Modeling Switchgrass Production Effects on Runoff Water Quality

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1. Introduction

The Rathbun Lake Watershed assessment consists of three assessment tools. One tool evaluates the riparian areas of the watershed to qualitatively rank the health of the streams and their associated biota. The second tool quantitatively evaluates the extent and severity of sheet and rill, gully, and streambank erosion. The third tool of the assessment is a modeling approach to evaluate the upland areas of the watershed for sediment production, pesticide runoff and nutrient runoff. This section of this report will address the selection, adaptation, implementation, and results from the third assessment tool--watershed modeling.

2. Objectives

The objectives of this part of the report are to:

1. Rank the 61 subbasins of Rathbun Lake Watershed on their relative sediment production, pesticide runoff, and nutrient runoff using the Soil and Water Assessment Tool.
2. Using the Soil and Water Assessment Tool (SWAT) study the water quality effects of changing land use and management practices from baseline conditions to one of growing switchgrass for biomass production.

3. Materials and Methods

3.1 Computer modeling

Numerous computer models are available to predict water quality impacts from agricultural watersheds. Selected features of the computer model were desired. The model must:

- be watershed-scale
- be continuous in time operation
- have the ability to develop and compare alternative management scenarios easily
- have sufficient resolution to compare the relative pollutant loading of the 61 subwatersheds
- be able to link to a GIS

With these features and the project objectives in mind, the Soil and Water Assessment Tool version 99.2 with the ArcView® (ESRI, Redlands, CA) interface (ArcView SWAT) was selected for this project.

3.2 SWAT

SWAT is a biophysical, semi-distributed, continuous, daily time step model designed to simulate water yield, sediment delivery, and nutrient and pesticide loading from large, ungaged watersheds. The model uses datasets typically available from government agencies. It is capable of predicting the relative impact of agricultural management and land use over long time periods.

The GIS interface of SWAT is set up as an extension of ArcView®. This configuration gives the interface the flexibility to use special features available in other ArcView® extension packages. The ArcView SWAT version of the model allows geo-referenced data to be preprocessed for entry into the model. After model simulation, the GIS component post-processes the model output and displays the data as graphics, charts or tables. This type of GIS interface is an example of close-coupling as explained by Tim (1995).

Key processes, which impact water quality, are discussed below.

<u>Water Yield.</u> The water balance is the basic driver of the model. The water balance equation used is:

$$SW_t = SW_0 + \sum(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where SW_t is the final soil water content (mm water), SW_0 is the initial soil water content (mm water), R_{day} is the amount of precipitation for the day (mm water), Q_{surf} is the amount of surface runoff for the day (mm water), E_a is the amount of evapotranspiration for the day (mm water), w_{seep} is the amount of water entering the vadose zone from the soil profile for the day (mm water), and Q_{gw} is the amount of return flow for the day (mm water). Because SWAT uses a daily time step, the water balance is calculated every day of the simulation.

The water yield from a given land area is important because it determines the concentration of pollutants being removed from the land area. The major component of water yield is surface runoff. The quantity of surface runoff impacts the amount of soil erosion that occurs.

<u>Sediment Yield.</u> The predicted soil erosion rate and sediment yield is calculated for each hydrologic response unit (HRU) with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). This equation uses surface runoff volume and peak rate to predict erosion rate and sediment delivery from small watersheds. MUSLE is derived from the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). The MUSLE equation adapted for use in the model is:

$$Sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE}$$

where *Sed* is the sediment yield (metric tons), 11.8 is a unit conversion constant, Q_{surf} is the surface runoff volume (mm water/ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the hydrologic unit area (HRU) in hectares, K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cropping and management factor, P_{USLE} is the USLE conservation support practices factor, and LS_{USLE} is the USLE slope length and steepness factor.

The Q_{surf} and q_{peak} are calculated every day precipitation occurs. If surface runoff occurs, then sediment yield is calculated for that day. Because crop growth affects Q_{surf} and q_{peak}, C_{USLE} is also updated daily to reflect changes in the plant growth and land cover.

Crop Growth. Crop growth is simulated in SWAT using the modeling approach used in the Erosion Productivity Impact Calculator (EPIC) (Williams et al., 1984). EPIC allows for the variation in growth for different plant species, and variation due to climate and growth conditions.

Pesticides. SWAT simulates the fate of pesticides applied to the soil surface and/or incorporated by tillage implements. The routines used are adapted from the model GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987). Six chemical or physical properties of a pesticide are necessary in order to simulate its movement and transformation by SWAT.

Nutrients. Nitrogen and phosphorus management and movement are simulated in SWAT using the modeling approach of GLEAMS. SWAT simulates the movement and transformations of nitrogen between two mineral (ammonium and nitrate) and three organic (active, stable and fresh) soil nitrogen pools. Monitoring three mineral (labile in solution, labile on soil surface and fixed in soil) and three organic pools (active, stable and fresh) of soil phosphorus simulates soil phosphorus movement and transformation.

3.3 Adapting SWAT to Rathbun Lake Watershed

Utilizing ArcView SWAT requires obtaining, formatting and entering several spatial and non-spatial databases into the model.

Spatial Data

The spatial (GIS) databases and coverages are discussed first. All of the spatial coverages prepared for this project were acquired and formatted by Tyler Jacobsen, GIS Specialist with the Rathbun Rural Water Association (Tyler Jacobsen, personal communication, August 1999, December 1999, February 2000, July 2001).

Digitized Elevation Model (DEM). (Fig. 1) The DEM is a graphical representation of the land slope steepness and aspect (direction). The DEM is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is given a single elevation value. This GIS coverage determines watershed and subbasin, (subwatershed) boundaries and thus, water flow direction and accumulation. The DEM is available through the Iowa Department of Natural Resources Geological Services Bureau (IDNR-GSB).

Streams. The digitized streams are line representations of accumulated perennial water flow over the soil surface. This coverage is important for the routing (i.e. movement and transformation) of runoff and pollutants originating in the watershed. The stream coverage was created by the hydrologic modeling component of SWAT utilizing the DEM.

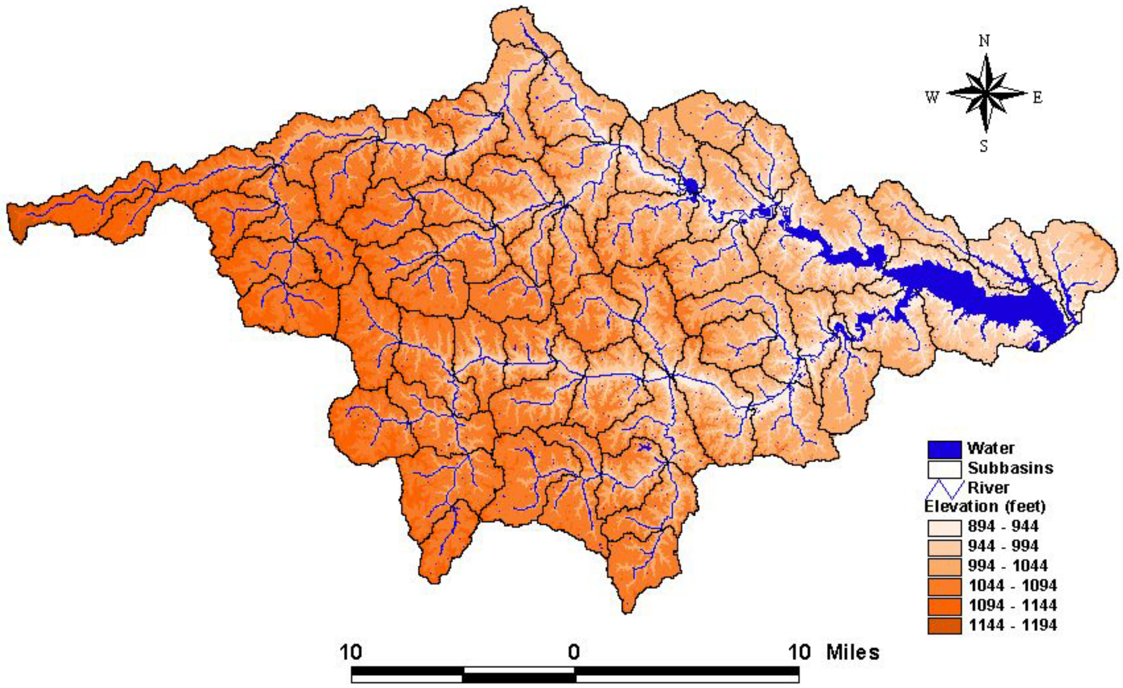


Figure 1 Digitized Elevation Model

Subbasins delineation. Subbasin outlets are geo-referenced points on a stream or river identifying the outlet of the subbasin. Outlets may occur in series on larger streams such that the outlet of one subbasin contributes channel flow to a downstream subbasin. A subbasin is the land area contributing surface runoff to the subbasin outlet. The subbasin file was created in-house following Natural Resources Conservation Service (NRCS) and USGS criteria for developing 14-digit Hydrologic Units. The file was not used directly in SWAT but was analyzed and an outlet point shape file was created for use in SWAT. This subbasin coverage created in SWAT closely matched a subbasin file previously created by the Chariton Valley RC&D for watershed management purposes.

Land use/land cover. (Figure 2) This coverage is a graphical representation of land cover type. The land use/land cover is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is designated a single land cover type. This coverage is used to define the plant growth characteristics SWAT will use to simulate the area. This coverage is part of the USGS National Land Cover Dataset using 1992 Landsat thematic mapper imagery and supplemental data (USGS, 2000).

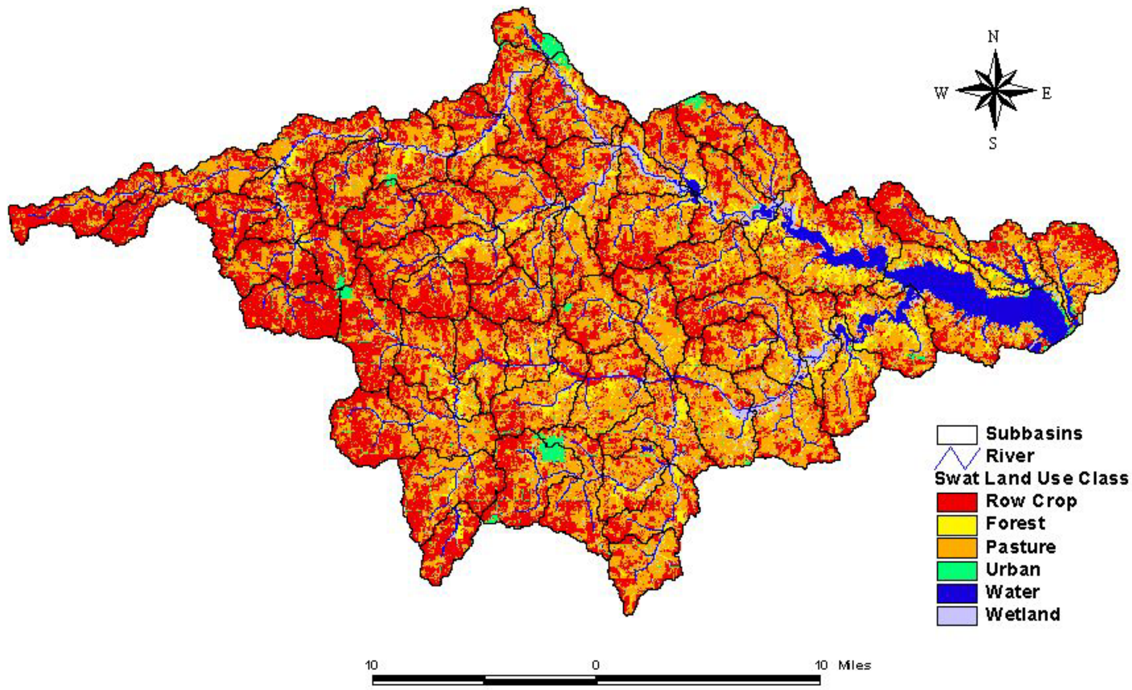


Figure 2 SWAT Land Use and Land Cover Coverage

Soils. (Figure 3) This coverage is a graphical representation of soil distribution. The soils coverage is prepared as a 30-meter grid polygon format. Each "cell" of this 30-meter by 30-meter grid is designated a single soil type. This coverage is used to define the soil chemical and physical properties SWAT will use to simulate the area. The township digital soil coverage of Appanoose, Clark, Decatur, Lucas, Monroe, and Wayne Counties and the Iowa Soil Properties and Interpretations Database (ISPAID) (Fenton, 2001) are the original sources of the information for the soils coverage. The Iowa soils data was linked to the SWAT soils database by use of the SCS Soils 5 column of ISPAID and the S5ID number from the soilsia.dbf in SWAT.

Weather. Three types of files are maintained to simulate weather. These files are the measured daily maximum and minimum temperature file, the measured daily precipitation file, and weather generator input file. The SWAT model comes complete with a climate generation model and the monthly average parameters for more than 1100 weather stations throughout the contiguous United States. For this project, measured daily maximum and minimum temperature and precipitation data from four long-term recording stations close to the watershed were obtained from Dennis Todey and used as input into the climate generator (Dennis Todey, personal communication, 1999). Monthly data for these recording stations were obtained from the Iowa State University Agronomy Department Agricultural Meteorology website at: http://www.agron.iastate.edu/climodat/. The weather stations are located near the towns of Centerville, Chariton, Corydon and Osceola. See Fig. 4. SWAT simulates the weather by subbasin. If data from multiple weather stations is available, the distance from the centroid of each subbasin to each weather station is calculated. The subbasins are then assigned to the closest weather station for their respective climate data.

