ILLINOIS RIVER BASIN -- TREATMENT PRIORITIZATION
FINAL REPORT

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TABLE OF CONTENTS

INTRODUCTION

The purpose of this project is to provide assistance in the implementation of the Illinois River Watershed Implementation Program, which is part of Oklahoma's Section 319 Management Program. This project is one component of a comprehensive program that addresses the wide range of pollution sources within the Illinois River Basin. The overall goal of the comprehensive program is to improve and protect the water quality in the Illinois River, which has been designated a Scenic River by the State of Oklahoma.

The Illinois River Basin is in northwest Arkansas and northeast Oklahoma. The Illinois River drains approximately 1.1 million acres, which includes Benton, Washington and Crawford Counties, Arkansas, and Delaware, Adair, Cherokee, and Sequoyah Counties, Oklahoma. The basin contains approximately 45 percent grassland, 44 percent forest, 2 percent cropland, 1 percent orchards and vineyards, 6 percent urban, and 2 percent other land uses (SCS, 1992).

The Oklahoma Conservation Commission stream monitoring program has shown significant variability in water quality in tributary streams, but cannot pinpoint sources, quantify their impact, or identify treatment options. Within watersheds there is a number of different land uses with varying water quality impact. The cost of changing the practices employed in these areas, and the water quality effectiveness of such changes are largely unknown at this time. This leaves the water quality management agency with complete flexibility and large uncertainty concerning the outcome from its implementation program. Bringing water quality and land-use information together will provide a rational process to keep implementation focused and account for water quality impact during implementation.

By concentrating treatment efforts in critical areas, a far greater improvement in water quality can be achieved with limited resources. This project presents a procedure using a simple loading model to prioritize fields within priority watersheds for phosphorus and sediment loading to streams. The procedure integrates land use and related data into a geographic information system. The loading model is validated and applied to two priority watersheds, Peacheater Creek and Battle Branch, located in the Oklahoma portion of the Illinois River Basin. This project is reported in three volumes describing the modeling system and framework, the application of the model, and detailed source code listings.

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Detailed field inventory data were obtained from the Oklahoma Cooperative Extension Service and the Oklahoma Conservation Commission. Validation data were obtained from the Agricultural Engineering Department at the University of Arkansas (Dwayne Edwards) and from the Biological and Agricultural Engineering Department at Louisiana State University (Richard L. Bengtson). Additional validation data for the research watershed used in this study were obtained from the Biological Systems Engineering Department (Saied Mostaghimi) and the Information Support Systems Laboratory (V.O. Shanholtz) at Virginia Tech, Blacksburg, Virginia as funded by the Department of Conservation and Recreation, Division of Soil and Water Conservation, Richmond, Virginia.

VOLUME 1: SIMPLE -Documentation

Chapter 1. SIMPLE -Overview

CHAPTER 1. SIMPLE -OVERVIEW

SIMPLE (Spatially Integrated Models for Phosphorus Loading and Erosion) is a distributed parameter modeling system developed to estimate watershed-level sediment and phosphorus loading to surface water bodies. The system encompasses a Phosphorous Transport Model, a Digital Terrain Model, a data base manager, and a menu driven user interface. To demonstrate its use, the SIMPLE modeling framework was applied to a 330 ha watershed. The predicted runoff volumes, sediment loss and phosphorus loadings were compared to measured values. The modeling framework, the testing procedures and results, and the model applicability are described in this manuscript.

A. INTRODUCTION

Surface runoff from agriculture, mining, oil and gas exploration, construction, silviculture, and other related activities contribute significant amounts of phosphorus and sediment to our surface waters. These nonpoint source pollutants have been shown to impair surface water quality. To identify potential nonpoint sources of pollution in a cost effective manner, computer models must be used that integrate state-of-the-art technologies, such as, geographic information systems (GIS) and remote sensing. These computer models can be used to target critical source areas of sediment and phosphorus for priority treatment. Given limited resources, the implementation of Best Management Practices (BMP's) in these critical source areas can minimize the potential for off-site water quality impacts.

Many factors affect sediment and phosphorus losses from nonpoint sources, such as soil properties, application of fertilizers or animal wastes, soil phosphorus levels, rainfall, soil properties, crop type, cover condition and density, topography, livestock activities, and others. To accurately and efficiently account for these physical, chemical, and biological factors at a watershed or basin scale, a computer model was developed called the Spatially Integrated Model for Phosphorus Loading and Erosion (SIMPLE).

SIMPLE is used to target and prioritize nonpoint sources of sediment and phosphorus and to evaluate the effects of BMP'S. The modeling system has a fully integrated data management tool, which efficiently manipulates large amounts of information. In addition, a GIS is used to visualize model results, and to develop data layers that are used by SIMPLE to estimate model parameters.

B. MODELING FRAMEWORK

SIMPLE is a modeling system consisting of a Phosphorous Transport Model (PTM), a Digital Terrain Model (DTM), and a database manager (Fig. 1). The system components communicate with each other via interface software, a standard SUN workstation X-view windows application. The interface significantly enhances the efficiency of command executions allowing the user to define the input and output parameters and to develop the required data bases.

The SIMPLE modeling system can be used in conjunction with the GRASS GIS (CERL, 1988). The format of the spatial data required by the system is the same as the format of ASCII files generated from GRASS raster data. However, SIMPLE does not require GRASS to run; it can be used independently, as long as the data files are formatted correctly. Spatial information generated by SIMPLE can be exported for display in GRASS.

SIMPLE provides two scales at which to simulate sediment and phosphorus loading: cell scale and field scale. A cell is the smallest element of a map in which the data are stored. A field is a group of adjacent cells with homogeneous soil and land use characteristics. The field-based option requires less simulation time because there are fewer fields than cells. However, considerable error may be produced if there are significant variations within a field.

Conducting SIMPLE simulations involves defining the simulation period, the simulation scale, and the type and level of outputs. If cell-scale simulations are to be conducted, the required topographic information and soil characteristics for each cell can be generated by the DTM and the soil data manager. Simulation results can be summarized in tables, and/or graphically displayed. SIMPLE provides in tabular form monthly and annual estimates of runoff volume, sediment yield, and soluble and sediment-bound phosphorus loading to streams. Such tables are generated field by field and for the entire watershed. The spatial distribution of runoff volume, sediment yield, and phosphorus loading estimated for the entire simulation period can also be displayed graphically.

The system components are briefly described below. Details on the system components and framework are presented in later chapters.

1. **Phosphorus Transport Model (PTM)**

The PTM is a physically based mathematical model developed to evaluate the potential phosphorus loading to streams from areas with homogeneous soil and management characteristics. The model operates on a daily time step. Independent simulations are based on factors such as rainfall, soil characteristics, fertilizer and animal waste applications, and topographic characteristics. The PTM is divided into four modules: runoff, soil erosion, phosphorus loss and delivery ratio.

1. Runoff Module: The runoff component is based on the SCS curve number method (SCS, 1985), where runoff volume is a function of rainfall volume and the curve number (CN) value. The CN value for a particular day is adjusted to reflect antecedent soil moisture conditions.

2. Sediment Loss Module: The Universal Soil Loss Equation (USLE) is used to estimate soil erosion caused by rainfall and runoff (Wishmeier and Smith, 1978). The USLE is a function of soil erodibility factor (K), cover and management factor (C), supporting conservation practice factor (P), slope length factor (L), slope steepness factor (S), and the rainfall/runoff factor (R). The K, P and C values are inputs, and L and S are calculated from the land slope (θ) and the

slope length (λ) (McCool et al., 1989, McCool et al., 1987). The slope (θ) is computed by the DTM model described below. The slope length, λ, is a user specified input. To calculate the R factor for the USLE, the equation described by Cooley (1980) is adopted. This equation provides an estimate of the R factor for each storm.

3. Phosphorus Module: This module estimates daily phosphorus status associated with the application of commercial fertilizer and animal manure. The processes considered in the module include solubilization of phosphorus in runoff, binding of phosphorus with sediment, and phosphorus mineralization. A daily mass balance is conducted on the top one cm of the soil profile. The phosphorus content in the soil is updated by adding phosphorus contained in the applied fertilizer or animal waste and subtracting phosphorus leaving the field in runoff and sediment. The model provides two options for the adsorption-desorption of phosphorus in the soil matrix and the concentration of phosphorus in surface runoff, the Langmuir isotherm (Novotny et al., 1978) and the linear isotherm (Williams et al., 1984).

4. Delivery Ratio Module: The amount of sediment and sediment-bound phosphorus leaving the field may be reduced along its route to the final receiving water body due primarily to deposition and trapping. Heatwole and Shanholtz (1991) developed a delivery ratio relationship to account for deposition and trapping. The delivery ratio is a function of the distance to the stream (D) and the slope along that distance (θ_D). The values of D and θ_D are computed by the DTM.

2. Digital Terrain Model (DTM)

The DTM provides estimates of the topographic parameters required to run the PTM. DTM uses digital elevation data (DEM) to estimate θ, D and θ_D. The DTM is divided into six components that contain procedures to: (1) detect and fill depressions, (2) define flow direction, (3) calculate flow accumulation values, (4) delineate channel networks, (5) define drainage boundaries, and (6) extract cell and drainage characteristics such as slope, and flow path length and slope.

1. Filling Depressions: The procedure used to generate a depressionless DEM is based on techniques developed by Jenson and Domingue (1988). The depressionless DEM is generated by filling single-cell depressions, identifying the cells constituting multi-cell depressions, and filling multi-cells depressions. Depressions are filled by raising their elevation values to the level of lowest neighbor elevation.

2. Flow Directions: The flow direction for a cell x is assigned on the basis of the steepest elevation gradient away from the cell. The gradient is taken as the change in elevations between cell x and the neighboring cell divided by the distance between the centers of the two cells. There are eight possible flow directions (Greenlee, 1987).

3. Flow Accumulations: The flow direction file is used to calculate the flow accumulation value for each cell. The flow accumulation value for cell x represents the total number of cells that have upstream flow paths passing through it. Cells located in lower elevations, such as channels, have high accumulation values.

4. Network Delineation: Channel networks are identified and enumerated based on the flow accumulation values and on a user defined threshold network density. Cells with flow accumulation values equal to or greater than the threshold value are identified as channel network cells. Once the channel network cells are defined, the channels are numbered; then they are divided at junction nodes into a series of branches (Storm, 1991). The initial junction for branch enumeration is found by following the maximum flow accumulation gradient. All first-order streams are enumerated sequentially, followed by the remaining stream orders. For hydraulic routing purposes, this ordering system allows the processing of all upstream branches prior to any downstream branch.

5. Watershed Delineation: This module identifies the watersheds in the study area and delineates their boundaries. Each watershed has one outlet or start cell, which is the channel outlet. A watershed is composed of all the cells with flow paths leading to this outlet. The start cell is identified and the flow directions are used to find the associated cells for each watershed. This collection of cells is given a watershed number. The watershed number of each cell is then compared with its neighbor cells to identify the watershed boundary cells.

6. Cell Characteristics: This component calculates θ, D and θ_D for each cell. Values of θ are estimated based on the neighborhood method (CERL, 1988). The neighborhood method considers the elevations of the eight neighboring cells and predicts the slope for the center cell. The D and θ_D estimates are based on the flow direction and network information previously described. To calculate D for a cell, the number of horizontal, vertical and diagonal flow directions between that cell and the first network cell to which it flows is calculated. A horizontal or vertical flow is then taken as the cell side length (ΔX), and a diagonal flow is $\Delta X * \sqrt{2}$. The θ_D is the difference in the start cell and the network cell elevations divided by D.

3. Database Manager

The database manager is a tool for developing the soil and land-use data bases. It is also used to generate the files that contain, for each cell, information on soil characteristics, such as percent clay content, percent organic carbon, CN, λ, K, soil available phosphorus content, and soil pH.

C. PROCEDURE

To demonstrate the use of SIMPLE and provide for watershed-level validation, we applied the modeling framework to a 330 ha portion (the QOD subwatershed) of the Owl Run watershed in Fauquier County, Virginia. The Owl Run watershed is part of a comprehensive nonpoint source monitoring program undertaken by the Department of Biological Systems Engineering at

Virginia Tech to quantify the impacts of animal waste BMPs on water quality. Precipitation, runoff, sediment, and nutrient loadings have been monitored continuously since 1986. In addition, spatial field boundary, soils, and land use data, as digitized by the Information Support Systems Laboratory at Virginia Tech, are available and were used in this study. A detailed description of the watershed, monitoring program, and procedures are presented in Mostaghimi et al. (1989).

The climate in that area is humid-continental type with an average of 105 cm annual rainfall. The soils in the watershed are generally shallow silt loams, with Penn, Buck and Montello Association being the major soil series. Land use in the subwatershed is mostly corn, hay, and pasture and there are two dairy operations within its boundaries. Data describing the spatial topography of the watershed was generated by digitizing USGS 1:24,000 topographic maps.

Runoff, erosion and phosphorus loadings were predicted for the period 1/l/86 to 6/30/87 by using a cell scale simulation. The watershed area was divided into 30 m x 30 m cells and gridded data for the site were generated from the digitized maps. Data describing soil characteristics and crop cover factors were obtained form the County Soil Survey for Fauquier County, Virginia, and from the Soil Conservation Service Agricultural Handbook 537 (SCS, 1978). Information describing crop practices and fertilizer applications were compiled from surveys answered by landowners.

D. RESULTS

The files describing cell soil characteristics were generated by the data base manager. The DTM was used to delineate the drainage networks and to determine the cell slopes, flow distances to stream, and slopes of the flow distances. Delineation of the network was conducted for several threshold density values, and the generated networks were compared to the first- and second-order blue line streams presented in the USGS maps at 1:24,000 scale. A threshold value of 100 cells provided the best visual match to the USGS streams (figure 2).

Observed and predicted monthly runoff volume, sediment yield, soluble phosphorus and total phosphorus loadings are presented in table 1. No calibration was applied to the model when generating the results. In general, the model under estimated the total runoff, soluble phosphorus, and total phosphorus loadings by 9, 57 and 50 percent, respectively. The model over-estimated total sediment loss by 70 percent. The values predicted by the model were within the range of the measured values.

In addition to the tabular data, the model predicted the levels of runoff, sediment yield, and phosphorus loadings for each cell. These results can be used to locate the areas with high loading potentials in the watershed. For example, figure 3 shows the spatial distribution of soluble phosphorus loadings in the watershed. The values ranged between 0.01 to 4.82 kg/ha. The highest loadings (> 4 kg/ha) were predicted from cornfields located near the streams, and the lowest loadings (< 1 kg/ha) from the forested areas.

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Table l.-Observed (Obs) and SIMPLE Predicted (Pred) Monthly Runoff Volume, Sediment Yield, Soluble and Total phosphorus Loading (1987-1988)

Month	Runoff Volume (cm)	Sediment Yield Loading (kg/ha)	Soluble Phosphorus Loading (kg/ha)	Total Phosphorus (kg/ha)

(1)	Obs (2)	Pred (3)	Obs (4)	Pred (5)	Obs (6)	Pred (7)	Obs (8)	Pred (9)
Jan	1.70	2.05	18	88	0.06	0.03	0.10	0.08
Feb	4.08	1.14	20	56	0.16	0.02	0.43	0.05
Mar	0.57	0.06	1	9	0.00	0.00	0.01	0.01
Apr	6.21	3.17	19	97	0.05	0.08	0.26	0.13
May	0.57	0.05	8	5	0.01	0.00	0.02	0.01
Jun	0.15	0.11	1	41	0.00	0.00	0.00	0.03
Jul	0.00	0.01	0	0	0.00	0.00	0.00	0.00
Aug	0.00	0.03	0	2	0.00	0.00	0.00	0.00
Sep	2.96	9.84	211	561	0.17	0.25	0.25	0.53
Oct	0.10	0.27	1	39	0.00	0.01	0.00	0.03
Nov	7.09	5.58	444	537	1.01	0.13	1.79	0.36
Dec	1.86	0.43	64	42	0.09	0.01	0.18	0.04
Jan	3.10	1.28	20	61	0.08	0.03	0.03	0.06
Feb	2.10	0.28	163	33	0.05	0.01	0.11	0.03
Mar	0.60	0.19	9	16	0.00	0.00	0.02	0.02
Apr	0.40	1.39	8	34	0.01	0.04	0.01	0.06
May	1.60	4.14	62	157	0.03	0.13	0.05	0.19
Jun	0.10	0.03	1	2	0.00	0.00	0.00	0.00
Total	33.19	30.05	1,050	1,780	1.72	0.74	3.26	1.63

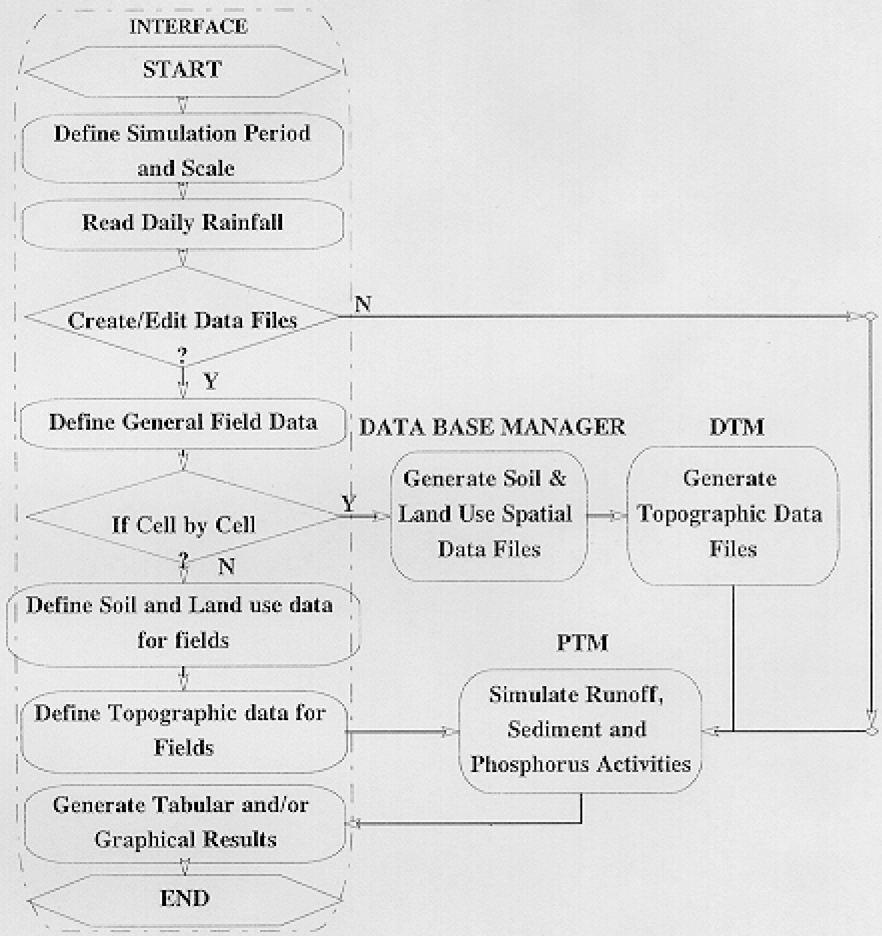

Figure 1.1 Schematic of SIMPLE modeling framework and interface flow chart.

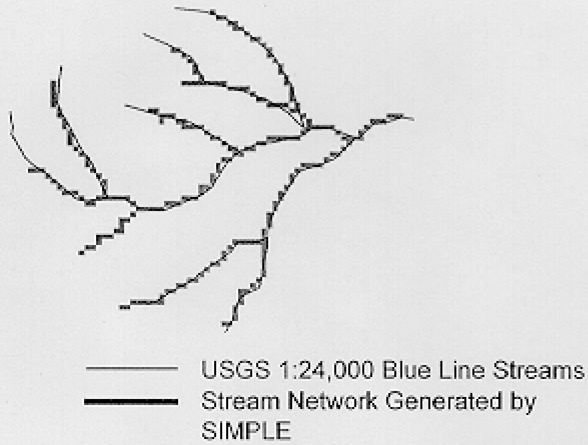

Figure 1.2 Comparison between USGS 1:24,000 blue line streams and channels defined by SIMPLE for a threshold value of 100 cells.

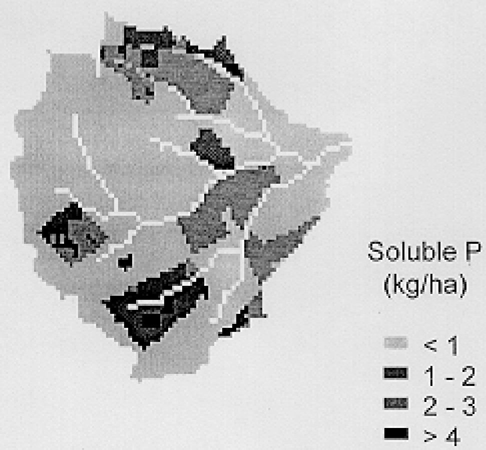

Figure 1.3 Spatial distribution of the predicted soluble phosphorus loading.

CHAPTER 2. PHOSPHORUS TRANSPORT MODEL - DESCRIPTION

A. INTRODUCTION

After reviewing a number of existing models and considering the development of an interface with a GIS, we decided to develop a new phosphorus-loading model. The new model has a number of advantages over existing ones. This model was developed specifically for long-term phosphorus loading. For the phosphorus transport process, the model employs more sophisticated approaches, including mass balance and adsorption-desorption concepts. And finally, the model is fully compatible with GRASS.

A conceptual diagram for the phosphorus-loading model is presented in Figure 2.1, with the components described in the following sections. It must be stipulated that the following processes are a simplification of actual field conditions. A number of assumptions are used in the model development due to unknown mechanisms or lack of available data. These simplifications and assumptions must be kept in mind when applying the model as to whether they are valid for a specific application and location.

B. COMPONENTS

1. Rainfall

Rainfall is the major driving force for phosphorus transport, resulting in surface runoff and soil erosion. Phosphorus is transported from the soil matrix in soluble and sediment-bound forms. Rainfall data are required to predict surface runoff and sediment yield. For a long-term analysis, the ideal situation is to apply an event-based model for each event for the period being analyzed and then sum up the results. This requires that rainfall parameters for each event be known. However, these data are not commonly available, and most rainfall data are recorded on a daily basis. Therefore, using daily rainfall instead of the event-based data in a model is more practical. Since daily rainfall records are available for most stations, or can be generated by a "weather generator" based on previous records, it is proposed that daily rainfall data be used in this model.

A daily weather generator based upon a first-order Markov chain model can be used (Richardson and Wright, 1984). The generator can predict daily variables including rainfall volume, maximum and minimum temperatures, as well as solar radiation. Rainfall generators have been built into some models, such as SWRRB (Arnold et al., 1990) and EPIC (Williams et al., 1984). The daily rainfall record would be very large even for a relatively short period of time, say, 10 years. The use of daily rainfall from a generator also gives results not pertaining only to a specific year. The input data for the generator are the latitude for a specific location and probability parameters, which are available for many stations throughout the U.S. (Richardson and Wright, 1984).

It is proposed that a weather generator be built into the model, and that the model also have the ability to read existing weather data if available. The model will be capable of randomly selecting weather data for a certain period of time from the entire record. Regardless of whether generated daily rainfall or actual rainfall record are used, the model will be easily utilized for Monte Carlo simulation to determine the probability distribution of phosphorus loadings over time. This will provide more complete information than using an event based simulation model.

2. Surface Runoff

Runoff volume from a rainfall event is estimated by the Soil Conservation Service (SCS) curve number method. This method has been widely used due to its simplicity and available data. Since daily rainfall is used, the rainfall and subsequent runoff is treated as a 24-hour event. Runoff volume for a rainfall event is calculated using (SCS, 1985):

$$V_q = \frac{(V_p - 0.2S)^2}{V_p + 0.8S} \tag{1}$$

$$S = \frac{2540}{CN} - 25.4 \tag{2}$$

where V_q is runoff volume (cm), V_P is rainfall volume (cm), S the maximum potential difference between rainfall and runoff (cm) starting at the time the storm begins, and CN is a weighted curve number. The weighed curve number is estimated by:

$$CN = W_1\, CN_1 + W_2 CN_2 + W_3 CN_3 \tag{3}$$

where W_1, W_2 and $W_3$are weighing factors, and CN_1 CN_2 and CN_3 are curve numbers for antecedent soil moisture conditions 1, 2 and 3, respectively. The weighing factors are estimated using:

$$W_1 = 1 \text{ if } V_P \le f_1 \; ; \; W_1 = \frac{f_1}{V_P} \text{ if } V_P > f_1 \tag{4}$$

$$W_2 = 0 \text{ if } V_P \le f_1 \; ; \; W_2 = \frac{V_P - f_1}{V_P} \text{ if } f_1 < V_P \le f_2 \; ; \; W2 = \frac{f_2 - f_1}{V_P} \text{ if } V_P > f_2 \tag{5}$$

$$W_3 = 0 \text{ if } V_P \le f_2 \; ; \; W_3 = \frac{V_P - f_2}{V_P} \text{ if } V_P > f_2 \tag{6}$$

where f_1 and f_2 are 1.25 cm and 2.75 cm during the dormant season, and 3.5 cm and 5.25 cm during the growing season, respectively (Smedema and Rycroft, 1983).

3. Erosion

Annual soil loss is estimated by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE was originally developed to estimate average annual gross soil erosion, although efforts have been made to apply it on an event basis (Williams and Berndt, 1977). The modified USLE, or MUSLE, (Williams, 1977; Williams and Brendt, 1972) was designed to be an event based model, however it requires an runoff volume and peak runoff rate for the rainfall event. These data are difficult to obtain without an extensive runoff model. Therefore, SIMPLE uses the USLE and applies it on a daily event basis.

The USLE is expressed as (Wischmeier and Smith, 1978):

$$A_e = 2.24 \; R \; K \; L \; S \; C \; P \tag{7}$$

where A_e is gross annual soil loss (Mg/ha/yr), R is a rainfall factor (English Units), K is a soil erosivity factor (English units), LS is the length and slope factor, C is a cover factor, and P is a practice factor. For a 24-hour rainfall, the rainfall factor is calculated on a storm basis using (Cooley, 1980):

$$f(D) = D^{0.0086} \tag{8}$$

$$R = \alpha \; D^{-\beta} \left[\frac{P_r}{2.54}\right]^{2.119 \, f(D)} \tag{9}$$

where P_r is total storm rainfall (cm), and α and β are constants for a given storm type. Values for α and β are given as (Cooley, 1980):

Storm Type	α	β
I	15.03	0.5780
IA	12.98	0.7488
II	17.90	0.4134
IIA	21.50	0.2811

For a 24-hour rainfall period, equations 8 and 9 can be simplified to:

$$R = \alpha \; 24^{-\beta} \left[\frac{P_r}{2.54}\right]^{2.178} \tag{10}$$

The length factor is estimated by (McCool et al., 1989):

$$m = \left[\frac{\beta}{1+\beta}\right]^{2.3} \tag{11}$$

$$\beta = \frac{11.16 \sin \theta}{3.0 \, [\sin \theta]^{0..8} + 0.56} \tag{12}$$

$$\theta = \tan^{-1} \left[\frac{s}{}\right. \tag{13}$$

$$\lfloor 100 \rfloor$$

$$L = \left[\frac{\lambda}{22.1}\right]^{m} \qquad (14)$$

where λ is slope length (m), m is an exponent, β is a parameter, θ is field slope (degrees), and s field slope in percent.

The approach described by McCool et al. (1987) was adopted to calculate the S factor. For slopes shorter than 4 m,

$$S = 3.0\,(\sin\theta)^{0.8} + 0.56 \qquad (15)$$

for slopes greater than or equal to 4 m and field slopes less than 9 percent,

$$S = 10.8 \sin\theta + 0.03 \qquad (16)$$

and for slopes greater than or equal to 4 m and field slopes greater than 9 percent,

$$S = 16.8 \sin\theta - 0.50 \qquad (17)$$

4. Defining Phosphorus Partitions

The total phosphorus in the soil is defined as:

$$q_t = q_i + q_o + q_m \qquad (18)$$

where q_t is total soil phosphorus (μg P/g soil), q_i is plant available phosphorus (μg P/g soil), q_o is organic phosphorus (μg Plg soil), and q_m is mineral phosphorus (μg P/g soil). The transformation of plant available P to mineral P is described by the function developed by Jones et al. (1984):

$$TR_q = q_i(t) - q_m(t)\,\frac{PSP}{1 - PSP} \qquad (19)$$

where TR_q is the amount of P transformed (μg P/g soil), (t) represents the current simulation day, and PSP is the phosphorus sorption coefficient taken as 0.5. If TR_q is greater than zero then:

$$q_m(t + 1) = q_m(t) + TR_q \qquad (20)$$

$$q_i(t + 1) = q_i(t) + TR_q \qquad (21)$$

where (t + 1) represents the next simulation day. If TR_q is less than zero then:

$$q_m(t + 1) = q_m(t) - 0.1\ TR_q \tag{22}$$

$$q_i(t + 1) = q_i(t) + 0.1\ TR_q \tag{23}$$

At the start of the computer simulation, the initial plant available phosphorus, q_i, is a model input, the initial mineral phosphorus, q_m, is assumed to be equal to q_i, and the initial organic phosphorus, q_o, is approximated by the percent organic carbon in the soil assuming a C:P ratio of 8:1 (Jones et al., 1984).

5. Application of Fertilizer

The application of commercial or manure fertilizer is assumed to increase the soil phosphorus content immediately after application. When applied by surface broadcast, all phosphorus is assumed to be added to the top one cm soil layer. When the fertilizer is incorporated by other methods, the phosphorus is assumed to be evenly distributed throughout the application depth. The available phosphorus content in the top 1 cm of the soil due to fertilizer application is calculated as:

$$q_f = 0.1\ \frac{P_f\, P_c}{P_b\, d_P} \tag{24}$$

where q_f is the increase of total available soil phosphorus content due to application of fertilizer (µg P/g soil), P_f is the amount of fertilizer applied (kg/ha), P_c is the fraction of the available phosphorus content in the fertilizer or manure, P_b is soil bulk density (g/cm^3) and d_p is the fertilizer application depth (cm) which must be greater than or equal to one cm.

Some phosphorus in animal manure is in organic forms, while others are in inorganic forms immediately available for plant uptake. Organic phosphorus can be mineralized and become available for plant uptake. The rate of mineralization depends upon various factors such as soil microbial activity and temperature. EPIC employs two equations to estimate the mineralization of plant residual and humic organic. These equations require various inputs which are not readily available. However, there is no equation in EPIC to deal with phosphorus mineralization from animal manure. SIMPLE assumes mineralization in animal manure is rapid and all

phosphorus becomes immediately available after application. This assumption, however, may tend to overestimate the soil available phosphorus content, but its potential error can be minimized since the model is typically used for long-term analysis.

