BASIN-WIDE POLLUTION INVENTORY FOR THE ILLINOIS RIVER COMPREHENSIVE BASIN MANAGEMENT PROGRAM

FINAL REPORT

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Daniel E. Storm
Associate Professor

George J. Sabbagh
Associate Researcher

Mark S. Gregory
Assistant Researcher

Michael D. Smolen
Professor

Dale Toetz
Professor

David R. Gade
Graduate Research Assistant

C. Tom Haan
Regents Professor

Ted Kornecki
@Graduate Research Assistant

Submitted
to the
Oklahoma Conservation Commission
for the
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Departments of
Biosystems and Agricultural Engineering,
Agronomy, and Zoology
Oklahoma State University

August 1996

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VOLUME 1

Estimating Nonpoint and Point Source Loading to the Upper Illinois River Basin

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. 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 (Newman, 1995; Puckett, 1995; Wagner et al., 1996). To identify and/or quantify potential nonpoint sources of pollution in a cost effective manner, computer models and geographic information systems can be utilized. In addition, 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.

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 of the Illinois River, which has been designated a Scenic River by the State of Oklahoma, and Lake Tenkiller. 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 49 percent grassland, 44 percent forest, 1 percent cropland, 0.3 percent orchards and vineyards, 3.5 percent urban, and 2.2 percent other land uses. The location of the Illinois River basin is shown in Figure 1.1.

There are currently a variety of distributed parameter watershed and basin scale models available to predict sediment and phosphorus loading to surface water. Examples of these models include AGNPS (Young et al., 1989), ANSWERS (Storm et al., 1988), SQWRRB-WQ (Arnold et al., 1990), and SWAT (Arnold et al., 1993). These models require a significant number of input parameters, and data to accurately estimate these parameters are often not available. When detailed data are available, these more sophisticated models may provide more accurate results. However, the uncertainty in model predictions due to parameter uncertainty may out weigh the use of simpler methods of estimating sediment and phosphorus loading (Heatwole and Shanholtz, 1991; Shanholtz et al., 1990; Hession and Shanhotz, 1988).

Presented is a modeling study that utilizes a less complex model than existing watershed scale models called the Spatially Integrated Model for Phosphorus Loading and Erosion (SIMPLE). SIMPLE estimates runoff volume, sediment yield, and dissolved and sediment-bound phosphorus loading to the stream. In the following study we apply SIMPLE to the Upper Illinois River Basin.

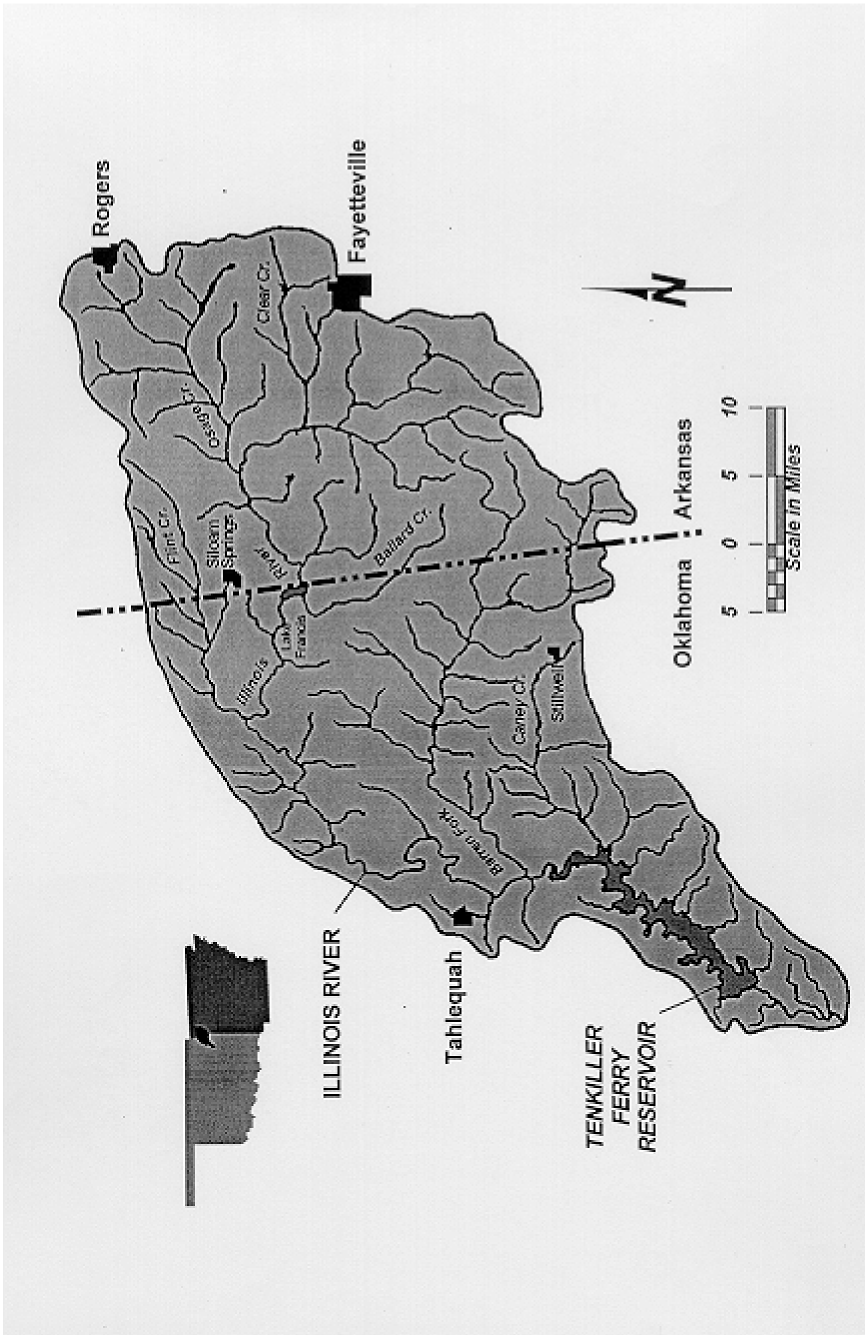


Figure 1.1 Location and description of the Illinois River basin in northeast Oklahoma and northwest Arkansas

CHAPTER 2. NONPOINT SOURCE LOADING

2.1 MODELING FRAMEWORK

2.1.1 SIMPLE - Overview

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 employed called the Spatially Integrated Model for Phosphorus Loading and Erosion (SIMPLE). SIMPLE 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 database manager, and a menu driven user interface.

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 too[, 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. Below is an overview of the SIMPLE model. Additional detail on the model and its application can be found in Sabbagh et al. (1995), Storm et al. (1995), Sabbagh et al. (1994), and Chen et al. (1994).

2.1.2 SIMPLE Modeling Framework

SIMPLE is a modeling system consisting of a Phosphorous Transport Model (PTM), a Digital Terrain Model (DTM), and a database manager (Figure 2.1). 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 databases.

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 are 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, errors may be introduced 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.

2.1.2.1 Phosphorus Transport Model

The phosphorus transport model (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 diffusion of phosphorus into surface runoff, and the exchange between mineral and plant available phosphorus. 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 commercial fertilizer or animal waste and subtracting phosphorus leaving the field in runoff and sediment. The model estimates the desorption of phosphorus in the soil matrix and the concentration of phosphorus in surface runoff using a 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 biological stabilization, deposition, and trapping. Heatwole and Shanholtz (1991) developed a delivery ratio relationship to account for deposition and trapping. The delivery of phosphorus 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.

2.1. 2.2 Digital Terrain Model

The digital terrain model (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-cell 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 higher 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.

2.1.2.3 Database Manager

The database manager is a tool for developing the soil and land-use databases. 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.

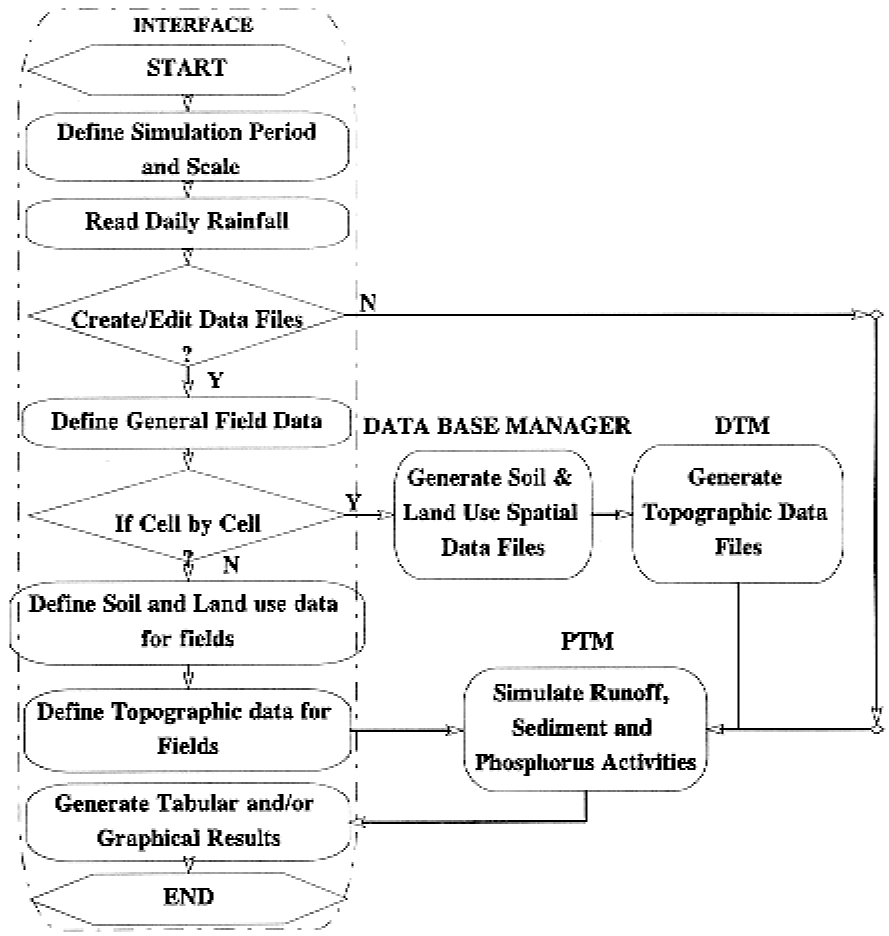


Figure 2.1 Schematic of SIMPLE modeling framework and interface flow chart.

2.2 DIGITAL SPATIAL DATA

Below is a description of the topography, soils and land use data used to model the sediment and phosphorus loading using SIMPLE. All model parameters utilized 30 m resolution data.

2.2.1 Topography

Using 7.5' USGS topographic maps, we created standard USGS digital elevation models (DEMS) for 25 USGS quadrangles: Blackgum, OK, Bunch, OK, Chance, OK, Cherokee City, AR-OK, Chewey, OK, Christie, OK, Colcord, OK, Cookson, OK, Gore, OK, Kansas, OK, Leach, OK, Moody's, OK, Park Hill, OK, Proctor, OK, Qualls, OK, Siloam Springs, AR-OK, Siloam Springs NW, OK, Stilwell East, OK-AR, Stilwell West, OK, Tailholt, OK, Tahlequah, OK, Thompson Comer, OK, Wafts, OK-AR, Westville, OK-AR, Zeb, OK. The University of Arkansas scan and created four topographic maps: Bentonville South, AR, Centerton, AR, Gentry, AR, Rogers, AR. The digital elevation data were obtained from optically scanning mylar separates of the elevation contour lines for each 7.5' quadrangle. The separates were clear mylar which only contain the contour or elevation lines present on a standard topographic quadrangle. The topographic mylars were scanned on an ANATech 3640 Eagle optical scanner at 400 dpi.

The scanned raster images were imported into a public domain software package called LTPLUS. Next the raster images were edited, vectorized, and then labeled. During the editing process procedures were employed to identify potential errors in the scanned images and correct them. In addition, after the image was vectorized, the vectors were plotted to scale, overlaid on the original mylar, and compared visually for accuracy and completeness. A second operator independently verified the elevation label values of previously labeled vectors. A supervisor then performed a final evaluation of the completed data (vectorized and labeled image). As another check the DEM model was created, imported into a geographic information system software package, and viewed in two and three dimensions to identify potential errors. Statistics were also generated on the DEM to identify potential errors. All potential errors were verified and corrected.

In the final step the vector images were sent to the USGS. The USGS input each vector image into LT4X, a commercial image processing software package, and created a 30 m DEM, which was then entered into their national database. Additional details on the use of LTPLUS are given in Appendix D.

There were seven missing DEM's for the quadrangles Elkins, AR, Fayetteville, AR, Lincoln, AR, Prairie Grove, AR, Sonora, AR, Springdale, AR, and West Fork, AR. For the quadrangles we re-sampled the USGS 1: 1 00,000 Fayetteville and Stilwell DEMs at 30 m and pasted the data into the missing quadrangles of the 1:24,000 DEM. Next we used a filter to smooth the gradient along the edges between the 1:24,000 and 1:100,000 DEMS. Although these 1:100,000 elevation estimates tended to underestimate field slopes, they still provided reasonable estimates given the lack of available data. The final composite DEM for the Upper Illinois River basin is given in Figure 2.2.

2.2.2 Soils

Soils data were digitized for the Oklahoma portion of the Upper Illinois River basin from NRCS County soil surveys. The University of Arkansas digitized the Arkansas portion of the basin. A 30 m resolution raster data layer was created from the vectorized images using GRASS. Additional details on the soils database in given in the next section. The distribution of soils for the Upper Illinois River basin is given in Figure 2.3.

2.2.3 Land Use

The land use data layer for the Illinois River Basin was obtained from the U.S. Environmental Protection Agency, which was produced under contract by Lockheed Corporation. The maps were derived from photo-

interpretation of 1:24,000 scale color infrared aerial film positives. The photography was flown August 30 through September 1, 1985.

The land use survey was completed utilizing a classification scheme adapted from Anderson et al. (1976). The Anderson scheme was modified to emphasize agricultural land uses. This classification scheme was further expanded during the digitization process to increase categories in the area of poultry, swine, and dairy operations.

After the aerial photography was interpreted in the original project, the information was transferred to clear, mylar overlays based upon USGS 7.5 minute (1:24000 scale) quadrangles, and digitized with an Altek graphic digitizer. Next, the features were labeled and the digitized quadrangle vector (polygon) data sets were merged into a single vector file so that edge-matching of polygons common to more than one quadrangle could be properly aligned. Finally the vector land use data set for the Illinois River Basin was converted to raster format with a 30 meter resolution. The land use data layer utilized by SIMPLE, Figure 2.4, composited several categories into: 1) urban, 2) pasture and range, 3) transportation, communications, utilities, 4) crop, 5) orchards, groves, vineyards, 6) Nurseries, 7) forest, 8) poultry operations, 9) dairy, 10) hog operations, and 11) water.

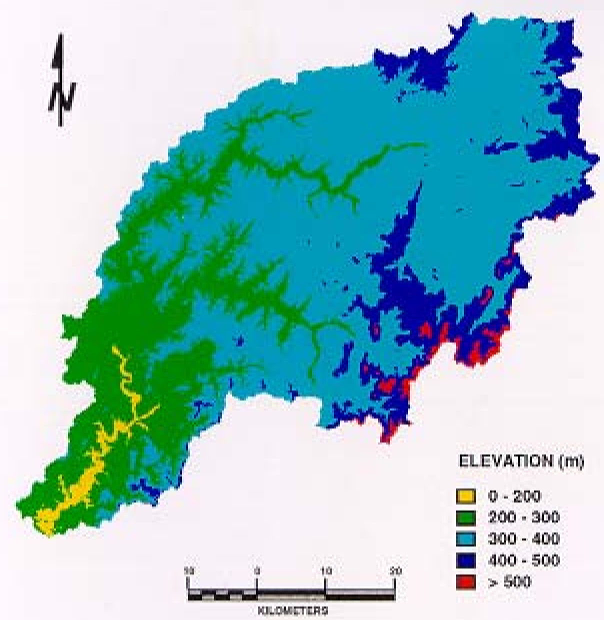


Figure 2.2 Topography of the Upper Illinois River basin using 1:24,000 DEM.

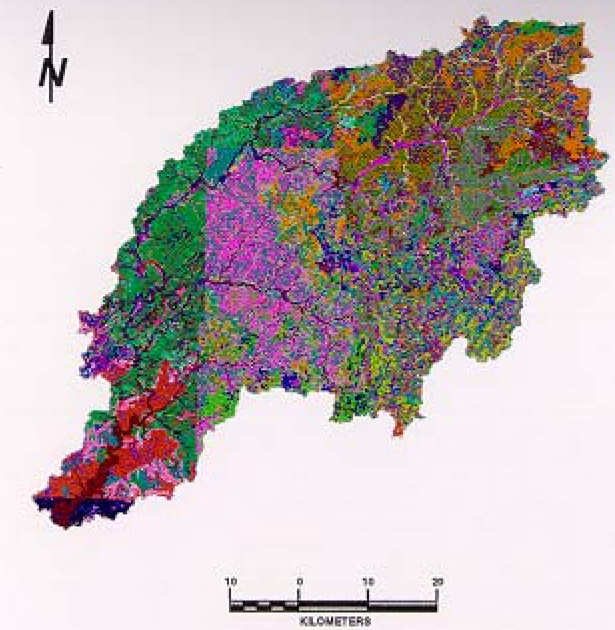


Figure 2.3 Soils distribution for the Upper Illinois River basin County level Soil Surveys.