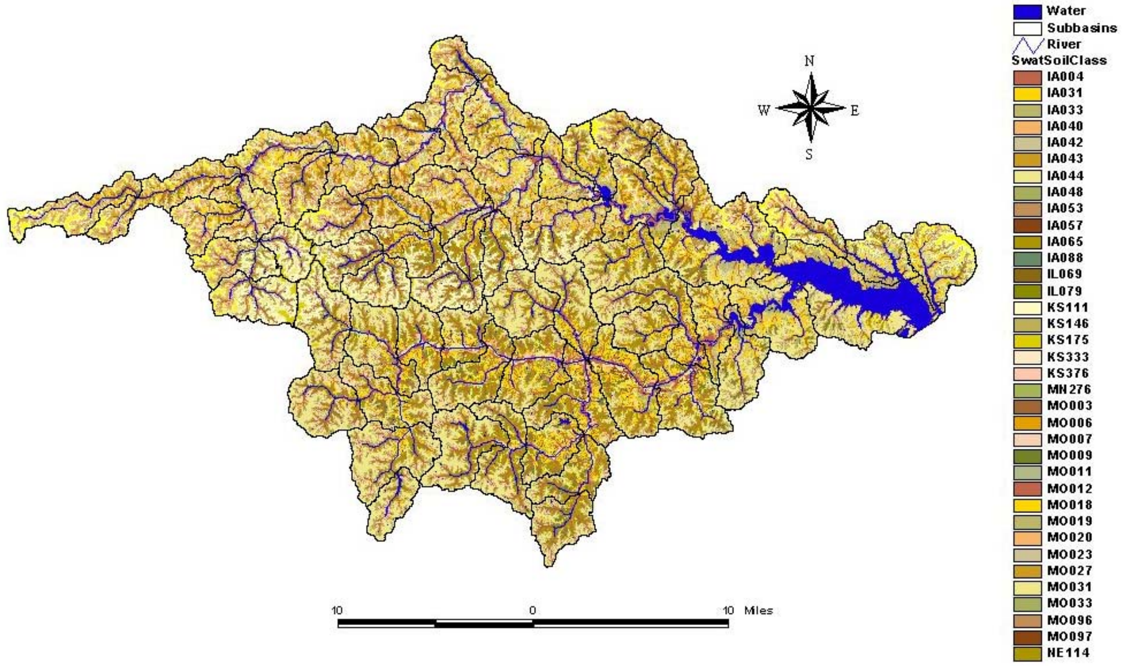


Figure 3 SWAT Soils Coverage

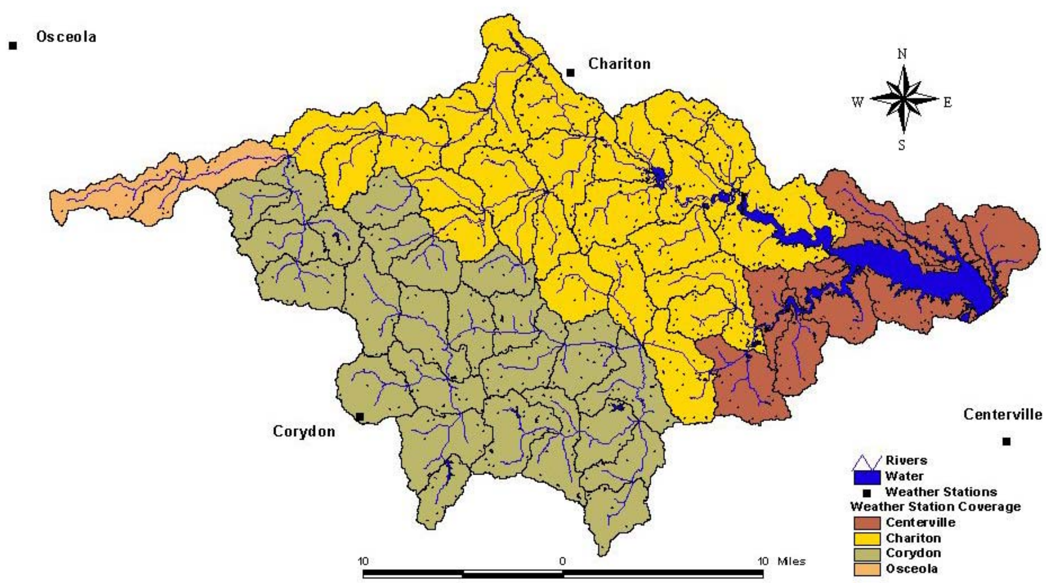


Figure 4 Weather Station Location and Simulation Coverage

<u>Non-spatial Data</u>

Non-spatial data required by the model include several databases needed to develop management practice schedules.

Crop Database. The crop database taken from the EPIC model contains the growth parameters of approximately 100 plants or generic crop growth types. The growth parameters for switchgrass (Panicum virgatum) were obtained from an updated version of the EPIC obtained from Phil Gassman (Phil Gassman, personal communication, 2000) and from Ken Moore, Professor of Agronomy, at Iowa State University (Ken Moore, personal communication, 2000). Important plant growth parameter values for corn, soybeans, smooth brome grass and switchgrass are listed in Table 1. The complete definitions of the crop growth attributes are available from the SWAT User's Manual Version 99.2 p. 158-160 (Neitsch et al., 1999).

Table 1 Listing of Crops and Selected Crop Growth Attributes Used in the Scenarios

CROP NAME	BIO_E	HVSTI	T_OPT	T_BASE	BLAI	DLAI	CHTMX	RDMX
SOYBEAN	25.0	0.30	25.0	10.0	5.0	0.90	0.8	2.00
CORN	40.0	0.50	25.0	8.0	5.0	0.80	2.0	2.00
BROME GRASS	35.0	0.02	25.0	6.0	3.0	0.85	0.8	1.30

SWITCHGRASS

47.0
0.01
30.0
10.0
5.0
0.70
2.5
2.20

BIO_E
Radiation-use efficiency or biomass-energy ratio ((kg/ha)/(MJ/m2)).

HVSTI
Harvest Index. This is the plant yield of seed divided by the total aboveground biomass ((kg/ha)/(kg/ha)).

T_OPT
Optimal temperature for plant growth (deg C).

T_BASE
Minimum (base) temperature for plant growth (deg C).

BLAI
Maximum potential leaf area index.

DLAI
Fraction of growing season when leaf area declines (heat units/heat units).

CHTMX
Maximum canopy height (m).

RDMX
Maximum root depth (m).

Pesticide Database. The pesticide database in SWAT was obtained from the GLEAMS model pesticide database (Leonard et al., 1987). Six chemical or physical characteristics of a pesticide are needed to model its fate within SWAT. The characteristics are: water solubility, soil adsorption coefficient (k_{oc}), foliar half-life, soil half-life, application efficiency and washoff fraction. The database was edited to add atrazine and acetochlor. The pesticide characteristics needed as input into the model were obtained from the Herbicide Handbook of the Weed Science Society (Ahrens, 1995) and from R. Don Wauchope, USDA-ARS, Tifton, GA (R. Don Wauchope, personal communication, 2000). The six chemical and physical characteristics necessary for each pesticide to be modeled are listed in Table 2 for Harness® (acetochlor), atrazine, Roundup® (glyphosate), and 2,4-D. The definitions of the pesticide characteristics were obtained from the SWAT User's Manual Version 99.2 p. 163-164 (Neitsch et al., 1999).

Fertilizer Database. The fertilizer database in SWAT contains 54 commonly available chemical fertilizers, organic fertilizers, and animal manures. To this database, a product called HLF fertilizer was added. This material is a by-product of a nearby corn lysine production plant (J. Sellers, Jr., personal communication, 2000). Table 3 lists the chemical and physical properties of fertilizers needed by the model for anhydrous ammonia (82-0-0), diammonium phosphate (18-46-0), urea (45-0-0) and HLF fertilizer. The definitions of the fertilizer characteristics were obtained from the SWAT User's Manual Version 99.2 p. 164-166 (Neitsch et al., 1999).

Table 2 Listing of Pesticides and Pesticide Characteristics

PNAME	SKOC	WOF	HLIFE_F	HLIFE_S	EFA	WSOL
Atrazine	100	0.45	5.0	60.0	0.75	33
Harness	100	0.40	3.0	60.0	0.75	223
2, 4-D	74.0	0.45	9.0	10.0	0.75	900.0
Roundup	500.0	0.60	2.5	30.0	0.75	12000.0

SKOC	Soil adsorption coefficient normalized for soil organic carbon content (mg/kg)/(mg/L)
WOF	Wash-off fraction
HLIFE_F	Degradation half-life of the chemical on the foliage (days)
HLIFE_S	Degradation half-life of the chemical in the soil (days)
EFA	Application efficiency
WSOL	Solubility of the chemical in water (mg/L or ppm)

Table 3 Fertilizers and Selected Fertilizer Characteristics Used in the Scenarios

Fertilizer Name	FMINN	FMINP	FORGN	FORGP	FNH3N
Anhydrous Ammonia	0.82000	0.00000	0.00000	0.00000	1.00000
Urea	0.45000	0.00000	0.00000	0.00000	1.00000
Diammonium Phosphate	0.18000	0.20200	0.00000	0.00000	0.00000
HLF (lysine by-product)	0.05600	0.00000	0.01400	0.01000	1.00000

FMINN	Fraction of mineral N (NO3 and NH4) in fertilizer (kg min-N/kg fertilizer)
FMINP	Fraction of mineral P in fertilizer (kg min-P/kg fertilizer)
FORGN	Fraction of organic N in fertilizer (kg org-N/kg fertilizer)
FORGP	Fraction of organic P in fertilizer (kg org-P/kg fertilizer)
FNH3N	Fraction of mineral N in fertilizer applied as ammonia (kg NH3-N/kg min-N)

3.4 Implementing SWAT to Rathbun Lake Watershed

Because SWAT is a semi-distributed model, it can simulate discrete, small homogeneous areas within a subbasin. However, to effectively use this small-scale capability, one must know the assumptions made within the model and the limitations imposed due to the variability of each of the inputs and the resolution of the spatial databases. The amount of detail required of the model will be determined, in part, by selected project objectives. Two objectives most important for this consideration were to (1) rank the 61 subbasins in the watershed based upon their relative environmental impact, and (2) compare the relative environmental impact of various management scenarios.

Delineating Hydrologic Response Units. Hydrologic Response Units (HRUs) are the unique combinations of land use and soil that occur within an individual subbasin. The SWAT model allows the user to select how an HRU is defined (Fig. 5). One option is to select the predominant land use and predominant soil for each subbasin. This would then be a single HRU for each subbasin. The second option available to the modeler, is to select multiple HRUs. This option is accomplished by moving adjustable threshold scale bars for land use and soil that define the threshold criteria. To develop a multiple HRU option, the threshold for land use is first selected. The sliding threshold scale bar ranges from 1% to the maximum percent of any land use in any subbasin in the watershed. For example, if 10% threshold for land use is selected, this means that within each subbasin, only those land uses that have at least 10% areal coverage in the subbasin will be used to define HRUs. Land uses comprising less than 10% areal coverage within the subbasin will not be simulated. The land area where these minor land uses exist will be distributed back to the remaining land uses in relative proportion to the initial extent of these land uses within the subbasin. This last step is done so that all of the land within a subbasin will have an HRU assigned to it.

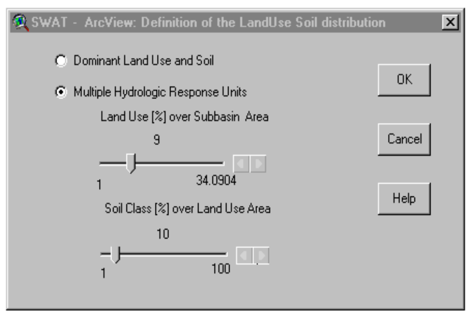


Figure 5 Selecting the Hydrologic Response Unit (HRU)

The same procedure is applied regarding the threshold selection for soils. However, when selecting the soils threshold level, the threshold applies to the areal extent of the soils within a specific land use within a subbasin. The scale bar for soils ranges from 1% to the maximum extent of any soil within any land use within any subbasin. The scale bars of the land use and soils operate independently of each other. Therefore, one can select 10% land use threshold and 20% soil threshold, for example.

The multiple HRU option was selected for this project. The threshold limits set for creating HRUs was 9% land use and 10% soils. This resulted in creating and simulating 513 HRUs within the 1427 km^2 watershed for the baseline scenario. These thresholds were selected for this project based upon the detail of the land use coverage, the detail of the soils coverage, and the project objectives. Table 4 relates how the multiple HRU land use threshold affects how the model "sees" the minor uses compared to the GIS data.

