EVALUATION OF MANAGEMENT PRACTICES AND EXAMINATION OF SPATIAL DETAIL EFFECTS USING THE SWAT MODEL

By

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CHAPTER 1 Introduction

Background

Water is perhaps the most important natural resource we have. Ironically we often don't realize this until it is impaired. Activities that occur in a watershed affect the water leaving that watershed. Unfortunately, the impact of an activity can only be observed after it has occurred. A water's quality often determines its suitability for a particular use. You may wish to choose activities that will permit a particular use. Attempting each activity and then observing it's effects is seldom feasible, expensive, and time consuming. Hydrologic models allow the impact of an activity on a watershed to be quantified in a timely and cost-effective manner. Armed with a model, different scenarios can be simulated. The relative impact of each scenario can be assessed and the economics can be evaluated. The scenarios with suitable economics and acceptable impacts are Best Management Practices (BMPs). One model to evaluate these BMPs is the Soils and Water Assessment Tool (SWAT), a distributed parameter hydrologic model. The Geographic Information Systems (GIS) interface used with the SWAT model was designed to use commonly available GIS data, and to use GIS layers of elevation, soils and land use data to generate the input files. The detail of these GIS data has an impact on the model's predictions. Therefore, the effect of spatial detail on the SWAT model needed to be examined.

SWAT was recently included in the release of the EPA hydrologic modeling suite BASINS 3.0 (Better Assessment Science Integrating Point and Nonpoint Sources). Along with BASINS, a data set of all necessary GIS data was compiled. The inclusion of SWAT in BASINS will increase the number of people using SWAT. With the release of BASINS 3.0 the technical expertise required was also reduced. These data require little or no modification by the user to be used by SWAT. The data set released with BASINS is far less detailed than that currently available from other sources, but is the most readily available data. More recent and detailed data are certainly available for any portion of the US.

More detail may not significantly improve results or may not be worth the additional effort. Increased spatial detail increases the difficulty and computation requirements. In some cases the additional effort may be very substantial. SWAT requires GIS data in a particular format, and it can be difficult to format recent GIS data for use in SWAT. In addition, some users may not be technically able to incorporate the more recent or higher resolution data. The question of which data to use becomes more important as the number of choices increase.

The first objective of this research was to evaluate and recommend BMPs for two areas, the Salt Fork and Lake Eucha Basins. The SWAT model was calibrated for these two distinctly different areas using observed data. The calibrated model was used to evaluate and recommend BMPs for each basin. The second objective was to determine the effect of data detail on the SWAT model. Using an uncalibrated SWAT model, simulations using several available data sources and resolutions were compared for each watershed. The model results were compared to observed data to determine the effect of spatial data detail. The difficully associated with importing each data set was rated. This research was intended to help the user decide what data to utilize in the model.

Overview of the SWAT Model

SWAT (Soil and Water Assessment Tool) is a distributed hydrologic model (Arnold, J.G. et al. 1998). Distributed hydrologic models allow a basin to be broken into many smaller subbasins to incorporate spatial detail. Water yield and loading are calculated for each subbasin, and then routed through a stream network to the basin outlet. SWAT goes a step further with the concept of Hydraulic Response Units (HRUs). A single subbasin can be further divided into areas with the same soils and land use. Areas inside a subbasin with the same soil and land use combination are defined as HRUs. Processes within a HRU are calculated independently, and the total yield for a subbasin is the sum of all the HRUs it contains. HRUs allow more spatial detail to be included by allowing more land use and soil classifications to be represented.

SWAT is a physically based continuous simulation model that operates on a daily time step. Long-term simulations can be performed using simulated or observed weather data. Relative impacts of different management scenarios can be quantified. Management is set as a series of individual operations (e.g. planting, tillage, harvesting, or fertilization).

SWAT is the combination of ROTO (Routing Outputs to Outlets) (Arnold et al., 1995) and SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). SWAT was created to overcome maximum area limitations of SWRRB. SWRRB can only be used on watersheds a few hundred square kilometers in area and has a limitation of 10 subbasins. SWAT can be used for much larger areas. The HUMAS (Hydrologic Unit Model for the United States), (Srinivasan et al., 1997) project used SWAT to model 350 USGS 6-digit watersheds in the 18 major river basins in the US.

Several models contributed to SWRRB and SWAT. CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980) , GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al.,1987), and EPIC (Erosion-Productivity and Impact Calculator) (Williams et al., 1984) all contributed to the development of SWRRB and SWAT.

Data sources

Several sources and resolutions of GIS data are used in this study. Soils, land cover, and topography GIS data will be modified and the resulting model will be compared with a baseline.

Soils

There is currently only one GIS coverage for soils nationwide, STATSGO (State Soil Geographic Database), which were compiled by the NRCS (Natural Resource Conservation Service). These data are most commonly used with SWAT, and are available in the BASINS database. STATSGO was created from generalizations of other soil surveys. The minimum mapping area is 625 ha. No soil group smaller than 625 ha is included. Each map unit consists of several soils. An associated MUIR (Map Unit Interpretations Record) database contains the properties and distribution of soils in each map unit.

Other more detailed soil data may be available depending on the study area. The NRCS is currently working on SSURGO (Soil Survey Geographic Database). SSURGO is far more detailed, but not available for all areas. SSURGO is a digitized version of the NRCS county-level soil survey, and is the most accurate soil data available. This study also uses a 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS, and other digitized soil surveys similar to SSURGO.

Topography

Digital Elevation Model (DEM) are used to define topography for SWAT. The US Geographic Survey (USGS) provide DEMs at a variety of scales. DEMs are available in a raster format at resolutions of 30, 60, 120, and in very limited areas at 10 meters. Thirty-meter data are the most detailed data addressed by this study. Topographic data included in BASINS have a resolution of 300 meters.

Land Cover

Land cover is more complicated to compare than soils or topography. Land cover can change over a relatively short time frame. Soils and topography take much longer to change significantly. Land cover is perhaps the most important GIS data used in SWAT. Several choices are available. The least detailed and easiest data to use with SWAT is USGS LULC (Land Use Land Cover) data. These data are available nationwide. The scale of these data is 1:250,000 and 1:100,000 for limited areas. Dates range from the late 70's to the early 80's. These data are available in the BASINS data set and are readily used by SWAT.

Several other sources of land cover data are available. The USGS and the EPA recently released NLCD (National Land Cover Database), which have a 30 meter resolution. Another recent land cover data set is from GAP (Gap Analysis Project). The GAP project maps vegetation based on 30 meter Landsat Thematic Mapper satellite imagery. The primary purpose of this information is to predict the range of native vertebrate species. However, the categorical information between these two data sets is quite different.

Study Areas

The effect of spatial resolution was examined in two separate basins. The first is the Lake Eucha basin in northeastern Oklahoma. This basin covers 93,000 ha of Delaware County, Oklahoma and Benton County, Arkansas. This basin is located in the Ozark Highlands and the Central Irregular Plains Ecoregion. The land cover is primarily pasture and forest. Forests are mostly deciduous, but pine trees are common. Pastures are used for hay and grazing cattle. Poultry litter is often applied to these pastures to increase their productivity. The topography is Karst, with exposed limestone in some areas. Soils are mainly of the ultisol order, and are typically thin and highly permeable. Average annual precipitation is approximately 45 inches.

This watershed is a primary source of drinking water for the City of Tulsa, Oklahoma. Lake Eucha is impacted by both point source and nonpoint source pollution. Lake Eucha and the basin are currently understudy to develop and implement BMPs (Best Management Practices) to reduce nutrient loading to the lake. The streams in the basin are well gaged with significant observed data available.

The second basin is dramatically different. The Great Salt Plains Reservoir is located in northwestern Oklahoma. This basin covers approximately 800,000 ha, with about 40% located in Oklahoma and the remainder in Kansas. The basin is located in the Southwestern Tablelands and the Central Great Plains Ecoregion. Land cover is mainly agricultural, rangeland, and woodland. Woodlands are typically deciduous and located only near sources of water such as streams. Native rangeland and small grains dominate the area. Wheat is the primary row crop. Topography is relatively flat, with rolling hills in the western portion. Average annual precipitation range from 23 inches in the northwest to 29 inches in the southeast.

The Great Salt Plains Lake is one of Oklahoma's most unique areas. On the shores of the lake lie 11,000 acres of salt plains, with the lake being part of the Salt Plains National Wildlife Refuge. The salt plains and lake are a seasonal home to many migratory birds. The lake averages only 4 feet deep. The lake water is about half as salty as ocean water. In recent years siltation has become an increasing problem for the lake and its tributaries. This basin is also currently understudy to develop and implement BMPs to reduce nutrients and sediment loads. This basin is gaged in only a few locations. There is very little observed nutrient or sediment data.

The contrast between these two basins makes them a good combination for this study. Both are located at a similar latitude, but have radically different precipitation, land cover, topography, and soils.

Research Objectives

There are three main objectives of this research.

- Evaluation of tillage and grazing BMPs for the Salt Fork Basin using the SWAT model.
- Simulate various poultry litter export scenarios and soil test phosphorous levels in permanent pastures in the Lake Eucha Basin using the SWAT model.
- Investigate the effect of soils, land cover, and topographic spatial detail on SWAT model predictions.

Salt Fork Basin

The SWAT model was calibrated using observed flow data. Several BMPs were simulated and evaluated based on predicted sediment and nutrient loads.

Lake Eucha Basin

SWAT was used to simulated the effect of poultry litter application/litter export and soil test phosphorous levels to permanent pastures on nutrient loads to Lake Eucha. Long-term simulations were performed to determine the effect of poultry litter application on soil test phosphorous levels. Simulations using different periods in the observed rainfall record were used to quantify uncertainty due to weather. The SWAT model was calibrated using observed flow and nutrient data.

The Effect of Spatial Detail

The ultimate level of spatial detail used by the model is a function of the input data and several parameters that determine how input data are divided into subbasins and HRUs. It is not within the scope of this research to fully explore the subdivision and aggregation of input data by the model. Other research has been conducted by Mamillapalli (1998), Binger et al. (1997), Norris and Haan (1993), and Jasso-Ibarra (1998) in this area.

The impact of available input data type and resolution on the SWAT model was assessed. Land cover, soils, and topography were examined separately. Several output parameters from each simulation were compared, and evaluated independently. Specifically my research addresses the following hypotheses:

1) Soil data source has a significant effect on SWAT predictions.

H_0 SWAT simulations using SSURGO (or high resolution equivalent) soils are significantly different as compared to simulations using STATSGO soils.

H_1 Choice of soil data source has no significant effect on SWAT predictions. STATSGO data are adequate.

2) DEM resolution has a significant effect on SWAT predictions.

H_0 SWAT simulations at DEM resolutions of 30, 60, 120, and 300 meters are significantly different.

H_1 SWAT simulations at various DEM resolutions are not significantly different.

3) Land cover data source has no significant effect on SWAT predictions.

H_0 SWAT simulations using LULC, GAP, and NLCD are significantly different.

H_1 Choice of land cover source is not important. LULC land cover data are adequate.

Literature Review

Several studies have been published relating spatial detail to SWAT model accuracy (Mamillapalli 1998; Binger et al., 1997; and Jasso-Ibarra, 1998). These studies deal with the issue of subdivision rather than detail or resolution of the input data. These issues are, however, closely related. Both affect the ultimate level of detail used by the SWAT model.

Mamillapalli (1998) determined that increasing the number of subbasins or HRUs improved the model accuracy for annual flow. He also found that model accuracy did not significantly improve after a certain level of representation, and concluded that soil and land cover detail were more important that topography in determining stream flow. Mamillapalli (1998) admits a limitation of this study was that sediment and nutrients were not considered. For parameters other than stream flow, topographic effects may be more important.

Binger et al. (1997) explored subdivision and its effect on simulated runoff and fine sediment yield using SWAT on the 21.3 km^2 Goodwin Creek Watershed. They suggested using a stream network similar to those defined by USGS 7.5-min topographic maps as a minimum. More complex stream networks, i.e. more subbasins, increased the accuracy of sediment yield predictions. They concluded that between 168 and 277 subbasins were needed to adequately represent the watershed corresponding subbasin areas were 0.1278 and 0.077 km^2, respectively. A far less complex stream network was required to adequately simulate water yield. Stream flow was acceptable even at 14 subbasins (average area of 1.5 km^2), the lowest level of subdivision attempted. The researchers also concluded that the determination of overland slopes is more accurate at higher levels of subdivision. Higher overland slope increases sediment yield from upland areas. They also suggested that total area of each land cover is more accurately represented at higher levels of subdivision. This study did not include HRUs.

Jasso-Ibarra (1998) studied steam flow accuracy at various subbasin sized using SWAT. They found no significant increase in stream flow accuracy at subbasin areas smaller than 1.2 km^2. This study was performed on a portion of the Walnut Gulch Experimental Watershed in southwest Arizona, and did not include HRUs, or sediment.

Casey (1999) examined the effect of subdivision on the NRCS TR-20 model. Casey concluded that the required level of subdivision was dependant on the variability of the watershed, and concluded that a higher level of subdivision tends to increase peak flow. Norris and Haan (1993) studied the effect of subdivision on stream flow hydrographs. They noted increase peak flows at higher levels of subdivision. They also concluded that different scenarios (land cover and retention structures) should be compared using the same number of subbasins. SWAT estimates daily flow not peak flow, but these studied are applicable when considering large basins where storm runoff may span several days.

These studies attempt to define a maximum area for each discrete portion of a basin. Casey (1999) made the decision whether to subdivide to a particular level based on the similarity between potential subdivisions. SWAT creates subbasins strictly based on topography. Jasso-Ibarra (1998) and Binger et al. (1997) generally agree on the average size of subbasins required to adequately simulate stream flow to be in the range of 1 km^2. These findings provide some insight into how resolution could affect water yield. However, neither of these studies used HRUs. Each subbasin is assigned the dominant soil and land cover, which is similar to decreasing the resolution of the soil and land cover data to an average cell size of 1 km^2. This is not to say that an average cell size of 1 km^2 is the same as 1 km^2 resolution; only that very low resolution soils and land cover data may have been sufficient in this case. Topographic data must be considered separably because they are not handled in the same manner.

Compared to water yield, accurate sediment predictions require far more spatial detail (Binger et al. 1997). Any conclusions applied to the current study must consider HRUs, which were not used by Binger et al. (1997). The addition of HRUs could modify this finding by ensuring a more detailed land cover representation. However, the slopes are derived at the subbasin level, and are unaffected by the addition of HRUs. Overland slope is a very important parameter affecting sediment yield.

Total basin area may also be important. Jasso-Ibarra (1998) and Binger et al. (1997) both used relatively small watersheds, and thus their conclusions may not apply to large basins. Large or highly uniform watersheds may not require as much subdivision or detail.

Methods

Before any spatial detail investigations were conducted, extensive modeling was performed on each basin. The calibration and BMP development procedures differ between the basins due to the characteristics of the basins and the existing cultural activities.

BMP Evaluations

Salt Fork Basin

The Salt Fork basin was calibrated using observed flow data. Insufficient nutrient data existed for calibration purposes. The effects of tillage and grazing potential BMPs were quantified. BMPs were selected to reduce sediment and nutrient loading to the Great Salt Plains Reservoir.

Lake Eucha Basin

The Eucha basin was calibrated using observed flow and nutrient data. A model sensitivity analysis was performed. The effect of soil test phosphorous and poultry litter export were examined. Uncertainty associated with rainfall was quantified by performing multiple simulations using different periods of observed rainfall data. Long term simulations were used to predict the effect of continued litter applications on soil test phosphorous levels.

Spatial Detail Effects

Spatial detail effects for each basin were tested separately. A model run was performed for each combination of GIS data. The impact of resolution changes was evaluated for soils, land cover, and topography separately. The following parameters were evaluated on an average annual basis:

- Water yield
- Surface runoff
- Baseflow
- Sediment yield
- Soluble phosphorous yield

- Sediment-bound phosphorous
- Nitrate

The model was not calibrated to make these comparisons. Calibration would, by definition, make all simulations match the observed data, regardless of what data were used in the model. All comparisons were made on a relative basis.

For each basin, the number of subbasins and HRUs remained nearly constant. The level of subdivision was selected based more on practicality and basin area than on the recommendations of previous research (Binger et al., 1997). Subbasin areas less than about 500 ha are not practical for basins as large as the ones selected for this study. The computational requirements would be too great.

CHAPTER 2 Lake Eucha Basin Management Practices

Introduction

Lake Eucha water quality is being degraded from excess algal growth. This excess growth is the result of an overabundance of nutrients in the lake, assumed to be primarily phosphorous. Phosphorus in the lake comes from two sources, internal and external. The sediments in the lake itself release phosphorus to the water column, i.e. internal loading. Phosphorous coming into the lake from the watershed is external loading. External loading originates from either point sources, such as the City of Decatur municipal waste water treatment plant, or from nonpoint sources like pastures. The majority of the phosphorous loading has been attributed to nonpoint sources (Wagner and Woodruff, 1997; White et al., 2001). Pastures in the Lake Eucha basin have received phosphorus from poultry litter applications for many years. Poultry litter is often applied to meet the crop's nitrogen requirements. When phosphorous in excess of what the crop can use is applied, phosphorous builds up in the soil. Runoff extracts soluble phosphorus from the soil and litter, and carries sediments containing phosphorous to the lake.

The SWAT (Soil and Water Assessment Tool) model was used to predict how external loads are affected by management changes. A range of soil test phosphorous levels and litter export scenarios were simulated. Additional simulations project how soil test phosphorus levels may change over the next 30 years with continued application of poultry litter.

SWAT Input Data

GIS data for topography, soils, land cover, and streams were used in the SWAT model. The data used were the most current at the time of compilation. Observed daily rainfall and temperature data were used in all modeling.

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be stochastically simulated.

Topography

Topography was defined by a Digital Elevation Model (DEM). DEMs for the United States are available for downloading via the Internet. The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Individual 1:24,000 thirty meter DEMs were stitched together to construct a DEM for the entire basin. When tiled, 1:24,000 DEMs often have missing data at the seams. These missing data must be replaced. A 3x3 convolution filter was applied to the DEM to produce a seamless filtered DEM. Any missing data at the seams of the original DEM were replaced with data from the filtered DEM. The resulting seamless DEM retains as much non-filtered data as possible (Figure 2.1). Filtering tends to remove both peaks and valleys from a DEM thereby reducing the perceived slope. For this reason the use of filtered data were kept to a minimum.

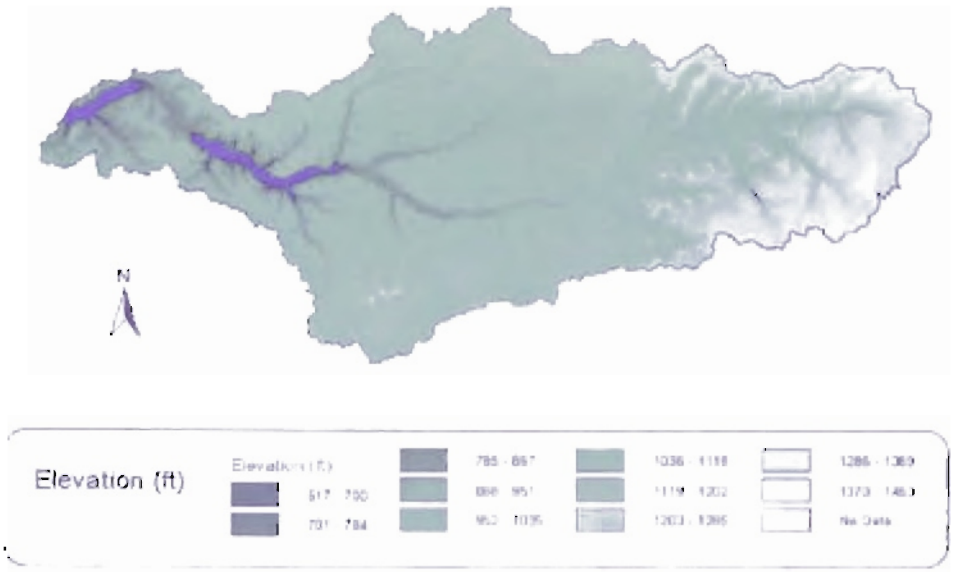


Figure 2.1 Seamless Digital Elevation Model (DEM) of the Eucha/Spavinaw Basin constructed from U.S. Geographic Survey 1:24,000 DEMs.

Soils

Soil GIS data are required by SWAT to define soil types. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes for any given soil. The GIS data must contain the S5ID (Soils5id number for USDA soil series), or STMUID (State STATSGO polygon number) to link an area to the STATSGO database.

The soils layer was derived from two separate GIS coverages. The Oklahoma portion is 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS. The Arkansas portion is a 1:20,000 order II soil survey digitized by the University of Arkansas. Basic properties of soils used by SWAT are listed in Appendix A.

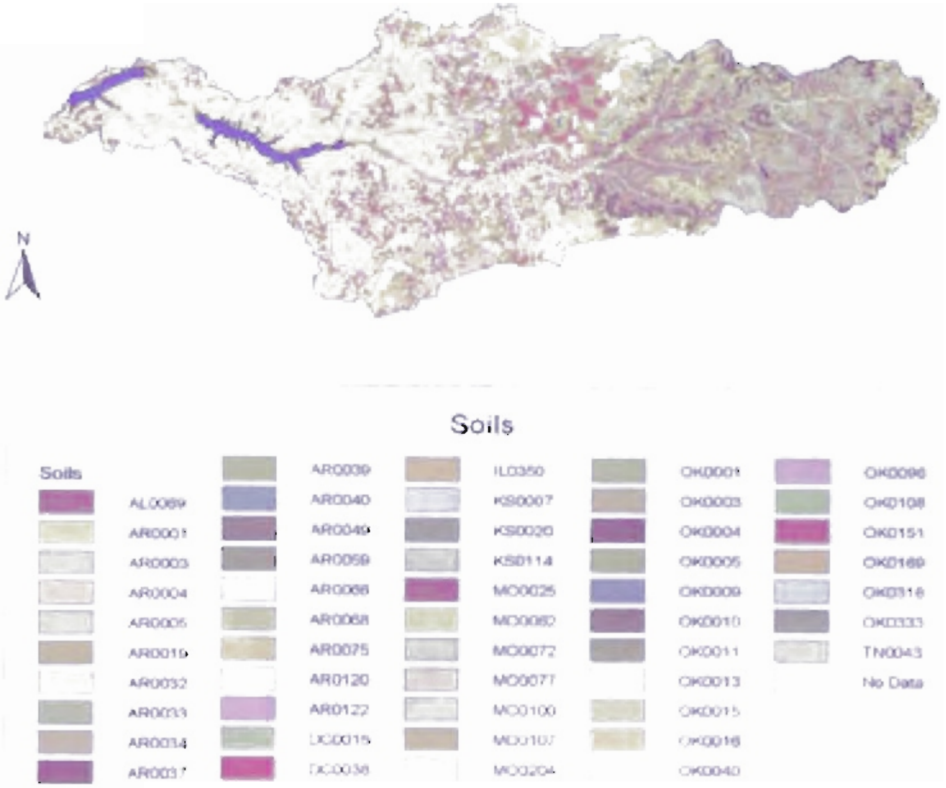


Figure 2.2 Soils of the Eucha/Spavinaw basin by 5 digit identification

Land Cover

Land cover is perhaps the most important GIS data used in the model. The land cover theme affects the amount and distribution of pastures and forest in the basin. These two land covers are radically different. Forested areas contribute little to the nutrient loading, while pastures are thought to be the primary source of the nutrient loading. It is important that these data be based on the most current data available, since land cover changes over time. Topography and soils cannot be changed so easily or rapidly by man.

Land cover was derived from Oklahoma and Arkansas GAP (Gap Analysis Program) data. The GAP project mapped vegetation based on 30 meter Landsat Thematic Mapper satellite imagery. The primary purpose of this information was to predict the range of native vertebrate species. GAP land cover defines many native vegetation categories, but very few agricultural categories. I simplified GAP categories to pasture, forest, urban, and water. The basin is composed of 43.2% pasture, 55.0% forest, 1.7% water, and 0.1% urban. These data were then combined to produce a seamless coverage of the entire area (Figure 2.3).

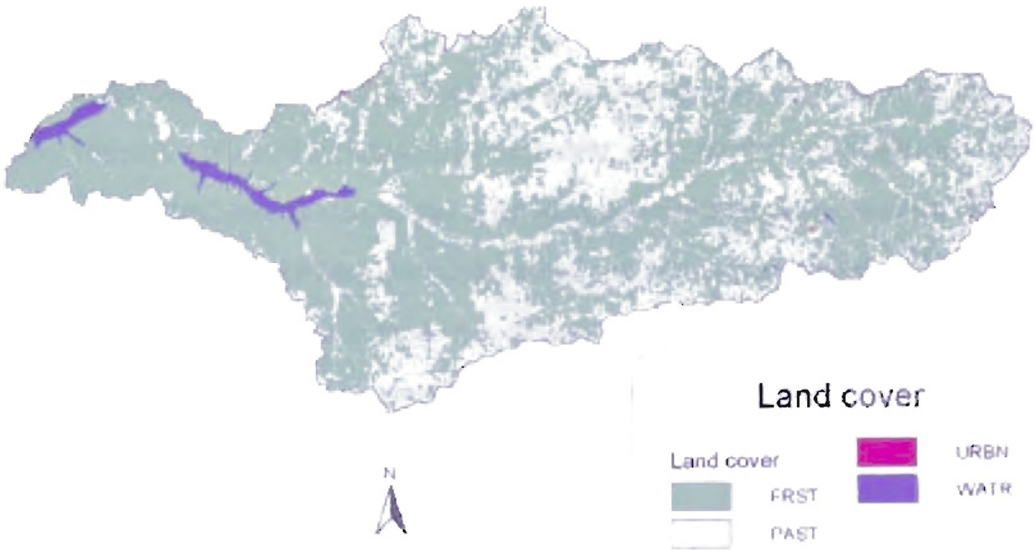


Figure 2.3 1:100,000 Gap Analysis Project derived land cover for the Eucha/Spavinaw basin

Weather

SWAT can use observed weather data or simulate it using a database of weather statistics from stations across the US. Observed daily precipitation and minimum and maximum temperature were used in the Eucha/Spavinaw model. National Weather Service COOP (Cooperative Observing Network) station data from 27 stations from 1/1/1950 to 4/30/00 were used to in the SWAT model (Figure 2.4). The location of each station is listed in Appendix A. COOP data are available from the NOAA (National Oceanic and Atmospheric Administration).

COOP data are seldom continuous for long periods of time. Missing days and even months are common. The period of record at stations are inconsistent, so the number of active stations changes with time. When SWAT detects missing data at a station, it generates simulated weather. Therefore, gaps in a station's record were filled using interpolated data from surrounding stations. Shepherd's weighted interpolation was used, because it is computationally efficient. Shepherd's method uses weighting factors derived from the distance to nearby stations within a fixed radius:

$$Z_0 = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i}$$

where Z_0 is the precipitation at the station of interest in mm, Z_i is the precipitation at station i in mm, and W_i is the weighting factor at station i. Weighting factors are calculated using the distance between stations:

$$W_i = (1 - \frac{d_i}{R})^2 \text{ for } \frac{d_i}{R} < 1 \text{ And } W_i = 0 \text{ for } \frac{d_i}{R} \geq 1$$

where R is the radius of influence in meters, and d_i is the distance from station of interest to station i in meters.

Because of the large amount of data associated with these weather files, all processing and formatting was done using custom programs written in VBA (Visual Basic for Applications) and Microsoft Excel. SWAT assigns each subbasin to the closest gage station to the subbasin centroid, so many of the original 27 stations were not used by SWAT. The purpose of these extra stations was to fill gaps in records for the stations that were used by SWAT.

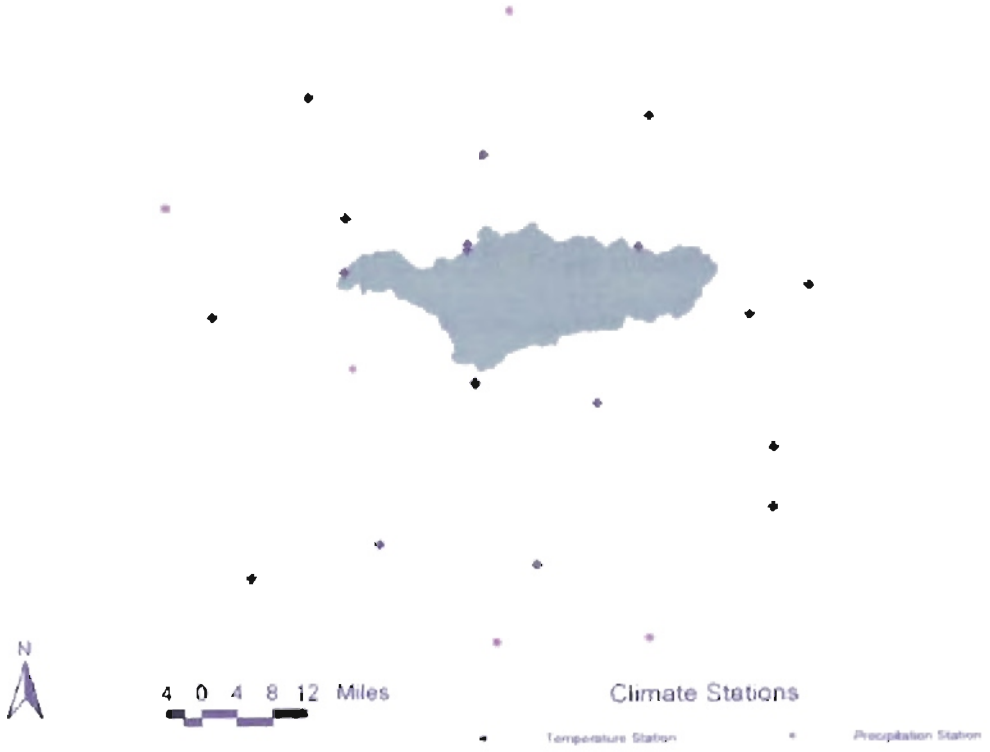


Figure 2.4 National Weather Service Cooperative Observation network precipitation and temperature station locations near the Eucha/Spavinaw Basin.

Subbasin Delineation

The subbasin layout was defined by SWAT using the DEM, a stream burn in theme, and a table of additional outlets. The stream burn in theme consists of digitized streams. Its purpose is to help SWAT define stream locations correctly in flat topography. A modified reach3 file from the Environmental Protections Agency's BASINS (Better Assessment Science Integrating Point and Non-point Sources) model was used. The theme was modified to remove the outline of both lakes, which the model confused with a stream path. Model predictions are only available at subbasin outlets, so additional outlets were added at points of interest such as gage stations, water quality stations, or lake boundaries (Appendix A). A stream threshold value of 1000 ha was used to delineate subbasins. Threshold area is the minimum contributing upland area required to define a single stream. The result is 58 subbasins (Figure 2.5). Fewer subbasins would simplify the modeling process, but this level of detail was needed to adequately represent the basin. Selected properties of each subbasin are given in Appendix A.

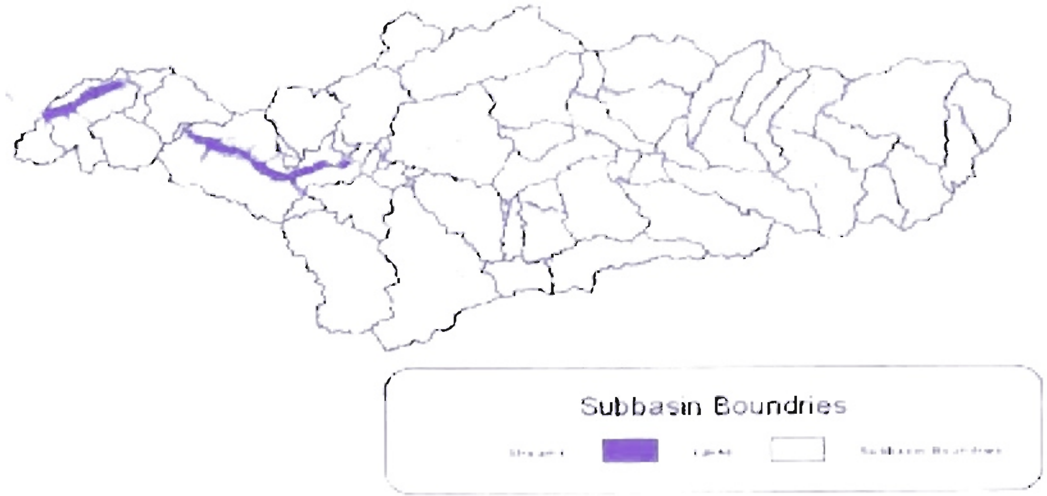


Figure 2.5 The Eucha/Spavinaw basin subdivided into 58 subbasins. This configuration was used in all SWAT model predictions.

HRU Distribution

Each of the 58 subbasins was split into HRUs (Hydraulic Response Units) by SWAT. The *land use [%] over subbasin area threshold* was changed from the default 20% to 10%. This threshold determines the minimum percentage of any land cover in a subbasin that will become an HRU. The *soil class [%] over subbasin area* was also reduced from its default value of 20% to 10%. By reducing these thresholds, the number of HRUs was increased to 351, allowing more spatial detail to be incorporated into the SWAT model.

Ponds

Ponds affect the hydrology by impounding water and trapping nutrients. Water in ponds is subject to evaporation and seepage into the shallow aquifer. Nutrients and sediment settle out and are trapped. Test runs using the SWAT model indicate ponds significantly reduced nutrient and sediment concentrations.

Because of the difficulty associated with counting ponds in each subbasin, ponds were assumed uniformly distributed in agricultural portions of the basin. Heavily forested areas were assumed to have no ponds (Figure 2.6). All ponds in a single Beaty Creek subbasin were counted and summarized. These estimates were applied to all subbasins considered to have ponds. Other subbasins with similar land cover appeared visually similar, indicating that ponds are somewhat uniformly distributed throughout pasture areas of the basin. These ponds were defined from 1:24,000 USGS DRG (Digital Raster Graphic). This level of detail was required to define the majority of ponds. The 1:100,000 GAP land cover displayed far fewer ponds than visual inspection of the same area.

Of the total area in each subbasin, 20% was routed through ponds. Total surface area of all ponds in a subbasin was estimated as 0.32% of the total area of that subbasin. Each pond was assumed to have an average depth of 1.5 meters. The ArcView interface was not used to create pond (.pnd) files for linguistic reasons. Pond files were generated for each subbasin using a custom VBA program.

Figure 2.6 Subbasins in the Eucha/Spavinaw basin assumed to have a significant number of ponds

Soil Phosphorous Content

Two distinctly different methods were used to estimate soil phosphorus content. Pasture soil phosphorous content was estimated using observed soil test data. Soil phosphorous content for forested areas was based on SWAT computer simulations.

Forest - Soil Phosphorous Content

Soil test phosphorous observations were unexpectedly high in forested portions of the basin. These forested portions have no history of litter application. I think the soil test phosphorous was bias due to the high organic matter content of these soils. Much of the organic phosphorous is digested during a Mehlich III extraction, and reported in the measurement. The SWAT model has separate inputs for mineral and organic phosphorous. Mineral phosphorous estimates should not include organic phosphorous, because this fraction is estimated from the soil organic matter content by the model. If the forest soil test phosphorous data were used, soil mineral phosphorous content would be overestimated.

Soil phosphorous estimates for forested areas were based on SWAT computer simulations of an undisturbed forested area in north central Arkansas (Figure 2.7). North Sylamore Creek (Station 07060710) is a HBN (Hydrologic Benchmark Network) station. Separate simulations were performed to back calculate soil test phosphorous from observed water quality data. GIS data for elevation, land cover, soils, and streams were compiled for the North Sylamore Creek watershed (Figure 2.8). Observed precipitation and simulated temperature data were used for each SWAT simulation. Modifications to soil phosphorous were made using the SWAT input parameter Sol_labp (Labile phosphorous concentration in the surface layer, mg/kg). This parameter also sets the amount of phosphorous in SWAT's phosphorous pools. Sol_labp was assumed to be related to soil test phosphorous by:

Mehlich III Soil test P (lb/acre) = 5 sol_labp (mg/kg)

Sol_labp was adjusted until the results of the simulation closely matched observed data. Model results for the period 10-79 to 9-90 were compared to observed data of the same period. The model was allowed to "warm up" for a period of 5 years before any data were compared (Table 2.1). The model was not calibrated on flow or sediment, therefore soluble phosphorous was considered to be more important than total phosphorous. Sediment yield is highly uncertain in an uncalibrated model, and sediment-bound phosphorous is closely linked with sediment yield. Comparisons of observed and simulated soluble phosphorous were favorable at a soil test value of 35 lb/acre (sol_labp value of 7 mg/kg). A value of 35 lb/acre was used for all forested areas of the Eucha/Spavinaw basin.

Table 2.1 Observed and SWAT simulated phosphorous comparisons at a soil test phosphorous level of 35 lb/acre in the North Slaymore Creek watershed.

Parameter	Observed	Predicted	Relative Error %
Average soluble P concentration (mg/L)	0.0082	0.0082	-1%
Flow weighted soluble P concentration (mg/L)	0.01	0.0079	21%
Average total P concentration (mg/L)	0.0151	0.0096	36%
Flow weighted total P concentration (mg/L)	0.04	0.0103	74%

Figure 2.7 North Sylamore Creek near Fifty Six, Arkansas (Station 07060710).

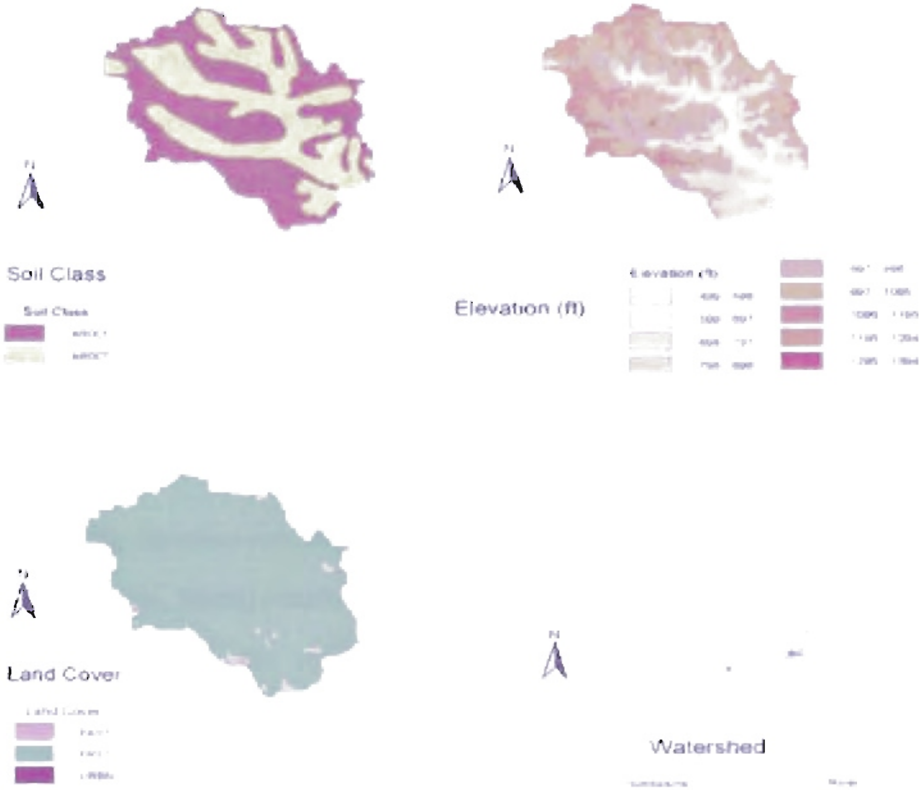


Figure 2.8 GIS data used in SWAT for the North Sylamore Creek watershed.

Pasture - Soil Phosphorous Content

Observed soil test data were used to determine the soil phosphorous content for the pasture portions of each subbasin. Soil samples collected by the Oklahoma Conservation Commission (OCC) were used for the Oklahoma portion of the watershed. A mean of 334 lb P/acre was derived from 261 soil samples of Benton County pasture, and was used for the Arkansas portion of the basin.

Marshall (1998) developed a nonparametric method to determine the number of samples required, within a 90% confidence interval, to estimate subbasin soil test phosphorous by land use for hydrologic/water quality modeling. This method was applied to the Eucha Basin, and a soil sampling plan was developed for pastures and forested areas. The Oklahoma Conservation Commission was contracted to collect these soil samples for the Oklahoma portion of the basin. A summary of the soil test data is given in Table 2.2

Soil samples from the OCC were double checked to ensure that their locations were within the indicated subbasin. Some 14 samples fell outside the Lake Eucha watershed or were unusable for other reasons. Samples less than 400 meters outside the basin were reassigned to the nearest subbasin (Table 2.2). Because SWAT defines its own subbasins, an approximation of Marshall 's (1998) original subbasin theme was used to determine where the samples were taken (Figure 2.9). An area weighted soil test phosphorous was calculated for each of SWAT's 58 subbasins (Figure 2.10).

I used a specially compiled version of the SWAT model. At our request, Susan Neitsch (SWAT team, USDA-ARS Temple, Texas) modified SWAT 99.2 such that the entire soil profile was set to the same soluble phosphorous as the surface layer. The original SWAT 99.2 allows only the soluble phosphorous in the top 10 mm of soil to be set by the user, and the remainder of the soil profile is set to a value of 20 mg P/kg soil. The original SWAT model was not very sensitive to changes in soil phosphorous. Adjustments to the phosphorous content of the top 10 mm made little difference to the total amount of phosphorous in the soil profile. Mixing between layers made the phosphorous content of the top 10 mm approach the default value of the layer beneath in a few years.

Table 2.2 Number of soil samples from each major subbasin used to calculate average soil test phosphorous used in SWAT.

Basin	Pasture Total	Forest Total
Eucha	5	3
Dry	25	11
Brush	29	5
Beaty	46	3
Cloud	33	4
Cherokee	41	5
Black Hollow	33	

Table 2.3 Soil test averages by subbasin (lb-nutrient/acre. Oklahoma portion only)

Subbasin	PH	Buffer Index	N	Melich III P	K
Eucha	6	7	17	91	323
Dry	6	7	14	69	306
Brush	6	7	11	150	268
Beaty	6	5	24	202	337
Cloud	5	7	9	120	291
Cherokee	6	6	26	297	363
Black Hollow	5	7	53	112	267

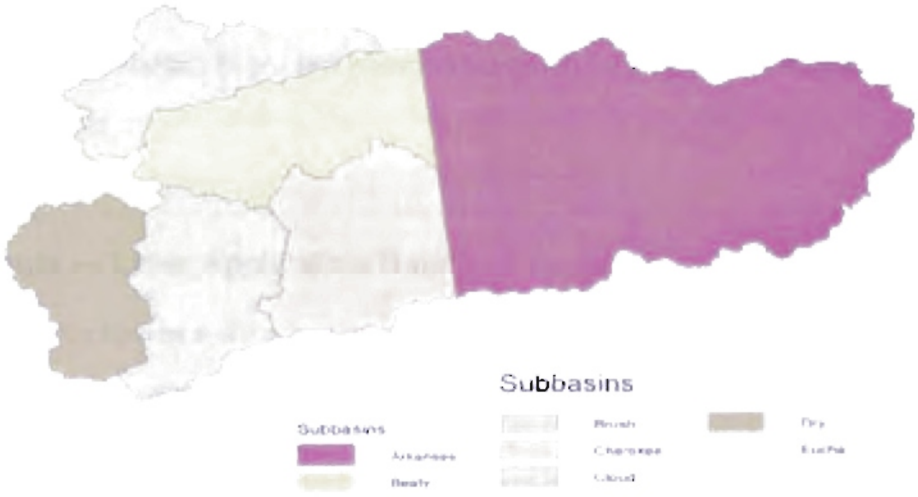


Figure 2.9 Approximation of Marshall (1998) original subbasins.

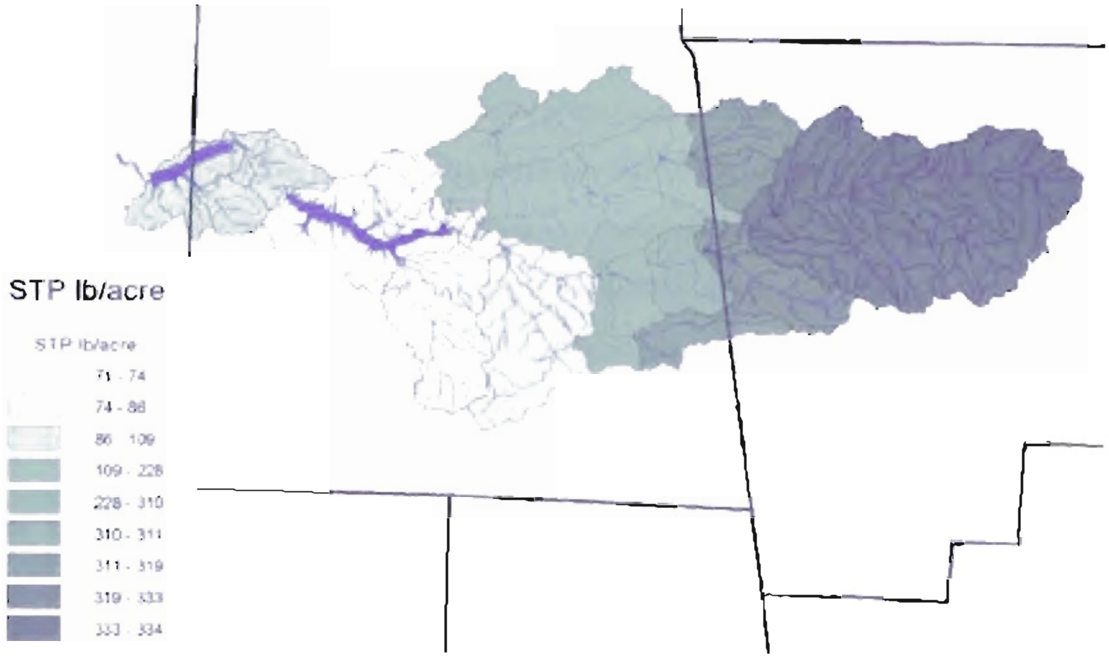


Figure 2.10 Average Mehlich III soil test phosphorous (STP) for pastures by subbasin for the Eucha/Spavinaw Basin

Nutrient Inputs --- Litter Application Rate

The number of poultry houses and the pasture area in each subbasin were used to determine litter application rates. All litter produced in a subbasin was assumed to be uniformly applied to pastures in that subbasin.

Broiler, layer, and turkey production all contribute to the total litter production. Each type of operation produces a different amount of litter, and litter of a different composition (Table 2.4). The fraction of nitrogen in poultry litter used in this study is considered high (approximately 20%) according to some other sources (OSU Extension facts F-2246). The amount of litter contributed basin-wide by each type of operation is summarized in *Table 2.5*. The average litter composition was determined by using the relative amount of each litter applied in the basin and it's composition (Table 2.6).

A minimum of one ton of litter was applied to pastures in each subbasin to prevent technical difficulties associated with zero application rates. This amount is negligible when spread over the area the size of a subbasin. The average amount of litter applied to pastures was 1750 kg/ha (0.77 ton/acre). The maximum litter rate was assigned to subbasin 27, 8007 kg/ha (3.53 ton/acre), which reflects the high number of poultry operations located in the small subbasin (Figure 2.11). A complete list of application rates by subbasin is available in Appendix A. A total of 83,800 tons of litter was estimated to be applied in the Eucha/Spavinaw Basin each year. This litter contained approximately 1,140,000 kg phosphorous (1260 ton) and 3,800,000 kg nitrogen (4190 ton).

Table 2.4 Annual litter production in the Eucha/Spavinaw Basin and fractional composition by operation type. (Broilers assumed 5 batches per year)

Operation	Litter per 20,000 animal capacity	Mineral N	Mineral P	Organic N	Organic P	Source
Broiler	100 ton/yr	0.01000	0.00400	0.04000	0.01000	Storm et al. (1999) and SWAT Database
Layer	200 ton/yr	0.01300	0.00600	0.04000	0.01300	Finley (1994) and SWAT Database
Turkey	310 ton/yr	0.00700	0.00300	0.04500	0.01600	Vest (1994) and SWAT Database

Table 2.5 Relative litter production in the Eucha/Spavinaw Basin by operation type.

Type	Animals	Houses	Litter production (t)	Total Litter (%)
Broilers	17937700	957	89689	88.6%
Layers	720800	82	7208	7.1%
Turkeys	282650	65	4381	4.3%

Table 2.6 Average fraction nutrient concentration of litter produced in Eucha/Spavinaw Basin.

Operation	Relative amount	Mineral N	Mineral P	Organic N	Organic P
Broiler	89%	0.010	0.004	0.040	0.0100
Layer, Breeder	7%	0.013	0.006	0.040	0.0130
Turkey	4%	0.007	0.003	0.045	0.0160
Average		0.010	0.0041	0.040	0.0105
Used in model		0.01	0.0045	0.04	0.0105

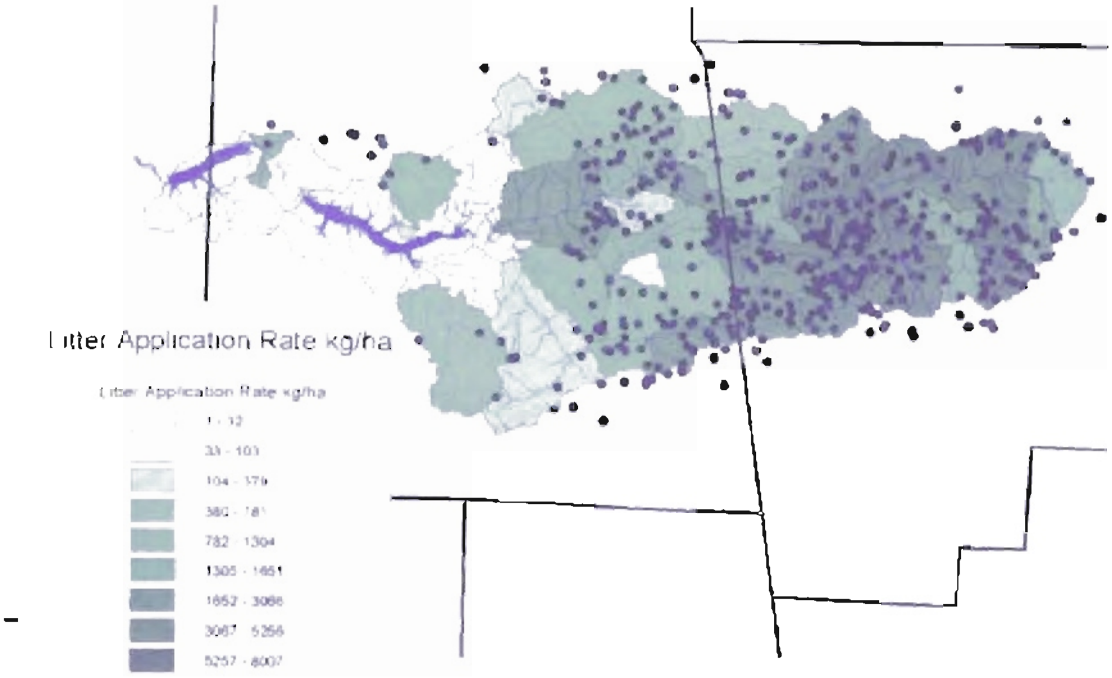


Figure 2.11 Litter applied by subbasin and poultry house locations (black dots).

Nutrient Inputs --- Commercial fertilizer applications

Commercial fertilizer sales in 1998 and 1999 for Delaware and Benton Counties were assumed to be uniformly applied to pastures in each county. The amount of pasture in each county was determined by USGS LULC (Land Use Land Cover) GIS data. LULC data were used because these data are readily available by county. Yearly rates for both counties were area weighed to estimate a single yearly application rate for the basin (4.8 kg/ha nitrogen and 0.1 kg/ha phosphorous). Appendix A contains additional information and calculations.

Observed Data

Observed Stream Flow

The Eucha/Spavinaw Basin contains three USGS stream gages (Figure 2.12). These gages were used to calibrate the hydrologic portion of the model. Each gage station has a different period of record (Table 2.7.)

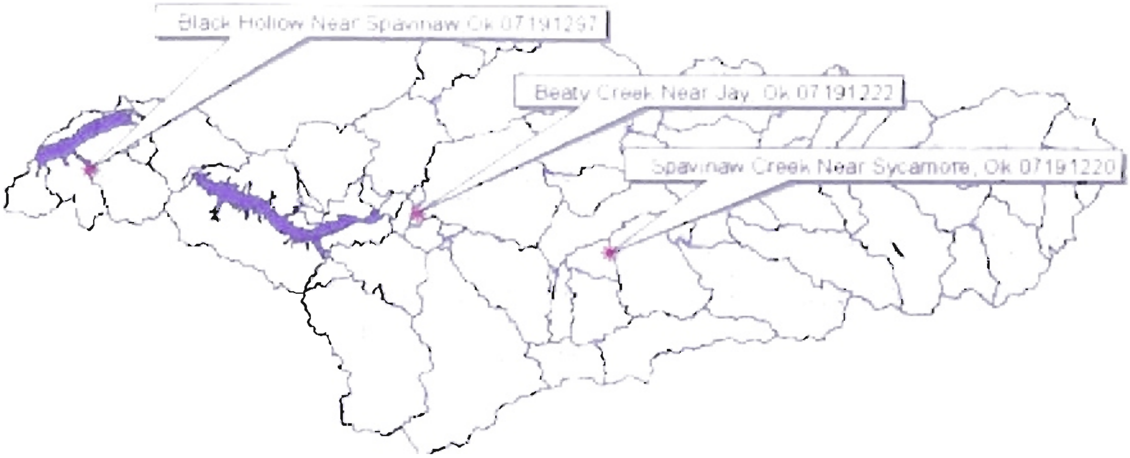


Figure 2.12 Active U.S. Geographic Survey stream gage stations used to calibrate the SWAT model.

Table 2.7 Period of record of U.S. Geographic Survey stream gage stations used to calibrate the SWAT model.

Gage Station	Start Date	End Date
Spavinaw Creek Near Sycamore	10/1/1961	Current
Beaty Creek Near Jay	7/31/1998	Current
Black Hollow Near Spavinaw	7/24/1998	Current

Baseflow Separation

Stream flow has two primary sources, surface runoff and ground water. Ground water contributions to stream flow are known as baseflow. The SWAT model was calibrated separately against observed surface and baseflow. Baseflow was separated from the total observed stream flow using the USGS HYSEP sliding interval method. The duration of surface runoff is calculated from the empirical relationship:

$$N=A^{0.2}$$

where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval $2N^*$ used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. I adjusted the interval to provide a range of acceptable baseflow values. The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [$0.5(2N^*-1)$ days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar $2N^*$ wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated (Figure 2.13).

Baseflow fractions were higher than expected throughout the basin, likely the result of the karst topography of the area. Karst features allow significant interaction between stream flow and ground water (Wagner and Woodruff 1997).

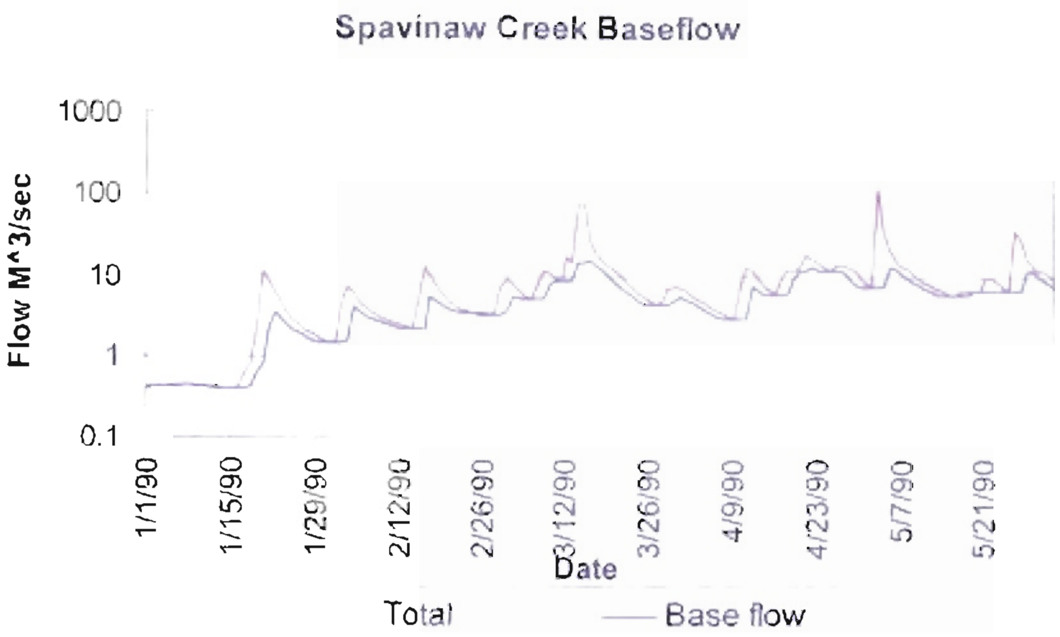


Figure 2.13 Spavinaw Creek baseflow separation example

Table 2.8 Observed average flow and baseflow fractions as determined by the HYSEP sliding interval method

Gage Station	Average Flow (m^3/sec)	Period	Baseflow	Surface Runoff
Spavinaw Creek Near Sycamore	3.8	1/90 to 4/00	66% - 60%	34% - 40%
Beaty Creek Near Jay	1.78	8/98 to 4/00	51% - 44%	49% - 56%
Black Hollow Near Spavinaw	0.12	8/98 to 4/00	79%	21%

Observed Loading Development

Water quality data were available for 10 suitable locations in the basin. Soluble phosphorous and total phosphorous loadings were estimated at each of these stations (Figure 2.14). Originally I only considered phosphorous, later it was deemed necessary to estimate nitrate loadings before calibrating SWAT for nutrients. Nitrate and phosphorous loadings were estimated separately. SWAT was calibrated for nutrients after the hydrologic calibration was completed.

Flow was estimated at each water quality station, because the observed water quality data have no associated flow information. I estimated daily flow from the closest stream gage and assumed flow was proportional to drainage area. Flow data before 8/1998 were estimated from the Spavinaw station only, because Spavinaw was the only active station before 8/1998. Daily flow was estimated for the period 1/1990 to 4/2000 at each water quality station. The stream gage used at each water quality station are listed in Appendix A. If more that one USGS station was used to estimate flow, the flow per unit area from all stations was averaged.

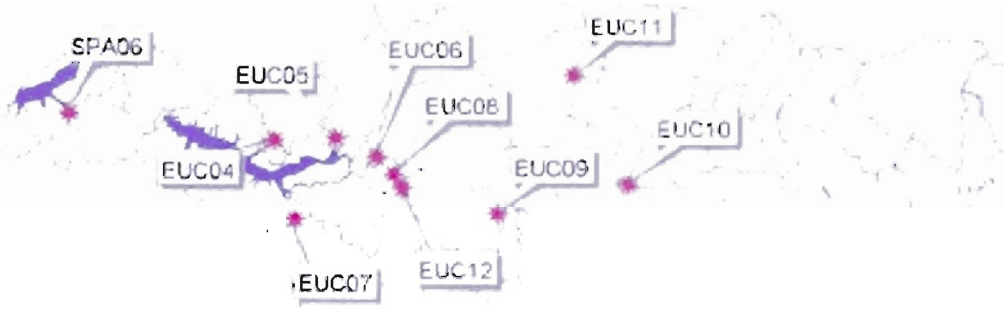


Figure 2.14 City of Tulsa water quality station locations used to calibrate the SWAT model.

Phosphorous Loading

Estimated flow was graphed against concentration to detect any significant relationship. If a significant (α=0.05) relationship was found, loading was determined using this relationship. If there was no significant (α=0.05) relationship the average concentration was used to calculate load. Water quality data were divided into pre-1998 and post-1998 groupings. Data collected after 1998 had quality assurance information and higher frequency sampling. Charts were generated for all available data and post 1998 only. The group of data that exhibited the best relationship was favored to estimate loading. Other considerations included the number of available data points and the possibility of loading increases in recent years. Increases in nitrate and phosphorous concentrations in the basin were apparent (Figure 2.15). All of these considerations were judged at each location to select the most appropriate data set. No water quality observations before 1990 were used to help minimize these errors.

If the regression was significant, the residuals were examined for seasonality. Where seasonality was apparent, separate regressions were developed for spring/summer and fall/winter. Separate regressions were necessary at only one station, EUC06 (Lower Beaty Creek) and only for soluble phosphorous. Estimated daily flow was used with any significant relationship or average concentration to determine a daily load. Table 2.9 contains average concentrations and total estimated load for the period 8-98 to 4-00. The following equation was used to estimate loads

$$L = \sum_{i=1}^{n} 86.4 Q_i C$$

where L is load in kg, Q_i is flow in m³/sec, n is the number of days, and C is concentration in mg/l

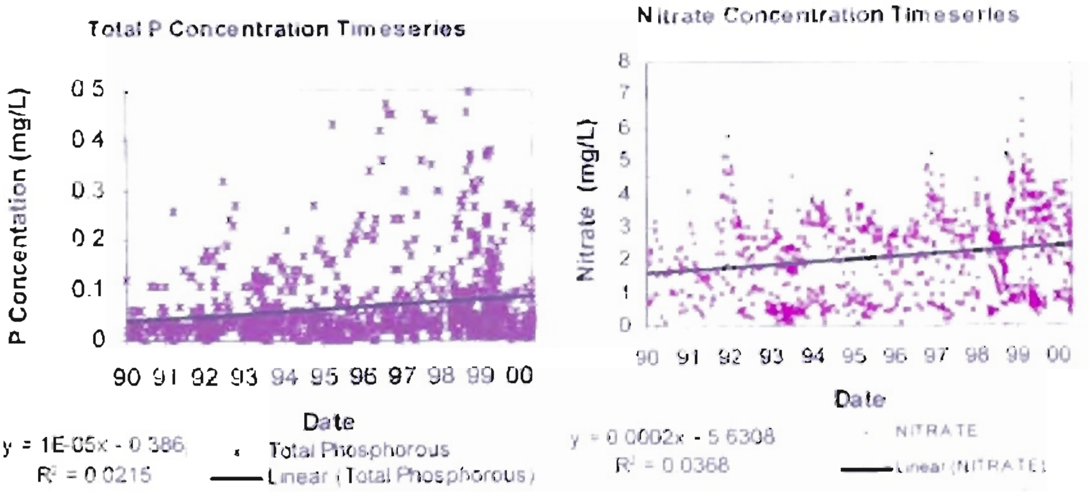


Figure 2.15 Observed nutrient concentrations over time. All City of Tulsa water quality stations combined.

Table 2.9 Estimated observed phosphorous loading by station.

SITE	Average Flow (m^3/sec)	Average Ortho P (mg/l)	Average Total P (mg/l)	Average Monthly Ortho P (kg/month)	Average Monthly Total (kg/month)	Area (km^2)
EUC04	0.24	0.0100	0.0143	6	25	20.9
EUC05	1.01	0.0117	0.0206	142	301	87
EUC06	1.78	0.041	0.057	521	546	152.8
EUC07	0.54	0.009	0.017	13	24	50.6
EUC08	5.07	0.045	0.062	1898	2774	516.9
EUC09	4.15	0.096	0.119	3146	3405	423.5
EUC10	2.64	0.231	0.249	1137	1313	268.9
EUC11	0.77	0.063	0 080	491	632	65.9
EUC12	0.69	0.017	0.033	75	59	64.3
SPA06	0.12	0.012	0.033	5	14	15.6

Nitrate Loading

Nitrate loading was estimated in a similar manner. Average nitrate concentration for post 1998 data was greater than average concentration of all data at the majority of stations. For this reason only post 1998 data were considered. Otherwise, the methods used were identical.

These loads were compared to loads calculated by the OCC for the period March 1993 to February 1994. Table 2.11 contains average annual nutrient loadings during the calibration period August 1998 to March 2000 compared to the previous OCC study. Note the reduction in nitrate loading in the period even though average nitrate concentration was higher than in 1993-1994. This is the result of differing stream flow. Table 2.12 displays loading calculated using flow data from 1993-1994 and the current regression equations.

Table 2.10 Estimated observed nitrate loading summary by station.

SITE	Average Flow (m^3/s)	Average Nitrates (mg/l)	Average Monthly Nitrate-N (kg)
EUC04	0.24	0.6016	752
EUC05	1.01	0.8674	2305
EUC06	1.78	2.072	9678
EUC07	0.54	0.661	942
EUC08	5.07	3.005	40024
EUC09	4.15	3.467	37801
EUC10	2.64	3.839	26597
EUC11	0.77	3.162	6364
EUC12	0.69	1.539	2787

Table 2.11 Calibration period estimated loadings compared to 1997 OCC study.Total P and ortho P as P and nitrate as nitrate nitrogen.

	Calibration Period (8-98 to 4-00)				OCC Study (3-93 to 2-94)		Relative Diffrences	
SITE	Flow (m^3/sec)	Ortho (kg/yr)	Total P (kg/yr)	Nitrate (kg/yr)	Total P (kg/yr)	Nitrate (kg/yr)	Total P	Nitrate
Rattlesnake	0.27	86	329	10068	324	7643	2%	24%
Brush	1.04	1743	3699	28315	1568	39087	58%	-38%
Beaty	1.80	6323	6624	117386	11602	156671	-75%	-33%
Dry	0.78	218	404	16137	1043	24805	-158%	-54%
Spavinaw	5.14	23061	33708	486393	13690	548817	59%	-13%
Eucha Laterals	0.80	1339	2842	21755				
MISC areas					1566	39087		
Entire basin	9.82	32769	47606	680054	29791	818110	37%	-20%

Table 2.12 Loading calculated using 93-94 hydrologic data compared to OCC Study. Total P and ortho P as P and nitrate as nitrate nitrogen.

