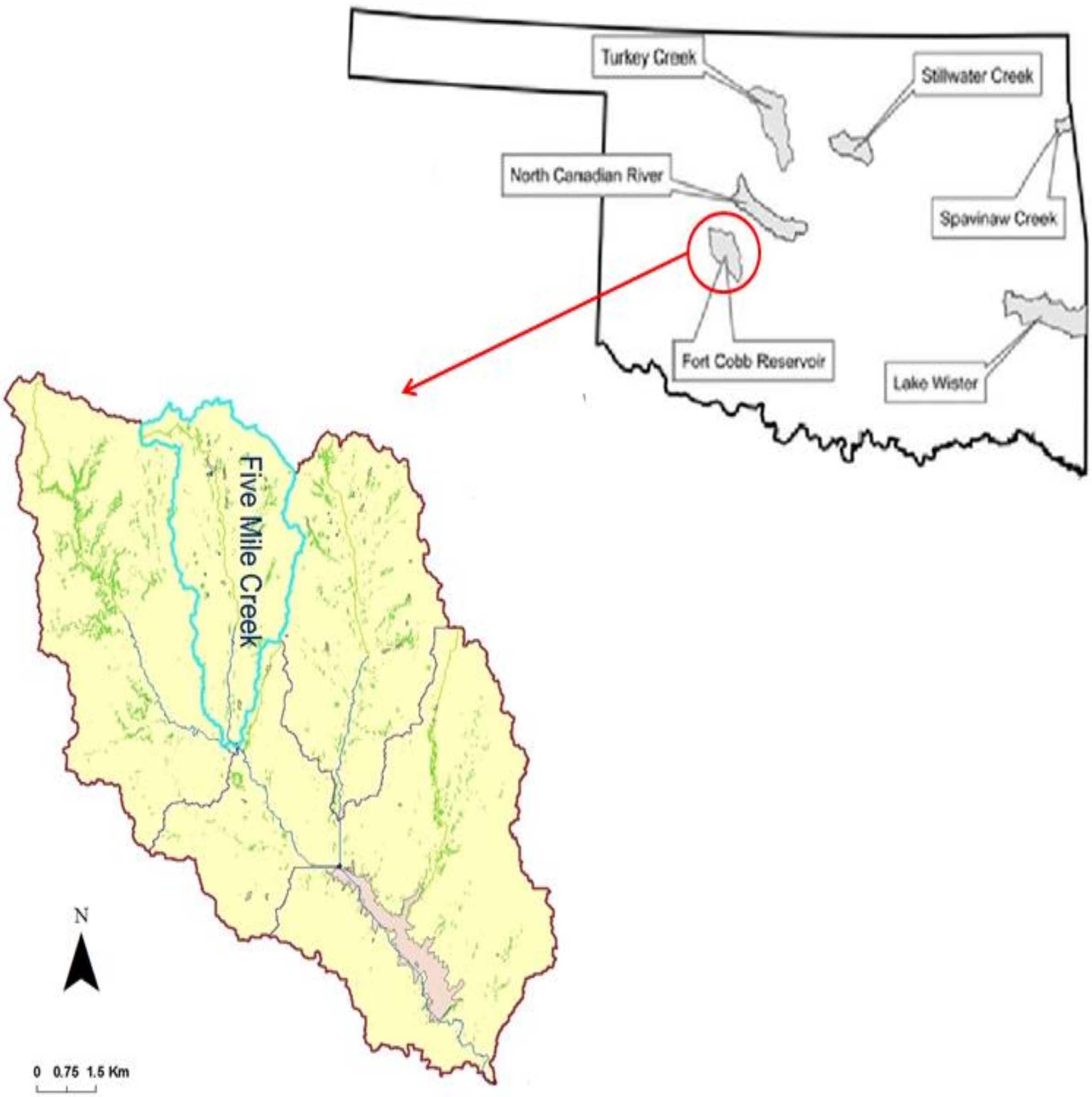
The specific objectives of this research are:

1) To identify the most effective BMPs for reducing runoff and soil erosion on land surfaces in the watershed;
2) To determine the effect of the BMPs on crop yields and their economic impact on gross margin;
3) To identify the least cost management options to minimize future soil erosion in the watershed to meet alternative erosion target.

Background

The Fort Cobb Basin is located in Southwestern Oklahoma in Caddo, Washita, and Custer Counties. The basin area is 314 square miles and the surface area of the Fort Cobb Reservoir is 4,100 acres (Storm et al., 2006). Structurally, the watershed lies in the axis of the Anadarko Basin and dips in a southwestern direction at a rate of 3.8 to 7.6 meters per kilometer (20 to 40 feet per mile) with the synclinal axis extending northwestward across the Pond Creek Basin (Davis, 1955). The Fort Cobb Reservoir and six stream segments in its basin are listed on the Oklahoma 303(d) list as being impaired by nutrients, pesticides, siltation, suspended solids, and unknown toxicity (Storm et al., 2006).

Soils in the Lake and Willow Creek sub-watersheds of the Fort Cobb Reservoir watershed are predominantly fine sandy loams with relatively large hydraulic conductivities. In the Cobb Creek sub-watershed, however, nearly one-half of the soils are predominantly silty, with lesser hydraulic conductivities. Agriculture in the Fort Cobb Reservoir watershed is predominantly cropland (43 percent, dominated mostly by winter wheat and other small grains) and pasture for cattle (33 percent). Irrigated crops, such as winter wheat and peanuts, have increased since the 1960s in the watershed (Starks, 2010). Field reconnaissance of the watershed revealed that a few of the older solid-set or side-roll irrigation systems are still used in the watershed, but that most irrigation systems have been upgraded to center-pivot systems (Starks, 2010).



Map 1: Fort Cobb Reservoir Watershed

***SWAT output

CHAPTER II

II. LITERATURE REVIEW

Overview of some biophysical models

Biophysical models are models that that predict all the components of a watershed including sediment, runoff, water quality and biomass growth. Biophysical models specially used for rural watersheds are for examples Agricultural Non-point Source Pollution (AGNPS), Areal Non-point Source Watershed Environment Response Simulation Model (ANSWERS), Soil and Water Assessment Tool (SWAT), Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS), and Environmental Productivity-Impact Calculator (EPIC) (Nisrani, 2006).

The intricacy of problems related to managing Non-Point Pollution led the U.S. Department of Agriculture (USDA) to develop the Agricultural Non-Point Source (AGNPS) pollution model of watershed hydrology. AGNPS simulates the behavior of runoff, sediment and nutrient transport from watersheds that have agriculture as their prime use. AGNPS is a distributed parameter, event-based model (Young et al., 1995) that operates on a cell basis. It was developed to evaluate the effect of management decision impacts in agricultural watershed-scale systems and addresses concerns related to the potential impacts of point and non-point source pollution on surface and groundwater quality. It uses the universal soil loss equation to predict erosion (Nisrani, 2006).

The AGNPS model was later improved into a continuous simulation model called AnnAGNPS. It includes all the features that were in the original AGNPS version plus pesticides, source accounting, settling of sediments due to in-stream impoundments, and utilizes the Revised Universal Soil Loss Equation (RUSLE) (Nisrani, 2006).

Both AGNPS and AnnAGNPS have limitations. There are no mass balance calculations tracking inflow and outflow of water. Likewise, spatially distributed variables like rainfall data cannot be incorporated into these models. Storm events like precipitation are considered uniform throughout the watershed. All these limitations can become a serious problem as the size of the watershed increases (León et al., 2004). The models take into account surface hydrology, stream flow and infiltration, but sub-surface hydrology is not accounted for. This can be a serious limitation with sandy soils, high water table soils, or soils with other unfavorable characteristics (Nisrani, 2006).

The ANSWERS (Areal Non-Point Source Watershed Environment Response Simulation) model was developed in the late 1970s (Dillaha et al., 2001). ANSWERS can be used to evaluate the effects of land use, management schemes and conservation practices or structures on the quantity and quality of water from both agricultural and non-agricultural watersheds. The distributed structure of this model allows handling spatial as well as the temporal variability of pollution sources and loads. It was initially developed on a storm event basis to enhance the physical description of erosion and sediment transport processes. The program has been used to evaluate management practices for agricultural watersheds and construction sites in Indiana. Recent model revisions include improvements to the nutrient transport and transformation subroutines (Dillaha et al., 2001). Some of the limitations of ANSWERS are: It is not well adapted for large watersheds nor for extremely long simulations due to computational requirements. The nutrient transformations and transport simulation rely on the empirical statistical equations. Thus, it works better for certain land uses and soil types than others. Model simulation is time-consuming and computationally intensive (Nisrani, 2006).

CREAMS model can simulate pollutant movement on and from a field site, including such constituents as fertilizers (N and P), pesticides and sediment (Knisel, 1980). The effects of various agricultural practices can be assessed by simulation of the potential water, soil, nutrient and pesticide losses in runoff from agricultural fields. The spatial scale of the model is intended to be the size of an agricultural field. The model structure consists of three major components: hydrology, sedimentation and chemistry. The hydrology component estimates the volume and rate of runoff, evapotranspiration, soil moisture content and percolation. In spite of its wide use, limitations of the model became apparent when CREAMS was used for hydrologic simulation of flat topography, sandy soils and high water-table watersheds in South Florida. In evaluating the suitability of the model for simulating nutrient yield from Coastal Plain watersheds in South Florida, it was determined that assumptions made in developing the model were not valid for the sandy soil prevalent in this region. Conceptual changes led to the development of the CREAMS-WT version which better represents the low phosphorus buffering capacity of these sandy soils and better represents the hydrology of flat, sandy, high water- table watersheds (Heatwole et al., 1987). Its limitation resides in the fact that it is limited to small size field and homogenous areas (Nisrani, 2006).

EPIC is a comprehensive model developed to determine the relationship between soil erosion and soil productivity throughout the United States. It continuously simulates the processes associated with erosion, using a daily time step and readily available inputs. EPIC is capable of computing the effects of management changes on outputs. It is composed of physically and biologically based components for simulating erosion, plant growth, and related processes and economic components for assessing the cost of erosion and for determining optimal management strategies. The EPIC physical and biological components include hydrology, climate simulation, erosion-sedimentation, nutrient cycling, plant growth and tillage. EPIC is limited to a single field and soil (Nisrani, 2006).

The Soil and Water Assessment Tool (SWAT) is a river basin, or watershed scale model developed by the USDA-ARS to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The fundamental strengths of SWAT are the flexibility in combining upland and channel processes and simulation of land management (Gassman et al., 2007). This model has been used in this study because of its capability of use in complex watersheds with varying soils and land uses. SWAT also subdivides sub-basin into Hydrological Response Units (HRUs) which make it possible to account for diversity within sub-basins. An HRU is a land unit that contains a single soil type with a common land use and slope. The pros and cons of each model are given in table 1.

Table 1: Biophysical model capabilities and limitations

Model type	AGNPS	AnnAGNPS	ANSWERS	CREAMS	EPIC	SWAT
Model capabilities	Simulates runoff and sediment transport primarily from agricultural watersheds; Event based model; Uses USLE	Includes features of AGNPS plus pesticides, settling of sediments due to in-stream impoundments; Continuous model; Distributed model; Uses MUSLE	Simulates runoff, erosion, nutrients and effectiveness of BMPs in reducing sediment and nutrients; Continuous model; Physically based distributed.	Simulates nutrients, pesticides and sediment. Continuous model	Physically based model for erosion productivity relation, hydrology, nutrients tillage, plant growth economics.	Predicts water, sediment and chemical yields; Can be used in complex watersheds with varying soils and land uses; Hydrologic Response Units allow SWAT to account for the diversity within a sub-basin.
Model limitations	No day to day tracking of sediment attached chemicals deposited in stream reaches; Considers only surface water including runoff, stream flow, and infiltration but not subsurface flow; Areal extent limited by the assumption of spatially uniform distributed rainfall.	Same limitations as AGNPS but it is continuous and uses MUSLE instead of USLE.	Not good for large watershed and long simulations; Nutrient transformations and transport relies on the empirical statistical equations; Does not work equally good for all land uses and soil types.	Applicable to field size and homogeneous areas.	Applicable to small and homogeneou s areas.	HRUs may not be spatially contingent; No interaction between HRUs; Uses invalidated assumptions for in-stream processes; Stream process algorithms are poor.

AGNPS (Agricultural Non-Point Source Pollution), AnnAGNPS (Continuous AGNPS), ANSWERS (Areal Non-Point Source Watershed Environment Response Simulation Model), CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems), EPIC (Environmental Productivity Impact Calculator), SWAT (Soil and Water Assessment Tool)

Source: (Nisrani, 2006)

SWAT Developmental History

The development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modeling experience that spans a period of roughly 30 years. SWAT comes from early previously developed USDA-ARS model including the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model, the Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) model and the Environmental Impact Policy Climate (EPIC) model, which was originally called the Erosion Productivity Impact Calculator (Williams, 1990). The current SWAT model is a direct descendant of the Simulator for Water Resources in Rural Basins (SWRRB) model, which was designed to simulate management impacts on water and sediment movement for ungauged rural basins across the U.S (Nisrani, 2006).

Development of SWRRB began in the early 1980s with modification of the daily rainfall hydrology model from CREAMS. A major enhancement was the expansion of surface runoff and other computations for up to 10 subbasins, as opposed to a single field, to predict basin water yield. Other enhancements included an improved peak runoff rate method, calculation of transmission losses, and the addition of several new components: groundwater return flow (Arnold and Allen, 1993), reservoir storage, the EPIC crop growth submodel, a weather generator, and sediment transport. Further modifications of SWRRB in the late 1980s included the incorporation of the GLEAMS pesticide fate component, optional USDA Soil Conservation Service (SCS) technology for estimating peak runoff rates, and newly developed sediment yield equations. These modifications extended the model's capability to deal with a wide variety of watershed water quality management problems.

Arnold et al. (1995b) developed the Routing Outputs to Outlet (ROTO) model in the early 1990s in order to support an assessment of the downstream impact of water management within Indian reservation lands in Arizona and New Mexico that covered several thousand square kilometers, as requested by the

U.S. Bureau of Indian Affairs. The analysis was performed by linking output from multiple SWRRB runs and then routing the flows through channels and reservoirs in ROTO via a reach routing approach. This methodology overcame the SWRRB limitation of allowing only 10 subbasins; however, the input and output of multiple SWRRB files was cumbersome and required considerable computer storage. To overcome the limitations of this arrangement, SWRRB and ROTO were merged into the single SWAT model. SWAT retained all the features that made SWRRB such a valuable simulation model, while allowing simulations of very extensive areas (Gassman et al., 2007).

SWAT has undergone continued review and expansion of capabilities since it was created in the early 1990s. Many versions of the model (SWAT94.2, 96.2, 98.1, 99.2, 2000, 2005 and 2009) have been developed ever since. The current version of the model (SWAT2012) is briefly described here to provide an overview of the model structure and execution approach.

SWAT Description

SWAT operates on a daily time step and is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is process based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, topographical, and soil characteristics. The HRUs are represented as a percentage of the sub-watershed area and may not be contiguous or spatially identified within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management (Arnold et al., 2011).

Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Simulation of watershed hydrology is separated into the land phase, which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin, and the in-stream or routing phase, which is the movement of water, sediments, etc., through the channel network of the watershed to the outlet. Below is a brief description of the processes simulated by SWAT. Details of these processes are given in the SWAT theoretical documentation (http://swatmodel.tamu.edu).

The hydrologic cycle is climate driven and provides moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity, that control the water balance. SWAT can read these observed data directly from files or generate simulated data at runtime from observed monthly statistics. Snow is computed when temperatures are below freezing, and soil temperature is computed because it impacts water movement and the decay rate of residue in the soil. Hydrologic processes simulated by SWAT include canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow, tile drainage, redistribution of water within the soil profile, consumptive use through pumping (if any), return flow, and recharge by seepage from surface water bodies, ponds, and tributary channels. SWAT uses a single plant growth model to simulate all types of land cover and differentiates between annual and perennial plants. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to predict sediment yield from the landscape. In addition, SWAT models the movement and transformation of several forms of nitrogen and phosphorus, pesticides, and sediment in the watershed. SWAT allows the user to define management practices taking place in every HRU (http://swatmodel.tamu.edu).

Once the loadings of water, sediment, nutrients, and pesticides from the land phase to the main channel have been determined, the loadings are routed through the streams and reservoirs within the watershed. The water balance for reservoirs includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir bottom, and diversions (Arnold et al., 2012). Model equations are given in the SWAT theoretical documentation (http://swatmodel.tamu.edu).

SWAT Sensitivity analysis, Calibration and validation

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or sub-watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000). In a practical sense, this first step helps determine the predominant processes for the component of interest. Two types of sensitivity analysis are generally performed: local, by changing values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity analysis is that it needs a large number of simulations. Both procedures, however, provide insight into the sensitivity of the parameters and are necessary steps in model calibration (Arnold et al., 2012).

The second step is the calibration process. Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Calibration can be accomplished manually or using auto-calibration tools in SWAT (van Griensven and Bauwens,2003; Van Liew et al. (2005) or SWAT-CUP (Abbaspour et al., 2007). .

The final step is validation for the component of interest (streamflow, sediment yields, etc.). Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals (Refsgaard, 1997). Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration (Arnold et al., 2012).

Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation. Data are most frequently split by time periods, carefully ensuring that the climate data used for both calibration and validation are not substantially different, i.e., wet, moderate, and dry years occur in both periods (Gan et al., 1997)

An extensive array of statistical techniques can be used to evaluate SWAT hydrologic and pollutant predictions; for example, Coffey et al. (2004) describe nearly 20 potential statistical tests that can be used to judge SWAT predictions, including the coefficient of determination (r^2), NSE (Nash-Sutcliffe Efficiency), root mean square error (RMSE), nonparametric tests, t-test, objective functions, autocorrelation, and cross-correlation. By far, the most widely used statistics reported for calibration and validation are r^2 and NSE. The r^2 statistic can range from 0 to 1, where 0 indicates no correlation and 1 represents perfect correlation, and it provides an estimate of how well the variance of observed values are replicated by the model predictions (Krause et al.,2005). NSE values can range between $-\infty$ to 1 and provide a measure of how well the simulated output matches the observed data along a 1:1 line (regression line with slope equal to 1). A perfect fit between the simulated and observed data is indicated by an NSE value of 1. NSE values ≤ 0 indicate that the observed data mean is a more accurate predictor than the simulated output.

These statistics provides valuable insight regarding the hydrologic performance of the model across a wide spectrum of conditions. To date, no absolute criteria for judging model performance have been firmly established in the literature, and for good reason: the criteria for judgment of model performance should be tied to the intended use of the model (Engel et al., 2007). Most reported SWAT studies contain both calibration and validation, while others performed only calibration due to a lack of observed data. In a few cases, calibration of SWAT was not performed. For example, Srinivasan et al. (2010) describe an uncalibrated application of SWAT for the Upper Mississippi River basin in the north-central U.S., which was conducted with the goal of determining how the default parameters represented crop yield and streamflow components of interest in the region.

Application of SWAT

The SWAT model has a wide range of applications. Its applications have expanded worldwide over the past decade. It is used by various government agencies, particularly in the United States and the European Union to assess anthropogenic, climate change, and other influences impact on a wide range of water resources.

SWAT was used to support the USDA Conservation Effects Assessment Project, which is designed to quantify the environmental benefits of conservation practices at both the national and watershed scales (Mausbach and Dedrick, 2004). The model is also being used to evaluate conservation practices for watersheds of varying sizes that are representative of different regional conditions and mixes of conservation practices. SWAT is increasingly being used to perform TMDL analyses, which must be performed for impaired waters by the different states as mandated by the 1972 U.S. Clean Water Act (Gassman, 2007).

SWAT has also been used extensively in the context of projects supported by various European Commission (EC) agencies. Several models including SWAT were used to quantify the impacts of climate change for five different watersheds in Europe within the Climate Hydrochemistry and Economics of

Surface-water Systems (CHESS) project, which was sponsored by the EC Environment and Climate Research Programme (Gassman, 2007).

Many of the applications reported in the literature are related to hydrologic (streamflow, surface runoff, groundwater flow…) and pollutant loss (sediment yield, phosphorus, nitrogen…); irrigation and brush removal scenarios; pesticides studies; scenarios of BMPs and land use impacts on pollutant losses; climate change impact studies; bacteria life cycle and transport; climate data resolution effects…

To illustrate the application of SWAT, some of the projects in which the model has been used are as follows:

- ✓ Aguaflash:

The AguaFlash project has for objective the development of a method to determine the risks of deterioration of waters quality in agricultural catchments during floods events, transposable to the Sudoe territory. This project regroups six teams of research including French, Spanish and Portuguese researchers.

- ✓ Assessment of Regional Water Endowments, Crop Water Productivity and Implications for Intra-Country Virtual water Trade in Iran;
- ✓ Catchment scale water quantity impact analysis related to life cycle assessment for forestry and agriculture;
- ✓ Coastal Watershed Assessment (Gulf of Maine);
- ✓ CONCERT'EAU- Collaborative Technological Platform for Implementation for WFD within agricultural context (French);
- ✓ Evaluating Economic and Environmental Benefits of Soil and Water Conservation Measures Applied in Missouri;
- ✓ Estimating Water Quality, Air Quality, and Soil Carbon Benefits of the Conservation Reserve Program;

- ✓ Great Salt Plains Reservoir (Department of Biosystems and Ag Engineering, Oklahoma State University);
- ✓ Hydrologic Modeling of Rio Grande/Rio Bravo International Watershed;
- ✓ Identifying Hydrologic Processes in Agricultural Watersheds Using Precipitation-Runoff Models;
- ✓ Linking GIS and QUAL2E with SWAT;
- ✓ Missouri Watershed Water Quality Initiative;
- ✓ Pesticide Fate and Transport by SWAT: Atrazine, Metolachlor and Trifluralin in the Sugar Creek Watershed;
- ✓ Use of county-level NRI data and SSURGO in SWAT simulations of 5 watersheds (Natural Resources Research Inventory & Analysis Institute, USDA NRCS;
- ✓ Use of SWAT to determine flow and chemistry variables for development of ecological indicators in stream ecosystems (Natural Resources Research Institute, University of Minnesota Duluth);
- ✓ Watershed Modeling of the Cannonsville Basin Using SWAT200 (Cornell University, NY).

Full details of the aforementioned projects can be found at USDA (2015, January). Retrieved from: http://swat.tamu.edu/applications.

SWAT-CUP

SWAT-CUP (SWAT Calibration and Uncertainty Procedures) is a program designed to integrate various calibration/uncertainty analysis programs for SWAT using the same interface. It is a computer program designed to facilitate sensitivity analysis, calibration, validation and uncertainty analysis of a SWAT model. It contained five optimization algorithms (SUFI2, PSO, GLUE, PARASOL and MCMC). The overall program structure is as shown in the Figure 1 below.

A number of previous SWAT application projects report automated calibration/validation and uncertainty analysis using SWAT-CUP. Abbaspour et al. (2007) performed a multi-objective calibration and validation of the Thur watershed in Switzerland using discharge, sediment, nitrate, and phosphate in the objective function with uncertainty analysis. Schuol et al. (2008a) calibrated with uncertainty analysis and validated models of west Africa and the entire continent of Africa. Yang et al. (2008) compared five different optimization algorithms in SWAT-CUP and calibrated a watershed in China using the MCMC algorithm. Faramarzi et al. (2009) used SWAT to build a hydrologic model of Iran and calibrated and validated it with the SUFI2 algorithm accounting for prediction uncertainty. Akhavan et al. (2010) calibrated a model of nitrate leaching for a watershed in Iran, and Andersson et al. (2009) used SWAT-CUP to calibrate a hydrologic model of the Thukela River basin in South Africa.

