EVALUATING WATER QUALITY IMPACTS OF ALTERNATIVE MANAGEMENT PRACTICES THROUGH DEVELOPMENT OF A BMP DATABASE

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Gary Brooks Butler, Jr.

Certificate of Approval:

Puneet Srivastava, Co-Chair
Assistant Professor
Biosystems Engineering

Wesley C. Zech, Co-Chair
Assistant Professor
Civil Engineering

John P. Fulton
Assistant Professor
Biosystems Engineering

Timothy McDonald
Associate Professor
Biosystems Engineering

Mark Dougherty
Assistant Professor
Biosystems Engineering

Kathryn Flynn
Associate Professor
School of Forestry & Wildlife Sciences

George T. Flowers
Interim Dean
Graduate School

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Gary Brooks Butler, Jr.

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Gary Brooks Butler, Jr.

Signature of Author

Date of Graduation

VITA

Gary Brooks Butler, Jr., son of Gary and Debbie Butler, Sr., was born April 29, 1983, in Tuscaloosa, Alabama. He grew up in Demopolis, Alabama, with his two brothers, Blake and Bart. After graduating from Demopolis High School in 2001, he attended Auburn University where he graduated with a Bachelors of Biosystems Engineering degree in May of 2005. Upon graduation, he entered Auburn University's Civil Engineering graduate program and worked as a graduate research assistant in the Biosystems Engineering department.

THESIS ABSTACT

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Gary Brooks Butler, Jr.

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Agriculture and forestry are two important industries in the State of Alabama, and each is historically known to cause nonpoint source (NPS) pollution problems. Currently, the U.S. Environmental Protection Agency (USEPA) considers NPS pollution to be its biggest water quality problem. Millions of dollars and an enormous amount of time and effort have been spent on NPS pollution abatement. Best management practices (BMPs) are often used to control NPS pollution in agricultural, forested, and urban watersheds. A BMP is any practice or method that is used to reduce or prevent NPS pollution. BMPs can be categorized as structural or nonstructural. For instance, a silt fence would be considered a structural BMP where as growing crops in a rotation would be a nonstructural BMP. Effectiveness of BMPs can be determined by collecting monitoring data under various hydrologic, geomorphic, and weather conditions.

However, collecting monitoring data can be expensive and time consuming. Furthermore, determining watershed-level reduction in NPS pollution due to the implementation of a specific BMP at a particular site is extremely difficult, if not impossible, through monitoring. Therefore, to assess watershed-level reduction in NPS pollutant loads derived from BMP implementation and to devise future NPS abatement plans, watershed-scale NPS pollution models are used.

The overarching goal of this project is to develop a comprehensive database of commonly used agricultural and forestry BMPs in Alabama and to evaluate the effectiveness of the Alabama P index (a BMP to reduce transport of P from land-applied broiler litter) in reducing watershed-level water quality impact using the BMP database and the Soil and Water Assessment Tool (SWAT). The SWAT model, supported by the USEPA, is one of the most commonly used watershed-scale models for developing Total Maximum Daily Loads (TMDLs) and BMP implementation plans. The specific objectives of this project were to: (1) develop a database of commonly used BMPs in the agricultural and forestry industries for the State of Alabama, (2) create an ArcView 3.X GIS (geographic information system) extension to load the database into the SWAT model, and (3) determine the effectiveness of the Alabama P index (as a BMP) in reducing P loads at the watershed-scale through the use of the Alabama BMP database and the SWAT model.

The BMP database will provide detailed information on how agricultural and forested lands are usually managed (i.e., how much fertilizer is used, what pesticides are used, how much animal waste is applied). This detailed information on agricultural and forestry BMPs is currently unavailable for the State of Alabama. Using the BMP

database along with the SWAT model, it will be possible to evaluate the site-specific effectiveness of BMPs and conduct more accurate assessments of NPS pollution, TMDLs, and BMP implementation plans. This will allow environmental professionals to make more confident BMP recommendations and manage watersheds more effectively and efficiently. Overall, the BMP database and the ArcView 3.X extension will significantly help reduce NPS pollution in agricultural and forested watersheds.

P pollution has become a major environmental concern in recent years, especially in agricultural watersheds where animal waste is being utilized as a fertilizer source. The P index is a BMP that is used to rate an area for the potential risk of contributing to P pollution. While this BMP has been shown to reduce P loads at the field scale, this study evaluates the P index effectiveness on a watershed-scale. The results of this study indicated that the Alabama P index is effective at reducing P loads at the watershed-scale; however, climate variability plays an important role in determining the level of effectiveness. The P index is most effective in dryer years, as opposed to years of heavy precipitation. The results of the study also showed little variation in P loading as the P index rating was increased from ‘very low/low’ to ‘extremely high’. Overall, the P index was effective at reducing P loads at the watershed-scale.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

For many people, nonpoint source (NPS) pollution is a foreign concept. In the past, pollution management focused mainly on industrial and sewage waste. Recently, members of the environmental community have widened their perspective and shifted their focus to controlling NPS pollution (Brannan et al., 2000). This shift was started in 1972 when Congress passed the Clean Water Act (CWA). This piece of legislation was the most far-reaching environmental legislative act to solve environmental problems. Section 101 (a) of the CWA states, “the objective of the act is to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” (Novotny, 2003). One of the most important parts of the CWA is the distinction between land pollution and industrial and municipal pollution. The acknowledgement of this difference brought about the concept of NPS pollution. Point source pollution is defined as pollution that enters the transport routes at discrete, identifiable locations and can usually be measured. Conversely, NPS pollution is defined as pollution that is difficult to identify and is usually associated with land or the use of land (Novotny, 2003). NPS pollution occurs when water, either from rainfall, snow melt, or irrigation moves over land or through the soil, and picks up pollutants and then deposits these pollutants into adjacent waters. The most common NPS pollutants are sediment and nutrients (Borah et al. 2006). Other pollutants include oil, pesticides, grease, toxic chemicals, and heavy metals. Agriculture, forestry, construction, and urban runoff are all sources of NPS pollution. Today, the USEPA considers NPS pollution to be the Nation’s largest water quality problem with agriculture being the main contributor of the degradation of 60% of the impaired river miles and half of the impaired lake acreage surveyed by states, territories, and tribes (USEPA, 2006a).

Two important sections of the CWA that pertain to NPS pollution abatement are sections 208 and 319. Section 208 recognized for the first time that it would take more than just controlling point source pollution to solve the United States' pollution problems. This section had two major outcomes: one included planning reports that identified the extent of point and NPS pollution and the other provided tools for these planning reports, such as hydrological and water quality watershed models (Novotny, 2003). The development of these tools has improved the way land management practices are assessed to determine how these practices affect water quality. Similarly, section 319 of the CWA is important because it provides funding for controlling NPS pollution. Because of this section, much research has been performed in the area of NPS pollution control. Section 319, like section 208, has resulted in the development of watershed models (Novotny, 2003). These models can provide information concerning ways to efficiently manage land in the future without adversely affecting water quality. Models also provide a method of evaluating current management practices to determine how water quality is being affected, as well as assess the effects that alternative management practices could have on water quality (Borah and Bera, 2003).

1.2 Best Management Practices (BMPs)

NPS pollution has become a major water quality problem across the United States and millions of dollars have been spent to find out how to control and limit NPS pollution. Many industries that are historically known for causing NPS pollution have turned to BMPs for reducing NPS pollution. A BMP is defined as any method, measure, or practice, either structural or nonstructural, that prevents or reduces NPS pollution (Brooks et al. 2003). In most scenarios, BMPs are recommendations and are not mandated by law; however, water quality degradation is strictly prohibited and is enforced under the CWA. Depending on the goal of NPS pollution abatement, environmental laws, availability of funds, and applicability, a structural BMP, nonstructural BMP, or a combination of the two is applied. For example, BMPs associated with road construction concentrate mainly on controlling erosion and sedimentation, thus utilizing structural BMPs (e.g., silt fence, broad based dip, or a wing ditch). Conversely, agriculture BMPs have numerous functions that range from reducing erosion, sedimentation, nutrient and pesticide losses to adjacent water, to increasing agricultural productivity. Agriculture is known for utilizing both structural and nonstructural BMPs.

Agriculture and forestry are two of the many professions that have adopted and are implementing BMPs on a regular basis to combat NPS pollution. Both structural and nonstructural BMPs can be effective at reducing NPS pollution. However, the effectiveness of BMPs is site-specific (Shukla and Mostaghimi, 2002). In other words, the effectiveness of BMPs depends on many site-specific factors (e.g., slope, soil properties, land use, and climatic conditions). Effectiveness of BMPs can be determined by collecting monitoring data under various hydrologic, geomorphic, and weather conditions; however, collecting monitoring data is expensive and time consuming (Santhi et al., 2006). Furthermore, determining watershed-level reduction in NPS pollution due to the implementation of a specific BMP is extremely difficult, if not impossible, through monitoring (Srivastava, 1999). Therefore, to assess watershed-level reduction in NPS pollutant loads derived from BMP implementation and to devise future NPS abatement plans, watershed-scale NPS pollution models are needed.

1.3 Watershed Modeling

Water resource management is extremely difficult because of the complexity of the numerous parameters that must be taken into consideration. While NPS pollution management at the field scale can be easily evaluated, watershed scale evaluations can be quite difficult (Chu et al., 2005). The difficulty in managing water resources effectively and efficiently has lead to the creation of watershed models. Watershed models are powerful tools that are used by environmental professionals to simulate how pollutants are transported to receiving water bodies (Bracmort et al., 2004). These models are capable of simulating and evaluating processes such as precipitation, evaporation, infiltration, and runoff, on a site-specific basis. Output from these simulations can include hydrographs, water inflows, and pollutant loadings. In recent years, the simplicity in using models has made them extremely popular. This simplicity can be attributed to the advances made in computer technology and numerical methods of solutions (James, 1984). Today, models are used for many different tasks that include assessing BMPs, developing total maximum daily loads (TMDLs), and urban planning.

There are various types of watershed models that are being used today to evaluate

NPS pollution and each has been designed with a particular purpose in mind. These models can differ in scale, complexity, and format. NPS pollution models can be classified as field scale models which only accounts for a small area, or watershed-scale models, which evaluates an entire watershed and all the processes that occur within the watershed. NPS pollution models can also be classified as single event or continuous simulation models. Models can further be described as being either distributed parameter or lumped parameter models.

Although there are many different types of models that can be useful in managing water resources, it is important to understand the many limitations that are associated with watershed modeling. Water quality prediction is not an exact science and each model has its own strengths and weaknesses. First and foremost, it should be noted that modeling is a simplification of what is actually occurring in the environment. Because of this, there will always be some level of uncertainty associated with modeling results. Numerous input parameters, which are often unknown and have to be estimated, are needed to conduct watershed modeling. This also adds to the level of uncertainty in the results of watershed modeling (Biswas, 1997). Before choosing a model, the strengths and the limitations of the model should be researched to assure that an acceptable level of uncertainty is achieved.

As previously mentioned, there are many watershed models available that can be used to appraise NPS pollution problems. The SWAT model (Neitsch et al. 2002) is one of the most popular models being used to evaluate NPS pollution in agricultural watersheds today. The SWAT model is currently supported by the USEPA for its TMDL program for development and implementation of TMDLs in agricultural watersheds. The

SWAT model is a river basin or watershed scale, continuous simulation model that was created to analyze the affects that different management practices have on water quality. SWAT, created by Dr. Jeff Arnold for the USDA, is a modification of the Simulator for Water Resources in Rural Basins (SWRRB) model (Williams et al., 1985; Arnold et al., 1990) and the Routing Outputs to Outlet (ROTO) model (Arnold et al. 1995). The SWRRB model had various limitations that caused problems for modelers. These limitations included watershed divisions being limited to only ten subbasins, as well as routing water and sediment out of the subbasins directly to the watershed outlet. Because of these limitations, the Routing Outputs to Outlet (ROTO) model was created. This model solved the problems associated with the SWRRB model by combining multiple SWRRB runs. Although the ROTO model did overcome the limitations of SWRRB, there were problems with running multiple SWRRB files. Each SWRRB file had to be run individually and then incorporated into the ROTO model. Because of the complications that were associated with these two models, they were combined into the SWAT model. With the creation of the SWAT model, environmental professionals have the capability to model large watersheds, as well as study the affects that different management practices have on these watersheds over time. Today, the SWAT model has become one of the most widely used models for the evaluation of NPS pollution (Neitsch et al., 2002).

1.4 Research Objectives

The overarching goal of this project is to create a database of BMPs that are commonly utilized by the agriculture and forestry industries in the State of Alabama and then load this database into the SWAT model using an ArcView® 3.X GIS extension.

The creation of this BMP database and ArcView® 3.X GIS extension will provide water resource managers with detailed, more accurate data for determining TMDLs and making management decisions in agricultural and forested watersheds located in the State of Alabama. Since water quality of a number of watersheds in Alabama is affected by broiler litter application, an additional goal was to evaluate the effectiveness of the Alabama P index in controlling transport of P to streams.

The specific objectives of this project were to:

1) Develop a database of BMPs commonly utilized by the agricultural and forestry industries in the State of Alabama;
2) Prepare an ArcView® 3.X GIS extension to load management scenarios for each of these BMPs into the SWAT model; and
3) Determine the effectiveness of the Alabama P index (as a BMP) in reducing P loads at the watershed-scale through the use of the Alabama BMP database and the SWAT model.

1.5 Organization of Thesis

This thesis is a combination of two technical papers that are presented in chapters 3 and 4. The first paper entitled "An Alabama Best Management Practice Database for Evaluating Water Quality Impacts of Management Alternatives in Agricultural and Forested Watersheds" explains the procedures and the methodology behind creating a comprehensive BMP database and an ArcView® 3.X GIS extension for use in the SWAT model. The second paper entitled "Watershed-level effects of Alabama P-index in an animal waste-applied watershed" shows the benefits of using the BMP database and the ArcView® 3.X GIS extension. This is done by modeling a watershed and evaluating specific BMPs that can be implemented to improve water quality. Chapter 2 is an extensive literature review that includes information on commonly used BMPs. This chapter also contains information on several popular models that are used to evaluate NPS pollution. The final portion of the literature review presents specific information about the SWAT model. Chapter 5 summarizes the overall project, presents the overall conclusions of this project, and highlights future research opportunities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Commonly Used Best Management Practices (BMPs)

BMPs are proven methods that can be utilized to reduce the amount of NPS loading to adjacent water bodies (Brannan et al., 2000). Countless hours of research and evaluation have lead to the development of a comprehensive list of BMPs that are effective at reducing NPS pollution. While many BMPs exist, each BMP has a particular method of reducing NPS pollution. Because of this, careful consideration must be taken when choosing which BMPs to implement. There are five different steps that should be taken before implementing a BMP. The first step should be to identify the water quality problem. Secondly, the pollutants that are contributing to the problem and their probable sources should be identified. Third, determine how each pollutant is delivered to the water. Fourth, a reasonable water quality goal should be set and determination of the level of treatment required to meet that goal should be made. A BMP should not only effectively reduce NPS pollution but it should also be economically feasible. Because of this, the fifth and final step should be to evaluate the feasibility of different BMPs for water quality effectiveness, economic feasibility, effects on groundwater, and suitability of the practice to the site (Novotny, 2003). Because many times the effectiveness of

BMPs is site-specific (Shukla and Mostaghimi, 2002) and because the economic feasibility of implementing BMPs should be considered a top priority, watershed models and other watershed evaluation tools are needed to assess the efficiency and effectiveness of implementing specific BMPs.

A common BMP that has been shown to reduce the effects of NPS pollution in agricultural watersheds is utilizing a crop rotation where crops are changed in a planned, thought-out sequence. By rotating crops, the number of years that fields are in row crops is minimized, allowing other conservation practices, such as cover crops to be utilized (Hairston, 1995a). Cover crops increase the amount of biomass, prevent excess nutrients and chemicals from entering adjacent waterbodies, and significantly reduce soil erosion. Another way that crop rotations reduce NPS pollution is that the life cycles of weeds, insects, and diseases are naturally broken down. This reduces the use and the cost associated with pesticides (CTIC, 2006). Crop rotations not only help improve water quality but research has shown that crop rotations can improve crop yields which in turn can increase crop nutrient removal from the soil (Katupitiya, et al., 1997). Additionally crop rotations improve water quality by minimizing the chance of disease outbreak by reducing populations of disease organisms that exist in the soil (McMullen and Lamey, 1999).

Integrated pest management (IPM) is another commonly used BMP that has been shown to reduce NPS pollution in agricultural and forested watersheds. IPM is a combination of practices that are used to control crop pests (e.g. weeds, insects, and diseases) while minimizing the adverse effects on water quality (Novotny, 2003). These practices include use of environmentally sound pruning, resistant crop varieties, crop rotations, minimal pesticide application rates and methods, as well as modified timing of pesticide applications (Novotny, 2003; Klassen et al., 2002). By using an IPM strategy, pesticides, tillage operations, and fertilizer applications are only used when absolutely necessary, minimizing the amount of sediment and polluted runoff that can enter adjacent waterbodies. This BMP also reduces the total amount of pesticide that the farmer has to apply. Not only does IPM reduce the environmental risk associated with applying pesticides, but it also reduces the costs associated with pest management (Klassen et al., 2002).

Nutrient management is another important BMP that is used to protect water quality from NPS pollution. Nutrient management is managing the amount, source, placement, form and timing of the application of nutrients and soil amendments (Lemunyon and Kuenstler, 2002). This is accomplished by altering the timing of nutrient application, application rates, and location of placement. Nutrient management also involves other practices such as crop rotations, cover crops, and fertilizer selection. The concept of nutrient management is based on the limiting nutrient theory that states that the fertilizer application rate should be based on the nutrient most needed by the plant. Research has shown that by implementing this BMP, nitrogen and phosphorus loss can be reduced by 20 to 90 percent (Novotny, 2003).

While in the past nitrogen was thought to be the main contributor to water quality problems, more recent research has shown that phosphorus can also be a contributing factor in the degradation of water bodies (Harmel et al., 2002). This is especially true when animal waste is used as a nutrient source (Jesiek and Wolfe, 2003). Excess phosphorus in surface water increases eutrophication which can lead to a significant loss in dissolved oxygen through biological oxygen demand (Carpenter et al., 1998). Because of the effects of excess phosphorus on water quality, it is extremely important that nutrients are managed properly. In Alabama, the Phosphorus Index (P index) is used to assess the likelihood of phosphorus transport to waterbodies under different management situations. By utilizing the P index, farmers can locate sites that have a potentially high risk of phosphorus movement and take the appropriate measures to reduce this risk. The P index works by utilizing specific field features and management practices to calculate a rating for an individual area (USDA, 2001). Each field feature and management practice has a different weighted factor and value rating. By multiplying the weighted factor by the value rating for each field or management practice, points are generated that are an indication of the risk of phosphorus loss. After summing all of the points, the field is given a rating of low, medium, high, very high, or extremely high. This rating gives an indication of what the safe application rate should be. For low P index ratings, manure can be applied at the nitrogen application rate. For a medium rating, manure can be applied at 3 times the phosphorus removal rate of the plant. A high rating indicates that the animal waste should be applied at 2 times the phosphorus removal rate of the plant. For a very high rating, animal waste should be applied at 1 times the phosphorus removal rate of the plant. If the P index rating is extremely high, then manure should be applied at 0 times the phosphorus removal rate of the plant (USDA, 2001).