Table 4 Comparison of the GIS Land Use Coverage and SWAT-Modeled Coverage of Minor Land Uses

Land Use	GIS Base Coverage (ha)	1% SWAT Threshold (ha)	9% SWAT Threshold (ha)
Forest **(mixed, deciduous)**	13,536	13,574 (100%)	10,505 (78%)
Urban **(residential, quarries commercial, urban grass, barren rock)**	3,010	2,856 (95%)	538 (19%)
Wetland **(wooded, herbaceous)**	6,798	6,798 (100%)	1,752 (26%)
Water	5,455	5,113 (94%)	4,424 (81%)

The multiple HRU option determines the number of unique land use and soil combinations simulated, and therefore, the amount of detail to be simulated. The smallest area theoretically to be simulated can be calculated as:

Average subbasin area X percent land use threshold X percent soil threshold = smallest area theoretically simulated.

For this project, that area would be:

2,340 ha. average subbasin area X 9% HRU land use threshold X 10% HRU soil threshold = ~ 21 ha.

Management Practice Schedules. Management practice schedules are the detailed cultural and management practices applied to a specific land use in the watershed. In this study, one management practice schedule is applied to all of a given land use within the watershed. Agricultural Land, Pasture/Hay land and Switchgrass have locally developed management practice schedules applied to them. These schedules were developed with input from local farmers and government agency staff familiar with farming practices in the watershed. Other land uses (e.g. Forest, Wetlands) have model-generated default management practice schedules applied. Figures 6 and 7 illustrate how management practice schedules are inputted into the model. The management practice schedules can be scheduled either by date or by heat units. When scheduling practices by date, the model simulates that cultural practice on the date specified every year. When scheduling practices by heat units, the model simulates that cultural practice on the date when sufficient heat units have accumulated for the specified year.

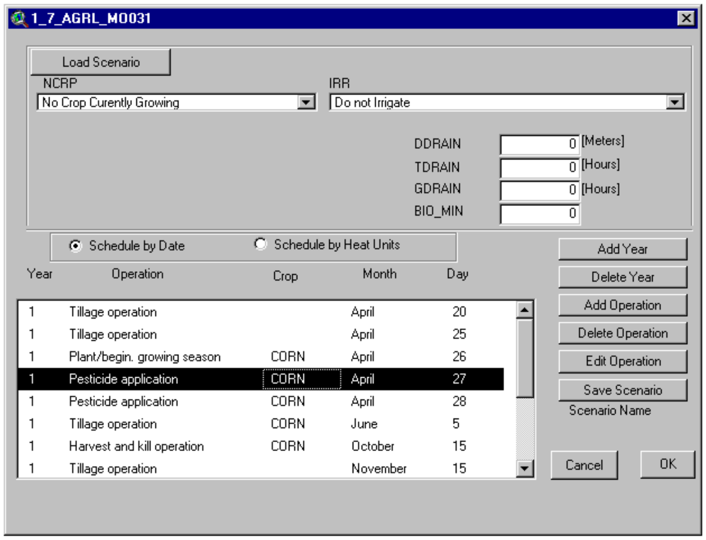


Figure 6 Management Practice Schedule First Data Entry Window

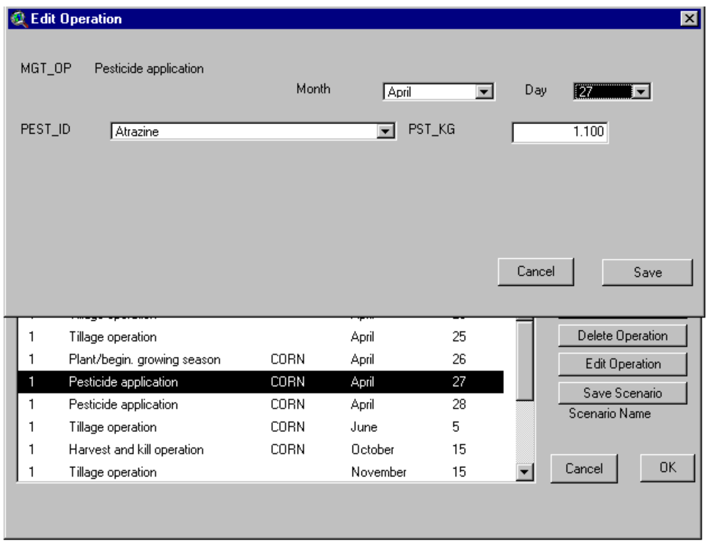


Figure 7 Management Practice Schedule Second Data Input Window

The locally developed management practice schedules for Agricultural Land, Pasture/Hay land and Switchgrass are detailed in Tables 5, 6 and 7.

Table 5 Agricultural Land Management Practice Schedule

Year	Operation	Crop	Month	Day	Description
1	Tillage		April	20	Field cultivate
1	Tillage		April	25	Field cultivate
1	Begin growing season	Corn	April	26	Plant
1	Pesticide	Corn	April	27	Atrazine @ 1.1 kg/ha
1	Pesticide	Corn	April	28	Harness @ 2.8 kg/ha
1	Tillage	Corn	June	5	Row cultivate
1	Harvest and kill	Corn	October	15	Harvest for grain
1	Tillage		November	15	Coulter chisel plow
2	Tillage		April	15	Tandem disk
2	Tillage		May	10	Field cultivate
2	Begin growing season	Soybeans	May	11	Plant
2	Pesticide	Soybeans	June	15	Roundup @ 0.56 kg/ha
2	Harvest and kill	Soybeans	October	1	Harvest for grain
2	Fertilizer		November	10	Anhydrous ammonia @ 168 kg/ha
2	Fertilizer		December	1	Diammonium phosphate @ 146 kg/ha

Table 6 Pasture/Hay Land Management Practice Schedule

Year	Operation	Crop	Heat Unit Proportion	Description
1	Fertilize		0.004	Urea @ 146 kg/ha
1	Begin growing season	Smooth brome grass	0.02	
1	Grazing operation	Smooth brome grass	0.1	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced
1	Grazing operation	Smooth brome grass	0.39	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced
1	Grazing operation	Smooth brome grass	0.75	30 days grazing, 16.8 kg/ha/day biomass dry matter consumed, 4.8 kg/ha/day dry beef manure produced

Table 7 Switchgrass for Biomass Management Practice Schedule

Year	Operation	Crop	Month	Day	Description
1	Begin growing season	Switchgrass	May	15	
1	Fertilize	Switchgrass	June	1	High lysine corn bi-product @ 1900 kg/ha
1	Pesticide	Switchgrass	June	2	Atrazine @ 1.68 kg/ha
1	Pesticide	Switchgrass	June	3	2,4-D @ 1.12 kg/ha
1	Harvest only	Switchgrass	October	25	Harvest index = 0.80

Scenarios Defined. Two SWAT projects were established, simulated and analyzed to measure the observed impacts of altering land management. One project scenario, which we will call "baseline," simulates the existing conditions of the watershed. The second project scenario, which we will call "switchgrass," simulates an alternative land use converting agricultural land to switchgrass for biomass production. The Chariton Valley RC&D staff developed the switchgrass scenario. It converts agricultural land with relatively high erosion and/or leaching potential to switchgrass for biomass production on approximately 21,700 ha. Figure 8 shows the areas of agricultural land converted to switchgrass for biomass production for the switchgrass scenario.

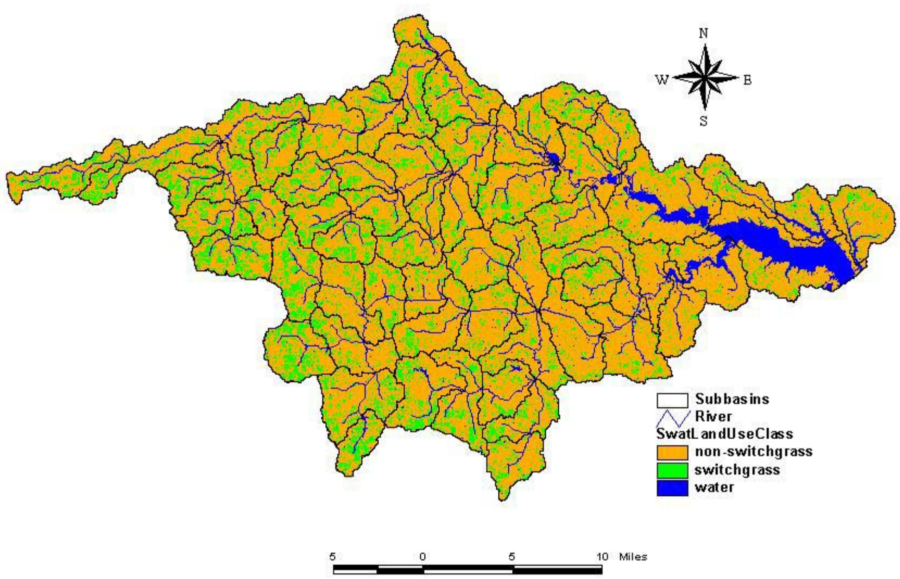


Figure 8 Areas of Agricultural Land Converted to Switchgrass for Biomass Production – Switchgrass Scenario

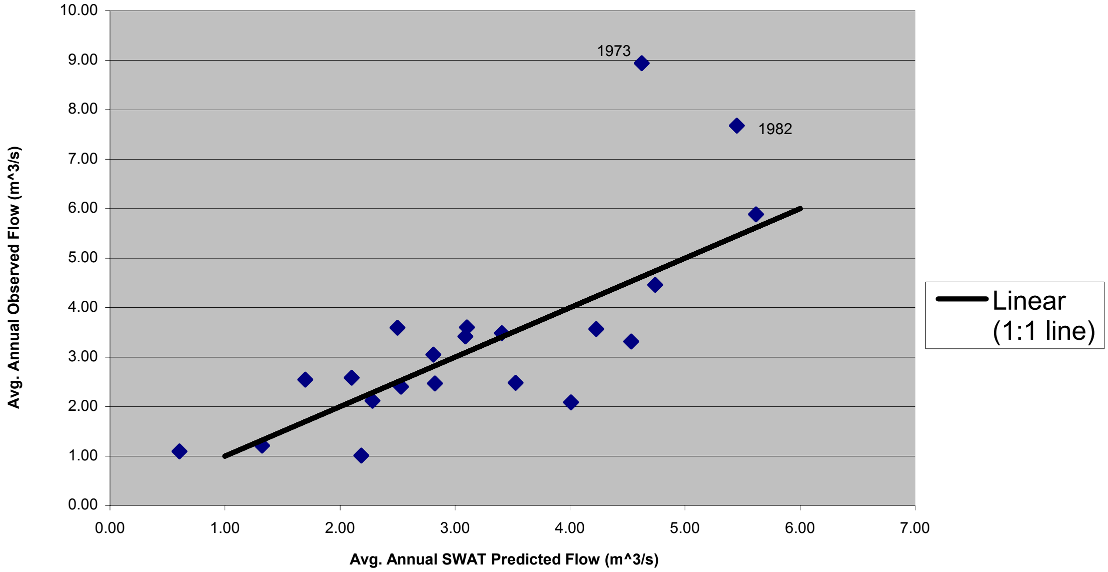
Baseline Water Yield Compared to Measured Water Yield. The SWAT model water yield prediction was compared to measured stream flow from USGS stream gage #06903400 on the Chariton River near the town of Chariton. The years of comparison were 1966-1986 (21 years of data). The basis of comparison was yearly average stream flow. SWAT was "calibrated" for this area by adjusting selected parameters that resulted in predicted water flow to acceptably approximate observed flow. According to Loague and Green, (1991, p. 58), "A model's performance is judged acceptable if it is not possible to reject the hypothesis of no difference between observed and predicted values." To evaluate the null hypothesis that there was no difference between the observed and predicted stream flow for this project, a t-test was completed using the average annual stream flows from 1966-1986. The t-statistic was calculated as follows:

$$t_{calculated} = \frac{\bar{x} - \bar{y}}{s / \sqrt{n}}$$

where $\bar{x}$ = the average of the predicted stream flow values, $\bar{y}$ = the average of the observed stream flow values, s is the standard deviation of the predicted stream flow values, and n is the number of observations (years). The t-statistic calculated is $|0.617|$. The tabular t-statistic at 0.05 probability and 20 degrees of freedom is 1.725. Based upon these t-statistic values, the null hypothesis cannot be rejected, that is, there is no difference between the observed and predicted stream flow. Figure 9 graphically displays the observed vs. predicted average annual stream flow. It is noted that the years 1973 and 1982 appear as outliers to the rest of the data. Both years exceeded long-term average precipitation by 50% and 43% respectively. No other years included in this dataset approached that extreme. However, 1973 and 1982 were included with the statistical analysis because the data appears to be correct.

Several model performance measures were calculated based upon the "calibrated" model comparing the average annual measured stream flow in cubic meters per second (m^3/s), to the predicted water yield as discussed by Loague and Green (1991). These calculated performance measures are listed in Table 8.

Figure 9 Chariton River Gage #06903400 Observed vs. SWAT Predicted Flow



With the model adjusted for water yield from the initial run, the model then simulated 1987-1999 (13 years) with no additional alterations made to the model. Performance measures were again calculated comparing the average annual measured stream flow measured as m^3/s and predicted water yield over this time span. The calculated performance measures are listed in Table 8.