In the above applications, the goodness of fit criteria is provided by P-factor and R-factor. The P-factor is the percentage of the measured data bracketed by the 95PPU (the 95% Prediction Uncertainties). This index provides a measure of the model's ability to capture uncertainties. As all the "true" processes are reflected in the measurements, the degree to which the 95PPU does not bracket the measured data indicates the prediction error. Ideally, the P-factor should have a value of 1, indicating 100% bracketing of the measured data, hence capturing or accounting for all the correct processes. The R-factor, on the other hand, is a measure of the quality of the calibration and indicates the thickness of the 95PPU. Its value should ideally be near zero, hence coinciding with the measured data. The combination of P-factor and R-factor together indicate the strength of the model calibration and uncertainty assessment, as these are intimately linked.

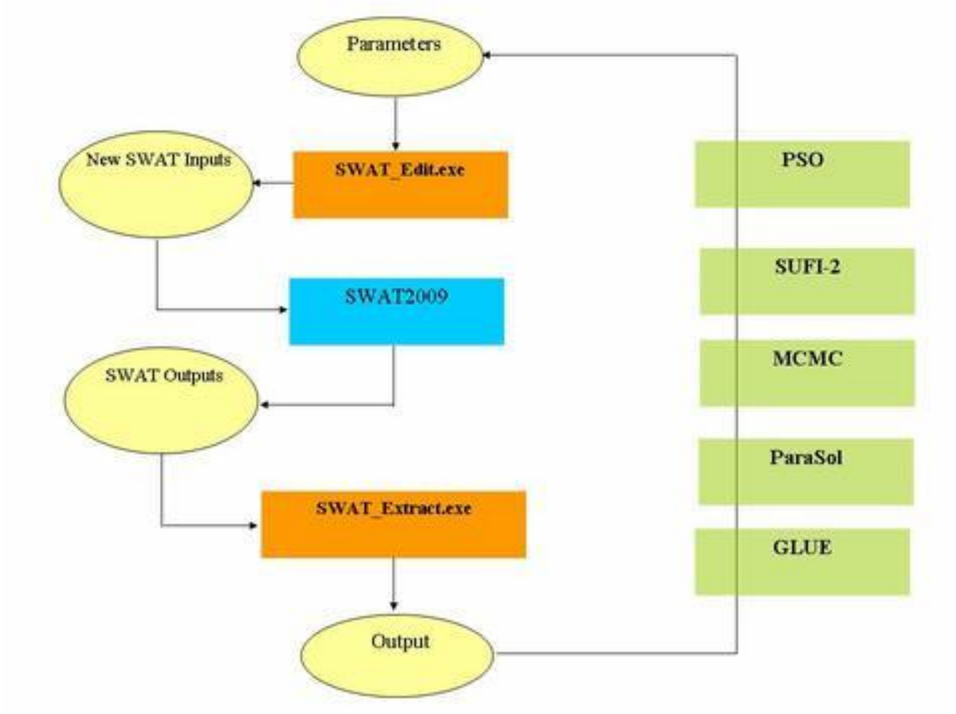


Figure 1: Interaction between a calibration program and SWAT in SWAT-CUP

**Source: (Abbaspour, 2015) SWAT-CUP manuel

Soil erosion and prediction

Soil erosion is the process of detachment and transportation of soil particles by erosive agents. The erosive agents are raindrops and surface runoff for sheet and rill erosion and wind for erosion by wind. In the case of wind erosion the process is described as creep, saltation, abrasion and suspension (AW-HASSAN, 1992). Soil erosion is a continuously occurring natural process. However, human activities, like cutting and clearing natural vegetative cover from land for crop and livestock production or for construction sites, accelerate the rate at which soil erodes beyond its geological levels (Pierce,1990). When these accelerated soil erosion rates continue unabated for a long period of time the soil's production potential for food and fiber can be impaired. Environmental resources, such as water bodies, water conveyance facilities, and water reservoirs can also be damaged by the deposition of sediments and chemicals dissolved in the runoff water (AW-HASSAN, 1992).

The first question to answer to address the soil erosion problem is how much soil erodes from a parcel of land with known characteristics in a given period of time. The Universal Soil Loss Equation (USLE) was developed by soil scientists after many decades of research to be able to predict losses from water erosion. The equation is: $A = R \times K \times LS \times C \times P$,

Where

A = Number of metric tons of soil lost per hectare per year;

R = Rainfall erosivity;

K = Erodibility of soil;

L = Length of slope;

S = Steepness of slope;

C = Cover type (grass, wheat, forest, etc.);

P = Practice used in erosion control (strip cropping, contour farming, etc.).

LS is a factor calculated from the steepness and length of slope.

The USLE has been widely used since the 1970s. In the early to mid-1990s, the equation was revised into a modern, computerized tool called the Revised Universal Soil Loss Equation (RUSLE). RUSLE still uses the same factors of USLE shown above, although now some of the factors are better defined, which improves the accuracy of predicting soil loss from water erosion (Daniel et al., 2002).

In 2003, the USDA-Natural Resources Conservation Service (NRCS) released the Revised Universal Loss Equation 2 (RUSLE2). Developed jointly by the USDA-Agricultural Research Service (ARS), the USDA-Natural Resources Conservation Service (NRCS), and the University of Tennessee, RUSLE2 like its predecessors, RUSLE and USLE, is used to predict the long-term average rate of rill and interrill erosion for several alternative combinations of crop system and management practice.

It also considers specified soil types, rainfall patterns, and topography. When these predicted losses are compared with soil loss tolerances, RUSLE2 provides specific guidelines for effective erosion control. RUSLE2 has a new, modern graphical user interface, making the model easy to use, but extremely powerful in the information that it displays and the types of situations that it can represent. The validation of RUSLE2 is proven by 10,000 plot years of data from natural runoff plots and 2,000 plot years of rainfall simulated plots (NRCS, 2003).

Erosion Impact on crop productivity and environmental resources

Soil erosion is a major environmental problem which threatens the sustainability and productive capacity of agriculture. Continuous excessive erosion which causes thinning of soils, removes plant nutrients, and changes soil properties jeopardizes the sustainability of high levels of crop production. According to David et al. (1995) crop yields on severely eroded soil are lower than those on protected soils because erosion reduces soil fertility and water availability. Corn yields on some severely eroded soils have been reduced by 12 to 21% in Kentucky, 0 to 24% in Illinois and Indiana, 25 to 65% in the southern Piedmont (Georgia), and 21% in Michigan (David et al., 1995).

Hagen and Dyke (1980) developed a yield/soil loss simulator, in which yield was a function of soil characteristics. The authors merged data from six different sources and applied the model to the 1985 Resources Conservation Act (RCA) appraisal. They concluded that over the next 100 years soil loss would reduce productivity in the United States by 8 percent. Putman et al. (1988) used the Erosion Productivity Impact Calculator (EPIC) to evaluate the impact of soil erosion on productivity. They simulated soil productivity with full erosion control and without erosion control. Ratios of the annual yields for the two estimates were pooled together for all tillage and crop sequence alternatives to estimate an erosion productivity coefficient. They found that productivity loss ranged from 0.9 percent in the Northern plains to over 7.1 percent in the Northeastern region of the United States.

Colacicco et al. (1989) used EPIC to determine the effects of soil erosion on crop yields and fertilizer use. The researchers then combined these effects with erosion rates from the 1982 NRI to estimate the yield losses from soil erosion over the next 100 years. Colacicco et al., assuming a constant technology, concluded that average future yields for corn, soybeans, and cotton will decline by 4.6, 3.5, and 4.5 percent, respectively. Average yields of wheat were estimated to decline by 1.6 percent.

In addition to the impact on productivity, soil erosion has a great impact on environmental resources outside the farm. Clark et al. (1985) conducted the first comprehensive evaluation of off-site damages caused by soil erosion. They estimated that soil eroding from all sources caused $6.1 billion annually (1980 dollars) in damage to in-stream facilities and off-stream water uses. They attributed about $2.2 billion of this damage to cropland erosion. Hugh (2015) in his study on the "Increased cost of erosion" concludes that soil erosion causes a yearly loss of more than 2 billion dollars to farmers.

Best Management Practices for controlling soil erosion

The aim of BMPs is to maintain the structure and fertility of soil and reduce pollutants delivery to the watershed while improving profitability. They can be grouped into upland managements (No-tillage farming, minimum tillage, strip cropping, crop rotation, terracing, cover crops…) and in-stream managements (detention ponds, grass waterways, filter strips, grade stabilization structures…). In this study, only the following upland managements will be considered.

No-tillage farming: No tillage describes the system whereby tillage is restricted to that necessary for planting the seed. Drilling takes place directly into the stubble of the previous crop and weeds are controlled by herbicides. Generally between 50 and 100 % of the surface remains covered with residue (Follett et al., 1985).

Strip Cropping: Strip Cropping is the practice of growing crops that require different types of tillage, such as row and sod, in alternate strips along the contours or across the prevailing direction of the water (Follett et al., 1985).

Contour farming: contour farming may be defined as plowing, seeding, cultivating and harvesting at right angles to the direction of the slope rather than down it. Carrying out ploughing, planting and cultivation on the contour can reduce soil loss from sloping land compared with cultivation up-and-down the slope (Follett et al., 1985).

Terracing: Terraces are an earthen embankment that follows contour of a hillside, breaking a long slope into smaller segments. Often land is formed into multiple terraces, giving a stepped appearance. They reduce rate of runoff and allow soil particles to settle, cleaner water is carried off in a non-erosive manner (Follett et al., 1985).

Conservation tillage: It is any method of soil cultivation that leaves most of the previous year's crop residue (such as corn or wheat stubble) on fields before and after the next crop to reduce soil erosion and runoff. To provide these conservation benefits, at least 30% of the soil surface must be covered with residue after planting the next crop (Follett et al., 1985).

Prior research on SWAT and Best Management Practices

Dechmi et al. (2013) evaluated best management practices under intensive irrigation using SWAT model. SWAT-IRRIG was used to simulate total streamflow, total sediment loads and phosphorus loads, and crop yields. According to Arnold et al. (1998), "SWAT-IRRIG model is a modification of SWAT2005 which is a continuous time, spatially semi-distributed, physically based model." To assure the accuracy of the simulated values, the SWAT-IRRIG was calibrated and validated for four crop yields (corn, alfalfa, sunflower and barley), total suspended loads and phosphorus loads, total streamflow using field data (observed data) from years 2008 (calibration) and 2009 (validation). The BMPs tested are related to nutrient management, irrigation management and tillage operations.

In total, 20 BMP scenarios which consist of nutrient management scenarios, irrigation management scenarios and tillage operations scenarios were tested by Dechmi et al. (2013). Six of the scenarios correspond to the individuals BMPs while the other 14 scenarios consist of combinations of the first six individuals BMPs. The best management practices analysis was conducted by comparing the simulation of the current conditions (baseline) with the 20 considered scenarios using the calibrated and validated model. The impact of BMP scenarios on water quality are presented as percent reduction in average annual losses of Irrigated Return Flow (IRF), Total Suspended Sediments (TSS), Organic Phosphorus (ORG-P) and Total Phosphorus (TP). A paired t-test was performed on the simulated monthly values of pre-BMP and post-BMP to test the significance of the change induced by application of each BMP. For economic analysis, pre-BMP and the 20 post-BMPs gross margins were estimated and analyzed for corn, alfalfa, sunflower, and barley.

The results of their study show that the implementation of nutrient BMP scenarios contributed to the reduction of losses for all phosphorus forms. However, it did not have any impact on IRF and TSS. Meanwhile, irrigation management scenarios and tillage management scenarios did significantly lower IRF, TSS and loss of all phosphorus forms. A comparison between irrigation and tillage management practices shows that conservation tillage (CST) was the best practice in reducing IRF and TSS. In general, the combined BMP scenarios were more efficient in lowering water, soil and phosphorus losses than individual BMPs. As for the economic impact of the BMPs, the combined management practices better increased the gross margin for corn, alfalfa, sunflower and barley. However, it is worth noting that the economic impact of the BMPs varies with crop and individual BMPs.

Xuyang et al. (2011) conducted research on agricultural BMPs to efficiently lower sediment load and organophosphate in surface runoff. In this research, SWAT 2005 was used to simulate streamflow, sediments and pesticide loads into the Orestimba Creek Watershed from 2000 to 2006. Model calibration was performed using data from 2003 to 2005 and data from 2006 was used for model validation. To identify parameters which highly influence streamflow, sediment yield and pesticide loads, LH-OAT (Latin-Hypercube One-factor-At-a-Time) sensitivity analysis was undertaken. Four BMPs were selected in the study: sediment ponds, vegetated ditches, buffer strips and pesticide use reduction. The effectiveness of BMP implementation was defined as the percent change between model outputs predicted from the baseline and from BMP scenarios.

Simulated results showed that sediment ponds were effective in removing sediment and pesticide loads. Sediment load was reduced by about 58% compared to the baseline scenario and 27-44% of pesticides were absorbed by the pond. Likewise, vegetative ditches, buffer strips and pesticide reduction use contributed to the reduction of sediment and pesticide loads. A sediment ditch reduced over 20% of sediment and pesticide loads. A five-meter buffer reduced sediment and pesticides by 37% and 59%, respectively. A 15% reduction of the current use of pesticides resulted in a load reduction of at least 28% and 26% for diazinon and chlopyrifos, respectively. The combination of pesticide use reduction with vegetated ditches and buffer strips showed the highest efficiency in removing dissolved diazinon and chlopyrifos, followed by buffer strips with vegetative ditches and buffer strips with pesticide use reduction. The combination of these individual BMPs is the best option in effectively reducing sediment and pesticide loads.

Mwangi et al. (2015) evaluated the impact of conservation practices on water and sediment yield in Sasumua Watershed, Kenya. The SWAT model was used to predict streamflow and sediment yield. The streamflow and sediment yield were calibrated using a monthly time-series data calculated from the reservoir water balance. Calibration was done manually where parameters were systematically varied during calibration as guided by sensitivity analysis results, which identified parameters most responsive to the ratio of fast runoff/base flow. Parameters which had been modified were mainly the curve number (CN) and soil evaporation compensation factor (ESCO) for surface runoff while those for base flow were threshold depth of water in the shallow aquifer (GWQMN), plant uptake compensation factor (EPCO), and ground water delay (GW_DELAY). The validated model was used to simulate sediment yield and surface runoff for the period 1970 to 2010. Four management practices (Filter strips, Contour farming, Parallel Terraces and Grassed Waterways) were assessed.

The results of their study showed that filter strips increased nonlinearly with width being optimum at 30 m (98.4 ft). A combination of 30 m (98.4 ft) wide filter strips and grassed waterways reduced sediment yield by 80%. Parallel terraces, 10 m (32.8 ft) filter strips, and grassed waterways reduced sediment yield by 75%; 10 m (32.8 ft) filter strips and grassed waterways reduced sediment yield by 73%; contour farming and grassed waterways reduced yield by 66%; and grassed waterways reduced yield by only 54%. Parallel terraces reduced surface runoff by 20% and increased base flow by 12%, while contour farming reduced surface runoff by 12% and increased base flow by 6.5%. The combination of BMPs is the best option in reducing surface runoff and sediment yields.

Prior research on Best Management Practices and crop and sediment yields

A study conducted by Zhou et al. (2009) on the cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed indicated that no-tillage was the most efficient practice. They used the WEPP (Water Erosion Prediction Project) model to simulate sediment yields from three tillage systems (chisel plow, disk tillage, and no-tillage) as well as three conservation structures (grassed waterways, filter strips, and terraces). Their findings showed that conservation structures had the most impact on sediment yield reduction when used in conjunction with chisel plow management and the smallest impact with the no-tillage system. The cost-benefit assessment of conservation practices revealed that no-tillage was the most economically efficient practice with the highest net benefit of \$94.5 ha^{-1} y^{-1} (\$38.2 ac^{-1} yr^{-1}).

Iraj Amini (2005) studied the best management for soybean cropping following barley. He conducted a split–split plot design based on complete blocks with two methods of residue management (burning or non-burning of barley residue) as the main plot factor, three tillage methods (plow + disk, double disk and no-tillage) as sub-plot factor, and three within row plant spacings (4, 8 and 12 cm, with 50 cm row width) as sub-subplot factor. Four replications and soybean cultivar hill was used. Comparison of means (Duncan's multiple range test) indicated that yield means of plow + disk and double disk were significantly different (2371 and 2412 kg/ha, respectively) compared with no tillage (2115 kg/ha), but the difference between them was not significant.

In the same way, research carried out by Parajuli et al. (2013) on the impact of crop-rotation and tillage on crop yields and sediment yield indicates that the corn yields under conventional tillage practice were greater than those for no- tillage practices. Parajuli et al., (2013) conducted their research on the impact of crop-rotation and tillage on crop yields and sediment yield using a modelling approach. The specific objective of his study was to assess the impact of corn (Zea mays L.), soybean (Glycine max (L.) Merr., and rice (Oryza sativa, L.) crop-rotations (corn after soybean, soybean after rice, continuous soybean) and tillage practices (conventional, conservation, no-till) on crop yields and sediment yield using the Soil and Water Assessment Tool (SWAT) model. The results of their study show that the cumulative (1981–2009) sediment yield at the end of the simulation period (2009) indicated a maximum difference of about 8 Mg ha^{-1} between no-till and conventional tillage practices, with no-till contributing the lowest sediment yield.

Erosion and Linear programming

According to Follett et al. (1985), the models much more suited for studying erosion economics are the linear programming (LP) models plus related models that have an associated LP subsystem. The models allow a detailed analysis of the use of land, water and other resources.

In fact, Sadeghi (2009) used a multiobjective linear optimization to identify the most suitable land allocation to different land uses, viz. orchard, irrigated farming, dry farming and rangeland targeting soil erosion minimization and benefit maximization. The objective function was structured to maximize economic return and minimize soil loss. The general benefit maximization problem was formulated as below:

$$\text{Max } (Z_1) = \sum_{i=1}^{n} C_{Bi} X_i$$

Where Z_1 is the total annual income in million Iranian Rails (mIR),C_{Bi} is annual income for each land use (mIR/ha), Xi is the area of each land use in ha and n stands for numbers of land uses.

The general soil erosion minimization problem was expressed as following form in which Z_2 is the total annual soil erosion (t) and C_{Ei} is the annual rate of soil erosion (t/ha) resulting from different land use.

$$\text{Max } (Z_2) = \sum_{i=1}^{n} C_{CEi} X_i \quad (1)$$

Both objective functions are subject to the following constraints:

Land capability constraints:

$X_1 \leq B_1$; (2)

$X_3 \leq B_2$; (3)

$X_4 \leq B_3$; (4)

$X_1 + X_3 \leq B_4$; (5)

Land availability constraint

$X_1 + X_2 + X_3 + X_4 \leq B_5$; (6)

Social and legislative constraint

$X_1 \geq B_6$ (7)

$X_2 \geq B_7$ (8)

Non-negativity constraints:

X_1, X_2, X_3 and $X_4 \geq 0$ (9)

Where B_1 to B_4 were the maximum allowable area to orchard (X_1), irrigated farming (X_3), dry farming (X_4), and summation of orchard and irrigated farming. B_5 denoted the maximum arable land resources. B_6 and B_7 also, respectively represented the minimum area of orchard and rangeland (X_2) in ha. Since there were sufficient and accessible water supply systems in Brimvand watershed, no constraint was defined for water availability. There were 10 springs with discharges from 2 to 453 l/s (16.9Mm3/year) and 128 wells with the total discharge capacity of 11.2Mm3/year in the study watershed. The main irrigation canal of Brimvand Dam with the average discharge of 5m3/s also passed along the entire watershed. The results of the study revealed that the amount of soil erosion and benefit could be respectively reduced and increased to 7.9 and 18.6%, by implementing the optimal allocation of the study land uses.

Sunandar et al. (2014) used linear programming and SWAT model to determine the optimal land use to reduce soil erosion in the Asahan Watershed. SWAT had been utilized to estimate surface runoff and erosion rates. The optimal land use had been determined via linear programming where the objective function is to minimize erosion:

$$\text{Min (Z)} = \sum_{j=1}^{n} C_j X_i$$

With the constraints function as follows in table 2:

Table 2: Constraint equations used in linear programming

No	Constraints function	Explanation
1	$\sum_{i}^{n} A_{i1} = \sum_{i}^{n} A_{i2}$	The total area of each land use must be equal to the watershed area.
2	$X_{3(2)} \geq X_{3(1)}$	Urban area can be larger from actual with maximum 10% area addition
3	$X_{1(2)} \geq X_{1(1)}$	Forest land area after optimization can be larger than actual
4	$X_{7(2)} \geq X_{7(1)}$	Paddy field can be larger than before
5	$Erosion_{\,i(2)} \geq 0$	Erosion from each land use is positive but minimizing to zero
6	$\sum_{i}^{n} Erosion_i \leq TSL$	Total soil loss after optimization should not over the limit (TSL)
7	$WY_{\,i(2)} \geq 0$	Water yield from each land use should be positive
8	$I_{i(2)} \geq I_{i(1)}$	Land value after optimization should not reduce then before (based on year 2013 price in North Sumatra province)
9	$X_i \geq 0$	Every land use area should be positive

The optimization results for the Asahan Watershed indicated that erosion can be reduced by increasing forest area, reducing dry land farm areas, and increasing plantation areas by eliminating barren land and shrubs. These land use areas change can reduce erosion without decreasing water yield and economic land value of the land. Forest area increase can be done through agroforestry, especially in areas with land capability categories that are not suitable for farmlands.

Farm policy: The Environmental Quality Incentives Program (EQIP) and the Conservation Reserve Program (CRP).

The United States Department of Agriculture (USDA) is the main agency regulating all agricultural programs is the USA. The USDA oversees many conservation programs dealing with water quality in agricultural and rural areas. Some of these programs include: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Emergency Conservation Program (ECP); Environmental Quality Incentives Program (EQIP); Environmental and Cultural Resource Compliance (ECRC); Highly Erodible Land Conservation and Wetland Conservation Compliance; Wetlands Reserve Program (WRP); Wildlife Habitat Incentives Program (WHIP); Farmland and Ranchland Protection Program (FRPP) and Conservation Technical Assistance (CTA).

The Environmental Quality Incentives Program (EQIP) is a voluntary program that provides a maximum of ten years financial and technical assistance to agricultural producers through contracts. The financial assistance consists in helping farmers plan and implement conservation practices that address natural resource concerns and improve soil, water, plant, animal, air and related resources on agricultural land and non-industrial private forestland. The main goal of EQIP is to help producers meet Federal, State, Tribal and local environmental regulations (USDA, 2014).

The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). Farmers enrolled in the program receive a yearly rental payment in order to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Farmers engage in at least 10 -15 year contracts. The long-run goal of the program is to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat by restoring agricultural land cover (USDA, 2015).

CHAPTER III

III. METHODS AND PROCEDURE

To achieve our objectives, this study uses SWAT to simulate crop yields, sediment loads and water runoff, with and without management practices, in the Fort Cobb watershed. The watershed was delineated and segmented into Hydrologic Responses Units (HRUs) using Digital Elevation Map (DEM), soil type map and land use map. Hydrologic response units are portions of a sub-basin and possess unique land use, slope range, and soil attributes (Neistch et al., 2004). Upon delineation and definition of the HRUs, crop yields, sediment loads and water runoff were simulated from 1990 to 2010. To identify the parameters which need to be modified in the SWAT model to obtain a simulated result close to observed data, sensitivity analysis, calibration and validation were conducted. The sensitivity analysis was done using SWAT-CUP. The calibration and validation was carried out using SWAT-CUP for surface runoff and sediment loads while for crop yields the SWAT model had been adjusted manually by modifying the parameters identified as very sensitive. The adjusted model was used to simulate crop yields, sediments loads and water runoff with and without management practices.