	Estimates for (3-93 to 2-94)				OCC study (3-93 to 2-94)		Relative Diffrences	
SITE	Flow (m^3/sec)	Ortho (kg/yr)	Total P (kg/yr)	Nitrate (kg/yr)	Total P (kg/yr)	Nitrate (kg/yr)	Total P	Nitrate
Rattlesnake	0.4	118	267	9444	324	7643	-21%	19%
Brush	1.4	1174	2368	39096	1568	39087	34%	0%
Beaty	2.5	5170	6081	162082	11602	156671	-91%	3%
Dry	1.2	327	605	24179	1043	24805	-72%	-3%
Spavinaw	8.4	24487	35106	796705	13690	548817	61%	31%
Eucha Laterals	1.1	902	1818	30039				
MISC areas					1566	39087		
Entire basin	15.0	32158	46243	1061546	29791	818110	36%	23%

Point Source Loadings

Although most of the nutrient loading was attributed to non-point source pollution, one significant point source is located in the Eucha/Spavinaw Basin at the City of Decatur. A poultry processing plant is located in Decatur, with waste from the plant processed by the City of Decatur waste water treatment plant. The treatment plant discharges to Colombia Hollow in subbasin 20. The US Environmental Protection Agency PCS (Permit Compliance System) contains estimated monthly loading from Decatur (NPDES ID AR0022292). Only the average daily load for the period November 1997 to August 2000 was used in the model (Table 2.13). The 1997 OCC study also estimated the loading from the City of Decatur for the period March 93 to February 94 and October 95 to September 96 (Table 2.14). Monthly loading data indicate a slight reduction in both nitrates and phosphorous over the period observed (Figure 2.15).

Table 2.13 City of Decatur point source daily load for the period 11-97 to 8-00

Parameter	Total P	Nitrate-N	Flow	Ammonia-N
Units	kg/day	kg/day	m^3/day	kg/day
Value	32	15	4894	31

Table 2.14 Average annual City of Decatur nutrient loadings. Derived from the US Environmental Protection Agency's Permit Compliance System.

	93-94 OCC Estimate	95-96 OCC Estimate	97-00 Updated Estimate
Total Phosporous (kg/yr)	8153	15923	11680
Total Nitrogen (kg/yr)	19567	38214	16790

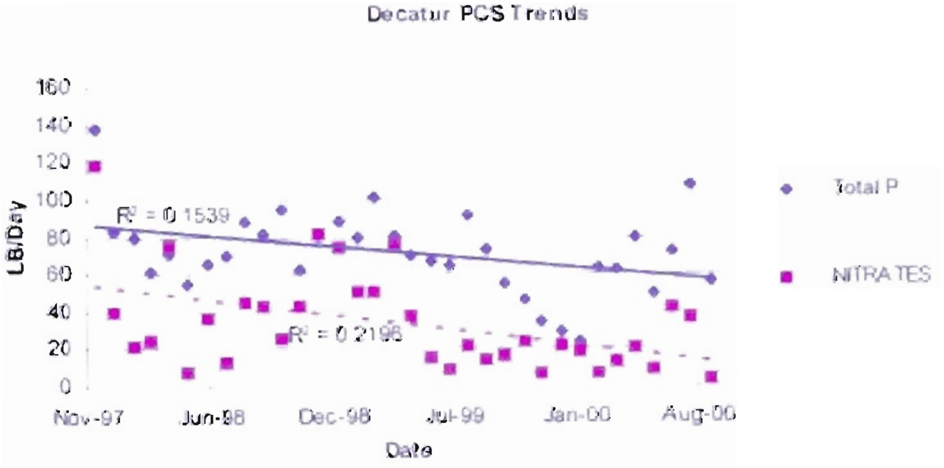


Figure 2.16 Decatur point source loading trends. Derived from the Environmental Protection Agency's Permit Compliance System. (Nitrate as nitrate nitrogen.)

Management

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date, or as a fraction of the total heat units required by the crop. Heat unit scheduling is the default. All forested HRUs use the default management generated by the ArcView SWAT interface. Pasture management was set up as a cattle grazing operation. Table 2.22 contains the individual operation and the approximate timing of each. The default management generated by the interface was modified to include several additional operations. "Plant Pasture" and "Harvest/Kill" are default operations that were not modified.

Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The amount of heat units accumulated each day is equal to the average daily temperature minus the base temperature of the plant. When no plant is growing the model uses a base temperature of 0° C and keeps a separate running total. This base 0° running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

Grazing was simulated at a stocking rate of 0.33 animal units per acre (Oklahoma State University Extension Facts 2855), with 9.35 kg of dry biomass consumed and 2.92 kg of dry manure deposited per hectare (ASAE D384.1). The grazing occurs for a maximum of 200 days. Any time there is less than 600 kg (dry weight) of biomass per hectare grazing is suspended. Some areas are quite sensitive to lower values of the parameter *Minimum biomass required for grazing*. This indicates that the grazing rate may be excessive in these areas.

When the fraction of the crop's required heat units reaches 0.25, litter and commercial fertilizers were applied. Litter was applied in two identical applications, both occurring the same day. It was necessary to make two applications because the maximum fertilizer application rate allowed by the model is less than that required in some areas.

Pasture management is not uniform across the basin. The amount of litter applied in each subbasin is different. I did not use the SWAT interface to generate these management files (.mgt), because that required each file to be manually modified. There is one management file for each of the 351 HRUs. With multiple management changes, the task would be daunting. Therefore, a program was written to create files identical in format to those generated by the interface.

Table 2.15 Pasture management operations used in the SWAT model.

Description	Heat Unit Fraction	Approximate Date
Plant Pasture	0.150	04/18
Graze 0.33 AU/acre	0.200	05/20
Litter Application	0.250	05/27
Litter Application	0.250	05/27
Commercial Fertilization	0.250	05/27
Harvest/Kill 1.2HU	1.200	08/25

Calibration

The SWAT model was calibrated using observed stream and nutrient data. Three stream gage stations and ten water quality stations were used in the calibration. The model was calibrated for total flow, surface flow, baseflow, soluble phosphorous, total phosphorous, and nitrate.

The model was first calibrated on stream flow at each of the three gages. Observed stream flow was split into surface runoff and baseflow. After hydrologic calibration the model was calibrated for nutrients. Predicted loads were compared to observed loads at 10 water quality stations, and relative error was calculated at each station. The load at each station and the area upstream each station was used to calculate an area weighted average relative error. This average was used to guide the nutrient calibration.

Hydrologic calibration

Three gage stations, shown in Figure 2.17, were used in the calibration of total flow, surface runoff, and base flow. The period of available data from the three stations is not the same, Beaty Creek and Black Hollow have less flow data. Spavinaw Creek has much more observed data and would therefore be considered a more accurate calibration.

I split the basin into three areas, each with a different set of calibration parameters. Subbasins not upstream of a gage were lumped with the most similar adjacent calibrated area. Land use, topography, and distances were used to determine how to lump each subbasin.

Preliminary calibration baseflow fractions were far lower than estimates from observed stream flow. I modified the soils database to allow increased crack infiltration, by setting crack potential for each soil to 0.75. This modification increased aquifer recharge and baseflow contributions to help compensate for the karst topography.

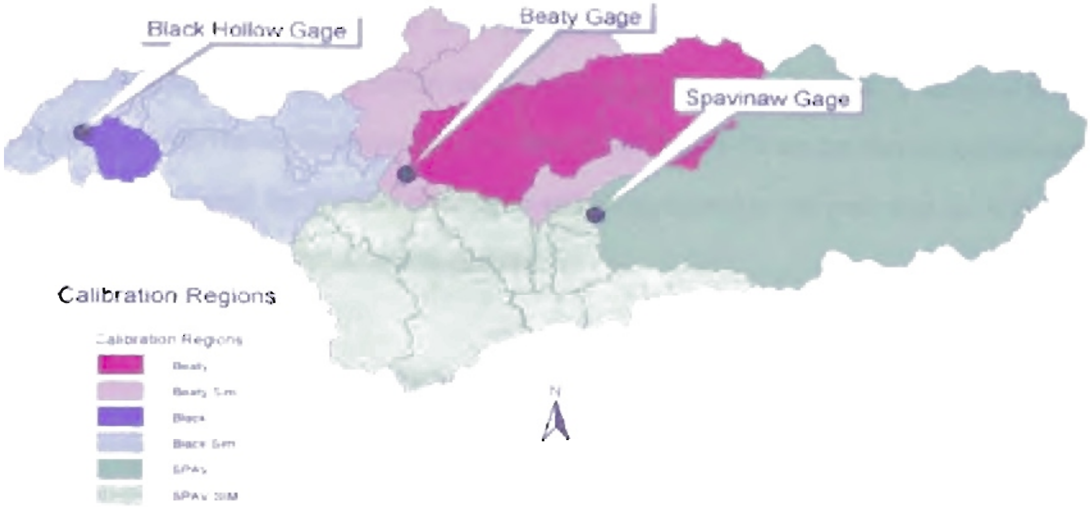


Figure 2.17 SWAT calibration regions for the Eucha/Spavinaw Basin (SIM denotes an area that is not upstream a gage station).

Time Dependant Model Output

Runoff characteristics of forested areas changed with time during the first calibration. The runoff characteristics were dependant on how long the model was allowed to "warm up". The period of available stream flow records at each stream gage station dictated the calibration period at each station. When the individual calibrations were combined into the final model, the model was ran for 15 years, 8 years longer than during the calibration at some stations. The flow at these stations became inconsistent with the calibration. The longer the simulation ran, the greater the average annual water yield. I assumed this was the result of residue accumulation in these forested areas. The default SWAT management was used for all forested areas.

In my experience SWAT's plant growth model is not well suited for unmanaged forests. I think that residue built up to unreasonable levels during the simulation. To prevent this accumulation, some of the forest was harvested. The plant portion considered yield, and thus harvested is called the harvest index. The harvest index can be set by the user. Figure 2.18 demonstrates the effect of harvest index on average yearly flow for a 50 year simulation on Black Hollow. The average observed flow at the Black Hollow station was 0.12 m^3/sec. A harvest index of 0.75 reduced the time dependancy of flow. The harvest index for all forest was set to 0.75. To ensure that no nutrients were removed from the forest, the fraction of nitrogen and phosphorous in the yield was set to 0. After these changes the entire calibration was updated.

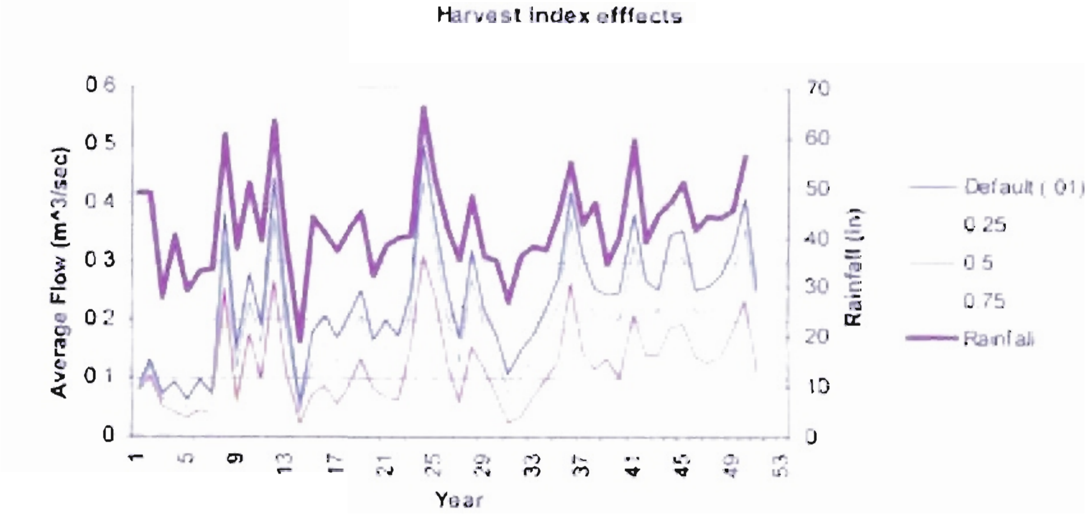


Figure 2.18 Effect of harvest index on flow over a 50 year period, as simulated by the SWAT model

Beaty Creek

Beaty Creek contains a higher fraction of pasture than the other two calibration areas. The nutrient loadings developed by the OCC for 1993-1994 indicated that Beaty Creek contributed disproportionate phosphorous load for its size. The updated loadings however, do not reflect this (Table 2.18).

USGS gage data for the period August 1998 to April 2000 were used to calibrate Beaty Creek and portions of Brush Creek. Adjustments to several parameters were necessary to calibrate Beaty Creek, specifically curve numbers were increased by 2.08. ESCO (Soil Evaporation Compensation

Factor) was increased from 0.95 (default) to 1, and parameters pertaining to ground water were adjusted to provide increased baseflow. These ground water parameters determine how the shallow aquifer interacts with surface flow. Relative error was used to compare observed and predicted data and to guide the calibration process.

Relative Error (%) = (Observed - Predicted)/Observed * 100 %

With calibration, relative error was reduced to 6.5% for the average total flow, and baseflow fell near the center of the estimated baseflow range. Surface runoff was sightly over predicted. Monthly predicted and observed values are compared in figures 2.19 and 2.20. Additional data are available in Appendix B.

Table 2.16 Beaty Creek (US Geographic Survey stream gage 07191222) calibration average flow and relative differences (all units are m^3/s). Upper and lower values of surface and baseflow are provided by adjusting the interval used during baseflow separation.

	Observed					Predicted			
Month	Flow	Baseflow (upper)	Baseflow (lower)	Surface (upper)	Surface (lower)	Flow	Surface	Base	Misc
Average	1.78	0.90	0.78	1.00	0.88	1.668	0.823	0.834	0.009
Relative Error	6.5%	7.4%	-7.2%	17.9%	6.4%				

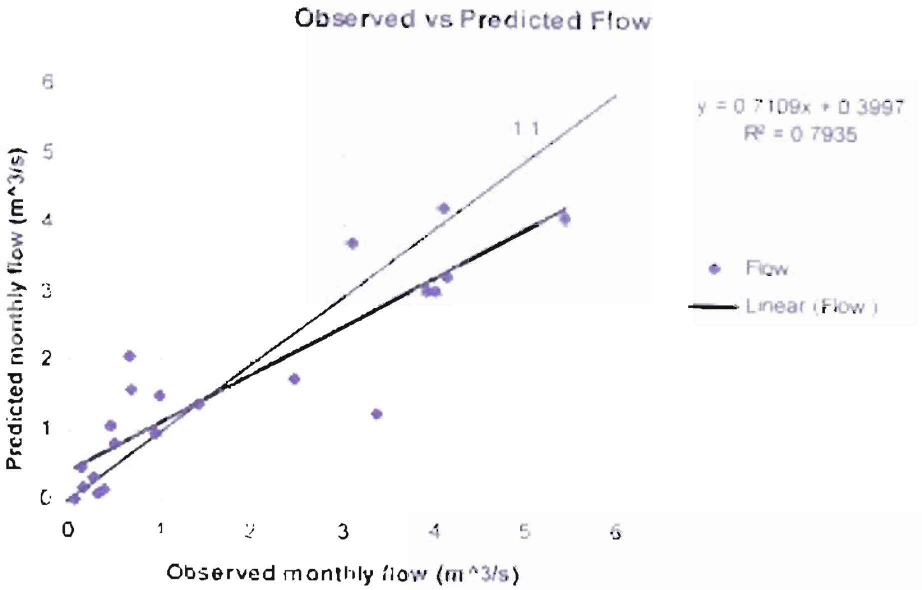


Figure 2.19 Beaty Creek (US Geographic Survey stream gage 07191222) monitoring vs SWAT predicted total stream flow (8-1998 to 4-2000)

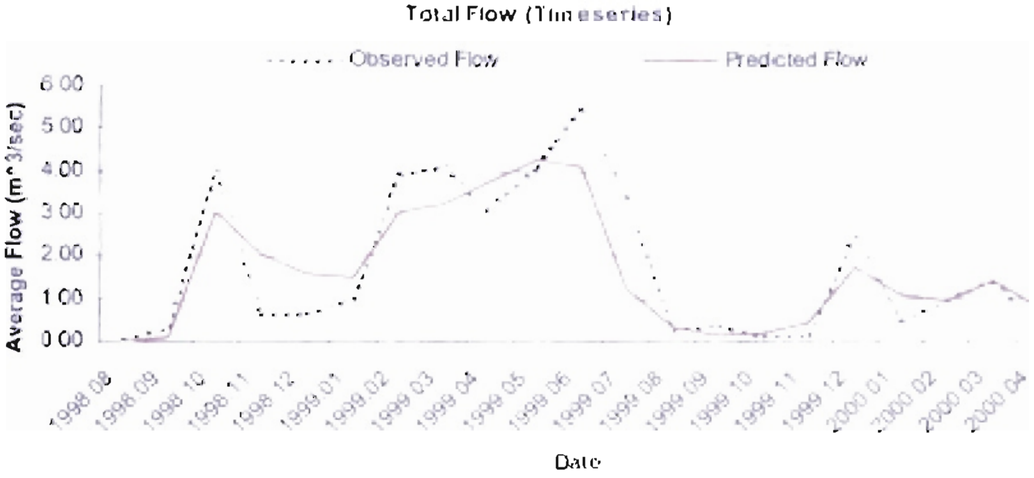


Figure 2.20 Beaty Creek (US Geographic Survey stream gage 07191222) observed and SWAT predicted total stream flow (time-series) after calibration.

Spavinaw Calibration

The Spavinaw gage station has more available data than any other gage. In addition, the drainage area at the Spavinaw gage station is greater than any other gage, therefore the calibration at Spavinaw should be considered more accurate than that at any other gage. Data from January 1990 to April 2000 were used for the calibration.

Parameter adjustments are listed in Appendix B. Average monthly flow was predicted within 2.5% after calibration, but baseflow was underestimated by 15.7% (Table 2.17). The under prediction of baseflow is of little concern, considering the uncertainty associated with estimating baseflow from observed data.

Good agreement was found between observed and predicted monthly flow (Figure 2.21). This was the best fit seen at any gage station. Visual inspection of observed and predicted flows over time (Figure 2.22) suggests the source of the under prediction was baseflow, particularly during dry periods. Additional data for Spavinaw are available in Appendix B.

Table 2.17 Spavinaw (US Geographic Survey stream gage 07191220) calibration average annual flow and relative differences (all units are m^3/s). Upper and lower values of surface and baseflow are provided by adjusting the interval used during baseflow separation.

	Observed					Predicted			
	Total	Baseflow (upper)	Baseflow (lower)	Surface (lower)	Surface (upper)	Total	Surface	Baseflow	Misc
Average	3.80	2.51	2.29	1.29	1.51	3.90	1.75	2.06	0.09
Relative Error	-2.5%	18.1%	10.2%	-35.5%	-15.7%				

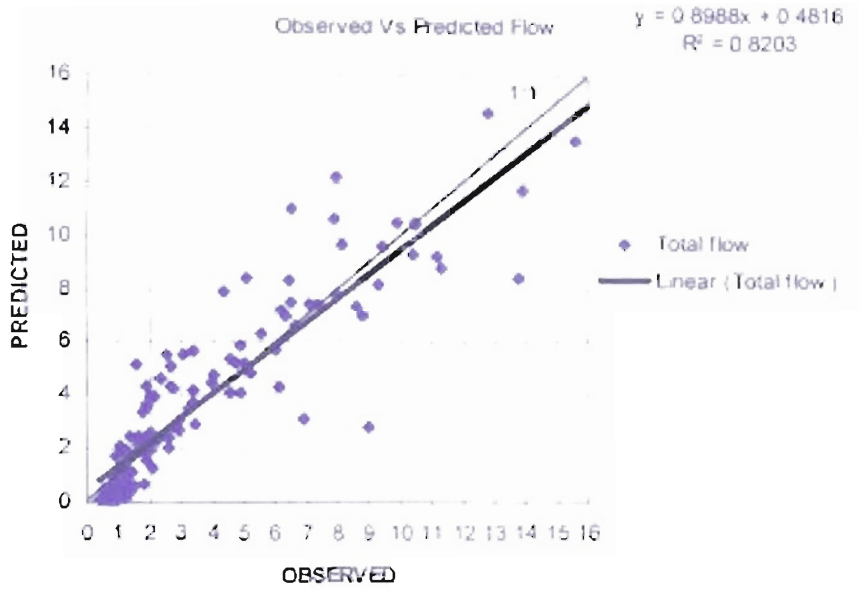


Figure 2.21 Spavinaw Creek (US Geographic Survey stream gage 07191220) observed vs SWAT predicted stream flow (1-1990 to 4-2000)

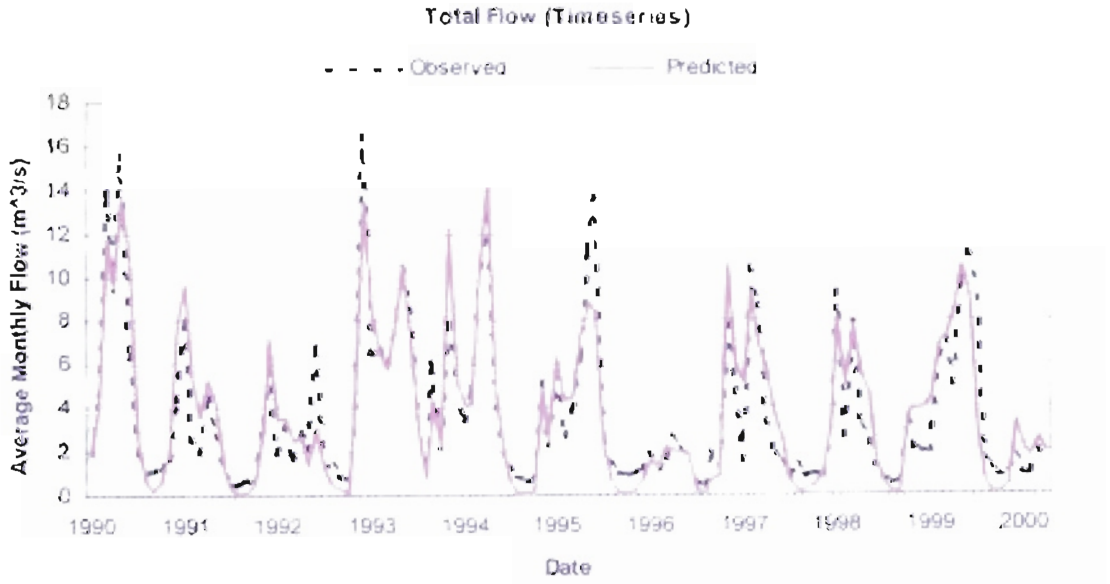


Figure 2.22 Spavinaw Creek (US Geographic Survey stream gage 07191220) observed flow vs SWAT predicted flow (time-series)

Black Hollow Calibration

The Black Hollow gage has the smallest contributing area of any gage in the basin, only 1559 ha. This area was represented as only one subbasin in the model. Almost the entire area is forested as determined from the GAP land cover; therefore, the entire basin was simulated as forest by the SWAT model.

No baseflow range was estimated for Black Hollow because of its small size, only a single interval was used to separate baseflow. Total flow comparisons were good with a relative error of -4.2% (Table 2.18). Again the fraction of baseflow was underestimated, but it is much less important than total flow.

The relationship between observed and predicted flow indicates over prediction at low flows (Figure 2.23). This over prediction was also apparent when flow was graphed against time (Figure 2.24). The observed gage data indicated no flow for long periods of time. The large error in November 1998 is thought to be the result of weather differences between the subbasin and the rain gage location. This area is more sensitive to weather because it consists of a single subbasin, and uses the observed data from only one weather station. Tabular data are located in Appendix B.

Table 2.18 Black Hollow (US Geographic Survey Gage 07191297) average flow and relative differences (all units are m^3/s).

	Observed			Predicted		
	Total	Baseflow	Surface	Total	Baseflow	Surface
Average	0.118	0.093	0.025	0.123	0.081	0.032
Relative Error	-4.2%	12.8%	-29.2%			

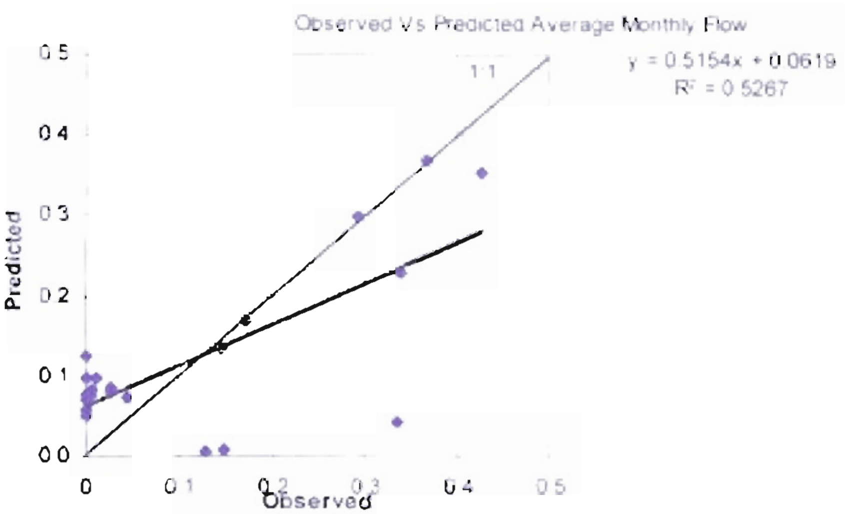


Figure 2.23 Black Hollow (US Geographic Survey Gage 07191297) observed vs SWAT predicted stream flow (8-1998 to 4-2000)

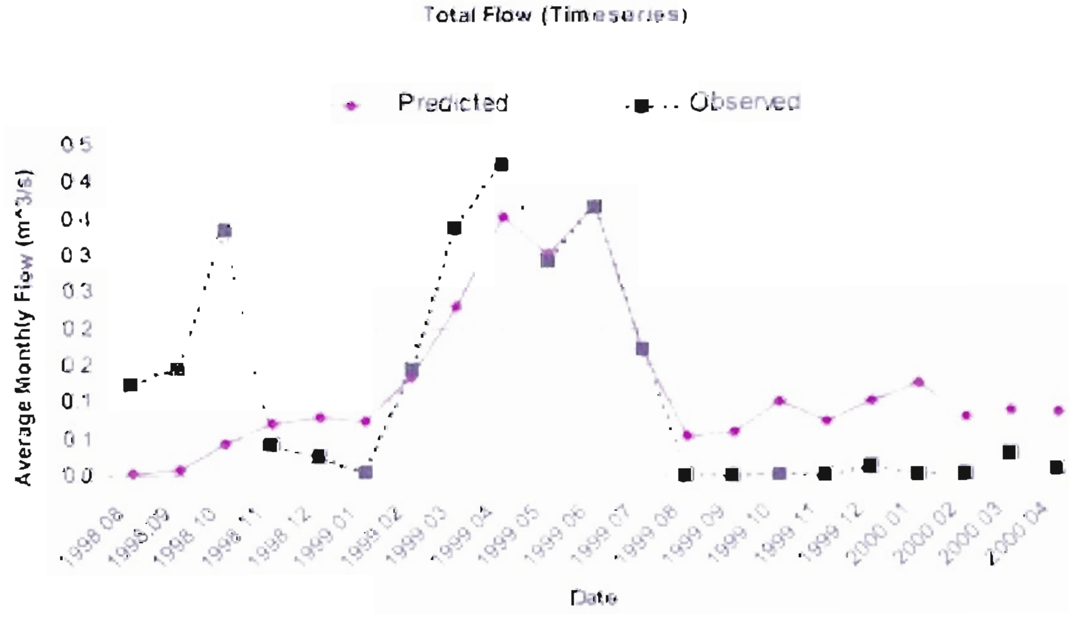


Figure 2.24 Black Hollow (US Geographic Survey Gage 07191297) observed flow vs SWAT predicted flow (time-series)

Nutrient Calibration

The nutrient calibration was performed in a different manner than the hydrologic calibration, because many nutrient parameters are basin wide. The basin was calibrated as a whole using comparisons at all stations simultaneously. Sediment was included because it has a large impact on nutrients and was adjusted only to reasonable levels for these land covers.

Sediment

No recent sediment data were available for the Eucha/Spavinaw Basin, so the calibration was stopped when sediment yields were reasonable based on literature values. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to calculate sediment yield. The MUSLE C factor is calculated internally from the total of surface residue and biomass and a minimum C factor. This minimum C factor can be related to the average annual C by the following set of equations:

$$MC = EXP(1.463 \ln(CVA) + 0.1034)$$

where ***MC*** is the minimum C factor and ***CVA*** is the average annual C factor.

A minimum C factor of 0.0003 was used for forest and 0.0009 for pastures. These minimum C factors correspond to average annual C factors of 0.0036 and 0.0077, for forest and pasture respectively. Average annual sediment yields for the period January 1990 to April 2000 are 62.7 kg/ha for pasture and 25.9 kg/ha for forest.

Nutrients

Observed and predicted loadings at each of the 10 stations were compared. Relative error was calculated at each station for nitrate, sediment-bound phosphorous, and total phosphorous. These relative errors were area weighted according to the contributing area at each water quality station,and the result was used to guide the calibration. The result of the nutrient calibration is shown in Table 2.19.

Relative error at any given station may be off by a substantial amount. Because the parameters are not distributed, there is no way to make an adjustment at one station without affecting all other stations. The results of the calibration are displayed in Table 2.19. The parameters recommended in the model documentation were used for nutrient calibration. The following parameters were adjusted in the basin input file (.bsn):

NPERCO (Nitrogen Percolation Coefficient) = 1

PPERCO (Phosphorous Percolation Coefficient) = 12

PHOSKD (Phosphorous Soil Partitioning Coefficient) = 400

BMIX (Biological Mixing Efficiency) = 0.3

Additional modifications were made uniformly to each Main Channel Input File (.rte). These modifications allow increased stream bank erosion, but did not significantly impact nutrient loading in the model.

CH_COV (Channel Cover Factor) = 0.2

CH_EROD (Channel Erodibility Factor) = 0.2

Table 2.19 Observed and SWAT predicted average annual nutrient loading for the period August 1998 to April 2000. (Nitrate as nitrate nitrogen)

Predicted										
			kg				mg/L			
Station	AREA (km^2)	Flow (m^3/s)	Sediment P	Soluble P	Total P	Nitrate	Sediment P	Soluble P	Total P	Nitrate
EUC04	20.9	0.17	6	210	217	6446	0.001	0.040	0.041	1.225
EUC05	87	0.99	173	2511	2684	52720	0.006	0.081	0.087	1.710
EUC06	152.8	1.67	29	7189	7218	162299	0.001	0.139	0.139	3.133
EUC07	50.6	0.46	3	420	423	12739	0.000	0.030	0.030	0.899
EUC08	516.9	5.06	375	25817	26192	423221	0.002	0.164	0.166	2.689
EUC09	423.5	4.29	609	25195	25804	403359	0.005	0.189	0.193	3.024
EUC10	268.9	2.86	2538	19248	21785	283655	0.029	0.217	0.245	3.194
EUC11	65.9	0.53	1	2482	2483	45062	0.000	0.150	0.150	2.723
EUC12	64.3	0.47	2	392	394	9712	0.000	0.027	0.027	0.658
SPA06	15.6	0.12	22	24	46	2903	0.006	0.006	0.012	0.761
USGS		3.54	1560	22192	23752	345604	0.014	0.202	0.216	3.139
Observed										
			kg				mg/L			
Station	AREA (km^2)	Flow (m^3/s)	Sediment P	Soluble P	Total P	Nitrate	Sediment P	Soluble P	Total P	Nitrate
EUC04	20.9	0.24	218	77	295	9019	0.03	0.0101	0.039	1.190
EUC05	87	1.01	1911	1702	3614	27663	0.06	0.0540	0.115	0.878
EUC06	152.8	1.78	298	6256	6553	116132	0.01	0.1129	0.118	2.097
EUC07	50.6	0.54	130	153	283	11307	0.01	0.0091	0.017	0.669
EUC08	516.9	5.07	10514	22772	33285	480292	0.07	0.1443	0.211	3.044
EUC09	423.5	4.15	3107	37749	40857	453606	0.02	0.2923	0.316	3.512
EUC10	268.9	2.64	2121	13639	15761	319163	0.03	0.1662	0.192	3.889
EUC11	65.9	0.77	1687	5896	7583	76366	0.07	0.2470	0.318	3.199
EUC12	64.3	0.69		905	712	33443		0.0422	0.033	1.558
SPA06	15.6	0.12	110	63	173	2648	0.03	0.0172	0.047	0.724
USGS		3.41								

Table 2.20 SWAT nutrient calibration relative error at City of Tulsa water quality stations.

Station	Area (km^2)	Sediment P	Nitrate	Soluble P	Total P
EUC04	20.9	97.1%	28.5%	-174.1%	26.6%
EUC05	87	91.0%	-90.6%	-47.5%	25.7%
EUC06	152.8		-39.8%	-14.9%	-10.1%
EUC07	50.6	97.4%	-12.7%	-174.4%	-49.6%
EUC08	516.9	96.4%	11.9%	-13.4%	21.3%
EUC09	423.5	80.4%	11.1%	33.3%	36.8%
EUC10	268.9	-19.6%	11.1%	-41.1%	-38.2%
EUC11	65.9	99.9%	41.0%	57.9%	67.3%
EUC12	64.3		71.0%	56.7%	44.7%

Simulated Nutrient Loading

Nutrient loadings were simulated at important locations throughout the basin. The nutrient load to Spavinaw Lake cannot be directly predicted since SWAT cannot fully simulate the processes that occur in Lake Eucha. However, a loading estimate for the area between Spavinaw and Eucha was required to determine if this area is a significant source of nutrients. The simulated outflow from Lake Eucha subtracted from the simulated loading to Spavinaw Lake from Spavinaw Creek was initially used to provide the estimate. Some loads to Spavinaw Lake were negative, indicating that more nutrients were assimilated by the stream than were being added. To eliminate the negative loadings, stream processes were ignored in the Spavinaw laterals portion of the basin (Figure 2.25).

Loading from the small portion of the basin between the Lake Eucha dam and Spavinaw Lake was insignificant when compared to the loading to Eucha Lake. The sediment-bound phosphorous for the Spavinaw portion does not entirely account for stream losses, and is much higher than in other portions of the basin. Nutrients associated with sediment from this portion of the basin should not be directly compared the Eucha portion. Charts and tables in the body of this report feature the Eucha portion. Additional data for both areas are included in the Appendix A.

Average annual loadings to Lake Eucha over the period August 1998 to April 2000 were near observed values for both nitrates and soluble phosphorous (Table 2.22). Sediment-bound phosphorous was under-predicted leading to an under-prediction of total phosphorous. Many attempts were made to increase sediment-bound phosphorous, but agreement was not possible without making unreasonable modifications to the model. I think that two issues contribute to this problem. The first is the stream erosion routines of the SWAT model. Sediment eroded in the channels did not appear to significantly impact sediment-bound phosphorous. Sediment resulting from channel degradation was increased two orders of magnitude and had little effect. I think that this was the major factor. The second issue was types of land cover not simulated by the model. Some very small land covers contribute comparatively vast amount of sediment. These very small areas were either not included in the GAP land cover or were too small to be simulated by the model. This problem is discussed further in model limitations.

An adjustment factor was used to correct for low sediment-bound phosphorous. The adjustment factor was calculated by dividing the observed estimate of sediment-bound phosphorous loading (14,800 kg/year) by the predicted loading (612 kg/year). The adjustment factor, 24, was multiplied by the results from the SWAT model to correct the predicted loading of sediment-bound phosphorous. Tables and figures using the adjustment note its use.

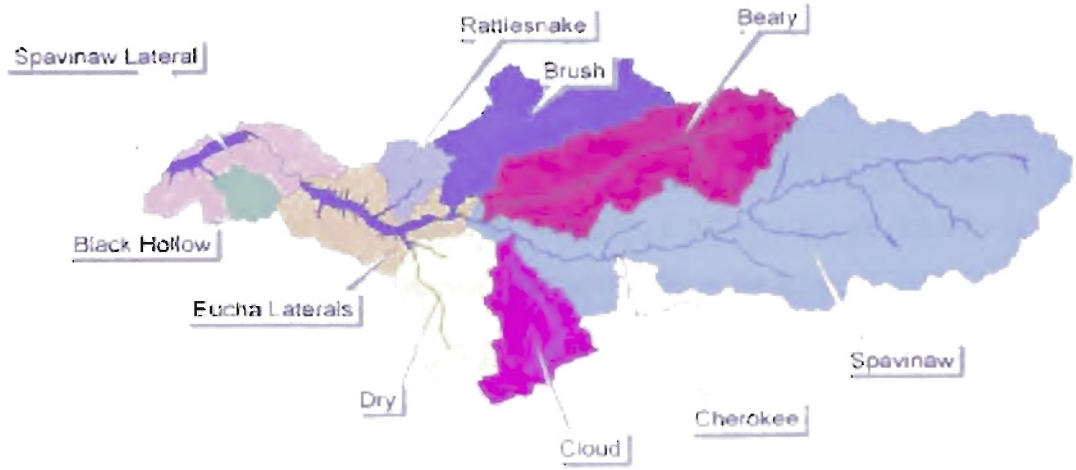


Figure 2.25 Contributing areas at each location where SWAT model output is generated. The contributing area for Spavinaw includes Beaty, Cloud, and Cherokee.

Table 2.21 SWAT simulated average annual nutrient loading August 1998 to April 2000. Spavinaw includes Beaty, Cloud, and Cherokee. Sediment-bound phosphorous and total phosphorous are unmodified.

Subbasin	Flow	Sediment P (mt)	Soluble P (kg)	Total P (kg)	NO3-N (kg)
Cherokee	0.42	2	1859	1861	34338
Cloud	0.48	1	396	398	9819
Dry	0.65	19	504	523	16577
Beaty	1.68	45	7155	7200	162602
Spavinaw	6.81	389	32748	33137	585802
Brush	1.01	119	2506	2625	52953
Rattlesnake	0.19	3	213	217	6895
Eucha Laterals	0.55	47	160	207	7225
Eucha Total	9.81	613	34485	35097	643936
Spavinaw Lateral	0.49	232	168	400	2867
Blackhollow	0.12	17	24	41	2908
Spavinaw Total - Eucha Outflow	0.61	248.66	191.87	440.53	621.0

Table 2.22 Observed and model estimated loading to Lake Eucha. No adjustment was made to account for sediment-bound phosphorous under predictions in this table.

Observed Estimates for Calibration Period (8-98 to 4-00)				Simulation (8-98 to 4-00)			
Flow	Soluble P (kg)	Total P (kg)	Nitrate-N (kg)	Flow	Soluble P (kg)	Total P (kg)	Nitrate-N (kg)
9.8	32769	47608	680054	9.8	34485	35097	643936

Background Loading Estimates

Background loading was estimated by simulating the entire basin as forest, using the flow calibration from Black Hollow. Black Hollow was used because it contains a higher fraction of forest than the other two calibration areas.

The anthropogenic effects appear to be large; soluble phosphorous was estimated to increase by 21 fold. The increase is a result of many factors, the City of Decatur point source and litter application appear to be the largest contributors, but changing forest to pasture and increases in STP are also important factors.

Table 2.23 SWAT simulated background and calibrated model loading to Lake Eucha (January 1990 to April 2000).

	Flow (m^3/s)	Sediment P (kg/yr)	NO3-N (kg/yr)	Soluble P (kg/yr)
Background Estimate	8.22	223	154578	1808
Calibrated Model	9.81	711	747798	40046
Percentage Increase	19%	220%	384%	2115%

Uncertainty Analysis

The uncertainty associated with water quality models is difficult to quantify. According to MacIntosh et al. (1984), there are two major types of uncertainty, knowledge uncertainty and stochastic uncertainty. Knowledge uncertainly stems from measurement errors and the inability of the model to accurately simulate the physical, chemical, and biological processes. Stochastic uncertainty is due to the random nature of natural systems, like rainfall. Rainfall is the driving force behind nutrient transport. Because rainfall is so important, it represents a major source of uncertainty. One method to quantify this uncertainty is to perform many simulations of the same scenario using different rainfall records. In this manner I can quantify the stochastic uncertainty associated with natural temporal variations in rainfall. I generated statistics from many simulations to estimate confidence intervals. This procedure accounts for only stochastic uncertainty associated with rainfall.

Thirty simulations were performed for each scenario. Observed rainfall records for the period 1/1/65 to 12/31/99 were used in these simulations. Each simulation covered a total of 6 years, the first 5 years allow the model to "warm-up" so that initial conditions are less important (Figure 2.26). Only data from the last year of the simulation were used. Custom software was written specifically to perform these simulations. The computational requirements to perform such simulations are enormous. In excess of 36 hours of processing time were often required to perform a single set of simulations.

A distribution was assumed and tested before confidence intervals were estimated. The results from 30 simulations of the calibrated model were analyzed to determine an acceptable distribution for each output parameter (Appendix C). The distribution type for each output parameter was assumed to be constant (Table 2.24). More detail and statistical tests are shown in Appendix C. Log-normal distributions are common for stream flow applications. By assuming a distribution, I can determine the probability that loading will be in a particular range (Figure 2.27 and 2.28).

The effect of rainfall variations on the system is dramatic, thus the confidence intervals are quite large. Rainfall has such a major effect that it could mask the effect of any BMP for a particular year. For example, there is approximately a 10% chance that the loading for any given year could be 60% greater than the average annual predicted loading.

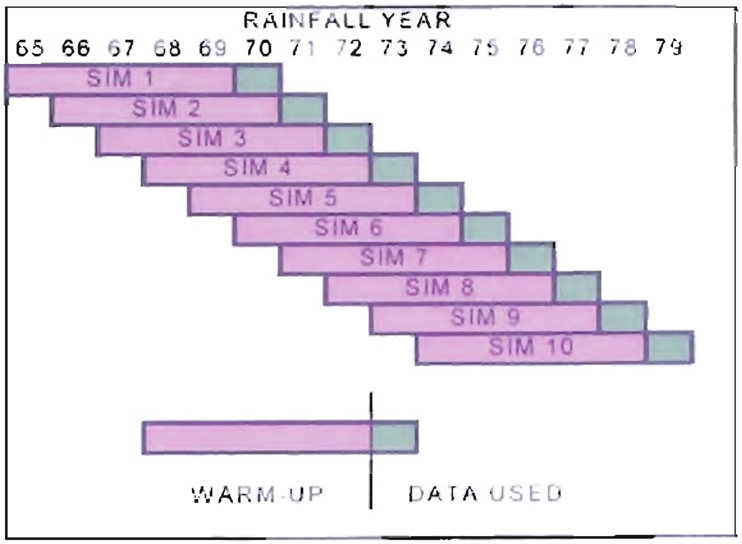


Figure 2.26 Simulation timing for the rainfall uncertainty analysis

Table 2.24 Assigned distribution used to determine confidence intervals.

Output Parameter	Distribution
Flow	LogNormal
Soluble P	LogNormal
Sediment Bound P	LogNormal
Nitrate	Normal

Table 2.25 Calibrated SWAT model output statistics. Derived from 30 simulations of the calibrated SWAT model.

Area	Flow (m^3/sec)		Soluble P (kg/yr)		Sediment P (kg/yr)		Nitrate-N (kg/yr)	
	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
Spavinaw	0.403	0.267	128	102	83	141	7557	4846
Eucha	9.13	4.62	31174	13604	665	620	507045	246838

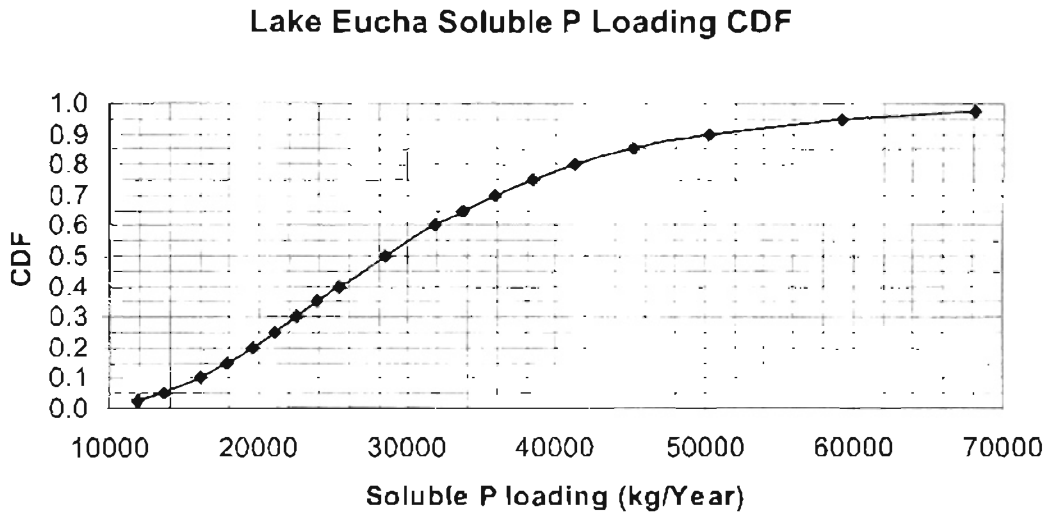


Figure 2.27 Cumulative Distribution Function (CDF) of soluble phosphorous loading to Lake Eucha under calibrated conditions as predicted by SWAT.

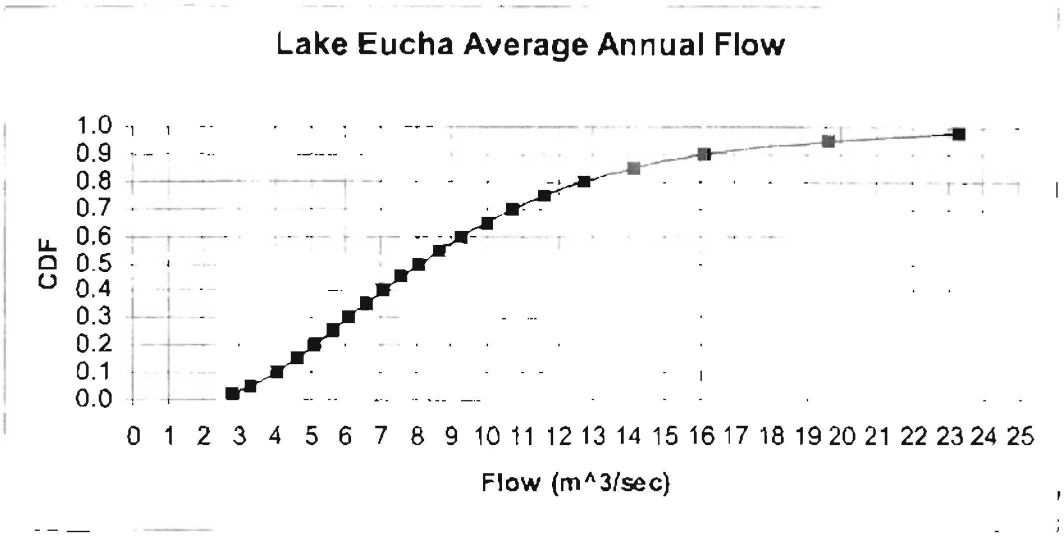


Figure 2.28 Cumulative Distribution Function (CDF) of predicted average annual streamflow to Lake Eucha, as predicted by SWAT. Derived from 30 simulations of the calibrated SWAT model.

Table 2.26 Confidence intervals at calibrated conditions. Derived from 30 simulations of the *calibrated SWAT model.*

Parameter	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
Flow (m^3/sec)	2.81	3.33	4.05	9.13	16.00	19.47	23.05
Soluble P (kg/yr)	11868	13657	16070	31174	50301	59188	68110
Sediment P (kg/yr)	144	177	225	665	1210	1539	1893
Nitrate-N (kg/yr)	23243	100997	191093	507045	822998	913094	990848

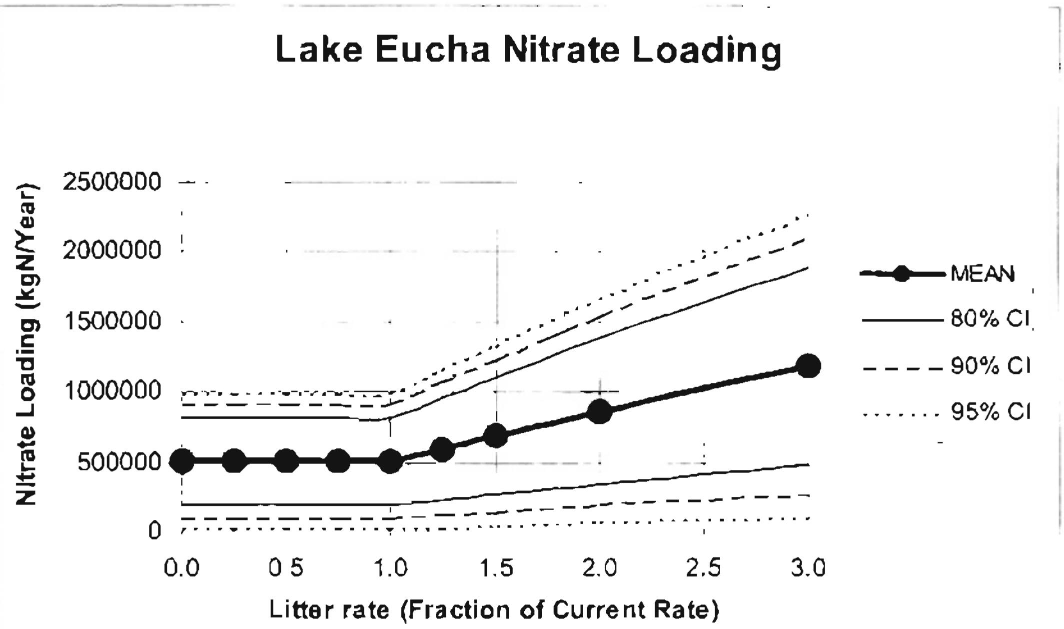
Management Practice Simulations

The calibrated model was modified to simulate a variety of BMPs and management practices. Litter application rate, soil test phosphorus, and grazing rate were each modified. An additional simulation was performed excluding the City of Decatur point source from the calibrated model. Each scenario is evaluated using the method detailed in the previous section. Additional charts and tables are located in Appendix D.

Litter Application Scenarios

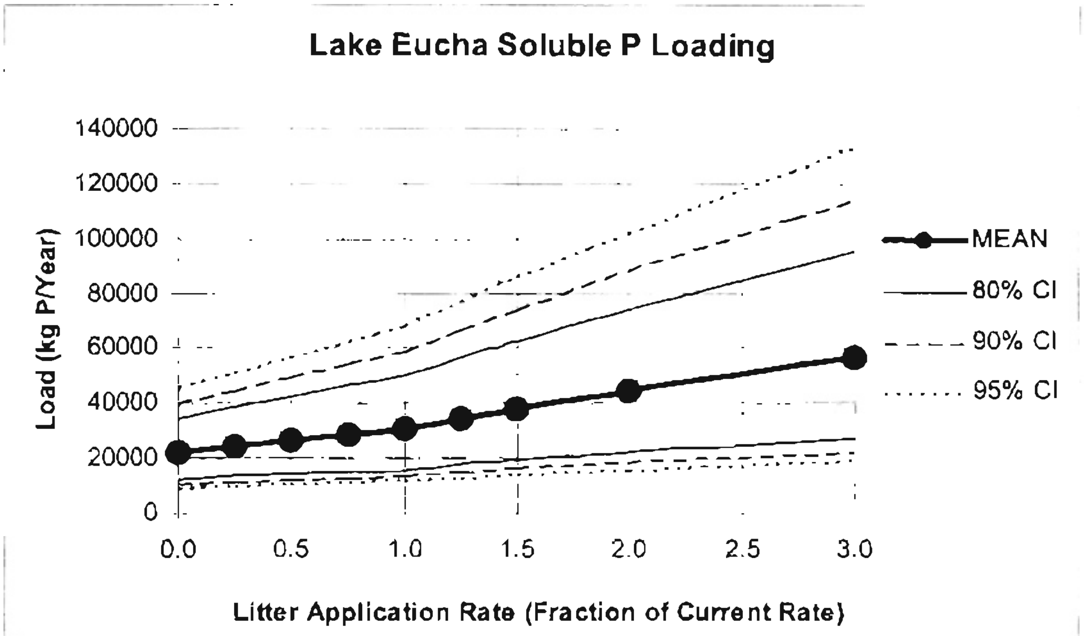
Litter application rates from 0 to 3 times the current rate were modeled. Commercial nitrogen was supplemented at litter application rates less than the current rate to maintain the current total nitrogen rate. Nitrate loading to Lake Eucha was nearly constant over this range (Figure 2.29). The model simulated a positive correlation between litter application rate and phosphorous loading (Figures 40 and 41). Litter application rates primarily affect nutrients, but do have some effect on the hydrology. Litter applications influence plant growth which in turn effects surface residue and evapo-transpiration.

Litter was assumed to be applied only to pastures, and the application rate varies by subbasin. The average amount of phosphorous applied in litter was 26.4 kg/ha. The average litter application rate was 1747 kg/ha (0.77 t/acre). The amount of litter applied in each subbasin was assumed to be equal to the estimated litter production in that subbasin. All litter produced in a subbasin was assumed to be applied uniformly to pastures in that subbasin. SWAT does not directly simulate the surface application of litter; it is treated as simple addition of nutrients to the surface soil layer. Litter application rates had a larger impact on nutrients than any other BMP simulated.



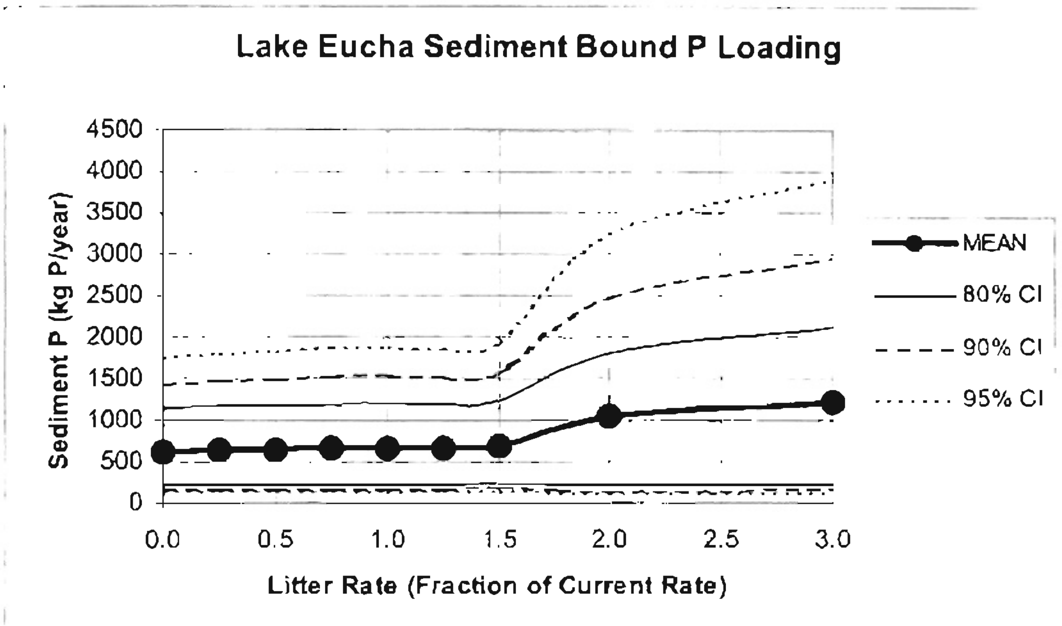
Litter Rate (X Current)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	23299	101209	191486	508073	824660	914937	992847
0.25	23428	101268	191464	507766	824068	914264	992104
0.50	23488	101281	191422	507532	823643	913784	991577
0.75	23451	101186	191261	507139	823018	913092	990828
1.00	23243	100997	191093	507045	822998	913094	990848
1.25	32147	123011	228297	597520	966742	1072029	1162892
1.50	44621	148018	267827	687978	1108128	1227937	1331334
2.00	64417	193168	342356	865535	1388715	1537902	1666654
3.00	96273	271234	473966	1184918	1895870	2098602	2273563

Figure 2.29 SWAT predicted average nitrate load to Lake Eucha as a function of applied litter.



Litter Rate (X Current)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	9563	10843	12541	22525	34800	40251	45636
0.25	10139	11545	13419	24636	38540	44796	51006
0.50	10742	12282	14345	26914	42627	49788	56927
0.75	11308	12973	15212	29048	46463	54481	62505
1.00	11868	13657	16070	31174	50301	59188	68110
1.25	12943	14938	17638	34758	56566	66790	77088
1.50	14019	16217	19199	38280	62719	74251	85894
2.00	15976	18546	22046	44773	74115	88101	102277
3.00	19286	22530	26976	56612	95413	114243	133455

Figure 2.30 SWAT simulated soluble phosphorous load to Lake Eucha as a function of litter application rate.



Litter Rate (X Current)	95% (Low)	90% (Low)	80% (Low)	MEAN	80% (High)	90% (High)	95% (High)
0.00	138	170	215	630	1133	1437	1763
0.25	140	172	218	640	1156	1466	1800
0.50	141	174	220	649	1177	1494	1836
0.75	142	174	222	660	1201	1528	1881
1.00	144	177	225	665	1210	1539	1893
1.25	145	177	225	657	1194	1514	1859
1.50	149	184	233	680	1241	1575	1935
2.00	113	149	203	1036	1805	2466	3227
3.00	117	155	215	1226	2127	2948	3908

Figure 2.31 SWAT simulated sediment-bound phosphorous loading to Lake Eucha as a function of litter application rate. Sediment-bound phosphorous is not adjusted in this figure.

Table 2.27 SWAT simulated effect of litter applications rate on loadings to Lake Eucha.

Scenario (Litter Rate)	Flow		Soluble P		Sediment P		Nitrate-N	
X Normal	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
0.00	9.13	4.62	22525	9031	630	609	508073	247334
0.25	9.13	4.62	24635	10138	640	612	507766	247111
0.50	9.13	4.62	26914	11337	649	615	507532	246962
0.75	9.13	4.62	29048	12470	660	623	507139	246780
1.00	9.13	4.62	31174	13604	665	620	507045	246838
1.25	9.23	4.65	34758	15436	657	594	597520	288455
1.50	9.31	4.66	38280	17163	680	610	687978	328243
2.00	9.42	4.68	44773	20428	1036	1958	865535	408734
3.00	9.51	4.70	56612	26585	1226	2489	1184918	555431

Soil Test Phosphorous Scenarios

To determine the relationship between STP and phosphorous loading, an additional set of model runs was made. The STP for all pastures was set to a single value and varied, but forest STP was not modified. To single out the effect of STP, no litter was applied in one set of these simulations. Two additional sets were performed that do include litter applications. Additional tables and figures are located in Appendix D.

Soil test phosphorous mainly effect soluble and sediment-bound phosphorous loadings. STP has little effect on flow and nitrates. Sediment-bound phosphorous was greater when no litter or supplemental nitrogen was applied. Plant growth depends on the litter as a source of nitrogen; without it there is much less growth and residue. With reduced residue and plant growth the soil surface is more exposed and subject to additional soil erosion. All simulations in this report at reduced litter application rates use enough supplemental commercial nitrogen to maintain the current total nitrogen application rate. It is also likely that producers will use more commercial fertilizer if they reduced their litter application rates.

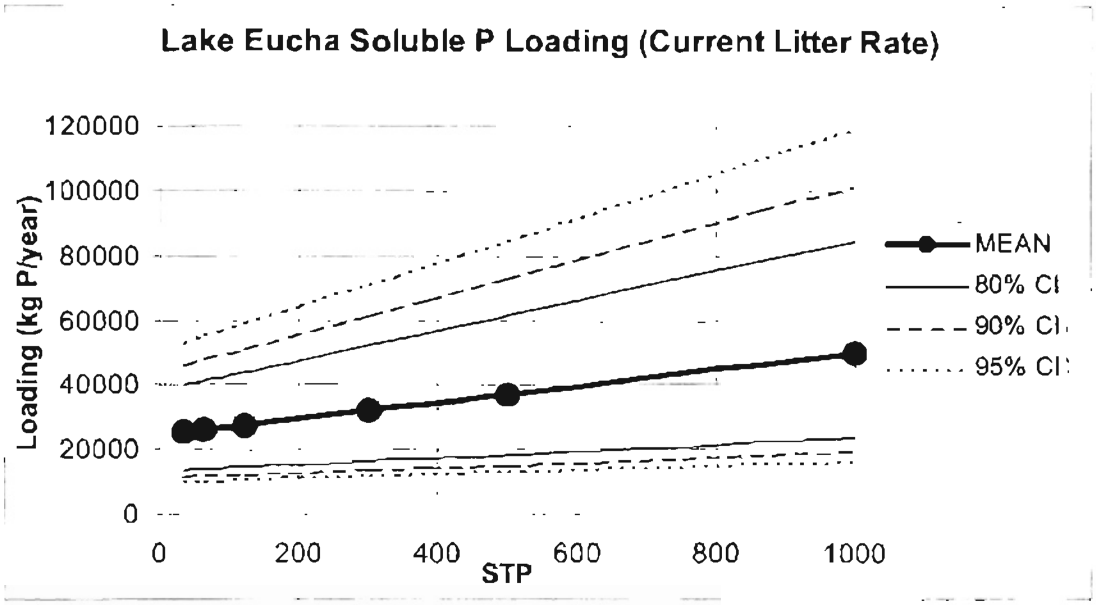


Figure 2.32 The effect of STP on soluble phosphorous loading to Lake Eucha as simulated by the SWAT model using the current litter application rate.

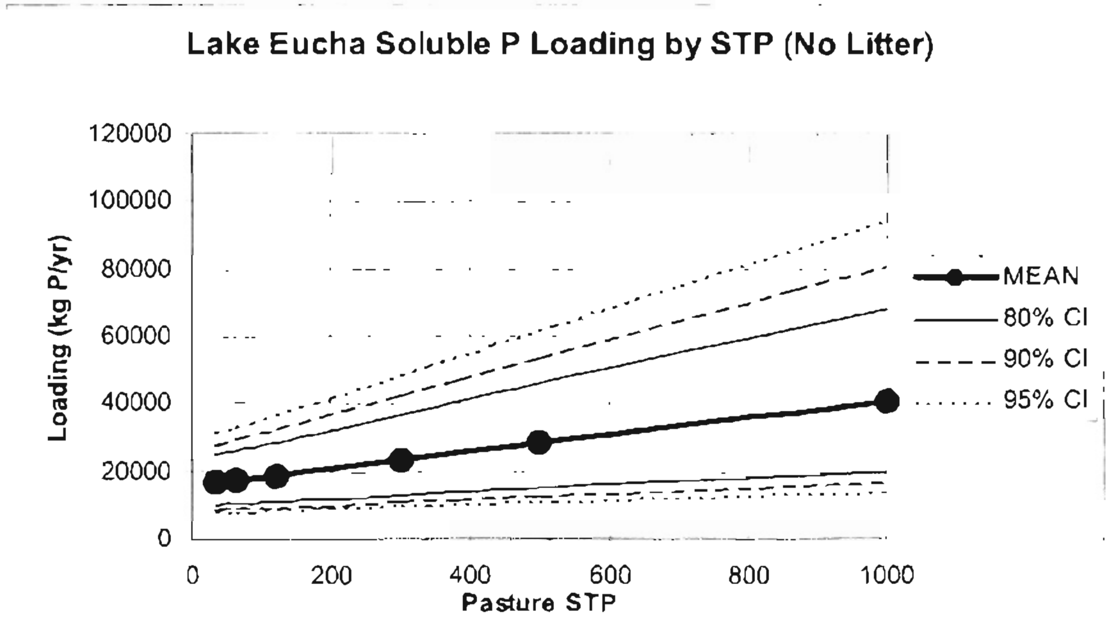


Figure 2.33 Soluble phosphorous loading to Lake Eucha, as simulated by SWAT. No applied litter, commercial nitrogen equivalent to current litter application rate is applied.

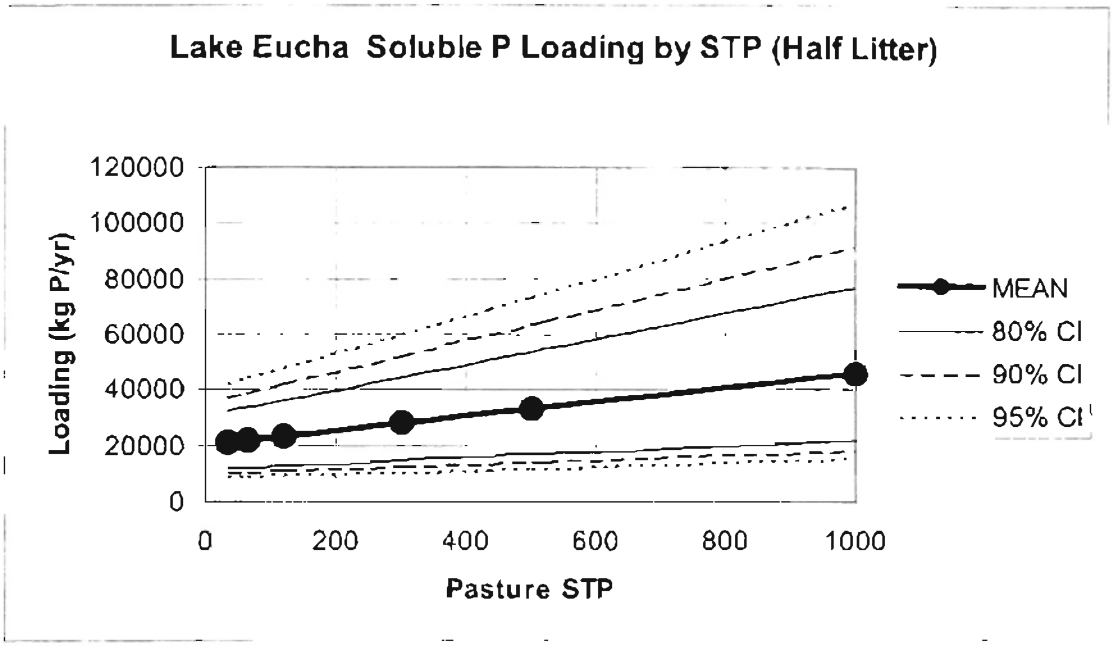


Figure 2.34 Soluble phosphorous loading to Lake Eucha as simulated by SWAT, half of the current litter rate is applied. Commercial nitrogen applied to maintain the total nitrogen application rate.

Table 2.28 *The effect of soil test phosphorous on the loadings to Lake Eucha as predicted by* SWAT (no litter, nitrogen supplemented)

Pasture	Flow m^3/s		Soluble P kg/yr		Sediment P kg/yr		Nitrate-N kg/yr	
STP	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	9.13	4.62	16812	6030	576	590	509066	247573
65	9.13	4.62	17535	6411	593	596	508923	247542
120	9.13	4.62	18918	7166	622	608	508713	247529
300	9.13	4.62	23496	9659	711	656	508114	247260
500	9.13	4.62	28587	12439	785	676	507524	246989
1000	9.13	4.62	40839	19111	923	729	506583	246511

Table 2.29 The effect of soil test phosphorous on the model loadings to Lake Eucha as predicted by SWAT(half of current litter rate, nitrogen supplemented).

