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A Gis-Based Watershed Impact Management Model

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A GIS- BASED WATERSHED IMPACT MANAGEMENT MODEL

CASE STUDY: YOCONA RIVER BASIN

NORTH MISSISSIPPI

A Thesis
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By

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ABSTRACT

Assessment of land use changes on hydrological processes is essential for the planning and development of sustainable land management practices and water resources. Understanding how land management practices influence hydrological components is essential for the prediction of hydrological consequences of changes in land use. Given the plethora of hydrological models, digital data sources, and the limited availability of observed data, it is difficult to quantify the impacts of land use changes on hydrology. In this study, a Watershed Impact Management (WIM) model framework was conceptualized. A case study of the Yocona River Basin, Mississippi was implemented with the Soil and Water Assessment Tool (SWAT) using the ArcGIS extension and interface. The objective of this study was to quantify the impacts of three different land use change scenarios. These scenarios were developed based on projected future land use planning for the City of Oxford and Lafayette County. Expanded urbanization in Scenario A was the strongest contributor to increased runoff and water yield. Incorporation of Best Management Practices (BMPs) in Scenario B resulted in a significant reduction of sediment yield and nutrient load. However, no changes were evident in groundwater nitrate loading despite the addition of BMPs. The replacement of all non-urban areas with forest trees in the Yocona River Basin, (Scenario C) resulted in decreased runoff and sediment yield. The WIM modeling approach in the quantification and assessment of impacts of land use change can be applied to all watersheds, even those with limited data availability and will provide quantitative information in planning and decision-making for land and water resource management.

DEDICATION

This thesis is dedicated to my mother Mrs. Chika Udeze, Oyindamola Akande and Dr. Louis Zachos. Without their support, this thesis would not be possible.

LIST OF ABBREVIATION AND SYMBOLS

ASCE	American Society Civil Engineers
BMPs	Best Management Practices
ETJ	Extra-Territorial Jurisdiction
GIS	Geographic Information System
HRU	Hydrologic Response Unit
LU/LC	Land Use/ Land Cover
LUC	Land use Change
LUP	Land use update
MDEQ	Mississippi Department Environmental Quality
NPS	Nonpoint Source
NSE	Nash-Sutcliffe Efficiency
RCWP	Rural Clean Water Program
SWAT	Soil and Water Assessment Tool
TMDL	Total Maximum Daily Loadings
USDA	United States Department of Agricultural
USDA-ARS	United States Department of Agricultural –Agricultural Research Service
USEPA	United States Environmental Protection Agency
USGS	United States Geological Service
WIM	Watershed Impact Management

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CHAPTER 1

INTRODUCTION

Nonpoint source (NPS) pollution is a major contributing factor to the deterioration of water bodies. Land use and land cover changes can potentially have detrimental effects on streamflow and water quality within a watershed. Land use and land use changes also impact the hydrologic processes within a watershed. Effective planning of watershed development, water resource use, and protection under changing conditions requires the use of hydrologic models that can simulate flow regimes under different land use and land use change scenarios, assess, and quantify impacts of these changes. The goal of watershed modeling is mainly to evaluate the impact of management scenarios such as agricultural operations, land use change and other anthropogenic activity on surface water, and on the watershed itself. Assessment the impacts of land use and land use changes on hydrologic components is the basis for any watershed impact management model.

Water quality issues attributed to agricultural runoff in the United States include: increased sediment loads, increased nutrient levels (nitrogen and phosphorus), and the presence of pesticides (Frimpong, Lee, & Ross-Davis, 2007; Smith, Haggard, Warnemuende, & Huang, 2005; Wang, Hapuarachchi, Takeuchi, & Ishidaira, 2010). The main sources of pollution in urban areas are known to be residential, commercial land, and industrial nonpoint sources. A major pathway by which pollutants enter receiving waters in urban areas is thought to be the wash-off of accumulations of airborne-derived contaminants from impervious surfaces.

In 1972, the National Eutrophication Survey was initiated to investigate the threat of accelerated eutrophication to fresh water lakes and reservoir. This survey was designed to gather information on nutrient sources and their impacts on selected freshwater lakes, and used as a basis for establishing comprehensive management practices relating to NPS pollution abatement in watersheds. An increase in the rate of land use change (Urban or Agricultural) creates problems for watersheds globally through increased surface runoff, sediment yield, and impairment of water quality. Management practices such as the Long Term Hydrologic Impact Assessment/ Nonpoint Source (L-THIA/NPS) pollution model (Baduri et al., 2000), and Total Maximum Daily Loads (TMDL) studies have been set in place to better quantify the impacts of progressive land use changes on watersheds. Research by Laurance (2007) and Bradshaw et al. (2007 indicated that deforestation can increase flood risk, because deforestation causes canopy interception storage, transpiration, and infiltration capacity to decrease (Clark, 1987). Urban land, in contrast with hydrological properties of forest, is characterized by decreased infiltration capacity as a result of impervious surfaces, vegetation removal and less water storage. The consequences of urbanization are increased flood risk and wash-off pollutions of water.

Geographical Information System (GIS) technology is a useful tool for the development of distributed hydrologic models and in visualizing various aspects of water resources (Wilson et al., 2000). A Watershed Impact Management (WIM) model assesses land degradation from mainly NPS pollution. NPS of pollution are difficult to identify and measure because they originate from diffuse sources spread over a large areal extent. Examples are streets and parking lot wash-off, salt runoff from roads, sediment-laden runoff from construction sites, and wet and dry atmospheric deposition. (Baduri et al. 2000). Water-quality problems in 35% of the watersheds in the United States have a greater contribution from nonpoint than point sources of pollution (Marsh and Rossa 1996). With the use of a GIS-based watershed model, environmentally sensitive areas can be identified and evaluated against alternative land use scenarios for impact management. Understanding the hydrologic response of watershed to physical changes is an important component of water resource planning and land management.

A WIM model is a proactive approach that coordinates land use and water management decisions to protect water resources and help communities define and prioritize local needs in relation to regional issues and goals. A WIM model can help assess present and future environmental degradation risks that accompany changes in land use. Models simulated and integrated with Best Management Practices (BMP) can result in proposals that show a decrease in the impact of change in land use in terms of nutrient loadings. The concept of BMP encompasses a wide variety of appropriate technologies and activities intended to minimize the effect of watershed development on flow regimes without altering riparian morphology (Perez-Pedini et al., 2005). Effective control or reduction of non-point source loads will require implementation of BMP in the watershed. BMP may involve efforts to change land-use practices or watershed activities in ways that reduce material exports, or the construction and operation of features that retain materials or reduce the rate at which they are transported within the watershed and its outlet. BMP effectiveness can be examined through spatial analysis and water quality models.

Various Best Management Practices (BMPs) have been developed and implemented for achieving the water quality goals in different states. To evaluate the effects of the BMP on water quality at basin-scale, a total of 21 watershed monitoring programs were initiated in 1980, under the Rural Clean Water Program (RCWP) administered by USDA and USEPA (USEPA, 1993). In addition to the RCWP watershed monitoring studies, several other studies, such as the Nomini

Creek watershed study (Mostaghimi et al., 1989) in Virginia, were also undertaken for evaluating watershed-scale effects of BMP on water quality.

Data that are generally required for input into WIM models include, but are not limited to climate, topography, soil physical properties, and land use/ land cover. When models are run, simulated estimates of surface runoff, water yield, nutrients and sediment yield at the watershed outlet are generated (USACE, 1999). Estimates provided by WIM is shown to be highly useful in water resource management application including predicting the effects of land use changes, assessing the use of BMP for water quality protection, predicting soil nutrient loss and yields in agricultural lands.

1.2 – BACKGROUND

Following the enactment of the Federal Water Pollution Control Act (the “Clean Water Act”) Amendment in 1972, studies were published that began to identify the significance of different land use impacts on watershed water quality. Results of these studies found significant positive correlations between nitrogen concentrations in runoff water and the area of watershed used for agriculture. In 1972, the US National Eutrophication Survey of 930 watersheds found the highest inorganic nitrogen concentration for agriculturally dominated basins (soil texture was also a significant influencing factor). It was calculated that over 95% of the total phosphorus on some lakes was contributed by NPS (Although this high rate might have been a result of underestimation of pollutant loadings contributed by land use and land use change processes).

Since the 1980’s, studies have extended the understanding of the influence of land use on pollutant loading concentrations in watershed hydrologic settings. The percentage of land use and its impact (e.g. agricultural land use and nitrate-N concentrations) have been positively correlated in catchments with significant land use development. In addition, the conversion from pervious to impervious surfaces can severely degrade the quality of storm and non-storm water runoff. Monitoring and modeling studies have shown consistently that urban pollutant loads increase with watershed imperviousness (Schueler, 1995). The outcome of these land use conversions can alter the natural hydrologic condition within a watershed. These alterations are typically reflected in the increase in volume and rate of surface runoff and decrease in groundwater recharge and base flow, which can eventually lead to larger and more frequent incidents of local to regional flooding (Field et al., 1982, Hall, 1984), reduced residential and municipal water supplies, and decreased base flow into stream channels during dry weather (Harbor, 1994).

Implementing a framework that can serve as a tool to develop and verify local and regional watershed models is essential for quantifying environmental effects. Watershed management models are effective planning and conservation tools in terms of identifying, assessing, and, forecasting environmental effects. Studies have shown that watershed modeling is a practical approach that can help save time and money because of their ability to simulate and predict effects of land use on hydrological process, water and soil quality. Furthermore, building a detailed framework that can direct users through data acquisition, watershed delineation, modeling, and simulation can help save time and improve evaluation and predicted results.

NEED FOR A WATERSHED IMPACT MANAGEMENT MODEL

Because of the correlation between pollution loading and land use, there is a potential for improving debilitating hydrological processes in a watershed with proper land use management practices (Perry and Vanderklein, 1996). Land use changes associated with social and economic development have resulted in changes in runoff, soil erosion, sediment transport and pollutants cycling rates in rivers, which are often primary source of water supply to local residents (Qi and Altinakar, 2011). Therefore, a need exists for development a GIS based Watershed Impact Management (WIM) model to evaluate the impact of land use and other anthropogenic activities on watershed. The conceptual framework resulting from a watershed impact management model can be applied to simulate and assess the effects on watershed hydrology. The development of a GIS-based watershed model can save time and money because of its ability to perform long term simulations of the effects of watershed processes and management activities on water quality, water quantity, and soil quality (Moriasi et al., 2007).

Understanding the hydrologic response of watershed to physical (land use) and climatic (rainfall and air temperature) change is an important component of water resource planning and management (Vorosmarty et al., 2000). The impacts of land use change on river basin hydrology are interlinked with impacts of climate change. In general, global warming and increased precipitation will lead to flooding due to excess basin runoff and increased presence of impervious surfaces from land use change. The existence of an effective management model is crucial for areas undergoing continued development. Basin runoff models that can simulate flow regimes under different land use scenarios can serve as an efficient water resource planning and protection tool.

Efficient planning for a watershed management model requires that model challenges be met, in terms of data acquisition and collection. In many parts of the world, including the United States, accurate modeling of flow regime is challenging because of the limited availability of future and historical climate and runoff data. Excess data availability can in some cases pose some challenges to hydrologic models. These challenges can be met by detailing a management framework application that can suggest ways to collect and apply data for useful simulations. GIS data quality can also have varying impacts on modeling results. The choice of data is critical for the realistic definition of the watershed and subwatershed boundaries and topographic input, and consequently simulated outputs (Luzio et al, 2005).

1.3. – GOALS AND OBJECTIVES

The goal of this study was to develop a conceptual approach using a GIS-based watershed model for evaluating the impacts of land use and land use changes on hydrological components and evaluating the effects of BMP on water quality parameters in a case study using the Yocona River Basin (located in the Yazoo River Basin Hills Region, Mississippi).

The specific objectives of this study were to:

1. Build a WIM model framework for Yocona River that is computationally efficient, allows considerable spatial detail, uses readily available input, is time continuous, and capable of simulating various land use scenarios
2. Obtain key spatial and climate data for the study area watershed by accessing publicly available data, modify and generate a highly accurate land use / land cover data using remote sensing and GIS technology.
3. Use the Soil and Water Assessment Tool (SWAT) to model and assess the current conditions of the study area.
4. Perform sensitivity analysis on the model to determine which parameters are most affected by land use, Calibrate the model using climate and streamflow data from 2000 to 2005 and validate the model using data for five years (2006 to 2010).
5. Analyze possible scenarios of land use changes impact on watershed hydrological components; develop recommendations based on the results of objectives 3 and 4, for a land use plan of action to reduce excess runoff in areas where there is increased risk of flooding as a result of land use change.
6. Evaluate the effectiveness of BMP on surface and ground water quality.

7. Address development challenges (such as data limitations) that come with watershed models and determine ways to use SWAT to model watershed systems in data-poor environments.

The main hypotheses tested in this study were:

H_1: The changes in land use and land cover type in a watershed are related to the changes in hydrological components (runoff, percolation, actual evapotranspiration etc.) and thus can be used to predict the effects of land management practices.

H_2: The implementation of BMP can significantly reduce the amount of pollutants/contaminants loadings (Nitrogen, phosphorus etc.) in surface runoff.

1.4 – RESEARCH QUESTIONS

The research questions to be answered in order to meet the objectives outlined above are:

1. Why do we need a watershed impact management model?
2. It is possible to establish a watershed impact management model framework that is *computationally efficient, allows for considerable spatial detail, uses readily available input, is time continuous, and capable of simulating various land use scenarios*.
3. What are the key input data requirements to reduce predictive uncertainty in the watershed model?
4. Does the model effectively simulate present hydrologic conditions at the Yocona River Basin?
5. How good are the model predicted scenarios?
6. How effective are BMP on ground water quality?
7. Does the general WIMM framework fit other watershed basins?

The above objectives were divided into 5 tasks which are presented in Chapters 2 through 7. In Chapter 2, a literature review pertaining to SWAT, investigations of land use effects on watershed-scale hydrological components and water quality, data limitations and uncertainty in modeling are presented. Several watershed-scale studies are reviewed to determine the feasibility of modeling a watershed in cases of limited data availability, and causes of uncertainty in establishing effects of land use changes and treatment (e.g., BMP). Chapter 3 starts with model formulation. This section details the development of a comprehensive GIS-based modeling framework; climate, land use database and modeling methodology are discussed. Chapter 4 describes and discusses the Soil and Water Assessment Tool, watershed model methodology and configuration, and simulations. Chapter 5, begins with an introduction to sensitivity analysis, calibration and uncertainty analysis followed by the results of the baseline model are presented. Chapter 6, the three land use scenarios are classified and processed, the classification process and methodology are discussed, SWAT2009_LUC is introduced and the results for the 3 scenarios are discussed. Chapter 7 presents and discusses the results from chapter 5 and 5, evaluating the impacts of land use change and effects BMP on ground water nutrient loadings on a subbasinal scale. Based on the results from Chapter (s) 5 and 6, conclusions and recommendations were made.

CHAPTER 2 – LITERATURE REVIEW

The purpose of this literature review is to provide the reader with a general overview of the following topics: (1) effects of land use and degradation of water quality, (2) the application of data-intensive models in data-poor environments, with an emphasis on Soil Water Assessment Tool (SWAT), and (3) parametric properties of hydrologic basins. The first part gives a brief description of previous research using SWAT for watershed modeling globally. Next, a brief discussion on hydrologic basin analysis and model evaluation methods is presented, along with a quick review of the effects of land use practices and their role in the degradation of surface waters. Finally, a review of uncertainty analysis and examples of studies that used SWAT model are presented.

2.1 – Effects of Land Use Practices on Surface Waters

A number of studies have shown marked changes in chemical water quality associated with land use change. Land use change can lead to significant changes in leaf area index, evapotranspiration (Mao and Cherkauer, 2009), soil moisture content and infiltration capacity (Fu et al., 2000; Costa et al., 2003), surface and subsurface flow regimes including baseflow contributions to streams (Tu, 2009) and recharge, surface roughness (Feddema et al., 2005), runoff, as well as soil erosion through complex interactions among vegetation, soils, geology and climate processes. Many streams have experienced severe instability leading to disruption of fluvial system due as a result of catchment land use change (Thorne, 1991). Therefore, assessing the impacts of land use changes on hydrologic component is the basis for watershed management and ecological restoration.

Research by Laurance (2007) and Bradshaw et al. (2007) showed that deforestation can increase flood risk because it causes canopy interception storage, transpiration, and infiltration capacity to decrease. Urbanization can also increase flood risk and pollution through the creation of impervious surfaces and wash-off respectively. Changes in land use associated with development have contributed in the degradation of surface water quality in many parts of the world. As land is developed, vegetative cover decreases and the amount of impervious surfaces increases, thus increasing the rates of erosion and runoff. Runoff from urban landscapes and construction sites is also known to be one of the most common sources of sediment and nutrients in surface waters. Environmental planning and regulatory mandates require assessment of water quality changes associated with distributed land use activities (Bolstad and Swank, 1997).

Land use associated with agricultural practices has been shown to have cascading and deleterious effects on downstream surface waters. Agricultural intensification often includes a substantial increase in the rates of nitrogen (N) fertilizer application, which improves crop yields but has deleterious consequences for downstream aquatic systems, where nutrient loading can drive eutrophication (Howarth et al. 1996; Vitousek et al. 1997; Boesch et al. 2001; Jenkinson 2001; Kemp and Dodds 2001; Tillman et al. 2001; Turner et al. 2003; Beman et al. 2005). While much of the developing world could benefit from modest increases in fertilizer use (Sánchez, 2002), large-scale intensive agriculture continues to the application of large amounts of N fertilizer to maximize yields despite the consequences of excess N in downstream ecosystems (Vitousek et al. 1997). In a study done by the USEPA (2002), 47% of lakes and reservoirs and 45% of rivers and streams in the United States were recognized as impaired with Nitrogen (N) and phosphorus (P) loadings from agricultural runoff cited as the major cause of impairment. These nutrients can cause problems including toxic algal blooms, oxygen deficiency, fish kills, and loss of biodiversity. Nutrient enrichment can also make the water unsuitable for drinking, industrial, agricultural and recreational use (Carpenter et al., 1998).

If land use changes in the future, the levels of contaminants will be changed accordingly. Hence, future land development and management should be considered with care (Tong, and Chen, 2002). This is especially the case if the land is going to be changed to agriculture or impervious urban lands. With better land use planning, we may be able to curtail some of the water quality problems. Use of models can help with management of land use and land use change.

2.2 – Application of data-intensive models in data-poor environments

The ability of a static model to simulate a watershed system depends on how well the watershed processes are represented by the model and how well the system is described by the model input parameters (Tripathi et al., 2006). The application of data-intensive models depends upon several factors: the purpose of the study, understanding the nature of the watershed (natural complexity of the system, spatial heterogeneity and temporal variability), data limitations (quantity and quality), and computational procedures of the model (Letcher et al., 1999). Therefore, in order to correctly model and perform watershed analysis, the right model selection depends on the objectives of the research and the availability of data.

Data types and amount required for a watershed-scale model simulation vary by hydrologic model and its intended application. Whether a model is data-intensive or simplistic, it is important to have high quality data input. One must consider data requirements, format, alternative data sources, and proper data management in order to ensure a cost-effective means of collecting high quality data (Schafer and Hanlon, 2001). The lack of available input data means that many of the model parameters have to be determined through calibration. This leads to a problem in that many different parameters sets will fit observed data, placing physical interpretation of the parameters into question (Letcher et al, 1999). According to Wheater et al. (1993), parameters that cannot be uniquely quantified cannot be deterministically linked to watershed characteristics. However, recent studies have shown that when modeling watersheds with limited availability of data, users can rely on the application of GIS and other dependable data sources to closely determine watershed parameters.

A series of different approaches to use data-intensive distributed models in data-poor environments have been explored. Letcher et al. (1999) combined a landscape-factor with a conceptual model to predict runoff. The landscape-factor uses an empirical but landscape driven method that allows for estimation of dynamics of runoff generation in response to precipitation in ungauged catchments. Another study by Elshorbagy and Ormsbee (2006) showed the potential use of a simulation dynamic approach in an object-oriented simulation environment, based on system dynamics concepts of surface water quality for management purposes, adapted to water quality modeling with insufficient data. The study confirmed that a model capable of representing complex systems in a realistic way is possible when an object-oriented simulation approach is used. They concluded that object-oriented simulation, based is a feasible alternative in data-poor conditions, although it is not a replacement for traditional hydrologic models.

Another system of modeling called AGNPS (Agricultural Non-Point Source Pollution Model) was applied to a study completed in Brazil with a limited observation dataset (Zilli Bacic et al. 2008). The model was calibrated based on a best guess for model parameters and on a pragmatic sensitivity analysis. These parameters were defined as initial parameter values adapted as closely as possible to reality according to available data. Since quantitative data for the model calibration and validation were lacking, the best guess scenario was adapted as an alternative to supplement limited calibration data. The authors concluded that their method showed that expert knowledge and information inferred from literature will allow the implementation of modeling in data-poor environments.

Model predictions vary depending on the level of aggregation of input data (Chang 2009, and Jha et al., 2004). Proper model use requires an understanding of how model predictions vary according to level of data aggregation and whether the variations can be attributed to differences in watershed characteristics (FitzHugh and Mackay, 2001). Distributed hydrological models divide watersheds into smaller subbasin units to represent heterogeneity within the watershed. The detail of input requirements and model calculation are dependent are on size of the watershed unit (Luzio et al., 2005). Model outputs are also affected by geomorphic resolution (Arabi et al., 2006). More detail in the input data is necessary and required to better describe spatial variability of the watershed.

Rouhani et al. (2006), Luzio et al. (2005), Jha et al. (2004) and Chang (2009) focused on how spatial resolution affects results from watershed subdivision and its influence on model – based predictions of long term impacts on streamflow, transport of sediments, and nutrients within watersheds. Variations in the size and number of subbasins are expected to affect the simulation results from the entire watershed (Tripathi et al., 2006). When analyzing the impact of model input aggregation on model output, Rouhani et al. (2006) concluded that the relationship between outlet sediment, streamflow yield and subbasin size changes depending on the watershed characteristics. However, Arabi et al. (2006) studied watershed subdivision for assessment of best management practices (BMP) on sediment yields and they concluded that predicted reductions in sediment yields as a result of BMP were more accurate when a coarse level of subdivisions was applied. Luzio et al. (2005) and Ghaffari (2011) concluded that decreasing the resolution of input beyond 30 m did not substantially affect the simulation of runoff but it did have a significant impact on simulation of sediment yield. This conclusion suggests that data generalization can be made without adversely affecting model predictions.

There is no unique established method for determining the optimal subbasin hydrologic response unit configuration (Arabi et al., 2006). Chang (2009) and Jha et al. (2006) recommended that watershed studies based on modeling should include a sensitivity analysis with varying subbasin size and number. Additional study is necessary to develop criteria that relate the watershed subdivision and the detail required to correctly represent its characteristics, while retaining the accuracy of the model prediction of runoff, nutrients and sediment yield. It is apparent that poor catchment representation of key hydrological features may lead to poor model performance.

2.3 – SOIL WATER ASSESSMENT TOOL (SWAT)

SWAT is a physically-based, semi empirical hydrologic and water quality model that makes calculations on a daily time step to predict the impact of land use, soil type, climate, and land management practices upon hydrology, sediment, nutrients, and pesticides in large ungauged catchments (Arnold and Fohrer, 2005; Gassman et al., 2007). SWAT models are internally organized in a nested spatial hierarchy, including Hydrologic Response Units (HRUs) within subwatersheds within watersheds (Bosch et al., 2011). The model uses readily available input databases. It is a continuation of a long-term effort of nonpoint source of pollution modeling by the USDA Agricultural Research Service (ARS), including development of CREAMS (Knisel, 1980), GLEAMS (Leonard et al., 1987), and SWRRB (Williams et al., 1985).

SWAT allows a basin to be divided into subbasins and hundreds of agglomerate-homogenous areas called Hydrologic Response Units (HRUs), which are unique combinations of land use – soil – slope – management (Neitsch et al., 2005) on which modeling and statistical computations are performed. The model simulates major hydrologic processes relating to overland and in-stream processes including water balance, sedimentation, and chemical transport. The SWAT model incorporates built-in databases, for land use, crops, soils, fertilizers and pesticides (Gassman et al., 2007). These embedded databases facilitate the modeling process, particularly for areas within the continental United States. Nevertheless, the SWAT model has been reported to be an effective tool for assessing water resources and nonpoint –source pollution problems for a wide range of scales of environmental conditions across the globe.

SWAT with limited digital data on land use, soil and topography, has been applied to model the hydrology of Sondu River Watershed in Kenya (Jayakrishnan et al., 2005). This model was limited by the lack of detailed digital data on landuse, soil and elevation for model input. Digital data were coarse (1 km resolution DEM 1000 m) and the information of one soil type was assumed over the entire watershed (3050 km^2). Records of climate and streamflow were available but had data gaps. There were no observed data for sediment yield to calibrate/validate the model prediction. Despite the incompleteness of data and poor Nash-Sutcliffe efficiencies (NSE) 0.10 of the evaluation results, the authors concluded that the application of SWAT is possible under these conditions. However, they stressed the need for additional model input data collection to improve the model parameter calibration.

SWAT has been applied to the Biobío River basin in Chile (Stehr et al., 2008). The model performed well at predicting monthly streamflows (NSE 0.93) in one of the test stations (control points), but problems with rainfall variability at the four test stations constrained the ability to accurately model water balance and streamflow in the 3 other control points. The authors proposed that further improvements in model performance could be made by seeking alternative and additional field data sets which would allow a long term application. SWAT has also been applied for modeling the WeruWeru basin in Northern Tanzania (Birhanu, 2007). Results for predicted mean daily streamflow were reported exactly as observed during the water balance simulation. Authors of this study concluded that the SWAT model could be used for watershed studies in mountainous catchments in tropical regions.

The SWAT results for sediment and nutrient transport simulation vary quite dramatically with the size and number of subbasins and SWAT model predictions are sensitive to HRU components and distribution (Arabi et al., 2006). The number of subbasins to delineate when modeling with SWAT depends on the need to minimize data and basin characteristics. A study done by Tripathi et al. (2006) pointed out that runoff volume predicted with SWAT is impacted by the number of subbasins and HRUs. Luzio et al. (2005) and Jha et al. (2004) reported that variation in the total number of subbasins had very little effect on streamflow; however, the opposite result was found on sediments and nutrients. They recommended that watershed subdivision should be restricted to an optimum threshold level to reduce input preparation efforts and efforts and computational evaluation. Luzio et al. (2005) recommended that data resolution and aggregation should be selected based on the model intent as large scale data sets, DEM, and land use maps can provide sensitive improvements for simulation results. Larger scale land use and soil maps can provide a higher number of HRUs and allow the formulation of more precise and diversified management strategies.

SWAT model has been applied worldwide in a wide range of applications and conditions (Gassman et al., 2010). Clear limitations still exist for how the model can be applied to some problems due to lack of input data. Several publications highlight the same major limiting factor in the success of SWAT simulations are lack of available high quality input data (Jacobs and

Srinivasan, 2005; Krysanova et al., 2005). The need for measured data collection to improve SWAT model evaluation has been highlighted by several authors (Tripathi et al., 2006). Krysanova et al. (2005) suggested that the following problems related to regional applications should be addressed and discussed: (a) choice of strategy for model validation, (b) general data needs and options to reduce data requirements, and (c) analysis of uncertainty related to model parameterization and input data.

2.4 – Parametric Properties of Hydrologic Basins

Every basin is a complex open system with component processes and state variables that may change rapidly over space and time (Beven and Kirkby, 1978). Even if the processes operating are fully understood, an impossibly large number of parameters would be necessary to model the response of the spatially structured system in any but crudest detail (Stephenson and Freeze, 1974). The use of a physically based hydrologic model is necessary in watersheds (urban and rural) because of the high spatial variability of land surface parameters, and the absence of complete calibration data. Hydrologic basin analysis evaluates the effects of rainfall and land-surface uncertainty on hydrologic predictions of extreme events in urban and rural environments. Guo and Adams (1998) carried out hydrologic analysis of a basin using a statistical approach to determine the probability density function of a runoff event volume and the expected average runoff volume over a catchment. This study showed that probabilistic models for discharge can be used an alternative to simulation modeling in determination of peak discharge or flood frequencies for urban catchment. Statistical methods such as the rainfall-runoff transformation (Rivera et al., 2005) can be used to predict and understand the effects of changing physical parameters of watersheds in rainfall events.

Estimating specific basin hydrologic properties is a difficult scientific task, since it requires good comprehension of the particular water system, knowledge of the geologic and geomorphic conditions and full series of relevant data (Zacharias et al., 2003). Many scientists have attempted to calculate some of the parameters in basins by using regression techniques (Jarboe and Haan, 1974) and by the implementation of conceptual models with high parameterization (Hughes, 1989). These approaches may provide credible results for site-specific cases; however, they are not widely applicable, since they include a significant amount of uncertainty (Zacharias et al., 2003). Chow et al. (1989) showed that hydrologic properties can be obtained by using maps, unit hydrographs and physically-based equations.

2.5 – Model Evaluation Guidelines

Hydrologic models that accurately predict the impact of land management scenarios on surface and ground water and nutrient transport are essential tools in developing a watershed impact management plan focused on assessing the impacts of alternative land management scenarios. Before using a model for such assessment and plan development, it is important that the model be evaluated with respect to its predictive abilities related to sediments, nutrients, surface and ground water. Watershed models can save time and money because of their ability to perform long term simulation effects of watershed processes and management activities on water quality and quantity (Moriasi et al., 2007). Nevertheless, in order to use a model output for tasks ranging from research to regulation, a model should be scientifically sound, robust, and defensible (U.S. EPA, 2002).

Moriasi et al. (2007) described “model evaluation” as the applicable steps to sensitivity analysis, calibration and uncertainty analysis, and validation. The general objective of the sensitivity analysis is to determine the rate of change in a model output with respect to changes in model input (parameters). Model calibration is the process of estimating model parameters by comparing model predictions for a given set of assumed conditions with observed data for the same conditions. According to Refsgaard (1997), 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. The main objective of model validation is to obtain a reliable modeling tool that can be used to evaluate such hydrologic responses. It is necessary to first perform sensitivity analysis, calibrate and then validate the model. Singh et al. (2004) recommended that before the evaluation process starts the parameter to be evaluated must be selected and tolerance limits for model must be fixed as the criteria or critical values for evaluation. Table 1, adapted from Singh et al. (2004) presents a general performance rating for model evaluation using three different statistical rating methods.

Graphical techniques provide a visual comparison of simulated and measured constituent data and a first overview of model performance (ASCE, 1993). Graphical plots are essential and provide a general overview of model abilities and accuracy. A general visual agreement between observed and predicted values will indicate adequate calibration and validation over the range of values being simulated (Singh et al., 2004).

Table 2.1: General performance ratings for recommended statistics for a monthly time step (Singh et al., 2004)

Performance Rating	RSR	NSE	PBIAS (%)		
			Streamflow	Sediment	N, P
Very good	0.00≤RSR≤0.50	0.75<NSE≤1.00	PBIAS<±10	PBIAS<±15	PBIAS<±25
Good	0.50≤RSR≤0.60	0.65<NSE≤0.75	±10≤PBIAS<±15	±15≤PBIAS<±30	±25≤PBIAS<±40
Satisfactory	0.60<RSR≤0.70	0.50<NSE≤0.65	±15≤PBIAS<±25	±30≤PBIAS<±55	±40≤PBIAS<±70
Unsatisfactory	RSR>0.70	NSE≤0.50	PBIAS≥±25	PBIA≥±55	PBIAS ≥±70

(1) RSR: Root mean squared error, observations standard deviation ratio
(2) NSE: Nash-Sutcliffe efficiency
(3) PBIAS: Percent Bias

With the actual evaluation procedures, large datasets for calibration and validation are needed. A problem for model evaluation arises when the model is applied to data-poor conditions, where there is limited or no observed data to evaluate model predictions. An option for evaluating predictions in data-poor environment is to take field measurements or use a small amount of available data to estimate long term observation. According to Sivapalan (2003), in some situations, a solution to the ungauged basin problem will be to take a small number of field measurements to help model evaluation. The question is how long a measured record is necessary to obtain an optimal model evaluation. Seibert and Beven (2009) raised the question of what total number of observation might be necessary to achieve a desired and cost-effective reduction in uncertainty. Monitoring plans to collect field data are labor intensive and expensive; therefore, it is unlikely that long term data collection in an ungauged watershed would be possible (Seibert and Beven, 2009). It can be inferred that new approaches and guidelines are needed for evaluating model predictions in data-poor environment.

2.6 – Uncertainty Analysis

It is impossible for any model to represent nature's processes perfectly (Muleta and Nicklow, 2005). Hence, simplifications must be applied in order to represent the system being modeled (Shirmohammadi et al, 2006). Simplification of the complex nature of watershed systems leads to many sources of uncertainty. Macintosh et al. (1994) defined uncertainty as "the inability to determine the true state of affairs in a system". Hattis and Burmaster (1994) stated "uncertainty is a description of the imperfection in knowledge of the true value of a specific parameter". Hession and Storm (2000) stated that uncertainty must be incorporated into watershed level assessment and management to enhance the decision making process.

Uncertainty can be either knowledge or stochastic (Helton, 1994; Hession and Storm, 2000; Walker et al., 2003). Stochastic uncertainty is due to random variability of the natural environment (Helton, 1994; MacIntosh et al., 1994; Hattis and Burmaster, 1994). Knowledge uncertainty, on the other hand, is due to incomplete understanding or oversimplification of the complex and variable real system (Helton, 1994; MacIntosh et al., 1994; Haan, 1989; Muleta and Nicklow, 2005). Additionally, much of the uncertainty of modeling predictions can be attributed to incomplete information quality and quantity of the model input and to uncertainty in the estimates of the parameters used as input for the analysis (Shirmohammadi et al. 2006; Muleta and Nicklow, 2005; Srivastav et al., 2007). Knowledge uncertainty in models can be further classified as model and data uncertainty (Hession and Storm, 2000). Srivastav et al. (2007) listed the following as the primary sources of knowledge uncertainty: input data, model parameters, model structure, and observed data used during calibration. Knowledge uncertainty can be decreased by using improved tools and with improvements in model formulation. In contrast, stochastic variability cannot be reduced, but can be quantified (Helton, 1994; Hession and Storm, 2000).

There are various approaches for representing uncertainty but probabilistic analysis is the predominantly used method. Probability distributions are used to provide more information about input uncertainty (Helton 1994). Model uncertainties are described by probability distributions, and the objective is estimation the output probability distributions (i.e. uncertainty associated with models). Sampling from each of these distributions provides a set of possible model inputs, which are used to state an output quantity. Repeat sampling over a long period of time, and combined output generated from each repetition provides a distribution, which represents the uncertainty present in the output.

2.7 – SWAT Uncertainty Analysis

Luzio et al. (2005) analyzed the effect of GIS data quality on small watershed stream flow and sediment simulations for Goodwin Creek Watershed in Mississippi by running the model (SWAT) for two different digital elevation model (DEM) resolutions, three different land use/ land cover map layers and two different soil maps. The authors concluded that the coarsest DEM resulted in inaccurate delineation of subbasins and underestimated watershed area with a corresponding decrease in runoff predictions. They concluded that a finer DEM data should be used to minimize uncertainties in predictions along with the use of detailed land use maps. Less detailed land use maps caused significant variations in runoff and fine sediment yield. A similar study was conducted by Chaubey et al. (2005) in which they analyzed the effect of input data resolution on uncertainty of SWAT predictions for Moores Creek watershed in Arkansas, running the model for seven different DEM resolutions. The authors concluded that DEM data at a finer resolution should be incorporated in SWAT in order to minimize uncertainty predictions.

Muleta and Nicklow (2005) applied SWAT to a watershed located in southern Illinois to analyze the uncertainty due to input data on streamflow and sediment yield using Generalized Likelihood Uncertainty Estimation (GLUE). Shirmohammadi et al. (2006) presented three case studies of uncertainty analyses using SWAT, with Monte Carlo, Latin-Hypercube-Monte Carlo, and GLUE approaches. They all concluded that large uncertainty should be expected when analyzing runoff when there is significant variability in curve number. Sohrabi et al. (2003) used Monte Carlo simulation techniques connected with Latin hypercube Sampling (LHS) to analyze the uncertainty of SWAT outputs with regarding to nutrient and sediment losses from agricultural lands. These authors concluded that using a best possible interval distribution for the input parameters reflect the impacts of soils and land use diversity may be more accurate than using average values for each input parameter. In fact, using average values for each input parameters can lead to a significant increase in uncertainty. Zhang (2009) conducted calibration and uncertainty analysis for SWAT using a Bayesian Model Averaging (BMA) and Genetic Algorithm (GA). The results obtained in the two studied watersheds showed that this combined method can provide deterministic predictions comparable to the best calibrated model using GA. Finally, Van Griensven and Meixner (2006) described several uncertainty analysis tools that have been recently incorporated directly within the SWAT model, including a modified Shuffled Complex Evolution (SCE) algorithm called “Parameter Solutions” (ParaSol), the Sources of Uncertainty Global Assessment using Split Samples (SUNGLASSES), and the Confidence Analysis of Physical Inputs (CANOPI).