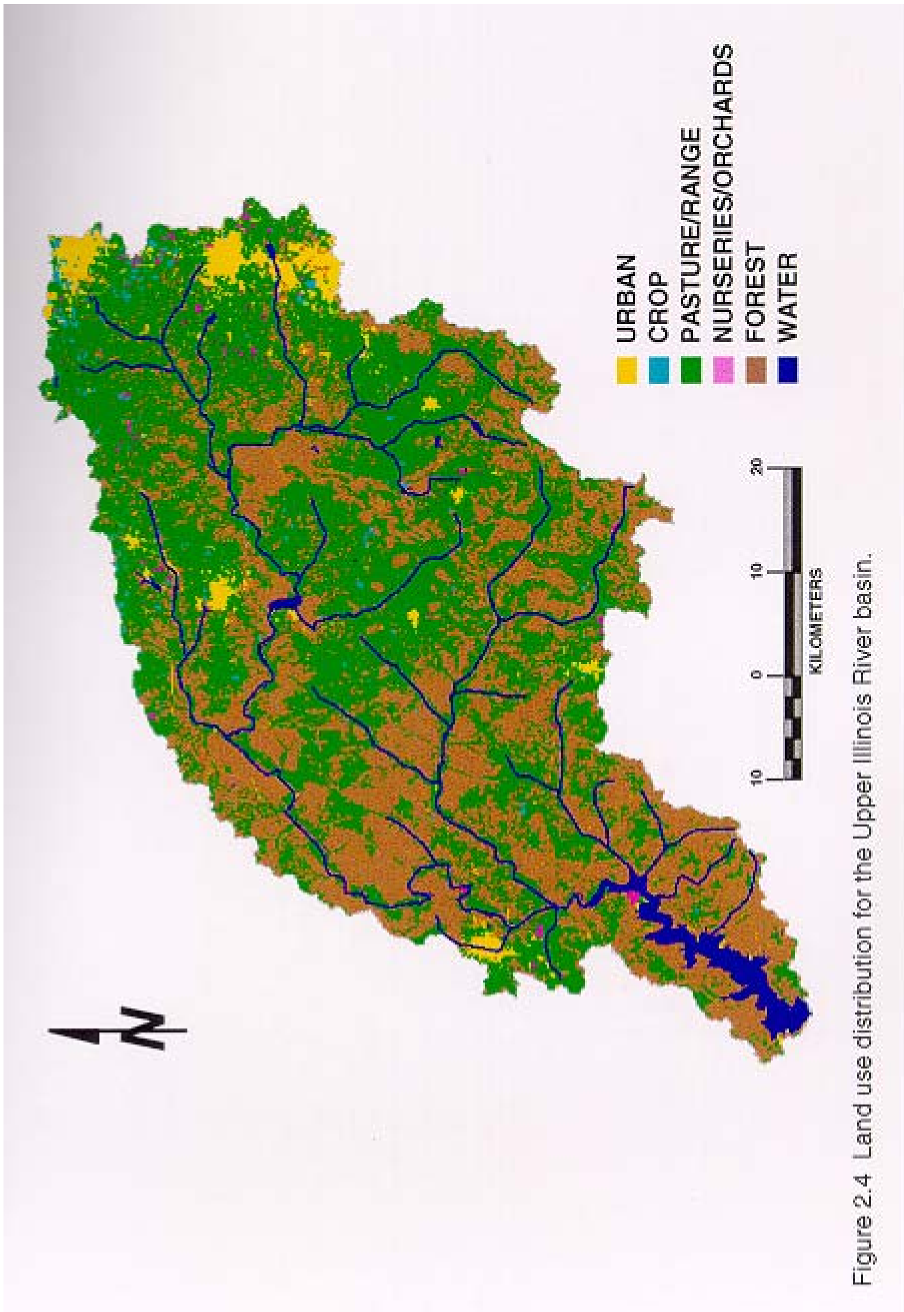


Figure 2.4 Land use distribution for the Upper Illinois River basin.

2.3 WATERSHED BOUNDARIES

The Upper Illinois River basin was divided into 15 sub-basins. The sub-basins and their UTM coordinates are: Osage (373720E 4003960N), Clear (379000E 3996460N), Fork (378955E 3996195N), Flint (344935E 4004175N), Baron (358060E 3974205N), Caney (328735E 3959345N), Benton (358285E 3999375N), River

(345205E 4003455N), Bord (331315E 3981045N), Tyner (339985E 3980645N), West (339715E 3980535N), Bbaron (327085E 3968715N), Bilin (327055E 3969045N), Lakeup (327295E 3966795N), and Lake (315355E 3940635N). The basin was divided into sub-basins to organize model results and to reduce the computer memory and hard disk requirements. The 15 sub-basins are shown in Figure 2.5.

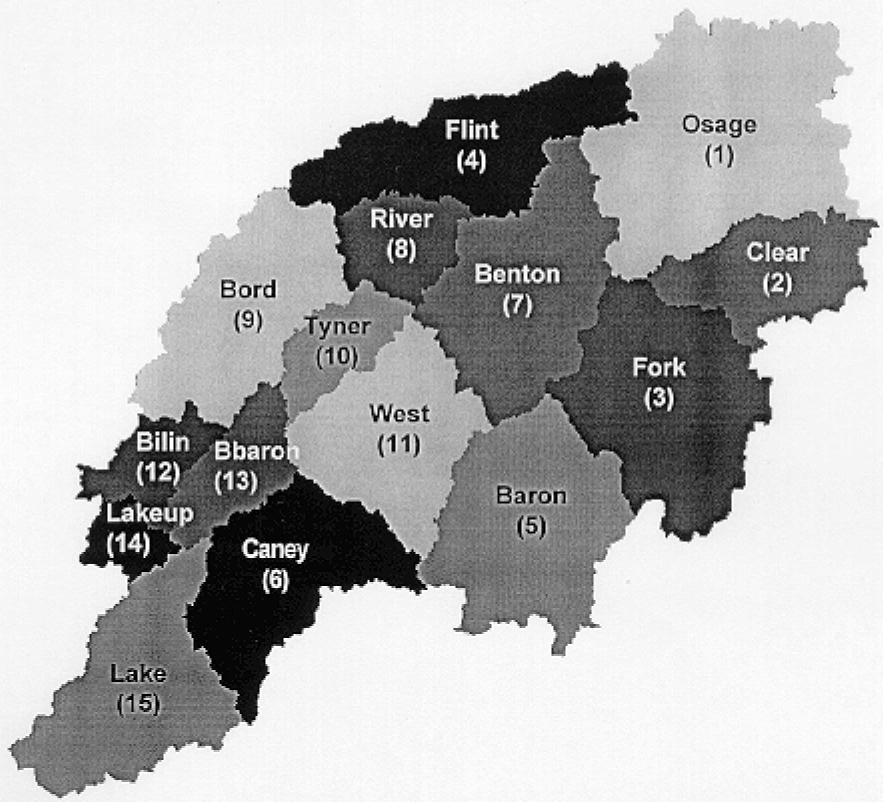


Figure 2.5. Subwatersheds identification for the Upper Illinois River Basin.

2.4 PARAMETER ESTIMATION

2.4.1 Topographic

SIMPLE requires cell/field slope, slope length, distance to stream and slope of distance to stream. The DTM used the 30 m DEM to estimate cell slope, and distance and slope to stream using procedures described by Sabbagh et al. (1994). However, the DEM was not detail enough to estimate slope length. Therefore, slope length was estimated using a modified procedure developed by the Oklahoma NRCS. Slope length (λ), as used in the USLE, was estimated based on county soil classification using two categories, upland soils and bottom land soils. All bottom land soils were assumed to have a slope length of 50 feet. The slope length for the upland soils was based on the soil mapping field slope as follows:

1. 0 to 1 percent slope - 600 foot slope length
2. 1 to 3 percent slope - 500 foot slope length
3. 3 to 5 percent slope - 400 foot slope length
4. 5 to 8 percent slope - 300 foot slope length
5. 8 to 12 percent slope - 200 foot slope length
6. > 12 percent slope - 50 foot slope length.

Table 2.1 presents field slope and slope length statistics for each watershed, and Table 2.2 gives the slope length for each soil type.

The next step was to define the stream network using the DTM. For each sub-basin we initially selected an arbitrary cut off value to define the stream network. By trial and error we changed the cut off value until the stream network visually approximated the 1:24,000 USGS blue line streams (continuous and intermittent flow steams). Next, distance to stream was estimated based on the flow path predicted by the DTM. The slope of this distance to stream was calculated as the ratio of the elevation drop to the stream and the distance to the stream. Distance to stream and slope of distance to stream is given in summarized in Table 2.1 for each watershed.

2.4.2 Soil and Management Parameters

Based on the Natural Resource Conservation Service (NRCS) County soils surveys, Table 2.3 gives the slope range and area for each soil type by county. Table 2.4 gives the USLE cover and management factors by land use based on USDA-SCS Handbook Number 537 (SCS, 1978). Hydrologic soil groups are given by land use in Table 2.5 based on NRCS County Soil Surveys.

2.4.4 Soil Phosphorus

Initial soil phosphorus is a very important input parameter for SIMPLE. We used the Mehlich III soil test values as an estimate of the available soil phosphorus that was input into SIMPLE. Soil test phosphorus is typically estimated for a field using a composite of 0 to 6 inch soil samples. It should be noted that SIMPLE requires the amount of available soil phosphorus in the upper one cm of the soil. However, based on validation and testing studies, we use the 0 to 6 inch composite Mehlich III soil test directly as the available soil phosphorus in the upper one cm of soil.

We had several data sources of soil phosphorus for the Upper Illinois River Basin. However, we only had detailed soil test phosphorus data for a few small watersheds within the basin. Therefore, we needed to develop a method to estimate soil phosphorus for the entire basin. First, we obtained all available soil test results from the Oklahoma State University Soil, Water, and Forage Analytical Laboratory. Data from Delaware County was from January 1993 through April 1995, Cherokee County data was from February 1993 through December 1994, and Adair County data were from January 1993 through May 1995. These data were identified by land use and county, but their specific location were unknown. Next, we obtained soil testing data from the Arkansas Soil and Water

Conservation during the period December 1991 through April 1995. These data were only for pasture and were identified by watershed. A summary of the soil test phosphorus data for pasture is given in Table 2.6 and Figure 2.6 shows the counties and watershed numbers. It should be noted that we assumed these data were representative of soil test phosphorus levels. This assumption is untested, but was the best available.

Soil phosphorus was assigned to fields based on land use for all land uses except pasture. A summary of the assigned soil phosphorus levels is given in Table 2.7. The poultry, dairy, and hog houses were assumed to be land Use of rooftop, and thus had a zero soil phosphorus status. For pasture two physically-based methods for assigning initial soil phosphorus were developed. The first option was to fit probability density functions to the observed soil test phosphorus data by county for Oklahoma and by watershed for Arkansas. Next, Monte Carlo simulation methods could be used to randomly assign soil phosphorus to pastures by county or watershed. Although this method would be acceptable, a second alternative was employed.

The second option, which was used in this project, assigned initial soil phosphorus to pasture as a function of distance from poultry house(s) and the average soil test phosphorus by county or watershed. The rationale for using distance from poultry house is that the owner of the poultry house(s) tends to apply litter on adjacent fields to minimize transportation costs. If the litter is applied to meet the nitrogen needs for forage production, then phosphorus will be over-applied and will build up in the soil profile with time. High soil test phosphorus levels have been observed in the Battle Branch and Peacheater Creek watersheds under the recent USDA Hydrologic Unit Projects in Oklahoma. These data will be presented shortly to illustrate high soil test phosphorus levels next to poultry houses.

The first step in assigning initial soil phosphorus to pasture was to determine the number of poultry houses per county or watershed. The NRCS 1985 poultry house survey was utilized. It should be noted that there was a significant expansion of poultry houses in the Oklahoma potion of the basin from 1985 through 1992. However, in the absence of more recent data, the 1985 survey was used.

The NRCS survey identified sites that had from one to 11 poultry houses. The area of influence for each site was mapped using the GRASS 4.1 command *s.voronoi,* which mapped a relative area of influence for each site. Due to GRASS limitations from the large number of sites, *s.voronoi* was run for each county and watershed independently. Next, the distance from poultry house data layer was calculated for the entire basin simultaneously using the GRASS 4.1 command r.cost An average number of poultry houses per site was calculated for each county or watershed (Table 2.8) and a weighing factor, W, was defined as:

$$W = \frac{\bar{P}_{st} \, H_n}{\bar{H}_n} \qquad 2.1$$

where $\bar{P}_{st}$ is the average soil test phosphorus for a county or watershed, $\bar{H}_n$ is the average number of poultry houses per site for a county or watershed, and H_n is the number of poultry houses per site. It should be noted that there are a number of weighting factors, W, one for each H_n.

The first approximation of the initial soil phosphorus for each 30 m cell, P_{soil1}, in the county or watershed was calculated using:

$$P_{soil1} = W \, \frac{D_{max} - D_H}{D_{max}} \qquad 2.2$$

where D_{max} is the distance in meters at which the soil phosphorus level reaches the native background level, and D_H is the distance from poultry house estimated from the r.cost function in meters. Next, the estimated average

initial soil phosphorus, $\bar{P}_{soil1}$, for the county or watershed was calculated and an adjusted initial soil test phosphorus for each 30 m cell, P_{soil2}, was calculated using:

$$P_{soil2} = \frac{P_{soil1} \, \bar{P}_{st}}{\bar{P}_{soil1}} \qquad 2.3$$

To keep realistic initial soil phosphorus values, P_{soil2}. was bounded between 15 and 1,200 lbs/ac. After bounding the data by 15 and 1,200, a new county or watershed average was calculated and the weighting function in equation 2.3 was employed a second time to ensure the average observed and predicted county of watershed soil phosphorus levels agreed. This process was repeated until the predicted and observed average county or watershed soil phosphorus were within five percent.

This methodology assigns a relatively high soil test phosphorus at a poultry house location, with phosphorus levels decreasing with distance from the poultry house. The rate at which the initial soil phosphorus decreased was governed by D_{max}. To estimate D_{max} the Peacheater Creek and Battle Branch watersheds were examined. For these watersheds detailed soil testing was conducted by the Oklahoma Cooperative Extension Service as part of two USDA Hydrologic Unit Area Projects. Figures 2.7 and 2.8 show the relationship between distance from poultry house and soil test phosphorus for Peacheater Creek and Battle Branch watersheds, respectively. Based on a linear regression and assuming a native soil phosphorus level of 15, D_{max} is 2,500 and 1,500 meters for the Peacheater Creek and Battle Branch watersheds, respectively.

The above methodology was initially applied to the Upper Illinois basin using a D_{max} of 2,500 meters. However, there was a significant portion of the estimated soil phosphorus levels that were in excess of 1,200 and some levels exceeded 3,000. By trial and error a D_{max} of 8000 meters was selected. The 8000 meter distance was selected based on visual comparison, and thus no statistical criteria were used. Using 8000 meters resulted in reasonable soil phosphorus levels compared to the observed soil test data. As indicated in Figures 2.7 and 2.8, there is considerable scatter in the data and a linear relationship may not necessarily be appropriate. However, the Peacheater Creek and Battle Branch watersheds are relatively small, 16,200 and 5,500 acres, respectively, and neighboring poultry houses outside the watershed are not taken into account. In addition, in the upper portion of the Peacheater Creek watershed there is a sizeable concentration of poultry houses that are owned by Hudson. The poultry litter from these houses is sold and none of the litter is applied to their adjacent pastures.

A comparison between the observed and predicted soil phosphorus levels for the Peacheater Creek and Battle Branch watersheds is shown in Figures 2.7 and 2.8, respectively. The slope of the predicted regression lines are much lower due to a D_{max} of 8000 meters. In addition, the grouping of predicted soil phosphorus parallel to the regression line is an artifact of the methodology. Throughout the watershed, soil phosphorus levels at each site of poultry house(s) is constant for a given number of poultry houses. Relative frequency comparisons for the Peacheater Creek and Battle Branch watersheds are given in Figures 2.9 and 2.10, respectively. As indicated in these figures, the agreement between observed and predicted soil phosphorus levels is poor.

Next, the methodology was applied to the entire basin. A comparison of the observed and predicted relative frequency distributions for each county/watershed is given in Figures 2.11 through 2.22. In general, the frequency distributions for the observed and predicted soil test values agreed. Figures 2.23 and 2.24 show the location of poultry houses and distance from poultry house for the Upper Illinois basin, respectively. Figure 2.25 shows the initial soil phosphorus for the basin used in SIMPLE.

The soil phosphorus data had units of lb P/ac. However, SIMPLE requires units of pg P/g soil. To convert lbs/ac to pg/g we assumed a dry soil bulk density of 1.5 g/CM3 and a soil depth of 0.5 ft, thus yielding

$$\frac{lbs\ P}{ac} * \frac{kg}{2.2\ lbs} * \frac{10^9\ \mu g}{kg} * \frac{ac}{43560\ ft^2} * \frac{1}{0.5\ ft} * \frac{(0.0328)^3\ ft^3}{cm^3} * \frac{cm3}{1.5\ g\ soil} * \frac{0.49\ \mu gP}{g\ soil} \qquad 2.4$$

or

$$\frac{lb}{ac} = 0.49\ \frac{\mu g}{g} \qquad 2.5$$

2.4.4 Fertilization

For the SIMPLE computer simulations, poultry litter was assumed to be applied to pasture/range land every April at a rate based on the number of poultry houses contained in the watershed. Each poultry house was assumed to hold 20,000 broilers and would produce 100 tons litter per year. This was based on 9.73 tons litter per 1000 ft^2 per year (Finley et al., 1994) and a 50 ft by 200 ft house. Next we assumed the litter contained 1.5 percent P, and thus each house produced 1400 kg P per year. The litter application rate to pasture for each of the watersheds is given in Table 2.9. It should be noted that we are neglecting commercial fertilizer, dairies, layers, pullets, and turkeys, and human water recreation impacts. However, relative to the broiler production these inputs were considered negligible.

For cropland we assumed an application of 20 kg P/ha/yr. For the remaining land uses we selected a P application rate that would keep the soil at approximately the same initial soil P level. We applied 0.3 kg P/ha/yr for urban areas, 0.06 kg P/ha/yr for transportation and utilities, 0.3 kg P/ha/yr for Orchards, Vineyards, and nurseries, and 0.03 kg P/ha/yr to forest land.

2.4.5 Precipitation

Daily precipitation as rainfall was required by SIMPLE. Weather stations located through the Illinois River Basin were located and the rainfall data compiled. As shown in Table 2.10, we used eight weather stations: Bentonville, Fayetteville, Kansas, Odell, Stilwell, Siloam Springs and Tahlequah. Figure 2.26 shows the location of weather stations and Table 2.10 indicates which weather station was used for each watershed.

Table 2.l. Topographic statistics by watershed for the Upper Illinois River Basin.