Pasture	Flow m^3/s		Soluble P kg/yr		Sediment P kg/yr		Nitrate-N kg/yr	
STP	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	9.13	4.62	21137	8306	606	597	508213	247306
65	9.13	4.62	21872	8707	620	603	508142	247223
120	9.13	4.62	23278	9466	647	615	507932	247205
300	9.13	4.62	27886	11975	731	663	507501	247026
500	9.13	4.62	33018	14771	801	682	506991	246864
1000	9.13	4.62	45605	21640	935	734	506333	246438

Table 2.30 The effect of soil test phosphorous on the model loadings to Lake Eucha as predicted by SWAT(at current litter rate).

Pasture	Flow m^3/s		Soluble P kg/yr		Sediment P kg/yr		Nitrate-N kg/yr	
STP	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	9.13	4.62	25353	10553	626	603	507636	247021
65	9.13	4.62	26126	10964	640	609	507565	247029
120	9.13	4.62	27528	11724	666	621	507492	246977
300	9.13	4.62	32146	14238	746	669	507031	246843
500	9.13	4.62	37283	17029	814	688	506741	246604
1000	9.13	4.62	50003	23980	946	739	506167	246239

Grazing Rate Scenarios

Grazing rate was modified to determine its effect on nutrient loading. Grazing rate is the amount of forage removed in a given area as apposed to stocking rate which is a number of animals per unit area. Stocking rate, the type, and size of animals can be used to estimate grazing rate, additional detail is located in the Observed Data-Management section. Based on the SWAT model, results indicate that alterations to the current estimated grazing rate do not significantly reduce nutrient loadings. Grazing rate does not have a major impact on soluble phosphorous loading to Lake Eucha (Figure 2.35). However, doubling the grazing rate used in the calibration does have a significant effect of sediment-bound phosphorous (Figure 2.36).

Grazing rate scenarios may require changes to other model parameters, for instance curve number. Over-grazed pastures have a higher curve number because of reduced surface vegetation and increased soil compaction. Likewise, under-grazing simulations have a lower curve number indicating more surface vegetation. Simulations at the 2X level have curve numbers increased for all pastures by 4. The minimum biomass at which grazing is allowed was reduced from 600 kg/ha to 300 kg/ha, so that overgrazing would be properly simulated. Simulations at the 0.5X level and no grazing scenario have curve numbers reduced by 4. At the 2X rate the amount of phosphorous loading increases dramatically. Areas that are over-grazed could be contributing far more than the same area would if the stocking rate were reduced.

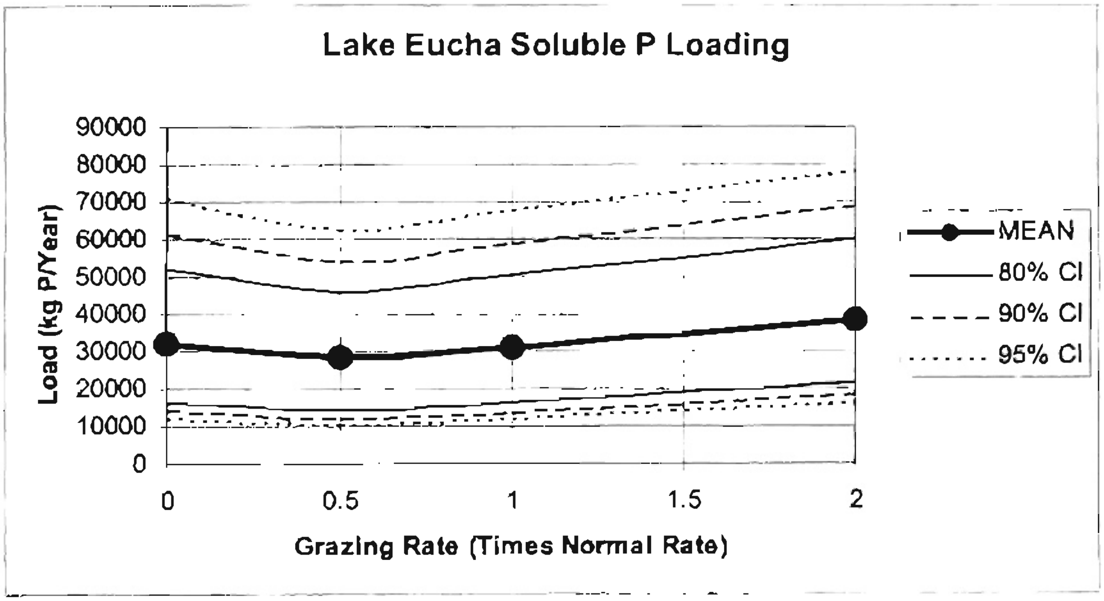


Figure 2.35 SWAT predicted soluble phosphorous loading to Lake Eucha as a function of grazing rate.

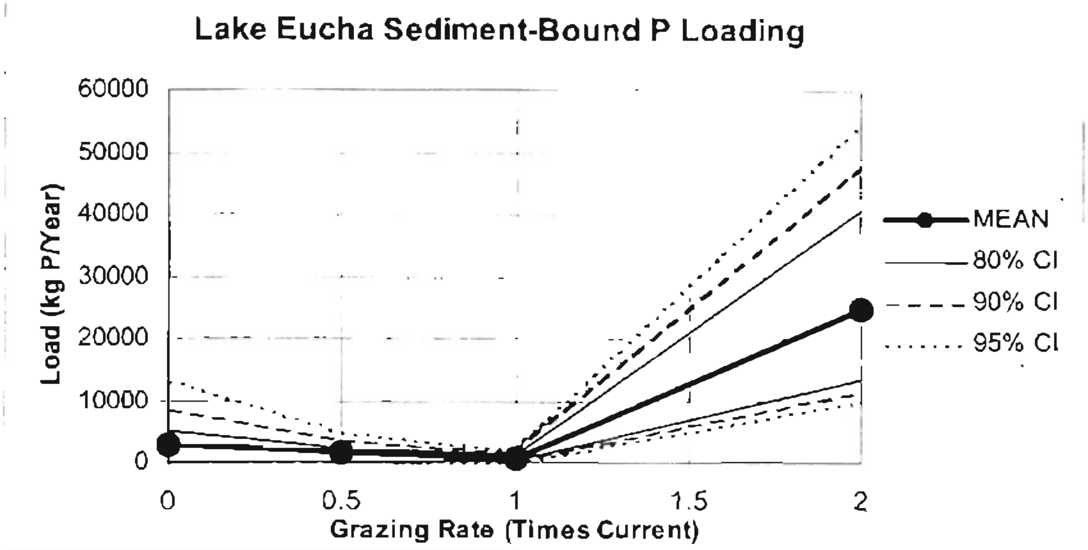


Figure 2.36 SWAT predicted sediment-bound phosphorous loading to Lake Eucha as a function of grazing rate.

Table 2.31 The effect of grazing rate on water yield and nutrient loading to Lake Eucha, as predicted by SWAT.

Grazing Rate	Flow m^3/s		Soluble P kg/yr		Sediment P kg/yr		Nitrate-N kg/yr	
X Normal	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
0	9.51	4.75	32334	14428	2975	6213	638659	315624
0.5	9.31	4.69	28257	12806	1438	3498	484828	252219
1	9.13	4.62	31174	13604	665	620	507045	246838
2	9.99	4.73	38629	14787	24891	7580	504688	214823

Decatur Point Source Control

Simulations were performed with a reduced Decatur point source contribution at 50% and 0% of the current load. Litter application and STP were not modified from the calibrated model. The contribution of the point source to the lake was estimated (Table 2.33). The observed total annual phosphorous point source loading is estimated to be 11,600 kg/year. The model indicates that 78% of the phosphorous added by the point source reaches the lake. Although SWAT does predict assimilation, on a long-term basis, almost all phosphorous entering the stream will eventually end up in the lake.

Table 2.32 Current nutrient loading of the Decatur point source. Estimated from Permit Compliance System data from the US Environmental Protection Agency for the period November 1997 to August 2000.

Parameter	Total P	Nitrates-N	Flow	Ammonia-N
Load	11,600 kg/yr	5,470 kg/yr	4,900 m^3/day	11,300 kg/yr
Concentration	6.53 mg/l	3.06 mg/l		6.33 mg/l

Table 2.33 Loading reduction to Lake Eucha at 50% and 0% of the current Decatur point source contribution as predicted by SWAT. Adjusted sediment-bound phosphorous used to calculate total phosphorous.

Point Source Loading	SOLUBLE P (kg/yr)	SEDIMENT P (kg/yr)	NITRATE-N (kg/yr	Total P(adj) (kg/yr)
100% of Current	31174	665	507045	47134
0% of Current	25301	531	501762	38045
50% of Current	28229	598	504385	42581
REDUCTION				
0% of Current	5872	134	5283	9088
50% of Current	2944	67	2660	4552

Long-term Simulations

A series of long-term simulations were performed to estimate long-term soil test phosphorous at different litter application rates. When phosphorous is applied in excess of what the crop can use, it builds up in the soil (Figure 2.38). When poultry litter is applied to meet the nitrogen requirements of the crop, phosphorous is over applied.

The default grazing rate was used for these simulations. Management operations, such as cutting hay, remove more nutrients from the pasture than grazing cattle, and may have a small impact on long-term Soil Test Phosphorous (STP). However, if the hay is fed inside the basin, the effect would be similar to grazing. Appendix D contains the calculations for STP at the current litter application rate.

STP was estimated by calculating an area weighted phosphorous balance for all pastures. Soil mineral phosphorous content and STP are quite different. STP is a measure of active and labile phosphorous. Soil mineral phosphorous includes active phosphorous and relative insoluble phosphorous compounds. These less soluble compounds represent the bulk of soil mineral phosphorous. Figure 2.37 depicts the steady-state partitioning of mineral phosphorus in the SWAT model.

The initial observed area weighted STP for pastures in the Lake Eucha Basin was estimated to be 250 lb/acre. The initial mineral phosphorous content, as estimated by SWAT's partitioning scheme (Figure 2.37), was 761 kg/ha (687 lb/acre). The net change was assumed to apply to only the top 6 inches of soil, the rest of the profile is assumed to have a constant STP. Organic phosphorous content was also assumed constant for all layers. The net change was added to the soil mineral phosphorous content from the previous year. STP was calculated from soil total mineral phosphorous each year using the same steady state partitioning as SWAT.

To check the SWAT model, the local history of the poultry industry was compared to SWAT simulations of STP. The poultry industry came to Delaware County about 25 years ago and about 40 years ago to Benton County (personal communication Jason Hollenback OSU Extension). At application rates of 0.5 and 0.75 of the current rate it would take 42 and 28 years for STP to increase from background to the current level of 250 lb/acre, respectively. Litter applications would have steadily increased from very little when there were few houses, to the current rate. Therefore, a fraction of the current rate between 0.5 and 0.75 is reasonable, and provides a reasonable verification of the method.

Figure 2.37 Steady state partitioning of mineral soil phosphorous in SWAT.

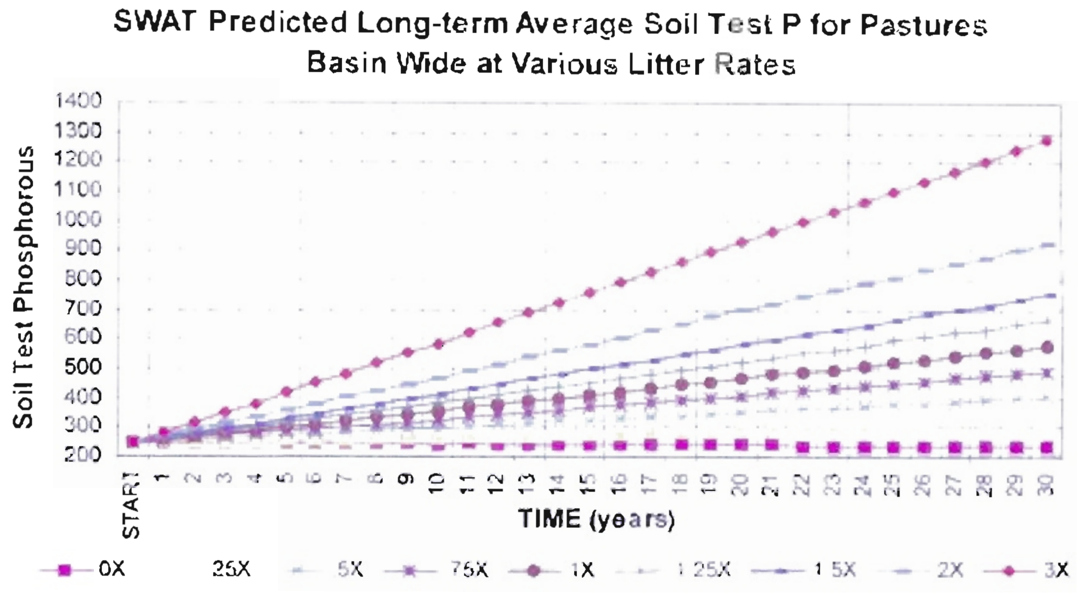


Figure 2.38 SWAT Model predicted Soil Test Phosphorous (STP) as a function of litter rate (fraction of current subbasin rate) over a 30 year period. These findings are model derived and subject to the same limitations

Table 2.34 SWAT model predicted Soil Test Phosphorous (STP) as a function of litter application rate over a 30-year period.

	Litter Application Rate (Times Normal Rate)								
YEARS	0X	.25X	.5X	75X	1X	1.25X	1.5X	2X	3X
START	250	250	250	250	250	250	250	250	250
1	250	252	255	258	261	264	266	272	283
2	249	254	260	265	271	277	282	294	317
3	249	256	264	272	280	288	297	313	348
4	247	257	268	279	290	301	312	335	381
5	247	260	273	287	301	315	329	358	415
6	246	262	278	295	311	328	346	380	449
7	246	263	282	302	321	341	361	401	482
8	246	267	289	311	334	357	380	426	519
9	245	269	293	319	344	370	396	448	552
10	244	270	297	325	353	382	411	468	584
11	245	274	305	337	368	400	432	495	623
12	244	275	308	341	376	410	445	514	654
13	243	278	314	351	388	426	463	539	689
14	243	280	320	360	400	440	480	561	724
15	242	282	325	368	412	455	498	585	760
16	241	284	329	374	420	466	512	605	791
17	240	286	334	383	432	481	530	628	826
18	240	288	340	391	443	495	547	651	861
19	239	291	345	400	455	510	565	675	896
20	238	292	349	406	463	521	579	695	928
21	238	295	355	416	476	537	598	720	964
22	237	298	361	425	488	552	616	743	999
23	236	299	364	430	496	563	629	763	1030
24	236	301	369	438	507	577	646	786	1065
25	235	304	375	447	520	592	665	810	1101
26	234	306	380	455	531	606	681	832	1135
27	234	308	386	464	542	620	699	855	1170
28	233	310	390	470	551	633	714	876	1202
29	232	313	397	480	565	649	733	902	1240
30	232	315	402	489	576	663	750	924	1274

Sensitivity Analysis

A sensitivity analysis was performed using many of the more easily modifiable parameters. It is not feasible to perform a sensitivity analysis on all parameters due to the number of parameters and the difficulty associated with modifying each one. The parameters selected include the more important parameters that are often used during the calibration of the SWAT model. To simplify calculations, loadings were calculated where Spavinaw Creek meets Lake Eucha (Figure 2.39), which contains the majority of the basin. The average annual outputs for a 20 year period was used to calculate sensitivity. A five year warmup period was used as in all previous simulations, and the model was run for the period 1/1/1975 to 12/31/1999.

Five observations were used to calculate relative sensitivity for each parameter. One observation was the calibrated model. Charts associated with each parameter and output are located in Appendix E. Relative sensitivity was calculated for the intervals between each of the five data points. The average of these four values is reported as the relative sensitivity.

One of the two equations below was used to calculate relative sensitivity. The equation used depends on how the parameter was modified. Input parameters may be modified by a percentage, by a fixed amount, or by directly setting the parameter value. A relative sensitivity calculation may in some cases require the use of an area weighted average, since SWAT is a distributed model. The relative sensitivity equations are:

$$S_r = \frac{(O_1 - O_2)/O_b}{(P_1 - P_2)/100}$$

where:

S_r = Relative sensitivity (non-dimensional)

O_b = Selected model output for baseline (calibrated) conditions

P_1 = Parameter adjustment %

P_{Δ} = Parameter adjustment %

O_1 = Selected model output @ P_1

O_2 = Selected model output @ P_2

$$S_r = \frac{P_b}{O_b} \cdot \frac{O_2 - O_1}{P_2 - P_1}$$

Where

S_r = Relative sensitivity (non-dimensional)

P_b = Parameter investigated baseline (calibrated) value

O_b = Selected model output for baseline (calibrated) conditions

P_1 = Parameter value adjusted less than P_b

P_2 = Parameter value adjusted greater than P_b

O_1 = Selected model output @ P_1

O_2 = Selected model output @ P_2

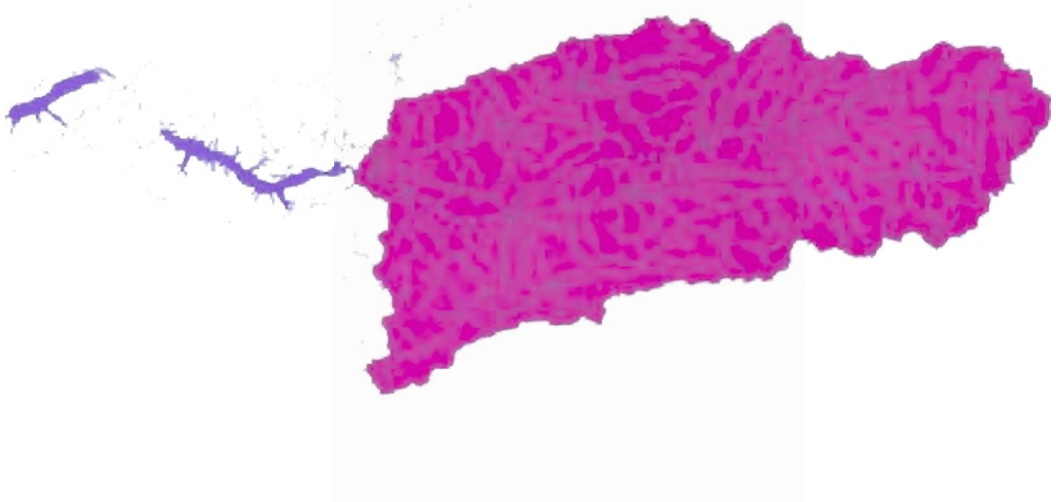


Figure 2.39 Portion of Lake Eucha Basin used in the sensitivity analysis

Table 2.35 Relative sensitivity for 18 primary SWAT input parameters.

Parameter	Flow	Sediment	Organic Nitrogen	Sediment P	Nitrate-N	Soluble P
Alpha Baseflow Factor	0.003	0.014	0.000	0.000	0.000	0.000
Soil Available Water Content	-0.817	-1.093	-1.917	-2.442	-0.708	-0.459
Biological Mixing Efficiency	-0.042	0.054	0.222	0.131	-0.263	-0.833
MUSLE "Minimum Crop Factor"	0.000	0.167	0.363	0.435	0.000	0.006
Channel Cover Factor	0.000	0.515	0.000	0.000	0.000	0.000
Channel Erodibility Factor	0.000	0.410	-0.053	-0.040	0.002	0.004
Channel K Factor	0.000	0.000	0.000	0.000	0.000	0.000
Curve Number	0.197	1.648	3.095	3.387	2.769	2.244
ESCO	2.214	1.616	1.021	0.992	0.842	0.868
Min. Depth in Shallow Aquifer for Baseflow	-0.006	-0.002	0.000	0.000	0.000	0.000
Nitrogen Percolation Coff.	-0.003	0.062	0.263	0.338	0.685	-0.033
PHOSKD	0.000	0.000	-0.059	-0.045	0.002	-0.914
Phosphorous Percolation Coff	0.000	0.000	0.016	0.076	-0.001	0.224
Min. Depth in Shallow Aquifer for Revap	0.006	0.002	0.000	0.000	0.000	0.000
Revap Factor	-0.019	-0.007	0.001	0.000	0.000	0.000
Slope Length	-0.001	0.079	0.340	0.386	-0.005	0.012
Slope	0.001	0.337	1.025	1.230	0.004	0.005
Soil Labile P (1 year warmup)	0.000	0.000	0.026	0.106	-0.001	0.198
Soil Labile P (5 year warmup)	0.000	0.000	0.014	0.176	-0.001	0.190

Model Limitations

There are several model limitations that should be noted. Model limitation may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is not perfect nor complete, and a model by definition is a simplification of the real world.

Weather is the driving force for any hydrologic model. Great care was taken to include as much accurate observed weather data as possible. The only weather information available was collected at weather stations. Data are collected at only a few points, and must be applied to an area of 1000 km^2. Rainfall can be quite variable, especially in the spring and summer when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence since they are typically not additive. This limitation, among others, cautions us against using model output on a daily basis or monthly basis.

Scenarios involving radical changes to the basin result in greater uncertainty. The SWAT model was calibrated using estimates of what is presently occurring in the basin. Large departures from calibration conditions raise the level of uncertainty.

Only a single point source was included in the model although there are many point sources in the basin. Other potential point sources include household septic systems, CAFOs other than poultry, and municipalities other than the City of Decatur; these could be significant

Land uses that cover only small areas were not represented in the model. Land uses that occupy limited areas such as unpaved roads, bare areas, construction sites, and row crops were not simulated. Most of these features were not depicted in the available GAP land cover. Some of these very small areas may contribute a thousand times more sediment than a pasture of the same area. Although significant, they cannot be simulated with the currently available data.

Each HRU in a subbasin was assumed to have the same characteristics by the model. For instance, the same slope was used for all pastures and forest HRUs in a single subbasin. Pastures are generally located in valleys or other flat areas. Forests generally occupy land that is steeper than pastures. This problem is more pronounced in a watershed of this type, where each land cover has such different topographical characteristics.

Long-term simulations of soil test phosphorous assume SWAT's soil phosphorous model is correct. The steady-state partitioning of phosphorous into SWAT's various soil phosphorous pools was used to estimate soil test phosphorous. In reality this partitioning varies by soil type and cultural practices.

There is a great deal of uncertainty associated with management. A single management scenario was applied uniformly to each particular land cover. These simulations assume all pastures are grazed, but not over-grazed. In the real world, management varies dramatically. Pastures may be cut for hay, over-grazed, under-grazed, planted with a particular forage, or not managed at all. It is not possible to easily determine what is happening where, or to simulate all these activities in the model. Therefore, a single reasonable management was selected and applied basin-wide.

An important limitation is that SWAT simulates poultry litter applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality poultry litter lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after application the litter interacts more closely with surface runoff than simulated by SWAT. In the field we would expect high phosphorous concentrations in surface runoff immediately following litter application. In the SWAT model, simulated phosphorous concentrations do not increase so dramatically when litter is applied. These limitations caution us against using SWAT predictions on daily or even monthly basis. On an average annual basis, these loading errors are less pronounced due to calibration.

As a check of the model the fraction of soluble phosphorous from each source was estimated from the model results (Figures 2.40 and 2.41). This is done to determine if the fraction attributed to each source is reasonable. The intent is not to claim that this is the actual breakdown. There are many assumptions that must be made in addition to those made in the model to perform this type of analysis. The assumptions made for this analysis were marginal and could not be used for all model outputs. These results are presented to reflect on the model accuracy only, and should be treated accordingly. The fraction of loading associated with each change to the model was isolated. For instance the contribution of the load due to the application of poultry litter was estimated as the difference in the predicted load between the 1x application rate and the 0x rate. The fraction associated with litter applications is a conservative estimate, due to model limitations at racially different management conditions. The other constituents were similarly calculated. The contribution of STP was estimated as the difference between the 300 lb/acre STP and 35 lb/acre scenarios. Sources were determined for soluble phosphorous and nitrates. Total phosphorous is linked with sediment, and there was too much interaction between the sources for this method to produce a reasonable breakdown for total phosphorous.

The fraction associated with deforestation was calculated by modeling background conditions with pastures and forest and subtracting the background loading. Background estimates were made assuming an all forest watershed. The additional loading associated with the conversion of forest to pastures is the result. Other sources were calculated such that the total loading from all sources matches the calibrated model loading. It should also be noted that these estimates assume there is no interaction between the sources. The relative percentages for each source were calculated using only the average annual model output. Rainfall uncertainty could cause a dramatic shift in the percentages from any given year.

SWAT models in-stream processes based, in large part, on unvalidated assumptions of channel and stream-bank properties. These in-stream processes are the primary cause of the low sediment-bound phosphorous prediction by the calibrated model. Sediment-bound phosphorous was under predicted in all simulations. I think this is the result of phosphorous being deposited with sediment in the stream, but not being reintrained during high flow periods. In the SWAT model, sediment that was re-entrained did not appear to contain phosphorous. Sediment from stream degradation was increased by two orders of magnitude, and there was little change in sediment-bound phosphorous.

Sediment-bound phosphorous was lost from the system as a result of the stream processes. This would not happen in the real world. Almost all nutrients entering the stream system would eventually reach the lake, provided there is no net deposition of sediment or nutrient export from the stream system. To adjust for this, a correction factor was estimated using the calibrated model and observed loadings. Sediment-bound phosphorous was underestimated by a factor of 24 in the calibrated model. This fraction was assumed to be constant for all scenarios, and applied only to the Lake Eucha Basin. This method produced reasonable estimates of total phosphorous for all BMPs simulated.

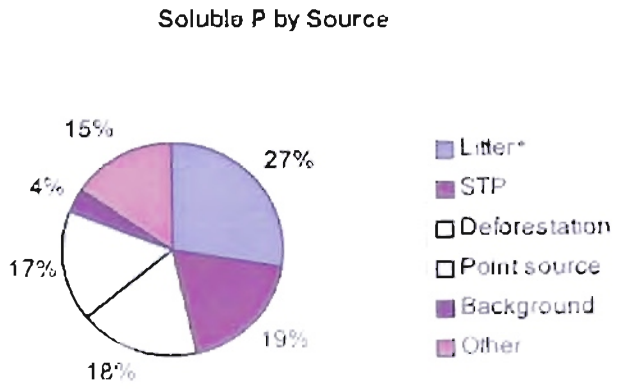


Figure 2.40 Soluble phosphorous loading to Lake Eucha breakdown by source, as predicted by SWAT. This analysis required many assumptions, these data are presented to illustrate model limitations, and should be used in that context. * Conservative estimate, litter applications should account for a greater percentage of the loading.

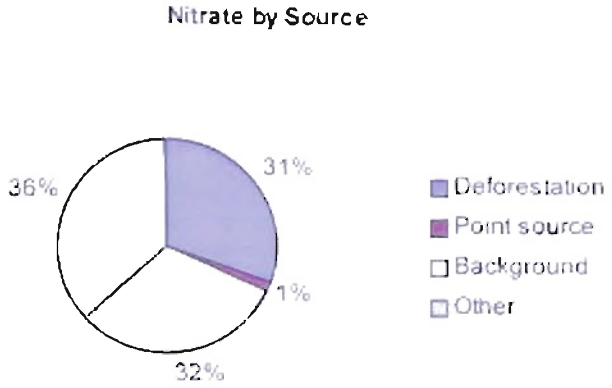


Figure 2.41 Nitrate loading to Lake Eucha breakdown by source, as predicted by SWAT. This analysis required many assumptions, these data are presented to illustrate model limitations, and should be used in that context

CHAPTER 3 Great Salt Plains Basin BMPs

Introduction

The Great Salt Plains Reservoir is one of Oklahoma's most unique areas. It is located just west of Cherokee, Oklahoma (Figure 3.1). On the shores of the lake lie 11,000 acres of salt plains, most of which is part of the Salt Plains National Wildlife Refuge. The salt plains and lake are the seasonal home of many migratory birds. This area is an important stopping place for ducks and geese during their migratory trip over the plains.

The salt plains are thought to be a remnant of ocean flooding millions of years ago. These plains are the only place in the world where hourglass shaped Selenite crystals can be found. Selenite crystal is a form of gypsum. These crystals grow just below the salt-encrusted surface. The crystals grow and dissolve with the changes in salinity of the brine that lies under the surface of the salt plains. The lake averages only 4 feet deep and is about half as salty as ocean water. In recent years, siltation has become an increasing problem for the lake and its tributaries. Sediment, pesticides, and nutrients from the rangeland and the wheat fields of Oklahoma and Kansas wash into tributaries that feed the reservoir. Excessive nutrients cause algae blooms that deplete the water of oxygen and kill fish.

Hydrologic Modeling

The basin covers some 8,000 square kilometers around the Oklahoma-Kansas border. Much of this area is used for farming and grazing cattle. The purpose of this project is to recommend BMPs (Best Management Practices) for agricultural lands in the basin. Computer modeling was used to simulate and compare BMPs. Soil and Water Assessment Tool (SWAT) is a hydrologic model that was used to predict how management changes effect basin loading of sediment, nutrients, and pesticides.

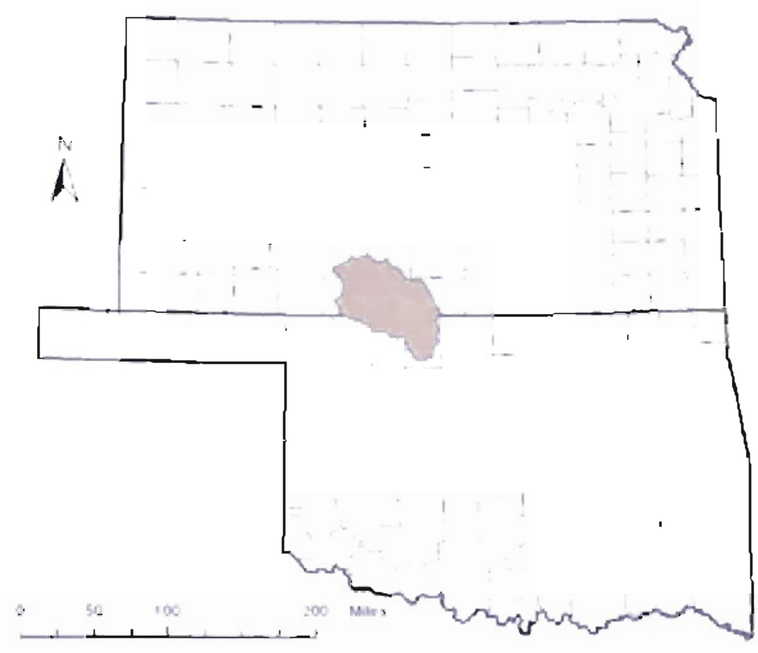


Figure 3.1 Location of the Great Salt Plains Reservoir Basin

SWAT Input Data

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be generated statistically.

Topography

Topography was defined by a DEM (Digital Elevation Model). DEMs for the United States are available for download via the Internet. The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Individual 1:24,000 thirty meter DEMS were stitched together to construct a DEM for the entire basin. When tiled, 1:24,000 DEMS often have missing data at the seams. These missing data must be replaced. A 3x3 convolution filter was applied to the DEM to produce a seamless filtered DEM. Any missing data at the seams of the original DEM were replaced with data from the filtered DEM. The resulting seamless DEM retains as much non-filtered data as possible (Figure 3.2). Filtering tends to remove both peaks and valleys from a DEM thereby reducing the perceived slope. For this reason the use of filtered data were kept to a minimum.

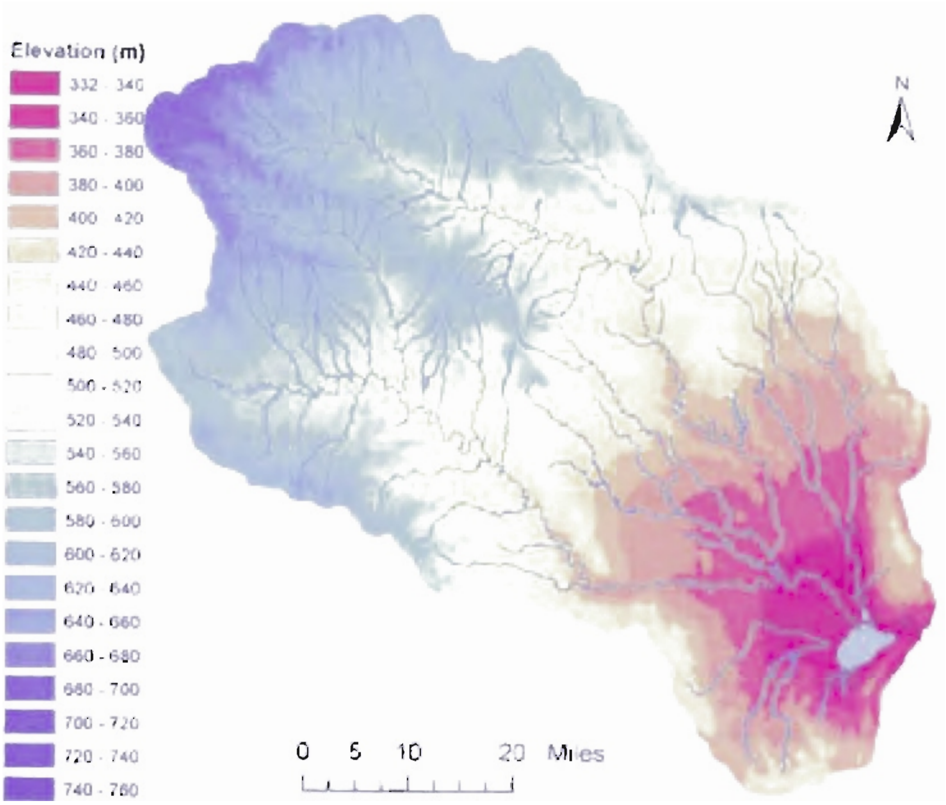


Figure 3.2 Digital Elevation Model (DEM) of the Great Salt Plains Basin with stream network Derived from US Geographic Survey 1:24,000 DEMs

Soils

Soil GIS data are required by SWAT to define soil types. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes. The GIS data must contain the S5ID (Soils5id number for USDA soil series) or STMUID (State STATSGO polygon number) to link a soil to the STATSGO database.

The soils layer was derived from three separate GIS coverages. The Alfalfa County, Oklahoma portion is 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS. The Woods County, Oklahoma portion is certified SSURGO (Soil Survey

Geographic) soils data from the Oklahoma NRCS. The Kansas portion is 1:24,000 detailed soils digitized by Kansas State University.

These highly detailed soils data are difficult to use with the SWAT model. The SWAT model has an internal database of soil properties based on STATSGO data. SSURGO data contains soils that are not available in this database. The most similar soils listed in the SWAT database were substituted for these unavailable soils. Similarity was based on soil properties weighted by their relative importance. Only soils with the same hydrologic soil group were considered for substitution. A score from zero to 1000 was given based on the formula:

Score =1000 -∑(Relative difference at parameter * Parameter importance)

Parameter importance is given in Table 3.1. A score of 1000 is a perfect match but any score above 800 was assumed to be a reasonable match (Figure 3.3). Any soils with matching S5IDs are automatically assigned a score of 1000. A program was written to search all soils in the STATSGO database for Oklahoma, Texas, and Kansas. The ten highest ranking soils were recorded and the best among them were manually selected. An example output from the program is located in the Appendix F (Table F1).

Table 3.1 Parameter importance used to match SSURGO (Soil Survey Geographic) Soils to the STATSGO (State Soil Geographic) database included with SWAT.

Parameter	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Fine earth fraction	15	10	8	5	2
Permeability low	10	7	5	4	2
Permeability high	10	7	5	4	2
Clay content low	8	6	4	3	2
Clay content high	8	6	4	3	2
Organic matter content low	8	6	4	3	2
Organic matter content high	5	6	4	3	2
Layer depth	8	4	4	3	2
Available water low	8	6	4	3	2
Available water high	8	6	4	3	2
Bulk density low	7	6	4	3	2
Bulk density high	7	6	4	3	2
% passing #4 sieve low	5	4	4	3	2
% passing #4 sieve low	5	4	4	3	2
% passing #200 sieve low	5	4	4	3	2
% passing #200 sieve low	5	4	4	3	2

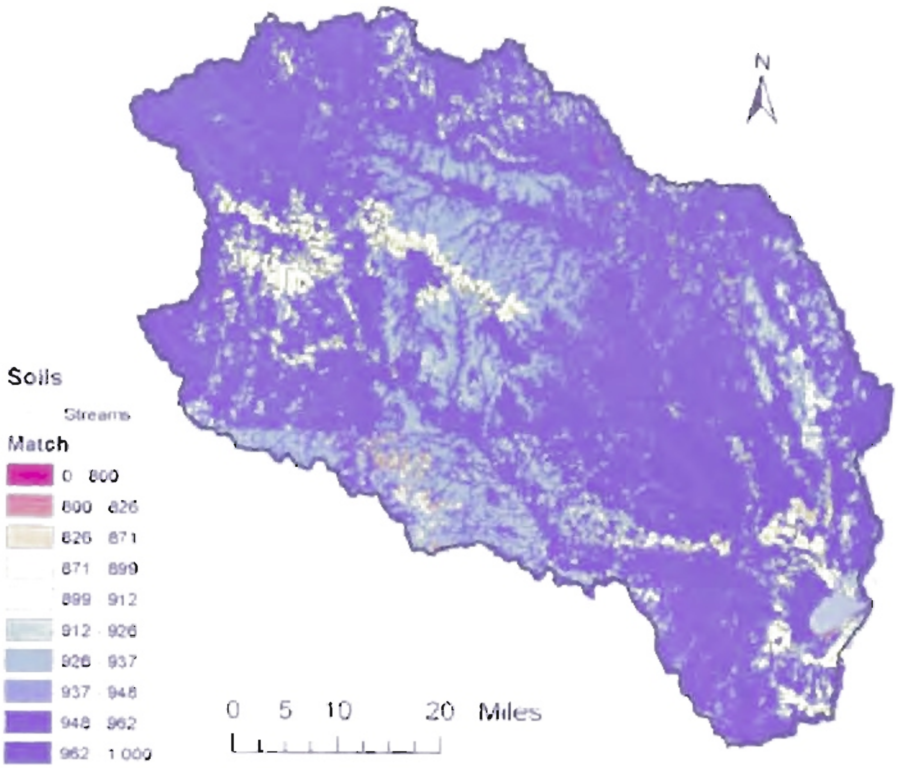


Figure 3.3 Results of high detail soils to SWAT soils matching algorithm.

Land Cover

Land cover is perhaps the most important GIS data used in the model. The land cover theme determines the amount and distribution of wheat and range in the basin. These two land covers are managed very differently. It is important that these data be based on the most current data available since land cover changes over time. Topography and soils cannot be changed so easily or rapidly by man. Land cover was derived from Oklahoma and Arkansas NLCD (National Land Cover Data). The NLCD project mapped vegetation based on 30 meter Landsat Thematic Mapper satellite imagery.

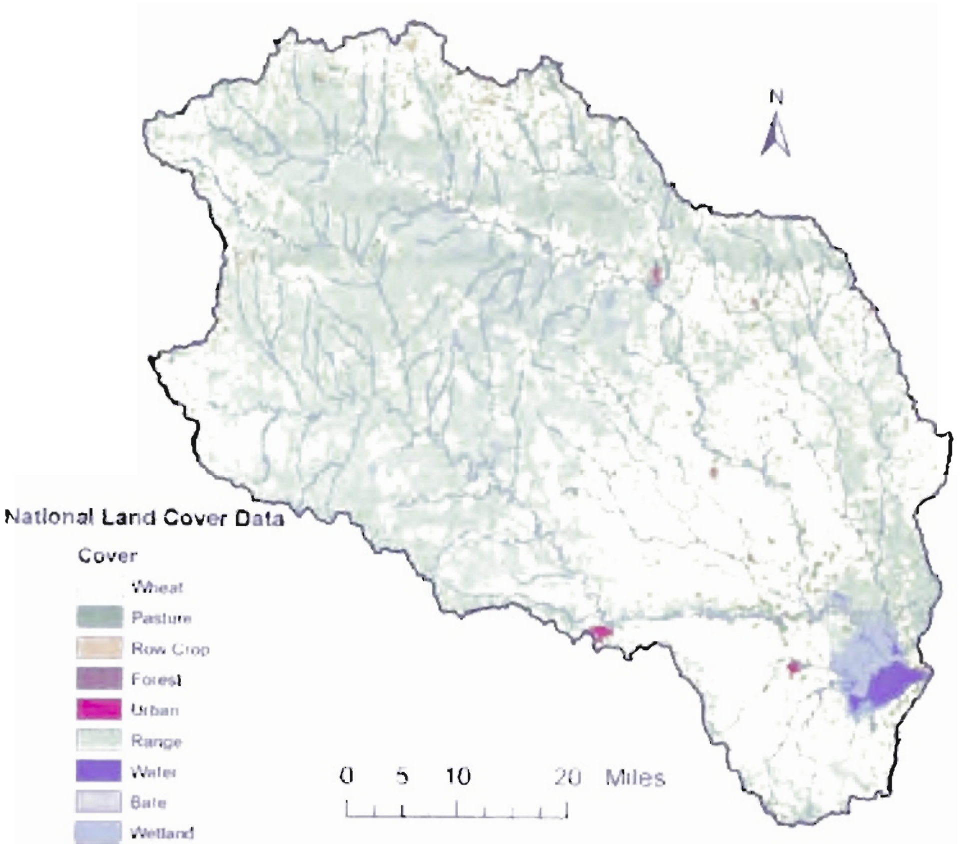


Figure 3.4 National Land Cover Data (NLCD) derived land cover for the Great Salt Plains Reservoir basin

Weather

SWAT can use observed weather data or simulate it using a database of weather statistics derived from stations across the US. Observed daily precipitation and minimum and maximum temperature data were used in the Great Salt Plains model. National Weather Service COOP (Cooperative Observing Network) station data from 28 stations from 1/1/1950 to 12/31/99 were used to in the SWAT model (Figure 3.5). COOP data are available from the NOAA (National Oceanic and Atmospheric Administration). Average annual precipitation varies by almost six inches across the basin (Figure 3.6), so it is important to have as many stations as possible.

COOP data are seldom continuous for long periods of time. Missing days and even months are common. The period of record at stations are inconsistent, so the number of active stations changes with time. When SWAT detects missing data at a station, it generates simulated weather. Gaps in a station's record were filled with interpolated data from surrounding stations. Shepherd's weighted interpolation was used because it is computationally efficient.

Shepherd's method uses weighting factors derived from the distance to nearby stations within a fixed radius:

$$Z_0 = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i}$$

where Z_0 is the precipitation at the station of interest in mm, Z_i is the precipitation at station i in mm, and W_i is the weighting factor at station i. Weighting factors are calculated using the distance between stations:

$$W_i = (1 - \frac{d_i}{R})^2 \text{ for } \frac{d_i}{R} < 1 \text{ And } W_i = 0 \text{ for } \frac{d_i}{R} \geq 1$$

where R is the radius of influence in meters and d_i is the distance from station of interest to station i in meters.

Because of the large amount of data associated with these weather files, all processing and formatting was accomplished with custom programs written in VBA (Visual Basic for Applications) and Microsoft Excel (Microsoft Corporation 1999). SWAT assigns each subbasin to the closest gage station to the subbasin centroid so many of the original 28 stations were not used by SWAT. The purpose of these extra stations was to fill gaps in records for the stations that were used by SWAT.

Figure 3.5 National Weather Service Cooperative Observation network precipitation and temperature station locations near the Great Salt Plains Reservoir Basin.

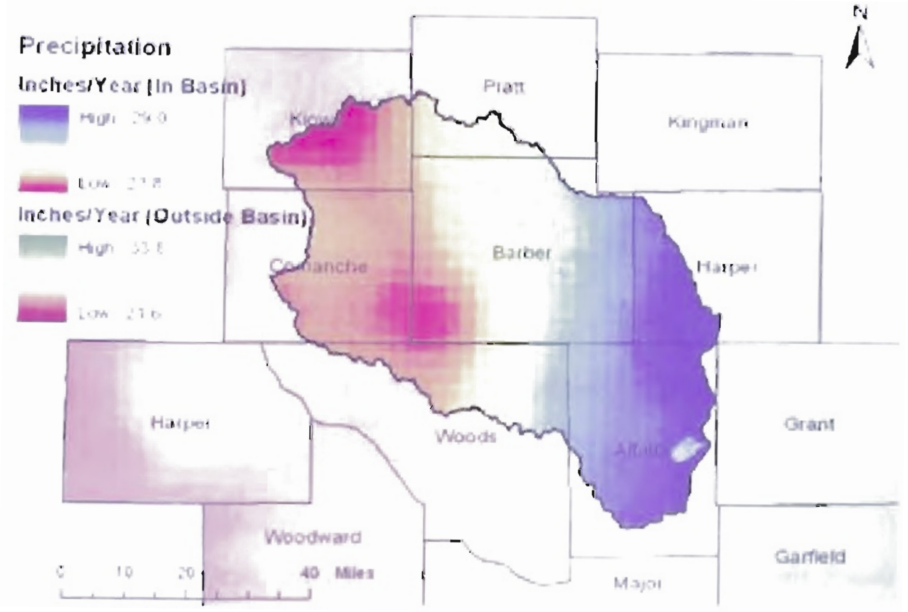


Figure 3.6 Precipitation based on PRISM (Parameter-elevation Regressions on Independent Slopes Model) data for the Great Salt Plains Reservoir Basin

Subbasin Delineation

The subbasin layout was developed using the DEM, a stream burn-in theme, and a table of additional outlets. A stream burn-in theme is simply digitized streams. Its purpose is to help SWAT define stream locations correctly in flat topography. Model output is only available at subbasin outlets so additional outlets were added at points of interest, such as gage stations. A stream threshold value of 1000 ha was used to delineate subbasins. Threshold area is the minimum contributing upland area required to define a single stream. This resulted in 210 subbasins (Figure 3.7). Fewer subbasins would simplify the modeling process, but this level of detail was needed to adequately represent the basin.

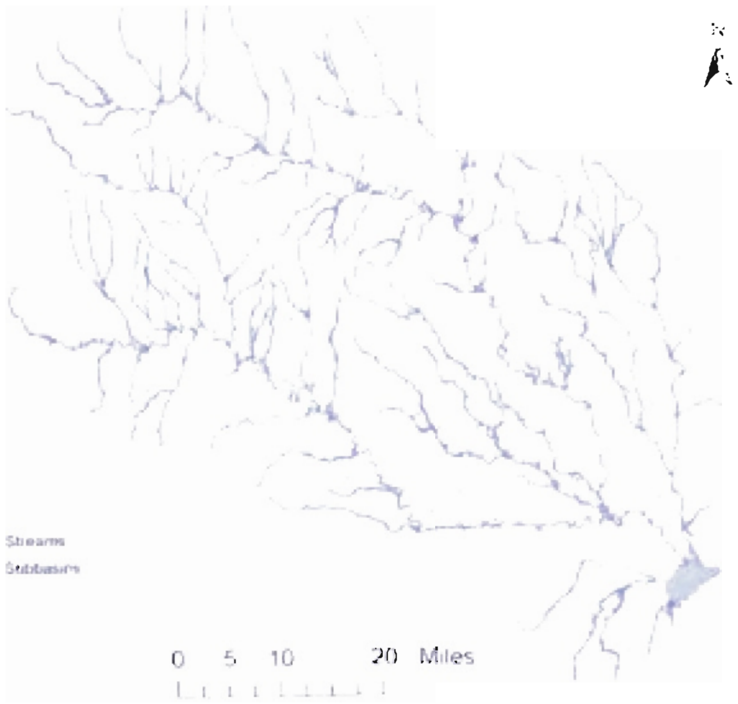


Figure 3.7 Subbasin layout used in SWAT model. The Great Salt Plains Reservoir Basin is simulated as 210 subbasins.

HRU Distribution

Each of the 210 subbasins was split into HRUs (Hydraulic Response Units) by SWAT. The *land use [%] over subbasin area threshold* was changed from the default 20% to 3%. This threshold determines the minimum percentage of any land cover in a subbasin that will become an HRU. The *soil class [%] over subbasin area* was also reduced from its default value of 20% to 10%. By reducing these thresholds, the number of HRUs was increased to 2,745, allowing more spatial detail to be incorporated into the SWAT model. The average area of each HRU was 2.97 square kilometers, but there was significant variability in sizes (Figure 3.8).

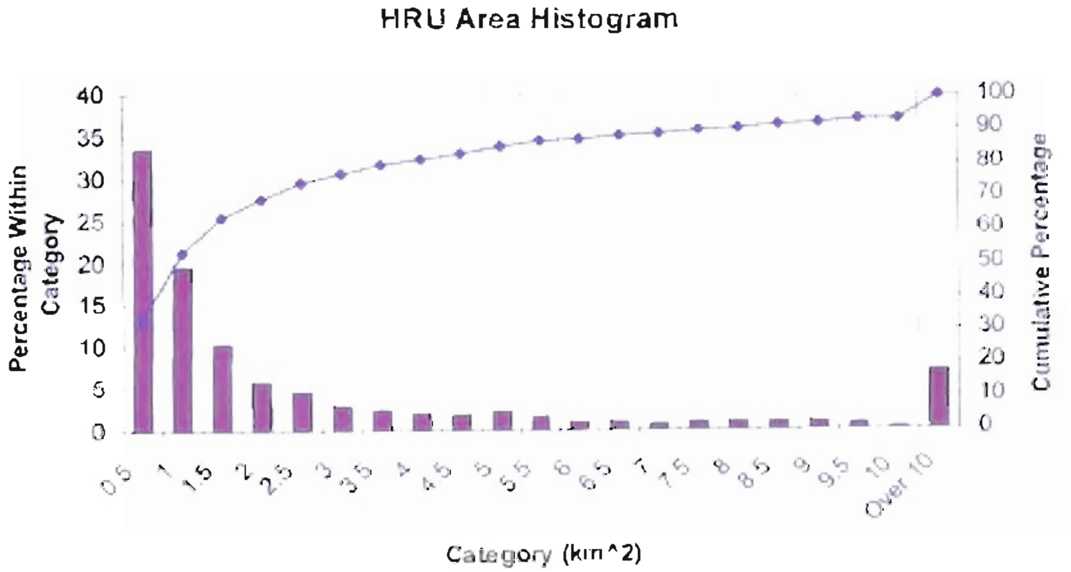


Figure 3.8 Histogram of Hydrologic Response Unit (HRU) sizes which make up the SWAT representation of the Great Salt Plains Basin

Soil Phosphorous Content

Two distinctly different methods were used to estimate soil phosphorus content. Soil phosphorous content for agricultural areas were estimated using observed soil test data. Soil phosphorous content for un-managed range was based on SWAT computer simulations.

Range - Soil Phosphorous Content

Soil phosphorous estimates for un-managed range areas were based on SWAT computer simulations. A reasonable phosphorous yield for rangeland was considered to be between 0.25 and 1.46 kg P/ha (Beaulac and Reckhow (1982) values for unfertilized grazed bluestem in Chickasha, Oklahoma). A value of 30 lb/acre phosphorous was selected for rangeland areas of the Salt fork calibration area, which produced a phosphorous yield of 1.1 kg P/ha. Modifications to soil phosphorous were made using the SWAT input parameter Sol_labp (Labile [soluble] phosphorous concentration in the surface layer, mg/kg). This parameter also sets the amount of phosphorous in SWAT's various phosphorous pools. Sol_labp was assumed to be related to soil test phosphorous by:

Melich III Soil test P (lb/acre) = 5 sol_labp (mg/kg)

Agricultural Crops - Soil Phosphorous Content

Observed Melich III soil test data were used to determine the soil phosphorous content for agricultural areas. County extension agents Bob Levalley, Kevin Sheltion and Tommy Puffenberger provided soil tests from different portions of Alfalfa and Woods counties. Annual county level BRAY II soil test summaries were provided by David Whitney (Extension State Leader Agronomy Program) for the Kansas portion. Summaries from 1995-1999 were averaged to provide estimates of STP for each county in the Kansas portion of the basin. Bray II and Melich III are comparable in the acidic soils which dominate the agricultural portions of the basin (Hailin Zhang OSU soil testing lab director, personal communication). These data are mapped in Figure 3.9. An area weighted soil test phosphorous was calculated for each of SWAT's 210 subbasins.

I used a specially compiled version of the SWAT model. At our request, Susan Neitsch (SWAT team, user assistance) modified SWAT 99.2 such that the entire soil profile was set to the same soluble phosphorous as the surface layer. The original SWAT 99.2 allows only the soluble phosphorous in the top 10 mm of soil to be set by the user, and the remainder of the soil profile is set to a value of

20 mg P/kg soil. The original SWAT was not very sensitive to changes in soil phosphorous. Adjustments to the phosphorous content of the top 10 mm made little difference to the total amount of phosphorous in the soil profile. Mixing between layers made the phosphorous content of the top 10 mm approach the default value of the layer beneath in a few years.

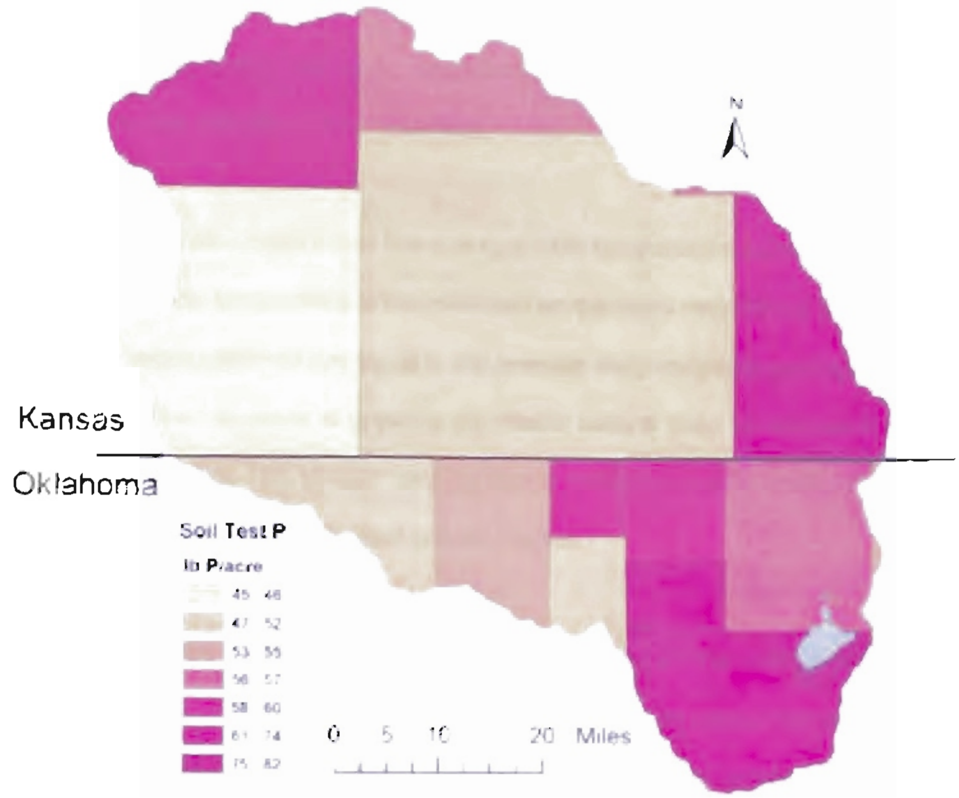


Figure 3.9. Soil test phosphorous for agricultural areas derived from soil samples of the Great Salt Plains Reservoir Basin.

Current Management

The current management was determined from a phone survey of producers in September 1999. Eighty-seven respondents answered a variety of questions about their wheat, sorghum, and alfalfa production. Data from this survey were used to determine how much wheat was used for grazing, for grain, or for both (Table 3.2). Survey information was also used to determine the relative proportion of moldboard plowing, stubble mulch tillage, and low-till wheat in Wood`s and Alfalfa counties.

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date or as a fraction of the total heat units required by the crop. Heat unit scheduling is the default. All forest, wetland, rangeland, and urban HRUs used the default management generated by the ArcView SWAT interface.

Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The heat units accumulated each day are equal to the average daily temperature minus the base temperature of the plant. When no plant is growing the model uses a base temperature of 0° C and keeps a separate running total. This base 0° running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

Wheat grazing was simulated at a stocking rate of 0.33 animal units per acre (Oklahoma State University Extension Facts 2855), with 9.35 kg of dry biomass consumed and 2.92 kg of dry manure deposited per hectare (ASAE D384.1). The grazing occurs for a maximum of 100 days. Any time there was less than 600 kg (dry weight) of biomass per hectare, grazing was suspended.

Originally, the small grains category from the NLCD was separated into nine categories, each with a different wheat management. Many categories were too small to be represented in the model. The number of wheat management categories was reduced from nine to four. The five deleted categorizes were redistributed among the remaining four based on the area of the remaining categories.

The management of each category was defined by a particular set of operations (Table 3.3). The individual operations and their timing was based on survey information, and recommended practices for wheat. The goal was not to emulate the exact management, as this varies by field, but to select reasonable management operations for each category.

Table 3.2 Managements for the Salt fork Basin derived from survey results.

	Wheat for grain only				Wheat for grazing only			
County	Sub-total	MB plow	Stubble	No till	Sub-total	MB plow	Stubble	No till
Alfalfa	31.2%	19.6%	10.1%	1.6%	6.5%	4.1%	2.1%	0.3%
Woods	59.7%	21.5%	35.2%	3.0%	11.0%	4.0%	6.5%	0.6%

	Wheat for grazing and grain			
County	Sub-total	MB plow	Stubble	No till
Alfalfa	62.3%	39.1%	20.1%	3.1%
Woods	29.3%	10.6%	17.3%	1.5%

Table 3.3 Management operations for wheat in the Great Salt Plains Basin.

Stubble Mulch (Grazing and Grain)

Operation	Date
70 lb/acre Nitrogen (surface)	1-Feb
Harvest	15-Jun
Duckfoot cultivator	15-Jul
30 lb/acre Phosphorous (surface)	1-Aug
40 lb/acre Nitrogen (sub-surface)	15-Aug
Disk	30-Aug
Plant Wheat	1-Sep
Grazing 0.33 Animal unit/acre (100 days)	1-Nov

Moldboard Plow (Grazing and Grain)

Operation	Date
70 lb/acre Nitrogen (surface)	1-Feb
Harvest	15-Jun
Moldboard plow	15-Jul
30 lb/acre Phosphorous (surface)	1-Aug
Disk	2-Aug
40 lb/acre Nitrogen (sub-surface)	3-Aug
Disk	20-Aug
Plant Wheat	1-Sep
Grazing 0.33 Animal unit/acre (100 days)	1-Nov

Moldboard Plow (Grain only)

Operation	Date
40 lb/acre Nitrogen (surface)	1-Feb
Harvest	1-Jul
Moldboard plow	15-Jul
30 lb/acre Phosphorous (surface)	10-Aug
Disk	11-Aug
40 lb/acre Nitrogen (sub-surface)	11-Aug
Disk	1-Sep
Plant Wheat	15-Sep

Stubble Mulch (Grain Only)

Operation	Date
40 lb/acre Nitrogen (surface)	1-Feb
Harvest	1-Jul
Duckfoot cultivator	15-Jul
30 lb/acre Phosphorous (surface)	1-Sep
40 lb/acre Nitrogen (sub-surface)	1-Sep
Disk	1-Sep
Plant Wheat	15-Sep

Calibration

Calibration is the process by which a model is adjusted to more closely match observed data. Calibration greatly improves the accuracy of a model. The SWAT model was calibrated using observed stream flow. However, insufficient water quality data were available to perform a sediment or nutrient calibration.

Calibration Areas

Three USGS flow gages have daily data useful for calibration: Medicine Lodge near Kiowa, Salt fork near Alva, and Salt Fork near Jay (Figure 3.10). The basin was divided into three areas:

- Area above the Salt Fork near Alva gage, referred to as the Salt Fork calibration area.
- Area above the Medicine Lodge near Kiowa gage, referred to as the Medicine Lodge calibration area.
- Area above the Salt Fork near Jay gage but not included in previous two areas. Referred to as the GSP (Great Salt Plains) Reservoir area since the gage that serves this area is just below the reservoir dam.

Calibration using data from the Salt Fork near Jay gage was limited to average annual total flow, because baseflow separation cannot be performed on data collected downstream of the reservoir.

Figure 3.10 River, streams and active gage stations in the Great Salt Plains Basin

Baseflow Separation

Stream flow has two primary sources surface runoff and ground water. Ground water contributions to stream flow is baseflow. The SWAT model was calibrated separately against observed surface runoff and baseflow. Baseflow was separated from the total observed stream flow using the USGS HYSEP sliding interval method. The method is given below.

The duration of surface runoff is calculated from the empirical relationship

$$N=A^{0.2}$$

where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval 2N* used for hydrograph separations is the odd integer between 3 and

11 nearest to 2N. I adjusted the interval to provide a range of acceptable baseflow values. The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated (Figure 3.11). Baseflow fractions were higher than expected throughout the basin. This could be the result of the shallow ground water and wetlands commonly found throughout the basin.

Table 3.4 Observed average flow and baseflow fractions as determined by the HYSEP sliding interval method.

Gage	Total Flow (m^3/sec)	Baseflow		Surface Runoff	
		High	Low	High	Low
Salt Fork	3.96	57%	51%	49%	43%
Medicine Lodge	5.26	63%	58%	42%	37%

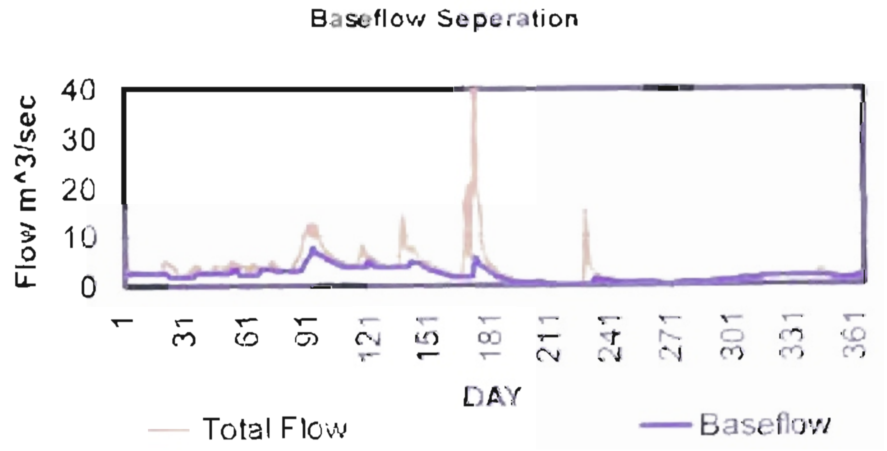


Figure 3.11 Baseflow separation hydrograph example

Calibration Results

Table 3.5 contains observed and SWAT simulated flow after calibration. Average annual total flow at all three areas was calibrated to within 3% of the observed flow (Table 3.6). Larger errors are permissible for both surface runoff and baseflow fractions since these fractions are only estimates.

Table 3.5 Observed and SWAT simulated flows for each calibration area.

	Simulated (m^3/sec)			Observed (m^3/sec)		
Area	Total flow	Surface runoff	Baseflow	Total flow	Surface runoff	Baseflow
Medicine Lodge Area	5.40	2.93	2.47	5.27	3.16	2.11
Salt Fork Area	3.99	2.29	1.70	3.96	2.00	1.96
Entire Basin	13.17	N/A	N/A	13.34	N/A	N/A

Table 3.6 Relative difference in flow from each calibration area.

	Relative Difference (%)		
Area	Total flow	Surface runoff	Baseflow
Medicine Lodge Area	-3	7	0
Salt Fork Area	-1	15	13
Entire Basin	1	N/A	N/A

Salt Fork Calibration

The Salt Fork calibration area is 982 square miles, and is represented by 55 subbasins and 465 HRUs in the SWAT model. Figures 3.12 and 3.13 contain the results of the calibration

The following modifications to the default SWAT model were made during the calibration:

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.005.
- Soil evaporation compensation factor was increased from 0.95 to 0.99.
- Initial depth of water in the shallow aquifer was increased to 100 mm.
- Depth of water in shallow aquifer required for baseflow was set to 100 mm.
- Depth of water in shallow aquifer required for revap was set to 300 mm.
- Recharge to the deep aquifer was set to 0.

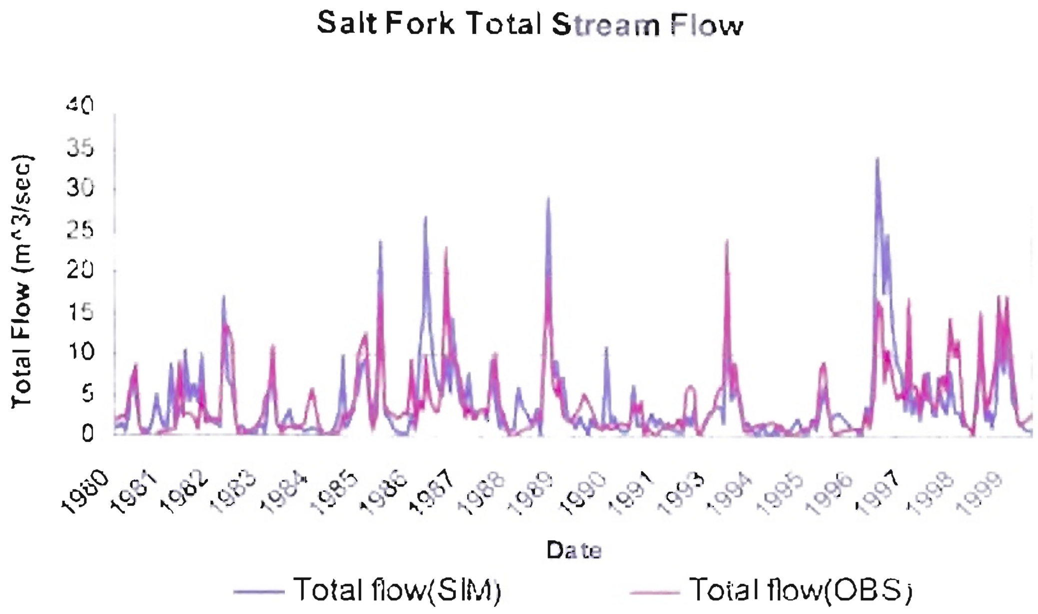


Figure 3.12 SWAT simulated and observed total flow for the Salt Fork calibration area

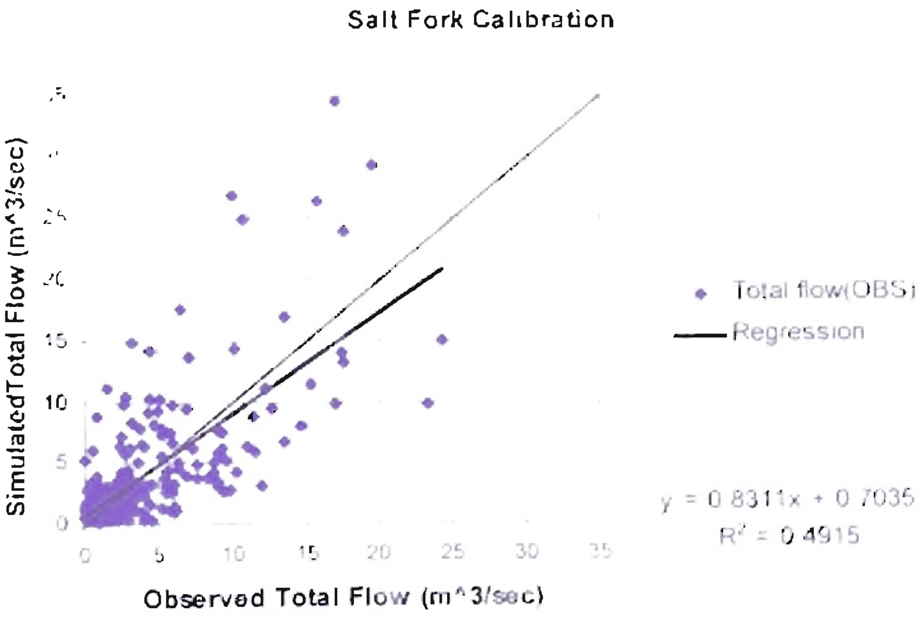


Figure 3.13 SWAT simulated vs. observed total flow for the Salt Fork calibration area.