2.8 – Work done on Case Study Area

The Yocona River Basin encompasses a 262 –square mile area of forested and wetlands in North –western Mississippi. The baseline hydrology of the watershed has been carefully documented by the USGS National Streamflow Information Program (NWIP) system. Their studies focused on the collection and analysis of rainfall and streamflow data as well as water quality parameters. The Yocona River Basin is drained by a network of dendritic pattern streams. The rainfall events are for this area is frequent in the spring and fall seasons. The dominant hydrological processes within the watershed are infiltration, channel erosion and river flow. Infiltration is controlled primarily by the antecedent soul moisture conditions and the hydraulic properties of the surface layer. Stream channel reaches is controlled primarily by the density of channel networks and surface runoff immediately adjacent to the reaches (Swann, 2007).

Studies done on the Yocona River Basins includes the ENID Lake eutrophication study of 1975, pollutant and sediment TMDL by the MDEQ (1994, 1996, 1998, 2002, 2004, and 2006), and investigative study done on Davidson Creek drainage basin which is adjacent to the Yocona River Basin. The National Eutrophication Survey was initiated in 1972 to investigate nation –wide threat of accelerated eutrophication of fresh water lakes and reservoirs. The study was designed to develop information on nutrient sources, concentrations, and impact on freshwater lakes as a basis for formulating comprehensive and coordinated nation, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement (EPA, 1975). Mathematical and statistical methods employed in the eutrophication survey were based model relating source, concentrations, and measurements of relevant parameters associated with lake degradation. The generalized model realized from these methods is transformed into an operational representation of the lake, its drainage basin, related nutrients. This transformation helps assess the potential for eutrophication control. The result from this study showed that Enid Lake was eutrophic and over 95% of the total phosphorus input to Enid Lake was contributed from non-point sources during the sampling year. 38.3% of the total phosphorus was contributed by Yocona River Canal, it is estimated that the export rate was 89kg/km^2/year which was termed as somewhat high.

The MDEQ (2008) conducted a Total Maximum Daily Load (TMDL) study to develop TMDLs for water bodies which is required by Section 303(d) of the Clean Water Act (CWA) and the EPA's Water Quality Planning and Management Regulations (40 CFR part 130). The TMDL process was designed to restore and maintain the quality of impaired water bodies through establishment of pollutant specific allowable loads. The pollutants in this case are sediments from land-use runoff and in-stream sediment processes. In this study, sediment data in numerous rivers in the Yazoo River Basin were collected to determine the range of sediment loadings in the effective discharge of streams. The Yocona River was one of the rivers identified to be a huge contributor to the sediments transported to the Yazoo River Basin. Nonpoint loadings of sediment in the Yocona River are as a result of sediment transport in water body by the process of gullying, sheet and rill erosion which is predominant in this area. The main sources identified included agriculture, rangeland, historical land-use activities and channel alterations, urban areas, roads and gullies.

Baseline conditions of flow, sediment concentrations and transport rates for streams in wide varieties of physiographic provinces and under a wide variety of land uses are poorly understood (Simon et al., 2002a). Therefore, the prediction of sediment load likely to cause stream impairment is difficult and complex. According to MDEQ et al. (1994) it was determined that the allowable range of sediment loads for the streams in the Yazoo River Basin is 0.0004 to 0.0021 tons per acre per day. The study concluded that the sediment estimates for the streams were 0.002 to 0.101 tons per acre per day therefore, considering the Yazoo River Basin a priority for streambank and riparian buffer zone restoration and any sediment reduction BMP, especially for road crossings, agricultural activities, and construction activities.

CHAPTER 3 – MODEL FORMULATION

3.1 – Comprehensive GIS-Based Framework and Methodology

The ability of a model to simulate a watershed system depends on how well the watershed processes are represented and described by model input parameters. The application of data-intensive simulation models depends upon several factors and conditions: the purpose of the study, understanding the nature of the watershed (natural complexity of the system, spatial heterogeneity and temporal variability), data limitations (quantity and quality), and computational procedures of the model (Letcher et al., 1999). Most importantly, developing a conceptual framework that serves as a "multi-input" infrastructure that enable terrain models (i.e. DEM) and spatial data to be coupled in standard architectural software is the first step to every management model. The Watershed model framework can serve as a decision making tool during planning and data collection.

Model framework development is the first stage in watershed planning and implementation process. The process of developing a conceptual model framework for a watershed impact management model involves collecting, organizing and processing data (spatial and temporal). The framework is a preliminary strategy that outlines hydrological modeling steps, data collection and "quality checking" in order to ensure that the objectives of the model are met. The framework of any hydrological model largely depends on the software being used for modeling. There is a variety of hydrological modeling software readily available that can perform specific tasks from modeling flow and water quality in streams, simulating and

and estimating runoff and sediments, contaminant transport, land use and climate changes. The aim of this study was to use a standard modeling tool that can assess and predict the impact of land management practices on watershed and SWAT suited our criteria. The SWAT model was selected from other hydrologic models because it proved to the most suitable model that could measure the environmental impacts of conservation efforts at benchmark watershed scale. Other models considered excluded curve number CN and options for estimating potential evapotranspiration (PET).

Soil and Water Assessment Tool (SWAT) was developed by Arnold et al. (1998) 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 practices. It is a physically based, continuous time, distributed parameter hydrologic model that uses spatial data on soil, land use, topography, and weather for hydrologic modeling and operates on a daily time step.

The structure of SWAT makes it useful in modeling ungauged watersheds and, more importantly, simulating the impact of alternative inputs such as changes in land use, management practices and climate (Neitsch et al., 2009; Arnold et al., 1998). SWAT is computationally efficient and is able to run simulations of very large basins or management practices without consuming a great amount of time or computational resources. This quality of the SWAT model aids in the quantification of long term impacts of land use changes and makes it the software of choice to satisfy the objectives of this study.

3.2 – MODEL FRAMEWORK

The Watershed Impact Management (WIM) Model process is divided into four major parts: (1) Defining model objectives, (2) data collection and preparation, (3) SWAT Model application, and (4) land use change.

Defining Model Objectives

The primary objective of the watershed model is to simulate hydrological processes in a watershed. After calibrating the model to fit available observed data, the model can be used to quantify impacts from specific land use change on the hydrological processes of a watershed. This model is expected to act as a decision making tool for city planners and storm water managers in order to assess the impacts of land management practices on watershed before implementation.

Data collection and Preparation

Hydrological modeling using SWAT requires the use of spatial datasets for land topography, land use or land cover, soil parameters for hydrological characteristics, and climate data for daily time step (Schuol and Abbaspour, 2007). The advantage for using SWAT is that the software comes with a global database for areas with insufficient. For this study, raw and incomplete datasets were processed and modified to acceptable standard before use in SWAT. A complete list of variables and utilized data sources is presented in table 3.1. Table 3.1 contains the input data required for a SWAT model to be simulated, the data sources are included.

The source and resolution choices for GIS datasets are critical for a realistic definition of the watershed and subwatershed boundaries and topographic input, and consequently simulated outputs. A review of literature was conducted in order to determine the appropriate sources for gathering GIS data and data format collection for accurate SWAT simulations. The information complied focused on the strengths and weaknesses of each source and formats for this modeling application.

<table>
<tr><th colspan="4">SWAT REQUIRED VARIABLES</th></tr>
<tr><th>Variable</th><th>Processed</th><th>Technique</th><th>Data source</th></tr>
<tr><td>Digital Elevation Model</td><td>No</td><td>-</td><td>USGS, spatial resolution 10m, GRID</td></tr>
<tr><td>Land use/ Land cover</td><td>Yes</td><td>Spatial analysis, Look-up table</td><td>Mississippi geospatial clearing house, GRID</td></tr>
<tr><td>Soil Map</td><td>Yes</td><td>Spatial analysis, Look-up table</td><td>STATSGO Database layer (USDA-SCS, 2006)</td></tr>
<tr><td>Precipitation</td><td>Yes</td><td>Access: SWAT readability</td><td>NCEP Global Weather data for SWAT</td></tr>
<tr><td>Temperature</td><td>Yes</td><td>Access: SWAT readability</td><td>NCEP Global Weather data for SWAT</td></tr>
<tr><td>Relative Humidity</td><td>Yes</td><td>Access: SWAT readability</td><td>NCEP Global Weather data for SWAT</td></tr>
<tr><td>Solar Radiation</td><td>Yes</td><td>Access: SWAT readability</td><td>NCEP Global Weather data for SWAT</td></tr>
<tr><td>Wind Speed</td><td>Yes</td><td>Access: SWAT readability</td><td>NCEP Global Weather data for SWAT</td></tr>
<tr><td>Streamflow</td><td>Yes</td><td>Baseflow separation</td><td>USGS National Water Information Service</td></tr>
<tr><td colspan="4">Land use and soil map are processed using spatial analysis tool in ArcView
Climate data are checked for completeness and then converted into database files via access
Streamflow is processed for baseflow (Appendix B)</td></tr>
</table>

Table 3.1: Datasets needed for SWAT model

The recommended sources and format were selected based on three factors: (1) adaptability and availability, (2) commonly used, accepted, and recommended in published literature, and (3) resolution of data provides sensitive information that can improve results.

The preprocessing of spatial and temporal data needed for simulation are shown diagrammatically in Figure 3.1.

Land use data

Land use and land management is an important factor affecting different processes within a watershed, including erosion, surface runoff, groundwater recharge and evapotranspiration. Following the basic principles of the USGS land use classification system (James et al., 2001), a schema was formulated that would appropriately represent land use within the case study area and at the same time allow for reclassification to match classes that are comparable to the SWAT land use database. A user lookup table was formulated to match the “Value” for input in order to create a relational database within SWAT. The raster data for land use class was clipped with the watershed area delineated polygon to ensure a 100% overlap with the watershed area.

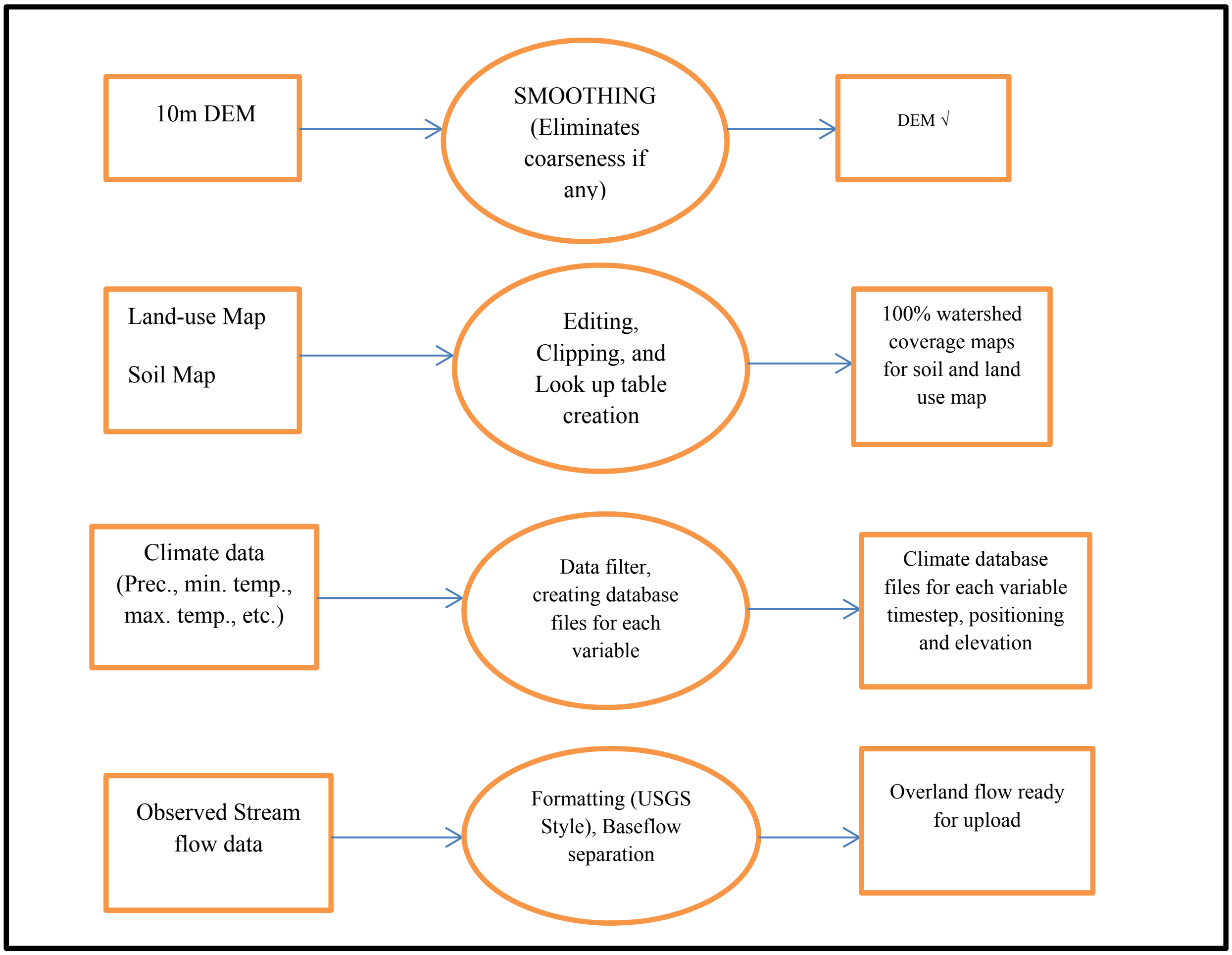


Figure 3.1: Flow chart showing input data quality check processing before use in SWAT

The chart above contains preprocessing steps of for aggregated data before use in SWAT, failure to preprocess or quality check (QC) data before use in modeling will lead to modeling errors, uncertainty, or a completely unrealistic representation of the watershed.

Soil Data

The SWAT model requires soil data including its texture, chemical composition, physical properties, available moisture content, and bulk density for each soil type (Setegen et al., 2009). The conditions and nature of the underlying soils determine the response of the watershed river basin to a rainfall event. Soil data were obtained from the USDA STATSGO soil data mart. The USDA soil data mart allows users to download soil tabular and spatial data for any area in the United States and generate soil reports. An advantage of SWAT software is that its "usersoil" database contains the names of all the United States soils, their chemical and hydraulic properties. This makes it easy to associate the soil map with the SWAT database.

Climate Data

The climate data used in the SWAT model consist of temperature, daily rainfall, wind speed, relative humidity, and solar radiation data for two locations within the area of intent. These variables obtained from the National Center for Environmental Prediction (NCEP). The data Collected were for the period of 2000-2010 for the weather stations close to Enid Dam and at Lafayette Springs in Mississippi. The daily rainfall values were compared to surrounding gauges in the area to ensure accurate estimation of rainfall distribution. The data from the rain gauges were plotted, exhibited similar in trends, and also satisfactory correlation.

Streamflow data

Daily stream flow data (Appendix C) were obtained from the USGS National Streamflow Information Program for the Yocona River gauging station (USGS 07274000) located near the outlet of the watershed. Base flow calculations (Appendix B) were made using the Base flow Index (BFI) program from the USGS. The stream flow data collected was from 2000-2010; data from 2000- 2010 were used for calibration and for validation, 2006-2010.

Summary

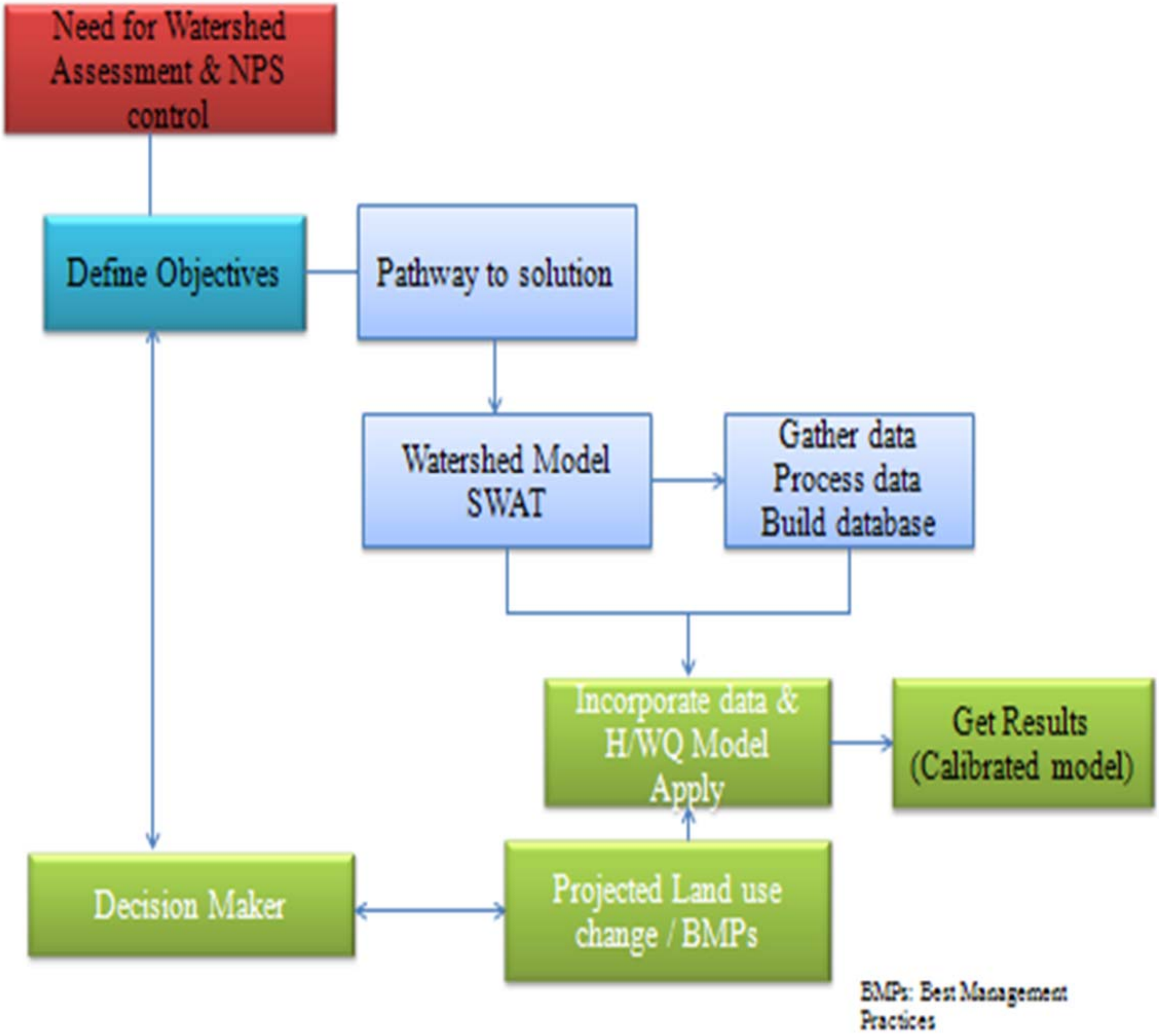


Figure 3.2 WIM model Framework

Figure 3.2 is a flow chart showing the conceptual framework of the WIM model. This framework is derived from the combination of processes involved in modeling a watershed from defining model objectives, gathering input data, modeling the watershed, and using it as an impact management model. The framework is based SWAT watershed model; coupling of the pieces of this framework can be readily applied to demonstrate to a real life case study.

CHAPTER 4 – MODEL IMPLEMENTATION

4.1 – STUDY AREA SUMMARY

The Yocona River Basin is located in the northern non-industrialized part of the state of Mississippi. In this study, the portion of the Yocona River Basin investigated is shared between Lafayette and Pontotoc County between latitudes 34.19^{o} to 34.27^{o} N and longitudes -89.69^{o} to -89.52^{o} W (Figure 4.1). The Yocona River originates in Pontotoc County and flows into Enid Lake. Elevations in the basin range from 80 to 191 m, and annual rainfall from 1200 to 1422 mm. The Yocona River Basin is characterized by 49% forest areas, 36% agriculture, 5.5% impervious surfaces (urban, roads etc.), 8.4% wetlands, and 1.2% water body. The Yocona River is impacted by widespread human activities including deforestation, agriculture, and urbanization. The watershed has not experienced any extensive urbanization over the past decade, a condition that is changing. Land uses range from nonurban native grass and forest areas and agricultural areas to typical low and medium-high density residential areas.

Characteristics of the Yocona River Basin Soils

An important factor in drainage basin analysis is the type of soils contained within the basin. The types of soils contained in the Yocona River Basin ranges from Smithdale Sandy Loam to Lexington silty loam. There are ten different soil units mapped within the Yocona River Basin (Figure 4.2). These soils as well as selected soil characteristics relevant to the objectives of this research are shown in table 4.1. The Smithdale sandy loam and the Tippah silt loam are the most common types of soils found in this basin. They are both described as having the characteristics of rapid runoff and this implies that a larger portion of precipitation will become overland flow and subsequently flow into the river drainage system. The dominant soil type within the Yocona River Basin is the Smithdale Sandy Loam.

Table 4.1: Soil Types in the YRB and Selected Characteristics (USDA NRCS)

Soil and Soil number	Permeability	Runoff	Erosion Hazard	Limits for Urban use	Available Water Capacity (In/In)	Comments
S3847-T-S-M	Moderate	Rapid	High Kf= 0.28-0.43	Severe	0.12-0.22	Fine sandy loam, silt loam
S3848 - C	Moderate to high	Rapid	Slight-Moderate Kf = 0.37-0.43	Frequently flooded	0.15-0.20	Silt loam, loam, clay loam
S3856 -A	Moderate to high	Moderate	Slight Kf = 0.32-0.37	Occasionally flooded	0.20-0.22	Silt loam
S3860 O -Ok-B	Severe	Slow	Slight Kf=0.24-0.43	Frequently flooded	0.07-0.20	Loamy and silty
S3861 –S – Gullied land	Moderate	Rapid	Slight Kf =0.24-0.28	Severe Slope	0.14-0.16	Loamy sand, steep slopes with gullies
S3862 –S-P-L	Moderate	Medium to slightly Rapid	Moderate Kf = 0.24-0.28	Severe	0.17-0.22	Loamy, silt loam,
S3863 –T - P	Moderate	Rapid	Moderate Kf = 0.43	Severe	0.19-0.22	Silt clay loam, silt loam
S3887 –S-R-L	Moderate	Fairly rapid	Moderate Kf = 0.20-0.28	Severe	0.12-0.17	Loamy sand, fine sandy loam, clay loam
S3936 –T-F	Slow	Slow to Medium	High Kf = 0.43-0.49	Severe	0.20-0.24	Silt loam, silt clay
S3974 – Bu-A	Low-moderate	Rapid	High Kf=0.37-.49	Moderate	0.12-0.22	Silt loam, silty clay loam, clay loam

T- Tippah
S- Smithdale
A - Arkabutla
C –Chenneby
O –OK-B: Ochlockonee, Oaklimeter, and Bruno Association
S-P-L: Smithdale, Providence and Lexington Association
S-R-L: Smithdale, Ruston, and Lexington Association
F- Falaya
Bu –A: Bude – Arkabutla Association
Kf: Erosion Factor
Soil information was largely derived from the United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS).

The Smithdale Sandy Loam and the related Smithdale - Udorthents complex soils were both noted as being either eroded and / or gullied, attesting to potential erosional concerns (Swann, 2007). This characteristic suggests that the drainage system is influenced by the nature and types of soils and is very vital to understanding the processes of a watershed.

Planners and others using soil survey information can evaluate the effects of specific land uses on water quality and on the environment in the study area. Prior knowledge of the soil properties is a vital tool for planners in order to maintain or create a land use pattern suitable with the natural soil. The soils in the Yocona River basin have good potential for increased agricultural production; however, erosion is a major concern for this area. Soils units such as Tippah and Providence having slopes of 2 to 5 percent are susceptible to erosion and wetness problems. Erosion control practices provide protective surface cover, reduce runoff, and increase infiltration (NRCS, 1981). Evaluation of soil physical and engineering properties prior to urban development is also an important factor in watershed management.

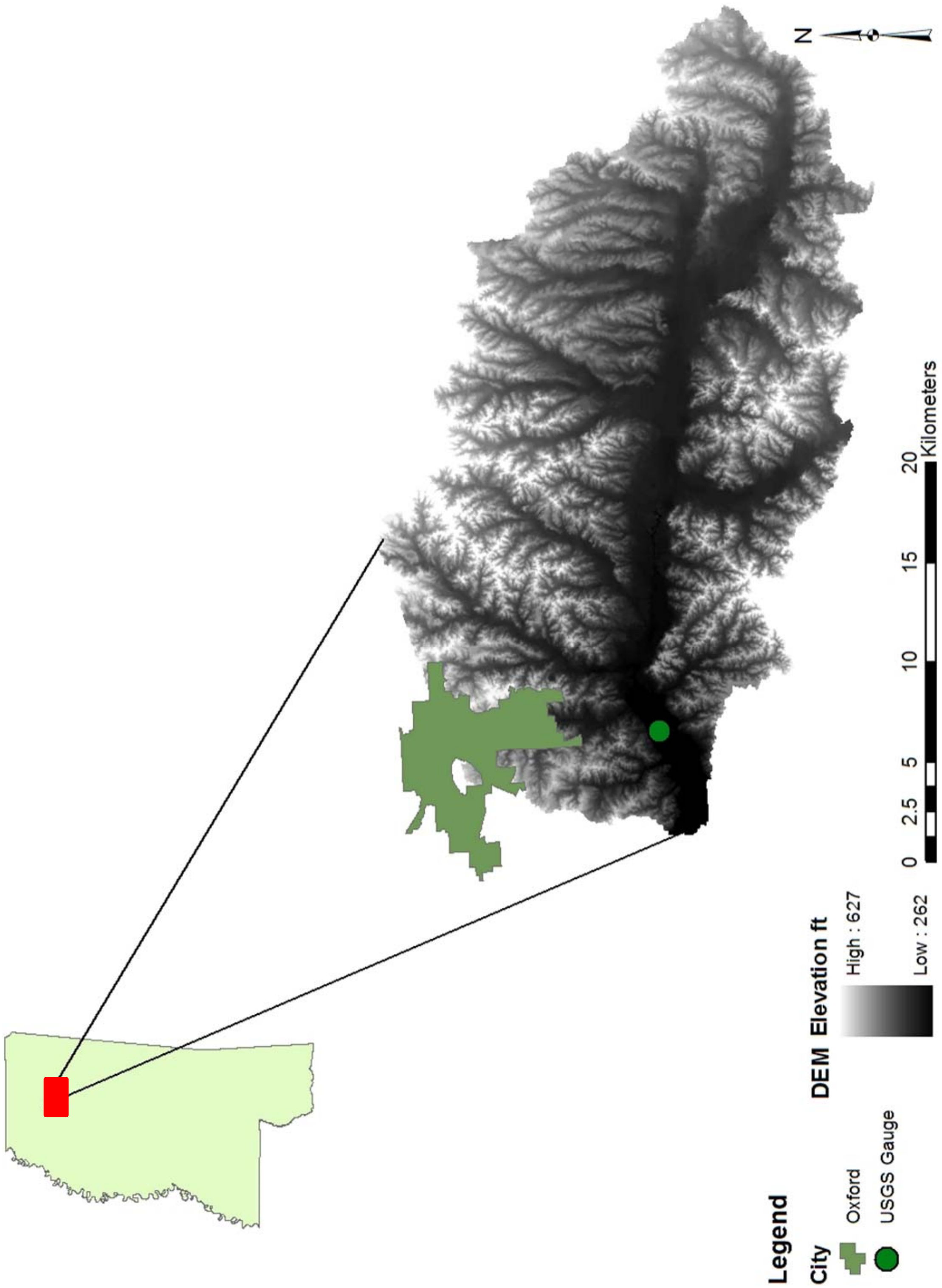


Figure 4.1: Location of Oxford, USGS Gauge, and elevation in the Yocona River Basin

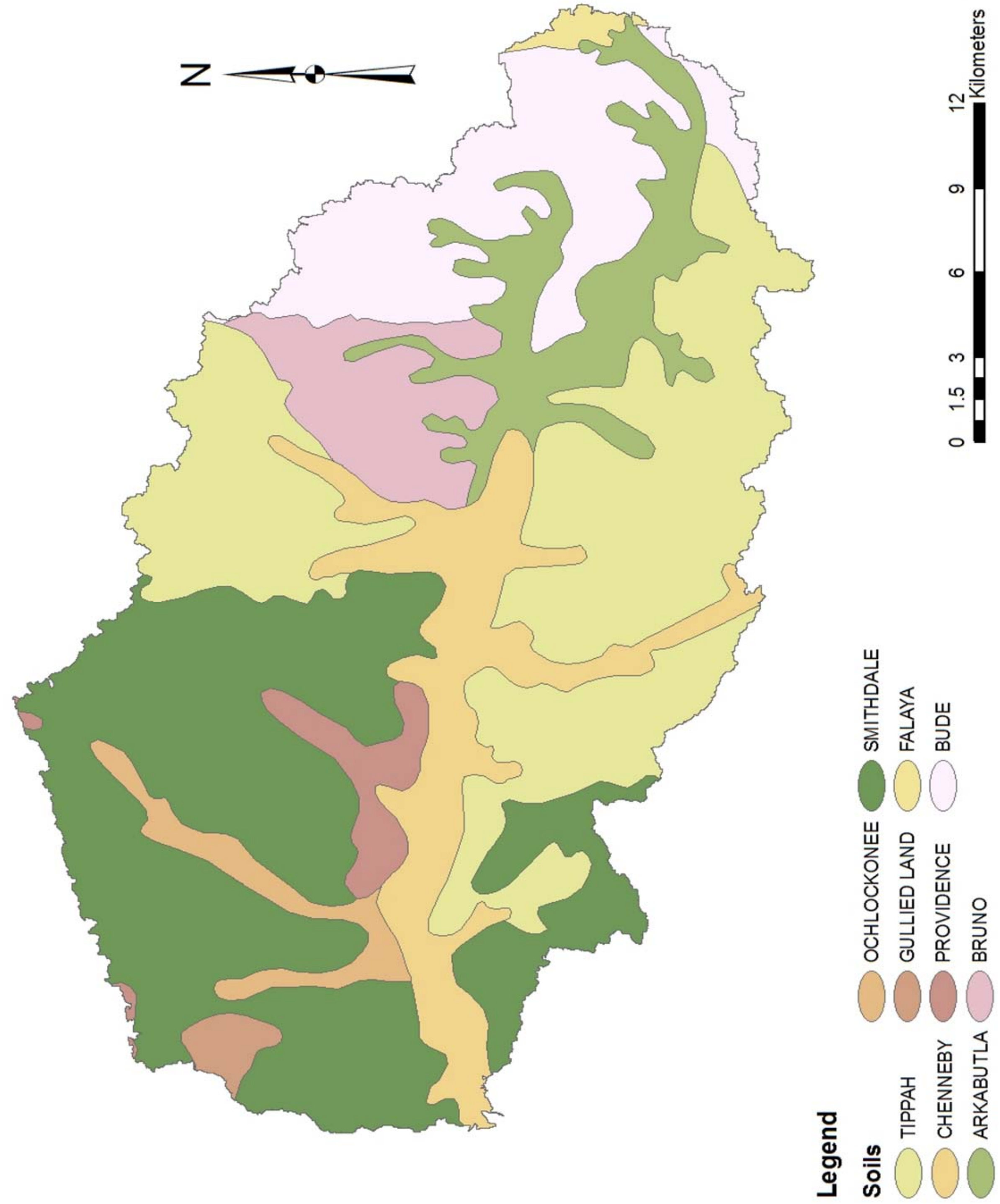


Figure 4.2: Map of soils distribution in the Yocona River Basin

4.2 – DESCRIPTION OF THE SWAT MODEL

The Soil and Water Assessment Tool is a river basin model that was developed for the USDA Agricultural research service by Blackland Research Center in Texas. SWAT is a widely known hydrologic tool that has been used to study watershed cases world-wide. SWAT has the ability to predict the impact of land management practices on water quality, sediment yield and agro-chemical yield in large complex basins (Neitsch et al., 1999). A complete description of the SWAT model can be found in Neitsch et al., (2002a, b). For this study, we limit ourselves to the hydrological components of the SWAT model. SWAT is a physically-based model and this is what distinguishes it from other runoff estimating techniques and probabilistic models.

The basic model inputs are rainfall, maximum and minimum temperature, solar radiation, wind speed, relative humidity, land use/ land cover, soil, and elevation map (DEM). The modeled watershed is subdivided into contiguous subbasins. This configuration preserves the natural channels and flow paths of the watershed. The subbasin watershed components can be categorized into the following components – hydrology, weather, erosion and sedimentation, soil temperature, plant growth, nutrients, pesticides and land management. A hydrologic Response Unit (HRU) is a portion of a subbasin that possesses unique combinations of land use/ land cover, slope, and soil attributes.

No matter what type of problem studied with SWAT, water balance is the driving force behind every process occurring in the watershed. To accurately predict sediment, nutrients or runoff, the hydrologic cycle as simulated by the model must represent to what is happening in the watershed. SWAT simulation of the hydrology of a watershed can be separated into two major phases. The first division is the land phase of the hydrologic cycle (Neitsch et al., 2009) is shown in Figure 4.3. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each subbasin. The second division is the water routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, and nutrients, etc. through the channel network of the watershed to the outlet. In the land phase of the hydrologic cycle, runoff is predicted separately for each subbasin and routed to obtain the total runoff for the watershed. Once the loadings (water, sediment, nutrients and pesticides) to the main channel are determined, they are routed through the stream network of the watershed. Hydrologic equations are applied in each HRU separately and surface and groundwater flow are routed to neighboring HRUs, up to the outlet of the basin (Arnold et al., 1999).

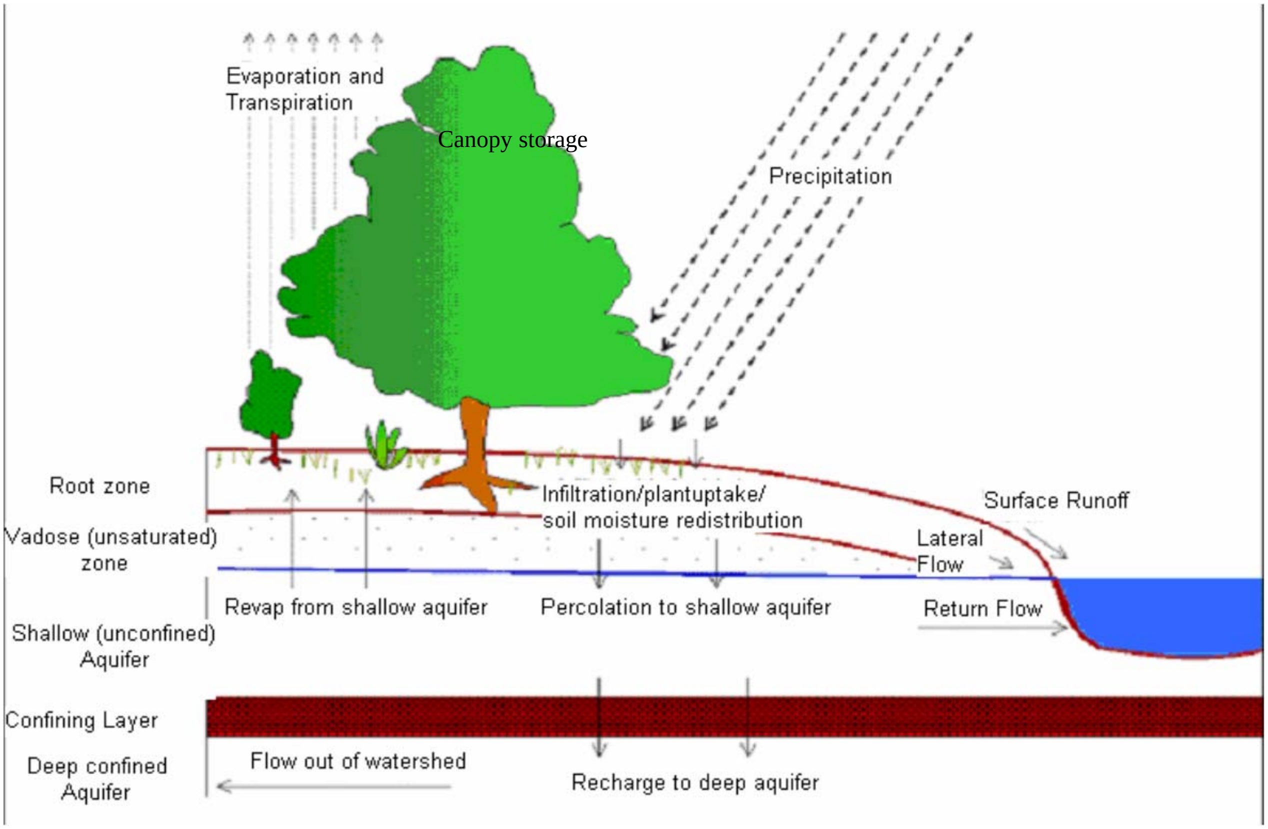


Figure 4.3: Schematic representation of the SWAT hydrologic cycle. (Modified from Neitsch et al, 2009)

The hydrologic cycle as simulated by SWAT is based on the following water balance equation (Arnold et al, 1999):

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_i - Q_i - ET_i - P_i - QR_i) \qquad (4.1)$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_i is the amount of precipitation on day i (mm H_2O), Q_i is the amount of surface runoff on day i (mm H_2O), ET_i is the amount of evapotranspiration on day i (mm H_2O), W_i is the amount of water entering the vadose zone from soil profile on day i (mm H_2O), and QR_i is the amount of return flow on day i (mm H_2O). Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed.