Table 8 SWAT Performance Measures

Performance Measure	"Ideal Value"	Calculated Value 1966-1986	Calculated Value 1987-1999
Maximum Error (ME)	0	4.32	4.22
Root Mean Square Error (RMSE)	0	38	40
Modeling Efficiency (EF)	1	0.56	0.59
Coefficient of Determination (CD)	1	2.19	3.03
Coefficient of Residual Mass (CRM)	0	0.05	0.17

If x_i = predicted value and y_i = observed value, $\bar{y}$ = average of the y_i values, and N is the number of observations, then:

Maximum Error (ME) =

$$ME = \max\left|x_i - y_i\right|$$

Root Mean Square Error (RMSE) =

$$RMSE = \frac{100}{\bar{y}}\left[\frac{\sum_{i=1}^{N}(x_i - y_i)^2}{N}\right]^{0.5}$$

Modeling Efficiency (EF) =

$$EF = \frac{\left[\sum_{i=1}^{N}(y_i - \bar{y})^2 - \sum_{i=1}^{N}(x_i - y_i)^2\right]}{\sum_{i=1}^{N}(y_i - \bar{y})^2}$$

Coefficient of Determination (CD) =

$$CD = \frac{\sum_{i=1}^{N}(y_i - \bar{y})^2}{\sum_{i=1}^{N}(x_i - \bar{y})^2}$$

Coefficient of Residual Mass (CRM) =

$$CRM = \frac{\left[\sum_{i=1}^{N} y_i - \sum_{i=1}^{N} x_i\right]}{\sum_{i=1}^{N} y_i}$$

Simulation Setup. The management practices schedules listed above are applied to their respective land use category to all subbasins. Initial conditions included setting fraction of soil water field capacity in the basin file to 0.6 and all other adjustments made during the calibration process. The simulation period for all the output maps discussed below is 1990-1999 inclusive. This time frame was selected because the model GIS land use coverage (from 1992) most closely approximates the current watershed land use. The revised crop, pesticide, fertilizer, and weather databases discussed earlier were used. Model output is presented as average annual output for the ten-year period.

4. Results

The results of the modeling component of the project are presented as a series of tables and maps produced from the SWAT model simulated output. The SWAT model is a tool watershed planners and others can use to understand the processes occurring in the watershed and what relative changes can be expected by manipulating the model inputs. Observed differences between the baseline and switchgrass scenarios are responses to the overall impact of adding an additional landuse to the model setup. Although the HRU thresholds for landuse and soil may remain the same, the change in the landuse distribution may alter the relative percentages of the landuses and which soil types are simulated. Differences between scenarios may be due to the switchgrass being simulated, different HRUs being created, or both. Although the model may give a particular output in absolute terms, it should be understood that the output is more meaningful in relative terms by comparing one management scenario to another, for example.

Table 9 provides the subbasin ranking of six output parameters discussed for the baseline scenario. Table 10 provides the subbasin ranking of the same output parameters for the switchgrass scenario. Figure 10 identifies the subbasin numbers referred to in the following tables, results and discussion.

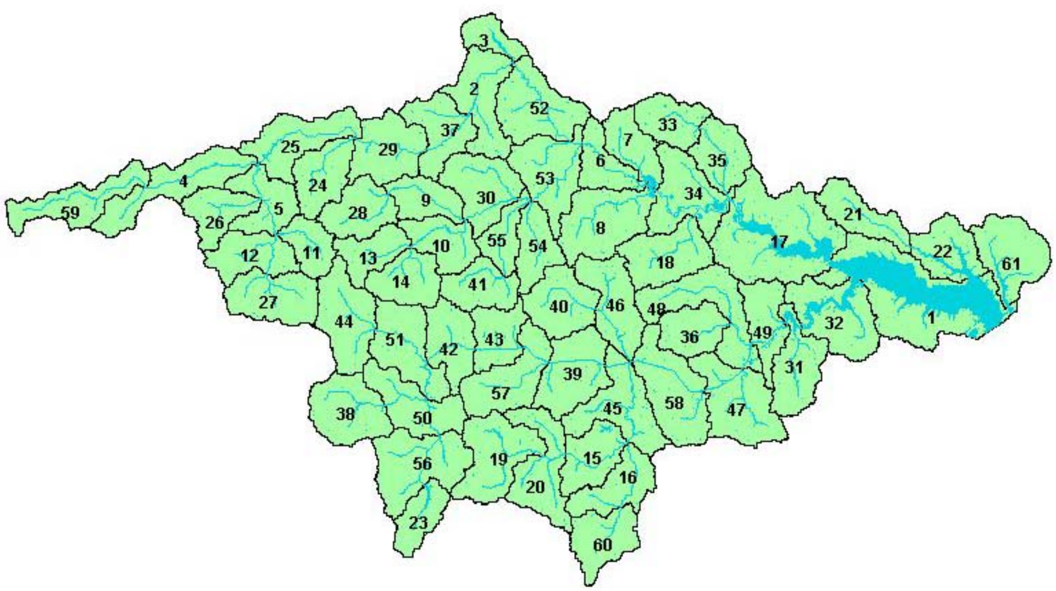


Figure 10 Subbasin Identification Numbers

Table 9 Selected SWAT-Generated Output -- Baseline Scenario

Sorted by Output Columns, Maximum to Minimum Values

SUB*	WYLD** mm/yr	SUB	SYLD[+] Mg/ha/yr	SUB	ORGN[++] kg N/ha/yr	SUB	SEDP[#] kg P/ha/yr	SUB	NSURQ[@] kg N/ha/yr	SUB	SOLP[%] kg P/ha/yr
4	250	17	0.87	9	50	9	9	23	7.8	37	0.6
59	233	38	0.68	37	40	21	8	26	7.5	2	0.6
37	225	48	0.68	24	40	37	8	38	7.5	53	0.6
2	224	53	0.61	38	39	4	8	27	6.7	30	0.6
53	222	58	0.59	4	39	38	8	49	6.5	25	0.6
25	222	4	0.58	30	36	24	8	42	6.5	52	0.6
29	222	8	0.56	21	36	59	7	53	6.4	6	0.6
49	218	52	0.53	2	34	14	7	2	6.3	29	0.6
52	218	47	0.52	35	33	41	7	20	6.3	49	0.6
32	211	18	0.52	29	33	26	7	25	6.2	4	0.5
31	206	30	0.50	41	33	2	7	43	6.1	40	0.5
27	206	56	0.49	33	33	33	7	37	6.1	46	0.5
9	206	9	0.48	59	32	30	7	31	6.0	9	0.5
17	206	29	0.47	14	32	27	7	5	6.0	35	0.5
6	205	40	0.47	52	32	23	7	56	5.9	18	0.5
30	204	25	0.45	53	31	44	6	50	5.8	31	0.5
18	203	39	0.45	25	31	25	6	60	5.7	58	0.5
46	203	46	0.44	8	31	29	6	29	5.7	15	0.5
40	201	2	0.44	18	31	28	6	4	5.6	26	0.5
24	197	32	0.43	36	30	56	6	11	5.6	8	0.5
48	196	37	0.42	26	30	52	6	30	5.5	24	0.5
26	195	51	0.42	40	30	18	6	52	5.5	33	0.5
3	193	34	0.41	7	29	35	6	40	5.4	48	0.5
22	193	24	0.41	48	29	5	6	12	5.3	34	0.5
38	192	36	0.40	13	28	40	6	46	5.3	59	0.5
33	187	45	0.39	10	28	13	6	51	5.3	27	0.5
23	187	57	0.38	28	28	12	6	47	5.3	42	0.5
8	187	31	0.38	44	28	8	6	18	5.2	17	0.5
35	187	49	0.37	5	27	53	6	32	5.2	47	0.5
58	185	50	0.37	27	27	7	6	15	5.1	7	0.5
42	184	44	0.36	56	26	36	6	6	5.1	50	0.5
34	184	35	0.36	23	25	10	5	57	5.0	43	0.4
36	181	19	0.35	12	25	48	5	9	4.9	38	0.4
21	179	1	0.34	50	25	19	5	58	4.9	36	0.4
5	178	59	0.34	16	24	50	5	35	4.8	5	0.4
7	177	42	0.33	42	24	42	5	19	4.8	12	0.4
47	177	21	0.32	34	24	51	5	48	4.8	32	0.4
15	176	20	0.31	51	24	54	5	59	4.7	23	0.4
61	175	43	0.31	54	24	16	5	17	4.7	51	0.4
43	173	16	0.31	22	24	20	5	28	4.7	21	0.4
12	173	10	0.31	46	23	11	5	8	4.6	56	0.4
51	172	41	0.27	55	23	22	5	39	4.5	16	0.4
19	166	27	0.27	17	22	55	4	34	4.5	3	0.4

Table 9 (continued)

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
41	166	22	0.27	19	21	34	4	16	4.5	41	0.4
16	165	14	0.27	43	21	46	4	33	4.4	39	0.4
1	159	33	0.26	31	21	60	4	24	4.4	20	0.4
56	156	5	0.26	11	21	43	4	36	4.4	54	0.4
10	154	7	0.24	49	21	17	4	45	4.3	19	0.4
50	152	28	0.23	20	20	57	4	21	4.2	10	0.4
39	150	26	0.21	57	20	31	4	7	4.1	55	0.4
54	147	15	0.21	39	20	39	4	14	4.1	60	0.4
55	145	54	0.21	47	19	49	4	13	3.8	11	0.3
11	142	60	0.21	60	19	45	4	22	3.6	22	0.3
20	140	12	0.20	45	18	47	4	44	3.6	45	0.3
45	132	61	0.20	58	17	3	4	41	3.5	13	0.3
14	131	13	0.19	32	17	32	3	3	3.5	57	0.3
60	127	6	0.18	6	16	6	3	1	3.4	14	0.3
57	126	23	0.18	3	15	58	3	10	2.9	28	0.3
44	123	55	0.16	61	14	15	3	54	2.8	61	0.3
28	122	11	0.12	15	14	61	2	55	2.8	1	0.3
13	117	3	0.06	1	8	1	2	61	2.5	44	0.3

* Subbasin number

** Water yield

\+ Sediment yield

++ Organic nitrogen yield attached to the sediment

\# Phosphorus yield attached to the sediment

@ Soluble nitrogen yield

% Soluble phosphorus yield

Table 10 Selected SWAT-Generated Output -- Switchgrass Scenario
Sorted by Output Columns, Maximum to Minimum Values

SUB*	WYLD** mm/yr	SUB	SYLD+ Mg/ha/yr	SUB	ORGN++ kg N/ha/yr	SUB	SEDP# kg P/ha/yr	SUB	NSURQ@ kg N/ha/yr	SUB	SOLP% kg P/ha/yr
4	223	17	0.51	9	33	9	6	49	5.1	6	0.5
32	217	4	0.41	4	26	37	5	31	5.0	49	0.5
49	217	48	0.38	37	25	4	5	53	4.6	53	0.5
59	210	47	0.37	21	23	21	5	47	4.5	30	0.5
31	209	58	0.36	24	22	24	5	6	4.3	58	0.5
29	204	53	0.33	59	21	29	4	2	4.2	37	0.5
53	201	38	0.33	29	21	59	4	37	4.2	31	0.5
37	201	32	0.32	30	21	2	4	32	4.1	2	0.4
2	200	56	0.32	53	20	5	4	58	4.0	46	0.4
17	200	8	0.31	2	20	30	4	30	4.0	52	0.4
6	196	39	0.31	35	20	14	4	20	4.0	29	0.4
46	193	40	0.30	5	20	53	4	25	3.9	47	0.4
52	192	18	0.30	14	20	38	4	26	3.9	25	0.4
25	189	57	0.29	33	19	40	4	43	3.9	17	0.4
30	185	51	0.29	40	19	35	4	46	3.9	34	0.4
47	184	46	0.29	38	18	33	4	17	3.9	35	0.4
40	183	31	0.27	7	18	18	4	29	3.8	40	0.4
22	183	29	0.27	52	18	25	4	50	3.8	8	0.4
9	182	9	0.27	36	17	26	4	52	3.7	32	0.4
3	177	30	0.27	8	17	7	4	42	3.6	33	0.4
18	177	52	0.26	26	17	41	4	60	3.5	15	0.4
58	176	19	0.25	41	17	56	4	39	3.4	39	0.4
26	173	49	0.24	18	17	52	4	34	3.4	42	0.4
33	173	2	0.24	25	17	48	4	4	3.3	50	0.4
42	172	37	0.24	48	17	36	4	33	3.3	48	0.4
24	170	45	0.24	54	16	44	4	35	3.3	9	0.3
34	170	34	0.23	42	16	8	4	5	3.3	18	0.3
5	169	59	0.23	51	16	51	3	40	3.2	4	0.3
48	169	25	0.23	56	16	42	3	15	3.2	7	0.3
35	168	42	0.22	49	16	46	3	8	3.2	43	0.3
61	167	44	0.22	46	16	54	3	51	3.1	24	0.3
8	166	36	0.21	31	15	31	3	57	3.1	26	0.3
7	164	1	0.21	44	15	27	3	45	2.9	51	0.3
43	163	20	0.21	34	15	57	3	48	2.9	36	0.3
27	163	24	0.21	22	15	19	3	18	2.9	5	0.3
21	160	50	0.20	10	15	49	3	23	2.8	16	0.3
1	159	35	0.19	39	15	23	3	1	2.8	3	0.3
19	155	43	0.19	17	15	17	3	16	2.7	20	0.3
36	155	61	0.19	57	15	28	3	56	2.7	22	0.3
51	155	21	0.18	58	14	13	3	22	2.7	61	0.3
39	153	5	0.18	27	14	10	3	7	2.7	54	0.3