Another important commonly used BMP is irrigation water management (IWM). IWM is a combination of several different tactics that control irrigation water to prevent NPS pollution problems and increase water use efficiency. Intensive irrigation can cause nutrient losses to surface waters and can also cause nitrate losses to groundwater through deep percolation (Hanson, 2003). Nitrogen loss in irrigated soils is a major problem because the soils that are commonly irrigated have high rates of leaching and nitrification and most crops that are irrigated require a high nitrogen application rate (Hairston, 1995b). Two other water quality problems that are associated with irrigation are salinization and increased surface runoff (Hairston, 1995c; Hanson, 2003). In order to prevent these water quality problems from happening, IWM is used. The tactics that make up IWM can include proper irrigation scheduling, efficient application, efficient transport systems, utilization and reuse of tailwater and runoff, and management of drainage water. IWM works by reducing leaching through seepage control, reducing excess runoff by improving the efficiency in the application of water, and proper timing to improve the efficiency of water use by minimizing evaporation (Novotny, 2003).

Pasture management is a BMP that can minimize the adverse effects of livestock on water quality. Pasture management is a series of practices that work to keep an adequate amount of biomass on improved pastureland (Novotny, 2003). The purpose of pasture management is to improve the health of selected plants, maintain a stable plant community, provide and maintain food, cover, and shelter for the livestock, improve animal health and productivity, reduce erosion, and maintain or improve water quality (ACES, 1997). These goals are achieved because pasture management practices allow the pasture to be permanently covered in high-quality, closely spaced vegetation. This decreases the amount of soil loss, as well as limits the amount of adsorbed pollutants that are lost from the land surface (Novotny, 2003). These practices include use of seeding, brush management, fencing, using proper stocking rates, and using grazing rotations. Benefits of pasture management include reductions in sediment loads, reduction in streambank erosion, expansion of the hyporheic zone, decreases in channel width, and increase in species diversity (Agouridis et al., 2004).

The fate of nutrients and chemicals in agricultural settings is often dependant on the condition of the soil surface and the tillage practices that have been used (Katupitiya et al., 1997). There have been many mechanical advances that have aided in the control of NPS pollution in agricultural watersheds. Conservation tillage, strip tillage, and zero tillage (no-till) are three examples of these mechanical advances. Conservation tillage is a method of reduced tillage where at least 30 percent of the soil remains covered by some type of organic residue. Strip tillage is a form of reduced tillage where the crop is planted on a strip that is 2 to 8 inches wide and 2 to 4 inches deep (Hairston, 1995d). Zero tillage is a method of minimum tillage where the crop is planted by opening a small slot in the soil that is sufficient to contain a seed without any disking operations (Katupitiya et al., 1997). Zero tillage makes maximum use of crop residue. These minimum tillage practices are effective BMPs that can conserve water and reduce erosion, conserve fuel because fewer trips are needed across a field, and improve soil structure (Hairston, 1995d).

2.2 Nonpoint Source Pollution (NPS) Models

Since the passage of the CWA, millions of dollars and an enormous amount of time has been spent researching and developing solutions to solve NPS pollution problems. As a result, many different models have been created that are used to evaluate land management decisions, BMP effectiveness and efficiency, and develop TMDLs (Borah and Bera, 2003). There are hundreds of models that have been created and each has been designed for a particular purpose. This section discusses several common models that are used to solve NPS pollution problems along with some of the advantages and disadvantages that are associated with each of the models.

2.2.1 Water Erosion Prediction Project

The Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) model is an important tool that is used to evaluate soil erosion and sediment delivery over different slopes and channels (Ascough, 1997). WEPP is a process-based, distributed parameter, continuous simulation model that predicts the amount of soil loss based on several environmental conditions, including infiltration, weather, soil physics, hydrology, and hydraulics (Flanagan et al., 2001). The WEPP model is mainly used to predict both rill and interill erosion on hill slopes and small watersheds. WEPP is capable of evaluating practices such as strip cropping, contour farming, irrigation practices, and crop rotations. The model allows for simulating weather, snow, frozen soils, infiltration, runoff, plant growth, water balance, soil disturbance, consolidation, erosion and deposition, and residue decomposition (Flanagan and Nearing, 1995).

The WEPP model works by analyzing the different components of a hill slope, (i.e. vegetation, weather, and soil type) and then calculates the erosion and sediment yield at the bottom of the slope. The first component of the model is the climate component. This consists of precipitation data, mean daily solar radiation, maximum and minimum temperatures, and mean daily wind speeds and directions. WEPP calculates solar radiation and maximum and minimum daily temperatures using a normal distribution function. The number and distribution of precipitation events are implemented using the two-state Markov chain model. WEPP incorporates a disaggregation model into the climatic component to calculate rainfall amount and duration. The model then uses this information and infiltration data to calculate surface runoff. WEPP uses the Green-Ampt infiltration equation to calculate infiltration data. The model uses two different methods for calculating surface runoff. The first method assumes broad sheet flow. The calculations are performed using the kinematic wave equation and using two regression equations, one for duration and one for peak runoff rate. The second runoff method analyzes areas that are composed of rills. WEPP assumes that the rills have a square cross section and then computes velocity and shear stress. Erosion for the entire runoff event is calculated by assuming a constant rate of time. The WEPP model uses the water balance equation to maintain a continuous balance of soil moisture in the vadose zone on a daily basis. As far as soil properties are concerned, WEPP looks specifically at random roughness, oriented roughness, wetting-front suction, bulk density, hydraulic conductivity, interill erodability, rill erodability, and the critical shear stress of the soil. WEPP uses SOILS-5 data to define the soil parameters that determine these properties. All of these factors significantly affect soil erosion (Flanagan and Nearing, 1995).

WEPP is an effective tool for analyzing the effects of erosion on hill slopes and small watersheds. Consequently, there are several benefits of using this model. WEPP can be used to evaluate constructed waterways such as, grassed waterways or terrace channels, and cropland ephemeral gullies having concentrated flow (Ascough II et al., 1997). Another benefit is that WEPP is capable of estimating both the temporal and spatial distribution of soil loss. Another advantage of using this model is that it has a broader range of uses when compared to other erosion prediction models because of the unique processed-based functions that it contains (USEPA, 2006b). One of the most notable benefits to using the WEPP model is that it is a computer based system that is relatively easy to learn and can efficiently simulate watershed processes.

Although there are various advantages to using the WEPP model, there are also several disadvantages. The WEPP model is only appropriate for use on small watersheds and hill slopes and has a field size limitation of approximately 640 acres (Foster and Lane, 1987) and has a rangeland watershed size limitation of approximately 100 acres (Baffaut et al., 1997). Baffaut et al. (1997) also found that the hillslope lengths should not exceed 100 meters. This is particularly a disadvantage when it comes to managing large areas. Another shortcoming of WEPP is that runoff is in the form of subsurface lateral flow, which has been determined to overestimate erosion when runoff is minimal (Covert et al., 2005). One more disadvantage is that WEPP cannot be used where there gullies or perennial stream channels containing headcut erosion, sloughing of sidewalls, seepage effects, and partial area hydrology (Ascough II et al., 1997).

2.2.2 Agricultural Nonpoint Source Pollution Model

Another commonly used model to evaluate NPS pollution is the Agricultural Nonpoint Source Pollution Model (AGNPS) (Young et al., 1987). This is an event-based model developed by the United States Department of Agriculture to evaluate pollution from agricultural and urban watersheds, based on a particular storm event (León et al., 2004). AGNPS is a distributed model that uses a square-grid cell system to represent the spatial distribution of the watershed’s properties. The three main components of this watershed-scale model include hydrology, nutrient pollution, and soil erosion (Srivastava, 1999). This model allows users to simulate sediments, chemical oxygen demand (COD), runoff, nutrients, and pesticides for point and nonpoint source pollution. This comprehensive model requires 22 different parameters to accurately represent management practices and other watershed conditions that have an effect on water quality (Bhuyan et al., 2003).

The AGNPS model works by first dividing the watershed into grids. It then evaluates each grid assuming that each grid area has uniform physical characteristics (Haregeweyn and Yohannes, 2003). The model then applies three lumped parameter models to each element. A lumped parameter model is a model whose parameters are assumed to apply over the entire region being modeled (PU, 2006). To calculate erosion, AGNPS uses the universal soil loss equation (USLE), while using the erosivity index for individual storm events. Sediment eroded by sheet and rill erosion are assumed to be transported to the stream networks without any deposition occurring. This model uses the Soil Conservation Service (SCS) Curve Number (CN) method as a basis for all hydrological calculations. The surface runoff is calculated for each grid and is then routed through the rest of the watershed based on the flow directions from one grid cell to the next (Grunwald and Norton, 1999). The model continues this type of routing until the drainage outlet has been reached. With the information gathered by using the SCS CN method, the model then uses the Smith Algorithm to calculate the peak flow of the watershed. In order to model the transport and interactions of soil particles, nutrients, and chemicals, the AGNPS model relies on the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel; 1980, USEPA, 2006c). The CREAMS model utilizes a nitrogen component that takes into account nitrification, mineralization, and denitrification processes. CREAMS then uses enrichment ratios to estimate the portion of nitrogen and phosphorus that is transported with the sediment. This model considers foliar interception, wash-off, adsorption, desorption, and degradation when analyzing pesticides and other chemicals (REM, 2002a).

The AGNPS model is a common model that is used to assess the pollution from agricultural and urban areas. There are several advantages that are associated with this model. One advantage is that this model allows the user to assess many different types of management practices. This is important in determining the importance and effectiveness of best management practices (León et al., 2004). Another advantage to using AGNPS is that it is a distributed model, meaning the model considers the influences that spatial variability has on the watershed being modeled. The AGNPS model also has the capability of being interfaced with a geographic information system (GIS) which will require less time to input data (León et al., 2004).

While there are several advantages to using the AGNPS model, there are also several disadvantages to using this model. One disadvantage is that the model assumes that all channels have a triangular shape (USEPA, 2006c). In natural settings, channels can take many different forms and can also change shape over time. Another disadvantage to using this model is that it can only be used for individual rainfall events. One more drawback to using AGNPS is that it is an empirical model which means that the functional form of the model is not derived from physical processes (Loague et al., 1998). Another disadvantage of using the AGNPS model is the extensive amount of information and data that are required to run the model (Parson et al., 1998).

2.2.3 Annualized Agricultural Nonpoint Source Pollution Model

The Annualized Agricultural Nonpoint Source (AnnAGNPS) Pollution Model (Cronshey and Theurer, 1998) is a watershed-scale, continuous simulation model that can be used to assess the affects of land management decisions on water quality (Baginska et al., 2003). AnnAGNPS modifies the AGNPS model by allowing simulation of annualized multiple rainfall events and model inputs that include daily climate data, watershed physical and management information (Yuan et al., 2001). The AnnAGNPS model can be used to evaluate both point and nonpoint source pollution in agricultural watersheds with model output including sediment, nutrient, and pesticide loadings to adjacent waterbodies. This model is capable of simulating hydrology, sedimentation, nutrients, and pesticides (Yuan et al., 2005). One of the most beneficial attributes of the AnnAGNPS model is that it has the capability of analyzing how BMPs affect a watershed. Because of the model's ability to evaluate BMPs on a watershed scale, AnnAGNPS is a valuable tool in determining ways to minimize the effects of NPS pollution in agricultural watersheds (USDA, 2006).

The AnnAGNPS model works by first sub-dividing the watershed into homogeneous drainage areas. Then the model integrates the drainage areas by the watershed's stream networks, routing the pollutants and runoff towards the watershed outlet (Yuan et al., 2003). AnnAGNPS has several key equations that it uses to depict actual processes which are occurring in the watershed. In order to simulate both surface and subsurface runoff, the model uses the SCS CN method. This enables the model to quantify daily runoff. Erosion is another important process that the AnnAGNPS simulates. It simulates this process by utilizing the Revised Universal Soil Loss Equation (RUSLE) and the Hydro-geomorphic Universal Soil Loss Equation (HUSLE). The RUSLE is used to calculate daily sheet and rill erosion, while the HUSLE is used to calculate the sediment delivery ratio. In order to simulate the hydrology of a watershed, the AnnAGNPS model uses the daily soil moisture balance technique (Samaresh et al., 2004). To simulate potential evapotranspiration in the watershed, the model uses the Penman method. The model then uses the Darcy equation or tile drain flow to simulate and quantify lateral subsurface flow throughout the watershed. AnnAGNPS uses a mass balance approach to simulate how chemicals are transported through the soil and water of the watershed (USEPA, 2006d).

AnnAGNPS is a powerful tool for evaluating agricultural management practices and the effect that these management practices have on water quality. There are several advantages to using the AnnAGNPS model. One advantage is that the model is a distributed parameter, watershed-scale model. This allows for the evaluation of many different processes that can occur over large areas (Yuan et al., 2006). Another advantage of using the AnnAGNPS model is that it is a continuous simulation model that enables environmental professionals to evaluate the management of land and water quality over a long period of time (USEPA, 2006d). Other benefits to using the AnnAGNPS model include its computational efficiency, spatial detail, and the ability to monitor the source and contribution of pollutants through the watershed to the outlet (Yuan et al., 2006). Although each of these are clear advantages of using this model, the most important benefit of using AnnAGNPS is its ability to evaluate BMPs, such as grassed waterways, irrigation, buffer strips, and agricultural practices (Yuan et al., 2001). This is extremely important because it provides a method of evaluating the efficiency and effectiveness of BMPs on a watershed-scale.

Although much can be said for using the AnnAGNPS model, this model does have several limitations. One disadvantage of using the AnnAGNPS model is that all runoff and associated pollutant loads for a single day are routed out of the watershed before the simulation of the next day. Another limitation of this model is that point sources are limited to constant loading rates throughout the entire simulation period. The AnnAGNPS model does not allow the user to account for spatial variability in rainfall, which in large watersheds is another disadvantage of this model. A final limitation of the AnnAGNPS model is that it does not track nutrients and pesticides attached to sediment deposited in streams from one day to the next (USEPA, 2006d).

2.2.4 Erosion Productivity-Impact Calculator

A commonly used watershed tool is the Erosion Productivity-Impact Calculator (EPIC) (Williams et al., 1984). EPIC is a field scale, physically based, continuous simulation model used to examine long-term effects of various components of soil erosion on crop production (Warner et al., 1997a). The EPIC model is capable of many different tasks, including: simulating erosion, plant growth and related processes, and assessing the cost of erosion. Additionally, it can be used to evaluate the impacts of crop rotations, tillage practices, nutrient management, and other land management factors that contribute to nutrient and pesticide fate and transport (Warner et al., 1997b). This model has nine major components that include: hydrology, weather, erosion, nutrients, soil temperature, plant growth, tillage operations, plant environment control and economics (Williams, 1990). Model inputs include weather data, crop parameters, soils data, and land management practices (Guerra et al., 2003).

The EPIC model works by continuously simulating weather and the affects that weather has on erosion and agriculture productivity. Surface runoff and runoff volume is calculated by using the SCS CN method (Williams, 1990). Two options exist for estimating peak runoff rate. The first option is by using the modified rational formula and the second option is by using the SCS TR-55 method. EPIC has four different methods of determining evapotranspiration, including the Penman, Penman-Monteith, Hargreaves and Samani, and the Priestley-Taylor methods (USEPA, 2006e). A storage routing technique is used by the EPIC model to simulate percolation. When soil water content exceeds field capacity, water flows through the soil layers. The corresponding reduction in soil water is simulated by a derived routing equation. Lateral subsurface flow and percolation are calculated collectively (Williams, 1990). In order to depict rainfall and runoff erosion, six equations are used by the EPIC model. These equations include the USLE, Onstad-Foster modification of the Modified Universal Soil Loss Equation (MUSLE), MUSLE, two recent variations of the MUSLE equation and a MUSLE structure that accepts input parameters (USEPA, 2006e). Another large component of the EPIC model is the simulation of contaminants transformation. The EPIC model can simulate denitrification, mineralization, immobilization, nitrification, volatilization, mineral phosphorus cycling, soluble phosphorus loss in surface runoff, nitrate loss, nitrogen transport as a result of sediment, and contaminant transport due to soil water evaporation (USEPA, 2006e).

The EPIC model is a tool that has been used for many years to evaluate the effect that erosion has on water quality, agriculture productivity, as well as the economic impacts. There are several advantages to using this model. One advantage is that EPIC can be used to evaluate the fate of pesticides that are used in agricultural practices (Warner et al., 1997b). Another advantage to using this model is that it not only describes the phosphorus cycle but it also differentiates between all forms of phosphorus (USEPA, 2006e). One of the biggest advantages of using the EPIC model is that it is a very well known model and has been used in many different applications across the U.S. and other regions of the world (Gassman et al., 2004).

There are several disadvantages that exist with the EPIC model. One disadvantage is that the EPIC model cannot represent watershed subsurface flow. Another disadvantage is that the model does not go into a lot of detail when simulating sediment routing. An additional disadvantage to using the EPIC model is that there is no mention of how the model deals with tile drains (USEPA, 2006e). Also seen as a disadvantage is that the EPIC model is a field scale model and is not capable of analyzing large watershed areas.

2.2.5 Groundwater Loading Effects of Agricultural Management Systems

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987) is a continuous simulation, physically based, field scale model that was developed to analyze how agricultural management practices, such as tillage operations, irrigation, and planting dates affect nutrient and pesticide leaching into groundwater sources (Reyes et al., 2004). Runoff and sediment losses can also be calculated for fields using this model. The GLEAMS model is an extension of the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980)(Gerwig et al., 2001). Hydrology, pesticide transport, nutrients, erosion, and sediment yield make up the primary components of the GLEAMS model (Reyes et al., 2001). This model is an extraordinary water quality tool that is capable of analyzing pesticides, soil properties, climate effects, and the effect of small-scale management decisions on surrounding waterbodies (USDA, 2006).

The GLEAMS model can be broken down into four major components that include: hydrology, erosion/sediment yield, pesticide transport, and nutrients (Reyes et al., 2001). A mass balance approach is used for the hydrology component of the GLEAMS model. Infiltration, runoff, irrigation, evapotranspiration and soil water movement within and through the root zone are considered under the hydrology component. The modified SCS CN method is used to calculate runoff while percolation is determined by the storage routing technique (Reyes et al., 2004). Two methods can be used to account for evapotranspiration. These methods include the Priestley-Taylor method and the Penman-Monteith method (Reyes et al., 2001). The erosion component is basically the same as the CREAMS model with minimal modifications (Leonard et al., 1987). In order to simulate erosion, the GLEAMS model utilizes the USLE and both detachment and transport processes are simulated. Another important portion of the GLEAMS model is the nutrient component. To adequately depict the actual processes that are occurring in the environment, the model simulates both the nitrogen and phosphorus cycle (USEPA, 2006f). The final main component of the GLEAMS model is the pesticide component. The GLEAMS model calculates the daily decay of the pesticide based on its half-life. From the partition coefficient, part of the pesticide is lost to runoff solution while the other is retained in the soil phase (Leonard et al., 1987).

The GLEAMS model is an excellent tool for evaluating water quality and land management decisions and there are several advantages to using this model. One advantage is that the model is fairly easy to use and has very few input requirements (USEPA, 2006f). Another advantage of using this model is that it is a continuous simulation model that allows users to evaluate the effects of management scenarios over a long period of time.

There are several limitations of using the GLEAMS model. One disadvantage of using the GLEAMS model is that it is a field-scale model. This means that it is limited to simulation of management on a very small scale. Another disadvantage of using this model is that it is limited to agricultural fields. The model cannot be used to simulate processes that are occurring in urban watersheds. One more disadvantage is that the model assumes that the field being modeled is homogenous and thus does not account for spatial variability (USEPA, 2006f).