The first subdivision of watershed is the subbasin. Subbasins are spatially contiguous and non-overlapping and each contains at least one hydrologic response unit, a reach or main channel and a tributary channel. The next level of subdivision is the hydrologic response unit (HRU). While individual HRU distribution may be scattered throughout the subbasin (i.e. non-contiguous), their areas are combined using the most dominant characteristics to form one HRU for calculation purposes. The HRUs account for the geomorphologic complexity within the subbasin. Loadings such as nutrients and sediment yield from each HRU are calculated separately and then summed together to determine total loadings from the subbasins respectively. The advantage of the SWAT HRU subdivision is the increase in accuracy it adds to the modeled loadings from the subbasin(s).

SWAT inputs are defined at three spatial resolution levels, namely watershed, subbasin, and HRU. At the watershed level, some processes such as the method selected to model potential evapotranspiration are modeled using one method for all HRUs in the watershed. At the subbasin level, inputs such as precipitation and temperature information are set at the same value for all HRUs within each subbasin. At the HRU level, inputs can be set to unique values for each HRU in the watershed. This is the level at which land uses are simulated in a specific HRU.

Surface Runoff

The SWAT model estimates surface runoff amounts using either the Green & Ampt infiltration method (Green and Ampt, 1911) or the Soil Conservation Service (SCS) curve number method (SCS, 1972). The Green and Ampt method was not considered for use in this study for two reasons: (1) the equation assumes excess water at the surface at all time, and (2) the equation assumes the soil profile is homogenous and antecedent moisture is uniformly distributed in the profile. The SCS curve number method was used instead. The SCS curve number method (CN) is an empirical model that estimates the volume of runoff under varying soil and land use types. It is a function of antecedent soil conditions, soil permeability and land use.

The SCS curve number equation is (SCS, 1972):

$$Q_i = \frac{(R_i - I_a)^2}{(R_i - I_a + S)} \tag{4.2}$$

Where Q_i is total runoff or excess rainfall (mm H_2O), R_i is the rainfall depth for day i (mm H_2O), I_a is the initial abstraction which includes storage, interception and infiltration prior to runoff (mm H_2O), and S is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soil, land use, management, slope, and soil water content. The retention parameter is defined as:

$$S = 25.4 \left(\frac{1000}{CN} - 10\right) \tag{4.3}$$

where CN is the curve number for the day. CN is a function of the soil's permeability, land use and antecedent soil water conditions (SCS, 1996).

PET Calculations

SWAT provides three methods that can be used to calculate potential evapotranspiration (PET). These are the Penman-Monteith method (Monteith, 1965), the Priestley-Taylor method (Priestley and Taylor, 1972), and the Hargreaves method (Hargreaves et al., 1985). The model can also read in daily PET values if the user prefers to apply a different potential evapotranspiration method. The three PET methods differ in input requirements. The Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestley-Taylor method requires solar radiation, air temperature and relative humidity. The Hargreaves method requires air temperature only. Because of its simplicity, the Hargreaves method was used in this model to estimate the potential evapotranspiration. Several improvements were made to the original equation and the form used in SWAT was published in 1985.

Canopy Storage

Canopy storage is the water intercepted by vegetative surfaces (canopy) where it is held and made available for evaporation. As rain falls, canopy interception reduces the erosive energy of droplets and traps a portion of the rainfall within the canopy. SWAT allows the maximum amount of water that can hold in canopy storage to vary from day to day as a function of the leaf area index:

$$can_{day} = can_{mx} * \frac{LAI}{LAI_{mx}} \qquad (4.4)$$

can_{day} is the maximum amount of water than can be trapped in the canopy on a given day (mmH_2O), can_{mx} is the maximum amount of water that can be trapped in the canopy when the canopy is fully developed (mmH_2O), LAI is the leaf area index for a given day, and LAI_{mx} is the maximum leaf area index for the plant.

Return Flow

Return flow, or baseflow, is the volume of streamflow originating from groundwater. SWAT partitions groundwater into two aquifer systems: a shallow, unconfined aquifer which contributes return flow to streams within the watershed and a deep, confined aquifer which contributes return flow to streams outside the watershed (Arnold et al., 1993). Water percolating past the bottom of the root zone is partitioned into two fractions, where each becomes recharge for one of the aquifers.

Redistribution

Redistribution refers to the continued movement of water through a soil profile after rainfall (or via irrigation) has ceased at the soil surface. Redistribution is caused by differences in water content in the soil profile. The redistribution component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Recharge (downward flow), or percolation, occurs when layer below is not saturated and the field capacity of a soil layer is exceeded. The flow rate is governed by the saturated conductivity of the soil layer. Redistribution is affected by soil temperature. If the temperature in a particular layer is 0^oC or below, no redistribution is allowed from that layer.

Land cover and plant growth

SWAT utilizes a single plant growth model to simulate all types of land covers. The model is able to differentiate between annual and perennial plants. Perennial plants maintain their root systems throughout the year, becoming dormant in the winter months. Annual plants grow from the planting date to the harvest date or until the accumulated heat units equal the potential heat units for the plants (Arnold et al, 1993). Perennial plants resume growth when the daily air temperature exceeds the minimum, or base temperature required.

Erosion

Erosion and sediment yield are estimated for each HRU with the modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. The substitution results in a number of benefits: the predictor accuracy of the model is increased, the need for a delivery ratio is eliminated, and single storm estimates of sediment yields can be calculated. The MUSLE equation is:

$$sed = 11.8 \times \left(Q_{surf} \times\ q_{peak} \times Area_{HRU}\right)^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \qquad (4.5)$$

Where *sed* is the sediment yield on a given day in metric tons, Q_{surf} is the surface runoff volume (mmH_2O), q_{peak} runoff rate (m^3/s), $Area_{HRU}$ is the area of the HRU (ha), K_{USLE} is the soil erodability factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor. The model supplies estimates of runoff volume and peak runoff rate which, with the subbasin area, are used to calculate the runoff erosive energy variable

Management

SWAT allows the user to define management practices taking place independently in every HRU. The user may define the beginning and the end of the growing season, specify the amount of fertilizer and pesticide, and add BMP and irrigation applications. At the end of the growing season, the biomass may be removed from the HRU as yield or placed on the surface as residue. Also routines to calculate sediment and nutrient loadings from urban areas are included.

4.3 – WATERSHED CONFIGURATION

The first step to setting up a watershed modeling is to delineate the watershed into subbasins (Figure 4.4). SWAT allows several different subbasins or objects to be defined within a watershed (Neitsch et al., 2002a):

- Subbasins
    I. HRUs (at least1 per subbasin)
    II. One wetland (optional) (1 per subbasin)
- Reach/main channel (1 per subbasin)
- Point sources (optional)

Subbasins possess a geographic position in the watershed and are spatially contiguous, i.e. the outflow from subbasin 30 enters subbasin 15 (Figure 4.4). Subbasins are based on the threshold area which defines the minimum drainage area required to form the origin of a stream.

Within the subbasins, HRUs are defined. A HRU is defined as the total area in the subbasin with similar (unique) combinations of land use, slope, management, and soil. While individual fields with a specific land use, slope, and soil type may be scattered across a subbasin, these areas are combined to form one HRU. Implied in the concept of the HRU is the assumption that there are no interactions between HRUs in one subbasin. Loadings transported by runoff from each HRU are calculated separately and summed together to determine the total loadings from each subbasin. A general rule of thumb is that a given subbasin should have 1-10 HRUs.

The SWAT model is able to simulate different processes both in the land phase and the routing phase of the hydrologic cycle that influence the fate of nutrient transport, loadings and volume of runoff.

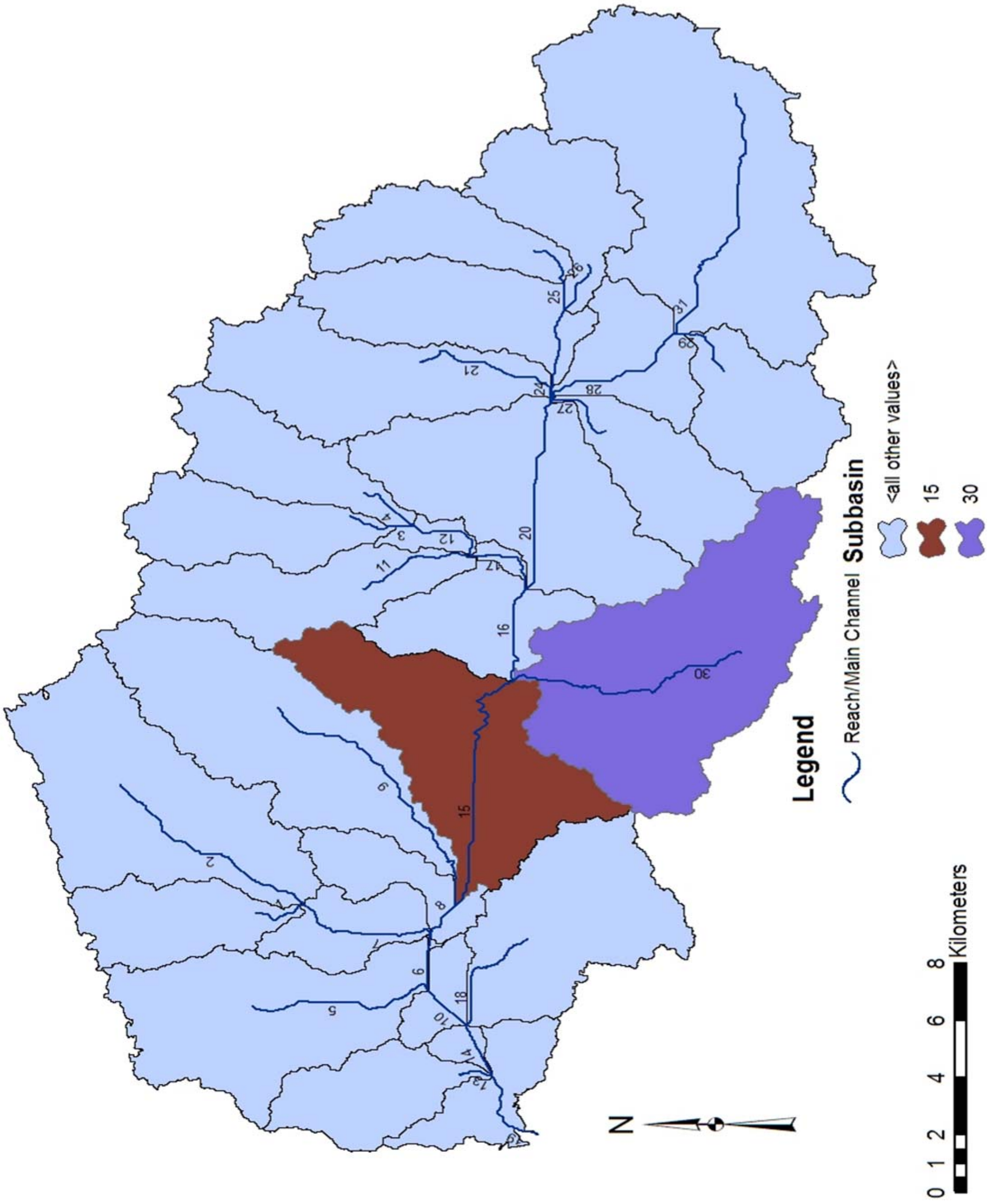


Figure 4.4: Subbasin delineation of the Yocona River Basin, Mississippi

A detailed modeling methodology used for this watershed can be found in Appendix A, along with the baseflow separation technique.

CHAPTER 5 – SWAT BASELINE MODEL ANALYSIS

5.1 – INTRODUCTION TO BASELINE MODEL

The SWAT model was implemented on the Yocona River Basin. Land use and soil data were acquired from the USDA-SRC. The 10 different soil types that appear in the subbasin were introduced into SWAT in the form of a feature class dataset. The soil pattern of the in combination with the land uses determines the HRUs of the catchment and, to a large extent, and also determines groundwater flow. The climatic and streamflow data were derived from two meteorological station located in Water Valley, and Lafayette Springs. Climatic data refers to daily precipitation and temperature for the period of 2000 to 2010. Additional daily values of wind speed, solar radiation, and relative humidity, for the same period, are also required for the calculation of evapotranspiration. Daily stream flow data were processed using USGS baseflow separation program (Appendix B). The stream flow data for the period of 2000 to 2001 were used for the simulation warm-up period of the model, data for the period 2002 to 2005 were used for the calibration of the model, while the data from 2006 to 2010, were used for validation.

5.2 – SWAT STATISTICAL ANALYSIS INTRODUCTION

The ability of a watershed model to mimic specified watershed hydrologic processes is assessed through the calibration and validation process. Sensitivity analysis is used to evaluate the ability of the watershed to sufficiently predict constituent yields and streamflow for a specific application. Sensitivity is measured as the response of an output variable to a change in input parameters, with the greater the change in output response corresponding to a greater sensitivity (White and Chaubey, 2005). This analysis evaluates how different parameters influence a predicted output. The sensitive parameters identified during the sensitivity analysis that most influence predicted output are often used to calibrate the watershed model. The model calibration entails the iterative modification of parameter values and comparison of model results to measured data until a defined objective function is achieved (James and Burges, 1982). The objective function for model calibration generally consists of a statistical test, such as minimization of relative error (RE), or optimization of the Nash-Sutcliffe Coefficient (NSE) (Santhi et al., 2001). The validation of the model ensues after the objective functions for the calibration have been satisfied. The validation of the model involves the comparison of measured and predicted values to ensure that the objective is met. The model parameters are adjusted during validation.

5.2.1 – Sensitivity Analysis

Sensitivity analysis was conducted to determine the influence a set of parameters (i.e. flow, sediment, and water quality) had on predicting streamflow. Sensitivity analysis of distributed parameter hydrologic models involves changing each parameter by a small amount, one at a time, from a reference value and calculating the corresponding change in the model output. Sensitivity is calculated as the change in predicted output divided by the change in input parameter and reflects the slope of the input-output relationship at the reference point (Mishra, 2009) via the SWAT auto-sensitivity tool. SWAT sensitivity analysis uses the SWAT simulated output from the subbasin where observed data is available. Sensitivity analysis in SWAT model can be done with or without observed flow data. The Yocona River Basin model sensitivity was done with the observed streamflow data. The SWAT sensitivity analysis method is called the Latin Hypercube One-factor-At-a-Time (LH-OAT), proposed by Morris (1991). The LH-OAT combines the strength of global and local sensitivity analysis methods (Van Griensven and

Srinivasan, 2005). First, the LH sampling (McKay et al., 1979) uses a stratified sampling approach that better covers the sampling hypercube with fewer sampling. For instance one LH will sample a parameter range of 0 to 1.0 within an interval of 0.1. The LH sampling is followed by OAT sampling which means parameter values will be changed at a set percentage range (e.g. 5%).

In SWAT, a dimensionless sensitivity analysis index (SI) is determined by calculating the ratio between the relative changes in the model output as a result of the change in the parameter. The user specifies one of the available functions such as sum of squared residuals (SSQ) observed flow data are available. See Van Griensven et al. (2006) for a description of auto-sensitivity analysis tool.

There are more than fifty parameters in SWAT model, each may vary by subbasin, soil and land use type. Some of the physical parameters such as channel width represent measureable quantities; however, some parameters such as soil evaporation compensation factor are difficult to measure directly. The top twenty (20) ranked parameters were selected after the sensitivity analysis was. Parameters resulting in the greatest were ranked top ten (Table 5.1). The parameters selected were related to: runoff, groundwater, and soil processes. The sensitivity analysis was done using 9 years of observed streamflow data. Parameter values as recommended by Van Griensven, (2002) were used as initial values of the parameters.

Van Griensven et al., (2006), characterize global rank 1 as "very important", rank 2 to 6 as "important", rank 7 to 19 as "slightly important" and rank 20 and above as "not important", Results of the analysis for this study is presented in table 5.1 above. Deep aquifer percolation and curve number "CN" (SCS curve number) are identified as the very important parameters, baseflow alpha factor (recession coefficient), soil evaporation compensation factor and canopy storage are identified as important parameters. These parameters significantly influence model output. Curve number (CN) has high sensitivity to each hydraulic simulation process, therefore, must be used for model parameter uncertainty analysis

Parameter Description	**Rank**		**Parameter control**
Deep aquifer percolation	1		Flow
Curve Number	2		Flow
Baseflow alpha factor	3		Flow
Soil evaporation compensation factor	4		Flow
Maximum canopy storage	5		Flow
Threshold water depth in shallow aquifer for flow	6		Flow
Channel effective hydraulic conductivity	7		Flow
Maximum potential leaf area index for land cover/ plant	8		Flow
Available Water capacity	9		Flow
Soil depth	10		Flow

Table 5.1: Sensitivity analysis result for baseline model simulation for years between 2002-2010

Parameters that control groundwater such as "threshold depth of water in shallow aquifer for revap to occur" ranked very low and can be considered insensitive in this case. Based on the result from using observed data for sensitivity analysis, "surface runoff lag time" losses its importance since time delay does not play an important role on the average model output values (streamflow). Irrespective of the objective function used in sensitivity analysis, the parameter "threshold water depth in shallow aquifer", which controls groundwater losses, is identified as sensitive. However, "threshold water depth in shallow aquifer" might lose its sensitive if study was done for a short term period, and this suggests that using a short term period for simulations (e.g. 2 years) may not accumulate sufficient information to identify some model parameters that control predictions of model output.

The results obtained from the sensitivity analysis demonstrate that the sensitivity tool built in SWAT model is robust and can be applied in an ungauged catchment for identifying hydrological controlling factors. However, data deficiency can still cause some insensitivity in certain parameters.

5.2.2 – Calibration and Uncertainty Analysis

ArcSWAT includes a multi-objective, automated calibration procedure that was developed by Van Griensven and Bauwens (2003). According to Duan et al.,(1992) the calibration procedure is based on a Shuffled Complex Evolution Algorithm (SCE-UA) and a single objective function. The goal of the single objective function is to find the "best" solution, which corresponds to the minimum or maximum value which lumps all different objectives into one. The single-objective function identifies a single optimal alternative; however, it can be used within a multiobjective framework.

The SCE-UA has been widely used in watershed model calibration and other areas of hydrology such as soil erosion, subsurface hydrology, remote sensing, and land surface modeling, and has generally been found to be effective and efficient (Duan 2003). The SCE algorithm is a global search algorithm for the minimization of a single function for up to 16 parameters (Duan et al. 1992). It combines the direct method of simplex procedure with the concept of a controlled random search, a systematic evolution of points in the direction of global improvement, and the concept of complex shuffling.

In the SWAT auto-calibration scheme, hydrologic parameters change over either the entire watershed or for selected HRUs. The parameters can be modified by replacement, by addition of an absolute change or by the multiplication of a relative change. Weight assignments for output variables that can be made in multi-objective calibrations (e.g., 50% streamflow, 30%

sediment, and 20% nutrients), the user can specify a particular objective function to be minimized. The objective function is an indicator of the deviation between a measured and a simulated series (Van Griensven and Bauwens 2003). Available objective function options include the sum of squares of residuals and the sum of squares of residuals ranked. The former represents the classical mean square error method that aims at matching a simulated time series to a measured series while the latter represents the fitting of the frequency distributions of the observed and simulated series. The auto-calibration is run in the Parasol mode whereby the auto-calibration tool searches for optimal calibration sets and groups them into “good” or “best” categories. Streamflow alone was used to calibrate the model due to the unavailability of other observational data such as sediment and nutrient yield. Autocalibration of the model was performed in subbasin 10 where streamflow data were observed. The streamflow data were created and uploaded from text files during the calibration process. The maximum number of iterations (trials before optimization is terminated) chosen for this process was 11000.

5.3 – MODEL CALIBRATION AND VALIDATION

Simulations set up using the correct set of input data were used to calibrate modeled monthly streamflow from 2000 to 2010 at the Yocona River Basin USGS gauge (Figure 5.1)

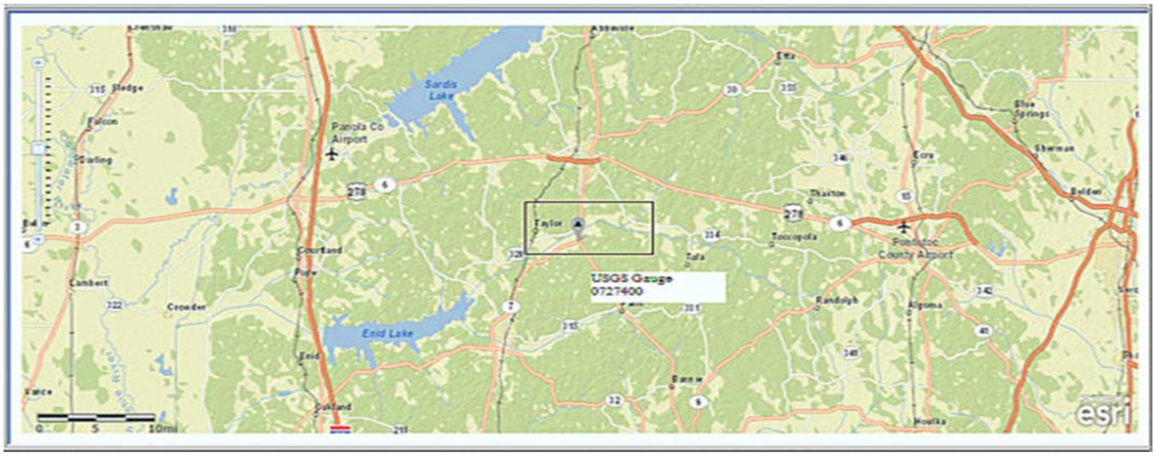


Figure 5.1: Yocona River Gauge at Taylor, Lafayette County, Mississippi

The model simulation was for a total of 11 years, the first two years were used as a warm up period, years 2002 – 2005 were used for calibration, and years 2006 to 2010 were used for validation of the model (The warm-up period allows the model to “initialize” and “stabilize” and then approach reasonable starting values for model state variables). Watershed validation was performed to test if the calibrated parameter set was appropriately selected for the watershed model. Validation requires that the same evaluation criteria used for the calibration be used. The only difference in the two processes is the time period range.

5.4 – MODEL EVALUATION CRITERIA

Five model evaluation criteria were selected to assess streamflow simulated by SWAT. The criteria chosen were based on the following factors: (1) robustness in terms of applicability in various constituents’ models, and climatic conditions; (2) commonly used, accepted, and recommended in published literature. The first four criteria were quantitative measures while the last criterion was a visual comparison of plots of simulated and observed values.

Pearson’s correlation coefficient (r) and coefficient of determination (R^2): Pearson’s correlation coefficient (r) and coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data. Pearson’s correlation coefficient, which ranges from -1 to 1, is an index of degree of linear relationship between observed and simulated data. If r = 1 or -1, a perfect positive or negative linear relationship exists. Similarly, R^2 describes the proportion of total variance in the observed data that can be explained by a linear model. Its range is from 0 to 1, and is calculated as

$$R^2 = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{obsmean}\right)\left(Y_i^{sim} - Y^{simave}\right)}{\sqrt{\left[\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{obsmean}\right)^2 \sum_{i=1}^{n}\left(Y_i^{sim} - Y^{simave}\right)^2\right]}}\right]^2 \tag{5.1}$$

where, Y^{Obs} and Y^{sim} are observed and simulated values, respectively. In the equation, $Y^{obsmean}$ and Y^{simave} are the mean observed and simulated data values respectively. R^2 with higher values indicate less error variance, and typically values grated than 0.5 are considered acceptable for modeling (Santhi et al., 2001, Van Liew et al., 2003)

Nash-Sutcliffe Efficiency (NSE): NSE is a normalized statistic that determines the relative magnitude of residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. It is computed as show in equation 5.2:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Y_{obs}-Y_{sim})^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{obsmean}\right)^2}\right] \qquad (5.2)$$

where, Y^{obs} and Y^{sim} are observed and simulated values, respectively. In the equation, $Y^{obsmean}$ is the mean observed data value. NSE values ranges between -∞ and 1 with NSE of 1 being the perfect value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values ≤0.0 indicates that the mean observed value is better predictor than the simulated values, which indicates unacceptable performance. Simulation results are considered very good if NSE > 0.75, while values above 0.5 is considered to be satisfactory (Moriasi et al., 2007). The major reasons for NSE evaluation criteria are: (1) it is recommended for use by ASCE (1993), and (2) it is very commonly used, which provides extensive information on reported values.

Percent Bias (PBIAS): PBIAS measures the average tendency of simulated data to be greater or smaller than the observed data. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate model underestimation bias (Gupta et al., 1999). PBIAS is calculated with equation 5.3:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{obs} \right)} \right] \tag{5.3}$$

PBIAS is the deviation of data being evaluated and expressed as a percentage. Model performance is considered satisfactory is PBIAS is ± 25% for streamflow (Moriasi et al., 2007). PBIAS was selected for model evaluation for the following reasons: (1) it has the ability to indicate poor model performance (Gupta et. al., 1999) and (2) PBIAS is recommended by ASCE (1993).

RMSE-Observation standard deviation ratio (RSR): Root mean squared error (RMSE) is commonly used for error index statistics (Singh et al., 2004, Vasquez-Amabile and Engel, 2005). It is usually accepted that the lower the RMSE, the better the model predictor performance, Singh et al. (2004) established a guideline to qualify what range is considered a low RMSE based on the observation standard deviation. Based on the recommendation by Singh et al. (2004), an evaluation statistics named RMSE-observation standard deviation ratio (RSR), was developed. RSR normalizes RMSE using the observation standard deviation, and it combines both an error index and the additional information recommended by Legates and McCabe (1999). RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the derived statistic and reported values can apply to various constituents. RSR varies from the optimal value of 0, which indicates zero RMSE or residual variation, and therefore a perfect model simulation, to a large positive value (Chin, 2007). Therefore, the lower RSR value, the lower the RMSE, and the better the model simulation performance. RSR is calculated as the ratio of the RMSE and the standard deviation of the observed data as shown in equation 5.4:

$$\mathrm{RSR} = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{obsmean}\right)^2}\right]} \tag{5.4}$$

where, Y^{Obs} and Y^{sim} are observed and simulated values, respectively. In the equation, $Y^{obsmean}$ is mean observed data value.

__Graphical Comparison__: Graphical techniques provide a visual comparison of simulated data and measured data constituent data and a first overview of model performance (ASCE, 1993). Hydrograph plots and percent probability curves are especially valuable for examining data distributions. Hydrographs help identify model bias (ASCE, 1993) and can identify differences in timing and magnitude of peak flow and recession curves (Moriasi et al., 2007).

5.5 – BASELINE MODEL RESULTS

Model Calibration and Validation

Flow calibration was conducted for the Yocona River for years 2002 to 2005, flow validation followed for 2006 to 2010. The USGS Yocona River gauge observed data was used for this objective. The model was calibrated by performing the auto-calibration operation in ArcSWAT. It is assumed that lateral flow is negligible, because of little or no obvious impervious layers (such as shales) in soil profiles (pre-requirement for general of lateral flow) in the Yocona River Basin. The optimal values used for the parameters are listed in table 5.2. All important parameters with mean sensitivity index greater than zero were considered for optimization; in this list (Table 5.1) nineteen parameters were optimized. The Nash and Sutcliffe coefficient *NSE* for - on monthly observed streamflow

The calibration/validation performance for SWAT model is considered acceptable when R^2 and NSE are greater than 0.5 (Moriasi et al., 2007). The performance is satisfied when larger than 0.5, adequate when NSE ranges from 0.54 to 0.65, and very good when NSE is larger than 0.65 (Moriasi et al., 2007). When the absolute value of PBIAS ranges from 15 to 25, the SWAT model is rated satisfactory, rated good when 10 to 15, and very good when smaller than 10 (Moriasi et al., 2007). The model is considered very good for RSR values closer to 0. Table 5.3 presents the criteria for examining the accuracy of the model calibration and Validation.

The model was calibrated at the outlet of reach 10, subbasin 10, where observed data were collected (Figure 5.2). Table 5.4 shows the mean observed and simulated streamflow values for the time series. From the Table 5.3, it can be inferred that the model results are very good from the NSE coefficient of 0.86.

Parameter Description	Default Value	Optimal Value
Deep aquifer percolation	1	0.20
Curve Number	30-92	*0.21
Baseflow alpha factor	0-1	0.039
Soil evaporation compensation factor	0.95	0.31
Maximum canopy storage	0-10	5.79
Threshold water depth in shallow aquifer for flow	0 – 5000m	4730
Channel effective hydraulic conductivity	0-150	86.9
Maximum potential leaf area index for land cover/ plant	0-1	0.77
Available Water capacity	±30	6.5m
Soil depth	±25	10.54
Groundwater delay	±10	-5.84
Manning's "n" value for the main channel	0 -1	0.065
Groundwater "revap" coefficient	±0.036	-0.013
Saturated hydraulic conductivity	±25	-12.84mm
Average slope steepness	0 -10	5.76
Surface runoff lag time	0-10	7.53

Table 5.2: Description, default, and optimal values from model auto-calibration and used for validation (* the multiply sign, means the default values of parameter are multiplied by the number following the "*")

Model Evaluation	NSE	R^2	PBIAS	RSR
CALIBRATION (2002 - 2005)	0.86	0.86	-0.24	0.38
VALIDATION (2006 – 2010)	0.91	0.92	7.7	0.29

Table 5.3: Criteria for examining the accuracy of the model calibration and validation

Yocona River	Mean (m^3)	Max (m^3/s)	Min (m^3/s)
Observed Streamflow	6.69	41.51	0.06
Simulated Streamflow	6.41	32.48	0.015

Table 5.4: Average monthly observed and simulated values for the total (2002 – 2010) time series

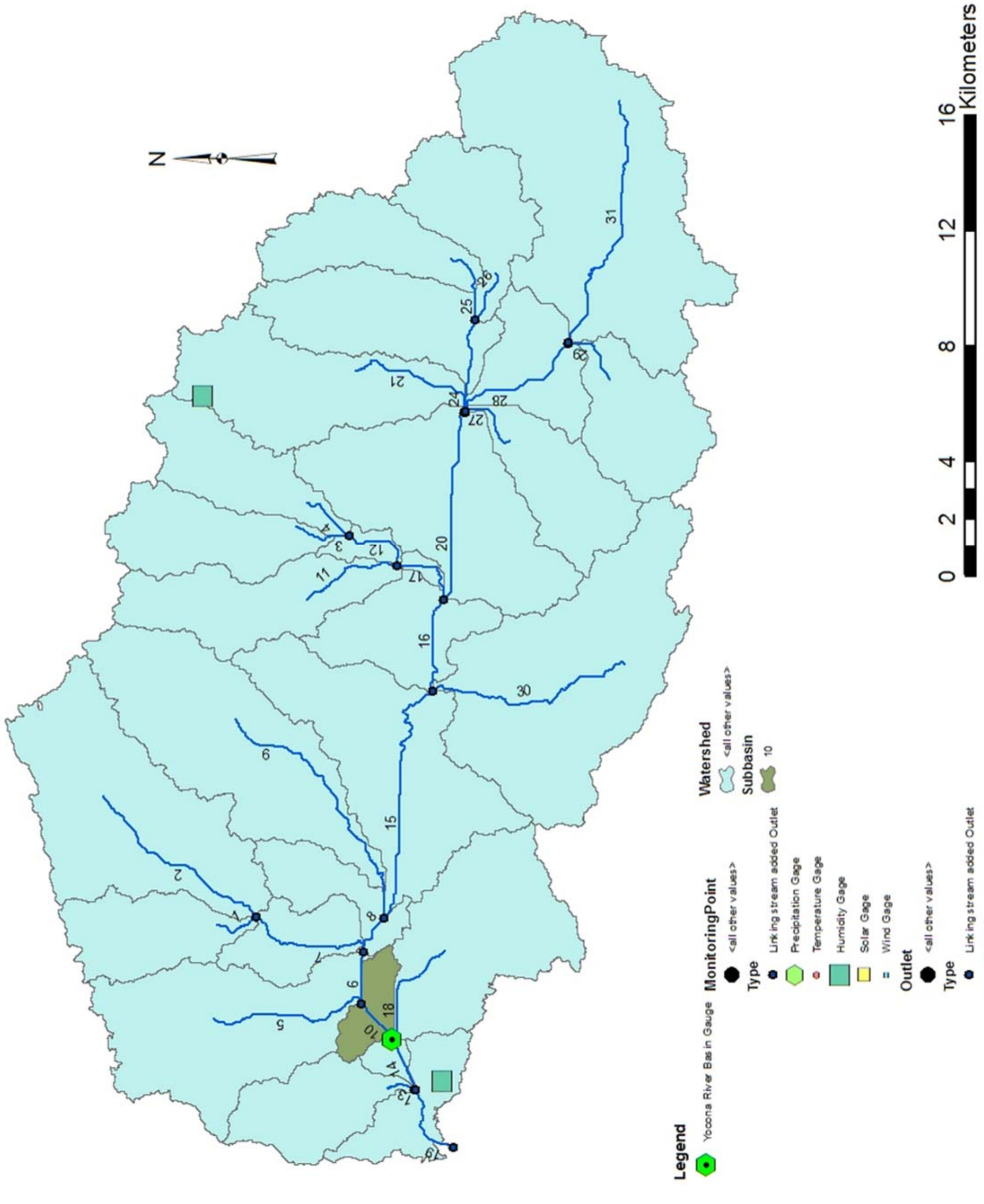


Figure 5.2: Map Showing Stream gauge location and subbasin 10 on the Yocona River Basin.

The calibration of the model was a complex and time-consuming process requiring multiple runs with over 10000 iterations for one run. The simulated discharges were compared to the observed on a monthly time step with the use of several model evaluation criteria (Table 5.3). The model was run for years 2000 to 2010 but the first two years were disregarded in the calibration process since they are required by the model as a warm-up period, in which the influence of initial condition is allowed to decay. This period is essential for the stabilization of the parameters (e.g. groundwater depth), as the results sometimes vary significantly from the observed values. Thus the final calibration and validation was from January 1 2002 to December 31, 2010.

The results of this case study proved satisfactory and are summarized in table 5.3 and 5.4, together with the mean observed values for discharge. Graphical comparison of the simulated to the observed discharge for the calibration and validation period indicates a very good fit of simulated to observed data (Figure 5.3).

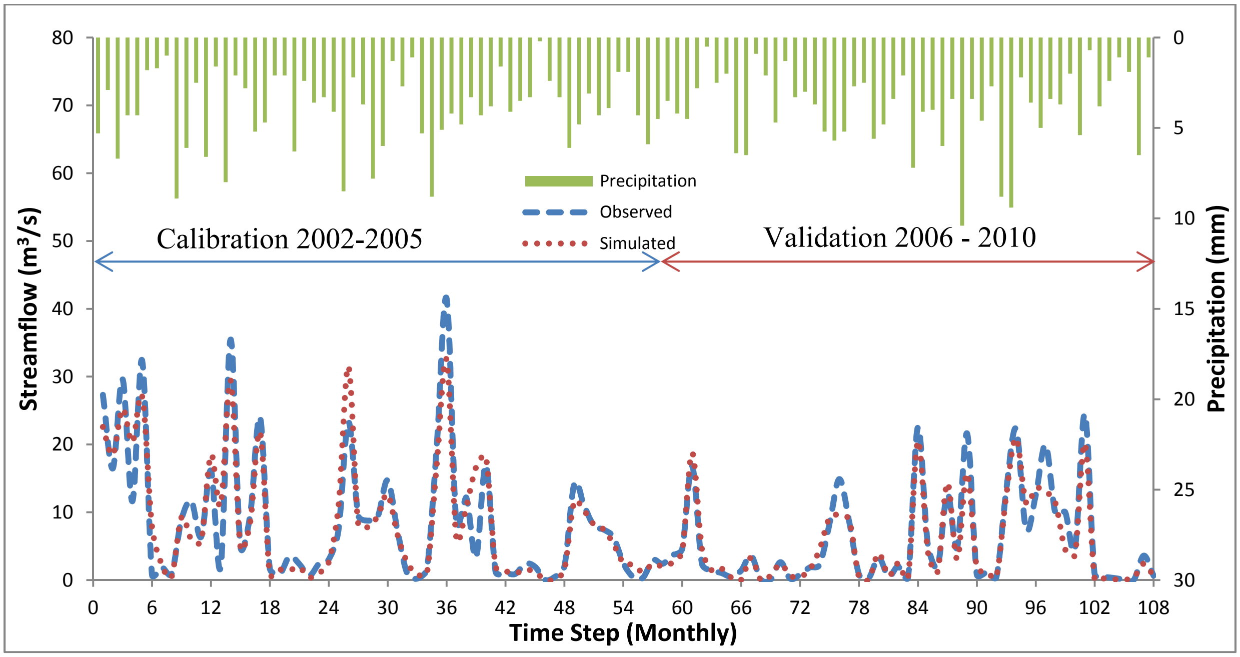


Figure 5.3: Comparison between the simulated and observed discharges in monthly time step for calibration and validation period.