Table 10 (continued)

SUB*	WYLD**	SUB	SYLD+	SUB	ORGN++	SUB	SEDP#	SUB	NSURQ@	SUB	SOLP%
	mm/yr		Mg/ha/yr		kg N/ha/yr		kg P/ha/yr		kg N/ha/yr		kg P/ha/yr
38	149	14	0.18	43	14	34	3	9	2.7	45	0.3
12	145	22	0.16	11	14	22	3	38	2.6	55	0.3
23	143	16	0.16	28	14	39	3	11	2.6	56	0.3
16	142	27	0.15	47	14	50	3	36	2.6	60	0.3
15	139	10	0.15	13	14	43	3	19	2.6	12	0.3
56	138	60	0.15	12	13	11	3	24	2.5	19	0.3
54	134	41	0.14	50	13	12	3	61	2.5	21	0.3
50	134	7	0.14	32	13	60	3	12	2.4	57	0.3
57	129	54	0.14	19	13	32	3	28	2.3	59	0.3
10	128	33	0.14	61	13	58	3	59	2.3	38	0.3
41	127	15	0.14	55	13	20	3	21	2.3	10	0.2
55	127	26	0.12	23	12	47	3	3	2.3	1	0.2
11	125	28	0.12	60	12	55	3	13	2.2	23	0.2
20	123	12	0.12	45	12	45	3	27	2.2	41	0.2
45	121	23	0.10	16	12	16	3	14	2.0	11	0.2
14	113	13	0.10	20	12	6	2	55	1.9	27	0.2
60	113	6	0.09	6	10	61	2	10	1.7	28	0.2
44	105	11	0.09	15	9	15	2	54	1.6	14	0.2
28	104	55	0.08	3	8	3	2	41	1.6	13	0.2
13	94	3	0.03	1	5	1	1	44	1.5	44	0.2

*	Subbasin number
**	Water yield
+	Sediment yield
++	Organic nitrogen yield attached to the sediment
#	Phosphorus yield attached to the sediment
@	Soluble nitrogen yield
%	Soluble phosphorus yield

4.1 Water Yield

Water yield is the amount of water that eventually flows in the stream and exits the watershed outlet. The water originates from precipitation falling on the watershed or is added to the system through irrigation and is partitioned into several pathways. The three pathways contributing to water yield are: surface runoff, lateral flow of water through the soil profile to the stream, and stream recharge from the shallow aquifer. Surface runoff is the dominant pathway contributing to water yield. Therefore, factors that increase surface runoff will increase water yield. Table 11 shows the effects soil type and landuse have on water yield. Water yield increases as percent imperviousness of land use increases (e.g. Forest WYLD < Row Crop WYLD < Urban WYLD). Water yield also tends to increase with decreasing soil water infiltration (e.g. soil hydrologic group B WYLD< soil hydrologic group C WYLD< soil hydrologic group D WYLD). Definitions for the soil hydrologic groups can be found in the SWAT User's Manual Version 99.2 (Neitsch et al., 1999, p. 98). Figures 11 and 12 illustrate the water yield from the 61 subbasins for the baseline and switchgrass scenarios, respectively.

Table 11 HRU Water Yield (WYLD) by Soil Type and Landuse Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
		--mm/yr--					
IA004	**B**	169	136	121			105
IA031	**B**			136			
IA033	**B**		134				
IA044	**B**						99
IA065	**B**	135	112	81			
KS111	**B**	178		117	169		
KS146	**B**	167	89	101	159		
KS175	**B**	211			190		
MO003	**B**					0	77
MO007	**B**	158		87			
IA040	**C**	273		216	256		
IA043	**C**				228		
IA053	**C**		178				
MO009	**C**			166	222		
MO011	**C**			187			
MO012	**C**		182				187
MO018	**C**	248	181	198			169
MO023	**D**		293	208			
MO031	**D**	238	240	203	280		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

4.2 Sediment Yield

Sediment yield is the amount of soil eroded from the subbasin and delivered to the stream reach. SWAT uses the MUSLE equation to estimate this amount of sediment produced. Sediment deposition in streams and water bodies clogs the drainage network, destroys habitat for fish and other invertebrates, and reduces storage capacity and water depth in lakes and reservoirs. Sediment in the water column causes turbidity and reduces light penetration. In addition, sediment is an important parameter for water quality because other potential pollutants are bound to the sediment. Therefore, as the quantity of sediment increases, the potential for other pollutants to be present increases. Table 12 shows the effect soil type and landuse has on sediment yield. Agricultural land (row crop) is the dominant source of upland sediment per hectare. Sediment yield tends to increase as water infiltration decreases (e.g. soil hydrologic group B SYLD< soil hydrologic group C SYLD< soil hydrologic group D SYLD). Figures 13 and 14 show the sediment yield for each of the 61 subbasins for the baseline and switchgrass scenarios, respectively.

Table 12 HRU Sediment Yield (SYLD) by Soil Type and Landuse Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
		--Mg/ha/yr--					
IA004	**B**	0.039	0.000	0.001			0.001
IA031	**B**			0.001			
IA033	**B**		0.000				
IA044	**B**						0.001
IA065	**B**	0.029	0.000	0.001			
KS111	**B**	0.095		0.003	0.000		
KS146	**B**	0.051	0.000	0.001	0.000		
KS175	**B**	0.064			0.000		
MO003	**B**					0.000	0.001
MO007	**B**	0.056		0.000			
IA040	**C**	0.153		0.012	0.000		
IA043	**C**				0.000		
IA053	**C**		0.000				
MO009	**C**			0.001	0.000		
MO011	**C**			0.000			
MO012	**C**		0.001				0.008
MO018	**C**	0.056	0.002	0.005			0.002
MO023	**D**		0.003	0.002			
MO031	**D**	0.239	0.002	0.010	0.000		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

4.3 Nutrients

Nitrogen and phosphorus are the two nutrients discussed. Both of these nutrients are present as sediment-bound (adsorbed) and as solutes in water. The nutrients dissolved in water will reach Lake Rathbun much more readily than the sediment-bound nutrients.

<u>Phosphorus.</u>

Sediment-bound Phosphorus. Table 13 shows the effect soil type and landuse has on sediment-bound (adsorbed) phosphorus yield. The adsorbed phosphorus is predominantly from agricultural (row crop) land. Of course, adsorbed phosphorus is directly related to the quantity of sediment yield. Figures 15 and 16 illustrate the quantity of phosphorus adsorbed to sediment from each subbasin for the baseline and switchgrass scenarios, respectively.

Table 13 Sediment Phosphorus Yield (SEDP) by Soil Type and Landuse Baseline Scenario

Soil	**Hyd Grp[1]**	**Landuse[2]**					
		AGRL	**FRSD**	**PAST**	**URMD**	**WATR**	**WETL**
		--kg/ha/yr--					
IA004	**B**	30.9	0.7	0.4			3.6
IA031	**B**			0.5			
IA033	**B**		0.4				
IA044	**B**						4.2
IA065	**B**	21.9	0.6	0.4			
KS111	**B**	49.6		1.8	1.4		
KS146	**B**	47.9	0.7	0.7	1.3		
KS175	**B**	36.1			1.4		
MO003	**B**					0.0	5.5
MO007	**B**	41.5		0.4			
IA040	**C**	60.6		4.0	1.4		
IA043	**C**				1.4		
IA053	**C**		1.6				
MO009	**C**			1.0	1.4		
MO011	**C**			1.1			
MO012	**C**		2.8				7.8
MO018	**C**	26.4	1.8	1.6			4.2
MO023	**D**		5.6	2.4			
MO031	**D**	47.5	4.1	4.0	1.2		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Soluble Phosphorus. Table 14 shows the effect soil type and landuse has on soluble phosphorus yield. Soluble phosphorus tends to increase as infiltration rate decreases (e.g. soil hydrologic group B SOLP < soil hydrologic group C SOLP< soil hydrologic group D SOLP). Pasture landuse had the highest soluble phosphorus yield. Figures 17 and 18 illustrate the soluble phosphorus yield from each subbasin for the baseline and switchgrass scenarios, respectively.

Table 14 Soluble Phosphorus Yield (SOLP) by Soil Type and Landuse Baseline Scenario

Soil	Hyd Grp[1]	Landuse[2]					
		AGRL	FRSD	PAST	URMD	WATR	WETL
		--kg P/ha/yr--					
IA004	B	0.122	0.063	0.451			0.258
IA031	B			0.511			
IA033	B		0.059				
IA044	B						0.189
IA065	B	0.088	0.040	0.260			
KS111	B	0.132		0.374	0.104		
KS146	B	0.120	0.047	0.368	0.091		
KS175	B	0.149			0.120		
MO003	B					0.000	0.295
MO007	B	0.114		0.333			
IA040	C	0.218		0.789	0.102		
IA043	C				0.124		
IA053	C		0.102				
MO009	C			0.620	0.115		
MO011	C			0.674			
MO012	C		0.129				0.561
MO018	C	0.176	0.113	0.763			0.387
MO023	D		0.207	0.813			
MO031	D	0.177	0.170	0.790	0.056		

[1]Soil Hydrologic Group

[2]Landuse Categories for HRUs: AGRL = Agricultural Land, FRSD = Forest, PAST = Pasture, URMD = Urban Land, WATR = Water, and WETL = Wetland

Nitrogen.

Sediment-bound Nitrogen. Adsorbed nitrogen followed the same trends as adsorbed phosphorus as related to soil type and landuse (data not shown). The source of adsorbed nitrogen is predominantly from agricultural (row crop) land and is directly related to the quantity of sediment yield. Figures 19 and 20 illustrate the adsorbed organic nitrogen yield from each subbasin.

Soluble Nitrogen. The effect of soil type and landuse on soluble nitrogen is similar to that of soluble phosphorus (data not shown). Soluble nitrogen tends to increase as infiltration rate decreases. Pasture landuse also has the highest soluble nitrogen yield. Figures 21 and 22 illustrate the soluble nitrogen yield from each subbasin.

4.4 Pesticides—Atrazine

Atrazine is routinely detected in the water of Lake Rathbun and tributaries flowing into the lake. (Kersh and Leonard, 1999) The U.S. Environmental Protection Agency (EPA) maximum contaminant level for atrazine is commonly exceeded in the late spring and summer based upon monitoring data. Figures 23 and 24 illustrate the simulated quantity, of sediment-bound atrazine being transported out of each subbasin for the baseline scenario and switchgrass scenario, respectively. Figures 25 and 26 illustrate the simulated quantity of soluble atrazine being transported out of each subbasin for the baseline and switchgrass scenario, respectively.

5. Discussion

The water yield is 19% and 17% of average annual precipitation for baseline and switchgrass scenarios, respectively. This is a reasonable value based upon simplified hydrologic cycle partitioning. The switchgrass scenario simulated less runoff compared to baseline conditions. This would be expected due to the perennial nature of the switchgrass. Established switchgrass would be expected to have more surface residue and an established root system improving soil structure to increase water infiltration. However, field experiments conducted in the study area comparing water runoff from corn ground and established switchgrass resulted in more runoff in the switchgrass land use. This discrepancy will need further investigation.

The switchgrass scenario reduced sediment yield 55% relative to the baseline condition by converting 15.3% of the watershed area to switchgrass. Figure 27 shows the change in sediment yield by subbasin. This value is the difference in Mg/ha/yr between the switchgrass scenario sediment yield and the baseline scenario sediment yield. Negative values indicate that growing switchgrass reduces the sediment yield compared to the baseline scenario. Figure 28 shows the sediment yield of the switchgrass scenario as a percentage of the baseline condition for each subbasin. Sediment yield for switchgrass was intermediate between agricultural land and pasture (data not shown). Switchgrass produced average sediment yields twice that of pasture, but a magnitude less that agricultural (row crop) land. Based upon this data, additional soil conservation practices may be needed to prevent excessive erosion from occurring on highly erosive soils when growing switchgrass.

Sediment-bound phosphorus is reduced 36% comparing the switchgrass scenario to the baseline scenario. This reduction is primarily due to the reduced sediment yield and the conversion of agricultural land to switchgrass production. This land use conversion reduces the potential loading of phosphorus because phosphorus fertilization is not part of the management practice schedule for growing switchgrass.

Soluble phosphorus yield is reduced 26% comparing the switchgrass scenario to the baseline scenario. Although this reduction could be attributed to the growing of switchgrass, greater reductions would be expected by implementing best management practices to pastureland. Pasture had the highest soluble phosphorus yield in both scenarios. Management practices encouraging a vigorous sod with adequate soil cover and uniform manure distribution will aid in reducing the amount of soluble phosphorus being lost.

Sediment-bound nitrogen is reduced 39% comparing the switchgrass scenario to the baseline scenario. This reduction in sediment-adsorbed nitrogen is due to the reduction of sediment produced by growing switchgrass rather than row crops.