The amount of phosphorus uptake by plants is a function of plant type and the state of growth. The uptake process occurs in the entire active root depth. Since only the top one cm of soil is used for mass balance calculation, it is relatively small compared to the root depth. Phosphorus uptake by plants in this one cm soil layer is assumed to be negligible. In addition, excluding a crop growth model simplifies the model substantially.

6. Soluble Phosphorus Concentration

A number of methods have been used to estimate soluble phosphorus concentration in surface runoff. Some methods estimate the concentration by an "extracting factor" in conjunction with the soil available phosphorus content (Frere et al., 1980). Others, such as SWRRB-WQ (Arnold et al., 1990), employ adsorption-desorption concepts. Still others use kinetic desorption equations (Sharpley and Smith, 1989). In this model the concentrations of dissolved and sediment-bound phosphorus are estimated based on the adsorption-desorption processes.

SIMPLE provides two options to estimate dissolved phosphorus concentration in the runoff: Langmuir isotherm with adsorption constants estimated by a regression equation and linear isotherm. The following assumptions are made when the isotherm is incorporated into the model: 1) the rainfall fully reacts with the top 1 cm of the soil, and 2) the adsorption is reversible and is in equilibrium. The Langmuir adsorption isotherm is expressed as:

$$q_e = \frac{Q^O bC}{1 + bC} \qquad (25)$$

where q_e is the sediment-bound phosphorus concentration (µg P/g soil), b is a constant related to adsorption energy (L/mg), Q^O is an adsorption maxima (µg P/g soil), C is the dissolved phosphorus concentration (mg/L). The value of b and Q^O depends on the soil properties such as clay, organic content, and soil pH. Ryden et al. (1972) provided regression equations to calculate b and Q^O based on soil pH, percent of clay and organic carbon:

$$Q^O = -3.47 + 11.60 \times 10^{-pH} + 10.66\ Clay + 49.52\ OC \qquad pH \leq 7.0 \qquad (26)$$

$$Q^O = 207.09 - 73\ 327 \times 10^{-pH} + 2.81\ Clay + 78.25\ 0\ C \qquad pH > 7.0 \qquad (27)$$

$$b = 0.061 + 169\ 832 \times 10^{-pH} + 0.027\ Clay + 0.76\ OC \qquad (28)$$

where Clay is percent clay content of the soil and OC is percent organic carbon.

The total mass of available phosphorus in the soil/water system after the rainfall can be expressed as:

$$D\ P_b\ q_e = D\ P_b\ q_t - V_q C \qquad (29)$$

where V_q is runoff volume (cm), D is thickness of soil (cm) which is assumed to be one cm for mass balance calculation, P_b is bulk density of soil (g/cm^3) and q_i is the plant available phosphorus in soil before the event (mg P/g soil). The dissolved phosphorus concentration in surface runoff, C, can be obtained by simultaneously solving equations 25 and 29, given as:

$$C = \frac{bDP_bq_t - DbP_bQ - V_q \pm V \sqrt{[(DP_bbQ + V_q - bDP_bq_t)2 + 4bV_qDP_bq_t]}}{2b\, V_q} \tag{30}$$

For the linear isotherm, the dissolved phosphorus concentration, C, is calculated by:

$$C = \frac{q_i}{K_d} \tag{31}$$

where K_d is a distribution coefficient taken as 175 cm^3/g (Williams et al., 1984).

7. Phosphorus and Sediment Loading to Receiving Waters

a. Sediment and Sediment-bound Phosphorus

Sediment-bound phosphorus and sediment loss can be calculated from the amount of eroded soil and the phosphorus content in the sediment. The amount of sediment-bound phosphorus leaving the field may be reduced along its route to the final receiving body due to deposition. The flow path, surface roughness, and slope must be known to estimate the actual loading. SIMPLE uses the relationship developed by Heatwole and Shanholtz (1991) to calculate a delivery ratio given as:

$$S_f = S_{fmin} + \exp[- k_2 (S + S_O)] \tag{32}$$

$$DR = EXP (- k_1 D_s S_f) \tag{33}$$

where DR is a delivery ratio, D_s is distance to the stream (m), S is slope (m/m), k_l, k_2, S_O, and S_{fmin}, are constants. Based on delivery estimates from Draper et al. (1979), Heatwole and Shanholtz (1991) defined $k_l = 0.0161\ m^{-1}$, $k_2 = 16.1$, $S_O = 0.057$, and $S_{fmin} = 0.6$. The amount of sediment reaching the stream, A_s, (Mg/ha), is estimated by:

$$A_s = A_e\, DR \tag{34}$$

Due to the selective deposition process, sediment contains finer soil particles than the original soil matrix. Thus, the phosphorus content is higher in the sediment than in the soil due to the higher adsorption capacity of the finer particles. Phosphorus concentration in the sediment is estimated based on the soil phosphorus content in the soil matrix and an enrichment ratio. The phosphorus enrichment ratio is defined as the ratio between phosphorus contents in sediment and the soil. The soil phosphorus content in the soil is obtained based on a daily mass balance. The phosphorus enrichment ratio is estimated by (Menzel, 1980):

$$\ln(PER) = 2 - 0.2 \ln \left[\frac{A_e}{1000} \right] \quad (35)$$

where PER is a phosphorus enrichment ratio. For sediment-bound phosphorus, the phosphorus reaching the stream is found using a delivery ratio and PER, given as:

$$P_i = 0.001\ q_i\ A_e\ PER\ DR \quad (36)$$

$$P_o = 0.001\ q_o\ A_e\ PER\ DR \quad (37)$$

$$P_m = 0.001\ q_m\ A_e\ PER\ DR \quad (38)$$

$$P_{sed} = P_i + P_o + P_m \quad (39)$$

where for the event P_{sed} is the sediment-bound phosphorus loss (kg/ha), P_i is plant available phosphorus loss (kg/ha), P_o is organic phosphorus loss (kg/ha), and P_m is mineral phosphorus loss (kg/ha).

b. Soluble Phosphorus

Dissolved phosphorus in surface runoff is assumed to be conservative, i.e. losses do not occur during transport to the receiving body. Under this assumption, dissolved phosphorus loading to the receiving body is equal to the dissolved phosphorus loss from the field. The dissolved phosphorus loading for an event can then be expressed as:

$$P_{sol} = 0.1\ V_q\ C \quad (40)$$

where P_{sol} is the soluble phosphorus loading in runoff (kg/ha), V_q is runoff volume (cm) and C is phosphorus concentration in runoff (mg/L).

c. Total Phosphorus

Total phosphorus loading for each day, P_t (kg/day), is calculated from:

$$P_t = P_{sol} + P_{sed} \quad (41)$$

P_{sed} and P_{sol} are equal to zero if there is no rainfall for the day. Monthly and annual total phosphorus loading is obtained by summing up the loading for each day.

8. Phosphorus Mass Balance

Many models predict the phosphorus concentration in runoff and sediment on an event basis. The soil phosphorus content before the rainfall is used as the basis of calculation. However, they seldom reevaluate the soil phosphorus content after the event, which becomes the initial condition for the next event. For a long-term simulation, an evaluation of the post-rainfall condition is needed for a more precise prediction. In this model a daily soil phosphorus mass balance calculation is performed.

The initial phosphorus in the top one cm of the soil is evaluated daily based on the gain and loss of phosphorus due to application of fertilizer or manure, and loss in runoff. The initial soluble phosphorus for the next day is then evaluated by the following equations:

$$q_i (t + 1) = q_i (t) + q_f - \frac{10 P_i}{P_b D} - \frac{10 P_{sol}}{P_b D} \tag{42}$$

$$q_o (t + 1) = q_o (t) - \frac{10 P_O}{P_b D} \tag{43}$$

$$q_m (t + 1) = q_m (t) - \frac{10 P_m}{P_b D} \tag{44}$$

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CHAPTER 3. PHOSPHORUS TRANSPORT MODEL - VALIDATION

A.PROCEDURE

Data sets from one site located in Baton Rouge (BH), Louisiana, and four sites in Northwestern Arkansas (WA, WB, RA and RB) were considered for the validation procedure. Information representing the five sites is summarized in Table 3.1. Parameter values for soil erodibility and crop factors were estimated from SCS (1 978). Field slope, slope length and soil characteristics were obtained from Sabbagh et al. (1991) and Edwards et al.(1993). In addition, we used a delivery ratio of 1.0 for all five fields. No model calibration of any type was performed.

The objective of this validation procedure is to test the predictive ability of the PTM runoff, erosion, and phosphorus loading modules. Runoff volumes and sediment loss predicted by the model were compared with the observed data collected at the five sites. Also, total and dissolved phosphorus loadings were simulated using the two options (Langmuir and Linear) available in the PTM and were compared with the observed data. Analysis of dissolved P was done for the four Arkansas sites only. Data on observed dissolved P were not available for the Ben Hur site.

Since equations used to predict phosphorus-loading are functions of runoff and sediment loss, the errors in predicting runoff and erosion are introduced in the prediction of phosphorus loadings. To evaluate the PTM phosphorus loading modules independently, a second set of validation runs was performed using measured daily runoff and sediment loss values were read into the PTM. Phosphorus loadings were then predicted and compared to observed values.

B. SITE DESCRIPTION

1. Baton Rouge Data

Six years of data (1981-1986) were used from the Ben Hur Research Farm of Louisiana State University, located 6 km south of Baton Rouge. The soil is described as Commerce clay loam formed in alluvial deposits. Rainfall was measured with a weighing type rain gauge. Surface runoff, measured with an H-Flume and water-stage recorder, was sampled at 20-minute intervals with an automatic sampler installed at the flume. The samples were analyzed for sediment and P concentration, and sediment and P loading were calculated for each storm. P fertilizer was applied prior to planting at 34 kg/ha. Silage corn was grown using conventional tillage. The corn was cultivated once a year in late May to control weeds, and was harvested for silage in July. Abundant weeds furnished cover against rainfall impact from harvest until the first frost (Bengtson and Sabbagh, 1990).

2. Arkansas Data

Data for the period between September 1, 1991 and April 30, 1993 were used from four fields in Northwestern Arkansas. Rainfall was measured with tipping bucket rain gages and recorded at 5

minutes increments. Pressure transducers, installed in H-Flumes stilling wells, were used to measure water stage and to determine runoff volumes at the field outlets. Runoff samples were collected with automatic samplers. Procedures for sampling analyses are described in detail by Edwards et al. (1993). The main crop cover for the four fields (RA, RB, WA and WB) was tall fescue, and the fields were used for grazing. During the study period, P was surface-applied once on field RA and twice on field RB in the form of poultry manure. The application rate for RA was 120 kg/ha on March 15, 1992; the application rates for WB were 63 kg/ha on March 23, 1993, and 52 kg/ha on April 13, 1993. A detailed description of the sites is presented in Edwards et al. (1993).

C. RESULTS AND DISCUSSION

Annual observed and predicted runoff volume, sediment loss and P loadings are summarized for the five study sites in tables 3.2 through 3.6. Observed and predicted values for each year, and the three year totals and percent difference (% diff) are given in the tables. Monthly observed and predicted values were regressed to linear equations.

1. Runoff Volume

The model over estimated total runoff volume for fields WA, WB and RB, and under estimated runoff for fields RA and BH. Comparing observed and predicted annual values, the model provides acceptable predictions of runoff patterns. Best estimates of runoff volume for the study duration were for fields RA and BH (within 10%) and the worst prediction was for field WB (89%). Linear regression statistics for the five fields are given in Figures 3.1 through 3.5. For all five fields, predicted runoff volumes were correlated with observed data, and except for WA, the slope of the regression lines were significantly different than 1.0 ($\alpha = 0.05$).

2. Sediment Loss

The model overestimated the total sediment loss for all the fields except field BH. The percent difference between observed and simulated sediment losses ranged between -14% (BH) and +85% (WB). In general, the predicted annual values corresponded well with the observed data. For all five fields, correlations between observed and predicted sediment loss were significant ($\alpha = 0.05$). However, slopes of the regression lines were significantly less than 1 ($\alpha = 0.05$). The regression slopes for the four Arkansas fields ranged between 0.38 and 0.61, and the regression slope for the BH field was 0.61 (Fig. 3.6-3.10).

3. Phosphorus Loading

The model predicted phosphorus loading poorly when the Langmuir isotherm equation was used. The predicted dissolved and total phosphorus losses were significantly greater than observed. The total P loading was over-predicted by more than 9670 times for field RB. Best estimates were for field BH (-3%). The poor performance of the Langmuir isotherm equation can be attributed to the regression equations used to predict the adsorption parameters b and Q^O.

The linear isotherm equation provided a better match to observed phosphorus loadings. Differences between observed and predicted dissolved P for WA, WB, RA and RB sites were 22%, 48%, 14% and 178%, respectively. Significant linear correlation between observed and predicted dissolved P existed (Fig. 3.11-3.14) ($\alpha = 0.05$), particularly for WA and RA fields where the coefficient of determination for the linear regression lines were 0.84 and 0.82, respectively. The total P loadings predicted by the model were higher than the observed values for all the sites. The best long-term estimate was for field RA (40%) and the worst estimate was for RB (178%). Comparison between observed and predicted monthly values (Fig 3.15 - 3.19) showed a significant linear correlation for fields WA, RA, RB and BH ($\alpha = 0.05$).

The dissolved and total P loading predicted with the linear equation using the observed runoff and sediment loss are summarized in Tables 3.7 - 3.1 1. The model under predicted dissolved P loss for fields WA, WB and RA and overestimated dissolved P for RB. Significant correlation existed between the observed and predicted values for fields WA, WB, RA and RB (Fig. 3.20-3.23) ($\alpha = 0.05$). The model also under estimated total P loading for all the fields except for RB. Significant correlation between observed and predicted total P values existed (Fig. 3.24-3.28) ($\alpha = 0.05$).

D. CONCLUSIONS

Several conclusions can be deducted from the analysis of the results:

(a) the model provides reasonable estimates for long term runoff, sediment loss and P loadings based on the linear isotherm equation,

(b) data calibration will improve model predictions since the model predicted the trend of the data, and

(c) better estimates of the Langmuir's adsorption constants are needed.

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Table 3.1. Characteristics for the Arkansas and Louisiana field sites (Edwards et al., Sabbagh et al., 1991).

Field code	Soil Series	Area (ha)	λ - USLE Slope Length (m)	K - USLE Soil Erodibility (Metric Units)	Slope (%)	CN2 Curve Number (ASM II)
WA	Linker-L	1.46	194	0.54	4	69
WB	Allegney-GL	1.06	180	0.49	4	61
RA	Captina-SiL	1.23	137	0.97	3	74

RB	Fayetteville-FSL	0.57	142	0.54	2	61
BH	Commerce-CL	1.55	200	0.52	0.1	85

Table 3.2. Annual observed and predicted runoff volume, sediment loss and P loadings – Field WA.

					Linear				Langmuir			
Year	Runoff (cm)		Sediment (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
1	8.6	10.0	106	104	2.0	2.2	1.5	2.6	2.0	115.0	1.5	115.0
2	14.9	16.4	157	180	2.8	3.5	3.1	4.2	2.8	3.2	3.1	3.2
3	2.2	2.0	3	23	0.2	0.4	0.2	0.5	0.2	0.3	0.2	0.3
Total	5.7	28.4	266	307	5.0	6.1	4.8	7.3	5.0	118.5	4.8	118.5
% diff	11		15		22		52		2,270		2,368	

Table 3.3. Annual observed and predicted runoff volume, sediment loss and P loadings - Field WB.

					Linear				Langmuir			
Year	Runoff (cm)		Sediment (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs,	Sim.	Obs.	Sim.
1	1.4	6.3	24	82	0.3	0.7	0.2	1.0	0.3	62.1	0.2	62.2
2	6.5	10.5	88	137	1.0	2.7	1.3	3.3	1.0	64.5	1.3	64.6
3	1.6	1.2	17	20	1.2	0.3	1.7	0.4	1.2	47.7	1.7	47.7
Total	9.5	18.0	129.0	239.0	2.5	3.7	3.2	4.7	2.5	174.3	3.2	174.5
% diff	89		85		48		47		6,872		5,353	

Table 3.4. Annual observed and predicted runoff volume, sediment loss and P loadings - Field RA.

					Linear				Langmuir			
Year	Runoff (cm)		Sediment (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)		Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
1	3.0	5.9	22	22	0.4	0.5	0.3	0.6	0.4	37.1	0.3	37.1
2	25.3	20.1	94	113	5.8	6.2	5.3	6.8	5.8	124.7	5.3	124.8
3	5.1	4.1	37	20	0.7	1.2	0.6	1.3	0.7	0.8	0.6	0.8
Total	33.4	30.1	153.0	155.0	6.9	7.9	6.2	8.7	6.9	162.6	6.2	162.7
% diff	-10		1		14		40		2,256		2,524	

Table 3.5. Annual observed and predicted runoff volume, sediment loss and P loadings - Field RB.

Year	Runoff (cm)		Sediment (kg/ha)		Linear Dissolved P (kg/ha)		Linear Total P (kg/ha)		Langmuir Dissolved P (kg(ha)		Langmuir Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
1	0.4	2.7	31	14	0.1	0.5	0.1	0.5	0.1	92.8	0.1	92.8
2	5.4	9.7	18	65	0.6	1.7	0.7	1.9	0.6	4.4	0.7	4.4
3	1.8	1.6	12	13	0.2	0.3	0.2	0.3	0.2	0.5	0.2	0.5
total	7.6	14.0	61.0	92.0	0.9	2.5	1.0	12.7	0.9	97.7	1.0	97.7
% diff	84		51		178		170		10,756		9,670	

Table 3.6. Annual observed and predicted runoff volume, sediment loss and P loadings - Field BH.

Year	Runoff (cm)		Sediment (kg/ha)		Linear Dissolved P (kg/ha)		Linear Total P (kg/ha)		Langmuir Dissolved P (kg/ha)		Langmuir Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs,	im.	Obs.	Sim.
1	11.8	11.9	580	1343	NA	NA	0.8	5.5	NA	NA	0.8	6.3
2	36.8	37.8	3582	5700	NA	NA	5.0	15.8	NA	NA	5.0	11.3
3	77.8	59.8	7198	7134	NA	NA	9.3	20.1	NA	NA	9.3	10.8
4	20.8	21.3	2968	12033	NA	NA	6.5	6.6	NA	NA	6.5	3.3
5	45.7	45.3	10013	4803	NA	NA	16.2	12.6	NA	NA	16.2	6.4
6	47.0	39.6	5560	4668	NA	NA	6.7	9.9	NA	NA	6.7	5.1
Total	239.9	215.7	29,901	25,681	NA	NA	44.50	70.50	NA	NA	44.50	43.20
% diff	-10		-14		NA		58		NA		-3	

Table 3.7. Annual P loading observed and predicted based on measured runoff and sediment loss – Field WA.

Year	Linear Dissolved P (kg/ha)		Linear Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.
1	2.0	0.7	1.5	1.0
2	2.8	1.9	3.1	2.4
3	0.2	0.0	0.2	0.2
Total	5.0	2.6	4.8	3.6
% diff	-48.0		-25.0	

Table 3.8. Annual P loading observed and predicted based on measured runoff and sediment loss – Field WB.

Year	Linear			
	Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.
1	0.3	0.1	0.2	0.2
2	1.0	0.4	1.3	0.6
3	1.2	0.1	1.7	0.2
Total	2.5	0.6	3.2	1.0
% diff	-76.0		-68.8	

Table 3.9. Annual P loading observed and predicted based on measured runoff and sediment loss – Field RA.

Year	Linear			
	Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.
1	0.4	0.4	0.3	0.4
2	5.8	3.4	5.3	3.6
3	0.7	0.6	0.6	0.7
Total	6.9	4.4	6.2	4.7
% diff	-36.2		-24.2	

Table 3.10. Annual P loading observed and predicted based on measured runoff and sediment loss Field RB.

Year	Linear			
	Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs,	Sim.	Obs.	Sim.
1	0.1	0.5	0.1	0.5
2	0.6	1.4	0.7	1.6
3	0.2	0.1	0.2	0.2
Total	0.9	2.0	1.0	2.3
% diff	122.2		130.0	

Table 3.11. Annual P loading observed and predicted based on measured runoff and sediment loss Field BH.

Year	Linear			
	Dissolved P (kg/ha)		Total P (kg/ha)	
	Obs.	Sim.	Obs.	Sim.
1	NA	NA	0.8	2.0
2	NA	NA	5.0	5.9
3	NA	NA	9.3	10.9
4	NA	NA	6.5	4.0
5	NA	NA	16.2	10.3
6	NA	NA	6.7	3.8
Total	NA	NA	44.5	36.9
% diff	NA		-17.08	

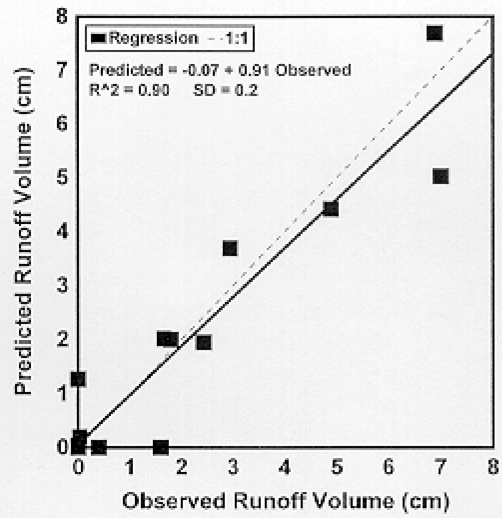

Figure 3.1 Observed and predicted monthly runoff volume for field WA.

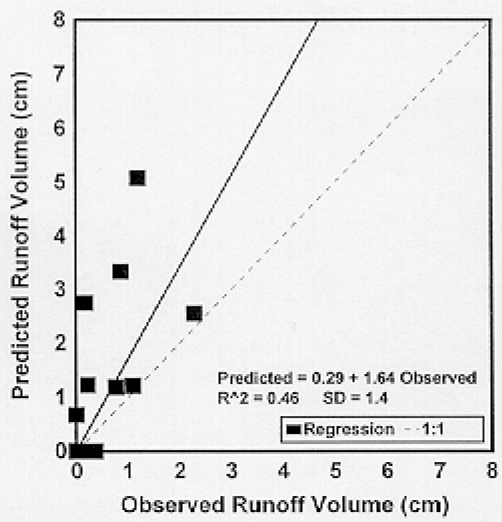

Figure 3.2 Observed and predicted monthly runoff volume for field WB.

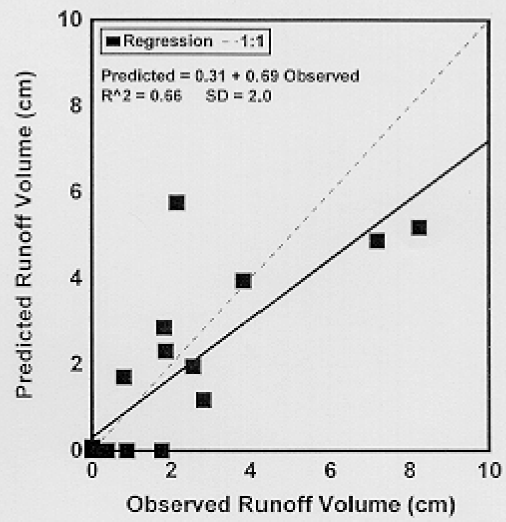

Figure 3.3 Observed and predicted monthly runoff volume for field RA.

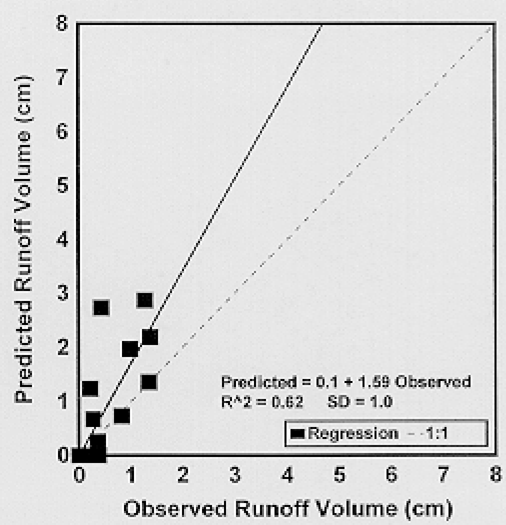

Figure 3.4 Observed and predicted monthly runoff volume for field RB.

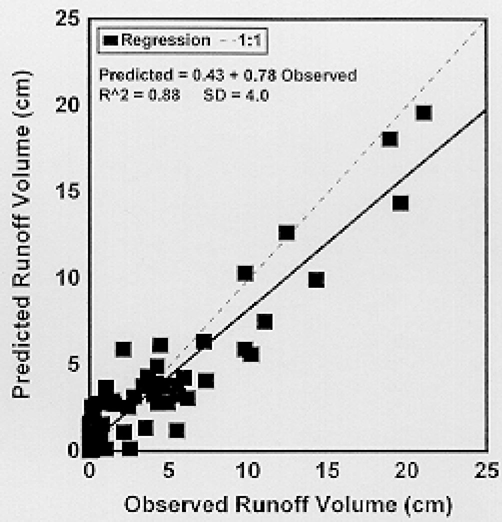

Figure 3.5 Observed and predicted monthly runoff volume for field BH.

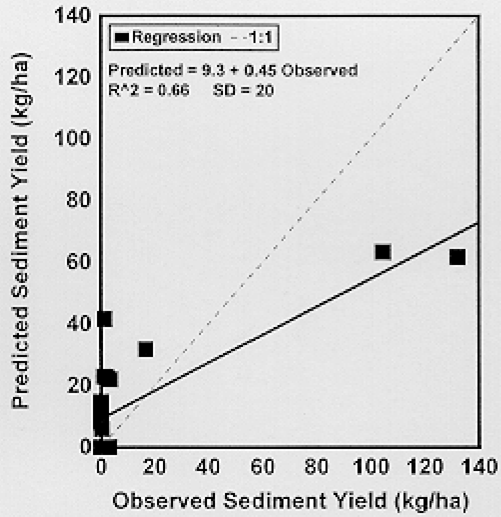

Figure 3.6 Observed and predicted monthly sediment yield for field WA.

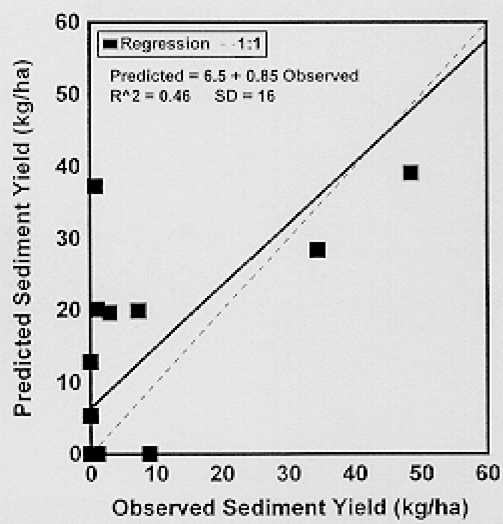

Figure 3.7 Observed and predicted monthly sediment yield for field WB.

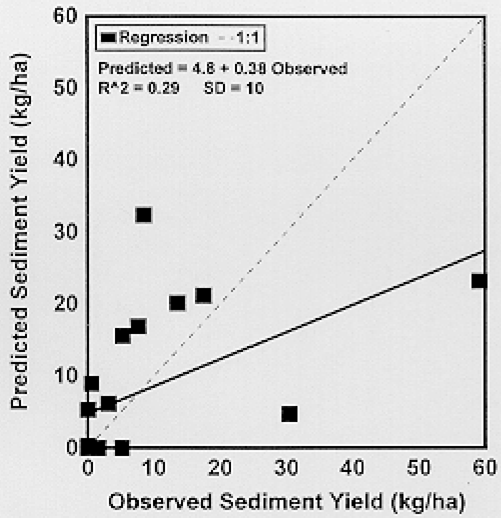

Figure 3.8 Observed and predicted monthly sediment yield for field RA.

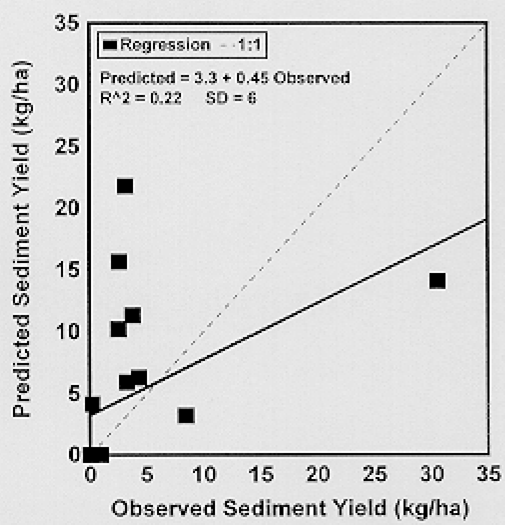

Figure 3.9 Observed and predicted monthly sediment yield for field RB.

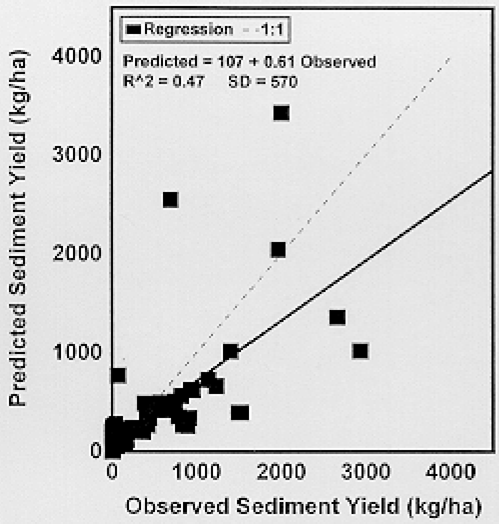

Figure 3.10 Observed and predicted monthly sediment yield for field BH.

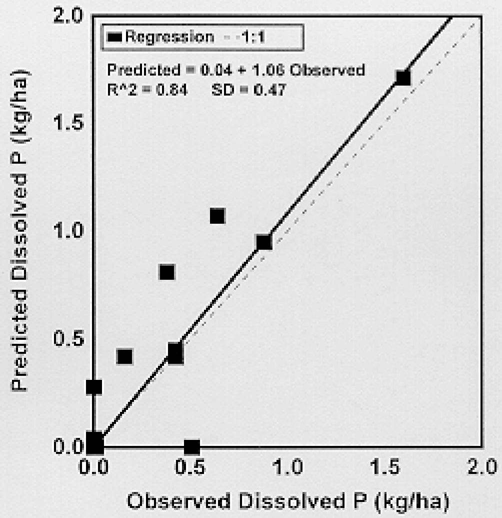

Figure 3.11 Observed and predicted monthly dissolved phosphorus loading for field WA using the Linear Isotherm method.