Medicine Lodge Calibration

The Medicine Lodge calibration area is 889 square miles, and is represented by 69 subbasins and 855 HRUs in the SWAT model. Figure 3.14 and 3.15 contain additional detail about the results of the hydrologic calibration.

The following modifications to the default model were made to calibrate this area:

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.027
- Soil evaporation compensation factor was increased from 0.95 to 0.99
- Initial depth of water in the shallow aquifer was increased to 100 mm
- Depth of water in shallow aquifer required for baseflow was set to 100 mm.
- Depth of water in shallow aquifer required for revap was set to 300 mm
- Recharge to the deep aquifer was set to 0

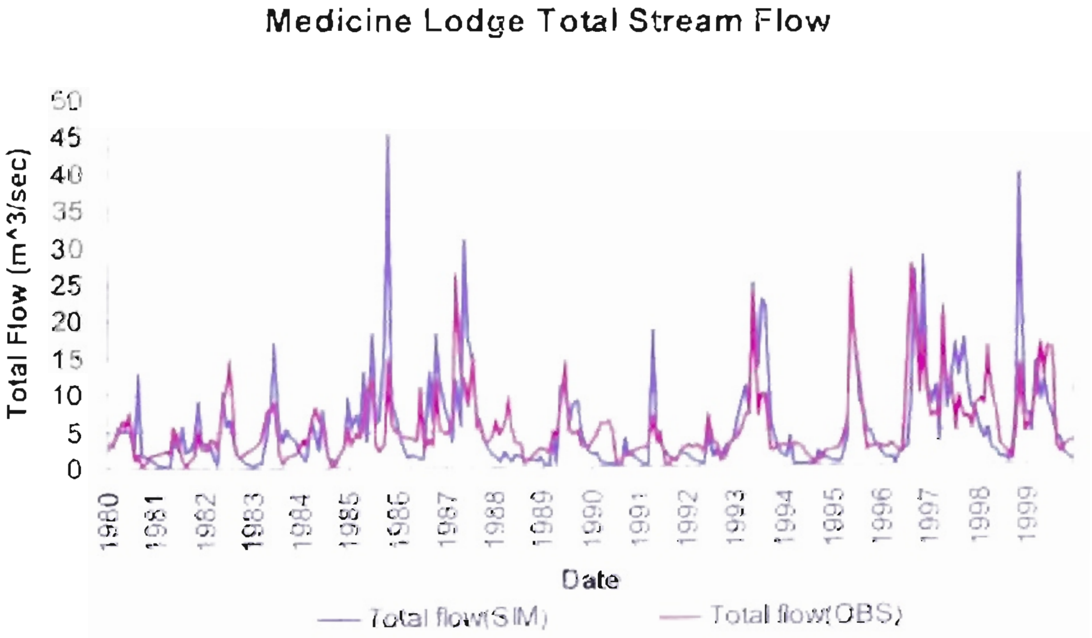


Figure 3.14 SWAT simulated and observed total flow for the Medicine Lodge calibration area

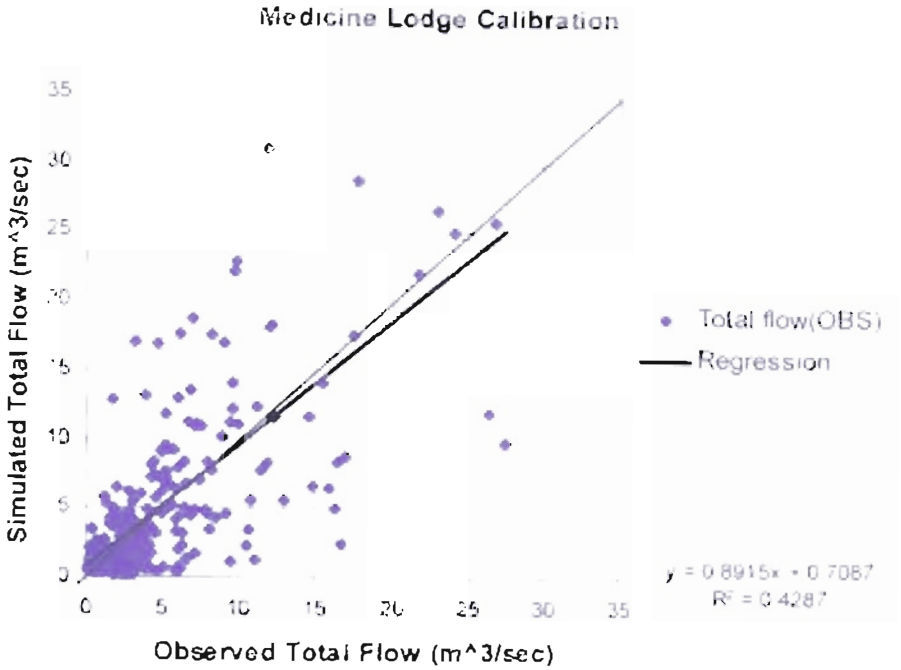


Figure 3.15 SWAT simulated vs. observed total flow for the Medicine Lodge calibration area

GSP Calibration Area

The area downstream the gages was calibrated using stream gage data taken downstream the Great Salt Plains Reservoir dam. The useful period of record at this USGS station (Salt Fork Arkansas River Near Jet, OK) was shorter than the pervious stations, 1980-1992. Because this station is downstream the reservoir, baseflow separation is not possible. Only total flow on an average annual basis was calibrated at this station. Annual comparisons are available in Figure 3.16.

The following modification to the default model were made to calibrate this area

- Curve numbers were reduced by 4.
- Soil available water capacity was reduced by 0.01
- Soil evaporation compensation factor was reduced from 0.95 to 0.94

- Initial depth of water in the shallow aquifer was increased to 100 mm
- Depth of water in shallow aquifer required for baseflow was set to 100 mm
- Depth of water in shallow aquifer required for revap was set to 300 mm
- Recharge to the deep aquifer was set to 0

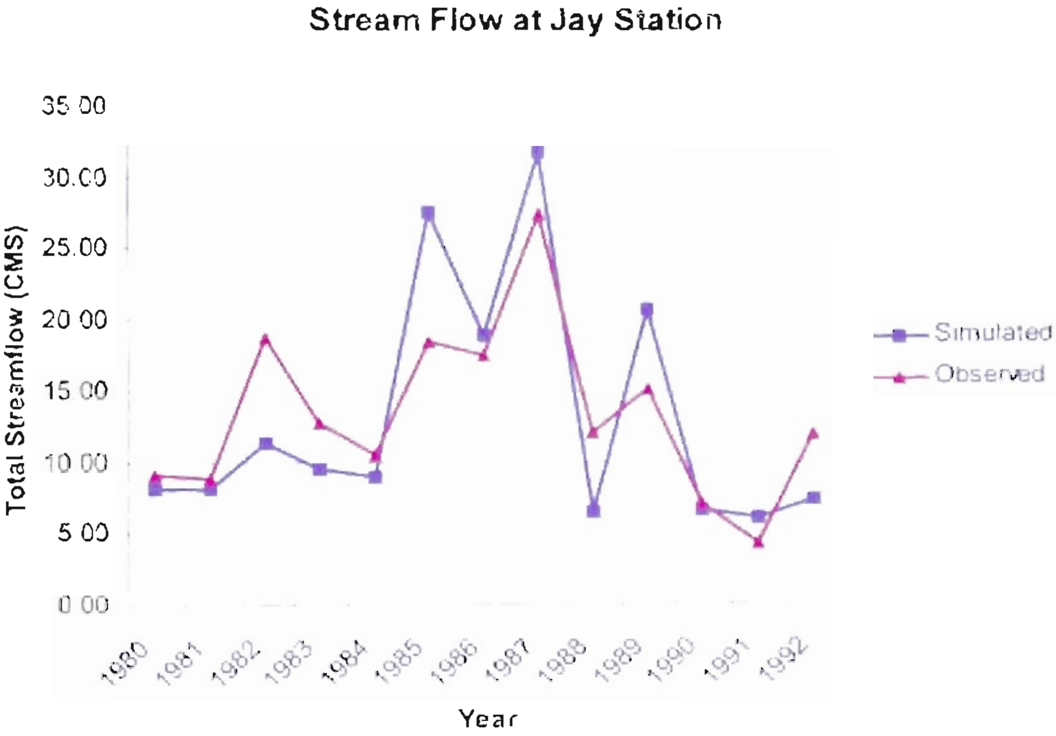


Figure 3.16 Observed and SWAT predicted annual total flow at the Jay gage station

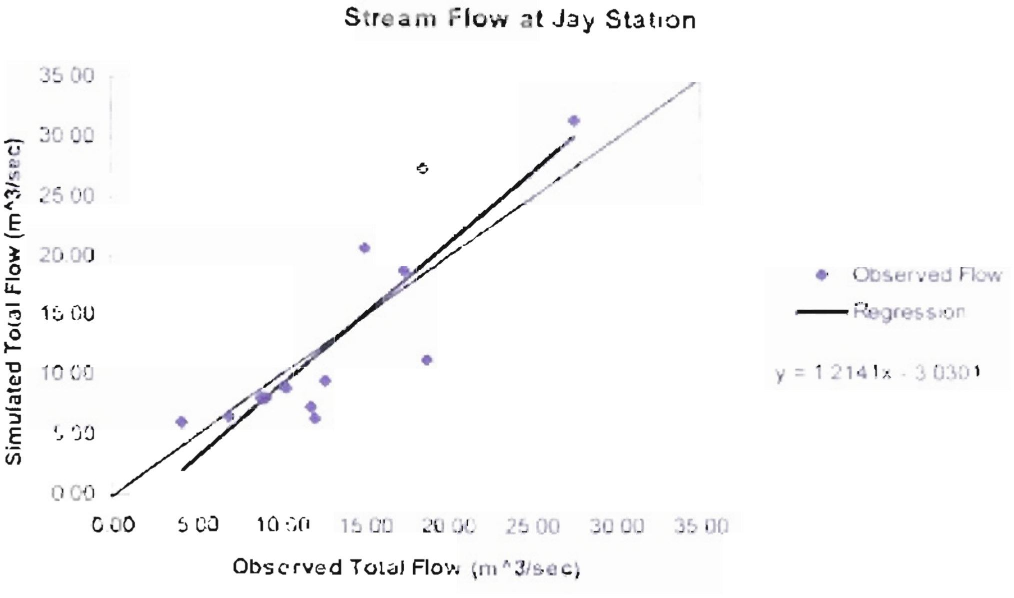


Figure 3.17 Observed vs SWAT predicted total flow at the Jay gage station

The Calibrated Model

Spatial Characteristics of the Calibrated Model

Because SWAT is a distributed model, it is possible to view model output as it varies across the basin. Since there were no data with which to calibrate the nutrient, sediment and pesticide components of the model, all results were compared on a relative basis. Model calibration was performed on stream flow that has been routed to the basin outlet. It is not possible to view these routed data on a per unit area basis in any meaningful manner. Figures depicting the spatial nature of model outputs use unrouted data only.

Figures 3.18 and 3.19 depict the variability of baseflow and surface runoff across the basin. North-central Barber County was estimated to have a high average surface runoff, particularly for a rangeland area. This is thought to be the result of steep slopes and the increased occurrence of soils with high runoff potential. Sediment yield (Figure 3.20) in the area was also high given the limited amount of wheat in the area; however, the wheat that is in this area produced much more sediment than wheat in other parts of the basin. Sediment yield for Alfalfa County was relatively low considering the amount of wheat produced in the area, possibly the result of the nearly flat topography of the area. Sediment-bound phosphorous is displayed in Figure 3.21. Sediment bound phosphorus and sediment yield display similar spatial trends. Soluble phosphorous yields (Figure 3.22) were highest in northern Barber and Alfalfa Counties. Nitrate losses in surface runoff is displayed in Figure 3.23. Nitrate losses appear to be the greatest in high runoff agricultural areas.

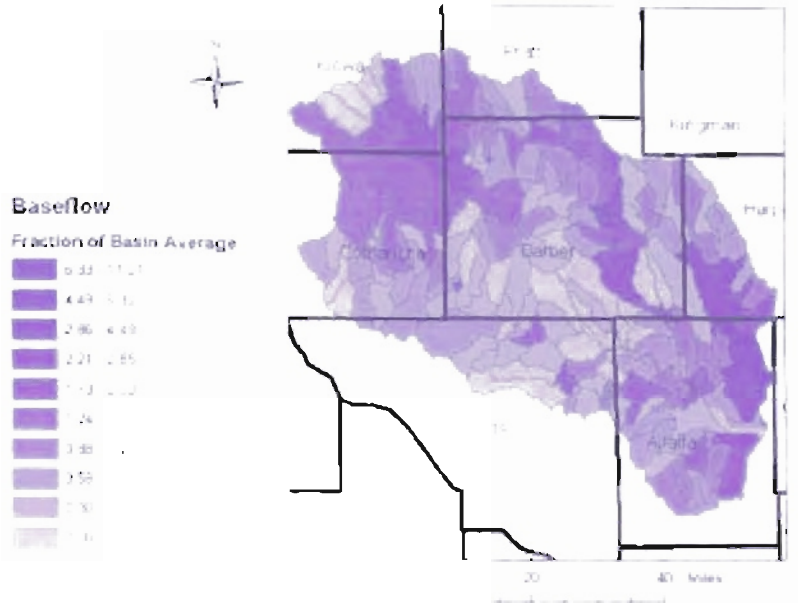


Figure 3.18 Baseflow as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

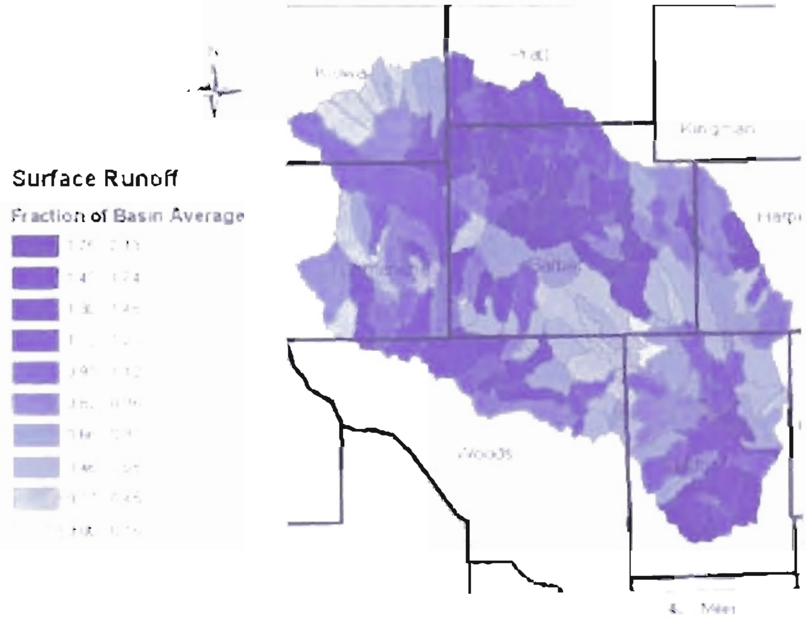


Figure 3.19 Surface runoff as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

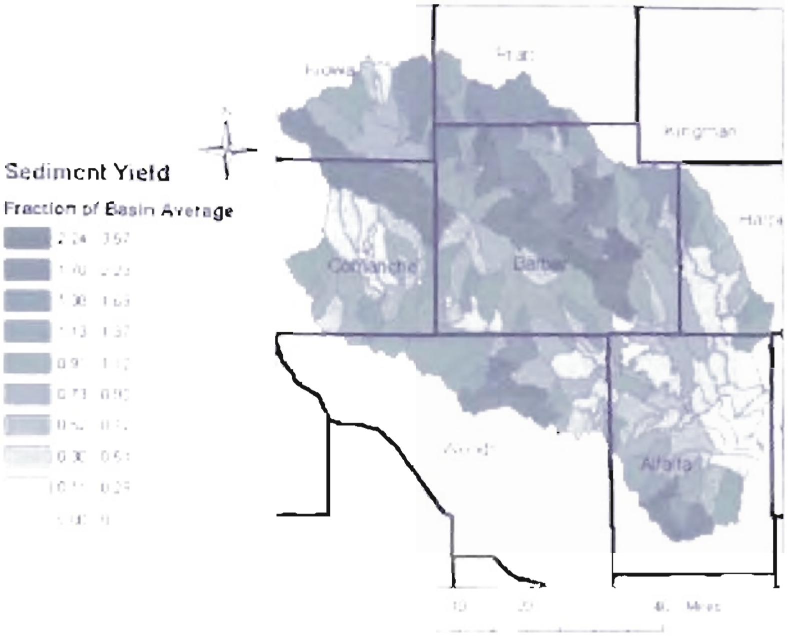


Figure 3.20 Sediment Yield as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

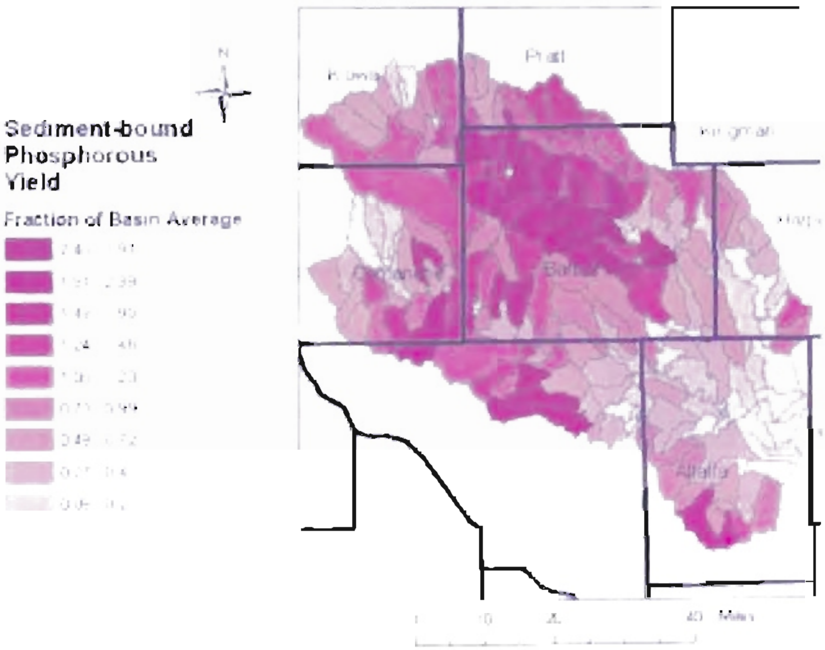


Figure 3.21 Sediment-bound Phosphorous as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation

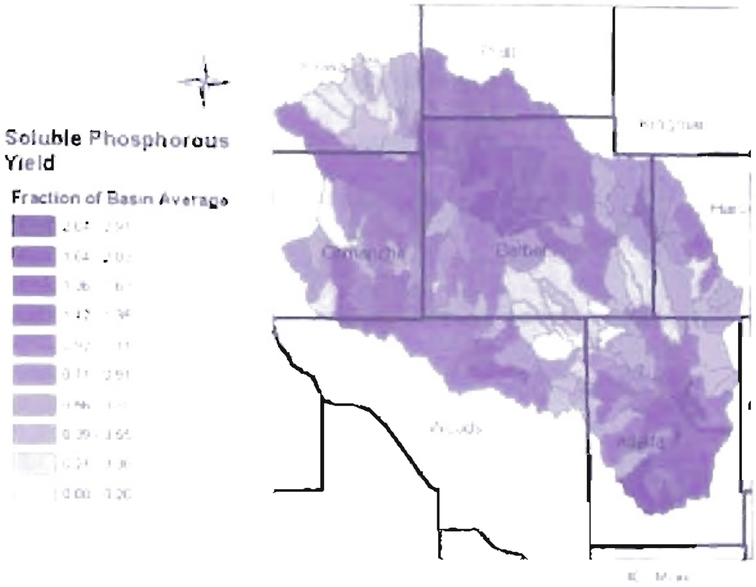


Figure 3.22 Soluble phosphorous as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

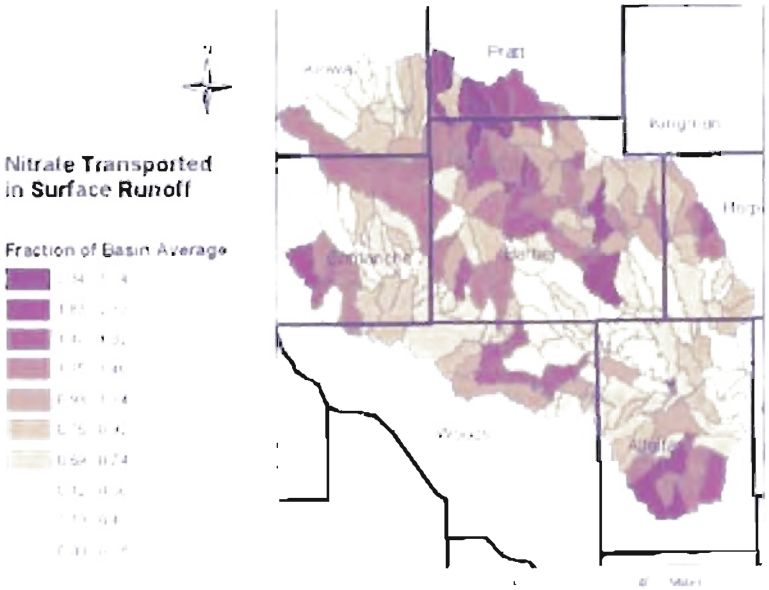


Figure 3.23 Nitrate transported in surface water as a fraction of the basin average as simulated by SWAT for the Great Salt Plains Reservoir basin. Derived from a 20-year (1980-1999) simulation.

Land Cover Comparisons

Each land cover represented in the model yielded different results. The differences are the result of not only its characteristics, but where that land cover is located in the basin. A particular land cover is often found in conjunction with a particular soil type or topography.

Because SWAT summarizes land cover and soils into HRUs it was not possible to simulate exactly the same land cover fractions as depicted in the original land cover GIS data. Any land cover that covered less than 3% of a subbasin was ignored to reduce the computational requirement of the model. This effectively reduced the total area of small or scattered land covers represented in the model (Figure 3.24). Forest is an example of a land cover which was reduced in the model's representation of the basin. Land covers such as range, which cover a vast fraction of the basin, tend to gain area.

SWAT predicted quite different results for each type of land cover. Predictions by land cover are available in Figures 3.25 and 3.26, and are displayed as a fraction of the basin average on a per unit area basis for each parameter. The total contribution of each land cover type is dependant on its total coverage area. SWAT predicts higher sediment yields for agricultural areas compared to rangeland on a per unit area basis.

The relative contribution of each land cover type and its area was used to determine how the total basin load by land cover type (Table 3.7 and Figure 3.27). Wheat was responsible for 66% of the sediment and 92% of the leached nitrate. Range accounts for the majority of runoff and phosphorous.

Table 3.7 SWAT predicted relative contribution of each land cover to the total basin load for 20 years of observed rainfall records

Land Cover	Runoff	Baseflow	ET	Sediment	Sed-Bound P	Nitrate in Runoff	Soluble P	Nitrate Leached	Organic N
Wheat	38.4%	32.6%	27.6%	66.5%	44.4%	53.1%	31.6%	92.5%	92.5%
Range	52.3%	59.1%	64.9%	25.0%	52.0%	42.2%	58.4%	3.4%	3.4%
Soybean	4.5%	3.4%	2.4%	7.8%	2.7%	2.4%	0.9%	0.4%	0.4%
Alfalfa	0.8%	3.3%	1.4%	0.5%	0.9%	0.3%	3.1%	3.4%	3.4%
Forest	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Urban	0.2%	0.1%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%
Wetlands	3.8%	1.4%	2.1%	0.0%	0.0%	2.0%	5.6%	0.1%	0.1%

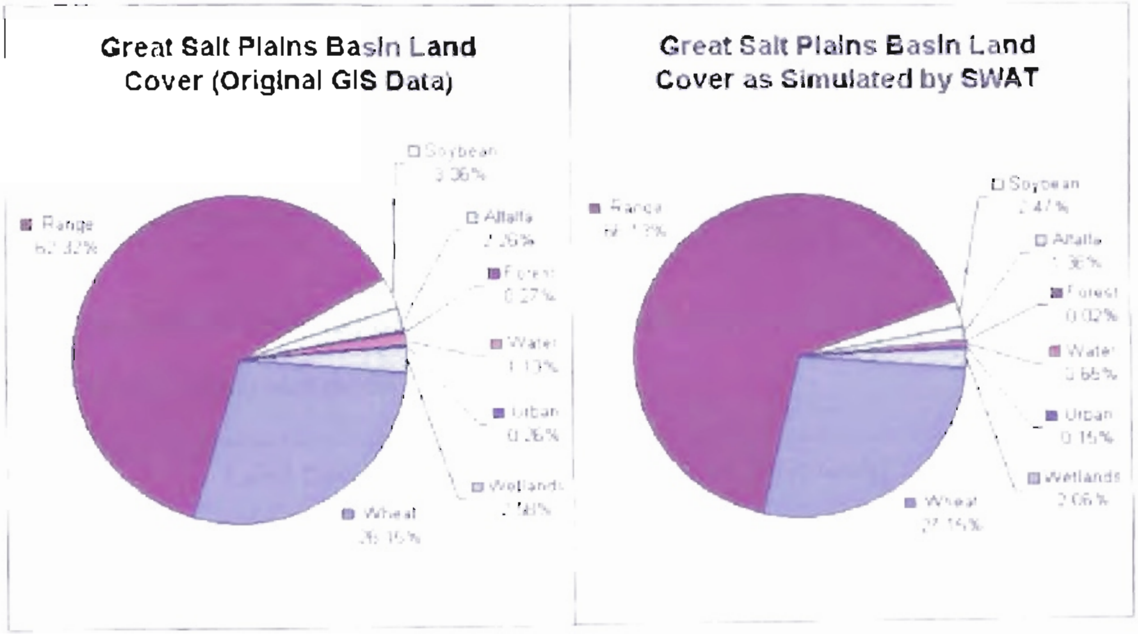


Figure 3.24 Land cover fractions of the original GIS data, and that used in all SWAT simulations

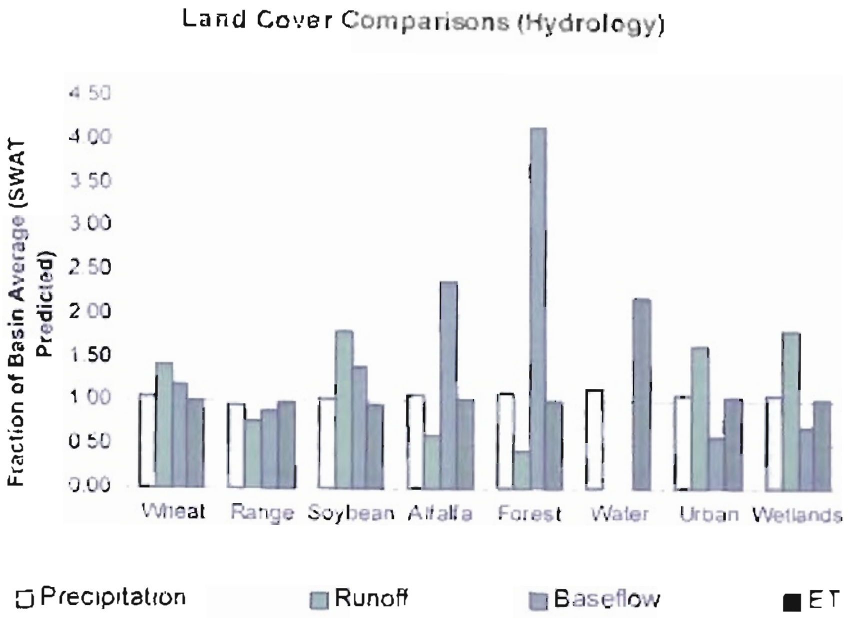


Figure 3.25 SWAT predicted land cover hydrological comparisons. Derived from a 20-year simulation of the calibrated model.

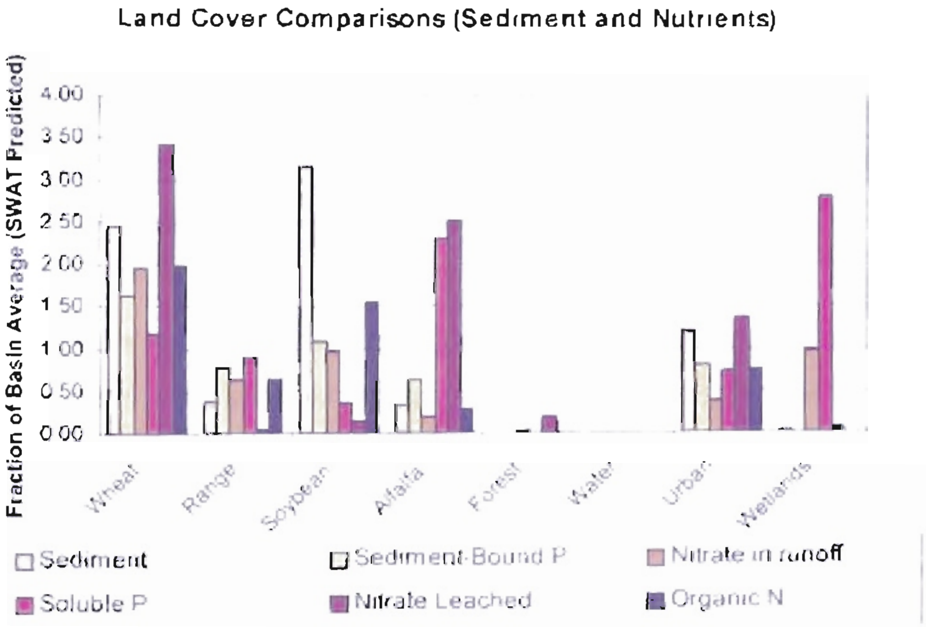


Figure 3.26 SWAT predicted land cover sediment and nutrient comparisons. Derived from a 20-year simulation of the calibrated model.

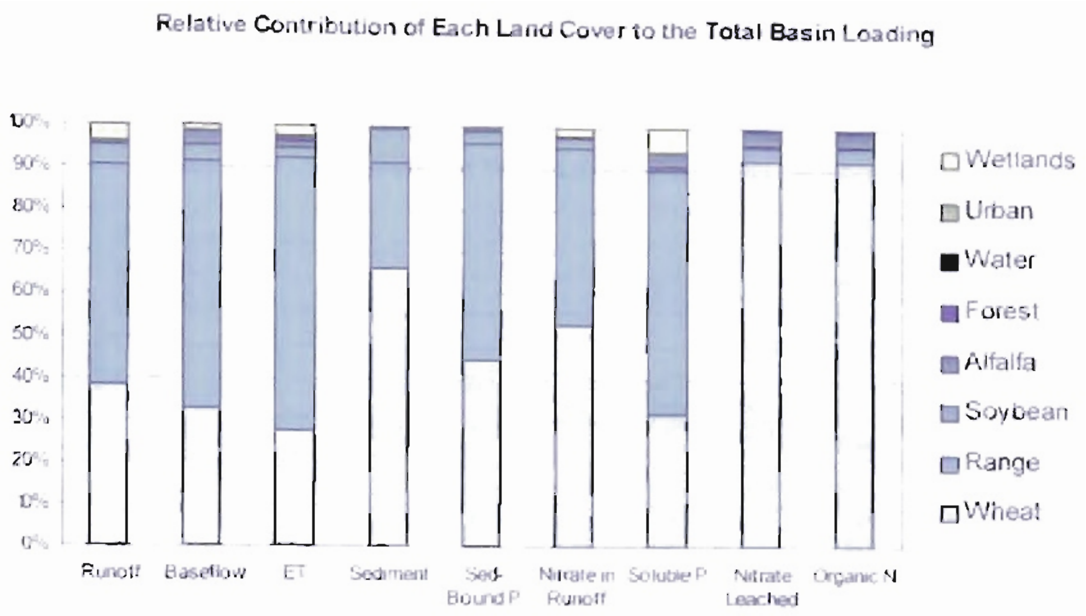


Figure 3.27 Relative contribution of each land cover to the total basin load. Derived from a 20-year simulation of the calibrated model

Temporal Nature of Model Outputs by Land Cover Type

Water and nutrient yields vary with time. Weather and land cover conditions influence these yields and thus they vary from month to month. Summarizing monthly simulation data gives additional insight about when nutrient or water yields are likely to be the greatest.

The effect of summer tillage on wheat is evident in Figure 3.28. Sediment yields were dramatically increased while the land was fallow. An increase in surface runoff is also apparent during this period even though there was no significant increase in precipitation. Figure 3.29 indicates increased sediment-bound nutrient yields for this time frame. Rangeland was not subject to tillage and retains a more uniform soil cover through the seasons. Figure 3.30 illustrates a much more consistent relationship between surface runoff and sediment yields. Rangeland nutrient yields are available in Figure 3.31. Alfalfa (Figures 3.32 and 3.33) exhibited an unusual sediment spike in the spring.

possibly due to slow simulated growth and the lack of surface residue from hay cuttings the previous year

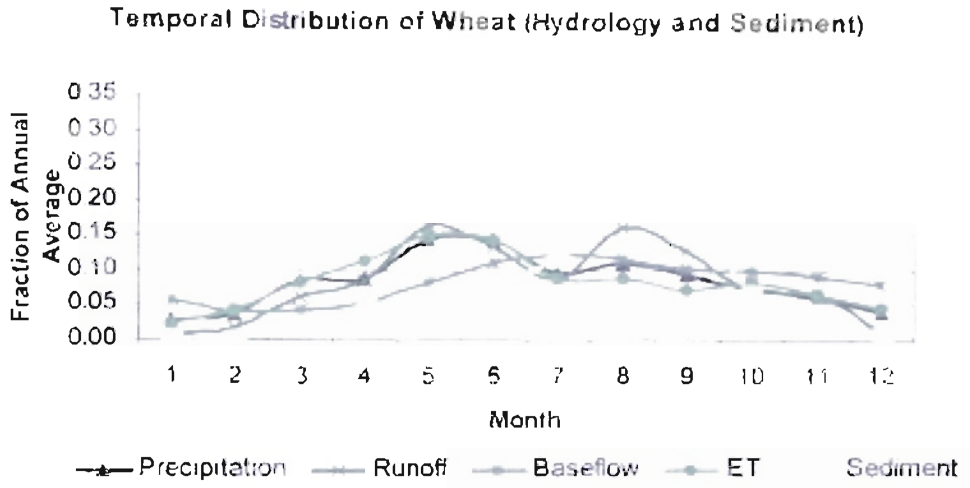


Figure 3.28 Hydrologic and sediment temporal characteristics of wheat as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

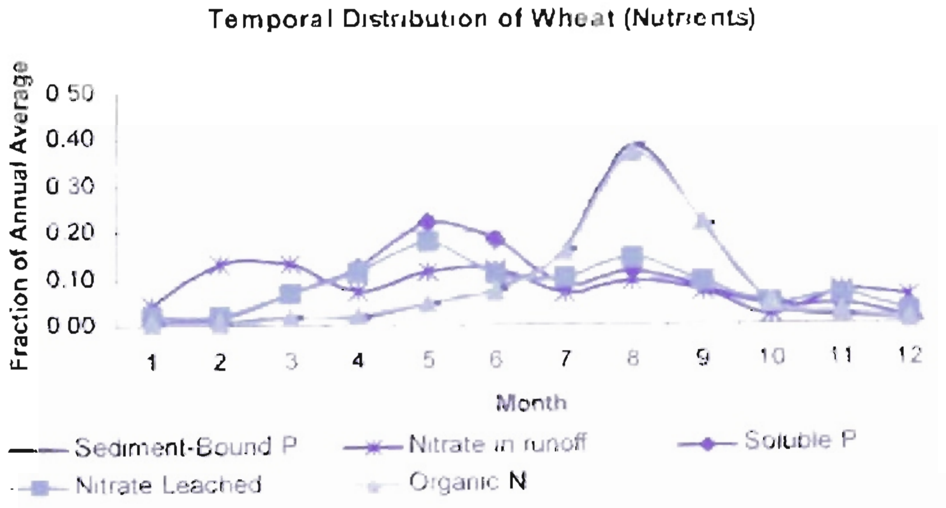


Figure 3.29 Nutrient temporal characteristics of wheat as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

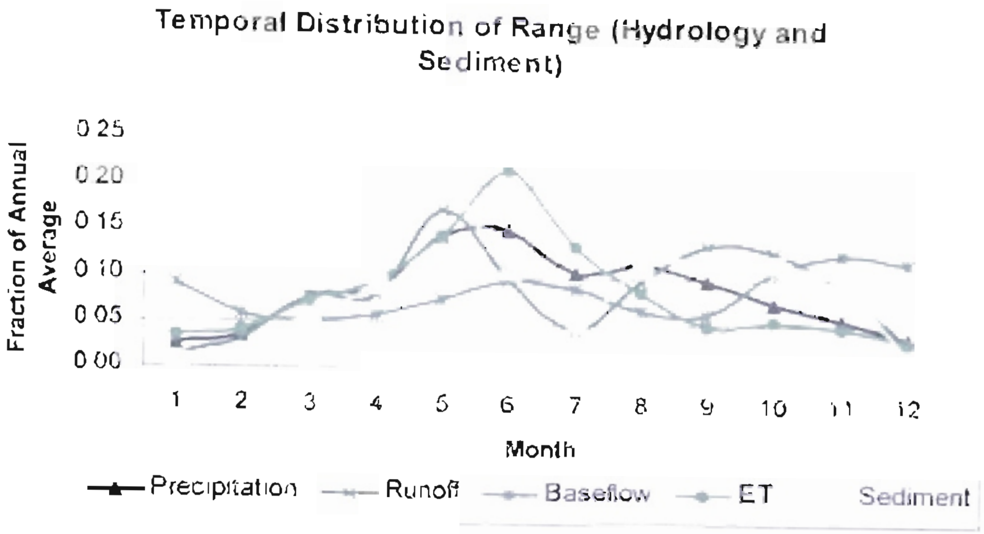


Figure 3.30 Hydrologic and sediment temporal characteristics of range as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

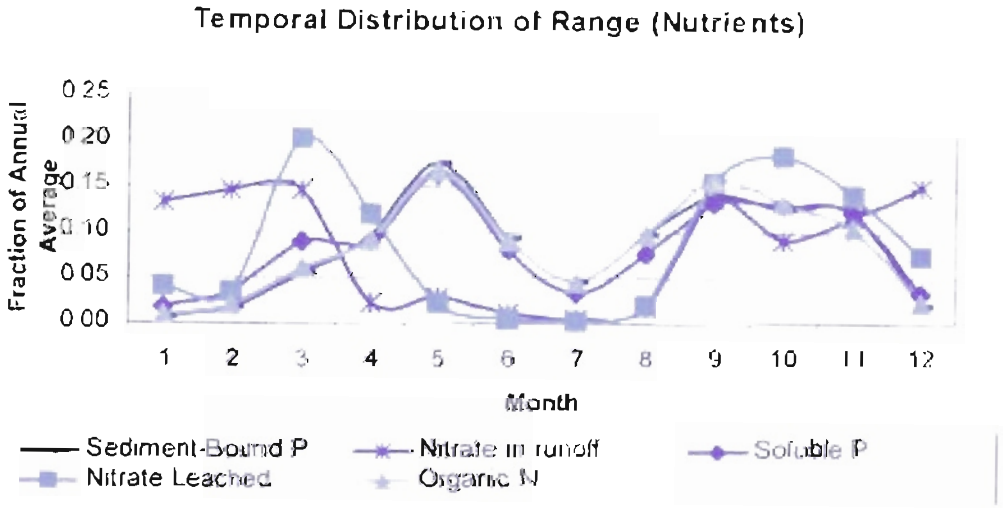


Figure 3.31 Nutrient temporal characteristics of range as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

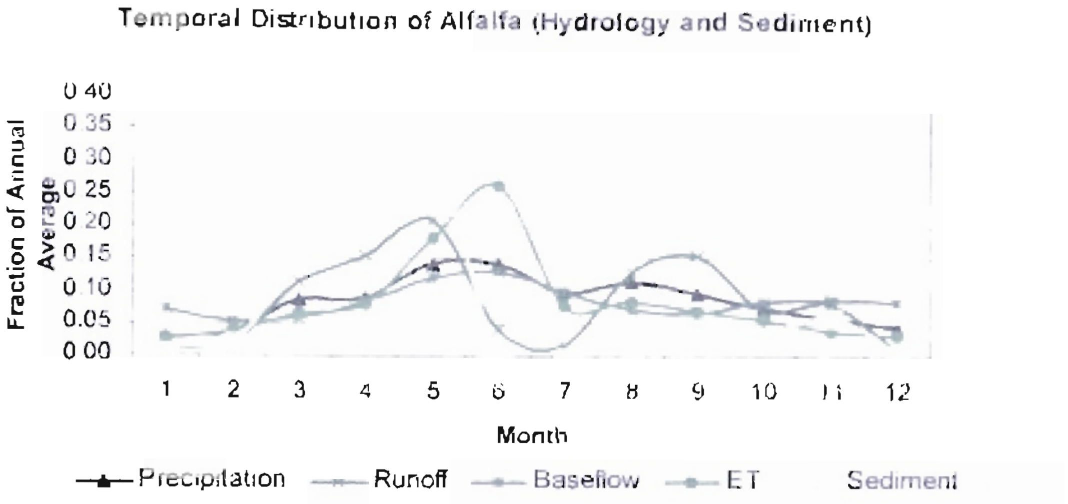


Figure 3.32 Hydrologic and sediment temporal characteristics of Alfalfa as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

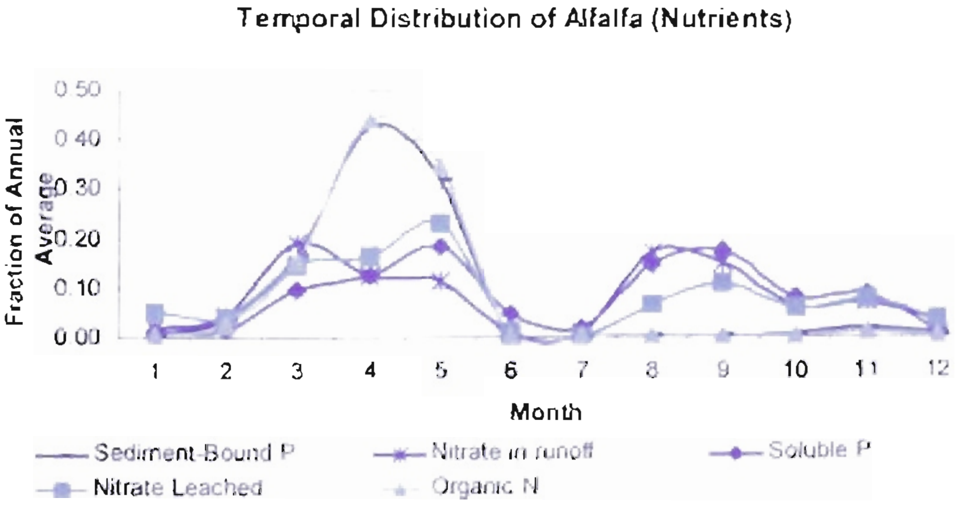


Figure 3.33 Nutrient temporal characteristics of Alfalfa as simulated by SWAT. Fraction of average annual yield occurring any given month derived from a 20 year SWAT simulation using observed weather data.

Best Management Practices

The calibrated SWAT model was modified to simulate the implementation of a variety of BMPs. These BMPs were selected to represent commonly occurring and recommended practices for wheat and alfalfa in north-west Oklahoma. In addition, the selected BMPs must be suitable for modeling with SWAT; some field scale BMPs such as filter strips are beyond the abilities of current basin scale models such as SWAT. Reasonable rates and operation timings were selected.

Statistical analyses were performed using SAS (Statistical Analysis Software). SAS programs used to perform the analysis are available in Appendix G. Each comparison was made using model output for the period January 1,1980 to December 31,1999. Year was blocked to account for the overwhelming error associated with year to year variations.

The following BMPs were examined using SWAT:

- Tillage and harvest type BMPs
    - Tillage type on wheat.
    - Harvest type on wheat.
- Fertilization BMPs
    - Nitrogen fertilizer timing on wheat.
    - Nitrogen fertilizer application rate on wheat.
    - Phosphorous fertilization rate on wheat.
- Pesticide BMPs
    - Herbicide application timing on wheat.
    - Insecticide application on alfalfa.

Tillage and Harvest Type BMPs

Tillage and harvest type were arranged in a 3x3 factorial experimental design. Each level of tillage was compared at each harvest type and vise versa. Tables 3.8 and 3.9 contain mean and standard deviations on a relative basis for each of the nine simulations. Management operation are listed in Tables 3.10 and 3.11 for each land cover and potential BMP.

Tillage BMPs

Tillage is required to control weeds and to prepare a suitable seedbed for planting. Many different implements can be used. SWAT simulates tillage by mixing the soil layers and incorporating residue from the soil surface. The degree of soil disturbance is more important than the actual implement used.

Three common types of tillage were selected:

- Moldboard Plow
- Stubble Mulch
- Low Till

Each type of tillage represents a different level of soil disturbance, with moldboard plow being the most disturbing and low till the least. Low till operations use herbicides to a greater extent to control weeds. Each tillage was simulated at three different cattle grazing scenarios. Tillage had a significant effect on sediment yield and sediment-bound nutrients (Figure 3.34). Figure 3.35 contains variations in tillage at a constant harvest type. Figure 3.36 presents a direct comparison of means for all levels of tillage and harvest type.

Harvest Type BMPs

Wheat is often used as a winter forage in Oklahoma before it is harvested for grain in the summer. Depending on market conditions, wheat may be grazed out or harvested for hay and not harvested for grain at all. These three grazing scenarios were simulated using SWAT:

- No grazing, harvested for grain only.
- Cattle grazing and harvested for grain.
- Grazing only, harvested for hay.

Fertilization rates and planting timing were adjusted for each scenario. Wheat grazing was simulated at approximately 0.33 animal units per acre (Oklahoma State University Extension Facts 2855) for a maximum of 100 days. Additional fertilization was based on stocking rate when also harvested for grain. An additional 30 lb/acre nitrogen was applied to compensate for nitrogen removal by cattle (Oklahoma State University Extension Facts F-2586). Any time there was less than 600 kg (dry weight) of biomass per hectare, grazing was suspended.

Table 3.8 Relative means of harvest and tillage BMP simulations, derived from 20 years of simulated data.

Tillage	Grazing	Runoff	Baseflow	ET	Sediment	Sediment-bound P	Nitrate in runoff	Soluble P	Nitrate leached	Organic N	Lateral N
Moldboard	Grain Only	0.98	0.97	1.00	1.07	0.99	0.93	0.87	0.66	1.06	0.82
Stubble Mulch	Grain Only	0.98	0.98	1.00	0.83	0.92	0.94	1.06	0.66	0.88	0.82
Low Till	Grain Only	0.98	0.98	1.00	0.69	0.99	0.96	1.54	0.65	0.81	0.82
Moldboard	Grain and Grazing	1.02	1.01	1.00	1.37	1.12	1.11	0.90	1.38	1.22	1.29
Stubble Mulch	Grain and Grazing	1.02	1.01	1.00	1.16	1.08	1.13	1.16	1.38	1.06	1.29
Low Till	Grain and Grazing	0.99	0.97	1.00	0.73	0.89	0.99	1.27	1.43	0.78	1.26
Moldboard	Grazing	0.69	0.50	1.05	0.91	0.90	0.70	0.52	0.56	0.96	1.10
Stubble Mulch	Grazing	0.69	0.51	1.05	0.50	0.51	0.76	0.79	0.59	0.50	1.15
Low Till	Grazing	0.70	0.52	1.05	0.41	0.74	0.84	1.75	0.58	0.52	1.16

Table 3.9 Relative standard deviation of harvest and tillage BMP simulations, derived from 20 years of simulated data.

Tillage	Harvest Type	Runoff	Baseflow	ET	Sediment	Sediment-bound P	Nitrate in runoff	Soluble P	Nitrate leached	Organic N	Lateral N
Moldboard	Grain Only	0.88	1.15	0.07	1.32	1.29	0.78	1.01	0.92	1.37	0.57
Stubble Mulch	Grain Only	0.88	1.15	0.07	1.04	1.17	0.79	1.16	0.92	1.14	0.57
Low Till	Grain Only	0.88	1.15	0.07	0.89	1.28	0.80	1.54	0.90	1.07	0.57
Moldboard	Grain and Grazing	0.85	1.10	0.15	1.38	1.18	0.86	1.04	1.71	1.25	0.97
Stubble Mulch	Grain and Grazing	0.85	1.11	0.15	1.20	1.12	0.88	1.23	1.71	1.06	0.97
Low Till	Grain and Grazing	0.86	1.12	0.07	0.92	1.13	0.67	1.17	1.88	1.00	0.98
Moldboard	Grazing	0.54	0.59	0.15	0.74	0.67	0.54	0.54	0.91	0.72	0.44
Stubble Mulch	Grazing	0.54	0.59	0 15	0.67	0.63	0.60	0.73	0.94	0.64	0.46
Low Till	Grazing	0.54	0.60	0.15	0.61	1.10	0.68	1.46	0.93	0.78	0.45

Table 3.10 Management operations for tillage and harvest type simulations for wheat.

Tillage	Moldboard Plow		Stubble Mulch		Low Till	
Harvest	Operation	Date	Operation	Date	Operation	Date
Grain Only	40 lb/acre Nitrogen (surface)	1-Feb	40 lb/acre Nitrogen (surface)	1-Feb	40 lb Nitrogen (surface)	1-Feb
	Harvest	1-Jul	Harvest	1-Jul	Harvest	1-Jul
	Moldboard plow	15-Jul	Duckfoot cultivator	15-Jul	30 lb/acre Phosphorous (surface)	1-Sep
	30 lb/acre Phosphorous (surface)	10-Aug	30 lb/acre Phosphorous (surface)	1-Sep	Chisle plow	1-Sep
	Disk	11-Aug	40 lb/acre Nitrogen (sub-surface)	1-Sep	40 lb/acre Nitrogen (sub-surface)	1-Sep
	40 lb/acre Nitrogen (sub-surface)	11-Aug	Disk	1-Sep	Plant Wheat	15-Sep
	Disk	1-Sep	Plant Wheat	15-Sep		
	Plant Wheat	15-Sep				
Grain and Grazing	70 lb/acre Nitrogen (surface)	1-Feb	70 lb/acre Nitrogen (surface)	1-Feb	70 lb/acre Nitrogen (surface)	1-Feb
	Harvest	15-Jun	Harvest	15-Jun	Harvest	1-Jul
	Moldboard plow	15-Jul	Duckfoot cultivator	15-Jul	30 lb/acre Phosphorous (surface)	1-Sep
	30 lb/acre Phosphorous (surface)	1-Aug	30 lb/acre Phosphorous (surface)	1-Aug	Chisle plow	1-Sep
	Disk	2-Aug	40 lb/acre Nitrogen (sub-surface)	15-Aug	40 lb/acre Nitrogen (sub-surface)	1-Sep
	40 lb/acre Nitrogen (sub-surface)	3-Aug	Disk	30-Aug	Plant Wheat	15-Sep
	Disk	20-Aug	Plant Wheat	1-Sep	Grazing 33 Animal unit/acre	1-Nov
	Plant Wheat	1-Sep	Grazing .33 Animal unit/acre	1-Nov		
	Grazing 33 Animal unit/acre	1-Nov				
Grazing and Hay	Harvest Hay	15-Apr	Harvest Hay	15-Apr	Harvest Hay	15-Apr
	Kill Crop	16-Apr	Kill Crop	16-Apr	Kill Crop	16-Apr
	Moldboard Plow	15-Jul	30 lb/acre Phosphorous (surface)	15-Jul	30 lb/acre Phosphorous (surface)	15-Jul
	30 lb/acre Phosphorous (surface)	1-Aug	Duckfoot cultivator	15-Jul	Chisle plow	15-Jul
	Disk	2-Aug	80 lb Nitrogen (subsurface)	15-Jul	80 lb Nitrogen (subsurface)	15-Jul
	80 lb/acre Nitrogen (sub-surface)	3-Aug	Disk	5-Aug	Plant Wheat	15-Aug
	Disk	5-Aug	Plant Wheat	15-Aug	Grazing .33 Animal unit/acre	1-Nov
	Plant Wheat	15-Aug	Grazing 33 Animal unit/acre	1-Nov		
	Grazing 33 Animal unit/acre	1-Nov				

Table 3.11 Management operations for land covers other than wheat.

Alfalfa		
Description	YEAR	Heat Unit Fraction
plant	1	0.150
30 lb/acre Phosphorous (surface)	1	0.300
Harvest Hay	1	0.400
Harvest Hay	1	0.800
Harvest Hay	1	1.200
30 lb/acre Phosphorous (surface)	2	0.300
Harvest Hay	2	0.400
Harvest Hay	2	0.800
Harvest Hay	2	1.200
30 lb/acre Phosphorous (surface)	3	0.300
Harvest Hay	3	0.400
Harvest Hay	3	0.800
Harvest Hay	3	1.200
30 lb/acre Phosphorous (surface)	4	0.300
Harvest Hay	4	0.400
Harvest Hay	4	0.800
Harvest/kill	4	1.200

Urban		
Description	YEAR	Heat Unit Fraction
Plant	1	0.150
Harvest/Kill	1	1.200

Wetland		
Description	YEAR	Heat Unit Fraction
Plant	1	0.160
Harvest/Kill	1	1.200

Range		
Description	YEAR	Heat Unit Fraction
Plant	1	0.150
Harvest/Kill	1	1.200

Soybeans		
Description	YEAR	Heat Unit Fraction
30 lb Phosphorous	1	0.03
80 lb Nitrogen	1	0.03
Disk	1	0.04
Plant	1	0.25
Harvest/kill	1	1.20

Forest		
Description	YEAR	Heat Unit Fraction
Plant	1	0.150
Harvest/Kill	1	1.200

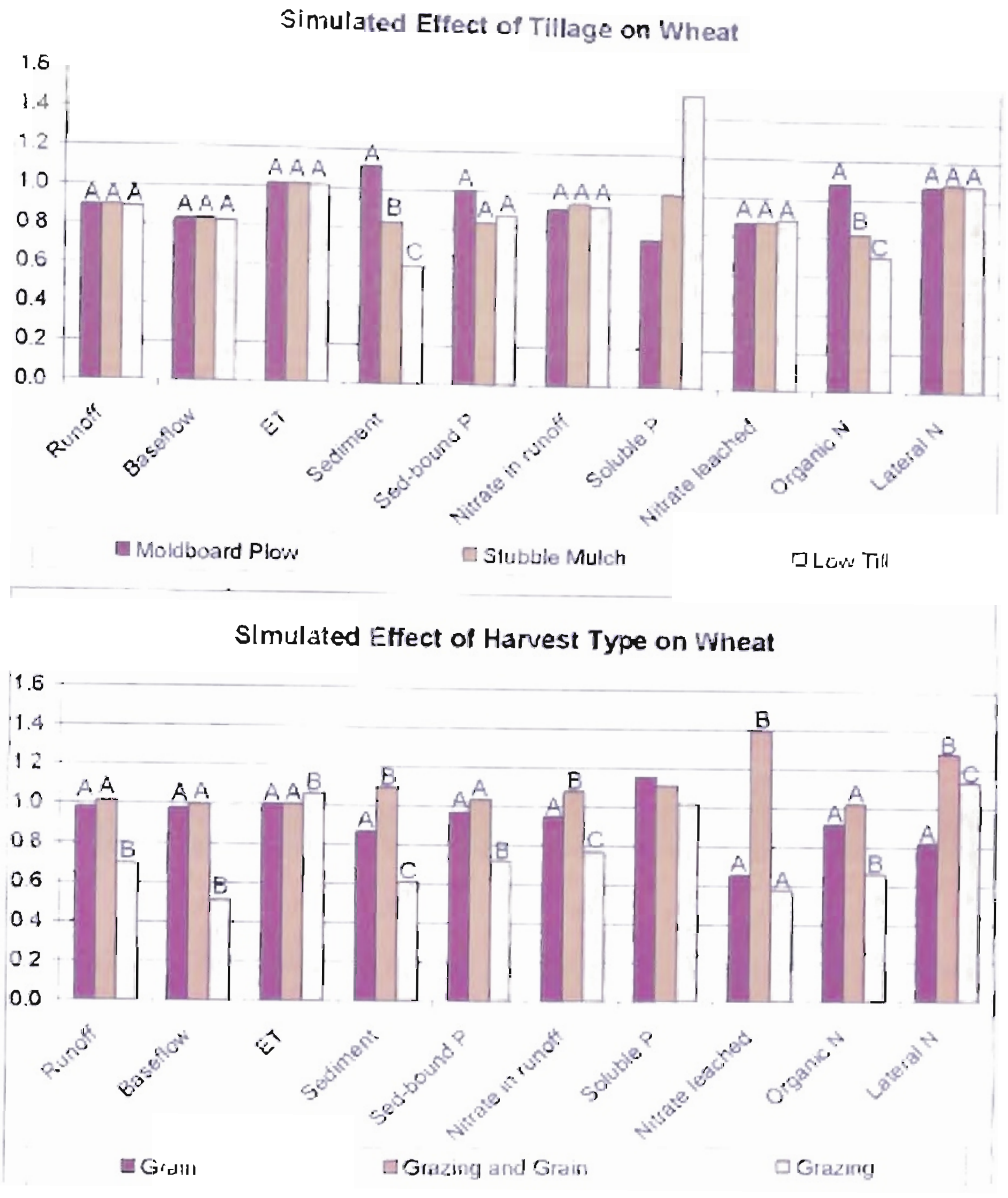


Figure 3.34 Main effects of tillage (moldboard, stubble, and low till) and harvest type (grain only, grazing and grain, and grazing and hay) (α = 0.05). Displayed as a fraction of calibrated wheat average. Main effect statistical comparisons are not appropriate for soluble phosphorous due to interactions. Derived from 20-year SWAT simulations.

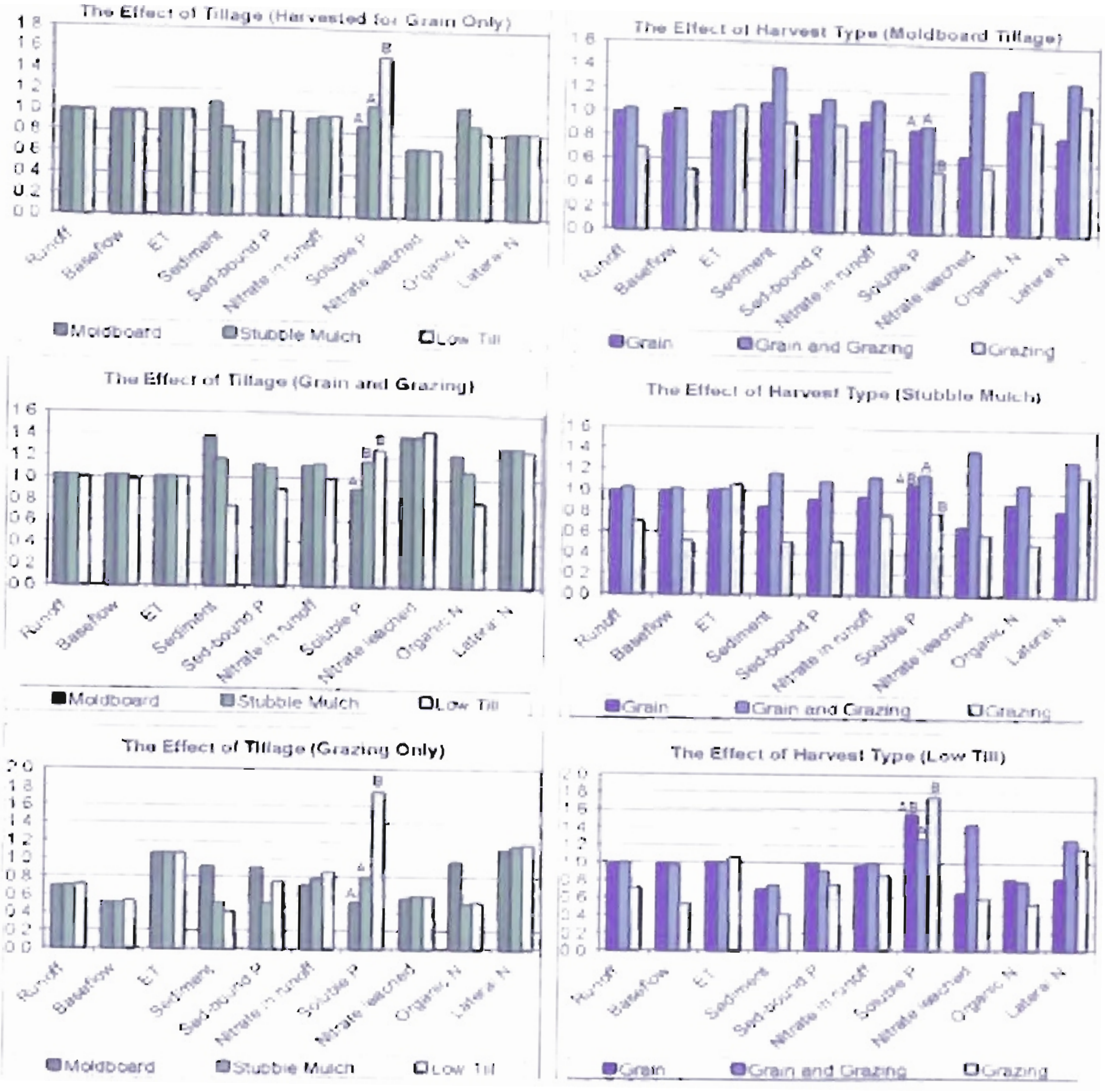


Figure 3.35 Tillage effects at constant harvest type (grain, grazing, or both) and harvest type effects at constant tillage (moldboard, stubble, or low till) (α = 0.05). Displayed as a fraction of calibrated wheat average. Statistics generated for soluble phosphorous due to interactions. Derived from 20-year SWAT simulations.

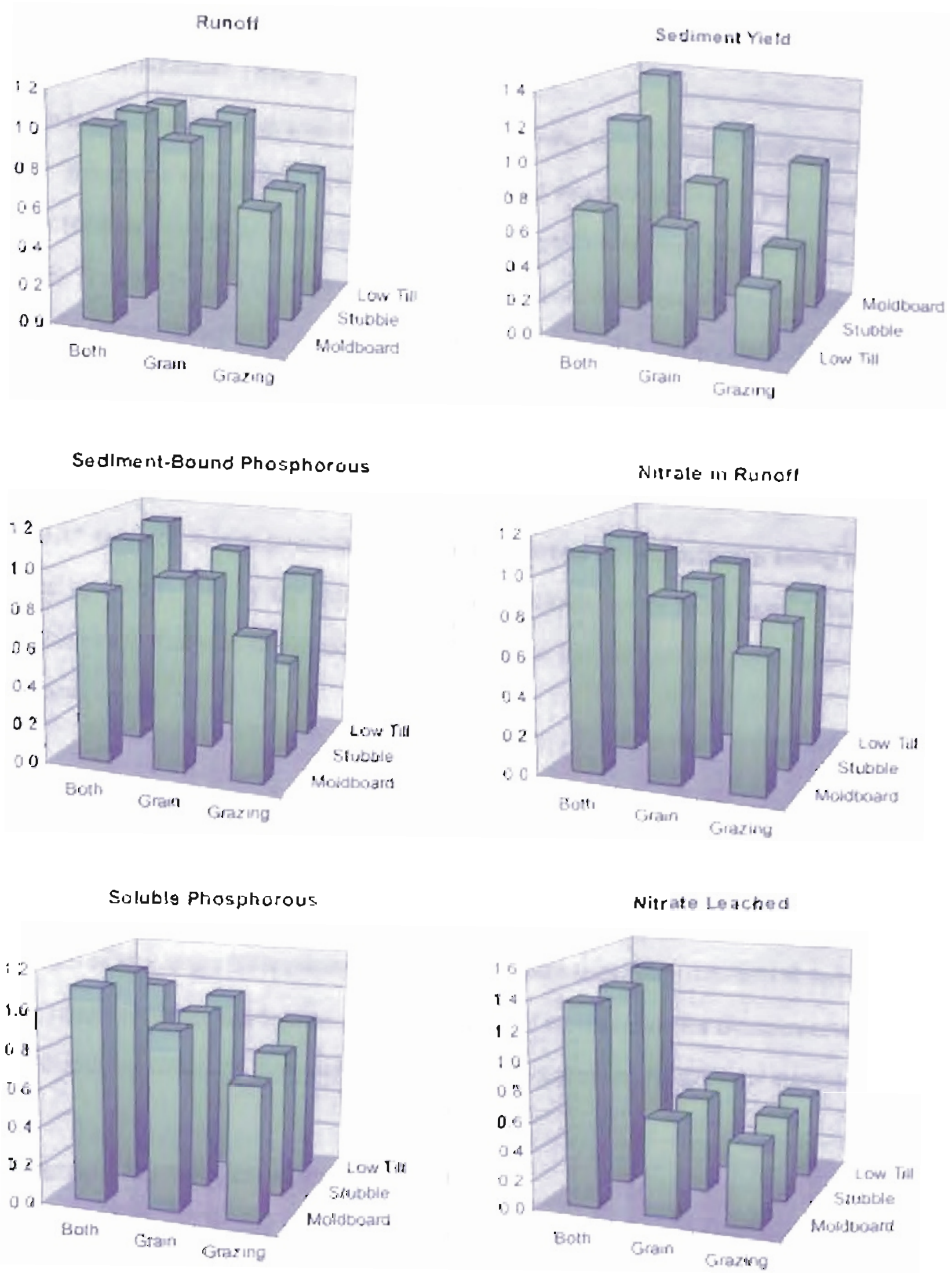


Figure 3.36 Relationship among tillage and harvest type for common SWAT model outputs. Displayed as a fraction of calibrated wheat average. Derived from 20-year SWAT simulations.