Soluble nitrogen yield is reduced 38% comparing the switchgrass scenario to the baseline scenario. This reduction is attributed primarily to the reduced surface runoff when growing switchgrass compared to growing row crops. However, confounding factors include changing the timing and method of nitrogen fertilization and the fertilizer product used in the scenarios. These factors were not investigated individually to determine their potential impact. A greater reduction response is would be expected by implementing best management practices to pastureland. Pasture had the highest soluble nitrogen yield in both scenarios. Management practices encouraging a vigorous sod with adequate soil cover and uniform manure distribution and introducing legumes to replace commercial nitrogen fertilizer will aid in reducing the amount of soluble nitrogen being lost.

The model predicted a decreased quantity of sediment-bound and soluble atrazine under the switchgrass scenario relative to the baseline scenario. This is explained due to the lower sediment yield and water yield of the switchgrass scenario. Simulated sediment-bound atrazine being delivered to Rathbun Lake is reduced approximately 83% (0.09 kg/yr atrazine vs. 0.53 kg/yr atrazine). Simulated soluble atrazine delivered to Rathbun Lake is reduced approximately 86% (4.0 kg/yr atrazine vs. 29.7 kg/yr atrazine) These estimates are based upon the model-predicted sediment-bound and soluble atrazine leaving subbasins 17, 22, 32, and 61 and entering subbasin 1 (Fig. 10). These subbasins contribute stream flow directly to Rathbun Lake.

The model simulated several subbasins increasing average adsorbed atrazine yield for the switchgrass scenario. This trend is noted particularly in subbasins 3, 4, 5, and 6. The exact cause of this "abnormally" was not conclusively determined, but it is believed that it is affiliated with construct of the HRUs for these subbasins.

6. Major Findings and Conclusions

6.1 Major Findings

- The switchgrass scenario reduced sediment yield 55% relative to the baseline scenario.
- Sediment-bound phosphorus and nitrogen are reduced 36% and 39%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- Soluble phosphorus and nitrogen are reduced 26% and 38%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- Sediment-bound atrazine and soluble atrazine quantities delivered to Rathbun Lake are reduced 83% and 86%, respectively, comparing the switchgrass scenario relative to the baseline scenario.
- The predicted reductions in sediment, nutrients, and atrazine are a result of the effects of changing landuse and also in the combinations of landuse and soils (HRUs) simulated by the model.

6.2 Conclusions

1. The SWAT model ranked the 61 subbasins of Rathbun Lake watershed for sediment production, nutrient runoff, and atrazine runoff.
2. Switchgrass for biomass production can be an environmentally friendly practice. However, excessive soil erosion may still occur on some highly erosive soils. The use of atrazine as part of the management practice schedule will continue to contribute to the environmental loading of this pesticide.
3. Quantities of sediment-bound pollutants are aligned with sediment yield.
4. A geographic information system used in this study enabled the user to manipulate large quantities of data, visualize data relationships, and develop output maps to convey information to others.
5. The Soil and Water Assessment Tool (SWAT) is an appropriate tool for this study and other large watershed- or basin-scale analyses. Appropriate field-scale models used in conjunction with SWAT will improve the overall predictive capability of SWAT by providing more detailed, process-oriented input for simulation.