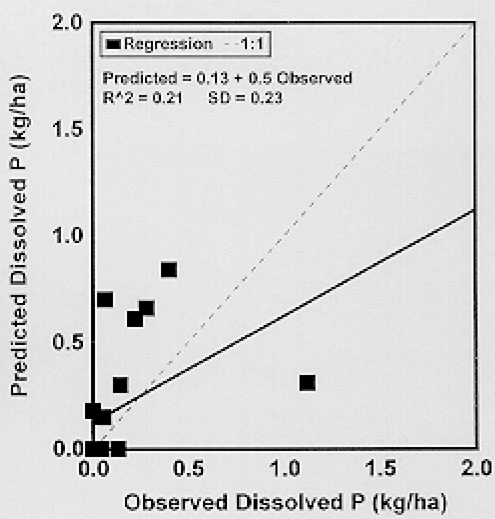

Figure 3.12 Observed and predicted monthly dissolved phosphorus loading for field WB using the Linear Isotherm method.

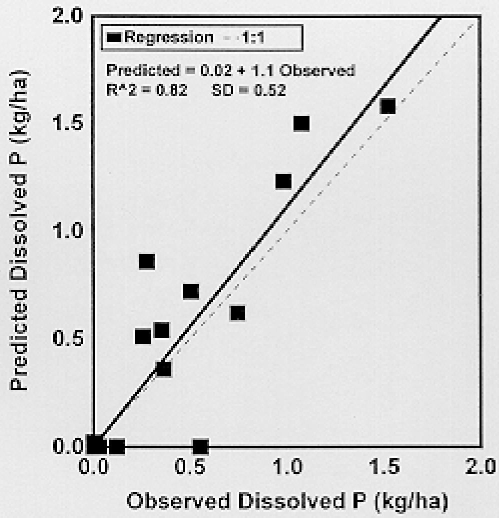

Figure 3.13 Observed and predicted monthly dissolved phosphorus loading for field RA using the Linear Isotherm method.

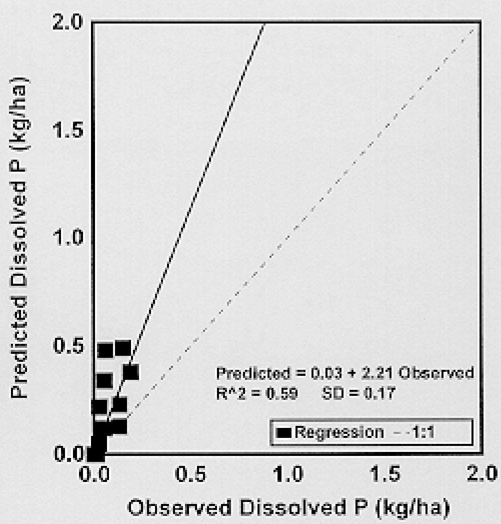

Figure 3.14 Observed and predicted monthly dissolved phosphorus loading for field RB using the Linear Isotherm method.

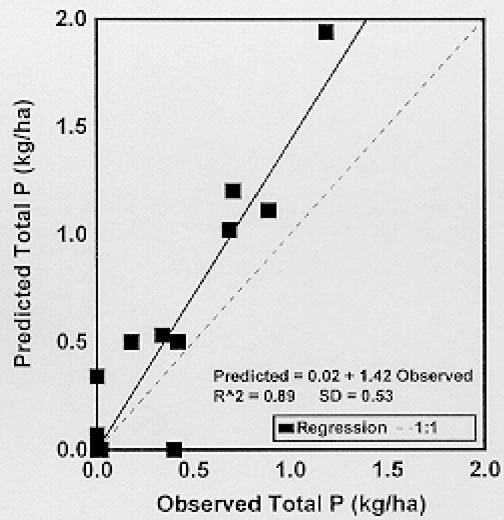

Figure 3.15 Observed and predicted monthly total phosphorus loading for field WA using the Linear Isotherm method.

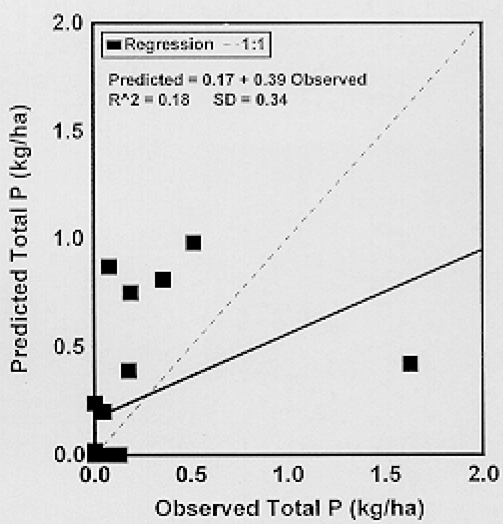

Figure 3.16 Observed and predicted monthly total phosphorus loading for field WB using the Linear Isotherm method.

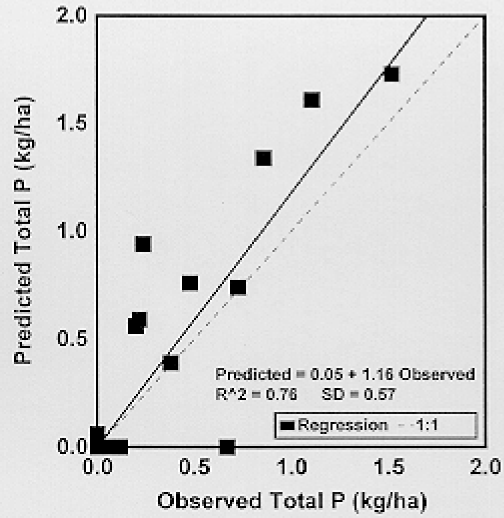

Figure 3.17 Observed and predicted monthly total phosphorus loading for field RA using the Linear Isotherm method.

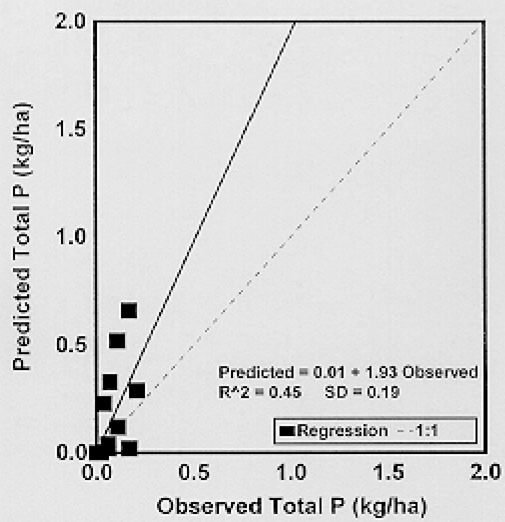

Figure 3.18 Observed and predicted monthly total phosphorus loading for field RB using the Linear Isotherm method.

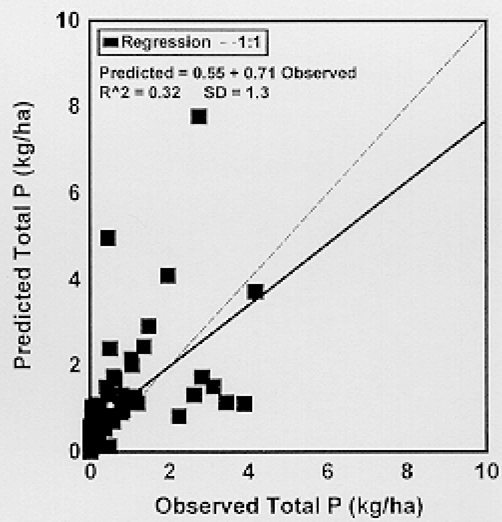

Figure 3.19 Observed and predicted monthly total phosphorus loading for field BH using the Linear Isotherm method.

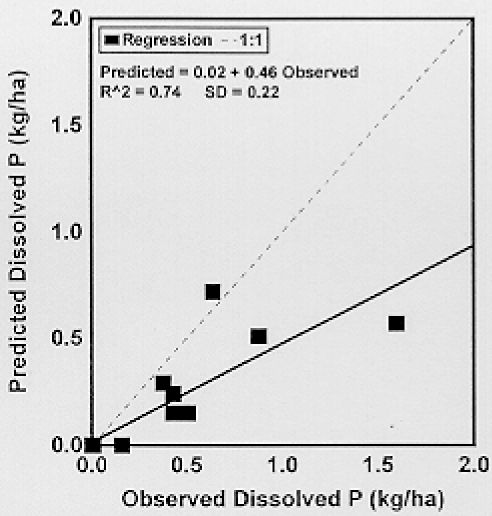

Figure 3.20 Observed and predicted monthly dissolved phosphorus loading for field WA using the Linear Isotherm method with observed runoff and sediment.

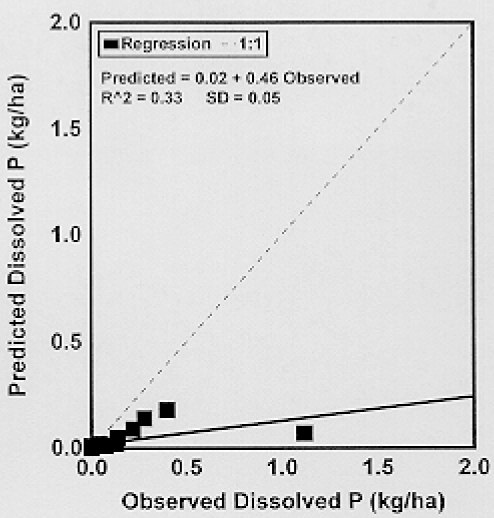

Figure 3.21 Observed and predicted monthly dissolved phosphorus loading for field WB using the Linear Isotherm method with observed runoff and sediment.

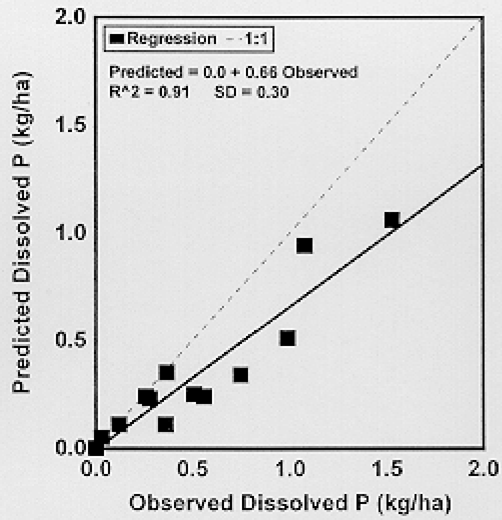

Figure 3.22 Observed and predicted monthly dissolved phosphorus loading for field RA using the Linear Isotherm method with observed runoff and sediment.

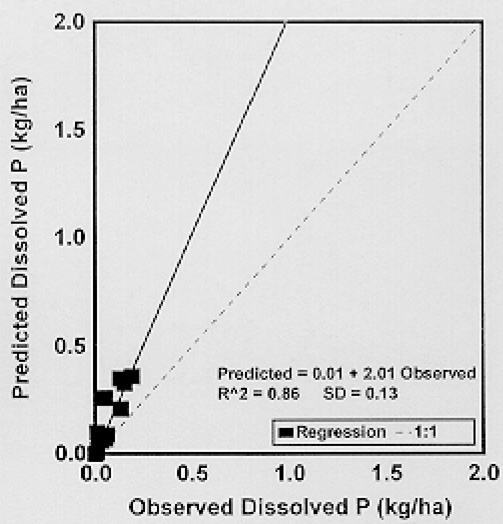

Figure 3.23 Observed and predicted monthly dissolved phosphorus loading for field RB using the Linear Isotherm method with observed runoff and sediment.

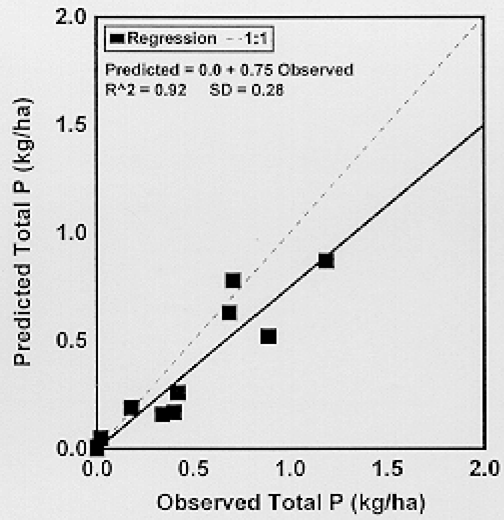

Figure 3.24 Observed and predicted monthly total phosphorus loading for field WA using the Linear Isotherm method with observed runoff and sediment.

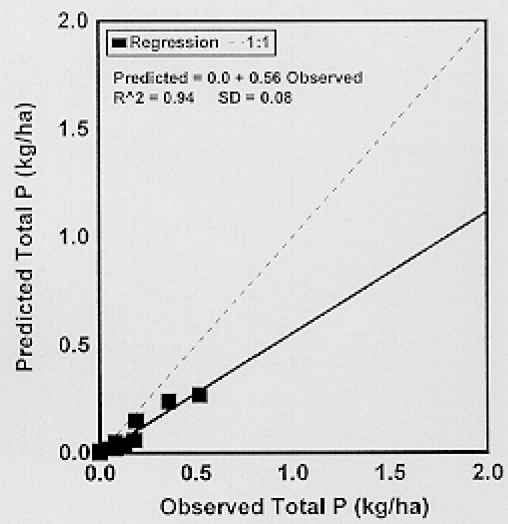

Figure 3.25 Observed and predicted monthly total phosphorus loading for field WB using the Linear Isotherm method with observed runoff and sediment.

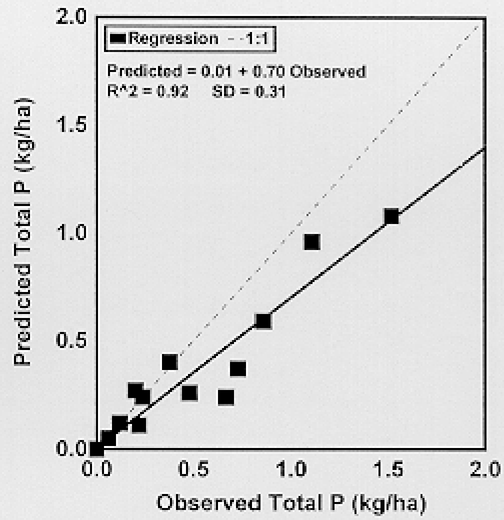

Figure 3.26 Observed and predicted monthly total phosphorus loading for field RA using the Linear Isotherm method with observed runoff and sediment.

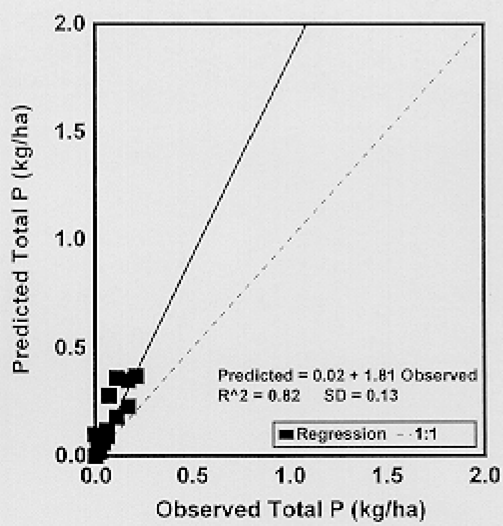

Figure 3.27 Observed and predicted monthly total phosphorus loading for field RB using the Linear Isotherm method with observed runoff and sediment.

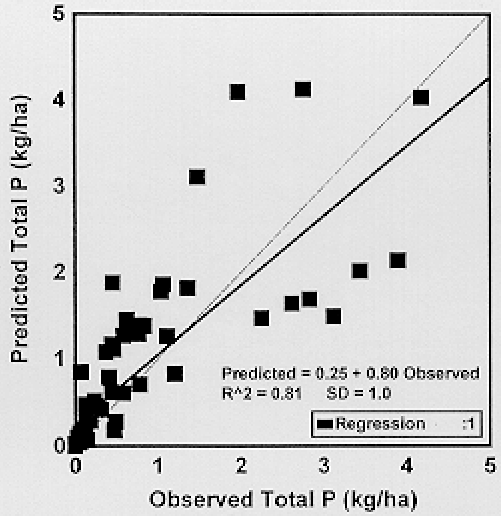

Figure 3.28 Observed and predicted monthly total phosphorus loading for field BH using the Linear Isotherm method with observed runoff and sediment.

CHAPTER 4. DIGITAL TERRAIN MODEL

A. BACKGROUND

The three principal methods for structuring networks using digital elevation data are the contour based network, triangulated irregular network and grided network (Moore et al., 1991). Although processes for delineating watershed boundaries and flow paths based on contour networks (O'Loughlin, 1986; Moore et al., 1988; Moore and Foster, 1990) and triangulated irregular networks (Palacious and Cuevas, 1991; Jones et al., 1990; Vieux, 1991; Tachikawa et al., 1994) generally provide reliable results, they required extensive data storage and computation time. Grid cell elevation models, on the other hand, have advantages for their computational efficiency and the availability of topographic databases (Tachikawa et al., 1994).

Most techniques developed to extract topographic information from gridded digital elevation data are based on neighborhood operations (Jenson and Domingue, 1988). These techniques are well described by Douglas (1986), Van Deursen and Kwadijk (1990), Quinn et al. (1991), and Smith and Brilly (1992). A serious problem with determining flow paths based on gridded elevation data is the presence of artificial depressions. Depressions are areas that are neighbored by higher elevation cells. Mark (1984) and O'Callaghan and Mark (1984) described smoothing methods to remove shallow depressions. Marks et al. (1984) and Jenson and Trautwein (1987) used the filling approach, where by values of depression cells are replaced by the value of a neighboring cell with the lowest elevation.

Slope is a basic input parameter for modeling hydrologic and water quality processes. Several approaches are available to estimate cell slopes from gridded elevation data. Among these approaches are the quadratic surface method (Zevenbergen and Thorne, 1987), the best-fit plane method (Beasly and Huggins, 1982), maximum slope method (Shantholtz et al., 1990) and the neighborhood method (CERL, 1988). Srinivasan and Engel (1991) provided an excellent discussion and comparison of these four methods.

B. MODEL COMPONENTS

The DTM was developed as a stand alone model. It is divided into five components that contain procedures to (1) detect and fill depressions, (2) define flow direction and calculate flow accumulation values, (3) delineate channel networks, (4) define drainage boundaries, and (5) extract cell and drainage characteristics such as slope, and path length and slope.

The first step in the DTM modeling framework is to transform the original gridded elevation data into a depressionless digital elevation model (DEM). The processed data set is then used to generate files defining the flow direction and the flow accumulation values for each cell. Based on these two files, networks are delineated and watershed boundaries are outlined. Also, parameters describing cells and watersheds characteristics are calculated. A simplified flow chart of the DTM modeling framework is presented in Figure 1.

1. Filling Depressions

The procedure used to generate a depressionless DEM is based on techniques developed by Jenson and Domingue (1988). A depression may be single or multi-cell (Figure 2a). The depressionless DEM is generated by (1) filling single-cell depressions, (2) determining flow direction, (3) identifying the cells constituting multi-cell depressions, (4) defining depression watersheds, (5) updating elevation values for each depression watershed cells, and (6) eliminating new depression watersheds.

A single-cell depression is filled by raising its elevation to the level of its lowest neighboring cell (Figure 2b). This step is conducted first to reduce the complexity of filling multi-cell depressions. The flow direction for each cell is then defined and stored (Figure 2c). A procedure to identify flow directions is described later. Based on flow directions, a flow path for each cell is defined and cells with flow paths not reaching the data set edges are identified as depression cells. Depression cells that flow into each other are given a unique watershed number (Figure 2d).

The watershed number for each depression cell is compared with its neighbors to identify the cells constituting the watershed boundary. For each boundary cell, elevations of neighboring cells outside of the watershed are compared, and the lowest elevation is identified as an elevation pour point. The lowest elevation pour point in a watershed is selected, and elevations for all the depression cells in the watershed are raised to that pour point elevation (Figure 2e).

The updated DEM created by filling individual depression watersheds may now include new depression watersheds. Steps 2 to 5 are repeated in an iterative fashion to eliminate all sinks and generate a depressionless DEM.

2. Flow Directions and Flow Accumulations

a. Flow Directions

The flow direction for a cell x is assigned on the basis of the steepest elevation gradient away from the cell. The gradient is taken as the change in elevations between cell x and the neighboring cell divided by the distance between the centers of the two cells. The value of the distance is one for neighbor cells aligned horizontally or vertically and $\sqrt{2}$ for the diagonal cells. There are eight possible flow directions as shown in Figure 3; the numbering scheme described by Greenlee (1987) is used.

Three possible situations exist when defining the flow direction for a cell x. The first situation occurs if only one gradient is the steepest; the flow direction is assigned to that cell. This situation is the most common. Situation 2 occurs if more than one steepest gradient exist. The flow direction in this case is determined from a predefined look-up table. The table is designed to allow a systematic selection of a flow direction based on all the possible flows.

The third situation occurs when one or more neighboring cell elevation is equal to cell x elevation and the other neighboring cells elevations are higher. This situation is addressed after flow directions for situations 1 and 2 are assigned. An iterative procedure is used, and cell x is assigned a flow direction pointing to an adjacent cell with similar elevation and with a flow path pointing away from the cell x.

b. Flow Accumulations

The flow direction file is used to calculate a flow accumulation value for each cell. The flow accumulation value for cell x represents the total number of cells that have upstream flow paths passing through it (Fig. 4b). Cells located in lower elevations, such as channels, will have high accumulation values. An iterative procedure is used to generate the flow accumulation file (Jenson and Domingue, 1988).

3. Network Delineation

Channel networks are identified and enumerated based on the flow accumulation values and on a user defined threshold network density. A threshold network density is simply a flow accumulation threshold value. Cells with flow accumulation values equal to or greater than the threshold value are identified as network cells. The channel network density may be increased by simply decreasing the threshold value. For example, at a threshold value of four, three cells are identified as network cells in the example presented in Figure 4 (Figure 4c). The same data set will have five network cells, if the threshold value is reduced to two (Figure 4d).

Once the network cells are defined, the channels are numbered, then they are divided at junction nodes into a series of branches (Storm, 1991). For each junction, there are eight possible flow directions, and branch numbering proceeds in a clockwise direction starting with the flow direction at the "1:30" clock position (Fig. 5a). The initial junction for branch enumeration is found by following the maximum flow accumulation gradient. After the upper most junction is enumerated, the second junction is evaluated. From this junction, a new path following the maximum accumulation gradient is established. This process is repeated until all branches are numbered for each channel.

Branches for each channel are renumbered using the stream ordering system illustrated in Figure 5b. All first-order streams are enumerated sequentially, followed by the remaining stream orders. If hydraulic routing is required, this ordering system is needed to allow the processing of all upstream branches prior to any downstream branch. Information describing the channels is saved in a network file.

4. Watershed and Subwatershed Delineation

The function of this component is to identify the watersheds and subwatersheds in the study area and to delineate their boundaries. The number of watersheds is determined by the number of independent channels. Each watershed has one outlet or start cell, which is the channel outlet (Figure 5b). This watershed is composed of all the cells with flow paths leading to its outlet. A watershed is composed of one or more subwatersheds, each subwatershed is associated with a branch of the channel. The branch outlet is the start cell of the corresponding subwatershed.

Drainage area delineation is divided into three steps. First, subwatershed start cells are identified (Fig. 4e), and the flow directions are used to find the associated subwatershed cells. These cells are given a subwatershed number (Fig. 4f). The numbering order of the subwatersheds is the same as the order used to enumerate branches. Next, the subwatershed number of each cell is compared with its neighbors to identify the boundary cells. And in the final step, cells are re-enumerated to reflect the associated watershed, and the boundary cells are identified.

5. Cell and Drainage Area Characteristics

This component is divided into three modules. The first module calculates the cell slope, the second estimates cell path length and path slope, and the third determines for each subwatershed, the average slope, maximum flow length and the associated flow slope.

Cell slope estimates are based on the neighborhood method (CERL, 1988). The neighborhood method considers the eight neighboring cells and predicts the slope for the center cell. The slope is a function of the elevations of the eight neighboring cells and the distance between the centers of the two cells. In this method, the elevation of the center cell is not considered for estimating the slope.

Cell path lengths and path slopes are based on the flow direction and network information. To calculate the path length for cell x (Cx), the model determines the number of horizontal, vertical and diagonal flow directions between that cell and the first network cell (Cn) where it flows. A horizontal or vertical flow is then taken as the cell side length (DX), and a diagonal flow is $DX*\sqrt{2}$. The path slope is estimated as the difference in Cx and Cn elevations divided by the path length.

A subwatershed slope is calculated by adding the slopes for cells with similar subwatershed number and dividing by the total number of cells in the subwatershed. A flow length is defined as the flow path distance between a cell and the start cell of the subwatershed. The model also calculates the path distances for the boundary cells, and the longest distance is the maximum travel length. The slope of this length is the difference in elevations between the two cells divided by the length.

C. APPLICATION EXAMPLE

To demonstrate the model performance, the DTM was applied to the Battle Branch watershed, a 6100 ha watershed located in Eastern Oklahoma. Battle Branch is a tributary of the Illinois River basin. The drainage area was divided into 30 m by 30 m cells, and gridded elevation data for the site were digitized from 7.5 minutes USGS quad maps (1:24,000 scale). The site drainage networks and boundaries were delineated, and cell slopes and path lengths were determined. The information generated by the DTM was imported in the GIS GRASS (US Army, 1985) for graphical display.

Delineation of the drainage network was conducted for several threshold network densities. The DTM generated networks were compared to USGS 1:24,000 blue line streams (Fig. 6). As the threshold value decreased, DTM generated network density increased. A threshold value of 400 provided a reasonable visual match to the USGS 1:24,000 blue line streams. Based on a threshold value of 400, subwatershed boundaries were delineated (figure 7). Also, cell slopes, distance to nearest stream and slope of that distance were determined and are presented in Volume 2.

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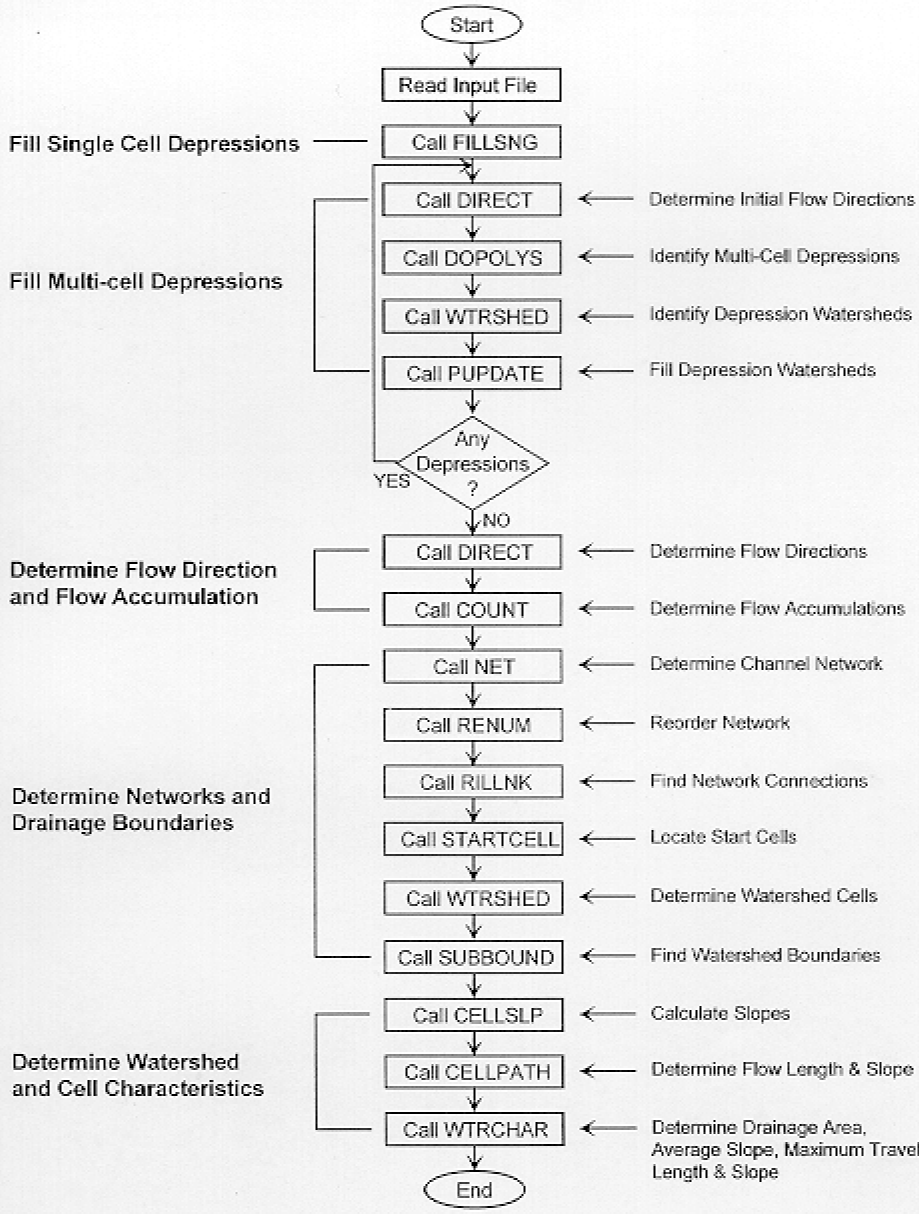

Figure 4.1 Simplified flow chart of the digital terrain model.

