An Alabama BMP Database for Evaluating Water Quality Impacts of Alternative Management Practices

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Abstract. *Best management practices (BMPs) are often used to control nonpoint source (NPS) pollutants from agricultural, forested, and urban watersheds. NPS models are used to estimate pollutant loads, devise NPS abatement plans, and develop and implement Total Maximum Daily Load (TMDL) plans. Accuracy of NPS model prediction depends on, among other things, 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 are usually unavailable. In the absence of regionally appropriate BMP database, simplified assumptions are often used. This practice can introduce input data uncertainty in models, which can lead to poor model predictability and mistrust in models. To alleviate this problem, a comprehensive database of commonly used agricultural and forestry BMPs in Alabama was developed. Using this database, various NPS pollution abatement measures can be evaluated using the SWAT (Soil and Water Assessment Tool) or other distributed parameter, continuous simulation NPS model. Specific objectives were: (1) to develop a database of commonly used BMPs in agriculture and forestry for the State of Alabama and (2) to create an ArcView® 3.X GIS (Geographic Information System) extension to load the database into the SWAT model. The complete database containing hundreds of BMPs and supporting documents are available at http://www.eng.auburn.edu/users/srivapu. The database provides environmental professionals with detailed information on management of agricultural and forested lands. 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 pollutant loads, 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.*

Agriculture and forestry are two of Alabama's largest industries and each is historically known to cause nonpoint source (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 United States, causing harmful effects to fisheries, wildlife, drinking water supplies, and other natural resources. NPS pollution is the primary reason why 40% 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% 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 (Hairston et al., 2001a). Other NPS pollutants include oil, grease, and pesticides. These pollutants can cause harmful effects such as decreased oxygen supply, increased turbidity, and increased eutrophication (Novotny, 2003). Eutrophication, the main water quality problem associated with agricultural NPS pollution, affects close to 50% 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 CWA 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 sources to solve the nation's pollution problems (Novotny, 2003). The two major outcomes of this section were (1) planning reports that identified the extent of point and NPS pollution and (2) tools, such as hydrological and water quality watershed models, for these planning reports. Similarly, Section 319 of the CWA is important because it provides funding for controlling NPS pollution. With the development of watershed models, land management practices could be analyzed to determine how they would

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affect water quality in adjacent water bodies (Novotny, 2003).

NPS pollution has become a major environmental concern, especially in agricultural watersheds (USEPA, 2007). 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, and 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 1 provides examples of structural and nonstructural BMPs.

Both structural and nonstructural BMPs have been proven to reduce NPS pollution. Each BMP functions differently, however. For instance, the primary goal of a silt fence is to prevent sediment from entering adjacent water bodies, 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 is often evaluated using watershed-scale NPS models.

Watershed models are powerful tools that are used to simulate transport of pollutants to receiving water bodies under different management scenarios. These models are capable of simulating and evaluating processes such as precipitation, evaporation, infiltration, runoff, and nutrient transport on a site-specific basis. Output from these models include 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, the simplicity in using models has made them extremely popular. Models are used for many different tasks today including urban planning, assessing BMPs, and developing Total Maximum Daily Loads (TMDLs). While models are widely used for managing water resources, it is necessary that detailed land management input data be available for predicting the effect of land management decisions on NPS pollution. 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 can lead to a greater level of uncertainty in model 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 efficiently and effectively manage watersheds and NPS pollution and develop more confident BMP recommendations using watershed models such as SWAT.

Table 1. A selected list of structural and nonstructural BMPs.

Structural BMPS	Nonstructural 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	Contour farming
Water control basins	Animal waste utilization
Grade stabilization structure	Stripcropping
Animal waste storage facilities	

Objective

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

- to develop a database of commonly used BMPs in agricultural and forestry industries; and
- to prepare an ArcView® 3.X geographic information system (GIS) extension to load management files for each of these BMPs in the SWAT model.