To evaluate the effect of best management practices on erosion and crop yields, the simulated output without management practices, (baseline data), was compared with the simulated output with management practices using t-statistics. The cost efficiency ratio (CER) was used to determine the economically efficient BMPs.

To identify the optimal best management options, a linear mathematical programming model had been developed using crop budget (cost per crop) and simulated data from SWAT.A synopsis of the different steps followed in this study is presented in figure 2:

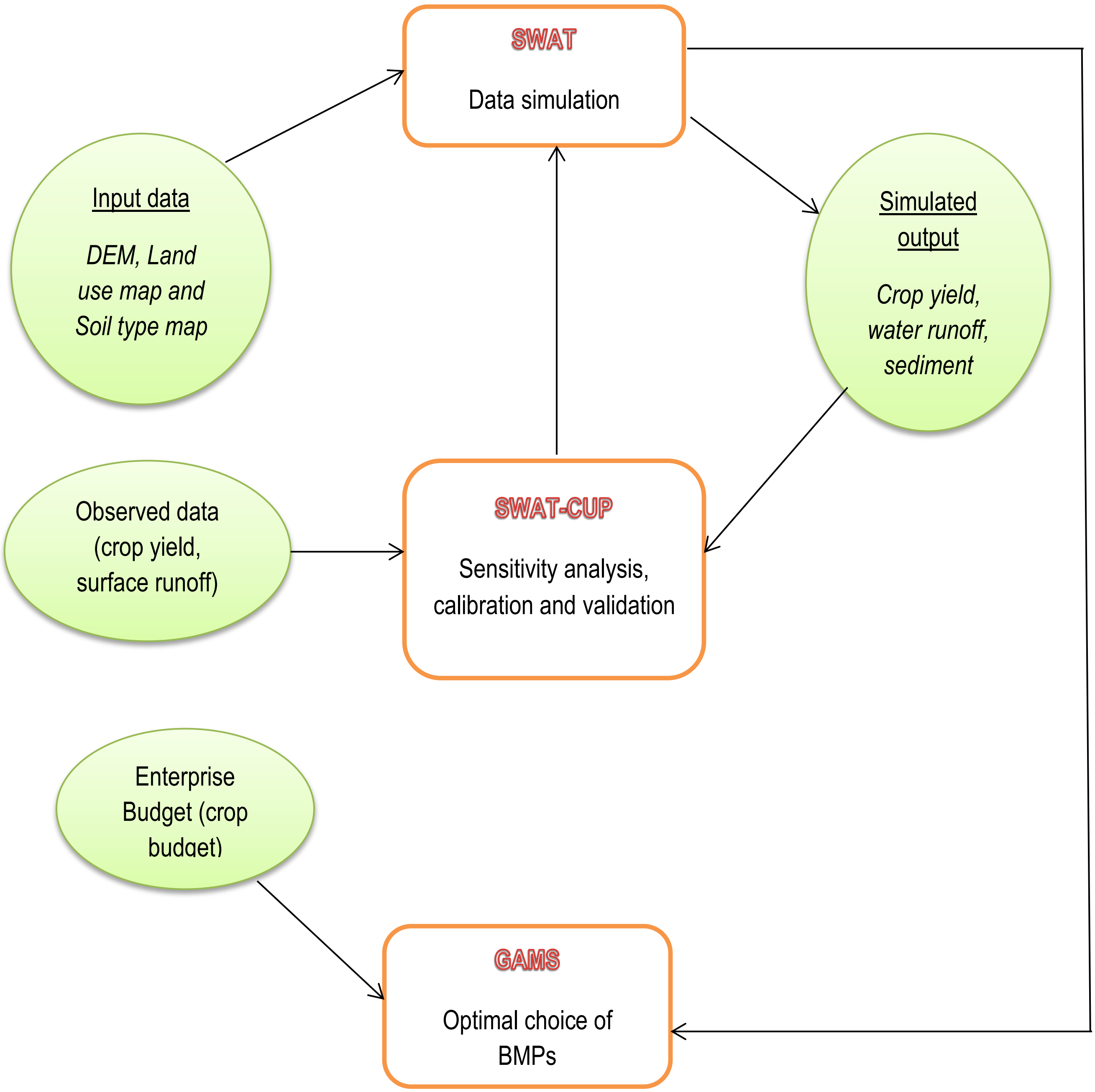


Figure 2: Methods and procedure illustration

It is worth noting that the analysis was restricted to five mile Creeks which is a sub-basin of the Fort Cobb watershed.

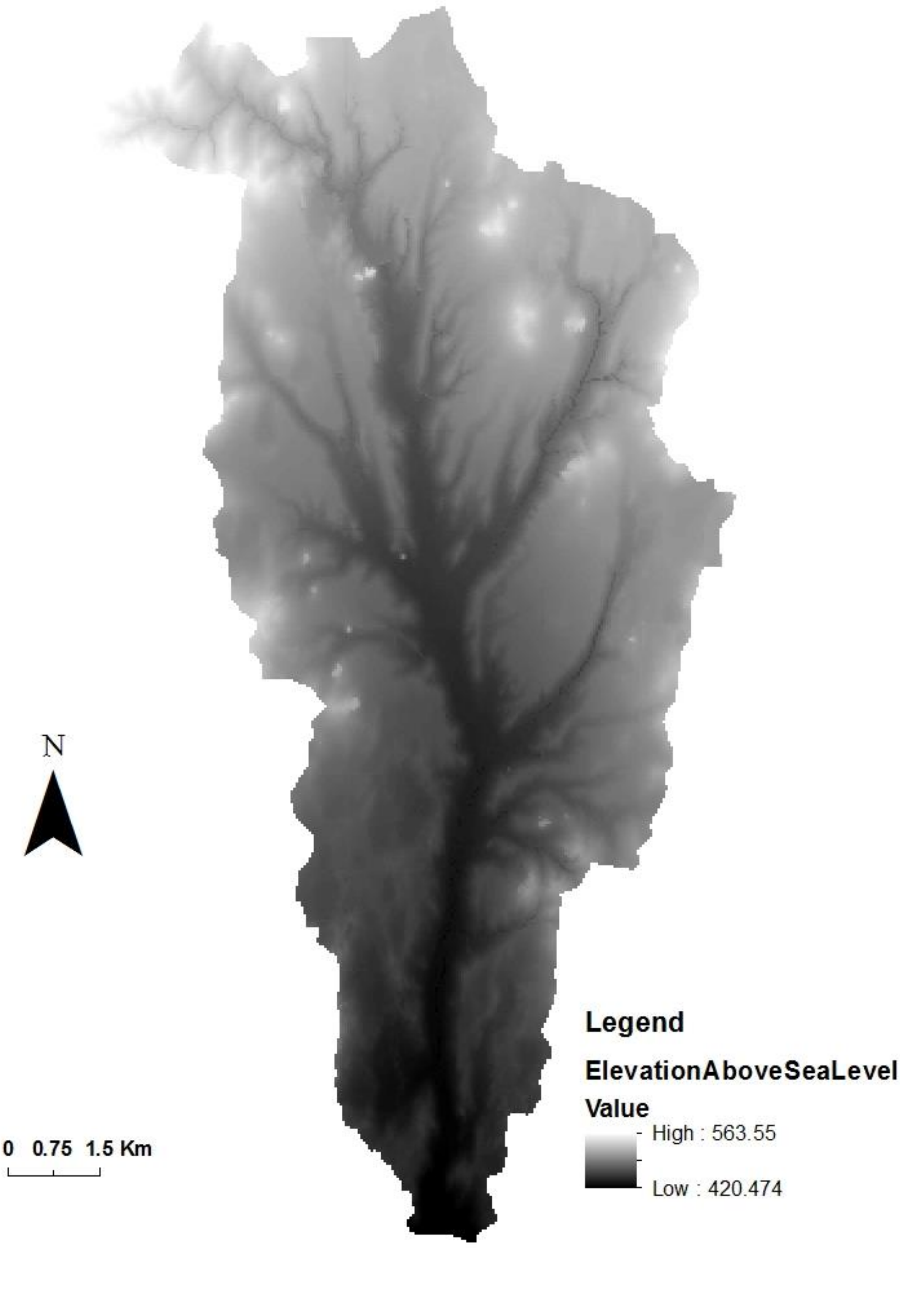
SWAT Model

Model input

SWAT is a comprehensive model that requires information provided by the user to simulate runoff, crop yields, phosphorus loads etc. The number of inputs for SWAT is overwhelmingly numerous and only inputs that are required for the purpose of our study were reviewed. The data required in our study are the Digital Elevation Model, soil data, land use data, precipitation and other weather data.

Digital Elevation Model

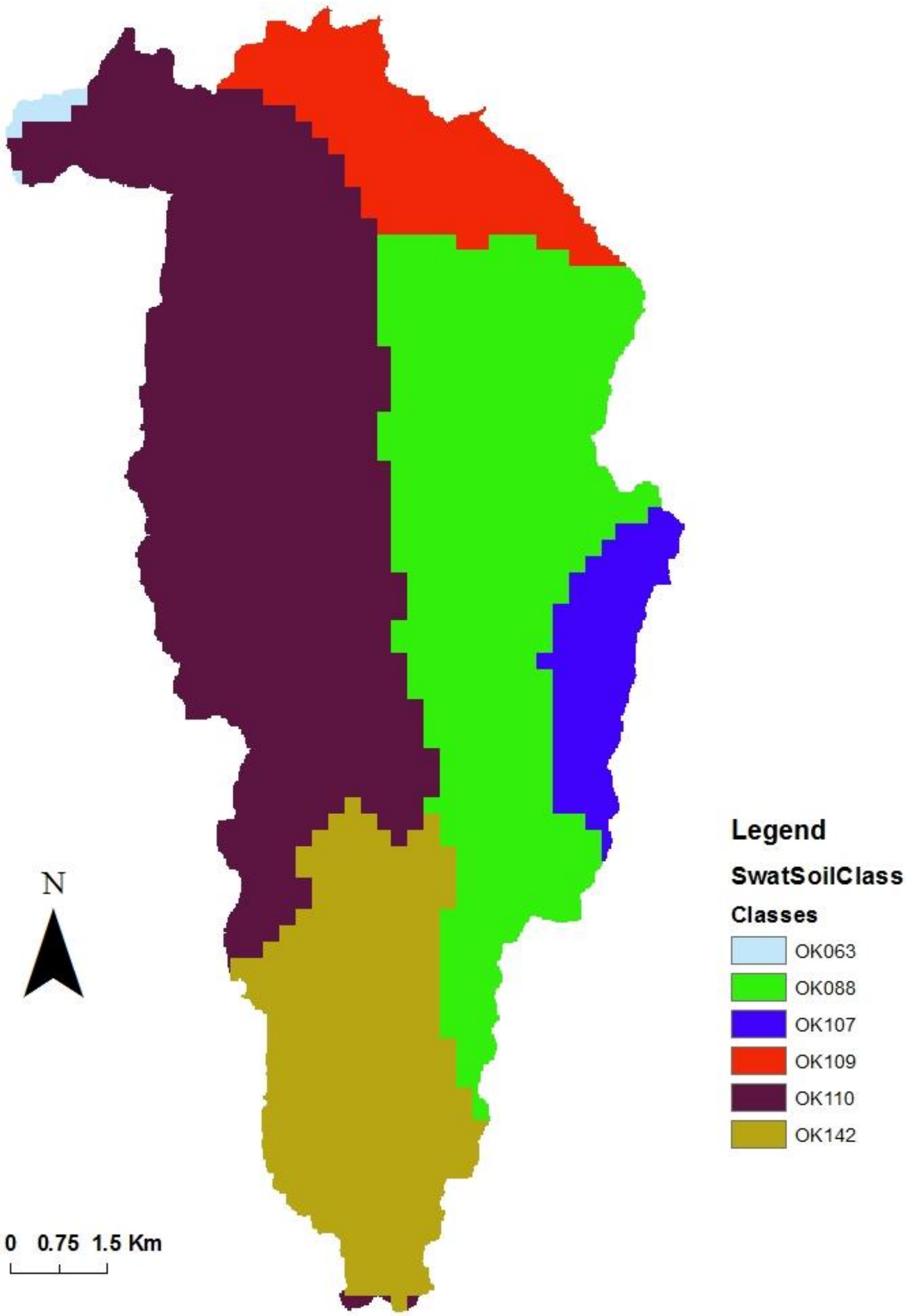
To delineate the watershed and sub-basins and to determine drainage networks, SWAT uses the digital representation of the topographic surface. DEM is the digital representation of the topographic surface. A 30-m seamless Digital Elevation Model (DEM) was used to define the topography of each watershed. DEM was collected from the USDA geospatial data gateway.



Map 2: Digital Elevation Map of Five Mile Creek Sub-basin

Soil map

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 area anywhere in the watershed to the STATSGO database. In this study, the STMUID was used. The STMUID (State STATSGO) is embedded into SWAT2012. Before proceeding with the HRU definition we should make sure that the soil dataset (STATSGO) available in SWAT has the same projection as our watershed. The soil data set was projected to Universal Transverse Mercator (UTM) under appropriate zone (zone 14 for the Fort Cobb Watershed). Oklahoma belongs to three UTM zones. 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. The following map 3 illustrates the soil map of the Five Mile Creek Sub-basin watershed.

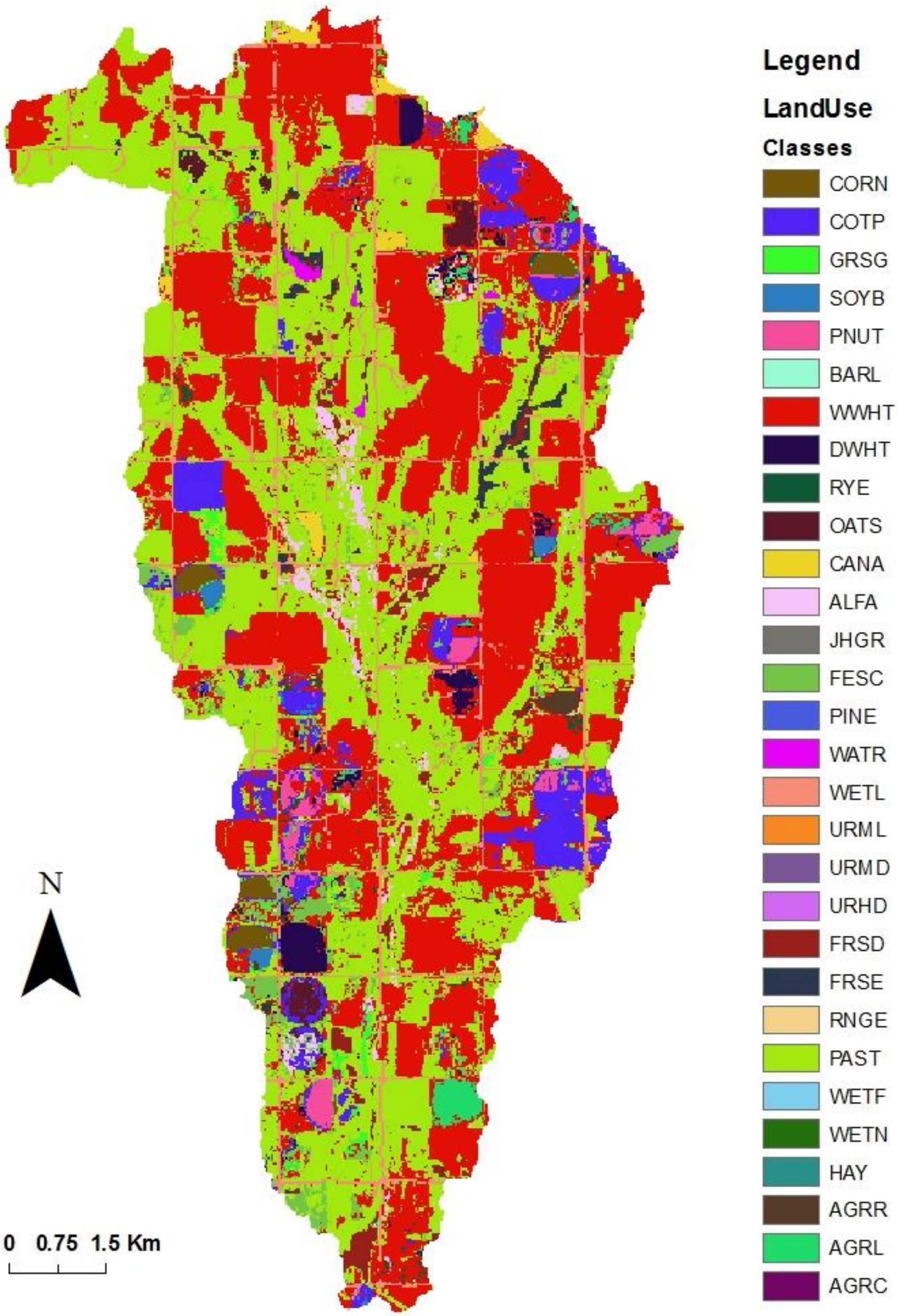


Map 3: Five Mile Creek Soil Types Map

Land use Map

Land cover is an 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. Besides, the land cover database built up in SWAT contains information needed by SWAT to simulate the growth of a particular land cover. The default set of land covers included in the model is by no means exhaustive and users may need to add plants to the list.

To facilitate linkage of land use and land cover, the cropland grid had been projected to Universal Transverse Mercator (UTM) under appropriate zone (zone 14 for the Fort Cobb Watershed). The following map 4 depicts the land use of the Five Mile Creek sub-basin watershed.



Map 4: Five Mile Creek Land Use Map

Table 3 summarizes the SWAT average land use distribution from 1990 to 2010 of the Five Mile Creek sub-basin. The output reveals that winter wheat, pasture, cotton and peanuts are the main crops in this sub-basin. In this study, only winter wheat, cotton and peanuts are taken into account in the cost benefit analysis.

Table 3: Average SWAT HRU distribution of crops of the Five Mile Creek Sub-basin

		Surface area of crop land (Hectares)					
Sub-basin	**Number of HRUs**	**Cotton**	**Peanut**	**Winter wheat**	**Pasture**	**Other crops**	**Total**
1	36	1.57	80.01	341.26	345.65	20.01	790.51
2	55	67.90	40.07	195.88	241.91	100.61	646.38
3	26	0.00	16.02	26.74	55.52	10.25	108.53
4	151	17.01	301.18	1099.40	1325.07	110.58	2853.23
5	12	0.00	0.00	53.63	25.80	7.29	86.73
6	117	131.35	13.56	647.40	516.68	303.39	1612.38
7	73	56.93	14.19	419.36	396.93	116.29	1003.72
8	114	36.23	25.01	451.45	379.85	161.69	1054.22
9	74	67.20	35.91	248.18	84.61	97.94	533.85
10	19	0.00	0.00	8.94	10.19	2.04	21.17
11	126	124.37	6.27	457.55	477.71	179.02	1244.93
12	82	44.38	25.80	108.37	204.03	226.86	609.45
13	86	10.43	0.39	288.02	198.0782	149.93	646.85
Total	971	557.38	560.60	4346.20	4262.047	1485.72	11211.96

Weather

The SWAT model 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, there are two options of incorporating the weather data into the model. 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 (Winchell et al., 2013).

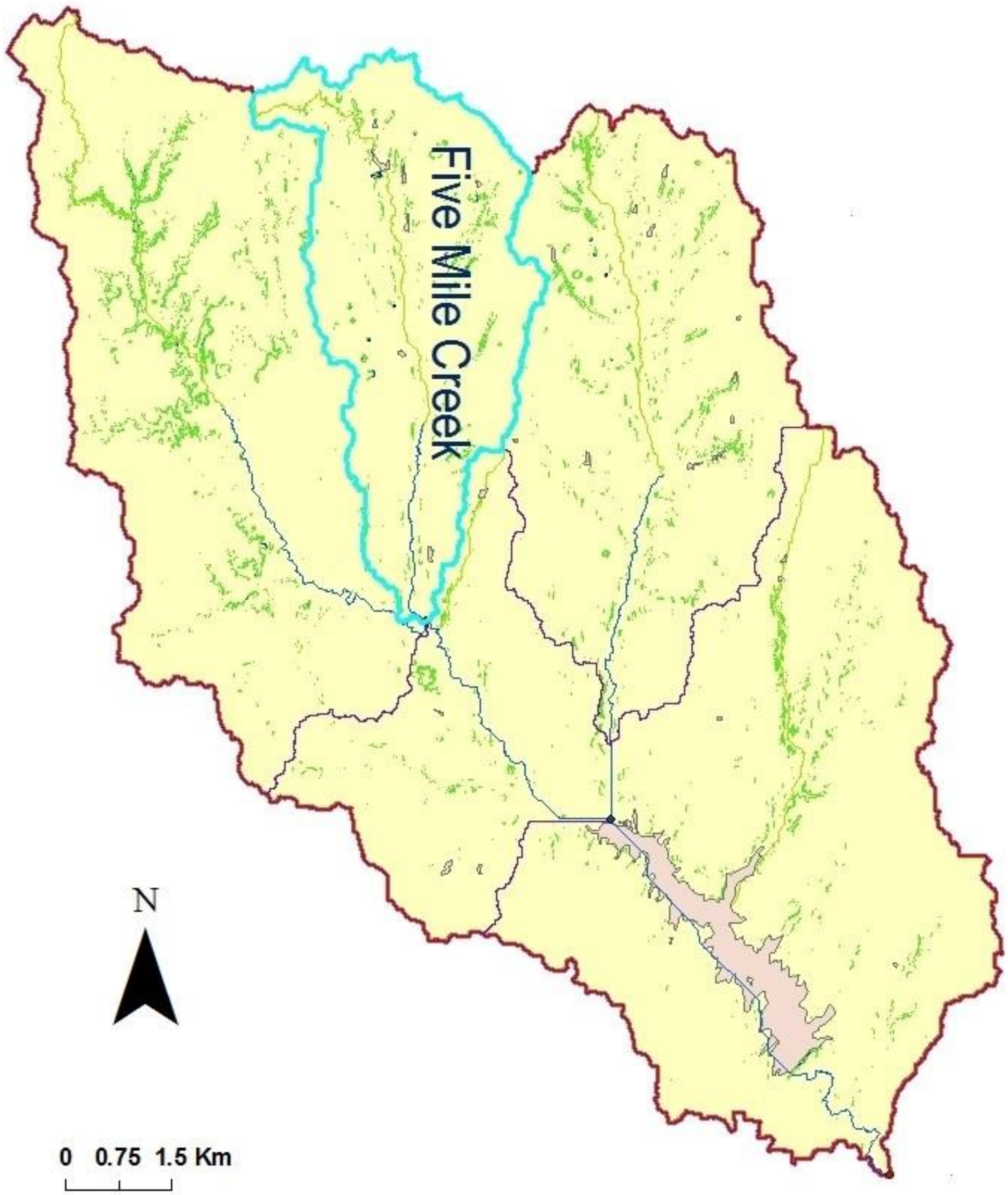
A combination of both observed and simulated weather data were used in this study. Observed weather data from USDA Agricultural Research Service were utilized to create files for daily precipitation, minimum and maximum daily temperatures. The rest of the weather parameters such as solar radiation, wind speed and relative humidity were generated using WGEN_US_FirstOrder embedded in the SWAT model. WGEN_US_FirstOrder contains weather information for 1041 first order climate stations around the United States. Weather generator uses average monthly values from selected weather stations to generate missing climate data. It is recommended to select the closest gauging station to the watershed during the HRU delimitation process. The rainfall, temperature, solar radiation, wind speed, relative humidity data can also be incorporated into the model in the form of a text table format if they are available but these options are optional. Weather data at county level are available at: http://ars.usda.gov/Research/docs.htm?docid=19390

Model Set-up

Watershed delineation

SWAT allows the user to delineate the watersheds and sub-basins based on an automatic procedure using the Digital Elevation Model (DEM) data in ESRI grid format. User specified parameters provide limits that influence the size and number of sub-basins created. In addition, the user has the option of importing and using a pre-defined digital stream network in ArcView shapefile or geodatabase feature class (PolyLine) format. The watershed delineation tool uses and expands ArcGIS and spatial Analyst extension functions to perform watershed delineations (Winchell et al., 2013).