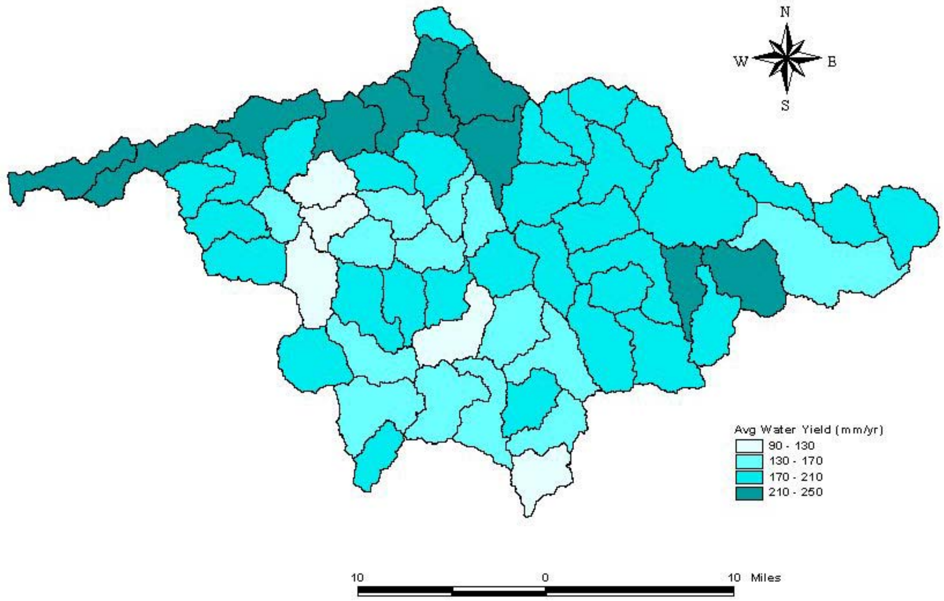


Figure 11 Average Water Yield – Baseline Scenario

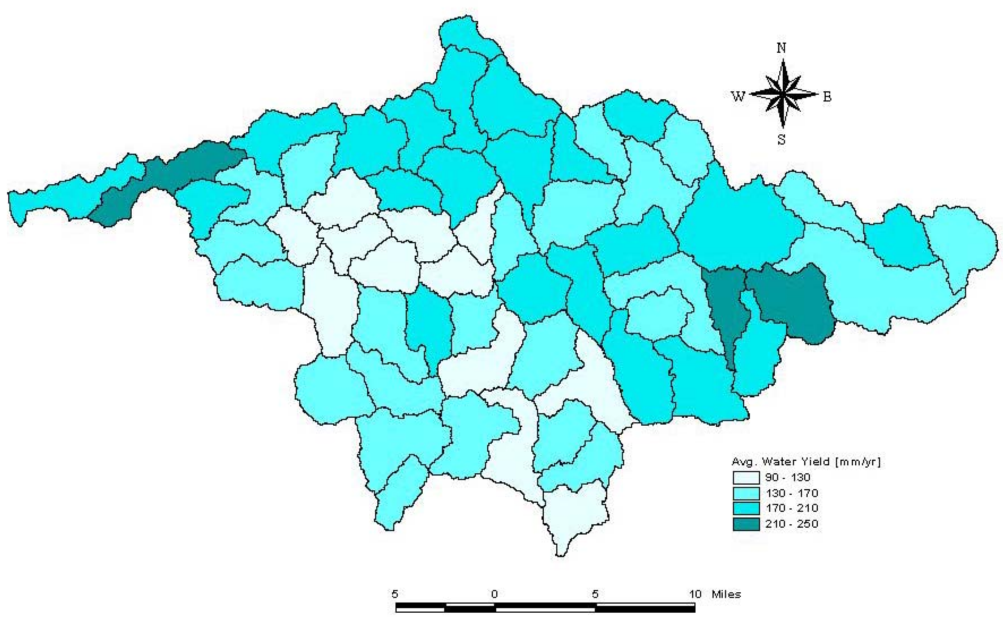


Figure 12 Average Water Yield – Switchgrass Scenario

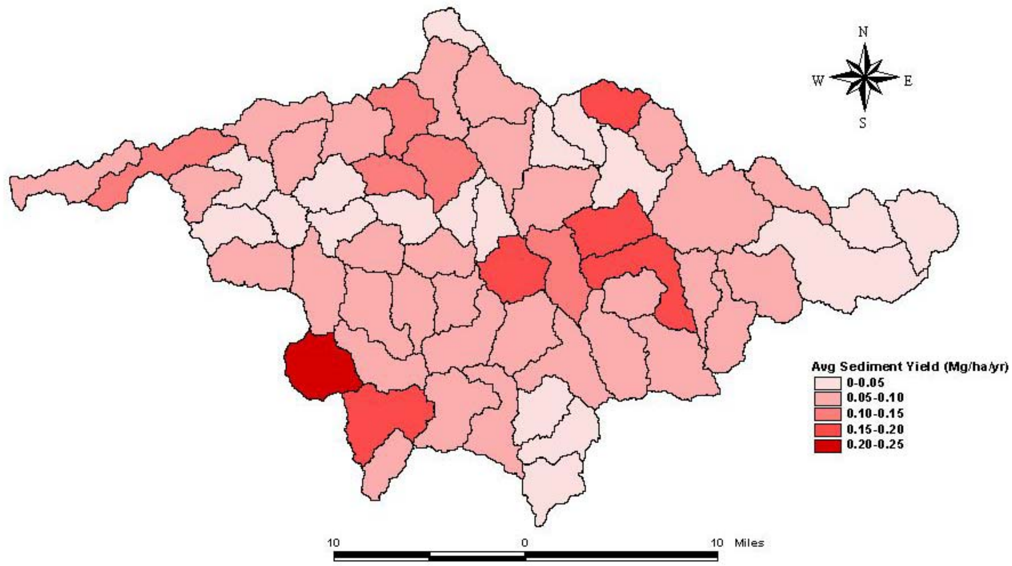


Figure 13 Average Sediment Yield – Baseline Scenario

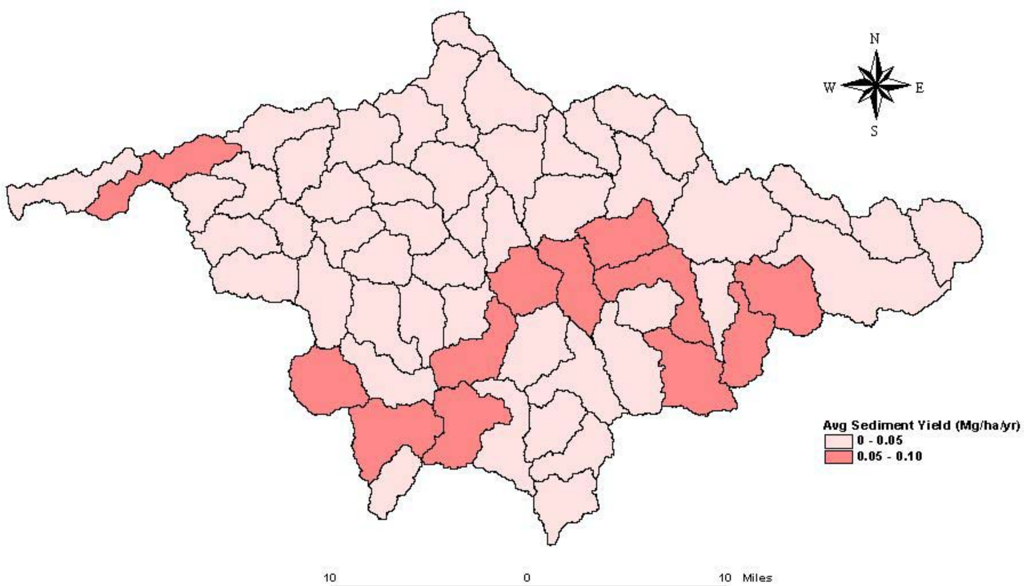


Figure 14 Average Sediment Yield – Switchgrass Scenario

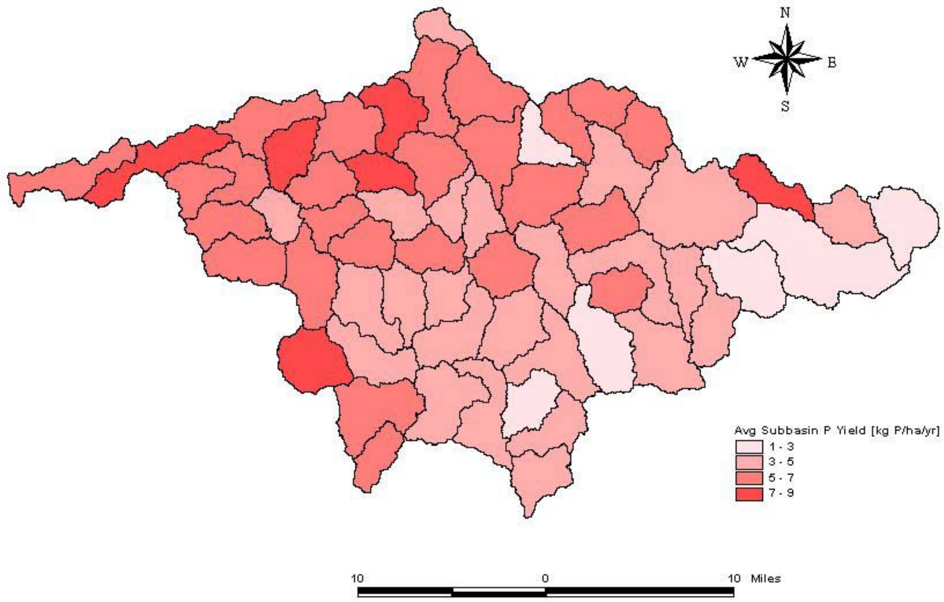


Figure 15 Average Adsorbed Phosphorus Yield – Baseline Scenario

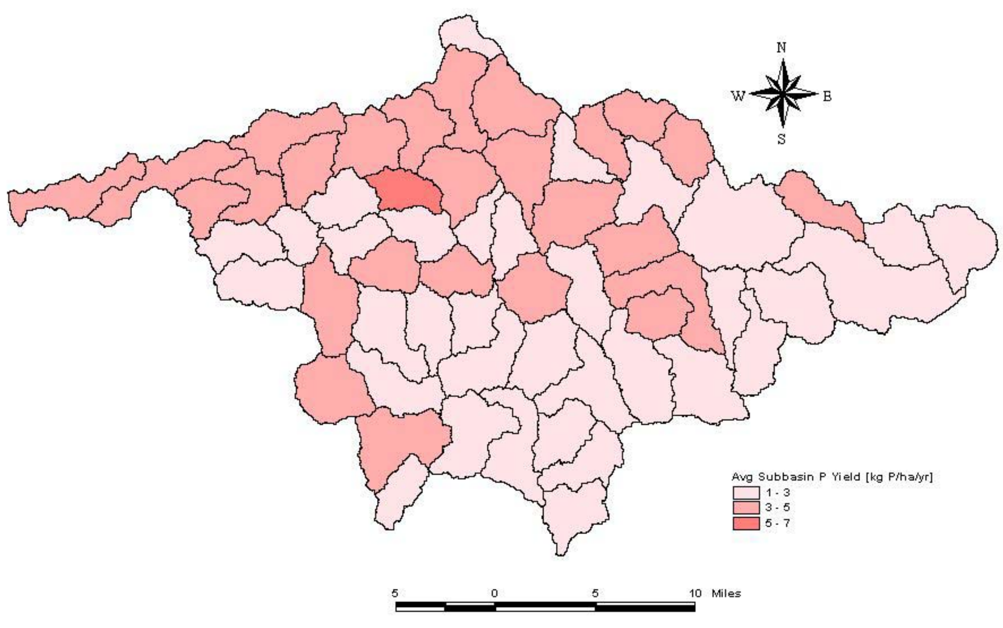


Figure 16 Average Adsorbed Phosphorus Yield – Switchgrass Scenario

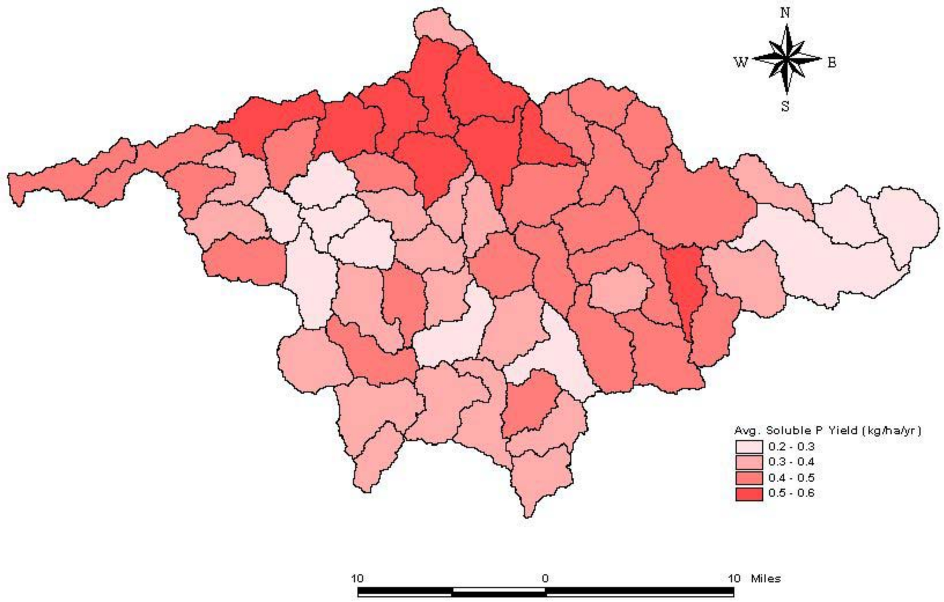


Figure 17 Average Soluble Phosphorus Yield – Baseline Scenario

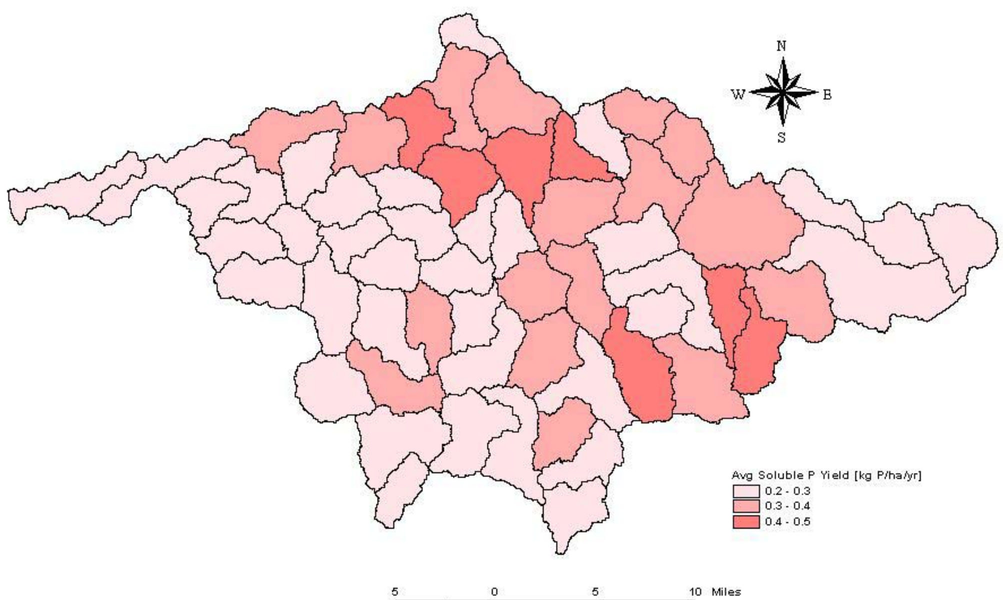


Figure 18 Average Soluble Phosphorus Yield – Switchgrass Scenario

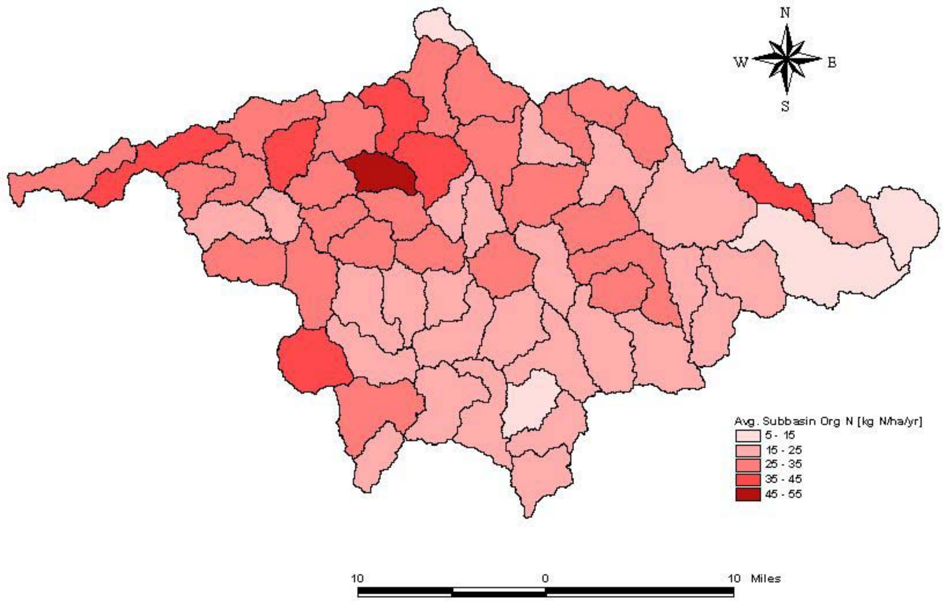


Figure 19 Average Adsorbed Nitrogen Yield – Baseline Scenario

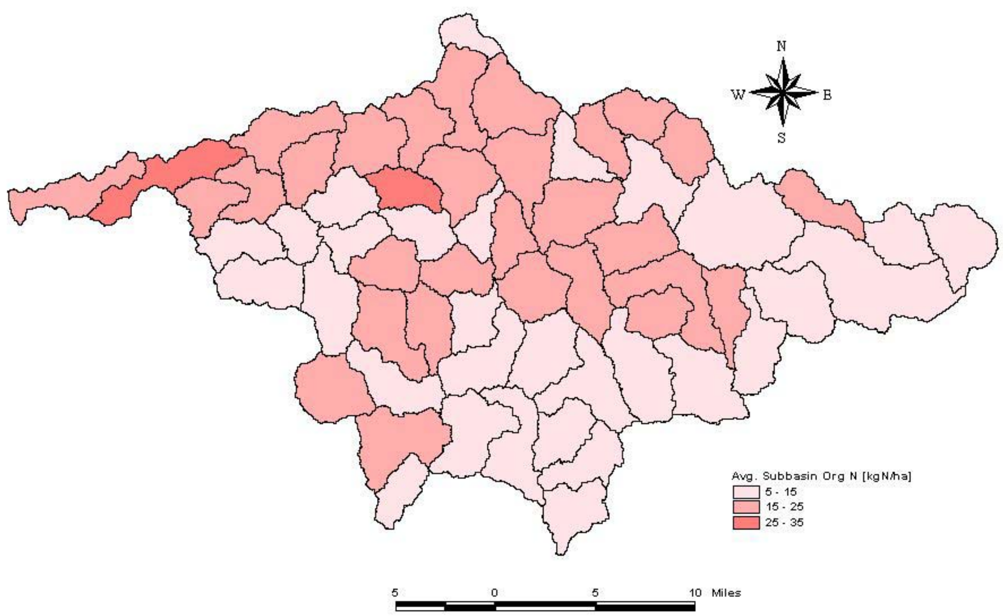