The SWAT model (Neitsch et al., 2002) is one of the most widely used watershed-scale, distributed-parameter, continuous simulation models for predicting point and NPS pollutant loads. An ArcView® 3.X GIS interface for the SWAT model (called AVSWAT 2000) was developed by Di Luzio et al. (2002). ArcView® 3.X GIS, developed by Environmental Systems Research Institute (www.esri.com), is one of the most often used GIS software.

The SWAT Model

Watershed models are powerful tools for assessing NPS pollution and evaluating watershed-level effectiveness of BMPs. The SWAT model (Neitsch et al., 2002) is one of the most widely used models to assess NPS pollution problems, to devise NPS control measures, and to develop and implement TMDLs in agricultural and forested watersheds. Even though the developed 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, among other things, for the purpose of analyzing the effects of management practices on water quality and is currently supported by the USEPA for its TMDL program (Neitsch et al., 2002).

SWAT is a modification of the Simulator for Water Resources in Rural Basins (SWRRB) and the Routing Outputs to Outlet (ROTO) models. The original SWRRB model had a number of limitations. These limitations included watershed divisions being limited to only 10 subbasins and the model routed water and sediment out of the subbasins directly to the watershed outlet. These limitations lead to the development of the ROTO model. The ROTO model solved the problems associated with 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. 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 (Neitsch et al., 2002).

The SWAT model has eight major components: 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, and then the model evaluates each individual area. This becomes important when different land uses are practiced 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 needed to run the SWAT model include digital elevation 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 for evaluating BMPs and for predicting NPS pollutant loads. The SWAT model allows for the input of land management information (i.e., BMP information) into the HRU management file (Neitsch et al., 2002). In this file, for individual HRUs, modelers can input land management practices such as pesticide applications, nutrient applications, tillage operations, planting and harvesting dates, animal waste applications, grazing practices, and irrigation practices. 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 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) of figure 1 show 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 effect of management practices on water quality.

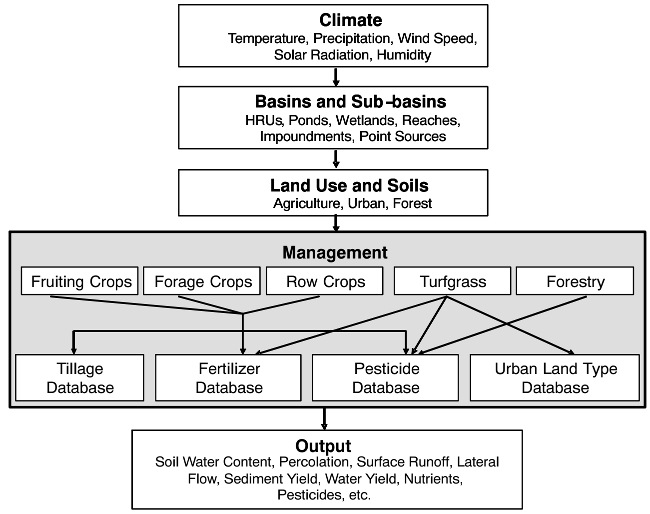

Figure 1. Flow of inputs in the SWAT model. The BMP database was developed for the management portion (highlighted in gray) of the SWAT model.

Methodology

BMP Selection Procedure

Agriculture and forestry are two important industries in Alabama and each has utilized BMPs to reduce NPS pollution created as a result of agricultural and forestry operations. Because of the importance of these two industries for the state, a comprehensive BMP database was developed that adequately represents the management practices being used in these two industries. Further, effort was directed towards the BMPs that can be evaluated using the watershed-scale NPS models such as SWAT. Data from the United States Department of Agriculture's National Agricultural Statistics Service (USDA-NASS, 2004) and Auburn University's College of Agriculture was used to determine the major crops grown in Alabama. When compared with other states, Alabama ranks third, third, and ninth in broiler production, peanut production, and cotton production, respectively (USDA-NASS, 2004). Alabama also ranks second in forest land cover with 22.9 million acres in timber land (USDA-NASS, 2004). Using this information along with the acreage of other crops, a number of major crops grown in Alabama were selected for the BMP database. These include row crops and forage crops (table 2). The forage crops are normally grown for hay or grazing purposes. Several grasses typically used in golf course management, athletic fields, and urban situations were included in the database. Fruiting crops were also included in the database. Animal waste applications were restricted to broiler litter and loblolly pine was the only tree considered in the forestry portion of the database (table 2).