In this study, The 30 meter DEM of Caddo County obtained from the USDA Agricultural Research Service website was loaded into ArcGIS in ESRI (Environmental System Research Institute) grid format. Stream network was defined for the whole DEM by SWAT using the concept of flow direction and flow accumulation. Before defining the stream network, the model processes the DEM map grid to remove all the non-draining zones (sinks). To define the origin of streams, a threshold area was defined. The threshold area defines the minimum drainage area required to form the origin of a stream. The size and number of sub-basins and details of stream network depends on this threshold area (Winchell et al., 2013). The threshold area was taken to be 10000 ha, suggested by Affuso. (2014). The threshold area, or critical source area, defines the minimum drainage area required to form the origin of a stream. The watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineated the Fort Cobb watershed of 84,042 ha (207,672 acres) and 5 sub-basins were produced. Five Mile Creek is 11,212 ha. Map5 shows the Fort Cobb Watershed and highlights the Five Mile Creek sub-basin



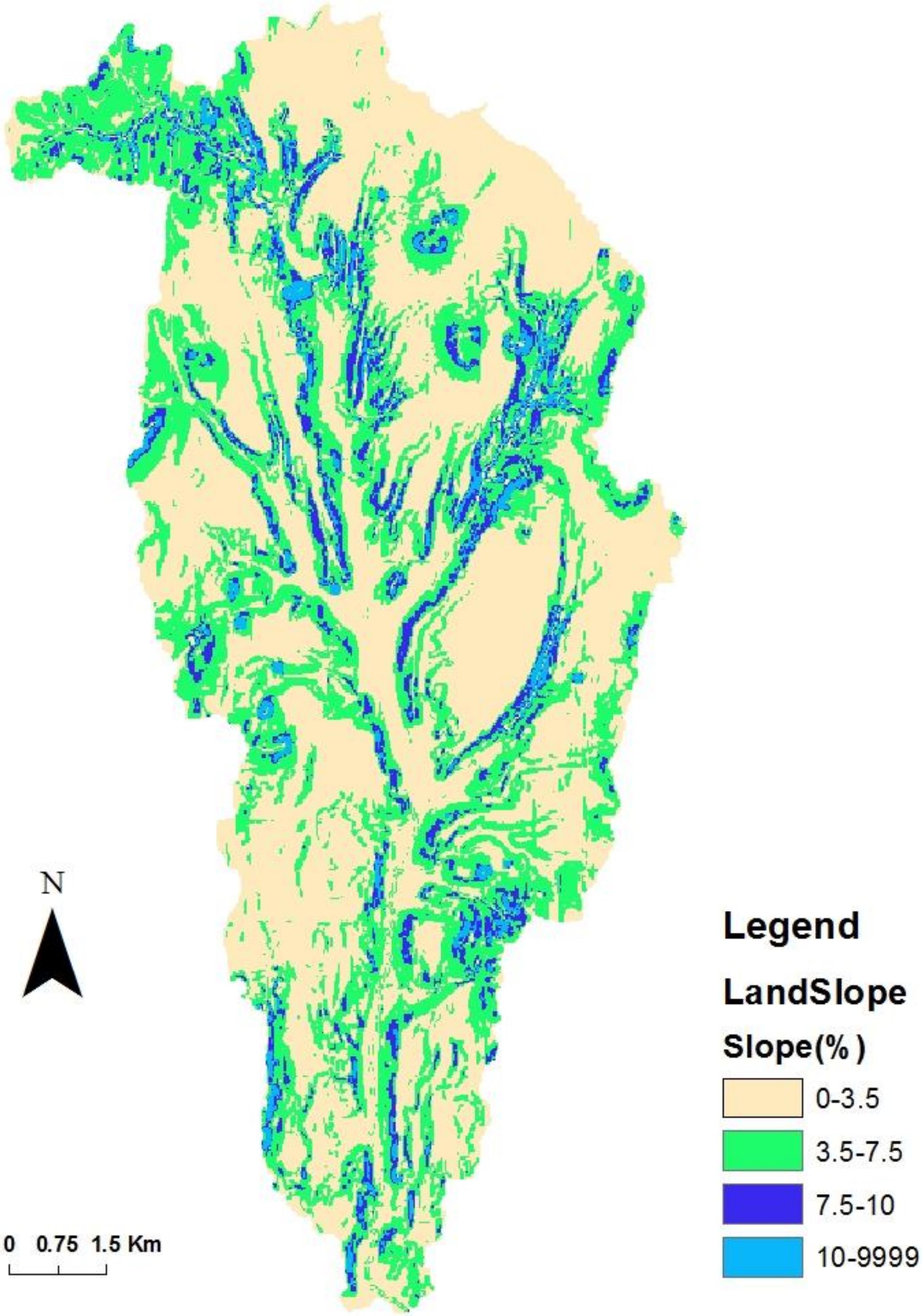
Map 5: Fort Cobb watershed delineated

HRU definition

Upon completion of the delineation, the watershed was subdivided into HRUs. Land use and soil type were imported into ArcGIS and four slopes (0-3.5%, 3.5-7.5%, 7.5-10% and 10 or more %) classes were defined. Subdividing the watershed into areas having unique land use and soil combinations enables the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils (Winchell et al., 2013).

The user has two options in determining the HRU distribution: assign a single HRU to each sub-watershed or assign multiple HRUs to each watershed. If a single HRU per sub-basin is selected, the HRU is determined by the dominant land use category, soil type, and slope class with each watershed. If multiple HRUs are selected, the user may specify sensitivities for the land use, soil and slope data that will be used to determine the number and kind of HRUs in each watershed (Winchell et al., 2013).

The multiple slope option was selected for this study and land use and soils threshold was set to 0%. By keeping these thresholds at 0%, the number of HRUs within a sub-basin was increased allowing more spatial detail to be incorporated in the SWAT model. The four slope classes were chosen based on the topography of the Five Mile Creek watershed. A total of 13 sub-basins with 971 HRUs were created for the Five Mile Creek Sub-basin.



Map 6: Slope Map of Five Mile Creek

Modifying SWAT management practices' input files

In ArcSWAT, we have two options of defining the management operations in the watershed: scheduling by date and scheduling by heat units. In this study, scheduling the management practices by date was preferred because of the lack of information on heat units of crops in the watershed. The basic operations are plant growing season, irrigation, fertilizer application, pesticide application, tillage and harvest and kill operation. The planting operation or the beginning of growing season is the time of planting the agricultural crops and initiation of plant growth for a land cover that requires several years to reach maturity. The tillage operation redistributes residue, nutrients, pesticides and bacteria. Harvest and kill operation stops plant growth in a way that the fraction of biomass is removed from the HRU as a residue on the soil surface (Winchell et al., 2013). These operations were provided to the model for each crop type based on the crop calendar found in the Oklahoma Agricultural Statistics. Generic conservation tillage was used as baseline in the SWAT model since this is the main practice in the Fort Cobb watershed. An example of operations prepared for winter wheat is summarized in the following table:

Table 4: SWAT operations input for Winter Wheat

Year	Month	Day	Operations	Crop
1	9	30	Plant/Begin growing season	Winter Wheat
1	10	3	Auto-fertilization	
1	10	5	Pesticide application	
1	6	1	Harvest and Kill operations	

Model sensitivity analysis

After setting up the model, the next step was to run the model. The results from the model run (first simulation) should not be directly used for further analysis but instead should be evaluated through sensitivity analysis, model calibration and model validation to sufficiently predict crop yields, sediment yields and stream flow (White and Chaubey, 2005).

Sensitivity analyses were conducted for the Five Mile Creek watershed hydrology to determine the parameters needed to improve simulation results and thus to better understand the behavior of the hydrologic system and to evaluate the applicability of the model. SWAT-CUP had been used to identify the most important parameters to alter to obtain surface flow output which is close to the reality. The algorithm used was the Sequential Uncertainty Fitting version 2 (SUFI2). Observed monthly discharges have been collected from USGS National Water Information system. These monthly discharges in cubic feet per second (ft^3/s) had been converted to cube meter per second (m^3/s) before being included into the SWAT-CUP model. The 95PPU plot is the following:

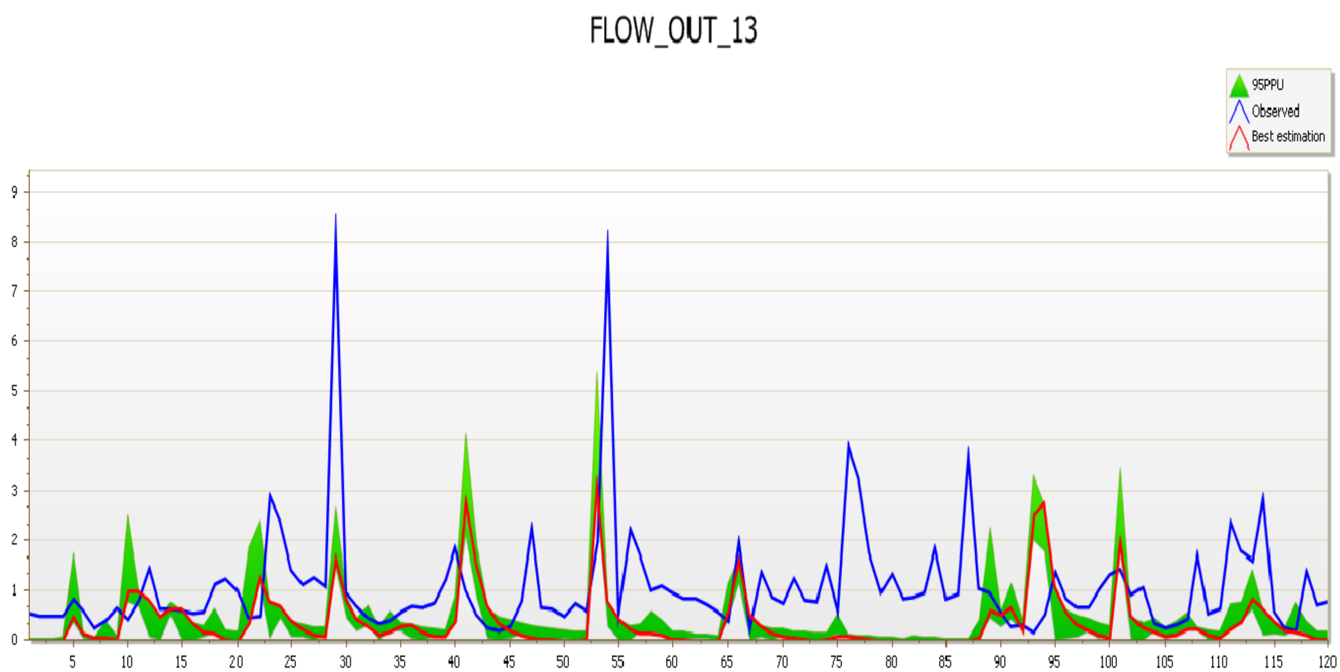


Figure 3: 95 percent prediction uncertainty plot.

The most important parameters identified by SWAT-CUP and their p-values are summarized in the following table:

Table 3: Sensitivity analysis table

Parameter names	Definition	t-statistics	P-value
GWQMN.gw	Threshold depth of water in the aquifer required for return flow to occur	2.62	0.01
GW_DELAY.gw	Ground water delay time	-0.05	0.95
ALPHA_BF.gw	Base flow factor	-0.83	0.40
CN2.mgt	Runoff curve number	-13.43	4.04×10^{-24}

This result shows that CN2 (runoff curve number) is the most sensitive followed by GWGMN (Threshold depth of water in the shallow aquifer required for return flow to occur (mm)). These parameters had been adjusted according after the sensitivity analysis.

Sensitivity analysis for crop yield and sediment yields were conducted following previous studies (Abbaspour, 2007; Yang et al., 2008). The main parameters that had been changed for crop yields are CN2, LAI_INIT (initial leaf area index), BIO-INIT (Initial dry weight biomass) and USLEP (Universal Soil Loss Equation conservation practice factor).

For sediment yields, LAT_SED (Sediment concentration in lateral and groundwater flow (mg/L)), EPCO (Plant uptake compensation factor), ESCO (Soil evaporation compensation factor), ERORGN (Organic N enrichment ratio for loading with sediment) and ERORGP (Phosphorus enrichment ratio for loading with sediment) had been modified. SWAT_CUP could not be used to determine the sensitivity analysis for sediment yields because of the lack of information. Only observed annual discrete sediment yields are available for Cobb Creek station near Eakly (USGS 07325800).

Model calibration and validation

Model calibration and validation followed sensitivity analysis. Flow calibration for the Five Mile Creek sub-basin was conducted based on a monthly record from 1991 to 2000. Likewise, flow validation for the Five Mile Creek watershed was carried out for the years 2001 to 2010. Crop yields and sediment yields were calibrated and validated from year 1990 to 2010 based on available crop yields and sediment yields data. The changes in parameters are shown in the following table:

Table 4: Flow calibration of the SWAT model for the Five Mile Creek

Parameter for flow calibration	Default value	Calibrated value
GWQMN	1000	100
REVAPMN	750	100
RCHRG-DP	0.05	0.1
DEEPEST	2000	1000
SHALLST	1000	100
ALPHA-BF	0.048	0.03
GW-SPYLD	0.003	0.03

**GWGMN (Threshold depth of water in the shallow aquifer required for return flow to occur (mm)).
**REVAPMN (Threshold depth of water in the shallow aquifer for return percolation to the deep aquifer to occur (mm).
** RCHRG-DP (Deep aquifer percolation fraction).
** DEEPEST (Initial depth of water in the deep aquifer).
** SHALLST (Initial depth of water in the shallow aquifer).
** ALPHA-BF (Baseflow Alpha Factor).
** GW-SPYLD (Specific yield of the shallow aquifer).

Table 5: Sediment yields calibration for the SWAT model for the Five Mile Creek

Parameter for sediment calibration	Default value	Calibrated value
CN2	77	74
EPCO	1	0.9
ESCO	0.95	0.8
ERORGN	0	0.5
ERORGP	0	0.5

** CN2 (runoff curve number)
** EPCO (Plant uptake compensation factor).
** ESCO (Soil evaporation compensation factor).
** ERORGN (Organic N enrichment ratio for loading with sediment)
** ERORGP ((Phosphorus enrichment ratio for loading with sediment).

Table 6: Winter wheat yield calibration

Parameter for yield calibration	Initial value	Calibrated value
BIOMIX	0.2	0.2
BIO_E	30	29
USLEP	1	1
HVSTI	0.4	0.3
OV_N	0.14	0.12
BLAI	4	3
FRGRW1	0.05	0.03
LAIMX1	0.05	0.03
CNYLD	0.025	0.02
CPYLD	0.0022	0.0018

** BIOMIX (Biological Mixing Efficiency).
** BIO_E (Radiation Use Efficiency or Biomass Energy Ratio).
** USLEP (Universal Soil Loss Equation Practice factor).
** HVSTI (Harvest index for optimal growing conditions).
** OV_N (Manning's roughness coefficient for overland flow).
** BLAI (Maximum potential leaf area index).
** FRGRW1 (Fraction of the plant growing season or fraction of total potential heat units corresponding to the 1st point on the optimal leaf area development curve).
** LAIMX1 (Fraction of the maximum leaf area index corresponding to 1st point on the optimal leaf area development curve).
** CNYLD (Normal fraction of nitrogen in yield)
** CPYLD (Normal fraction of phosphorus in yield)

The model goodness-of-fit was evaluated both on a monthly and on a yearly basis. The average yearly winter wheat yield (ton/ha) is shown on the following graph:

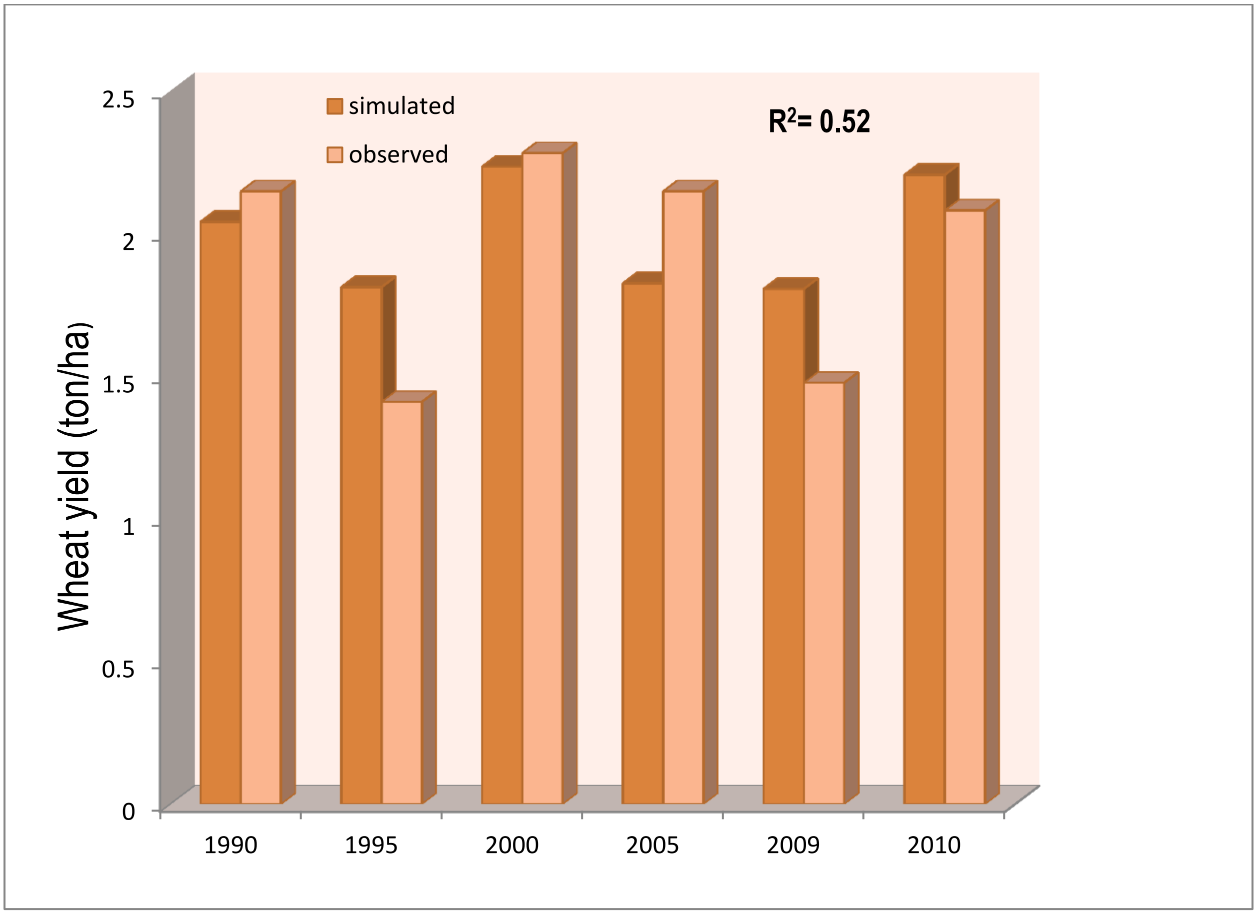


Figure 4: Observed and simulated Winter Wheat yields (ton/ha)

A synopsis of the simulated data (surface runoff, sediment yields, crop yield) for each HRU can be found in Appendix 1.

Management practices and scenarios

SWAT gives options for the user to consider different management practices (irrigation management, fertilizer management, pesticide management, urban management, conservation practices like porous pavement, filter strips, grade stabilization structure, grassed waterway, infiltration trench, rain garden, pipe slope drain, sediment basin etc.). In this study the following conservation practice scenarios will be defined for three crops (winter wheat, peanuts and cotton).

Scenario I: Conservation tillage

For this scenario, the generic conservation tillage built up in SWAT and the regular crop calendars were used. This scenario is used as baseline in our economic analysis.

Scenario II: Conservation tillage plus contour farming

This scenario describes the combination of two management practices (conservation tillage and contour farming). To model this scenario in SWAT the following parameters had been modified according to Mazdak et al. (2007). The Manning's roughness coefficient for overland flow (OV-N parameter) was adjusted and the default CN2 value had been reduced by 3 (Mazdak et al., 2007). The USLE-P (USLE practice factor) was modified according to Mazdak et al. (2007) and in reference to the SWAT user manual. The recommended USLE-P values for each land slope are given in table 9.

Scenario III: Conservation tillage plus strip cropping

Two conservation practices were implemented. Conservation tillage was used as baseline operation and strip cropping was the management practice. To model this scenario in SWAT, OV-N and USLE-P and CN2 values were adjusted according to Mazdak et al. (2007) and following the recommendations in the SWAT user manual. The recommended USLE-P values for each land slope are given in table 9.

Scenario IV: Conservation tillage plus terraces

Like scenario II and scenario III, generic conventional tillage was the baseline operation. For terrace farming, the default CN2 value were reduced by 6 units, OV-N and USLE-P were modified according to Mazdak et al. (2007) and following the recommendations in the SWAT user manual. Table 9 summarizes the recommended USLE-P value for each land slope.

Scenario V: No-till farming

For this scenario, only no-tillage operation was used as the baseline operation. The agricultural calendar of each crops were set up according to the calendar from the Oklahoma Agricultural statistics 2014 (NASS, 2014).

Table 7: USLE-P value for contour farming, strip cropping and terracing

Land Slope %	USLE-P		
	Contour farming	Strip cropping	Terracing
1 to 2	0.6	0.3	0.12
3 to 5	0.5	0.25	0.1
6 to 8	0.5	0.25	0.1
9 to 12	0.6	0.3	0.12
13 to 16	0.7	0.35	0.14
17 to 20	0.8	0.40	0.16
21 to 25	0.9	0.45	0.18

Source: SWAT 2013 User's guide (Winchell et al., 2013).

Crop budget

Oklahoma State University's Enterprise Budget Software is an Excel based program designed to aid the farm manager in making his production decisions by providing a user-friendly system to enter and format the cost and returns of production. One feature that enhances the software is that it contains estimates of production cost and returns as well as the management practices typical of the area. In this software, past year yields and prices are given and fertilizer calculation is automatically done. The budget software has a section to calculate machinery costs for each crop. These costs were crosschecked using the Machsel software. The Machsel program calculates the variable machinery costs of fuel, lubrication, repairs, and labor and the fixed costs of interest, taxes, insurance, and depreciation. These estimates are based on technical coefficients established by research on machinery operation costs. The default machinery cost for each crop in each county of Oklahoma is set up in the software (Doye et al., 2009).

Machinery operating costs only occur when a machine is used. Budget examples include fuel, lubrication, and repairs. Only implements with engines incur a fuel cost and the rate of fuel consumption depends on the PTO hp (horsepower).