Comparing Simulated Total Nitrogen (TN) and Phosphorus to acceptable EPA Standards

Because of the absence of water quality data for the study area, a comparison was made between the simulated total nitrogen and phosphorus values (N, P) and the acceptable estimated values published by the EPA CWA 2009. According to the EPA (2009), the total nitrogen is the sum of the total kjeldahl nitrogen (organic and reduced nitrogen), ammonia, and nitrate-nitrite. It can be derived by monitoring for total nitrogen (TN), ammonia and nitrate-nitrite individual and summing the components together. The EPA concluded that an annual range of 2.0 and 4.87 mg/L target for total nitrogen and 0.04 to 0.16mg/L for total phosphorus are the acceptable ranges of concentration for rivers.

The annual average estimated loading for TN (point source) in Yocona River flowing from Enid Lake was found to be 11,714lbs/day for an average annual discharge of 1270cfs (EPA, 2009). In this study, the baseline model TN loadings were converted to EPA units to estimate if the values are within the same magnitude for the loadings published by the EPA. The location of observed data was upstream from the Yocona River (figure 5.1), the study area for this project did not include the Enid Lake because the dam's operations (i.e. outflow and inflow) are highly managed, natural processes play a secondary role, and therefore, it is difficult to determine the exact value for discharge. However, TN loading for the baseline model was estimate and compared using the EPA estimation equation (EPA, 2009), equation 5.5.

$$Nutrient\ load\ \left(\frac{lb}{day}\right) = flow(cfs) \times 5.394(conversion\ factor) \times nutrient\ concentration\ \left(\frac{mg}{L}\right)$$

Using monthly values of observed stream flow, EPA conversion factor and the model output for nutrient load, the results show that the average non-point source TN concentration at the observed station is 1.72mg/L*.

Total phosphorus values were compared to the total phosphorus values listed in the SPARROW EPA GIS Data access tool http://gispub2.epa.gov/npdat/ . The value published for mean annual total phosphorus yield at study area in 2002 is >200kg/km^2/year, the baseline model simulated phosphorus value for 2002 as ≥ 323kg/km^2/year.

The absence of observed data makes it very difficult to confidently calibrate and compare sediment and nutrients loading values output from SWAT. However, the basic comparison from published data values and SWAT output shows that the model does a good job of predicting values relative to published EPA values with the presence of some uncertainties.

5.6 - DISCUSSION

The flow prediction was most sensitive for the parameters such as curve number, deep aquifer percolation, baseflow alpha factor, soil evaporation compensation factor, threshold water depth in the shallow aquifer, channel effective hydraulic conductivity. These flow parameters are used to calculate the total amount of flow from the basin. These parameters were adjusted from the SWAT initial estimates to fit the model simulation with observed flow data. These parameters and their calibrated values are displayed in table 5.2.

The SWAT flow predictions were calibrated against monthly flow from 2002 to 2005 and validated against monthly flow from 2006 – 2010 at the location of the USGS Yocona River Basin gauging station 07274000, (shown in figure 5.1). The simulated monthly flow matched the observed values for calibration period with NSE, RSR, and PBIAS equal to 0.86, 0.38, and -0.24% respectively. For the validation period, the agreement as indicated by the NSE, RSR, and PBIAS is equal to 0.91, 0.29, and 7.7% respectively. These model fit statistics are within ranges of literature values for the Yazoo Hills reion (e.g. Luzio et al., 2005). Luzio et al. (2005) reported NSE = 0.87 – 0.93 for monthly observed flow calibration in the Goodwin Creek watershed, Oxford Mississippi. These results indicate that the SWAT model reasonably simulated the basin response at the Yocona River Basin using the given set of parameters.

The model slightly under-predicted the flow on the rising limb and slightly over predicted the flow on the receding limb in the calibration and validation periods (Figure 5.3). There could be many reasons for the slight over and under prediction of flow but most likely it is due to curve number method that was used to predict the surface runoff. The SCS curve number method (SCS, 1972) method assumes a unique relationship between cumulative rainfall and cumulative runoff for the same antecedent moisture condition. Watersheds behave differently depending on how much moisture is stored in the watershed, suggesting that saturation processes play an important role in watershed response.

Basinal Responses

The 31 subbasins output table for the baseline model (Appendix E) shows the mean monthly outputs for each subbasins (108 months timestep) and includes the following information for each: sediment yield (ton/ha), water yield (mm), evapotranspiration (mm), surface runoff (mm), percolation (mm).

Sediment yields (ton/ha) are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). While the USLE uses rainfall as an indicator of erosive energy. MUSLE uses runoff to simulate sediment yield and erosion resulting in a sediment yield map (Figure 5.4). This substitution improves the accuracy of the model and eliminates the need for a delivery ratio. Hydrological models supply estimates of runoff volume and peak runoff rate which, with the subbasin area, are used to calculate the runoff erosive energy variable (Neitsch et al., 2001). The model shows sediment yield from subbasins 10 and 19 to be relatively high. This high yield of sediment is attributed to the major land cover types in the area which are mainly agriculture. The soil types associated with both subbasins (10, 19) are Smithdale and Chenneby which are known to have moderate to high erodability.

A map water yield conditions (Figure 5.5) indicates subbasin 19 has the highest water yield. This excess water yield is a result of the dominant land use type (agriculture) and the poor integrity of the soils in the area.

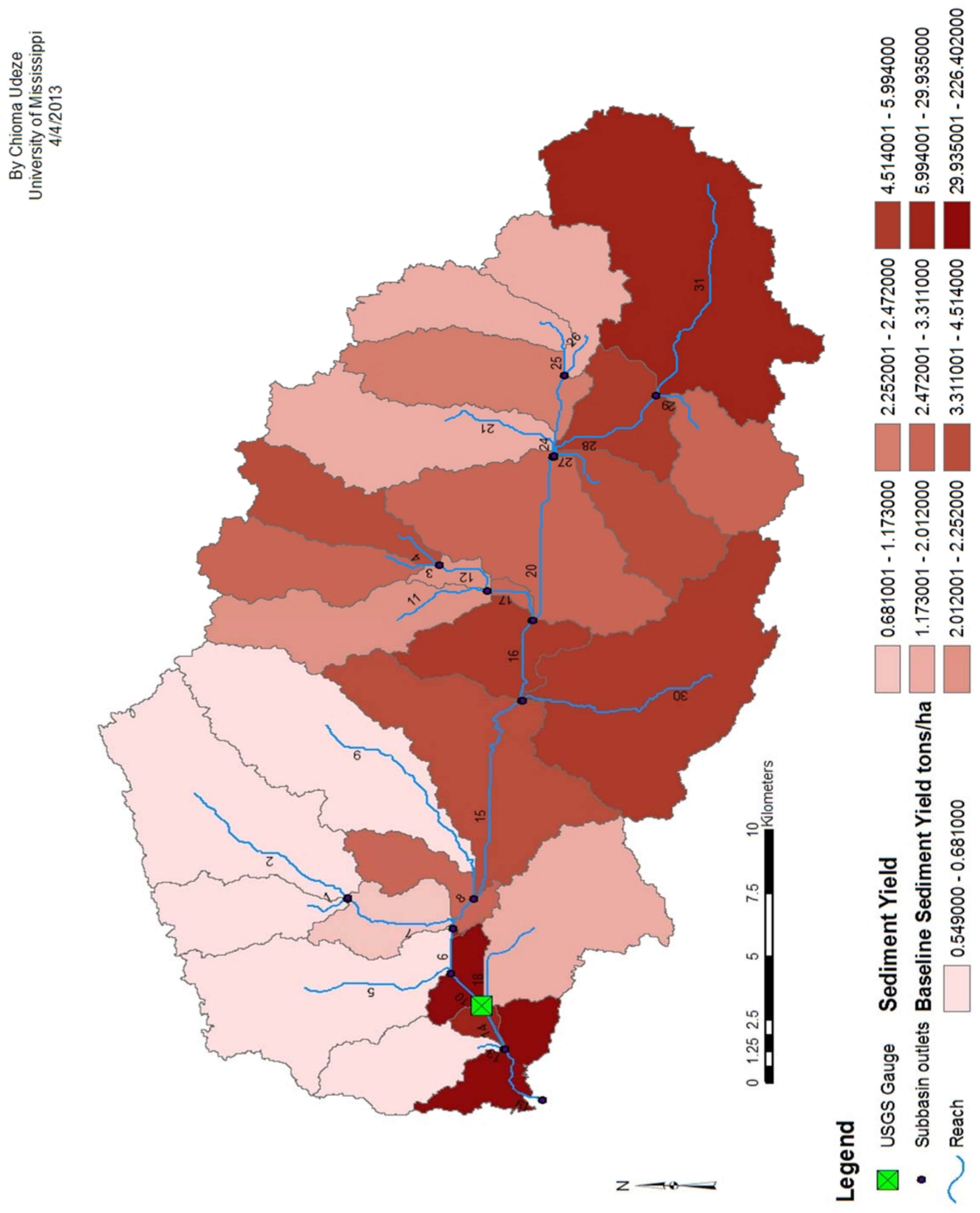


Figure 5.4: Sediment yield map for baseline model (actual conditions) generated by ArcSWAT

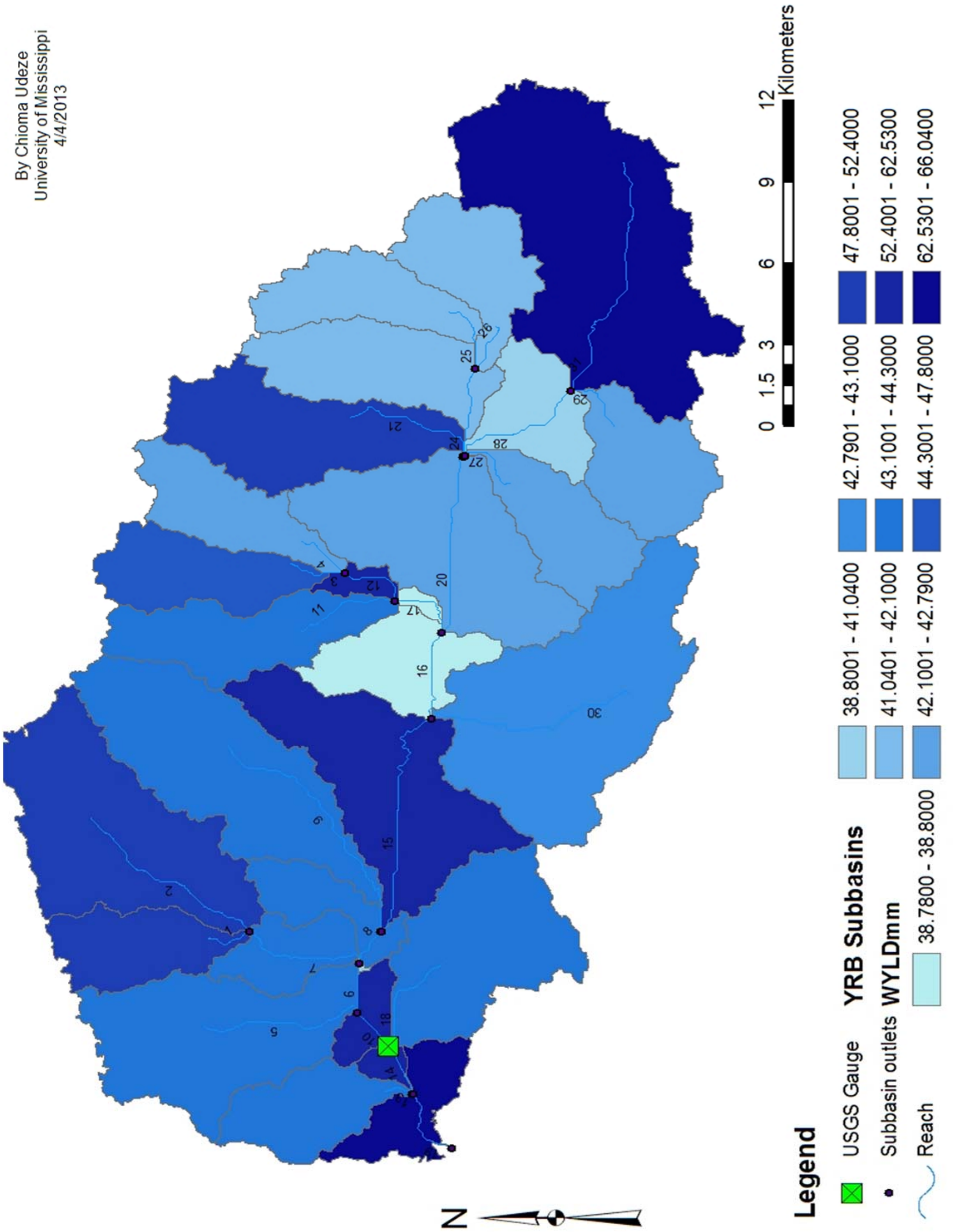


Figure 5.5: Water yield map for baseline model generated by ArcSWAT

Evapotranspiration

Evapotranspiration is a collective description for all processes by which water (liquid or solid phase) at or near earth's surface becomes atmospheric water vapor. This term includes evaporation from rivers and lakes, vegetative land covers, bare soil, canopy (i.e. plant cover transpiration), and sublimation from ice. SWAT computes evaporation from soils and plants separately. The potential soil water evaporation is estimated as a function of PET and leaf index (i.e. area of plant relative to the area of the HRU). Subbasins with high water yield (Figure 5.5) have somewhat low ET (Figure 5.6); this might be as a result of the land use, soil, and slope combination within the subbasins.

Percolation

Water percolates in the root zone of plants and trees during the time step of the simulation. Water is allowed to percolate if the water content exceeds the field capacity water content for the first soil layer and the layer below is not saturated. There is potentially a lag time between when the water leaves the bottom of the root zone and reaches the shallow aquifer. With time, water percolated at land surface should equal groundwater percolation. The baseline model percolation map (Figure 5.7) can be compared with the ET map (Figure 5.6). Subbasins with high percolation rates have low ET rates which might be a result of the leaf area index (canopy size).

Surface Runoff

Surface runoff (Figure 5.8) (Overland flow), occurs along a sloping surface. Using daily precipitation data, SWAT simulates surface runoff volumes and peak runoff rates for each HRU.

Surface runoff volume is calculated in SWAT using the SCS curve number method or the Green & Ampt Infiltration method. The method used in this model is the SCS curve number method. The curve number method varies the curve number non-linearly with the moisture content of the soil. The curve number drops as the soil approaches wilting point and increases to near 100 as the soil reaches saturation.

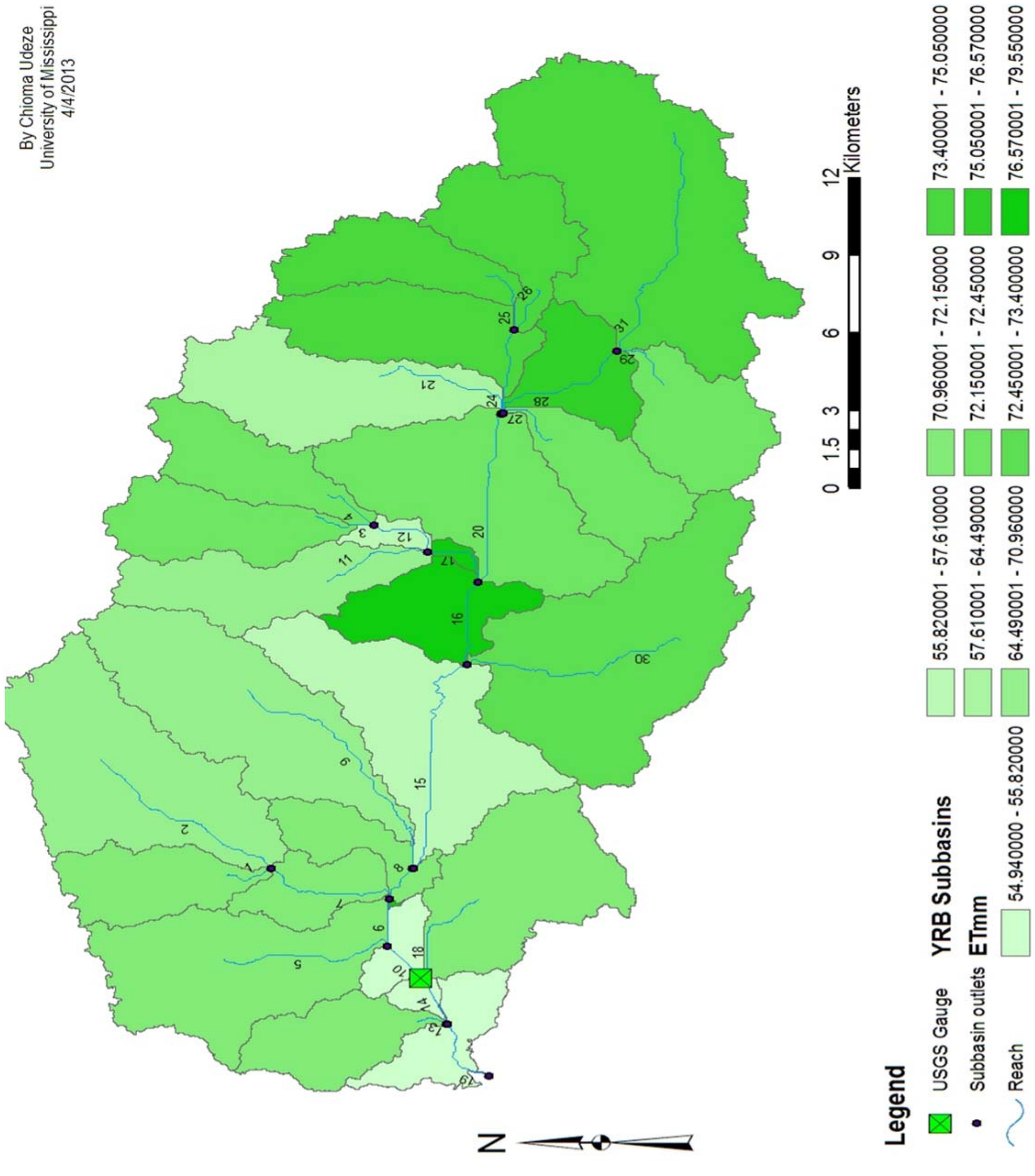


Figure 5.6: Evapotranspiration map for baseline model generated by ArcSWAT

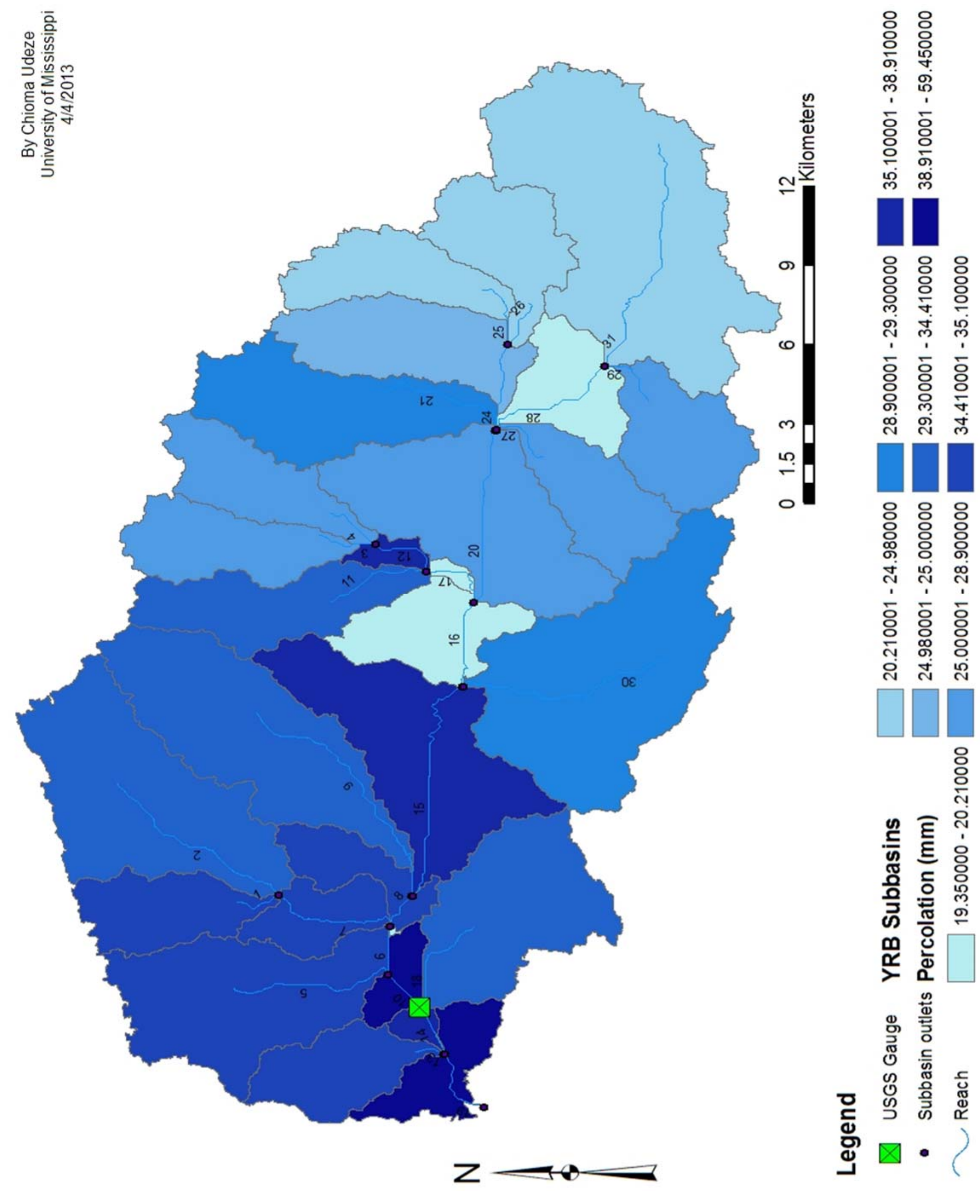


Figure 5.7: Percolation Map for baseline model generated by ArcSWAT

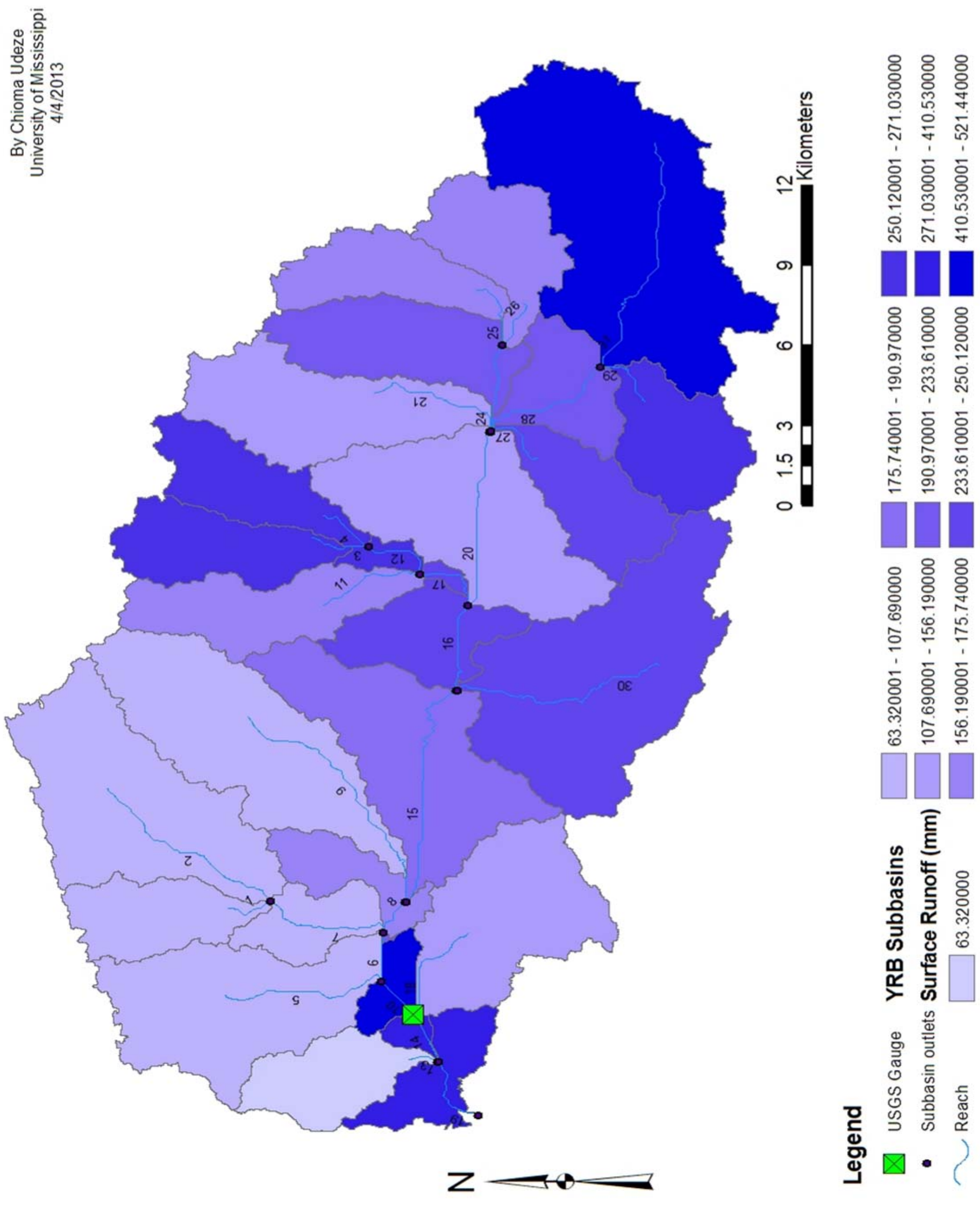


Figure 5.8: Surface runoff map for baseline model generated by ArcSWAT

Streamflow Results

Streamflow (Figure 5.9) is the flow of water in streams, rivers, and is a major element of the water cycle. It is a component of runoff of water from land surface to water bodies, the other component being surface runoff. Water flowing in channels originates from surface runoff from adjacent hill slopes, water discharge pipes (irrigation included), and from groundwater return flow.

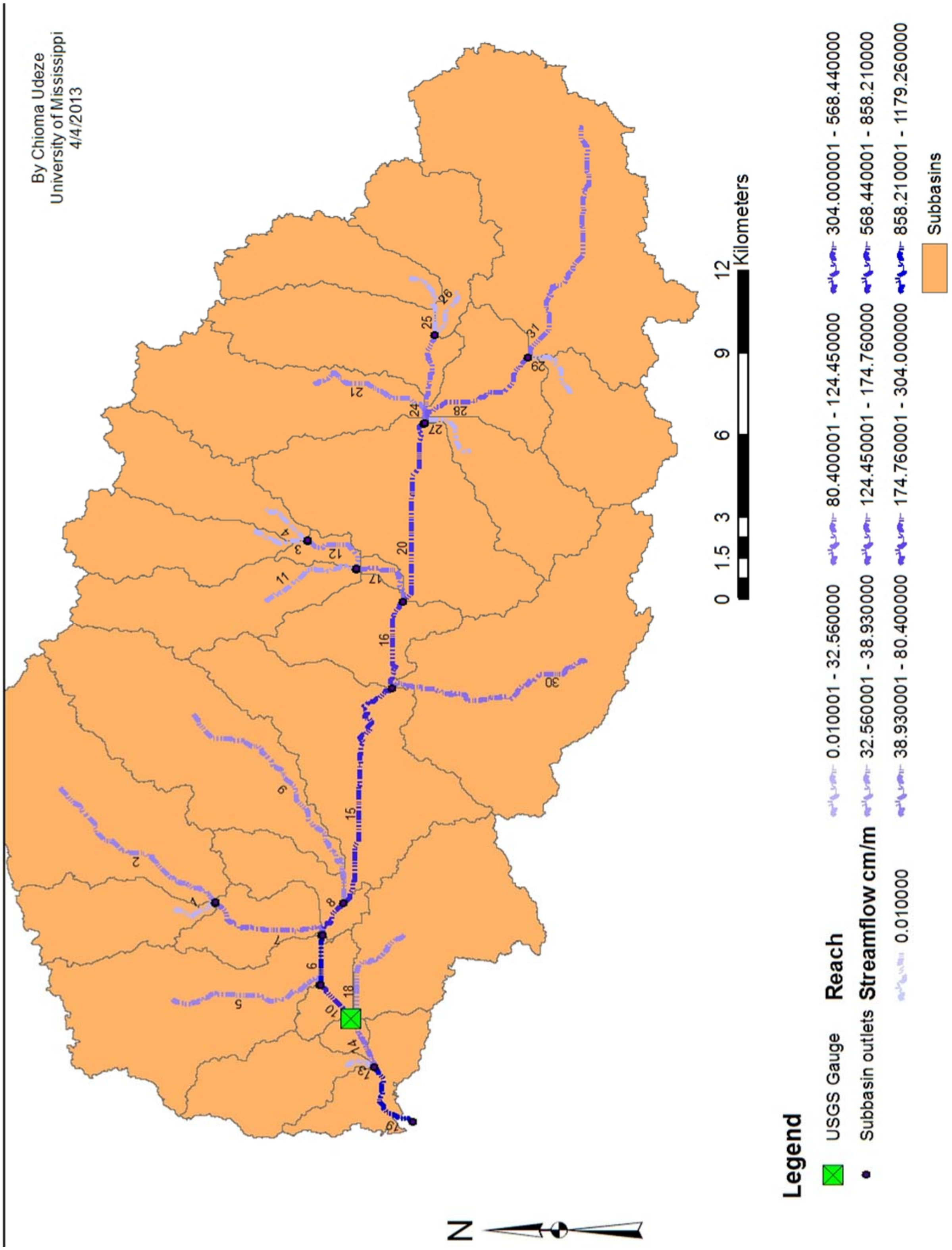


Figure 5.9: Streamflow map for baseline model (matching actual conditions) generated by ArcSWAT

CHAPTER 6 – LAND USE CHANGE SCENARIO

6.1 – INTRODUCTION

Land use scenarios

After calibration and validation the baseline SWAT model of the Yocona River Basin, three alternative land use scenarios were implemented and tested to assess the impacts of land use change and BMPs on runoff, sediment yield, percolation, actual evapotranspiration AET, surface water quality. These scenarios were compared with the baseline model results in the case study area. A nine year simulation period was run for each scenario in order to assess long-term effects. The scenarios are presented in the following sections

Baseline

The baseline scenario was defined according to the current land use system in the Yocona River Basin (Figure 6.1). This definition was based on available spatial data, remote sensing, and ground truthing. The land uses under existing conditions were used to simulate the model discussed in the previous section. Results for runoff and observed data were used to calibrate the model from 2000 to 2010. The sensitive parameter values from this model were held constant after achieving a validation NSE value of 0.86.

6.2 – SCENARIO PLANNING

Among the various causes of water quality degradation, land use can have one of the greatest impacts (Saraswat and Pai, 2011). Temporal land use changes (LUCs) either due to urbanization or deforestation associated with other land use purposes have been widely reported to influence the water cycle (Miller et al., 2002). Understanding hydrological alterations resulting from land use changes has been identified as a major research need (DeFries and Eshleman, 2004), and its quantification has become an integral aspect of many catchment scale water assessment studies (Calder, 1999; DeFries et al., 2004).

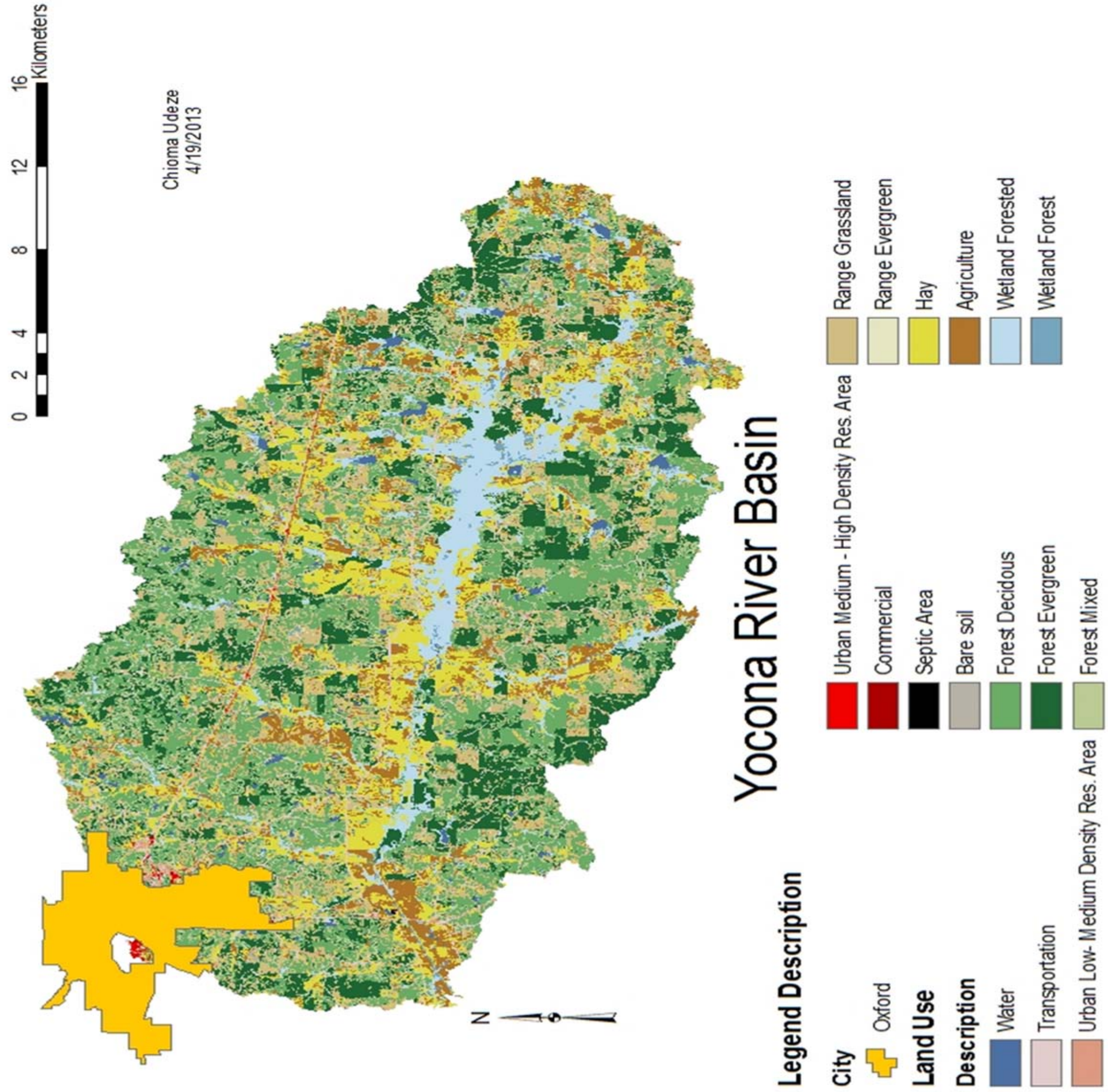


Figure 6.1: Baseline model land use map and the city of Oxford inset; this map shows the location of Oxford within the Yocona River Basin and the distribution of land use.

Assessment of projected land use change impact is conducted using a new land use geospatial raster dataset in the calibrated SWAT model. The use of a single land use layer could result in stationarity of model responses (Saraswat and Pai, 2011). SWAT only receives information from a single land use layer, which could possibly be a source of additional model uncertainty. Therefore, spatially updating the land use file to reflect projected land management practices is a key aspect for hydrologic impact studies and different scenario assessment.

The most significant part of this study is the assessment of the impact that land use changes will have on runoff and other hydrologic components in to the results from the baseline scenario. For this study, 3 land use/land cover change scenarios were examined: (A) projected development associated with the City of Oxford and some changes in the extra-territorial jurisdiction (ETJ) within the Yocona River Basin, (B) projected development using BMPs, and (C) total reforestation of the study area. Different methods were employed to generate three scenarios of land use data change for the Yocona River Basin.

Preliminary Work: Decision making

A meeting was arranged with Mr. Tim Akers, City planner, Oxford City planning department on the 7th of February 2013. The reason for this visit was to obtain some information on the expected developments for areas in the Yocona River Basin so as to generate realistic land use change scenarios. A number of significant developments are expected to fall within the Yocona River Basin (Figure 6.2). Mr. Akers detailed the projected developments expected to take place in the City of Oxford and ETJ within the Yocona River Basin between now and 2016.