Figure 20 Average Adsorbed Nitrogen Yield – Switchgrass Scenario

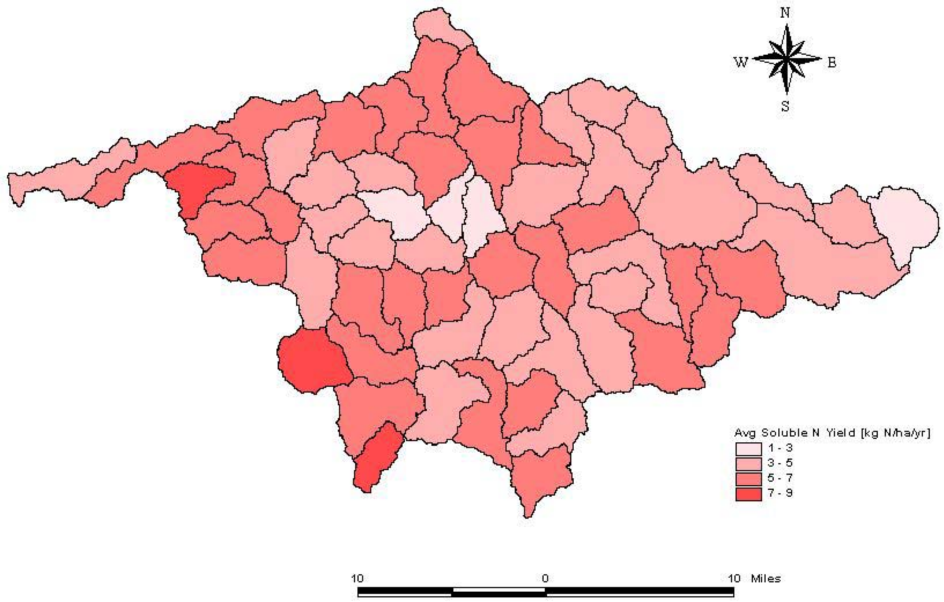


Figure 21 Average Soluble Nitrogen Yield – Baseline Scenario

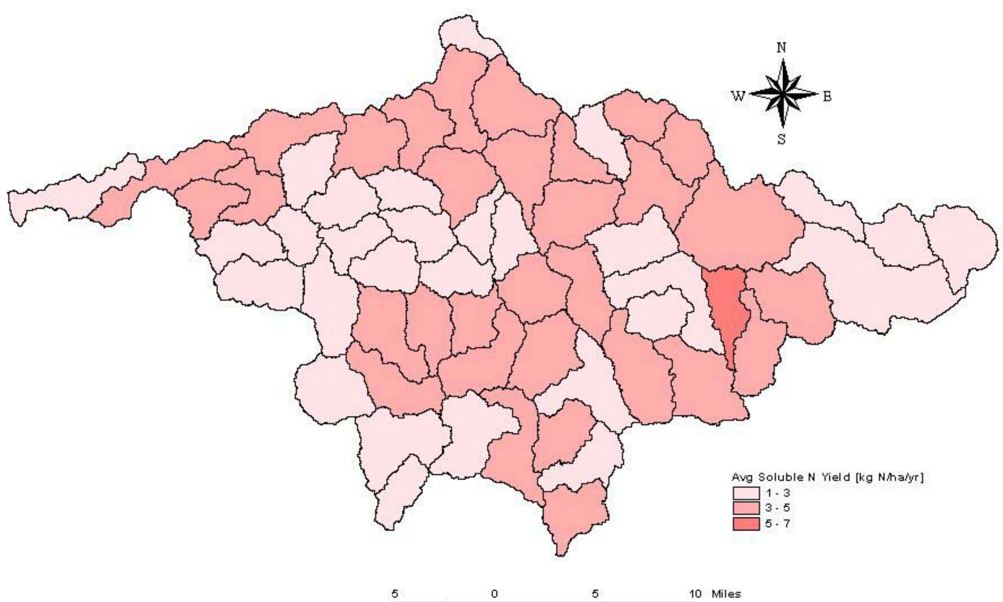


Figure 22 Average Soluble Nitrogen Yield – Switchgrass Scenario

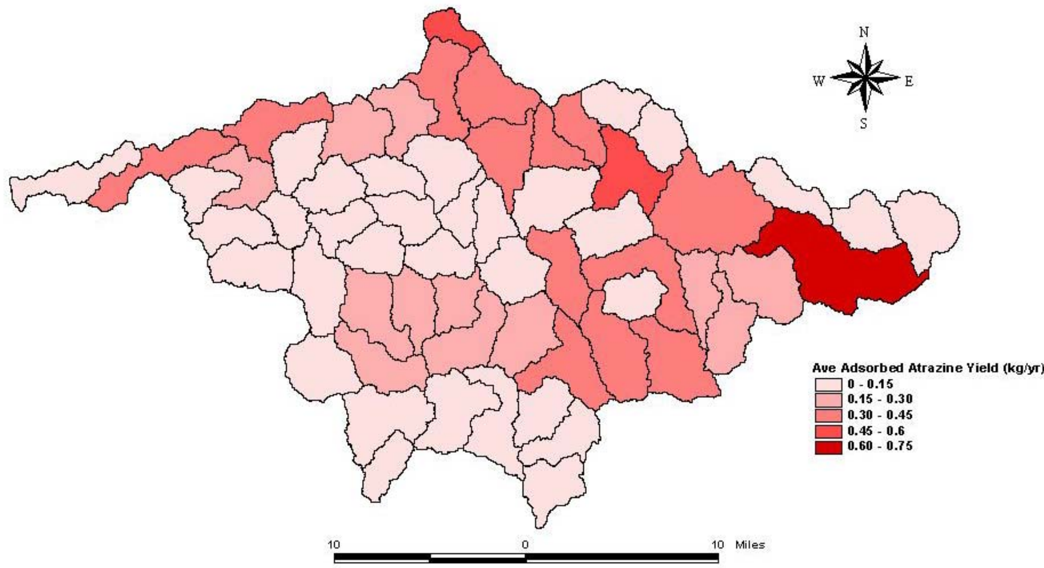


Figure 23 Average Adsorbed Atrazine Yield – Baseline Scenario

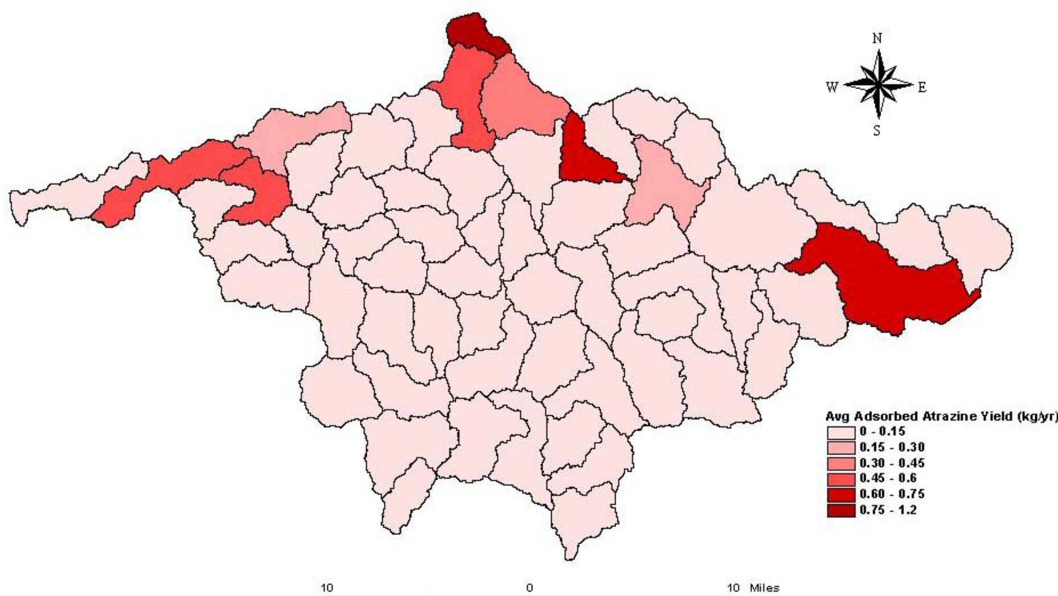


Figure 24 Average Adsorbed Atrazine Yield – Switchgrass Scenario

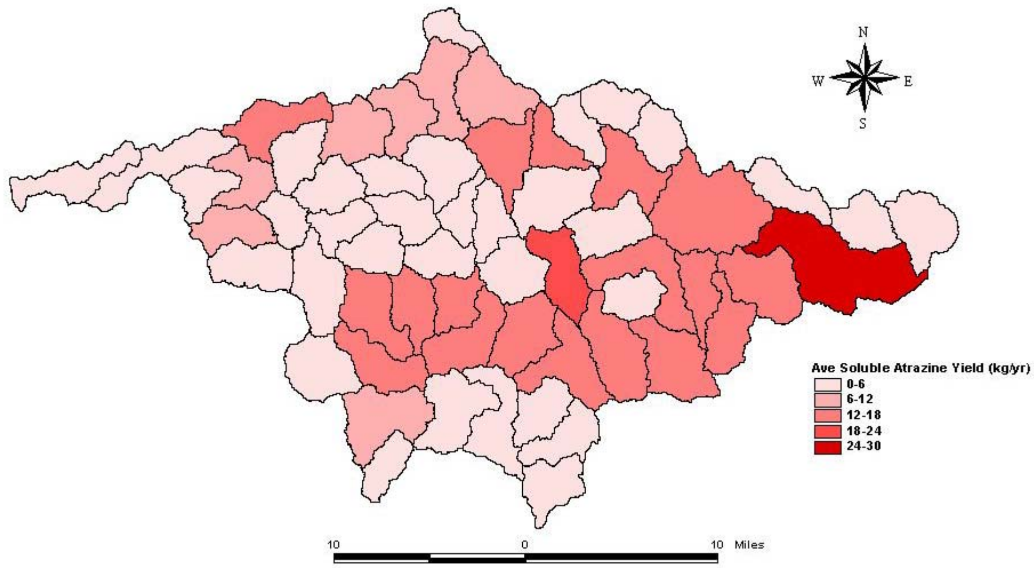


Figure 25 Average Soluble Atrazine Yield – Baseline Scenario

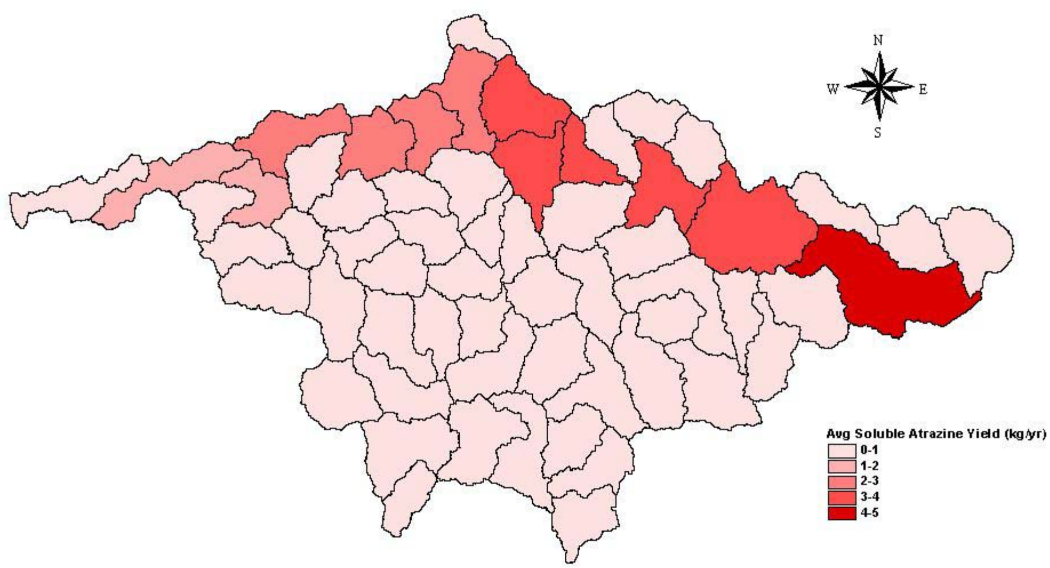


Figure 26 Average Soluble Atrazine Yield – Switchgrass Scenario

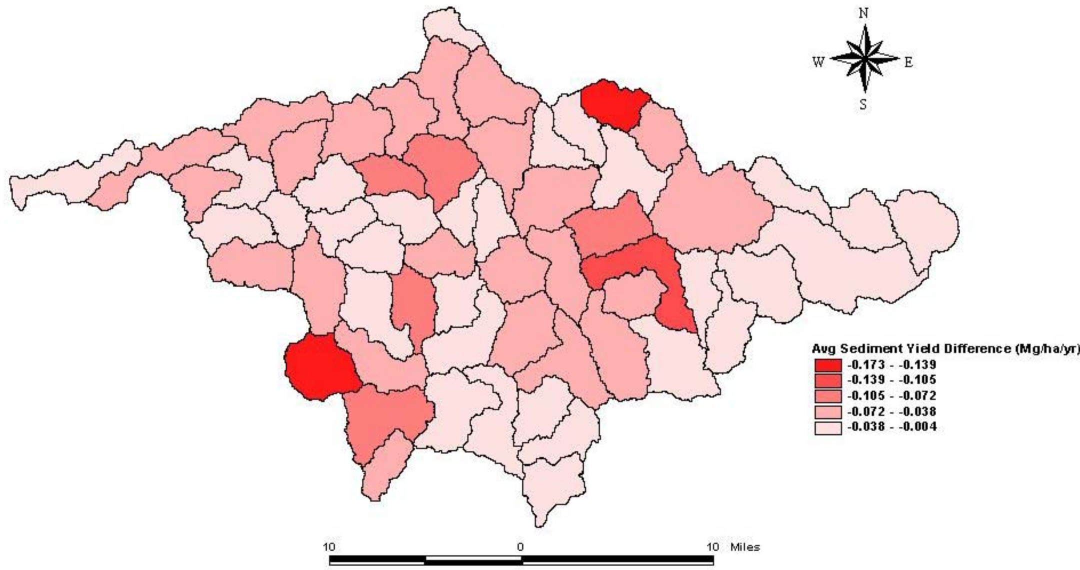


Figure 27 Change in Sediment Yield (Switchgrass Scenario – Baseline Scenario)

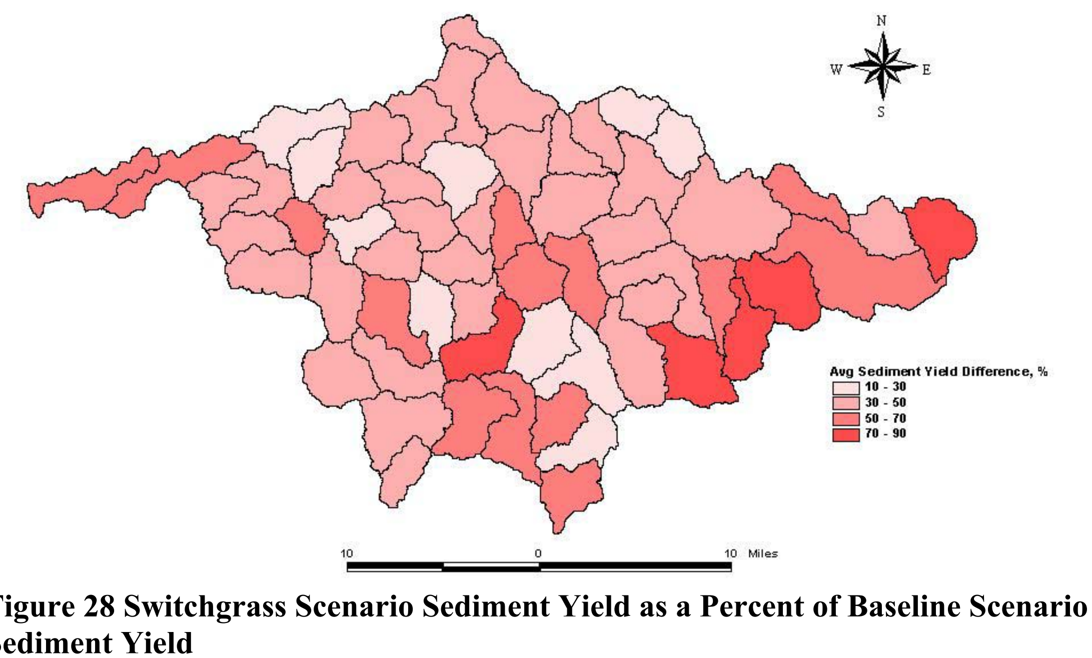


Figure 28 Switchgrass Scenario Sediment Yield as a Percent of Baseline Scenario Sediment Yield