Watershed	Parameter	Slope (%)	Slope Length (meters)	Distance to Stream (meters)	Slope to Stream (%)
Osage	Mean	5.2	81	650	2.5
	Standard Deviation	4.5	47	463	2.2
	Minimum	0.0	15	0	0.0
	Maximum	30.8	306	2932	22.4
Clear	Mean	5.4	72	799	2.2
	Standard Deviation	4.7	40	576	1.9

	Minimum	0.0	15	0	0.0
	Maximum	30.0	183	3848	19.2
Fork	Mean	2.1	85	622	0.8
	Standard Deviation	5.1	34	896	2.6
	Minimum	0.0	15	0	0.0
	Maximum	42.0	183	5384	22.0
Flint	Mean	6.8	83	601	3.1
	Standard Deviation	5.6	44	423	2.5
	Minimum	0.0	15	0	0.0
	Maximum	32.5	183	2428	19.7
Baron	Mean	5.3	65	810	2.8
	Standard Deviation	6.2	42	488	3.8
	Minimum	0.0	10	0	0.0
	Maximum	72.0	189	3146	36.0
Caney	Mean	8.6	101	566	4.6
	Standard Deviation	6.0	39	415	3.2
	Minimum	0.0	15	0	0.0
	Maximum	33.0	189	2194	25.3
Benton	Mean	5.8	65	974	3.0
	Standard Deviation	6.0	45	423	3.6
	Minimum	0.0	15	0	0.0
	Maximum	50.0	201	2108	35.6
River	Mean	6.8	98	590	3.2
	Standard Deviation	6.4	42	414	2.9
	Minimum	0.0	15	0	0.0
	Maximum	26.6	189	1874	18.5
Bord	Mean	11.3	68	546	4.1
	Standard Deviation	7.6	39	413	3.7
	Minimum	0.0	15	0	0.0
	Maximum	34.7	183	1944	52.0

Table 2.1 (continued). Topographic statistics by watershed for the Upper Illinois River Basin.

Watershed	Parameter	Slope (%)	Slope Length (meters)	Distance to Stream (meters)	Slope to Steam (%)
Tyner	Mean	8.2	105	515	5.5
	Standard Deviation	6.6	30	397	4.1
	Minimum	0.0	15	0	0.0
	Maximum	40.2	184	2088	37.8
West	Mean	8.6	98	554	3.6
	Standard Deviation	6.2	35	432	2.7

	Minimum	0.0	15	0	0 ' 0
	Maximum	33.0	189	2260	23.3
Bbaron	Mean	6.9	81	590	3.9
	Standard Deviation	6.1	45	496	3.6
	Minimum	0.0	15	0	0.0
	Maximum	29.2	183	3218	30.4
Bilin	Mean	7.3	75	648	3.0
	Standard Deviation	6.9	43	518	2.8
	Minimum	0.0	15	16	0.0
	Maximum	38.7	183	2897	16.2
Lakeup	Mean	6.3	97	629	1.9
	Standard Deviation	5.0	43	523	2.1
	Minimum	0.0	15	15	0.0
	Maximum	23.6	183	2035	10.8
Lake	Mean	8.5	95	684	5.0
	Standard Deviation	6.0	47	497	5.5
	Minimum	0.0	0	0	0.0
	Maximum	40.4	168	3352	117.6

Table 2.2. Soil characteristics for the Upper Illinois River Basin (USLE K factor in English units).

Soil Number	USLE K	Hydrologic Soil Group	pH	Organic Carbon (%)	Clay (%)	Bulk Density (g/cm^3)	Slope Length (m)
1	0.28	B	6.10	0.44	14	1.45	122
2	0.28	B	5.25	0.44	14	1.45	61
3	0.28	B	5.25	0.44	14	1.45	61
4	0.37	C	5.25	0.44	25	1.45	152
5	0.43	B	5.00	0.74	25	1.43	152
6	0.43	B	5.00	0.74	25	1.43	152
7	0.37	B	5.00	1.18	25	1.39	189
8	0.37	B	5.00	1.18	25	1.39	152
9	0.37	B	5.00	1.18	25	1.39	152

10	0.37	B	5.40	1.18	25	1.39	122
11	0.01	B	7.00	0.01	0.01	1.00	15
12	0.1	C	5.80	0.74	13	1.51	152
13	0.19	C	5.00	0.85	17	1.50	152
14	0.28	B	6.70	2.65	25	1.28	15
15	0.28	B	6.70	2.65	24	1.34	15
16	0.43	C	5.80	0.01	18	1.51	189
17	0.43	C	5.50	1.47	18	1.39	152
18	0.28	B	4.55	1.03	10	1.52	152
19	0.28	B	4.55	1.03	10	1.52	122
20	0.28	B	4.55	1.03	19	1.48	122
21	0.28	B	4.55	1.03	19	1.48	122
22	0.28	D	6.20	1.47	37	1.29	15
23	0.49	D	5.80	0.44	25	1.45	183
24	0.32	D	7.25	0.01	33	1.54	152
25	0.37	C	6.45	1.18	33	1.34	183
26	0.37	C	6.45	0.10	33	1.34	152
27	0.37	C	6.45	1.18	33	1.34	122
28	0.37	C	6.45	1.18	33	1.34	122
29	0.43	D	5.00	2.06	18	1.34	15
30	0.49	C	5.55	0.44	25	1.45	183
82	0.01	D	7.00	0.01	0.01	1.00	152
87	0.01	D	7.00	0.01	0.01	1.00	152
88	0.01	D	7.00	0.01	0.01	1.00	152
98	0.01	B	7.00	0.01	0.01	1.00	152
102	0.28	B	5.25	1.74	18	1.37	152
103	0.28	B	5.50	1.74	18	1.37	152
104	0.33	B	5.25	1.18	14	1.42	122
105	0.43	B	5.50	1.18	12	1.43	152
108	0.28	B	4.80	0.74	12	1.46	122
109	0.28	B	4.80	0.74	25	1.43	61
110	0.28	B	4.80	0.74	25	1.43	30
114	0.37	D	6.05	1.18	25	1.39	122
116	0.37	A	6.45	0.88	25	1.42	15
117	0.1	C	5.80	0.74	10	1.54	122
118	0.19	B	5.00	0.88	10	1.53	152
119	0.43	C	5.80	0.01	18	1.51	183
120	0.28	B	4.55	1.03	10	1.52	137

Table 2.2 (continued). Soil characteristics for the Upper Illinois River Basin (USLE K factor in English units).

Soil Number	USLE K	Hydrologic Soil Group	pH	Organic Carbon (%)	Clay (%)	Bulk Density (g/cm^3)	Slope Length (m)
121	0.37	B	5.00	0.59	12	1.48	152
122	0.37	B	6.05	1.18	18	1.41	183
123	0.37	B	6.05	1.18	18	1.41	152
124	0.37	B	6.05	1.18	18	1.41	91
128	0.43	C	6.45	1.18	33	1.38	152
129	0.43	C	6.45	1.18	33	1.38	122
130	0.28	D	6.45	1.47	45	1.31	15
132	0.01	D	7.00	0.01	0.01	1.00	152
133	0.37	B	6.45	0.74	12	1.46	15

134	0.37	B	6.45	0.74	12	1.46	15
135	0.37	B	6.45	0.74	15	1.54	15
136	0.37	B	6.45	0.74	15	1.54	107
137	0.32	B	6.45	1.76	25	1.35	15
138	0.3	B	6.45	1.76	24	1.35	15
139	0.49	D	5.00	1.18	12	1.43	183
140	0.37	C	6.45	1.18	33	1.34	137
141	0.49	C	5.55	0.44	25	1.45	183
142	0.32	D	8.15	1.18	24	1.46	107
143	0.32	D	8.15	1.18	24	1.46	30
206	0.23	C	5.00	1.00	13	1.51	15
210	0.19	D	5.50	0.88	1.1	1.53	122
211	0.19	D	5.50	0.88	1.1	1.53	90
212	0.37	C	4.80	1.10	1.1	1.48	122
221	0.43	B	5.00	1.03	15	1.43	152
222	0.43	B	5.00	1.03	18	1.43	122
223	0.43	B	5.00	1.03	18	1.43	122
229	0.37	B	5.00	0.10	22	1.43	15
234	0.32	D	7.25	0.01	33	1.54	15
236	0.49	D	4.75	1.00	15	1.44	183
238	0.49	C	5.00	1.18	12	1.43	152
241	0.37	C	6.45	1.18	33	1.34	152
320	0.28	B	5.50	1.76	18	1.38	122
321	0.28	B	5.50	1.76	18	1.38	61
322	0.28	B	5.50	1.76	18	1.38	30
323	0.28	B	5.50	1.76	18	1.38	15
335	0.37	C	5.25	0.88	15	1.43	107
336	0.37	C	5.25	0.88	15	1.43	61
345	0.43	B	5.50	1.18	8	1.45	152
346	0.43	C	5.50	1.18	12	1.43	400
348	0.43	B	5.50	1.18	8	1.45	122
349	0.43	B	5.50	1.18	8	1.45	122
352	0.43	B	6.20	0.74	18	1.47	152
356	0.28	B	4.80	0.74	25	1.44	30
357	0.28	B	4.80	0.74	25	1.44	15
374	0.37	A	6.45	0.88	8	1.51	15
381	0.28	B	6.70	1.76	25	1.36	15

Table 2.2 (continued). Soil characteristics for the Upper Illinois River Basin (USLE K factor in English units).

Soil Number	USLE K	Hydrologic Soil Group	pH	Organic Carbon (%)	Clay (%)	Bulk Density (g/cm^3)	Slope Length (m)
401	0.37	B	6.05	1.76	14	1.38	15
402	0.2	B	7.00	0.01	8	1.27	122
404	0.37	B	6.05	1.76	14	1.38	15
409	0.43	B	5.80	0.01	6	1.53	152
410	0.43	B	5.80	XX	6	1.53	122
411	0.43	B	5.50	0.88	12	1.47	152
413	0.43	C	5.50	0.88	12	1.47	152
414	0.32	C	4.55	1.18	18	1.43	183
415	0.37	C	4.55	1.18	18	1.43	152
423	0.49	C	6.20	1.18	35	1.34	152

442	0.33	B	6.05	1.18	18	1.43	152
443	0.32	B	5.00	1.18	18	1.43	107
444	0.32	B	5.00	1.18	18	1.43	61
445	0.43	C	5.00	1.18	18	1.43	107
453	0.28	B	5.50	1.18	18	1.43	61
454	0.28	B	5.50	1.18	18	1.43	30
455	0.28	B	5.50	1.16	18	1.43	15
464	0.32	B	5.90	1.76	25	1.36	152
465	0.32	B	5.25	1.76	25	1.36	122
466	0.32	B	5.25	1.74	18	1.41	107
467	0.37	B	5.25	1.16	12	1.45	152
469	0.37	B	5.25	1.18	12	1.45	107
471	0.43	B	5.25	1.03	18	1.44	152
472	0.43	B	5.00	1.03	18	1.44	107
473	0.43	B	5.00	1.03	18	1.44	107
474	1.43	B	5.00	1.03	18	1.44	61
489	0.37	B	6.70	1.18	18	1.49	15
493	0.37	B	6.70	1.18	18	1.43	15
494	0.37	B	6.70	1.18	18	1.43	15
497	0.01	D	1.00	0.01	0.01	2.65	152
501	0.32	B	5.80	1.18	17	1.41	15
506	0.37	B	6.95	2.65	25	1.29	15
507	0.32	C	7.25	0.01	25	1.51	152
515	0.37	D	6.45	1.18	42	1.31	183
516	0.37	D	6.45	1.18	42	1.31	152
517	0.37	D	6.45	1.18	42	1.31	107
518	0.37	D	6.45	1.18	42	1.31	76
519	0.37	D	6.45	1.18	42	1.31	30
520	0.37	D	6.45	1.76	33	1.29	107
521	0.37	D	6.45	1.76	33	1.29	61
522	0.37	D	6.45	1.47	37	1.30	152
523	0.49	C	5.55	0.44	12	1.47	183
524	0.49	D	5.55	0.44	12	1.47	152
525	0.49	C	5.55	0.44	12	1.47	152
526	0.37	B	5.00	0.01	13	1.53	107
533	0.28	A	5.80	0.74	8	1.48	107
534	0.28	A	5.80	0.74	8	1.48	61

Table 2.2 (continued). Soil characteristics for the Upper Illinois River Basin (USLE K factor in English units).

Soil Number	USLE K	Hydrologic Soil Group	pH	Organic Carbon (%)	Clay (%)	Bulk Density (g/cm')	Slope Length (m)
601	0.24	A	4.55	1.47	19	1.46	107
602	0.24	A	4.55	1.47	19	1.46	91
603	0.24	A	4.55	1.47	19	1.46	61
604	0.24	A	4.55	1.47	19	1.46	61
605	0.24	A	4.55	1.47	19	1.46	15
611	0.28	A	5.00	1.03	12	1.50	107
612	0.28	A	5.00	1.03	12	1.50	61
613	0.28	A	5.00	1.03	12	1.50	31
614	0.28	A	5.00	1.03	19	1.50	15
615	0.28	A	5.00	1.03	19	1.50	61
622	0.19	A	5.50	0.88	15	1.53	15

627	0.37	A	5.00	1.18	19	1.49	152
628	0.37	A	5.00	1.18	19	1.49	91
629	0.37	A	5.00	1.18	19	1.49	91
630	0.2	C	6.05	0.59	13	1.55	350
638	0.43	C	5.90	1.18	13	1.43	152
639	0.43	C	5.90	1.18	13	1.43	152
640	0.32	B	6.45	1.18	16	1.51	15
645	0.37	A	6.45	0.88	12	1.47	15
646	0.37	A	6.45	0.88	19	1.51	15
655	0.32	C	4.55	1.18	19	1.49	91
656	0.32	C	4.55	1.18	19	1.49	91
657	0.32	C	4.55	1.18	19	1.49	91
658	0.32	C	4.55	1.88	19	1.49	61
659	0.32	C	4.55	1.18	19	1.49	61
662	0.32	C	4.55	1.76	16	1.47	91
664	0.32	C	4.55	1.76	16	1.47	30
668	0.28	C	4.55	1.61	19	1.45	61
669	0.28	C	4.55	1.61	19	1.45	61
684	0.24	B	6.05	1.18	16	1.51	91
685	0.24	B	6.05	1.18	16	1.51	61
686	0.24	B	6.10	1.18	16	1.51	31
687	0.24	B	6.10	1.18	16	1.51	15
688	0.17	B	5.90	1.00	13	1.53	10
689	0.15	C	5.50	0.88	10	1.55	152
690	0.15	C	5.50	0.88	10	1.55	61
691	0.15	C	5.50	0.88	11	1.55	61
708	0.28	B	4.55	1.03	4	1.52	107
712	0.33	B	4.55	1.03	19	1.50	152
714	0.28	B	4.55	1.03	19	1.50	91
716	0.28	B	4.55	1.03	13	1.51	91
717	0.28	B	4.55	1.03	13	1.51	61
724	0.28	C	5.25	0.74	18	1.47	91
725	0.2	B	5.25	1.18	6	1.54	30
726	0.2	B	5.25	1.18	6	1.54	91
727	0.2	B	5.25	1.18	6	1.54	15

Table 2.2 (continued). Soil characteristics for the Upper Illinois River Basin (USLE K factor in English units).

5011 Number	USLE K	Hydrologic Soil Group	pH	Organic Carbon (%)	Clay (%)	Bulk Density (g/cm')	Slope Length (m)
791	0.49	C	6.05	1.76	25	1.36	152
794	0.49	C	6.05	1.76	25	1.36	152
795	0.37	B	4.55	1.03	10	1.54	152
796	0.37	B	4.55	1.03	10	1.54	91
834	0.32	C	4.55	1.76	16	1.47	15
852	0.25	C	4.90	1.10	13	1.53	30
882	0.28	B	4.55	1.03	4	1.52	15
917	0.17	D	5.25	1.18	10	1.53	90
931	0.2	B	5.00	1.03	16	1.53	120
938	0.26	B	4.75	1.10	16	1.52	30
939	0.26	B	4.75	1.10	16	1.52	15
999	0.01	D	7.00	0.01	0	1.00	152

Table 2.3. Soils database.

County	Soil Number	Soil Name/Classification	Slope Range (%)	Area (ha)	Watershed Coverage (%)
Adair, OK	1	Bodine very cherty silt loam	1-8	21,7535.17	
	2	Bodine stony silt loam	5-15	5279	1.25
	3	Bodine stony silt loam	steep	30,284	7.20
	4	Craig cherty silt loam	1-5	417	0.10
	5	Dickson silt loam	1-3	5339	1.27
	6	Dickson cherty silt loam	0-3	8370	1.99
	7	Etowah silt loam	0-1	601	0.14
	8	Etowah silt loam	1-3	2215	0.53
	9	Etowah gravelly silt loam	1-3	4038	0.96
	10	Etowah and Greendale soils	3-8	6376	1.52
	11	Gravelly alluvial land	--	3245	0.77
	12	Hector complex	--	6397	1.52
	13	Hector-Linker fine sandy loams	1-5	1815	0.43
	14	Huntington silt loam	--	400	0.10

	15	Huntington gravelly loam	---	993	0.24
	16	Jay silt loam	0-2	1258	0.30
	17	Lawrence silt loam	---	231	0.05
	18	Linker fine sandy loam	1-5	556	0.13
	19	Linker fine sandy loam	3-5	109	0.03
	20	Linker loam	3-5	473	0.11
	21	Linker loam	3-5	117	0.03
	22	Sage clay loam	--	178	0.04
	23	Parsons silt loam	0-1	203	0.05
	24	Sogn soils	---	562	0.13
	25	Summit silty clay loam	0-1	254	0.06
	26	Summit silty clay loam	1-3	379	0.09
	27	Summit silty clay loam	3-5	163	0.04
	28	Summit silty clay loam	3-5	63	0.02
	29	Taft silt loam	--	600	0.14
	30	Taloka silt loam	0-1	81	0.02
	82	Borrow Pits	--	30	0.01
	83	Gravel Pits	--	34	0.01
	87	Pits Quarries	--	6	0.00
	88	Quarries	--	36	0.01
	98	water	--	5730	1.36
Cherokee & Delaware, OK	102	Baxter silt loam	1-3	1069	0.25
	103	Baxter cherty silt loam	1-3	1070	0.25
	104	Baxter-Locust complex	3-5	1317	0.31
	105	Captina silt loam	1-3	2504	0.60
	108	Clarksville very cherty silt loam	1-8	10941	2.60
	109	Clarksville stony silt loam	5-20	6575	1.56
	110	Clarksville stony silt loam	20-50	30516	7.25
	111	Collinsville fine sandy loam	2-5	14	0.00
	114	Eldorado silt loam	3-5	625	0.15
	115	Eldorado soils	3-12	267	0.06
	116	Elsah soils	---	4451	1.06

Table 2.3 (continued). Soils database.