Projected Developments

Figure 6.2: Projected development for Oxford

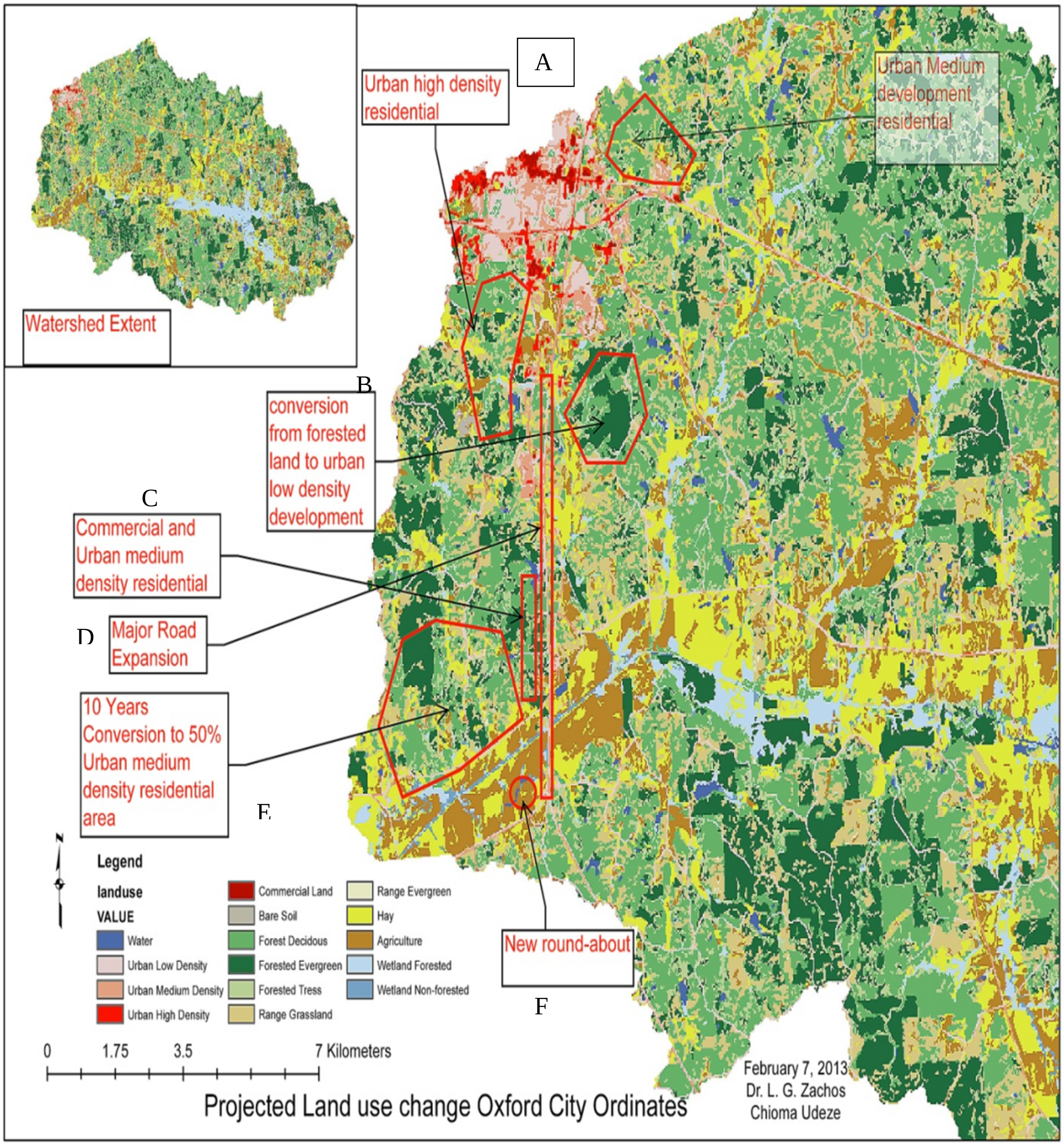


Figure 6.2: Projected developments in Oxford and Yocona River Basin, Mississippi

6.3 – LAND USE SCENARIO DESCRIPTION

SCENARIO A: Projected development in Oxford city limits and ETJ

With the increase in the population the Oxford area, it is expected that growth will increase the demand for land with the result that part of forested areas within the city will be cleared and converted into residential and commercial areas. In this scenario, there are projected to be significant changes within the city limits of Oxford and ETJ of the Yocona River Basin (Figure 6.2). Highway 7 which runs north-south (Figure 6.2D) is expected to expand to 4 lanes along with new commercial and urban medium density residential areas along its edges (Figure 6.2C). In the southwest corner of the map (Figure 6.2E), there is a projected 50% conversion of forested land into urban medium density residential areas. Majority of the projected land use changes in this area are mainly conversion of deciduous forested lands into medium to high density residential areas and commercial lands (Figure 6.2 A & B). In general, there would be about 20% increase in impermeable surfaces within Oxford City limits and ETJ in the Yocona River Basin.

Changes to baseline land use data (Figure 6.1) were made using ArcView spatial analysis reclassification and append process (See appendix D), processed and updated in the SWAT functional database via SWAT2009_LUC. The SWAT2009_LUC (Pai and Saraswat, 2011) is a computer-based, geospatial tool that ingest land use / land cover geospatial dataset and other associated information interactively and updates the Land Use Change model in SWAT.

SCENARIO B: Urban development with BMP

The projected land development for the City of Oxford also involves adding green spaces as a new requirement by the city planning office as an adoption of best management practices. This scenario is a continuation of scenario A with BMPs added. The BMP added included, filter strips, grassed waterways, field borders, and parallel terraces. The best management practices were added to investigate if there would be a reduction in the rate of runoff, surface water nitrogen, and phosphorus loading at the Yocona River Basin outlet. Land use changes occurring upstream of the watershed are projected to be conversion of forested lands to agricultural lands with some BMP such as buffers along the streams. The purpose of this scenario (figure 6.3) is to quantify land use and management changes on the aforementioned parameters as part of an effort to evaluate the effects of BMP under the “new conservation effects assessment” being adopted by the City of Oxford.

SCENARIO C: Total reforestation of the Yocona River Basin

Total reforestation scenario is the reestablishment and expansion of a forest which was previously destroyed or degraded. This scenario involved replacing agricultural lands and impervious surfaces with forest trees such as oak and pine for almost the entirety of the Yocona River Basin. Clearly this scenario is unrealistic for application in the whole of the basin with total area of around 650 km^2, 60% of which is occupied by forest and grassland. The ability of the SWAT model to partition a basin into subbasins was taken advantage of in this case, by editing the subbasin(s) database, and directing SWAT to assign forest trees as the current land use to 80% of the entire watershed. The reforestation of about 90% of the watershed (Figure 6.4) is more realistic instead of a 100% reforestation of the entire watershed.

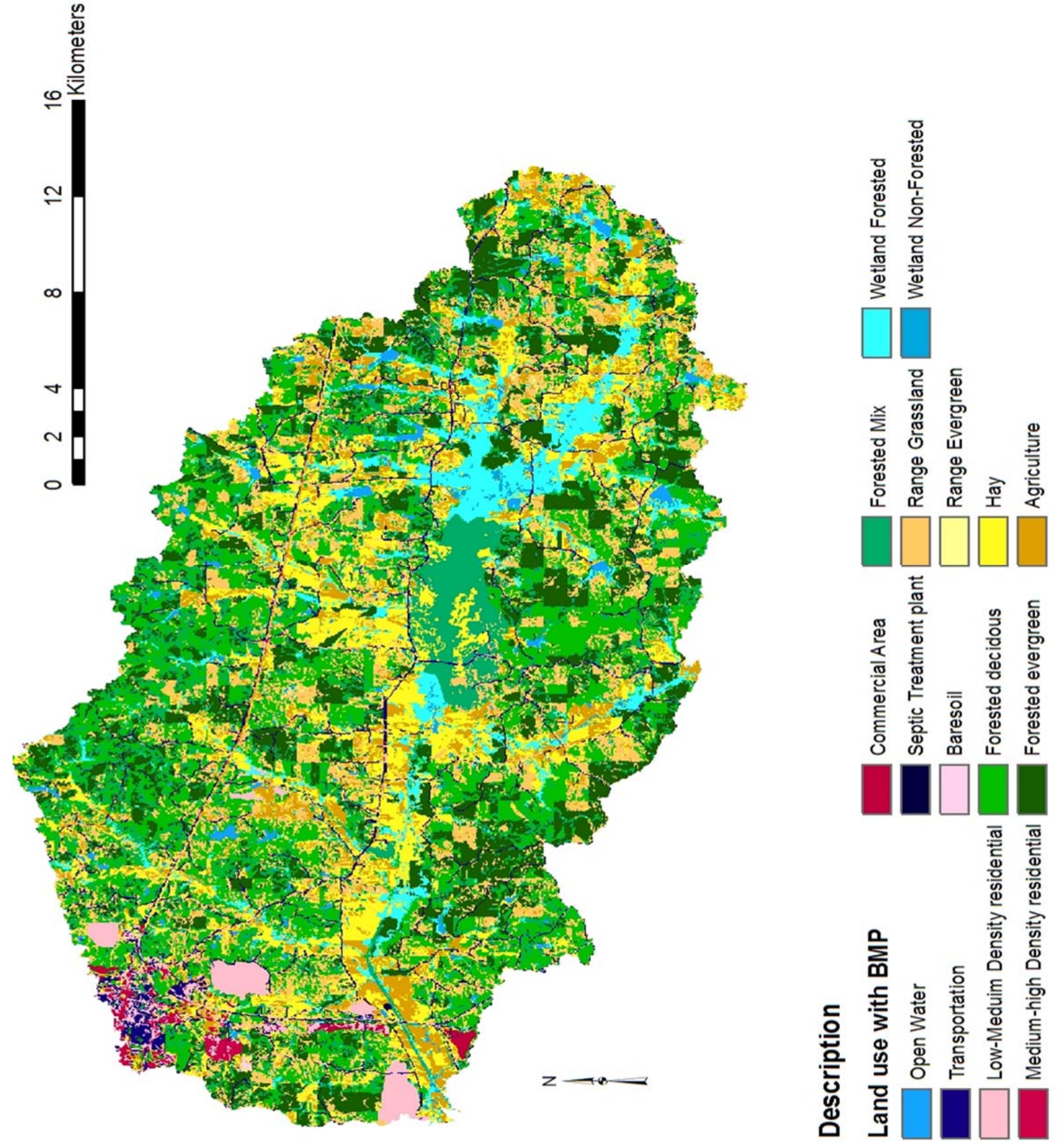


Figure 6.3: Scenario B, showing BMP added to land use and land cover alteration along flood plain (Yocona River Basin)

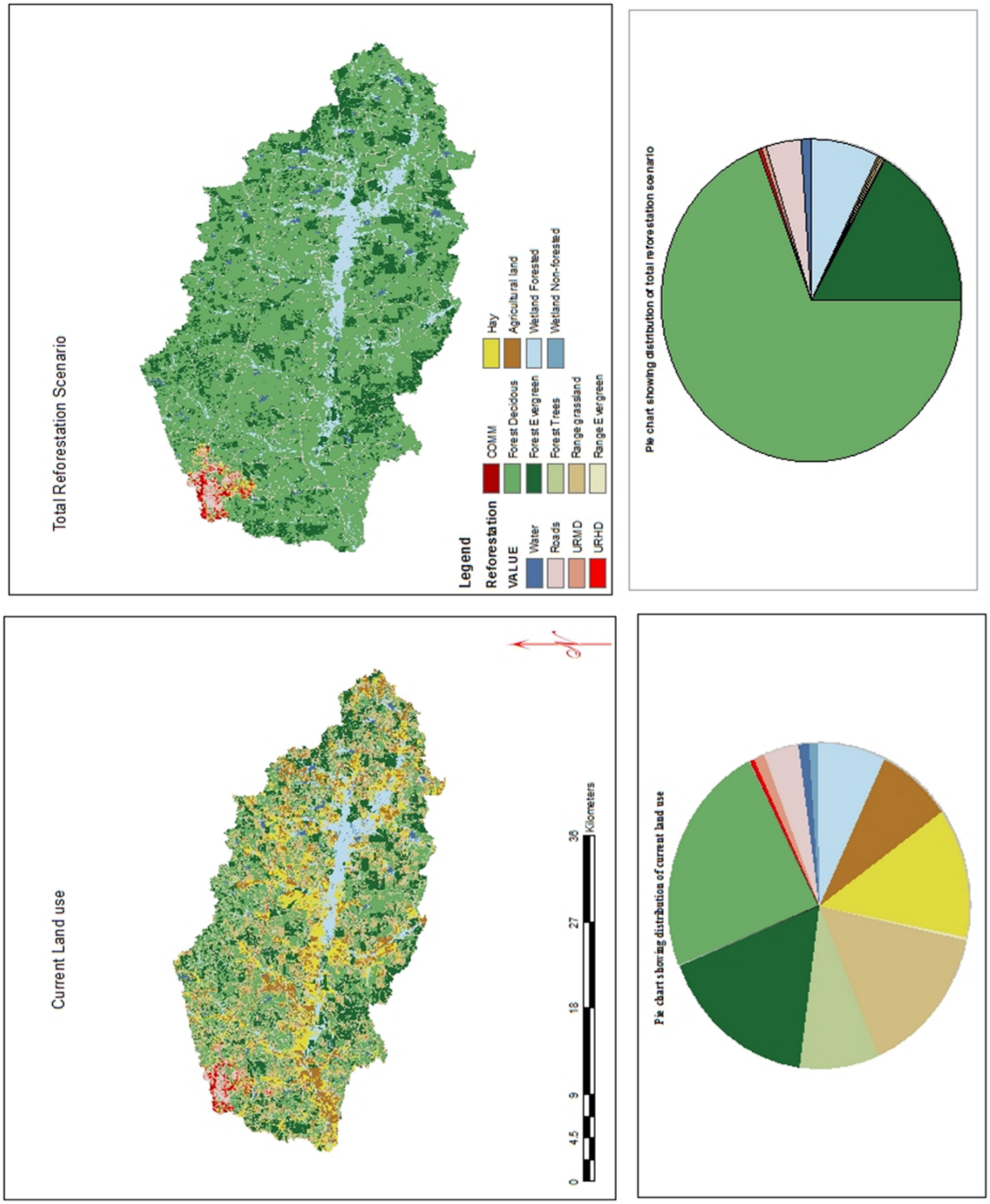


Figure 6.4: Before and after reforestation of the Yocona River Basin

6.4 –SCENARIO RESULTS

SCENARIO A: Projected development in Oxford City Limits

The land use raster dataset for the baseline model was edited to reflect projected developments within the city limits of Oxford and ETJ. The major changes to land use were the addition of impervious layers associated with the conversion of forested land to residential (medium and high density) and commercial areas. In general, there is 67% and 43.07% cumulative increase and decrease in monthly streamflow and sediment yield values respectively (Figure 6.5, & 6.6). Streamflow increase is attributed to the type of applied land use changes. In addition, the significant increase in discharge during the months of September and October for months 84-90 (Figure 6.5b) is most probably due to high rainfall and the result of the immediate runoff response of the expanded urban land to the rainfall even, depending little in the antecedent soil moisture.

As the amount of impervious surfaces increase, more runoff is created and less water is able to infiltrate into the ground. For the 9 years of simulated data (Figure 6.5ban increase in discharge is observed during wet months and a decrease during dry ones. This result can be mainly attributed to the type of applied land use change. The amount of urban or impervious areas dominantly control the volume of runoff produced from a watershed. The proportional extent of impervious surfaces (i.e. roads, residential areas, commercial areas) increased from 1.57% to 2.62%, (relative expansion of 40% of impervious surface) for this scenario.

When the annual basin values for total water yield, surface discharge, percolation, and sediment yield for scenario A and baseline model are compared (Table 6.1), the average annual water yield over the watershed is 2.87 mm higher in scenario A. Similar to water yield, the average annual surface runoff increase 3.12 mm in scenario A. The average sediment yield for the overall subbasin was expected to decrease, on the contrary, the average sediment yield increase by 0.13 ton per hectare. This increase is attributed to the large amounts of rainfall in 2005, 2007, and 2009 which produced high sediment yield. On a subbasinal scale, the sediment yield decreased due to the addition of impervious surfaces in subbasins 1, 7, 5, and 10. The comparison of variation of percolation in this scenario suggests that the decrease in the average annual basin percolation could be mainly attributed to the removal of pervious surfaces. Consequences of land use change on ET are more complicated than other hydrological components. The average annual basin ET decreases from 740.82 mm to 730.26 mm for scenario A; watersheds with a large number of impervious surfaces will experience a decrease in ET due to recession of land covers such as forested trees.

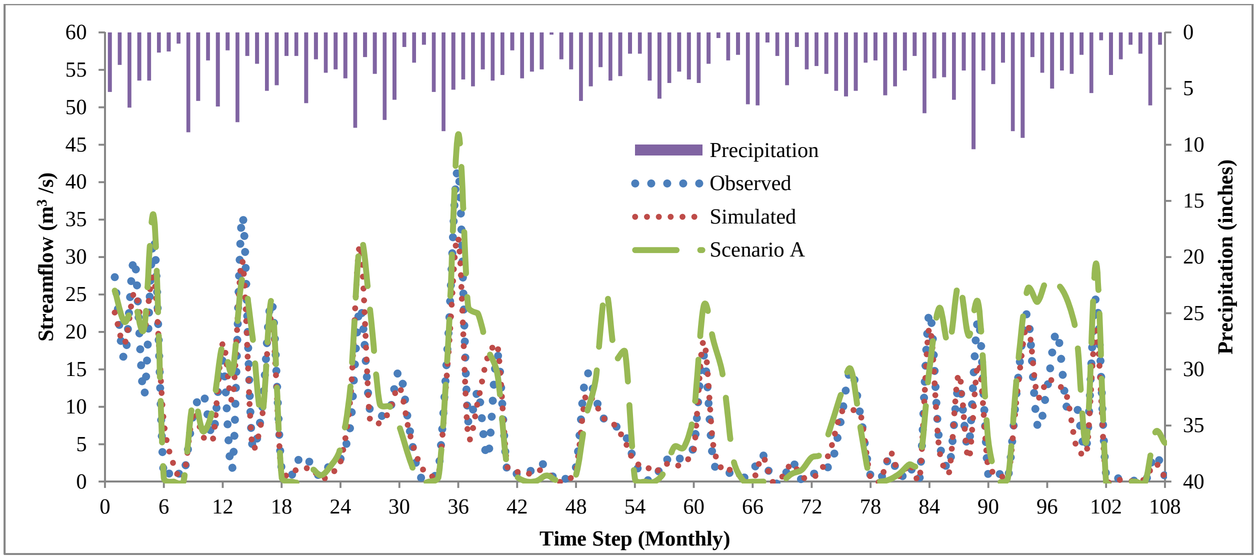
Scenario	Water Yield (mm)	Surface runoff (mm)	Percolation (mm)	ET (mm)	Sediment yield (t/ha)
Baseline	607.6	198.10	370.22	740.82	1.09
Scenario A	610.47	201.22	362.63	730.26	1.22

Table 6.1: Baseline model and Scenario A land use changes, average annual basinal values of hydrological components and change with land use for the Yocona River Basin.

Streamflow

Comparison of the baseline model to scenario A (Figure 6.5a and b), shows significant increase in mean monthly flow rate. The addition of impervious surfaces within the city limits of Oxford and ETJ accounts for the increase in streamflow volume. This is the expected result.

(a)



(b)

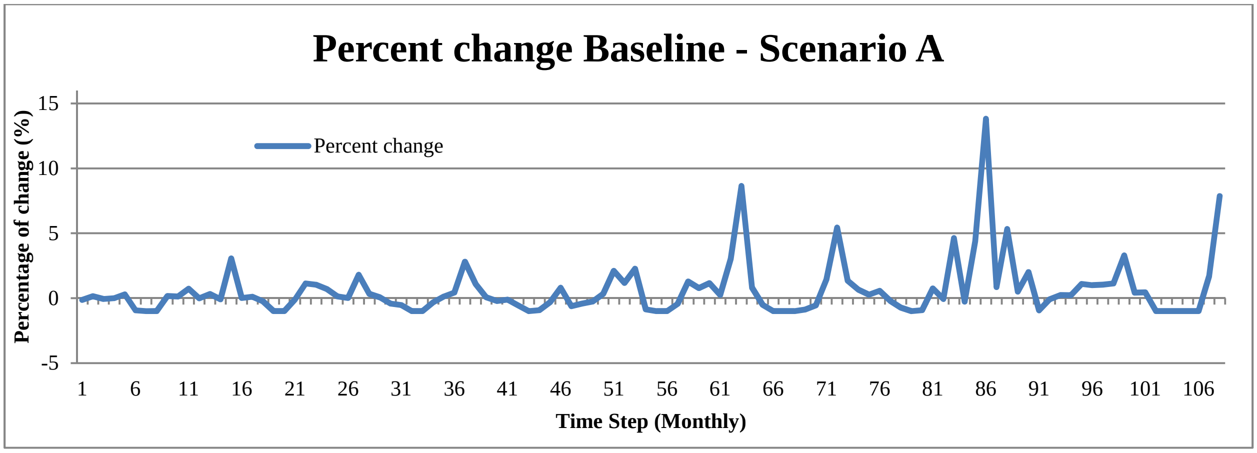


Figure 6.5: (a) Monthly values of total streamflow for base model and the projected development scenario A, (b) monthly streamflow runoff change (%) for years 2002-10 (108 months) of the corresponding scenario.

Sediment Yield

The accuracy of the baseline model was evaluated based on available observed data and location of observed data. Due to the unavailability of sediment data, the baseline model was calibrated with only observed streamflow data from the Yocona River gauge 07274000. Even though sediment calibration was not done for the baseline model, a comparison between the sediment yield from the baseline scenario and the projected development scenario was made. The model results (Figure 6.6) indicate a decrease in sediment yield. This significant decrease can be attributed low sediment wash off from impervious surfaces due to the elimination of pervious land. The soils in the Yocona River basin are highly erodible, during months with constant rainfall (Months 94, 95, and 95) there is peak in sediment yield from the basin.

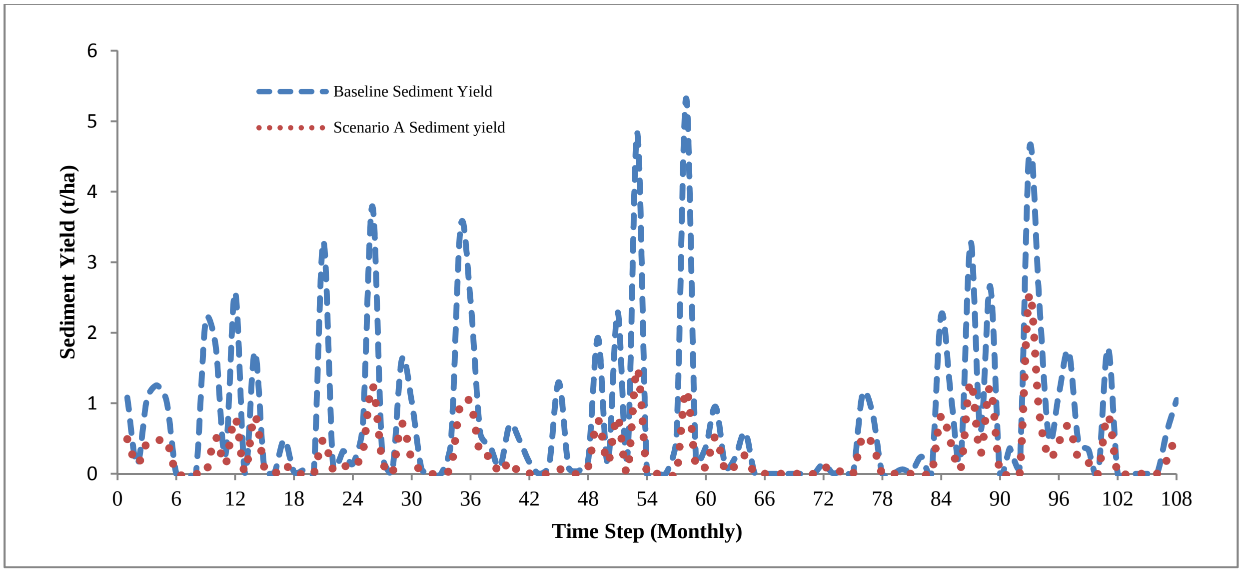


Figure 6.6: Graphical comparison of monthly sediment yield (ton per ha) for the base model and projected development scenario A

Percolation

The percolation component of SWAT uses a water storage routing technique to predict flow through soil layers in the root zone. As water infiltrates underground, capillary forces is the primary force moving water downward. The downward flow rate during percolation is governed by the saturated conductivity of the soil layer. Upward flow may later occur when a lower layer of soil exceeds basin capacity. Basins dominated by impervious surfaces would generally experience a shift, to little or no percolation. The reason for this shift in percolation is the changes (pervious to impervious) would lead to decrease in the volume of water that percolates into pervious ground, and a resulting increase in volume of surface water. Percolation rates are generally highest in winter and early spring when there is a large amount of rainfall. The percolation rate trend for scenario A (Figure 6.7) shows a slight shift and decrease; however, there are peaks in percolation in months with expected high rates of rainfall.

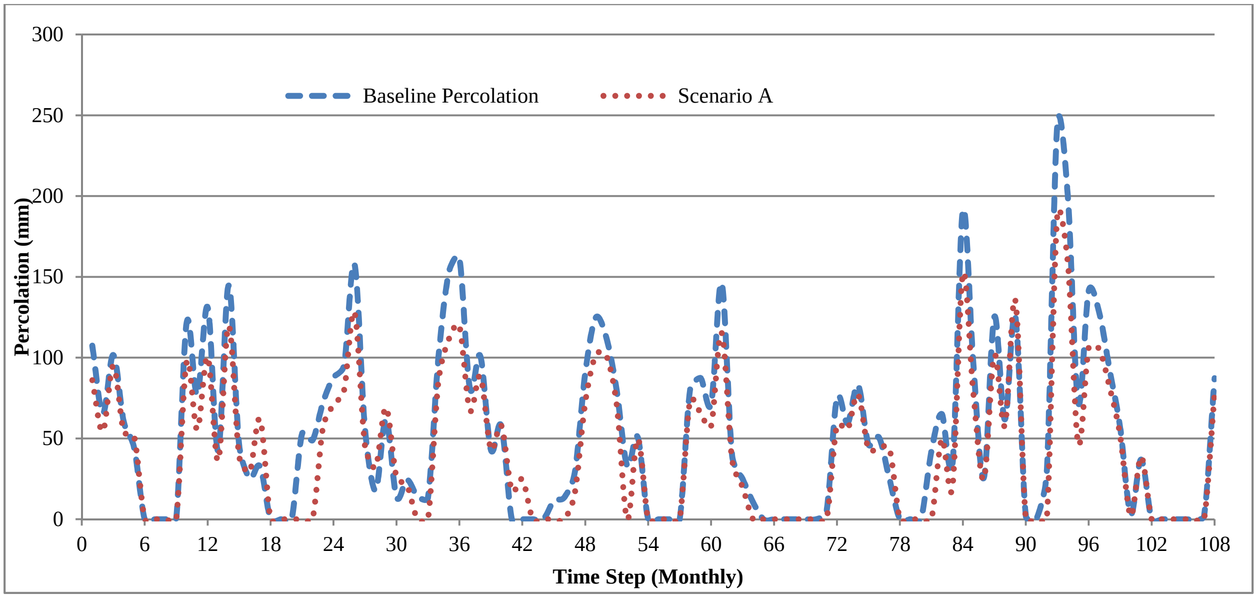


Figure 6.7: Graph showing a shift in percolation rates for scenario A compared to baseline model.

Actual Evapotranspiration AET

Evapotranspiration, a collective term that includes evaporation from the plant canopy, transpiration, sublimation, and evaporation from the soil, is the primary mechanism by which water is removed from a watershed (Dingman, 1994). AET is an important component of the hydrologic cycle in the watershed, so accurate quantification is crucial to evaluating the effects of land use change. A direct measurement of AET is difficult, costly, and time consuming because it is related to a number of factors that may vary both spatially and temporally. These factors include changes in leaf area, plant height, crop characteristics, degree of canopy cover, rate of crop development, canopy resistance, soil and climate conditions, and land management practices (Doonrenbos and Pruitt, 1977).

SWAT estimates AET based on potential evapotranspiration (PET), which can be estimated using an appropriate method with available climate data as inputs. There are many methods available to estimate PET. However, these methods give inconsistent values because of varying calculation assumptions, input data requirements, or because they were developed for specific climate regions (Lu et al., 2005). The Hargreaves method (Hargreaves and Samani, 1985) a temperature-based method in SWAT was used for estimating PET for simulations. The Hargreaves method was selected for this study because it seemed to be superior to the two other methods in SWAT (Priestley-Tailor and the Penman-Monteith), and it gave the best fit for simulated discharge values.

Urbanization or the removal of forested/ crop lands led to significant decrease in evapotranspiration values during months with temperature increase (Figure 6.8).

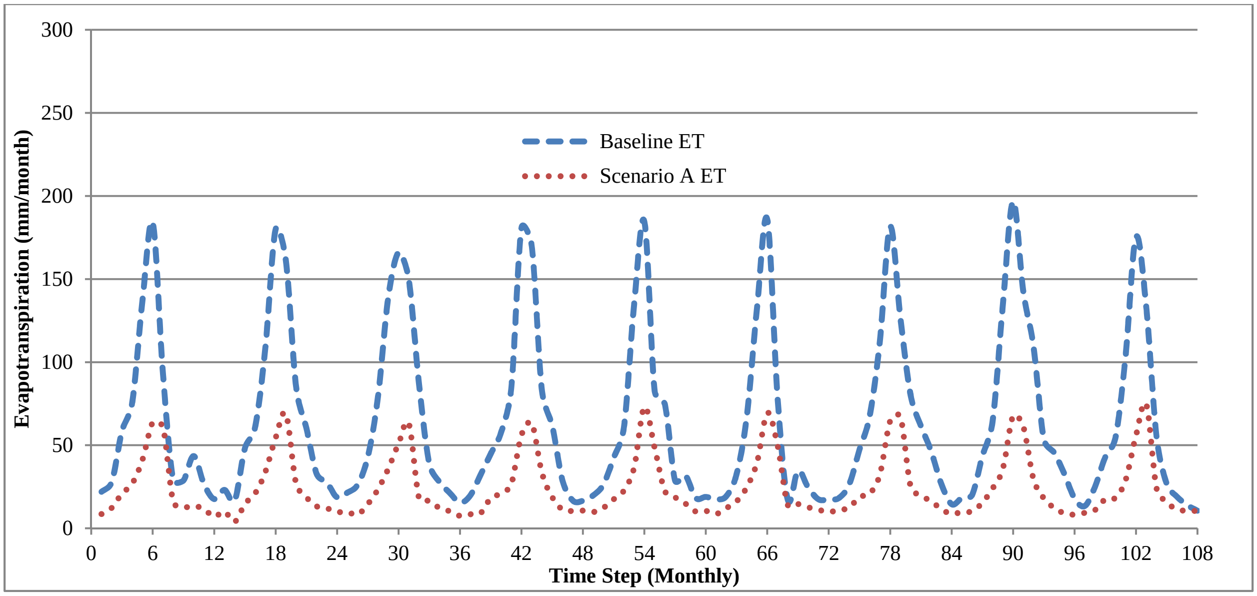


Figure 6.8: Change in evapotranspiration between baseline model and scenario A

SCENARIO B: Urban Developments with BMP

This scenario examined the changes in sediment and nutrient load from a combination of hypothetical BMP implementation. The SWAT model has the capacity to represent many commonly used practices in agricultural fields through alteration of its input parameters. However, the model does not offer a complete established method for some of the BMP implemented in this scenario. Filter strips (riparian buffers) and cover crops were added to scenario A to examine the changes in water quality. These BMP were added both spatially and by editing the management operations within SWAT. For this scenario a change in surface water quality parameters are examined: (1) nitrogen yield (kg N/ha), (2) phosphorus yield (kg P/ha), (3) nitrate transported by surface runoff (kg N/ha), (4) SedP i.e. mineral P yield attached to sediments transported by surface runoff (kg P/ha), (5) Sediment yield (metric tons/ha), and (6) groundwater NO_3 yield (kg N/ha). Water quality parameters from scenario B were compared to that from scenario A to evaluate the effectiveness of BMP implemented at the subbasinal scale. Also the impact of scenario B (BMP added) on nitrate loading in groundwater is also presented. Although there are no available data for Yocona River Basin to substantiate the nitrate loading in groundwater and other water quality parameters presented, a comparison (Figure 6.9) between scenarios B, baseline model and scenario A aims to show the impact of land use change and BMP on surface and groundwater.

BMP are routinely used to reduce non-point source pollution resulting from agricultural practices and improve water quality. This scenario demonstrates how structural BMP practices such as adding filter strips can improve water quality. The BMP added in this scenario (Table 6.2) were expected to be fully functional; however, their duration of functionality is unknown.

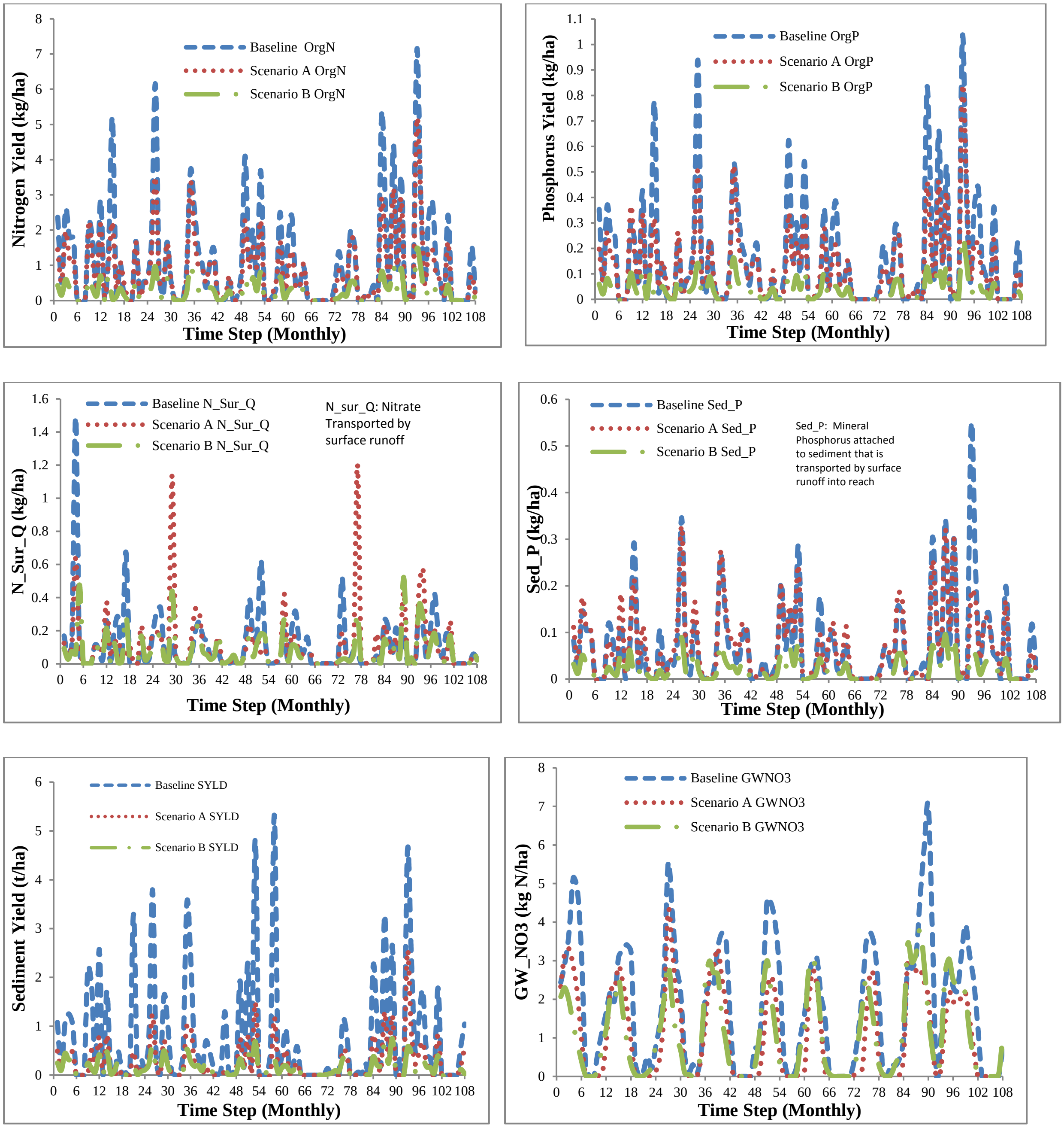


Figure 6.9: Clockwise from top (i.e. a, b, c, d, e, and f). Graphs showing (a) total Nitrogen yield from the baseline model, scenario A and B with a significant reduction in scenario B, (b) Total Phosphorus yield from baseline model, scenario A and B, (c) Nitrate transported by surface runoff from baseline model, scenario A and B, (d) Mineral Phosphorus yield attached to sediment that is transported by surface runoff into the reach, (e) Sediment yield

transported from basin into reach during simulation time step and (f) NO_3 transported into main channel in the groundwater loading from the HRU (kg N/ha).

BMP such as grassed waterways and field borders were added by modifying variables such as channel cover factor and channel erodability factor in SWAT. Implementation of these BMP (Table 6.2) did not alter the parameters from the calibrated model. The resulting annual average loadings of nitrogen N, phosphorus P, N_SUR_Q (Nitrate transported by surface runoff), SYLD (Sediment yield), and GW_NO_3 (NO_3 loading in groundwater) of this scenario are compared to those of the baseline model and scenario A.