Annual Fuel Cost = PTO hp × FCM × Fuel Price Per Gallon × HOURS

FCM is the Fuel Consumption Multiplier and HOURS is the number of hours the power unit is used. The Fuel Consumption Multiplier is the rate of fuel usage in gallons per hour and is assumed to be 0.048.

Repair cost equations estimate the total annual repair costs based on the accumulated hours of lifetime use. Repair and maintenance calculations are based on ASAE referenced equations.

$$\text{Annual repair cost} = \frac{\text{List price} \times \text{RC1} \times \text{RC2} \times \text{Percent life}^{\text{RC3}}}{\text{Years}}$$

RC1 is the ratio of total lifetime accumulated repairs to the initial list price of the machine. RC2 and RC3 determine the timing of repair costs over the life of the machine. Percent Life is the proportion of machine life that will have expired when the current operator trades in or no longer uses the machine. The estimated number of years of use is defined as YEARS. The formula for estimating percent life is:

$$\text{Percent Life} = \frac{\text{Years} \times \text{Hours} \times 100}{\text{Hours of life}}$$

Total annual machinery operating costs per complement are allocated to the enterprise by multiplying the implement's cost per hour by the number of hours per acre each machine is used in performing a field operation.

In our study the default operating inputs (seed, fertilizer, custom harvest, pesticide, harvest aids, crop insurance, annual operating capital, machinery labor, machinery fuel, irrigation etc.) for Caddo County were used to evaluate the cost of conversation tillage and no-tillage wheat, cotton and peanut budgets. More information about the operating inputs computation is available in the Enterprise Budget user's manual (Doye et al., 2009).

The average costs ($/acre) for each management practices (contour farming, strip cropping and terracing) in Oklahoma were obtained from Oklahoma Environmental Quality Incentives Program (Doye et al., 2009). The implementation of contour farming with conservation tillage incurs an average additional cost of 5 to 8 dollars per acre based on the crop and the machinery used as compared to conservation tillage. Likewise, conservation tillage with strip cropping entails an average additional cost of 8 to 10 dollars in reference to conservation tillage. Based upon the literature reviewed and information provided by Oklahoma Environmental Quality Incentives Program officials, establishment costs for terracing are estimated to range from $0.35 to $2.40/foot. Though there is no fixed ratio for feet of terrace per acre of land, a reasonable range is 175 to 300 linear feet of terrace per acre. This implies an average per acre cost of $61.25 to $720. Terraces, if properly constructed and maintained, may be expected to have a life expectancy of approximately 20 years (EPA, 1986). Based on this information, the cost of building and maintaining terraces were depreciated over an average of 10 years. Depreciation costs are estimated as:

$$\text{Annual Average Depreciation Cost} = \frac{\text{Average cost - Salvage Value}}{\text{Years}}$$

The costs for management practice (conservation tillage, no-tillage, contour farming, strip cropping and terracing) in winter wheat, peanuts and cotton can be found in appendices.

Profit maximization solutions

Linear programming was used to identify the most cost-effective combination of management practices maximizes return to the producers while insuring sediment from the watershed does not exceed a specified target. The data generated by SWAT for crop yield, surface runoff and sediment loads (sediment, nitrogen, and phosphorus) were combined with price and cost data in a linear programming model using GAMS. The objective function was to maximize returns per acre based on crop produced by changing management practices subject to constraints on sediment, nitrogen, and phosphorus runoff. Mathematically stated the model is as follows:

$$Maximize\ return = \sum_{i=1}^{I}\sum_{j=1}^{J}\left(\left(\left(P_i \times Y_{ij}\right) + F_i\right) - C_i\right) \times X_{ij}\ \ (1)\ subject\ to:$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} Ph_{ji} \times X_{ij} \leq Ph_{limit}\ (2)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} N_{ji} \times X_{ij} \leq N_{limit}\ \ (3)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} SED_{ji} \times X_{ij} \leq SED_{limit}\ \ (4)$$

$$\sum_{i=1}^{I} X_{ij} = Acres_j\ \ (5)$$

$$X_{ij} \geq 0\ (6)$$

Where:

P_i	Price of Crop I
Y_{ij}	Yield of $Crop_i$ on HRU_j under each scenario
F_i	Forage Value for $Crop_i$
C_i	Total Cost to produce $Crop_i$ under each scenario
Ph_{ji}	Phosphorus runoff from HRU_j under $Crop_i$ and each scenario
N_{ji}	Nitrogen runoff from HRU_j under $Crop_i$ and each scenario
SED_{ji}	Sediment runoff from HRU_j under $Crop_i$ and each scenario
$Acres_j$	Acres in HRU_i
X_{ji}	The Variable: the number of acres of Crop I in HRU_j.

Average crop prices were obtained from the Oklahoma Agricultural Statistics 2014. The forage value and the cost for each crop were computed based on the information available in the Oklahoma State University's Enterprise Budget software. Crop yield, phosphorus and nitrogen runoff, sediment yields were simulated using the SWAT model.

An example of the GAMS Linear Programming model used to test each scenario is included in Appendix 2 to show how the data was entered and used. The sediment, nitrogen, and phosphorus limits were set to 0%, 50%, 75% and 95% reduction of the total loads of the baseline.

The linear programming model was set up based on the following assumptions:

- ✓ All land was allocated. Each HRU was assigned some cover type so that no HRU could be removed from calculation.
- ✓ HRUs that were covered in water, urban area or forest in the baseline were assumed to be either physically or economically unable to be converted to crop use so they remained in their base use.

- ✓ Yield data from SWAT was assumed to represent actual production from each HRU in each particular land use.
- ✓ Crop prices and input costs for each crop type are constant for each HRU.
- ✓ The total runoff levels for sediment, nitrogen, and phosphorus from the baseline were assumed to be the starting levels for abatement in each of the scenarios.

CHAPTER IV

IV. RESULTS AND DISCUSSION

The results are subdivided into five sections. The first section presents the impacts of implementing the scenarios (II, III, IV and V) on surface runoff and sediment yields as compared to scenario I (baseline). In the second section, the effects of these scenarios on crop yields of three crops (winter wheat, cotton and peanuts) are shown. The third section contains information related to the cost-effectiveness of these scenarios. The fourth and last sections of the results show the spatial allocation of land use which will maximize profits to farmers subject to sediment yields, phosphorus and Nitrogen constraints.

Part I: Assessing the effectiveness of Best Management Practices on surface runoff and sediment yields.

✓ **Impact of Best Management Practices on surface runoff**

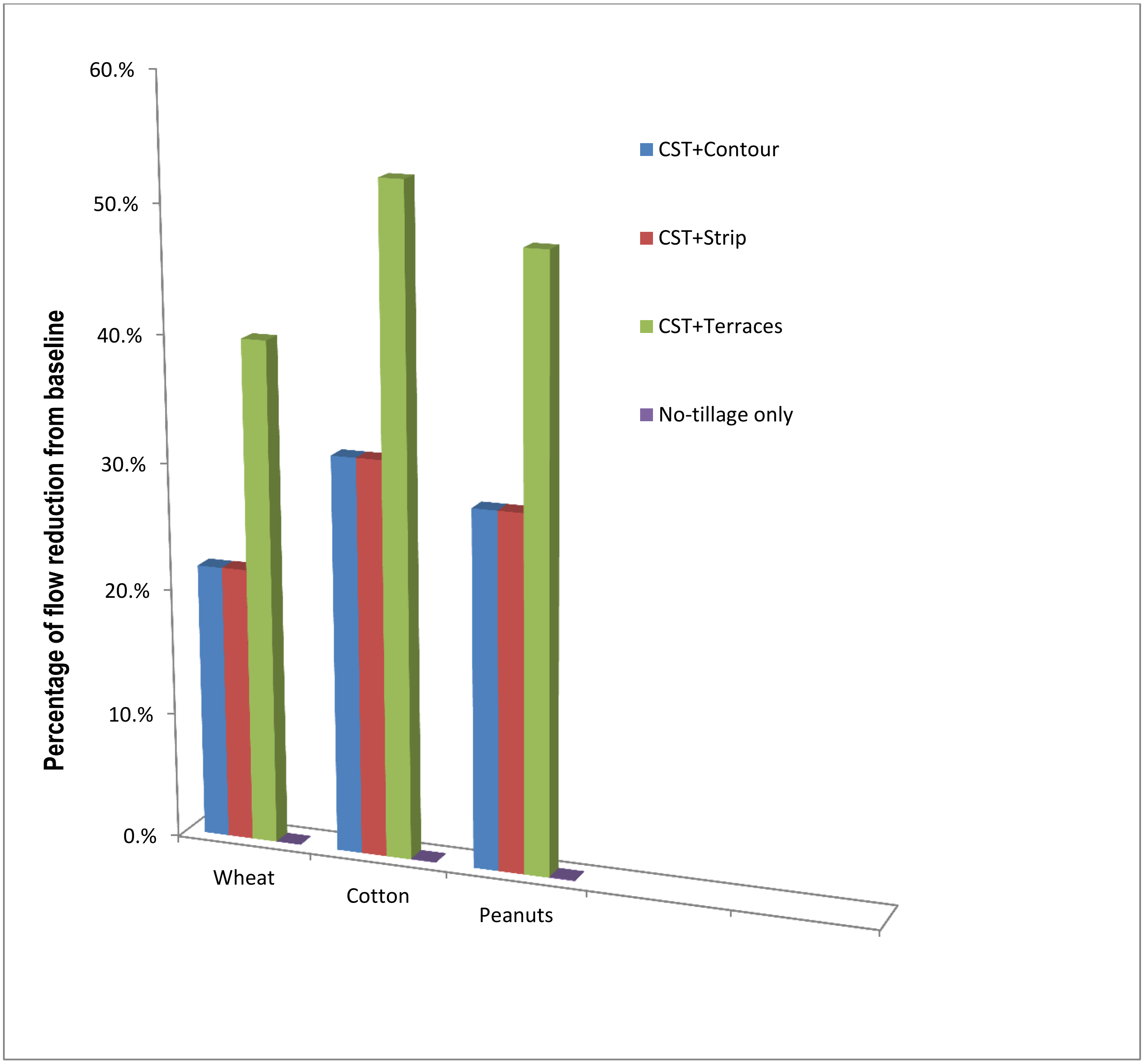


Figure 5: Percentage reduction of surface runoff under each scenario

Figure 6 illustrates the percentage reduction of surface runoff under each scenario for three crops. The percentage reduction was computed based on the simulation results from the SWAT model summarized in the following table 10. The results show that surface runoff decreased under each scenario as compared to the baseline

Table 8: Total surface runoff in millimeter per hectare for three crops under each scenario

Total surface runoff in millimeter (mm/ha) for all HRUs					
Scenario **Crop**	***Scenario I*** (Baseline)	***Scenario II*** (CST+Contour)	***Scenario III*** (CST+Strip)	***Scenario IV*** (CST+Terrace)	***Scenario V*** (No tillage)
Wheat	159.91	125.07	125.05	96.18	159.90
Cotton	251.35	172.30	172.30	118.92	251.24
Peanut	313.47	224.38	224.38	162.26	313.26

Impact of scenario II (Conservation tillage plus contour farming) on surface runoff

Under this scenario, surface runoff was reduced by 21.78%, 31.45% and 28.42% respectively for winter wheat, cotton and peanuts. The results of the t-statistics (t= 1.31 and p-value = 0.0301 for winter wheat) reveal that the mean of surface runoff at each HRU under scenario II is statistically different from the mean at the baseline at 5% significance level. Hence, the combination of contour farming and conservation tillage significantly reduces surface runoff.

Impact of scenario III (Conservation tillage plus strip cropping) on surface runoff

With this scenario, surface runoff was reduced by 21.79%, 31.45% and 28.42% respectively for winter wheat, cotton and peanuts. These results are similar to those of scenario III. Likewise, the results of the t-statistics (t=1.31 and p=0.0301) show a statistically significant difference between the mean of the baseline and the mean at each HRU under scenario III.

Impact of scenario IV (conservation tillage plus terracing) on surface runoff

Under this scenario, surface runoff was reduced by 39.85%, 52.68% and 48.23% respectively for winter wheat, cotton and peanuts. The results of the t-statistics (t=2.57 and p-value = 0.0103) reveal that there is a significant different between the means of the baseline (conservation tillage) and scenario IV (conservation tillage plus terraces). A combination of conservation tillage plus terraces significantly reduces surface runoff as compared to conservation tillage alone.

Impact of scenario V (No-tillage) on surface runoff

With the scenario V (no-tillage), surface runoff was reduced by 0.0028%, 0.0429% and 0.0681% respectively for winter wheat, cotton and peanuts. The t-statistics (t=- 0.000 and p-value = 0.9999) shows that there is no significant difference between the two means (baseline and scenario V) at 5% significance level. No-tillage farming does not have substantial impact on surface runoff compared to conservation tillage.

✓ **Impact of Best Management Practices on sediment yields**

Table 9: Average sediment yields in tons per hectare for each crop under each scenario

Total sediment yield in tons/ha for all HRUs					
Scenario / **Crop**	***Scenario I*** (Baseline)	***Scenario II*** (CST+Contour)	***Scenario III*** (CST+Strip)	***Scenario IV*** (CST+Terrace)	***Scenario V*** (No tillage)
Wheat	3.63	1.36	0.68	0.20	3.62
Cotton	36.51	12.19	6.11	1.69	36.49
Peanut	29.58	9.90	4.95	1.37	29.06

Table11 summarizes the average sediment yields under each scenario for three crops obtained from the SWAT simulation model and figure 7 shows the percentage reduction of sediment yields under each scenario for these three crops (winter wheat, cotton and peanut) in comparison to conservation tillage alone. The results from table11 and figure7 show that each scenario reduces sediment yields as compared to conservation tillage alone.

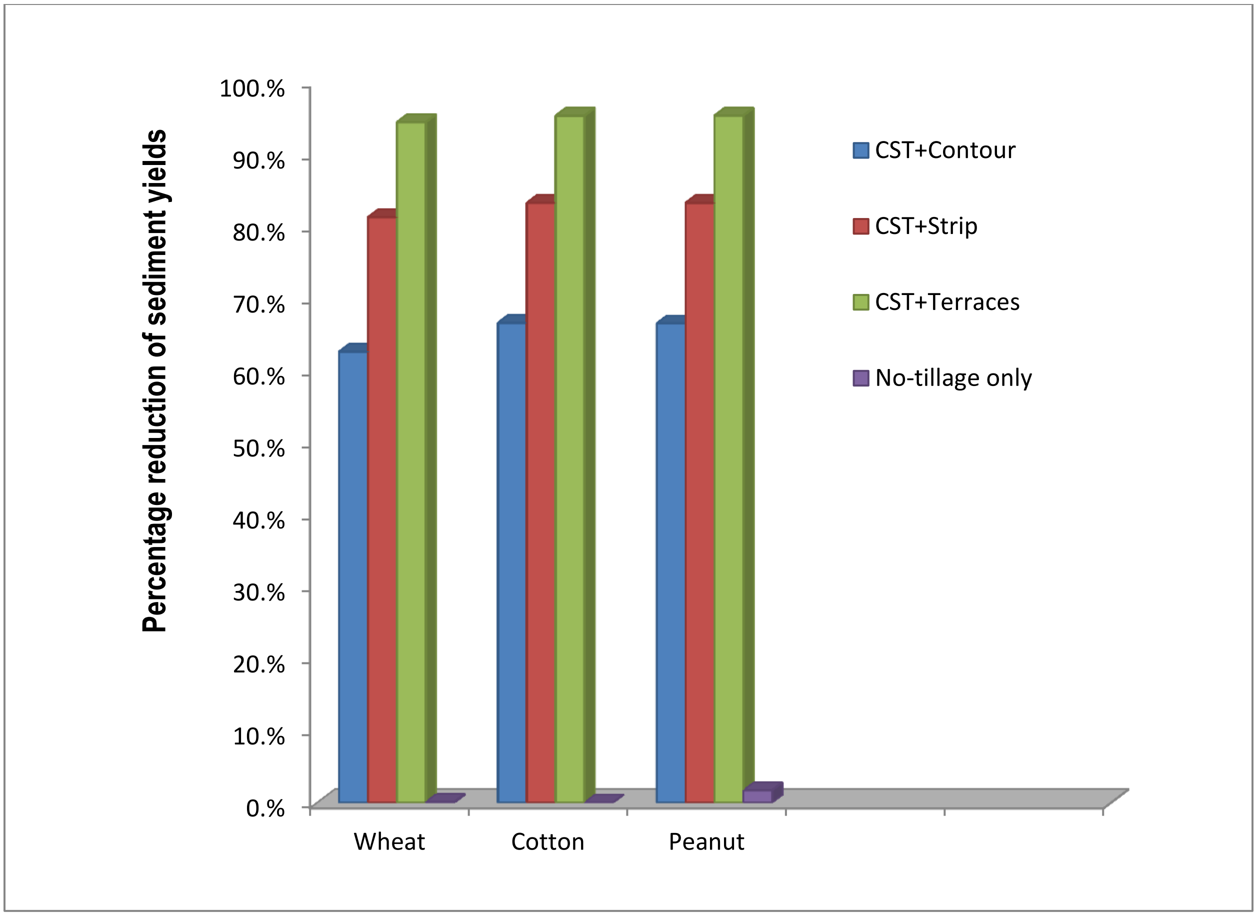


Figure 6: Percentage reduction of sediment yields under each scenario

Impact of scenario II (Conservation tillage and contour farming) on sediment yield

Under this scenario (adding contour farming to conservation tillage), sediment inflow was reduced by 62.60%, 66.60% and 66.52% respectively for winter wheat, cotton and peanuts. The results of the t-statistics (t= 3.91 and p-value = 0.0001 for winter wheat) reveal that the mean of sediment inflow at each HRU under scenario II is statistically different from the mean at the baseline at 5% significance level. Therefore, the combination of contour farming and conservation tillage significantly reduces sediment inflow.

Impact of scenario III (Conservation tillage and strip cropping) on sediment yield

With this scenario, sediment inflow was reduced by 81.27%, 83.26% and 83.26% respectively for winter wheat, cotton and peanut. The results of the t-statistics ($t=5.34$ and $p\text{-value}<0.0001$) show a statistically significant difference between the mean of the baseline and the mean at each HRU under scenario III.

Impact of scenario IV (conservation tillage and terracing) on sediment yield

Under this scenario, sediment inflow was reduced by 94.46%, 95.36% and 95.37% respectively for winter wheat, cotton and peanut. The results of the t-statistics ($t=6.31$ and $p\text{-value} < 0.0001$) reveal that there is a significant different between the means of the baseline and scenario IV. A combination of conservation tillage and terrace farming shows a meaningful reduction of sediment inflow as compared to the baseline.

Impact of scenario V (No-tillage) on sediment yield

With the scenario V, sediment inflow was reduced by 0.11%, 0.04% and 1.74% respectively for winter wheat, cotton and peanuts. The t-statistics ($t=- 0.01$ and $p\text{-value} > 0.9955$) shows that there is no significant difference between the two means (baseline and scenario V) at 5% significance level. No-tillage farming does not have substantial impact on sediment yield as compared to conservation tillage. These results are similar to those conducted by Mwangi et al (2015) and Parajuli et al. (2013).

In terms of sediment inflow and surface runoff reduction, scenario IV is the best management practices relative to the other management practices. Contour farming and strip cropping are also good at reducing soil erosion. While there was insufficient time to test no-till with contour tillage and with terracing, it is expected that the results would be similar to those obtained with conservation tillage.

Part II: Assessing the effectiveness of Best Management Practices on crop yields.

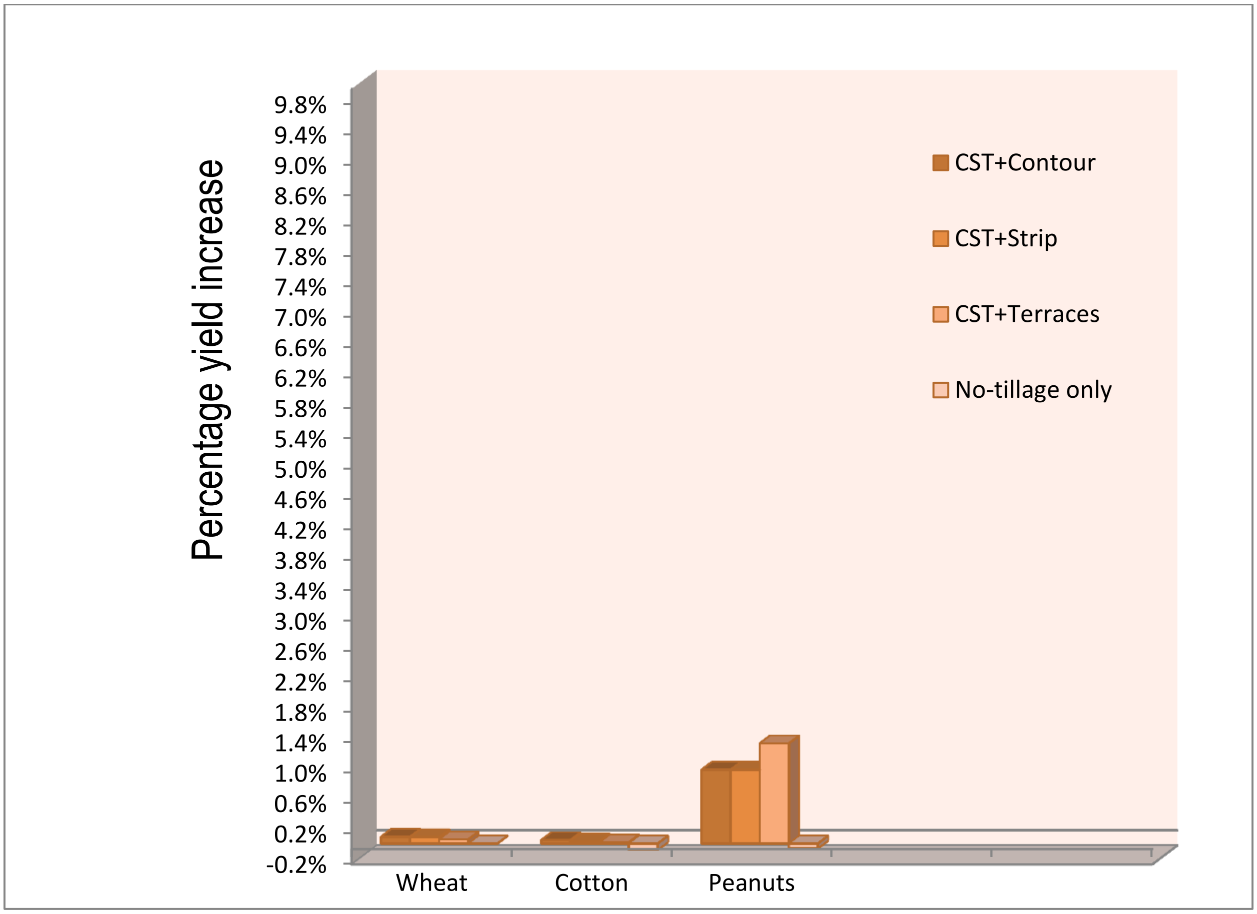


Figure 7: Percentage increase in crop yield under each scenario

Table 10: Total crop yields for the Five Mile Creek Sub-basin under each scenario

Total production in tons					
Scenarios / **Crops**	***Scenario I (Baseline)***	***Scenario II (CST+contour)***	***Scenario III (CST+Strip)***	***Scenario IV (CST+Terrace)***	***Scenario V (No-tillage)***
Winter Wheat	67476	67535	67532	67513	67477
Cotton	17438	17446	17446	17443	17424
Peanut	72610	73314	73314	73566	72563

Table 11: Average crop yield in tons per hectare

Average crop yields in tons/ha					
Scenarios / **Crops**	***Scenario I (Baseline)***	***Scenario II (CST+contour)***	***Scenario III (CST+Strip)***	***Scenario IV (CST+Terrace)***	***Scenario V (No-tillage)***
Winter Wheat	2.4153	2.4187	2.4186	2.4194	2.4152
Cotton	0.6306	0.6306	0.6306	0.6307	0.6304
Peanuts	2.544	2.5745	2.5746	2.5911	2.5424

Figure 8 shows the impact of each scenario on crop yields as compared to the baseline (conservation tillage). The total crop production for the Five Mile Creek Sub-basin is given in table 12 and the average crop yield in tons per hectare for each crop is summarized in table13. There is not a significant different between the average yield under each scenario. Thus, to show the impact the implementation of BMPs can have on crop yields, the total crop production of the Five Mile Creek for each crop under the different scenarios is compared to the baseline (Conservation tillage).