County	Soil Number	Soil Name/Classification	Slope Range (%)	Area (ha)	Watershed Coverage (%)
Cherokee & Delaware, OK	117	Hector fine sandy loam	2-5	2072	0.49
	118	Hector-Linker association hilly	--	12681	3.01
	119	Jay silt loam	0-2	611	0.15
	120	Linker fine sandy loam	2-5	664	0.16
	121	Locust cherty silt loam	1-3	3539	0.84
	122	Newtonia silt loam	0-1	58	0.01
	123	Newtonia silt loam	1-3	827	0.20
	124	Newtonia silt loam3-5	---	338	0.08
	125	Newtonia silt loam	2-5	100	0.02
	127	Okemah silty clay loam	0-1	366	0.09
	128	Okemah silty clay loam	1-3	708	0.17
	129	Okemah silty clay loam	3-5	162	0.04
	130	Osage clay	---	377	0.09
	132	Rough stony land	--	2698	0.64
	133	Sallisaw silt loam	0-1	383	0.09

	134	Sallisaw silt loam	1-3	1549	0.37
	135	Sallisaw gravelly silt loam	1-3	2149	0.51
	136	Sailisaw gravelly silt loam	3-8	5125	1.22
	137	Staser silt loam	--	1106	0.26
	138	Staser gravelly loam	-	2748	0.65
	139	Stigler silt loam	0-1	925	0.22
	140	Summit silty clay loam	2-5	317	0.08
	141	Taloka silt loam	0-1	323	0.08
	142	Talpa-Rock outcrop complex	2-8	1294	0.31
	143	Talpa-Rock outcrop complex	15-50	4771	1.13
Sequoyah, OK	203	Cleora fine sandy loam	--	21	0.01
	206	Hector-Linker-Enders complex	5-40	7110	1.69
	210	Linker@Hector complex	2-5	1118	0.27
	211	Linker-Hector complex	5-8	64	0.02
	212	Linker and Stigler soils	2-8	50	0.01
	216	Mason silt loam	-	269	0.06
	221	Pickwick loam	1-3	307	0.07
	222	Pickwick loam	3-5	414	0.10
	223	Pickwick loam	2-5	56	0.01
	224	Razort fine sandy loam	--	62	0.01
	227	Rosebloom silt loam	--	21	0.01
	229	Rosebloom and Ennis soils broken	--	325	0.08
	230	Sallisaw complex	8-30	14	0.00
	231	Sailisaw loam	1-3	24	0.01
	232	Sallisaw loam	3-5	59	0.01
	233	Sailisaw loam	2-5	34	0.01
	234	Sogn complex	10-25	483	0.11
	236	Stigler-Wrightsville silt loams	0-1	104	0.02
	238	Stigler silt loam	1-3	414	0.10
	239	Stigler silt loam	2-5	7.38	0.00
	241	Summit silty clay loam	1-3	56	0.01
	242	Summit silty clay loam	3-5	140	0.03

Table 2.3 (continued). Soils database.

County	Soil Number	Soil Name/Classification	Slope Range (%)	Area (ha)	Watershed Coverage (%)
Washington & Benton, AR	320	Baxter cherty silt loam	3-8	118	0.03
	321	Baxter cherty silt loam	8-12	298	0.07
	322	Baxter cherty silt loam	12-20	240	0.06
	323	Baxter cherty silt loam	20-45	1914	0.45
	335	Britwater gravelly silt loam	3-8	1320	0.31
	336	Britwater gravelly silt loam	8-12	13	0.00
	345	Captina silt loam	1-3	17124	4.07
	348	Captina silt loam	3-6	1534	0.36
	349	Captina silt loam	3-6	5587	1.33
	352	Craytown silt loam		204	0.05
	356	Clarksville cherty silt loam	12-50	11213	2.67
	357	Clarksville cherty silt loam	12-60	10874	2.58
	374	Elsah soils		1988	0.47
	381	Fatima silt loam occasionally flooded		559.17	0.13
	401	Guin cherty silt loam	3-8	1143	0.27
	402	Healing silt loam		473.22	0.11

	404	Healing silt loam occasionally flooded		1949	0.46
	409	Jay silt loam	1-3	4212	1.00
	410	Jay silt loam	3-8	951	0.23
	411	Johnsburg silt loam		3553	0.84
	413	Johnsburg complex mounded		260	0.06
	414	Leaf silt loam		1163	0.28
	415	Leaf complex mounded		573	0.14
	423	Mayes silty clay loam		267	0.06
	442	Newtonia silt loam	1-3	374	0.09
	443	Nixa cherty silt loam	3-8	22615	5.38
	444	Nixa cherty silt loam	8-12	5729	1.36
	445	Nixa very cherty silt loam	3-8	2.88	0.00
	453	Noarkvery cherty silt loam	8-12	370	0.09
	454	Noark very cherty silt loam	12-20	990	0.24
	455	Noark very cherry silt loam	20-45	1524	0.36
	464	Pembroke silt loam	1-3	762	0.18
	465	Pembroke silt loam	3-6	1065	0.25
	466	Pembroke gravelly silt loam	3-8	613	0.15
	467	Peridge silt loam	1-3	2013	0.48
	469	Peridge silt loam	3-8	1646	0.39
	471	Pickwick silt loam	1-3	844	0.20
	472	Pickwick silt loam	3-8	5529	1.31
	473	Pickwick gravelly loam	3-8	150	0.04
	474	Pickwick gravelly loam	8-12	68	0.02
	489	Razort loam		679	0.16
	493	Razort silt loam occasionally flooded		1726	0.41
	494	Razort gravelly silt loam occasionally flooded		2182	0.52
	497	Rock land		191	0.05
	501	Secesh gravelly silt loam occasionally flooded		4506	1.07

Table 2.3 (continued). Soils database.

County	Soil Number	Soil Name/Classification	Slope Range (%)	Area (ha)	Watershed Coverage (%)
Washington & Benton, AR	506	Sloan silt loam		1962	0.47
	507	Sogn rocky silt loam		573	0.14
	515	Summit silty clay	0-1	1647	0.39
	516	Summit silty clay	1-3	325	0.08
	517	Summit silty clay	3-8	416	0.10
	518	Summit silty clay	3-15	21	0.01
	519	Summit silty clay	8-12	77	0.02
	520	Summit stony silty clay	3-12	335	0.08
	521	Summit stony silty clay	12-25	45	0.01
	522	Summit complex mounded		92	0.02
	523	Taloka silt loam	0-1	3651	0.87
	524	Taloka silt loam	1-3	697	0.17
	525	Taloka complex mounded		531	0.13
	526	Tonti cherty silt loam	3-8	7977	1.90
	533	Waben very cherty silt loam	3-8	781	0.19
	534	Waben very cherty silt loam	8-12	62	0.01
	601	Allegheny gravelly loam	3-8	138	0.03

	602	Allegheny gravelly loam	3-8	201	0.05
	603	Allegheny gravelly loam	8-12	87	0.02
	604	Allegheny stony loam	8-12	235	0.06
	605	Allegheny stony loam	12-40	272	0.06
	611	Allen loam	3-8	238	0.06
	612	Allen loam	8-12	220	0.05
	613	Allen loam	12-20	127	0.03
	614	Allen stony loam	12-35	132	0.03
	615	Allen soils	8-20	36	0.01
	622	Allen-Hector complex	20-40	167	0.04
	627	Apison loam	1-3	113	0.03
	628	Apison loam	3-8	1125	0.27
	629	Apison gravelly loam	3-8	203	0.05
	630	Cane loam	3-8	135	0.03
	638	Cherokee silt loam		2031	0.48
	639	Cherokee complex mounded		244	0.06
	640	Cleora fine sandy loam		1893	0.45
	645	Elsah gravelly soils		1244	0.30
	646	Elsah cobbly soils		890	0.21
	655	Enders gravelly loam	3-8	106	0.03
	656	Enders gravelly loam	3-8	640	0.15
	657	Enders gravelly loam	3-12	398	0.09
	658	Enders gravelly loam	8-12	242	0.06
	659	Enders gravelly loam	8-12	204	0.05
	662	Enders stony loam	3-12	2531	0.60
	664	Enders stony loam	12-30	132	0.03
	668	Enders-Allegheny complex	8-20	8062	1.92
	669	Enders-Allegheny complex	20-40	10162	2.42
	684	Fayetteville fine sandy loam	3-8	1814	0.43

Table 2.3 (continued). Soils database.

County	Soil Number	Soil Name/Classification	Slope Range (%)	Area (ha)	Watershed Coverage (%)
Washington & Benton, AR	685	Fayetteville fine sandy loam	8-12	471	0.11
	686	Fayetteville fine sandy loam	12-20	178	0.04
	687	Fayetteville stony fine sandy loam	12-35	340	0.08
	688	Fayetteville-Hector complex	20-40	782	0.19
	689	Hector-Mountainburg gravelly fine sandy loams	3-8	1136	0.27
	690	Hector-Mountainburg gravelly fine sandy loams	8-12	285	0.07
	691	Hector-Mountainburg stony fine sandy loams	3-40	6533	1.55
	708	Linker fine sandy loam	3-8	877	0.21
	712	Linker loam	1-3	284	0.07
	714	Linker loam	3-8	2950	0.70
	716	Linker gravelly loam	3-8	851	0.20
	717	Linker gravelly loam	8-12	47	0.01
	724	Montevallo soils	3-12	308	0.07
	725	Montevallo soils	12-25	37	0.01

	726	Mountainburg stony sandy loam	3-12	29	0.01
	727	Mountainburg stony sandy loam	12-40	16	0.00
	791	Samba silt loam		63	0.15
	794	Samba complex mounded		118	0.03
	795	Savannah fine sandy loam	1-3	656	0.16
	796	Savannah fine sandy loam	3-8	3893	0.93
Crawford, AR	834	Enders stony fine sandy loam	12-45	46	0.01
	852	Enders-Mountainburg Association rolling		70	0.02
	882	Linker fine sandy loam	3-8	22	0.01
	917	Mountainburg stony fine sandy loam	3-12	3	0.00
	931	Nella gravelly fine sandy loam	3-8	7	0.00
	938	Nella-Enders Association rolling		68	0.02
	939	Nella-Enders Association steep		204	0.05
	999			490	0.12

Table 2.4. USLE C factors.

Land Use	Julian Day	USLE C Factor
Urban	---	0.003
Transportation, Communications, Utilities	---	0.003
Crop	1	0.40
	70	0.31
	90	0.24
	120	0.13
	150	0.10
	180	0.08
	210	0.08
	211	0.40
	300	0.20
	365	0.40
Pasture/Range	---	0.003
Orchards, Groves, Vineyards	---	0.30
Nurseries	---	0.30
Forest	---	0.003
Poultry Operations	---	0
Dairy	---	0
Hog Operations	---	0
Water	---	0

Table 2.5. Hydrologic soils group and curve number.

Hydrologic Soil Group	Land Use Number	Land Use	Curve Number
A	1	Urban	71
B			78
C			84
D			86
A	2	Transportation	72
B			82
C			87
D			89
A	3	Crop	63
B			75
C			83
D			87
A	4	Pasture/Range	49
B			69
C			79
D			84
A	5	Orchards	41
B			55
C			69
D			71

A	6	Nurseries	69
B			75
C			82
D			86
A	7	Forest	36
B			60
C			73
D			79
A	8	Poultry Operations	100
B			100
C			100
D			100
A	9	Dairy	100
B			100
C			100
D			100
A	10	Hog Operations	100
B			100
C			100
D			100
A	11	Water	100
B			100
C			100
D			100

Table 2.6. Observed soil test phosphorus statistics for pasture in the Upper Illinois River Basin from 1992 to 1995.

County or Watershed Number	State	Number of Samples	Mean (lb/ac)	Median (lb/ac)	Standard Deviation (lb/ac)	Minimum (lb/ac)	Maximum (lb/ac)
Delaware	OK	370	93	56	80	7	520
Adair	OK	214	159	64	188	9	1224
Cherokee	OK	109	52	41	35	9	167
Sequoyah	OK	0	-	-	-	-	-
010	AR	25	341	226	194	77	717
020	AR	37	297	203	231	45	999
030	AR	167	301	245	194	45	999
040	AR	25	239	127	233	54	883
050	AR	3	295[1]	-	-	-	-
060	AR	26	358	337	176	53	785
070	AR	54	227	161	194	31	999
080	AR	27	261	254	148	17	656
081	AR	0	242[2]	-	-	-	-

[1] Approximated as the average of watersheds 030, 060 and 070.
[2] Approximated as the average of watersheds 040, 070 and 080.

Table 2.7. Initial soil test phosphorus by land use for the Upper Illinois River Basin.

Land Use	Soil Test Phosphorus (lb/ac)	Area (ha)	Area (%)
Urban	60	14,985	3.5
Transportation, Communication, and Utilities	15	1,227	0.3
Crop	60	4,140	1.0
Pasture and Range	Variable[1]	211,518	49.
Orchards, Groves, Vineyards	60	1,425	0.3
Nurseries	60	148	0.03
Forest	10	186,205	44.
Poultry, Dairy, and Hog Houses	0	1,653	0.4
Water	0	6,912	1.6

[1]Defined as a function of distance from poultry house.

Table 2.8. Poultry house and area statistics for the Upper Illinois River Basin for 1985.

County or Watershed Number	State	Houses	Sites	Houses Per Site	Area (ha)
Delaware	OK	64	34	1.88	20,070
Adair	OK	313	158	1.98	102,960
Cherokee	OK	73	34	2.15	109,300
Sequoyah	OK	0	0	0	?
010	AR	214	102	2.10	24,230
020	AR	227	105	2.16	20,440
030	AR	751	306	2.45	58,430
040	AR	268	126	2.13	18,840
050	AR	95	37	2.57	16,030
060	AR	200	91	2.20	17,140
070	AR	111	49	2.27	12,390
080	AR	260	143	1.82	21,910
081	AR	141	61	2.31	5,710

Table 2.9. Number of poultry houses, pasture applied phosphorus and pasture area by watershed.

Watershed Number	Watershed Name	Number of Poultry Houses	Pasture Applied Litter (kg/ha)	Pasture Area (ha)
1	Osage	739	1,804	38,244
2	Clear	219	1,794	11,392
3	Fork	462	1,697	25,411
4	Flint	280	1,350	19,362
5	Baron	412	2,026	18,976
6	Caney	48	374	11,988
7	Benton	286	1,176	22,702
8	River	17	280	5,669
9	Bord	40	376	10,172
10	Tyner	17	294	5,395
11	West	143	958	14,910
12	Bbaron	24	179	5,077
13	Bilin	5	124	3,777
14	Lakeup	0	100	3,667
15	Lake	0	100	5,756

Table 2.10. Watershed numbering convention with weather station and watershed area.

Watershed Number	Watershed Name	Weather Station	Watershed Area (ha)
1	Osage	Bentonville	57,350
2	Clear	Fayetteville	20,897
3	Fork	Fayetteville	41,467
4	Flint	Kansas	32,110
5	Baron	Odell	39,214
6	Caney	Stilwell	31,568
7	Benton	Siloam Spring	37,610
8	River	Kansas	13,018
9	Bord	Kansas	33,022
10	Tyner	Kansas	10,893
11	West	Stilwell	30,450
12	Bbaron	Tahlequah	13,009
13	Bilin	Tahlequah	10,156
14	Lakeup	Tahlequah	5,379
15	Lake	Webber Fall	34,085

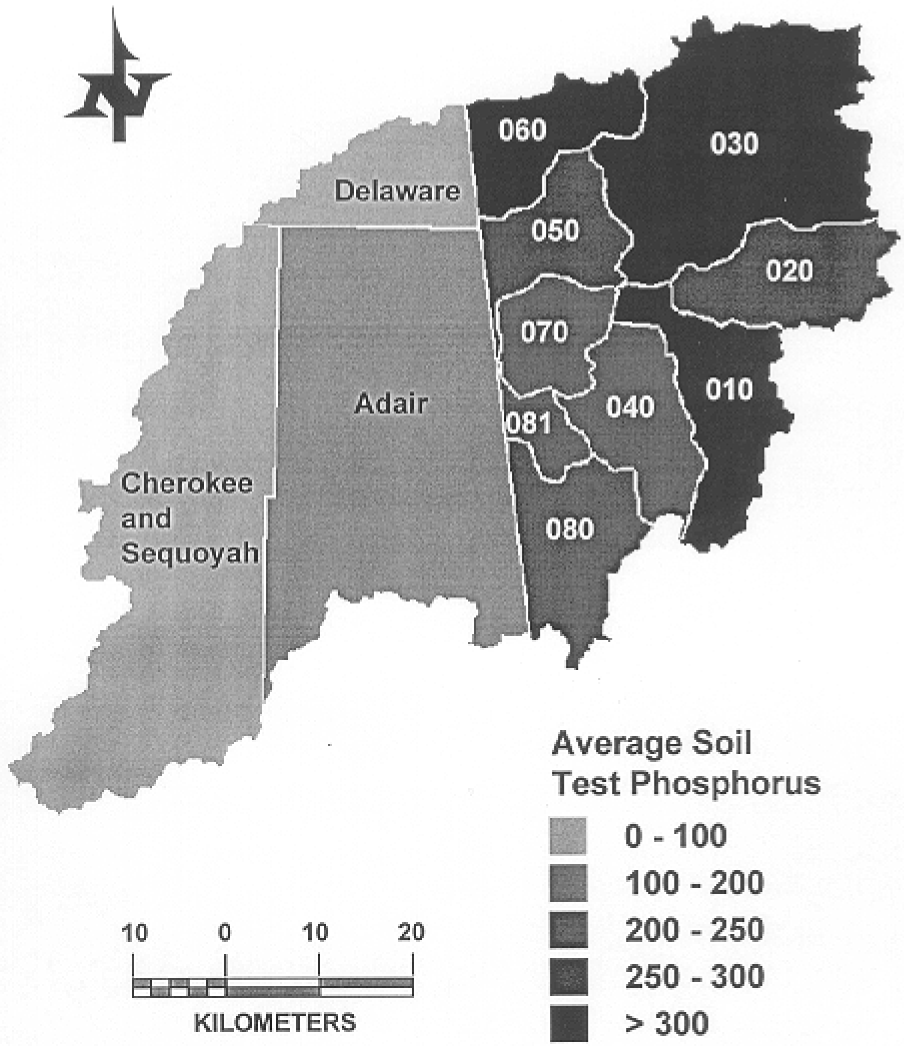


Figure 2.6 Observed average soil test phosphorus for pastures by county/watershed for the Upper Illinois River Basin.