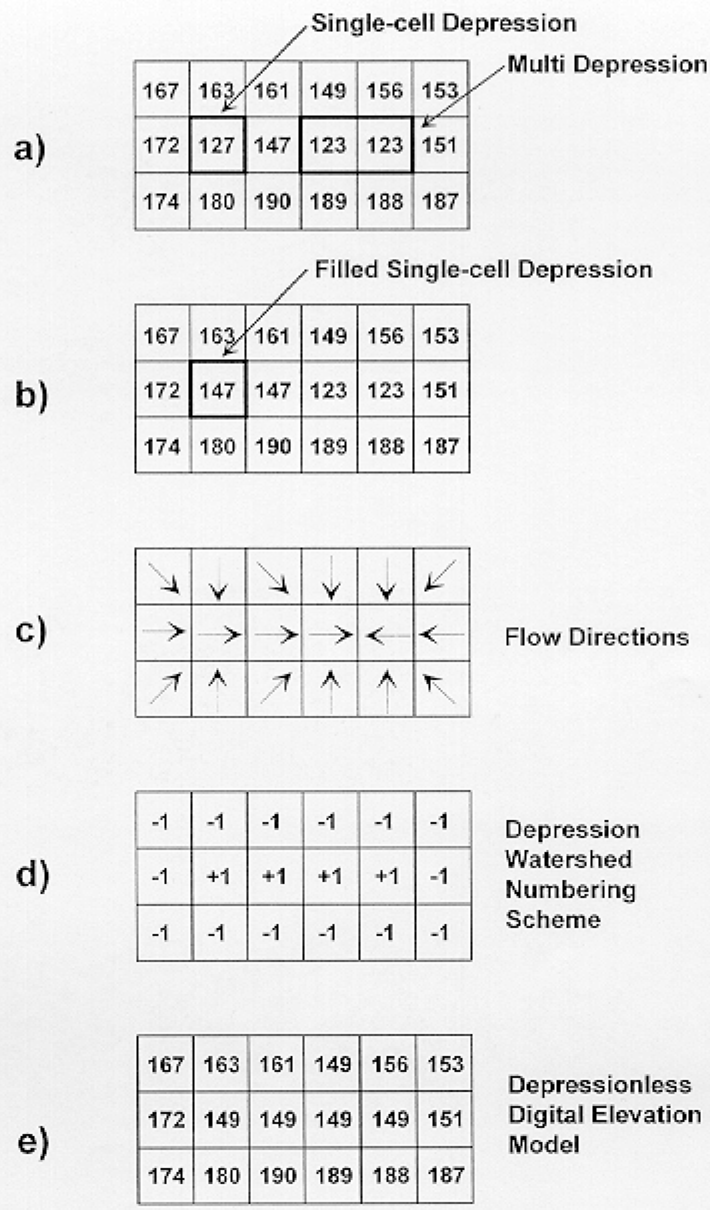

Figure 4.2 Generating depressionless digital elevation model.

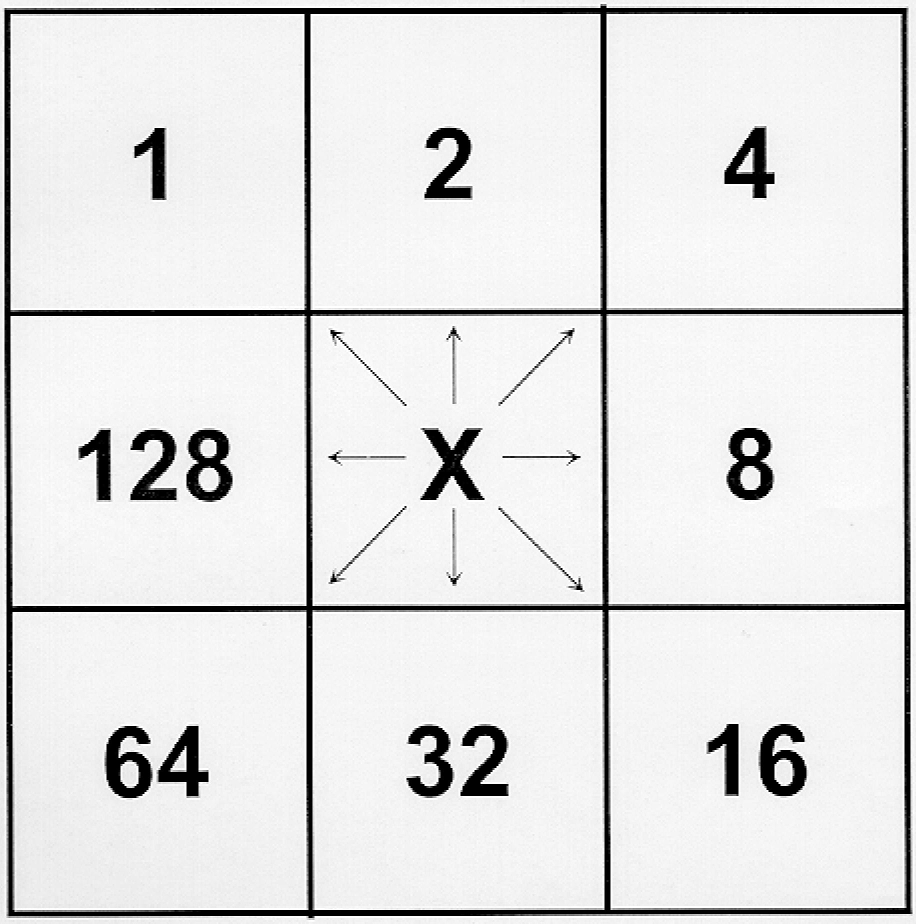

Figure 4.3 Flow direction data codes for cell x.

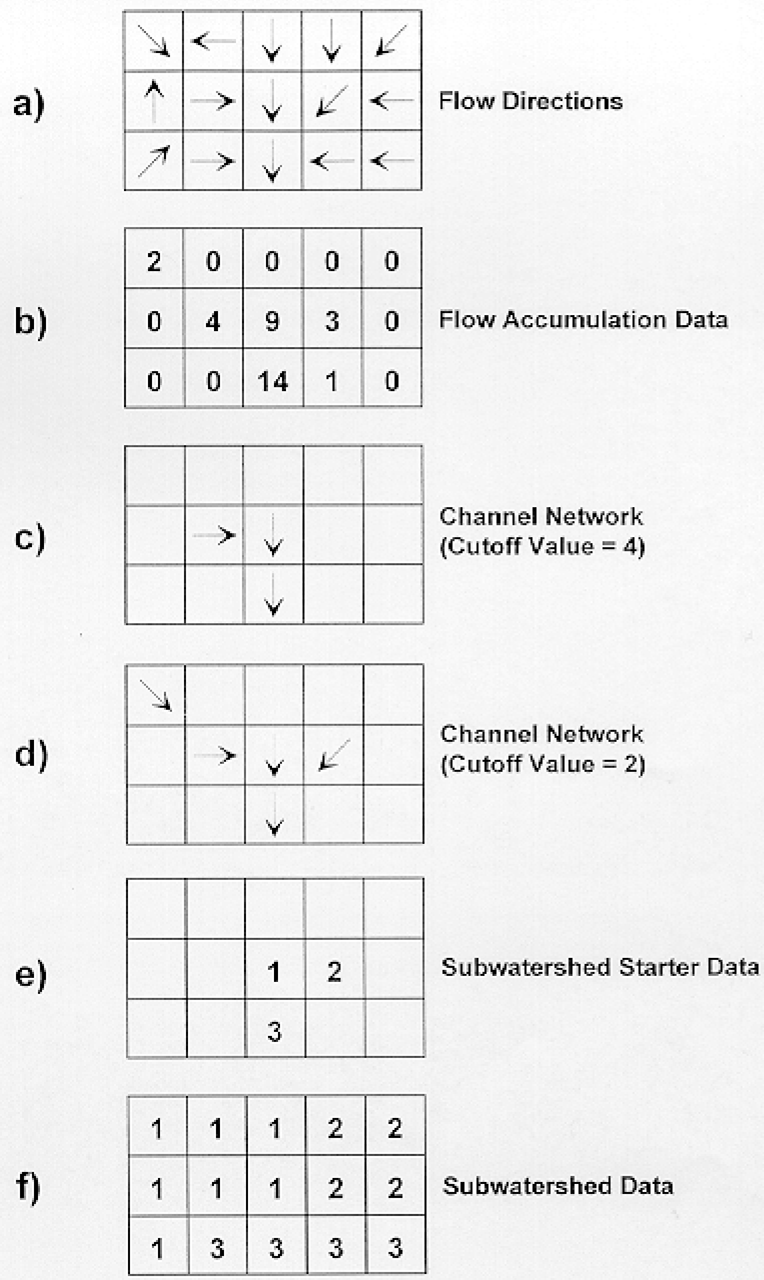

Figure 4.4 Delineation of channel networks, and defining subwatershed starter cells.

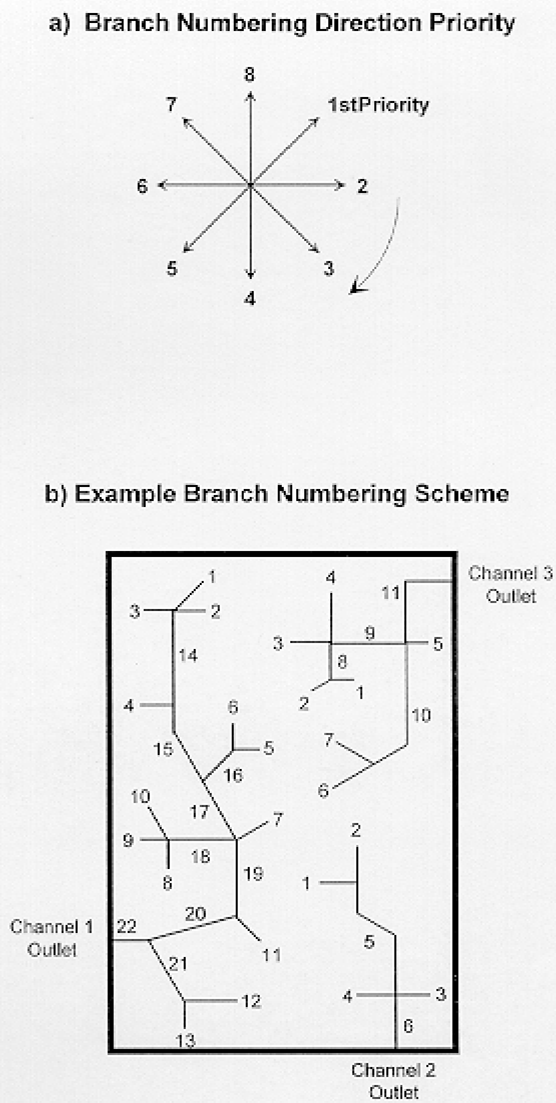

Figure 4.5 Scheme to prioritize and enumerate network branches.

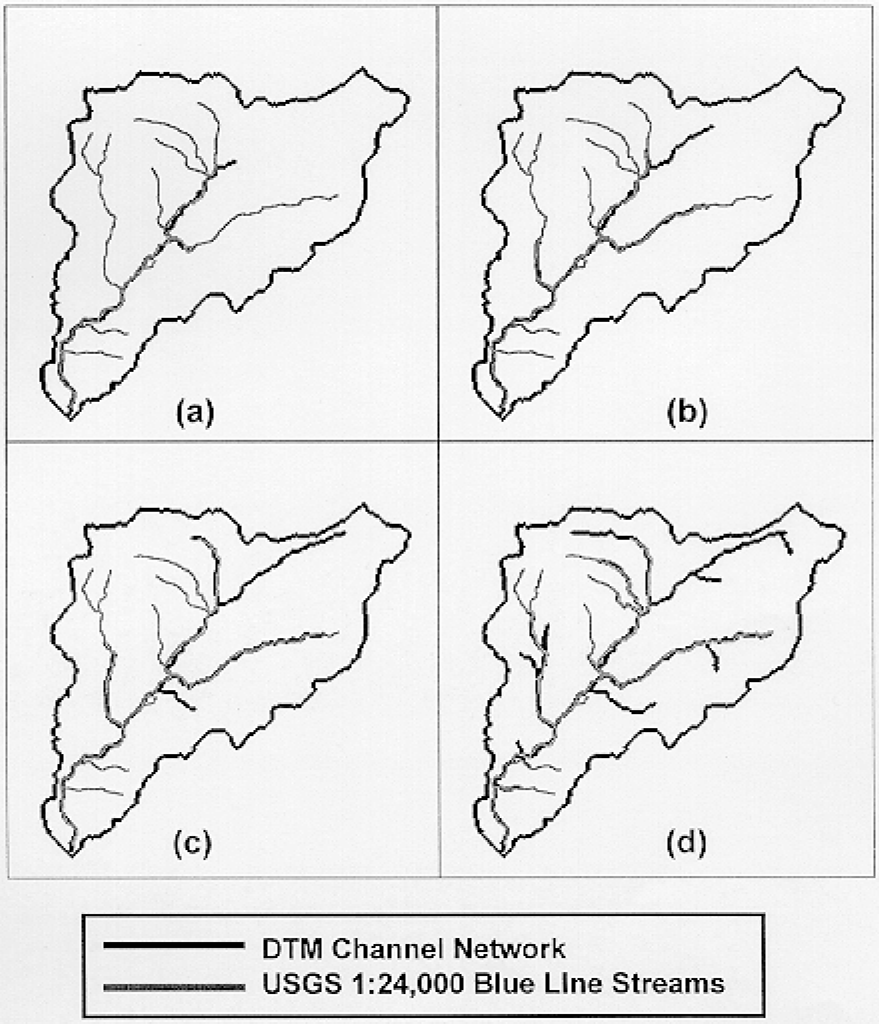

Figure 4.6 Comparison between USGS 1:24,000 blue line streams and channels defined by the digital terrain model for threshold values of a) 4000, b) 2000, c) 1000 and d) 400 cells.

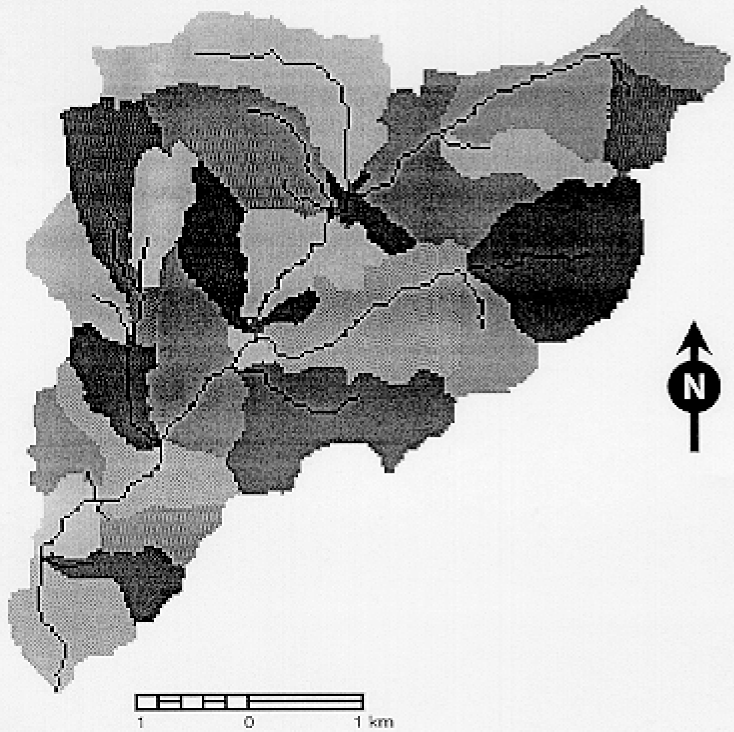

Figure 4.7 Drainage boundaries and channel network generated by the digital terrain model using a threshold density of 400 cells.

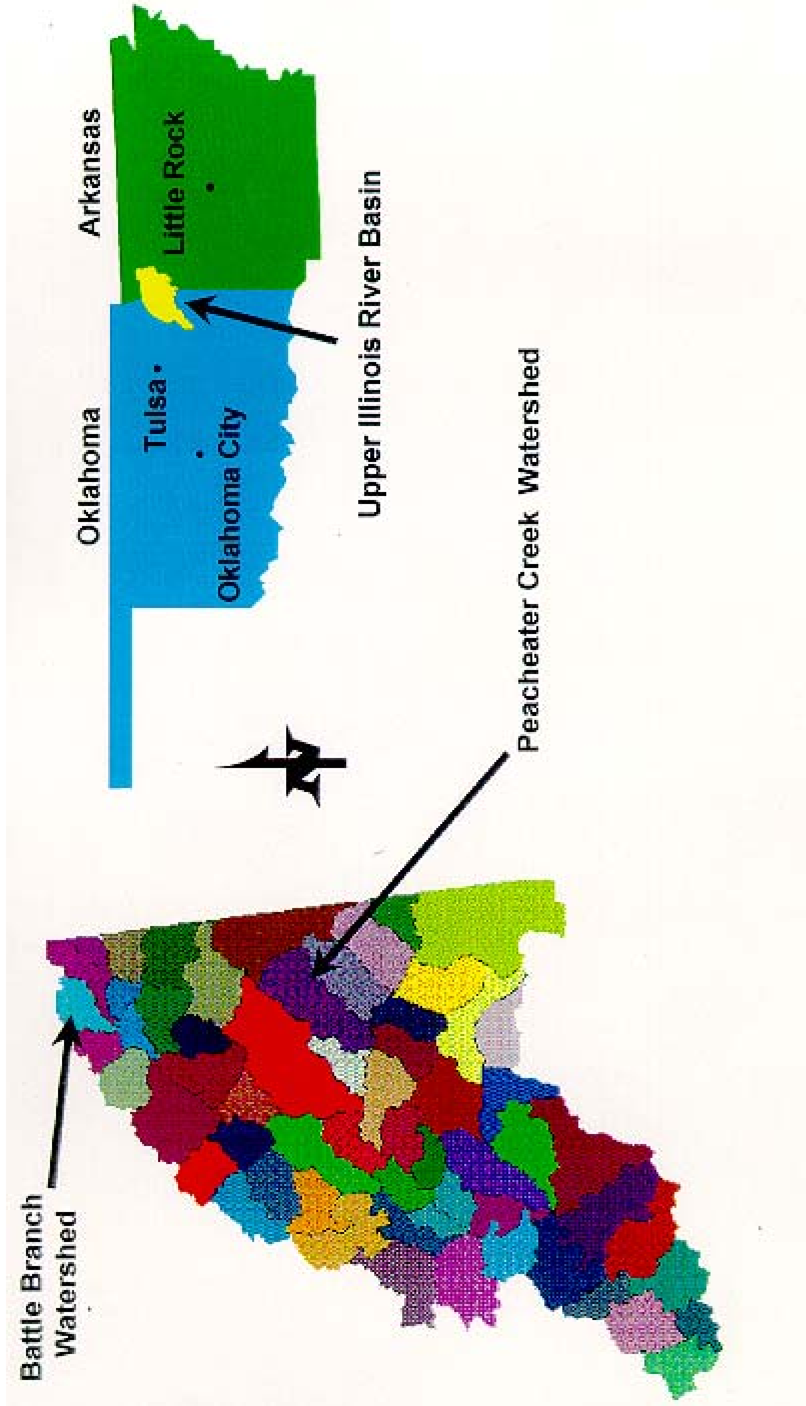

Figure 1.1 - Location of Battle Branch and Peacheater Creek Watersheds in the Oklahoma side of the Illinois River Basin.

VOLUME 2: APPLICATION STUDIES

Chapter 1: Overview

A. INTRODUCTION

Battle Branch and Peacheater Creek are tributaries of the Illinois River (Fig. 1.1), a designated scenic river in Oklahoma and the primary contributor stream to Lake Tenkiller. The Illinois River is used extensively for contact recreation and water supply. The watersheds are among the nations leading poultry producing areas. High concentrations of poultry and dairy operations in relatively small areas have created a potential for off-site water quality impacts from excessive application of animal manures to permanent pastures.

This study is being conducted on the Battle Branch and Peacheater Creek watersheds to identify and rank potential phosphorus (P) and sediment sources to surface waters associated with present watershed management practices. Spatial and characteristic data describing the watersheds were compiled. The SIMPLE modeling system was applied to the watersheds, and long term simulation runs were conducted to estimate the potential average annual runoff volume, sediment yield, and P loading produced from the watershed. Average annual runoff, sediment and P loading were also determined for each of the fields within the watershed. The fields were ranked based on the predicted loading, and fields with high potential off-site impact were identified. This volume describes the procedures followed in this study and provides details on the results obtained.

B. PROCEDURE

Prior to conducting the simulation runs, basic data describing the watersheds were required. Digital elevation models were developed for the watersheds by scanning USGS 1:24,000 scale topographic mylar separates with a high resolution gray tone scanner. These scanned raster images were edited, cleaned, labeled, and vectorized using LtPlus. The vector images were sent to the USGS who created a standard format digital elevation model. Soils data were developed by digitizing the NRCS county soil survey, and creating a 30-m GRASS raster data layer for each watershed. All digitizing was performed using GRASS 4.0.

A detailed land use inventory was conducted by the Oklahoma Cooperative Extension Service (OCES). The detailed land use inventory with field boundaries was drawn on transparent paper overlaid onto ASCS black and white aerial photography at a scale of 8 inches equal to 1 mile. These boundaries were then digitized and labeled. In addition to identifying specific land uses and management, soil samples were taken and sent to the OSU Soil Testing Laboratory for analysis. The final GRASS data layers were field boundaries, land use, and soil test phosphorus.

The digital data were stored in the GIS GRASS raster format, and ASCII files that represent the raster information were generated. Once the data bases were developed and digital representation of the spatial data generated, the Digital Terrain Model (DTM), a component of SIMPLE, was used to delineate the watershed channel networks, to outline the boundaries for the corresponding subwatersheds, and to calculate slopes and distance to streams. In addition, the data base manager, another component of SIMPLE, was used to generate spatial representations of soil and land use characteristics.

Based on historical rainfall records (1950-1989) from the Arkansas Agricultural Experiment Station in Fayetteville, Arkansas, 40 one-yr simulation runs were conducted on a cell-by-cell basis. Cumulative averages of the simulation results were calculated and used to determine a suitable length period for the long-term simulation runs. Simulation runs for the selected length period were conducted at a 30 m cell level, and long-term average values of runoff, and sediment and P loadings were estimated for each field. The simulation runs used a poultry lifter application rate of 2.0 Mg/ha with a 1.25% P content applied to all pastures and meadow-hay fields on April 1 of each year. The long-term average predictions were then used to identify the field with high environmental risk potentials.

Chapter 2. Battle Branch Watershed

A. SITE AND DATA DESCRIPTION

The Battle Branch watershed is located in southern Delaware County in northeast Oklahoma (Fig. 1.1). The watershed area covers about 5500 acres. The watershed is in the Ozark Highland Land Resource Area. The topography is primarily rough steep hills with a blackjack-postoak tree cover. The major land use is agriculture. Fifty-two farms are located within the watershed. Distribution of soil associations, land use, elevation and fields are presented in Figures 2.1-2.4.

The study area includes 19 different soil types (Table 2.1). The predominant soil in the watershed is in the Clarksville-Baxter-Locust association. The Clarksville soils are cherty silt clay loam soils and generally have high steep slopes with high runoff potential. The Baxter and Locust soils are cherty silty clay loam soils and are found on the nearly level to gently sloping ridge tops. Soils samples were taken by the OCES and tested by the OSU Soil Testing Laboratory to determine plant available P (Fig. 2.5) and pH for each field. Values for other soil characteristic, such as clay content, bulk density, slope length, erodibility factor, organic carbon content, and hydrologic group were estimated from the Delaware County Soil Survey (Table 2.2).

There are 178 different fields in the study area (Table 2.3); they can be grouped into 6 land use types (Table 2.4). Pasture and woodlands cover more than 90% of the watershed. The crop cover factors (C) associated with the various land use types were determined from the SCS Agriculture Handbook 537. An average annual C value of 0.003 was used for fields that are considered pasture, meadow-hay, urban and homesteads. Average annual C values of 0.001 and 0.1 were used for woodlands and cropped lands, respectively. Curve numbers (CNs) were estimated based on land use cover and hydrologic soil group (Fig. 2.6).

B. RESULTS

The watershed drainage network and corresponding subwatershed boundaries were delineated based on a threshold network density value of 400 (Fig. 2.7). This threshold value provided the best visual match to the first- and second-order streams presented in the USGS maps at 1:24,000 scale. Also, cell slopes (Fig. 2.8), distance to nearest stream (Fig. 2.9) and slope of that distance (Fig. 2.1 0) were estimated by the DTM.

Annual runoff volume, sediment loss and P loading estimates for each of the 40 1-yr simulation runs are summarized in Table 2.5. Average values for 1 to 40 years were computed and plotted to determine the number of simulation years needed to overcome the effect of the weather data on the long-term average values. Figures 2.11 and 2.12 show that a simulation period of at least 20 years is needed before the changes in average values reach a negligible stage.

A computer simulation with 20 years of rainfall records (1970-1989) was conducted. SIMPLE generated 5 files that include total predicted runoff volume, sediment loss and P loadings for each cell in the watershed. These files were imported into GRASS, and graphical representations of the results were generated (Fig. 2.13-2.17).

The results predicted at cell levels were summarized and annual average values for runoff, sediment and P loadings were computed for each field. The fields were then ranked in ascending order based on their total P loading (Table 2.6). Average annual total P loading was also computed for each land use type (Table 2.7). Average annual total P loading ranged between 0 kg/ha (fields 185) and 9.35 kg/ha (field 88). Field 88 had the highest dissolved P loading (9.35 kg/ha) and field 5 had the highest sediment-bound P loading (3.05 kg/ha). Predicted P loadings from woods and homesteads were significantly smaller than cropped fields, pastures, and meadow-hay fields.

Table 2.1 - Soil types located within the Battle Branch watershed.

#*	Description	Area (ac)	Area (ha)	% Cover
2	Baxter silt loam, 1 to 3 % slopes	294.00	118.98	5.32
3	Baxter cherry silt loam, 1 to 3 % slopes	677.62	274.23	12.26
4	Baxter Locust complex, 3 to 5 % slopes	705.87	285.66	12.77
5	Captina silt loam, 1 to 3 % slopes	397.63	160.92	7.19
8	Clarksville very cherty silt loam, 1 to 8 % slopes	382.07	154.62	6.91
9	Clarksville stony silt loam, 5 to 20 % slopes	677.40	274.14	12.25
10	Clarksville stony silt loam, 20 to 50 % slopes	845.08	342.00	15.28
19	Jay silt loam, 0 to 2 % slopes	44.26	17.91	0.80
21	Locust cherty silt loam, 1 to 3 % slopes	140.11	56.70	2.53
22	Newtonia silt loam, 0 to 1 % slopes	40.47	16.38	0.73
23	Newtonia silt loam, 1 to 3 % slopes	93.85	37.98	1.70
33	Sallisaw silt loam, 0 to 1 % slopes	6.45	2.61	0.12
34	Sallisaw silt loam, 1 to 3 % slopes	68.94	27.90	1.25
35	Sallisaw gravelly silt loam, 1 to 3 % slopes	98.52	39.87	1.78
36	Sallisaw gravelly silt loam, 3 to 8 % slopes	318.68	128.97	5.76
37	Staser silt loam	144.11	58.32	2.61
38	Staser gravelly loam	345.82	139.95	6.25
39	Stigler silt loam, 0 to 1 % slopes	203.04	82.17	3.67
41	Taloka silt loam, 0 to 1 % slopes	44.92	18.18	0.81
Total		5528.84	2237.49	100.00

* Soil reference number

Table 2.2 - Soil characteristics used by SIMPLE for Battle Branch watershed.

# *	K	pH	% OC	% Clay	BD	HGRP	λ

2	0.33	5.25	1.76	19	1.37	B	152
3	0.33	5.50	1.76	19	1.37	B	152
4	0.33	5.50	1.76	19	1.37	B	121
5	0.36	5.50	1.18	12	1.43	B	152
8	0.39	4.80	0.74	12	1.46	B	15
9	0.43	4.80	0.74	25	1.43	B	60
10	0.43	4.80	0.74	25	1.43	B	30
19	0.37	5.80	1.18	18	1.51	C	167
21	0.40	5.00	0.59	12	1.48	B	152
22	0.37	6.10	1.18	18	1.41	B	182
23	0.37	6.10	1.18	18	1.41	B	152
33	0.41	6.45	0.74	33	1.46	B	15
34	0.41	6.45	0.74	33	1.46	B	15
35	0.39	6.45	0.74	12	1.46	B	15
36	0.39	6.45	0.74	12	1.46	B	15
37	0.34	6.45	1.76	25	1.35	B	15
38	0.34	6.45	1.76	25	1.35	B	15
39	0.36	5.00	1.18	12	1.43	D	182
40	0.44	5.55	0.44	25	1.45	D	182

*#: soil reference number
K: USLE erodibility factor (English units)
pH: pH level
% OC: percent organic carbon content
% Clay: percent clay content
BD: bulk density (g/cm^3)
HGRP: hydrologic soil group
λ: USLE slope length (m)

2.4

Table 2.3 - Fields descriptions for the Battle Branch watershed.

# *	Description	Area	Area (ha)	% Cover
1	Max Shelley – S of barn	9.56	3.87	0.17
2	Max Shelley - 2nd bench, N of barn	9.56	3.87	0.17
3	Max Shelley - 1st bench, N of barn	12.89	5.22	0.23
4	Max Shelley - S of road	3.55	1.44	0.06
5	Max Shelley - N of house	3.11	1.26	0.06
6	Max Shelley - hillside, N of barn	25.79	10.44	0.47
7	Max Shelley - N of broiler house	6.00	2.43	0.11
8	Jack Smith - S field	5.78	2.34	0.10
9	Jack Smith - N field, horse pasture	24.68	9.99	0.45
10	Jack Smith - N of pond and chicken house	8.89	3.60	0.16
11	Jack Smith - N of house	9.34	3.78	0.17
12	Keith Mitchell - N field (woods)	2.00	0.81	0.04
13	Keith Mitchell - chicken house pasture	3.55	1.44	0.06
14	Keith Mitchell - newly cleared ground	21.79	8.82	0.39
16	Keith Mitchell - calf pasture	3.33	1.35	0.06
17	Keith Mitchell - NE of chicken house	8.89	3.60	0.16
18	Keith Mitchell - wheat pasture, E of chicken	2.22	0.90	0.04
19	Bill Lovelace - S hilltop	14.90	6.03	0.27
20	Bill Lovelace - fescue field	11.78	4.77	0.21
21	Bill Lovelace - bermuda, W of creek	4.44	1.80	0.08
22	Bill Lovelace - W high pasture	9.56	3.87	0.17
23	Bill Lovelace - bottom, N of house	1.55	0.63	0.03
24	Bill Lovelace - hickory nut hollow	5.11	2.07	0.09
25	Bill Lovelace - W along creek	11.78	4.77	0.21
26	Bill Lovelace - bottom, E along creek	9.11	3.69	0.16
27	Bill Lovelace - W hay meadow	12.23	4.95	0.22
28	Joe Martin - S one-half of N 40 acres	13.79	5.58	0.25
29	Joe Martin - W of turkey houses	8.45	3.42	0.15
30	Joe Martin - middle field	26.01	10.53	0.47
31	Joe Martin - N one-half of N 40 acres	12.00	4.86	0.22
32	Joe Martin - hay field	25.35	10.26	0.46
33	Joe Martin - S of house	5.78	2.34	0.10
34	Joe Martin - bull pasture	1.77	0.72	0.03
35	Toady Yeckel - horse pasture	5.33	2.16	0.10
36	Toady Yeckel - W hay meadow	5.55	2.25	0.10
37	Toady Yeckel - middle hay meadow	24.90	10.08	0.45
38	Toady Yeckel - E hay meadow	10.89	4.41	0.20
39	Mike Thompson - field at end of chicken house	2.66	1.08	0.05
40	Mike Thompson - first bench SE of chicken	6.22	2.52	0.11
41	Mike Thompson - creek bottom SE of house	3.55	1.44	0.06
42	Mike Thompson - field by cabin	4.89	1.98	0.09
43	Mike Thompson - S field to property line	8.22	3.33	0. 15

Table 2.3 (continued) Fields descriptions for the Battle Branch watershed.