2.2.6 Riparian Ecosystem Management Model

The Riparian Ecosystem Management Model (REMM) (Inamdar et al., 1998) is a process-based model that was developed to evaluate the effect that riparian buffer strips have on water quality (Inamdar et al., 1999a). REMM simulates how nutrients and sediment are transported from an agricultural field through a riparian area to a waterbody. This model uses a daily time step and considers that the riparian buffer zone consists of three different zones, each of which can vary in vegetation type, soil type, slope, and width (Lowrance et al., 2006). REMM has the ability to evaluate a number of different processes that include: buffer strip effectiveness, the effects of buffer strip width, and the fate of nutrients in buffer strips. (Dukes and Evans, 2003).

As previously stated, REMM considers three distinct zones between the drainage area and the waterbody (Lowrance et al., 2006). For each of the three zones, hydrology, erosion, carbon and nutrient dynamics, vertical and horizontal subsurface flow, and plant growth are modeled. To simulate both movement and storage of water within the riparian buffer a combination of mass balance and rate control equations are used. REMM then uses the explicit form of the modified Green-Ampt equation to simulate infiltration. From this, the model can calculate surface runoff. This is done by assuming that when total rainfall exceeds infiltration capacity or when the top soil layer is completely saturated, runoff will occur (Inamdar et al., 1999b). REMM also considers the effect of subsurface drainage in both the lateral and vertical direction using gravitational drainage between soil horizons and as deep groundwater seepage from the lower layer. The USLE is used to calculate the amount of overland erosion and sediment routing is simulated by using the equations of the AGNPS model (USEPA, 2006g). REMM uses a simple routing scheme to distribute the upland runoff down through the buffer strip based on its depth and velocity. To simulate carbon dynamics in the buffer strip REMM uses the Century model (Inamdar et al., 1999b). The Century model divides carbon in the soil and litter layers into different pools. Both organic and inorganic forms of soil nitrogen are simulated, along with nitrification, denitrification, and immobilization of nitrogen from plant residues. Next, the model uses the Langmuir isotherm to calculate partitioning of phosphorus into dissolved and absorbed fractions. The model can then simulate the effects of vegetation in the buffer strip by considering 12 plant types and two different canopy levels. From this, the model can simulate the consumption of water and nutrients which is related to the amount of biomass of the vegetation in the buffer strip (USEPA, 2006g).

Like any other model, there are distinct advantages and disadvantages of using this model to evaluate water quality. An advantage of using this model is that it has the capability of simulating subsurface interactions. Another advantage of using this model is that it is extremely detailed when analyzing nutrient cycling (USEPA, 2006g). One more advantage of using this model is that it allows for the evaluation of a specific BMP under many different circumstances that could possibly change the effectiveness of the BMP (Dukes and Evans, 2003).

One of the limitations of using REMM is that it is a complex model that requires an enormous amount of input data. Another disadvantage of using this model is that because of the simplified method that is used to distribute incoming upland runoff, the accuracy of flow routing is limited, which in turn limits the accuracy of the infiltration calculations (USEPA, 2006g). One more disadvantage of this model is that only riparian buffer strips can be evaluated. The model would not be suited for evaluating other processes in the watershed that could have an effect on water quality.

2.3 Soil and Water Assessment Tool

The Soil and Water Assessment Tool (SWAT) (Neitsch et al., 2002) is a river basin or watershed scale, continuous simulation model that was developed to analyze how different land management factors, such as implementing best management practices, climate change, and groundwater removal, affect water quality. The main components of the SWAT model include hydrology, soil temperature, crop growth, weather, sedimentation, nutrients, and land management (Saleh et al., 2000).

The SWAT model works by subdividing larger watersheds into sub-watersheds, and then further divides these sub-watersheds into hydraulic response units (HRUs), and then evaluates each individual HRU. A HRU is an area in the watershed that contains unique features, such as soils, land cover, land use, or management (Kannan et al., 2005). Subdividing the watershed into smaller HRUs becomes important when there are many different land uses and management practices in different areas of the watershed. For each particular HRU, the model simulates erosion, sediment transport, pesticide and nutrient cycling, and hydrology. The SWAT model uses two different components to simulate hydrology processes: (i) the land phase and (ii) the routing phase. The land phase determines the amount of water, sediment, nutrients, and pesticides that will be transported to the stream. This phase of the hydrologic cycle is based on the water balance. The routing phase of the SWAT model moves water, sediment, nutrients, and pesticides through channel networks to the watershed outlet (Srivastava et al., 2006). The SCS CN method or the Green-Ampt infiltration method is used to evaluate runoff flow and volume (Kalin and Hantush, 2006). The excess surface runoff not lost to other processes is routed to the streams. Once infiltration is calculated, the model simulates water moving into the soil profile and then routes the water through the different soil layers. For soils information, the model uses a soil database that has the capability of utilizing STATSGO or SSURGO soils data. The soils database contains information such as soil texture, depth, type, and hydrologic classification. Erosion is determined by the model, using the Modified Universal Soil Loss Equation (MUSLE) (Santhi et al., 2006). This, along with the model's ability to allow input of different management practices, such as application of nitrogen, phosphorus, and pesticides, allows the model to simulate movement of these particles through the stream networks of the watershed.

The SWAT model has played a huge role in the abatement of NPS pollution and has improved the effectiveness and efficiency of watershed management. There are many advantages to using this model. One such advantage is that SWAT is a physically based model (Spruill et al., 2000). This means that the model does not use regression equations to describe the relationships of the watershed. SWAT uses the physical characteristics of the watershed, namely soil properties, vegetation, and topography.

Because of this characteristic, SWAT is able to simulate watersheds that do not have any monitored data. Another benefit of using a model that is based on physical characteristics is that the changing variables of a watershed, such as vegetation, and infiltration rates, can be quantified and analyzed to determine if another alternative can be used. An additional benefit to using the SWAT model is that it is capable of simulating large watersheds with many different types of management strategies with very little time or money needed (Santhi et al., 2006). One more advantage of using this model is the minimal input data that is required to run the model is readily available and easily accessed on government web-sites. The ability to study watersheds on a long term basis is another advantage to using this model. This enables different practices, such as BMPs, to be evaluated to determine how they affect the watershed over long periods of time (Neitsch et al., 2002).

Although a lot can be said about the benefits of using the SWAT model, there are several limitations to using the model as well. One limitations of using the model is that it is very complex and can be overwhelming for new users to learn. Also, while the model is capable of handling large areas, this can be difficult because of the numerous input files that are associated with large watersheds. Another limitation is that this model is a continuous model; therefore, single storm events or flooding cannot be modeled (Neitsch et al., 2002). Also discouraging is the fact that the model only routes one pesticide each time through the watershed's stream network. The model also assumes well mixed one-dimensional streams and reservoirs that are typically not found in nature. An additional disadvantage is that the SWAT model does not allow the user to specify actual areas for nutrient applications (USEPA, 2006h).

2.4 Conclusions Drawn From Literature Review

NPS pollution is a huge problem that is associated with agricultural and forestry industries. As a result, many BMPs have been developed to minimize the effects of management practices on water quality; and thousands of models have been created that allow simulation of actual field processes, such as erosion, nitrification, runoff, nutrient uptake by plants, and others that occur in nature.

Many BMPs exist and each plays a certain role in reducing the effects of NPS pollution. Before a BMP is implemented, the economic feasibility and the effectiveness of NPS pollution reduction should be evaluated. Determining these two factors is extremely difficult. One way of determining the effectiveness of a BMP is through water quality monitoring. However, this method is not only expensive and time consuming, but the effectiveness of BMPs is often site specific, meaning that while one BMP is effective at reducing NPS pollution in one situation it might not be effective under different circumstances. Because of the challenges associated with assessing and evaluating a variety of BMPs, watershed models are needed to analyze how BMPs can be implemented to reduce the effects of NPS pollution.

The models discussed in this section are commonly used to determine the optimum way to control NPS pollution. With so many models to choose from, it is often difficult to determine which one is the best. Two primary factors must be considered when trying to determine which model should be used: (i) application and (ii) scale (Loague, 1998). First, the size of the area that is going to be modeled should be determined. Some models have limitations on how large or small an area can be. For example, for evaluating small-scale fields or roads, a field-scale model such as WEPP should be used. On the other hand, when analyzing the processes that are occurring on a large area, a watershed-scale model should be used. Secondly, the modeler should consider how the model is going to be applied. For instance, an event-based model would not be used to analyze how a watershed reacts to different management practices over a long period of time. For each individual situation, careful consideration must be taken to determine which is the best model for that particular situation.

CHAPTER THREE

AN ALABAMA BMP DATABASE FOR EVALUATING WATER QUALITY IMPACTS OF ALTERNATIVE MANAGEMENT PRACTICES IN AGRICULTURAL AND FORESTED WATERSHEDS

3.1 Abstract

Best management practices (BMPs) are often used to control nonpoint source (NPS) pollution from agricultural, forested, and urban watersheds. To estimate NPS pollutant loads, to devise NPS abatement plans, and to develop and implement Total Maximum Daily Load (TMDL) plans, NPS pollution models are often used. The accuracy of NPS model predictions depends on the accuracy of input data, which includes accurate description of BMPs. Although detailed BMP description can be obtained by using extension manuals and talking to experts, a comprehensive BMP database for use by watershed modelers and water resource managers is usually unavailable. In the absence of regionally appropriate BMP databases, simplified assumptions are often used. This practice introduces input data uncertainty in models and leads to poor model predictability and mistrust in models. To alleviate this problem, a comprehensive database of commonly used agricultural and forestry BMPs in Alabama has been developed. Using this database, various NPS pollution abatement measures can be evaluated using the Soil and Water Assessment Tool (SWAT) or other distributed parameter, continuous simulation NPS pollution models. Specific objectives were to: (1) develop a database of commonly used BMPs in agriculture and forestry for the State of Alabama and (2) create an ArcView® 3.X geographic information system (GIS) extension to load the database into the SWAT model. The database provides environmental professionals with detailed information on how agricultural and forested lands are usually managed in Alabama. This type of detailed information is currently unavailable in Alabama and many other states. Using the BMP database with the SWAT model, environmental professionals will be able to evaluate the site-specific effectiveness of BMPs and conduct more accurate assessments of NPS pollution, TMDLs, pollutant trading, and BMP implementation plans. Overall, this will allow environmental professionals to make more confident BMP recommendations and manage watersheds more effectively. Additionally, the methodology presented can be used by other states to develop region-specific BMP databases.

Keywords. SWAT, Modeling, Nonpoint Source Pollution, TMDL, Pollutant Trading, Water Quality

3.2 Introduction

Agriculture and forestry are two of Alabama's largest industries and each is historically known to cause NPS pollution problems. NPS pollution is defined as pollution that originates from a diffuse source and is usually associated with land or the use of land (Novotny, 2003). According to the U.S. Environmental Protection Agency (USEPA), NPS pollution is the leading cause of water quality problems in the U.S., causing harmful effects, to fisheries, wildlife, drinking water supplies, and other natural resources. NPS pollution is the primary reason why 40 percent of the nation's surveyed rivers, lakes, and estuaries are not clean enough to meet basic uses (USEPA, 2006). Agricultural practices have been identified as the leading contributor of NPS pollution, degrading 60 percent of the impaired rivers and half of the surveyed lakes (USEPA, 2006). The most notable NPS pollutants found in rural environments are sediment and nutrients such as nitrogen and phosphorus (Hariston et al., 2001). Other NPS pollutants include oil, grease, and pesticides. These pollutants can cause harmful effects such as decreased oxygen supply, increased turbidity, and increased eutrophication. Eutrophication, the main water quality problem associated with agricultural NPS pollution, affects close to 50 percent of the lakes and reservoirs assessed in the United States (Gitau et al., 2005).

Since the passage of the Clean Water Act (CWA) of 1972, much has been done to improve the quality of the Nation's waters. Two important sections of the Clean Water Act that are specifically concerned with NPS pollution abatement are sections 208 and 319. Section 208 recognized for the first time that it would take more than just controlling point source pollution to solve the United States' pollution problems (Novotny, 2003). The two major outcomes of this section were planning reports that identified the extent of point and NPS pollution and providing tools for these planning reports, such as hydrological and water quality watershed models. Similarly, Section 319 of the CWA is important because it provides funding for controlling NPS pollution. This also led to the development of watershed models. With the development of watershed models, land management practices could be analyzed to determine how they would affect water quality in adjacent water bodies (Novotny, 2003).

NPS pollution has become a major environmental concern, especially in agricultural and forested watersheds. Many industries that are historically known for contributing to NPS pollution problems, such as forestry, agriculture, and construction, have developed best management practices (BMPs) to reduce NPS pollution. A BMP is defined as any method, measure, or practice, either structural or nonstructural, that prevents or reduces water pollution (Brooks et al., 2003). A structural BMP would include a silt fence, wing ditch, or a broad based dip, whereas a nonstructural BMPs would include crop rotations, integrated pest management, grazing management and nutrient management. Depending on the goal of NPS pollution control, environmental laws, availability of funds, and applicability, a structural BMP, a nonstructural BMP or a combination is implemented. Table 3.1 provides examples of structural and nonstructural BMPs.

Table 3.1. A Selected List of Structural and Nonstructural BMPs

STRUCTURAL BMPs	**NONSTRUCTRURAL BMPs**
Silt Fence	Crop Rotations
Livestock Exclusion Fencing	Irrigation Water Management
Broad-based Dip	Nutrient Management
Wing ditch	Critical Area Planting
Water Bar	Integrated Pest Management
Erosion Control Mats	Conservation Tillage Practices
Culvert	Precision Agriculture
Constructed Wetlands	Conservation Cover
Dams	Pasture Management
Terraces	Streamside Management Zones
Diversions	Prescribed Grazing
Detention Ponds	Irrigation Water Management
Water Control Basins	Contour Farming
Grade Stabilization Structure	Animal Waste Utilization
Animal Waste Storage Facilities	Stripcropping

Both structural and nonstructural BMPs have been proven to reduce NPS pollution; however, each BMP functions differently. For instance, the primary goal of a silt fence is to prevent sediment from entering adjacent waterbodies, whereas, the goal of conservation tillage is to reduce erosion from row crop agriculture. Furthermore, BMPs should not only be effective at reducing NPS pollution, but implementation of BMPs should also be economically feasible (Novotny, 2003). Since effectiveness of BMPs is site-specific, evaluating the effectiveness of a particular BMP through water quality monitoring is often expensive and time consuming. Further, determining watershed-level reduction in NPS pollution due to the implementation of a specific BMP through monitoring is extremely difficult, if not impossible (Srivastava, 1999). Therefore, watershed-level effectiveness of BMPs are often evaluated using watershed models.

Watershed models are powerful water resource tools that are used to simulate how pollutants are transported to receiving waterbodies under different management circumstances. These models are capable of simulating and evaluating processes such as precipitation, evaporation, and infiltration, on a site specific basis. Output from these simulations includes hydrographs, water inflow and outflow, pollutant loading, as well as other valuable information that can be used to manage watersheds and combat NPS pollution. In recent years, increased simplicity in using models has made them extremely popular. Models are used for many different tasks today including urban planning, assessing BMPs, and developing TMDLs. While models are becoming widely used in managing water resources, it is necessary that detailed land management input data be available for determining how to minimize NPS pollution from land management decisions. Currently, the State of Alabama does not have detailed information on BMPs for forested and agricultural watersheds. Because of this, generalized land management information is used which leads to a greater level of uncertainty in modeling results and less confident BMP recommendations. By developing a BMP database for agricultural and forested watersheds for the State of Alabama, water resource professionals will be able to more efficiently and effectively manage watersheds and NPS pollution and develop more confident BMP recommendations because of less uncertainty in modeling results. The ArcView® GIS extension will provide a convenient way for the BMP database to be distributed and uploaded into the SWAT model. The BMP database and GIS extension will be helpful in reducing NPS pollution.

3.3 Objectives

The overarching goal of this study is to create a database of predominantly used BMPs in agriculture and forestry industries in the State of Alabama for use with watershed models. Specific objectives of this project were to:

(1) Develop a database of commonly used BMPs in the agricultural and forestry industries in Alabama; and

(2) Prepare an ArcView® 3.X GIS extension to load management files for each of these BMPs into the SWAT model.

3.4 Methodology

3.4.1 BMP Selection Procedure

Agriculture and forestry are two important industries in the State of Alabama and each has utilized BMPs to reduce the amount of NPS pollution created as a result of agricultural and forestry operations. Because of the importance of these two industries in Alabama, we developed a comprehensive BMP database that adequately represents the management practices being used in these two industries in Alabama. Further, we concentrated on the BMPs that can be evaluated using a watershed-scale NPS pollution model, SWAT. Data from the United States Department of Agriculture's National Agricultural Statistics Service (USDA-NASS) and Auburn University's College of Agriculture were used to establish the major commodities produced in Alabama. When compared with other states, Alabama ranks third in broiler production with 1.04 billion birds (USDA-NASS, 2004). The state ranks third in peanut production and ninth in cotton production with 190,000 and 525,000 acres, respectively, harvested annually

(USDA-NASS, 2004). The State ranks second in forest land cover with 22.9 million acres in timberland (USDA-NASS, 2004). By reviewing this information along with the acreage of other crops, a number of major crops grown in Alabama were selected for the BMP database. The row crops included in the database are corn, cotton, soybeans, peanuts, and wheat, while the forage crops included were alfalfa, bahiagrass, dallisgrass, hybrid bermudagrass, sericea lespedeza, summer annuals, fescue, and winter annuals. These forage crops are normally grown for hay or grazing purposes. Several grasses typically used in golf course management, athletic fields, and urban situations were also included in the database. These grasses included commercial bermudagrass, zoysiagrass, centipede lawn, and winter lawn. Fruiting crops included in the database are blueberries, pecans, and peaches. Animal waste applications were restricted to broiler litter and loblolly pine was the only tree that was considered in the forestry portion of the database. Table 3.2 lists major crops grown in Alabama along with the BMPs that were considered when developing the BMP database.

Table 3.2 Major Crops of Alabama and Associated BMPs Considered for the BMP Database

	Crops	BMPs
Row Crops	Corn Cotton Soybeans Peanuts Wheat	Crop Rotations IPM Nutrient Management Tillage Practices IWM
Forage Crops	Alfalfa Bahiagrass Dallisgrass H. Bermudagrass Sericea Lespedeza Summer Annuals Winter Annuals Fescue	Nutrient Management Grazing Management Animal Waste Applications IPM
Fruiting Crops	Blueberries Peaches Pecans	IPM IWM Nutrient Management
Turfgrass	Commercial Bermudagrass Zoysiagrass Centipede Lawn Winter Lawn	Nutrient Management IPM
Forestry	Loblolly Pine	IPM

3.4.2 SWAT Model

Watershed models are powerful tools for assessing NPS pollution problems and evaluating watershed-level effectiveness of BMPs. The CWA has led to the creation of many different watershed models that are available for analyzing NPS pollution problems. The SWAT model (Neitsch et al., 2002) is one of the most popular models that is currently being used by water resource managers to evaluate NPS pollution problems, to devise NPS control measures, and to develop and implement TMDLs (Total Maximum Daily Loads) in agricultural and forested watersheds. Even though the database can be used with other watershed-scale, distributed parameter, continuous simulation models, our database can be readily loaded and used with the SWAT model. The SWAT model was created for the sole purpose of analyzing the effect that different management practices have on water quality and is currently supported by the USEPA for its TMDL program for development and implementation of TMDLs in agricultural watersheds (Neitsch et al., 2002).