Fertilization BMPs

Nitrogen Fertilization Timing

Nitrogen is typically applied to wheat either pre-plant during summer tillage and/or topdress in early spring. Anhydrous ammonia is typically the most cost effective choice for pre-plant nitrogen. A granular fertilizer such as ammonium nitrate or urea is typically surface applied in early spring (top-dressing). Top dressing is typically more expensive than a single large anhydrous application, but it allows a farmer to adjust the total nitrogen application rate several months after planting. Unpredictable winter moisture accumulation and changing cattle and grain market conditions often make top-dressing preferable.

Figure 3.37 contains means and statistical tests performed among different timing scenarios as simulated by SWAT. The all fall application scenario stands out as being quite different from the others, indicating that split applications are preferred to reduce nutrient yields over single large applications.

Nitrogen Fertilizer Application Rate

The effect of nitrogen application rate on wheat was examined at several different rates in two application scenarios. Nitrogen was applied as either a split application (50% fall, 50% topdress) (Figure 3.38) or as a single fall application (Figure 3.39). Both application methods showed increasing nitrogen yields at higher application rates. The rate of increase varies by component. Organic nitrogen displayed almost no increase and nitrate leached showed the greatest increase.

Phosphorous Fertilization Application Rate

Phosphorous applications were simulated at four levels between 15 and 60 lb-P_2O_5/acre. A single management (grazing and grain, stubble mulch tillage) was selected to simplify the analysis. The trend lines shown in Figure 3.40 were very linear (r^2> 0.99). This is likely the result of SWAT`s phosphorous component. SWAT calculates phosphorous yield based on soil phosphorous concentration in the surface layer.

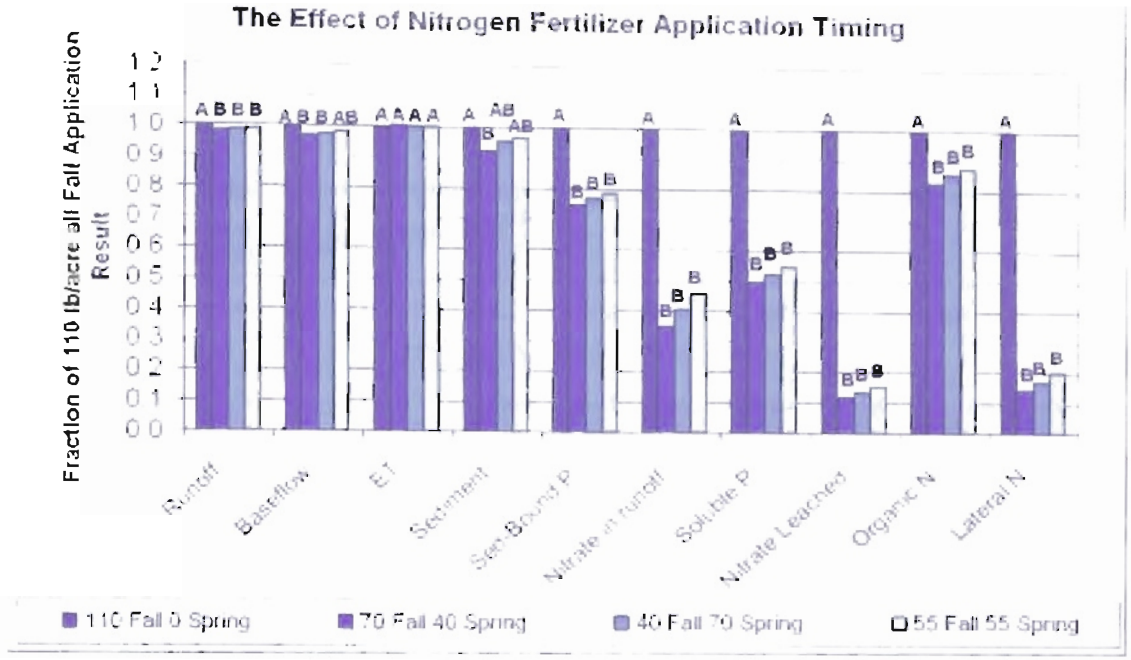


Figure 3.37 The effect of nitrogen application timing on the SWAT model. Lettering indicates significant difference among treatments (α= 0.05). Derived from 20-year SWAT simulations.

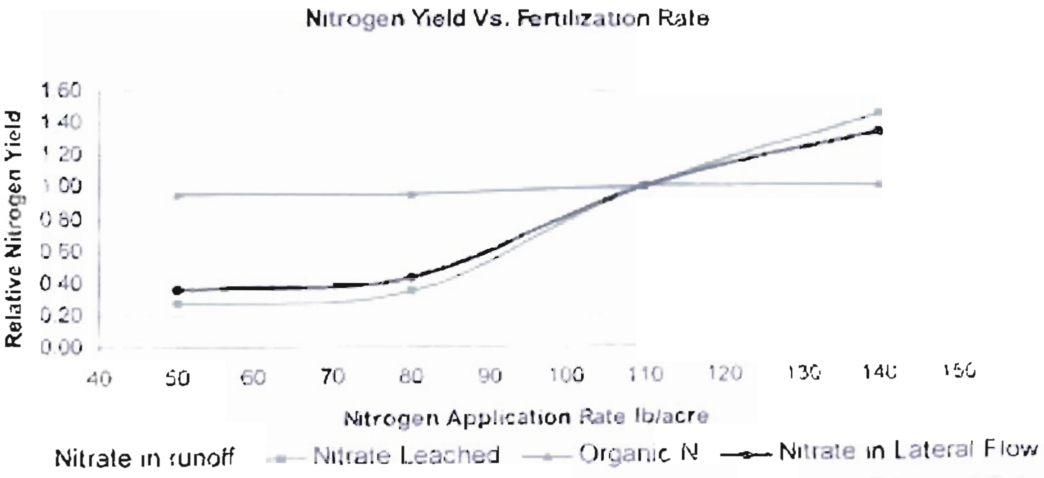


Figure 3.38 SWAT predicted nitrogen yield as a function of application rate. Application split 50% preplant 50% topdress, nitrogen yield relative to 110 lb/acre rate.

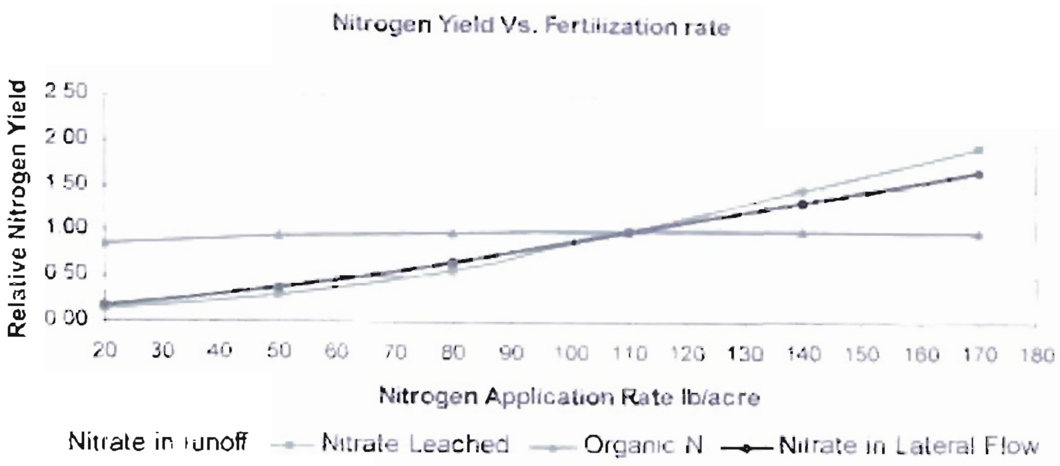


Figure 3.39 SWAT predicted nitrogen yield as a function of application rate. Anhydrous ammonia applied preplant, nitrogen yield relative to 110 lb/acre rate. Derived from 20-year SWAT simulations

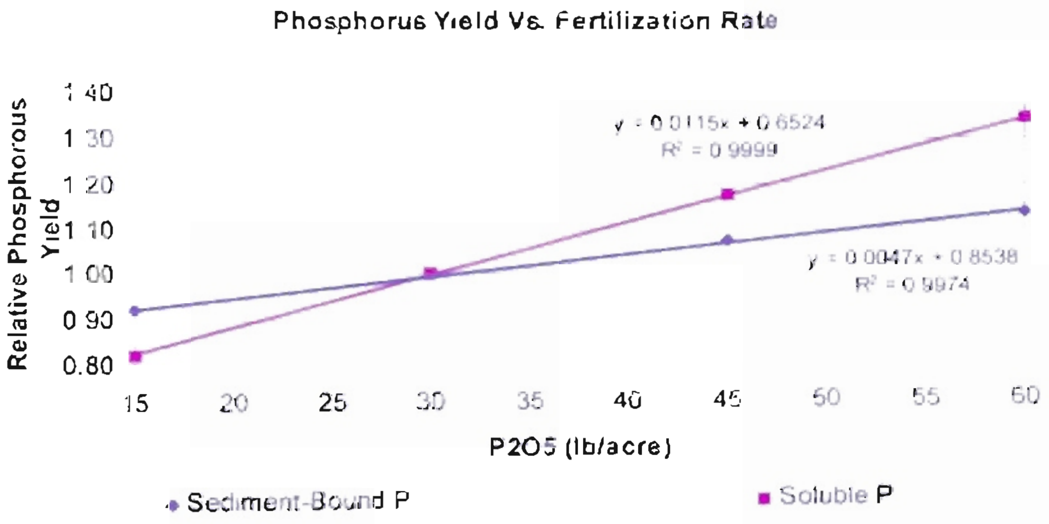


Figure 3.40 SWAT predicted phosphorous yield as a function of application rate. Single application before summer tillage, phosphorous yield relative to 30 lb./acre rate. Derived from 20-year SWAT simulations

Pesticide BMPs

Pesticides are commonly used on crops in the Great Salt Plains Basin. Herbicides are commonly used on wheat to control cheat grass, and occasionally used on alfalfa. Insecticides are commonly used on alfalfa to treat a variety of pests, but it is seldom profitable to treat wheat for insects. Kenith Fails at the Burlington CO-OP and Jeff Wilber of Wilber Fertilizer Service were contacted to determine the most commonly used pesticides in the area. Application rates were determined from product labels.

Pesticide applications for all fields in the basin were made on a single date in the model. In reality, the timing varies from field to field. This limitation has a greater influence on short duration pesticide yield which are more sensitive to rainfall soon after application.

Herbicide Application Timing on Wheat

Two herbicides were originally considered for wheat, Maverick™ and Finesse™. Finesse™ was rejected because it has multiple active ingredients, and would dramatically increase modeling complexity. Maverick™ was applied at a rate of 0.035 kg/ha active ingredient. Applications were made at the following times of year:

- Preemergence - applied after planting but before wheat seedling emergence.
- Postemergence Fall - Applied after seedling emergence during November.
- Postemergence Spring - Applied before the wheat jointing stage, during February.

Figures 3.41 and 3.42 display simulated herbicide yields at the basin outlet relative to the postemergence scenario. The preemergence application resulted in a very large spike which occurred in October 1995. Examination of the rainfall record indicated several large rainfall events soon after application which could be responsible. Figure 3.42 shows some years with much smaller pesticide yields; This is thought to be the result of rainfall timing and amount relative to application timing.

Insecticide Application on Alfalfa

Bathroid™ and Lorsban™ are both commonly applied to alfalfa. Alfalfa is generally treated once each year during March. The exact date of treatment depends on whether the producer uses the calendar or IPM (Integrated Pest Management). Calender applications usually occur in March. IPM applications depend on the level of insect infestation and weather factors, both of which vary from year to year. SWAT does not model insect growth, so a single application date was necessary. Average IPM applications were also in March. The same date was used for both insecticides. The following rates were used:

- Bathroid™ - 0.0393 kg/ha active ingredient.
- Lorsban 4E™ - 1.12 kg/ha active ingredient.

Figures 3.43 and 3.44 contain simulation results for insecticides used on alfalfa. These data are displayed as a fraction of their respective yield. It is not meaningful to compare two different pesticides relative to each other. These two insecticides showed the same relative changes, because of SWAT's simplistic pesticide model and their identical application date. When compared on a non-relative basis, there are orders of magnitude difference between the two insecticides. Figure 3.44 indicates the majority of insecticide yield occurs in just a few years; presumably the result of rainfall timing and relatively short residue life. Significant yields can only occur when rainfall occurs soon after application, while residue insecticide is still available to runoff.

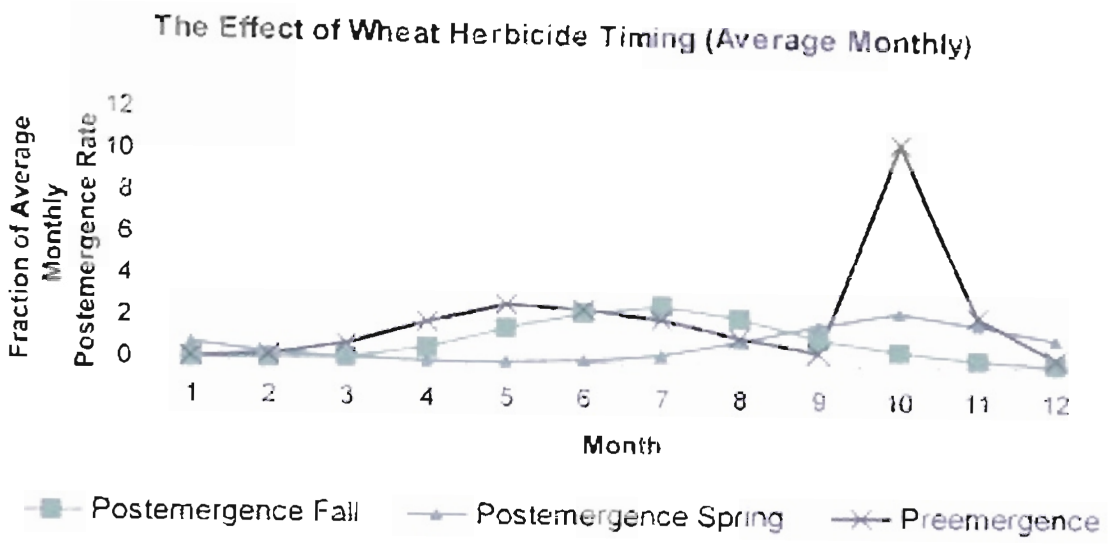


Figure 3.41 The effect of wheat herbicide (Maverick™) timing on average monthly pesticide yield. Derived from 20-year SWAT simulations

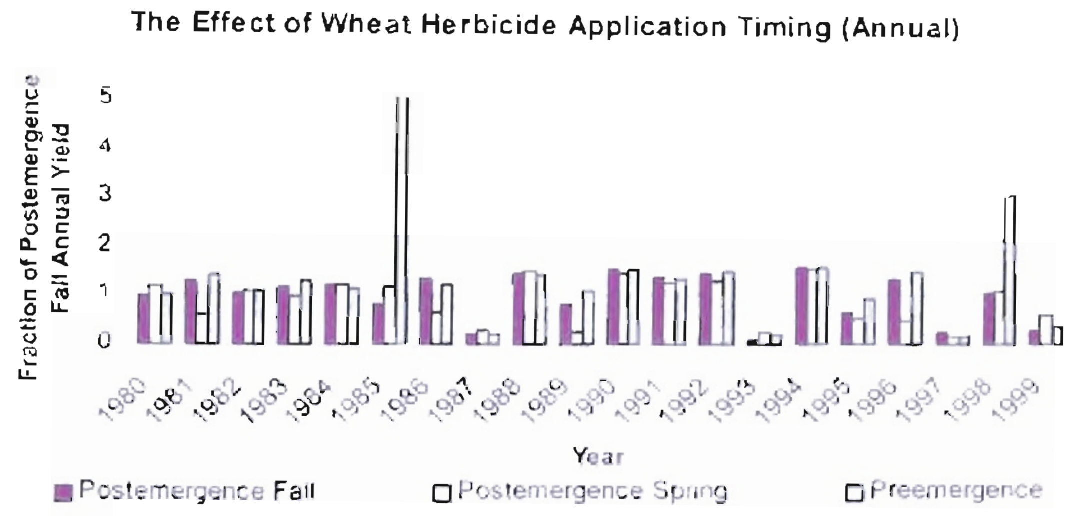


Figure 3.42 The effect of wheat herbicide (Maverick™) timing on annual pesticide yield. Derived from 20-year SWAT simulations

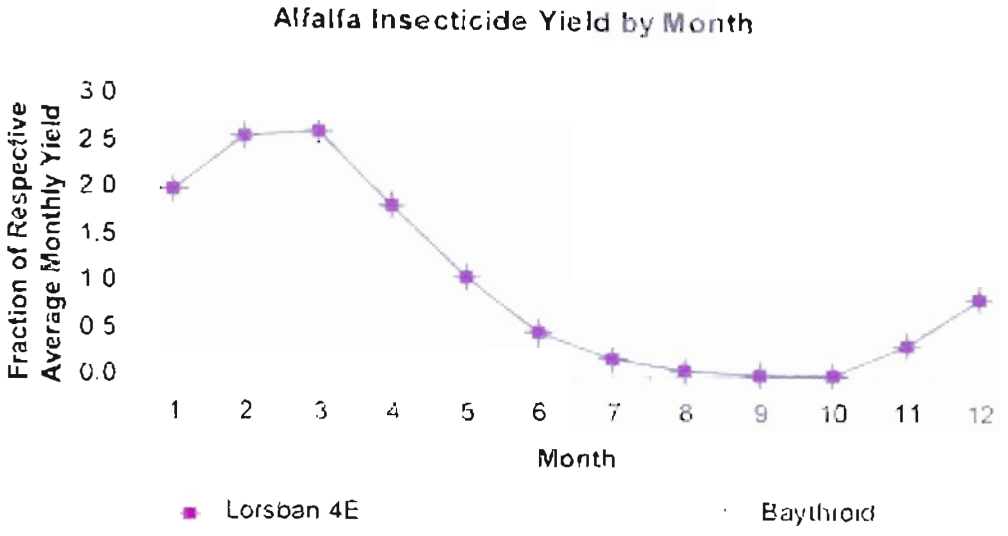


Figure 3.43 Alfalfa insecticide yields monthly trends. Derived from 20-year SWAT simulations

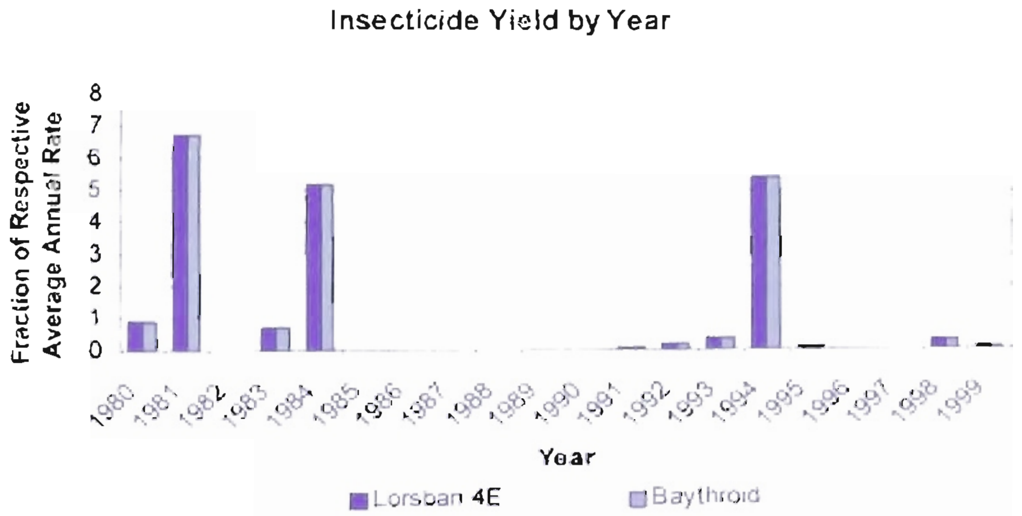


Figure 3.44 Alfalfa insecticide annual trends. Derived from 20-year SWAT simulations

Sediment Hot Spots

SWAT model predictions and the original high resolution GIS data were used to create a high resolution (30-meter) map of likely high sediment yielding areas (hot spots) (Figure 3.45). The land cover and soil combinations from the 50 highest sediment producing HRUs were recorded. Of these 50 HRUs, less that half were unique combinations. The original GIS data were used to determine where in the basin these combinations occur. Simply having a known high sediment yielding land cover and soil combination does not necessarily mean an area is a problem, slope plays a major role. Slope was derived for each pixel using the original 30m DEM. The average slope for all these possible problem areas was used as a cutoff; Any area with less than the average slope was removed. Only areas of higher than average slope, and a known high sediment yielding land cover and soil combination remained, referred to as hot spots. The importance of these hot spots was determined by slope, the higher the slope the hotter the spot.

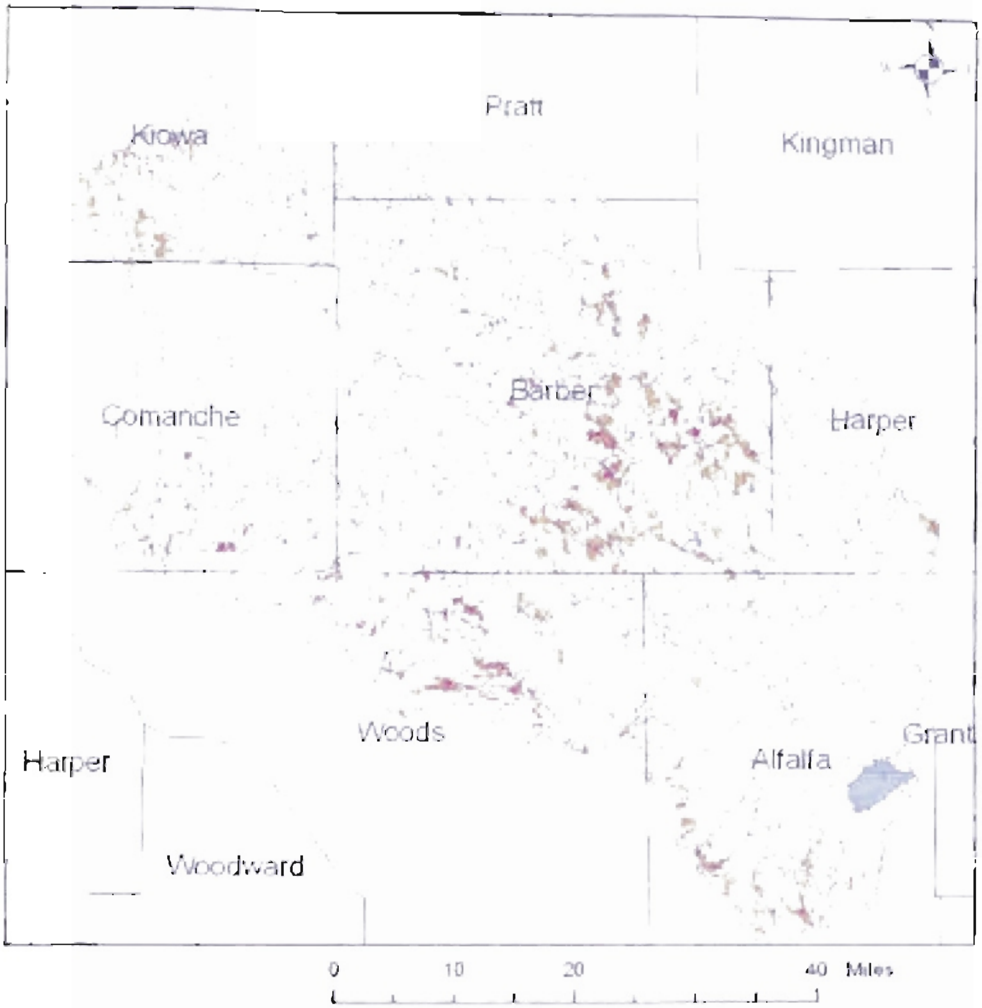


Figure 3.45 Sediment hot spots extrapolated from SWAT model output and 30 meter resolution soils, land cover, and DEMs. Darker red indicates higher sediment yield.

Conclusions

Models can provide a great deal of information not otherwise easily obtained, but it is important that they be used in the proper context. Model results in this report are presented on a relative basis to reduce the uncertainty of these predictions. Actual model output for the calibrated model is given in the appendix, but these data should not be used to make absolute predictions.

A number of important conclusions can be drawn from these simulations:

- The model indicates 67% of all sediment entering the reservoir comes from wheat fields even though wheat covers only 27% of the basin.
- Wheat accounts for 92% of all nitrate currently entering the ground water from nonpoint surface sources according to the model.
- Low till wheat contributes 46% less sediment on average than moldboard tillage when wheat is grazed and harvested for grain in SWAT simulations
- SWAT estimates 58% of the soluble phosphorous entering the reservoir comes from rangeland. Rangeland covers 66% of the basin.
- Tillage as simulated by SWAT has little effect on runoff volume.
- Split nitrogen applications reduce nitrate in surface runoff by more than 55%, and more than 85% in leachate in SWAT simulations.
- SWAT indicates increased nitrogen fertilizer application results in increased nitrogen losses to both surface and ground water.

Model Limitations

There are several model limitations that should be noted. Model limitations may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is neither perfect nor complete. A model by definition is a simplification of the real world. Weather is the driving force for any hydrologic model. Great care was taken to include as much accurate observed weather data as possible. The only weather information available was collected at weather stations. Data collected at a few points must be applied to an area of thousands of square miles. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence. This limitation among others caution us against using model output on a daily or monthly basis.

Scenarios involving radical changes to the basin result in greater uncertainty. The model was calibrated using estimates of what is presently occurring in the basin, large departures from these conditions raise the level of uncertainty.

Land uses that cover only a small area were not represented in the model. Land uses that occupy limited areas such as unpaved roads, bare areas, construction sites, and row crops were not simulated. Most of these features were not depicted in the available land cover. Some of these very small areas may contribute many times more sediment than rangeland of the same area. Although significant, they cannot be simulated with the currently available data.

Each HRU in a subbasin was assumed to have the same characteristics by the model. For instance, the same slope was used for all rangeland and agricultural HRUs in a single subbasin. Agricultural land is generally located in valleys or other flat areas. Rangeland generally occupies land that is unsuitable for row crop production.

There is a great deal of uncertainty associated with management. These simulations assume wheat management is limited to three tillage and three harvest types. In reality, management varies significantly from field to field; a producer can manage their field any way they wish. It is not possible to easily determine what is happening where, or to simulate all these activities in the model. Therefore, categories were created to cover reasonable managements choices only.

Pesticide application for the basin entire was made on a single date in the model. In reality the timing varies from field to field. This limitation has a greater influence on short duration pesticides yields which are more sensitive to rainfall soon after application. Assuming farmers will not apply pesticides to their fields if rainfall is predicted, the model likely overestimated the variability of year to year pesticide yields.

CHAPTER 4 The Effect of Data Detail on the SWAT Model

Study Areas

The Lake Eucha and Great Salt Plains Basins were both included in this portion of the study. The contrast between these two basins makes them a good combination for this study. Both are located at a similar latitude, but have radically different precipitation, land cover, topography, and soils (Figure 4.1).

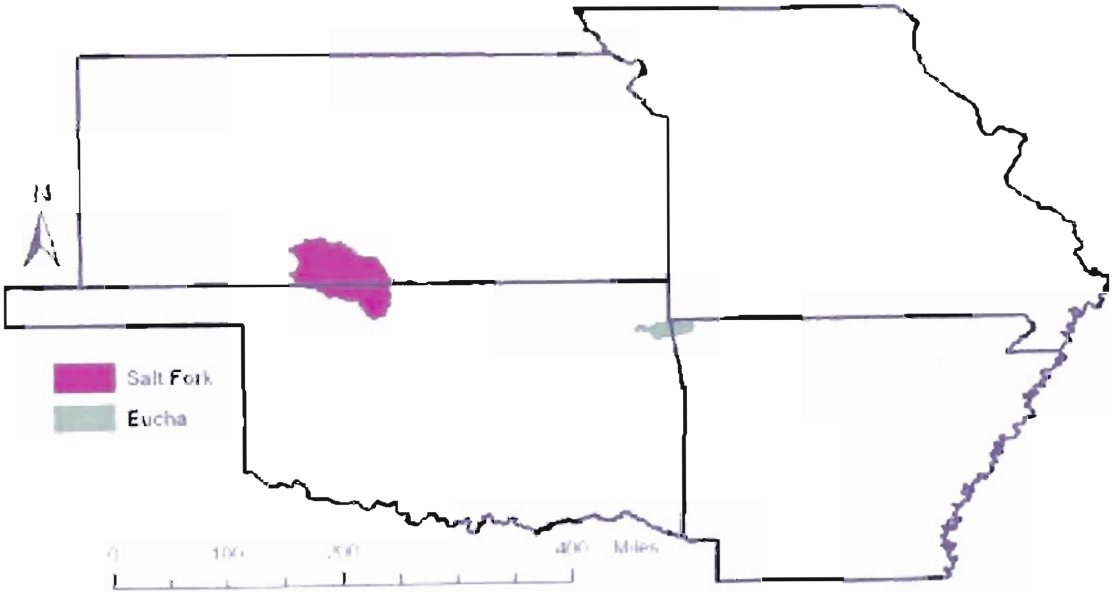


Figure 4.1 Study basin locations

Data Types

Topography

DEMs (Digital Elevation Models) are used to define topography for SWAT (Figure 4.2). The US Geographic Survey (USGS) provides DEMs at a variety of scales. DEMs are available in a raster format at resolutions of 30, 60, 120, and in very limited areas at 10 meters. Thirty meter data are the most detailed that is addressed by this study. Topographic data included in BASINS have a resolution of 300 meters. Thirty-meter data developed for use in SWAT BMP simulations were resampled to 60, 120 and 300 meters. These four levels of DEM resolution were included in the study.

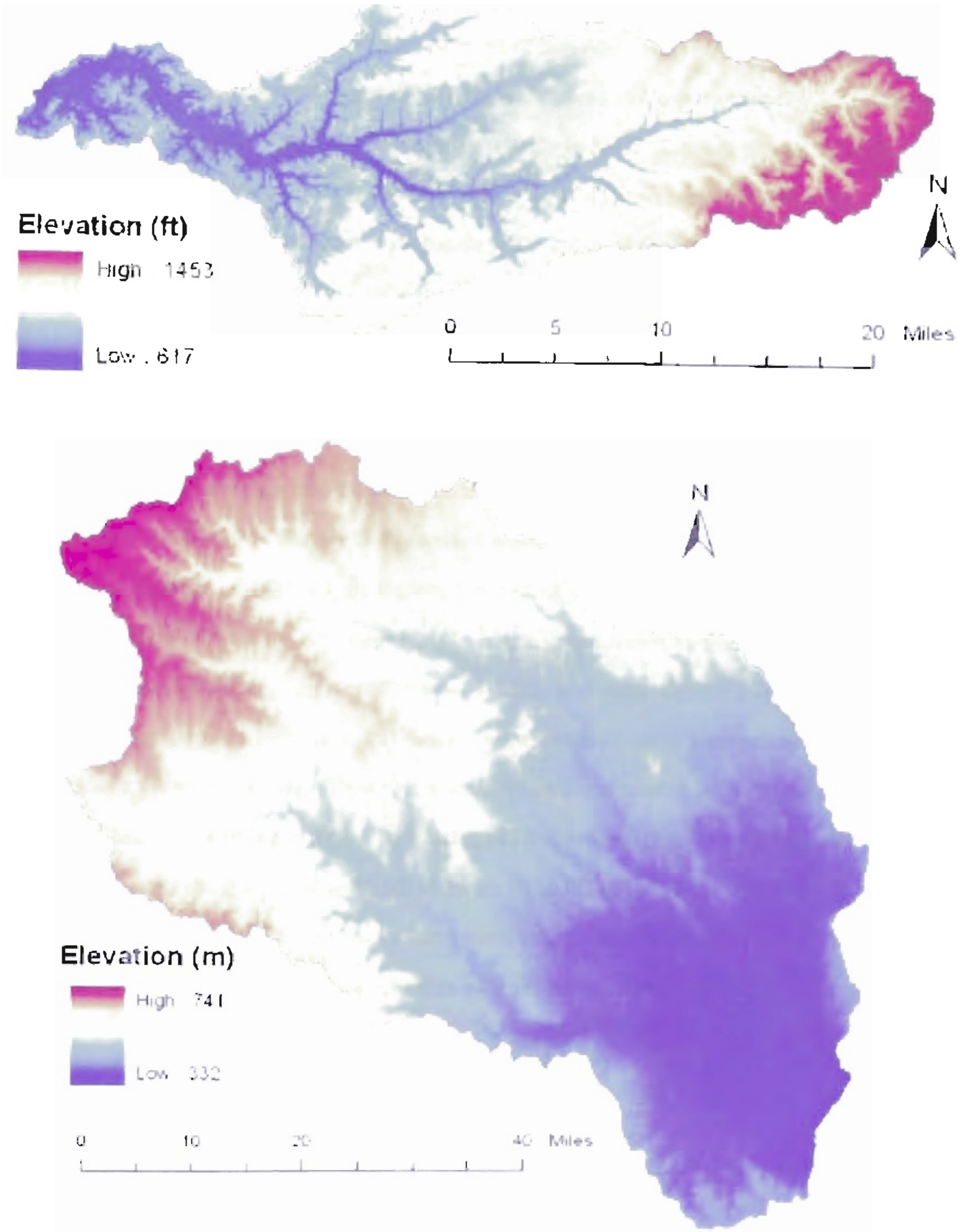


Figure 4.2 Lake Eucha Basin and Salt Fork Basin elevation derived from 30 meter Digital Elevation Models

Soils

There is currently only one GIS coverage for soils nationwide, STATSGO (State Soil Geographic Database), which were compiled by the NRCS (Natural Resource Conservation Service). These data are most commonly used with SWAT, and are available in the BASINS database. STATSGO was created from generalizations of other soil surveys. The minimum mapping area is 625 ha. No soil group smaller than 625 ha is included. Each map unit consists of several soils. An associated MUIR (Map Unit Interpretations Record) database contains the properties and distribution of soils in each map unit. Both low detail soils coverage were classified by MUID (Map Unit IDentification) (Figures 4.3 and 4.5).

Other more detailed soil data may be available depending on the study area. The NRCS is currently working on SSURGO (Soil Survey Geographic Database). SSURGO is far more detailed, but not available for all areas. SSURGO is a digitized version of the soil survey, and is the most accurate soil data available. This study also uses a 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS, and other digitized soil surveys similar to SSURGO. High detailed soils for both basins were developed using a combination of these data. Details about the development of these high details data are available in Chapters 2 and 3. Soils of the Eucha Basin were linked to SWAT by S5ID (Soils 5 IDentifier) (Figure 4.4). Soils of the Salt Fork Basin were linked using a modified MUID know as STMUID (STate Map Unit IDentification) which simply substitutes a two digit number for each state abbreviation and a sequence number (Figure 4.6). The addition of a soil sequence specifies a particular soil in each MUID.

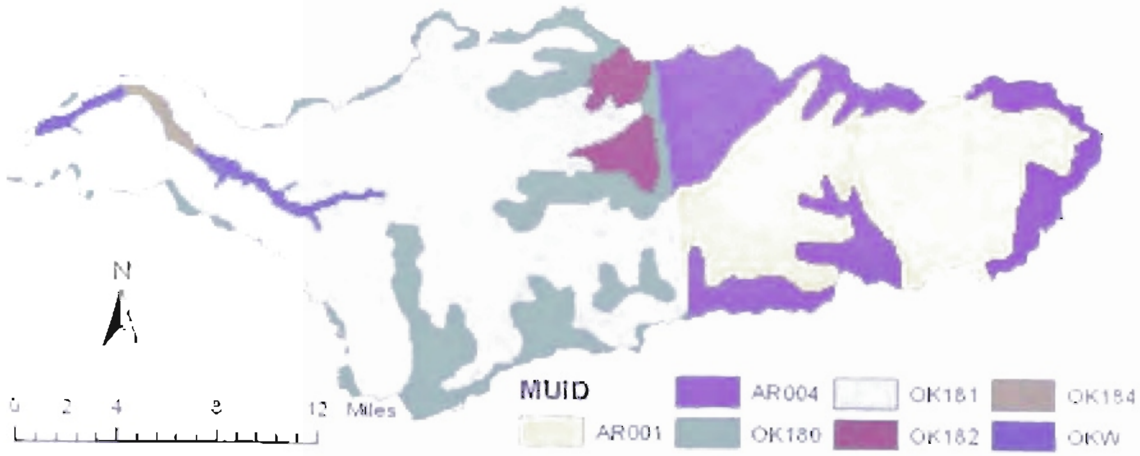


Figure 4.3 STATSGO (State Soil Geographic) derived soil data for the Lake Eucha Basin

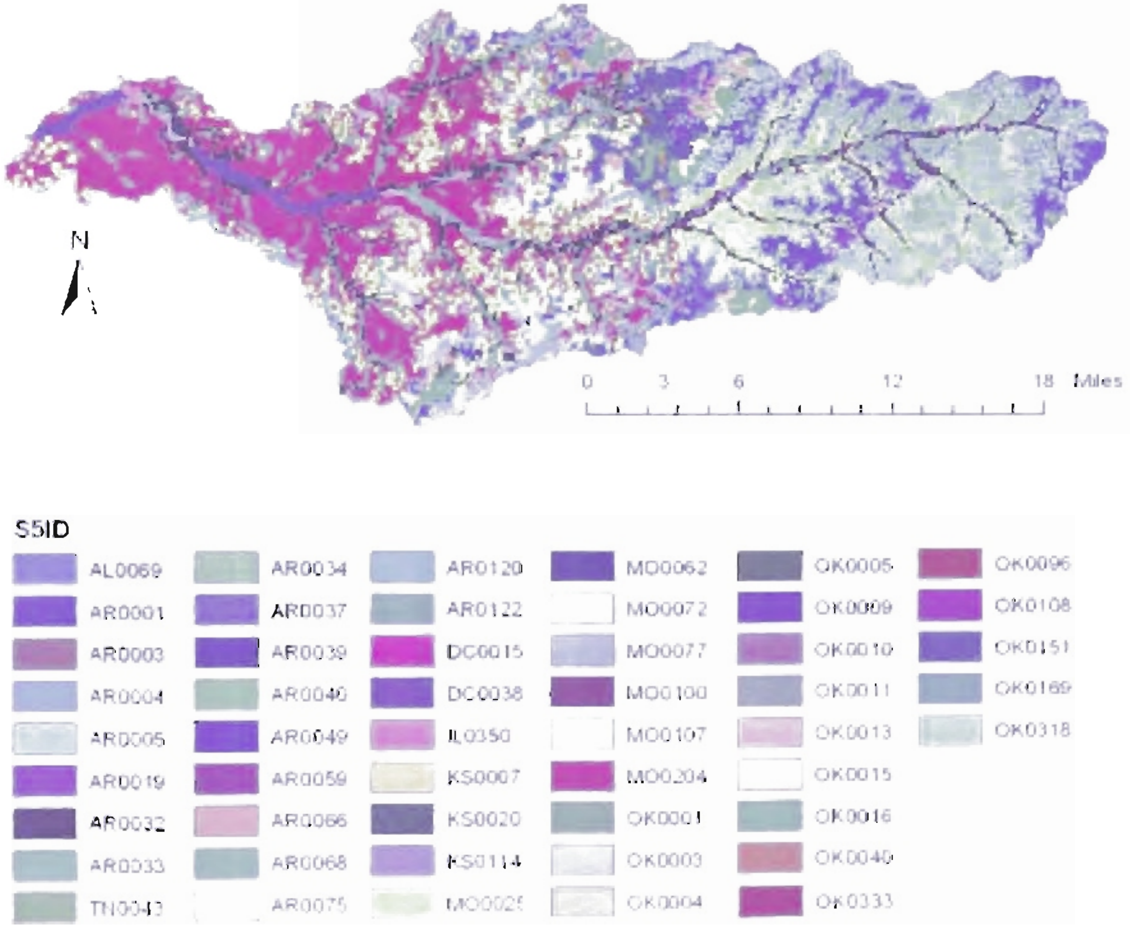


Figure 4.4 High resolution soils data for the Lake Eucha Basin

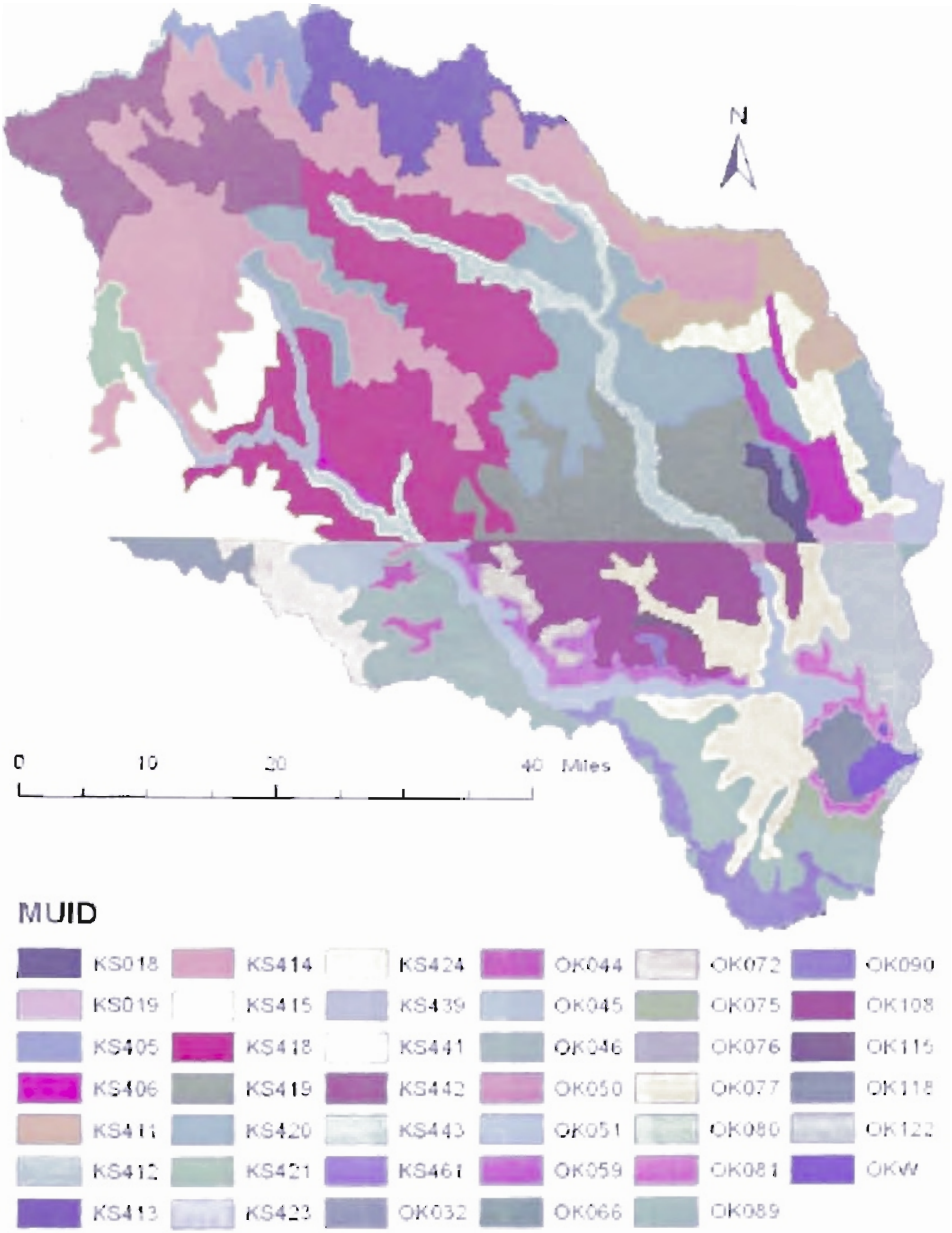


Figure 4.5 Low resolution STATSGO (State Soil Geographic) derived soil data for the Salt Fork Basin.

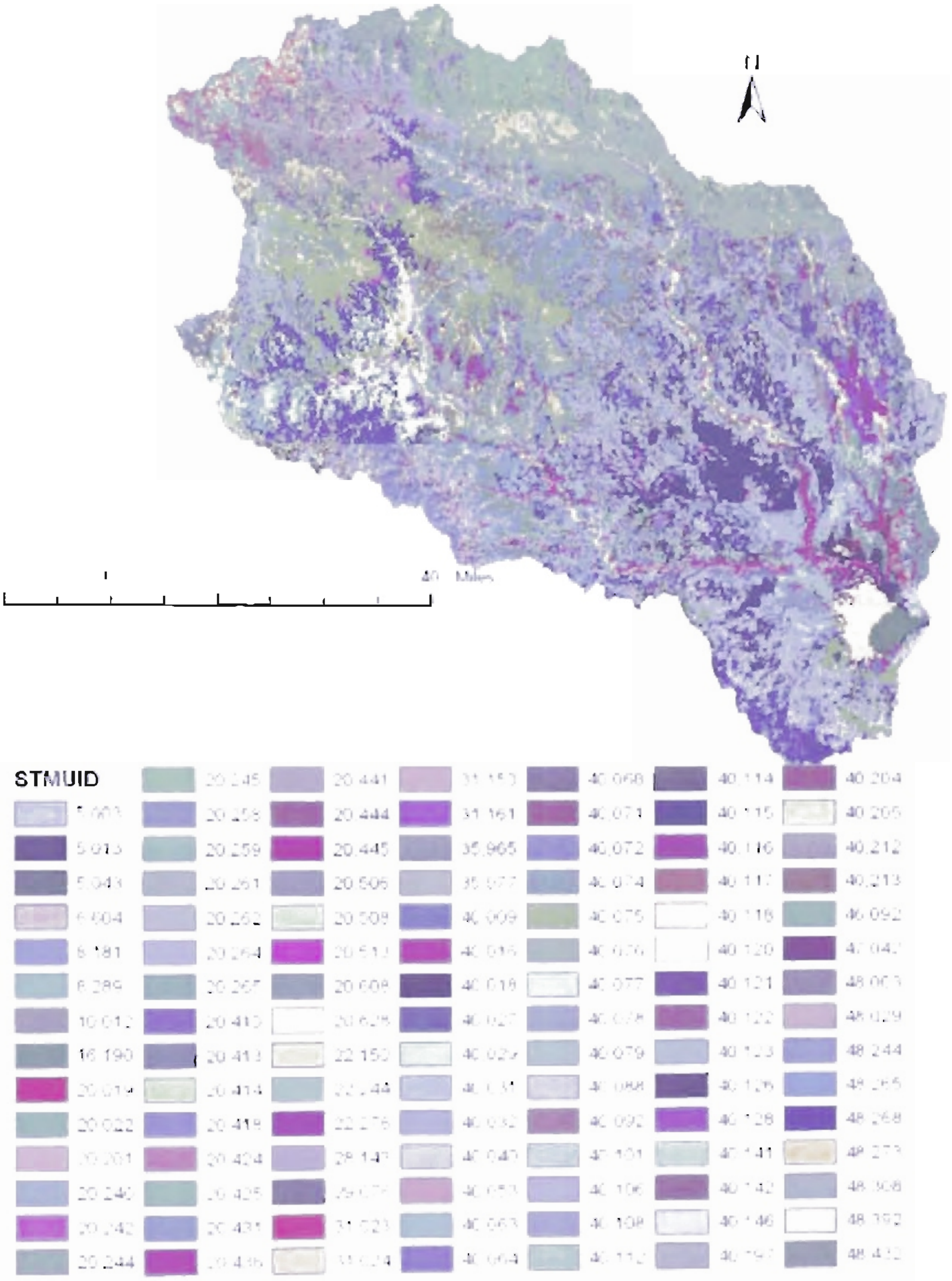


Figure 4.6 High resolution soils data of the Salt Fork Basin

Land Cover

Land cover is more complicated to compare than soils or topography. Land cover can change over a relatively short time frame. Soils and topography take much longer to change significantly. Land cover is perhaps the most important GIS data used in SWAT. Several choices are available. The least detailed, easiest data to use with SWAT is USGS LULC (Land Use Land Cover) data. These data are available nationwide. The scale of these data is 1:250,000 and 1:100,000 for limited areas. Dates range from the late 70's to the early 80's. These data are available in the BASINS data set and are readily used by SWAT. LULC data were used to define the land cover for low detail simulations of both basins (Figures 4.7 and 4.9).

Several other sources of land cover data are available. The USGS and the EPA recently released NLCD (National Land Cover Database), which have a 30 meter resolution. These data were used to define land cover for the Salt Fork Basin (Figure 4.10). Another recent land cover data set is from GAP (Gap Analysis Project). The GAP project maps vegetation based on 30 meter Landsat Thematic Mapper satellite imagery. The primary purpose of this information is to predict the range of native vertebrate species, and the categorical information between these two data sets is quite different. GAP data were used to determine land cover for the Eucha Basin (Figure 4.8). Additional details about the development of land cover data for both basins are available in Chapters 2 and 3.

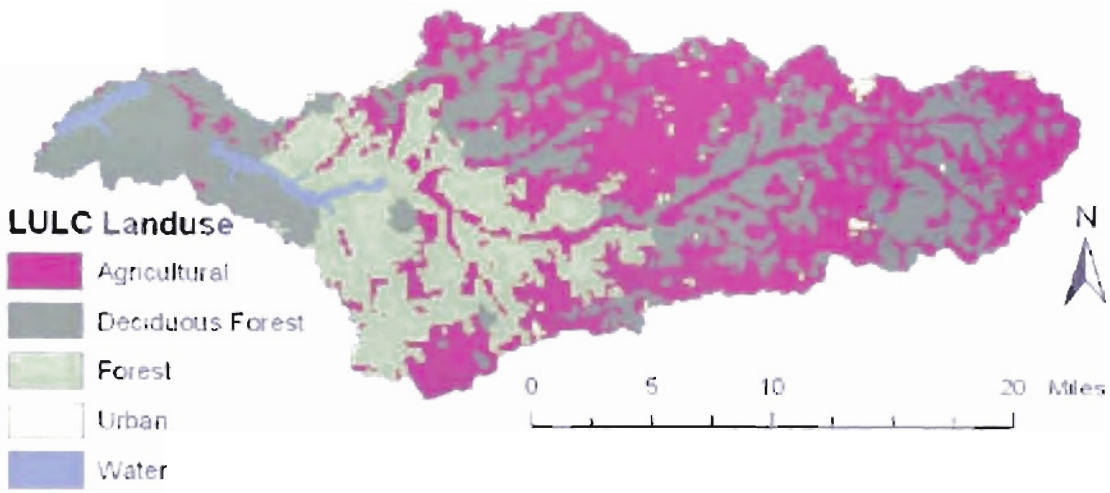


Figure 4.7 USGS LULC (Land Use Land Cover) derived land cover data for the Lake Eucha Basin

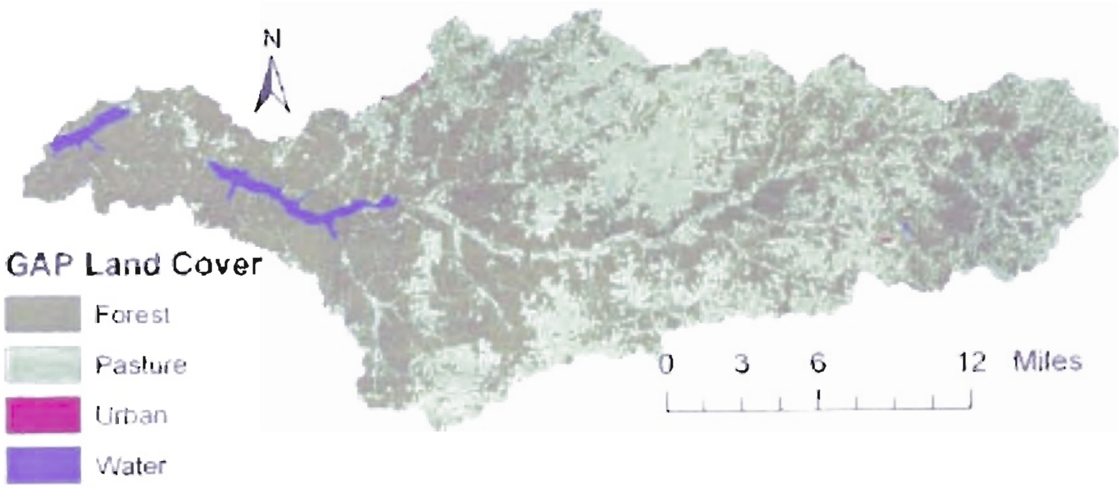


Figure 4.8 GAP (Gap Analysis Project) derived land cover data for the Lake Eucha Basin

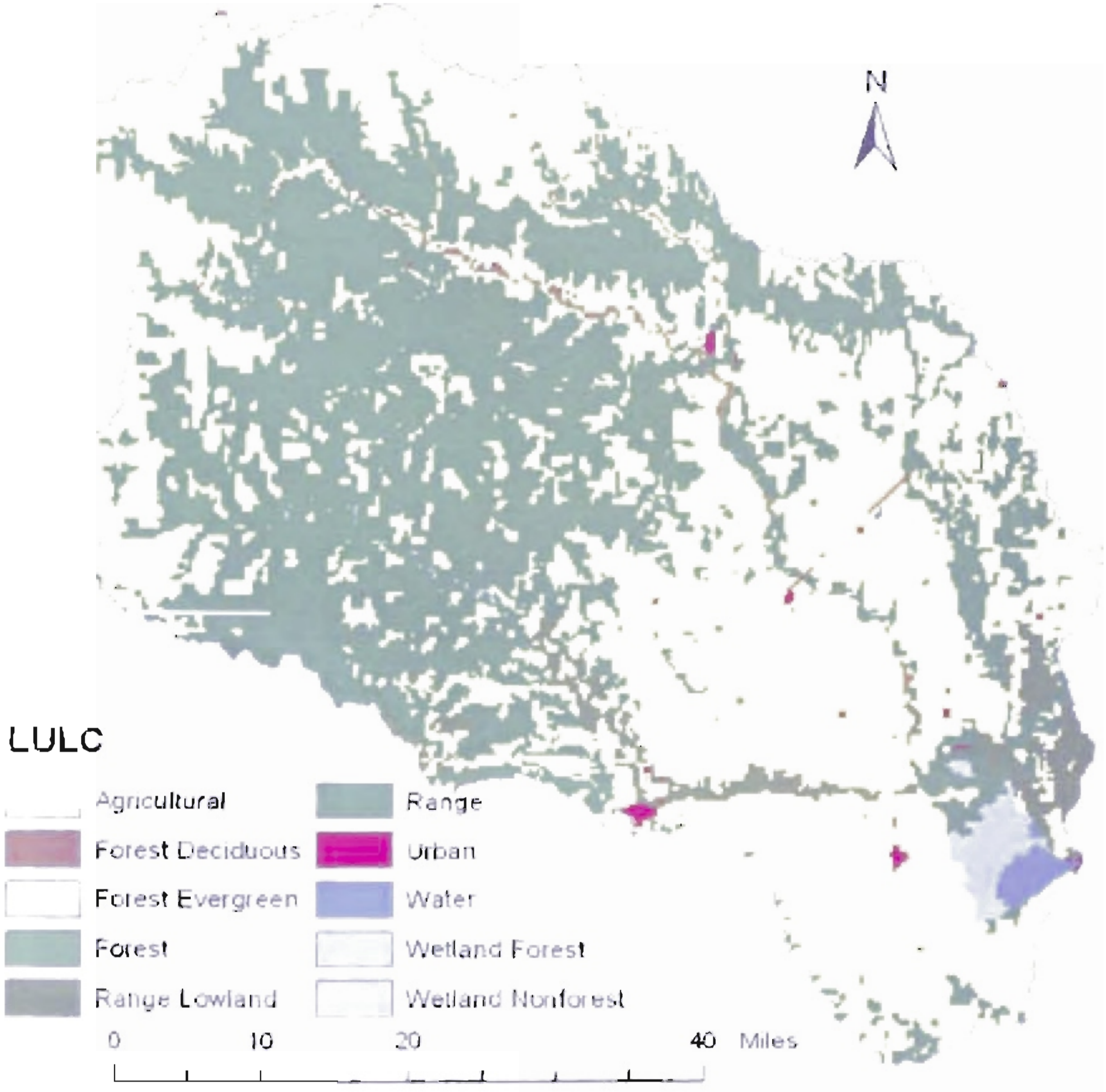


Figure 4.9 USGS LULC (Land Use Land Cover) derived land cover data for the Salt Fork Basin

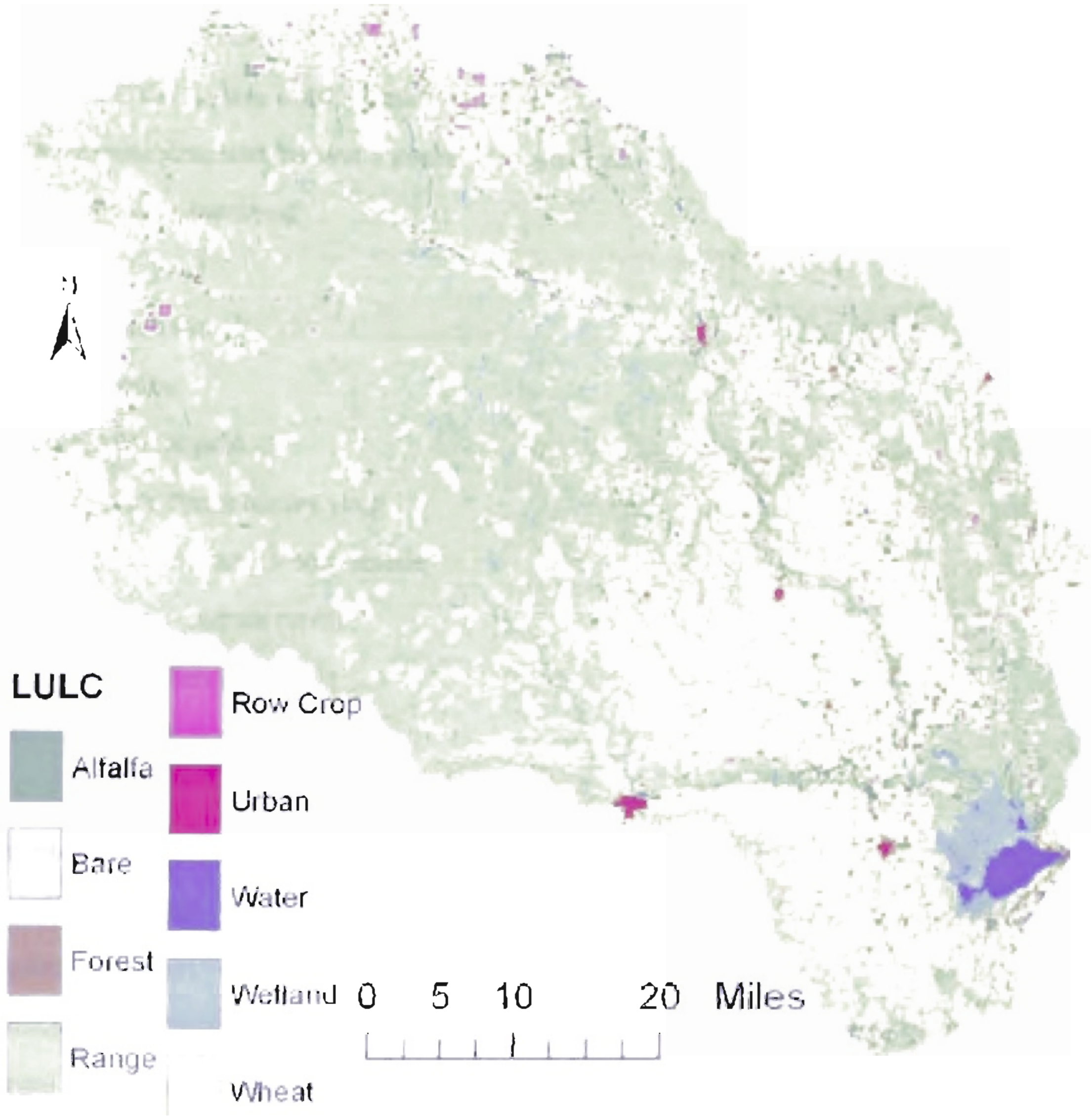


Figure 4.10 Thirty-meter resolution USGS NLCD (National Land Cover Data) derived data for the Salt Fork Basin

Methods

Each basin was examined separately with a model run for each combination of GIS data. A factorial experimental design was used (Table 4.1). Twenty average annual data points were taken from 25 year simulations, with the first 5 years removed to allow the model to "warm up". The following parameters were examined:

- Water yield
- Surface Runoff
- Baseflow
- Sediment yield
- Soluble Phosphorous yield
- Sediment-bound Phosphorous
- Nitrate in surface runoff
- Evapo-Transpiration
- Sediment-bound Nitrogen

The model was not calibrated since the calibration would tend to make all results similar regardless of the included data. Comparisons between model runs were made relative to the baseline or most detailed model run. Relative results across multiple parameters are more easily compared than absolute results because they are more similar in magnitude. The number of subbasins and HRUs remain nearly constant for all simulations of a particular basin. It is not possible to use the same number of subbasins and HRUs for each simulation. These are based partly on the input data which vary by simulation. This level of subdivision was selected based more on practicality than the recommendations of previous research (Binger et al., 1997). The approximate number of subbasins for each basin is 50. A stream threshold area of 1,000 ha was used for Lake Eucha Basin, and 10,000 ha for the Salt Fork Basin. HRU threshold settings were set as close to 10% land use over subbasins area and 9% soil over subbasin area as possible for both basins. Two simulations for the Salt Fork Basin required the soil over subbasin threshold to be reduced to 8% from the default value of 20%.

Results were derived from non-routed model outputs obtained using a custom VBA (Visual Basic for Applications) program. Annual subbasin data were summarized on a per unit area basis to determine a basin average for each output studied. This program was also used in the Salt Fork Basin BMP study.

Table 4.1 Combinations of DEM resolution, soils, and land cover compared.

DEM Resolution (m)	Soils Detail	Land Cover Detail
30	High	High
30	High	Low
30	Low	High
30	Low	Low
60	High	High
60	High	Low
60	Low	High
60	Low	Low
120	High	High
120	High	Low
120	Low	High
120	Low	Low
300	High	High
300	High	Low
300	Low	High
300	Low	Low

Results

Data from each of the 32 simulations were analyzed to determine the effect of changing data types or resolutions. Table 4.2 contains the mean from each simulation and averages across each level of GIS data type. Model predictions were analyzed using SAS (Statistical Analysis Software). The SAS programs are available in Appendix G. A factorial design was chosen to enable a comprehensive statistical analysis. Interaction between the different data types prohibited the analysis of main effects. One way to overcome this problem is to analyze only the simple effects Because there are two basins, each with a 4x2x2 factorial experimental design and nine study parameters, analysis of simple effects is a prohibitively difficult task. In addition, all these simple effects would be very difficult to display in any meaningful manner in the context of this report. To overcome these difficulties only a select few simple effects were included in the statistical analysis.

At a DEM resolution of 30 meters land cover detail has a significant impact on more parameters than soils detail. Table 4.3 contains soils and land cover low detail simulations compared to the baseline condition. The effect of land cover detail is the result of more than simple detail differences. Each land cover type in the original GIS data must be matched to a corresponding category in SWAT by a conversion table. SWAT is able to incorporate LULC data directly using a conversion table, which is included in the interface. This table may not be accurate for all areas. A large portion of the Eucha basin was determined to be AGRL (Generic Agriculture) when the LULC data were imported. In reality, these areas are improved pastures which have dramatically different characteristics. This results in the dramatic changes when low detail land cover was included in the simulation. This problem is far less evident in the Salt Fork Basin, the LULC conversion table is more suited to this type of area.

Statistical comparison for DEM resolution levels are displayed in Table 4.4. These are simple effects calculated from only a fraction of the entire data set. DEM resolution has the greatest effect on sediment and sediment-bound nutrients. Presumably because slope is derived from the DEM. The resolution of the DEM also has other affects in the SWAT model. All additional GIS data included in the model are resampled to the same resolution as the DEM by the interface. This is thought to contribute to the interaction that prevented statistical analysis of main effects.

Figures 4.11 to 4.18 display graphical representation of some of the information displayed in Table 4.2. Figure 4.11 to 4.14 show how DEM resolution affects both basins. Figures 4.11 and 4.13 were constructed using the entire data set without concern for land cover and soils. Very large sediment yields in Figure 4.13 were the result of the incorporation of low detail land cover data. These spikes are not seen in Figure 4.14, which does not include the LULC data for the Lake Eucha Basin; however, the overall treads of reduced sediment with decreased resolution are similar.

Figures 4.12 and 4.14 are the simple effects, which have corresponding statistical tests in Table 4.4. Only high resolution soils and land cover were considered in these figures. Figures 4.15 to 4.18 contain comparison between soils and land cover combinations. Figures 4.15 and 4.17 contain averages across all levels of DEM. Figures 4.16 and 4.18 display only simple effects. The effect of adding LULC data to the Eucha Basin is illustrated in Figure 4.18, which resulted in a 94 fold increase in sediment. The addition of low detail soils data had the opposite effect on sediment and sediment-bound nutrients.