#*	Description	Area	Area (ha)	% Cover

44	Mike Thompson - second field N of property line	8.22	3.33	0.15
45	Mike Thompson - E field, W of old barn	1.77	0.72	0.03
46	Carl Denny - W of house	9.34	3.78	0.17
47	Carl Denny - S of pond	8.00	3.24	0.14
48	Carl Denny - E of house	10.67	4.32	0.19
49	Carl Denny - N of creek, E of Mike Thompson	7.56	3.06	0.14
50	Carl Denny - high-line field	4.00	1.62	0.07
51	Carl Denny - S of road	3.33	1.35	0.06
52	Carl Denny - field E of Mike Thompson	6.89	2.79	0.12
53	Marion Duncan - E of hay shed	13.78	5.58	0.25
54	Marion Duncan - S forty acres	34.91	14.13	0.63
55	Marion Duncan - wild meadow	4.00	1.62	0.07
56	Marion Duncan - by pond	17.34	7.02	0.31
57	Marion Duncan - cave field	9.11	3.69	0.16
58	Marion Duncan - NE hay meadow	12.00	4.86	0.22
59	Tim Billips - S of house	8.67	3.51	0.16
60	Kenneth Riley - S of house	14.01	5.67	0.25
61	Kenneth Riley - SW of house	9.34	3.78	0.17
64	Ronald Duncan - silage field	20.23	8.19	0.37
65	Ronald Duncan - little calves	4.89	1.98	0.09
67	Ronald Duncan - red top field	15.78	6.39	0.29
68	Ronald Duncan - bermuda grass hay meadow	25.57	10.35	0.46
69	Ronald Duncan - calf pasture	4.44	1.80	0.08
70	Ronald Duncan - Raymond's bermuda grass	2.89	1.17	0.05
71	Ronald Duncan - day pasture	44.92	18.18	0.81
73	Ronald Duncan - hay field, E of house	8.45	3.42	0.15
74	Ronald Duncan - S hay field, across road	16.45	6.66	0.30
75	Ronald Duncan - SW hay field, 10 acres	7.33	2.97	0.13
76	Ronald Duncan - fescue field	3.78	1.53	0.07
77	Ronald Duncan - night side	21.79	8.82	0.39
78	Leroy Chamberlain - N of house	2.22	0.90	0.04
79	Leroy Chamberlain - SE of barn	26.01	10.53	0.47
80	Leroy Chamberlain - pasture S of barn	25.35	10.26	0.46
81	Leroy Chamberlain - fescue S of cow pasture	19.79	8.01	0.36
82	Leroy Chamberlain - N of barn	51.37	20.79	0.93
83	Leroy Chamberlain - N field	18.23	7.38	0.33
84	Leroy Chamberlain - bermuda grass	0.22	0.09	0.00
85	Leroy Chamberlain - S of city road, E of barn	17.12	6.93	0.31
86	Charles Chamberlain - N of pond	16.01	6.48	0.29
87	Charles Chamberlain - N 20 acres	17.34	7.02	0.31
88	Charles Chamberlain - E of house, between	19.57	7.92	0.35
89	Charles Chamberlain - N of house	17.56	7.11	0.32

Table 2.3 (continued) Fields descriptions for the Battle Branch watershed.

#*	Description	Area	Area (ha)	% Cover
90	Eddy Martin - E of house	29.35	11.88	0.53
91	Eddy Martin - S of county road	27.35	11.07	0.49

92	Eddy Martin - W and S of county road	40.91	16.56	0.74
93	Vernon Stevens - hay meadow	14.23	5.76	0.26
94	Joe Chamberlain - E of barn	35.13	14.22	0.64
95	Willis Price - N pasture	12.67	5.13	0.23
96	Willis Price - W pasture	4.00	1.62	0.07
97	Willis Price - S pasture	10.22	4.14	0.19
98	Ronnie Amos - N 40 acres	35.36	14.31	0.64
99	Ronnie Amos - W 40 acres	34.24	13.86	0.62
100	Ronnie Amos - S 40 acres	42.03	17.01	0.76
101	Bill Beck - N of road	36.24	14.67	0.66
102	James Chamberlain - top pasture	46.03	18.63	0.83
103	James Chamberlain - bottom pasture	20.23	8.19	0.37
104	James Chamberlain - W side	22.01	8.91	0.40
105	Junior Robinson - hay meadow	15.78	6.39	0.29
106	Junior Robinson - N pasture	17.34	7.02	0.31
107	Clinton Jenks - meadow between barns	34.02	13.77	0.62
108	Clinton Jenks - SE pasture	65.16	26.37	1.18
109	Clinton Jenks - E pasture	47.81	19.35	0.86
110	Clinton Jenks - W pasture	18.68	7.56	0.34
111	Mark Mowery - N of house	20.23	8.19	29.35
112	L. E. Larmen - back of house	15.78	6.39	27.35
113	Imogene Cockrell - S of house	9.56	3.87	40.91
114	Imogene Cockrell - W of house	4.00	1.62	0.07
115	Jerral Shelley - field 1	22.90	9.27	0.41
116	Jerral Shelley - field 2	15.56	6.30	0.28
117	Jerral Shelley - field 3	18.45	7.47	0.33
118	Jerral Shelley - field 4	18.45	7.47	0.33
119	Roy Hurt - S of house	9.34	3.78	0.17
120	Edward Billups - E fescue	18.90	7.65	0.34
121	Edward Billups - N of house	10.45	4.23	0.19
122	Edward Billups - bermuda grass field	17.79	7.20	0.32
123	Edward Billups - by church	9.56	3.87	0.17
124	Jim Sumpter - S of house	5.33	2.16	0.10
125	Sanfords Place - N center field	45.36	18.36	0.82
126	Sanfords Place - NE pasture	32.69	13.23	.59
127	Sanfords Place - S bottom	19.79	8.01	0.36
128	Sanfords Place - SE bermuda grass	45.14	18.27	0.82
129	Sanfords Place - E of trailer	12.00	4.86	0.22
130	Sanfords Place - SE of trailer	9.78	3.96	0.18
131	Sanfords Place - SW of trailer	.56	3.87	0.17

Table 2.3 (continued) Fields descriptions for the Battle Branch watershed.

#*	Description	Area	Area (ha)	% Cover
132	Sanfords Place - NW of trailer, NW corner	1.77	0.72	0.03
133	Sanfords Place - NE of trailer	23.35	9.45	0.42
134	Marlyn Potter - E of Courtney's	0.66	0.27	0.01

135	Marlyn Potter - E of pond	3.11	1.26	0.06
136	Marlyn Potter - NW of pond	6.22	2.52	0.11
137	Marlyn Potter - SE of pond	8.00	3.24	0.14
140	Ricky Reed - E bermuda grass	10.00	4.05	0.18
141	Ricky Reed - E of house	4.89	1.98	0.09
142	George Porter - bermuda grass by old house	13.12	5.31	0.24
143	George Porter - fescue	6.67	2.70	0.12
144	George Porter - proposed alfalfa field	6.22	2.52	0.11
145	George Porter - home 40 acres	28.91	11.70	0.52
146	Clark-Beals Ranch - SE 40 acres, E of red barn	31.57	12.78	0.57
147	Clark-Beals Ranch - SW 1 00 acres, red barn	100.85	41.22	1.84
148	Clark-Beals Ranch - S pasture, NW of ponds	28.46	11.52	0.51
149	Clark-Beals Ranch - SE hay field	48.48	19.62	0.88
150	Clark-Beals Ranch - bermuda grass W of house	25.57	10.35	0.46
151	Clark-Beals Ranch - S of house	11.34	4.59	0.21
152	Clark-Beals Ranch - N center 80 acres	72.27	29.25	1.31
153	Clark-Beals Ranch - NE 80 acres	33.35	13.50	0.60
154	Jackie Londagin - NE pasture	11.34	4.59	0.21
155	Jackie Londagin - NW pasture	17.12	6.93	0.31
156	Jackie Londagin - E center fescue	6.00	2.43	0.11
157	Jackie Londagin - 50 acre fescue hay field	42.47	17.19	0.77
158	Jackie Londagin - S 20 acres bermuda grass	15.34	6.21	0.28
159	E. Ford - N 40 acres	34.69	14.04	0.63
160	E. Ford - S 40 acres	10.89	4.41	0.20
163	Joe Stansell - SW SE, Sect. 29 (40 acres)	2.66	1.08	0.05
164	Joe Stansell - SE SW, Sect. 29 (30 acres)	2.66	1.08	0.05
165	Joe Stansell - bermuda grass field, section 30	32.69	13.23	0.59
166	Susie Cockrel - S 40 acres	40.47	16.38	0.73
167	Bud Duncan - E of house	0.44	0.18	0.01
168	Bud Duncan - SE of house	16.01	6.48	0.29
169	Bud Duncan - S and E of broiler house	24.01	9.72	0.43
170	Bud Duncan - N and W of broiler house	31.35	12.69	0.57
171	Bud Duncan - 20 acres W of road	12.45	5.04	0.23
172	Leo Chamberlain - E 40 acres	43.58	17.64	0.79
173	Leo Chamberlain - W 40 acres	14.01	5.67	0.25
174	Leo Chamberlain - Sue Mills place	37.13	15.03	0.67
175	Charles Kaiser - E of house	15.78	6.39	0.29
176	Charles Kaiser - S of house	22.01	8.91	0.40

Table 2.3 (continued) Fields descriptions for the Battle Branch watershed.

# *	Description	Area	Area (ha)	% Cover
177	Floyd Hager - E of house	40.91	16.56	0.74
178	John Londagin - bermuda grass S of house	20.01	8.10	0.36
179	John Londagin - fescue S of house	20.45	8.28	0.37
181	Ralph Chamberlain - E of house	19.57	7.92	0.35
182	Ralph Chamberlain - S of house	18.23	7.38	0.33

183	Richard Harris - W of house	2.00	0.81	0.04
185	Forest	1855.62	750.96	33.56
186	Grassland	547.52	221.58	9.90
188	Homestead	110.97	44.91	2.01
189	Dairy	4.67	1.89	0.08
190	Poultry	12.67	5.13	0.23
TOTAL		5528.84	2237.49	100.00

* Field reference number

Table 2.4 - Generalized land uses within the Battle Branch watershed.

# *	Description	Area (ac)	Area (ha)	% Cover
1	Pasture	3179.73	1286.82	57.51
2	Woods	1857.62	751.77	33.6
3	Meadow-hay	314.01	127.08	5.68
4	Cropped Land	20.24	8.19	0.37
5	Urban	46.26	18.72	0.84
6	Homesteads	110.97	44.91	2.01
TOTAL		5528.84	2237.49	100

* Land use reference number

Table 2.5 - Annual runoff volume, soil loss, and P loading generated by the 40 1-yr simulations for Battle Branch watershed.

				Phosphorus Loading		
Year	Rainfall (cm)	Runoff Volume (cm)	Soil Loss (Mg/ha)	Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
1	128.94	12.72	0.04	0.75	0.04	0.79
2	122.38	4.65	0.01	0.29	0.02	0.30
3	88.51	7.17	0.02	0.44	0.02	0.46
4	90.65	2.58	0.01	0.16	0.01	0.17
5	89.83	4.94	0.01	0.31	0.02	0.32

6	95.98	1.37	0	0.08	0.01	0.09
7	98.39	2.38	0.01	0.15	0.01	0.16
8	158.55	11.07	0.03	0.68	0.04	0.73
9	115.61	6.25	0.02	0.39	0.02	0.41
10	100.04	2.6	0.01	0.16	0.01	0.17
11	108.16	19.67	0.06	1.15	0.05	1.20
12	145.07	13.63	0.03	0.82	0.04	0.86
13	122.37	8.26	0.02	0.51	0.03	0.54
14	54.99	1.56	0.01	0.1	0.01	0.11
15	91.67	4.33	0.01	0.26	0.02	0.28
16	100.73	3.81	0.01	0.24	0.01	0.25
17	95.54	5.49	0.02	0.28	0.02	0.30
18	97.57	4.62	0.01	0.29	0.02	0.30
19	116.31	2.29	0.01	0.14	0.01	0.16
20	114.71	10.73	0.03	0.59	0.04	0.63
21	111.16	4.93	0.02	0.29	0.03	0.32
22	88.93	3.1	0.01	0.19	0.01	0.20
23	103.96	10.3	0.03	0.63	0.04	0.66
24	165.67	8.8	0.02	0.54	0.03	0.57
25	133.57	10.82	0.02	0.67	0.04	0.70
26	124.13	3.87	0.02	0.23	0.02	0.25
27	79.63	1.94	0.01	0.12	0.01	0.13
28	103.58	2.81	0.01	0.17	0.02	0.19
29	108.81	5.91	0.02	0.37	0.02	0.39
30	95.54	0.74	0	0.04	0	0.04
31	71.3	1.1	0	0.07	0.01	0.07
32	114.21	3.64	0.01	0.22	0.02	0.23
33	135.16	21.96	0.06	1.3	0.07	1.36
34	94.16	2.23	0	0.13	0.01	0.14
35	127.08	3.7	0.01	0.23	0.02	0.25
36	134.95	9.34	0.02	0.58	0.03	0.61
37	133.38	14.26	0.03	0.86	0.04	0.90
38	123.16	5.3	0.02	0.33	0.02	0.36
39	102.88	3.53	0.01	0.14	0.01	0.15
40	94.69	1.67	0	0.11	0.01	0.1

Table 2.6 - Predicted average annual runoff volume, sediment loss and P loadings for each field in the Battle Branch watershed.

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading: Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
185	6.17	0.00	0.00	0.00	0.00

12	6.27	0.00	0.05	0.00	0.05
190	30.27	0.00	0.17	0.00	0.17
189	29.75	0.00	0.43	0.00	0.43
188	17.35	0.00	0.58	0.00	0.58
145	30.00	0.05	1.49	0.06	1.56
144	10.12	0.32	2.18	0.33	2.51
84	7.32	0.00	3.62	0.00	3.62
134	7.32	0.00	3.64	0.00	3.64
122	8.16	0.02	3.85	0.10	3.95
164	8.02	0.01	3.93	0.08	4.01
137	8.33	0.01	4.04	0.04	4.08
163	8.25	0.02	4.04	0.13	4.17
79	8.94	0.00	4.19	0.01	4.20
183	7.94	0.01	4.10	0.10	4.21
115	8.73	0.02	4.14	0.10	4.24
135	8.92	0.00	4.27	0.00	4.27
92	9.43	0.02	4.19	0.08	4.27
38	8.75	0.02	4.23	0.08	4.31
50	10.12	0.07	4.11	0.25	4.37
74	8.91	0.01	4.36	0.05	4.41

			Phosphorous Loading		
Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
97	10.06	0.00	4.47	0.00	4.47
70	8.61	0.04	4.20	0.29	4.49
69	9.98	0.00	4.50	0.00	4.50
19	9.66	0.02	4.44	0.07	4.51

136	8.42	0.01	4.46	0.05	4.51
68	9.31	0.00	4.51	0.01	4.51
56	10.12	0.04	4.35	0.17	4.51
154	9.02	0.01	4.49	0.07	4.56
54	10.12	0.01	4.50	0.06	4.56
111	10.09	0.00	4.56	0.01	4.57
65	9.48	0.00	4.58	0.00	4.58
94	9.71	0.00	4.59	0.00	4.59
80	9.90	0.01	4.58	0.03	4.61
102	10.08	0.01	4.59	0.03	4.62
150	8.75	0.02	4.51	0.12	4.63
165	9.41	0.02	4.51	0.11	4.63
61	10.12	0.04	4.46	0.17	4.63
128	9.90	0.08	4.33	0.31	4.64
129	9.91	0.00	4.64	0.00	4.64
78	9.56	0.03	4.44	0.20	4.64
105	9.21	0.00	4.65	0.00	4.65
60	10.12	0.01	4.59	0.08	4.67
116	9.92	0.00	4.65	0.02	4.67

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading Dissolved (kg/ha)	Phosphorous Loading Sediment-bound (kg/ha)	Phosphorous Loading Total (kg/ha)
124	10.12	0.00	4.68	0.00	4.68
130	10.05	0.00	4.68	0.00	4.68
75	9.01	0.00	4.69	0.00	4.69
107	8.67	0.00	4.69	0.00	4.69
81	9.20	0.01	4.63	0.07	4.69
166	9.30	0.02	4.52	0.17	4.69

90	9.93	0.01	4.65	0.05	4.70
16	10.12	0.00	4.71	0.00	4.71
133	10.01	0.01	4.69	0.06	4.75
73	9.67	0.00	4.76	0.00	4.76
93	10.03	0.02	4.69	0.07	4.76
8	10.01	0.06	4.44	0.33	4.76
112	10.08	0.03	4.61	0.16	4.77
117	9.75	0.03	4.65	0.13	4.78
131	9.79	0.01	4.70	0.10	4.80
101	10.94	0.00	4.81	0.00	4.81
95	10.07	0.06	4.57	0.24	4.81
57	10.05	0.05	4.55	0.25	4.81
14	10.12	0.00	4.82	0.00	4.82
10	9.63	0.00	4.84	0.00	4.84
37	9.99	0.04	4.67	0.19	4.85
104	10.00	0.05	4.60	0.26	4.86
11	9.05	0.01	4.78	0.10	4.88
110	9.18	0.00	4.87	0.02	4.88

2.13

			Phosphorous Loading		
Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
28	10.12	0.00	4.89	0.01	4.89
41	8.54	0.02	4.69	0.21	4.90
51	10.12	0.09	4.50	0.40	4.90
46	10.12	0.00	4.91	0.00	4.91
47	10.12	0.00	4.91	0.00	4.91
20	10.12	0.05	4.68	0.24	4.92
173	9.54	0.00	4.91	0.01	4.92

132	9.77	0.03	4.66	0.26	4.92
176	10.54	0.02	4.81	0.11	4.92
108	10.02	0.04	4.72	0.22	4.94
113	10.05	0.07	4.64	0.31	4.95
91	10.76	0.01	4.90	0.05	4.95
120	9.98	0.11	4.51	0.44	4.95
159	9.85	0.03	4.75	0.21	4.96
118	9.78	0.09	4.53	0.44	4.97
143	10.12	0.00	4.95	0.02	4.97
175	8.78	0.00	4.95	0.03	4.97
9	9.76	0.00	4.97	0.00	4.98
160	10.12	0.05	4.74	0.24	4.98
44	10.12	0.04	4.79	0.21	5.00
23	8.52	0.00	4.96	0.04	5.00
59	9.97	0.06	4.74	0.31	5.05
123	9.66	0.14	4.45	0.65	5.10
125	9.99	0.16	4.44	0.67	5.11
155	9.10	0.02	4.94	0.17	5.11

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
31	10.12	0.01	5.10	0.02	5.12
126	10.08	0.18	4.41	0.71	5.12
109	9.93	0.00	5.13	0.00	5.13
58	10.12	0.04	4.89	0.24	5.13
77	10.00	0.00	5.14	0.01	5.15
42	9.73	0.15	4.56	0.61	5.17
34	10.12	0.03	5.01	0.16	5.17
39	10.12	0.24	4.33	0.85	5.18

76	9.79	0.01	5.11	0.09	5.20
96	10.12	0.17	4.52	0.72	5.24
142	10.12	0.00	5.28	0.00	5.28
67	9.92	0.01	5.25	0.05	5.30
83	11.95	0.01	5.25	0.07	5.32
170	9.34	0.03	5.07	0.25	5.32
156	10.01	0.12	4.64	0.68	5.32
121	9.94	0.19	4.45	0.91	5.35
146	10.81	0.00	5.37	0.00	5.37
186	9.85	0.00	5.34	0.03	5.37
151	9.95	0.03	5.22	0.17	5.39
148	9.81	0.05	5.08	0.31	5.39
36	9.89	0.08	4.93	0.47	5.39
140	9.68	0.03	5.23	0.18	5.41
29	10.04	0.01	5.35	0.05	5.41
30	10.09	0.00	5.42	0.00	5.42

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
21	10.12	0.05	5.13	0.31	5.44
49	10.12	0.11	4.78	0.67	5.45
13	9.77	0.03	5.26	0.20	5.46
48	10.12	0.01	5.44	0.05	5.49
114	10.12	0.23	4.42	1.09	5.52
17	10.12	0.03	5.35	0.20	5.55
2	10.12	0.04	5.32	0.23	5.55
45	9.42	0.07	5.04	0.51	5.55

157	9.93	0.03	5.36	0.19	5.55
24	9.99	0.10	4.90	0.65	5.56
25	9.80	0.09	4.94	0.62	5.57
71	10.03	0.09	5.16	0.43	5.59
158	9.95	0.11	4.95	0.63	5.59
32	10.09	0.07	5.27	0.33	5.60
27	10.12	0.08	5.14	0.46	5.60
7	10.12	0.15	4.99	0.62	5.61
152	10.77	0.00	5.60	0.01	5.61
141	10.12	0.08	5.14	0.48	5.62
167	10.12	0.00	5.61	0.02	5.63
106	10.08	0.00	5.64	0.01	5.65
178	10.02	0.03	5.47	0.19	5.67
43	10.12	0.05	5.34	0.33	5.67
52	9.57	0.04	5.30	0.38	5.68
26	9.98	0.09	5.07	0.62	5.69

2.16

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading		
			Dissolved (kg/ha)	Sediment-bound (kg/ha)	Total (kg/ha)
168	10.04	0.01	5.64	0.05	5.69
177	12.73	0.01	5.64	0.05	5.69
55	10.12	0.09	5.06	0.64	5.70
172	9.78	0.01	5.63	0.07	5.70
22	10.05	0.05	5.42	0.29	5.72
147	10.07	0.11	5.18	0.58	5.76
53	9.98	0.07	5.36	0.47	5.83
35	10.12	0.04	5.51	0.35	5.86

3	9.78	0.06	5.47	0.40	5.87
6	10.12	0.14	5.35	0.54	5.89
179	9.81	0.05	5.52	0.38	5.90
174	11.06	0.00	5.89	0.02	5.91
33	9.79	0.06	5.46	0.47	5.93
98	12.14	0.00	5.95	0.00	5.95
127	9.93	0.18	4.99	1.05	6.04
103	10.02	0.26	4.87	1.21	6.08
40	10.12	0.05	5.74	0.39	6.1
1	10.12	0.11	5.46	0.68	6.14
86	11.92	0.00	6.161	0.00	6.16
99	14.17	0.00	6.18	0.00	6.18
64	19.85	0.03	6.21	0.01	6.22
119	10.05	0.15	5.53	0.76	6.29
181	11.95	0.01	6.25	0.08	6.33
4	10.12	0.10	5.67	0.69	6.37

2.17

Field Number	Runoff Volume (cm)	Soil Loss (Mg/ha)	Phosphorous Loading Dissolved (kg/ha)	Phosphorous Loading Sediment-bound (kg/ha)	Phosphorous Loading Total (kg/ha)
171	11.87	0.02	6.21	0.20	6.41
18	8.72	0.88	4.01	2.42	6.43
82	16.09	0.00	6.65	0.01	6.66
153	15.84	0.00	6.68	0.02	6.70
169	13.08	0.03	6.69	0.20	6.89
85	16.32	0.01	6.99	0.05	7.04
149	15.98	0.02	7.95	0.11	8.06
100	19.37	0.00	8.13	0.00	8.13
5	10.12	0.7	5.57	3.06	8.63

182	19.48	0.00	9.01	0.01	9.03
89	18.55	0.00	9.05	0.01	9.06
87	18.72	0.00	9.06	0.00	9.06
88	20.39	0.00	9.35	0.00	9.35

Table 2.7 - Predicted average annual runoff volume, sediment loss and phosphorous loadings by land use for the Battle Branch watershed.

Land Use	Runoff Volume	Soil Loss	Phosphorus Loading		
			Dissolved	Sediment	Total
	(cm)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
	Pasture 5.40	10.60	32.00	5.23	0.17
Forest	6.17	4.15	0.00	0.00	0.00
Meadow/hay	10.56	30.44	5.27	0.14	5.41
Crop	19.85	30.68	6.21	0.01	6.22
Urban	30.05	31.75	1.02	0.04	1.06
Homesteads	17.34	0.00	0.58	0.00	0.58

2.19

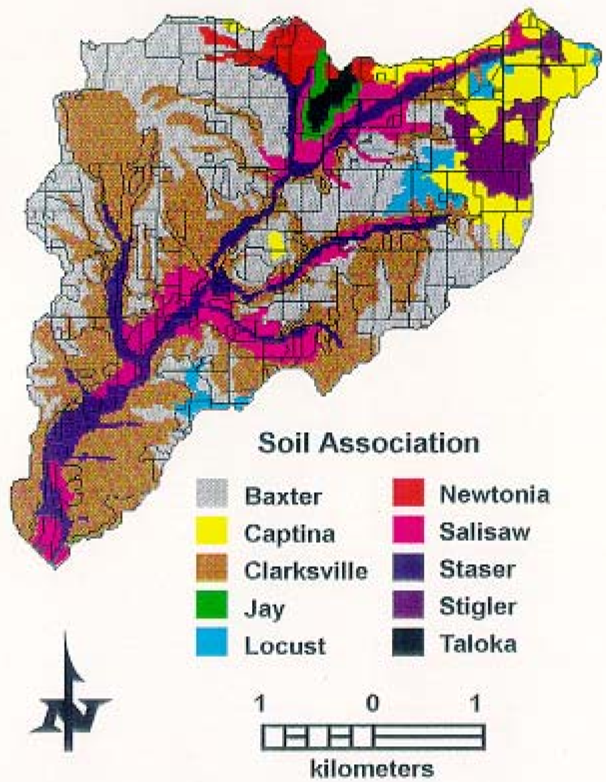

Figure 2.1 - Soil associations in the Battle Branch Watershed.

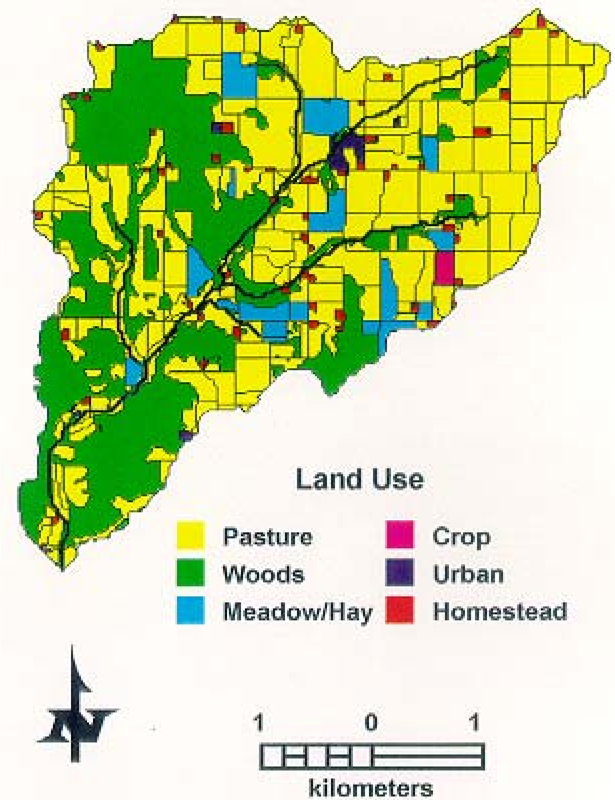

Figure 2.2 - Land use distribution in the Battle Branch Watershed.

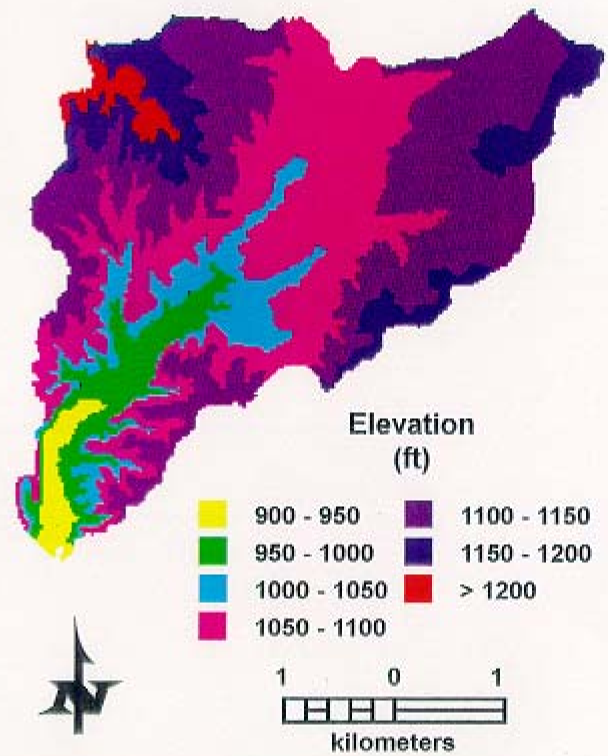

Figure 2.3 - Topography in the Battle Branch Watershed.

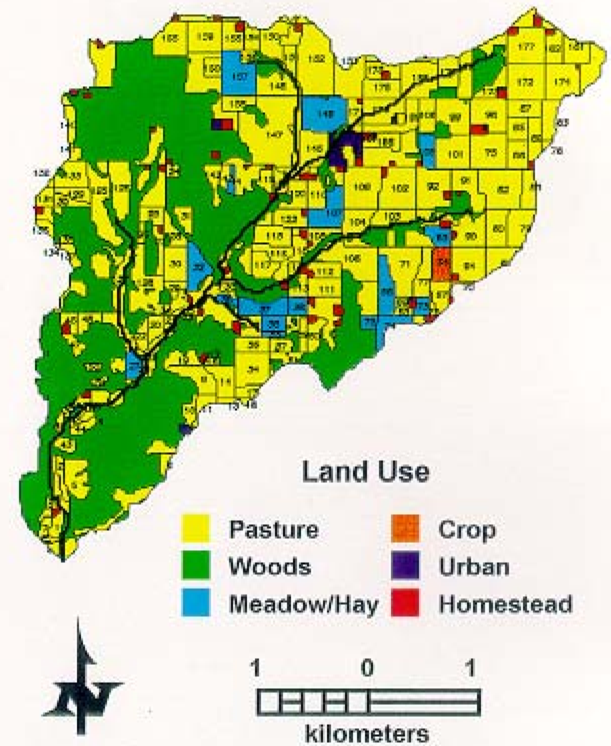

Figure 2.4 - Field numbers for the Battle Branch Watershed.