Data Collection Procedure

There are many crops grown across Alabama and different geographic regions utilize different cropping and management practices. For instance, the majority of the peanut crop is grown in south Alabama. The central and Blackbelt regions have a few peanut farmers, while peanut

Table 2. Major crops of Alabama and associated BMPs considered for the BMP database.

	Crops	BMPs
Row crops	Corn	Crop rotations
	Cotton	Integrated pest management
	Soybeans	Nutrient management
	Peanuts	Tillage practices
	Wheat	Irrigation water management
Forage crops	Alfalfa	Nutrient management
	Bahiagrass	Grazing management
	Dallisgrass	Animal waste applications
	Hybrid bermudagrass	Integrated pest management
	Sericea lespdeza	
	Summer annuals	
	Winter annuals	
	Fescue	
Fruiting crops	Blueberries	Integrated pest management
	Peaches	Irrigation water management
	Pecans	Nutrient management
Turfgrass	Commercial bermudagrass	Nutrient management
	Zoysiagrass	Integrated pest management
	Centipede lawn	
	Winter lawn	
Forestry	Loblolly pine	Integrated pest management

farming is nonexistent in the northern portion. 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 take place. For example, crops have to be planted later in the year for farms that are located in the cooler climate of north Alabama as opposed to the 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 (fig. 2). By dividing the state into four geographic regions and developing BMPs based on these four areas, the BMP database provided a better account of actual management practices being performed by the farmers. Blackbelt is a unique soil region and the cropping and management practices in this region are different from the other three regions. That is why, in addition to the north, central, and south regions, cropping and management practices were separately developed for the Blackbelt region.

Appropriate crops were selected for inclusion in the database and a group of experts including extension agents were consulted to construct the BMP database. 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. Information was also obtained from several Alabama Cooperative Extension System's publications. This information includes operational dates, irrigation scheduling, grazing practices, pesticide applications, fertilizer applications, and tillage operations. The management data was then evaluated to determine which BMPs could be depicted in the SWAT model.

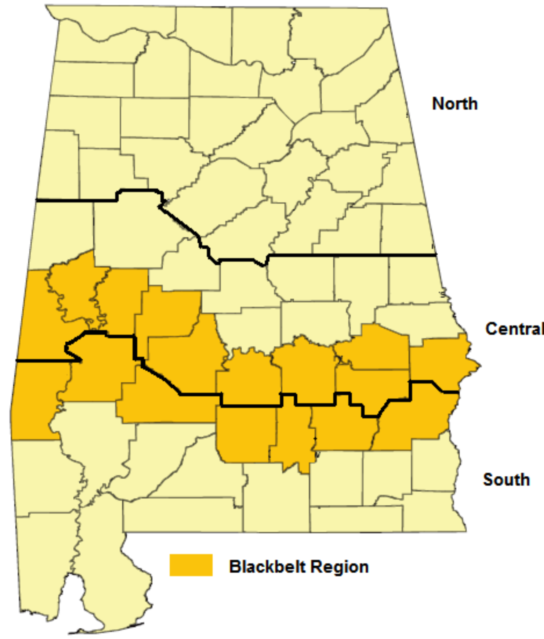

Figure 2. Geographic regions of Alabama for which BMP database was developed.