SWAT is a watershed-scale, continuous simulation model created by Dr. Jeff Arnold for the USDA, and is a modification of the Simulator for Water Resources in Rural Basins (SWRRB) model and the Routing Outputs to Outlet (ROTO) model. There were several limitations associated with the SWRRB model. These limitations included watershed divisions limited to only ten subbasins and routing of water and sediment from subbasins directly to the watershed outlet. These shortcomings lead to the development of the ROTO model. The ROTO model solved the problems associated with the SWRRB model by combining multiple SWRRB runs. While the ROTO model corrected most of the limitations associated with the SWRRB model, it still lacked perfection. There were problems with running multiple SWRRB files and each SWRRB file had to be run individually and then incorporated into the ROTO model. Because of these complications, the ROTO and SWRRB models were combined to create the SWAT model. The creation of the SWAT model made it possible to model large watersheds and to study the effects of different management practices on watersheds over a long period of time (Neitsch et al., 2002). This is one of the main reasons the SWAT model is one of the most popular models for the evaluation of NPS pollution in agricultural and forested watersheds.

The primary goal of any watershed model is to accurately simulate field processes such as hydrology, weather, and land management, and to evaluate how these processes affect water quality. The SWAT model has eight major components, including hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Borah and Bera, 2002). The SWAT model simulates these processes by subdividing larger river basins into smaller basins, then the model evaluates each individual area. This becomes important when different land uses are found in various areas of the watershed (REM, 2002). These subwatersheds are further grouped based on climate, hydrologic response units (HRU), ponds, ground water, and main channels (Borah and Bera, 2002). HRUs are areas of land that have unique characteristics, such as land cover, soil, or land management practices (Neitsch et al., 2002). Primary input data that is needed to run the SWAT model include digital elevation (DEM) data, soils data, climate data, land cover data, and land management information.

The land management portion of the SWAT model makes the model a powerful tool in evaluating NPS pollution. The SWAT model allows for the input of land management information into the HRU management file (Neitsch et al., 2002). In this file, for individual HRUs, modelers can input and evaluate land management practices such as pesticide applications, nutrient applications, tillage operations, planting and harvesting dates, animal waste applications, grazing practices and irrigation practices. BMPs can be entered into the SWAT model through this HRU management file and can be evaluated to determine how effective the BMPs are at reducing NPS pollution. Specific BMPs that can be simulated in the HRU management file include crop rotations, conservation tillage practices, integrated pest management, irrigation water management, nutrient management, and grazing management. Figure 3.1 provides a flow chart that describes how the SWAT model takes the input data, uses the input data to evaluate the watershed, and then generates output data that can be used for making watershed management decisions. The management portion (highlighted in gray) of Figure 3.1 shows how the BMP database works in the SWAT model. More specifically, the database developed provides a number of scenario files and supporting data, such as planting and harvesting dates, crop rotations, and pesticide applications. Once a particular management scenario has been chosen, the SWAT model can utilize the four databases to simulate actual field operations and then evaluate the management practices to see how they affect water quality.

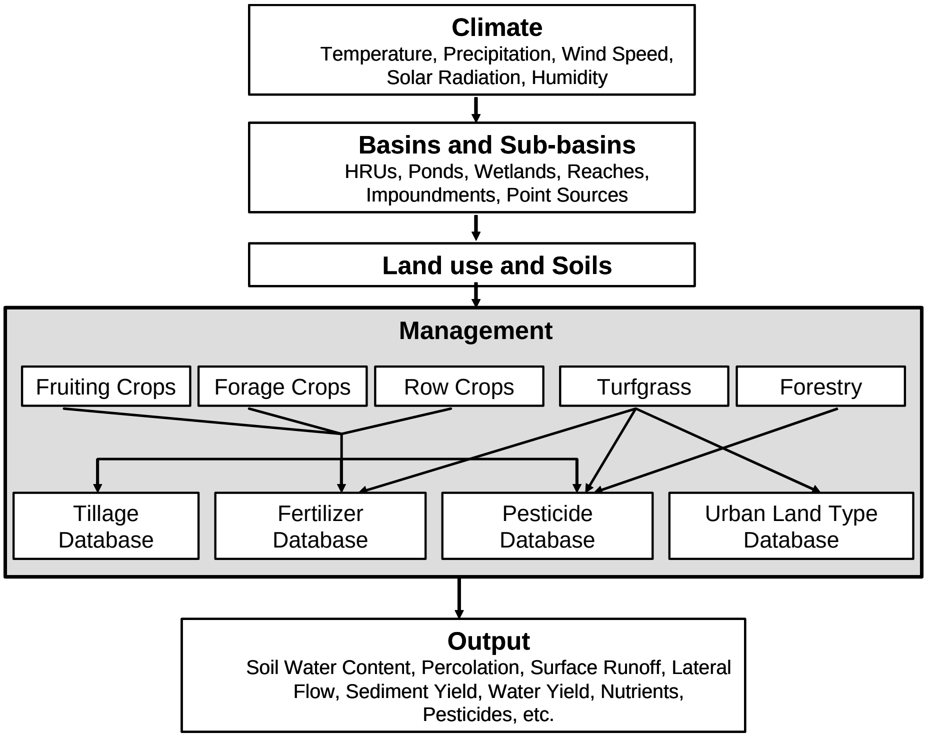

Figure 3.1. A Flowchart Showing Where the BMP Database is Located (highlighted in gray) in the SWAT Model.

3.4.3 Data Collection Procedure

There are many crops grown across Alabama with different geographic regions utilizing different management practices. For instance, the majority of the Alabama peanut crop is currently grown in South Alabama. The Central and Blackbelt regions of Alabama have a few peanut farmers, while peanut farming is nonexistent in the northern portion of the State. Another important factor dependent on geographic region is the timing of management practices, such as planting dates, harvesting dates, tillage operations, and fertilizer applications. Weather is the primary driving force in determining when these management operations should occur. For example, crops have to be planted later in the year for farms that are located in the cooler climate of Northern

Alabama as opposed to farms that are located in the warm climate of South Alabama. Because of these factors, geographic location had to be considered when developing the BMP database. To accomplish this, the State was divided into four different regions: south, central, north, and the Blackbelt region (Figure 3.2). By dividing the state into four geographic regions and developing BMPs based on these four areas of the State, the BMP database will provide a better account of actual management practices being performed in the field by Alabama farmers.

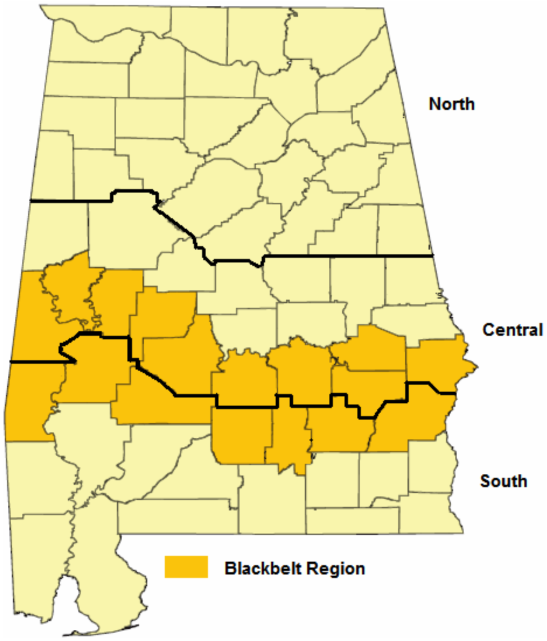

Figure 3.2 Geographic Regions of Alabama for Which BMP Database was Developed.

After determining which crops were going to be used to construct the BMP database, a list of well known crop experts for the State of Alabama was assembled. These individuals have experience, and valuable knowledge of how the crops included in the database are managed. These experts include extension agents, agronomists, entomologists, plant pathologists, foresters, engineers, and university professors. Each expert was contacted to determine the key management practices that are used and how these management practices could best be represented in the BMP database. Also, information was obtained from several of the Alabama Cooperative Extension System's publications. This information included operational dates, irrigation scheduling, grazing practices, pesticide applications, fertilizer applications, and tillage operations. To further ensure that the database contained accurate land management information specific to the four regions of Alabama, a small portion of the crop experts was chosen to review all land management data before it was input in the database. All land management information was reviewed by at least one crop expert before being included in the BMP database. After gathering all of the management information, the data was evaluated to determine which BMPs could be depicted in the SWAT model.

3.4.4 Crop Rotations

A major BMP used by Alabama farmers is crop rotations. By rotating crops in an organized, preplanned sequence, farmers can reduce NPS pollution. Crop rotations reduce the amount of NPS pollution by decreasing the chance of insects and disease infestation and by limiting the amount of time that a field is in row crops (Novotny, 2003). Increased soil microbial biomass is also an advantage of utilizing crop rotations (Adeboye et al., 2006). By increasing the amount of vegetative cover and by decreasing the amount of time that a field is in row crops, soil loss can be significantly reduced (Novotny, 2003). Because of the variety of crops that are grown in various areas of Alabama and to ensure that crop rotations were accurately incorporated into the BMP database, careful consideration was taken when determining which rotations should be used. Extension agents with knowledge of commonly used crop rotations by farmers were contacted. Agents from all four regions were contacted so that each region was adequately represented in the BMP database. After contacting the agents in all four regions, the BMP database consisted of over 300 different management scenarios.

3.4.5 Nutrient Management

Nutrient management is an important BMP for both environmental protection and crop production. It requires taking into account all aspects of the crops being grown, soil fertility, and the availability of nutrients prior to applying any type of fertilizer (Tyson, 2000). Nutrient management works to reduce NPS pollution by decreasing the amount of excess nutrients that can enter surface and ground waters. This is done by improving application rates, timing, and fertilizer placement location (Novotny, 2003). It is extremely difficult to incorporate nutrient management into the BMP database because of the variability in soil types and crop management. Nutrient management was represented in this BMP database by using the Auburn University College of Agriculture's Department of Agronomy and Soils soil test nutrient recommendations. It should be noted that for most cases the application rates that are used in the BMP database are considered to be on fields with a medium rating for phosphorus and potassium. For more accurate results in modeling output, refer to www.ag.auburn.edu/agrn/croprecs/.html for all soil test nutrient recommendations for Alabama crops or use individual soil test recommendations.

3.4.6 Animal Waste Applications

The poultry industry is an important part of Alabama’s economy, and many farmers are utilizing poultry litter as a fertilizer source. Recently, concern has grown over how over-applying animal waste can lead to excessive phosphorus loadings in surface waters (Sharpley and Beegle, 2001). To reduce NPS phosphorus pollution, the phosphorus index (P-index) of Alabama was created. The P-index is a powerful tool for evaluating management practices and land areas for potential risk of phosphorus transport. The P-index assesses the potential risk of phosphorous transport by analyzing eleven different field factors or management practices and then suggests an appropriate amount of fertilizer to apply (USDA, 2001). Because of the size of the poultry industry in the State of Alabama, poultry litter applications were included in the BMP database. Poultry litter is commonly applied on forage crops that are used for either hay production or for animal grazing (Mitchell, 2006). Cotton and corn are the only row crops that were considered suitable for using poultry litter as a source of nutrients in the BMP database (Mitchell, 2006). The resulting score of the P-index indicates that fertilizer should be applied at the nitrogen rate (very low/low potential risk), 3 times the phosphorus uptake rate (medium potential risk), 2 times the phosphorus uptake rate (high potential risk), 1 times the phosphorus uptake rate (very high potential risk), and 0 times the phosphorus uptake rate (extremely high potential risk). To make the database easy to use, poultry litter applications are based on a very low/low potential risk result. Adjustments should be made in the application rates using Table 3.3 if individual field characteristics suggest a different P-index rating. Table 3.3 contains the appropriate applications rates based on the P-index rating.

Table 3.3 Application rates (lb/acre) of Poultry Litter for Alabama Crops as a Function of P-Index Rating[†]

Crop	**Yield (per acre)**	**P-Index Rating**				
		Very Low/Low	**Medium**	**High**	**Very High**	**Extremely High**
Corn	70 (bu)	4,138	2,897	1,931	966	0
Irrigated Corn	145 (bu)	6,207	6,000	4,000	2,000	0
Cotton	2.25 (bale)	3,104	2,793	1,862	931	0
Alfalfa (hay)	3 (ton)	-	3,724	2,483	1,241	0
Hybrid Bermudagrass (hay)	5 (ton)	10,345	6,207	4,138	2,069	0
Fescue (hay)	3 (ton)	4,138	2,793	1,862	931	0
Bahiagrass (hay)	5 (ton)	4,138	3,621	2,414	1,207	0

[†] Please note that most farmers round to the nearest ½ ton (1,000 lb) per acre for poultry litter applications.

3.4.7 Integrated Pest Management

Another important BMP that is incorporated into the database is integrated pest management (IPM). IPM minimizes NPS pollution by controlling crop pests such as diseases, weeds, insects, and fungi (Novotny, 2003). Pesticides are applied more efficiently and at minimal rates to keep the crop healthy. Resistant crop varieties and more appropriate pesticide application timing also plays a role in reducing NPS pollution (Novotny, 2003). Integrated pest management is another BMP that is difficult to represent because of the numerous pesticides that are available to farmers, and because of the various strategies that are used to manage crop pests. To develop the IPM portion of the database, several different resources were used including talking to plant pathologists, entomologists, and extension agents. Also, crop budgets from the Auburn University College of Agriculture’s Department of Agricultural Economics were used to determine commonly used pesticides. Application rates were based on IPM publications from the Alabama Cooperative Extension System. The SWAT model has a comprehensive pesticide database; however, it did not contain all the pesticides that are currently used by Alabama farmers. To remedy this, the SWAT model allows for the input of new pesticides. The following is the needed information to input a new pesticide into the SWAT pesticide database: soil adsorption coefficient normalized for soil organic carbon content (mg/kg)/(mg/L), wash-off fraction, degradation half-life of the chemical on the foliage (days), degradation half-life of the chemical in the soil (days), application efficiency, and the solubility of the chemical in water (mg/L or ppm). Finding these values is difficult and several sources, including chemical companies, were contacted to obtain the information. Other sources included chemical material safety data sheets

(MSDS), chemical labels, the California Department of Pesticide Regulation, and the USEPA. For all of the chemicals added to SWAT's pesticide database, the application efficiency was assumed to be 0.5, the wash-off fraction was considered to be 0.75 and where data was not available, the degradation half-life on the foliage was considered to be half of the degradation half life in the soil. Table 3.4 provides a list of pesticides that were added to the SWAT model's pesticide database.

Table 3.4 Chemicals Added to SWAT's Pesticide Database

Trade Name	Common name
Stratego®	Propiconazole and Trifloxystrobin
Intrepid®	Methoxyfenozide
Provado®	Imidacloprid
Indar®	Mancozeb
Tracer® 4SC	Spinosad
Cadre®	Ammonium salt of imazapic
Escort®	Metsulfuron methyl
Warrior®	lambday-cyhalothrin
Onestep®	Isopropylamine salt of Imazapyr
Oustar®	Hexazinone and Sulfometuron Methyl
Pristine®	Pyraclostrobin and Boscalid
Abound®	Azoxystrobin
Decree®	Fenhexamid
Switch®	Cyprodinil and Fludioxonil
Cabrio™	Pyraclostrobin
Express®	Tribenuron methyl

3.4.8 Irrigation Water Management

Irrigation water management (IWM) is another BMP that has been commonly used by Alabama farmers. IWM reduce NPS pollution by improving irrigation scheduling, efficiency, and utilization (Novotny, 2003). By incorporating IWM into farming practices, not only is water quality being protected, but water loss is being reduced and crop production is not being compromised. Corn is the only row crop that has irrigation water practices represented in the BMP database. IWM is another BMP that is somewhat difficult to represent in the BMP database because of the variety of irrigation systems that exist. The SWAT model has an option for automatically applying irrigation if the actual plant growth falls below a specified water stress threshold rather than specifying a fixed amount and time for irrigation practices to occur. The water stress threshold ranges from 0 to 1.0, with 0 indicating no plant growth and 1.0 indicating no reduction in plant growth (Neitsch et al., 2002). This auto-application of irrigation was used to simulate how farmers apply irrigation to corn. The water stress threshold was set at the recommended 0.925 level (Neitsch et al., 2002). For more detailed information on the water requirements for corn, see Table 3.5 below.

Table 3.5. Estimated Water Use by Corn for Alabama Farms

Days After Planting	Growth Stage	Inches Per Day	Total Water Use (inches)
0-20	Seeding	0.06	1.2
20-30	5”-10”	0.09	0.9
30-40	10”-20”	0.15	1.5
40-50	20”-50”	0.20	2.0
50-60	50”-80”	0.21	2.1
60-70	80”-Silking	0.25	2.5
70-100	Silking-Grainfill	0.33	10.0
100-110	Grainfill	0.25	2.5
110-120	Maturity	0.23	2.3
0-120	---------------	---------------	25.0

Source: Alabama Corn Newsletter: May 2004 Archives

3.4.9 Grazing Management

Many farmers in Alabama use pastures for grazing purposes. Because of this, it was important that grazing management be implemented in to the BMP database. Pasture management is a BMP that minimizes NPS pollution by protecting the vegetative cover of pastures. This is accomplished by properly stocking pastures and proper grazing use (Novotny, 2003). The following table shows database inputs for grazing periods that correspond to individual crops (Ball, 2006).

Table 3.6 Typical Grazing Periods for Alabama Farms

Crop	**Start Grazing**	**End Grazing**	**No. Days of Grazing**
Bahiagrass	April	October	165
Dallisgrass	April	October	205
H. Bermudagrass	May	October	167
Sericia Lespedeza	May	October	175
Summer Annual	June	October	155
Fescue	April	June	75
	September	November	70
Stockpiled Fescue	April	June	75
	November	December	42
Winter Annuals	February	May	75
	November	December	30
Overseeding Pasture w/ Winter Annuals	February	May	75

The SWAT model requires that the user input the dry weight of biomass consumed daily by the animals and the dry weight of manure deposited daily by the animals. A lot of variability exists in the number of animals that are grazed by Alabama farmers. According to the USDA-NASS, 39% of Alabama farmers have between 100 and 499 head of cattle (USDA-NASS, 2006). The default setting used in the database was 100 head of cattle, each of which was assumed to weigh 1350 pounds. It was assumed that it takes an average of 2.5 acres of land to support 1 cow/calf (Kriese-Anderson, 2006). It is also assumed that the dry weight of biomass that is removed daily by the cattle is 2% of the cow’s body weight (Ball, 2006). These numbers can be adjusted based on the management practices of the watershed being examined.

3.4.10 Tillage Operations

Agricultural technological advances have lead to the adoption of reduced tillage practices that minimize NPS pollution from tillage operations. These improved tillage practices include minimum tillage, zero tillage (no-till), and strip tillage. Benefits of reduced tillage operations include conserving soil and water, reducing the amount of fuel needed for machinery, improving soil structure, and reduction in pesticide and nutrient losses (Hairston et al., 2001). These conservation tillage practices are commonly used on Alabama farms. Research was conducted to determine which cropping systems actually use conservation tillage practices. This information was obtained from extension agents in the four regions of the State who are interacting with Alabama farmers on a continuous basis. The information was then input into the SWAT model by altering the SCS CN that was associated with tillage operations.