Table 4.2 The effect of data detail on several SWAT output parameters. All values are fractions relative to the most detailed simulation (30m DEM with high soils and land cover). "X" indicates averages across all categories.

Basin	DEM	Soils	Land Cover	Runoff	Water Yield	ET	Sediment	Organic N	Sed-Bound P	Nitrate in runoff	Soluble P	Ground water
Salt Fork	30	High	High	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30	High	Low	1.39	1.35	0.97	2.10	1.49	1.21	0.85	0.82	1.01
	30	Low	High	0.94	1.02	0.99	0.91	0.93	0.95	1.04	0.95	2.41
	30	Low	Low	1.35	1.37	0.95	2.07	1.44	1.24	0.92	0.84	1.96
	60	High	High	1.01	0.99	1.00	0.73	0.82	0.84	1.02	1.02	0.79
	60	High	Low	1.37	1.33	0.97	1.55	1.29	1.11	0.84	0.82	1.11
	60	Low	High	0.94	1.01	0.99	0.69	0.79	0.83	1.05	0.95	2.53
	60	Low	Low	1.35	1.36	0.96	1.55	1.24	1.14	0.93	0.86	2.06
	120	High	High	1.01	0.99	1.00	0.52	0.64	0.66	1.03	1.02	0.98
	120	High	Low	1.40	1.34	0.97	1.12	1.05	0.97	0.85	0.82	1.14
	120	Low	High	0.94	1.01	0.99	0.50	0.63	0.67	1.06	0.96	2.57
	120	Low	Low	1.38	1.36	0.96	1.08	0.99	0.96	0.94	0.86	2.11
	300	High	High	1.17	1.11	0.99	0.47	0.60	0.59	1.06	1.06	0.65
	300	High	Low	1.38	1.32	0.97	0.75	0.79	0.79	0.84	0.81	1.18
	300	Low	High	0.93	0.99	0.99	0.34	0.46	0.49	1.04	0.94	2.63
	300	Low	Low	1.35	1.34	0.96	0.76	0.79	0.79	0.93	0.85	2.12
	30	X	X	1.17	1.19	0.98	1.52	1.22	1.10	0.95	0.90	1.59
	60	X	X	1.17	1.17	0.98	1.13	1.03	0.98	0.96	0.91	1.62
	120	X	X	1.18	1.17	0.98	0.80	0.83	0.81	0.97	0.91	1.70
	300	X	X	1.21	1.19	0.98	0.58	0.66	0.66	0.97	0.92	1.65
	X	High	X	1.22	1.18	0.88	1.03	0.96	0.90	0.94	0.92	0.98
	X	Low	X	1.15	1.18	0.97	0.99	0.91	0.88	0.99	0.90	2.30
	X	X	High	0.99	1.02	0.99	0.84	0.73	0.75	1.04	0.99	1.70
	X	X	Low	1.37	1.34	0.96	1.37	1.14	1.03	0.89	0.84	1.59
Eucha	30	High	High	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30	High	Low	1.36	1.13	0.92	94.19	10.99	3.82	0.76	0.32	0.90
	30	Low	High	1.07	0.98	1.00	0.23	0.13	0.12	1.14	1.08	0.82
	30	Low	Low	1.42	1.11	0.93	18.06	7.40	3.79	0.83	0.33	0.79
	60	High	High	1.00	0.99	1.01	0.72	0.46	0.46	0.99	1.00	1.01
	60	High	Low	1.36	1.13	0.93	69.12	10.03	3.73	0.76	0.32	0.90
	60	Low	High	1.07	0.98	1.00	0.17	0.08	0.07	1.13	1.08	0.93
	60	Low	Low	1.42	1.11	0.93	13.26	6.11	3.74	0.83	0.33	0.79
	120	High	High	1.00	1.00	1.00	0.44	0.14	0.14	1.01	1.01	1.02
	120	High	Low	1.36	1.12	0.93	43.22	8.79	3.62	0.76	0.32	0.91
	120	Low	High	1.07	0.98	1.00	0.15	0.12	0.08	1.15	1.09	0.94
	120	Low	Low	1.42	1.10	0.93	8.55	4.58	3.56	0.83	0.33	0.79
	300	High	High	1.00	0.98	1.01	0.24	0.04	0.03	1.00	1.01	1.01
	300	High	Low	1.36	1.12	0.93	23.12	6.62	3.28	0.76	0.32	0.91
	300	Low	High	1.07	0.98	1.00	0.06	0.05	0.05	1.14	1.08	0.93
	300	Low	Low	1.42	1.10	0.93	4.58	2.68	2.30	0.83	0.33	0.79
	30	X	X	1.21	1.05	0.96	28.37	4.88	2.18	0.93	0.68	0.90
	60	X	X	1.21	1.05	0.97	20.82	4.17	2.00	0.93	0.68	0.91
	120	X	X	1.22	1.05	0.96	13.09	3.41	1.85	0.94	0.69	0.91
	300	X	X	1.21	1.04	0.97	7.00	2.35	1.42	0.93	0.69	0.91
	X	High	X	1.18	1.06	0.97	29.00	4.76	2.01	0.88	0.66	0.96
	X	Low	X	1.25	1.04	0.97	5.63	2.64	1.71	0.99	0.71	0.86
	X	X	High	1.04	0.99	1.00	0.37	0.25	0.24	1.07	1.04	0.97
	X	X	Low	1.39	1.11	0.93	34.26	7.15	3.48	0.80	0.33	0.85

Table 4.3 Parameters which show a significant difference when compared to the 30m high detail soils and land cover simulation.

Basin	Coverage	Runoff	Water Yield	ET	Sediment	Organic N	Sed-Bound P	Nitrate in runoff	Soluble P	Groundwater
Salt Fork	Land Cover	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	0.962
	Soils	0.103	0.505	**0.003**	0.350	0.255	0.220	0.099	**0.016**	**<.001**
Eucha	Land Cover	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
	Soils	**<.001**	0.052	0.696	0.813	**0.010**	**<.001**	**<.001**	0.177	**<.001**

Table 4.4 Means and multiple comparison tests of simple effects for levels of DEM. Soils and land cover detail are high for all tests. Main effects cannot be analyzed due to interaction. Values in a column with the same letter are not significantly different from each other at α=0.05.

Basin	DEM	Runoff	Water Yield	ET	Sediment	Organic N	Sed-Bound P	Nitrate in runoff	Soluble P	Groundwater
Salt Fork	30	1.01 a	0.99 a	1.00 a	0.73 a	0.82 a	0.84 a	1.02 a	1.02 a	0.79 a
	60	1.01 a	0.99 a	1.00 ab	0.73 a	0.82 b	0.84 b	1.02 ab	1.02 a	0.79 a
	120	1.01 a	0.98 a	1.00 b	0.52 b	0.64 c	0.66 c	1.03 ab	1.02 a	0.98 a
	300	1.17 b	1.11 b	0.99 a	0.47 b	0.6 d	0.59 c	1.06 b	1.06 a	0.65 a
Eucha	30	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a	1.00 a
	60	1.00 a	0.99 ab	1.01 a	0.72 a	0.46 ab	0.46 b	0.99 a	1.00 a	1.01 a
	120	1.00 a	1.00 a	1.00 a	0.44 a	0.14 b	0.14 c	1.01 a	1.01 a	1.02 a
	300	1.00 a	0.98 b	1.01 b	0.24 a	0.04 b	0.03 c	1.00 a	1.01 a	1.01 a

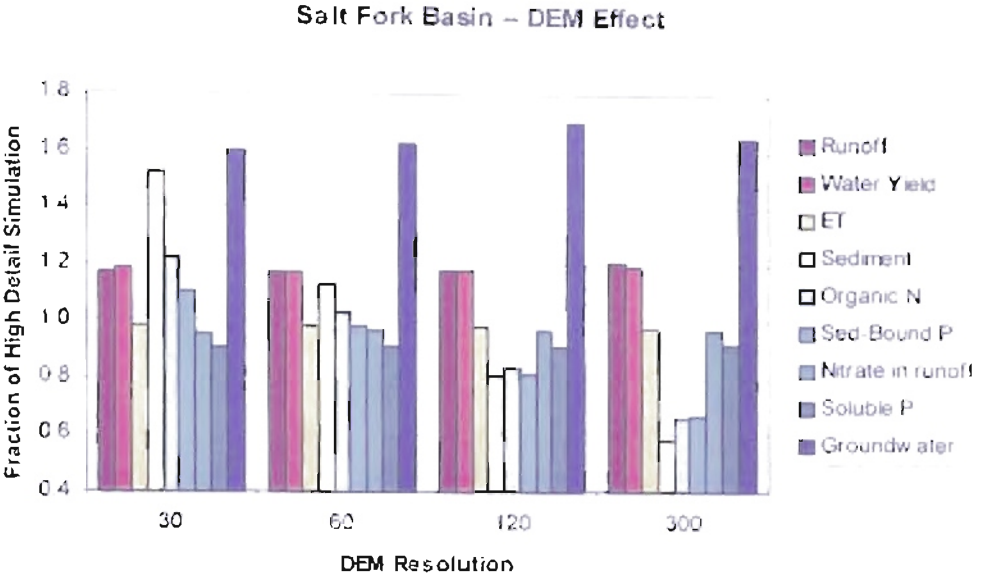


Figure 4.11 The effect of DEM resolution on the Salt Fork Basin averaged across all levels of soils and land cover. Displayed as a fraction of the 30m high detail soils and land cover simulation

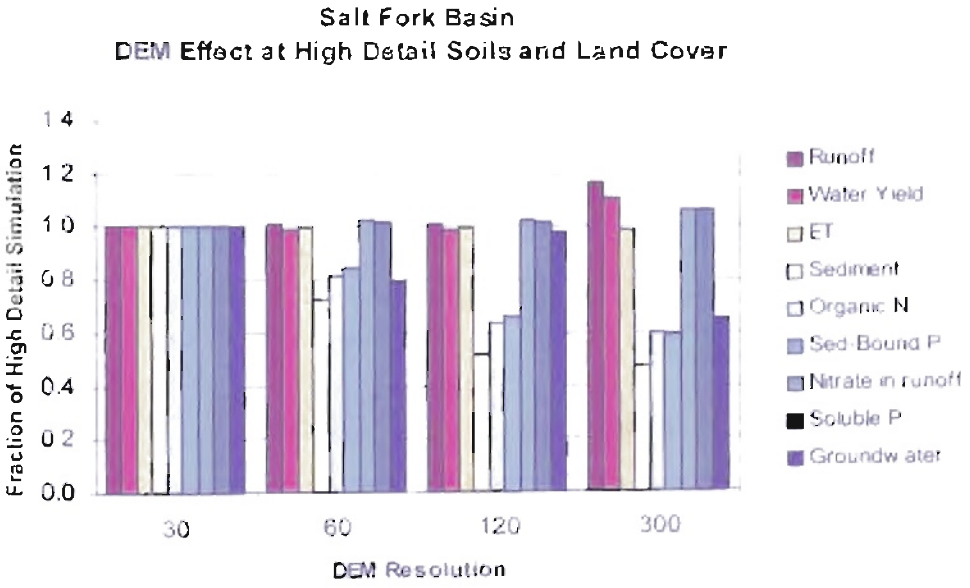


Figure 4.12 The effect of DEM resolution on the Salt Fork Basin at high detail soils and land cover Displayed as a fraction of the 30m high detail soils and land cover simulation.

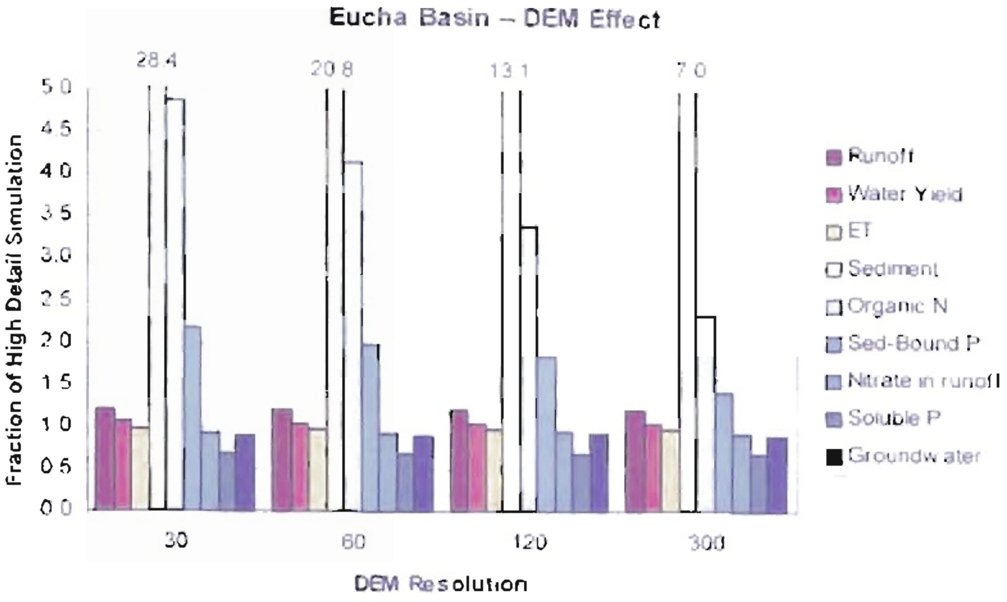


Figure 4.13 The effect of DEM resolution on the Lake Eucha Basin averaged across all levels of soils and land cover. Displayed as a fraction of the 30m high detail soils and land cover simulation.

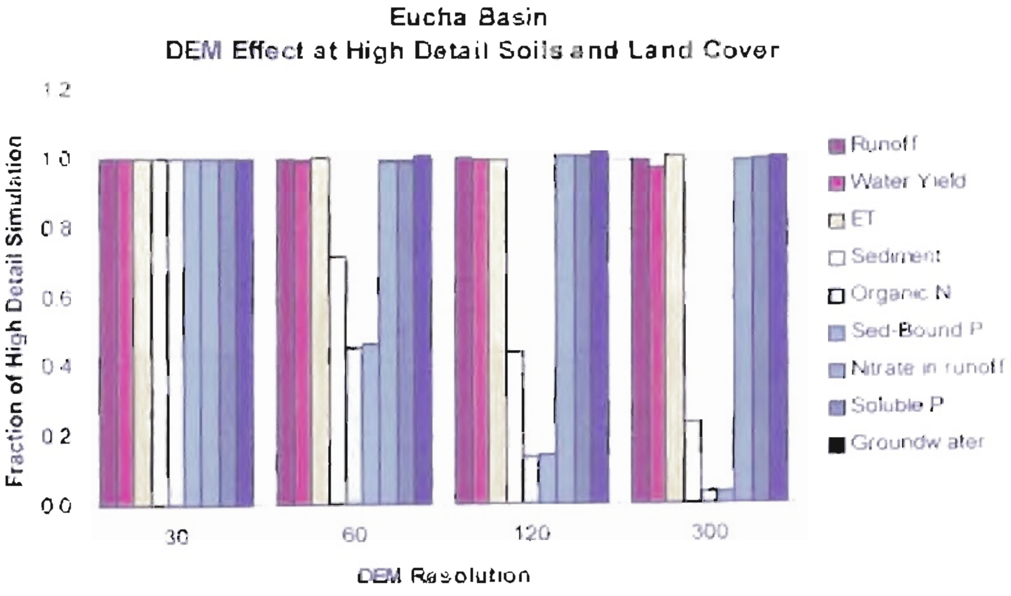


Figure 4.14 The effect of DEM resolution on the Lake Eucha Basin at high detail soils and land cover. Displayed as a fraction of the 30m high detail soils and land cover simulation.

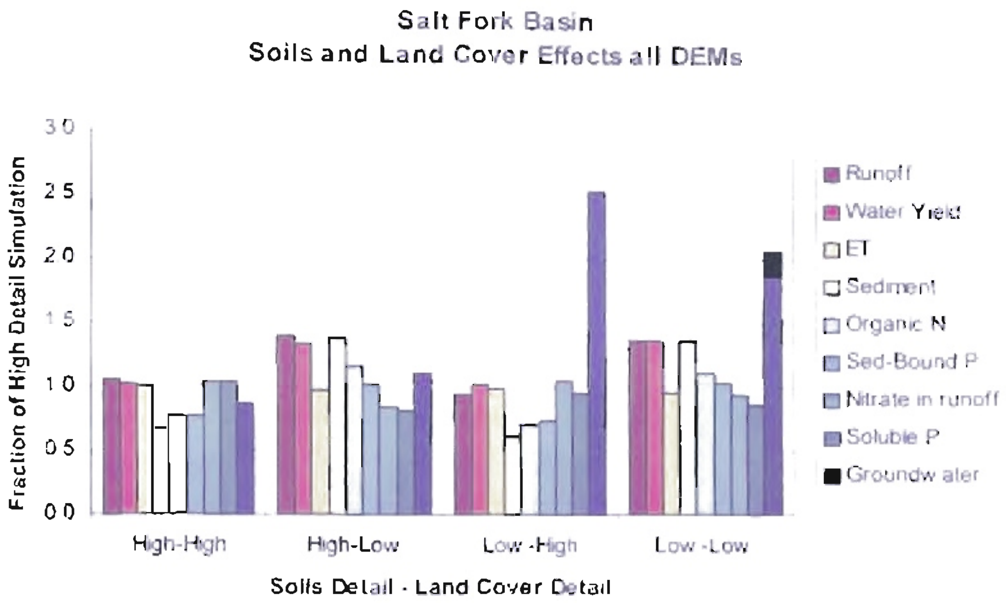


Figure 4.15 The effect of soils and land cover detail across all levels of DEMs for the Salt Fork Basin. Displayed as a fraction of the 30m high detail soils and land cover simulation.

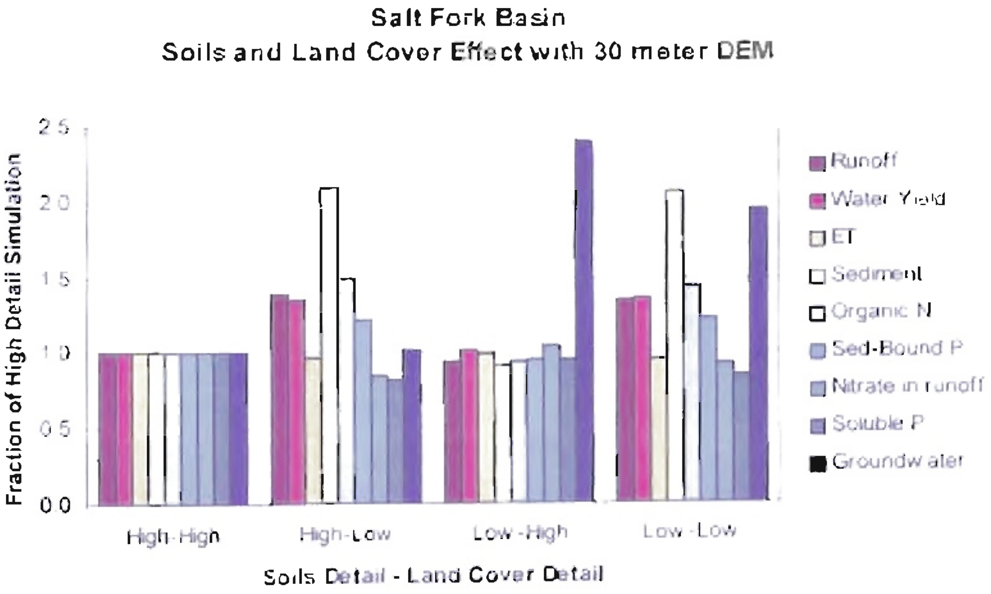


Figure 4.16 The effect of soils and land cover detail across 30 meter DEMs for the Salt Fork Basin. Displayed as a fraction of the 30m high detail soils and land cover simulation.

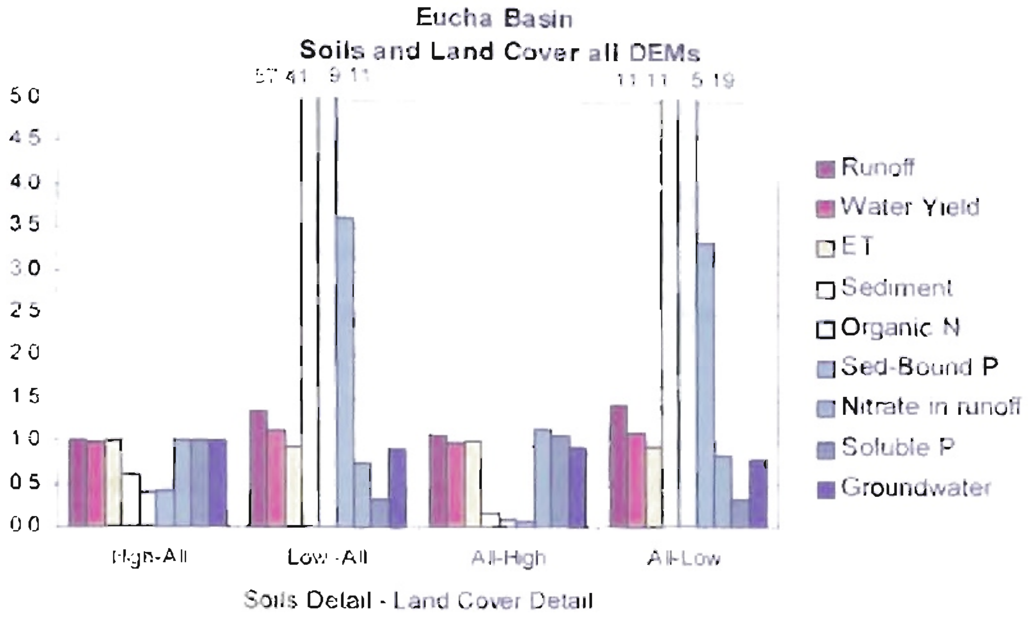


Figure 4.17 The effect of soils and land cover detail across all levels of DEMs for the Lake Eucha Basin. Displayed as a fraction of the 30 m high detail soils and land cover simulation.

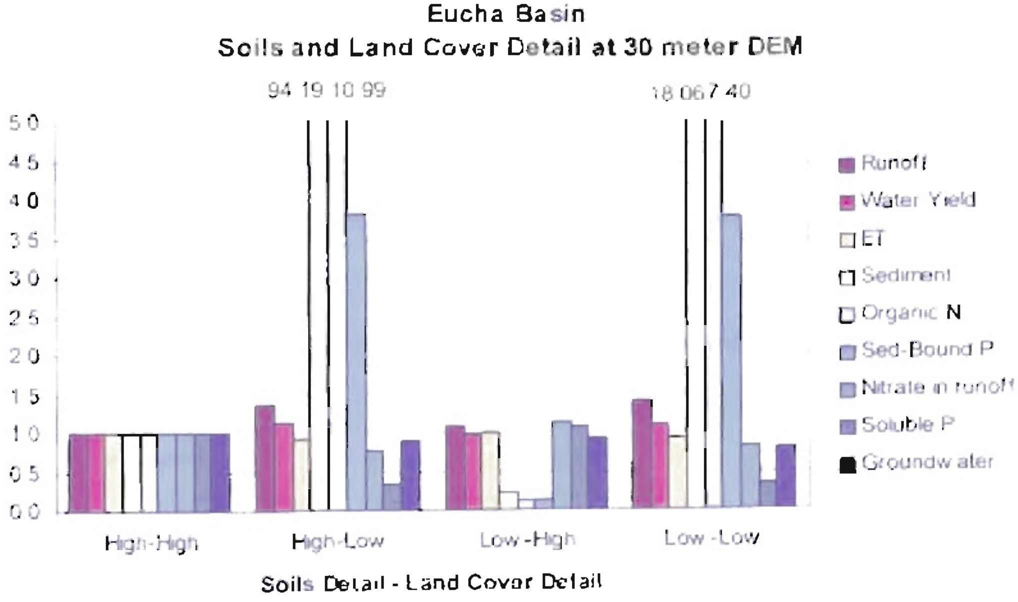


Figure 4.18 The effect of soils and land cover detail across 30 meter DEMs for the Salt Fork Basin. Displayed as a fraction of the 30 m high detail soils and land cover simulation.

Conclusions

The goal of this study was to evaluate the following hypotheses:

1) Soil data source has a significant effect on model output.

H0: SWAT simulations using SSURGO (or high resolution equivalent) soils are significantly different as compared to simulations using STATSGO soils.

H1: Choice of soil data source has no significant effect on SWAT predictions. STATSGO data are adequate.

H0 was not rejected.

Soils data type had little effect for the majority of outputs for both basins, but there were significant differences between basins. For instance, sediment and sediment-bound nutrients showed much greater differences for the Eucha Basin than for Salt Fork Basin. The importance of soils data is largely a function of how the model is to be used. In some situations, soil detail effects would not be significant, i.e. you are interested only in total water yields. Typically, it would be very advantageous to use low detail soils data due to the difficulty incorporating highly detailed soils data.

2) DEM resolution has a significant effect on model output.

H0: SWAT simulations at DEM resolutions of 30, 60, 120, and 300 meters are significantly different.

H1: SWAT simulations at various DEM resolutions are not significantly different.

H0 was not rejected.

Sediment and sediment-bound nutrients decreased as DEM resolution increases. This trend was apparent in both basins. If sediment and sediment-bound nutrients were of no interest, there would be little benefit in using very high resolution DEMs. Only the 300 meter Salt Fork simulations showed any significant difference in runoff.

3) Land cover data source has no significant effect on model output.

H0: SWAT simulations using LULC, GAP, and NLCD are significantly different.

H1: Land cover data source is not important. LULC land cover data are adequate.

H0 was not rejected.

Land cover was the single most influential data type tested. Land cover exhibited a significant effect at almost ever parameter of both basins. Land cover variations produced the largest departure from the baseline outputs for both basins. All SWAT simulations should use the most detailed and recent land cover available.

An additional goal of this research was to rate the difficulty of manipulating and including the various data types discussed into the SWAT model (Table 4.5). The purpose was to provide additional information to SWAT users to help them choose which data to include. These measurements are subjective in nature, but are the product of significant experience both using and teaching SWAT.

Table 4.5 Subjective relative difficulty developing and including selected GIS data types and resolution into SWAT (10 = high level of difficulty; 1 = minimal difficulty).

Data type	Coverage	Relative Difficulty 1-10
Land Cover	LULC	2
	GAP	4
	NDLC	3
Soils	SSURGO	10
	MIADS	5
	STATSGO	4
Topography	30 m DEM	6
	60 m DEM	5
	120 m DEM	4
	300 m DEM	2

CHAPTER 5 Summary and Future Work

Summary

The purpose of this study was to evaluate management practices and examine the effect of spatial detail using the SWAT model on two Oklahoma basins. The Great Salt Plains Basin and the Lake Eucha Basin were selected for this study. Current management practices in both basins were simulated to recommend changes which should reduce nutrient and sediment loads. The effect of spatial detail was examined by performing simulations using various GIS data available in Oklahoma for both basins. Digital Elevation Models (DEM), soils, and land cover were included in this study.

Lake Eucha Management Practices

Lake Eucha water quality is being degraded from excess algal growth. This excess growth is the result of an overabundance of nutrients in the lake, assumed to be primarily phosphorous. The majority of the phosphorous loading has been attributed to non-point sources (Wagner and Woodruff, 1997; White et al., 2001). Pastures in the Lake Eucha basin have received phosphorus from poultry litter applications for many years. Runoff extracts soluble phosphorus from the soil and litter, and carries sediments containing phosphorous to the lake.

The SWAT (Soil and Water Assessment Tool) model was used to predict how external loadings are affected by management changes. A range of soil test phosphorous levels and litter application rates were simulated. Long-term simulations project how soil test phosphorus likely changes over the next 30 years. Observed data were used to calibrate the SWAT model for phosphorous load to Lake Eucha. After which a variety of management practice scenarios were evaluated through SWAT model simulations. The effects of soil test phosphorous, litter application rates, cattle grazing rates, and the City of Decatur point source were each evaluated through model simulations. The stochastic variability associated with rainfall was quantified, and used to estimate confidence intervals. The following is a summary of the findings from this study:

- The observed average total phosphorous loading to Lake Eucha is estimated to be 47,600 kg per year.
- Some areas contribute a disproportionate amount of phosphorous.
- The City of Decatur wastewater treatment plant accounts for approximately 24% of the estimated total phosphorous load to Lake Eucha.
- Anthropogenic non-point sources account for 73% of the total phosphorous loading to Lake Eucha.
- Eastern portions of the basin have a higher pasture soil test phosphorous.
- Phosphorous load per unit pasture area, as estimated from monitoring data, is higher in the eastern portion of the basin.
- The SWAT model predicts a positive correlation between phosphorous loading to Lake Eucha and poultry litter application rate.
- The SWAT model predicts that increases in STP will result in increased loading to Lake Eucha.
- Dramatic increases in soil test phosphorous are predicted by the SWAT model with continued application of poultry litter.
- There are some discrepancies with phosphorous loadings between our estimates and the 1997 Phase 1 Oklahoma Conservation Commission study.

Great Salt Plains Reservoir BMPs

The Great Salt Plains Reservoir is the heart of the Salt Plains National Wildlife Refuge. In recent years, sediment and nutrients from range and wheat land in the 8,000 square kilometer basin threaten fish and migratory birds. The purpose of this project is to recommend BMPs (Best Management Practices) for wheat and other agricultural lands in the basin. SWAT, a distributed basin scale water quality model, was used to simulate and compare BMPs.

Because SWAT is a distributed model and operates on a daily time step, it is possible to view model outputs as they vary both spatially and temporally. Model outputs were grouped by land cover and examined. The following conclusions were drawn from the calibrated model:

- Sediment and nutrient yields vary dramatically across the basin.
- Wheat is the largest source of sediment.
- Each land cover has unique temporal nutrient and sediment distributions.
- Wheat accounts for 92% of all surface nonpoint source nitrate contributions to ground water.

Several tillage, harvest type, fertilization, and pesticide BMPs were compared. All comparisons were made strictly on a relative basis since the model was not calibrated for the majority of the outputs examined. The following conclusions were drawn from SWAT model BMP simulations:

- Splitting fertilizer applications reduced nitrogen losses.
- Switching from moldboard to low till reduced sediment yields by half.
- Harvest type had a greater influence than tillage on soluble nutrients.

The Effect of Data Detail on the SWAT Model

The purpose of this study to determine how the inclusion of low detail data effects the SWAT model. SWAT was recently included in the release of the EPA hydrologic modeling suite BASINS 3.0 (Better Assessment Science Integrating Point and Nonpoint Sources). Along with BASINS, a data set of all necessary GIS data was compiled. The data set released with BASINS is far less detailed than that currently available from other sources, but is very easy to use. More detailed data may significantly improve results, or may not be worth the additional effort.

GIS layers of soils, land cover, and topography were examined in the SWAT model. Each basin was examined separately with a model run for each combination of GIS data. Comparisons between model runs were made relative to the baseline or most detailed model run. The number of subbasins and HRUs remain nearly constant for all simulations of a particular basin. Results were derived from non-routed model outputs obtained using a custom VBA (Visual Basic for Applications) program. The following are conclusions drawn from this study:

- Soils data detail had little effect for the majority of outputs for both basins.
- Sediment and sediment-bound nutrients decreased as DEM resolution increases.
- Land cover was the single most influential data type tested. Land cover exhibited a significant effect at almost ever parameter for both basins.

Future Work

Water quality models, such as SWAT, are being applied to a greater range of problems than ever before. These models are powerful tools when used correctly, but are not the tool to solve every problem. As models become easier to use, with user friendly interfaces, the number of people using them will increase. It is important that there be sufficient resources available to guide these users in all aspects of modeling, from data selection, parameter estimation, to the interpretation of results.

Interpretation of Model Results

Results from any modeling effort may be interpreted in a variety of ways. Not all of these may be proper given the situation. The utility of a model is increased when sufficient observed data are available to support the modeling effort. SWAT can be used with ungaged basins, but will be more accurate and contain lower uncertainty when observed water quality and stream flow records are available for use in calibration. Due to the high level of model uncertainty without calibration, model results should be compared only on a relative basis. Identification and compilation of this and other guidelines for the proper use of a model such as SWAT for a variety of scenarios will be quite useful to new users.

Effects of Data Detail

The effect of GIS data detail on the SWAT model was briefly studied in this document. The relatively large impacts of the original GIS data in the model results underscore the importance of proper data selection. There are many additional aspects of this problem that were ignored in this thesis. Only the effect of the original GIS data were investigated. Additional research should include the level of subdivision for both subbasins and HRUs while studying these input data. It seems likely that all these variables are interdependent, which will make the analysis very complex.

Suggested Model Improvements

SWAT is a very good model, which has and will continue to be constantly improved. Models evolve as their supporting science grows. There will never be a perfect model, because a model by definition is in error. In this error lie the room for improvement.

Improved Manure Application Component

SWAT simulates manure applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality manure often lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after application it interacts more closely with surface runoff than simulated by SWAT. In the field we expect high nutrient concentrations in surface runoff immediately following application. In the SWAT model, simulated phosphorous concentrations do not increase so dramatically when litter is applied, thus monthly nutrient loadings are quite uncertain. Average annual nutrient loading should be used when manure applications are involved.

HRU Characteristics

Each HRU in a subbasin was assumed to have the same characteristics by the model. For instance, the same slope was used for all agricultural and nonagricultural HRUs in a single subbasin. Agriculture is generally located in valleys or other flat areas, and tends to have different topographical characteristics than nonagricultural areas. This problem is more important in a basin in which each land cover has very different topographical characteristics, such as the Lake Eucha Basin.

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APPENDIX

Table A1 Excerpt from SWAT database file "sol.dbf".

SNAM	S5ID	NLAYERS	HYDGRP	ALB	USLEK	CRK	Z1	BD1	AWC1	K1	CBN1	CLAY1	SILT1	SAND1	ROCK1
CAPTINA	AR0001	5	C	0.02	0.43	0.75	228.60	1.36	0.21	3.20	1.16	14.00	71.84	14.16	2.08
NIXA	AR0005	5	C	0.02	0.32	0.75	50.80	1.40	0.12	4.50	1.16	18.50	54.40	27.10	49.67
PERIDGE	AR0019	4	B	0.02	0.37	0.75	203.20	1.40	0.21	2.90	1.16	15.00	71.01	13.99	2.70
BRITWATER	AR0032	4	B	0.04	0.37	0.75	152.40	1.40	0.17	5.80	0.87	20.00	53.40	26.60	7.02
HEALING	AR0033	3	B	0.01	0.37	0.75	381.00	1.42	0.21	2.80	1.74	17.50	68.92	13.58	2.75
NOARK	AR0034	5	B	0.02	0.28	0.75	76.20	1.45	0.12	5.40	1.16	17.50	53.35	29.15	50.74
TONTI	AR0037	5	C	0.10	0.37	0.75	152.40	1.20	0.19	46.00	1.00	0.00	61.40	38.60	20.00
WABEN	AR0040	4	B	0.03	0.28	0.75	127.00	1.35	0.12	8.30	1.02	12.50	56.59	30.91	48.96
JAY	AR0066	3	C	0.01	0.37	0.75	406.40	1.48	0.21	2.20	1.45	18.50	69.86	11.64	2.86
TONTI	AR0120	4	C	0.02	0.37	0.75	177.80	1.40	0.17	8.20	1.16	17.50	53.35	29.15	21.53
RAZORT	AR0122	3	B	0.02	0.32	0.75	203.20	1.38	0.15	7.30	1.16	17.50	53.35	29.15	19.99
WATER	DC0038	1		0.23	0.00	0.75	25.40	0.00	0.02	75.00	0.00	0.00	0.00	0.00	0.00
ELSAH	IL0360	3	B	0.10	0.24	0.75	254.00	1.60	0.10	6.10	0.44	13.00	56.26	30.74	57.06
CLARKSVIL	MO0025	3	B	0.06	0.28	0.75	330.20	1.30	0.09	2.30	0.73	17.00	53.68	29.32	54.72
DONIPHAN	MO0077	4	B	0.06	0.28	0.75	304.80	1.20	0.13	1.70	0.73	22.50	52.72	24.78	37.21
SECESH	MO0100	5	B	0.08	0.32	0.75	279.40	1.20	0.20	2.30	0.58	20.00	53.40	26.60	7.13
MACEDONIA	MO0107	4	B	0.06	0.37	0.75	355.60	1.35	0.19	1.50	0.73	20.00	53.40	26.60	7.95
CLARKSVIL	MO0204	3	B	0.06	0.28	0.75	330.20	1.30	0.14	4.90	0.73	21.00	52.74	26.26	30.00
TALOKA	OK0016	2	D	0.10	0.49	0.75	711.20	1.40	0.19	1.90	0.44	20.00	53.40	26.60	0.00
STIGLER	OK0040	4	D	0.02	0.49	0.75	609.60	1.42	0.22	5.20	1.16	15.00	54.97	30.03	0.00
NEWTONIA	OK0151	5	B	0.02	0.37	0.75	279.40	1.42	0.22	1.30	1.16	17.00	69.33	13.67	0.00

Table A2 Locations of COOP (Cooperative Observation) stations From the NOAA (National Oceanic and Atmospheric Administration)

ID	NAME	X COORD	Y COORD
1	ANDER_P	372176	4056797
2	BENTON_P	390485	4019931
3	CHELSE_P	283196	4039711
4	F_DRAK_P	394546	3984381
5	F_EXP_P	394679	3995473
6	F_GIB_P	298665	3971626
7	GRAND_P	316325	4037832
8	GRAVE_P	370021	4032419
9	GROVE_P	341639	4049538
10	HOLLOW_P	297661	4082654
11	JAY_P	338623	4031838
12	JAY_T_P	338644	4032947
13	KANSAS_P	339967	4007399
14	LYONS_P	343616	3959619
15	MARBLE_P	335069	3937582
16	MIAMI_P	332450	4083008
17	ODELL_P	371657	3960278
18	PRYOR_P	291677	4019520
19	QUAPAW_P	341549	4092822
20	ROGERS_P	401321	4025348
21	ROSE_P	317534	4010059
22	SILOAM_P	362393	4003688
23	SPAV_P	316113	4027848
24	STILW_P	351092	3973914
25	TAHL_P	322277	3977777
26	VINITA_P	309648	4060177
27	WYAN_P	346591	4076082

Projection UTM Zone 15

Units are meters

Table A3 Locations of additional outlets. The locations are used to define points of interest such as water quality stations, stream gages, and where streams enter lakes.

ID	NAME	X coordinate	Y coordinate
1	EUC04	333743	4025683
2	EUC05	337841	4025835
3	EUC06	340623	4024634
4	EUC07	335194	4020498
5	EUC08	341812	4023471
6	EUC09	348744	4020929
7	EUC10	357572	4022854
8	EUC11	353848	4030058
9	EUC12	342395	4022513
10	EUC13	326250	4027537
11	EUC14	323914	4030144
12	LAK_BD	329860	4026675
13	LAK_BD	331174	4026114
14	LAK_BD	331483	4025708
15	LAK_BD	332624	4025070
16	LAK_BD	333223	4025186
17	LAK_BD	336490	4024452
18	LAK_BD	337805	4024684
19	LAK_BD	338771	4024317
20	LAK_BD	334731	4022306
21	LAK_BD	334654	4021900
22	LAK_BD	333571	4022287
23	LAK_BD	332411	4022557
24	LAK_BD	329608	4024336
25	LAK_BD	327231	4024838
26	LAK_BD	327443	4024355
27	LAK_BD	327830	4024201
28	LAK_BD	326225	4027158
29	LAK_BD	319914	4027595
30	LAK_BD	318344	4027595
31	LAK_BD	316499	4026927
32	LAK_BD	321838	4031206
33	SPA01	316287	4028149
34	SPA06	319943	4027436
35	USGS	352735	4022185

Projection:
UTM 27, Zone 15

Table A4 Subbasin properties estimated by ArcView SWAT interface.

SUBBASIN	AREA (km^2)	Channel Length (km)	Channel Slope(m/m)	Channel Width (m)	Subbasin Slope Length (m)	Slope (m/m)
1	12.9	17.5	0.011	6.00	61.0	0.091
2	49.5	17.5	0.008	13.41	61.0	0.073
3	27.9	10.3	0.008	9.50	91.5	0.022
4	19.9	10.0	0.007	7.77	122.0	0.019
5	0.1	0.4	0.064	0.22	36.6	0.101
6	12.6	9.7	0.010	5.90	122.0	0.015
7	15.9	10.8	0.008	6.79	91.5	0.040
8	11.9	10.8	0.008	5.69	91.5	0.034
9	48.2	15.6	0.008	13.19	61.0	0.073
10	14.5	13.8	0.009	6.44	61.0	0.085
11	27.8	10.6	0.009	9.51	61.0	0.062
12	10.2	11.9	0.009	5.21	91.5	0.045
13	15.6	13.8	0.009	6.71	61.0	0.071
14	32.5	13.8	0.009	10.42	61.0	0.099
15	10.8	8.5	0.011	5.39	61.0	0.083
16	12.6	15.7	0.010	5.90	61.0	0.081
17	16.6	11.9	0.008	6.97	61.0	0.073
18	17.5	15.7	0.010	7.18	36.6	0.101
19	8.1	15.7	0.013	4.55	24.4	0.134
20	29.1	15.7	0.009	9.75	61.0	0.081
21	18.9	10.0	0.008	7.51	61.0	0.069
22	11.4	7.8	0.010	5.55	36.6	0.104
23	1.7	3.5	0.023	1.74	24.4	0.132
24	3.7	21.1	0.018	2.86	18.3	0.163
25	28.1	12.2	0.011	9.55	18.3	0.164
26	0.3	1.0	0.051	0.68	61.0	0.057
27	4.0	14.7	0.019	2.96	24.4	0.123
28	39.4	14.7	0.010	11.69	61.0	0.089
29	5.7	9.2	0.014	3.67	24.4	0.143
30	13.3	9.2	0.011	6.10	36.6	0.107
31	19.9	11.9	0.006	7.77	61.0	0.064
32	5.9	6.5	0.014	3.74	61.0	0.098
33	10.8	21.1	0.011	5.39	91.5	0.043
34	25.6	14.1	0.006	9.03	61.0	0.051
35	20.9	16.7	0.012	8.00	24.4	0.150
36	24.6	12.0	0.026	8.82	24.4	0.153
37	48.8	13.5	0.009	13.30	36.6	0.118
38	50.7	13.9	0.009	13.59	24.4	0.130
39	1.1	1.9	0.039	1.35	15.2	0.215
40	0.6	1.5	0.048	0.95	24.4	0.120
41	5.3	14.7	0.010	3.53	24.4	0.145
42	5.5	5.5	0.013	3.58	91.5	0.039
43	64.3	21.1	0.006	15.69	61.0	0.099
44	0.7	16.7	0.050	1.03	24.4	0.125
45	1.3	2.4	0.025	1.48	18.3	0.191
46	1.2	2.0	0.030	1.42	18.3	0.172
47	2.0	16.7	0.026	1.99	18.3	0.163
48	2.0	2.7	0.027	1.97	24.4	0.156
49	18.7	21.1	0.011	7.47	36.6	0.117
50	2.9	13.9	0.022	2.47	18.3	0.183
51	68.4	16.7	0.005	16.28	24.4	0.137
52	0.0	0.3	0.063	0.19	24.4	0.136
53	6.5	6.4	0.019	3.98	18.3	0.181
54	26.8	9.4	0.006	9.28	18.3	0.161
55	15.6	6.4	0.019	6.71	15.2	0.212
56	29.4	14.1	0.009	9.81	36.6	0.100
57	18.7	8.7	0.012	7.48	18.3	0.171
58	7.8	5.6	0.018	4.43	18.3	0.176

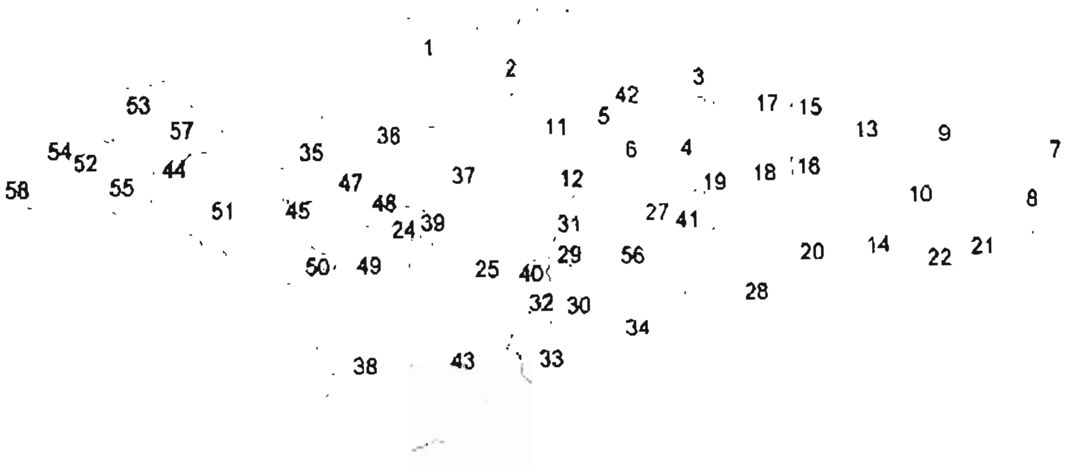


Figure A1 Subbasin locations and numbering.

Table A5 Litter application rates by subbasin.

Subasin	Litter (t)	% Pasture	Sub Area (ha)	Pasture(ha)	Litter Rate (kg/ha)
1	320	65.6%	1294	849	342
2	3691	55.3%	4947	2734	1224
3	1475	70.0%	2769	1952	685
4	2000	69.8%	1993	1391	1304
5	1	51.8%	5	3	347
6	2535	84.7%	1260	1066	2156
7	1000	72.9%	1592	1161	781
8	1265	69.4%	1185	822	1396
9	5850	45.7%	4816	2201	2410
10	850	34.3%	1455	498	1547
11	3580.5	70.7%	2784	1967	1651
12	285	66.6%	1022	681	379
13	2921.5	55.4%	1561	864	3066
14	6512.5	40.4%	3250	1312	4504
15	1200	49.4%	1083	535	2033
16	3037.5	47.3%	1257	595	4633
17	1987.5	48.1%	1661	799	2258
18	4547.5	44.9%	1747	785	5256
19	300	20.7%	811	168	1620
20	8037.5	56.4%	2912	1643	4436
21	4358.5	51.8%	1886	977	4044
22	737.5	40.5%	1137	460	1454
23	1	39.2%	165	65	14
24	1	38.1%	374	142	6
25	950	31.0%	2807	869	992
26	1	82.3%	34	28	32
27	1725	49.2%	397	195	8007
28	5579.5	51.7%	3939	2036	2485
29	1	37.1%	569	211	4
30	840	47.6%	1329	632	1205
31	2173.5	64.0%	1992	1274	1548
32	200	57.2%	588	336	540
33	1170	79.3%	1084	860	1234
34	3573.5	63.1%	2562	1618	2003
35	585	25.9%	2092	542	980
36	1	29.7%	2460	730	1
37	5450	35.1%	4883	1712	2888
38	1000	30.7%	5065	1552	584
39	1	13.1%	107	14	65
40	200	67.8%	60	41	4459
41	862.5	34.8%	532	185	4234
42	225	61.1%	549	336	608
43	1072	47.0%	6434	3025	321
44	1	13.1%	68	9	103
45	1	2.6%	125	3	280
46	1	9.6%	118	11	81
47	1	14.2%	204	29	31
48	1	18.2%	203	37	25
49	1	29.1%	1868	544	2
50	1	11.9%	294	35	26
51	1	10.1%	6843	688	1
52	1	0.0%	4	0	1
53	160	15.7%	652	102	1421
54	1	8.3%	2680	223	4
55	1	5.0%	1560	78	12
56	1560	50.7%	2940	1489	950
57	1	18.2%	1871	341	3
58	1	8.9%	783	70	13

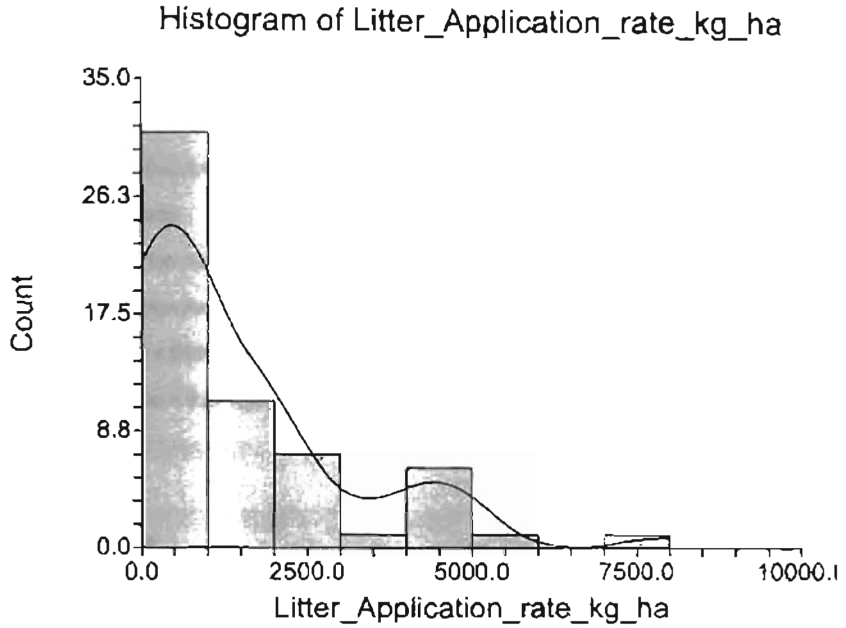


Figure A2 Histogram of litter application rates by subbasin (kg/ha).

Appendix A Eucha Basin Properties

Commercial fertilizer application rate.

Benton County

Total area = 218895 ha

Pasture + crop=107600 ha

Determined from USGS LULC GIS data

Total N for Benton County

July 98-june99 3016 ton Ammonium Nitrate 170 ton Urea TOTAL N = 1073 ton

July 97-june98 2956 ton Ammonium Nitrate 358 ton Urea TOTAL N = 1140 ton

Average 1100 ton/year = 998000 kg

Average application rate = 9.27 kg/ha

Total P Negligible

Delaware County

Total Area = 209211 ha

Pasture + crop = 100601 ha

Determined from USGS LULC GIS data

Nitrogen

99 190 ton as N,

98 327 ton as N

Average= 258 ton = 234500 kg/year

Average application rate = 2.33 kgN/ Ha/year

Total P

99 2.10 ton p205

98 79.7 ton P205

Average = 40.9 ton/yr p205

Average 18 ton as P or 16,300 kg P

Application rate = .162 kg/ ha

Area weighted average

64.31% of EUCHA is located in OK

35 69% of Eucha is in AK

Nitrogen

4.8 kg/Ha per year as N

Total P

0.1042 kg/ha year as P

Table A6 Source of flow data at each water quality station.

Station	1-90 to 7-98 flow based on Stations	8-98 to 9-00 flow data based on Stations
EUC04	Spavinaw	Beaty
EUC05	Spavinaw	Beaty
EUC06	Spavinaw	Beaty
EUC07	Spavinaw	Beaty and Spavinaw ave.
EUC08	Spavinaw	Spavinaw
EUC09	Spavinaw	Spavinaw
EUC10	Spavinaw	Spavinaw
EUC11	Spavinaw	Beaty
EUC12	Spavinaw	Beaty and Spavinaw ave.
SPA06	Spavinaw	Black Hollow

Table A7 P loading per unit area estimated from observed water quality data.

SITE	Sum of TOTAL (Kg/yr)	Total Area (km^2)	Pasture Area (km^2)	Forest Area (km^2)	Estimated Total P from Forest (kg/yr)	Total P from Pastures (kg/ha/yr)
4	295	20.9	5.4	15.5	78	0.40
5	3614	87.0	43.1	43.9	220	0.79
6	6553	152.8	89.9	62.9	315	0.69
7	283	50.6	15.5	35.1	175	0.07
8	33285	516.9	253.0	263.9	1319	1.26
9	40857	423.5	216.4	207.1	1036	1.84
10	15761	268.9	151.8	117.1	586	1.00
11	7583	65.9	47.3	18.6	93	1.58
12	712	64.3	27.5	36.8	184	0.19
SPAV06	173	15.6	0.8	14.9	74	1.32
Total	109116	1666	851	816	4079	
					Average	0.915

P from forests assumed to be 0.05 kg/ha/yr

Table B1 Observed and predicted flow at Beaty Creek (US Geographic Survey stream gage 07191222). (All units are m³/sec)

	Observed					Predicted			
Month	Flow	Baseflow (upper)	Baseflow (lower)	Surface (upper)	Surface (lower)	Flow	Surface	Base	Misc
Aug-98	0.07	0.06	0.05	0.02	0.01	0.00	0.00	0.00	0.00
Sep-98	0.32	0.10	0.09	0.23	0.22	0.10	0.09	0.00	0.01
Oct-98	4.00	1.15	0.88	3.12	2.85	3.05	2.80	0.24	0.01
Nov-98	0.64	0.39	0.34	0.30	0.25	2.06	1.07	0.98	0.01
Dec-98	0.68	0.51	0.44	0.24	0.17	1.57	0.06	1.50	0.01
Jan-99	0.99	0.77	0.69	0.29	0.22	1.50	0.19	1.30	0.01
Feb-99	3.92	1.85	1.53	2.39	2.07	3.06	1.78	1.26	0.01
Mar-99	4.13	2.62	2.18	1.95	1.51	3.25	1.76	1.49	0.01
Apr-99	3.08	1.59	1.39	1.69	1.50	3.74	2.09	1.64	0.01
May-99	4.10	2.23	2.08	2.02	1.87	4.26	2.27	1.98	0.01
Jun-99	5.43	1.71	1.54	3.89	3.72	4.11	2.53	1.56	0.01
Jul-99	3.36	1.91	1.56	1.80	1.45	1.27	0.28	0.97	0.01
Aug-99	0.26	0.23	0.22	0.05	0.04	0.32	0.00	0.31	0.01
Sep-99	0.38	0.27	0.25	0.13	0.12	0.13	0.01	0.11	0.01
Oct-99	0.16	0.15	0.14	0.01	0.01	0.17	0.00	0.16	0.01
Nov-99	0.13	0.08	0.07	0.06	0.05	0.45	0.26	0.18	0.01
Dec-99	2.45	1.08	0.87	1.58	1.37	1.75	1.11	0.62	0.01
Jan-00	0.45	0.41	0.40	0.05	0.04	1.07	0.16	0.90	0.01
Feb-00	0.94	0.48	0.41	0.54	0.47	0.96	0.25	0.70	0.01
Mar-00	1.41	0.96	0.86	0.55	0.44	1.39	0.49	0.89	0.01
Apr-00	0.49	0.38	0.35	0.14	0.11	0.79	0.07	0.71	0.01
AVE	1.78	0.90	0.78	1.00	0.88	1.666	0.823	0.834	0.009

Calibration parameter adjustments for Beaty Creek:

ESCO = 1
Curve Number = +2.08
Initial depth of water in the shallow aquifer = 50
Revap coefficient = 0.002
Groundwater delay = 1
Minimum depth of water in shallow aquifer for revap to occur = 50
Minimum depth of water in shallow aquifer for baseflow to occur = 50
Fraction of water in shallow aquifer that percolated to the deep aquifer = 0

Table B2 Observed and simulated flow at Spavinaw Creek (US Geographic Survey stream gage 07191220). (all units are m^3/sec)

	Observed					Predicted			
Year.mo	Flow	Baseflow (upper)	Baseflow (lower)	Surface (lower)	Surface (upper)	Flow	Surface	Base	MISC
Jan-90	1.86	1.02	0.88	0.84	0.98	1.84	1.71	0.08	0.05
Feb-90	4.55	3.06	2.75	1.49	1.81	4.10	3.09	0.93	0.07
Mar-90	13.93	7.22	6.44	6.72	7.49	11.69	8.08	3.37	0.24
Apr-90	9.44	7.06	6.46	2.38	2.98	9.62	4.17	5.25	0.19
May-90	15.59	7.69	6.98	7.90	8.60	13.52	6.94	6.34	0.23
Jun-90	6.53	4.47	4.14	2.07	2.39	11.05	5.95	4.92	0.18
Jul-90	1.91	1.81	1.77	0.09	0.13	2.46	0.00	2.41	0.04
Aug-90	1.04	0.98	0.95	0.07	0.09	0.58	0.00	0.55	0.03
Sep-90	1.07	0.89	0.84	0.19	0.23	0.19	0.11	0.02	0.06
Oct-90	1.29	1.19	1.16	0.10	0.13	0.52	0.39	0.06	0.07
Nov-90	1.68	1.12	0.99	0.56	0.69	1.91	1.54	0.31	0.05
Dec-90	4.36	2.89	2.66	1.47	1.70	7.90	5.79	1.95	0.16
Jan-91	8.11	5.88	5.43	2.23	2.68	9.70	4.78	4.64	0.29
Feb-91	2.56	2.46	2.41	0.11	0.15	5.48	0.00	5.43	0.05
Mar-91	1.92	1.86	1.84	0.05	0.08	3.56	0.06	3.47	0.03
Apr-91	4.56	2.89	2.53	1.69	2.05	5.33	3.16	2.11	0.06
May-91	2.71	1.84	1.70	0.67	1.02	4.24	2.12	2.05	0.07
Jun-91	1.06	0.97	0.94	0.09	0.12	1.19	0.00	1.16	0.03
Jul-91	0.51	0.49	0.49	0.02	0.02	0.26	0.00	0.23	0.02
Aug-91	0.41	0.41	0.41	0.01	0.01	0.07	0.00	0.00	0.07
Sep-91	0.73	0.60	0.55	0.13	0.18	0.09	0.00	0.00	0.09
Oct-91	0.55	0.49	0.47	0.06	0.08	0.44	0.40	0.00	0.04
Nov-91	3.42	2.19	1.83	1.23	1.60	2.93	2.47	0.32	0.13
Dec-91	6.17	3.34	2.79	2.83	3.38	7.23	4.85	2.18	0.20
Jan-92	1.90	1.79	1.75	0.10	0.15	3.50	0.07	3.36	0.07
Feb-92	3.23	2.33	2.05	0.89	1.17	3.53	0.69	2.75	0.08
Mar-92	1.64	1.59	1.57	0.05	0.07	2.48	0.00	2.44	0.03
Apr-92	2.92	1.86	1.64	1.03	1.28	2.69	1.24	1.42	0.03
May-92	2.06	1.73	1.66	0.33	0.40	1.29	0.28	0.97	0.04
Jun-92	6.87	4.40	3.80	2.47	3.07	3.10	2.03	0.91	0.16
Jul-92	1.41	1.32	1.30	0.09	0.11	1.09	0.07	0.96	0.05
Aug-92	1.34	1.20	1.15	0.14	0.19	0.35	0.03	0.28	0.04
Sep-92	0.91	0.85	0.82	0.07	0.09	0.28	0.21	0.02	0.05
Oct-92	0.65	0.63	0.63	0.02	0.03	0.09	0.00	0.03	0.06
Nov-92	4.74	2.28	1.88	2.45	2.86	5.20	4.44	0.66	0.10
Dec-92	16.58	6.71	5.57	9.87	11.01	13.40	10.03	3.15	0.22
Jan-93	6.45	5.22	4.93	1.23	1.52	8.32	2.89	5.28	0.15
Feb-93	6.65	4.72	4.30	1.92	2.35	6.60	1.81	4.70	0.08
Mar-93	6.01	4.60	4.07	1.40	1.94	5.74	1.03	4.57	0.15
Apr-93	7.38	5.18	4.53	2.20	2.85	7.47	2.44	4.87	0.16
May-93	10.50	5.07	4.43	5.43	6.07	10.47	5.29	5.05	0.13
Jun-93	8.61	5.51	4.57	3.09	4.04	7.34	2.95	4.22	0.16
Jul-93	2.72	2.42	2.34	0.30	0.38	2.86	0.32	2.48	0.06
Aug-93	1.28	1.16	1.12	0.12	0.16	0.75	0.02	0.69	0.04
Sep-93	6.12	2.21	1.87	3.91	4.25	4.30	4.10	0.10	0.10
Oct-93	2.21	2.04	2.00	0.17	0.22	2.30	0.68	1.43	0.18
Nov-93	7.94	4.08	3.42	3.85	4.51	12.20	9.00	3.06	0.15
Dec-93	5.02	4.50	4.33	0.52	0.69	5.24	0.68	4.44	0.12
Jan-94	3.35	3.17	3.11	0.18	0.24	4.15	0.52	3.59	0.04
Feb-94	4.89	3.86	3.59	1.03	1.29	4.07	1.44	2.56	0.07
Mar-94	10.45	8.28	7.70	2.17	2.76	10.42	6.29	3.92	0.20
Apr-94	12.83	7.01	6.33	5.82	6.50	14.62	9.37	5.09	0.17
May-94	4.05	3.37	3.19	0.68	0.86	4.77	0.03	4.66	0.07
Jun-94	1.83	1.72	1.68	0.11	0.15	2.10	0.09	1.98	0.03
Jul-94	1.18	1.09	1.06	0.09	0.11	0.53	0.03	0.47	0.03
Aug-94	0.80	0.76	0.74	0.04	0.06	0.07	0.00	0.01	0.07
Sep-94	0.66	0.64	0.64	0.02	0.03	0.07	0.00	0.00	0.07
Oct-94	0.68	0.65	0.64	0.03	0.04	0.08	0.00	0.00	0.08
Nov-94	5.19	2.76	2.40	2.43	2.78	4.81	4.07	0.57	0.18
Dec-94	2.33	1.87	1.74	0.45	0.59	2.46	0.43	1.94	0.09

Table B2 Observed and simulated flow at Spavinaw Creek (US Geographic Survey stream gage 07191220). (all units are m^3/sec) (Continued)

Year.mo	Flow	Baeflow (upper)	Baeflow (lower)	Surface (lower)	Surface (upper)	Flow	Surface	Base	MISC
Jan-95	5.56	3.33	3.01	2.23	2.54	6.34	3.54	2.66	0.14
Feb-95	2.67	2.52	2.47	0.14	0.20	4.33	0.70	3.58	0.06
Mar-95	3.95	2.90	2.66	1.06	1.29	4.50	1.41	3.04	0.06
Apr-95	6.52	3.84	3.33	2.68	3.19	7.48	4.53	2.83	0.13
May-95	11.30	6.46	5.86	4.83	5.44	8.79	3.86	4.71	0.21
Jun-95	13.78	6.07	5.46	7.71	8.31	8.43	4.13	4.15	0.15
Jul-95	2.59	2.45	2.41	0.14	0.18	2.39	0.23	2.11	0.05
Aug-95	1.41	1.33	1.30	0.07	0.11	0.50	0.00	0.48	0.03
Sep-95	1.00	0.89	0.86	0.10	0.14	0.09	0.00	0.02	0.07
Oct-95	0.88	0.85	0.83	0.04	0.05	0.08	0.00	0.00	0.08
Nov-95	0.94	0.91	0.90	0.03	0.04	0.09	0.00	0.00	0.08
Dec-95	1.14	0.96	0.90	0.18	0.24	0.58	0.53	0.01	0.04
Jan-96	1.86	1.49	1.38	0.37	0.48	1.56	1.03	0.45	0.09
Feb-96	1.16	1.10	1.07	0.06	0.09	1.27	0.00	1.23	0.04
Mar-96	1.61	1.18	1.06	0.44	0.56	2.15	1.01	1.11	0.03
Apr-96	2.58	2.19	2.05	0.40	0.53	1.98	0.11	1.80	0.07
May-96	2.04	1.53	1.42	0.51	0.61	1.91	0.04	1.84	0.03
Jun-96	1.40	1.20	1.14	0.19	0.25	1.80	0.93	0.84	0.03
Jul-96	0.68	0.64	0.63	0.04	0.05	0.22	0.00	0.19	0.03
Aug-96	0.41	0.38	0.36	0.03	0.05	0.07	0.00	0.00	0.06
Sep-96	1.84	0.64	0.46	1.20	1.38	0.63	0.57	0.00	0.06
Oct-96	1.23	0.99	0.92	0.24	0.31	0.85	0.65	0.12	0.08
Nov-96	7.87	4.08	3.60	3.79	4.26	10.63	8.23	2.12	0.29
Dec-96	4.85	3.60	3.41	1.05	1.44	5.65	0.01	5.64	0.19
Jan-97	1.59	1.54	1.52	0.05	0.07	5.15	0.70	4.43	0.03
Feb-97	10.38	4.02	3.51	6.38	6.87	9.31	6.65	2.58	0.08
Mar-97	8.81	6.47	5.83	2.34	2.98	6.98	2.00	4.73	0.25
Apr-97	3.35	3.10	3.01	0.25	0.34	5.65	0.16	5.41	0.08
May-97	1.86	1.77	1.73	0.10	0.13	3.62	0.15	3.43	0.04
Jun-97	1.37	1.25	1.21	0.12	0.16	2.48	1.06	1.37	0.05
Jul-97	0.91	0.87	0.86	0.04	0.05	0.64	0.05	0.56	0.03
Aug-97	1.24	0.89	0.81	0.35	0.43	0.17	0.01	0.10	0.06
Sep-97	0.79	0.72	0.69	0.07	0.10	0.15	0.09	0.00	0.06
Oct-97	0.99	0.86	0.81	0.13	0.18	0.38	0.21	0.12	0.05
Nov-97	0.84	0.79	0.78	0.05	0.07	0.96	0.51	0.40	0.05
Dec-97	2.95	2.05	1.84	0.90	1.11	3.06	1.95	1.03	0.09
Jan-98	9.28	5.76	4.64	3.52	4.64	8.16	4.36	3.55	0.26
Feb-98	2.64	2.51	2.46	0.14	0.18	5.06	0.18	4.79	0.10
Mar-98	7.94	5.29	4.51	2.65	3.42	7.81	3.01	4.63	0.17
Apr-98	3.08	2.85	2.75	0.23	0.33	5.49	0.50	4.91	0.08
May-98	2.36	1.85	1.71	0.50	0.65	4.59	1.49	3.05	0.05
Jun-98	1.29	1.20	1.16	0.10	0.13	1.74	0.01	1.68	0.05
Jul-98	0.69	0.67	0.66	0.02	0.03	0.52	0.00	0.49	0.03
Aug-98	0.51	0.49	0.48	0.02	0.03	0.10	0.00	0.05	0.05
Sep-98	0.50	0.44	0.41	0.07	0.10	0.09	0.00	0.00	0.09
Oct-98	3.40	1.48	1.27	1.92	2.13	3.74	3.27	0.31	0.17
Nov-98	2.18	1.83	1.72	0.35	0.46	3.94	2.17	1.58	0.18
Dec-98	2.05	1.94	1.91	0.10	0.14	3.96	0.24	3.58	0.14
Jan-99	1.88	1.70	1.63	0.18	0.24	4.35	0.72	3.57	0.06
Feb-99	6.34	3.27	2.75	3.07	3.59	6.99	3.78	3.08	0.12
Mar-99	7.08	5.05	4.25	2.03	2.84	7.43	3.72	3.57	0.14
Apr-99	5.07	3.59	3.29	1.48	1.77	8.38	3.90	4.37	0.11
May-99	9.86	5.25	4.85	4.60	5.00	10.47	5.50	4.74	0.23
Jun-99	11.16	3.85	3.61	7.31	7.55	9.26	5.34	3.81	0.11
Jul-99	9.01	4.73	4.09	4.28	4.91	2.83	0.68	2.04	0.10
Aug-99	1.51	1.44	1.41	0.06	0.10	0.56	0.00	0.54	0.03
Sep-99	1.17	1.09	1.06	0.08	0.11	0.12	0.01	0.04	0.06
Oct-99	0.83	0.81	0.80	0.02	0.03	0.07	0.00	0.00	0.07
Nov-99	0.96	0.90	0.88	0.06	0.08	0.35	0.31	0.00	0.04

Table B2 Observed and simulated flow at Spavinaw Creek (US Geographic Survey stream gage 07191220). (all units are m^3/sec) (Continued)

	Observed					Predicted			
Date	Flow	Baeflow (upper)	Baeflow (lower)	Surface (lower)	Surface (upper)	Flow	Surface	Base	MISC
Dec-99	1.76	1.45	1.34	0.31	0.42	3.38	2.62	0.61	0.14
Jan-00	1.02	0.94	0.91	0.08	0.11	2.11	0.33	1.74	0.04
Feb-00	0.88	0.84	0.83	0.04	0.05	1.71	0.17	1.51	0.03
Mar-00	2.01	1.70	1.59	0.31	0 42	2.59	0.74	1.77	0.08
Apr-00	1.23	1.18	1.16	0.05	0.07	1.90	0.25	1.63	0.02
Average	3.80	2.51	2.29	1.29	1.51	3 90	1.75	2.06	0.09

Calibration parameter adjustments for the Spavinaw Creek area:

ESCO = .98
Curve Number = -2.08
Available Water content = +0.02
Initial depth of water in the shallow aquifer = 50
Revap coefficient =0 .002
Groundwater delay = 1
Minimum depth of water in shallow aquifer for revap to occur = 50
Minimum depth of water in shallow aquifer for baseflow to occur = 50
Fraction of water in shallow aquifer that percolated to the deep aquifer = 0

Table B3 Observed and simulated flow at Black Hollow (US Geographic Survey stream gage 07191297). (All units are m^3/sec)

	Observed			Predicted		
Date	Flow	Baseflow	Surface flow	Flow	Baseflow	Surface flow
Aug-98	0.004	0.000	0.000	0.127	0.126	0.001
Sep-98	0.008	0.000	0.000	0.148	0.141	0.007
Oct-98	0.043	0.008	0.016	0.335	0.255	0.079
Nov-98	0.072	0.053	0.005	0.044	0.042	0.002
Dec-98	0.080	0.072	0.000	0.027	0.025	0.002
Jan-99	0.074	0.068	0.001	0.004	0.003	0.001
Feb-99	0.133	0.088	0.037	0.145	0.113	0.031
Mar-99	0.228	0.138	0.079	0.338	0.258	0.080
Apr-99	0.353	0.173	0.168	0.427	0.275	0.151
May-99	0.299	0.186	0.097	0.293	0.266	0.027
Jun-99	0.368	0.140	0.211	0.367	0.272	0.095
Jul-99	0.170	0.126	0.027	0.172	0.137	0.035
Aug-99	0.051	0.043	0.000	0.000	0.000	0.000
Sep-99	0.058	0.044	0.002	0.000	0.000	0.000
Oct-99	0.098	0.091	0.000	0.000	0.000	0.000
Nov-99	0.070	0.059	0.006	0.000	0.000	0.000
Dec-99	0.098	0.068	0.020	0.011	0.009	0.003
Jan-00	0.123	0.117	0.000	0.000	0.000	0.000
Feb-00	0.077	0.073	0.000	0.000	0.000	0.000
Mar-00	0.086	0.078	0.000	0.027	0.024	0.003
Apr-00	0.082	0.076	0.000	0.006	0.005	0.001
AVE	0.123	0.081	0.032	0.118	0.093	0.025

Calibration parameter adjustments for Black Hollow:
ESCO = 0.9
Curve Number = -2.0
Available Water content = +0.02
Initial depth of water in the shallow aquifer = 50
Revap coefficient = 0.002
Groundwater delay = 1
Minimum depth of water in shallow aquifer for revap to occur = 50
Minimum depth of water in shallow aquifer for baseflow to occur = 50

Normality Test Section of LOG10(Flow)

Test Name	Test Value	Prob Level	10% Critical Value	5% Critical Value	Decision (5%)
Shapiro-Wilk W	0.9516097	0.186674			Accept Normality
Anderson-Darling	0.5872039	0.126087			Accept Normality
Martinez-Iglewicz	1.295037		1.148522	1.228175	Reject Normality
Kolmogorov-Smirnov	0.1326432		0.146	0.159	Accept Normality
D'Agostino Skewness	-1.7603	0.078360	1.645	1.960	Accept Normality
D'Agostino Kurtosis	1.7951	0.072630	1.645	1.960	Accept Normality
D'Agostino Omnibus	6.3211	0.042401	4.605	5.991	Reject Normality

Plots Section of LOG10(Flow)

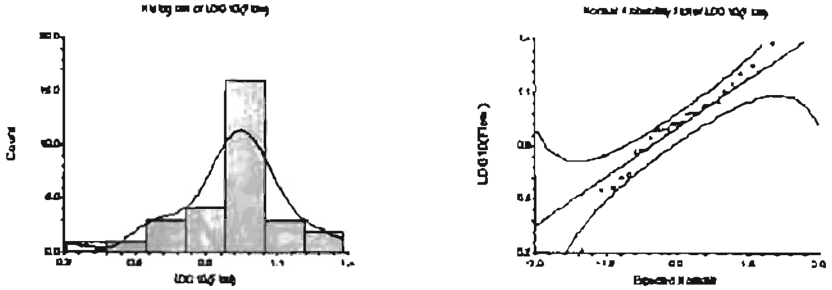


Figure C1 Flow distribution calculations and statistical tests.