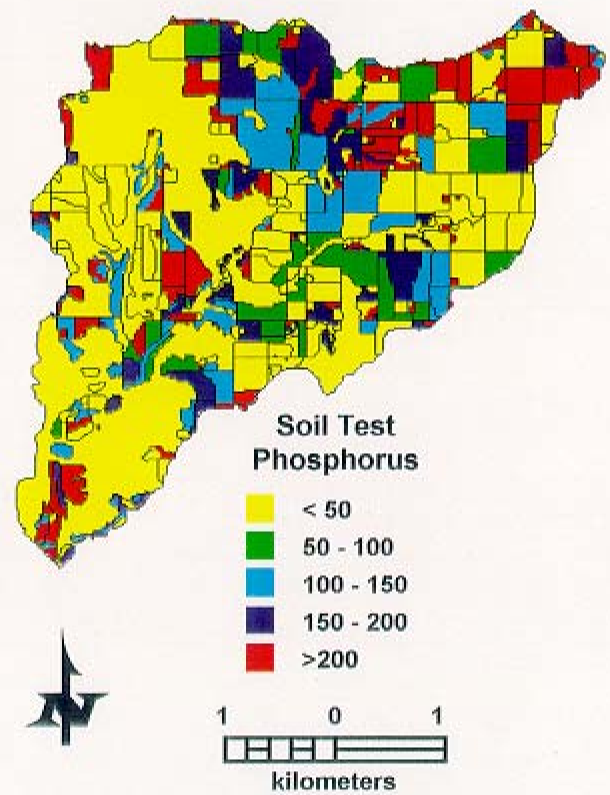

Figure 2.5 - Distribution of soil test phosphorus in the Battle Branch Watershed.

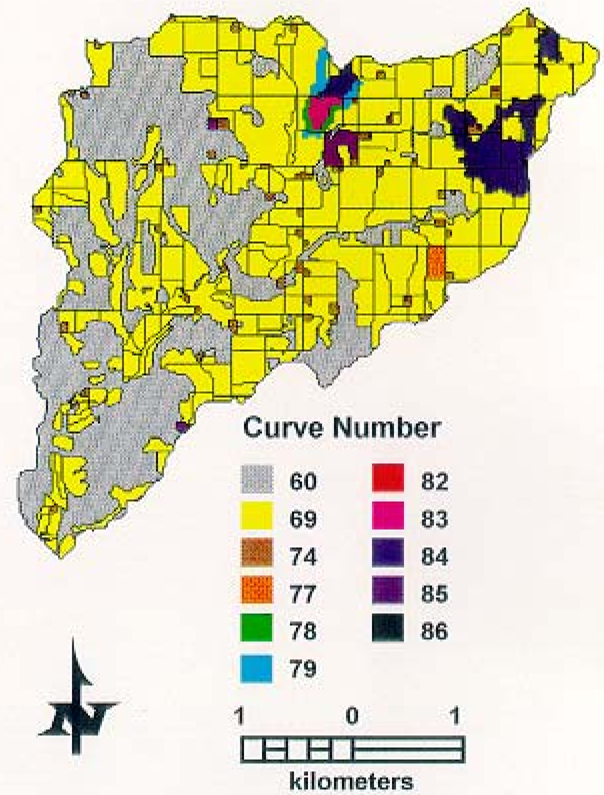

Figure 2.6 - Distribution of curve numbers in the Battle Branch Watershed.

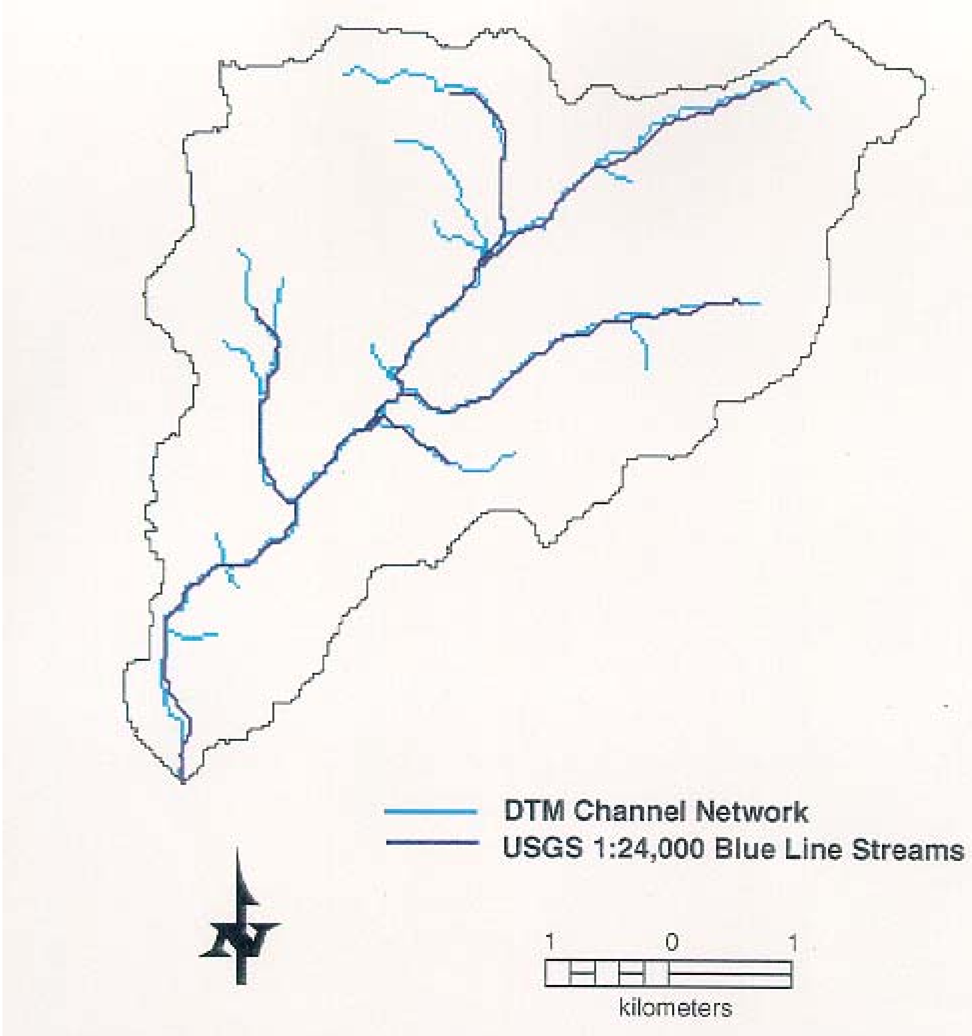

Figure 2.7 - Comparison between USGS 1:24,000 blue line streams and channels defined by the digital terrain model for a threshold value of 400 cells for Battle BranchWatershed

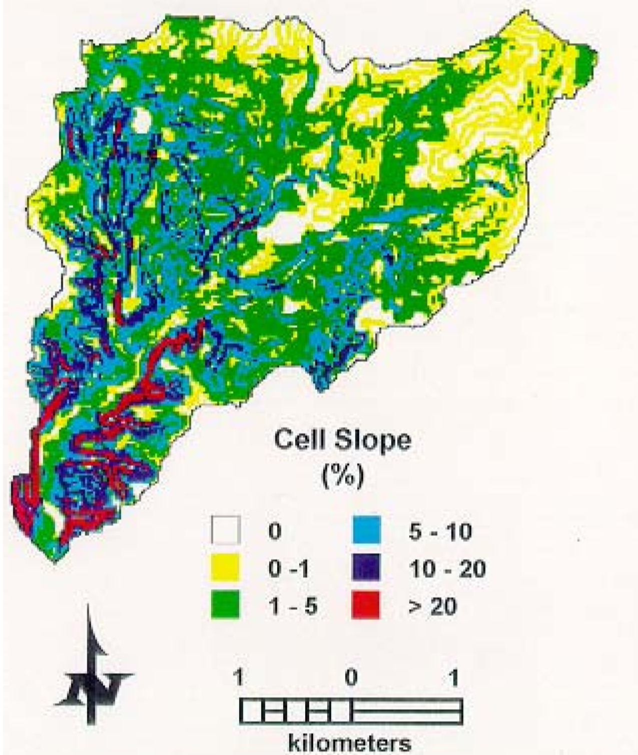

Figure 2.8 - Cell slope defined by the digital terrain model for Battle Branch Watershed.

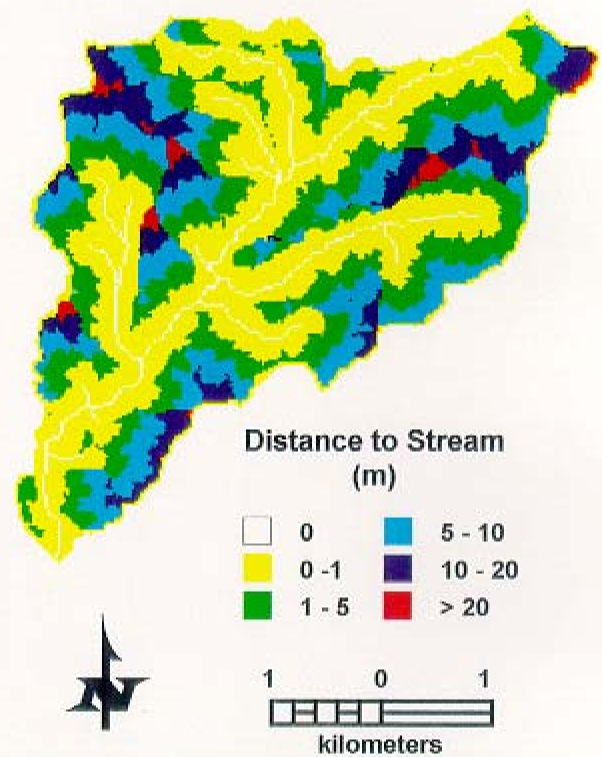

Figure 2.9 - Flow distance from cell to stream calculated by the digital terrain model using a threshold density of 400 cells for Battle Branch Watershed.

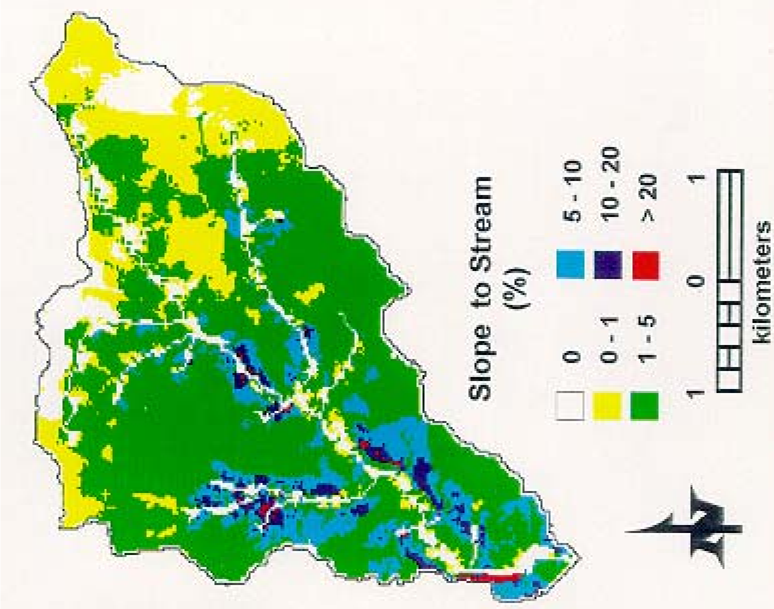

Figure 2.10 - Slope of flow path from cell to stream calculated by the digital terrain model using a threshold density of 400 cells for Battle Branch Watershed.

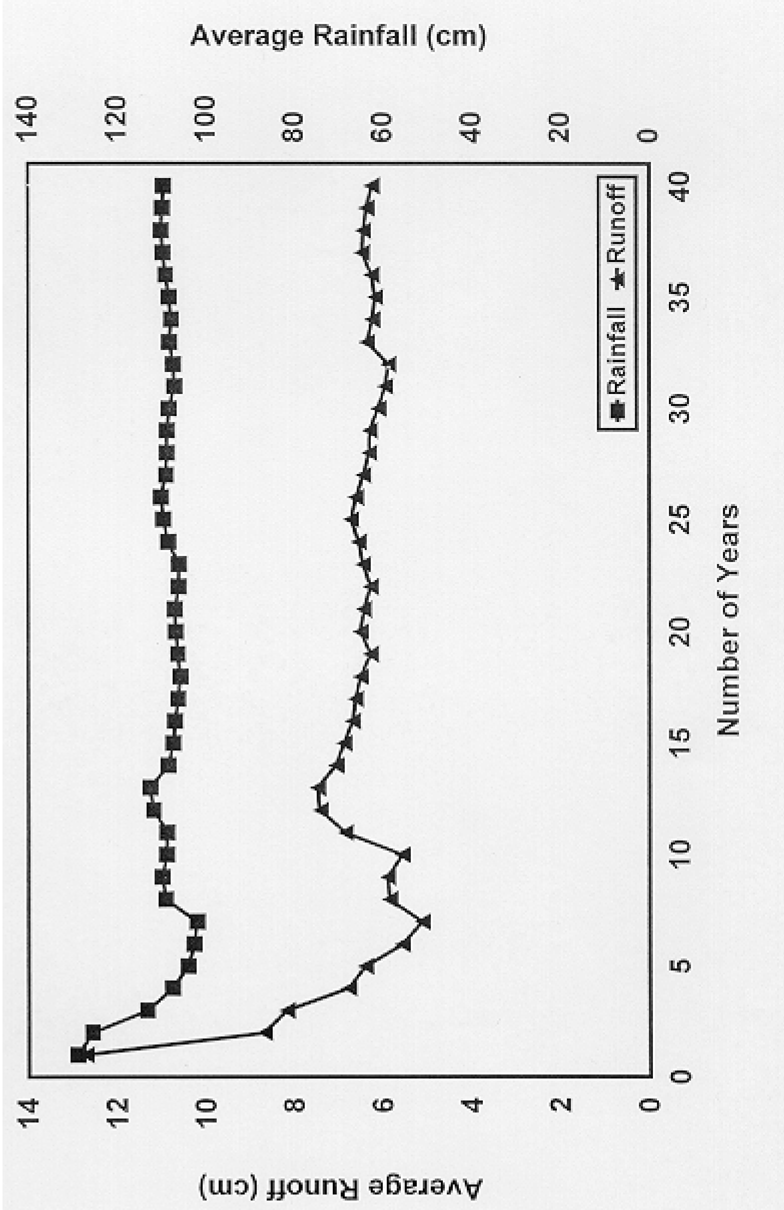

Figure 2.11 Predicted cumulative annual average rainfall and runoff using 40 one-year simulation runs for Battle Branch Watershed.

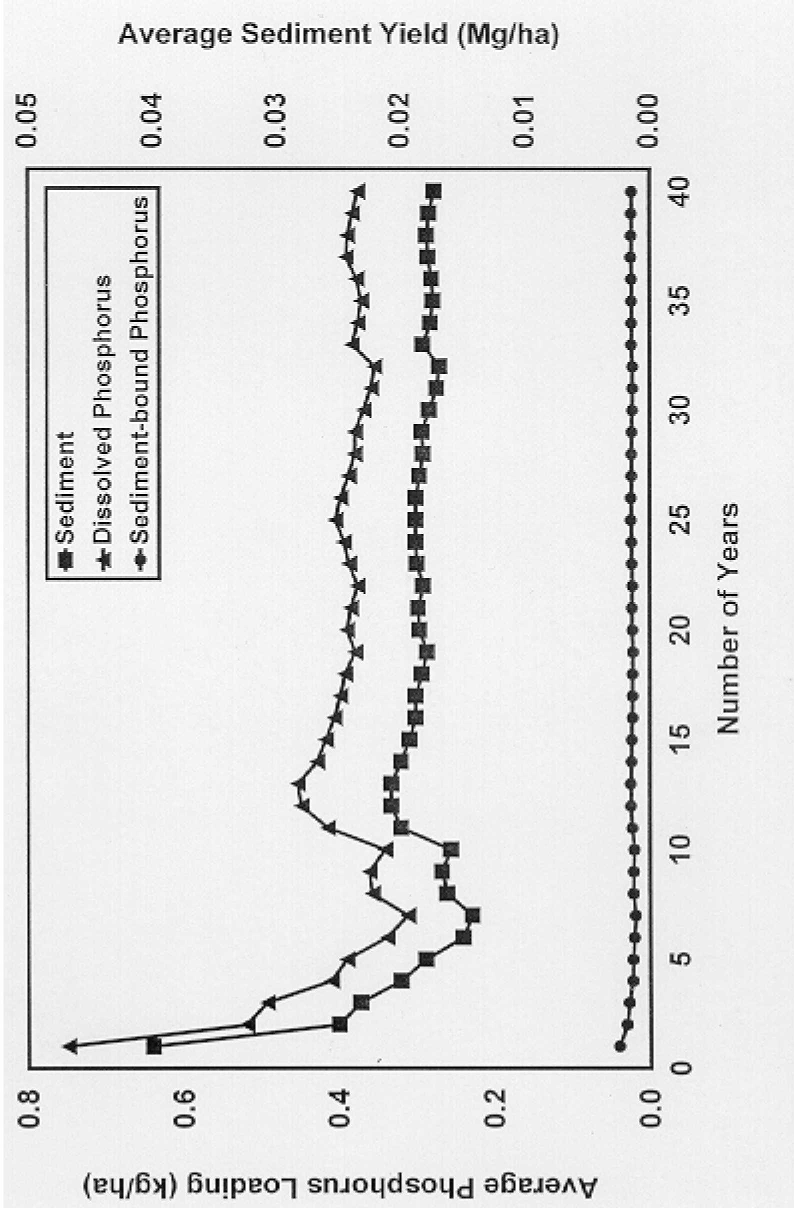

Figure 2.12 Predicted cumulative annual average sediment and total phosphorus loading using 40 one-year simulation runs for Battle Branch watershed.

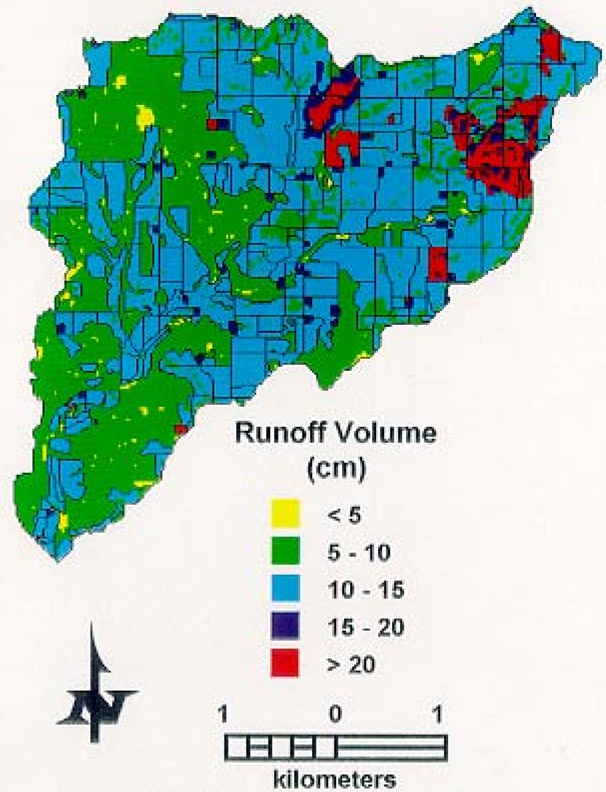

Figure 2.13 - Average annual runoff volume predicted by SIMPLE for Battle Branch Watershed.

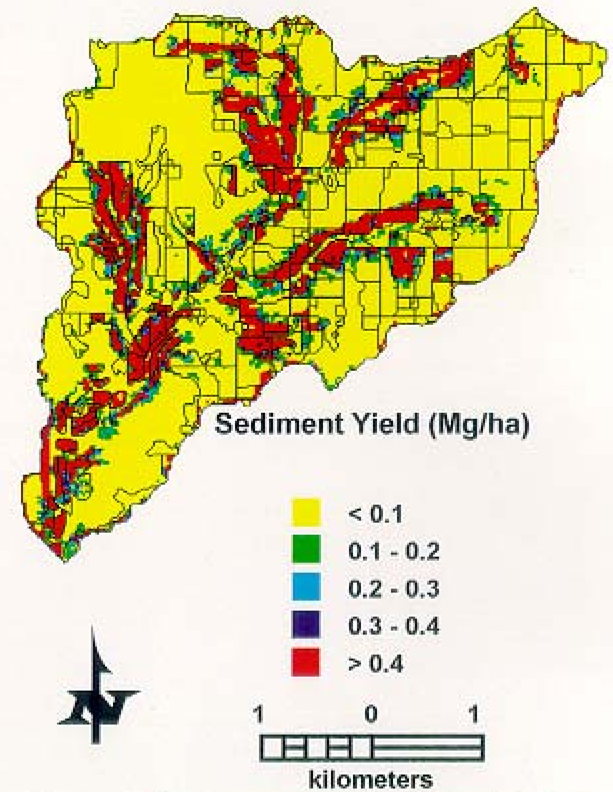

Figure 2.14 - Average annual sediment loading to stream predicted by SIMPLE for Battle Branch Watershed.

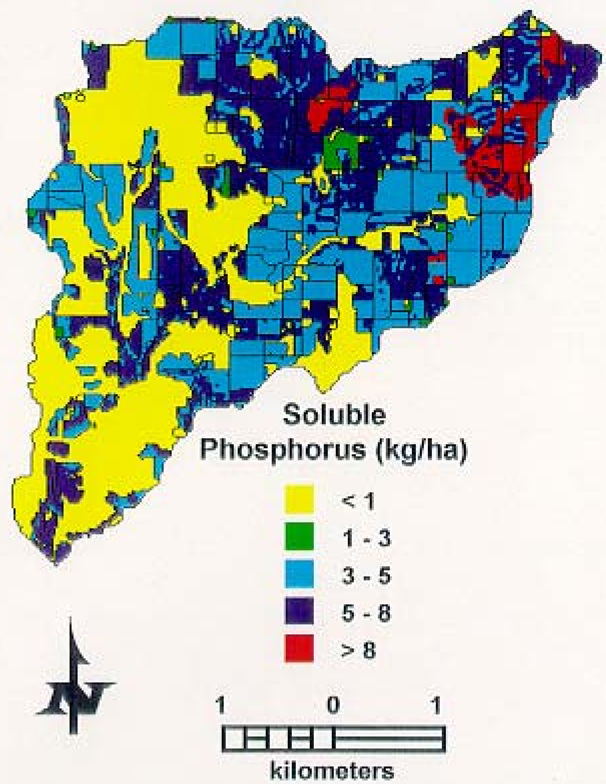

Figure 2.15 - Average annual soluble phosphorus loading to stream in runoff predicted by SIMPLE for Battle Branch Watershed.

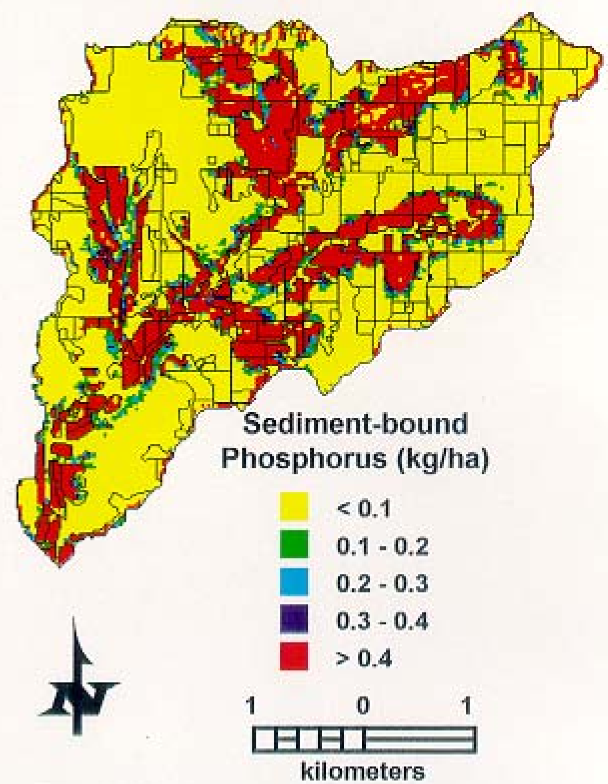

Figure 2.16 - Average annual sediment-bound phosphorus loading to stream predicted by SIMPLE for Battle Branch Watershed.

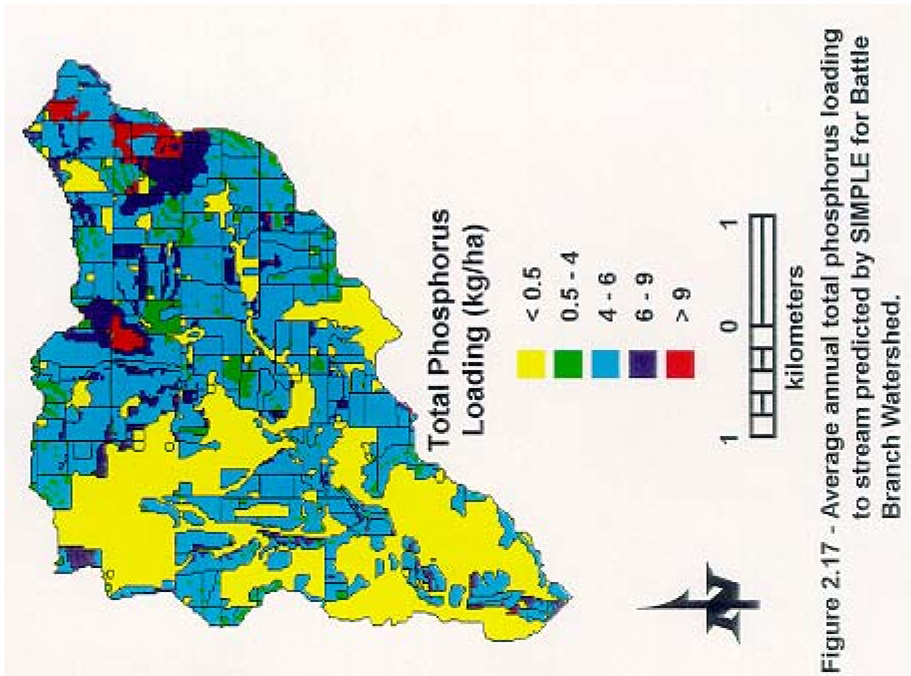

Figure 2.17 - Average annual total phosphorus loading to stream predicted by SIMPLE for Battle Branch Watershed.

Chapter 3. Peacheater Creek Watershed

A. SITE AND DATA DESCRIPTION

Peacheater Creek watershed is located in southern Delaware County in northeast Oklahoma (Fig. 1.1). The watershed area covers approximately 16,200 acres. The watershed is in the Ozark Highland Land Resource Area. The topography is primarily rough steep hills with a blackjack-postoak tree cover. The major land use is agriculture. 140 farms are located within the watershed.

There are 59 poultry houses located within the Peacheater Creek watershed. These operations maintain an average of 1.1 million broilers, layers, breeder hens, and pullets per year. In addition there are nine dairies with a total of 800 dairy animals, an undetermined population of swine, and about 3000 unconfined beef cattle located within the watershed.

The study area includes 18 different soil types (Table 3.1). The predominant soils are in the Bodine association. The Bodine soils are loamy soils and generally have steep slopes with high runoff potential. There are 261 different fields in the study area with 218 fields located within the watershed boundaries (Table 3.3); they can be grouped into 7 land use types (Table 3.4). Pasture and woodlands cover more than 99% of the watershed. Distribution of soil associations, land use, elevation and fields are presented in Figures 3.1 - 3.4.

Soils samples were taken and tested by the OCES to determine soil test P levels for the hay and pasture fields (Fig. 3.5). Values for other soil characteristic, such as clay content, bulk density, slope length, erodibility factor, organic Carbon content, and hydrologic group were estimated from the NRCS county soil survey (Table 3.2). The crop cover factors (C) associated with the various land use types were determined from the SCS Agriculture Handbook 537. An average annual C value of 0.003 was used for fields that are considered pasture, meadow-hay, urban and homesteads. Average annual C values of 0.0003 and 0.12 were used for woodlands and cropped lands, respectively. Curve numbers (CNs) were estimated based on land use cover and hydrologic soil group (Fig. 3.6).

B. RESULTS

The watershed drainage networks and corresponding subwatershed boundaries were delineated based on a threshold network density value of 275. This threshold value provided the best visual match to the first- and second-order streams presented in the USGS maps at 1:24,000 scale (Fig. 3.7). Also, cell slopes (Fig. 3.8), distance to nearest stream (Fig. 3.9) and slope of that distance (Fig.3.10) were estimated by the DTM.

Annual runoff volume, sediment loss and P loading values estimated for each of the 40 one-year simulation runs are summarized in Table 3.5. The rainfall data were obtained from a weather

station located in Fayetteville, Arkansas. Average values for 1 to 40 years were computed and plotted to determine the number of simulation years needed to overcome the effect of the weather data on the long-term average values. Figures3.11 and 3.12 show that a simulation period of at least 20 years is needed before the changes in average values reach a negligible stage.

A simulation run with 20 years of rainfall records was conducted. SIMPLE generated 5 files that include total predicted runoff volume, sediment loss and P loadings for each cell in the watershed. These files were imported into GRASS, and graphical representations of the results were generated (Fig. 3.13-3.17). Distribution of runoff volume levels corresponded well with the distribution of CN values shown in figure 3.6.

The results predicted at cell levels were summarized and annual average values for runoff, sediment and P loadings were computed for each field. The fields were then ranked in ascending order based on their total P loss values (table 3.6). Average annual total P loadings ranged between 0.01 kg/ha (fields 260 and 261) and 34.88 kg/ha (field 39). Field 39 had the highest dissolved P loading (34.32 kg/ha) and field 244 had the highest sediment-bound P loading (3.55 kg/ha).

Average annual total P loading was also computed for each land use type (Table 3.7). Predicted P loadings from woodlands were significantly smaller than the values predicted for cropped lands, pasture and hay lands. The expected average total P loading values from hay and pasture land are 0.75 and 0.85 kg/ha/yr (Beaulac and Reckow, 1982). The high total P loadings from pasture and hay lands are due to high soil P levels.

Table 3.1 - Soil types located within the Peacheater Creek watershed.