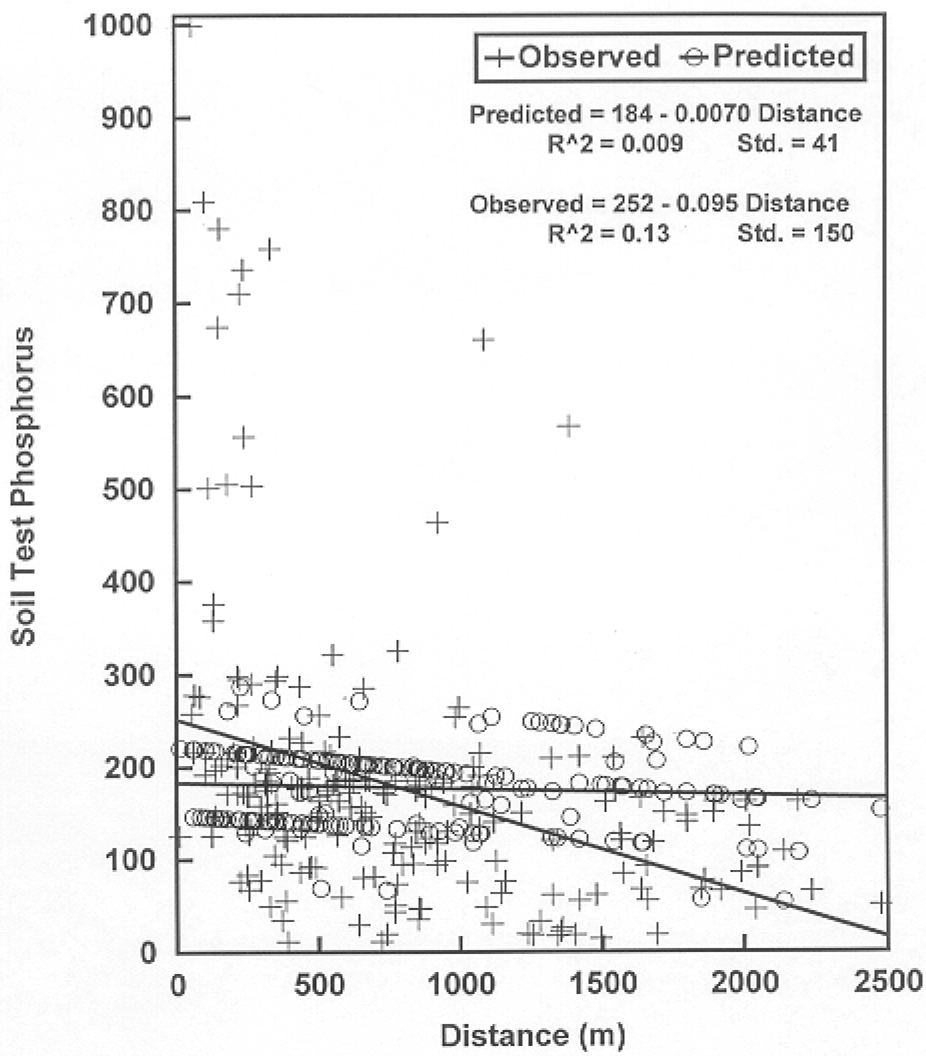


Figure 2.7. Observed and predicted soil test phosphorus for pasture related to distance from poultry house for the Peacheater Creek Watershed, Oklahoma.

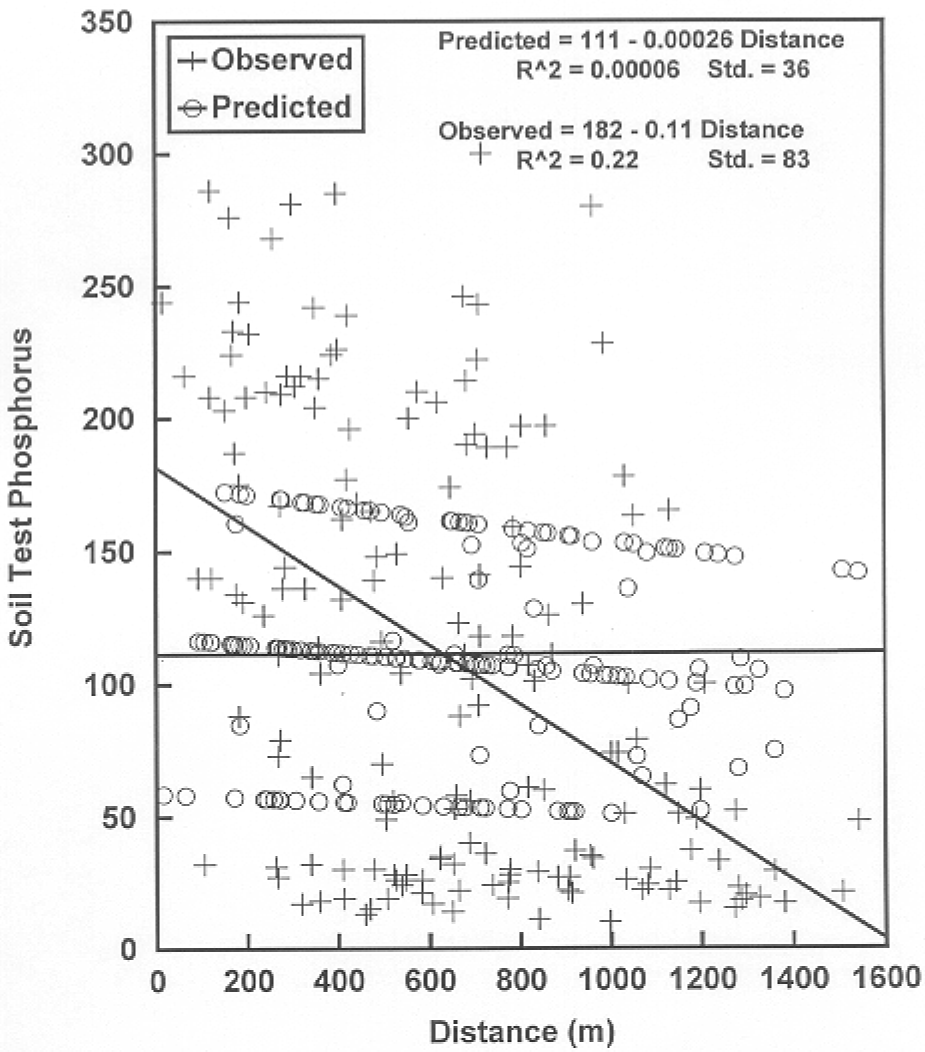


Figure 2.8. Observed and predicted soil test phosphorus for pasture related to distance from poultry house for the Battle Branch Watershed, Oklahoma.

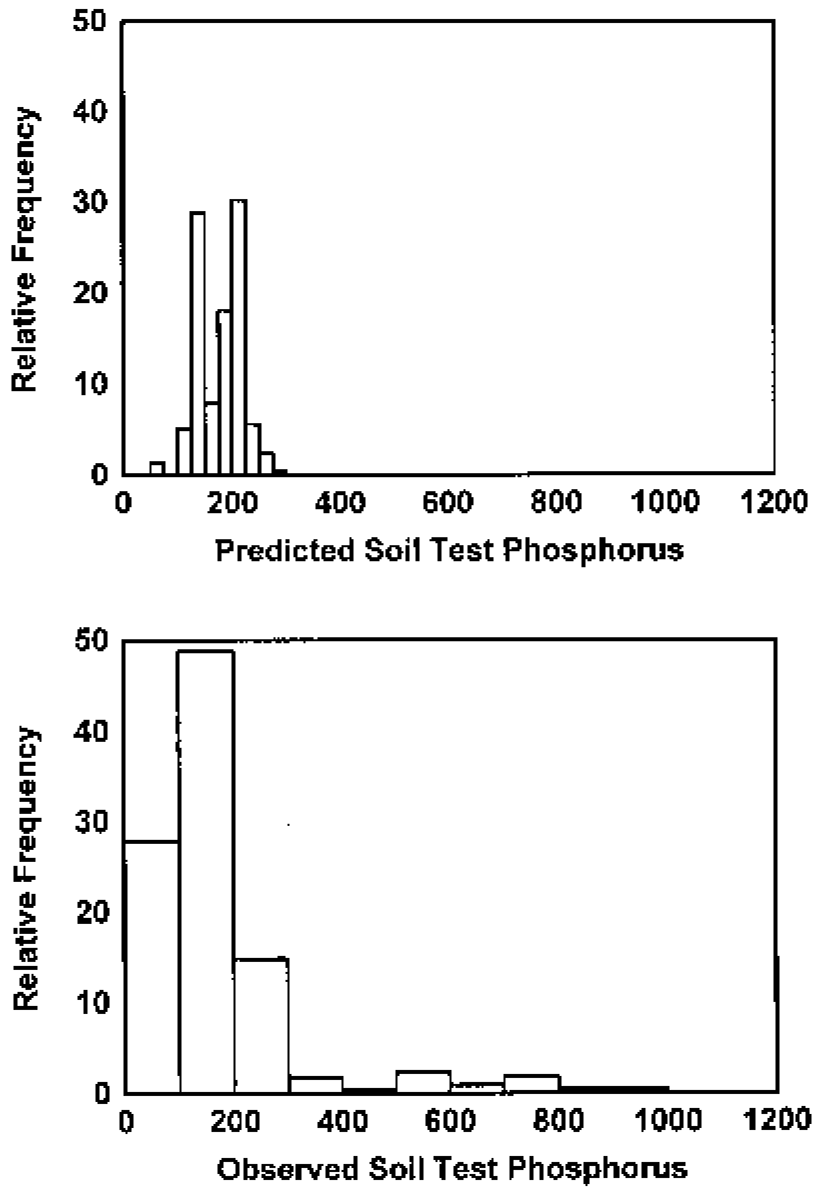


Figure 2.9. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in the Peacheater Creek Watershed, Oklahoma.

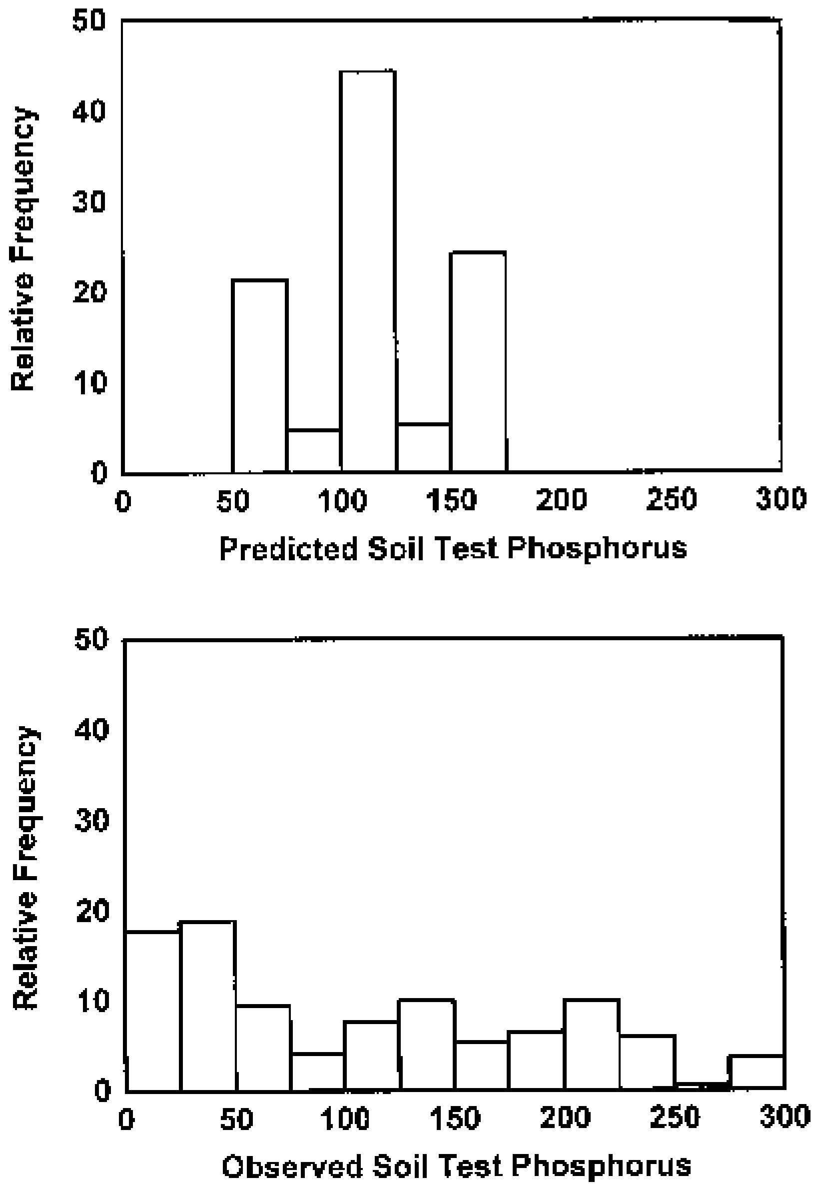


Figure 2.10. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in the Battle Branch Watershed, Oklahoma.

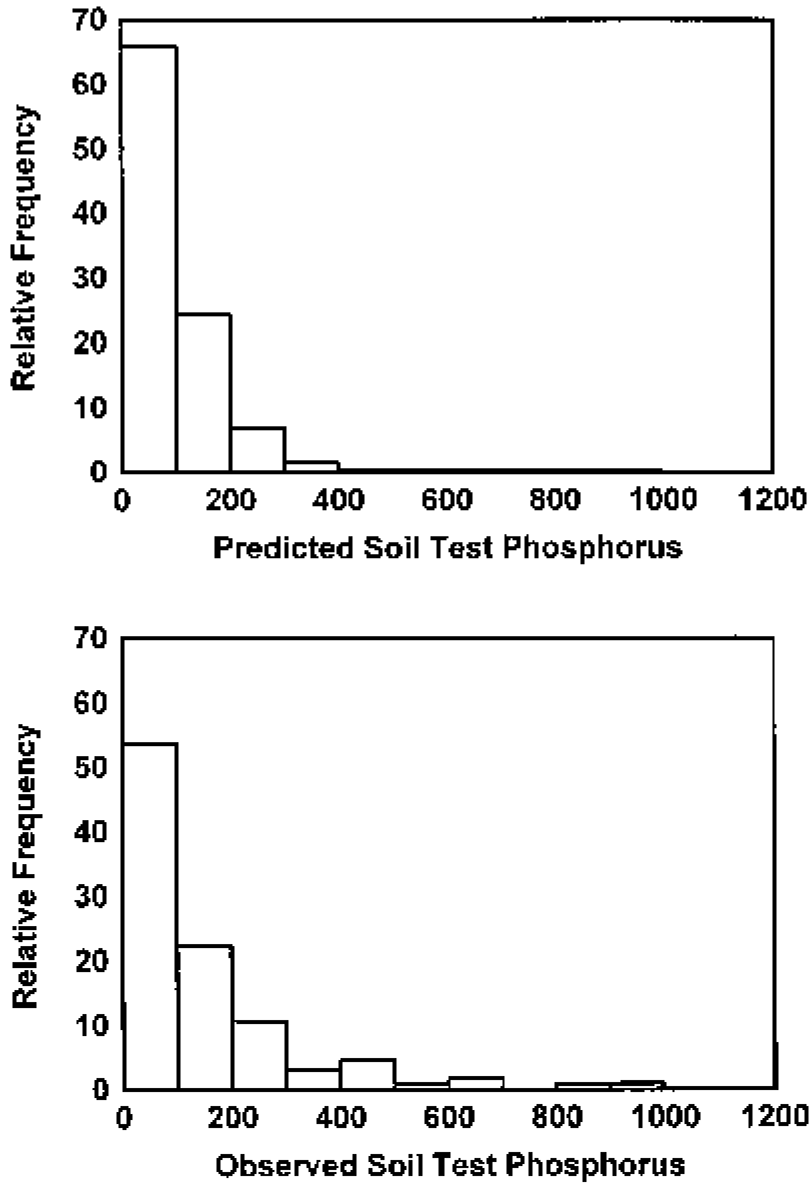


Figure 2.11. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Adair County, Oklahoma.

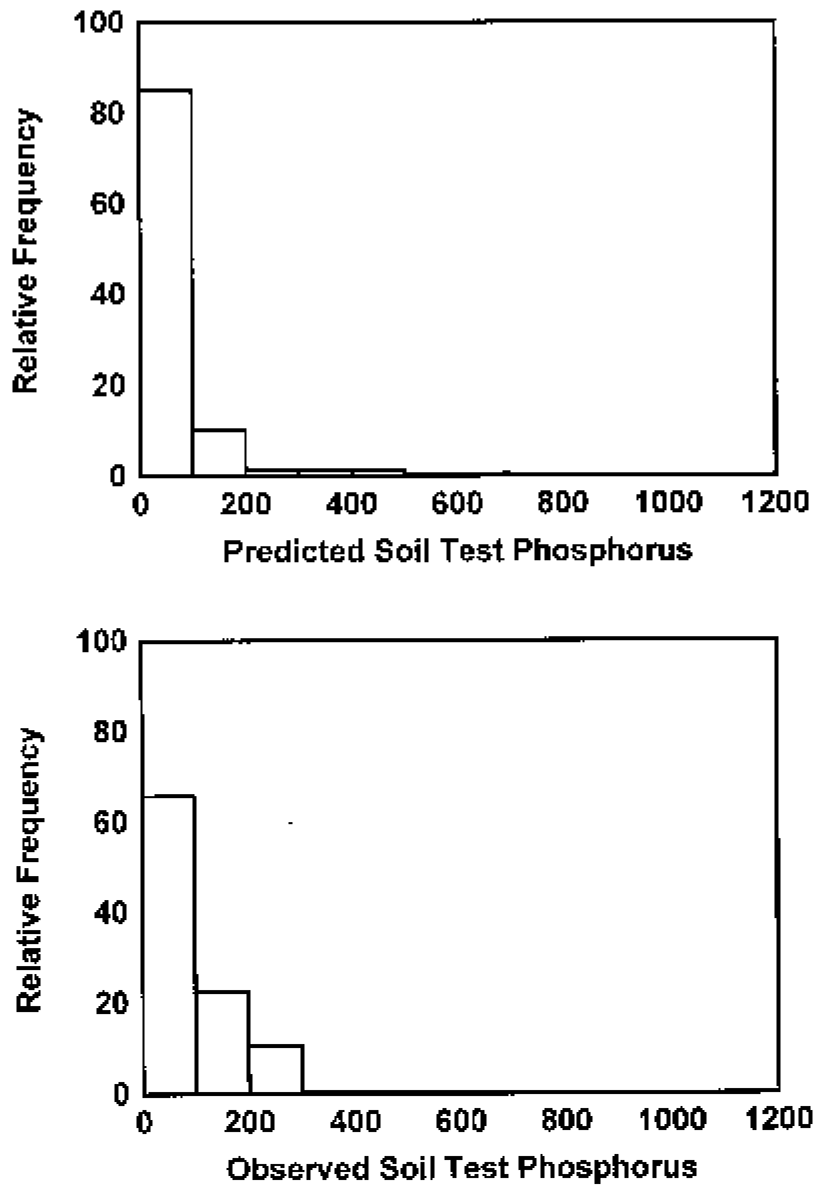


Figure 2.12. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Delaware County, Oklahoma.