Normality Test Section of LOG10(Solp)

Test Name	Test Value	Prob Level	10% Critical Value	5% Critical Value	Decision (5%)
Shapiro-Wilk W	0.9876576	0.973493			Accept Normality
Anderson-Darling	0.1392713	0.975020			Accept Normality
Martinez-Iglewicz	1.029754		1.148522	1.228175	Accept Normality
Kolmogorov-Smirnov	5.663631E-02		0.146	0.159	Accept Normality
D'Agostino Skewness	-0.7545	0.450534	1.645	1.960	Accept Normality
D'Agostino Kurtosis	0.6471	0.517569	1.645	1.960	Accept Normality
D'Agostino Omnibus	0.9880	0.610168	4.605	5.991	Accept Normality

Plots Section of LOG10(Solp)

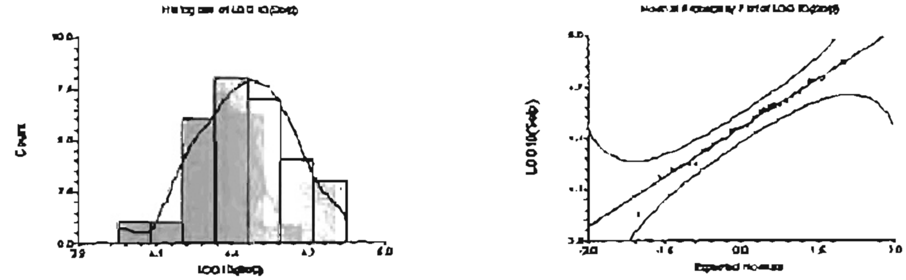


Figure C2 Soluble P distribution calculations and statistical tests.

Normality Test Section of Nitr

Test Name	Test Value	Prob Level	10% Critical Value	5% Critical Value	Decision (5%)
Shapiro-Wilk W	0.9637678	0.385167			Accept Normality
Anderson-Darling	0.3260925	0.521037			Accept Normality
Martinez-Iglewicz	1.084014		1.148522	1.228175	Accept Normality
Kolmogorov-Smirnov	0.1069857		0.146	0.159	Accept Normality
D'Agostino Skewness	1.8013	0.071652	1.645	1.960	Accept Normality
D'Agostino Kurtosis	1.1407	0.253982	1.645	1.960	Accept Normality
D'Agostino Omnibus	4.5460	0.103001	4.605	5.991	Accept Normality

Plots Section of Nitr

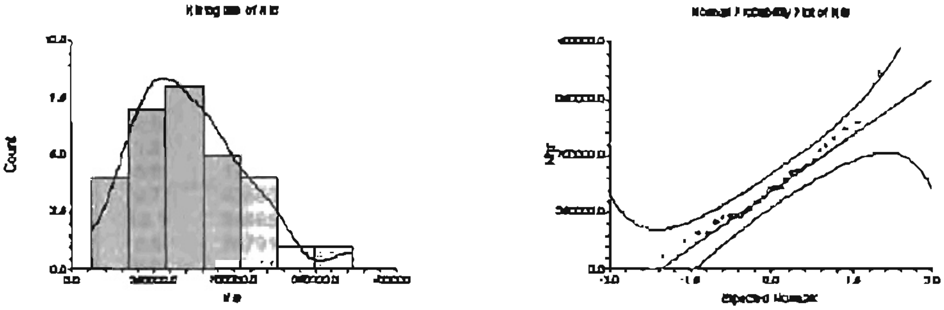


Figure C3 Sediment-bound P distribution calculations and statistical tests.

Normality Test Section of LOG10(Sedp)

Test Name	Test Value	Prob Level	10% Critical Value	5% Critical Value	Decision (5%)
Shapiro-Wilk W	0.9719931	0.595032			Accept Normality
Anderson-Darling	0.2634603	0.699807			Accept Normality
Martinez-Iglewicz	1.156542		1.148522	1.228175	Accept Normality
Kolmogorov-Smirnov	8.087213E-02		0.146	0.159	Accept Normality
D'Agostino Skewness	1.5162	0.128960	1.645	1.960	Accept Normality
D'Agostino Kurtosis	1.4723	0.140926	1.645	1.960	Accept Normality
D'Agostino Omnibus	4.4728	0.106843	4.605	5.991	Accept Normality

Plots Section of LOG10(Sedp)

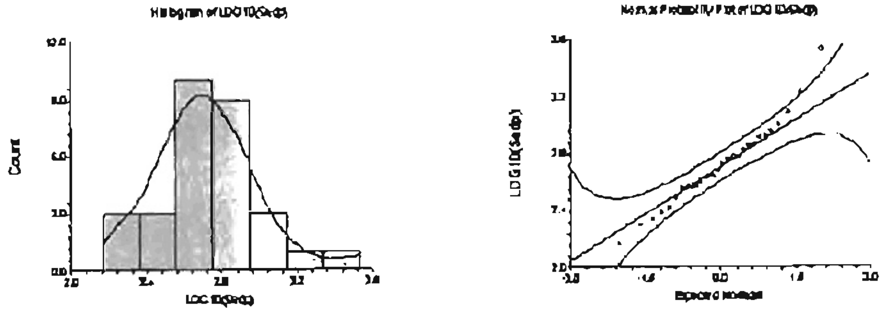


Figure C4 Nitrate distribution calculations and statistical tests.

Appendix C Eucha Basin Calibrated Model

Table C1 Loadings to Eucha from thirty simulations of the calibrated model using different weather data. Total phosphorous calculated using an adjustment factor. (Nitrate as nitrogen)

	EUCHA					Spavinaw			
Year	Flow (m^3/s)	Soluble P (kg/yr)	Sediment P (kg/yr)	Nitrate-N (kg/yr)	Total P (adjusted kg/yr)	Flow (m^3/s)	Soluble P (kg/yr)	Sediment P (kg/yr)	Nitrate-N (kg/yr)
1970	9.4	38084	571	639002	51791	0.07	22.8	14.2	2207.1
1971	4.2	16396	218	316426	21634	0.09	21.9	45.2	2173.4
1972	8.2	35343	602	594242	49792	0.46	262.0	0.2	13665.9
1973	24.2	69949	1705	1208910	110879	0.97	341.7	328.9	18530.5
1974	16.1	55575	813	902386	75080	0.75	265.7	6.0	12386.2
1975	10.5	29584	598	549105	43928	0.42	76.3	14.5	6324.8
1976	6.9	27462	586	173490	41522	0.07	40.1	0.2	1949.9
1977	4.3	17619	242	326404	23423	0.37	122.8	0.2	11326.4
1978	11.1	36709	846	413503	57002	0.35	72.6	224.0	5051.1
1979	3.7	16976	309	223191	24396	0.11	32.7	16.0	2852.5
1980	1.6	8945	145	78178	12430	0.02	2.0	0.2	867.0
1981	3.5	14941	198	330604	19682	0.03	2.7	0.2	1098.5
1982	5.8	22629	378	354286	31698	0.07	23.9	16.6	2110.2
1983	6.0	17684	439	217337	28212	0.25	41.2	60.1	3859.8
1984	9.7	43880	673	809006	60021	0.27	156.1	113.2	9162.4
1985	18.1	54485	1228	868457	83967	0.97	336.6	707.7	17717.1
1986	8.5	24791	368	328502	33612	0.45	102.2	85.4	6714.5
1987	8.6	39441	433	734051	49822	0.34	117.2	45.6	7798.0
1988	6.4	20829	396	369664	30335	0.48	81.7	94.8	6201.0
1989	7.7	23485	3439	288448	106018	0.20	22.0	29.4	2036.8
1990	12.9	46817	1001	664573	70847	0.66	239.6	194.5	13315.9
1991	7.9	28225	364	608982	36964	0.41	97.4	18.0	6961.2
1992	7.8	28775	483	401911	40371	0.46	225.6	0.2	9886.6
1993	14.1	40374	901	762648	61999	0.68	129.7	23.3	7002.4
1994	10.6	32837	526	499529	45461	0.55	220.3	48.9	11761.0
1995	9.7	31310	717	445755	48526	0.49	139.2	27.7	6788.0
1996	6.0	24140	262	486467	30439	0.36	163.4	13.5	9446.0
1997	7.7	21500	363	498860	30220	0.36	68.6	92.9	5256.1
1998	9.6	27664	420	614724	37756	0.55	126.0	133.9	9381.5
1999	11.0	38758	716	502723	55931	0.84	291.0	133.5	12878.6
MEAN	9.1	31174	665	507045	47125	0.40	128.2	83.0	7557.0
STD	4.6	13604	620	246838	23799	0.27	101.5	141.1	4845.8
MIN	1.6	8945	145	78178	12430	0.02	2.0	0.2	867.0
MAX	24.2	69949	3439	1208910	110879	0.97	341.7	707.7	18530.5
MEDIAN	8.5	28500	505	492664	42725	0.39	109.7	28.5	6874.6

Table D1 Spavinaw basin section model output vs litter application rate. (nitrogen supplemented at litter rates less than the current rate)

Pature Litter Rate	Flow (m^3/s)		Soluble P (kg/yr)		Sediment P (kg/yr)		Nitrate-N (kg/yr)	
X Current	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
0.00	0.403	0.267	120	96	83	141	7557	4846
0.25	0.403	0.267	122	97	83	141	7557	4846
0.50	0.403	0.267	124	99	83	141	7557	4846
0.75	0.403	0.267	126	100	84	142	7557	4846
1.00	0.403	0.267	128	102	83	141	7557	4846
1.25	0.404	0.267	132	104	82	138	7653	4910
1.50	0.404	0.267	136	107	83	149	7761	4972
2.00	0.404	0.267	142	110	90	159	7937	5070
3.00	0.404	0.267	154	118	85	145	8297	5316

Table D2 Spavinaw model output and confidence intervals. (Nitrate as nitrate nitrogen)

Flow(m^3/s) Litter Rate	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0	0.039	0.053	0.077	0.403	1.052	1.526	2.104
0.25	0.039	0.053	0.077	0.403	1.052	1.526	2.104
0.5	0.039	0.053	0.077	0.403	1.052	1.526	2.104
0.75	0.039	0.053	0.077	0.403	1.052	1.526	2.104
1	0.039	0.053	0.077	0 403	1.052	1.526	2.104
1.25	0.039	0.053	0.077	0.404	1.052	1.527	2.105
1.5	0.039	0.054	0.078	0.404	1.053	1.527	2.104
2	0.039	0.054	0.078	0.404	1.051	1.524	2.099
3	0.039	0.054	0.078	0.404	1.052	1.525	2.100

Soluble P (kg/yr) Litter Rate	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0	5.6	8.5	13.6	120.0	379.5	609.9	918.5
0.25	5.7	8.6	13.9	122.0	386.4	621.0	935.3
0.5	5.8	8.8	14.1	124.2	393.9	633.2	953.6
0.75	5.9	8.9	14.3	126.1	400.9	644.7	971.4
1	6.4	9.6	15.2	128.2	398.8	635.3	949.4
1.25	6.2	9.4	15.1	132.2	422.6	679.4	1023.5
1.5	6.9	10.4	16.5	136.2	425.7	676.9	1010.1
2	7.7	11.4	18.0	141.8	435.8	686.5	1016.2
3	8.9	13.1	20.5	154.1	467.6	730.4	1073.4

Sediment P (kg/yr) Litter Rate	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0	0.1	0.3	0.8	83.0	398.5	969.8	2089.2
0.25	0.1	0.3	0.8	83.0	398.5	969.8	2089.2
0.5	0.1	0.3	0.8	83.0	398.5	969.8	2089.2
0.75	0.1	0.3	0.8	83.6	402.8	981.2	2115.7
1	0.1	0.3	0.8	83.0	398.5	969.8	2089.2
1.25	0.2	0.3	0.8	82.0	408.0	989.4	2124.9
1.5	0.1	0.2	0.6	82.7	418.0	1064.3	2384.2
2	0.4	0.7	1.6	90.0	371.0	809.2	1586.0
3	0.3	0.7	1.5	85.0	370.3	812.4	1600.4

Nitrate-N (kg/yr) Litter Rate	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0	0.0	0.0	1354.4	7557.0	13759.6	15528.3	17054.7
0.25	0.0	0.0	1354.4	7557.0	13759.6	15528.3	17054.7
0.5	0.0	0.0	1354.4	7557.0	13759.6	15528.3	17054.7
0.75	0.0	0.0	1354.1	7556.8	13759.4	15528.2	17054.6
1	0.0	0.0	1354.4	7557.0	13759.6	15528.3	17054.7
1.25	0.0	0.0	1368.2	7652.7	13937.3	15729.3	17275.9
1.5	0.0	0.0	1396.3	7761.0	14125.7	15940.7	17507.0
2	0.0	0.0	1447.7	7937.1	14426.5	16277.0	17874.0
3	0.0	0.0	1492.7	8297.1	15101.4	17041.7	18716.2

Table D2 Confidence intervals for Lake Eucha at varying STP (current litter application rate) (Nitrate as nitrate nitrogen)).

FLOW (m^3/sec) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	2.81	3.33	4.05	9.13	16.00	19.47	23.05
65	2.81	3.33	4.05	9.13	16.00	19.47	23.05
120	2.81	3.33	4.05	9.13	16.00	19.47	23.05
300	2.81	3.33	4.05	9.13	16.00	19.47	23.05
500	2.81	3.33	4.05	9.13	16.00	19.47	23.05
1000	2.81	3.33	4.05	9.13	16.00	19.47	23.05

SOLUBLE P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	10246	11696	13633	25353	39955	46574	53163
65	10458	11953	13954	26126	41331	48251	55148
120	10831	12408	14525	27528	43845	51326	58800
300	12036	13882	16377	32146	52204	61587	71029
500	13385	15525	18436	37283	61539	73078	84762
1000	16687	19546	23476	50003	84872	101940	119404

SED. P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	140	171	217	626	1123	1419	1738
65	141	173	219	640	1155	1464	1796
120	143	176	224	666	1215	1547	1906
300	147	183	236	746	1408	1816	2263
500	153	191	249	814	1577	2052	2575
1000	164	209	275	946	1902	2506	3180

NITRATE (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	23475	101287	191449	507636	823822	913985	991797
65	23390	101204	191369	507565	823762	913927	991741
120	23417	101215	191361	507492	823623	913770	991567
300	23219	100974	191072	507031	822990	913087	990843
500	23396	101077	191087	506741	822394	912405	990085
1000	23538	101104	190981	506167	821353	911230	988795

Total P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	13921	16220	19363	40381	67066	80062	93286
65	14163	16524	19756	41486	69172	82703	96491
120	14593	17066	20461	43501	73032	87559	102399
300	15957	18790	22706	50053	85672	103529	121905
500	17605	20814	25271	56815	98552	119656	141468
1000	21594	25686	31407	72706	128687	157350	187169

Table D3 Confidence intervals for Lake Eucha at the differing levels of STP (half of the current litter application rate). Nitrogen is supplemented. (Nitrate as nitrate nitrogen)

FLOW (m^3/sec) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	2.81	3.33	4.05	9.13	16.00	19.47	23.05
65	2.81	3.33	4.05	9.13	16.00	19.47	23.05
120	2.81	3.33	4.05	9.13	16.00	19.47	23.05
300	2.81	3.33	4.05	9.13	16.00	19.47	23.05
500	2.81	3.33	4.05	9.13	16.00	19.47	23.05
1000	2.81	3.33	4.05	9.13	16.00	19.47	23.05

SOLUBLE P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	9142	10339	11923	21137	32412	37379	42274
65	9334	10575	12222	21872	33723	38974	44158
120	9706	11032	12796	23278	36227	42021	47761
300	10916	12514	14661	27886	44500	52133	59764
500	12251	14147	16713	33018	53804	63564	73398
1000	15514	18125	21705	45605	76847	92026	107516

SED. P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	136	167	211	606	1078	1361	1664
65	138	169	213	620	1113	1408	1725
120	140	172	218	647	1175	1494	1838
300	144	179	231	731	1374	1772	2206
500	151	189	246	801	1547	2011	2522
1000	163	207	272	935	1876	2471	3134

NITRATE (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	23493	101394	191661	508213	824764	915031	992933
65	23585	101460	191697	508142	824588	914824	992700
120	23409	101279	191509	507932	824355	914585	992455
300	23329	101142	191307	507501	823695	913859	991673
500	23138	100900	191005	506991	822976	913082	990844
1000	23315	100943	190893	506333	821774	911724	989352

Total P (kg/yr) STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	12536	14564	17327	35674	58605	69724	81003
65	12767	14856	17708	36760	60683	72331	84167
120	13212	15416	18434	38809	64592	77237	90122
300	14620	17189	20736	45423	77294	93243	109630
500	16287	19237	23329	52234	90250	109451	129276
1000	20271	24101	29453	68048	120219	146916	174676

Table D4 Confidence intervals for Lake Eucha at various levels of STP (zero litter application rate). Nitrogen is supplemented.(Nitrate as nitrate nitrogen)

FLOW (m^3/sec)							
STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	2.81	3.33	4.05	9.13	16.00	19.47	23.05
65	2.81	3.33	4.05	9.13	16.00	19.47	23.05
120	2.81	3.33	4.05	9.13	16.00	19.47	23.05
300	2.81	3.33	4.05	9.13	16.00	19.47	23.05
500	2.81	3.33	4.05	9.13	16.00	19.47	23.05
1000	2.81	3.33	4.05	9.13	16.00	19.47	23.05

SOLUBLE P (kg/yr)							
STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	7999	8928	10141	16712	24777	28143	31413
65	8192	9167	10443	17440	26043	29667	33197
120	8548	9609	11005	18833	28490	32629	36680
300	9749	11088	12871	23443	36629	42520	48359
500	11072	12711	14916	28573	45801	53746	61701
1000	14271	16612	19810	40918	68101	81211	94536

SED. P (kg/yr)							
STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	131	160	202	576	1015	1278	1559
65	133	162	205	593	1053	1330	1627
120	135	166	211	622	1121	1422	1747
300	141	175	226	711	1331	1714	2132
500	148	185	241	785	1512	1964	2463
1000	161	204	269	923	1848	2433	3084

NITRATE (kg/yr)							
STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	13197	92153	183641	509066	825317	916805	995762
65	13117	92062	183538	508923	825123	916599	995544
120	12932	91872	183342	508713	824884	916354	995294
300	12868	91730	183109	508114	824017	915397	994258
500	12823	91595	182871	507524	823048	914324	993095
1000	12837	91461	182565	506583	821545	912649	991274

Total P (kg/yr)							
STP	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
35	11017	12753	15109	30646	49615	58781	68042
65	11265	13065	15513	31767	51750	61448	71267
120	11722	13640	16259	33847	55706	66399	77262
300	13183	15475	18632	40558	68532	82517	96859
500	14881	17558	21266	47418	81550	98776	116541
1000	18848	22394	27344	62990	110964	135493	160979

Table D5 Effect of STP for the smaller Spavinaw portion of the basin. No litter applied, nitrogen supplemented.

Pasture STP Level	Flow (m^3/sec)		Sol P (kg/yr)		Sed P (kg/yr)		Nitrate-N (kg/yr)	
(lb/acre)	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	0.403	0.267	111.5	88.97	79.23	136.2	7557	4845.8
65	0.403	0.267	115.1	91.64	80.79	137.8	7557	4845.8
120	0.403	0.267	121.6	96.84	83.6	141.8	7557	4845.8
300	0.403	0.267	142.3	113.7	93.02	155.8	7557	4845.8
500	0.403	0.267	165.1	132.4	103.5	173	7557	4845.8
1000	0.403	0.267	217.4	176.4	130.3	221.5	7557	4845.8

Table D6 Effect of STP for the smaller Spavinaw portion of the basin. Half litter rate applied, nitrogen supplemented.

Pasture STP Level	Flow (m^3/sec)		Sol P (kg/yr)		Sed P (kg/yr)		Nitrate-N (kg/yr)	
(lb/acre)	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	0.403	0.2666	115.6	91.81	79.23	136.2	7557	4845.8
65	0.403	0.2666	119.2	94.54	80.79	137.8	7557	4845.8
120	0.403	0.2666	125.7	99.82	83.6	141.8	7557	4845.8
300	0.403	0.2666	146.5	116.5	93.02	155.8	7557	4845.8
500	0.403	0.2666	169.2	135.3	103.5	173	7557	4845.8
1000	0.403	0.2666	221.7	179.5	130.3	221.5	7557	4845.8

Table D7 Effect of STP for the smaller Spavinaw portion of the basin. No litter applied, nitrogen supplemented.

Pasture STP Level	Flow (m^3/sec)		Sol P (kg/yr)		Sed P (kg/yr)		Nitrate-N (kg/yr)	
(lb/acre)	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
35	0.403	0.267	119.5	94.66	79.23	136.2	7557	4845.8
65	0.403	0.267	123.4	97.28	80.85	137.9	7557	4845.8
120	0.403	0.267	129.6	102.5	83.66	141.9	7557	4845.8
300	0.403	0.267	150.4	119.4	93.02	155.8	7557	4845.8
500	0.403	0.267	173.1	138.1	103.5	173	7557	4845.8
1000	0.403	0.267	225.8	182.4	130.3	221.5	7557	4845.8

Table D8 Grazing rate simulations, confidence intervals for model outputs (Nitrate as nitrate nitrogen).

Flow (m^3/sec) Grazing Rate (X normal)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	0.04	0.06	0.08	0.41	1.05	1.52	2.08
0.50	0.04	0.05	0.07	0.40	1.05	1.53	2.12
1.00	0.04	0.05	0.08	0.40	1.05	1.53	2.10
2.00	0.05	0.06	0.09	0.42	1.07	1.53	2.08

Soluble P (kg/yr) Grazing Rate (X normal)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	13	18	27	154	414	613	858
0.50	5	8	12	116	377	613	932
1.00	6	10	15	128	399	635	949
2.00	19	26	37	186	483	697	955

Sediment P (kg/yr) Grazing Rate (X normal)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	0.4	0.7	1.5	70.8	253.6	528.6	996.3
0.50	0.2	0.3	0.7	60.3	227.4	514.9	1042.7
1.00	0.1	0.3	0.8	83.0	398.5	969.8	2089.2
2.00	641.3	757.2	918.0	1954.0	3542.4	4294.5	5070.8

Nitrate (kg/yr) Grazing Rate (X normal)	95%(Low)	90%(Low)	80%(Low)	MEAN	80%(High)	90%(High)	95%(High)
0.00	0	0	1720	8552	15385	17333	19015
0.50	0	0	1028	6573	12118	13700	15064
1.00	0	0	1354	7557	13760	15528	17055
2.00	0	142	2239	9593	16946	19043	20853

Table D9 Response of the Spavinaw only portion to changes in grazing rate.

Grazing Rate X Normal	FLOW (kg/yr)		SOL P (kg/yr)		SED P (kg/yr)		NITRATE-N (kg/yr)	
	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
0	0.407	0.266	154	113	71	123	8552	5338
0.5	0.399	0.265	116	94	60	106	6573	4332
1	0.403	0.267	128	102	83	141	7557	4846
2	0.422	0.271	186	126	1954	554	9593	5745

Table D10 Loading to Lake Eucha without the point source included in the model.(Nitrate as nitrate nitrogen)

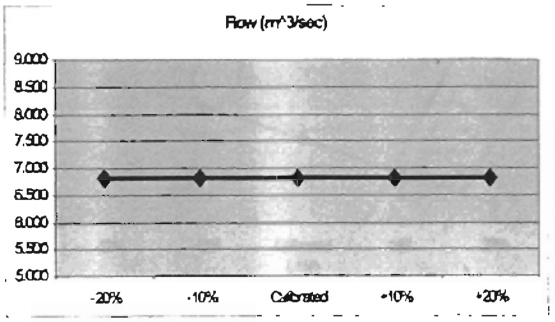
TIME	FLOW (m^3/sec)	SOL P (kg/yr)	SED P (kg/yr)	NITRATE (kg/yr)
1970	9.35	32284	421	634002
1971	4.12	10476	91	310426
1972	8.17	29543	455	589242
1973	24.18	64049	1563	1203910
1974	16.01	49675	675	897386
1975	10.43	23684	465	544105
1976	6.87	21562	452	168490
1977	4.25	11749	106	321404
1978	11.01	30809	677	408503
1979	3.62	11076	150	218191
1980	1.57	3075	16	72678
1981	3.45	9131	76	324604
1982	5.76	16829	244	349286
1983	5.94	11884	279	211337
1984	9.65	37980	546	804006
1985	18.02	48685	1068	863457
1986	8.44	18991	255	323502
1987	8.59	33541	324	729051
1988	8.39	14929	268	363664
1989	7.64	17585	3297	283448
1990	12.85	40917	891	659573
1991	7.81	22325	244	602982
1992	7.75	22875	368	396911
1993	14.12	34474	750	756648
1994	10.50	26937	399	494529
1995	9.64	25410	586	440755
1996	5.94	18240	115	480467
1997	7.64	15600	232	493860
1998	9.56	21764	312	609724
1999	10.97	32958	619	496723
MEAN	9.07	25301	531	501762
STD	4.62	13602	617	246933
MIN	1.57	3075	16	72678
MAX	24.18	64049	3297	1203910
MEDIAN	8.41	22600	384	487164

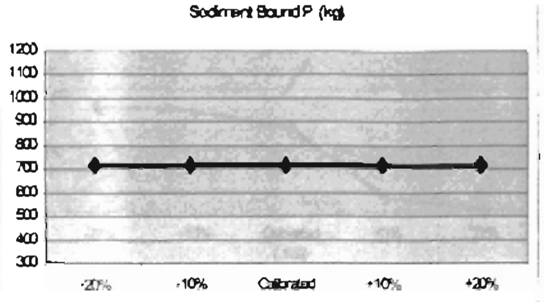
Table D11 Phosphorous balance at current litter application rate for a 30 year period. All units are kg phosphorous / hectare, except STP which is lb P/acre.

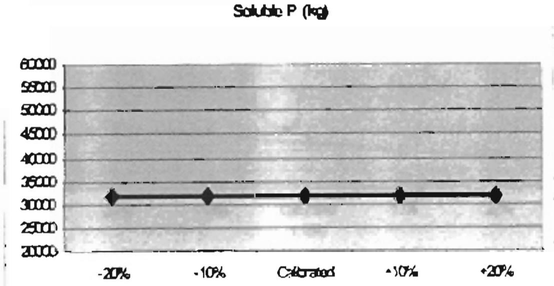
DATE START	TOTAL P 781	NET	INPUTS	OUTPUTS	STP 250	SED P in runoff	SOL P in runoff	Plant uptake	Active to labile P	Active to stable P	Applied in fert	Organic to mineral P
1	791	30.3	56	26	261	0.45	0.43	25.2	9.5	6.6	26.9	29.4
2	822	31.0	60	29	271	0.00	0.17	28.4	10.4	8.8	26.9	32.7
3	850	27.5	61	33	280	0.01	0.58	32.9	8.5	9.7	26.9	34.1
4	879	29.4	68	38	290	0.06	1.36	36.8	8.5	8.8	26.9	40.8
5	913	33.6	70	36	301	0.04	1.13	35.1	11.6	9.9	26.8	43.1
6	946	32.5	70	37	311	0.06	0.56	36.7	11.1	9.9	25.9	42.9
7	976	30.0	69	39	321	0.09	0.53	38.3	9.7	10.0	27.0	41.9
8	1014	38.0	74	36	334	0.03	0.30	35.3	15.1	10.9	26.9	46.8
9	1046	32.2	69	36	344	0.05	0.79	35.6	11.4	10.1	26.8	41.9
10	1073	27.2	70	43	353	0.03	0.29	42.5	8.4	9.9	27.0	43.0
11	1118	45.3	78	33	368	0.00	0.09	32.8	18.5	11.5	26.8	51.3
12	1140	21.7	69	47	376	0.01	0.25	46.6	6.3	10.9	27.1	41.6
13	1179	38.8	77	38	388	0.03	0.48	37.3	15.3	10.4	26.9	49.8
14	1214	35.3	72	37	400	0.07	0.35	36.4	14.0	10.9	26.9	45.2
15	1249	35.1	73	38	412	0.23	1.05	36.6	14.2	10.8	26.8	46.2
16	1276	26.6	69	42	420	0.25	1.37	40.9	8.8	9.8	26.9	42.1
17	1310	34.5	75	40	432	0.03	0.54	39.7	13.7	9.9	27.0	47.8
18	1345	34.5	75	41	443	0.07	0.94	39.6	14.2	10.7	26.6	48.3
19	1381	35.9	74	38	455	0.04	0.44	37.5	14.9	10.7	26.9	47.0
20	1407	25.9	71	45	463	0.08	0.50	44.8	9.0	10.5	26.8	44.5
21	1446	38.9	78	39	478	0.35	1.21	37.4	17.0	10.5	26.9	51.0
22	1482	36.6	74	37	488	0.09	0.65	36.4	16.0	11.6	26.8	46.9
23	1506	24.0	72	48	496	0.20	0.67	47.3	8.5	10.7	27.1	45.1
24	1541	34.2	78	44	507	0.18	1.01	42.4	13.9	10.2	26.8	50.9
25	1578	37.2	78	41	520	0.13	0.80	39.8	16.2	11.3	28.9	51.0
26	1611	32.9	75	42	531	0.18	0.76	41.3	14.0	11.1	26.9	48.2
27	1646	35.0	76	41	542	0.12	0.56	40.1	15.6	11.9	26.8	49.0
28	1674	28.2	75	46	551	0.16	0.48	45.8	11.7	11.2	26.9	47.8
29	1714	40.6	80	40	585	0.16	0.68	38.9	18.3	12.1	26.8	53.5
30	1748	33.2	77	44	576	0.13	0.99	42.8	15.1	11.9	26.9	50.2

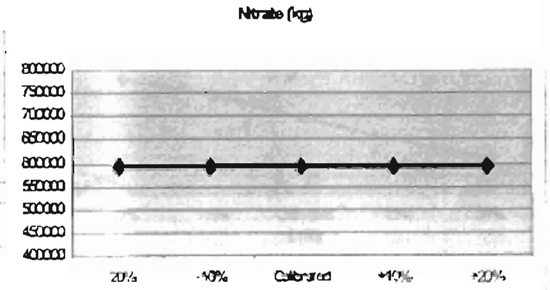
Alpha baseflow factor

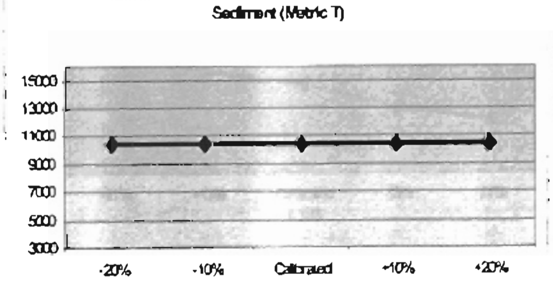
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-20%	6.814	10410	4045	713	593500	31920
-10%	6.817	10430	4045	713	593600	31920
Calibrated	6.819	10440	4045	713	593500	31920
+10%	6.821	10460	4045	713	593500	31920
+20%	6.822	10470	4045	713	593500	31920
Relative Sensitivity	0.00293	0.01438	0.00000	0.00000	0.00000	0.00000

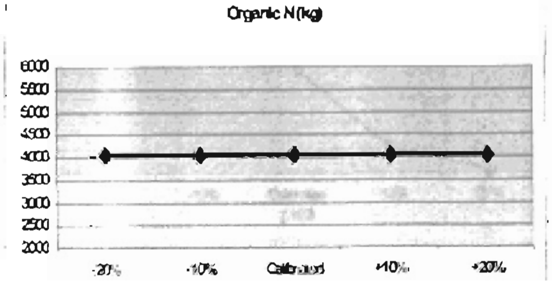












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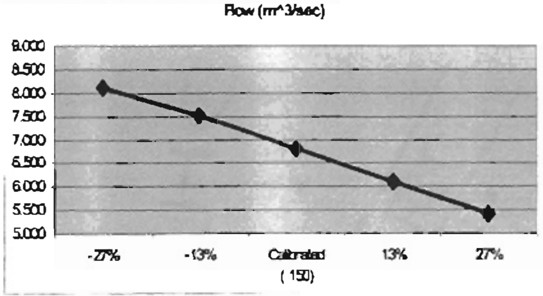
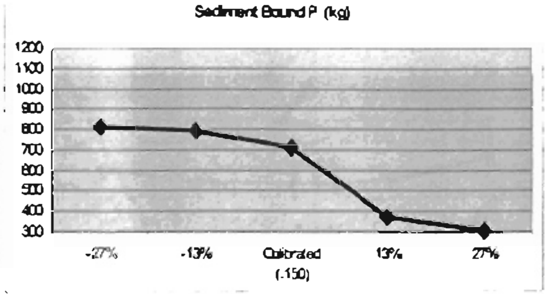
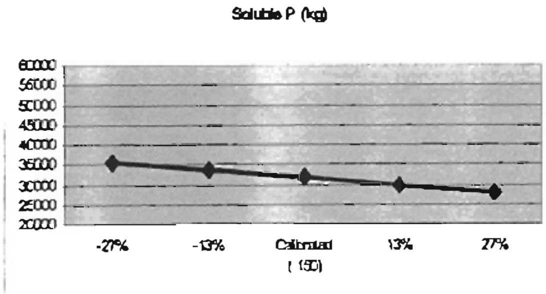
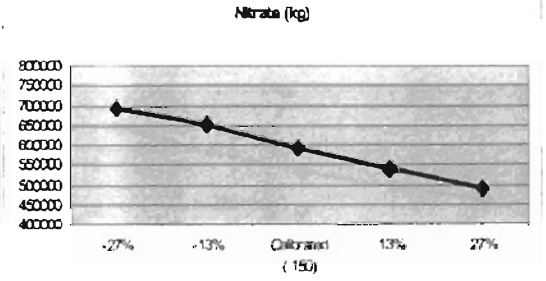
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-27%	8.102	12830	4803	815.3	696400	35330
-13%	7.514	11720	4580	794.1	652400	33850
Calibrated (.150)	6.819	10440	4045	713	593500	31920
13%	6.088	8680	2479	373.5	540400	29880
27%	5.413	7558	2093	306.1	489900	28020
Relative Sensitivity	-0.81721	-1.09333	-1.91747	-2.44154	-0.70775	-0.45931

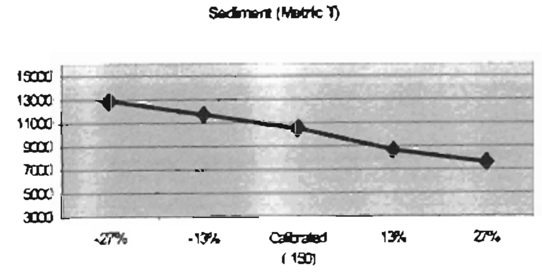
AWC Calibrated value determined by area weighted average.

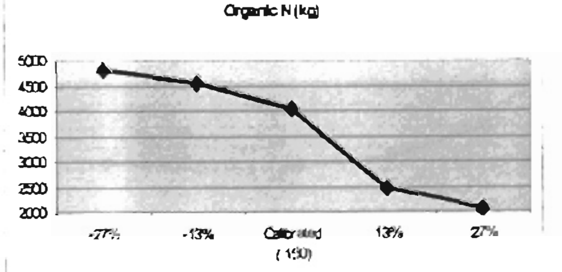

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)

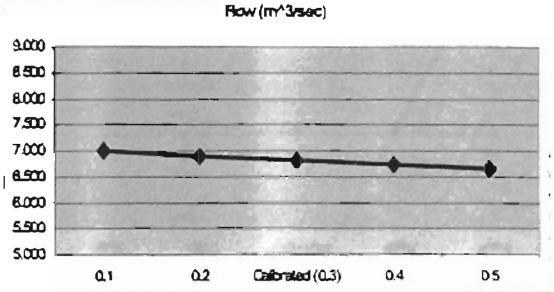

Nitrate (kg)

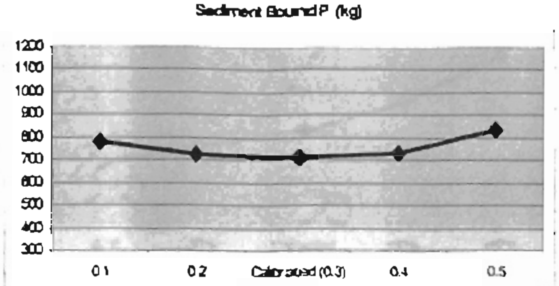

Sediment (Metric T)

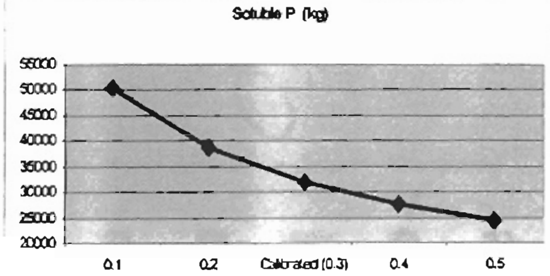

Organic N (kg)

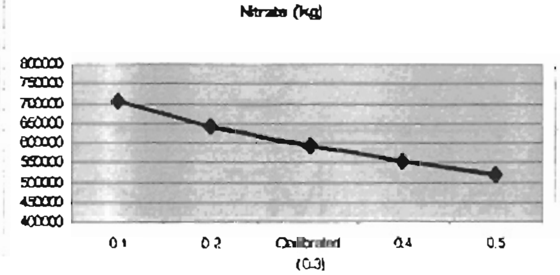
BIOMX

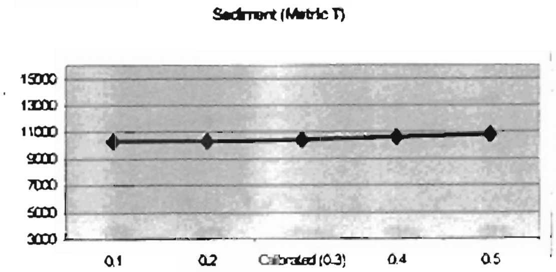
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
0.1	7.001	10320	4118	781.4	706400	50520
0.2	6.905	10350	4002	725.5	641800	38670
Calibrated (0.3)	6.819	10440	4045	713	593500	31920
0.4	6.737	10610	4279	729.5	563400	27510
0.5	6.663	10870	4970	836.3	520300	24370
Relative Sensitivity	-0.04246	0.05384	0.22196	0.13068	-0.26335	-0.63318

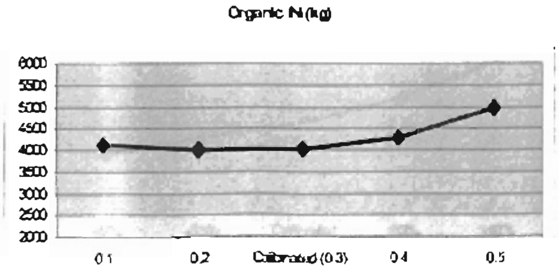






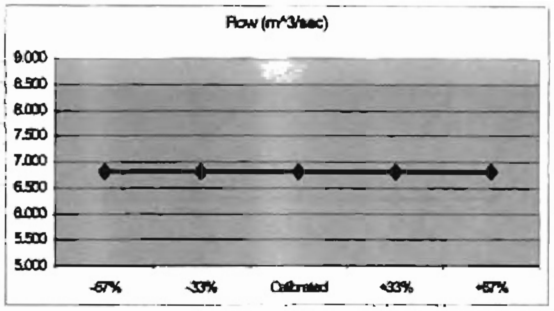


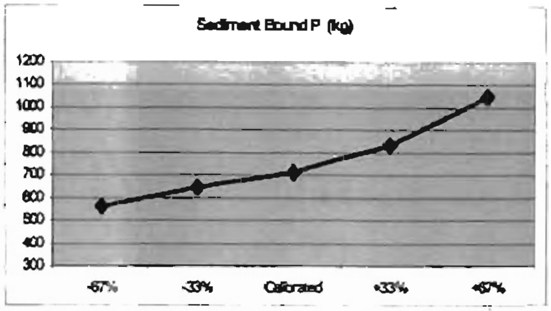


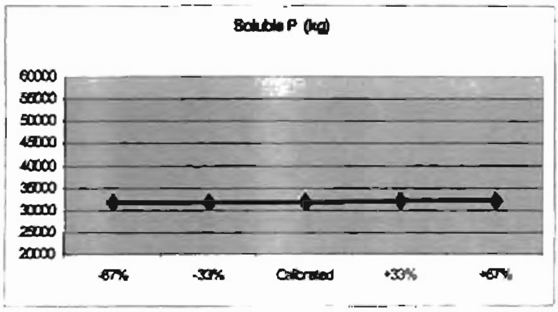


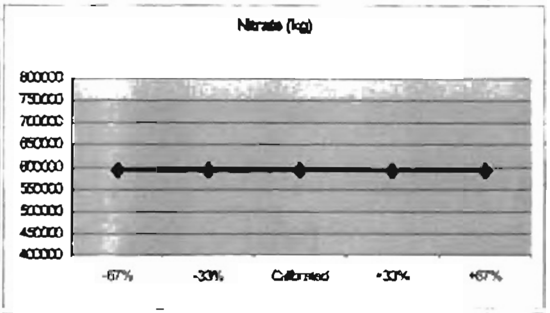
C factor

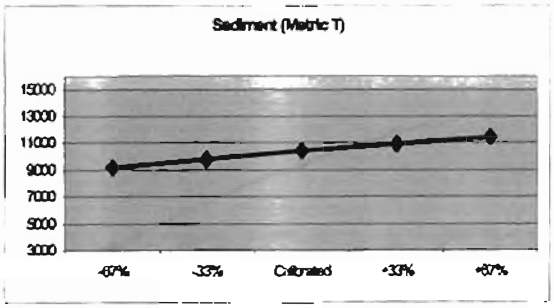
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-67%	6.819	9147	3277	563	593500	31820
-33%	6.819	9842	3673	644.1	593400	31860
Calibrated	6.819	10440	4045	713	593600	31920
+33%	6.819	10990	4618	836.7	593400	32000
+67%	6.819	11480	5470	1051	593500	32060
Relative Sensitivity	0.00000	0.16714	0.36336	0.43607	0.00000	0.00569

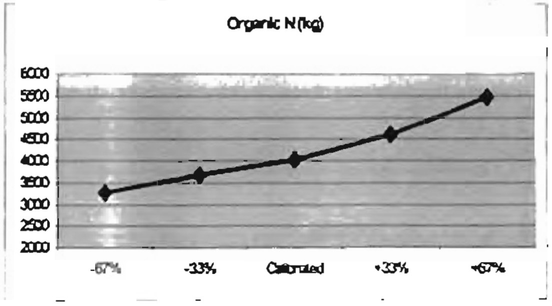






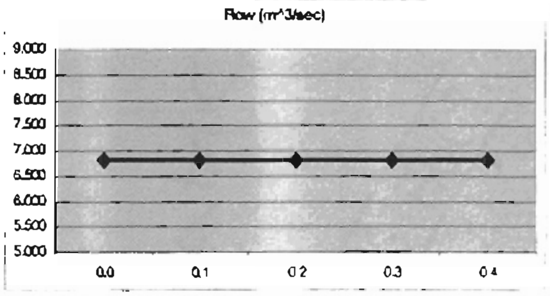


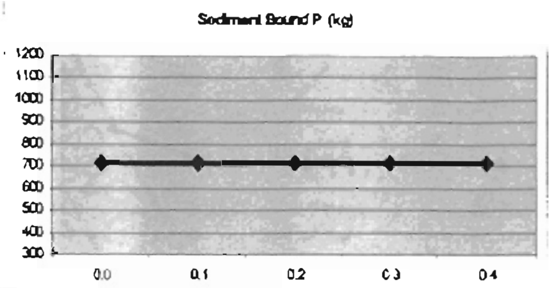


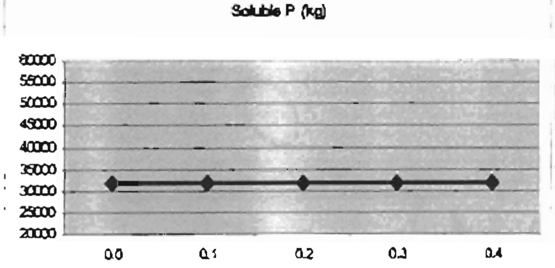


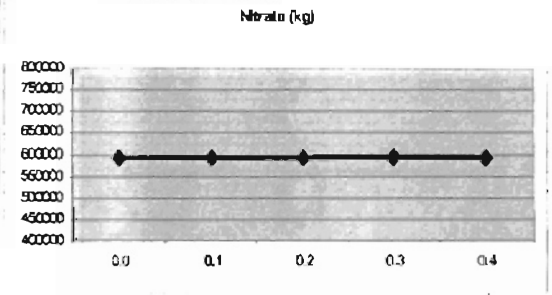
Channel cover

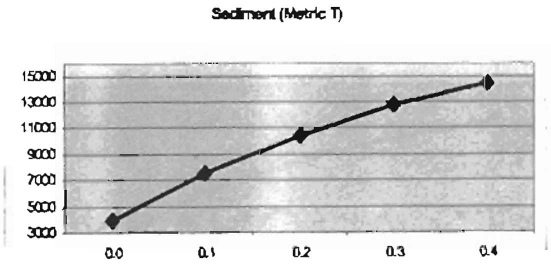
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
0.0	6.819	3933	4045	713	593500	31920
0.1	6.819	7509	4045	713	593500	31920
0.2	6.819	10440	4045	713	593500	31920
0.3	6.819	12790	4045	713	593500	31920
0.4	6.819	14490	4045	713	593500	31920
Relative Sensitivity	0.00000	0.51456	0.00000	0.00000	0.00000	0.00000

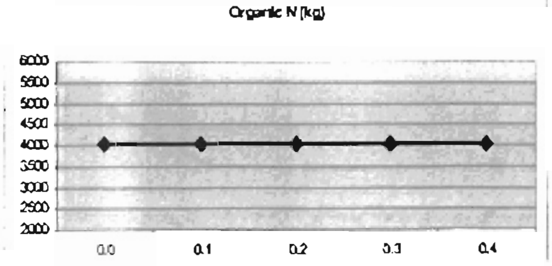






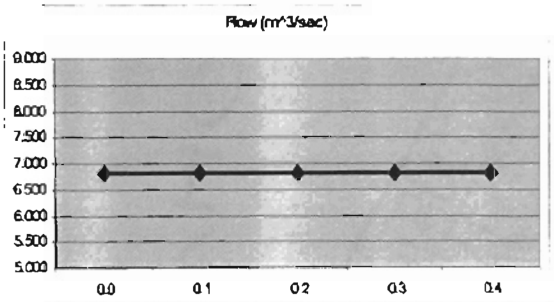


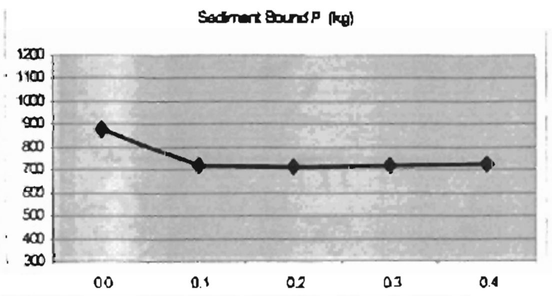


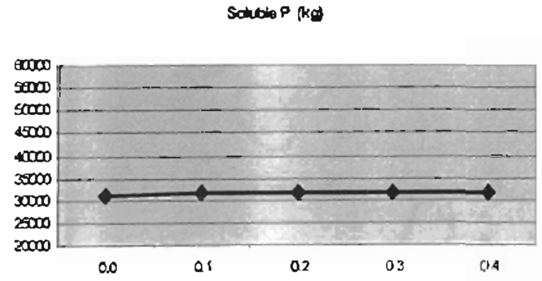


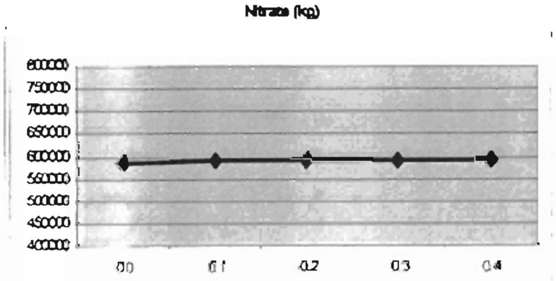
Channel Erode

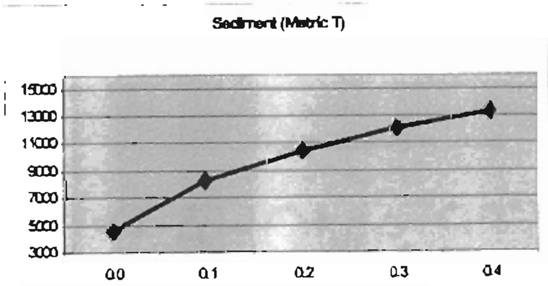
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
0.0	6.820	4537	5295	875.9	586300	31160
0.1	6.819	8258	4109	721.8	593100	31890
0.2	6.819	10440	4045	713	593500	31920
0.3	6.818	12060	4078	716.7	593300	31910
0.4	6.818	13280	4164	727.8	592800	31860
Relative Sensitivity	-0.00015	0.40976	-0.05335	-0.04042	0.00211	0.00439

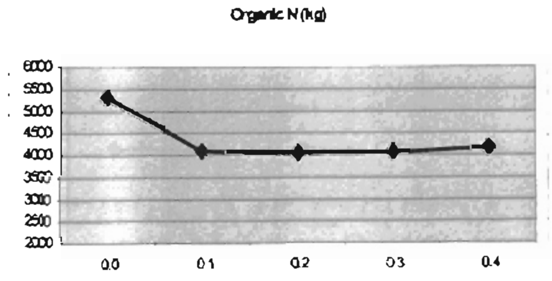






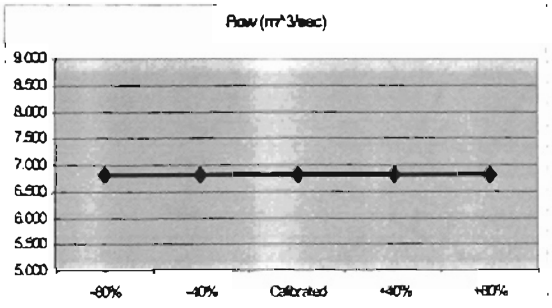


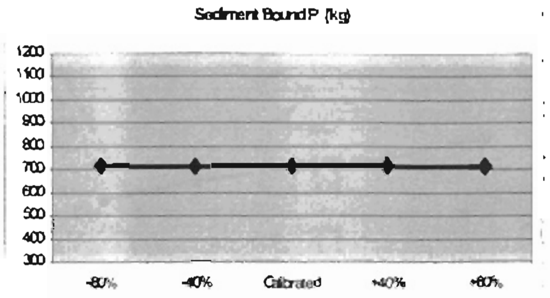


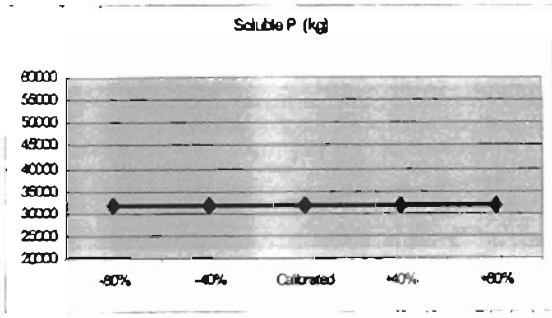


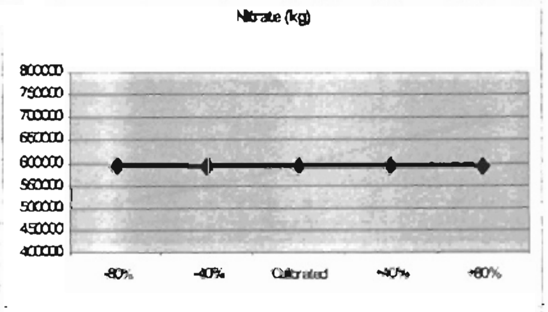
Channel K

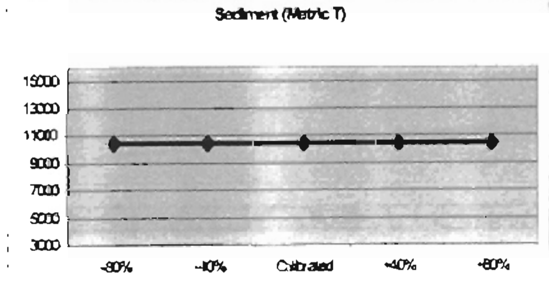
PRAM VALUE	Flow(m^3/sec)	SED(Matric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-80%	6.821	10460	4048	713.3	593500	31920
-40%	6.822	10450	4047	713.2	593500	31920
Calibrated	6.819	10440	4045	713	590500	31920
+40%	6.822	10450	4047	713.2	593500	31920
+80%	6.821	10460	4048	713.3	593500	31920
Relative Sensitivity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

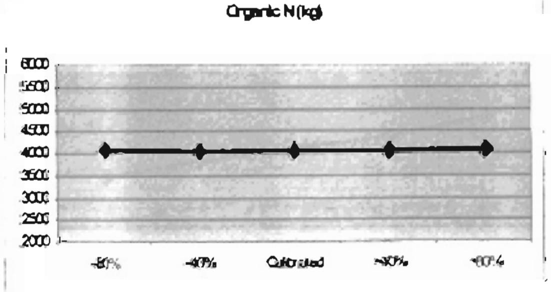








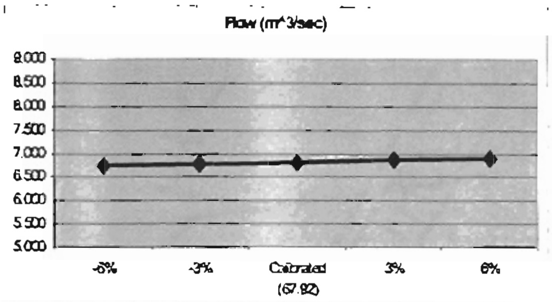


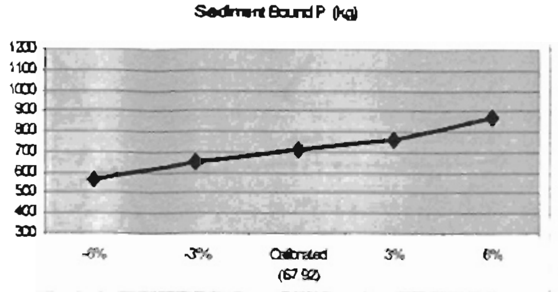


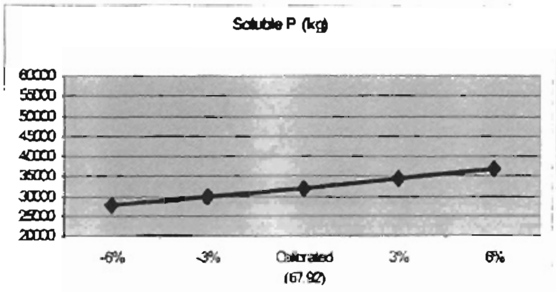
Curve Number

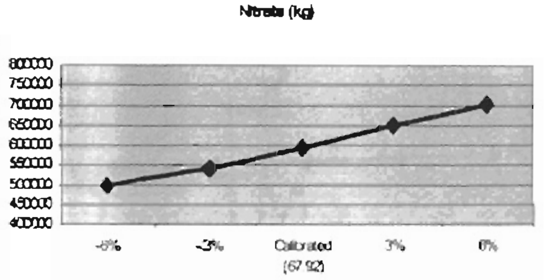
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-6%	6.749	9454	3283	564.8	497000	27780
-3%	6.780	9953	3717	652.7	541800	29690
Calibrated (67.92)	6.819	10440	4045	713	593600	31920
3%	6.862	10980	4328	762.3	648800	34320
6%	6.911	11580	4863	868.7	703100	36710
Relative Sensitivity	0.19707	1.64814	3.09514	3.38665	2.768884	2.24357

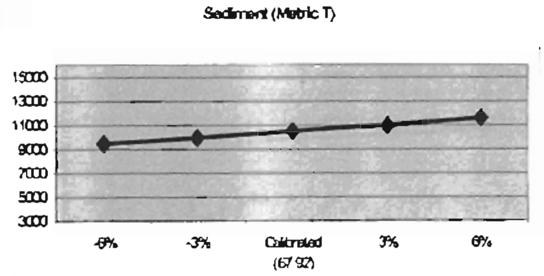
CN Calibrated value determined by area weighted average

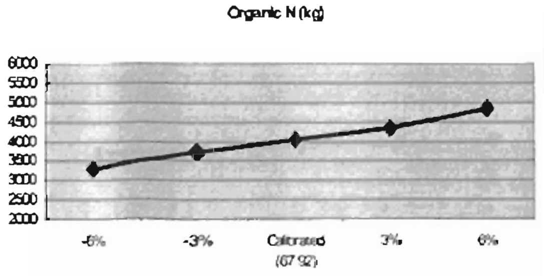




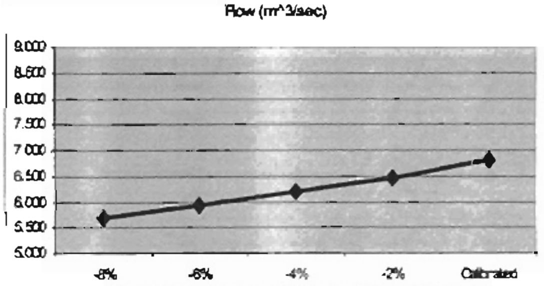


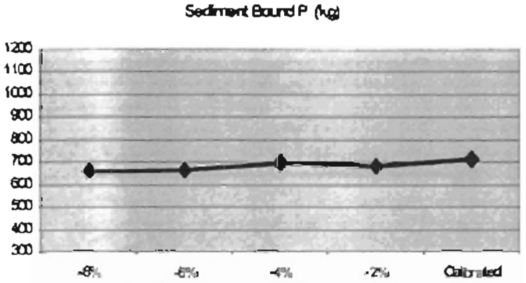


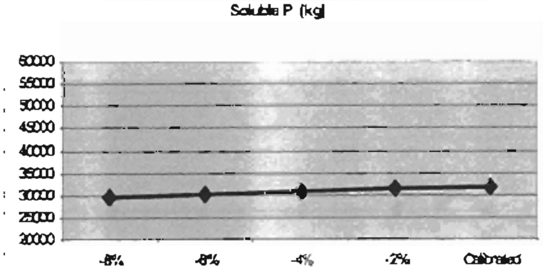


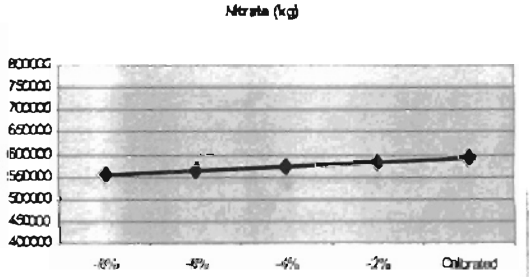


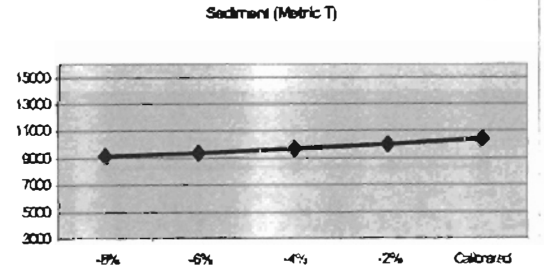
ESCO						
PRAM VALUE	**Flow(m^3/sec)**	**SED(Matric T)**	**Organic N (kg)**	**Sed P (kg)**	**NO3 (kg)**	**SOL P (kg)**
-8%	5.689	9154	3722	657.5	554500	29760
-6%	5.921	9416	3788	666.8	563700	30250
-4%	6.189	9745	3946	694	573300	30800
-2%	6.478	10060	3917	686.8	583000	31320
Calibrated	6.819	10440	4045	713	593500	31920
Relative Sensitivity	2.21381	1.61621	1.02130	0.99165	0.84245	0.86819