BMP	**FUNCTION**
Filter Strip	Reduce runoff, filtering out sediments and nutrients.
Grassed Waterway	Increase channel cover
	Reduce channel erodability
	Increases channel roughness
Field Border	Increase sediment trapping
Parallel Terrace	Reduce Overland flow
	Reduce Sheet erosion

Table 6.2: Representation of BMP in SWAT

Results indicated (Table 6.3) that these BMP are effective in reducing the amounts of nutrients in surface waters. However, their effectiveness on the amount (average annual loadings) of nutrients infiltrating into groundwater cannot be adequately quantified in this study. The average annual loadings of nitrate transported to ground water increased 1.65%. Although, parallel terrace operation, is likely to influence runoff prediction parameters (overland slope and curve number), runoff volume and stream flow at the outlet of the Yocona Basin were not significantly affected by the implementation of BMPs.

	ORG_N (kg N/ha)	**ORG_P (kg P /ha)**	**N_SUR_Q (kg N/ha)**	**SYLD (t/ha)**	**GW_NO_3 (kg N/ha)**
Baseline	1.19	0.16	1.13	1.09	1.49
Scenario A	1.25	0.17	1.08	1.22	1.00
Scenario B	0.93	0.12	0.29	0.65	1.51

Table 6.3: Average annual basinal loadings of nutrients for the Yocona River Basin

This outcome was expected, because BMP selections were targeted at nutrients and sediment reduction. The impacts of the implemented BMP on streamflow at a watershed scale are not of major concern.

The average annual sediment yield for the Yocona River Basin is summarized in table 6.3. Comparing the model outputs for BMP with outputs for the baseline model (no BMP) reveals the efficacy of the implemented BMP. Although, the model was not calibrated for sediment yield due to lack of data availability for sediment yield in the study area, sediment yield values from the baseline model were compared to those published by the Mississippi Department of Environmental Quality Report (MDEQ, 2008, Table 6.4).

The Yocona River Basin (Lafayette and Pontotoc County) falls in the Yazoo River Basin Hills (Figure 6.10) region 65, and was listed as biologically impaired due to sediment (MDEQ, 2007). The red rectangular box in figure 6.10 shows the location of the Yocona River Basin

A TMDL study done by MDEQ (2008) characterizes the water bodies in the Yazoo Hills as "unstable", and estimated loads that would be expected for unstable bodies (Table 6.5)

Ecoregion	WLA (t/ha/day)	LA (t/ha/day)	MOS (t/ha/day)	TMDL (t/ha/day)
65	0.0082 to 0.0346*	0.0082 to 0.0346*	implicit	0.0082 to 0.0346*
WLA: Wasteload Allocation (Permitted sources) LA: Load Allocation (Unpermitted sources) MOS: Implicit margin of safety TMDLs: Total Maximum Daily load *tons per hectare per day at the effective discharge Table is modified from MDEQ TMDL report 2008				

Table 6.4: Total Maximum daily loads for Yazoo Hills

Level III Ecoregion	Unstable Streams Sediment Yield Range*
Ecoregion 65	0.736 to 4.586
*tons per hectare per day at the effective discharge Table modified from MDEQ TMDL report 2008 For load TMDLs the WLA and LA are summed to calculate TMDL.	

Table 6.5: Unstable Stream Sediment Yield Ranges for Level III Ecoregion within the Yazoo Hills

The Yazoo River Hills are composed of highly erodible soils and channels are extremely unstable producing an average annual sediment yield about twice the national average at ~1000 t/ km^2 (10t/ha) (Shields et al. 1995),. The Yocona River Basin is over 10 times smaller than the Yazoo River Basin, therefore average annual estimates of sediment yield within the range of 1 – 0.7 t/ha can be assumed for the Yocona River Basin. The range of uncertainties in literature indicates that the Yocona River Basin model output values fall within the literature value range with uncertainties.

Shields et al. (2009) conducted a study to estimate the nitrogen and phosphorus levels in the Yazoo River Basin. The mean annual N and P loading rates for streams in the Yazoo River Basin averaged at 35.8 kg/ha and 3.9 kg/ha respectively. The baseline model output values for nutrients and sediment loadings are within the same magnitude with published values. For comparative purposes, the baseline model output can then be compared to scenario B simulation outputs. However, absolute values of yield may not be exact. The aim of this study is to evaluate the hydrological changes associated with land use and land management changes.

Figure 6.10: Modified from MDEQ (2008). Location of Yazoo Hills Region, Northern Portion

Difficulty in evaluating the BMP effects on NO_3 loading in groundwater was encountered in this study. This difficulty might stem from the complexities of N cycling at watershed scale, surface and groundwater interactions, inherent variability in soil-air-water process which determine the attenuation and movement of N to groundwater and baseflow (USEPA, 1993), N transport lag time, and a host of other uncertainties that remain unknown. In general, there is a decrease in average annual loadings for water quality parameters examined in this scenario compared to the baseline model (Table 6.6).

Water Quality Parameter	**Percentage Change (%)**	**Increase/ Decrease**
Nitrogen	-40.42	Decrease
Phosphorus	-3.33	Decrease
Nitrate transported by surface runoff	-88.04	Decrease
Groundwater Nitrate	2.44	Increase
Sediment Yield	-40.49	Decrease

Table 6.6: Percentage change in water quality parameters between baseline model and Scenario B

SCENARIO C: Reforestation of the Yocona River Basin

There is significant change in this land use scenario (Figure 6.4) when compared to the first two scenarios. The resulting pattern of scenario C shows a decrease in surface runoff and slight increase in sediment yield in subbasins with a particular land use type (Alfalfa plant) and soil. A cumulative decrease in discharge reached 30.2% (for 9 years) when compared to the average baseline model. This decrease can be explained by taking into consideration the addition of pervious surfaces in the basin. In this scenario, the curve number (CN2) changed from 68.6 to 64.6, resulting in a moderately significant decrease of the curve number and increase in baseflow. Five responses (Figure 6.11) are evaluated in this scenario: (1) runoff, (2) sediment, (3) percolation, (4) actual evapotranspiration, and (5) soil water content. These responses are compared to those of the baseline model and scenario A to analyze the changes in these hydrologic components due to land use change.

The reforestation scenario was implemented as an almost complete replacement of land by forest across the Yocona River Basin. The only impervious surfaces in this scenario are residential and commercial. Agricultural, range grass, wetlands, and bare soil areas were completely eliminated. This scenario provided 46% increase in forest land, therefore accounting for a cumulative total of 95% of total land use and explores the changes in hydrological components associated with reforestation of the Yocona River Basin (Table 6.7).

The resulting changes for this reforestation scenario on a basinal scale reflect the benefits of reforestation as an option for land management in order to restore a watershed (Table 6.8).

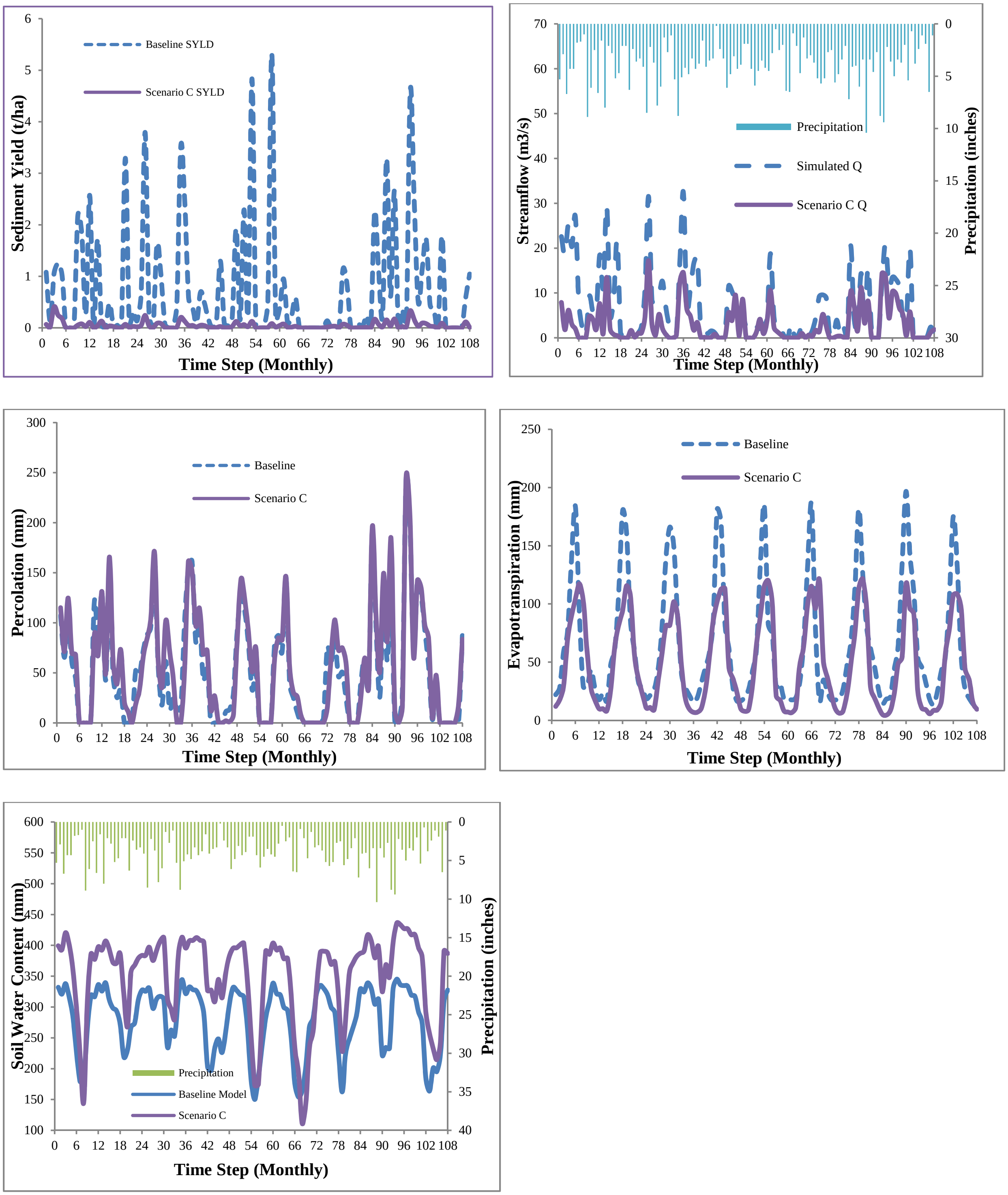


Figure 6.11: Clockwise from top (a ,b, c, d, and e) Graphs of monthly (a) sediment yield, (b) streamflow, (c) percolation, (d) actual evapotranspiration and (e) soil water content for years 2002-10 (108 months) period for the Yocona River Basin

Land Use	**Baseline land use (%)**	**Scenario C land use (%)**	**Description**
Water	1.16	1.16	Ponds, lakes
Roads	3.68	3.68	Transportation
Residential Areas	1.51	0	1-4 unit/acre
Commercial lands	0.06	0	Business, commercial lands
Septic Area	0.005	0	Septic
Bare soil	0.03	0	Open field
Forest Trees Deciduous	23.51	31.84	Oak, Maple
Forest Trees Evergreen	16.86	41.29	Pine
Forest Trees Mixed	8.58	22.03	Pine, Oak, Aspen
Rangeland	15.56	0	Grasses, shrubs, pasture
Agriculture	20.72	0	Soybean, cotton, corn,
Wetlands	8.32	0	Wetlands (Forested, non-forested, mixed)
Total	100	100	

Table 6.7: Land use percentage (%) for baseline model and scenario C

	Sediment yield (t/ha)	**Water yield (mm)**	**Percolation (mm)**	**Surface Runoff (mm)**	**ET (mm)**
Baseline Model	1.09	607.61	370.22	198.1	740.82
Scenario C	0.28	805.41	482.17	163.44	486.14
% difference	-74.30	32.60	30.24	-17.50	-34.38

Table 6.8: Average annual basinal values for hydrological components for baseline model and scenario C

The reforestation of the Yocona River Basin resulted in a substantial decrease in average annual sediment yield of 74.3% (Table 6.8). This significant decrease might be a result of the reduction in siltation and a decrease in curve number. The water quantity calculations (Water yield and surface runoff) showed an increase in water yield and a decrease in surface runoff, these findings serves as a useful indicator for both hydrological improvements (e.g., enhanced baseflow and percolation) and reductions in sediment yield. An association between the increase in percolation and reforestation can be indicated from the comparison between variations of average annual basinal percolation/water yield and changes in land use and land cover.

The 34.38% decrease in average annual ET (Table 6.8) suggest that majority of the precipitation percolates and might not be readily available for ET due to massive plant and leaf cover. ET values were expected to increase in scenario C due addition of forested lands (tree cover), however, low evapotranspiration rates can be attributed to shallow roots of trees and access at water depths. The Smithdale and Tippah soil types are mainly loose sandy soils that encourage rapid infiltration which might be an indication that trees will most likely experience severe water stress, which can result in a sharp decline in transpiration through loss of foliage and in extreme cases, death.

CHAPTER 7 – SCENARIO ANALYSIS

To explore the sensitivity of model / subbasins output to land use/ land cover changes, mainly on the sediment yield, surface runoff, nitrogen and phosphorus yield, and groundwater nitrate loadings of the Yocona River Basin, three land use scenarios were developed and explored. Attempts were made to ensure the scenarios were realistic scenarios within the study area.

It is crucial to know the subbasinal response of hydrological processes to changes in land use scenario in order to quantify the impacts associated. Select results from the three scenarios introduced in chapter 6 are discussed and presented in digitized format to show changes in subbasinal level.

Scenario A

The changes discussed in this section pertain to sediment yield, surface runoff, and streamflow. In comparison with the baseline model, there is a significant increase in sediment yield in subbasins 1 and 14 for scenario A (Figure 7.1). Sediment yield from other subbasins remained the same or decreased. Sediment yield increase in these subbasins (1 & 14) and this might be due to urbanization in subbasin 5 (City of Oxford). Another possible reason for this increase in sediment yield is an increase in discharge/surface runoff from newly urbanized surfaces. Subbasin 14 is directly down gradient from subbasin 5, the volume of runoff from subbasin(s) 5 and 10 would add to the increase in sediment yield from subbasin 14. According to Douglas (1996), urbanization could increase sediment yield from unstable terrain by two to three orders of magnitudes in catchments of several km^2.

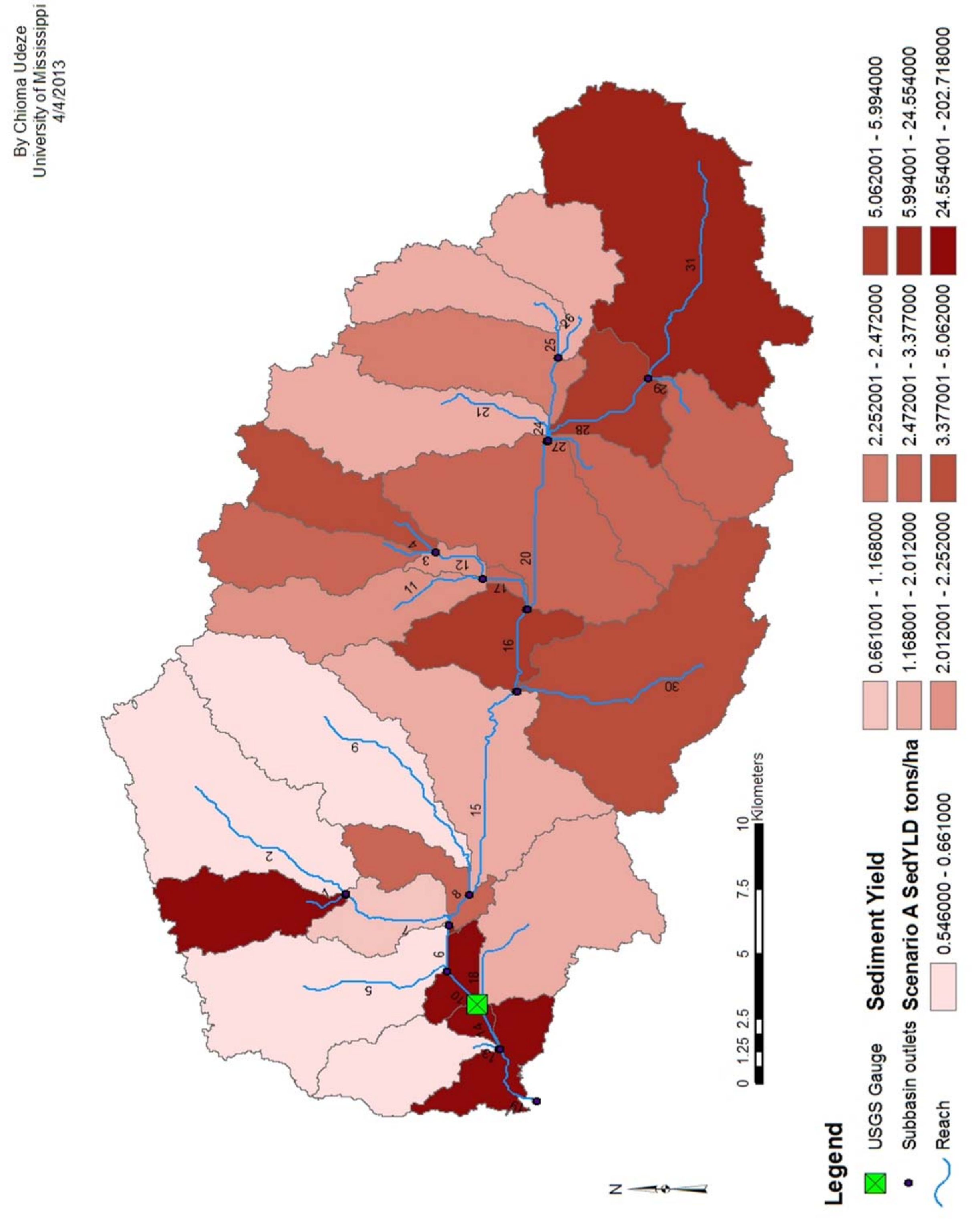


Figure 7.1: Sediment Yield for Scenario A generated by ArcSWAT

There is a significant increase in surface runoff associated with scenario A in subbasin 1 (Figure 7.2.), this is as a result of urbanization in the subbasin 5. There is a positive correlation between sediment yield and increase in in surface runoff for subbasin 1.

Streamflow response in scenario A is with an increase in the reach (stream channel) in the subbasins downstream (Figure 7.3). Flow downstream increases at least 30% in reaches associated subbasins 1, 6, 7, 14, 10 and 19. It can be inferred that peak discharge occurs when infiltration is reduced by impervious surfaces.

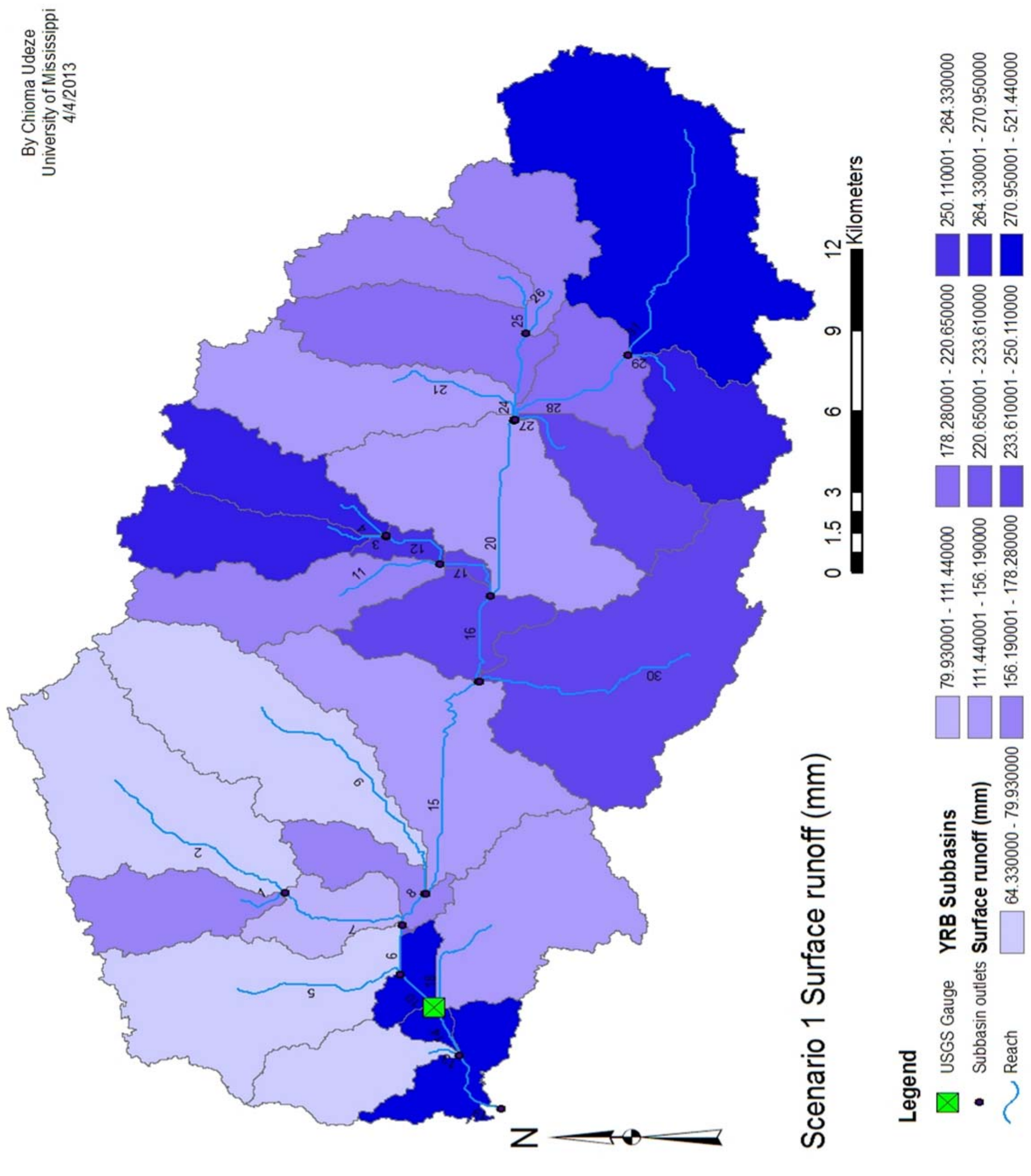


Figure 7.2: Surface Runoff for Scenario A generated by ArcSWAT

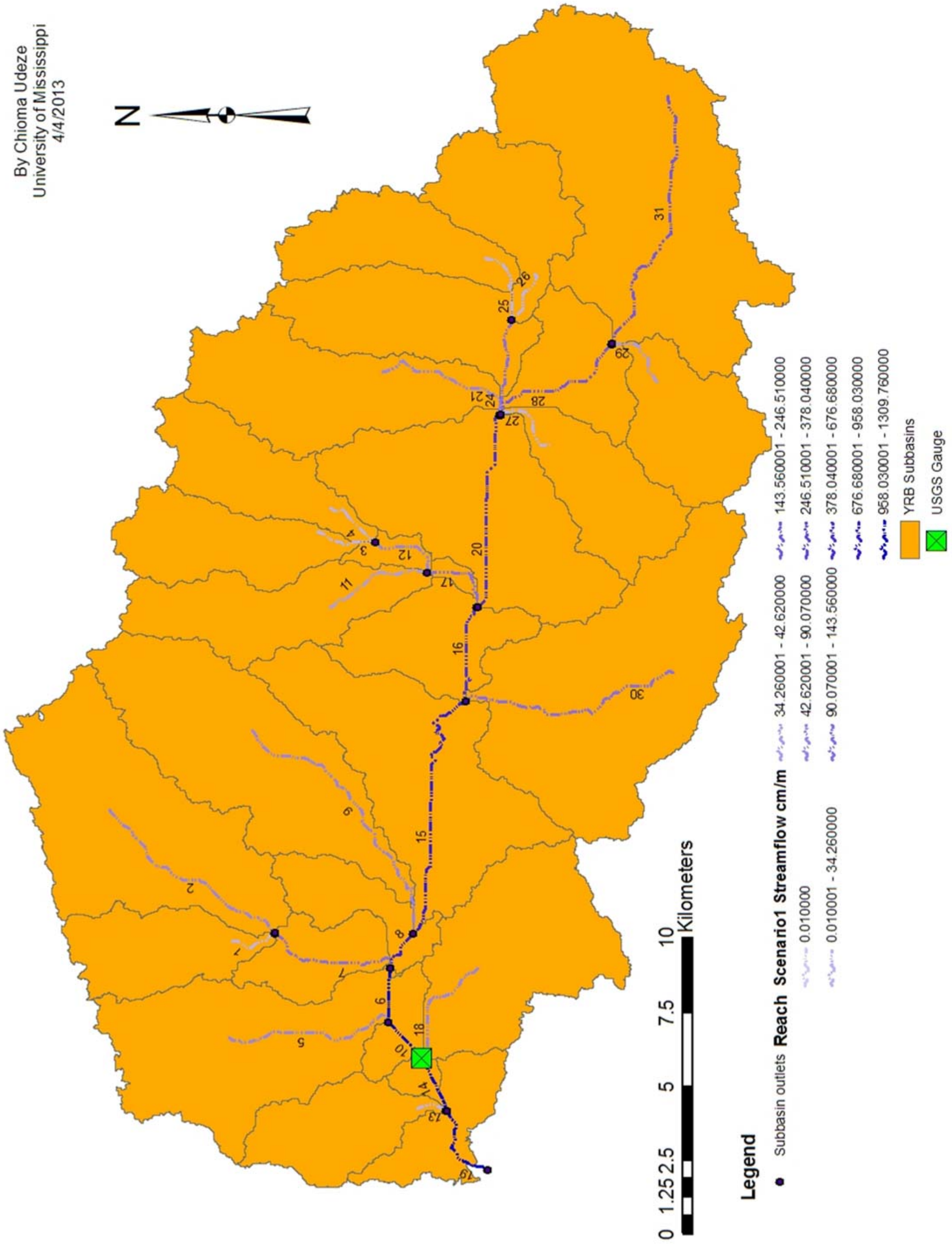


Figure 7.3: Streamflow map for scenario A generated by ArcSWAT

SCENARIO B

The impacts of BMP in the Yocona River Basin were examined by presenting basinal-scale changes. Sediment yield, nitrogen and phosphorus yield, and nitrate transported into groundwater are presented examined in for this scenario. Scenario B results were compared to results from scenario A to assess the effectiveness of adding BMP to the basin.

Parallel terraces and field borders are implemented to reduce soil loss from upland areas, their efficacy can be evaluated at the watershed scale. Model predictions for scenario B (Figure 7.4) shows a significant reduction in sediment yield, the most significant reductions being in subbasins 1, 6, 10, 14, and 19. Subbasin 19 being the most positively impacted by the addition of BMPs. The change in subbasin 19 is from 226.402 t/ha of sediment yield to 12.465t/ha. This order of magnitude in reduction occurs because the cumulative effectiveness of structural BMP applied upstream and also as a result of the cumulative reductions in sediment from all the subbasins. On the downside, sediment yield from subbasin 12, 15 and 28 increased, the reason for this increase might be attributed to the unsuitability of the types of BMP implemented and the types of soils in the subbasins. Subbasin 15 and 28 are dominated by Chenneby and Providence soils (silt loam), these soils are known to be frequently flooded and highly susceptible to erosion. The best solution for this subbasin would be not to implement any type of structural BMPs in these subbasins (15 &28) because their sediment prior to were stable.

Total N and total P yields (Figure 7.5 and 7.6) from the subbasins are highly correlated to simulated sediment yields (Figure 7.4). The effects of instream processes that could cause changes in the fate of nutrients were negligible for the study. Without BMP (Scenario A), total P predictions by the SWAT model were over 200 percent higher in subbasins 10, 14, and 19, in comparison to scenario B.

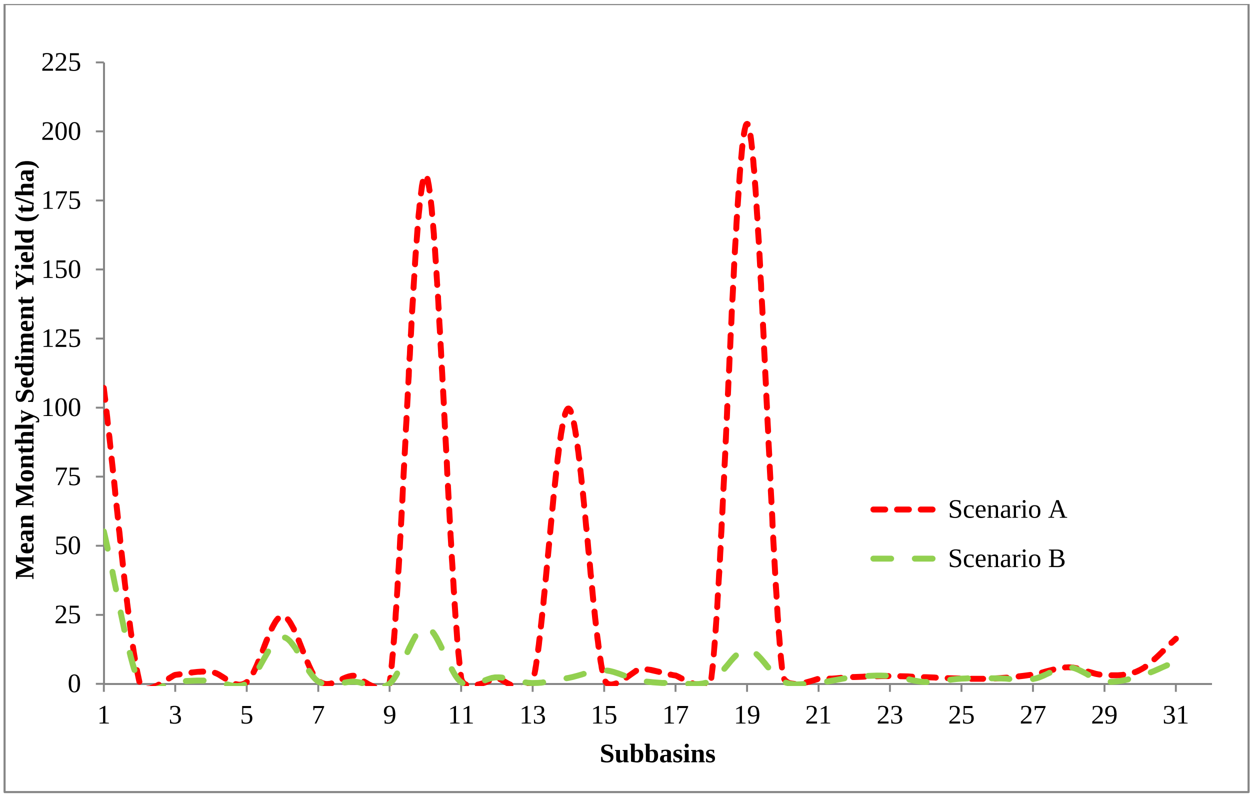


Figure 7.4: Mean monthly sediment yield in subbasins for scenario (s) A and B

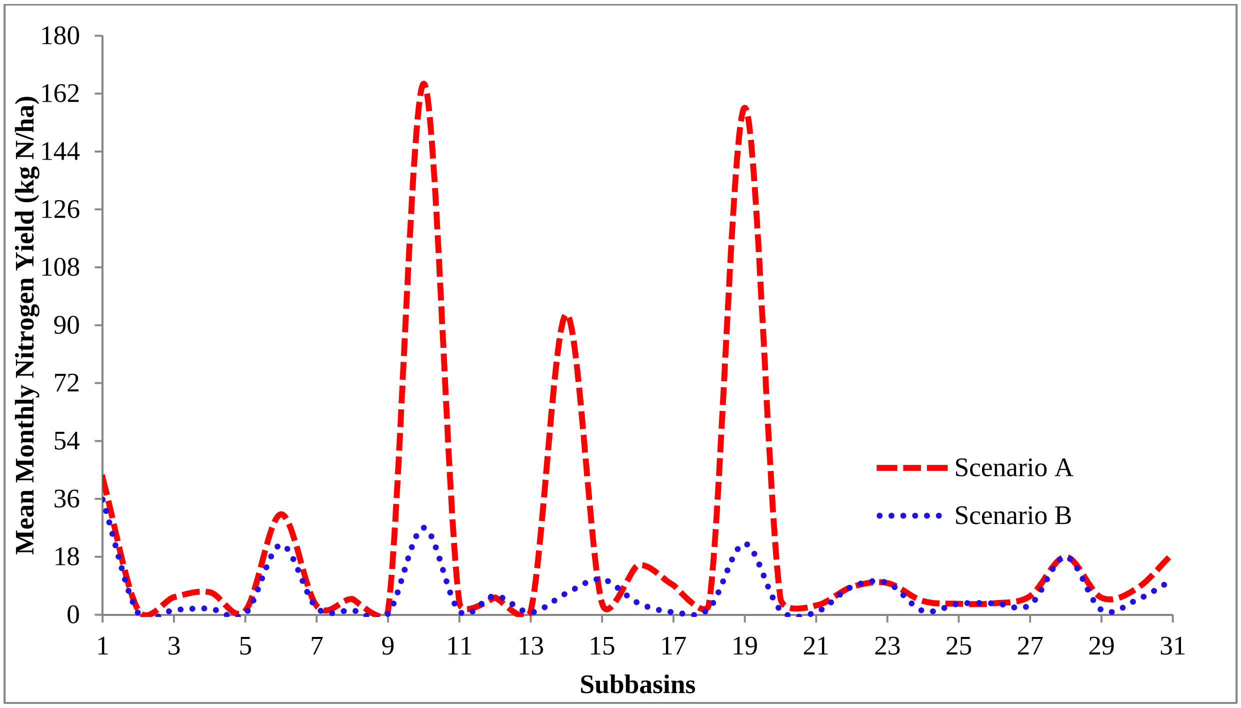


Figure 7.5: Mean monthly total N yield in subbasins for scenario (s) A and B

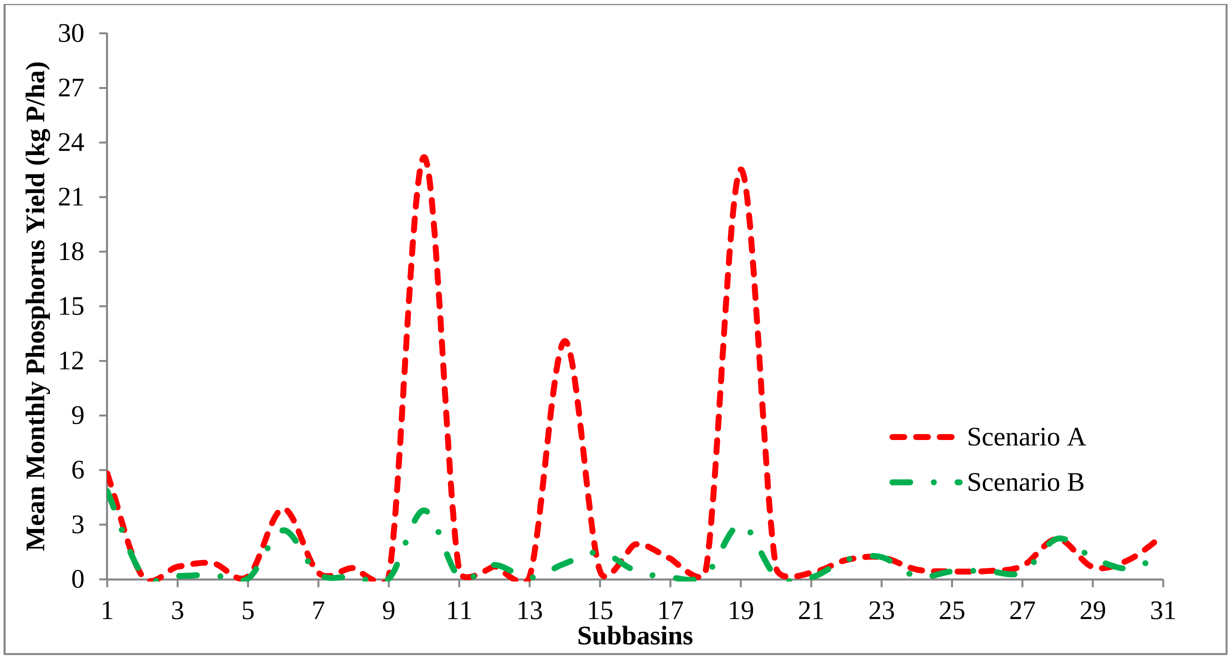


Figure 7.6: Mean monthly total P yield in subbasins(s) for scenarios A and B

BMP effect on groundwater

While BMPs did not contribute to appreciable nitrate loading reductions in groundwater (Figure 7.7), there is a significant increase in the nitrates transported into groundwater in subbasins 10, 14, 15, and 19. This was anticipated because the effectiveness of BMP on reducing nutrients leaching into groundwater is unknown. The types of structural BMP implemented might not have been suitable for subbasin 15 hence the increase in groundwater nitrate loadings. This result implies that it might not be beneficial to implement the same type of BMP on all subbasins in the watershed. Interestingly, although the increase in groundwater loadings in the above subbasins, nitrates loadings for subbasins 1- 13, 16, 18, 20-30 decreased an average of 18%, this indicates that not only the types of BMP but also their locations in the basin play a significant role.