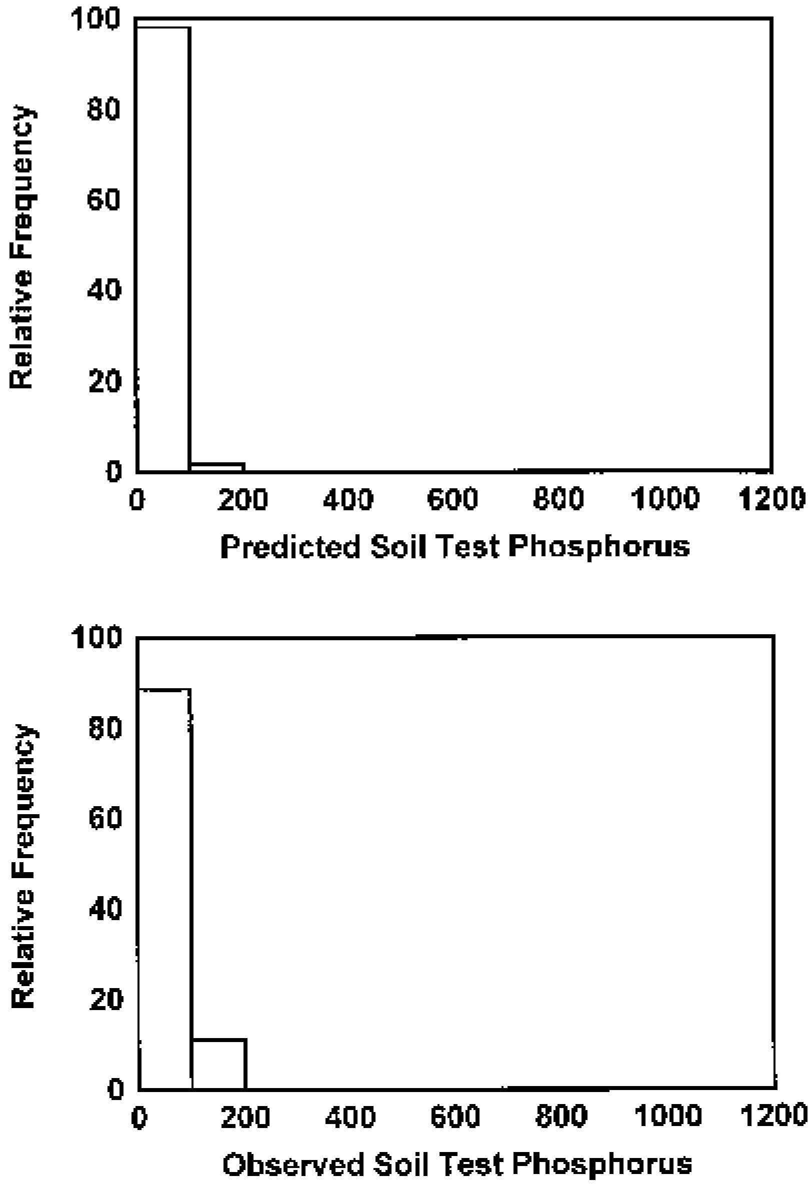


Figure 2.13. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Cherokee County, Oklahoma.

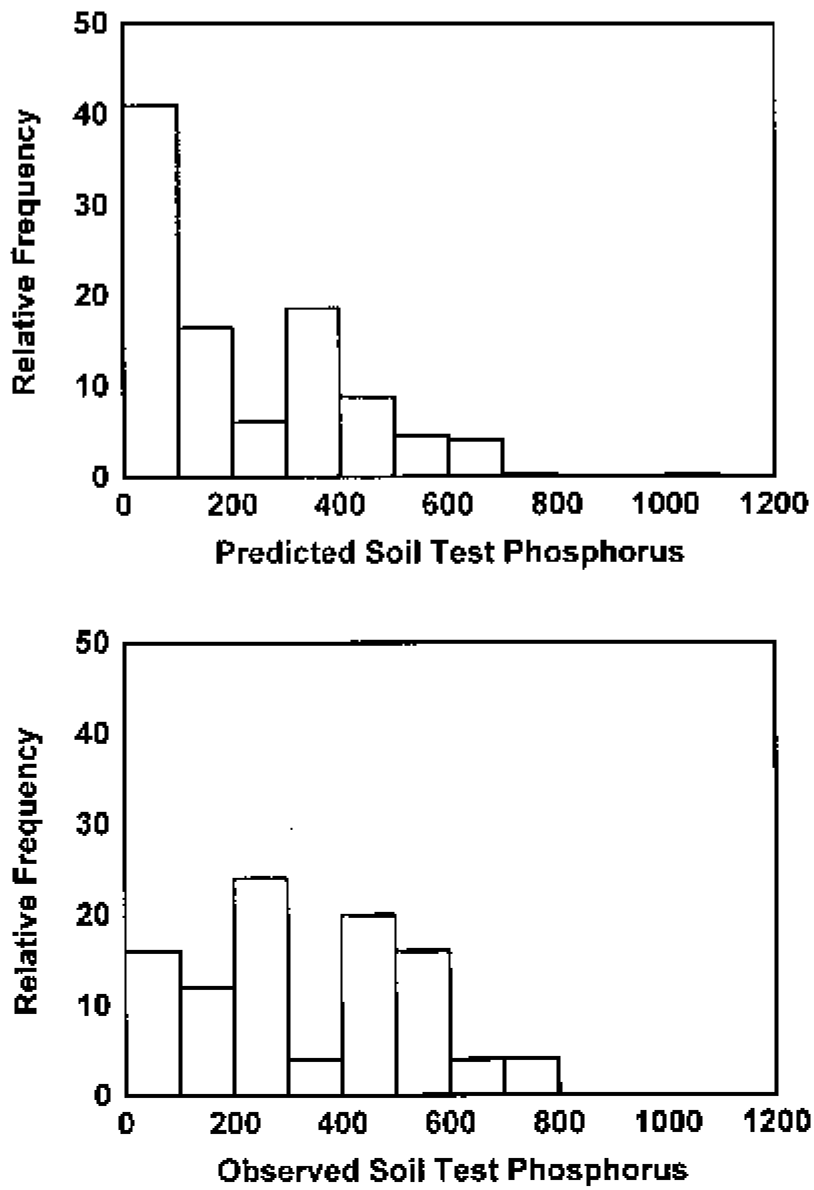


Figure 2.14. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 010, Arkansas.

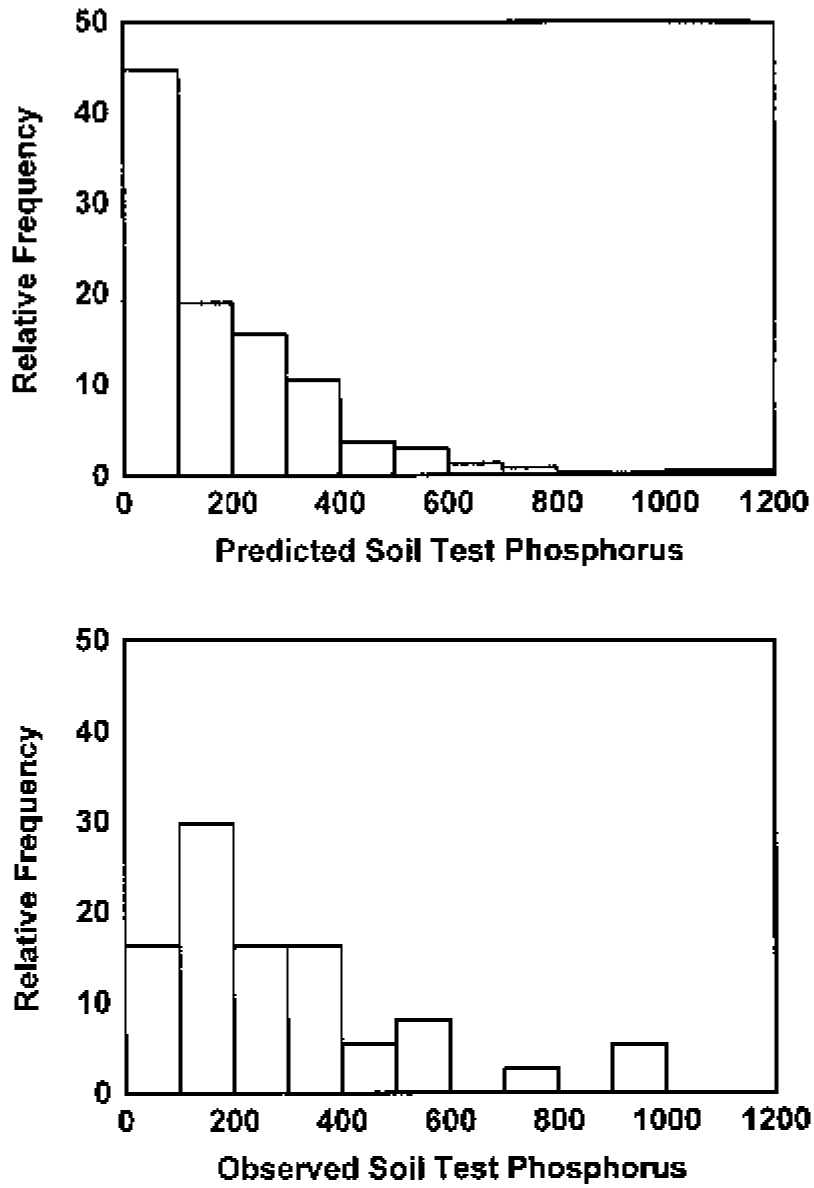


Figure 2.15. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 020, Arkansas.

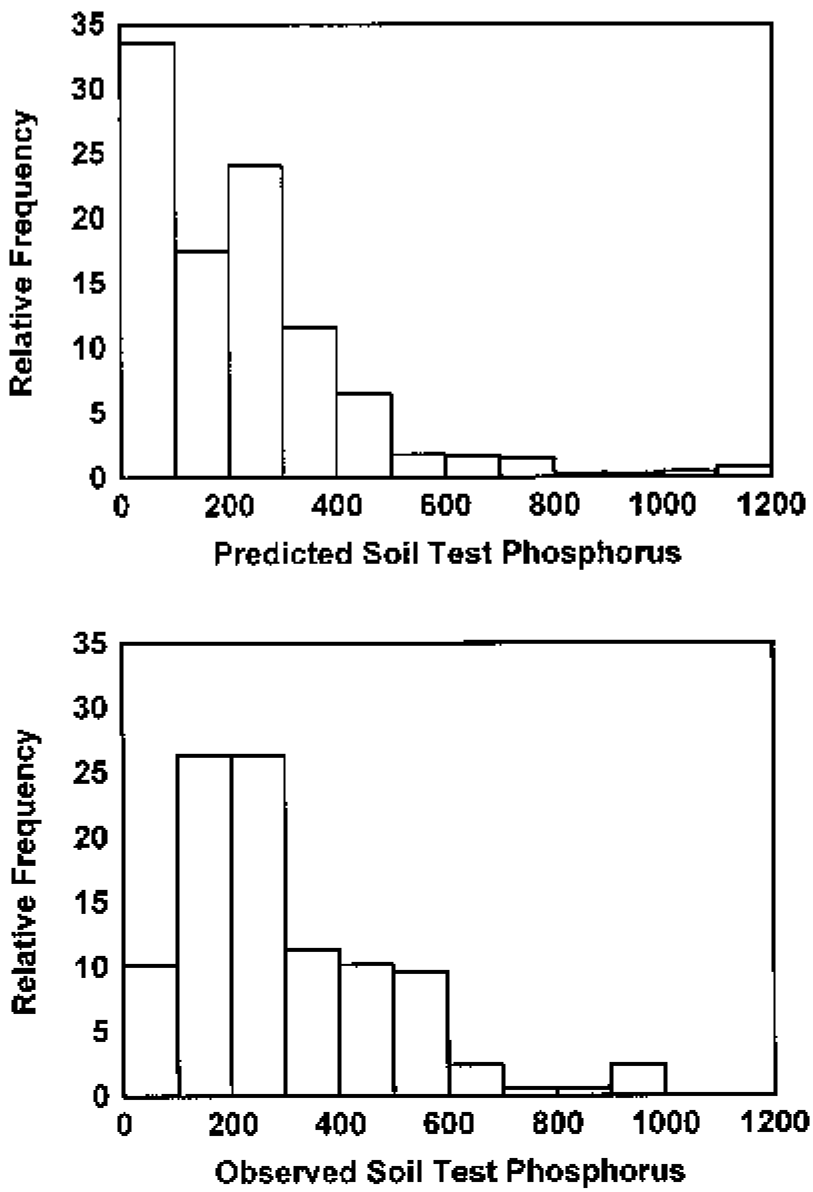


Figure 2.16. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 030, Arkansas.

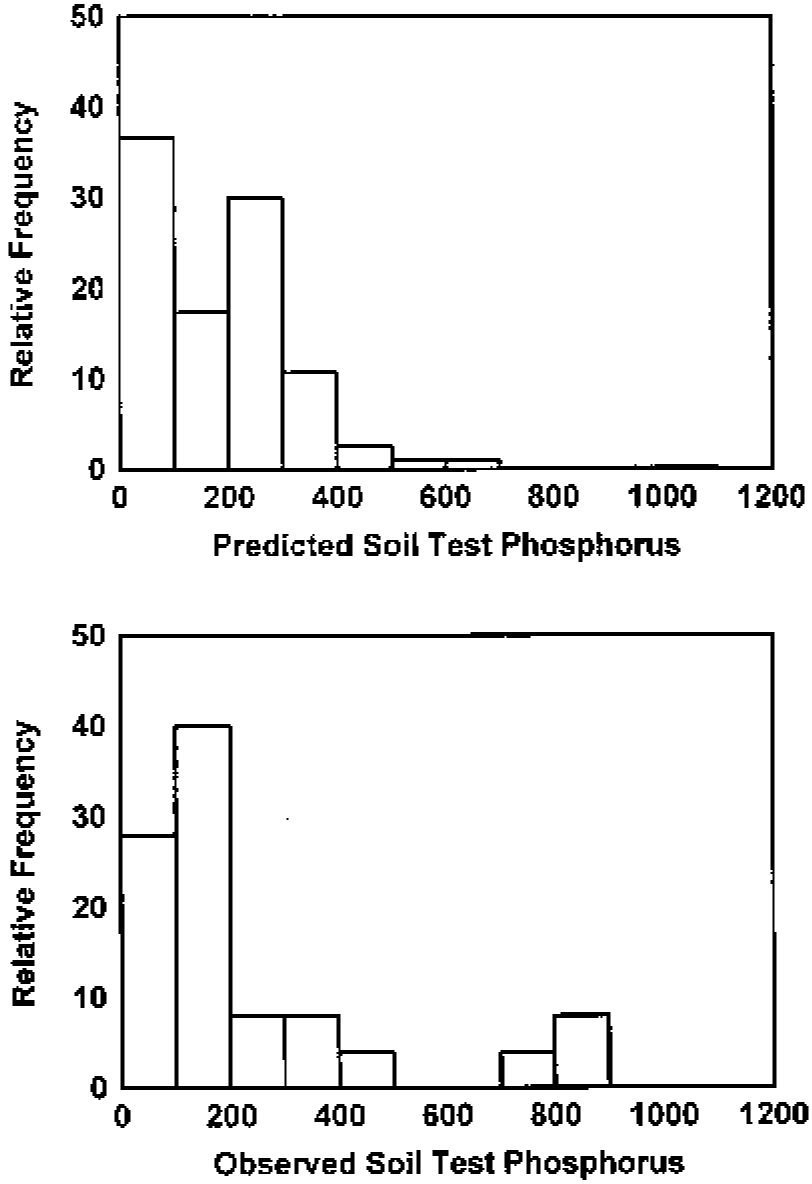


Figure 2.17. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 040, Arkansas.