The results show that scenario II, III and IV increases crop yield compared to the baseline. Conversely, scenario V (No-tillage farming) does not increase crop yields in comparison to conservation tillage.

Under scenario II, crop yield was increased by 0.08%, 0.04% and 0.96% respectively for winter wheat, cotton and peanuts. With scenario III, it was increased by 0.08%, 0.03% and 0.96% respectively. It was increased by 0.05%, 0.013% and 1.3 % respectively under scenario IV. By contrast, with scenario V it was reduced by 0.0005%, 0.08% and 0.06% respectively. The results of the t-statistics test do not show any significant difference between means at 5% level of significance. Nevertheless, it is worth noting that, apart from scenario V, these scenarios have improved crop yields because the average cumulative difference during the simulation period (1990-2010) for peanuts is 703 ton between scenario I (baseline) and scenario II, 704 ton between scenario III and scenario I, 956 ton between scenario IV and scenario I. The cumulative average yield was reduced by 46 ton under scenario V as compared to scenario I. These results are similar to the ones found by Iraj Amini (2005) and Parajuli et al. (2013).

Part III: Assessing the Cost-Effectiveness of Best Management Practices

To identify the scenarios which reduce soil erosion at least cost, the cost per ton of erosion avoided (CEA) for each scenario had been calculated. CEA = $\left(\frac{C_b - C_m}{E_b - E_m}\right)$ where C_b is the net returns/acre from the baseline management practice, C_m is the net returns/acre under alternative scenario, E_b is the level of sediment yield under baseline scenario and E_m is the level of sediment yield under the alternative scenario to be compared with the baseline. The lower is the computed CEA, the most effective is the scenario in reducing sediment loads into the watershed. The results are given in the following table:

Table 12: Cost Effectiveness analysis based on Cost per ton of Erosion Abated (CEA)

Crops	Scenarios	CEA $/ton/year
Winter Wheat	CST+Contour	10.64
	CST+Strip	10.51
	CST+Terraces	47.25
	No-tillage	511.46
Cotton	CST+Contour	8.12
	CST+Strip	7.48
	CST+Terraces	41.51
	No-tillage	466.42
Peanut	CST+Contour	12.43
	CST+Strip	11.98
	CST+Terraces	51.19
	No-tillage	303.78

The results show that scenario II (conservation tillage + contour farming) and scenario III (conservation tillage + strip cropping) are more cost-effective in terms of cost per unit of soil erosion abatement than scenario IV (conservation tillage + terraces) and scenario V (No-tillage farming).

To determine the impact of each scenario on farmer's income, we calculated the gross margin per acre of crops for each scenario. Gross margin is the difference between revenue and cost before accounting for certain other costs. The results are given in the following table:

Table 13: Effectiveness analysis based on crop gross margin

	Gross margin of crop produced ($/Acre/year)		
Scenario	Wheat	Cotton	Peanut
CST	73.80	32.82	(139.67)
CST+Contour	70.30	28.85	(144.62)
CST+Strip	69.22	28.22	(145.64)
CST+Terraces	48.77	3.67	(168.89)
No-tillage	108.44	37.49	(108.02)

From above we see that scenario V (no-tillage) and scenario I (Conservation tillage) generate more income to farmers than the other scenarios if we do not consider sediment inflow into the watershed. These findings are conformed to the results from the study conducted by Zhou et al. (2009) on the cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed indicated that no-tillage was the most efficient practice.

Part IV: Spatial allocation of management practices to maximize profit using linear programming

The spatial allocation of BMPs depends on the erosion reduction target we want to achieve. In other words, the implementation of some management practices to meet soil erosion target may entail additional cost to the farmers and/or the general public. To illustrate how the erosion reduction target can influence the spatial distribution of management practices and the net income of farmers, we set up four levels of target (T-0-0-0, T-50-50-50, T-75-75-75 and T-95-95-95). T-0-0-0 means 0% reduction of sediment yield, 0% reduction of nitrogen and 0% reduction of phosphorus into the watershed. T-75-75-75 stands for 75% reduction of sediment yield, 75% reduction of nitrogen and 75% of phosphorus into the watershed.

The linear programming results of the different level of constraints are summarized in the following table:

Table 14: Profit and sediments level with different level of sediment, nitrogen and phosphorus limits

Target	Profit ($)	Sediment (ton)	Nitrogen (Kg)	Phosphorus (kg)	Main scenario
T-0-0-0	1,129,862	15301	32332	3463	Scenario5
T-50-50-50	878,012	4365	16275	1731	Scenario3,4,5
T-75-75-75	570,306	1968	8163	865	Scenario3,4,5
T-95-95-95	113	872	2843	301	Scenario4

**Scenario5 (No-tillage farming)
**Scenario3 (Conservation tillage + strip farming)
**Scenario4 (Conservation tillage + Terraces)

The shadow prices which are the marginal cost per ton of sediment, nitrogen or phosphorus abated at different targets (T-0-0-0, T-50-50-50, T-75-75-75, T-95-95-95) are summarized in the following table:

Table 15: Shadow prices at different targets

Shadow prices in dollars			
Target	Sediment ($/ton)	Nitrogen ($/Kg)	Phosphorus ($/kg)
T-0-0-0	0.00	0.00	0.00
T-50-50-50	23.02	15.68	145.40
T-75-75-75	41.96	23.75	215.38
T-95-95-95	78.29	38.31	357.28

The marginal cost per ton of sediment abated at T-50-50-50 is $ 23.02. Likewise, the marginal cost per kilogram of Nitrogen abated at T-50-50-50 is $ 15.68 and the marginal cost per kilogram of phosphorus abated at T-50-50-50 is $145.40. Knowing the marginal cost per kilogram of sediment abated will help the police maker identify the level of subsidy to allocate to farmers to incentivize them into adopting efficient management practices. The level of subsidy will depend of the level of sediments eroded per acre. The average sediments eroded per acre from the SWAT output is 0.55 ton/acre. For instance, if a farmer has 100 acres of crop land and we want to achieve 50% reduction in sediment, we will allocate to him $ 863.

The optimal surface area covered by each management practice under the four targets (T-0-0-0; T-50-50-50; T-75-75-75 and T-95-95-95) for each sub-basin is presented in the followings tables:

Table 16: Optimal area to be covered by each scenario under target T-0-0-0

Target T-0-0-0			
	Area covered by each scenario in Acres		
Sub-basin	CST+Strip	No-tillage	Total
1	0.00	1935.95	1935.95
2	0.00	1597.24	1597.24
3	0.00	268.18	268.18
4	0.97	7049.54	7050.51
5	0.00	214.30	214.30
6	0.58	3983.70	3984.28
7	0.00	2480.22	2480.22
8	0.78	2604.29	2605.07
9	0.00	1319.18	1319.18
10	0.00	52.32	52.32
11	16.86	3059.42	3076.28
12	3.202	1502.75	1505.94
13	41.66	1556.75	1598.41
Total	**64.05**	**27623.86**	**27687.91**

**CST+Strip (Conservation tillage + strip cropping)
**No-tillage (No-tillage farming)
**Acres of CST+Contour = 0
**Acres of CST+Terraces = 0
**Acres of CST = 0

.

Table 17: Optimal area to be covered by each scenario under target T-50-50-50

Target T-50-50-50				
	Area covered by each scenario in Acres			
Sub-basin	**CST+Strip**	**CST+Terraces**	**No-tillage**	**Total**
1	0.00	0.00	1935.95	1935.95
2	0.19	0.00	1597.05	1597.24
3	0.00	268.18	0.00	268.18
4	76.73	2.91	6970.87	7050.51
5	0.19	0.00	214.11	214.3
6	1084.35	1.36	2898.59	3984.3
7	22.86	0.19	2457.16	2480.21
8	145.91	4.65	2454.51	2605.07
9	79.6	63.75	1175.83	1319.18
10	3.29	32.75	16.28	52.32
11	894.63	827.4	1354.25	3076.28
12	568.9	492.56	444.51	1505.97
13	627.62	576.27	394.51	1598.4
Total	**3504.27**	**2270.02**	**21913.62**	**27687.91**

**Acres of conservation tillage = 0
**Acres of conservation tillage + contour farming = 0

Table 18: Optimal area to be covered by each scenario under target T-75-75-75

T-75-75-75				
	Area covered by each scenario in Acres			
Sub-basin	**CST+Strip**	**CST+Terraces**	**No-tillage**	**Total**
1	71.31	0.00	1864.63	1935.94
2	0.78	0.19	1596.27	1597.24
3	0.00	268.18	0.00	268.18
4	880.29	228.26	5941.97	7050.52
5	1067.36	0.19	214.12	1281.67
6	0.00	1546.58	1370.34	2916.92
7	160.06	23.06	2297.11	2480.23
8	216.83	445.1	1943.14	2605.07
9	26.74	352.27	940.16	1319.17
10	2.52	44.37	5.43	52.32
11	422.22	2254.31	399.74	3076.27
12	84.68	1196.33	224.96	1505.97
13	298.79	1219.59	80.03	1598.41
Total	**3231.58**	**7578.43**	**16877.9**	**27687.91**

**Acres of conservation tillage = 0
**Acres of conservation tillage + contour = 0

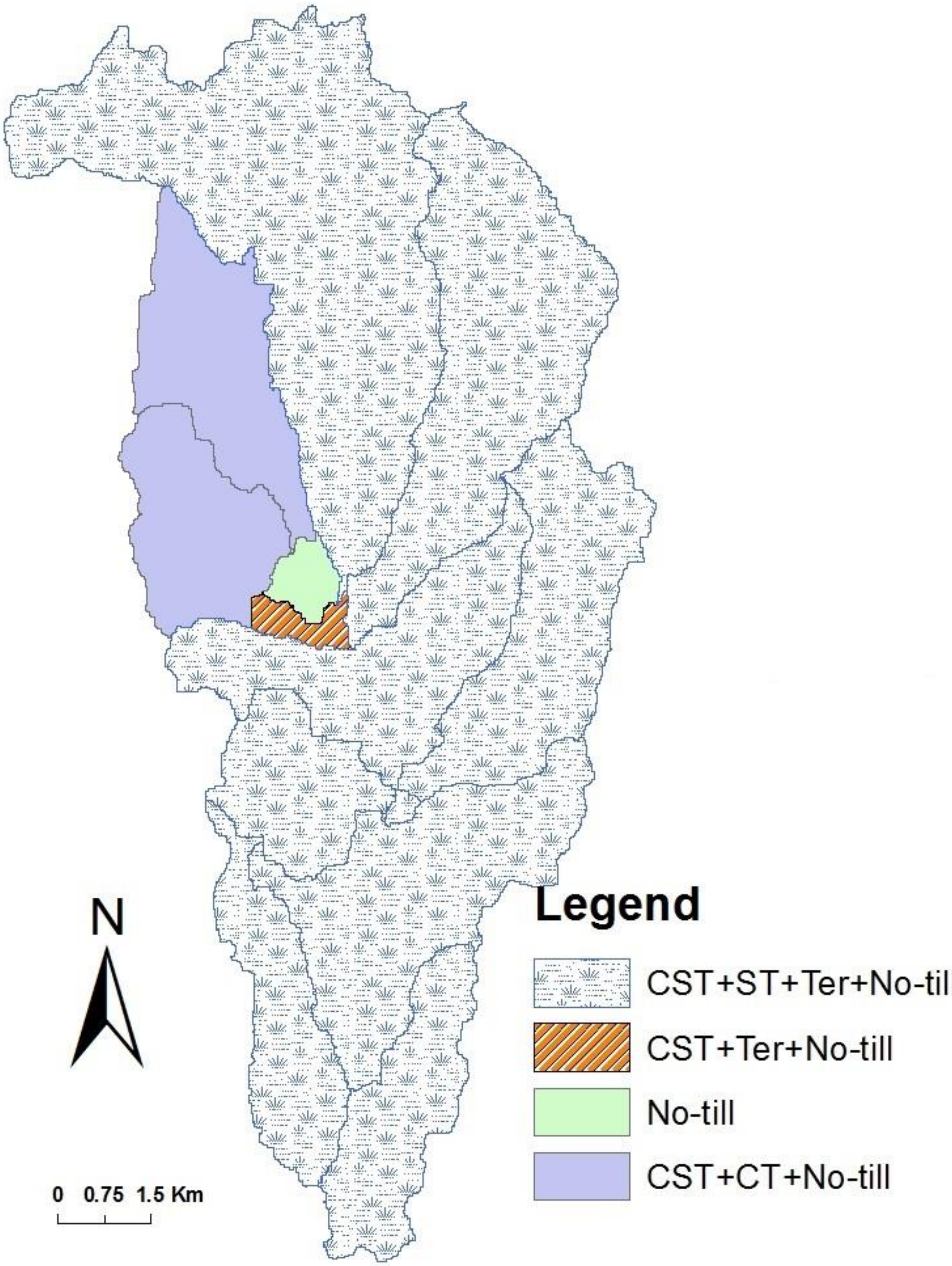
Table 19: Optimal area to be covered by each scenario under target T-95-95-95

Target T-95-95-95				
	Area covered by each scenario in Acres			
Sub-basin	**CST+Contour**	**CST+Strip**	**CST+Terraces**	**Total**
1	0.00	0.19	1935.75	1935.94
2	0.00	0.00	1597.24	1597.24
3	0.00	0.00	268.18	268.18
4	5.43	1.74	7043.34	7050.51
5	0.00	0.19	214.12	214.31
6	4.07	10.27	3969.95	3984.29
7	0.00	0.00	2480.22	2480.22
8	0.00	0.00	2605.07	2605.07
9	0.00	0.19	1318.98	1319.17
10	0.00	0.00	52.32	52.32
11	0.00	0.00	3076.28	3076.28
12	0.00	0.58	1505.39	1505.97
13	0.00	0.19	1598.22	1598.41
Total	**9.5**	**13.35**	**27665.06**	**27687.91**

**Acres of conservation tillage = 0
**Acres of no-tillage alone = 0

The linear programming model results show that no-tillage farming is the appropriate management practice when the level of soil erosion abated in null (zero). As long as the target increases, the surface area of no-tillage practice reduces while the surface area of conservation tillage plus contour, conservation tillage plus strip and conservation tillage plus terraces increases. To reach a high level of sediments abated, conservation tillage plus strip, conservation tillage plus contour farming and conservation tillage plus terraces are more appropriate.

The linear programming model also gives the optimal spatial distribution of each management practices by HRUs (Hydrologic Response Units) under each scenario. We will not present the results by HRUs. However, to illustrate where each management practice need to be implemented we summarize the results of target T-75-75-75 which shows the spatial distribution of each scenario by sub-basin.



Map 7: Spatial distribution of Best Management Practices under T-75-75-75

With T-0-0-0, the main management practice to be implemented in all the sub-basins is scenario V (No–tillage farming which covered 27623.86 acres). With this scenario, the profit is high, but the level of sediment, nitrogen and phosphorus that flows into the watershed is equally high. We can conclude from this result that no-tillage is a better option for increasing profit if producers do not have any regards for water pollution.

Under target T-50-50-50, the main management practices to be carried out are conservation tillage plus strip cropping (3504.27); conservation tillage plus terraces (2270.02 acres) and no-tillage farming (21913.62 acres). Under target T-75-75-75, the same practices are to be implemented but the surface area covered by these practices are 3231.58 acres, 7578.43 acres and 16877.9 acres respectively for conservation tillage plus strip cropping; conservation tillage plus terraces and No-tillage farming. With these targets, the surface area covered by conservation tillage plus strip cropping and conservation tillage plus terraces increases as compared to target T-0-0-0. These practices contribute to reach the optimal profit while maintaining a reduced level of sediment, nitrogen and phosphorus that flows into the watershed. We can conclude that No-tillage farming alone is cost-efficient in terms of soil erosion when in combination with strip cropping, contour farming or terrace. Moreover, these targets (T-50-50-50 and T-75-75-75) seem to be the efficient options that lead to a reasonable profit level while contributing substantially to the reduction of sediment loads, nitrogen and phosphorus inflow into the watershed.

With T-95-95-95, the principal management practice to be executed is scenario IV (Conservation tillage plus terrace farming which covered 27687.91 acres). This scenario contributes to a significant reduction of sediment, nitrogen and phosphorus loads. However, the optimal profit is too small. Conservation tillage plus terrace farming is the best option of reducing soil erosion but their implementation is associated with high cost.

We can conclude from this finding that only the combination of management practices within the watershed can guarantee an optimal profit to the farmers while maintaining an environmentally-friendly level of sediment load and nitrogen inflow into the watershed. If farmers want to maximize their own benefit to the detriment of water quality, no-tillage farming may be the best option. Contour farming and strip cropping are effective in reducing soil erosion at least cost. Terracing is the most effective but yet it incurs high cost (see table 16).

Thus, the government or local administrative agencies should provide scientific guidance and allowance for soil erosion mitigation measures such as strip cropping, contour farming and terracing for their widespread adoption. In other words, farmers need to be subsidized in order to implement management measures that will significantly reduce soil erosion since the off-site benefits from soil erosion reduction and social costs are external to farmers.

Part V: Spatial distribution of management practices based on slopes

The slope of the HRUs (Hydrologic Response Units) can influence the spatial distribution of the management practices to put in place to efficiently reduce soil erosion and surface runoff. To determine the importance of slope in identifying the appropriate management practices to reduce soil erosion at least cost, a cross tabulation of the outputs from the linear programming model was built based on the slopes of the HRUs, the BMPs and the area covered by each management practice are summarized in the following table 22:

Table 20: Optimal spatial distribution of each BMP based on slopes under each target

	T-0-0-0		T-50-50-50			T-75-75-75			T-95-95-95		
Slopes	**CST+ST**	**No-tillage**	**CST+ST**	**CST+TER**	**No-tillage**	**CST+ST**	**CST+TER**	**No-tillage**	**CST+CT**	**CST+ST**	**CST+TER**
0-3.5	38.56	11165.02	1256.94	966.33	8720.49	1088.12	2703.67	6355.65	5.62	9.3	11188.65
3.5-7.5	21.51	8672.72	1046.36	633.63	7009.98	932.22	2304.71	5878.36	0.58	0.58	8688.81
7.5-10	1.35	5668.62	749.31	238.49	4785.51	976.78	1193.04	3504.32	1.74	3.49	5668.91
>10	3.68	2133.88	451.66	431.57	1415.1	234.46	1377.02	1156.99	1.55	0.00	2136.11
Total	**65.1**	**27640.24**	**3504.27**	**2270.02**	**21931.05**	**3231.58**	**7578.44**	**16895.32**	**9.49**	**13.37**	**27682.48**

**CST+CT: Conservation tillage + contour farming

**CST+ST: Conservation tillage + Strip cropping

**CST+CT: Conservation tillage + Terraces

**No-tillage: No-tillage only

**The absence of any scenario under each target means the area covered by this scenario is zero

The results from the table22 show that the slopes of the HRUs are key elements in choosing the appropriate management practices. When the target is T-0-0-0, scenario III (conservation tillage plus strip cropping) and scenario V (no-tillage farming) are identified by the linear programming as being the optimal combination of management practices on all the HRUs with slope varying from 0 to 10 percent or more. These scenarios are less expensive as compared to scenario IV (conservation tillage plus terraces).

If we change from target T-0-0-0 to target T-50-50-50, the surface area covered by scenario III (conservation tillage plus strip) has become higher with each slope especially slope (>10) and the surface area covered by scenario V (No-tillage) has decreased with each slope. Scenario IV (conservation tillage plus terraces) which was not selected by the LP model when it comes to target T-0-0-0 is now part of the optimal combination of management practice with target T-50-50-50. To achieve higher level of sediment reduction, the model optimally selected scenario II (conservation tillage plus contour farming), scenario III (conservation tillage plus strip cropping) and scenario IV (conservation tillage plus terraces) with respect to slope by reducing the surface area covered by scenario V (No-tillage only). In other words, the surface area covered by scenarios III and IV on HRUs with slopes higher than 3.5 percent is higher with target T-50-50-50 compared to target T-0-0-0.

When we move from target T-50-50-50 to T-75-75-75, scenario III (conservation tillage plus strip cropping); scenario IV (conservation tillage plus terraces) and scenario V (no-tillage only) are still the most efficient combination of BMPs to implement on all HRUs. However, the surface area covered by scenarios III and IV on HRU with slopes comprised between 3.5 and 10 percent or more is higher. Meanwhile the surface area covered by scenarios V has been reduced.

Under target T-95-95-95, scenario IV (conservation tillage plus terraces) was implemented on quite all the HRUs. Since the target to achieve is high (reducing the sediment flows, surface runoff and phosphorus load by 95% in reference to the baseline), quite all the HRUs with steep slopes (7.5 or more) are covered by conservation tillage plus terraces.

We can conclude from these results that scenario II (conservation tillage + contour farming) and scenario III (conservation tillage + strip cropping) are effective at reducing soil erosion at least cost. However, there are more effective when the slope of the HRUs they will be applied on is high. Scenario IV (conservation tillage + terraces) is the best management practice to implement to highly reduce soil erosion but they are costly. This scenario will only be needed on HRUs with steep slope. Scenario V (no-tillage farming) is less expensive compared to the other scenarios. It becomes efficient in terms of reducing soil erosion when combined with the other management practices.

CHAPTER V

V. CONCLUSION

The soil and water assessment tool model, (SWAT), provides a reasonable performance in simulating surface runoff, sediment loads, nitrogen and phosphorus outflow in the study area. However, to improve its accuracy, sufficient and accurate data is required for its' calibration and validation. The lack of daily sediment data makes it difficult to calibrate the model using SWAT-CUP. This deficiency in the SWAT modelling may be off-set by the surface runoff calibration as long as surface runoff and sediment inflow are intrinsically correlated. In fact, despite the absence of daily measured sediment data, the simulations were found to be reasonably good, plausible and realistic.

In reference to conservation tillage, contour farming and strip cropping and terracing are more effective in reducing soil erosion than no-till farming alone. However, no-till farming is the most economical in terms of profit maximization with disregards to sediment reduction. From this study, contour farming and strip cropping are the most efficient practices in terms of cost per unit of soil prevented from soil erosion. Terracing is the most effective in reducing soil loss but not prove to be the most cost-effective except when 75% or more of the sediment was to be reduced. Because the off-site benefits and social costs from soil erosion are external to farmers, they will be more inclined to adopt soil erosion mitigation measures which are less costly. Thus, the government or local administrative agencies should provide scientific guidance and subsidies so as to facilitate the implementation of conservation practices (contour farming, strip cropping and terracing) that may be relatively expensive and yet very effective in reducing soil erosion.