3.4.11 Land Cover Input

The SWAT model has an extensive land cover/plant database that covers a broad range of different types of plants. This database, however, did not include all of the crops that were common to Alabama. To remedy this problem, the SWAT model development staff was contacted to determine the most appropriate way to represent the missing crops in the database. The forage crops that were not included in the database include sericia lespedeza, dallisgrass, and bahiagrass. SWAT's land cover/plant database contains a generic pasture land cover that uses bermudagrass values for simulating growth and other processes. This generic pasture land cover input was used for forage crops that were not available in the land cover/plant database. Another generic land cover available in the

SWAT models land cover/plant database was orchards. This was used to represent pecans and peaches in the BMP database. Blueberries were another land cover that was added to the database. The values for grapes were used to simulate the growth and other processes that are associated with blueberries. In order to simulate the processes that are associated with centipede lawn, Zoysia, and St. Augustine grass, the values for sideoats grama were modified with the potential leaf area index being set to 1 and the potential rooting depth being set to 0.4. The crop height was also reduced to adequately represent a turfgrass situation (Kiniry, 2006).

3.4.12 Forestry BMPs

Forestry is one of Alabama's largest industries, and according to the Alabama Forestry Commission supports approximately 170,000 people. Because of the enormity of the forest industry in Alabama, it was important that forestry be adequately represented in the BMP database. Many of the forestry BMPs are structural and cannot be simulated in the SWAT model because SWAT is a land-based model. However, certain site preparation and release treatments are included in the BMP database. The BMP database contains the major crop species that are grown in the State of Alabama. Approximatly 94 percent of the trees that are planted in Alabama are loblolly pine (Enebak, 2007). Because of this, loblolly pine was the only tree species included in the database. All chemical applications were based on IPM strategies, chemical manufacturer's labels, and USEPA regulations.

3.4.13 Extension Development

With the creation of a GIS extension, the BMP database can be distributed and loaded into the GIS interface of the SWAT model. This will allow individuals working in the water resources field across the State to utilize this tool. The extension is created using the AVENUE programming language provided by the ArcView® GIS program. AVENUE is ArcView®'s programming language that is used for customizing and developing ArcView® applications (DU-ITS, 2005). The development of the extension provides an easy method for distributing the BMP database.

3.5 Results

3.5.1 Row Crops

The majority of the BMP database consists of row crop management scenarios. Table 3.7 below shows various crop rotations that have been included in the database and the SWAT model for various regions of Alabama. These rotations are specific for each of the four regions of Alabama. Each of these crop rotations consists of additional BMPs that include irrigation water management, conservation tillage operations, integrated pest management, and nutrient management. Table 3.8 provides a complete management scenario for a cotton-wheat rotation along with timing and application rates of fertilizers and pesticides, tillage practices, and other land management information.

Table 3.7 Crop Rotations by Alabama Regions

Region	Crop Rotations		
North	continuous cotton cotton-wheat(cc) cotton-rye(cc) cotton-corn	cotton-cotton-corn cotton-cotton-corn silage cotton-soybean cotton-irrigated corn	cotton-corn silage cotton-cotton-irrigated corn
Central	continuous cotton corn-soybean-corn corn silage-soybean-corn silage corn-cotton-corn corn silage-cotton-corn silage corn-soybean-cotton corn silage-soybean-cotton	corn-wheat-soybean corn silage-wheat-soybean cotton-cotton-cotton-peanut cotton-cotton-peanut cotton-ryegrass(graz) irrigated corn-soybean- irrigated corn	Irrigated corn-soybean-cotton Irrigated corn-wheat-soybean corn silage-soybean-cotton corn silage-wheat-soybean irrigated corn-cotton- irrigated corn
South	peanut-cotton cotton-cotton-peanut peanut-corn silage	cotton-wheat(cc)-peanut cotton-rye(cc)-peanut cotton-corn silage	bahiagrass-bahiagrass-bahiagrass-peanut cotton-ryegrass(graz)
Blackbelt	cotton-wheat(cc)-peanut wheat-corn-wheat-soybean cotton-corn-cotton-corn-soybean peanut-ryegrass(graz)-cotton cotton-irrigated corn-soybean	corn-corn-soybean cotton-corn-soybean corn silage-corn silage-soybean cotton-corn silage-soybean wheat-corn silage-wheat-soybean irrigated corn- irrigated corn-soybean cotton-irrigated corn-soybean	cotton-corn silage-cotton-corn silage-soybean wheat-corn silage-wheat-soybean wheat-irrigated corn-wheat-soybean cotton-irrigated corn-cotton-irrigated corn-soybean irrigated corn-irrigated corn-soybean

*cc=cover crop, graz= grazing,

Table 3.8 A Complete Management Scenario for a Cotton-Wheat(cc) Rotation with Associated Tillage, Nutrient, and other Management Practices

Date (month/day)	**Practice**
Cotton (Strip Tillage)	
4/1	Apply Roundup (1lb/acre)
4/1	Apply Prowl (1 lb active /acre)
4/10	Stripping
4/15	Plant
4/15	Apply 45 lb/acre of nitrogen
4/15	Apply 40 lb/acre of phosphorus
4/15	Apply 40 lb/acre of potash
4/15	1 application of Temik (4 lb active /acre) on 40% of the acreage
4/15	1 application of Orthene 90 SP (.15 lb active/acre) on 20% of the acreage
5/5	Apply Roundup (1 lb/acre)
5/10	Apply 0.5 applications of Bidrin 8EC (.2 lb active/acre) on 100% of the acreage
6/10	Apply 45 lb/acre of nitrogen
6/10	Apply mixture of Roundup (1 lb/acre) and Diurone (1 lb active/acre)
6/15	1.5 applications of Ammo 2.5 EC (0.06 lb active/acre) on 100% of the acreage
7/1	Apply mixture of Diuron (1 lb active/acre) and MSMA (1.5 lb active/acre)
7/15	0.5 applications of Karate Z 2.08 CS (0.3 lb active/acre) on 75% of the acreage
8/1	1 application of Karate Z 2.08CS (0.3 lb active/acre)on 75% of the acreage
8/15	2 applications of Bidrin 8 EC on 100% of the acreage
9/15	Harvest
Wheat (cover crop)	
9/16	Chisel plow
9/16	Light disk
10/15	Plant
2/15	Apply 30 lb/acre of nitrogen
2/15	Apply 60 lb/acre of phosphate
2/15	Apply 60 lb/acre of potash
2/15	Apply 10 lb/acre of sulfur

3.5.2 Forage Crops

Although forage crop management is not as intense as managing row crops, BMPs can still lead to improved water quality. Table 3.9 provides a list of the major Alabama forage crops that are included in the BMP database. Information was obtained to determine which forages are used for grazing versus which are used for hay production. Management information on establishing a particular forage crop was also included in the BMP database. Specific BMPs that are included under forage crops include, pasture management, nutrient management, and integrated pest management. Table 3.10 presents a situation where a farmer is using hybrid bermudagrass for grazing. This table explains the timing and the rate that nutrients should be applied, as well as how long grazing should be allowed.

Table 3.9 The Major Forage Crops of Alabama that are Included in the BMP Database

Establishment	**Grazing**	**Hay**
Alfalfa	Bahiagrass	Alfalfa
Bahiagrass	Dallisgrass	Bahiagrass
Dallisgrass	Hybrid Bermudagrass	Dallisgrass
Hybrid Bermudagrass	Sericia Lespedeza	Hybrid Bermudagrass
Sericia Lespedeza	Summer Annuals	Sericia Lespedeza
Fescue	Fescue	Fescue
	Winter Annuals	Summer Annuals

Table 3.10 A Complete Management Scenario for Hybrid Bermudagrass Used for Grazing

Date (month/day)	**Practice**
Hybrid Bermudagrass (grazing)	
4/5	Apply 60 lb/acre of nitrogen
4/5	Apply 40 lb/acre of phosphate
4/5	Apply 40 lb/acre of potash
5/25	Begin grazing
6/5	Apply 60 lb/acre of nitrogen
10/5	End grazing

3.5.3 Fruting Crops

Three of Alabama's primary fruiting crops, peaches, pecans, and blueberries, are included in the BMP database. The BMP database considers that management practices for blueberries will be different from year to year until the plants reach maturity. For instance, management strategies for year 2 will differ from the management practices in year 7. The database contains BMP information for blueberries ranging from first establishment to year 7. BMPs for the management of peaches and pecans assume that the orchards were mature and that year to year management is the same. The following example (Table 3.11) shows the type of information that is contained in the BMP database for these fruiting crops. Table 3.11 displays a management scenario for blueberries that are in their second year and includes information on the time and application rates of fertilizers and pesticides, as well as irrigation practices and other information related to second-year blueberry management.

Table 3.11 Complete Management Scenario for Alabama Blueberries in Year 2

Date (month/day)	**Practice**
Blueberries year 2	
3/5	Apply 140 lb/acre of 12-4-8
3/xx	Irrigate (1.5 inches per week)
4/10	Spot spray Roundup Weathermax (2 pt/acre)
5/10	Spot spray Roundup Weathermax (2 pt/acre)
5/20	Apply 60 lb/acre 12-4-8
5/xx	Irrigate (1.5 inches per week)
6/1	Spot spray Roundup Weathermax (2pt/acre)
6/xx	Irrigate (1.5 inches per week)
7/1	Apply 100 lb/acre of 12-4-8
7/5	Spot spray Roundup Weathermax (2 pt/acre)
7/xx	Irrigate (1.5 inches per week)
8/1	Spot spray Roundup Weathermax (2pt/acre)
9/1	Spot spray Roundup Weathermax (2pt/acre)
9/xx	Irrigate (1.5 inches per week)
10/1	Spray Dervinol 50 DF (4 lb/acre) and Princep 4L (0.5 gal/acre)

3.5.4 Turfgrass Management

The turfgrass portion of the database includes BMPs for centipede lawn, commercial sod, bermudagrass, zoysiagrass, St. Augustine lawn, winter lawns, as well as athletic fields and golf course fairways. Table 3.12 provides an example of the BMP information that is included in the database for turfgrass management. This table shows the management practices for a golf course fairway that has not been overseeded. The table displays information on fertilizer and pesticide application rates and timing.

Table 3.12 Complete Management Scenario for Alabama Golf Course Fairway that is not Overseeded

Date (month/day)	Practice
Golf course fairway (not overseeded)	
5/1	Apply 50 lb/acre of nitrogen
5/1	Apply phosphorus and potassium per soil test recommendation
7/1	Apply 50 lb/acre of nitrogen
7/1	Apply phosphorus and potassium per soil test recommendation
8/1	Apply 50 lb/acre of nitrogen
8/1	Apply phosphorus and potassium per soil test recommendation
9/1	Apply 50 lb/acre of nitrogen
9/1	Apply phosphorus and potassium per soil test recommendation
9/1	Apply Aatrex (0.12 lb/acre)
2/1	Apply 25 lb/acre of nitrogen

3.5.5 Forestry BMPs

Because the majority of forestry BMPs are structural, and focus on minimizing NPS pollution from forest roads, it was difficult to include forestry BMPs in the database. Although many forestry BMPs exist, such as wing ditches, water bars, culverts, and streamside management zones (SMZ), the specific BMPs that are contained in the database deal with chemical site preparation operations and release treatments of loblolly pine plantations. For example, information that is included in the database includes the timing and applications rates of pesticides that are used for site preparation, herbaceous and woody release treatments, as well as planting dates.

3.6 Summary and Conclusion

Best management practices have been widely used to control NPS pollution. Watershed-scale NPS pollution models are often used to estimate NPS pollutant loads from watersheds, develop and implement TMDLs, and to evaluate effectiveness of BMPs. The accuracy of model prediction depends on the accuracy of input data of which description of BMPs is an integral part. Even though such data is available in various publications and through consultation with experts, in the absence of a comprehensive database modelers often resort to simplified assumptions. These practices introduce input data uncertainty, which leads to output uncertainty. This paper describes the development of a BMP database and a GIS extension that can be used to evaluate and manage agricultural and forested watersheds in the State of Alabama. To ensure that the database represents actual management practices that are currently being used by Alabama farmers, information was gathered from a variety of sources and experts from across the State of Alabama. Information obtained and added to the database included: (i) planting and harvesting dates, (ii) tillage practices, (iii) integrated pest management strategies, (iv) nutrient management, as well as other management information. The BMP database contained over 300 different management scenarios that are commonly found across the State of Alabama. These scenarios contained information for forestry operations, turfgrass management, animal waste management, fruiting crop management, grazing management, forage crop management, and agronomic crop management. Specific BMPs comprised in the database include: crop rotations, IPM, nutrient management, pasture management, irrigation water management, and conservation tillage practices. The BMP database described here provides a powerful watershed management tool with several benefits. Currently, in the State of Alabama and in many other states, such a database does not exist. While conducting watershed assessments, generalized data is used to represent field operations. By using the BMP database, more accurate estimations of how management practices are affecting water quality will lead to more confident environmental and land management recommendations. As a consequence, this database will allow environmental professionals to evaluate BMPs effectiveness at a watershed-level. The ArcView® GIS 3.X extension will allow the database to be easily distributed to environmental professionals across the State of Alabama. The BMP database will help improve the way agricultural and forested watersheds are managed in the State of Alabama, which will help reduce NPS pollution.

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CHAPTER FOUR

WATERSHED-LEVEL EFFECTS OF ALABAMA P-INDEX IN AN ANIMAL WASTE-APPLIED WATERSHED

4.1 Abstract

A major concern among the agricultural and environmental community is the adverse effects of phosphorus (P) pollution as a result of over application of animal waste. The Alabama Phosphorus index (P index) is a tool that evaluates a particular site and its associated management practices for the potential risk of P movement to nearby surface waters. Research has shown that not all areas of a watershed contribute equally to P pollution. The P index works to identify those areas with high potential risk so application rates can be adjusted to eliminate over-application. This study uses the Soil and Water Assessment Tool (SWAT) and the Alabama BMP database to evaluate how current management practices are affecting water quality in a Randolph County, Alabama watershed and to evaluate the effectiveness of the Alabama P index in managing P pollution at a watershed-scale. Based on the analysis, current level of animal waste application is not contributing to P pollution in the study watershed. However, by adding other poultry farms to the watershed with similar land management practices, P loads will increase significantly. The Alabama P index was effective at reducing P loads in the watershed, but the results indicated that the P index was most effective in dryer years, as opposed to years where there was heavy precipitation. This would suggest that climate variability is playing an important role in P transport. The results showed little variation in P loads as the P index rating was increased from ‘very low/low’ to ‘extremely high’. This could be a result of the limitations of the SWAT model. Overall, the Alabama P index was effective at reducing P loads at the watershed-scale.

Keywords. SWAT, Modeling, Nonpoint Source Pollution, Phosphorus, Poultry litter

4.1 Introduction

Throughout the agricultural community concern exists over the adverse effects of nonpoint source pollution (NPS) on water quality. The U.S. Environmental Protection Agency (USEPA) has determined that NPS pollution is the main source of water quality impairments in the U.S. (USEPA, 2006). Agriculture alone is responsible for degrading 60 percent of the impaired rivers and half of the surveyed lakes in the U.S. (USEPA, 2006). In recent years, a major concern in NPS pollution abatement has been reducing P loadings from agricultural watersheds (Sharpley and Beegle, 2001). The main problem associated with surface waters with excessive P loadings is eutrophication (Carpenter et al., 1998). Eutrophication can have a drastic effect on water quality that include reduced oxygen levels, increased turbidity, odor, and decreased species diversity (Hansen et al., 2002).

The use of animal waste as a fertilizer source is an excellent way to supply crops with the amount of nutrients needed to produce acceptable crop yields; however, excessive P loadings to surface waters are a common consequence of runoff from agricultural fields where animal manure is being utilized as a fertilizer source (Jesiek and Wolfe, 2003). When P is applied as animal waste it tends to move slowly through the soil because of its sorption to soil particles (Snyder et al., 2001). If application rates of animal waste exceed plant nutrient requirements, then P can accumulate in the soil and can potentially enter adjacent streams through surface and subsurface pathways. For years, animal waste recommendations were based on crop nitrogen requirements; which can lead to over application of P because of relatively high P to N ratio in many animal wastes, resulting in impaired surface waters (DeLaune et al., 2004). Research has shown that 90 percent of P runoff from fields where animal manure is used as a fertilizer source is in the soluble form (Edwards and Daniel, 1993). This is troublesome because soluble P is directly available to algae and macrophytes, while particulate P is only bioavailable after being transformed to inorganic P (Sonzogni et al., 1982).

Due to increasing P pollution problems that occur as a result of utilizing animal waste as a fertilizer source, many different best management practices (BMPs) have been developed and implemented in an attempt to reduce P pollution (Gitau et al., 2005). Research has shown that P losses do not occur in uniform concentrations or quantities from all areas within the watershed. Furthermore, sub-portions of individual fields do not contribute equally to P losses (Snyder et al., 2001). Because of these factors, many states developed phosphorus indicies to determine areas where the risk for P loss is highest. A P index is an evaluation tool that is based on the concept that P losses occur in relatively small areas of the watershed during only a few rainfall events (critical source area concept) (Pionke et al., 1997). Quite simply, a P index works by assessing the risk of P losses by rating the vulnerability of an area from ‘low’ to ‘extremely high.’ Application rates can then be determined based on the rating given by a P index. For example, for an area that receives a high P index rating, a lower application rate should be used and other BMPs should be implemented to further reduce the amount of P loss.

P index has been the source of much research and discussion by environmental professionals all across the U.S. and research has warranted the transport and source factors to be incorporated into the P index (Sharpley et al., 2001). Consequently, P index is a field-scale tool that has been shown to reduce P loadings on a field scale. However, effective NPS control at the watershed scale is much more difficult and is dependent on numerous factors including hydrology, topography, management practices, soil properties, and land use (Djodjic et al., 2002). This paper describes a modeling approach to determine how the addition of several poultry farms to a watershed affects water quality and evaluates how effective the Alabama P index is at P load at a watershed-scale.

4.3 Objective

The specific objective of this project was to determine the effectiveness of the Alabama P index (as a BMP) at reducing P loads at the watershed-scale through the use of the Alabama BMP database and the SWAT model.

4.4 Methodology

4.4.1 Study Watershed

To address the objective of this study, the Grant's Branch watershed located in Randolph County, Alabama, was selected. This watershed (Figure 4.1) is a sub-watershed of the Tallapoosa River Basin and is part of the Tallapoosa Watershed Project currently being conducted by the Department of Fisheries and Allied Aquaculture at Auburn University.

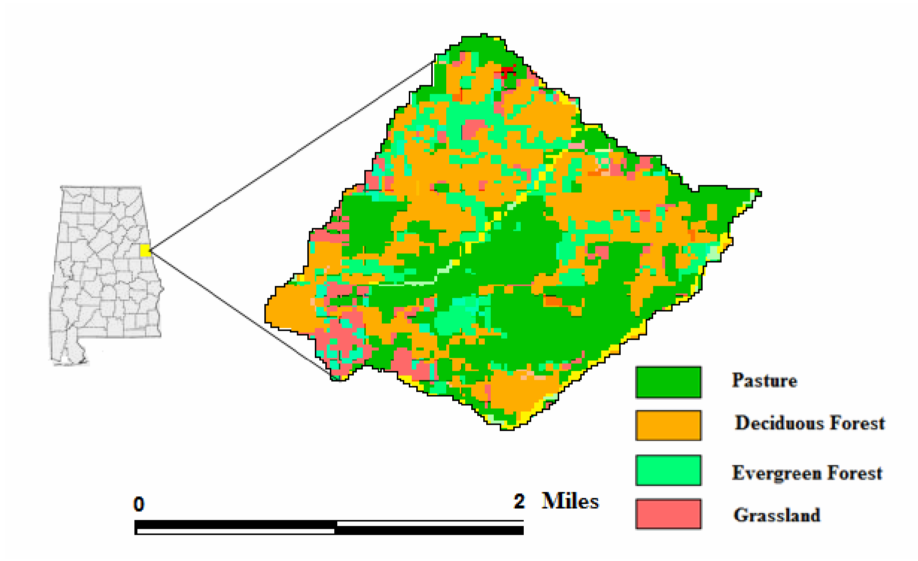

Figure 4.1 Location of Grants Branch Watershed in the Tallapoosa River Basin of Alabama.