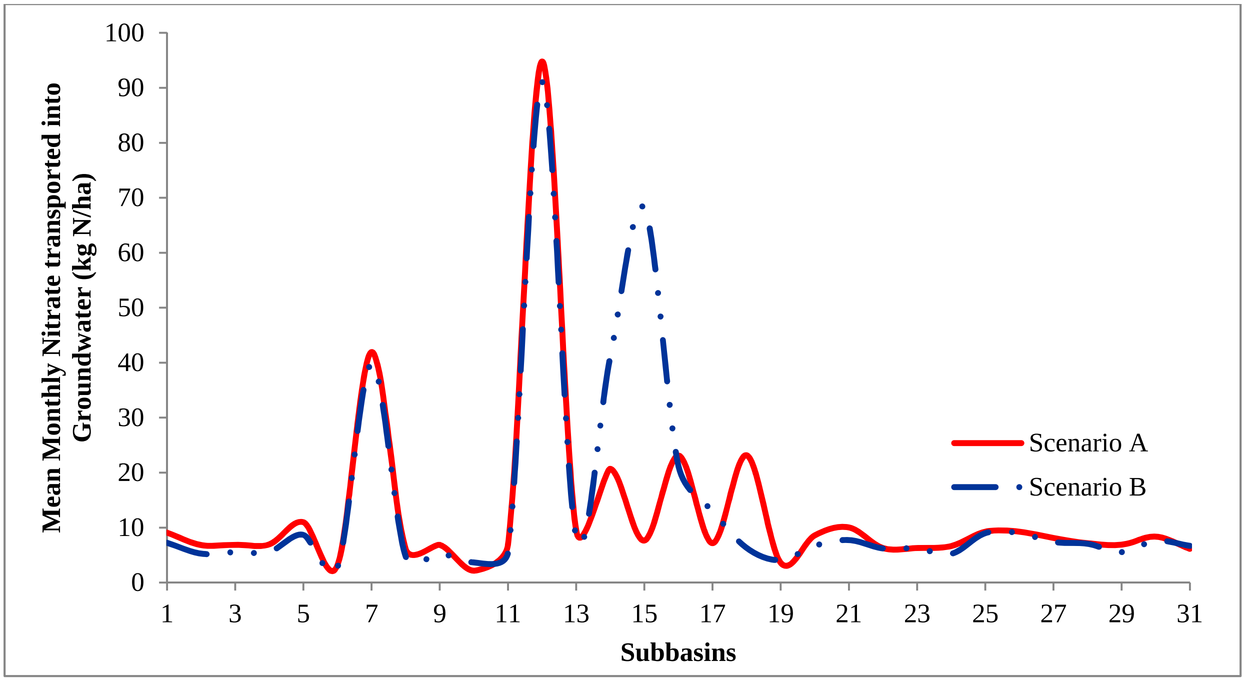


Figure 7.7: Mean monthly nitrates transported into groundwater in subbasins for scenario(s) A and B

SCENARIO C

The largest impacts on hydrologic processes occurred in the reforestation scenario, in which all agricultural, residential, and grassland areas were converted back into forest land uses. This scenario resulted in a massive overall decrease in sediment yield (Figure 7.8). Sediment yield response to forest land use change was anticipated. Subbasins 6, 10, 14, and 19 showed a significant decrease in their sediment yield, this is usually what happens when agricultural land is converted to forested land. Partial reforestation of the Yocona River Basin might be a solution to the sediment impairment problem of the river basin (MDEQ, 2008). The main sources of sediment flux in the basin are agriculture, rangelands, urban areas, gullies, land use activities and channel alterations. Conversion of rangeland which covers 15% of the land use area in Yocona River Basin to mixed forested areas would create significant changes in the sediment yield.

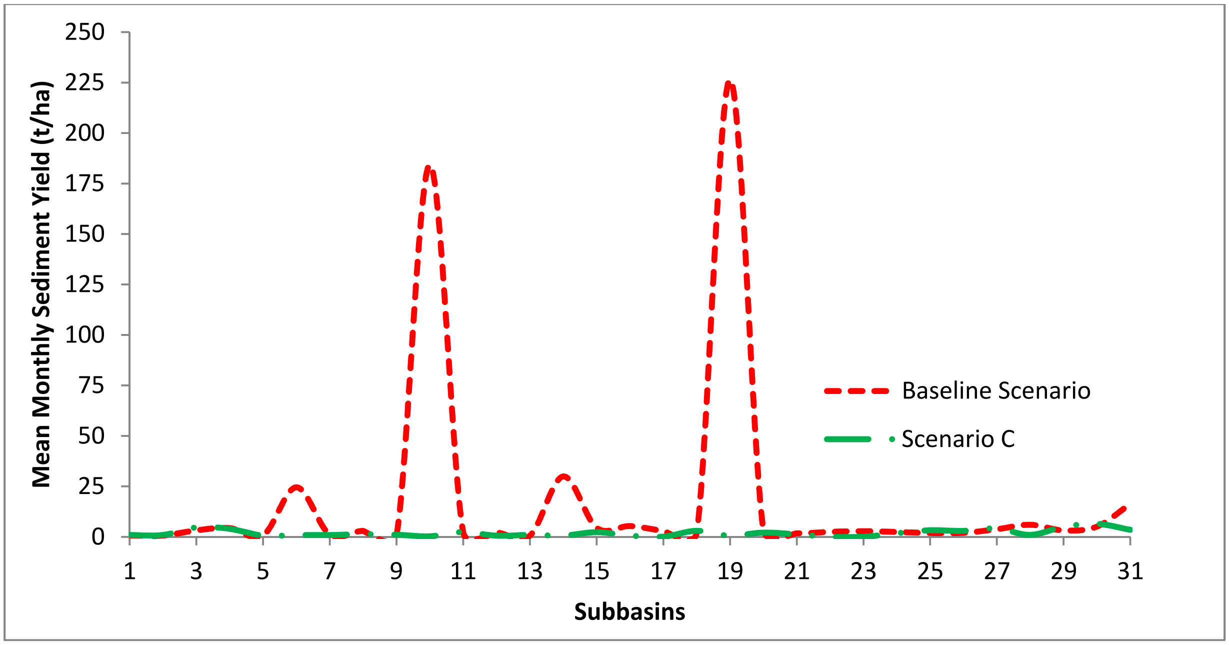


Figure 7.8: Mean monthly sediment yield in subbasins for baseline scenario and scenario C

Basin Scale Evaluation

The results from these scenarios showed which subbasins were susceptible to erosion and flooding and this information is useful for catchment management planning. For the baseline scenario, there was a reasonable agreement between modeled streamflow predictions and measured streamflow. Scenario A showed that urbanization will increase the amount of effective discharge during a high storm event, hence leading to erosion. Subbasins 1, 14, 10, 15, and 19 were tagged as areas susceptible to flooding and erosion due to their responses to the addition of impervious surfaces.

The impacts of BMP investigated in scenario B showed that BMP are effective in reducing sediment, total N, and total P loadings in a watershed. Structural BMP such as parallel terraces and field borders are very effective in reducing soil loss from upland areas; however, not all BMP are suitable for HRU combinations in a watershed. Subbasins 15 and 28 experienced an increase an increase in sediment yield after BMP were applied; this indicates that these subbasins are quite sensitive to land management practices. The effectiveness of BMP on groundwater nitrate loading could not be adequately quantified in this study. The groundwater nitrate loading in subbasin 15 increased when BMP were introduced. It can be concluded that BMP might not be the direct solution to groundwater impairment; rather, a control in fertilizer application should be implemented.

The reduction in sediment yield for scenario B well agrees with Santhi et al. (2009) findings that showed reduction in sediment and nutrient yield up to 99% at farm level (subbasin 19) and at least 2% at watershed level. The overall response to BMP application in scenario C indicated that its implementation was effective in reductions for sustainable water resource management at a basinal scale.

The changes in hydrological components associated with basin reforestation showed an overall improvement in sediment yield. The result from this scenario could just be the solution to sediment yield and periodical flooding in the Yocona River Basin. Analyses of result gathered from the three scenarios were used to designate “sensitive” subbasins (Figure 7.9).

Subbasin 1, 10, 15, 19, and 28 are very sensitive to land use and land management practices (Figure 7.9). These subbasins either showed worsening, slight improvements or no change at all when land use change was implemented. The properties of the soils (Table 4.1) that dominate the aforementioned subbasins have high susceptibility to erosion, slope instability and flooding.

These subbasins are very sensitive to flooding and sediment yield, proper assessment must be done before land management practices are implemented on these subbasins. Subbasin 15 falls into the flood plain of the Yocona River Basin and could either be converted into a forested wetland as a step towards ecological reforestation.

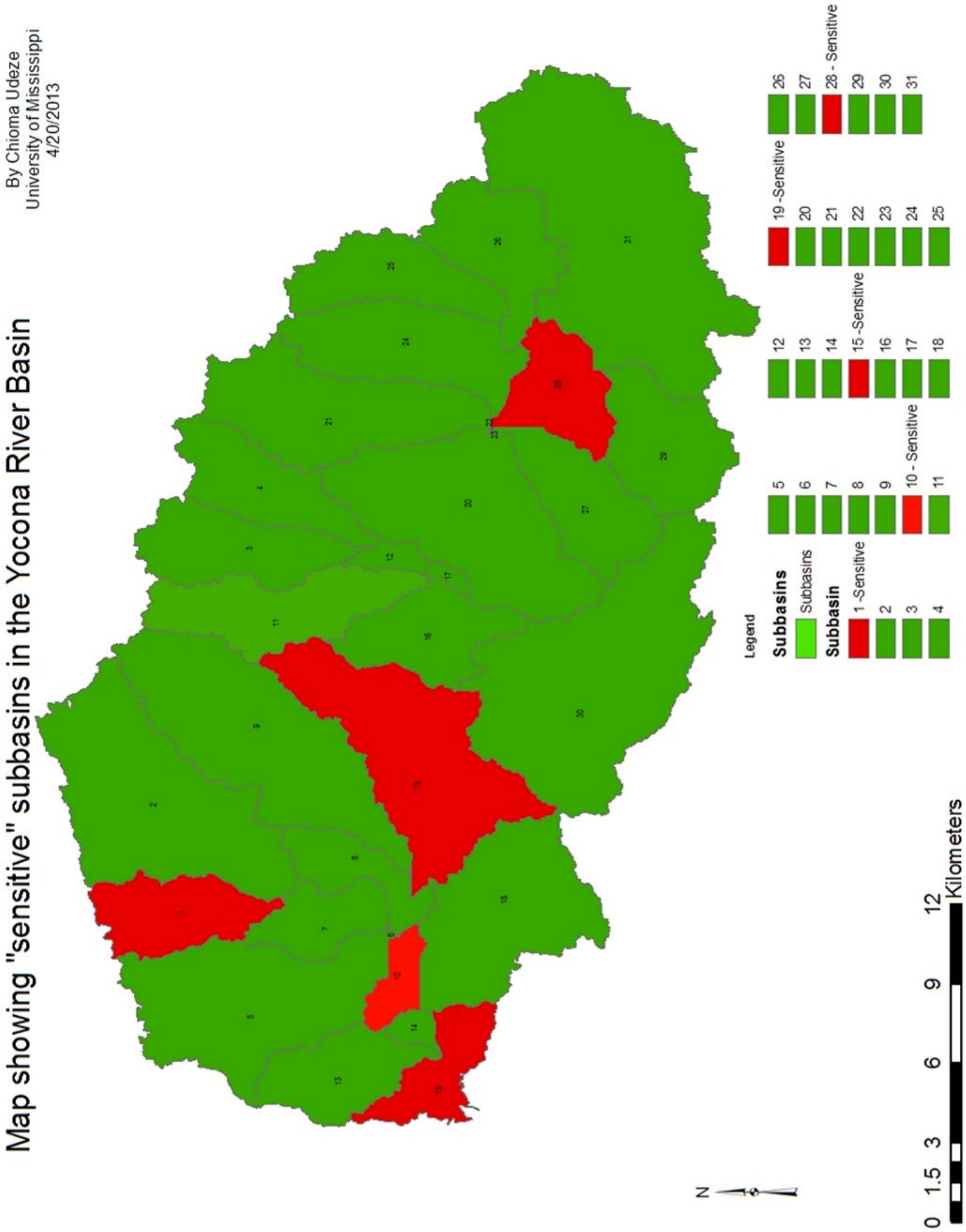


Figure 7.9: Map showing flood and excess sediment yield "sensitive" subbasins in the Yocona River Basin, Mississippi.

CONCLUSION

In this study, the impact of land use change is examined for the Yocona River Basin in Mississippi. The developed framework and methodology for the WIM model can be applied in other watersheds with limited data availability. SWAT was the hydrological model of choice for processes simulation and land use impact assessment. Three different land use change scenarios were applied to the study basin and their outputs were compared to the ones of the baseline run. All three scenarios responded different according to the land use and land management practice implemented.

The response of the basin can be summarized in the following:

1. Expansion of impervious cover in the City of Oxford and ETJ by at least 50% resulted in a mean monthly increase in the river discharge up to 30% as observed in the simulation.
2. The addition of BMP in the basin resulted in a significant decrease in sediment, total N, and P yield in the basin. However, the effectiveness of BMP on groundwater loadings is inconclusive. A definitive interpretation of the quantitative groundwater nitrate loading results cannot be evaluated.
3. The final reforestation scenario of the Yocona River basin produced a significant improvement (reductions) in sediment yield and surface runoff.

The WIM model can serve as a decision making tool for city planners as a land management assessment technique before actual implementation. It simplifies the watershed modeling processes for users not familiar with SWAT and other spatial analysis software. The

WIM model also helps the user make decision on the source and type of data needed during the data aggregation process.

The overall results from this study showed that SWAT is a very useful tool for investigating alternative watershed management strategies on watershed hydrologic and water quality response. Calibration and validation of the model is a key factor in reducing uncertainty and increase user confidence in its predictive abilities, which makes the application of the model very effective for planning purposes.

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LIST OF APPENDICES

APPENDIX A: DETAILED MODELING METHODOLOGY

APPENDIX A

DETAILED MODELING METHODOLOGY

SWAT MODELING PROCESS

The process involved in modeling a watershed using SWAT depends on the objectives of the model. In this study, the model objective is to quantify the impacts of land use on the watershed.

SWAT Model setup for the Yocona River Basin

The SWAT model was set up using data described in chapter 3 and the ArcSWAT interface. The interface facilitated creation of the stream network, delineation of the watershed boundary from the DEM and subdivision the watershed. HRUs were generated from the land cover and soil layers. Climate data was integrated spatially and assigned to the various subbasins.

The model setup steps are detailed below:

Automated Watershed Delineation

A 10 meter grid cell resolution Digital Elevation Model (DEM) (Figure A1) is a digital representation of area topography. The Automated Watershed Delineation process requires a DEM to determine watershed boundaries, contributing source area, and watershed outlet. The automated watershed delineation process automatically processes all the digital hydrologic properties of the watershed and outputs the entire subbasins that contribute to the flow at the outlet.

The minimum and maximum elevations of the study area DEM are 262 and 627 feet (approximately 81.6 and 191.1 meters, respectively); the total area covered by the basin is 638.3 km^2. Flow direction and flow accumulation are automatically calculated during the watershed delineation process. A contributing source area (CSA) for the watershed is required during this process to determine the level of geometric complexity in the delineated watershed. It is the threshold at which flow becomes channelized. Lower CSAs produce more watershed elements; higher CSAs, fewer subbasins. The CSA used in this study was 1400; the value produced the most reasonable elements given that the DEM covered such a large area. Because this model acts as a pollution model as well, it is necessary to make the CSA large, so it can cover as much detail as possible for instance, increase area for accurate pollution values. The number of subbasins and outlets produced after the automated delineation process was 31. Watershed outlet location is defined as the location where observed streamflow exits the subbasin. Adding outlets at the location of monitoring stations is required for comparison of measured and predicted flows.

HYDROLOGIC RESPONSE UNIT Analysis HRU

This is one of the most important steps involved in watershed modeling using SWAT. Hydrologic Response Units are portions of the subbasins possessing unique combinations of land use, management or soil attributes and are incorporated into the SWAT model to account for the complexity of the landscape within the sub-basins (Neitsch et al., 2005). The calculation of subbasin parameters done in the automated watershed delineation step are divided into different HRUs based on their combinations of land use, soil and slope combinations. This stage of watershed modeling requires the land use map, soil map, and slope definition. All spatial datasets can either be in ESRI grid, shapefile, or geodatabase feature class format.

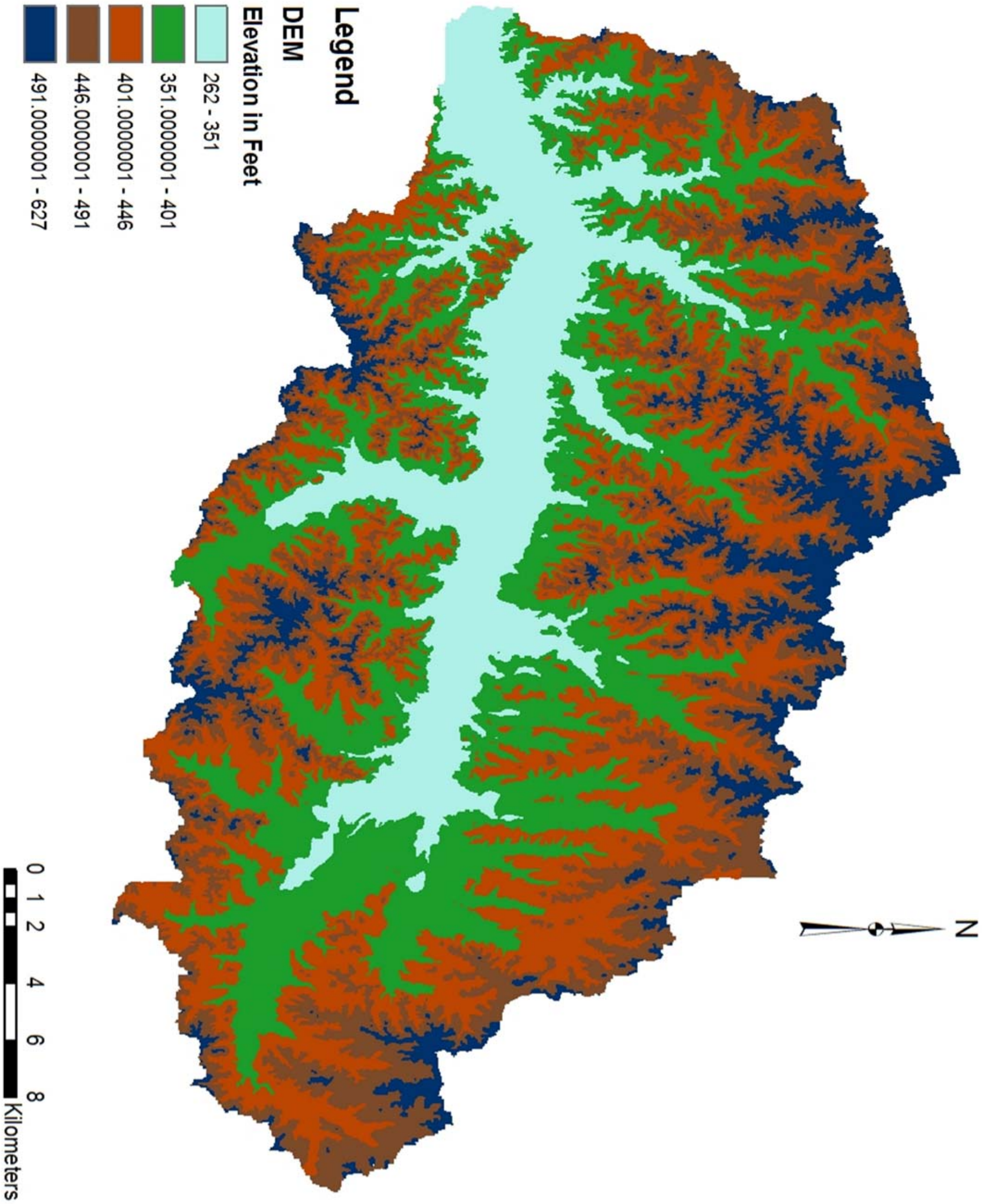


Figure A1: Digital elevation map of the study area watershed generated by ArcSWAT

Land Use/Soil/Slope Definition

Hydrologic parameters must be derived from the topography as well as the land use and soil data to ensure that the simulation parameters are accurate in the watershed being modeled. Hydrologic models require different sets of parameters. Land use and soil datasets must be in the aforementioned formats and must the same spatial reference as the SourceDEM; this step permits SWAT to appropriately upload the files to fit the delineated watershed area.

Land use and soil maps are imported along with their respective user tables. This process links the maps and slopes to the SWAT database and performs an overlay. SWAT has the option to either upload a classified user table of the land use and soil maps or choose LULC USGS Table, soil name or STMUID.

The land use and soil maps used for this study were in part user classified, therefore, the option for uploading the user table was chosen. The user table is a personalized list of land use classes and soil names that is linked to the SWAT ***userssoil*** and ***LULC table*** database for easy access by the user.

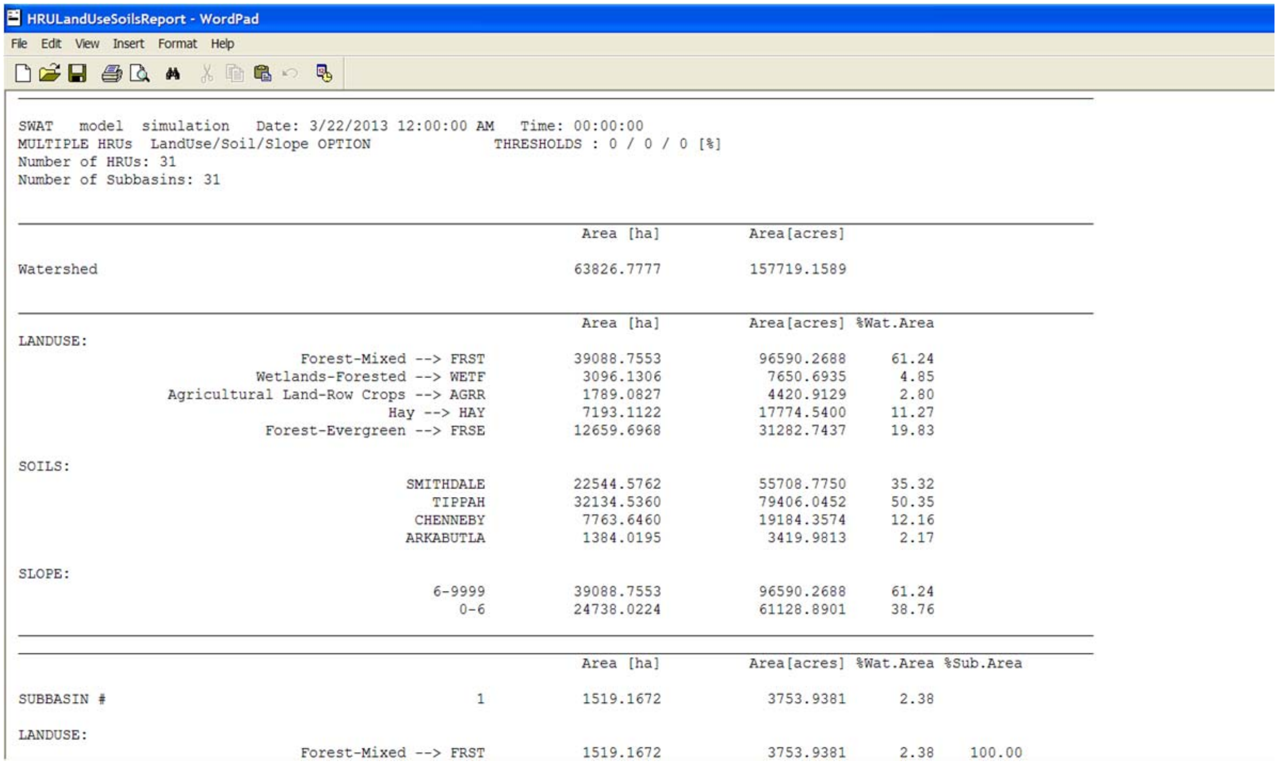
SWAT checks for minor errors in raster datasets and user tables. If the landuse and soil maps imported are correctly spatially referenced and correspond to the look-up user table then the datasets can be reclassified to match the coding in the SWAT database. A detailed description of the steps involved the Land Use/Soil/Slope Definition is reviewed in Section 6 of the ArcSWAT Documentation (Srinivasan et. al., 2010).

After the raster datasets have been imported and reclassified, the next procedure for HRU definition is the slope discretization. The slope discretization for the watershed is performed using commands from the HRU Analysis menu on the ArcSWAT toolbar. The slope discretization determines land use/soil/slope class combination for each sub basin. Slope characterization is based upon the DEM defined in the watershed delineation process. For this model, the multiple slope option was chosen, the number of slope classes chosen was 2 and 6% was used as the slope upper limit.

The layers are overlaid to create a new layer called *FullHRU* which is added to the model table of contents. This layer contains the unique combinations of the land use, soil, and slope classes. Reports (Figure A2) named HRULandusesoils report and Final HRU Distribution are generated during the overlay process. This report provides a detailed description of the distribution of the land use, soil, and slope classes in the watershed and subbasins

Steps	**Land Use Layer**	**Soil Layer**	**Slope**
1	Import referenced land use Layer	Import referenced soil layer	-
2	Select grid field = Value	Select grid field = STMUID	-
3	Upload lookup table	Upload lookup table	-
4	Verify land use fields	Verify soil names	
5	Reclassify	Reclassify	-
6	-	-	Define slope
7	-	-	Choose upper/lower limit
8	OVERLAY	OVERLAY	OVERLAY

Table A1: A step by step procedure of the HRU analysis stages.



```
SWAT   model  simulation   Date: 3/22/2013 12:00:00 AM   Time: 00:00:00
MULTIPLE HRUs  LandUse/Soil/Slope OPTION              THRESHOLDS : 0 / 0 / 0 [%]
Number of HRUs: 31
Number of Subbasins: 31


                                                                Area [ha]          Area[acres]

Watershed                                                      63826.7777          157719.1589


                                                                Area [ha]          Area[acres] %Wat.Area
LANDUSE:
                                Forest-Mixed --> FRST          39088.7553           96590.2688     61.24
                           Wetlands-Forested --> WETF           3096.1306            7650.6935      4.85
                 Agricultural Land-Row Crops --> AGRR           1789.0827            4420.9129      2.80
                                          Hay --> HAY           7193.1122           17774.5400     11.27
                            Forest-Evergreen --> FRSE          12659.6968           31282.7437     19.83

SOILS:
                                            SMITHDALE          22544.5762           55708.7750     35.32
                                               TIPPAH          32134.5360           79406.0452     50.35
                                             CHENNEBY           7763.6460           19184.3574     12.16
                                            ARKABUTLA           1384.0195            3419.9813      2.17

SLOPE:
                                               6-9999          39088.7553           96590.2688     61.24
                                                  0-6          24738.0224           61128.8901     38.76


                                                                Area [ha]          Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                          1           1519.1672            3753.9381      2.38

LANDUSE:
                                Forest-Mixed --> FRST           1519.1672            3753.9381      2.38    100.00
```

Figure A2: HRU report generated by ArcSWAT

HRU definition

Once the land use, soil and slope data layers have been imported and overlaid, the distribution of hydrologic response units (HRUs) within the watershed must be determined. Unique land use/soil/slope combinations will be created for each subbasin by subdividing them into groups having similar unique land use and soil combinations. SWAT uses this process to show differences in evapotranspiration, runoff, and other hydrologic conditions for different land use/covers and soils. Runoff is predicted separately for each HRU to obtain runoff for the watershed (Srinivasan et al., 2010). According to Srinivasan (2009) this increases the accuracy of flow and sediment yield predictions and provides a much better physical description of water balance.

The selections in the HRU definition routing, under the HRU analysis section determines how detailed the HRUs will be; more detail creates more HRUs which causes the model to take longer to run. For this study, multiple HRUs threshold was chosen for the hydrologic model because of the lack of homogeneity within the subbasins created. Multiple HRU option creates multiple HRU within each subbasin. The combinations of land use, soil and slope class in the subbasin are used to generate the HRU. When the HRUs are generated, the definition is complete. A report named Final HRU Distribution is generated; this report provides a detailed description of the land use, soil, and slope classes after the application of thresholds for the watershed and all subbasins.

INPUT WEATHER DATA

The climate data used in this model are daily precipitation, solar radiation, wind speed, relative humidity and temperature data from January 1, 2000 – December 31, 2010. The climate data were obtained from the NCEP global weather center for the National Oceanic and Atmospheric Administration (NOAA) *GHCND: University, MS, Lafayette Springs, MS, and Water Valley, MS,* gauging station located at Lafayette County, Mississippi. The climate records from these stations were used for generating the precipitation, solar radiation, temperature, relative humidity, and wind speed files for running SWAT. The files were processed by using Excel software to convert the original rainfall data, which was in tenths of a millimeter to millimeter and then saved in a .dbf format. The weather database files (Table A2) were saved in the Yocona model database. A custom database for Yocona River was created for input as a custom weather database. The weather station information was then appended onto the *Swat2009database*. This process generates spatial layers of the weather stations and loads the observed weather data into SWAT weather files.

Climate Data	**Format**	**Fields**	**Files**
Precipitation	Database .dbf	Station Name, Lat., Long., Elevation (m)	Data (mm), position,
Temperature	Database .dbf	Station Name, Lat., Long., Elevation (m)	Data (Celsius), min, max
Solar Radiation	Database .dbf	Station Name, Lat., Long.	Data (MJ/m^2)
Wind Speed	Database .dbf	Station Name, Lat., Long.	Data (m^2)
Relative Humidity	Database .dbf	Station Name, Lat., Long.	Data (fraction)

Table A2: Weather database format, fields and data units

For each weather component loaded, each subbasin is linked to the nearest gauge. After the weather data has been loaded correctly, the model is now ready to write its input files.

INPUT FILES

The write input tables menu of SWAT contains items that allow the user to build database files containing information needed to generate a preliminary simulation for SWAT. SWAT uses Manning’s N and heat input values to calculate the heat units required to reach maturity for different vegetation types. The files written in this process are: watershed configuration file, soil data, weather generator data, general subbasin data, HRU general data, main channel data, groundwater data, water use data, management data, soil chemical data, pond data, stream water quality data, watershed general data, watershed water quality data, and master watershed file. The next step after all the default inputs have been generated is the SWAT Simulation

RUN DEFAULT SIMULATION – BASELINE MODEL

The model is ready to run a simulation **only** after the required inputs are loaded correctly. The simulation dates are from the period of January 1, 2000 to December 31, 2010. The first 2 years

(2000 -2001) were used as a warm up period. The next 4 years were simulated for calibration and the last 5 years simulated were used for validation of the model. The results from the baseline model are discussed in chapter 5.

APPENDIX B: BASEFLOW SEPARATION

APPENDIX B

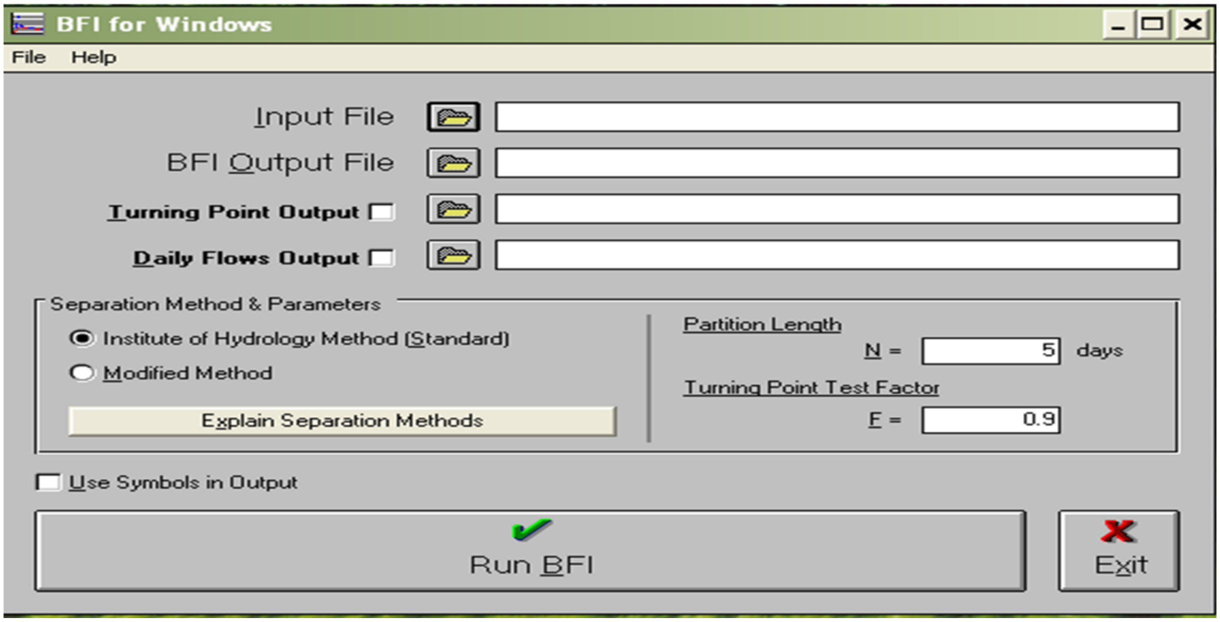
BASE FLOW SEPARATION

Stream flow, or discharge, is the volume of water that moves over a designated point over a fixed period of time. It is often expressed as cubic feet per second (ft^3/sec). Streamflow is directly related to the amount of water being carried out of the watershed into the stream channel. Groundwater seepage into a stream channel is called base flow. When collecting streamflow data, the total volume of flow is given i.e. base flow and runoff. However, SWAT simulation uses rainfall to simulate overland flow in a watershed as its output. In order to determine the contribution from overland flow in a watershed to the streams in the watershed, it is important to remove base flow from stream gauge data.

There are a variety of techniques suggested for separating base flow and direct runoff; however, it is unlikely that any two calculations for base flow separation will be the same for a particular area. A program called Base Flow Index (BFI) (Figure B1) was developed using the Institute of Hydrology procedures that were developed in 1980 (Wahl and Wahl, 1995). It was developed to make the base-flow separation process less tedious and more objective. The baseflow index is the total volume of base flow divided by the total volume of runoff for a period (Wahl and Wahl, 1995). The method combines a local minimums approach with a recession slope test. The program estimates the annual base-flow volume of unregulated rivers and streams and computes an annual base-flow index (BFI, the ratio of base flow to total flow volume for a given year) for multiple years of data at one or more gauge sites. Although the method may not yield the true base flow as might be determined by a more sophisticated analysis, the index has been found to be consistent and indicative of base flow, and thus may be useful for analysis of long term base-flow trends (Wahl and Wahl, 1995).

Using BFI for base flow separation

The BFI program was used to separate baseflow from total flow from stream gauge data downloaded from the USGS NSIP (National Streamflow Information Program). BFI program is software (Figure B1) that reads text formatted stream flow data as its input files and outputs results for baseflow and total flow. The only parameters required by the BFI interface are “N” number of days) and “F” (turning point factor). N refers to the number of days over which a minimum flow is determined. It is the connection of these minimum points that determines the baseflow.