#*	Description	Area (ac)	Area (ha)	% Cover

1	Bodine very cherty silt loam, 1-8% slopes	4801.84	1943.28	30.07
2	Bodine stony silt loam, 5-15% slopes	1203.79	487.17	7.54
3	Bodine stony silt loam, steep	4085.30	1653.30	25.59
5	Dickson silt loam, 1-3% slopes	1852.06	749.52	11.60
6	Dickson cherty silt loam, 0-3% slopes	1376.59	557.10	8.62
7	Etowah silt loam, 0-1 % slopes	0.66	0.27	0.00
8	Etowah silt loam, 1-3% slopes	197.70	80.01	1.24
9	Etowah gravelly silt loam, 1-3% slopes	619.57	250.74	3.88
10	Etowah and Greendale soils, 3-8% slopes	638.03	258.21	4.00
11	Gravelly alluvial land	463.90	187.74	2.91
13	Hector-Linker fine sandy loams, 1-5% slopes	55.82	22.59	0.35
15	Huntington gravelly loam	120.53	48.78	0.75
16	Jay silt loam, 0-2% slopes	344.03	139.23	2.15
17	Lawrence silt loam	8.45	3.42	0.05
20	Linker loam, 3-5% slopes	33.58	13.59	0.21
21	Linker loam, 3-5% slopes, eroded	67.82	27.45	0.42
26	Summit silty clay loam, 1-3% slopes	50.70	20.52	0.32
29	Taft silt loam	45.81	18.54	0.29
TOTAL		15966.26	6461.46	00.00

* Soil reference number

Table 3.2 - Soil characteristics used by SIMPLE for the Peacheater Creek watershed.

#*	K	HGRP	pH	% OC	% Clay	BD	λ

1	0.28	B	6.10	0.44	14.00	1.45	122
2	0.28	B	5.25	0.44	14.00	1.45	61
3	0.28	B	5.25	0.44	14.00	1.45	61
5	0.43	B	5.00	0.74	25.00	1.43	152
6	0.43	B	5.00	0.74	25.00	1.43	152
7	0.37	B	5.00	1.18	25.00	1.39	189
8	0.37	B	5.00	1.18	25.00	1.39	152
9	0.37	B	5.00	1.18	25.00	1.39	152
10	0.37	B	5.40	1.18	25.00	1.39	122
11	0.21	B	5.00	0.01	1.00	1.34	15
13	0.19	C	5.00	0.85	17.00	1.50	152
15	0.28	B	6.70	2.65	24.00	1.34	15
16	0.43	C	5.80	0.01	18.00	1.51	189
17	0.43	C	5.50	1.47	18.00	1.39	152
20	0.28	B	4.55	1.03	19.00	1.48	122
21	0.28	B	4.55	1.03	19.00	1.48	122
26	0.37	C	6.45	0.10	33.00	1.34	152
29	0.43	D	5.00	2.06	18.00	1.34	15

*#: Soil reference number
K: USLE Soil Erodibility Factor (English Units)
HGRP: Hydrologic group
pH: Soil pH
% OC: % Organic Carbon Content
% Clay: % Clay content
BD: Bulk Density (g/cm^3) USLE slope length (m)

Table 3.3 - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
1	fred favor - forest/pasture	21.79	8.82	0.14
2	fred favor - forest/pasture	16.90	6.84	0.11

3	mike wolf - pasture	24.46	9.90	0.15
4	mike wolf - pasture	22.23	9.00	0.14
5	mike wolf - pasture	4.44	1.80	0.03
6	wallace blue - pasture/hay	9.34	3.78	0.06
7	lucille rates - pasture/hay	7.78	3.15	0.05
9	warren favor - pasture/hay	48.03	19.44	0.30
10	warren favor - pasture/hay	0.22	0.09	0.00
12	warren favor - pasture	4.44	1.80	0.03
13	warren favor - pasture	4.67	1.89	0.03
14	bob campbell - pasture/hay	24.90	10.08	0.16
15	bob campbell - pasture/hay	2.89	1.17	0.02
16	fred favor - hay	12.67	5.13	0.08
17	fred favor - tilled	2.66	1.08	0.02
18	fred favor - pasture	25.57	10.35	0.16
19	fred favor - pasture	17.34	7.02	0.11
20	fred favor - pasture	18.90	7.65	0.12
21	tim farrier - pasture/hay	5.56	2.25	0.03
24	vera raincoat - pasture/hay	3.11	1.26	0.02
26	larry hern - pasture	48.03	19.44	0.30
27	larry hern - pasture	30.91	12.51	0.19
28	larry hern - pasture	8.00	3.24	0.05
29	patricia dodd - pasture	12.67	5.13	0.08
30	patricia dodd - pasture	9.11	3.69	0.06
31	patricia dodd - pasture	12.67	5.13	0.08
32	patricia dodd - pasture	12.45	5.04	0.08
33	patricia dodd - hay	3.78	1.53	0.02
34	patricia dodd - hay	5.78	2.34	0.04
35	larry kindle - pasture/hay	17.34	7.02	0.11
37	leo beard - hay	9.78	3.96	0.06
38	leo beard - hay	12.45	5.04	0.08
39	leo beard - corn	0.89	0.36	0.01
40	leo beard - hay	0.89	0.36	0.01
41	gene atkins - pasture	42.25	17.10	0.27
42	gene atkins - pasture	8.00	3.24	0.05
43	larry kindle - pasture/hay	38.02	15.39	0.24
44	larry hern - pasture	24.24	9.81	0.15
46	lyle benton - pasture	15.56	6.30	0.10
47	lyle benton - pasture/hay	22.01	8.91	0.14
48	a.g. richmond - pasture	31.57	12.78	0.20
49	calico - pasture	7.78	3.15	0.05

Table 3.3 (continued) - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
50	calico - pasture/hay	8.89	3.60	0.06
51	shirley sims - pasture/hay	7.11	2.88	0.04
52	roger vaugh - pasture/hay	4.22	1.71	0.03
53	danny mcmurtry - hay	5.33	2.16	0.03

54	danny mcmurtry - hay	5.56	2.25	0.03
58	warren sanders - pasture	20.01	8.10	0.13
60	bobby williams - pasture	4.67	1.89	0.03
66	bobby williams - pasture	1.55	0.63	0.01
67	bobby williams - pasture	3.11	1.26	0.02
68	bobby williams - pasture	9.11	3.69	0.06
74	hudson - hay	10.23	4.14	0.06
76	hudson - hay	3.78	1.53	0.02
77	cecil crittenden - pasture	20.46	8.28	0.13
78	todd snyder - hay	14.46	5.85	0.09
79	todd snyder - pasture	16.23	6.57	0.10
80	todd snyder - pasture	25.35	10.26	0.16
81	todd snyder - pasture	18.45	7.47	0.12
86	ricky williams - pasture	18.23	7.38	0.11
87	ricky williams - hay	21.34	8.64	0.13
89	ricky williams - hay	19.34	7.83	0.12
90	ricky williams - hay	10.89	4.41	0.07
91	ricky williams - hay	9.34	3.78	0.06
92	ricky williams - pasture	17.79	7.20	0.11
93	james noah - pasture/hay	4.67	1.89	0.03
94	james noah - pasture/hay	6.44	2.61	0.04
95	james noah - pasture/hay	28.24	11.43	0.18
96	james noah - pasture/hay	21.57	8.73	0.14
97	james noah - pasture/hay	70.05	28.35	0.44
98	mitchell sheffield - hay	12.23	4.95	0.08
99	mitchell sheffield - pasture	10.45	4.23	0.07
100	mitchell sheffield - hay	24.68	9.99	0.15
101	mitchell sheffield - hay	20.68	8.37	0.13
102	mitchell sheffield - pasture	12.00	4.86	0.08
103	mitchell sheffield - pasture	36.47	14.76	0.23
104	mitchell sheffield - pasture	25.79	10.44	0.16
105	vernon butler - pasture	21.79	8.82	0.14
106	vernon butler - pasture	20.90	8.46	0.13
108	vernon butler - hay	14.67	5.94	0.09
109	bill galyean - hay	11.34	4.59	0.07
118	bill galyean - pasture	37.36	15.12	0.23
119	kris kirk - hay	52.92	21.42	0.33
120	kris kirk - hay	47.81	19.35	0.30

Table 3.3 (continued) - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
121	kris kirk - pasture	16.45	6.66	0.10
123	mitchell sheffield - pasture	7.33	2.97	0.05
124	mitchell sheffield - hay	60.93	24.66	0.38
125	mike davis - pasture/hay	74.72	30.24	0.47
126	mike davis - pasture/hay	37.13	15.03	0.23
127	mike davis - pasture/hay	30.91	12.51	0.19

128	james noah - pasture/hay	18.90	7.65	0.12
129	james noah - pasture/hay	32.24	13.05	0.20
130	james noah - pasture/hay	30.69	12.42	0.19
131	james noah - pasture/hay	55.82	22.59	0.35
132	james noah - pasture	44.03	17.82	0.28
133	james noah - pasture/hay	46.25	18.72	0.29
134	james noah - pasture/hay	31.13	12.60	0.20
135	james noah - pasture/hay	23.12	9.36	0.15
136	james noah - pasture/hay	39.36	15.93	0.25
137	james noah - pasture/hay	28.91	11.70	0.18
138	butch edgmon - hay	39.80	16.11	0.25
139	butch edgmon - pasture	57.37	23.22	0.36
140	mitchell sheffield - hay	31.13	12.60	0.20
141	mitchell sheffield - pasture	8.22	3.33	0.05
144	hudson - hay	29.80	12.06	0.19
145	olin vaughn - pasture	16.90	6.84	0.11
146	olin vaughn - pasture	94.29	38.16	0.59
147	olin vaughn - pasture	98.29	39.78	0.62
148	sam langley - pasture	12.00	4.86	0.08
149	marty vaughn - hay	15.12	6.12	0.09
150	marty vaughn - pasture	15.34	6.21	0.10
151	marty vaughn - pasture	45.14	18.27	0.28
152	neil maggard - pasture	9.34	3.78	0.06
153	neil maggard - pasture	12.45	5.04	0.08
157	sam langley - pasture	67.16	27.18	0.42
158	sam langley - pasture	193.03	78.12	1.21
159	sam langley - pasture	75.83	30.69	0.48
160	sam langley - pasture/hay	37.58	15.21	0.24
161	sam langley - hay	32.02	12.96	0.20
162	sam langley - hay	13.12	5.31	0.08
163	earl johnson - pasture	76.72	31.05	0.48
164	earl johnson - hay	23.35	9.45	0.15
165	wayne langley - hay	9.34	3.78	0.06
166	wayne langley - wheat	26.46	10.71	0.17
167	wayne langley - pasture	17.56	7.11	0.11
168	wayne langley - pasture	38.25	15.48	0.24

Table 3.3 (continued) - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
169	dennis neely - pasture/hay	32.02	12.96	0.20
170	dennis neely - hay	30.02	12.15	0.19
171	sam langley - hay	31.80	12.87	0.20
172	sam langley - pasture	21.57	8.73	0.14
173	sam langley - hay	19.34	7.83	0.12
174	barnie nubble - pasture	43.14	17.46	0.27
175	barnie nubble - hay	23.12	9.36	0.15
176	barnie nubble - hay	10.45	4.23	0.07

177	barnie nubble - pasture	9.78	3.96	0.06
178	barnie nubble - pasture	48.03	19.44	0.30
179	jack davis - pasture	44.47	18.00	0.28
180	jack davis - pasture	3.33	1.35	0.02
181	jack davis - pasture	15.79	6.39	0.10
182	jack davis - pasture	16.90	6.84	0.11
183	jack davis - hay	9.34	3.78	0.06
184	jack davis - hay	24.24	9.81	0.15
185	robert williams - hay	14.67	5.94	0.09
186	earnest buffington - pasture/hay	9.34	3.78	0.06
187	wendall wood - pasture/hay	193.25	78.21	1.21
188	wendall wood - pasture	49.37	19.98	0.31
189	wendall wood - pasture/hay	13.12	5.31	0.08
190	wendall wood - pasture/hay	28.24	11.43	0.18
191	wendall wood - pasture	20.01	8.10	0.13
192	dennis neely - pasture	25.57	10.35	0.16
193	dennis neely - hay	165.90	67.14	1.04
194	dennis neely - pasture	54.48	22.05	0.34
195	dennis neely - pasture	5.78	2.34	0.04
196	dennis neely - pasture	8.89	3.60	0.06
197	earnest buffington - pasture	3.11	1.26	0.02
198	earnest buffington - pasture	239.29	96.84	1.50
199	sam cox - pasture	69.16	27.99	0.43
200	barney nubble - pasture	23.12	9.36	0.15
201	barney nubble - pasture	41.80	16.92	0.26
202	barney nubble - pasture/hay	7.11	2.88	0.04
204	tom farrier - pasture/hay	18.01	7.29	0.11
205	tom farrier - pasture/hay	31.35	12.69	0.20
206	tom farrier - pasture	37.80	15.30	0.24
207	larry kindle - pasture/hay	44.25	17.91	0.28
208	larry kindle - pasture/hay	26.24	10.62	0.16
209	larry kindle - pasture/hay	9.56	3.87	0.06
210	l and k poultry - pasture	94.73	38.34	0.59
211	l and k Poultry - pasture	19.34	7.83	0.12

Table 3.3 (continued) - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
212	1 and k poultry - pasture	35.36	14.31	0.22
213	1 and k poultry - pasture	14.23	5.76	0.09
214	1 and k poultry - pasture	10.67	4.32	0.07
215	andrew pilcher - pasture	4.67	1.89	0.03
216	andrew pilcher - pasture	20.01	8.10	0.13
217	emment hopkins - hay	17.12	6.93	0.11
218	larry kindle - pasture/hay	4.44	1.80	0.03
219	larry kindle - pasture/hay	10.23	4.14	0.06
220	sam cox - pasture	4.67	1.89	0.03
221	sam cox - pasture	10.00	4.05	0.06

222	sam cox - pasture	21.57	8.73	0.14
223	sam cox - pasture	22.90	9.27	0.14
224	sam cox - pasture	10.23	4.14	0.06
225	sam cox - pasture	28.68	11.61	0.18
226	patrica dodd - pasture/hay	17.34	7.02	0.11
227	patrica dodd - pasture/hay	5.33	2.16	0.03
228	patrica dodd - pasture/hay	12.23	4.95	0.08
229	patrica dodd - pasture/hay	16.90	6.84	0.11
230	patrica dodd - pasture/hay	6.89	2.79	0.04
231	moss and blake littlejohn - pasture	19.57	7.92	0.12
232	moss and blake littlejohn - pasture	5.56	2.25	0.03
233	moss and blake littlejohn - pasture	57.15	23.13	0.36
234	moss and blake littlejohn - pasture	20.01	8.10	0.13
235	verlin and blake littlejohn - pasture/hay	28.47	11.52	0.18
236	verlin and blake littlejohn - pasture/hay	21.34	8.64	0.13
237	verlin and blake littlejohn - pasture/hay	8.00	3.24	0.05
238	verlin and blake littlejohn - pasture/hay	10.89	4.41	0.07
239	verlin and blake littlejohn - pasture	29.13	11.79	0.18
240	verlin and blake littlejohn - pasture	23.35	9.45	0.1
241	garland mcmurtry - pasture	11.78	4.77	0.07
242	garland mcmurtry - hay	14.01	5.67	0.09
243	garland mcmurtry - pasture	0.44	0.18	0.00
244	garland mcmurtry - pasture	12.89	5.22	0.08
245	earnest buffington - pasture	7.56	3.06	0.05
246	earnest buffington - pasture	30.02	12.15	0.19
247	earnest buffington - pasture	69.60	28.17	0.44
248	earnest buffington - pasture	74.05	29.97	0.46
249	earnest buffington - pasture	14.45	5.85	0.09
250	earnest buffington - pasture/hay	8.00	3.24	0.05
251	forest	72.94	29.52	0.46
252	forest/pasture	5774.35	2336.85	36.22

Table 3.3 (continued) - List of fields in the Peacheater watershed.

#*	Description	Area (ac)	Area (ha)	%cover
253	pasture	519.28	210.15	3.26
254	other	2993.14	1211.31	18.77
255	pasture/hay	792.59	320.76	4.97
256	hay	3.33	1.35	0.02
257	road	222.61	90.09	1.40
258	pond	33.35	13.50	0.21
259	river	6.44	2.61	0.04
260	homestead	27.57	11.16	0.17
261	poultry houses	39.58	16.02	0.25

* Field reference number

Table 3.4 - Land use in the Peacheater Watershed.

#*	Description	Area (ac)	Area (ha)	% Cover
1	Crop	0.89	0.36	0.01
2	Confined Animal	33.35	13.50	0.21
3	Forest	5774.35	2336.85	36.22
4	Pasture & Range	10061.59	4071.87	63.11
5	Roads	39.58	16.02	0.25
6	Urban	27.57	11.16	0.17
7	Water	6.44	2.61	0.04

* Land use reference number

Table 3.5 - Annual runoff volume, soil loss, and total P loadings generated by the 40 1-yr runs for the Peacheater Creek watershed.

Year	Rainfall (cm)	Runoff (cm)	Soil Loss (Mg/ha)	Phosphorus Loading (kg/ha)		
				Dissolved	Sediment	Total
1	128.96	15.97	0.17	1.33	0.17	1.50
2	122.39	6.59	0.05	0.47	0.06	0.53
3	88.51	9.66	0.08	0.86	0.10	0.96
4	90.65	3.93	0.06	0.30	0.04	0.34
5	89.83	6.87	0.05	0.63	0.07	0.70
6	95.98	2.04	0.03	0.13	0.03	0.16
7	98.39	3.64	0.03	0.33	0.05	0.38
8	158.53	15.86	0.13	1.33	0.17	1.50
9	115.60	9.15	0.07	0.83	0.10	0.9
10	100.03	3.94	0.05	0.38	0.07	0.45
11	108.16	22.14	0.24	1.83	0.20	2.04

12	145.07	17.71	0.14	1.55	0.17	1.73
13	122.35	11.58	0.10	1.04	0.12	1.16
14	55.00	2.60	0.02	0.25	0.03	0.28
15	91.66	6.12	0.06	0.56	0.08	0.64
16	100.73	5.63	0.04	0.51	0.05	0.56
17	95.53	7.31	0.08	0.46	0.07	0.53
18	97.58	6.68	0.05	0.61	0.07	0.67
19	116.29	3.69	0.05	0.32	0.07	0.40
20	114.72	15.80	0.11	1.23	0.13	1.36
21	111.17	7.87	0.06	0.73	0.09	0.81
22	88.92	3.96	0.03	0.35	0.04	0.39
23	103.97	13.89	0.12	1.23	0.13	1.36
24	165.68	12.71	0.09	1.14	0.13	1.27
25	133.57	15.35	0.09	1.36	0.13	1.49
26	124.15	5.45	0.07	0.48	0.09	0.57
27	79.63	2.65	0.03	0.25	0.04	0.28
28	103.58	4.18	0.05	0.35	0.06	0.42
29	108.79	8.75	0.07	0.76	0.09	0.85
30	95.53	1.05	0.02	0.10	0.04	0.14
31	71.29	1.78	0.02	0.17	0.03	0.20
32	114.22	5.04	0.06	0.46	0.09	0.56
33	135.17	27.65	0.24	2.33	0.24	2.56
34	94.16	3.33	0.02	0.30	0.03	0.34
35	127.08	5.58	0.07	0.52	0.07	0.59
36	134.96	13.10	0.09	1.13	0.11	1.24
37	133.39	18.82	0.13	1.63	0.16	1.79
38	123.17	8.22	0.06	0.76	0.09	0.86
39	102.89	5.51	0.04	0.44	0.06	0.50
40	94.71	2.71	0.02	0.21	0.03	0.24

Table 3.6 - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed. Fields are ranked based on their predicted total P loading.

Field	Runoff (cm)	Soil Loss (kg/ha)	Phosphorus Loading Dissolved (kg/ha)	Phosphorus Loading Sediment (kg/ha)	Phosphorus Loading Total (kg/ha)
260	21.69	0.00	0.01	0.00	0.01
261	21.17	0.00	0.01	0.00	0.01
257	31.75	0.08	0.01	0.01	0.02
251	6.24	0.01	0.03	0.00	0.03
1	10.12	0.01	0.05	0.00	0.05
252	9.95	0.00	0.54	0.00	0.54
254	11.07	0.03	0.55	0.02	0.57
17	10.12	0.06	0.53	0.05	0.58
2	10.04	0.00	0.74	0.01	0.75
76	7.48	0.00	3.59	0.03	3.62
74	8.72	0.01	3.96	0.06	4.03
144	9.12	0.02	3.97	0.08	4.05

79	8.05	0.02	4.01	0.13	4.14
196	10.12	0.04	4.11	0.11	4.22
194	10.12	0.02	4.20	0.06	4.26
248	10.12	0.02	4.22	0.06	4.27
46	10.12	0.02	4.25	0.04	4.29
195	10.12	0.01	4.33	0.03	4.36
242	10.12	0.26	3.70	0.67	4.36
103	10.07	0.01	4.33	0.04	4.38
229	10.12	0.02	4.32	0.08	4.40
250	10.08	0.04	4.28	0.13	4.41
249	9.81	0.01	4.37	0.03	4.41
169	9.81	0.01	4.38	0.05	4.43
78	8.91	0.02	4.35	0.10	4.45
152	8.12	0.05	4.27	0.26	4.53
80	9.23	0.00	4.51	0.02	4.53
223	10.12	0.01	4.53	0.02	4.55
237	10.12	0.01	4.54	0.02	4.56
176	10.05	0.00	4.57	0.00	4.57
123	9.64	0.04	4.35	0.22	4.57
209	9.87	0.08	4.31	0.26	4.57
206	10.00	0.04	4.43	0.15	4.59
170	9.92	0.04	4.40	0.19	4.59
43	10.12	0.05	4.47	0.14	4.61
190	10.12	0.03	4.50	0.11	4.61
197	10.10	0.18	4.14	0.50	4.64
140	9.74	0.00	4.65	0.00	4.65
24	10.12	0.01	4.63	0.01	4.65
52	10.12	0.03	4.51	0.15	4.65

Table 3.6 (continued) - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed.

			Phosphorus Loading		
Field	Runoff (cm)	Soil Loss (kg/ha)	Dissolved (kg/ha)	Sediment (kg/ha)	Total (kg/ha)
120	10.30	0.00	4.69	0.00	4.69
227	10.12	0.00	4.69	0.00	4.69
150	10.10	0.04	4.56	0.13	4.69
225	10.12	0.02	4.65	0.07	4.71
119	10.15	0.03	4.58	0.14	4.71
99	10.08	0.02	4.60	0.12	4.72
141	10.12	0.00	4.72	0.01	4.73
192	10.10	0.18	4.17	0.57	4.74
151	9.65	0.00	4.73	0.02	4.74
153	9.29	0.01	4.76	0.04	4.81
193	10.11	0.16	4.33	0.49	4.82
238	10.10	0.01	4.81	0.02	4.83
58	10.12	0.03	4.75	0.10	4.85
228	10.08	0.00	4.88	0.00	4.88

54	10.12	0.06	4.67	0.21	4.88
96	9.88	0.03	4.74	0.13	4.88
148	8.96	0.11	4.38	0.51	4.89
138	9.99	0.09	4.53	0.36	4.89
255	10.12	0.00	4.90	0.01	4.91
245	10.03	0.01	4.86	0.05	4.91
105	9.37	0.02	4.82	0.09	4.91
231	9.89	0.00	4.91	0.00	4.91
230	10.05	0.03	4.80	0.10	4.91
198	10.12	0.04	4.75	0.16	4.91
161	9.83	0.01	4.87	0.05	4.92
186	9.98	0.22	4.24	0.68	4.92
50	10.12	0.04	4.72	0.20	4.92
40	10.12	0.03	4.83	0.10	4.93
171	9.74	0.04	4.77	0.19	4.96
104	10.03	0.11	4.44	0.51	4.96
102	10.01	0.10	4.50	0.46	4.96
149	10.08	0.03	4.82	0.14	4.96
139	10.02	0.00	4.97	0.01	4.97
160	9.82	0.02	4.92	0.07	4.99
3	10.07	0.13	4.48	0.52	4.99
163	9.98	0.02	4.91	0.09	5.00
97	10.12	0.04	4.82	0.19	5.00
42	10.04	0.09	4.64	0.37	5.01
16	10.18	0.04	4.80	0.22	5.02
124	10.02	0.06	4.73	0.29	5.02

Table 3.6 (continued) - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed.

			Phosphorus Loading		
Field	Runoff (cm)	Soil Loss (kg/ha)	Dissolved (kg/ha)	Sediment (kg/ha)	Total (kg/ha)
106	9.61	0.02	4.93	0.09	5.02
147	9.34	0.00	5.05	0.00	5.06
98	10.00	0.00	5.05	0.01	5.06
164	9.52	0.00	5.05	0.02	5.07
246	9.98	0.11	4.65	0.42	5.07
125	9.98	0.00	5.07	0.00	5.07
49	10.12	0.08	4.67	0.41	5.08
93	10.02	0.01	5.04	0.04	5.08
157	9.90	0.06	4.84	0.24	5.09
199	10.12	0.23	4.32	0.78	5.10
159	10.07	0.04	4.98	0.13	5.10
77	9.99	0.12	4.51	0.60	5.11
81	9.98	0.04	4.91	0.20	5.11
101	10.30	0.04	4.92	0.20	5.12
92	10.12	0.00	5.17	0.00	5.17
108	10.12	0.01	5.14	0.04	5.18

200	10.10	0.39	4.16	1.03	5.19
256	9.96	0.14	4.67	0.53	5.19
215	10.12	0.43	3.99	1.21	5.21
26	9.64	0.05	4.93	0.28	5.21
205	10.10	0.35	4.13	1.10	5.23
86	9.81	0.02	5.13	0.11	5.24
253	10.20	0.13	4.79	0.47	5.25
189	10.12	0.13	4.74	0.53	5.27
187	10.04	0.26	4.29	1.00	5.29
222	10.12	0.24	4.56	0.73	5.29
188	10.12	0.07	4.93	0.37	5.30
172	9.96	0.11	4.75	0.55	5.30
21	9.00	0.46	3.99	1.31	5.30
89	10.06	0.00	5.30	0.00	5.30
109	9.83	0.02	5.18	0.12	5.31
28	9.88	0.08	4.91	0.42	5.33
130	9.93	0.06	5.04	0.29	5.33
90	10.27	0.00	5.33	0.00	5.34
118	9.61	0.07	4.98	0.36	5.34
182	10.12	0.01	5.29	0.08	5.36
232	10.02	0.09	4.97	0.39	5.37
95	10.00	0.12	4.82	0.57	5.39
88	9.89	0.02	5.31	0.10	5.41
145	9.98	0.01	5.34	0.06	5.41

Table 3.6 (continued) - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed.

Field	Runoff (cm)	Soil Loss (kg/ha)	Phosphorus Loading Dissolved (kg/ha)	Phosphorus Loading Sediment (kg/ha)	Phosphorus Loading Total (kg/ha)
218	10.12	0.08	5.02	0.40	5.42
38	10.07	0.25	4.50	0.91	5.42
126	9.94	0.03	5.28	0.17	5.45
240	10.12	0.18	4.76	0.71	5.47
220	10.12	0.29	4.49	0.98	5.47
94	9.68	0.12	4.87	0.62	5.49
175	10.06	0.01	5.50	0.04	5.54
48	10.02	0.10	5.02	0.53	5.55
208	10.12	0.57	4.01	1.54	5.55
31	10.12	0.04	5.46	0.15	5.61
241	10.12	0.45	4.26	1.36	5.61
162	10.07	0.15	4.95	0.69	5.65
233	10.12	0.10	5.16	0.51	5.67
20	10.02	0.12	5.15	0.53	5.68
234	10.03	0.09	5.22	0.46	5.68
15	10.12	0.09	5.26	0.43	5.69
146	10.05	0.10	5.19	0.51	5.70
168	10.08	0.17	5.02	0.69	5.71

51	10.12	0.16	4.95	0.79	5.75
6	10.05	0.28	4.62	1.14	5.76
131	10.10	0.00	5.74	0.02	5.76
41	10.07	0.27	4.74	1.05	5.79
226	9.77	0.00	5.80	0.00	5.80
32	9.47	0.02	5.68	0.12	5.80
127	9.89	0.12	5.15	0.66	5.81
173	10.07	0.26	4.72	1.09	5.82
207	10.09	0.40	4.51	1.31	5.83
224	10.09	0.51	4.44	1.40	5.84
247	10.11	0.25	4.81	1.05	5.86
158	10.06	0.21	4.99	0.89	5.88
239	10.01	0.20	4.95	0.94	5.89
210	10.12	0.54	4.27	1.66	5.94
191	10.04	0.54	4.40	1.56	5.96
137	9.83	0.42	4.59	1.38	5.97
128	10.10	0.07	5.59	0.39	5.97
37	10.05	0.15	5.17	0.81	5.98
18	10.09	0.33	4.69	1.29	5.98
19	9.79	0.11	5.34	0.64	5.98
34	10.01	0.00	6.01	0.00	6.01
219	9.72	0.16	5.24	0.78	6.03

Table 3.6 (continued) - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed.

			Phosphorus Loading		
Field	Runoff (cm)	Soil Loss (kg/ha)	Dissolved (kg/ha)	Sediment (kg/ha)	Total (kg/ha)
33	9.95	0.00	6.04	0.00	6.04
121	12.84	0.03	5.90	0.18	6.08
204	10.02	0.33	4.75	1.35	6.10
221	10.12	0.37	4.74	1.40	6.13
236	10.12	0.19	5.26	0.88	6.14
177	10.01	0.32	4.91	1.23	6.14
202	9.87	0.36	4.76	1.38	6.14
14	10.10	0.10	5.58	0.57	6.15
100	12.88	0.13	5.55	0.64	6.19
27	10.08	0.19	5.31	0.87	6.19
132	10.02	0.09	5.71	0.50	6.21
47	10.81	0.14	5.51	0.70	6.21
216	10.04	0.77	3.96	2.29	6.25
243	10.12	0.43	4.64	1.62	6.26
235	10.09	0.25	5.11	1.20	6.31
44	10.09	0.20	5.25	1.06	6.31
185	9.72	0.16	5.41	0.92	6.33
136	9.90	0.05	6.04	0.33	6.37
201	10.03	0.24	5.21	1.16	6.38
91	12.78	0.01	6.41	0.03	6.44

183	10.12	0.01	6.43	0.03	6.45
9	14.72	0.02	6.41	0.06	6.46
212	10.03	0.24	5.26	1.29	6.55
129	10.08	0.27	5.24	1.33	6.57
213	10.06	0.38	4.94	1.69	6.64
30	10.12	0.14	5.82	0.85	6.66
35	10.04	0.42	4.98	1.70	6.68
135	10.08	0.07	6.29	0.39	6.68
134	10.12	0.02	6.62	0.09	6.70
165	9.43	0.02	6.54	0.17	6.71
217	10.12	0.37	5.07	1.67	6.74
4	10.12	0.69	4.66	2.20	6.86
180	10.04	0.09	6.33	0.56	6.89
174	9.90	0.77	4.44	2.46	6.90
29	10.02	0.43	5.35	1.68	7.03
87	13.85	0.00	7.07	0.01	7.08
214	9.85	0.37	5.21	1.94	7.15
5	10.12	0.38	5.38	1.78	7.16
53	14.24	0.11	6.69	0.53	7.22
179	10.12	0.21	5.99	1.26	7.26

Table 3.6 (continued) - Predicted average annual runoff volume, sediment loss and P loadings by field for the Peacheater Creek watershed.