Crop Rotations

Crop rotation is widely used by Alabama farmers as a BMP. An organized, preplanned sequence of crop rotation can reduce NPS pollution. Crop rotations reduce the amount of NPS pollutant load by decreasing the chance of insects and disease infestation and by limiting the amount of time a field is in row crops (Novotny, 2003). Increased soil microbial biomass is also an advantage of using 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 grown in various areas of Alabama and to ensure that crop rotations were accurately incorporated into the BMP database, care was taken when determining rotations to be used. Extension agents with knowledge of commonly used crop rotations 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.

Nutrient Managment

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 including soil fertility and the availability of nutrients prior to applying any type of fertilizer (Tyson, 2000). It 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 specific nutrient management into the BMP database because of the variability in soil types and crop management. Therefore, it was represented in the BMP database using the Auburn University College of

Agriculture's Department of Agronomy and Soils soil test nutrient recommendations. For most cases the application rates 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 http://www.ag.auburn.edu/agrn/croprecs/NutrientRecsIndex.html for all soil test nutrient recommendations for Alabama crops or use individual soil test recommendations.

Animal Waste Applications

The poultry industry is an important part of Alabama's economy, and many farmers are utilizing poultry broiler litter as a fertilizer source. Recently, concern has grown over how over-applying animal waste can lead to excessive phosphorus loadings to surface waters (Sharpley and Beegle, 2001). To reduce NPS phosphorus loads, the phosphorus index (P-index) of Alabama was created. The P-index is a tool for evaluating a specific management practice on a particular land for potential risk of phosphorus transport. The P-index analyzes 11 different field factors and cropping and management practices and suggests an appropriate amount of poultry litter (or fertilizer) to be applied (USDA-NRCS, 2001). Poultry litter is commonly applied to forage crops that are used hay production (Mitchell, 2006). Cotton and corn are the only row crops that often utilize poultry litter as a source of nutrient (Mitchell, 2006). When P-index is applied to a particular land in a particular cropping and land management, it indicates whether the litter can be applied, for the crop being grown, at the nitrogen uptake rate (very low/low potential risk of phosphorus transport), three times the phosphorus uptake rate (medium potential risk of phosphorus transport), two times the phosphorus uptake rate (high potential risk of phosphorus transport), one times the phosphorus uptake rate (very high potential risk of phosphorus transport), and zero times the phosphorus uptake rate (extremely high potential risk of phosphorus transport). To make the database easy to use, the poultry litter applications implemented in the database were based on a very low/low potential risk of phosphorus transport (i.e., nitrogen uptake rate of the crop being grown). Adjustments should be made in the application rates using table 3 data if individual field and management characteristics suggest a different P-index rating.

Integrated Pest Management

Another important BMP that was incorporated into the database was integrated pest management (IPM). IPM minimizes NPS pollution by controlling crop diseases, weeds, insects, and fungi. (Novotny, 2003). Pesticides are applied more efficiently and at minimal rates to keep the crop healthy. In addition, resistant crop varieties and more appropriate pesticide application timing plays a role in reducing NPS pollution (Novotny, 2003). Integrated pest management is another BMP that was 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 which pesticides were commonly used. 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 commonly used in Alabama. To remedy this, the SWAT model allows for the input of new pesticides. For each pesticide, the SWAT pesticide database needs soil adsorption coefficient normalized for soil organic carbon content, wash-off fraction, degradation half-life of the chemical on the foliage, degradation half-life of the chemical in the soil, application efficiency, and the solubility of the chemical in water. Finding these values was extremely difficult and several sources, including chemical companies, were contacted to obtain the information. Other sources include chemical material safety data sheets (MSDS), chemical labels, California Department of Pesticide Regulation, and 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 4 provides a list of pesticides added to the SWAT model's pesticide database.