The Grants Branch Watershed is a 1,914 acre agricultural watershed that contains a four-chicken-house poultry farm that utilizes poultry litter as a fertilizer source on nearby pasture fields. Cattle grazing is another way that the agricultural land is being used in this watershed. The major land use/cover includes: pasture (716 acres), deciduous forest (668 acres), evergreen forest (241 acres), and grassland (142 acres). Other land uses in the watershed include: forested wetland (< 1 acre), shrubs/scrub (52 acres), barren land (2 acres), mixed forest land (8 acres), developed open space (54 acres), residential medium density (3 acres), and residential low density (15 acres). The dominant soil found in the Grants Branch Watershed is a stony sandy loam Lousia series. This is a shallow, well drained soil with slopes ranging from 15 to 40 percent. Low available water capacity and rapid runoff and percolation is associated with this soil type. Approximately 18 percent of the watershed is composed of this soil type. The gravelly fine sandy loam Madison series is another dominant soil type found is this watershed.

This soil is a well-drained soil with moderately high available water capacity and slopes ranging from 6 to 10 percent. Nearly 17 percent of the watershed contains this soil type. Another dominant soil found in the Grants Branch watershed is a gravelly clay loam Madison series soil. This is a well-drained soil that has slopes that range from 10 to 15 percent and is characterized by rapid runoff and low available water capacity. This soil makes up approximately 11 percent of the watershed area. Bermudagrass, bahiagrass, and fescue are common forage crops on pastures in this watershed. These forage crops are predominantly used for hay production and cattle grazing. The Tallapoosa Watershed Project has a gauging station at the outlet of this watershed and flow and water quality data is available at this gauging station. Even though currently this watershed does not have a lot of chicken houses, the Tallapoosa River Basin is experiencing tremendous growth in poultry production. It is expected that in near future this watershed will have a significant amount of broiler production.

4.4.2 Data

Members of the Tallapoosa Watershed Project have collected monitoring data from the outlet of the selected watershed for a period ranging from February 2004 to January 2006. Throughout this period, daily flow data, storm event water quality, as well as monthly baseflow water quality data was collected for total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), alkalinity, and soluble reactive phosphorus (SRP). Maximum and minimum temperatures were collected from a nearby weather station in Ashland, Alabama. Rainfall data from 2001 through 2006 was obtained from a local Alabama Cooperative Extension System agent who maintained a rain gauge near the outlet of the watershed. Since the watershed is only about 1,914 acres in size, it was assumed that the spatial variability of rainfall did not affect stream flows at the outlet of this watershed and that the rain gauge adequately represented the precipitation occurring in the watershed. However, whenever possible, spatial variability of climate variables (especially precipitation) should be considered, which can lead to more accurate modeling results (Srivastava et al., 2006). Other weather data required by the SWAT model, such as solar radiation, wind speed, and relative humidity, were simulated using the SWAT model's built in weather generator, the WXGEN weather generator model (Sharpley and Williams, 1990).

The land use/cover data used in this project was obtained from the Alabama Cooperative Extension System. This data had a spatial resolution of 30 meters and was developed as a part of the national land cover database by the Multi-Resolution Land Characteristics Consortium (ACES, 2006a). Digital elevation model (DEM) data used to determine the watershed boundary was also obtained from the Alabama Cooperative Extension System and also had a spatial resolution of 30 meters (ACES, 2006b). In order to best simulate actual watershed conditions, SSURGO (USDA-NRCS, 2006) soils data was used as opposed to State Soil Geographic Database (STATSGO) data. Land management information was gathered by contacting the county extension agent, as well as contacting several poultry farmers that are using poultry litter as a fertilizer source. It was determined that most of the farms in the watershed have between 50 and 100 head of cattle. During the modeling process it was assumed that each of the pasture hydrologic response units (HRUs) had 50 head of grazing cattle. After contacting several poultry farmers it was determined that poultry litter is commonly applied to forage crops that are being used by farmers for hay production and for cattle grazing. The application rate varies anywhere from 2 to 3 tons per acre with the majority of the poultry litter being applied in the Spring. In the selected watershed, for current management practices, it was assumed that fields near the poultry farm were receiving 3 tons per acre of poultry litter annually in the Spring and the pastures in other areas of the watershed were not receiving poultry litter applications. The BMP database (Butler and Srivastava, 2007) was used to upload the specific management information that pertains to the Alabama P index rating for each individual HRU. An HRU is an area with unique land cover, soils, or management characteristics. While modeling the effects of the P index, it was assumed that no cattle grazing occurred in the watershed and that fescue was the only forage crop being grown in the watershed.

4.4.3 Modeling Approach

The SWAT model has become one of the most popular models for assessing agricultural watersheds and land management impacts on water quality. The selected watershed for this study has multiple land uses, numerous soil types, and also has variable topography. Because of these factors and the need for evaluating the effectiveness of the P index at a watershed-scale, the SWAT model was chosen for this study. The SWAT model was set up using the data described earlier and SWAT’s ArcView® geographic information system interface (AVSWAT). SWAT simulations were run using the Penman-Monteith method for potential evapotranspiration, for a period of time spanning from 2001 through 2006.

SWAT is a continuous simulation, distributed parameter, watershed-scale model developed by Dr. Jeff Arnold for the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS). The model was developed specifically for evaluating how land management practices affect water quality (Neitsch et al., 2002). SWAT is a modification of the Simulator for Water Resources in Rural Basins (SWRRB) model and the Routing Outputs to Outlet (ROTO) model. The various limitations associated with these two models led to the creation of the SWAT model. Hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and land management are the eight major components that make up the SWAT model (Borah and Bera, 2002). SWAT simulates these processes by dividing the watershed into sub-watersheds or sub-basins and then further divides these sub-watersheds based on climate, HRUs, ponds, groundwater, and main channels (Borah and Bera, 2002). The model then evaluates and simulates actual field processes for each of these individual areas.

SWAT allows P to be added to the soil in the forms of organic P, inorganic P, and P available in plant residue. SWAT simulates the removal of P from the soil in the forms of plant uptake and erosion (Neitsch et al., 2002). Once P is added to the soil, it is divided into six different pools. Of these six pools, three are considered in the organic form and the other three are considered mineral P (Chaubey et al., 2006). Plant residue and microbial biomass contribute to organic P, whereas soil humus contributes to the active and stable organic P pools. Soil inorganic P is separated into active, solution, and stable pools with the solution pool and the active pool being in rapid equilibrium (days or weeks). The active pool and the stable pool are in slow equilibrium (Neitsch et al., 2002). SWAT allows the user to input the amount of soluble and organic phosphorus before the simulation, however, if the user elects not to enter an initial amount, SWAT will initialize the level of P in all soil levels using a value 5 mg/kg of soil in unmanaged land and a value of 25 mg/kg of soil for cropland (Neitsch et al., 2002).

Transformations of the six soil P pools are accomplished using algorithms that simulate mineralization, decomposition, and immobilization (Chaubey et al., 2006). For mineralization, the model considers the fresh organic P pool and the active organic P pool. Mineralization takes into account immobilization and is allowed to occur as long as the temperature of the soil layer is above 0° C. P in the humus fraction is partitioned between the active P pool and the stable P pool using the ratio of active organic N to stable organic N. Mineralization and decomposition are dependent on both water availability and temperature. SWAT allows mineralization and decomposition of the fresh organic pools to occur only in the first soil layer. The model simulates mineralization and decomposition by controlling the decay rate constant, which defines the portion of residue decomposed on a daily basis (Neitsch et al., 2002).

Because many studies have shown that solution P concentration decreases rapidly with time after application of a soluble P fertilizer, the SWAT model assumes a rapid equilibrium between solution P and active mineral P. This equilibration is controlled by the P availability index, which indicates the portion of fertilizer P that is in solution after the rapid reaction period. SWAT simulates the slow sorption reaction by assuming there is slow equilibrium between the active and stable pools. When at equilibrium, the stable mineral pool is 4 times the size of the active mineral pool. SWAT simulates the movement of P through the soil by diffusion. Diffusion is the migration of ions over short distances (1-2 mm) in the soil solution in response to a concentration gradient. The leaching of soluble P is restricted to the top 10 mm of the soil in the first layer. This is mainly because of the low mobility associated with P (Neitsch et al., 2002).

The SWAT model allows user to apply both inorganic and organic fertilizer to

HRUs through the SWAT model's management file. Required information to perform this application includes: application rate, date, fertilizer type, and the depth of distribution. To simulate the interaction of the fertilizer with soil and runoff, SWAT assumes that runoff only transports nutrients that are in the top 10 mm of the soil. For applications of organic manure, such as poultry litter, the following equations are used by the model to partition the amount of P to the fresh organic pools and the humus organic pools (Chaubey et al., 2006)

$$\text{Organic } \mathbf{P}_{\text{fresh, fert}} = 0.5(\text{fert}_{\text{organic P}})(\text{fert}) \tag{1}$$

$$\text{Organic } \mathbf{P}_{\text{humus, fert}} = 0.5(\text{fert}_{\text{organic P}})(\text{fert}) \tag{2}$$

where,

organic $\mathbf{P}_{\text{fresh,fert}}$ = the amount of P in the fresh organic pool added to the soil as a result of fertilizer application (kg P/ha),

$\text{fert}_{\text{organicP}}$ = the fraction of organic P in fertilizer,

fert = the amount of fertilizer applied to the soil (kg/ha), and

organic $\mathbf{P}_{\text{humus,fert}}$ = the amount of P in the humus organic pool added to the soil as a result of fertilizer application.

The SWAT model allows user to include or exclude in-stream processes in simulations. In cases where the in-stream process is selected, the SWAT model uses the algorithms of the QUAL2E model (Brown and Barnwell, 1987). The equations taken from the QUAL2E model were modified to account for the SWAT model's daily continuous simulation. These modifications included adding a dynamic variable for variable rates and flow travel time, as well as providing user with the opportunity to adjust organic P inputs on a daily basis. However, after evaluation of the two model's, minimal differences were seen when comparing the results of the concentration equations (Chaubey et al., 2006).

SWAT can be extremely helpful in assessing and managing P loads in agricultural watersheds, but it is important to understand the limitations with SWAT's P simulation. One of the most important limitations is the spatial detail that is required to accurately simulate P transport and other field processes. Another limitation of the model is that it simulates P desorption at the same rate as adsorption. While research has shown that this does not occur under field conditions, other watershed models also make this same assumption. One other limitation of the SWAT model is that it assumes that when animal waste is applied, it is added directly to the soil pools in the upper 1 cm of the soil. This causes P to be under estimated shortly after animal manure has been applied. Other limitations include not being able to simulate the effects of vegetative filter strips or buffer strips, or simulate sediment routing and detailed event based floods (Chaubey et al., 2006).

4.4.4 Model Calibration

While SWAT is a physically-based model and is a powerful watershed assessment tool, it does not have a formal optimization process to fit observed data (Santhi et al., 2006). Therefore, calibration of the SWAT model requires manual alteration of model parameters that are not well-defined or cannot be measured. These parameters include the Soil Conservation Service curve number (SCS CN) and the universal soil loss equation (USLE) cropping factors.

4.4.4.1 Calibration of Hydrology Module

Model calibration was done using monitoring data, collected by the members of the Tallapoosa Watershed Project, for a two-year period (from February 2004 to January 2006). Because a USGS gauging station was not present at the outlet of this small study watershed (as is the case with most small watersheds), long-term stream flow data were not available. However, it should be noted that these two years include one very dry year and one wet year, so both dry conditions and wet conditions were well represented in the dataset. The SWAT model has an initialization period when simulated base flow is zero for the first couple of weeks. For calibration, the model was run from 2001 through 2006; however, only model output from February 2004 through January 2006 was used for model calibration. The first few years of simulation was considered the initialization period. Upon completion of the initialization period, simulated base flows were representative of actual observed base flows. In order to better represent actual field processes, surface flow, base flow, and total flow were used in the model calibration. The sliding interval method of the USGS's Hydrograph Separation Program (HYSEP) was used to separate base flow from surface flow (USGS, 2007). Once the separation was complete, the model was calibrated for surface flows and base flows separately; first on an annual time scale and then on a monthly time scale.

Calibration of the watershed's hydrology (base flow, surface flow, and total flow) on the annual time scale was the first step during the model calibration process. This task was completed by following the model calibration procedures specified in the SWAT model's user manual (Neitsch et al., 2001). Average annual surface flow was calibrated first. This was done by adjusting model parameters, such as SCS CN (CN2) and the soil evaporation compensation factor (ESCO). Once the average annual surface flow was calibrated, the average annual base flow was calibrated. This was done by altering the ground water “revap” coefficient (GW_REVAP), threshold depth of water in the shallow aquifer for “revap” to occur (REVAPMN), the threshold depth of water in the shallow aquifer required for base flow to occur (GWQMN), ground water delay time (GWDELAY), and the deep aquifer percolation fraction (RCHRG_DP). Once the average annual base flow and surface flow were calibrated, the average annual total flow were within an acceptable range (i.e., the model parameters were adjusted until there was less than a 5 percent difference in the simulated average annual flow values and the actual observed average annual flow values). Once the average annual flow values were calibrated, adjustments were made to calibrate monthly flows. Modeling parameters were adjusted to improve the goodness-of-fit statistics.

4.4.4.2 Calibration of Phosphorus Transport Module

Currently, the watershed has only one poultry farm with four chicken houses. Poultry litter is only being applied to a couple of fields in the watershed. Due to these factors, the current nutrient loadings from the Grants Branch watershed are relatively small. Not only was this shown in the monitoring data but both the County extension agent and the members of the TWP indicated that the watershed was not producing significant nutrient loadings. Because of these factors, nutrient calibration was not performed.

4.4.5 Model Validation

Because only two years of monitored data was available, model validation was attempted using the Rice Branch watershed. This watershed is also located in Randolph, County Alabama and is being studied as a part of the Tallapoosa Watershed Project. All of the necessary input data was gathered from the same sources described in the data section of this paper. It should be noted that this watershed did not have a rain gauging station so the Grants Branch rainfall data was used in the model validation attempt. The Rice Branch watershed is an 828 acre predominantly agricultural watershed with dominant land uses being pasture (496 acres), deciduous forest (172 acres), evergreen forest (95 acres), developed open space (27 acres), shrub/scrub (17 acres), residential low density (10 acres), grassland (6 acres), barren land (3 acres), mixed forest (2 acres), and residential medium density (2 acres). Currently there are not any poultry farms in this watershed but poultry litter is being transported into the watershed and is being applied on forage crops for hay production and grazing practices.

To conduct model validation, the same changes were made to the parameters describe in the model calibration portion of this paper. The model was then run and goodness-fit-statistics were calculated to determine how well the model was simulating actual field processes. After examining the goodness-of-fit statistics, it was clear that model validation was unsuccessful. The unsuccessful model validation was more than likely caused by not adequately representing spatial variability in rainfall data. To improve modeling accuracy, whenever possible, spatial variability should be accounted for.

4.4.6 Model Error Measures

Monthly model calibration was accomplished using relative goodness-of-fit statistics. Goodness-of-fit statistics are non-dimensional statistics that evaluate how successful a model is at accurately representing actual field conditions (Grace, 2005). Three different goodness-of-fit statistics were used to evaluate how well the SWAT model performed. These statistics include the Nash-Sutcliffe Coefficient of Efficiency (E) (Nash and Sutcliffe, 1970), percent bias (PBIAS), and the ratio of the root mean square error to the standard deviation (RSR) (Moriasi et al., 2007).

The first goodness-of-fit statistic was E. An E value of 1 indicates a perfect prediction while a 0 value suggests that the modeling results are no more accurate than predicting the average of observed values for all i (Srivastava et al., 2006). The Nash-Sutcliffe Coefficient of Efficiency (E) is given by

$$E = 1 - \left[\sum_{i=1}^{n} (Y^{obs}{}_{i} - Y^{sim}{}_{i})^2 \Big/ \sum_{i=1}^{n} (Y^{obs} i - Y^{mean})^2 \right] \tag{3}$$

where,

Y^{obs}_{i} = the measured value at time i,

Y^{sim}_{i} = the predicted value at time i,

Y^{mean} = the mean of the measured value, and

n = the total number of observations.

The next goodness-of-fit statistic used to evaluate the model outputs was PBIAS. PBIAS is a measure of the average tendency of the simulated stream flow to be larger or smaller than their observed values (Van Liew et al., 2005). The optimal value for PBIAS is 0 with small values indicating model accuracy (Moriasi et al., 2007). Positive PBIAS values suggest model underestimation bias, while negative PBIAS values suggest that there is an overestimation bias (Gupta et al., 1999). PBIAS is given by

$$PBIAS = \left[\sum_{i=1}^{n} (Y^{obs}{}_i - Y^{sim}{}_i) * (100) / \sum_{i=1}^{n} (Y^{obs}{}_i) \right] \tag{4}$$

where,

$Y^{obs}{}_i$ = the observed value at time i,

$Y^{sim}{}_i$ = the predicted value at time i, and

n = the total number of observations.

The final goodness-of-fit statistic that was used to evaluate the modeling results was the ratio of the root mean square to the standard deviation of measured data (RSR) (Moriasi et al., 2007). RSR can range from the optimal value of 0,, which indicates zero residual variation, to a large positive number (Moriasi et al. 2007). The RSR can be calibrated using the following equation:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} (Y^{obs}{}_i - Y^{sim}{}_i)^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} (Y^{obs}{}_i - Y^{mean})^2} \right]} \tag{5}$$

where,

$Y^{obs}{}_i$ = the observed value at time i,

$Y^{sim}{}_i$ = the simulated value at time i,

Y^{mean} = the mean of the observed values, and

n = the total number of observations.

4.4.7 Alabama Phosphorus Index

Alabama has a large poultry industry that plays an important role in the State's economy. Many poultry farmers in Alabama are using poultry litter as a fertilizer source on hayland, as well as other crops such as cotton and corn (Mitchell, 2006). In order to minimize P loadings from applications of poultry litter, the P index is used. Alabama's P index works to reduce P pollution by using 11 different field and management characteristics to determine critical areas where runoff is probable (USDA, 2001). The 11 field characteristics include: soil test P value, P application rates, nutrient application methods, grazing animals, subsurface drainage and underground outlet system, erosion rate, hydrologic soil group, field slope, distance to water, filter strip width, and impaired or outstanding waters (USDA, 2001). Once the areas that have a high probability of runoff are located, the animal waste application rates can be determined. For a 'very low/low' potential risk P index rating, animal waste can be applied at the crop's nitrogen rate. For a P index rating of 'medium', animal waste should be applied at 3 times the crop's P uptake rate. If the P index ratings indicate a 'high' potential risk, animal waste should be applied at 2 times the crop's P uptake rate. For a P index rating of 'very high', animal waste should be applied at 1 times the crop's P uptake. In situations where the P index rating indicates an 'extremely high' potential for runoff, no animal waste should be applied. Table 4.1 below describes the amount of poultry litter that should be applied under various P index ratings for Alabama crops.