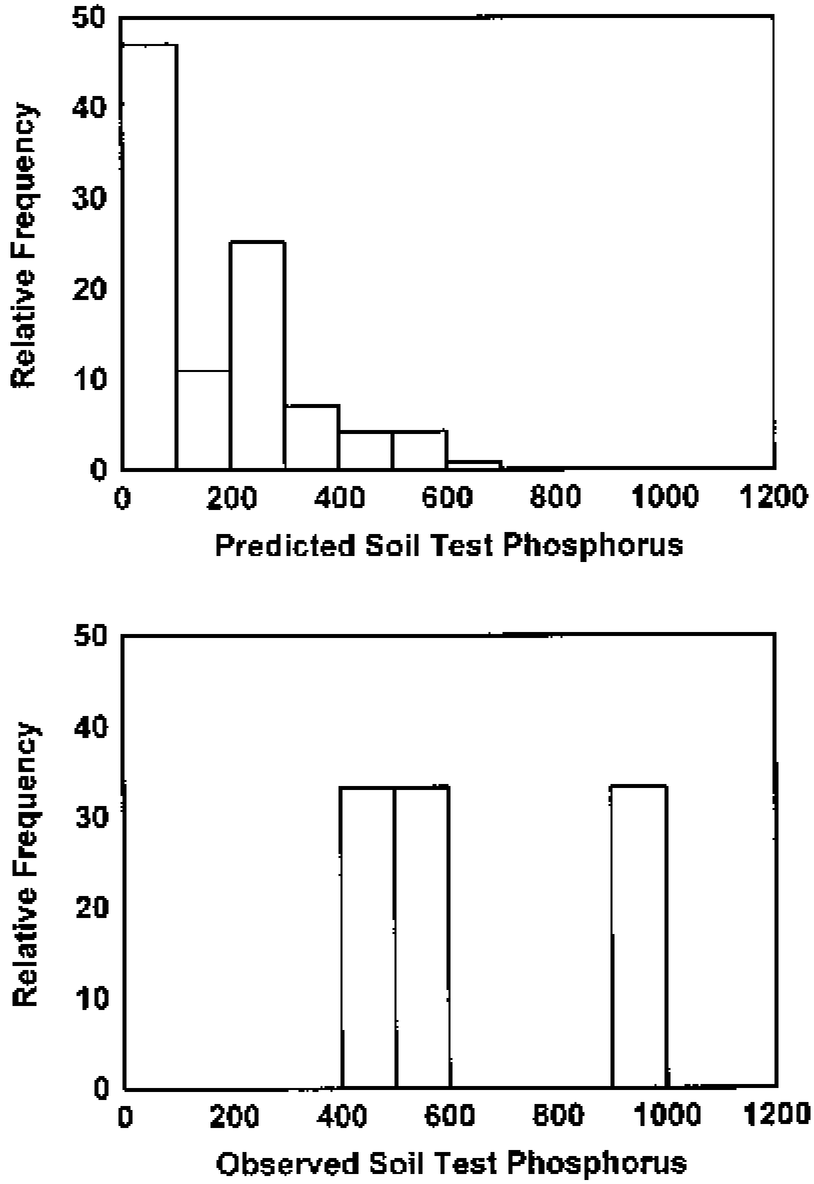


Figure 2.18. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 050, Arkansas.

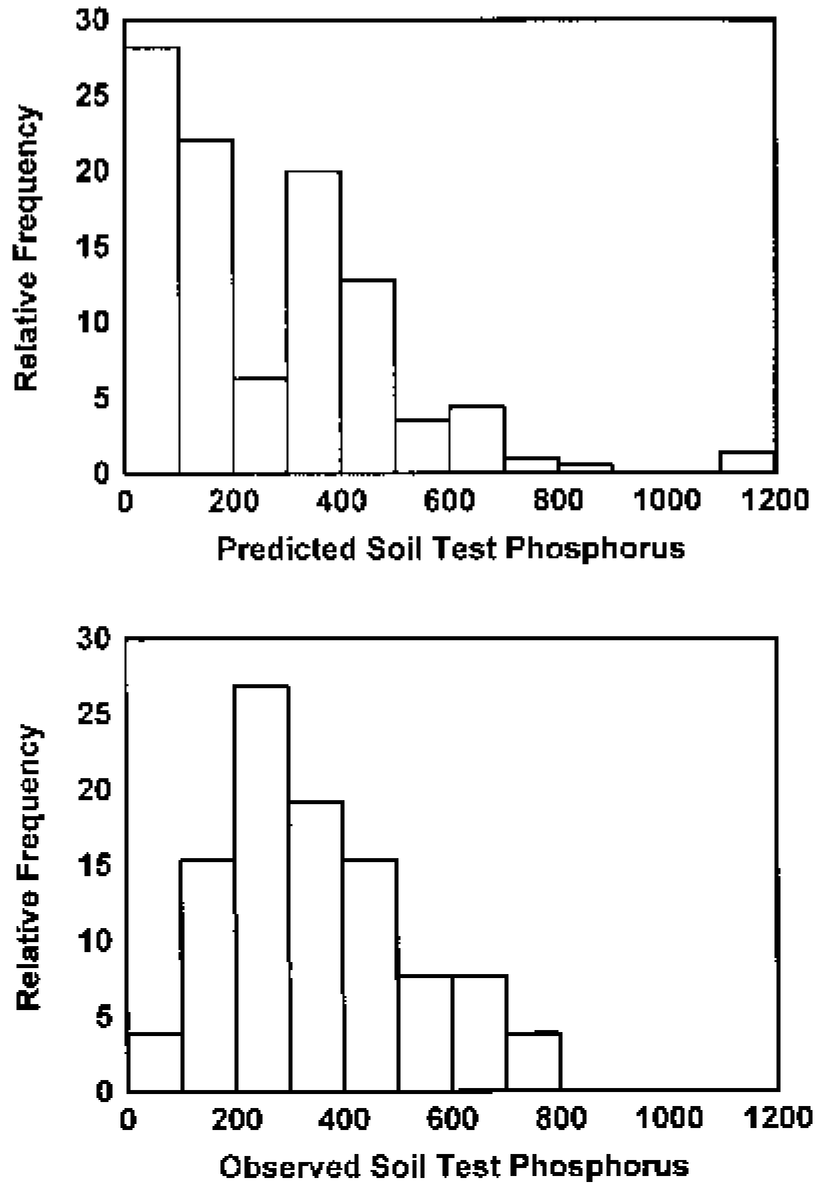


Figure 2.19. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 060, Arkansas.

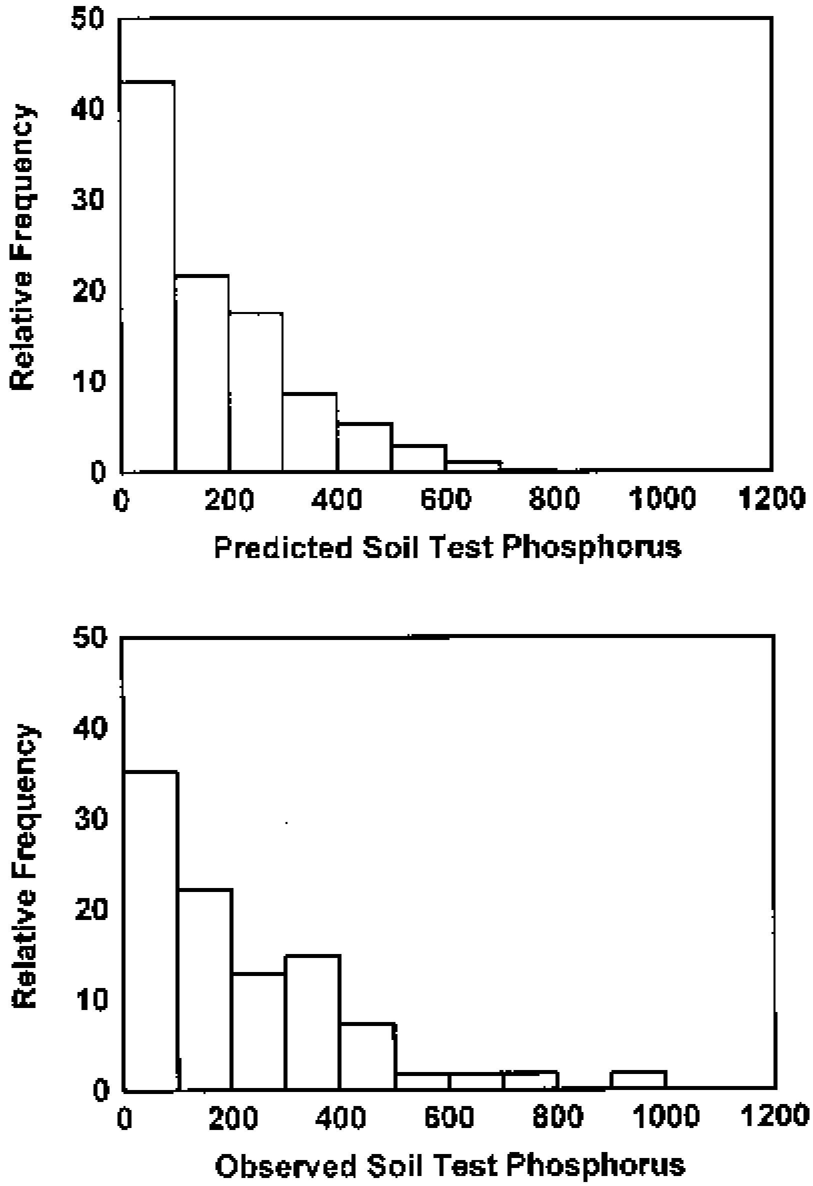


Figure 2.20. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 070, Arkansas.

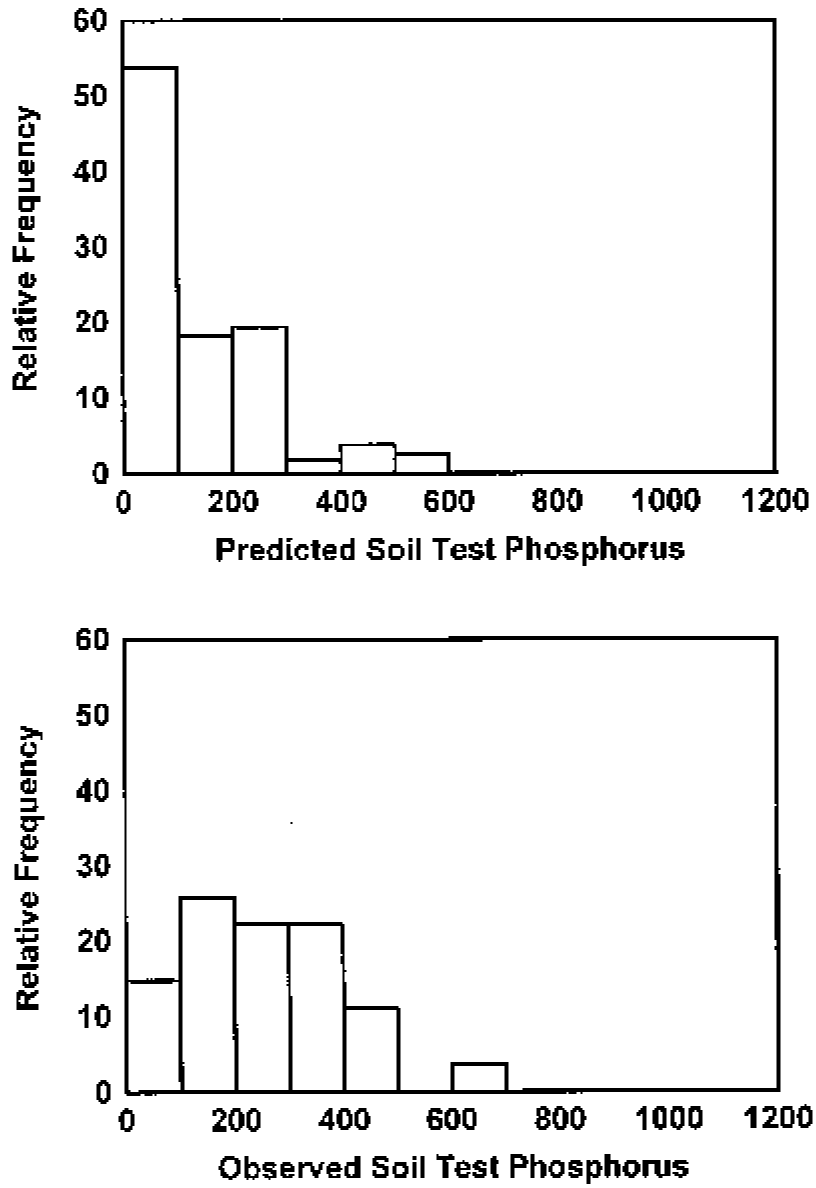
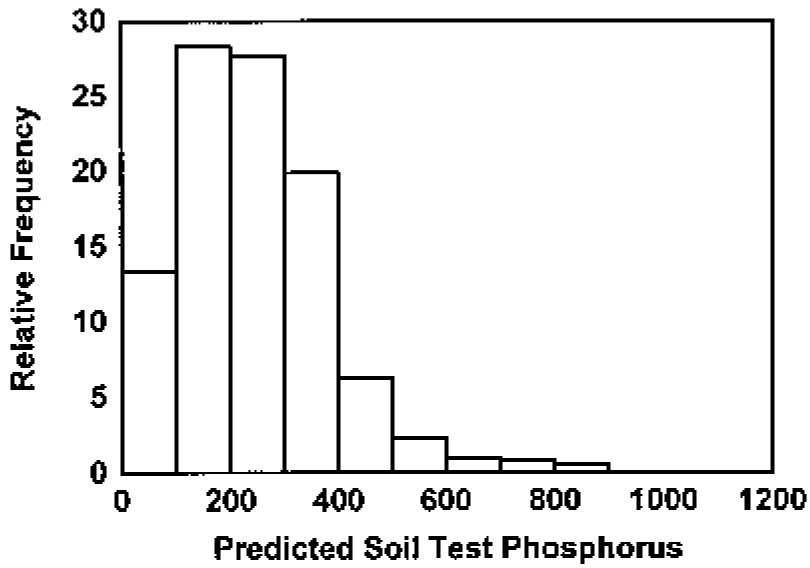


Figure 2.21. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 080, Arkansas.



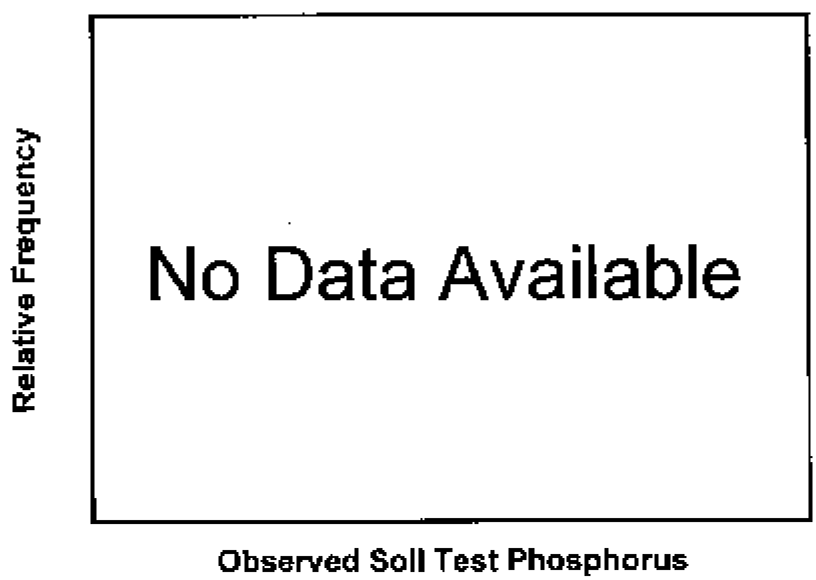


Figure 2.22. Observed and predicted relative frequency distributions of soil test phosphorus for pasture in Watershed Number 081, Arkansas.

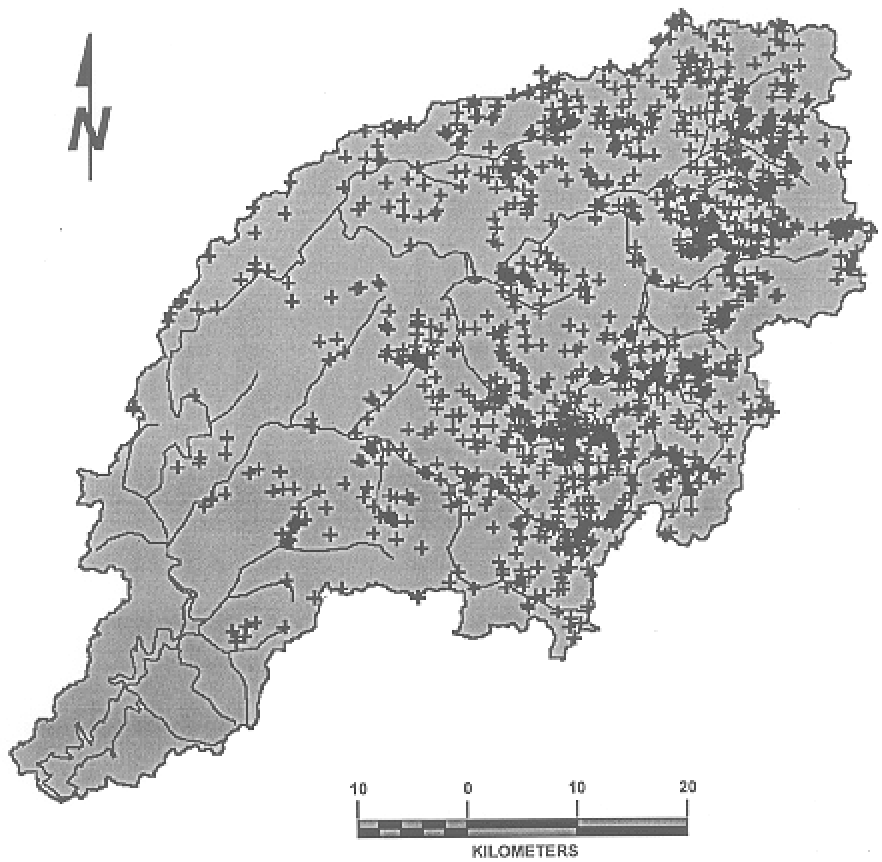


Figure 2.23. Poultry house locations for the Upper Illinois River basin.