For further research, it is worth noting that the combination of no-tillage farming, contour and terraces farming were not included in the cost analysis. The inclusion of these combinations of management practices in the cost analysis may change the outcome of this study since no-tillage alone is economically efficient and yet less effective in reducing soil erosion. The combination of this practice (no-tillage) with those which prove to be effective in reducing soil erosion may reach better optimal level of soil erosion while ensuring a substantial income to the farmers. A study of this kind must be a follow-up of this study. A conversion of cropland to pasture is also a promising alternative management practice to be studied.

Moreover, a socioeconomic survey is also required to determine farmers' preferences for each best management practice. The socioeconomic survey will help identify the management practices which will be easily adopted by farmers. Despite the limitations aforementioned, the results of this study can be used to guide the development of watershed management programs.

REFERENCES

Abbaspour K. C., M. Vejdani, and S. Haghighat. 2007. SWATCUP calibration and uncertainty programs for SWAT*. In Proc. Intl. Congress on Modelling and Simulation (MODSIM'07)*, 1603-1609. L. Oxley and D. Kulasiri, eds. Melbourne, Australia: Modelling and Simulation Society of Australia and New Zealand.

Andersson, J. C. M., A. J. B. Zehnder, G. P. W. Jewitt, and H.Yang. 2009. Water availability, demand, and reliability of in situ water harvesting in smallholder rainfed agriculture in the Thukela River basin, South Africa. *Hydrol. Earth System Sci.*13(12): 2329-2347.

Akhavan, S., J. Abedi-Koupai, S. F. Mousavi, M. Afyuni, S. S. Eslamian, and K. C. Abbaspour. 2010. Application of SWAT model to investigate nitrate leaching in Hamadan-Bahar watershed, Iran. *J. Agric. Ecosystem and Environ*. 139(4): 675-688.

Arnold J. G., D. N. Moriasi, P. W. Gassman, K. C. Abbaspour, M. J. White, R. Srinivasan, C. Santhi, R. D. Harmel, A. van Griensven, M. W. Van Liew, N. Kannan, and M. K. Jha. 2012. SWAT: Model Use, Calibration and Validation. *American Society of Agricultural and Biological Engineers*. Vol. 55(4):1491-1508.

Arnold, J.G., and P.M. Allen. 1993. A comprehensive surface–ground water flow model. J. Hydrol. 142: 47-69.

Arnold, J.G., P.M. Allen, R.S. Muttiah, and G. Bernhardt. 1995a. Automated base flow separation and recession analysis techniques. Groundwater 33(6): 1010-1018.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modelling and assessment part 1: model development. *Journal of American Water Resource Association* 34(1), 73-89.

Aw-Hassan Aden Abdullahi. 1992. A long term analysis of the impact of wheat tillage systems on soil erosion and private and social returns in north central Oklahoma. *PhD dissertation.* Department of Agricultural Economics.*Oklahoma State University*.

Becker and Steiner. 2011. “Integrated Science to Support the Assessment of Conservation Practices in the Fort Cobb Watershed,Southwestern Oklahoma”. Sientific Inveatigations *Report* 2010-5257.

Clark, Edwin H. II, Jennifer A. Haverkamp and William Chapman. 1985. Eroding Soils: The Off-farm Impacts. 'The Conservation Foundation,Washington, D. C.

Coffey, M. E., S. R. Workman, J. L. Taraba, and A. W. Fogle. 2004. Statistical procedures for evaluating daily and monthly hydrologic model predictions. *Trans. ASAE* 47(1): 59-68.

Colacicco, D., T. Osborn, and K. Alt. (1989). Economic Damage from Soil Erosion. *Journal of Soil and Water Conservation.* 44:35-39.

Daniel D. C., John P. R., and OLIVER S. O., 2002. “Soil Conservation and Sustainable Agriculture” in *Natural Resource Conservation 8th edition*. By Prentice-Hall, Inc. Upper Saddle River, New Jersey.

David Pimentel, C. Harvey, P. Resosudarmo, K. Sinclair, D. kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton,

R. Saffouri, and Blair R., 1995. “Environmental and Economic Costs of Soil Erosion and Conservation Benefits.” *Journal of American Association for the Advancement of science*. Vol. 267, No. 5201

Davis, L.V., 1955, Geology and ground water resources of Grady and northern Stephens counties,Oklahoma: Oklahoma Geological Survey, Bulletin 73, 184 p.

Dillaha, T. A., M. L. Wolfe, A. Shirmohammadi, F. W. Byne. 2001. ANSWERS-2000. Non-point source water quality models: Their use and application. Final Report of USDA-CSREES southern region research project S-273 Development and Application of Comprehensive Agricultural Ecosystems Models.

Dechmi, F., and A. Skhiri. 2013. “Evaluation of best management practices under intensive irrigation using SWAT model.” *Journal of Agricultural Water Management (123):55-64.*

Damona Doye, Roger Sahs, Darrel Kletke and Mike Hardin. 2009. OSU Enterprise Budget Software Advanced User’s Guide.

Engel, B., D. Storm, M. White, J. Arnold, and M. Arabi. 2007. A hydrologic/water quality model application protocol. *J. American Water Resources.* Assoc. 43(5): 1223-1236.

EPA. 1986. An evaluation of the cost effectiveness of agricultural best management practices and publicly owned treatment works in controlling phosphorus pollution in the great lakes basin. CONTRACT NO. 68-01-7047. WORK ASSIGNMENT NO. 52.

Faramarzi, M., K. C. Abbaspour, R. Schulin, and H. Yang. 2009. Modeling blue and green water availability in Iran. *Hydrol. Proc*. 23(3): 486-501.

Follett R. F. and B. A. Stewart. 1985. “Assessment of Soil Erosion and Crop Productivity with Economic Models” *in Soil erosion and crop productivity*. By the American Society of Agronomy, Inc. ISBN 0-89118-087-7.

Gan, T. Y., E. M. Dlamini, and G. F. Biftu. 1997. Effects of model complexity and structure, data quality, and objective functions on hydrologic modeling. *J. Hydrol*. 192(1): 81-103.

Gassman, P. W., M. Reyes, C. H. Green, and J. G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans. ASABE 50(4): 1211-1250.

Hugh H. B., (2015). “The Increased cost of Erosion”. *Annals of the American Academy of Political and Social Science, Vol.142, pp.170-176.*

Hagen, Linda L. and Paul T. Dyke. 1980. Merging Data from Disparate Source. *Agricultural Economics Research, 32(4):45-49.*

Heatwole, C.D., K.L. Campbell, and A.B. Bottcher 1987. Modified CREAMS hydrology model for coastal plain flatwoods. Transactions of the ASAE 30 (4): 1014-1022.

Iraj Amini. 2005. “Determination of the best management for soybean cropping following barley”. *Journal of science direct*. 84 (2005) 168–174

James, L.D. and S.J. Burges, 1982. Selection, Calibration, and Testing of Hydrologic Models. In: Hydrologic Modeling of Small Watersheds, C.T. Haan, H.P. Johnson, and D.L. Brakensiek (Editors). ASAE Monograph, St. Joseph, Michigan, pp. 437-472.

Kelvin K. K. Kuok, Darrien Y. S. Mah, P. C. Chiu. 2013. Evaluation of C and P Factors in Universal Soil Loss Equation on Trapping Sediment: Case Study of Santubong River. *Journal of Water Resource and Protection, 2013, 5, 1149-1154*

Knisel, W. G., ed. 1980. CREAMS: a field-scale model for chemicals, runoff, and erosion from agricultural management systems. U. S. Department of Agriculture, Conservation Research Report No. 26.

León, L.F., G.S. Bowen, and W.G. Booty, 2004. Verification of the AGNPS model trace source contribution algorithm for use in southern Ontario watersheds. IEMSs University of Osnabrück, Germany.

Ma, L., J. C. Ascough II, L. R. Ahuja, M. J. Shaffer, J. D. Hanson, and K. W. Rojas. 2000. Root Zone Wate Quality Model sensitivity analysis using Monte Carlo simulation. Trans. ASAE 43(4): 883-895.

Mausbach, M.J., and A.R. Dedrick. 2004. The length we go: Measuring environmental benefits of conservation practices. *J. Soil Water Cons*. 59(5): 96A-103A.

Muleta, M.K. 2010. “Comparison of Model Evaluation Methods to Develop a Comprehensive Watershed Simulation Model.” *Proceedings of the 2010 Conference of the Environmental and Water Resources Institute, ASCE, Providence, Rhode Island, May 16-20*

Neistch J. R., Arnold J. G., Kiniry J. R., Srinivasan R. and Williams J. R. 2004. Input/Output File Documentation Version 2005. Grassland, Soil and Water Research Laboratory, Agricultural

Research Service, Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas 76502.

Nisrami M. G. 2006. Environmental and economic modeling of Non-Point Source Pollution control: optimized land use systems and vegetative filter strips. *Master's dissertation*. Department of Biosystems and agricultural Engineering. Oklahoma State University.

NASS, 2014. National Agricultural Statistics Service. "Oklahoma Agricultural Statistics" p14-21.

NRCS, 2003. Revised Universal Soil Loss Equation 2. http://soilwater.okstate.edu/CCA/StudyGuide%20pdfs/RUSLE2.pdf consulted: 5/26/2015

OCC, 2009. Fort Cobb watershed implementation, Final report. Oklahoma Conservation Commission.

ODEQ, 2006. TMDL Development for Cobb Creek Watershed and Fort Cobb Lake, Final Report. Oklahoma Department of Environmental Quality.

Parajuli P.B., P. Jayakodya, G.F. Sassenrathb, Y. Ouyangc, and J.W. Potea. 2013. "Assessing the impacts of crop-rotation and tillage on crop yields and sediment yield using a modeling approach". *Journal of Agricultural water management.*119 (2013) 32– 42

Pimentel D, Harvey C and P. Resudarmo. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267:1117-1123.

Putman, John, Jimmy Williams and David Sawyer, 1988. Using the Erosion Productivity Impact Calculator (EPIC) Model to Estimate the impact of soil Erosion for the 1985 RCA apprisail. *Journal of soil and water conservation.* 43:321-326.

Refsgaard, J. C. 1997. Parameterisation, calibration, and validation of distributed hydrological models. *J. Hydrol.* 198(1): 69-97.

Schuol, J., K. C. Abbaspour, R. Srinivasan, and H. Yang. 2008a. Estimation of freshwater availability in the west African subcontinent using the SWAT hydrologic model. *J. Hydrol*. 352(1-2): 30-49.

Sadeghia S. H. R., Jalili Kh., and D. Nikkamib 2009. Land use optimization in watershed scale. *Land Use Policy* 26 (2009) 186–193

Srinivasan, R., X. Zhang, and J. G. Arnold. 2010. SWAT ungauged: Hydrological budget and crop yield predictions in the Upper Mississippi River basin. *Trans. ASABE* 53(5): 1533-1546.

Starks, J. P., J. A. Daniel, D. N. Moriasi, and J. L. Steiner. 2010. Assessment of Conservation Practices in the Fort Cobb Reservoir Watershed, Southwestern Oklahoma. *US Geological Survey Scientific Investigations report*: 2010–5257.

Storm D. E., Busteed R. P. and M. J. White. 2006. Fort Cobb basin modeling and land cover classification. Draft submitted to Oklahoma Department of Environmental Quality. Oklahoma State University.

USDA. 2014. Environmental Quality Incentives Program. Retrieved from:

http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

USDA. 2015. Conservation Reserve Program. Retrieved from:

http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

Van Griensven, A., and W. Bauwens. 2003. Multiobjective autocalibration for semidistributed water quality models. *Water Resources*. 39(12): 1348-1356.

Van Liew, M. W., J. G. Arnold, and D. D. Bosch. 2005. Problems and potential of autocalibrating hydrologic model. Trans. *ASAE* 48(3): 1025-1040.

Xuyang Z., and Z. Minghua, 2011. "Modeling effectiveness of agricultural BMPs to reduce sediment load and organophosphate in surface runoff." *Journal of Science of the Total Environment (409)1949-1958.*

Yang, J., K. C. Abbaspour, P. Reichert, and H. Yang. 2008. Comparing uncertainty analysis techniques for a SWAT application to Chaohe basin in China. *J. Hydrol*. 358(1-2): 1-23.

Young, R.A., C.A Onstad., D.D Bosch, and W.P. Anderson. 1995. AGNPS: An agricultural non-point source model, in Singh V.P. (ed.), Computer models of watershed hydrology: Highlands ranch, Colorado, *Water Resources Publications* 1011-1020.

Williams, J.R. 1990. The erosion productivity impact calculator (EPIC) model: A case history. Phil.Trans. R. Soc. Lond. 329: 421-428.

Winchell M., Srinivasan R., Di Luzio N., and J. Arnold. 2013. SWAT2012 User's Guide. Grassland, Soil and Water Research Laboratory, Agricultural Research Service, BlackLand Research and Extension Center, USDA Agricultural Research Service, Temple, Texas 76502.

Zhou X., M.J. Helmers, M. Al-Kaisi, and H.M. Hanna. 2009. "Cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed". *Journal of soil and water conservation*. 64(5):314-323

APPENDICES

Appendix 1: Synopsis of the simulated data.

LULC	HRU	SUB	YEAR	SURQ_GE(mm)	SYLD t/ha	ORGN kg/ha	ORGP kg/ha	YLDt/ha
WWHT	1	1	1990	35.778	0.254	1.239	0.126	2.159
WWHT	2	1	1990	39.727	0.876	3.272	0.334	2.163
WWHT	3	1	1990	40.136	1.291	4.551	0.464	2.163
WWHT	4	1	1990	35.881	0.296	1.408	0.144	2.159
WWHT	5	1	1990	41.067	3.778	10.388	1.061	2.165
WWHT	6	1	1990	27.928	2.92	7.691	0.793	2.165
WWHT	7	1	1990	35.387	0.324	1.663	0.169	2.159
WWHT	8	1	1990	40.931	2.43	7.894	0.803	2.163
WWHT	9	1	1990	40.733	1.558	5.319	0.542	2.163
WWHT	10	1	1990	36.571	0.44	1.874	0.191	2.16
WWHT	11	1	1990	41.023	2.369	7.206	0.737	2.165
WWHT	12	1	1990	35.199	0.161	0.843	0.086	2.159
WWHT	13	1	1990	41.105	4.301	11.432	1.167	2.165
WWHT	14	1	1990	36.1	0.362	1.681	0.171	2.159
WWHT	15	1	1990	39.575	2.087	6.599	0.673	2.164
WWHT	16	1	1990	40.857	2.361	7.163	0.732	2.164
WWHT	17	1	1990	39.601	1.016	3.599	0.367	2.162
WWHT	18	1	1990	34.539	0.23	1.051	0.107	2.158
WWHT	19	1	1990	40.96	3.172	9.088	0.928	2.165
WWHT	20	1	1990	35.44	0.308	1.415	0.144	2.159
WWHT	21	1	1990	39.141	1.935	6.165	0.628	2.163
WWHT	22	1	1990	41.137	4.067	10.913	1.114	2.165
WWHT	23	1	1990	28.009	2.792	7.461	0.769	2.165
WWHT	24	1	1990	39.112	2.248	6.994	0.712	2.163
WWHT	25	1	1990	36.096	0.555	2.204	0.224	2.159
WWHT	26	1	1990	129.368	1.902	2.632	0.607	2.146
WWHT	27	1	1990	35.173	0.248	1.169	0.119	2.159
WWHT	28	1	1990	39.336	1.518	4.991	0.509	2.163
WWHT	29	1	1990	26.659	3.726	9.192	0.968	1.51
WWHT	30	1	1990	39.115	2.397	7.689	0.783	2.163

WWHT	31	1	1990	41.039	4.87	12.581	1.284	2.165
WWHT	32	1	1990	36.233	0.454	2.134	0.217	2.159
WWHT	33	1	1990	28.036	3.326	8.482	0.874	2.165
WWHT	34	1	1990	36.222	0.179	0.974	0.1	2.16
WWHT	35	1	1990	39.044	1.011	3.558	0.364	2.163
WWHT	36	1	1990	35.306	0.176	0.912	0.093	2.159
WWHT	37	2	1990	43.284	0.704	2.813	0.288	2.164
WWHT	38	2	1990	41.441	1.671	5.67	0.578	2.163
WWHT	39	2	1990	41.609	1.47	5.089	0.519	2.164
WWHT	40	2	1990	44.375	0.386	1.867	0.192	2.163

*********missing data****

WWHT	943	13	1990	72.724	1.945	6.556	0.693	2.118
WWHT	944	13	1990	44.379	0.25	1.14	0.117	2.164
WWHT	945	13	1990	159.388	19.597	20.134	1.953	1.699
WWHT	946	13	1990	153.727	28.88	24.206	2.353	1.683
WWHT	947	13	1990	165.765	11.681	15.079	1.459	1.722
WWHT	948	13	1990	171.991	3.776	7.026	0.683	1.746
WWHT	949	13	1990	172.223	2.648	5.757	0.56	1.747
WWHT	950	13	1990	165.763	11.235	14.752	1.428	1.722
WWHT	951	13	1990	153.899	30.076	24.615	2.392	1.684
WWHT	952	13	1990	159.39	19.811	20.25	1.964	1.699
WWHT	953	13	1990	169.141	6.074	9.861	0.955	1.736
WWHT	954	13	1990	171.98	1.783	4.187	0.408	1.746
WWHT	955	13	1990	70.255	14.736	30.214	3.178	2.118
WWHT	956	13	1990	72.45	3.071	9.906	1.046	2.118
WWHT	957	13	1990	69.491	16.641	32.695	3.439	2.118
WWHT	958	13	1990	71.881	9.221	22.442	2.362	2.118
WWHT	959	13	1990	35.177	1.824	5.807	0.592	2.163
WWHT	960	13	1990	41.57	0.939	3.483	0.356	2.164
WWHT	961	13	1990	43.329	0.432	1.88	0.193	2.164
WWHT	962	13	1990	154.904	30.676	24.83	2.411	1.688
WWHT	963	13	1990	171.914	3.388	7.324	0.712	1.746
WWHT	964	13	1990	165.431	13.167	16.631	1.609	1.721
WWHT	965	13	1990	159.584	22.945	21.871	2.119	1.699
WWHT	966	13	1990	170.981	2.495	5.372	0.522	1.742
WWHT	967	13	1990	72.691	2.035	7.471	0.79	2.118
WWHT	968	13	1990	71.983	7.288	18.909	1.991	2.118
WWHT	969	13	1990	171.912	3.28	6.968	0.677	1.746
WWHT	970	13	1990	168.963	8.846	13.001	1.256	1.736
WWHT	971	13	1990	172.137	1.537	3.926	0.382	1.747

Appendix 2: GAMS Model

```
$TITLE FORT COBB WATERSHED RUN 1

$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF

OPTION LIMROW=0, LIMCOL=0

OPTION SOLPRINT=OFF;

SETS

J HRU

/HRU1, HRU2, HRU3, HRU4, HRU5, HRU6, HRU7, HRU8, HRU9, HRU10, HRU11, HRU12,HRU13,

……….HRU971/

S SUB

/SB1, SB2, SB3, SB4, SB5, SB6, SB7, SB8, SB9, SB10, SB11, SB12, SB13/

JS(J,S)

/(HRU1, HRU2, HRU3, HRU4, HRU5, HRU6, HRU7, HRU8, HRU9, HRU10, HRU11, HRU12, HRU14,

HRU15, HRU16, HRU17, HRU18, HRU19, HRU20, HRU21, HRU22, HRU23,HRU24, HRU25, HRU26,

HRU27, HRU28, HRU29, HRU30, HRU31, HRU32, HRU33, HRU34, HRU35,HRU36).SB1…../

I INPUT

/Scenario1

 Scenario2

 Scenario3

 Scenario4

 Scenario5/

PARAMETER C(I) COST TO PRODUCE CROP I PER ACRE

/Scenario1     220.82

 Scenario2     225.75

 Scenario3     226.75
```

```
 Scenario4     271.84
 Scenario5     176.84/;
PARAMETER R(I)
/Scenario1     27705.34044
 Scenario2     27705.34044
 Scenario3     27705.34044
 Scenario4     27705.34044
 Scenario5     27705.34044/;

PARAMETER P(I) PRICE OF CROP I
 /Scenario1      6.00
  Scenario2      6.00
  Scenario3      6.00
  Scenario4      6.00
  Scenario5      6.00/;
PARAMETER ACRES(J)  ACRES IN SUB BASIN J
/HRU1        3.487887075
 HRU2        0.387559482
 HRU3        3.29390965
 HRU4        6.394336085
 HRU5        8.138403175
 HRU6        2.712965795
****missing data

HRU970       14.9201999
 HRU971       0.581339223   /;
TABLE Y(J,I)   CROP YIELD FOR SUB BASIN J UNDER EACH SCENARIO
             Scenario1             Scenario2             Scenario3             Scenario4             Scenario5
```

```
 HRU1        37.0633062787700       37.0633062787700       37.0633062787700       37.0633062787700
37.0782090959308

****missing data***

HRU971             34.3509935555146              34.4404104584791              34.4404104584791              34.4106048241576

          34.3509935555146 ;

TABLE PH(J,I)  PHOSPORUS YIELD IN SUBBASIN J UNDER EACH SCENARIO

            Scenario1     Scenario2     Scenario3     Scenario4     Scenario5

 HRU1        0.0060       0.0020       0.0010       0.0000       0.0060

***** missing data*****

HRU971       0.1370       0.0570       0.0290       0.0090       0.1330 ;

TABLE N(J,I)   NITROGEN YIELD IN SUBBASIN J UNDER EACH SCENARIO

            Scenario1     Scenario2     Scenario3     Scenario4     Scenario5

 HRU1        0.0590       0.0160       0.0080       0.0010       0.0580

*****missing data****

HRU971       1.3390       0.5560       0.2840       0.0860       1.2810 ;

TABLE SED(J,I) SEDIMENT YIELD IN SUBBASIN J WITH EACH SCENARIO

            Scenario1     Scenario2     Scenario3     Scenario4     Scenario5

 HRU1        0.0090       0.0020       0.0010       0.0000       0.0090

****missing data

HRU971       0.4850       0.1870       0.0930       0.0280       0.4850 ;

PARAMETER GRSMRGN (I,J);

GRSMRGN (I,J) = (((P(I)*Y(J,I))+F(I))-C(I));

DISPLAY GRSMRGN;

SET L /RUN1 * RUN1/;

PARAMETER TARGET (L)
```

```
/RUN1    3938.750346/ ;

SCALAR CURRENT;

PARAMETER NITRO (L)

/RUN1 8178.171928/ ;

SCALAR NITROG;

PARAMETER PHOSP (L)

/

RUN1  865.6446798/;

SCALAR PHOSPH;

VARIABLES

X(I,J)

Z;

POSITIVE VARIABLE X;

EQUATIONS

OBJ

ROWS(I)

PRUNOFF

NRUNOFF

SRUNOFF

LAND(J);

OBJ.. Z =E= SUM((I,J), GRSMRGN(I,J)*X(I,J));

LAND(J)..   SUM(I,X(I,J)) =E= ACRES(J);

ROWS(I)..   SUM(J,X(I,J)) =L= R(I);

PRUNOFF..   SUM((J,I),PH(J,I)*X(I,J)) =L= PHOSPH;

NRUNOFF..   SUM((J,I),N(J,I)*X(I,J)) =L= NITROG;

SRUNOFF..   SUM((J,I),SED(J,I)*X(I,J)) =L= CURRENT;

MODEL Leon /ALL/;

PARAMETER REPORT (*,*);
```

```
LOOP ( L, CURRENT = TARGET(L); NITROG = NITRO(L); PHOSPH = PHOSP(L);

SOLVE Leon USING LP MAXIMIZING Z;

REPORT ("SRUNOFF", L) = SRUNOFF.L;

REPORT ("NRUNOFF", L) = NRUNOFF.L;

REPORT ("PRUNOFF", L) = PRUNOFF.L;

REPORT ("Z", L) =  Z.L;

REPORT(I, L) = SUM(J,X.L(I,J));

 );


DISPLAY REPORT;


PARAMETER   ASUB, ASUBII, PHOST, NITT, SEDT, PROFIT2, SBRUNOFF, BMPS;

SBRUNOFF(S, "SEDIMENT") =  SUM((J,I)$JS(J,S), X.L(I,J) * SED(J,I));

SBRUNOFF(S, "NITROGEN") =  SUM((J,I)$JS(J,S), X.L(I,J) * N(J,I));

SBRUNOFF(S, "PHOSPHORUS") =  SUM((J,I)$JS(J,S), X.L(I,J)*PH(J,I));

PROFIT2 = SUM((I,J), GRSMRGN(I,J)*X.L(I,J));

PHOST = SUM((I,J), X.L(I,J)*PH(J,I));

NITT = SUM((I,J), X.L(I,J)*N(J,I));

SEDT = SUM((I,J), X.L(I,J)*SED(J,I));

ASUB(S,I) = SUM((J)$JS(J,S), X.L(I,J));

ASUBII(J,I) = X.L(I,J);

SBRUNOFF(S, "TOTAL ACRES") = SUM((I,J)$JS(J,S), X.L(I,J));

BMPS(I) =  SUM(J,X.L(I,J));

DISPLAY PROFIT2, SEDT, NITT, PHOST, BMPS, ASUB, SBRUNOFF, ASUBII;
```