Table 4.1. Application Rates (lb/acre) of Poultry Litter for Alabama Crops as a Function of P-index Rating[†]

Crop	Yield (per acre)	P-Index Rating				
		Very Low/Low	**Medium**	**High**	**Very High**	**Extremely**
Corn	70 (bu)	4,138	2,897	1,931	966	0
Irrigated Corn	145 (bu)	6,207	6,000	4,000	2,000	0
Cotton	2.25 (bale)	3,104	2,793	1,862	931	0
Alfalfa (hay)	3 (ton)	-	3,724	2,483	1,241	0
Hybrid Bermudagrass (hay)	5 (ton)	10,345	6,207	4,138	2,069	0
Fescue (hay)	3 (ton)	4,138	2,793	1,862	931	0
Bahiagrass (hay)	5 (ton)	4,138	3,621	2,414	1,207	0

[†] Please note that most farmers round to the nearest ½ ton (1,000 lb) per acre for poultry litter applications.

The objective of this project was to determine how effective the Alabama P index is at reducing P load at a watershed-scale and to determine what the environmental effects are of adding poultry farms to this watershed. To do this, current management practices were modeled to determine the effect that current land management strategies have on P load. After modeling the current management practices, the model was used to simulate how adding additional poultry farms would affect water quality. The management practices that are currently used were applied to all pastures in the watershed. It was assumed that all pasture land would have poultry litter applications and that poultry litter would be applied at 3 tons/acre. After the model simulated how this alternative management scenario would affect water quality, the Alabama BMP database (Butler and Srivastava, 2007) was used to simulate how this alternative management scenario would affect water quality if the management decisions were based on the Alabama P index. The model was run five different times, starting with poultry litter applications rates that correspond with a 'Very Low/Low' P index rating. In each of the last four modeling simulations the P index ratings were increased and the poultry litter applications were altered to adhere to the recommended applications rates set forth by the P index. After all of the management scenarios were modeled, the data was analyzed to determine how current management practices were affecting water quality, how additional poultry farms would affect water quality, and to see if the Alabama P index is an effective tool in managing P load at the watershed-scale.

4.5 Results

4.5.1 Model Calibration

Before analyzing the effectiveness of the Alabama P index and determining the effect of adding several other poultry farms to the watershed, the model had to be calibrated. In order to determine how well the model performed, goodness-of-fit statistics were used. Monthly calibration was performed until the statistics indicated that modeling outputs were satisfactory, while keeping the predicted and observed average annual flows within reasonable guidelines (+/- 5%). Moriasi et al. (2007) reported that modeling results are satisfactory if $E > 0.50$, $RSR \leq 0.70$, and PBIAS for streamflow < 25%. Table 4.2 below shows the average annual observed and predicted flows.

Table 4.2 Average Annual Flow Values

	Total Flow	**Surface Flow**	**Base Flow**
Observed (mm)	477.56	160.28	317.00
Predicted (mm)	483.57	161.57	322.00
Percent Diff. (%)	1.25	0.80	1.58

For monthly surface flow, calibration yielded E = 0.56 and RSR= 0.66. For monthly base flow calibration, the following goodness-of-fit statistics were achieved: E = 0.61 and RSR = 0.62. Calibration of monthly total flow yielded values of E = 0.73, PBIAS = 5.55% and RSR = 0.62. Figures 4.2 and 4.3 show the observed and predicted daily and monthly stream flow data for the calibration period.

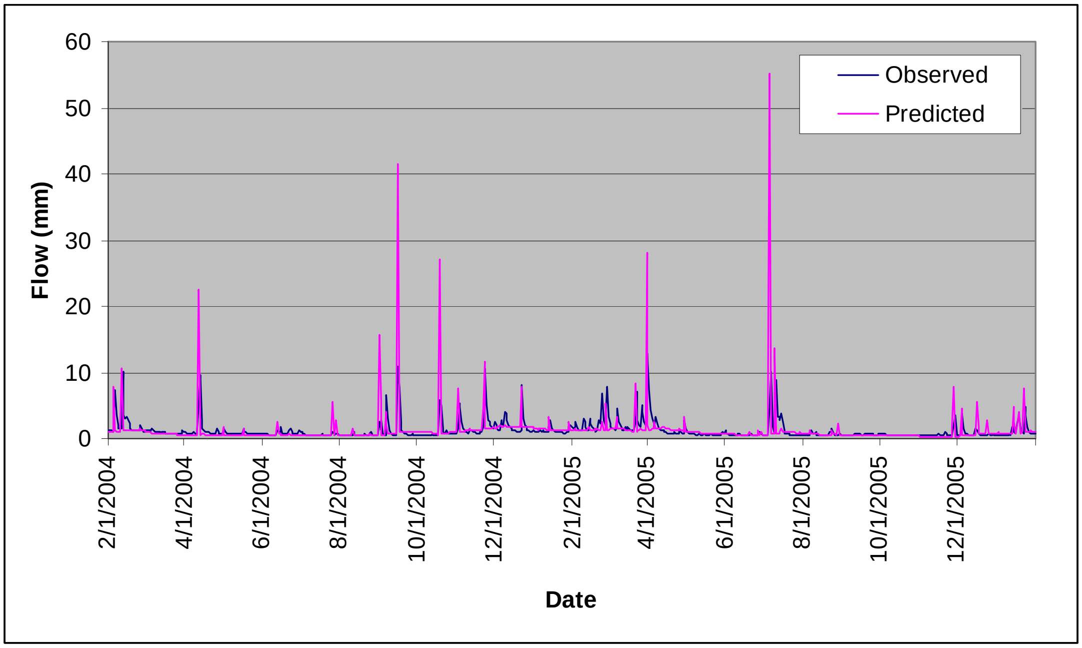

Figure 4.2 Predicted and Observed Daily Stream Flow for the Selected Watershed.

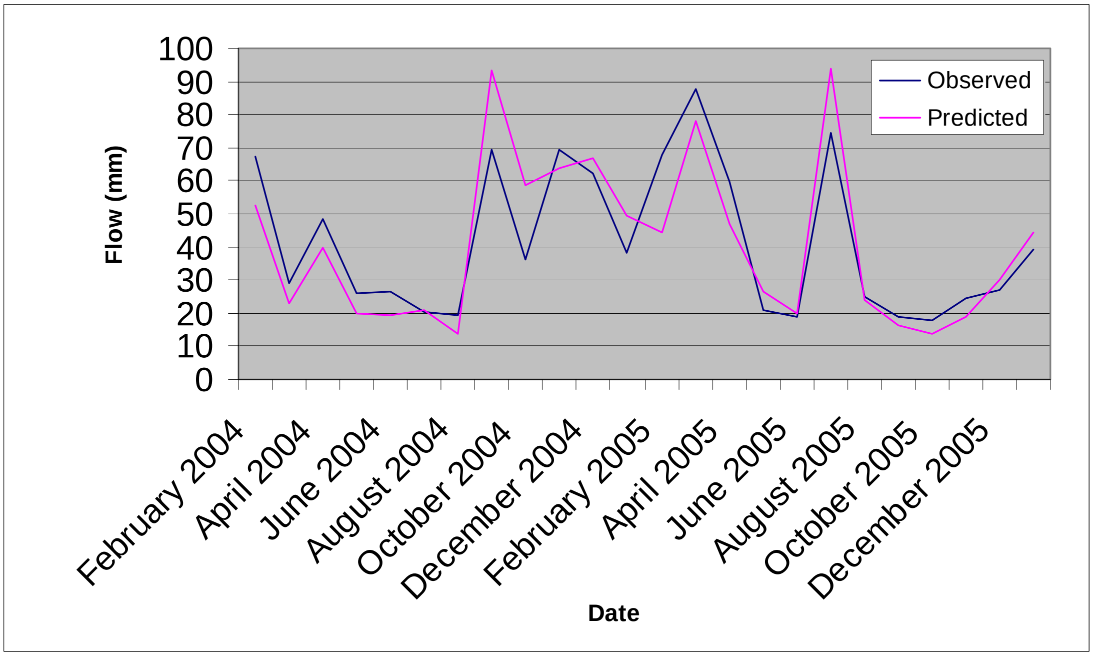

Figure 4.3 Predicted and Observed Monthly Steam Flow for the Selected Watershed.

Nutrient calibration was considered, but because poultry litter was only being applied to a small portion of the watershed, nutrient loads were quite small. This was not only confirmed by members of the TWP and the County extension agent, but also by the monitored data. SWAT model nutrient load predictions under current litter application practices were also small. Nutrient calibration was not performed because of the low nutrient levels associated with the current land management practices. Table 4.3 provides the observed and the SWAT generated data for TP and TN loadings that were used in an attempt to calibrate the model.

Table 4.3 Daily Predicted and Observed Loadings (kg/ha) for TP and TN.

Date	Observed TP	Predicted TP	Observed TN	Predicted TN
02/12/04	0.016	0.000	0.184	0.100
02/19/04	0.000	0.000	0.011	0.000
03/11/04	0.000	0.000	0.005	0.000
04/08/04	0.000	0.000	0.007	0.000
05/03/04	0.000	0.000	0.010	0.000
06/02/04	0.000	0.000	0.002	0.000
07/07/04	0.000	0.000	0.002	0.000
08/04/04	0.000	0.000	0.001	0.010
09/07/04	0.010	0.010	0.121	0.120
09/27/04	0.000	0.000	0.002	0.010
10/12/04	0.000	0.000	0.002	0.000
11/03/04	0.004	0.010	0.068	0.060
12/01/04	0.001	0.000	0.017	0.010
12/09/04	0.011	0.000	0.151	0.030
01/06/05	0.000	0.000	0.005	0.000
02/15/05	0.000	0.000	0.013	0.010
02/21/05	0.001	0.000	0.021	0.010
02/24/05	0.004	0.000	0.083	0.040
03/08/05	0.009	0.000	0.119	0.030
03/16/05	0.001	0.000	0.017	0.000
04/07/05	0.001	0.000	0.032	0.020
04/12/05	0.000	0.000	0.012	0.010
05/11/05	0.000	0.000	0.005	0.000
05/31/05	0.000	0.000	0.007	0.060
06/09/05	0.000	0.000	0.005	0.000
07/07/05	0.010	0.000	0.110	2.780
07/11/05	0.009	0.000	0.100	0.920
07/27/05	0.000	0.000	0.004	0.000
08/30/05	0.000	0.000	0.005	0.000
09/29/05	0.000	0.000	0.002	0.000
10/19/05	0.000	0.000	0.002	0.000
11/09/05	0.000	0.000	0.003	0.000
11/29/05	0.002	0.000	0.047	1.600
12/07/05	0.000	0.000	0.008	0.010
01/18/06	0.001	0.130	0.028	0.480
01/23/06	0.003	0.000	0.055	1.060

4.5.2 Analysis of Management Practices

Modeling was conducted to see how the current land management practices were affecting water quality and to determine how the addition of other poultry farms to the watershed would affect water quality. Upon completion of modeling these scenarios, the Alabama P index was evaluated to determine how effective it was at reducing NPS pollution. Total nitrogen (TN) and total phosphorus (TP) were evaluated on an annual and monthly basis. Tables 4.4 and 4.5 show model output for nutrient loadings based on the current management practices, an alternative management practice scenario where new poultry farms are added to the watershed and are applying the current land management practices, as well as nutrient loadings for the six other land management practice scenarios where land management practices are based on the Alabama P index recommendations.

Table 4.4 Annual TP Loadings (kg/ha) for Current Management Practices, Alternate Management (Additional Poultry Farms), and Management Under Different Potential P Index Ratings.

Year	**Precip. (mm)**	**Load (kg/ha)**						
		Current Mgmt	Alternate Mgmt.	Very low/Low	Medium	High	Very High	Extremely high
2001	2151.20	11.71	17.69	15.70	14.41	12.97	11.29	8.93
2002	1757.90	1.32	2.73	3.73	3.23	2.6	1.80	0.63
2003	1859.40	3.24	7.14	3.87	3.33	2.7	1.89	0.50
2004	1803.60	2.86	6.43	7.01	6.06	4.85	3.21	0.89
2005	1595.30	6.25	17.32	3.16	2.80	2.36	1.68	0.47
2006	1407.40	2.90	5.98	2.74	2.38	1.91	1.25	0.30

Table 4.5 Annual TN Loadings (kg/ha) for Current Management Practices, Alternate Management (Additional Poultry Farms), and Management Under Different Potential P Index Ratings.

Year	**Precip. (mm)**	**Load (kg/ha)**						
		Current Mgmt.	Alternate Mgmt.	Very low/Low	Medium	High	Very High	Extremely high
2001	2151.20	71.43	84.85	82.83	81.37	79.95	78.43	73.99
2002	1757.90	9.08	21.45	13.81	12.73	11.43	9.82	7.72
2003	1859.40	12.77	30.65	11.28	10.39	9.40	8.04	6.32
2004	1803.60	11.88	30.43	19.5	20.67	15.29	12.14	9.52
2005	1595.30	23.55	64.61	9.21	8.56	7.79	6.02	5.66
2006	1407.40	10.61	20.95	8.33	7.52	6.47	5.06	4.21

Figure 4.4 shows monthly TP loadings for the current management practices, as well as the monthly TP loadings for an alternative management scenario where other poultry farms have been introduced to the watershed. Figure 4.4 also displays the monthly TP loadings of the watershed if the Alabama P index were to be implemented in the watershed.

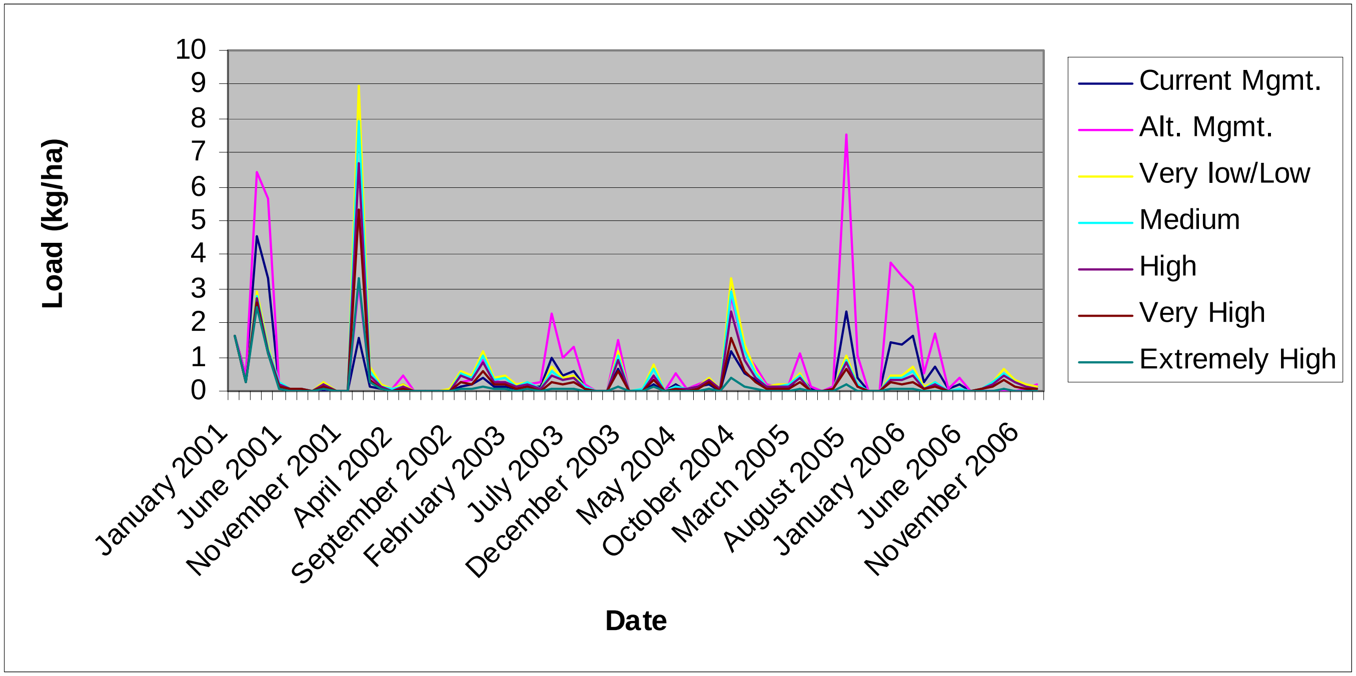

Figure 4.4 Monthly TP Loadings for Different Management Scenarios.

4.6 Discussion

After analyzing the current management practices, it was determined that the relatively small area that is receiving poultry litter applications is currently not contributing to P pollution. However, by analyzing the alternative management scenario, where multiple poultry farms are added to the watershed and are using the current land management techniques, P pollution would significantly increase (increase of average annual TP load of 4.83 ton/ha). By managing the watershed based on the recommendations of the Alabama P index (Table 4.1), TP loadings were almost always reduced. Average annual reductions in TP loads include: 3.51 ton/ha for ‘very low/low’ rating, 4.18 ton/ha for ‘medium’ rating, 4.98 ton/ha for ‘high’ rating, 6.03 ton/ha for ‘very high’ rating, and 7.64 ton/ha for an ‘extremely high’ rating. These results are expected since the application rate is being decreased as the relative P index rating is increased from ‘very low/low’ to ‘high’. In several instances, the TP loading was even less than the loadings associated with the current land management practices. It also appears that the P index is more effective at reducing P pollution in dryer years than in years of heavy precipitation (Table 4.4). For all P index ratings, the most significant percentage reduction in TP loads occurred during the driest years (2005 and 2006). This would indicate that climate variability is playing an important role in P transport and if fertilizer application rates could be based on expected weather conditions, then nutrient loadings could be further reduced. Equally important, it should be noted that by adding other poultry farms to the watershed and implementing the same management practices that are currently being used, annual TN loads will increase. By using the P index, annual TN loads were reduced each year. While the Alabama P index was effective at reducing P pollution, loading variations between ‘very low/low’ and ‘extremely high’ P index ratings was not substantial. This could be because the SWAT model assumes that P in manure is added directly to the pools in the upper 1 cm of the soil and is not freely available for transport. A few studies (need references) have suggested that P can remain soluble in a manure layer for a long time and is more readily available for transport. As a result, SWAT could underpredict P movement after animal waste applications (Chaubey et al., 2006).

4.7 Summary and Conclusion

Many poultry farmers are using poultry litter as a fertilizer source on nearby pastures and hayfields. P pollution is a major concern in situations where animal waste is being used, and over-application can lead to adverse environmental effects such as eutrophication. BMPs are often implemented to reduce these adverse environmental effects. In Alabama, a commonly used BMP to combat P pollution is the Alabama P index. The P index is a management tool that is used to determine areas that have the potential to significantly contribute to P pollution. In this study, the SWAT model was used to evaluate how current management practices were affecting water quality in a watershed in Randolph County, Alabama, as well as how the addition of other poultry farms to the watershed would affect the watershed. The Alabama BMP Database (Butler and Srivastava, 2007) was then used to evaluate how applying poultry litter using the Alabama P index recommendations would affect water quality. Model simulations included current management practices and an alternative management scenario where all the fields in the watershed were receiving 3 tons/acre of poultry litter. Other model simulations included land management and poultry litter applications based on the five different P index ratings (very low/low, medium, high, very high, extremely high). Hydrologic calibration of the model was done using three goodness-of-fit statistics that included Nash-Sutcliffe Coefficient of Efficiency, percent bias, and the ratio of the root mean square to the standard deviation of the observed data. Parameters were altered until all of these statistics indicated that the model output was satisfactory.