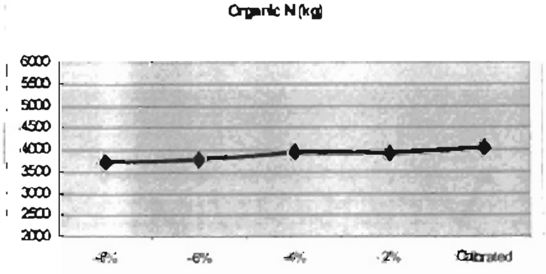

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)

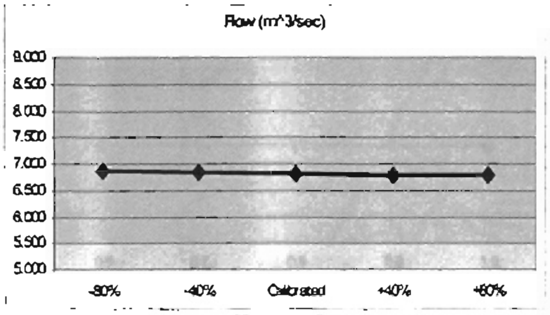

Nitrate (kg)

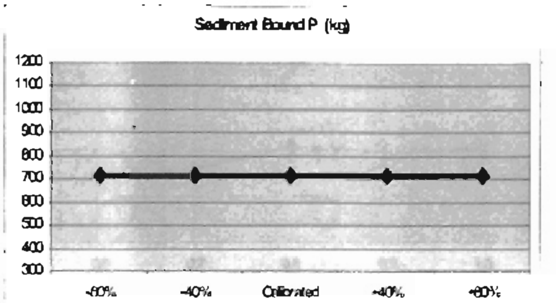

Sediment (Metric T)

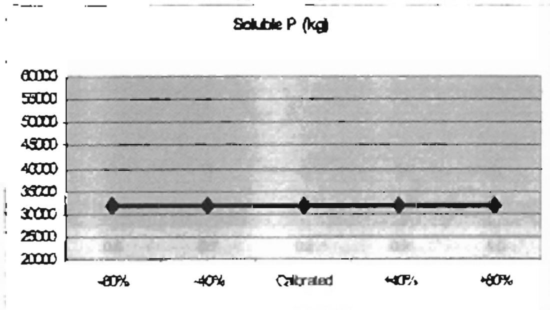

Organic N (kg)

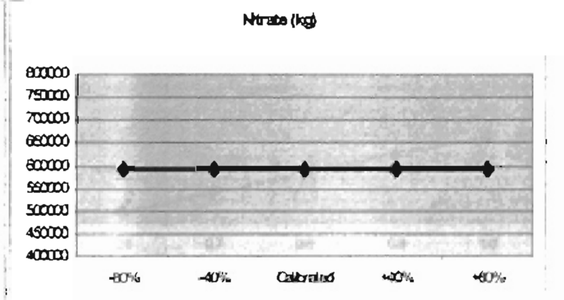
GWQ mn

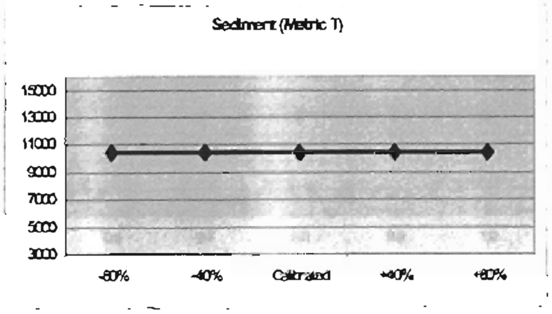
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-80%	6.855	10460	4045	713	593600	31920
-40%	6.853	10460	4045	713	593600	31920
Calibrated	6.819	10440	4045	713	593500	31920
+40%	6.789	10420	4046	713.1	593600	31920
+80%	6.788	10420	4046	713.1	593600	31920
Relative Sensitivity	-0.00612	-0.00239	0.00015	0.00009	0.00000	0.00000

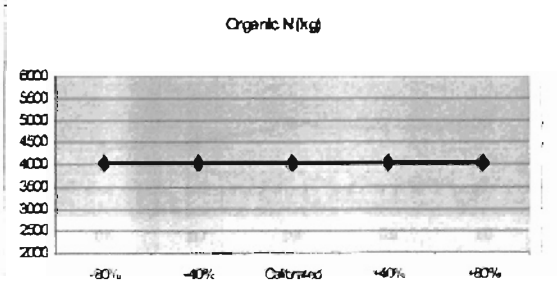

Flow (m^3/sec)


Sediment Bound P (kg)

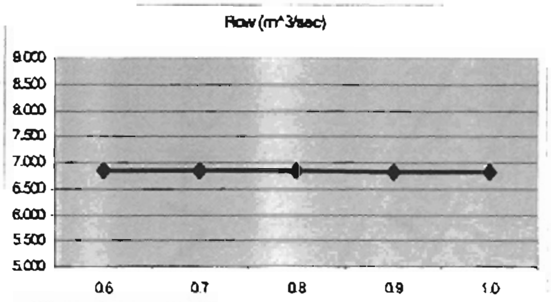

Soluble P (kg)

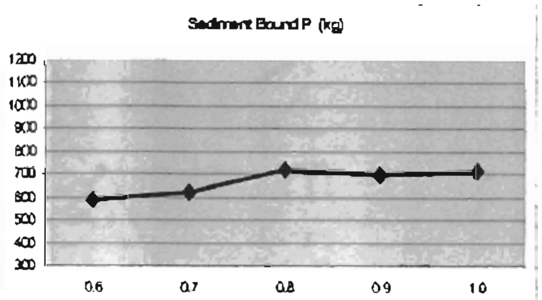

Nitrate (kg)

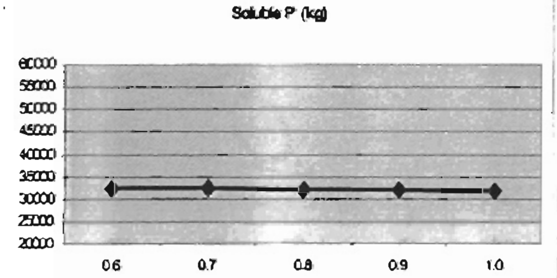

Sediment (Metric T)

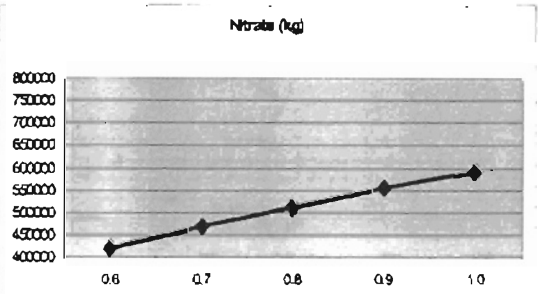

Organic N (kg)

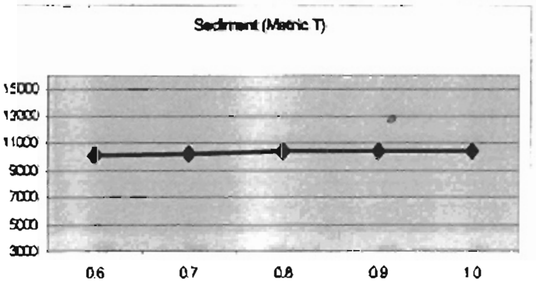
NPERCO						
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
0.6	6.829	10110	3510	592.7	420600	32410
0.7	6.833	10220	3657	622.2	469100	32330
0.8	6.827	10400	4067	718.4	513100	32170
0.9	6.822	10430	3977	698.4	554700	32040
1.0	6.819	10440	4045	713	593500	31920
Relative Sensitivity	-0.00348	0.05232	0.26308	0.33755	0.68462	-0.03281

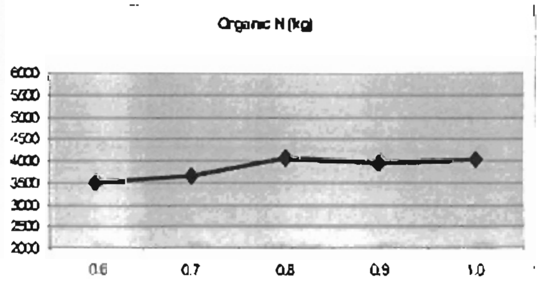






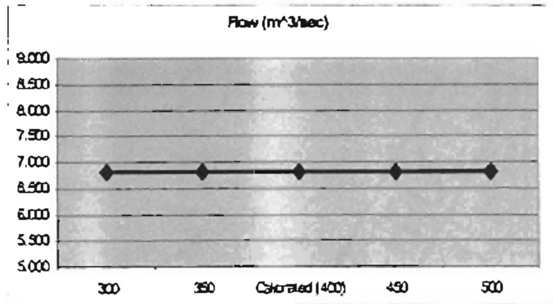


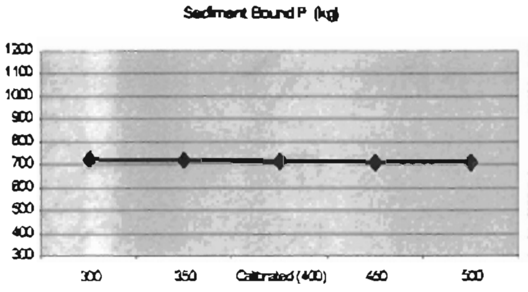


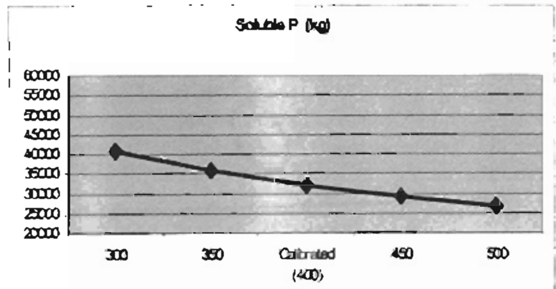


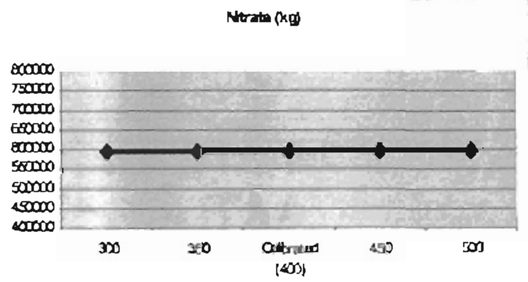
PHOSKD

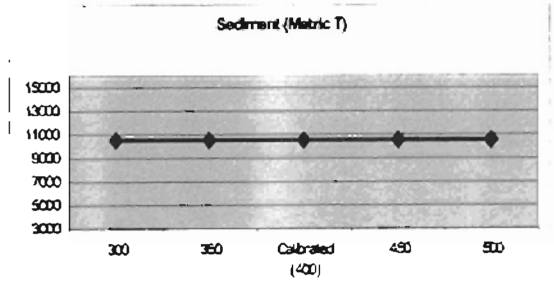
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
300	6.819	10440	4104	720.8	593100	40540
350	6.819	10440	4074	716.9	593300	35620
Calibrated (400)	6.819	10440	4045	713	593500	31920
450	6.819	10440	4018	709.3	593600	29040
500	6.819	10440	3992	705.8	593800	26720
Relative Sensitivity	0.00000	0.00000	-0.05863	-0.04459	0.00248	-0.91375

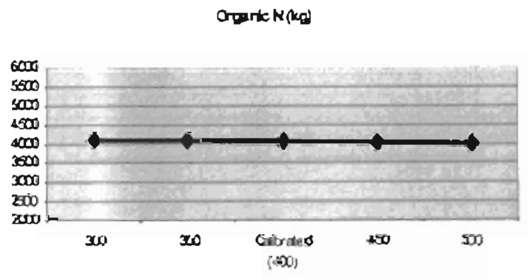












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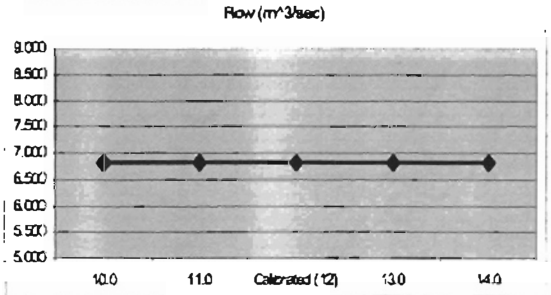
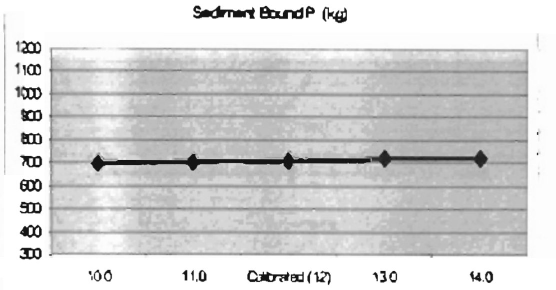
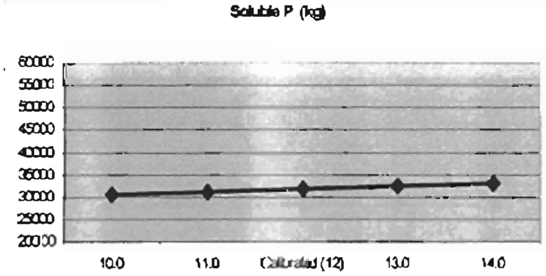
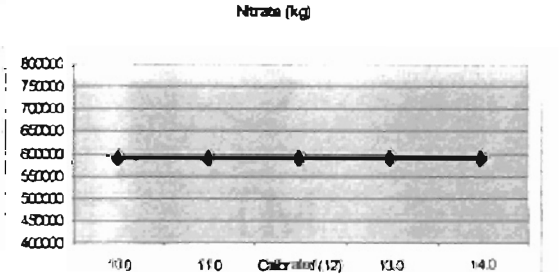
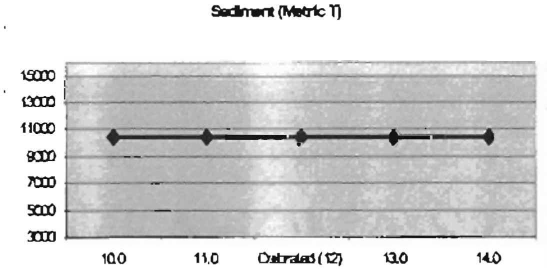
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
10.0	6.819	10440	4033	703	593500	30610
11.0	6.819	10440	4040	708.4	593500	31310
Calibrated (12)	6.819	10440	4045	713	593500	31920
13.0	6.819	10440	4050	717.1	593400	32460
14.0	6.819	10440	4054	720.7	593400	32940
Relative Sensitivity	0.00000	0.00000	0.01594	0.07638	-0.00055	0.22388

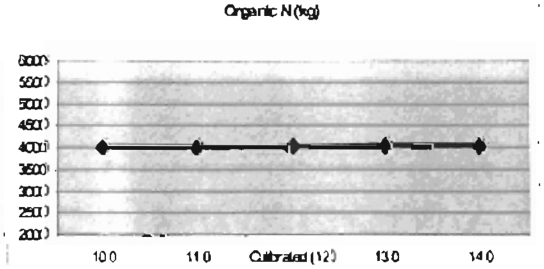

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)

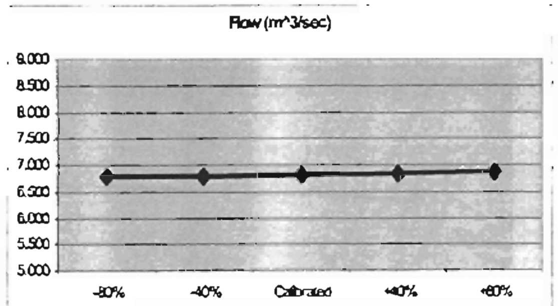

Nitrate (kg)

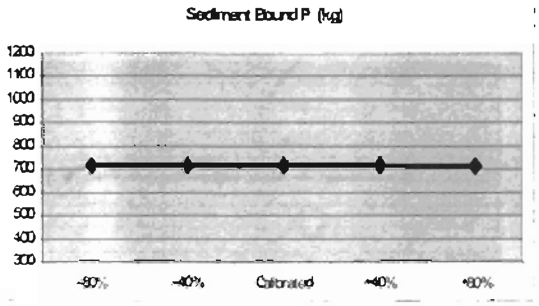

Sediment (Metric T)

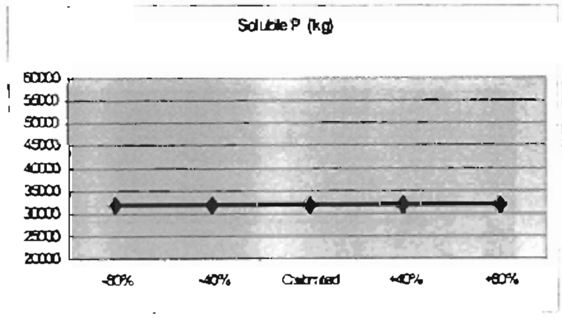

Organic N (kg)

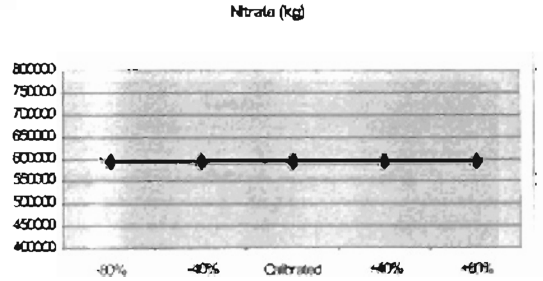
Revap mn

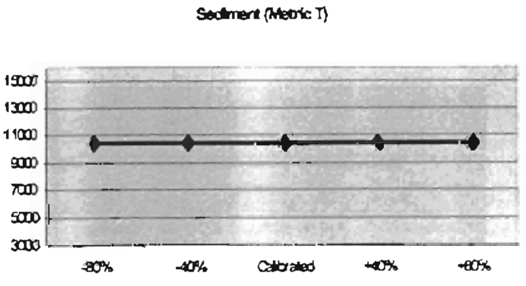
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-80%	6.789	10420	4046	713.1	593600	31920
-40%	6.789	10420	4046	713.1	593600	31920
Calibrated	6.819	10440	4045	713	593500	31920
+40%	6.848	10460	4045	713	593600	31920
+80%	6.855	10460	4045	713	593500	31920
Relative Sensitivity	0.00606	0.00240	-0.00015	-0.00009	0.00000	0.00000

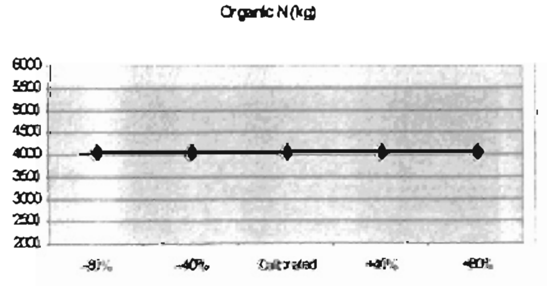

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)

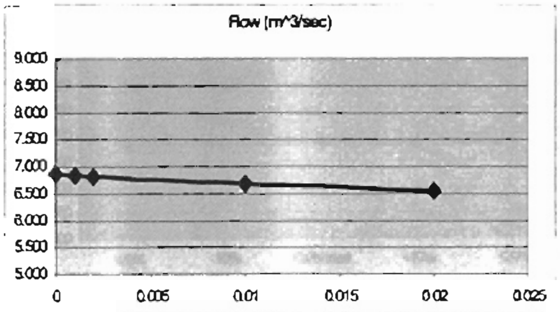

Nitrate (kg)

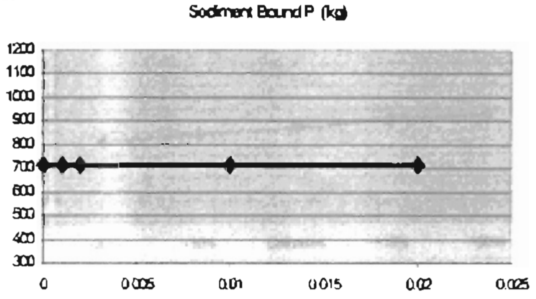

Sediment (Metric T)

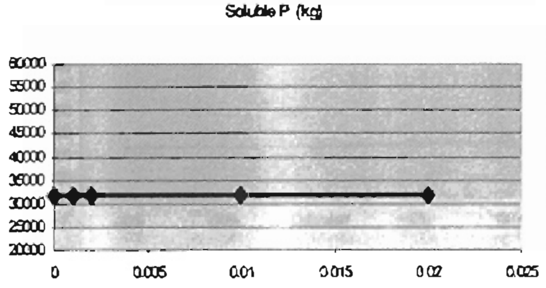

Organic N (kg)

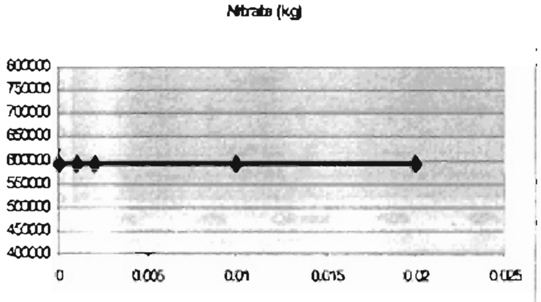
Revap

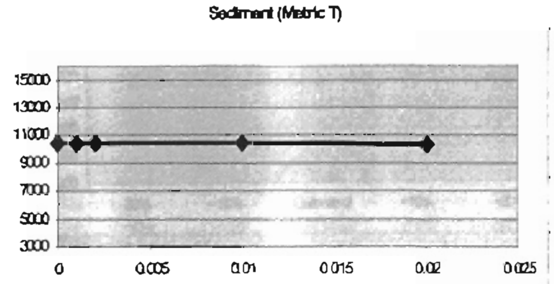
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
0	6.855	10460	4045	713	593600	31920
0.001	6.838	10450	4045	713	593600	31920
0.002	6.819	10440	4045	713	593600	31920
0.01	6.691	10380	4047	713.4	593500	31920
0.02	6.547	10290	4050	713.8	593500	31920
Relative Sensitivity	-0.01899	-0.00690	0.00062	0.00046	0.00000	0.00000

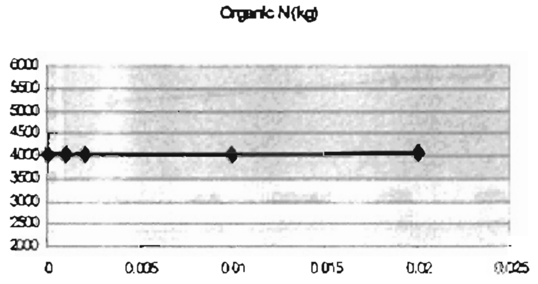






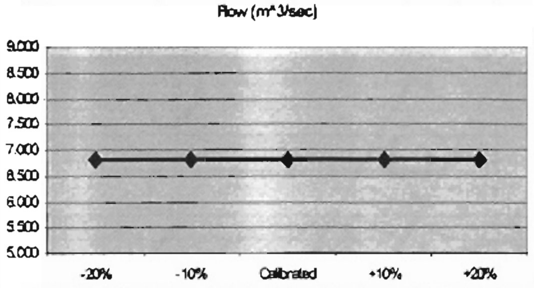


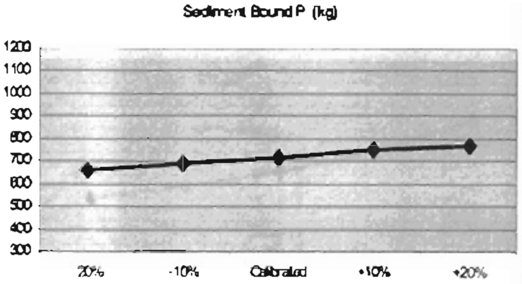


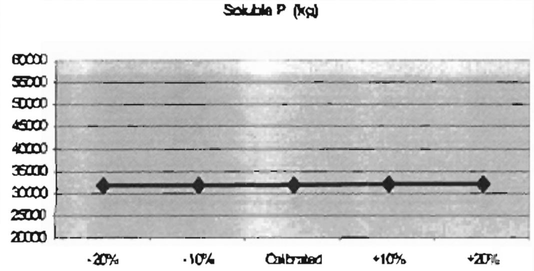


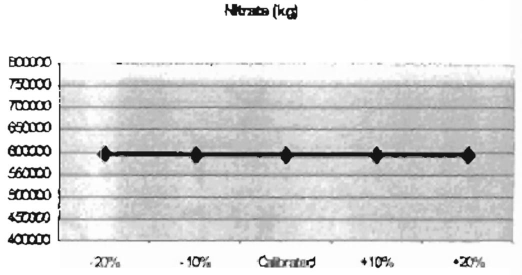
Slope length

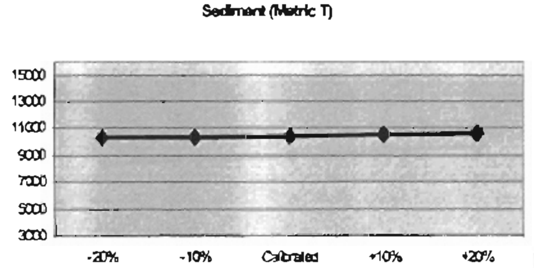
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-20%	6.819	10280	3774	659.3	593900	31820
-10%	6.819	10360	3906	686.7	593700	31870
Calibrated	6.819	10440	4045	713	593500	31920
+10%	6.818	10540	4211	750.2	593100	31950
+20%	6.816	10610	4313	767.1	592700	31970
Relative Sensitivity	-0.00110	0.07931	0.33956	0.39640	-0.00506	0.01177

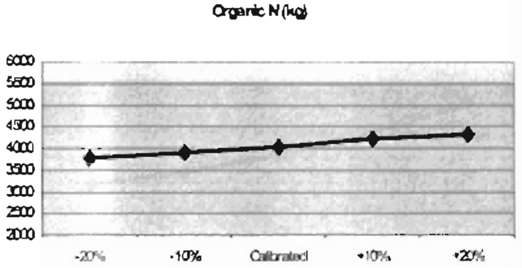






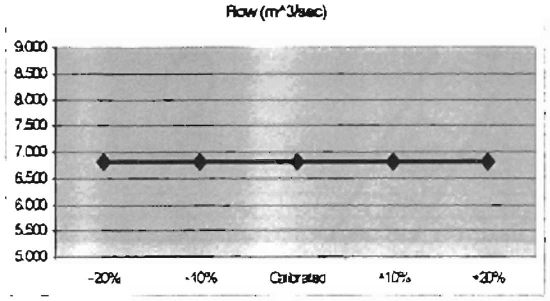


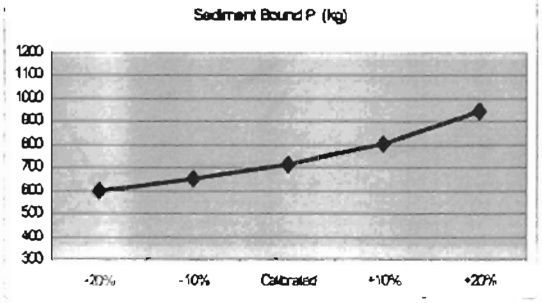


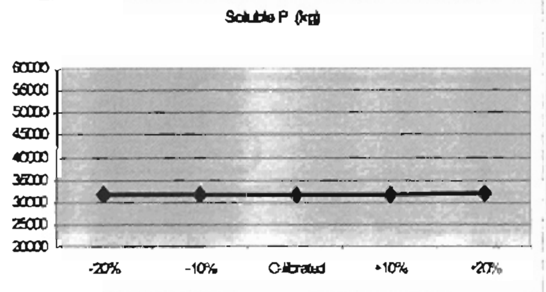


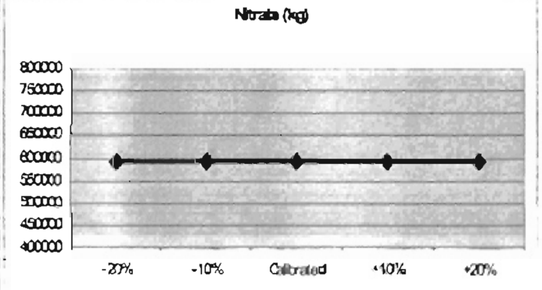
Slope

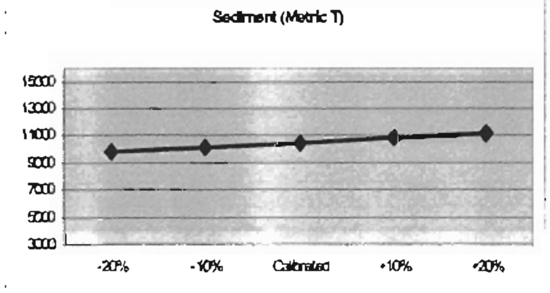
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-20%	6.817	9782	3448	596.5	592800	31880
-10%	6.818	10110	3733	651.2	593100	31900
Calibrated	6.819	10440	4045	713	593500	31920
+10%	6.819	10790	4494	806.6	593700	31930
+20%	6.819	11170	5091	945.5	593700	31950
Relative Sensitivity	0.00073	0.33729	1.02520	1.22979	0.00379	0.00548

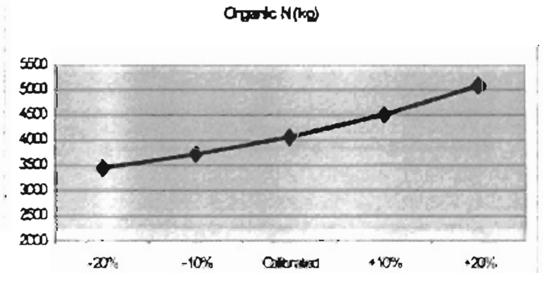

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)


Nitrate (kg)

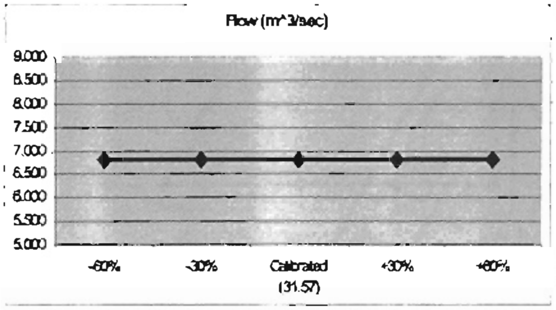

Sediment (Metric T)

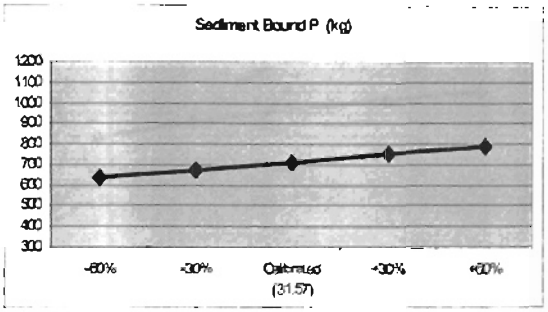

Organic N (kg)

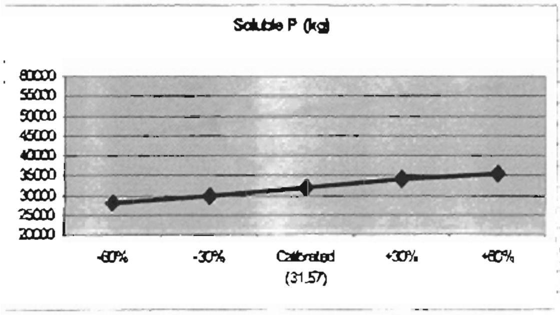
Soil Labile P (5 year warmup)

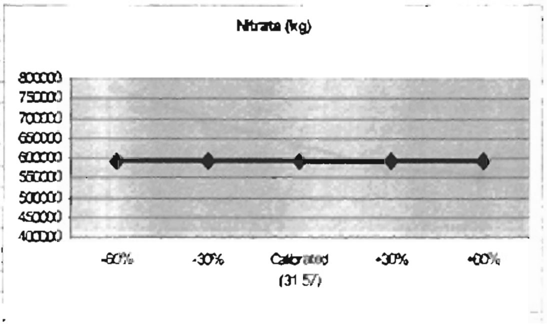
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-60%	6.819	10440	4004	635.3	593700	28030
-30%	6.819	10440	4026	674.2	593600	29960
Calibrated (31.57)	6.819	10440	4045	713	593500	31920
+30%	6.819	10440	4062	751.6	593400	33870
+60%	6.819	10440	4074	789.6	593300	35440
Relative Sensitivity	0.00000	0.00000	0.01441	0.17633	-0.00056	0.18974

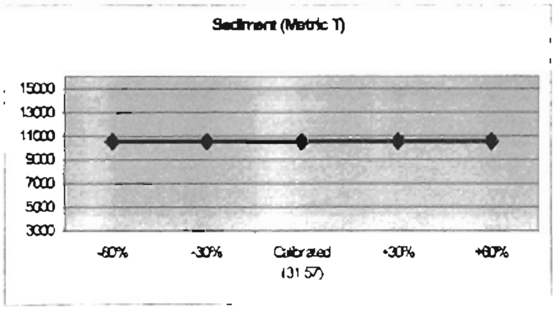
Calibrated soil labile P determined by area weighted average.

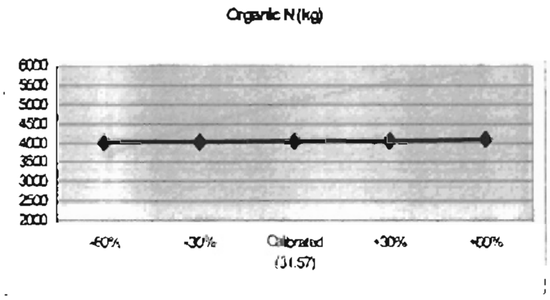

Flow (m^3/sec)


Sediment Bound P (kg)


Soluble P (kg)


Nitrate (kg)

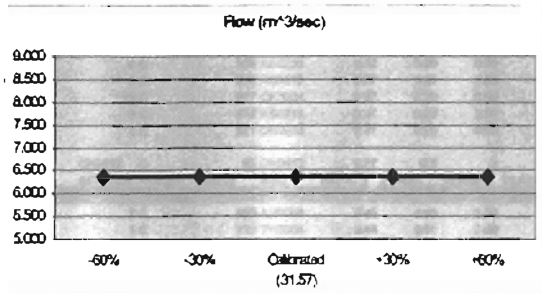

Sediment (Metric T)

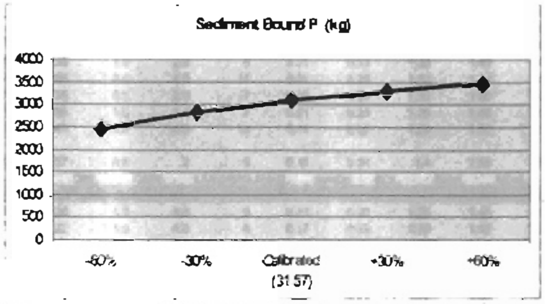

Organic N (kg)

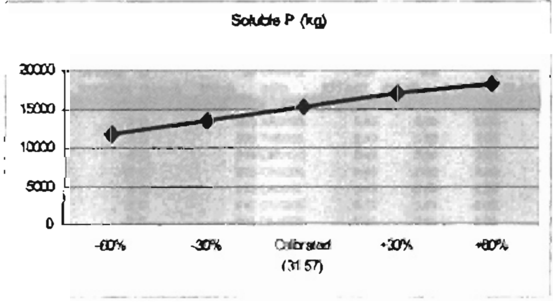
Soil Labile P (5 year warmup No Litter Applied)

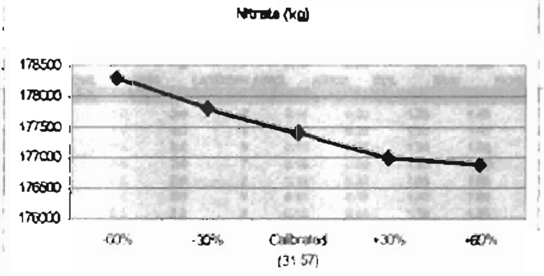
PRAM VALUE	Flow(m^3/sec)	SED(Metric T)	Organic N (kg)	Sed P (kg)	NO3 (kg)	SOL P (kg)
-60%	6.364	13390	13700	2479	178300	11750
-30%	6.364	13390	13790	2829	177800	13560
Calibrated (31.57)	6.364	13390	13860	3094	177400	15320
+30%	6.364	13390	13910	3317	177000	16980
+60%	6.364	13390	13960	3492	176900	18310
Relative Sensitivity	0.00000	0.00000	0.01503	0.27226	-0.00658	0.34897

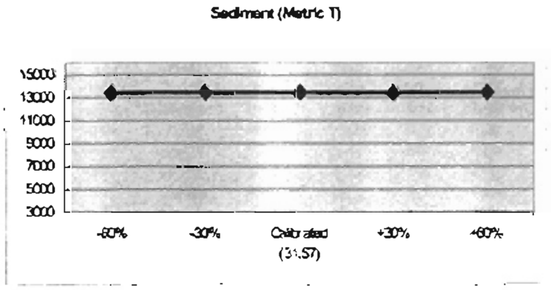
Calibrated soil labile P determined by area weighted average. DIFFERENT CHART RANGES

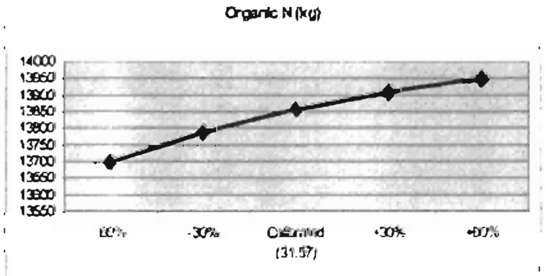












Appendix F Salt Fork Model

Table F1 Example result from the soils matching program. First record is the soil to be matched. Last ten records are candidate soils. Highlighted record is selected as the closest match. Many additional parameters are considered, selected parameters from layer 1 are shown in this example. Standard STATSGO parameter names applied.

151BsnB2	OK0059	C	85	OK0059	0.37	0.2	0.6	27	35	1	3	4	0.18	0.22	1.3	1.5	100
MUID	SEQNUM	Hydgrp	Match	SSID	KFFACT	PERML	PERMH	CLAYL	CLAYH	OML	OMH	LAYDEPH	AWCL	AWCH	BDL	BDH	NO4L
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	1.0	3.0	14	0.16	0.24	1.30	1.50	100
KS145	14	C	959	MO0020	0.37	0.20	0.80	27	32	1.0	3.0	6	0.18	0.20	1.35	1.50	100
KS418	15	C	940	TX0250	0.32	0.20	0.60	27	35	1.0	3.0	6	0.12	0.18	1.30	1.45	100
KS103	1	C	936	MO0001	0.37	0.20	0.80	28	35	1.0	4.0	11	0.18	0.20	1.35	1.45	100
KS104	13	C	932	KS0072	0.37	0.20	0.80	27	40	2.0	4.0	9	0.21	0.23	1.35	1.45	100
KS343	9	C	928	KS0200	0.32	0.20	0.60	27	35	1.0	3.0	6	0.21	0.23	1.30	1.40	100
KS316	5	C	918	KS0012	0.37	0.20	0.60	27	35	2.0	4.0	14	0.21	0.23	1.30	1.40	100
OK196	15	C	917	OK0204	0.37	0.20	0.60	27	35	0.5	2.0	7	0.15	0.20	1.30	1.60	85
KS304	8	C	912	KS0213	0.37	0.20	2.00	27	38	1.0	3.0	7	0.23	0.23	1.35	1.45	100
KS160	1	C	911	OK0015	0.37	0.20	0.80	27	45	1.0	4.0	13	[illegible]	0.20	1.25	1.50	90

151BuB	OK0412	C	95	OK0412	0.37	0.6	2	16	27	0.5	2	6	0.15	0.24	1.4	1.65	98
MUID	SEQNUM	Hydgrp	Match	SSID	KFFACT	PERML	PERMH	CLAYL	CLAYH	OML	OMH	LAYDEPH	AWCL	AWCH	BDL	BDH	NO4L
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.37	0.60	2.00	12	27	0.5	1.0	8	0.22	0.24	[illegible]	[illegible]	[illegible]
KS207	7	C	920	AR0093	0.43	0.60	2.00	8	20	1.0	3.0	9	0.14	0.20	1.25	1.46	95
OK187	1	C	919	TN0056	0.43	0.60	2.00	12	22	1.0	4.0	8	0.17	0.27	1.30	1.40	100
OK203	8	C	914	LA0014	0.49	0.60	2.00	8	18	0.5	2.0	2	0.15	0.22	1.35	1.66	100
OK197	17	C	910	OK0204	0.43	0.60	2.00	16	28	0.5	2.0	7	0.16	0.24	1.30	1.66	85
OK196	8	C	910	OK0133	0.43	0.60	2.00	15	28	0.5	2.0	9	0.13	0.22	1.30	1.60	86
OK194	5	C	907	OK0208	0.43	0.60	2.00	15	28	0.5	2.0	9	0.10	0.16	1.30	1.60	85
OK192	7	C	904	OK0230	0.43	0.60	2.00	16	28	0.5	2.0	8	0.13	0.24	1.30	1.56	75
OK195	5	C	904	OK0227	0.43	0.60	2.00	10	20	0.5	2.0	7	0.13	0.20	1.30	1.60	85
OK164	7	C	901	TX0265	0.49	0.60	2.00	5	18	0.5	1.0	10	0.12	0.16	1.45	1.80	100

151BuC	OK0412	C	88	OK0412	0.37	0.6	2	16	27	0.5	2	7	0.15	0.24	1.4	1.56	98
MUID	SEQNUM	Hydgrp	Match	SSID	KFFACT	PERML	PERMH	CLAYL	CLAYH	OML	OMH	LAYDEPH	AWCL	AWCH	BDL	BDH	NO4L
KS201	12	C	925	KS0050	0.37	0.60	2.00	12	27	0.5	1.0	8	0.22	0.24	1.25	1.35	100
KS207	7	C	923	AR0093	0.43	0.60	2.00	8	20	1.0	3.0	9	0.14	0.20	1.26	1.46	95
OK187	1	C	920	TN0056	0.43	0.60	2.00	12	22	1.0	4.0	8	0.17	0.27	1.30	1.40	100
OK196	8	C	914	OK0133	0.43	0.60	2.00	15	28	0.5	2.0	9	0.13	0.22	1.30	1.60	86
OK197	17	C	913	OK0204	0.43	0.60	2.00	16	28	0.5	2.0	7	0.15	0.24	1.30	1.66	85
OK203	8	C	912	LA0014	0.49	0.60	2.00	8	18	0.5	2.0	2	0.15	0.22	1.36	1.66	100
OK194	5	C	910	OK0208	0.43	0.60	2.00	15	28	0.5	2.0	9	0.10	0.16	1.30	1.60	86
OK192	7	C	904	OK0230	0.43	0.60	2.00	15	[illegible]	0.5	2.0	8	0.13	0.24	1.30	1.55	76
OK195	1	C	904	OK0279	0.43	0.60	2.00	15	[illegible]	0.5	2.0	9	0.10	0.16	1.30	1.60	[illegible]
OK195	5	C	903	OK0227	0.43	0.60	2.00	10	20	0.5	2.0	7	0.13	0.20	1.30	1.60	85

Table F2 Calibrated model output by subbasin for the Salt Fork Basin.

Subbasin	AREAkm2	SURQmm	WYLDmm	ETmm	SYLDt/ha	ORGNkg/ha	SEDPkg/ha	NSURQkg/ha	SOLPkg/ha	GW_Qmm
1	40.27	47.0	76.4	625	1.71	3.69	0.88	2.51	0.13	29.1
2	28.93	53.5	94.6	606	1.78	3.33	0.78	3.06	0.13	40.7
3	27.74	11.2	19.4	608	0.49	0.23	0.08	0.40	0.03	7.4
4	33.61	8.8	9.9	617	1.02	1.77	0.50	0.41	0.02	1.2
5	9.88	15.6	58.2	569	0.16	0.00	0.00	0.27	0.04	38.6
6	28.55	7.8	51.2	577	0.26	0.09	0.03	0.13	0.02	37.3
7	39.39	20.2	33.3	692	1.73	4.17	1.05	0.93	0.05	12.2
8	28.50	13.9	34.8	592	1.27	3.18	0.78	0.47	0.04	17.0
9	3.46	29.0	66.9	560	1.32	0.00	0.00	1.00	0.07	31.3
10	17.47	23.1	84.2	543	0.79	3.25	0.69	0.63	0.03	50.5
11	38.99	32.0	70.6	631	1.32	2.98	0.73	1.04	0.10	36.6
12	24.62	47.2	82.9	618	3.09	7.07	1.76	2.71	0.14	34.2
13	0.12	29.8	175.8	526	0.23	0.00	0.00	0.81	0.06	139.0
14	21.31	41.0	75.0	626	2.65	4.69	1.08	2.18	0.12	32.8
15	35.62	21.1	60.4	566	0.78	3.04	0.63	0.72	0.02	38.3
16	88.65	23.2	57.4	562	0.96	4.35	1.04	0.72	0.04	31.8
17	52.47	6.8	7.9	619	0.62	1.65	0.46	0.32	0.02	1.0
18	73.22	6.3	7.5	620	0.63	1.78	0.47	0.29	0.02	0.9
19	64.38	21.3	35.5	590	1.62	4.66	1.19	0.94	0.05	13.0
20	17.68	33.3	66.0	536	1.34	4.25	1.13	0.65	0.06	49.3
21	93.23	43.3	74.3	627	2.51	6.76	1.73	2.30	0.13	30.0
22	60.58	49.2	65.3	636	2.58	6.67	1.60	2.79	0.15	15.8
23	64.73	57.1	80.9	620	2.68	6.37	1.63	3.66	0.16	23.5
24	34.58	40.0	87.2	667	1.13	4.86	1.23	1.25	0.14	44.3
25	10.75	29.0	73.2	554	0.85	2.76	0.88	0.57	0.07	36.8
26	48.02	24.5	76.1	585	0.42	2.01	0.46	1.14	0.04	44.5
27	24.02	46.1	89.8	664	2.82	5.82	1.34	1.75	0.16	42.0
28	16.24	36.9	88.5	656	0.65	4.70	1.24	0.79	0.13	45.7
29	49.25	41.4	90.2	684	1.55	5.85	1.42	1.31	0.14	45.7
30	22.40	41.5	98.7	656	1.20	5.33	1.35	1.21	0.14	50.1
31	63.78	42.9	81.6	620	2.31	6.78	2.48	1.31	0.13	33.6
32	42.31	42.6	101.7	576	1.09	4.56	1.32	1.54	0.12	54.0
33	26.87	33.1	67.7	634	1.27	5.53	1.63	1.31	0.11	29.1
34	5.15	46.3	52.3	629	2.17	4.94	2.67	1.87	0.17	6.6
35	37.10	51.8	82.8	618	5.15	10.27	2.21	3.18	0.15	29.6
36	11.37	39.9	53.1	627	1.37	5.02	1.54	2.05	0.15	12.6
37	2.17	55.5	161.3	591	0.60	0.00	0.00	2.49	0.21	98.4
38	6.82	44.3	55.5	625	1.36	4.93	1.84	2.12	0.16	10.7
39	14.60	44.4	66.0	668	2.46	5.29	1.71	1.86	0.15	36.8
40	23.04	38.2	90.9	663	0.87	4.58	1.19	0.95	0.14	46.1
41	31.01	49.7	87.2	667	1.76	6.48	1.99	1.80	0.16	33.6
42	63.47	58.3	80.4	674	3.15	9.43	2.91	2.31	0.23	20.5
43	49.72	27.0	78.5	602	1.14	4.60	1.89	0.98	0.09	42.4
44	20.22	30.1	70.8	610	1.27	5.03	2.06	1.30	0.11	33.2
45	48.92	52.4	74.5	680	2.23	7.48	2.81	1.95	0.20	20.3
46	8.48	68.2	89.8	684	4.58	6.18	2.33	2.83	0.25	19.9
47	14.51	61.4	89.1	664	2.48	5.58	1.41	2.58	0.20	26.9
48	28.60	66.0	75.9	678	3.82	8.56	4.05	2.35	0.26	9.5
49	44.20	47.2	61.2	674	1.09	5.66	1.94	1.44	0.18	30.1
50	24.26	60.7	84.7	669	2.98	6.36	2.48	2.46	0.21	23.4
51	39.09	32.1	69.1	612	1.20	5.28	1.99	1.46	0.12	30.9
52	55.38	62.2	98.2	656	3.33	7.08	3.66	2.12	0.24	30.2
53	38.29	54.3	64.1	690	2.58	5.67	3.06	1.89	0.22	9.4
54	32.10	39.8	72.5	682	1.37	4.28	1.46	1.43	0.14	31.1
55	53.79	50.7	84.9	669	4.10	7.10	2.67	1.68	0.16	32.3
56	38.97	45.3	88.8	665	2.68	4.61	1.44	1.52	0.14	41.3
57	58.41	32.0	49.9	705	1.60	4.23	1.01	1.28	0.10	15.3
58	25.08	44.6	70.5	681	1.18	2.03	0.50	2.16	0.11	25.1
59	28.26	60.1	126.6	627	1.94	1.64	0.48	2.64	0.16	64.6
60	9.06	40.4	128.0	628	2.36	0.87	0.20	1.71	0.12	60.3
61	39.08	32.7	58.3	716	1.39	2.23	0.62	1.28	0.09	24.1
62	72.11	30.6	47.7	726	1.87	5.54	1.28	1.04	0.10	14.3
63	40.35	64.4	91.0	663	3.03	6.79	3.72	2.21	0.25	23.0
64	25.91	68.2	78.2	676	2.99	5.99	3.33	2.37	0.25	9.7
65	11.04	27.8	141.7	612	1.04	0.38	0.09	1.16	0.08	109.4
66	28.57	45.3	64.2	690	3.22	5.27	3.42	1.41	0.17	17.6
67	76.58	30.8	59.4	714	1.96	5.06	1.32	1.10	0.10	26.3
68	61.77	30.2	45.1	726	1.53	3.34	0.99	1.19	0.09	13.6
69	442.12	30.3	57.4	596	2.60	5.75	1.18	1.52	0.11	23.1
70	43.93	16.1	27.7	653	0.55	3.12	1.03	0.70	0.06	8.1

Table F2 Calibrated model output by subbasin (continued).

Subbasin	AREAkm2	SURQmm	WYLDmm	ETmm	SYLDt/ha	ORGNkg/ha	SEDPkg/ha	NSURQkg/ha	SOLPkg/ha	GW_Qmm
71	25.53	43.6	65.8	707	1.16	0.93	0.30	1.74	0.12	21.4
72	20.03	39.4	58.9	714	1.42	1.09	0.34	1.65	0.11	18.7
73	48.39	17.8	51.8	549	0.18	0.46	0.11	0.75	0.06	30.9
74	45.13	12.1	27.3	554	0.08	0.28	0.07	0.60	0.04	13.6
75	23.87	55.3	112.8	641	4.42	7.42	1.90	2.32	0.16	56.2
76	29.27	31.8	77.3	677	2.23	5.51	1.40	1.52	0.11	40.8
77	0.78	24.7	144.4	608	0.04	0.00	0.00	0.48	0.09	118.5
78	44.13	51.7	76.0	678	5.40	7.91	2.05	1.83	0.19	22.8
79	45.01	31.3	56.8	717	1.44	2.83	0.80	1.13	0.09	23.7
80	42.98	44.1	58.3	716	0.74	0.57	0.17	1.53	0.14	11.7
81	58.67	29.5	68.6	612	0.60	3.06	0.91	0.80	0.09	32.0
82	23.00	37.3	50.8	630	1.17	5.08	1.62	1.15	0.12	11.8
83	72.30	5.8	36.2	603	0.15	0.17	0.04	0.31	0.01	22.5
84	7.21	4.0	14.1	667	0.02	0.00	0.00	0.12	0.02	10.0
85	21.08	58.9	111.5	640	4.74	8.63	1.99	2.20	0.15	53.2
86	28.89	49.8	95.4	658	5.10	8.48	2.83	1.43	0.14	42.6
87	40.29	42.3	59.3	715	0.94	1.29	0.42	1.43	0.13	16.3
88	37.14	28.8	54.5	719	0.37	0.12	0.04	1.00	0.08	25.3
89	35.72	28.8	35.0	720	2.49	5.95	1.79	0.97	0.09	7.5
90	59.85	25.9	44.1	711	0.88	3.91	1.03	0.78	0.10	11.7
91	38.22	22.0	54.2	632	0.57	3.32	1.01	1.18	0.08	21.2
92	67.17	26.4	60.1	626	0.86	4.38	1.31	1.33	0.09	26.3
93	12.63	17.8	63.2	618	0.58	2.51	0.80	0.41	0.08	38.2
94	2.18	10.7	60.5	621	0.15	0.00	0.00	0.25	0.04	42.5
95	23.33	35.2	65.7	615	1.12	5.18	1.60	1.02	0.11	23.6
96	1.09	1.6	86.3	615	0.01	0.00	0.00	0.03	0.01	56.7
97	52.71	29.2	68.7	614	0.34	1.84	0.54	0.80	0.09	34.1
98	38.45	33.7	51.7	628	0.92	3.87	1.21	1.08	0.11	16.2
99	23.92	20.0	41.7	639	0.46	1.70	0.53	0.58	0.06	19.6
100	104.52	38.9	60.1	620	1.44	6.53	1.98	1.21	0.12	17.7
101	37.47	14.3	22.2	554	0.71	0.69	0.19	1.27	0.03	7.0
102	62.09	26.6	41.2	588	1.32	2.73	0.69	2.75	0.06	14.4
103	41.60	45.7	62.2	617	1.36	4.50	1.38	1.65	0.14	14.5
104	54.61	45.7	64.0	615	1.33	3.92	1.18	1.68	0.14	17.2
105	25.59	27.1	80.5	620	1.20	5.04	1.52	0.90	0.09	29.4
106	56.32	39.3	52.9	628	1.21	4.41	1.46	1.90	0.12	12.5
107	40.45	20.8	58.7	624	0.28	1.02	0.30	0.65	0.07	31.8
108	14.80	28.7	44.3	637	0.67	2.60	0.82	1.00	0.09	13.8
109	0.00	2.8	105.8	576	0.01	0.00	0.00	0.06	0.01	98.8
110	42.08	17.7	22.0	552	0.87	1.96	0.50	1.13	0.05	3.7
111	54.75	31.9	46.3	633	1.78	5.45	1.66	1.19	0.10	12.6
112	43.73	15.2	24.4	654	1.10	3.57	0.92	0.57	0.05	8.7
113	4.82	4.6	75.3	612	0.11	0.00	0.00	0.12	0.01	62.6
114	43.58	28.3	39.5	647	0.93	3.75	1.24	1.58	0.09	8.9
115	22.80	30.3	48.7	637	1.08	4.69	1.47	1.02	0.10	17.0
116	34.75	28.9	47.1	638	1.33	5.33	1.63	0.84	0.09	16.2
117	39.08	13.6	82.3	713	0.13	0.00	0.00	0.34	0.03	61.5
118	26.44	32.1	54.2	741	0.57	0.23	0.08	0.83	0.11	21.4
119	33.45	48.3	62.6	623	1.69	5.44	1.74	2.63	0.14	13.4
120	18.00	21.0	31.9	654	0.55	2.91	0.94	1.17	0.08	10.4
121	13.38	20.8	88.4	727	0.52	0.17	0.04	0.57	0.08	45.5
122	39.51	31.8	64.4	730	1.07	2.75	0.77	1.40	0.10	31.3
123	39.61	16.3	37.1	649	0.25	1.47	0.46	1.02	0.07	14.8
124	54.66	38.4	47.5	639	1.37	4.72	1.84	2.18	0.12	7.8
125	55.78	21.8	33.9	737	1.59	4.38	1.06	0.88	0.05	11.7
126	8.62	27.3	84.0	876	1.39	0.69	0.13	1.18	0.07	53.2
127	2.20	19.1	97.5	876	0.23	0.00	0.00	0.49	0.04	78.1
128	38.40	16.0	24.9	744	0.85	2.22	0.53	0.70	0.04	8.8
129	168.74	37.0	75.3	611	1.37	3.87	1.44	0.94	0.08	19.6
130	0.87	16.2	91.0	595	0.04	0.00	0.00	0.37	0.05	69.7
131	75.25	34.9	46.1	639	1.07	3.95	1.31	1.99	0.11	9.5
132	13.75	29.3	34.1	652	0.89	4.20	1.39	1.00	0.11	4.5
133	21.62	24.2	118.3	677	0.20	0.00	0.00	0.78	0.05	91.0
134	53.18	31.3	73.2	721	0.95	2.35	0.64	1.41	0.09	39.4
135	45.60	28.3	48.2	710	3.38	6.17	1.44	1.29	0.08	19.1
136	32.89	19.8	33.1	724	1.93	4.23	0.87	1.10	0.05	13.0
137	90.73	12.7	22.1	862	1.26	3.47	0.90	0.68	0.04	8.5
138	61.80	28.8	46.9	712	2.93	5.64	1.29	1.22	0.07	19.0
139	9.52	21.7	47.9	636	2.24	2.58	0.79	1.12	0.06	23.0
140	31.21	21.2	40.0	645	1.74	4.07	0.98	0.99	0.06	16.3

Table F2 Calibrated model output by subbasin (continued).

Subbasin	AREAkm2	SURQmm	WYLDmm	ETmm	SYLDt/ha	ORGNkg/ha	SEDPkg/ha	NSURQkg/ha	SOLPkg/ha	GW_Qmm
141	116.98	24.5	89.5	684	0.30	0.40	0.14	0.79	0.07	59.6
142	151.52	20.4	32.2	738	1.36	4.15	1.06	0.77	0.05	11.6
143	34.56	51.2	83.8	778	2.54	7.46	1.95	1.45	0.16	32.5
144	47.43	12.6	24.9	731	0.47	1.24	0.31	0.81	0.03	12.3
145	30.46	18.7	34.5	721	0.67	1.68	0.43	1.14	0.05	15.7
146	122.41	18.7	30.1	723	2.42	6.50	1.45	0.64	0.05	10.7
147	32.78	50.5	107.2	653	3.26	5.18	1.46	1.99	0.15	52.3
148	51.34	35.9	68.1	619	1.39	4.02	1.41	1.29	0.10	13.5
149	22.10	44.2	70.0	615	1.56	3.88	1.21	1.67	0.12	8.1
150	36.88	49.4	62.8	698	5.03	7.43	3.21	2.23	0.19	12.6
151	81.98	19.9	38.3	720	1.58	4.01	0.91	1.13	0.05	16.2
152	35.43	51.8	102.0	657	2.07	2.52	0.83	2.43	0.12	49.5
153	1.35	21.9	37.1	722	1.22	0.00	0.00	1.11	0.05	14.7
154	9.69	23.0	41.4	716	1.31	1.37	0.34	1.44	0.06	18.2
155	33.89	52.9	98.1	764	1.08	1.48	0.38	1.63	0.18	44.3
156	78.60	21.9	149.9	691	0.24	0.30	0.09	0.33	0.07	118.4
157	17.18	49.6	82.4	780	2.80	4.93	1.26	1.24	0.16	32.6
158	40.31	66.9	112.2	751	3.99	10.15	2.54	2.08	0.19	45.1
159	59.35	28.5	51.2	706	1.57	3.45	0.98	0.84	0.11	19.2
160	57.62	54.7	62.7	697	7.58	8.58	2.61	2.94	0.21	7.6
161	73.02	59.2	100.1	762	2.09	5.36	1.40	1.43	0.20	40.0
162	75.97	44.7	73.9	788	1.30	3.85	1.03	1.14	0.15	29.2
163	33.93	53.0	93.2	769	1.20	2.73	0.77	1.42	0.19	39.9
164	4.22	87.1	173.9	690	0.70	0.00	0.00	3.72	0.27	82.6
165	33.13	61.4	111.7	751	0.59	0.46	0.12	1.44	0.26	49.8
166	44.18	62.5	100.3	762	1.22	1.79	0.45	1.72	0.24	37.1
167	28.35	53.4	99.7	762	1.28	1.44	0.41	1.44	0.20	46.0
168	2.11	67.7	156.6	706	0.38	0.00	0.00	2.13	0.22	87.9
169	30.52	20.7	40.1	716	0.59	1.38	0.35	1.34	0.06	19.2
170	11.73	26.3	66.3	693	1.23	1.01	0.22	1.10	0.08	37.3
171	11.46	34.2	69.2	691	1.37	0.19	0.05	1.49	0.09	33.3
172	29.17	22.7	45.5	749	1.42	4.11	1.14	1.30	0.06	21.6
173	22.38	32.5	60.7	697	0.80	1.03	0.29	1.65	0.08	27.5
174	38.55	27.8	47.9	711	1.68	2.91	0.73	1.02	0.08	18.9
175	70.90	53.4	110.1	752	1.89	4.68	1.35	1.38	0.22	55.5
176	20.43	57.1	84.8	777	2.52	4.97	1.41	1.87	0.19	27.8
177	42.36	22.2	132.3	708	0.27	0.07	0.02	0.28	0.07	102.7
178	21.38	19.8	147.7	693	0.24	0.00	0.00	0.23	0.07	110.2
179	105.03	36.4	45.2	714	6.86	9.04	2.78	1.89	0.14	8.2
180	25.08	47.5	118.7	642	1.73	1.17	0.32	1.93	0.13	67.7
181	41.01	49.3	81.0	782	3.66	10.09	2.39	1.47	0.16	31.5
182	74.93	58.2	90.6	772	4.12	11.63	2.73	1.71	0.21	32.0
183	4.58	32.8	143.4	687	0.07	0.00	0.00	0.45	0.11	76.8
184	0.08	0.0	143.4	697	0.00	0.00	0.00	0.00	0.00	0.0
185	15.83	27.1	135.4	705	0.07	0.00	0.00	0.52	0.12	27.1
186	30.31	58.0	109.8	728	0.02	0.00	0.00	1.05	0.31	3.3
187	85.99	74.0	99.5	762	1.55	4.09	1.18	2.20	0.29	25.4
188	9.15	88.0	136.1	726	0.48	0.00	0.00	2.64	0.35	33.7
189	0.32	29.6	125.8	728	0.00	0.00	0.00	0.52	0.17	0.0
190	42.03	40.1	151.3	689	0.28	0.03	0.02	0.92	0.15	55.5
191	29.28	57.3	96.4	766	2.14	4.96	1.46	1.87	0.19	39.1
192	37.10	84.8	152.4	712	3.12	7.06	2.01	3.65	0.26	66.4
193	50.07	47.8	83.8	729	0.99	2.25	0.64	1.78	0.16	29.4
194	70.42	51.9	98.8	713	1.43	3.74	1.15	2.28	0.17	44.3
195	31.66	32.8	53.5	742	1.79	3.93	1.21	1.92	0.11	20.2
196	73.96	68.4	99.7	713	3.10	6.43	2.18	2.58	0.23	30.3
197	22.32	48.1	78.0	733	1.96	3.57	1.06	1.92	0.15	29.2
198	8.29	38.9	65.5	743	1.44	2.59	0.72	1.91	0.12	26.2
199	27.42	65.4	89.5	724	2.79	6.44	1.99	2.46	0.23	23.0
200	22.52	43.1	69.5	743	2.82	7.30	1.86	1.90	0.15	24.7
201	16.51	17.7	34.6	652	0.18	1.32	0.36	0.54	0.06	14.3
202	12.92	49.7	137.0	725	1.70	1.10	0.26	1.28	0.17	85.5
203	41.40	76.8	103.6	758	0.04	0.00	0.00	1.38	0.41	22.2
204	49.02	34.6	114.2	727	0.08	0.01	0.01	0.55	0.16	88.8
205	0.08	58.0	108.3	731	0.00	0.00	0.00	1.00	0.31	0.0
206	0.12	38.8	333.8	506	0.00	0.00	0.00	0.44	0.12	245.9
207	91.48	51.6	121.6	630	2.89	7.54	1.81	2.39	0.14	68.6
208	0.07	28.0	190.1	571	0.41	0.00	0.00	0.50	0.08	135.1
209	15.41	46.9	75.9	684	1.53	2.01	0.68	0.71	0.11	26.9
210	1.99	34.6	132.0	709	0.71	0.00	0.00	0.39	0.07	63.8

Appendix G Salt Fork SAS Programs

SAS program written to analyze fertilizer timing model simulations.

```
*FILENAME timing.SAS;
DATA ONE;
INFILE 'A:TIMING.TXT';
INPUT year TRT$ SURQ GWQ ET SYLD SEDP NSURQ SOLP NO3L Orgn LATN;
*PROC PRINT;
PROC MIXED;
CLASS YEAR TRT;
MODEL SURQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL GWQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL ET = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL SYLD = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL SEDP = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL NSURQ = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL SOLP = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL NO3L = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL Orgn = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;
PROC MIXED;
CLASS YEAR TRT;
MODEL LATN = TRT/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TRT/DIFF;

RUN;
```

Appendix G Salt Fork SAS Programs

SAS program written to analyze tillage/harvest type model simulations.

```
*FILENAME STATS.SAS;
DATA ONE;
INFILE 'A:STATS.PRN';
INPUT year Tillage$ grazing$ PRCP SURQ GWQ ET SYLD SEDP NSURQ SOLP NO3L Orgn LATN;
*PROC PRINT;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL PRCP = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SURQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL GWQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL ET = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SYLD = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL NSURQ = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL SOLP = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL NO3L = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL Orgn = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
PROC MIXED;
CLASS YEAR TILLAGE GRAZING;
MODEL LATN = TILLAGE|GRAZING/DDFM=SATTERTH;
RANDOM YEAR;
LSMEANS TILLAGE*GRAZING/SLICE=(TILLAGE GRAZING) DIFF;
LSMEANS TILLAGE GRAZING/DIFF;
RUN;
```

Appendix H Salt Fork Hot Spots

Table H1 High sediment yielding soil and land cover combinations. Soils classified by STATSGO (State Soil Geographic) database MUID (Map Unit IDentification) and sequence.

Soil	Land cover
KS201_12	WWT
KS506_8	WWT
OK072_1	WWT
OK088_3	WWT
OK108_6	WWT
TN042_6	WWT
TX265_1	WWT
TX268_2	WWT
TX273_3	WWT
TX432_9	WWT
TX524_8	WWT
TX524_8	WWT
KS245_2	SOYB
OK072_1	SOYB
OK088_3	SOYB
OK108_6	SOYB
OK213_14	SOYB
TX268_2	SOYB

VITA

Michael J. White

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Master of Science

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