Appendix 3: t-test results

The TTEST Procedure

Variable: SEDIMENT (SEDIMENT)

BMP	N	Mean	Std Dev	Std Err	Minimum	Maximum
CST	971	16.2255	75.5124	2.4233	0.000194	1351.7
CST+Terrace	971	0.8988	4.3153	0.1385	0	78.1280
Diff (1-2)		15.3268	53.4825	2.4273		

BMP	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
CST		16.2255	11.4700	20.9811	75.5124	72.2968	79.0296
CST+Terrace		0.8988	0.6270	1.1705	4.3153	4.1315	4.5163
Diff (1-2)	Pooled	15.3268	10.5665	20.0871	53.4825	51.8514	55.2202
Diff (1-2)	Satterthwaite	15.3268	10.5635	20.0900			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	1940	6.31	<.0001
Satterthwaite	Unequal	976.34	6.31	<.0001

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	970	970	306.21	<.0001

Appendix 4: No tillage wheat budget

No-tillage wheat budget					
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat	Bu.	5.75	29.39	168.9925
	Small Grain Pasture	Acre	67.1	1	67.1
	Other Income	Acre	0	0	0
Total Receipts					236.0925
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat Seed	Bu./acre	9.6	1.5	14.4
	Fertilizer	Acre	54.2832 6	1	54.28
	Custom Harvest	Acre	0	0	0
	Pesticide	Acre	25.861	1	25.86
	Crop Insurance	Acre	8	1	8
	Annual Operating Capital	Dollars	0.0625	62.2468 9	3.89
	Machinery Labor	Hrs.	15	0.53325 7	7.95
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	5.15	1	5.15
	Machinery Fuel, Lube, Repairs	Acre	30.1693 1	1	30.17
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Rent	Acre	0	0	0
	Other Expense	Acre	0	0	0
Total Operating Costs					**149.7**
Returns Above Total Operating Costs					86.3925
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		5.85
	Taxes at	Dollars	0.01		1.45
	Insurance	Dollars	0.006		0.56
	Depreciation	Dollars			10.27
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**18.13**
Total Costs (Operating + Fixed)					**167.83**

(Doye et al.,2015)

Appendix 5: Conservation tillage wheat budget

Conservation tillage winter wheat budget					Total
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat	Bu.	$ 5.75	29.39	$ 168.99
	Small Grain Pasture	Acre	$ 67.10	1	$ 67.10
	Other Income	Acre	$ -	0	$ -
Total Receipts					**$ 236.09**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat Seed	Bu./acre	$ 9.60	1.50	$ 14.40
	Fertilizer	Acre	$ 49.30	1	$ 49.30
	Custom Harvest	Acre	$ -	0	$ -
	Pesticide	Acre	$ 27.62	1	$ 27.62
	Crop Insurance	Acre	$ 8.00	1	$ 8.00
	Annual Operating Capital	Dollars	6.25%	95.08	$ 5.94
	Machinery Labor	Hrs.	$ 15.00	1.05	$ 15.75
	Irrigation Labor	Hrs.	$ -	0.00	$ -
	Custom Hire	Acre	$ 5.15	1	$ 5.15
	Machinery Fuel, Lube, Repairs	Acre	$ 53.17	1	$ 53.17
	Irrigation Fuel, Lube, Repair	Acre	$ -	0	$ -
	Rent	Acre	$ -	0	$ -
	Other Expense	Acre	$ -	0	$ -
Total Operating Costs					**$ 179.33**
Returns Above Total Operating Costs					**$ 56.76**
FIXED COSTS		**Units**	**Rate**		**$/Acre**
	Machinery/Irrigation	$/value			
	Interest at	Dollars	6.20%		$ 7.46
	Taxes at	Dollars	1.00%		$ 1.85
	Insurance	Dollars	0.60%		$ 0.72
	Depreciation	Dollars			$ 13.11
	Interest at	Dollars	0.00%		$ -
	Taxes at	Dollars	0.00%		$ -
Total Fixed Costs					**$ 23.14**
Total Costs (Operating + Fixed)					**$ 202.47**

(Doye et al.,2015)

Appendix 6: Contour farming wheat budget

Contour farming wheat budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat	Bu.	5.75	29.39	168.9925
	Small Grain Pasture	Acre	67.1	1	67.1
	Other Income	Acre	0	0	0
Total Receipts					236.0925
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat Seed	Bu./acre	9.6	1.5	14.4
	Fertilizer	Acre	49.29695	1	49.3
	Custom Harvest	Acre	0	0	0
	Pesticide	Acre	27.6185	1	27.62
	Crop Insurance	Acre	8	1	8
	Annual Operating Capital	Dollars	0.0625	107.6	6.73
	Machinery Labor	Hrs.	15	1.25	18.75
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	5.15	1	5.15
	Machinery Fuel, Lube, Repairs	Acre	53.16554	1	53.17
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Rent	Acre	0	0	0
	Other Expense	Acre	0	0	0
Total Operating Costs					**183.12**
Returns Above Total Operating Costs					52.9725
FIXED COSTS		**Units**	**Rate**		**$/Acre**
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		7.46
	Taxes at	Dollars	0.01		1.85
	Insurance	Dollars	0.006		0.72
	Depreciation	Dollars			13.11
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**23.14**
Total Costs (Operating + Fixed)					**206.26**

(Doye et al.,2015)

Appendix 7: Strip cropping wheat budget

Strip cropping wheat budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat	Bu.	5.75	29.39	168.9925
	Small Grain Pasture	Acre	67.1	1	67.1
	Other Income	Acre	0	0	0
Total Receipts					**236.0925**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat Seed	Bu./acre	9.6	1.5	14.4
	Fertilizer	Acre	49.29695	1	49.3
	Custom Harvest	Acre	0	0	0
	Pesticide	Acre	27.6185	1	27.62
	Crop Insurance	Acre	8	1	8
	Annual Operating Capital	Dollars	0.0625	105.6	6.6
	Machinery Labor	Hrs.	15	1.33	19.95
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	5.15	1	5.15
	Machinery Fuel, Lube, Repairs	Acre	53.16554	1	53.17
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Rent	Acre	0	0	0
	Other Expense	Acre	0	0	0
Total Operating Costs					**184.19**
Returns Above Total Operating Costs					51.9025
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		7.46
	Taxes at	Dollars	0.01		1.85
	Insurance	Dollars	0.006		0.72
	Depreciation	Dollars			13.11
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**23.14**
Total Costs (Operating + Fixed)					**207.33**

(Doye et al.,2015)

Appendix 8: Conservation tillage plus terraces wheat budget

Terracing wheat budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat	Bu.	5.75	29.39	168.9925
	Small Grain Pasture	Acre	67.1	1	67.1
	Other Income	Acre	0	0	0
Total Receipts					**236.0925**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Wheat Seed	Bu./acre	9.6	1.5	14.4
	Fertilizer	Acre	49.29695	1	49.3
	Custom Harvest	Acre	0	0	0
	Pesticide	Acre	27.6185	1	27.62
	Crop Insurance	Acre	8	1	8
	Annual Operating Capital	Dollars	0.0625	95.08431	5.94
	Machinery Labor	Hrs.	15	1.054857	15.75
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	5.15	1	5.15
	Machinery Fuel, Lube, Repairs	Acre	53.16554	1	53.17
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Rent	Acre	0	0	0
	Other Expense	Acre	0	0	0
Total Operating Costs					**179.33**
Returns Above Total Operating Costs					56.7625
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		7.46
	Taxes at	Dollars	0.01		1.85
	Insurance	Dollars	0.006		0.72
	Depreciation	Dollars			38.49
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**48.52**
Total Costs (Operating + Fixed)					**227.85**

(Doye et al.,2015)

Appendix 9: Conservation tillage cotton budget

Conservation tillage cotton budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Cotton Lint	Lbs	0.62	456	282.72
	Cotton Seed	Cwt	10	6.38	63.8
	Other Income	Dollars	0	0	0
Total Receipts					**346.52**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Seed	Acre	41.14	1	41.14
	Fertilizer	Acre	36.64286	1	36.64
	Custom Harvest	Acre	77.52	1	77.52
	Pesticide	Acre	26.535	1	26.54
	Growth Regulators/Harvest Aids	Acre	1.28	1	1.28
	Crop Insurance	Acre	20	1	20
	Annual Operating Capital	Dollars	0.0625	119.3288	7.46
	Machinery Labor	Hrs.	15	1.488	22.35
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	0	0	0
	Machinery Fuel, Lube, Repairs	Acre	48.11737	1	48.12
	Irrigation Cost	Acre	0	0	0
	Rent	Acre	0	0	0
	Ginning/Processing	Acre	30.78	1	30.78
	Other Expense	Acre	4	1	4
Total Operating Costs					**315.83**
Returns Above Total Operating Costs					30.69
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		11.72
	Taxes at	Dollars	0.01		2.94
	Insurance	Dollars	0.006		1.13
	Depreciation	Dollars			20.92
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**36.71**
Total Costs (Operating + Fixed):					**352.54**

Appendix 10: Contour farming cotton budget

Contour farming cotton budget					Total
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Cotton Lint	Lbs	0.62	456	282.72
	Cotton Seed	Cwt	10	6.38	63.8
	Other Income	Dollars	0	0	0
Total Receipts					**346.52**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Seed	Acre	41.14	1	41.14
	Fertilizer	Acre	36.64286	1	36.64
	Custom Harvest	Acre	77.52	1	77.52
	Pesticide	Acre	26.535	1	26.54
	Growth Regulators/Harvest Aids	Acre	1.28	1	1.28
	Crop Insurance	Acre	20	1	20
	Annual Operating Capital	Dollars	0.0625	130.02	8.13
	Machinery Labor	Hrs.	15	1.71	25.65
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	0	0	0
	Machinery Fuel, Lube, Repairs	Acre	48.11737	1	48.12
	Irrigation Cost	Acre	0	0	0
	Rent	Acre	0	0	0
	Ginning/Processing	Acre	30.78	1	30.78
	Other Expense	Acre	4	1	4
Total Operating Costs					**319.8**
Returns Above Total Operating Costs					26.72
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		11.72
	Taxes at	Dollars	0.01		2.94
	Insurance	Dollars	0.006		1.13
	Depreciation	Dollars			20.92
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**36.71**
Total Costs (Operating + Fixed):					**356.51**

(Doye et al.,2015)

Appendix 11: Strip cropping cotton budget

Strip cropping cotton budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Cotton Lint	Lbs	0.62	456	282.72
	Cotton Seed	Cwt	10	6.38	63.8
	Other Income	Dollars	0	0	0
Total Receipts					**346.52**
OPERATING INPUTS		Units	Price	Quantity	$/Acre
	Seed	Acre	41.14	1	41.14
	Fertilizer	Acre	36.64286	1	36.64
	Custom Harvest	Acre	77.52	1	77.52
	Pesticide	Acre	26.535	1	26.54
	Growth Regulators/Harvest Aids	Acre	1.28	1	1.28
	Crop Insurance	Acre	20	1	20
	Annual Operating Capital	Dollars	0.0625	135.02	8.44
	Machinery Labor	Hrs.	15	1.73	25.95
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	0	0	0
	Machinery Fuel, Lube, Repairs	Acre	48.11737	1	48.12
	Irrigation Cost	Acre	0	0	0
	Rent	Acre	0	0	0
	Ginning/Processing	Acre	30.78	1	30.78
	Other Expense	Acre	4	1	4
Total Operating Costs					**320.41**
Returns Above Total Operating Costs					26.11
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		11.72
	Taxes at	Dollars	0.01		2.94
	Insurance	Dollars	0.006		1.13
	Depreciation	Dollars			20.92
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**36.71**
Total Costs (Operating + Fixed):					**357.12**

(Doye et al.,2015)

Appendix 12: Conservation tillage plus terraces cotton budget

Terracing cotton budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Cotton Lint	Lbs	0.62	456	282.72
	Cotton Seed	Cwt	10	6.38	63.8
	Other Income	Dollars	0	0	0
Total Receipts					**346.52**
OPERATING INPUTS		Units	Price	Quantity	$/Acre
	Seed	Acre	41.14	1	41.14
	Fertilizer	Acre	36.64286	1	36.64
	Custom Harvest	Acre	77.52	1	77.52
	Pesticide	Acre	26.535	1	26.54
	Growth Regulators/Harvest Aids	Acre	1.28	1	1.28
	Crop Insurance	Acre	20	1	20
	Annual Operating Capital	Dollars	0.0625	119.3288	7.46
	Machinery Labor	Hrs.	15	1.488	22.35
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	0	0	0
	Machinery Fuel, Lube, Repairs	Acre	48.11737	1	48.12
	Irrigation Cost	Acre	0	0	0
	Rent	Acre	0	0	0
	Ginning/Processing	Acre	30.78	1	30.78
	Other Expense	Acre	4	1	4
Total Operating Costs					**315.83**
Returns Above Total Operating Costs					30.69
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		11.72
	Taxes at	Dollars	0.01		2.94
	Insurance	Dollars	0.006		1.13
	Depreciation	Dollars			50
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**65.79**
Total Costs (Operating + Fixed):					**381.62**

(Doye et al.,2015)

Appendix 13: No-tillage cotton budget

No-tillage cotton budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Cotton Lint	Lbs	0.62	456	282.72
	Cotton Seed	Cwt	10	6.38	63.8
	Other Income	Dollars	0	0	0
Total Receipts					**346.52**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Seed	Acre	41.14	1	41.14
	Fertilizer	Acre	36.64286	1	36.64
	Custom Harvest	Acre	77.52	1	77.52
	Pesticide	Acre	26.535	1	26.54
	Growth Regulators/Harvest Aids	Acre	1.28	1	1.28
	Crop Insurance	Acre	20	1	20
	Annual Operating Capital	Dollars	0.0625	110.33	6.9
	Machinery Labor	Hrs.	15	1.21	18.15
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	0	0	0
	Machinery Fuel, Lube, Repairs	Acre	48.11737	1	48.12
	Irrigation Cost	Acre	0	0	0
	Rent	Acre	0	0	0
	Ginning/Processing	Acre	30.78	1	30.78
	Other Expense	Acre	4	1	4
Total Operating Costs					**311.07**
Returns Above Total Operating Costs					35.45
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		11.72
	Taxes at	Dollars	0.01		2.94
	Insurance	Dollars	0.006		1.13
	Depreciation	Dollars			20.92
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**36.71**
Total Costs (Operating + Fixed):					**347.78**

(Doye et al.,2015)

Appendix 13: Conservation tillage peanuts budget

Conservation tillage peanuts budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Peanuts	Pound	0.17	2750	467.5
	Contract Harvested	Pound	0	0	0
	Additionals Harvested	Pound	0	0	0
	Hay Crop	Ton	0	0	0
	Other Income	Acre	0	0	0
Total Receipts					**467.5**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Tamrun 96 Seed	lbs./acre	0.77	90	69.3
	Fertilizer	Acre	23.125	1	23.13
	Custom Harvest	Acre	0	0	0
	Disease	Acre	96.19	1	96.19
	Insects	Acre	0	0	0
	Weeds	Acre	15.86	1	15.86
	Crop Insurance	Acre	34.034	1	34.03
	Annual Operating Capital	Dollars	0.0625	103.1315	6.19
	Machinery Labor	Hrs.	15	2.054	30.75
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	30.9	1	30.9
	Machinery Fuel, Lube, Repairs	Acre	102.3232	1	102.32
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Cash Rent	Acre	0	0	0
	Quota Rent	Pound	0	0	0
	Other Expense	Acre	68.5	1	68.5
Total Operating Costs					**477.17**
Returns Above Total Operating Costs					-9.67
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		40.25
	Taxes at	Dollars	0.01		10.27
	Insurance	Dollars	0.006		3.9
	Depreciation	Dollars			75.58
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**130**
Total Costs (Operating + Fixed)					**607.17**

Appendix 13: No-tillage peanuts budget

No-tillage peanuts budgets					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Peanuts	Pound	0.17	2750	467.5
	Contract Harvested	Pound	0	0	0
	Additionals Harvested	Pound	0	0	0
	Hay Crop	Ton	0	0	0
	Other Income	Acre	0	0	0
Total Receipts					**467.5**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Tamrun 96 Seed	lbs./acre	0.77	90	69.3
	Fertilizer	Acre	23.125	1	23.13
	Custom Harvest	Acre	0	0	0
	Disease	Acre	96.19	1	96.19
	Insects	Acre	0	0	0
	Weeds	Acre	47.99	1	47.99
	Crop Insurance	Acre	34.034	1	34.03
	Annual Operating Capital	Dollars	0.0625	100.067	6
	Machinery Labor	Hrs.	15	1.186	17.85
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	30.9	1	30.9
	Machinery Fuel, Lube, Repairs	Acre	73.9445	1	73.94
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Other Expense	Acre	68.5	1	68.5
Total Operating Costs					**467.83**
Returns Above Total Operating Costs					-0.33
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		33.15
	Taxes at	Dollars	0.01		8.49
	Insurance	Dollars	0.006		3.21
	Depreciation	Dollars			62.84
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**107.69**
Total Costs (Operating + Fixed)					**575.52**

(Doye et al.,2015)

Appendix 14: Contour farming peanuts budget

Contour farming peanuts budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Peanuts	Pound	0.17	2750	467.5
	Contract Harvested	Pound	0	0	0
	Additionals Harvested	Pound	0	0	0
	Hay Crop	Ton	0	0	0
	Other Income	Acre	0	0	0
Total Receipts					**467.5**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Tamrun 96 Seed	lbs./acre	0.77	90	69.3
	Fertilizer	Acre	23.125	1	23.13
	Custom Harvest	Acre	0	0	0
	Disease	Acre	96.19	1	96.19
	Insects	Acre	0	0	0
	Weeds	Acre	15.86	1	15.86
	Crop Insurance	Acre	34.034	1	34.03
	Annual Operating Capital	Dollars	0.0625	113.2	6.79
	Machinery Labor	Hrs.	15	2.34	35.1
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	30.9	1	30.9
	Machinery Fuel, Lube, Repairs	Acre	102.3232	1	102.32
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Other Expense	Acre	68.5	1	68.5
Total Operating Costs					**482.12**
Returns Above Total Operating Costs					-14.62
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		40.25
	Taxes at	Dollars	0.01		10.27
	Insurance	Dollars	0.006		3.9
	Depreciation	Dollars			75.58
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**130**
Total Costs (Operating + Fixed)					**612.12**

(Doye et al.,2015)

Appendix 14: Strip cropping peanuts budget

Strip cropping peanuts budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Peanuts	Pound	0.17	2750	467.5
	Contract Harvested	Pound	0	0	0
	Additionals Harvested	Pound	0	0	0
	Hay Crop	Ton	0	0	0
	Other Income	Acre	0	0	0
Total Receipts					**467.5**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Tamrun 96 Seed	lbs./acre	0.77	90	69.3
	Fertilizer	Acre	23.125	1	23.13
	Custom Harvest	Acre	0	0	0
	Disease	Acre	96.19	1	96.19
	Insects	Acre	0	0	0
	Weeds	Acre	15.86	1	15.86
	Crop Insurance	Acre	34.034	1	34.03
	Annual Operating Capital	Dollars	0.0625	125.2	7.51
	Machinery Labor	Hrs.	15	2.36	35.4
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	30.9	1	30.9
	Machinery Fuel, Lube, Repairs	Acre	102.3232	1	102.32
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Other Expense	Acre	68.5	1	68.5
Total Operating Costs					**483.14**
Returns Above Total Operating Costs					-15.64
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		40.25
	Taxes at	Dollars	0.01		10.27
	Insurance	Dollars	0.006		3.9
	Depreciation	Dollars			75.58
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**130**
Total Costs (Operating + Fixed)					**613.14**

(Doye et al.,2015)

Appendix 14: Terracing peanuts budget

Terracing peanuts budget					**Total**
PRODUCTION		**Units**	**Price**	**Quantity**	**$/Acre**
	Peanuts	Pound	0.17	2750	467.5
	Contract Harvested	Pound	0	0	0
	Additionals Harvested	Pound	0	0	0
	Hay Crop	Ton	0	0	0
	Other Income	**Acre**	**0**	**0**	**0**
Total Receipts					**467.5**
OPERATING INPUTS		**Units**	**Price**	**Quantity**	**$/Acre**
	Tamrun 96 Seed	lbs./acre	0.77	90	69.3
	Fertilizer	Acre	23.125	1	23.13
	Custom Harvest	Acre	0	0	0
	Disease	Acre	96.19	1	96.19
	Insects	Acre	0	0	0
	Weeds	Acre	15.86	1	15.86
	Crop Insurance	Acre	34.034	1	34.03
	Annual Operating Capital	Dollars	0.0625	108.2	6.49
	Machinery Labor	Hrs.	15	2.5	37.5
	Irrigation Labor	Hrs.	0	0	0
	Custom Hire	Acre	30.9	1	30.9
	Machinery Fuel, Lube, Repairs	Acre	102.3232	1	102.32
	Irrigation Fuel, Lube, Repair	Acre	0	0	0
	Other Expense	Acre	68.5	1	68.5
Total Operating Costs					**484.22**
Returns Above Total Operating Costs					-16.72
FIXED COSTS		Units	Rate		$/Acre
	Machinery/Irrigation	$/value			
	Interest at	Dollars	0.062		40.25
	Taxes at	Dollars	0.01		10.27
	Insurance	Dollars	0.006		3.9
	Depreciation	Dollars			97.75
	Land	$/acre	0		
	Interest at	Dollars	0		0
	Taxes at	Dollars	0		0
Total Fixed Costs					**152.17**
Total Costs (Operating + Fixed)					**636.39**

(Doye et al.,2015)

VITA

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