Field	Runoff (cm)	Soil Loss (kg/ha)	Phosphorus Loading Dissolved (kg/ha)	Phosphorus Loading Sediment (kg/ha)	Phosphorus Loading Total (kg/ha)
211	10.08	0.92	4.39	2.90	7.29
184	10.03	0.00	7.46	0.01	7.47
167	10.08	0.11	6.95	0.57	7.53
60	10.12	0.00	7.66	0.00	7.66
133	10.06	0.09	7.05	0.63	7.68
66	10.12	0.00	7.82	0.00	7.83
244	10.12	0.96	4.60	3.55	8.15
181	10.01	0.10	7.36	0.84	8.20
12	18.03	0.01	8.14	0.07	8.21
68	9.23	0.02	8.04	0.22	8.26
13	19.46	0.01	8.65	0.10	8.75
7	19.89	0.01	8.70	0.05	8.76
10	18.17	0.00	8.92	0.00	8.92
178	10.12	0.32	7.25	1.94	9.19
67	10.86	0.12	9.25	1.07	10.33
166	9.90	0.00	11.92	0.02	11.94
39	14.94	0.03	34.32	0.55	34.88

Table 3.7 - Predicted average annual runoff volume, sediment loss and P loadings by land use for the Peacheater Creek watershed.

Land Use	Runoff (cm)	Soil Loss (kg/ha)	Phosphorus Loading Dissolved (kg/ha)	Sediment (kg/ha)	Total (kg/ha)
Cropped Land	14.94	1372.25	14.45	0.52	14.97
Confined Animals	31.75	0	0.01	0	0
Forest	6.24	7.73	0.03	0	0.03
Pasture/Hay	10.19	122.14	4.27	0.46	4.73
Roads	21.17	1.69	0.01	0	0.01
Urban	21.69	0	0.01	0	0.01

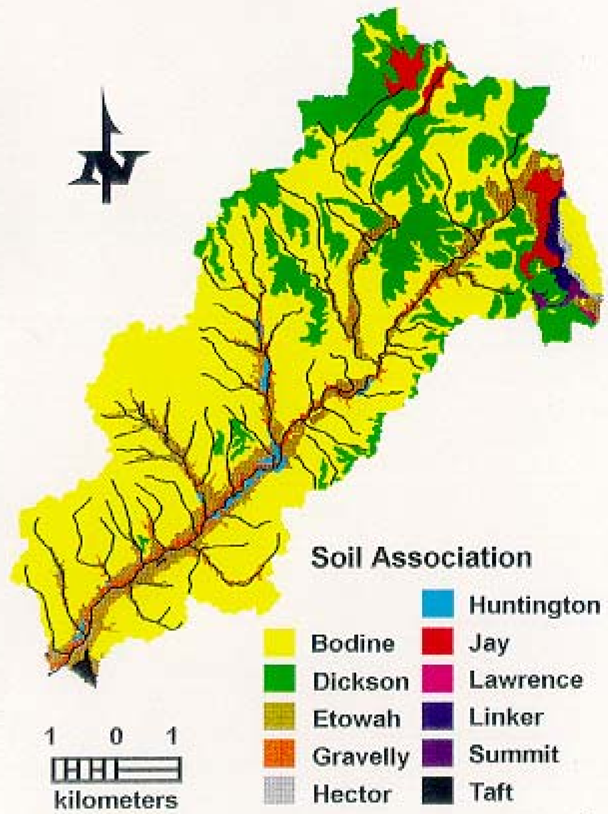

Figure 3.1 - Soil associations in the Peacheater Creek Watershed.

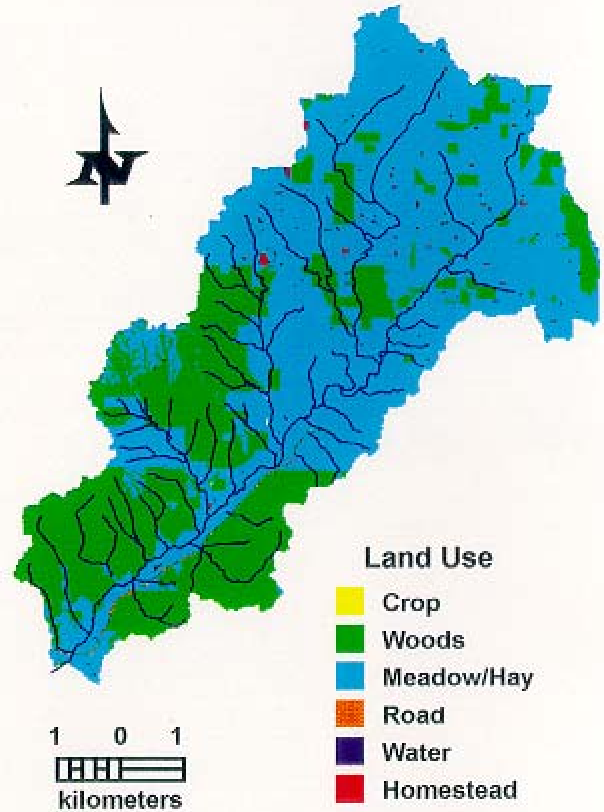

Figure 3.2 - Land use distribution in the Peacheater Creek Watershed.

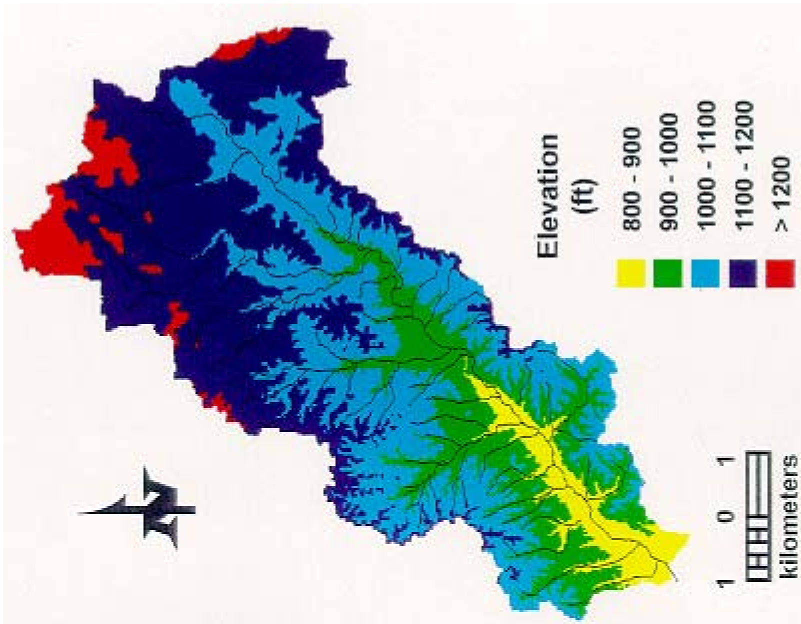

Figure 3.3 - Topography in the Peacheater Creek Watershed.

Figure 3.4 - Field Boundaries in the Peacheater Creek watershed.

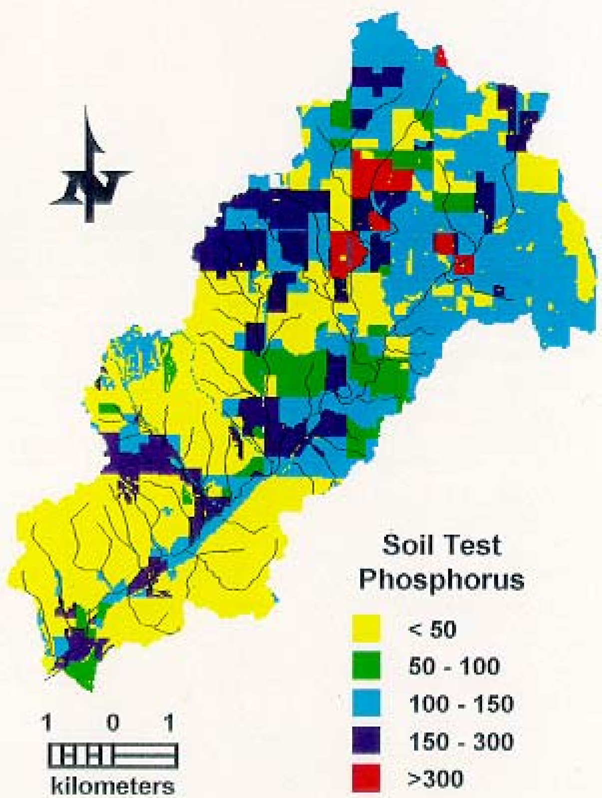

Figure 3.5 - Distribution of soil test phosphorus in the Peacheater Creek Watershed.

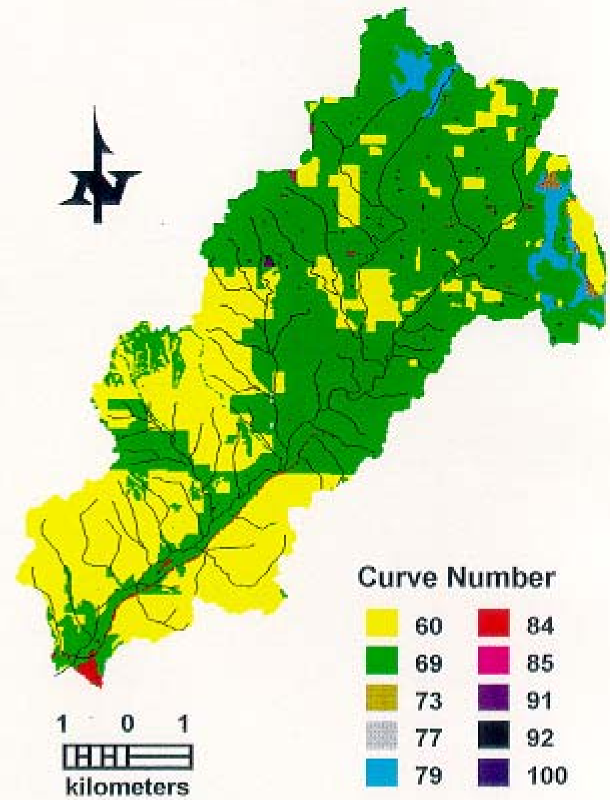

Figure 3.6 - Distribution of curve numbers in the Peacheater Creek Watershed.

Figure 3.7 - Comparison between USGS 1:24,000 blue line streams and channel defined by the digital terrain model for threshold value of 275 cells for the Peacheater Creek Watershed.

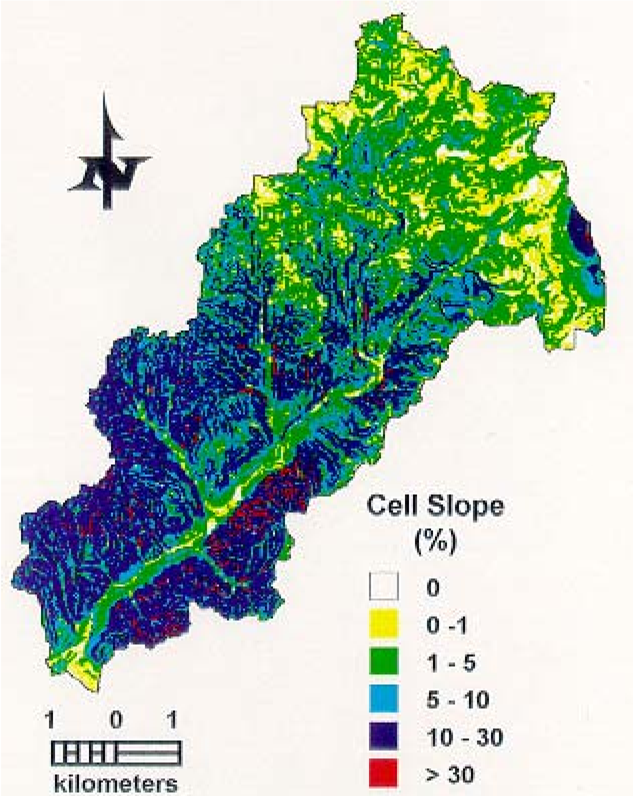

Figure 3.8 - Cell slope defined by the digital terrain model for Peacheater Creek Watershed.

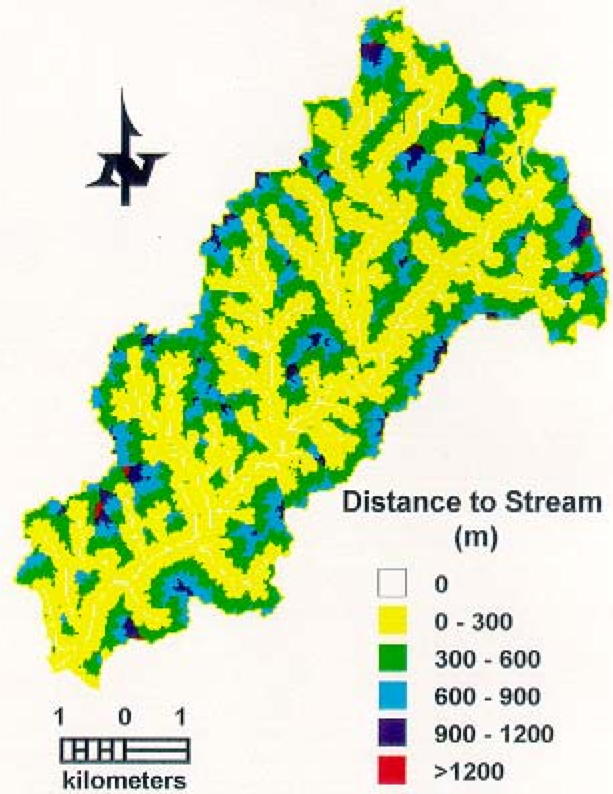

Figure 3.9 - Flow distance from cell to stream calculated by the digital terrain model using a threshold density of 275 cells for Peacheater Creek Watershed.

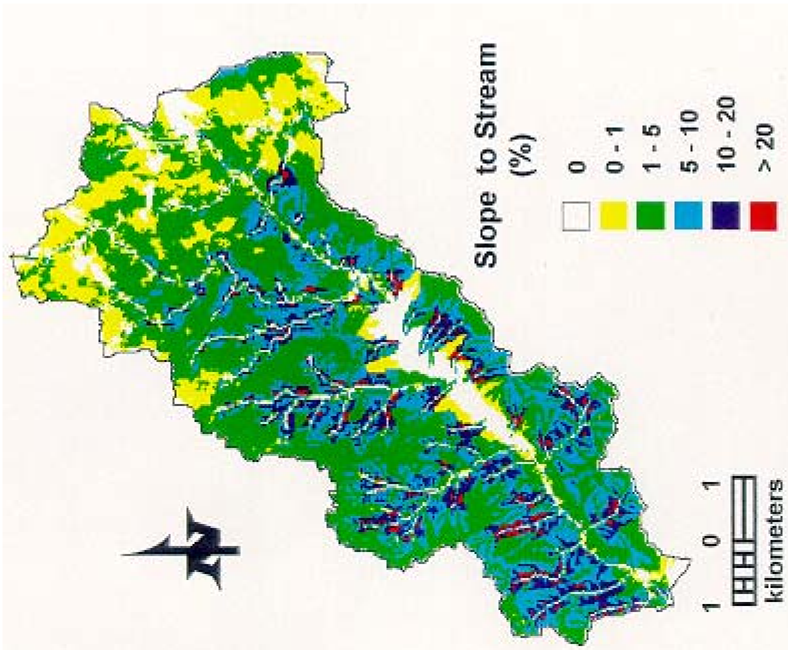

Figure 3.10 - Slope of flow path from cell to stream calculated by the digital terrain model using a threshold density of 275 cells for Peacheater Creek Watershed.

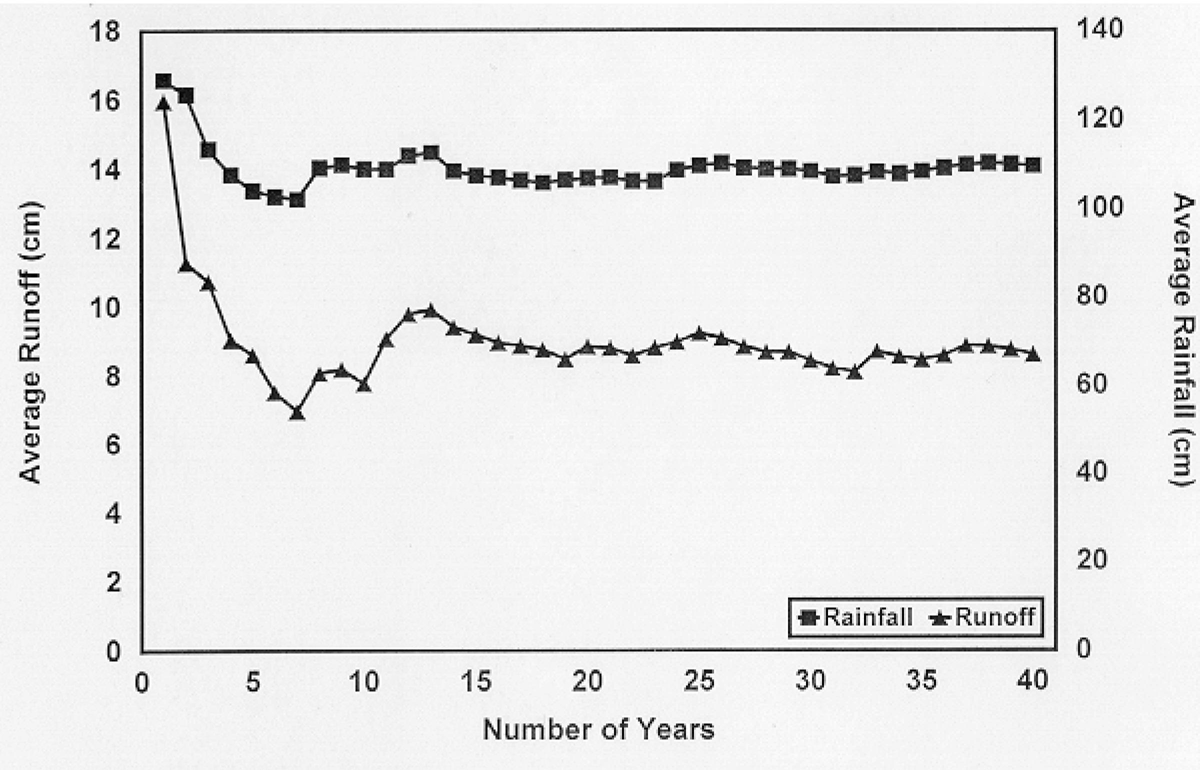

Figure 3.11 Predicted cumulative annual average rainfall and runoff using 40 one-year simulation runs for Peacheater Creek watershed.

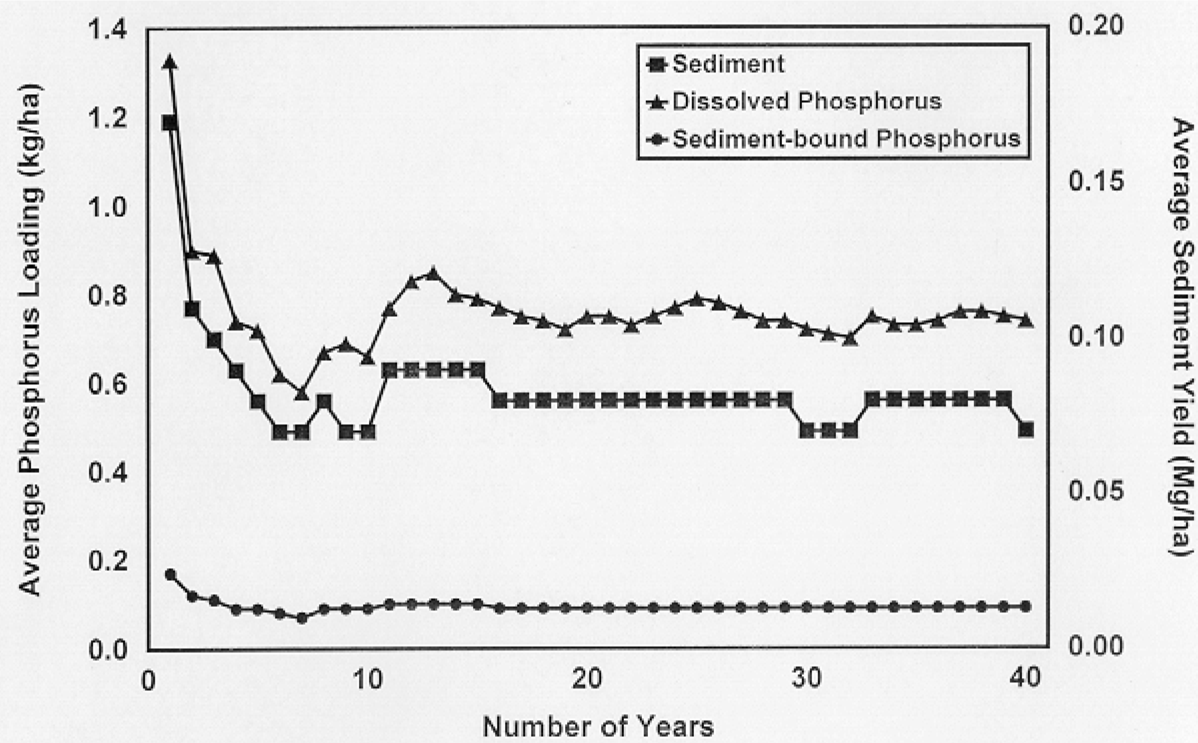

Figure 3.12 Predicted cumulative annual average sediment and total phosphorus loading using 40 one-year simulation runs for Peacheater Creek watershed.

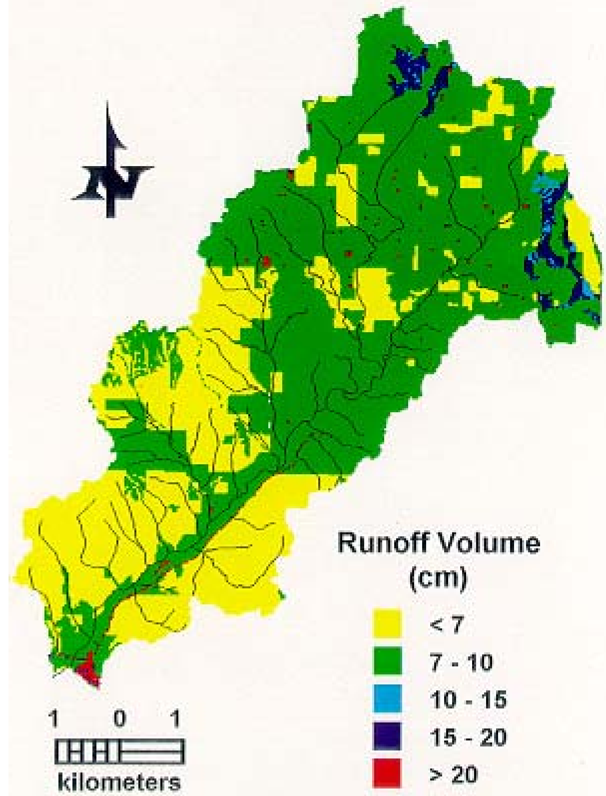

Figure 3.13 - Average annual runoff volume predicted by SIMPLE for Peacheater Creek Watershed.

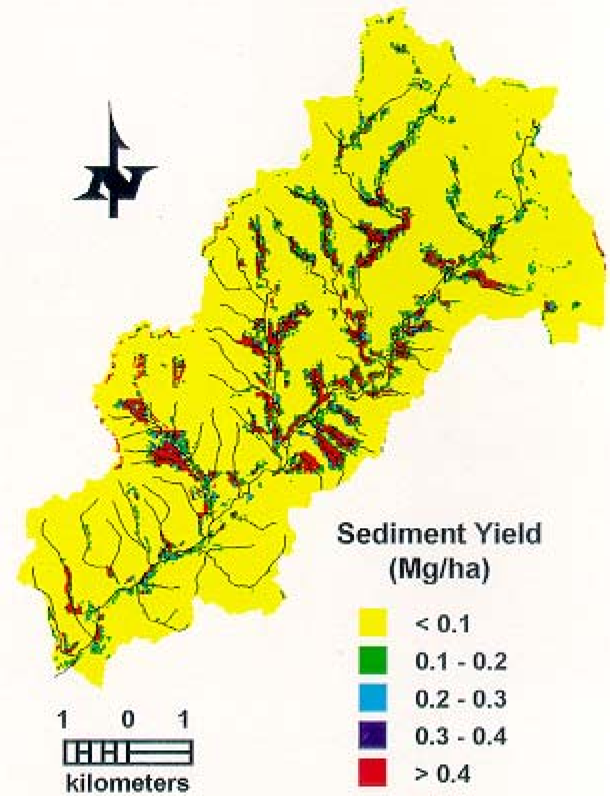

Figure 3.14 - Average annual sediment loading to stream predicted by SIMPLE for Peacheater Creek Watershed.

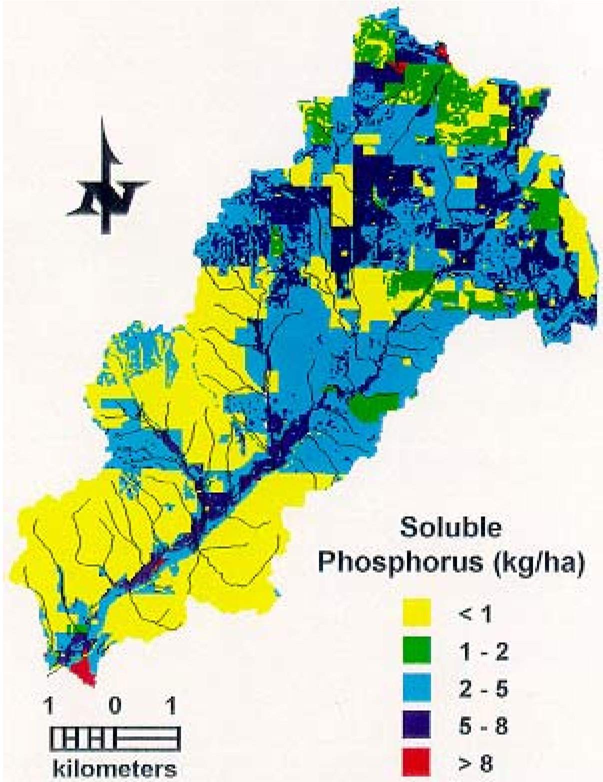

Figure 3.15 - Average annual soluble phosphorus loading to stream in runoff predicted by SIMPLE for Peacheater Creek Watershed.

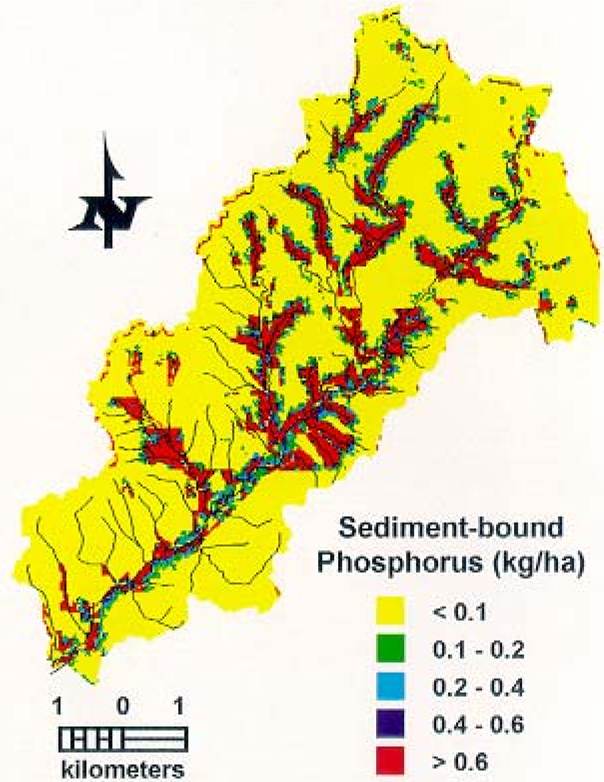

Figure 3.16 - Average annual sediment-bound phosphorus loading to stream predicted by SIMPLE for Peacheater Creek Watershed.

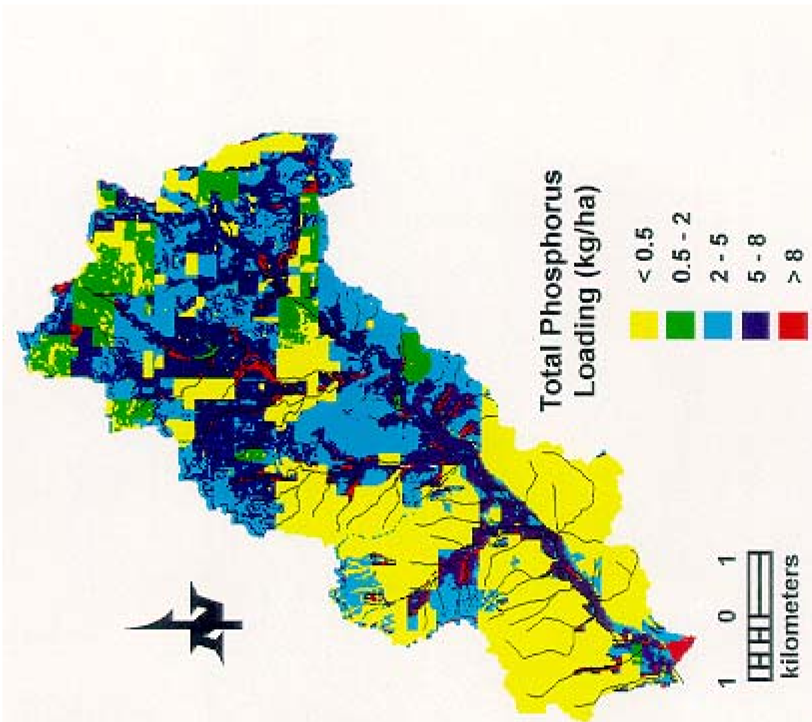

Figure 3.17 - Average annual total phosphorus loading to stream predicted by SIMPLE for Peacheater Creek Watershed.