Turning Point Output ☐

Daily Flows Output ☐

● Institute of Hydrology Method (Standard)

○ Modified Method

Partition Length

N = 5 days

Turning Point Test Factor

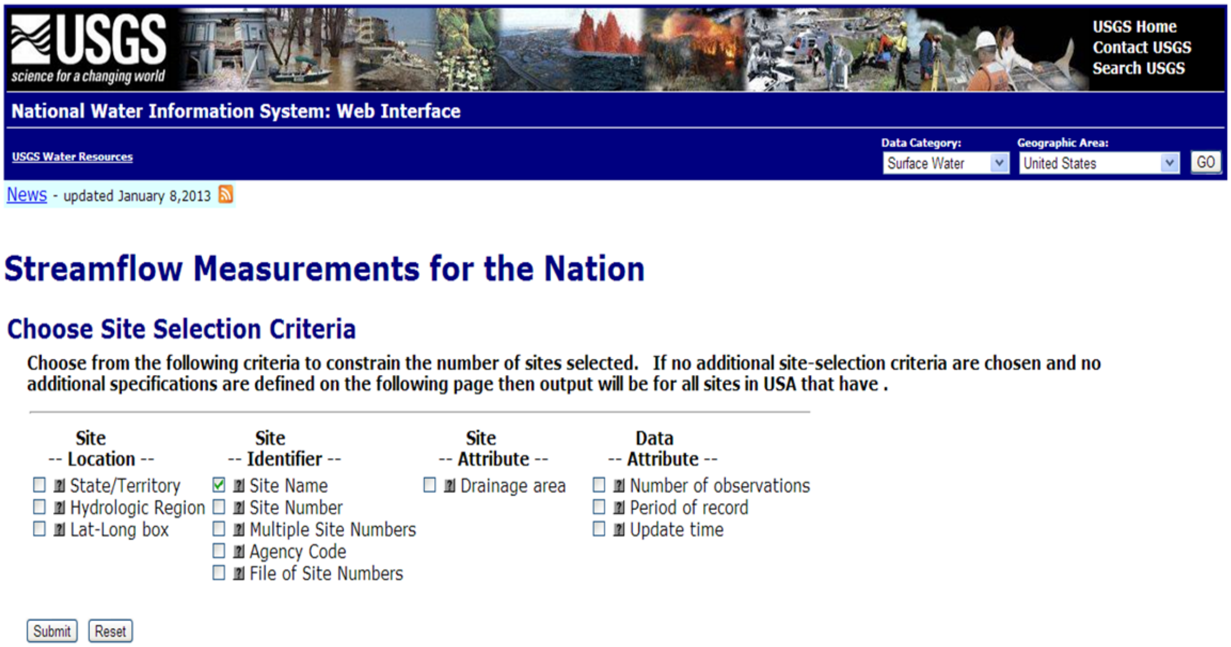
F = 0.9

☐ Use Symbols in Output

Figure B1: Base flow separator program interface

The input file for this program is directly from the USGS stream gauge data (Figure B2) that can be downloaded at http://nwis.waterdata.usgs.gov/nwis/measurement. The method of site identification was site number (07274000). Data for Yocona River Basin, Oxford were downloaded for 2000 – 2010 in tab separated format.

The BFI program is executed with the downloaded daily streamflow data (Figure B3), a file called flow3.bfi (Figure B4) contain the yearly values for baseflow index and a file called flow3.q (Figure B5) contains daily base flow and total flow for the Yocona Rive gauge.



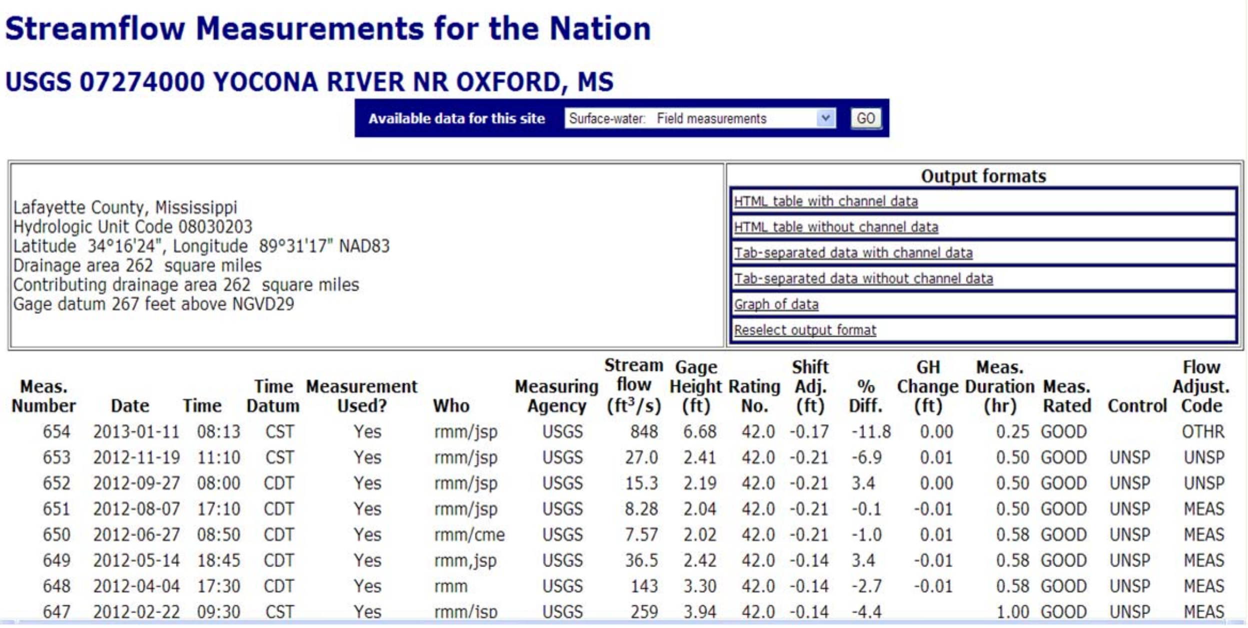
Streamflow Measurements for the Nation

Choose Site Selection Criteria

Choose from the following criteria to constrain the number of sites selected. If no additional site-selection criteria are chosen and no additional specifications are defined on the following page then output will be for all sites in USA that have .

Site -- Location --	Site -- Identifier --	Site Attribute --	Data -- Attribute --
☐ State/Territory	☑ Site Name	☐ Drainage area	☐ Number of observations
☐ Hydrologic Region	☐ Site Number		☐ Period of record
☐ Lat-Long box	☐ Multiple Site Numbers		☐ Update time
	☐ Agency Code		
	☐ File of Site Numbers		

Figure B2: USGS streamflow data download site



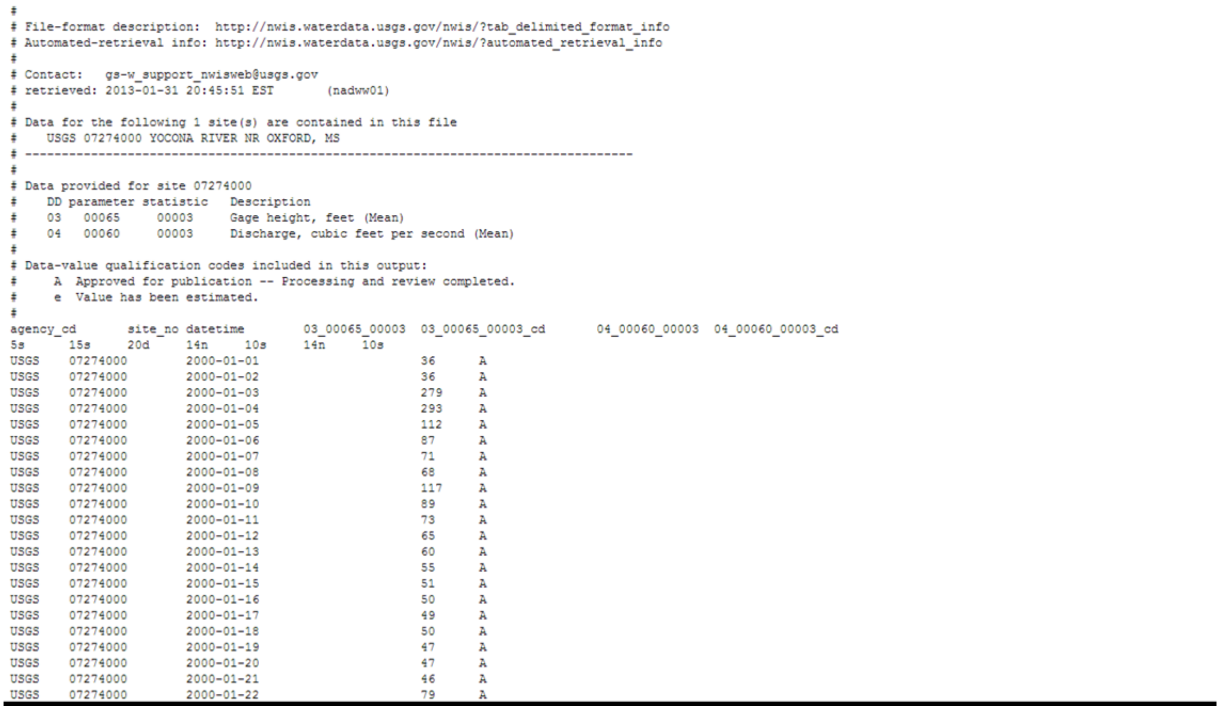
Streamflow Measurements for the Nation

USGS 07274000 YOCONA RIVER NR OXFORD, MS

Lafayette County, Mississippi
Hydrologic Unit Code 08030203
Latitude 34°16'24", Longitude 89°31'17" NAD83
Drainage area 262 square miles
Contributing drainage area 262 square miles
Gage datum 267 feet above NGVD29

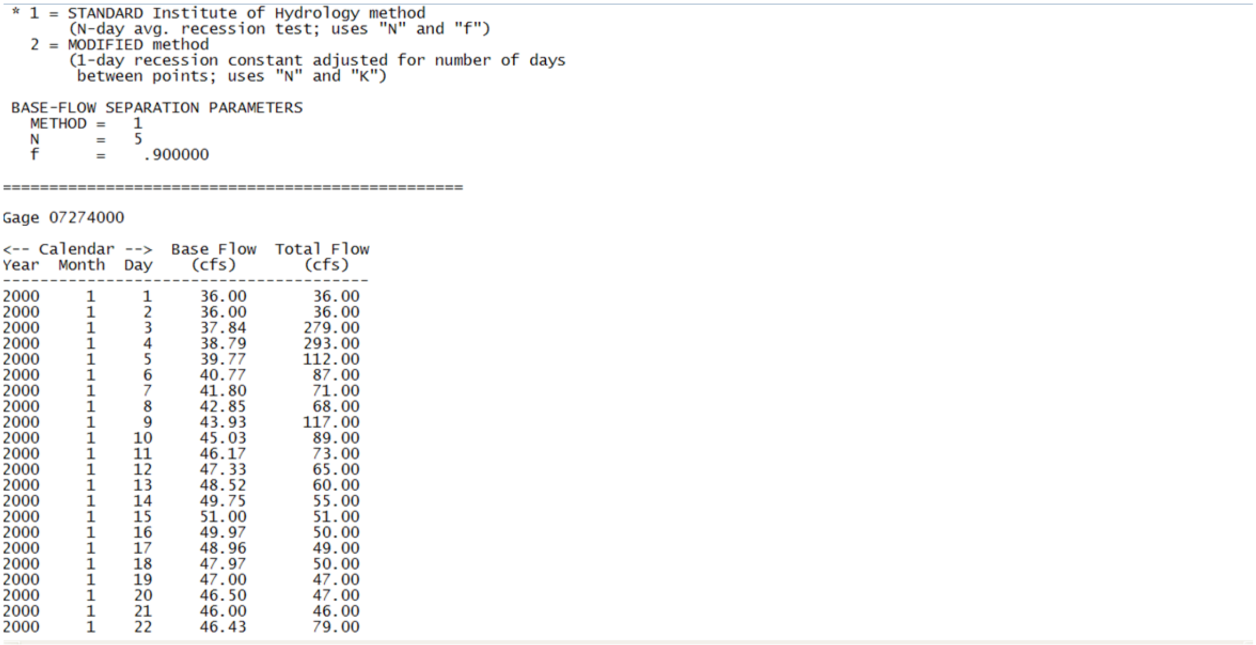
Meas. Number	Date	Time	Time Datum	Measurement Used?	Who	Measuring Agency	Stream flow (ft^3/s)	Gage Height (ft)	Rating No.	Shift Adj. (ft)	% Diff.	GH Change (ft)	Meas. Duration (hr)	Meas. Rated	Control	Flow Adjust. Code
654	2013-01-11	08:13	CST	Yes	rmm/jsp	USGS	848	6.68	42.0	-0.17	-11.8	0.00	0.25	GOOD		OTHR
653	2012-11-19	11:10	CST	Yes	rmm/jsp	USGS	27.0	2.41	42.0	-0.21	-6.9	0.01	0.50	GOOD	UNSP	UNSP
652	2012-09-27	08:00	CDT	Yes	rmm/jsp	USGS	15.3	2.19	42.0	-0.21	3.4	0.00	0.50	GOOD	UNSP	UNSP
651	2012-08-07	17:10	CDT	Yes	rmm/jsp	USGS	8.28	2.04	42.0	-0.21	-0.1	-0.01	0.50	GOOD	UNSP	MEAS
650	2012-06-27	08:50	CDT	Yes	rmm/cme	USGS	7.57	2.02	42.0	-0.21	-1.0	0.01	0.58	GOOD	UNSP	MEAS
649	2012-05-14	18:45	CDT	Yes	rmm,jsp	USGS	36.5	2.42	42.0	-0.14	3.4	-0.01	0.58	GOOD	UNSP	MEAS
648	2012-04-04	17:30	CDT	Yes	rmm	USGS	143	3.30	42.0	-0.14	-2.7	-0.01	0.58	GOOD	UNSP	MEAS
647	2012-02-22	09:30	CST	Yes	rmm/jsp	USGS	259	3.94	42.0	-0.14	-4.4		1.00	GOOD	UNSP	MEAS

Figure B3: Streamflow data for the Yocona River Basin



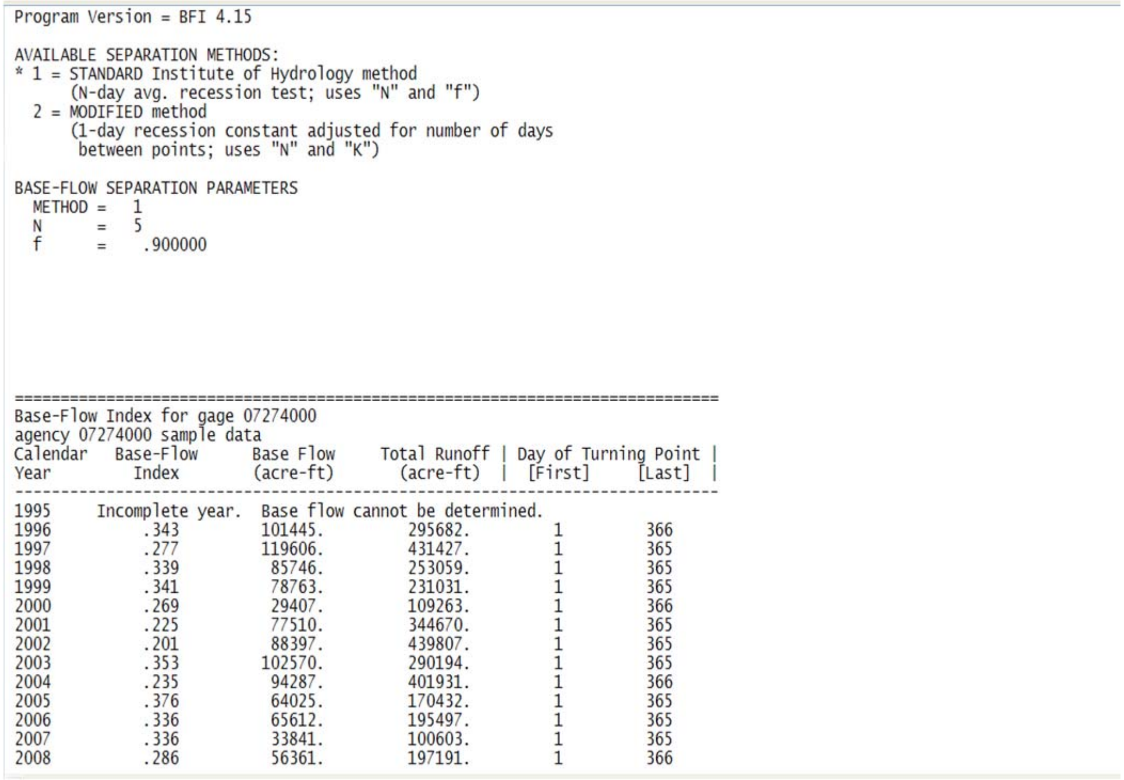
```
#
# File-format description:  http://nwis.waterdata.usgs.gov/nwis/?tab_delimited_format_info
# Automated-retrieval info: http://nwis.waterdata.usgs.gov/nwis/?automated_retrieval_info
#
# Contact:   gs-w_support_nwisweb@usgs.gov
# retrieved: 2013-01-31 20:45:51 EST       (nadww01)
#
# Data for the following 1 site(s) are contained in this file
#    USGS 07274000 YOCONA RIVER NR OXFORD, MS
# -----------------------------------------------------------------------------------
#
# Data provided for site 07274000
#    DD parameter statistic   Description
#    03   00065     00003     Gage height, feet (Mean)
#    04   00060     00003     Discharge, cubic feet per second (Mean)
#
# Data-value qualification codes included in this output:
#     A  Approved for publication -- Processing and review completed.
#     e  Value has been estimated.
#
agency_cd       site_no datetime        03_00065_00003  03_00065_00003_cd       04_00060_00003  04_00060_00003_cd
5s      15s     20d     14n     10s     14n     10s
USGS    07274000        2000-01-01                      36      A
USGS    07274000        2000-01-02                      36      A
USGS    07274000        2000-01-03                      279     A
USGS    07274000        2000-01-04                      293     A
USGS    07274000        2000-01-05                      112     A
USGS    07274000        2000-01-06                      87      A
USGS    07274000        2000-01-07                      71      A
USGS    07274000        2000-01-08                      68      A
USGS    07274000        2000-01-09                      117     A
USGS    07274000        2000-01-10                      89      A
USGS    07274000        2000-01-11                      73      A
USGS    07274000        2000-01-12                      65      A
USGS    07274000        2000-01-13                      60      A
USGS    07274000        2000-01-14                      55      A
USGS    07274000        2000-01-15                      51      A
USGS    07274000        2000-01-16                      50      A
USGS    07274000        2000-01-17                      49      A
USGS    07274000        2000-01-18                      50      A
USGS    07274000        2000-01-19                      47      A
USGS    07274000        2000-01-20                      47      A
USGS    07274000        2000-01-21                      46      A
USGS    07274000        2000-01-22                      79      A
```

Figure B4: Yocona River Basin discharge daily data upload format for BFI program



```
 * 1 = STANDARD Institute of Hydrology method
       (N-day avg. recession test; uses "N" and "f")
   2 = MODIFIED method
       (1-day recession constant adjusted for number of days
        between points; uses "N" and "K")

 BASE-FLOW SEPARATION PARAMETERS
   METHOD =   1
   N      =   5
   f      =    .900000

==================================================

Gage 07274000

<-- Calendar -->  Base Flow  Total Flow
Year  Month  Day    (cfs)       (cfs)
----------------------------------------
2000     1     1     36.00       36.00
2000     1     2     36.00       36.00
2000     1     3     37.84      279.00
2000     1     4     38.79      293.00
2000     1     5     39.77      112.00
2000     1     6     40.77       87.00
2000     1     7     41.80       71.00
2000     1     8     42.85       68.00
2000     1     9     43.93      117.00
2000     1    10     45.03       89.00
2000     1    11     46.17       73.00
2000     1    12     47.33       65.00
2000     1    13     48.52       60.00
2000     1    14     49.75       55.00
2000     1    15     51.00       51.00
2000     1    16     49.97       50.00
2000     1    17     48.96       49.00
2000     1    18     47.97       50.00
2000     1    19     47.00       47.00
2000     1    20     46.50       47.00
2000     1    21     46.00       46.00
2000     1    22     46.43       79.00
```

Figure B5: Daily base flow .q file output for Yocona River Basin



```
Program Version = BFI 4.15

AVAILABLE SEPARATION METHODS:
* 1 = STANDARD Institute of Hydrology method
      (N-day avg. recession test; uses "N" and "f")
  2 = MODIFIED method
      (1-day recession constant adjusted for number of days
       between points; uses "N" and "K")

BASE-FLOW SEPARATION PARAMETERS
  METHOD =   1
  N      =   5
  f      =    .900000




=============================================================================
Base-Flow Index for gage 07274000
agency 07274000 sample data
Calendar   Base-Flow      Base Flow     Total Runoff | Day of Turning Point |
Year         Index       (acre-ft)       (acre-ft)  |  [First]     [Last]  |
-----------------------------------------------------------------------------
1995     Incomplete year.  Base flow cannot be determined.
1996          .343        101445.         295682.        1          366
1997          .277        119606.         431427.        1          365
1998          .339         85746.         253059.        1          365
1999          .341         78763.         231031.        1          365
2000          .269         29407.         109263.        1          366
2001          .225         77510.         344670.        1          365
2002          .201         88397.         439807.        1          365
2003          .353        102570.         290194.        1          365
2004          .235         94287.         401931.        1          366
2005          .376         64025.         170432.        1          365
2006          .336         65612.         195497.        1          365
2007          .336         33841.         100603.        1          365
2008          .286         56361.         197191.        1          366
```

Figure B6: Annual base flow index values for Yocona River Basin

Figure B6 includes the base-flow index, total base flow for the year in acre-ft, the total runoff for the year in acre-ft, and some statistical data at the bottom (Not shown). The base-flow index cannot be computed for a year that has missing data. Again the base-flow index is the ratio of the total base flow to the total runoff.

It is important to note that the watershed delineated for the Yocona River basin does not have an upstream gauge so this data is complete as shown. For an analysis of any watershed that has gauges upstream of the gauge of interest, the upstream gauge data must be subtracted from the downstream gauge data. This can be done by running the program for all gauges involved, copying the data into a spreadsheet, subtracting the upstream gauge total base flow from the downstream gauge total base flow, subtracting the upstream gauge total runoff from the downstream gauge total runoff, and recalculating the base-flow index using these differences (Wahl and Wahl, 1995).

The Q (flow) file shows the daily base flow and total flow values in cubic feet per second (cfs). Data that is missing shows up as -99.00. This data can be used to graph the total flow and base flow trends over one or more years. Total base flow is only accurate for time periods longer than a day since the program uses daily data. Calculating total base flow for a month or more would be acceptable, although it is probably best to calculate over a year or more. Daily runoff would be calculated by subtracting the total base flow from the total flow for each day. Below is a graph of the base flow separation for the watershed of the Yocona River Basin Gauge 2006. This was created using the Q data file (Figure B7).

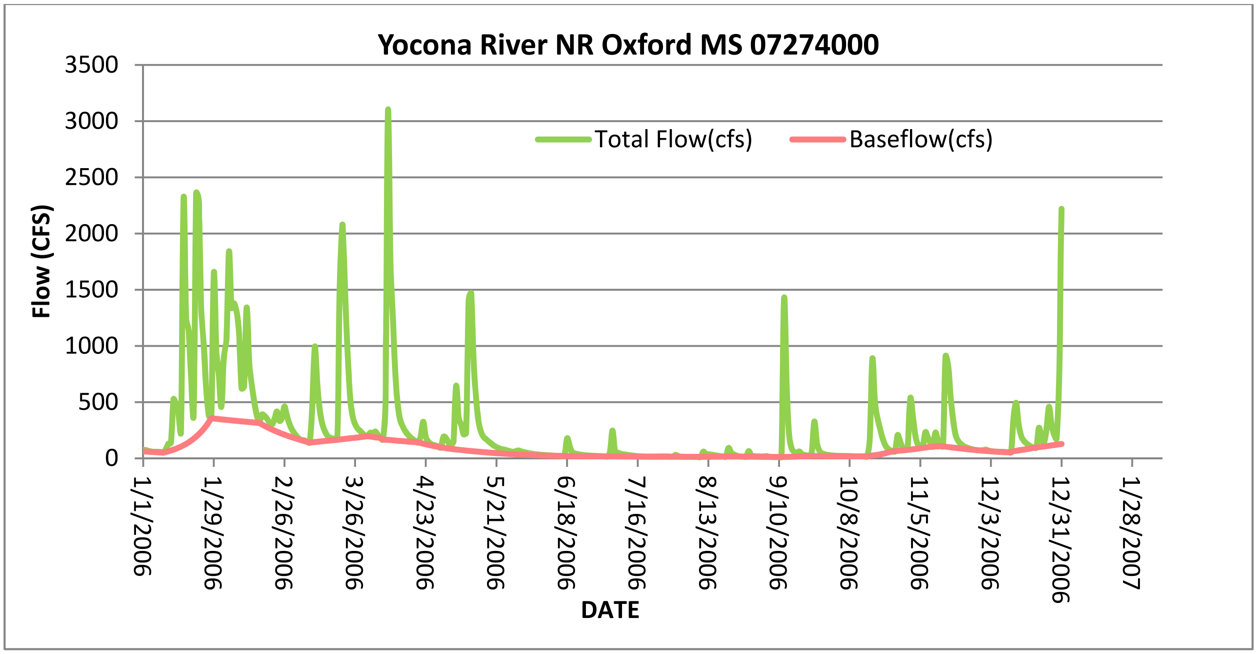


Figure B7: Plots showing base flow separated from streamflow for Yocona River Basin for the year 2006

The streamflow resulting from the separation of base flow from total flow will be used for sensitivity analysis and calibration.

APPENDIX C: OBSERVED STREAMFLOW DATA, MONTHLY

APPENDIX C

OBSERVED STREAMFLOW DATA, MONTHLY

2000	1	1.12
2000	2	1.51
2000	3	6.05
2000	4	18.23
2000	5	0.64
2000	6	0.58
2000	7	0.27
2000	8	0.20
2000	9	0.03
2000	10	0.04
2000	11	2.59
2000	12	6.36
2001	1	12.93
2001	2	25.84
2001	3	6.86
2001	4	11.83
2001	5	2.18
2001	6	12.42
2001	7	0.25
2001	8	0.74
2001	9	4.65
2001	10	3.20
2001	11	19.60
2001	12	26.11
2002	1	27.31
2002	2	16.46
2002	3	29.62
2002	4	11.62
2002	5	32.36
2002	6	0.76
2002	7	1.90
2002	8	0.92
2002	9	8.98
2002	10	11.68
2002	11	6.37
2002	12	16.12
2003	1	1.99
2003	2	35.46
2003	3	5.01
2003	4	9.59
2003	5	23.98
2003	6	1.70
2003	7	0.85
2003	8	3.47
2003	9	2.37
2003	10	0.62
2003	11	2.39
2003	12	3.03
2004	1	7.45
2004	2	23.30
2004	3	9.53
2004	4	8.77

2004	5	9.41
2004	6	14.71
2004	7	7.24
2004	8	0.93
2004	9	0.21
2004	10	1.70
2004	11	19.87
2004	12	41.51
2005	1	8.24
2005	2	12.17
2005	3	3.35
2005	4	16.96
2005	5	1.18
2005	6	1.06
2005	7	0.91
2005	8	2.40
2005	9	1.98
2005	10	0.06
2005	11	0.45
2005	12	2.05
2006	1	14.15
2006	2	10.99
2006	3	8.03
2006	4	7.43
2006	5	6.31
2006	6	2.50
2006	7	0.46
2006	8	0.35
2006	9	2.93
2006	10	2.40
2006	11	3.69
2006	12	4.63
2007	1	16.87
2007	2	2.43
2007	3	1.41
2007	4	1.04
2007	5	0.50
2007	6	1.41
2007	7	3.61
2007	8	0.09
2007	9	0.08
2007	10	2.64
2007	11	0.21
2007	12	0.81
2008	1	1.87
2008	2	2.28
2008	3	8.32
2008	4	14.89
2008	5	8.62
2008	6	0.83
2008	7	0.33
2008	8	3.30
2008	9	0.55
2008	10	2.03
2008	11	0.42
2008	12	22.53
2009	1	5.38

```
2009   2        1.85
2009   3        12.76
2009   4        4.83
2009   5        21.63
2009   6        0.80
2009   7        1.20
2009   8        0.48
2009   9        13.33
2009  10        22.28
2009  11        7.56
2009  12        12.50
2010   1        19.91
2010   2        9.88
2010   3        10.02
2010   4        4.74
2010   5        24.45
2010   6        0.88
2010   7        0.50
2010   8        0.30
2010   9        0.10
2010  10        0.06
2010  11        3.60
2010  12        0.65
```

APPENDIX D: LAND USE SCENARIO CHANGE METHODOLOGY

APPENDIX D

LAND USE SCENARIO CHANGE METHODOLOGY

Modeling land-use changes is critical for establishing effective environmental management strategies. This is done by the use of land use spatial analysis techniques in ArcGIS, editing in SWAT and the use of processing applications such as SWAT2009_LUC to modify HRU database used for simulations. These processes are used in this study to reclassify and modify land use scenarios for the study area.

Scenario changes in SWAT can be done in three ways. SWAT has a built-in land use update tool called SWAT2009_LUP which was used to update the current land use in a model for land use changes that are most frequent, for instance every 2 or 3 years. The second method involves editing the subbasin management table within ArcSWAT whereby land use can be changed per subbasin, soil type and slope. This method is useful when the land use change occurs in 100% of the subbasin at once. The third method of changing land use data is the use of a stand-alone program called SWAT2009_LUC.

SWAT2009_LUC allows the use of a new land use raster dataset for model simulations without change to the parameters of the original calibrated model. The advantage of the SWAT2009_LUC is that multiple land use layers can be used for simulations without altering the optimal parameters of the calibrated model.

SWAT2009_LUC module was chosen as the preliminary method for changing the land use data for scenario assessment. However, before SWAT2009_LUC model can be used, the land use raster data has to be edited and reclassified in ArcMap to reflect the projected land management (land use) changes.

Editing Land –use Raster data

This process is performed in ArcCatalog and ArcMap using the following procedure:

1. Create a shapefile polygon in ArcCatalog (Shapefile must have the same spatial reference as the original land use layer in the model)
2. Import the shapefile and the land use layer (land use layer for reclassification), activate the editing tool and the spatial analyst extension in ArcMap
3. Edit the polygon within the land use layer, according to the extent of the projected land use change
4. Save edits
5. Use the Clip tool to clip the raster features into the edited shapefile geometry. A new raster of the clipped land use data is created
6. Reclassify: The new raster created according to projected land use. A new reclassified land use data is created
7. Mosaic the reclassified raster data to the existing original land use raster. This appends the changes from the new reclassified data to the existing land –use data.

It is necessary to create a new lookup table if new classes are defined.

After reclassifying all of the data and appending it to the existing land use, the new raster data is ready for processing in the **SWAT2009_LUC** module.

The LUC module allows the user to update land use data by updating the HRU_FR variable during the model run. HRU_FR is the fraction of total watershed area in the HRU file which ranges from 0 to 1, with a higher HRU_FR number indicating larger occupation in the subbasin.

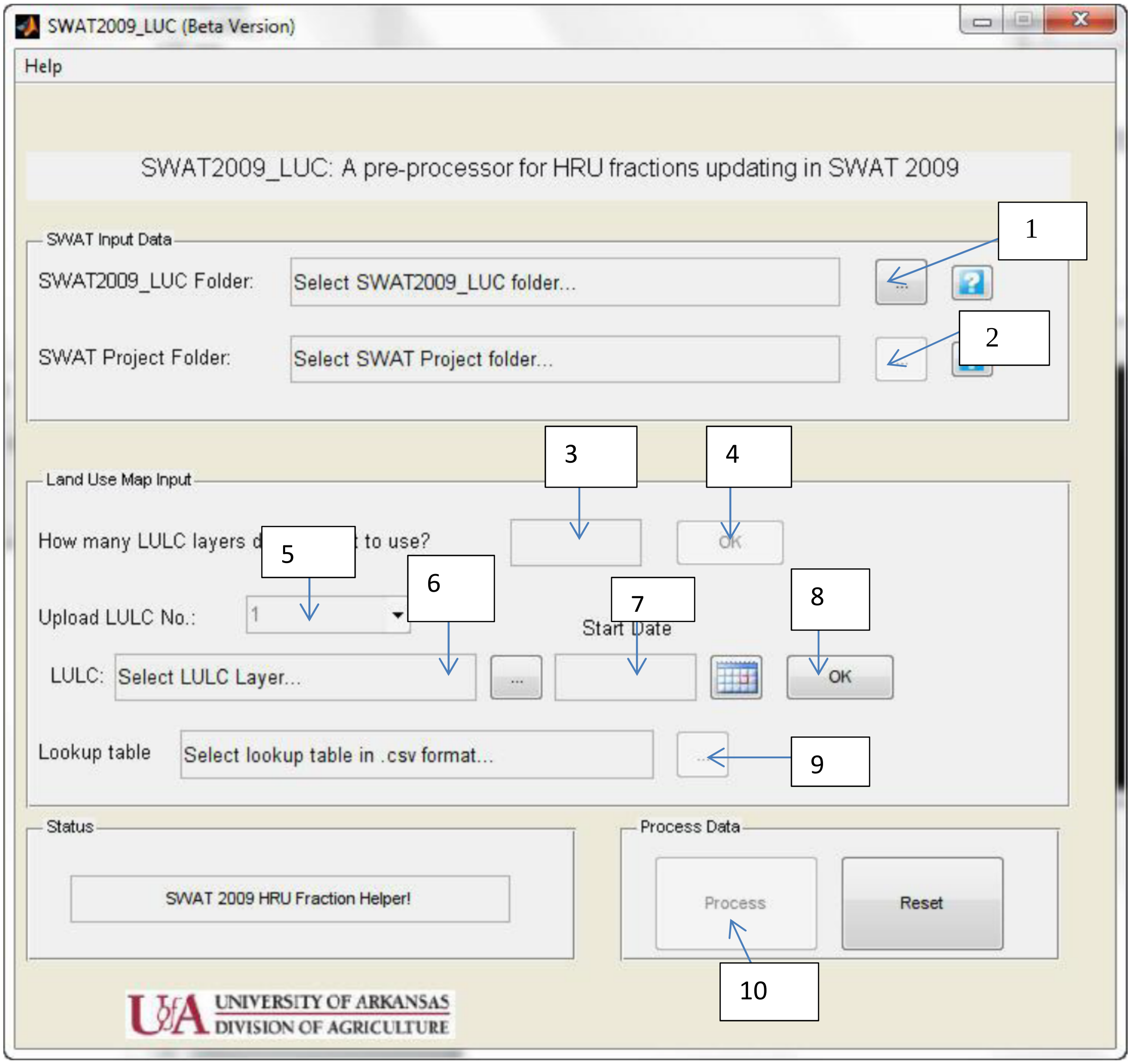
SWAT2009_LUC Procedure

In order to utilize the LUC module for a new scenario, the model uses two files in the TxtInOut folder: lup.dat and a user defined HRU fraction text file, file1.dat. The lup.dat file provides the model with information when the land use has been updated or changed, while the file1.dat provides updated values of HRU_FR for each HRU for a particular year.

The LUC processor has three major panels i.e. SWAT input data, Land Use Map Input, and Process Data. These panels make the LUC procedure easy (Figure E1):

1. Select an empty folder as the SWAT2009_LUC destination folder
2. Select current SWAT project folder
3. Choose how many land use data layers i.e. reclassified land use layer for scenario
4. Upload land use data
5. Choose a start date
6. Upload land use lookup table
7. Process data

An output folder is created in the destination folder and contains lup.dat and a file1.dat files that will be used to replace the lup.dat file in the SWAT project folder. After the lup.dat files are exchanged, the SWAT model is then rerun with the new lup.dat file.



SWAT2009_LUC: A pre-processor for HRU fractions updating in SWAT 2009

SWAT2009_LUC Folder: Select SWAT2009_LUC folder...

SWAT Project Folder: Select SWAT Project folder...

How many LULC layers d… t to use?

Upload LULC No.: 1

LULC: Select LULC Layer...

Lookup table: Select lookup table in .csv format...

SWAT 2009 HRU Fraction Helper!

Figure D1: SWAT2009_LUC quick steps

APPENDIX E: BASELINE SIMULATION BASINAL OUTPUT

APPENDIX E

Subbasins	Sediment Yield (t/ha)	Water Yield (mm)	ET (mm)	Surface runoff (mm)	Percolation (mm)
1	0.681	50.1	72.08	80.46	35
2	0.635	49.8	70.91	79.34	33.99
3	3.227	47.8	72.4	270.29	28.86
4	4.353	42.79	72.4	270.95	28.9
5	0.667	44.14	72.12	79.67	34.97
6	24.554	41.04	79.55	233.61	19.71
7	1.173	44.1	72.15	107.69	35.1
8	2.93	44.1	72.13	175.74	34.8
9	0.549	44	70.92	79.93	34
10	184.199	61.1	55.82	521.44	52.07
11	2.252	43.96	70.96	175.65	34.41
12	2.163	59.4	57.4	263.33	38.41
13	0.552	44.17	72.11	63.32	34.75
14	29.935	62.53	54.94	386.26	38.3
15	4.514	60.2	57.61	190.97	38.91
16	5.367	38.78	78.54	248.68	19.35
17	3.026	38.8	78.55	248.68	19.47
18	1.995	44.3	72.04	156.19	33.8
19	226.402	64.45	54.97	410.53	59.45
20	3.311	42.78	72.43	138.41	28.88
21	1.814	52.4	64.49	139.14	29.3
22	2.472	40.68	76.56	260.29	20.21
23	2.84	40.6	76.56	260.27	20.21
24	2.413	42.1	75.02	220.6	25
25	1.909	42.1	75.01	172.52	24.97
26	2.012	42.08	75.03	172.52	24.96
27	3.77	42.76	72.44	249.47	28.83
28	5.994	40.7	76.57	217.98	20.18
29	3.178	42.7	72.45	271.03	28.8
30	5.062	43.1	73.4	250.12	29.15
31	16.342	66.04	75.05	492.06	24.98

Table E1: Baseline Simulation basinal output

VITA

Education:	**Bachelor of Science in Geology** May 2009
	University of Mississippi, University 38677
Work Experience:	**Geoscience Intern,** summer 2011
	Addax Petroleum, Lagos, Nigeria
Memberships:	American Association of Petroleum Geologists
	Air and Waste Management Association