Irrigation Water Management

Irrigation water management (IWM) is another BMP commonly used by Alabama farmers. IWM reduces NPS pollutant load by improving irrigation scheduling, efficiency, and water utilization (Novotny, 2003). By incorporating IWM into farming practices, not only water quality is protected, but also water loss is reduced and crop production is improved. Corn is the only row crop that has irrigation

Table 3. Application rates (lb/acre) of poultry litter for Alabama crops as a function of P-index rating.[a]

		Poultry Litter Application Rates (lb/acre) for Various P-Index Ratings				
Crop	Yield (per acre)	Very Low/Low	Medium	High	Very High	Extremely High
Corn	70 (bu)	4,138	2,897	1,931	966	–
Irrigated corn	145 (bu)	6,207	6,000	4,000	2,000	–
Cotton	2.25 (bale)	3,104	2,793	1,862	931	–
Alfalfa (hay)	3 (ton)	–	3,724	2,483	1,241	–
Hybrid bermudagrass (hay)	5 (ton)	10,345	6,207	4,138	2,069	–
Fescue (hay)	3 (ton)	4,138	2,793	1,862	931	–
Bahiagrass (hay)	5 (ton)	4,138	3,621	2,414	1,207	–

[a] For example, if the P-index for a particular field in corn had very low/low rating (i.e., potential of phosphorus transport), then poultry litter can be applied at the rate of 4,138 lb/acre. Also, note that most farmers round to the nearest – ton (1,000 lb) per acre for poultry litter applications.

Table 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

water practices represented in the BMP database. IWM is another BMP that was somewhat difficult to represent in the BMP database because of the variety of irrigation systems used. 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 irrigation to corn. The water stress threshold was set at the recommended 0.925 level (Neitsch et al., 2002). Table 5 provides more detailed information on corn's water requirements. This information, in conjunction with the rainfall data, can be used to incorporate a more accurate IWM in the SWAT model.

Grazing Managment

Many farmers in Alabama use their pastures for grazing purposes. Because of this, it was important that grazing management be implemented in the BMP database. Grazing 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

Table 5. Estimated water use by corn for Alabama farms.

Days after Planting	Growth Stage	Water Use (in./day)	Total Water Use (in.)
0-20	Seeding	0.06	1.2
20-30	5-10 in.	0.09	0.9
30-40	10-20 in.	0.15	1.5
40-50	20-50 in.	0.20	2.0
50-60	50-80 in.	0.21	2.1
60-70	80 in.-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.

Table 6. Typical grazing periods for Alabama farms.

Crop	Start Grazing	End Grazing	No. Days of Grazing
Bahiagrass	April	October	165
Dallisgrass	April	October	205
Hybrid bermudagrass	May	October	167
Sericia lespedeza	May	October	175
Summer annual	June	October	155
Fescue	April September	June November	75 70
Stockpiled fescue	April November	June December	75 42
Winter annuals	February November	May December	75 30
Over seeding pasture w/ winter annuals	February	May	75

database inputs for grazing periods that correspond to individual crops (Ball, 2006).

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 the farmers. According to USDA-NASS (2006), 39% of farmers have between 100 and 499 head of cattle. The default setting used in the database is 100 head of cattle, each of which is assumed to weigh 1350 lb. It is 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 cows body weight (Ball, 2006). These numbers can be adjusted based on the management practices of the watershed being examined.

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 reduce 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., 2001b). These conservation tillage practices are commonly used in Alabama farms. Research was conducted to determine which cropping systems actually use conservation tillage practices. This information was obtained from extension agents working in each of the four regions of the state (fig. 2). The information was then input into the SWAT model by altering the Soil Conservation Services (SCS) curve number associated with the tillage operations.

Land Cover Input

The SWAT model has an extensive land cover/plant database that covers different types of plants. This database, however, did not include all of the crops grown in 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 added to 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 is orchards. This was used to represent pecans and peaches in the BMP database. Blueberries were also added to the BMP 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 side oats grama were modified with the potential leaf area index set to 1 and the potential rooting depth set to 0.4. The crop height was also reduced to adequately represent a turfgrass situation (Kiniry, 2006).