This study showed that the current level of animal waste application in the Grants Branch Watershed is not significantly contributing to P load; however, the model indicates that if several poultry farms were added to the watershed, TP loadings would increase substantially. By altering the management practices based on the Alabama P index, nutrient loads were almost always reduced. Therefore, it was found that the P index was effective at reducing P load; however, it was most effective in dryer years, indicating that climate variability is playing an important role in P transport. Although the P index is effective at reducing P pollution, there was not a lot of variability in nutrient loads as the application rate was decreased. This is probably a result of the limitations of the SWAT model.

4.8 Acknowledgements

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CHAPTER FIVE

SUMMARY AND CONCLUSIONS

5.1 Introduction

Nonpoint source pollution (NPS) is a serious environmental problem and agriculture and forestry are two industries that contribute to NPS pollution. BMPs are used to reduce NPS pollution from agricultural and forestry operations. Watershed-scale models are often used to evaluate specific BMP performance, develop TMDLs, and estimate NPS pollutant loads from watersheds. Watershed models are powerful tools in evaluating NPS pollution; however, the model's performance is dependant on the accuracy of the input data, of which description of BMPs plays an important role. While BMP data is available in bits and pieces in publications and through consultation with experts, the absence of a comprehensive database leads to input of simplified assumptions which can lead to greater error in model output. Therefore, the overall goal of this project was to develop a database of common agricultural and forestry BMPs that are used in the State of Alabama. Since water quality of a number of watersheds in Alabama is affected by broiler litter application, an alternate goal was to evaluate the effectiveness of the Alabama P index in controlling transport of P to streams. The specific project objectives were to:

1) Develop a database of BMPs commonly utilized by the agricultural and forestry industries in the State of Alabama;
2) Prepare an ArcView® 3.X GIS extension to load management scenarios for each of these BMPs into the SWAT model; and
3) Determine the effectiveness of the Alabama P index (as a BMP) in reducing P loads at the watershed-scale through the use of the Alabama BMP database and the SWAT model.

5.2 Completion of Project Objectives

In order to develop the BMP database, many different resources from across Alabama were utilized, including: extension agents, professors, crop budgets, engineers, foresters, entomologist, extension publications, and plant pathologist. Information obtained from these resources included: crop rotations specific to individual areas of Alabama, timing and application rates for pesticides and fertilizers, tillage operations, irrigation application rates, and specific operational dates for other land management practices. After compiling an extensive list of BMPs and land management scenarios, they were loaded into the SWAT model. The database is comprised of over 300 different management scenarios containing information that pertains to agronomic crops, turfgrass management, animal waste management, forage crops, fruiting crops, grazing management and forestry operations. Specific BMPs that are included in the database are: crop rotations, integrated pest management, irrigation water management, grazing management, animal waste applications, nutrient management, cover crops, and conservation tillage practices.

To make the database easily distributed, it was necessary to create a GIS extension. The GIS extension will enable water resource professionals all across the State of Alabama to access the BMP database easily through the use of ArcView® GIS. The extension was created using ArcView®'s AVENUE programming language. The extension simply takes the BMP management files and loads them into the correct folder so that anyone using the SWAT model can have access to the database.

The BMP database was then used to determine the effectiveness of the Alabama P index (a BMP used to reduce P transport from land-applied broiler litter) in reducing P loads in a predominantly agricultural watershed in Randolph County, Alabama. A calibrated SWAT model was used to determine the effect of current management practices, as well as to simulate how additional poultry farms would affect the watershed. In addition, the BMP database was used to load management information based on the Alabama P index so that the P index could be evaluated.

5.3 General Conclusion

Currently, in the absence of detailed BMP data, watershed assessments are conducted using generalized data which can lead to output uncertainty. The BMP database and ArcView® GIS 3.X extension that has been described will provide modelers with more accurate data for modeling agricultural and forested watersheds in the State of Alabama. This database will help to reduce NPS pollution by providing an efficient and more accurate method for evaluating and implementing BMPs and TMDLs. The GIS extension will allow the database to be easily distributed to water resource professionals across the State of Alabama.

The Alabama P index is a commonly used BMP in watersheds where poultry litter is being utilized as a fertilizer source. This study showed that the P index was effective at reducing P pollution at the watershed-scale. However, the degree of effectiveness in P reductions was strongly influenced by precipitation. The P index was more effective at reducing P pollution during dryer periods as opposed to periods of heavy rainfall. This indicated that climate variability plays an important role in NPS pollution. Nutrient loads could be further reduced if fertilizer application rates in the future could be based on expected climate conditions.

5.4 Opportunities for Future Research

The BMP database can be used in many ways and there are many available opportunities for future research. Future research should focus on large agricultural watersheds where there are many different agricultural crops being grown and where a variety of BMPs are being utilized. This type of modeling situation will show how the BMP database can make the modeling process easier while yielding more accurate results in model output. Also, in this type of situations, several different crop rotations can be modeled to determine how they affect water quality. Other research projects could use the BMP database to evaluate other specific BMPs to determine how effective they are at reducing NPS pollution at the watershed-scale. Another research project could include using the information contained in the database to model the effect of year-to-year climate variability on water quality. Long term data should be used to try to determine if management practices (i.e. fertilizer application rates) could be determined by the expected weather conditions. For future modeling projects, if at all possible, watersheds should be chosen with sufficient weather data so that model validation and calibration can be conducted. By conducting model validation and calibration, modelers will have a greater level of confidence in modeling results.

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APPENDIX A

ALABAMA BLACKBELT MANAGEMENT INFORMATION

APPENDIX B

NORTH ALABAMA MANAGEMENT INFORMATION

APPENDIX C

CENTRAL ALABAMA MANAGEMENT INFORMATION

APPENDIX D

SOUTH ALABAMA MANAGMENT INFORMATION

APPENDIX E

ALABAMA FORAGE CROP MANAGEMENT INFORMATION

APPENDIX F

ALABAMA FRUITING CROP MANAGEMENT INFORMATION

APPENDIX G

ALABAMA FORESTRY BMP INFORMATION

APPENDIX H

ALABAMA TURFGRASS MANAGEMENT INFORMATION

APPENDIX I

ARCVIEW® 3.X EXTENSION SCRIPT

```
================================================================'
' Name:         Alabama.Database
'
' Headline:      ArcView extenstion for Alabama_database
'
' Description:   Developing an ArcView extension as follows:
'
'      1. Add alabama_crop.dbf to crop.dbf located in C:\AVS2000\AvSwatDB
'      2. Add alabama_fert.dbf to fert.dbf located in C:\AVS2000\AvSwatDB
'      3. Add alabama_pest.dbf to pest.dbf located in C:\AVS2000\AvSwatDB
'      4. Replace mgtrng.dbf located in C:\AVS2000\AvSwatDB with alabama_mgtrng.dbf
'      5. Replace mgtoprng.dbf located in C:\AVS2000\AvSwatDB with
           alabama_mgtoprng.dbf
'      6. Add files in folder alabama_bmp to folder mngtscen located in
           C:\AVS2000\AvSwatDB
'
' History:  AV 3.2a, 27 April 2007.  by Biosystems Eng, Auburn University
'
'================================================================

'*********************************
' Extracting directories
'*********************************
AvSwatPath = MsgBox.Input("Please enter Full Path to the folder for the AVSWAT
database ","FULL PATH TO THE AVSWAT DATABASE","C:\AVS2000\AvSwatDB")

if (AvSwatPath = nil) then
  return nil
elseif (AvSwatPath.AsFileName.IsDir.Not) then
  MsgBox.Error( AvSwatPath.AsFileName.GetFullName++"is not a directory", "")
  exit
elseif (File.IsWritable(AvSwatPath.AsFileName).Not) then
  MsgBox.Error( AvSwatPath.AsFileName.GetFullName++"is not writable", "")
  exit
else
```

```
'  theProject.SetWorkDir( newDir.AsFileName )
  'exit
end

ALdbPath = MsgBox.Input("Please enter Full Path to the folder for the AVSWAT
database ","FULL PATH TO THE AVSWAT DATABASE","D:\ALDatabase")

if (ALdbPath = nil) then
  return nil
elseif (ALdbPath.AsFileName.IsDir.Not) then
  MsgBox.Error( ALdbPath.AsFileName.GetFullName++"is not a directory", "")
  exit
"elseif (File.IsWritable(ALdbPath.AsFileName).Not) then
  'MsgBox.Error( ALdbPath.AsFileName.GetFullName++"is not writable", "")
  'exit
else
'  theProject.SetWorkDir( newDir.AsFileName )
  'exit
end
'**************************************************
' Check Database files in Directories for Alabama
'**************************************************
 CheckCrop=ALdbPath+"\crop.dbf"
CC = TextFile.Make(CheckCrop.AsFileName, #FILE_PERM_READ)
if (CC = nil) then
  MsgBox.Info("The file '" + CheckCrop + "' does not exists or cannot be accessed.", "")
  return False
end
CheckFert=ALdbPath+"\fert.dbf"
CF = TextFile.Make(CheckFert.AsFileName, #FILE_PERM_READ)
if (CF = nil) then
  MsgBox.Info("The file '" + CheckFert + "' does not exists or cannot be accessed.", "")
  return False
end
CheckPest=ALdbPath+"\pest.dbf"
```

```
CP = TextFile.Make(CheckPest.AsFileName, #FILE_PERM_READ)
if (CP = nil) then
  MsgBox.Info("The file '" + CheckPest + "' does not exists or cannot be accessed.", "")
  return False
end
CheckMgt=ALdbPath+"\mgtrng.dbf"
CM = TextFile.Make(CheckMgt.AsFileName, #FILE_PERM_READ)
if (CM = nil) then
  MsgBox.Info("The file '" + CheckMgt + "' does not exists or cannot be accessed.", "")
  return False
end
CheckMgtOP=ALdbPath+"\mgtoprng.dbf"
CMO = TextFile.Make(CheckMgtOP.AsFileName, #FILE_PERM_READ)
if (CMO = nil) then
  MsgBox.Info("The file '" + CheckMgtOP + "' does not exists or cannot be accessed.",
"")
  return False
end
'************************************************************
' Table Append_1 for crop.dbf, fert.dbf, and pest.dbf
'============================================================
' Add alabama_crop.dbf to crop.dbf located in AVSWAT drectory
'************************************************************
'  totable = self.get(0)
'  fromtable = self.get(1)
'cropFileName=FileName.Make("C:\temp\crop.dbf")
'alcropFileName=FileName.Make("C:\temp\ALDatabase\alabama_crop.dbf")

cropFileName=FileName.Make(AvSwatPath+"\crop.dbf")
alcropFileName=FileName.Make(ALDBPath+"\crop.dbf")

if (VTab.CanMake(cropFileName)) then
  tmergeFtab = Vtab.Make(cropFileName, False, False)
  if (tmergeFtab.HasError) then
    MsgBox.Error("Failed")
```

```
  else
    totable=Table.Make(tmergeFtab)
  end
end
if (VTab.CanMake(alcropFileName)) then
  tinVTab = Vtab.Make(alcropFileName, False, False)
  if (tinVTab.HasError) then
    MsgBox.Error("Failed")
  else
    fromtable=Table.Make(tinVTab)
  end
end
  mergeFtab = totable.getVtab '(receiving Table)
  inVTab  = fromtable.getVtab
'  mergeFtab = VTab.Make("C:\temp\crop.dbf".AsFileName,dBase)
'  inVTab  = VTab.Make("C:\temp\al_crop.dbf".AsFileName,dBase)
'  mergeFtab = "C:\temp\crop.dbf".AsFileName.getVtab
'  inVTab  = "C:\temp\al_crop.dbf".AsFileName.getVtab
'  mergeFtab = av.GetProject.FindDoc(totable).getVtab '(receiving Table)
'  inVTab  = av.GetProject.FindDoc(fromtable).getVtab

    if (inVTab.GetSelection.Count = 0) then
    theRecordsToMerge = inVTab
    numRecs = inVTab.GetNumRecords
  else
    theRecordsToMerge = inVTab.GetSelection
    numRecs = theRecordsToMerge.Count
  end
  fieldlist = mergeFtab.getFields
  mergeFtab.seteditable(true)
  for each rec in theRecordsToMerge
    av.showstopbutton
    test=av.SetStatus( (rec / numRecs) * 100 )
    if (test=FALSE) then
      mergeFtab.seteditable(false)
```

```
   av.ClearMsg
   av.ClearStatus
   'geowait.close
   return(nil)
  end
  newRec = mergeFtab.AddRecord
   if (fieldList.Count > 0) then
   for each f in fieldList
    fName    = f.GetName
    inField  = inVTab.FindField( fName )
    if ( inField <> Nil ) then
     outField = mergeFtab.FindField( fName )
     aValue    = inVTab.ReturnValue( inField, rec )
     mergeFTab.SetValue( outField, newRec, aValue )
    end
   end   ' for each f
  end   ' if count
 end   ' for each rec
mergeFtab.seteditable(false)
'End of Table_Append_1 for crop.dbf)
'**************************************************************
' Table Append_2 for crop.dbf, fert.dbf, and pest.dbf
'==============================================================
' Add alabama_fert.dbf to fert.dbf located in AVSWAT drectory
'**************************************************************
cropFileName=FileName.Make(AvSwatPath+"\fert.dbf")
alcropFileName=FileName.Make(ALDBPath+"\fert.dbf")
if (VTab.CanMake(cropFileName)) then
 tmergeFtab = Vtab.Make(cropFileName, False, False)
 if (tmergeFtab.HasError) then
  MsgBox.Error("Failed")
 else
  totable=Table.Make(tmergeFtab)
 end
end
```

```
if (VTab.CanMake(alcropFileName)) then
  tinVTab = Vtab.Make(alcropFileName, False, False)
  if (tinVTab.HasError) then
    MsgBox.Error("Failed")
  else
    fromtable=Table.Make(tinVTab)
  end
end
  mergeFtab = totable.getVtab '(receiving Table)
  inVTab  = fromtable.getVtab
    if (inVTab.GetSelection.Count = 0) then
    theRecordsToMerge = inVTab
    numRecs = inVTab.GetNumRecords
  else
    theRecordsToMerge = inVTab.GetSelection
    numRecs = theRecordsToMerge.Count
  end
  fieldlist = mergeFtab.getFields
  mergeFtab.seteditable(true)
  for each rec in theRecordsToMerge
    av.showstopbutton
    test=av.SetStatus( (rec / numRecs) * 100 )
    if (test=FALSE) then
      mergeFtab.seteditable(false)
      av.ClearMsg
      av.ClearStatus
      'geowait.close
      return(nil)
    end
    newRec = mergeFtab.AddRecord
       if (fieldList.Count > 0) then
      for each f in fieldList
        fName    = f.GetName
        inField  = inVTab.FindField( fName )
```

```
    if ( inField <> Nil ) then
     outField = mergeFtab.FindField( fName )
     aValue    = inVTab.ReturnValue( inField, rec )
     mergeFTab.SetValue( outField, newRec, aValue )
    end
   end   ' for each f
  end   ' if count
 end   ' for each rec
mergeFtab.seteditable(false)
'End of Table_Append_2 for fert.dbf)
'**************************************************************
' Table Append_3 for crop.dbf, fert.dbf, and pest.dbf
'==============================================================
' Add alabama_pest.dbf to fert.dbf located in AVSWAT drectory
'**************************************************************
cropFileName=FileName.Make(AvSwatPath+"\pest.dbf")
alcropFileName=FileName.Make(ALDBPath+"\pest.dbf")
if (VTab.CanMake(cropFileName)) then
 tmergeFtab = Vtab.Make(cropFileName, False, False)
 if (tmergeFtab.HasError) then
  MsgBox.Error("Failed")
 else
  totable=Table.Make(tmergeFtab)
 end
end
if (VTab.CanMake(alcropFileName)) then
 tinVTab = Vtab.Make(alcropFileName, False, False)
 if (tinVTab.HasError) then
  MsgBox.Error("Failed")
 else
  fromtable=Table.Make(tinVTab)
 end
end
 mergeFtab = totable.getVtab '(receiving Table)
 inVTab  = fromtable.getVtab
```

```
    if (inVTab.GetSelection.Count = 0) then
    theRecordsToMerge = inVTab
    numRecs = inVTab.GetNumRecords
  else
    theRecordsToMerge = inVTab.GetSelection
    numRecs = theRecordsToMerge.Count
  end
  fieldlist = mergeFtab.getFields
  mergeFtab.seteditable(true)
  for each rec in theRecordsToMerge
    av.showstopbutton
    test=av.SetStatus( (rec / numRecs) * 100 )
    if (test=FALSE) then
      mergeFtab.seteditable(false)
      av.ClearMsg
      av.ClearStatus
      'geowait.close
      return(nil)
    end
    newRec = mergeFtab.AddRecord
       if (fieldList.Count > 0) then
      for each f in fieldList
        fName    = f.GetName
        inField  = inVTab.FindField( fName )
        if ( inField <> Nil ) then
          outField = mergeFtab.FindField( fName )
          aValue    = inVTab.ReturnValue( inField, rec )
          mergeFTab.SetValue( outField, newRec, aValue )
        end
      end   ' for each f
    end   ' if count
  end   ' for each rec
mergeFtab.seteditable(false)
```

```
'End of Table_Append_3 for pest.dbf)
'Successful Massage.
'MsgBox.Info("Successfully added AL database to in AvSwatDB.", "")
'***********************************************************************
' Replace mgtrng & mgtoprng dbf located in AVSWAT directory with alabama dbf.
'***********************************************************************
mapFileName_1=FileName.Make(AvSwatPath+"\mgtrng.dbf")
mapFileName_2=FileName.Make(ALdbPath+"\mgtrng.dbf")
mapFileName_3=FileName.Make(AvSwatPath+"\mgtoprng.dbf")
mapFileName_4=FileName.Make(ALdbPath+"\mgtoprng.dbf")
'mapFileName_1=FileName.Make("C:\crop.dbf")
'if(mapFileName = nil) then exit end
if(file.exists(mapFileName_1)) then
'  file.candelete(mapFileName)
  file.delete(mapFileName_1)
end
if(file.exists(mapFileName_3)) then
'  file.candelete(mapFileName)
  file.delete(mapFileName_3)
end
file.copy(mapFileName_2,mapFileName_1)
file.copy(mapFileName_4,mapFileName_3)
'MsgBox.Info("Successfully replaced AL database to in AvSwatDB"+nl+"regarding
mgtrng.dbf and mgtoprng.dbf, "")
'***********************************************************************
' Copy all files on alabama_bmp on your disk.
'***********************************************************************
FullPath=ALdbPath+"\MgtScen"  'Directory name, \MgtScen ????
dirOrig = FullPath.AsFileName
dirDest = AvSwatPath+"\MgtScen"
rootO = dirOrig
rootD = dirDest
n = 0
fnList = rootO.Read("*")
```

```
allList = {}
For each fln in fnList
  allList.Add({fln, rootD})
End
acaba = FALSE
While (acaba.Not)
  aux1 = {}
   For Each elem in allList
      fln = elem.Get(0)
    rootD = elem.Get(1)
    n = n + 1
    If (fln.IsDir) then
   '      av.Run("MakeDir", {rootD + "\" + fln.GetBaseName})

      For each newDir in fln.Read("*".AsPattern)
        aux1.Add({newDir, (rootD + "\" + fln.GetBaseName)})
      End
        Else
          File.Copy(fln, (rootD + "\" + fln.GetBaseName).AsFileName )
        End
    End
    allList = aux1
    If (allList.IsEmpty) then
    acaba = TRUE
  End
End
MsgBox.Info("Successfully executed", "")
```