Forestry Bmps

Forestry is one of Alabama's largest industries. Because of the enormity of the forest industry in Alabama, it was important that forestry BMPs be adequately represented in the BMP database. Many of the forestry BMPs are structural (e.g., broad-based dip, wing ditch, and water bar) that cannot be simulated in the SWAT model. The reason being, the SWAT model does not allow simulation of small structural BMPs that are applied on a hillslope. A hillslope-scale model might be more appropriate for these BMPs. However, certain site preparation and release treatments were included in the BMP database. Approximately 94% of the trees 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 on loblolly pine were based on IPM, chemical manufactures labels, and USEPA regulations.

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 (AVSWAT). This will allow individuals working in the water resources field all across the state to utilize the database. The extension was created using the AVENUE programming language provided by the ArcView® GIS. The extension allows the BMP database files and data to be copied at the appropriate directory locations in AVSWAT. Once the extension is executed, the data will be easily available through AVSWAT. The data and extension can be requested by contacting the authors or can be downloaded from the website listed in the abstract.

RESULTS

ROW CROPS

The majority of the BMP database consists of row crop management scenarios. Table 7 shows various crop rotations that were included in the database for different regions of Alabama. Each of these crop rotations consists of additional BMPs that include IWM, conservation tillage operations, IPM, and nutrient management. As an example, table 8

Table 7. Crop rotations by Alabama regions.

Region	Crop Rotations[a]		
North	Continuous cotton	Cotton-cotton-corn	Cotton-corn silage
	Cotton-wheat(cc)	Cotton-cotton-corn silage	Cotton-cotton-irrigated corn
	Cotton-rye(cc)	Cotton-soybean	
	Cotton-corn	Cotton-irrigated corn	
Central	Continuous cotton	Corn-wheat-soybean	Irrigated corn-soybean-cotton
	Corn-soybean-corn	Corn silage-wheat-soybean	Irrigated corn-wheat-soybean
	Corn silage-soybean-corn silage	Cotton-cotton-cotton-peanut	Corn silage-soybean-cotton
	Corn-cotton-corn	Cotton-cotton-peanut	Corn silage-wheat-soybean
	Corn silage-cotton-corn silage	Cotton-ryegrass(graz)	Irrigated corn-cotton- irrigated corn
	Corn-soybean-cotton	Irrigated corn-soybean- irrigated corn	
	Corn silage-soybean-cotton		
South	Peanut-cotton	Cotton-wheat(cc)-peanut	Bahiagrass-bahiagrass-bahiagrass-peanut
	Cotton-cotton-peanut	Cotton-rye(cc)-peanut	Cotton-ryegrass(graz)
	Peanut-corn silage	Cotton-corn silage	
Blackbelt	Cotton-wheat(cc)-peanut	Corn-corn-soybean	Cotton-corn silage-cotton-corn silage-soybean
	Wheat-corn-wheat-soybean	Cotton-corn-soybean	Wheat-corn silage-wheat-soybean
	Cotton-corn-cotton-corn-soybean	Corn silage-corn silage-soybean	Wheat-irrigated corn-wheat-soybean
	Peanut-ryegrass(graz)-cotton	Cotton-corn silage-soybean	Cotton-irrigated corn-cotton-irrigated corn-soybean
	Cotton-irrigated corn-soybean	Wheat-corn silage-wheat-soybean	Irrigated corn-irrigated corn-soybean
		Irrigated corn- irrigated corn-soybean	
		Cotton-irrigated corn-soybean	

[a] cc = cover crop, graz = grazing.

Table 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	Apply 1 application of Temik (4 lb active /acre) on 40% of the acreage
4/15	Apply 1 application of Orthene 90 SP (0.15 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	Apply 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	Apply 0.5 applications of Karate Z 2.08 CS (0.3 lb active/acre) on 75% of the acreage
8/1	Apply 1 application of Karate Z 2.08CS (0.3 lb active/acre)on 75% of the acreage
8/15	Apply 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

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.

Forage Crops

Although forage crops are not managed as intensively as the row crops, BMPs can still lead to improved water quality. Table 9 provides a list of the major forage crops included in the BMP database. Information was obtained to determine various forage crops that were used for grazing and hay production. Also, management information on establishing a particular forage crop was also included in the BMP database. Specific BMPs that were included under forage crops include, grazing management, nutrient management, and IPM. As an example, table 10 shows a complete management scenario for hybrid bermudagrass used for grazing. This table explains the timing and rate of nutrient application as well as period of grazing.

Table 9. Major forage crops 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 10. A complete management scenario for a 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

Fruiting Crops

Three of Alabama's main fruiting crops, peaches, pecans, and blueberries, were included in the BMP database. Once the blueberries are planted, the management practices from year to year are different until the plants reach maturity. For instance, management strategies for year 2 will differ from the management practices in year 7. The database contains management information for blueberries from establishment year (year 1) 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. As an example, table 11 shows year 2 management of blueberries.

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

Table 11. Complete management scenario for Alabama blueberries in year 2.

Date (month/day)	Practice
3/5	Apply 140 lb/acre of 12-4-8
3/xx	Irrigate (1.5 in./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 in./week)
6/1	Spot spray Roundup Weathermax (2 pt/acre)
6/xx	Irrigate (1.5 in./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 in./week)
8/1	Spot spray Roundup Weathermax (2 pt/acre)
9/1	Spot spray Roundup Weathermax (2 pt/acre)
9/xx	Irrigate (1.5 in./week)
10/1	Spray Dervinol 50 DF (4 lb/acre) and Princep 4L (0.5 gal/acre)

Table 12. Complete management scenario for Alabama golf course fairway that is not over seeded.

Date (month/day)	Practice
Golf course fairway (not over seeded)	
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

golf course fairways. As an example, table 12 provides BMP information for golf course fairway. The table provides information on fertilizer and pesticide application rates and timing.

SUMMARY

BMPs have been widely used to reduce NPS pollutant loads. Watershed-scale NPS models are often used to estimate NPS pollutant loads from watersheds, to develop and implement TMDLs, and to evaluate effectiveness of BMPs. The accuracy of model predictions depends on accuracy of input data, of which description of BMPs is an integral part. Even though such data is available in bits and pieces in various publications and through consultation with experts, in the absence of a comprehensive database modelers often resort to simplified assumptions. This practice introduces input data uncertainty, which can lead to output uncertainty. This article describes the development of a BMP database and a GIS extension that can be used to evaluate and manage agricultural and forested watersheds in Alabama. To ensure that the database represents actual management practices that are currently being used by farmers, information was gathered from a variety of sources and experts from all across the State. Information obtained and included in the database include: planting and harvesting dates, tillage practices, IPM, nutrient management, as well as, other management information. The BMP database contains over 300 different management scenarios. These scenarios contain information for forestry operations, turfgrass management, animal waste management, fruiting crop management, grazing management, forage crop management, and agronomic crop management. Specific BMPs included were crop rotations, IPM, nutrient management, grazing management, IWM, and conservation tillage practices. The BMP database provides a powerful watershed management tool with several benefits. Currently, in 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. Also, this database will allow environmental professionals to evaluate BMPs effectiveness at a watershed-level. The ArcView® GIS extension will allow the database to be easily distributed to environmental professionals across Alabama. The BMP database will help improve the way agricultural and forested watersheds are managed, which will help reduce NPS pollution.

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REFERENCES

Adeboye, M. K. A., E. N. O. Iwuafor, and J. O. Agbenin. 2006. The effects of crop rotations and nitrogen fertilization on soil chemical and microbial properties in a Guinea Savanna Alfisol of Nigeria. *Plant and Soil* 281(1-2): 97-107.

Ball, D. 2006. Personal communication. Professor and Extension Specialist, Agronomy and Soils Department, Auburn University, Auburn, Ala. 25 May.

Borah, D. K., and M. Bera. 2002. SWAT Model Background and Application Reviews. ASAE Meeting Paper No. 032054. St. Joseph, Mich.: ASAE.

Brooks, K. N., P. F. Folliott, H. M. Gregersen, and L. F. DeBano. 2003. *Hydrology and the Management of Watersheds.* Ames, Iowa.: Blackwell Publishing.

Di Luzio, M., R. Srinivasan, J. G. Arnold, and S. L. Neitsch. 2002. ArcView interface for SWAT2000: User's guide. TWRI Report TR-193. College Station, Tex.: Texas Water Resources Institute.

Enebak, S. 2007. Personal communication. Professor, School of Forestry and Wildlife Sciences, Auburn University, Auburn, Ala. 20 February.

Gitau, M. W., W. J. Gburek, and A. R. Jarrett. 2005. A tool for estimating best management practice effectiveness for phosphorus pollution control. *J. of Soil and Water Conservation* 60(1): 1-10.

Hairston J. E., L. Stribling, and J. M. Beck. 2001a. Controlling agricultural nonpoint source pollution through Best Management Practices. Alabama Cooperative Extension System. Auburn, Ala.

Hairston J. E., L. Stribling, and J. M. Beck. 2001b. Reduced tillage practices for soil management. Alabama Cooperative Extension System. Auburn, Ala.

Kiniry, J.R. 2006. Personal communication. Research agronomist, USDA-ARS, Grassland Soil and Water Research Laboratory, Temple, Tex. 31 July.

Kriese-Anderson, L. 2006. Personal communication. Associate Professor and Extension Specialist, Department of Animal Science, Auburn University, Auburn, Ala. 28 August.
Mitchell, C. 2006. Personal communication. Professor and Extension Specialist, Agronomy and Soils, Auburn University, Auburn, Ala. 17 July.
Neitsch, S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. 2002. Soil and Water Assessment Tool User's Manual. College Station, Tex.: Texas Water Resources Institute.
Novotny, V. 2003. *Water Quality: Diffuse Pollution and Watershed Management*. New York: John Wiley and Sons
Rankins, D. 2006. Personal communication. Professor, Department of Animal Science, Auburn University, Auburn, Ala. 28 November.
REM. 2002. Soil and Water Assessment Tool. Register of ecological models. Available at: http://eco.wiz.uni-kassel.de/model_db/mdb/swat.html. Accessed 11 August 2006.
Sharpley, A. N., and D. Beegle. 2001. Managing phosphorus for agriculture and the environment. College of Agricultural Sciences, The Pennsylvania State University, University Park, Pa.
Srivastava, P. 1999. A GIS, genetic algorithm, and ANNAGNPS integrated system for non-point pollution assessment. Ph.D. dissertation. The Pennsylvania State University, Department of Agricultural and Biological Engineering. University Park, Pa.
Tyson T. W. 2000. Best management practices for animal feeding operations. Alabama Cooperative Extension System. Auburn, Ala.
USDA-NASS. 2004. Alabama agricultural statistics. Washington, D.C.: USDA National Agricultural Statistics Service.
USDA-NASS. 2006. Alabama data- cattle operations-percents. USDA National Agricultural Statistics Database. Washington D.C.: USDA National Agricultural Statistics Service. Available at www.nass.usda.gov. Accessed 29 August 2006.
USDA-NRCS. 2001. Phosphorus index for Alabama. A planning tool to assess and manage P movement. Agronomy Technical Note AL-72. USDA Natural Resource Conservation Service, Auburn, Ala.
USEPA. 2006. What is Nonpoint Source(NPS) Pollution? Questions and Answers. Washington D.C.: USEPA. Available at: www.epa.gov/owow/nps/qa.html. Accessed 11 August 2006.
USEPA 2007. Nonpoint source pollution: The nation's largest water quality problem. EPA841-F-96-004A. Washington, D.C.: USEPA. Available at: http://www.epa.gov/owow/nps/facts/point1.htm. Accessed 29 May 2007.