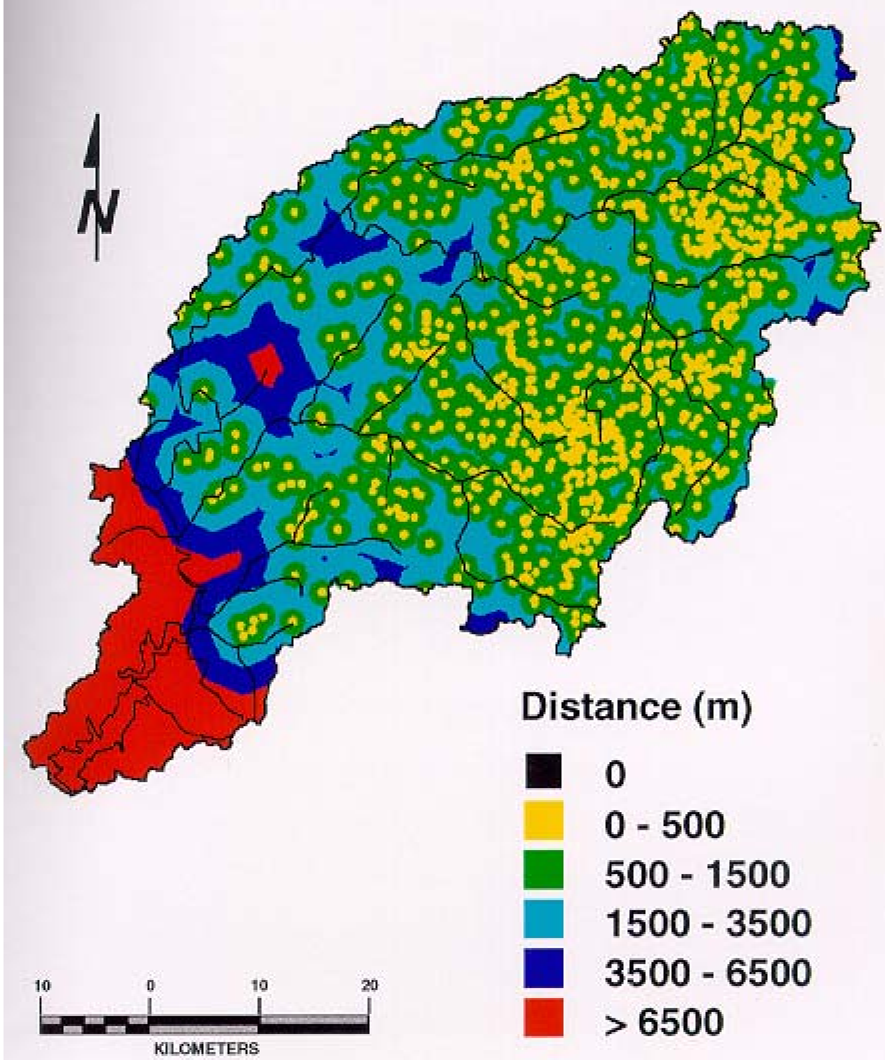


Figure 2.24. Distance from poultry house for the Upper Illinois River basin.

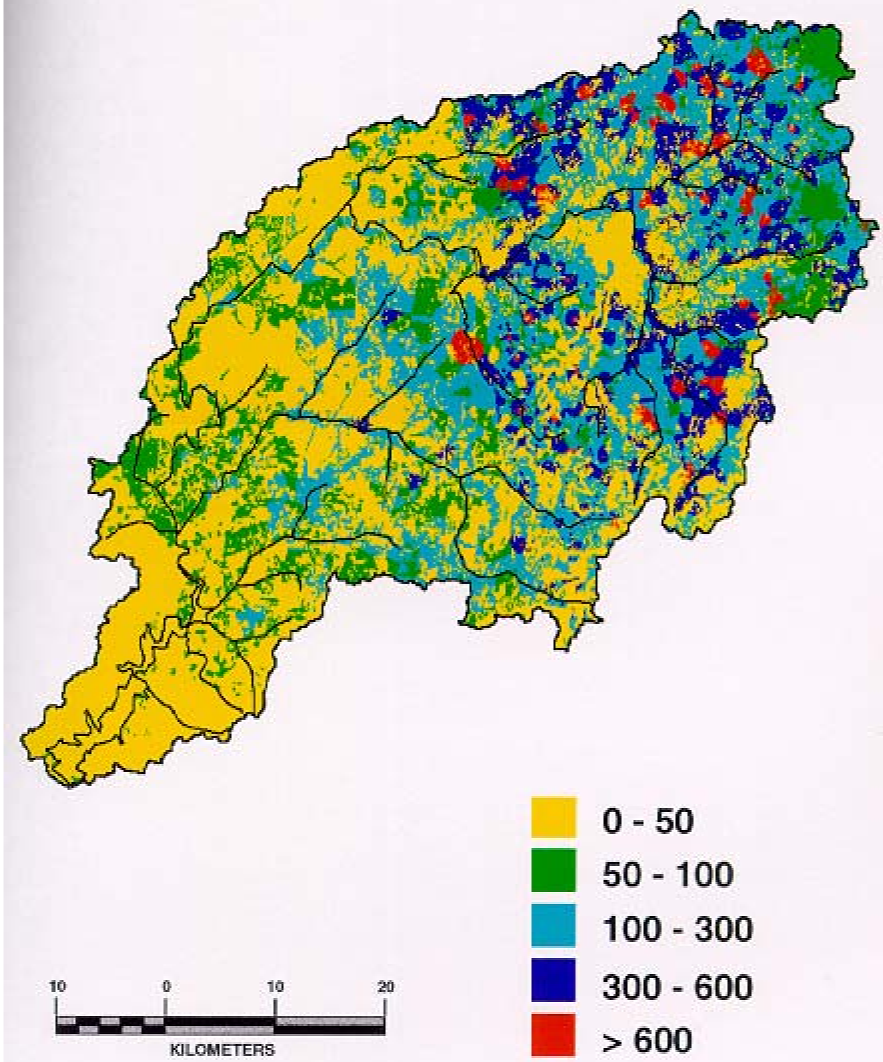


Figure 2.25. Initial soil phosphorus for the Upper Illinois River basin.

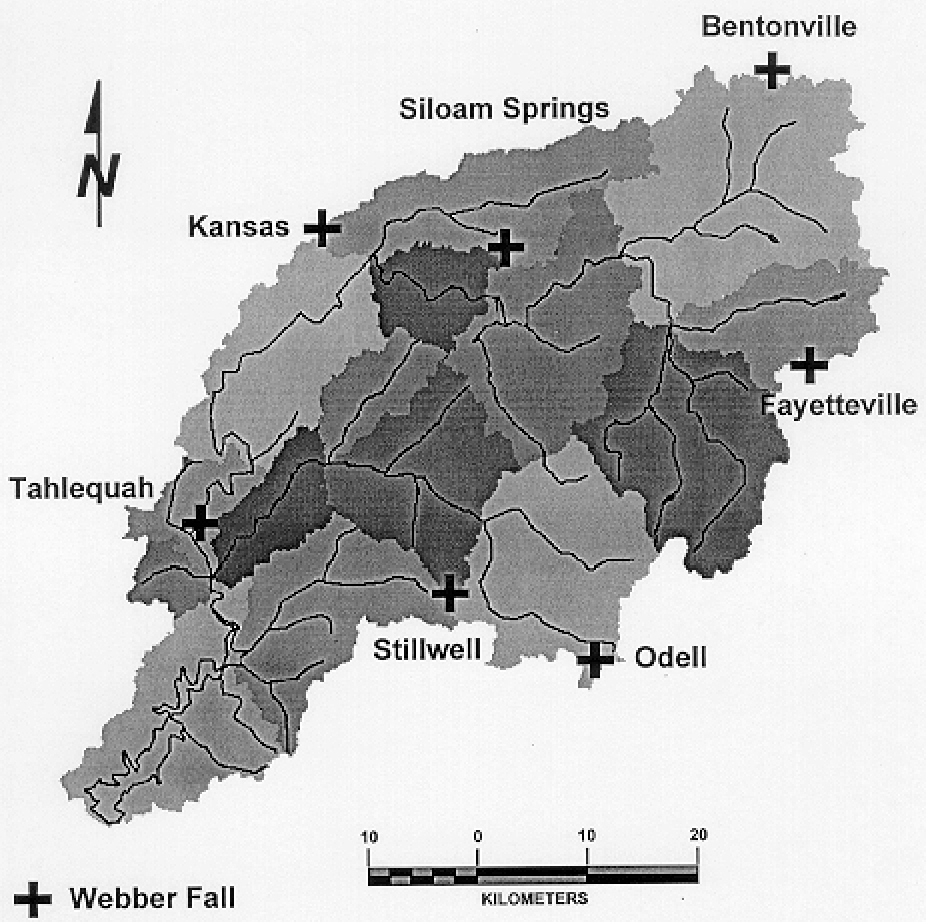


Figure 2.26. Location of weather stations for the Upper Illinois River basin.

2.5 SIMPLE SIMULATION PROCEDURES

2.5.1 Watershed Validation and Evaluation of Cell and Field Methods

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 land use and management practices characteristics. The field-based option requires less simulation time because there are fewer fields than cells. However, error may be introduced if there is significant parameter variation within a field. The following section compares SIMPLE simulations results for the cell and field methods to determine if SIMPLE can be applied to the Upper Illinois River Basin using the field method. In addition, a watershed level validation of SIMPLE is presented for two watersheds. It should be noted that no calibration of the SIMPLE model was applied.

2.5.1.1 Evaluation Procedure

To test the impact of cell and field level simulations, SIMPLE was applied to the Battle Branch watershed in Oklahoma and the QOD subwatershed of the Owl Run watershed in Virginia. Observed data from these watersheds were compared with simulated results by means of simple linear regression. Regression was evaluated by testing hypotheses for slope (β_0) and intercept (α_0) adapted from Haan (1977) using the following equation:

$$Y = \alpha + \beta X \qquad 2.6$$

A Students t test was performed:

1. Test null hypothesis Ho $\alpha_0 = 0$ vs alternative Ha $\alpha_0 \neq 0$, using t value equal to: $t=(a- \alpha_0)/S_a$
2. Test null hypothesis Ho $\beta_0 = 1$ vs alternative Ha $\beta_0 \neq 1$ using t value equal to: $t=(b- \beta_0)/S_b$
3. Test null hypothesis Ho $\beta_0 = 0$ vs alternative Ha $\beta_0 \neq 0$ using t value equal to: $t=(b- \beta_0)/S_b$ and
   all three tests checked versus tabulated value of t with confidence $1-\alpha/2=0.975$ and degree of freedom of n-2.

To run the field-method simulation requires parameters averaged over all cells in a field. Parameters include curve number, the erosion factors K, C, P, slope, slope length and the distance to stream, and the phosphorus loading parameters, initial phosphorus, percent clay, pH, and percent organic carbon. A Fortran program was written to obtain the arithmetic mean of these parameters for each field using:

$$P_{AVG} = \frac{P_1 + P_2 + \ldots + P_{n-1} + P_n}{n} \qquad 2.7$$

where P_{avg} is average parameter for a given field, P, to P, are parameter for each cell contained in the field and n is number of cells. These parameters were then input into SIMPLE.

2.5.1.2 Watershed Descriptions

The Battle Branch watershed is located in southern Delaware County in northeast Oklahoma. The watershed area is approximately 5500 acres. This hydrologic unit is in the Ozark Highland Land Resource Area. The topography is primarily rough steep hills with blackjack-postoak tree cover. Baffle Branch is a tributary of the Illinois River. The watershed is located in one of the nation’s leading poultry producing areas. There are 31 chicken houses located within the unit. In addition to an intensive poultry production there are 9 dairies with 550 dairy animals and about 1000 grazed beef cattle within the watershed area. The major land use within the watershed is agriculture. The watershed area includes 19 different types of soils. Four type of soils predominate in the watershed and they are associated with the Clarksville-Baxter-Locust type: Clarksville stony silt loam with area of

845 hectares and 20 to 50% of slopes having the highest runoff potential; Baxter Locust complex with area of 706 acres and slopes from 3 to 5%; Baxter cherty silt Loam with area of 677 acres and 1 to 3% slopes, Clarksville stony silt loam having area of 677 acres and slopes from 5 to 20%.

There are 178 different fields identified in the Battle Branch watershed; they are grouped into 6 land use types: pasture with 58% area, woods with 33% of area, Meadow-hay with 6% area, cropped land, urban, and homesteads with 3% of the area. 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 wood lands and cropped lands, respectively. The curve numbers (CN) were obtained based on the land use cover and the hydrologic soil group.

Daily precipitations were obtained from The National Climatic Data Center for Oklahoma. (Kansas, OK weather station). Battle Branch flow and phosphorus loadings were obtained from Oklahoma Conservation Commission. Stage recorder charts were collected and kept from August 1986 to November 1987. Five storm events were sampled during the above time period. Flow measurements at three different stages were taken and plotted to develop a rating table. With the assistance of the school of Forestry at OSU all of the stage charts and rating curves were digitized. Fortran programs were used to combine two sets of data to give total flow and interval flow and to calculate nutrient summaries and total loadings from rising, falling, and baseline water quality averages.

The Owl Run watershed is located in Fauquier County, Virginia about 165 km south west from Washington D.C. The watershed area is 1153 hectares. QOD is a part of Owl Run watershed with an area of 334 hectares. Over 70% of the area is used for agriculture. The narrow, rolling to hilly uplands, underlain chiefly by granite rocks, occur between the foothills. The Rappahannock River, Coose Creek and many of their tributaries originate in the Blue Ridge and its foothills. The northern and eastern parts of the Fauquier County are drained by streams that are parts of the Potomac River drainage System.

The climate of Fauquier County, is the humid continental type with an average annual rainfall of about 104 cm. Temperatures of 32° C to 35° C in summer and -9°C to -6°C in winter are frequent extremes. The average annual rainfall in the county is fairly well distributed during whole year, although the greatest amount occurs in spring and summer. The soils on the watershed are generally shallow (0.3 to 0.6 meters deep) silt loams overlying Triassic shale. The shale layer is exposed in some areas, and the more intensely used fields are thought to be eroding at high rate. The major soil series underling the watershed are Penn, Bucks and Montalto associations which cover over 72 % of the watershed area. The Penn soils are derived from Triassic red shale and sandstone, the silt loam from the shale and the loam from the sandstone. The surface soil is reddish-brown to dark reddish brown. Slopes range from 2-7% for the undulating phase and 7 -14% for rolling phase. Runoff is medium and internal drainage is medium to rapid.

The Owl Run watershed is a 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 best management practices on water quality. Precipitation, runoff, sediment and nutrient loadings have been monitored continuously since 1986. Data describing soil characteristics and crop cover factors were obtained from 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 obtained from landowner surveys.

2.5.1.3 Battle Branch Watershed Results

Comparison between results obtained from cell and field simulations were analyzed by means of regression. For Battle Branch watershed comparison involved simulated results for a period of 16 months (August 1986 to November 1987). Statistical summaries for runoff and total phosphorus are presented in Table 2.1 1.

Runoff regression between field and cell level simulations showed a near perfect linear relationship indicating that the field-level simulation can be used instead of the cell level for the Battle Branch watershed. However, both methods underestimated observed runoff volume by 30 percent. Total phosphorus loss regression between field and cell simulations showed a strong relationship which indicates that field-level simulations can be used instead cell simulations. Both methods of simulation overestimated observed total phosphorus yield by 100%. The 16 months simulation results for Battle Branch watershed are presented in table 2.12.

2.5.1.4 Owl Run QOD Subwatershed Results

Comparing results obtained from cell and field simulations with observed data were analyzed using simple regression. Simulations for Owl Run watershed (QOD subwatershed) were compared with observed runoff, sediment and total phosphorus loss for a period of 18 months (January 1987 to July 1988). Statistical summaries for runoff, sediment yield and total phosphorus are presented in table 2.13.

Runoff regression between field and cell simulations showed a strong linear relationship which indicates that field simulations can be used instead of the cell simulation. Both simulation methods, cell and field, showed a fair linear relationship between observed runoff volume. Regression between field and cell simulations for sediment yield showed a strong relationship which indicates that the field method can be used instead cell simulations. Cell and field methods overestimated observed values for sediment by 69 and 62 percent, respectively. Regression between field and cell simulations for total phosphorus showed a strong linear relationship, indicating that the field method can be used. Both methods underestimated observed total phosphorus by 100 percent. The 18 months simulation results for QOD are presented in table 2.14.

2.5.1.5 Conclusions

Results obtained from simulations for the Battle Branch and QOD subwatersheds showed that field simulations provide similar results compared to cell simulation. Therefore, field scale simulations of SIMPLE were applied to the Upper Illinois River basin. The use of the field level simulations saved considerable computer simulation time and disk storage.

2.5.2 Field Boundary Delineation

To define the field boundaries we overlaid a 1500 m by 1500 m grid (225 ha cell). Using the GRASS 4.1 r.clump command we grouped contiguous cells with the same land use within each of the 225 ha areas. Thus each contiguous area with the same land use within each 225 ha area we defined as a separate field. We reduced the total number of fields by accumulating all minor land uses into a single field in a watershed. There was one field per watershed for the following land categories: urban, transportation and utilities, crop, orchards and vineyards, nurseries, forest, poultry operations, dairy, hog operations, and water. Forest and pasture/range land uses were not regrouped.

2.5.3 Time Scale, and Independent and Continuous Simulation Modes

To determine the number of years required to give a stable long-term annual average loading sediment and phosphorus, we applied the SIMPLE model the Peacheater Creek and Battle Branch watersheds. Figure 2.27 and 2.28 show the running average annual rainfall and runoff, and sediment, and dissolved and sediment-bound P, respectively, for the Battle Branch watershed for 40 simulation years. Figures 2.29 and 2.30 show similar results for the Peacheater Creek watershed. From these figures we selected a simulation duration of 25 years (1962-1986).

The SIMPLE model was run using two simulation modes. The first mode, called the independent annual simulation mode, re-initialized all parameters to their initial value January 1 of each year. This represents the best estimator of the average current sediment and phosphorus load. The second mode, called the continuous annual simulation mode, does not re-initialize the parameters but allows them to vary through the entire simulation period. This mode represents the expected outcome of continual land use through the time period.

Table 2.1 1. Regression parameters for runoff and total phosphorus loss for Battle Branch watershed using cell-by-cell and field simulations.

Parameter/Method	R^2	Slope	Intercept
Runoff Volume			
Observed vs Cell by Cell	0.89	1.03	-1.28
Observed vs Field by Field	0.89	1.03	-1.29
Field by Field vs Cell by Cell	0.99	0.99	-0.013
Total Phosphorus Yield			

Observed vs Cell by Cell	0.66	1.88	0.003
Observed vs Field by Field	0.63	1.73	0.002
Field by Field vs Cell by Cell	0.99	0.943	-0.002

Table 2.12. Observed and SIMPLE predicted cell by cell and field monthly runoff and total phosphorus yield for Baffle Branch watershed.

	Runoff (cm)			Total Phosphorus Yield (kg/ha)		
Month	Observed	Predicted Cell	Predicted Field	Observed Cell	Predicted Field	Predicted
August	0.95	0.02	0.01	0.01	0	0
September	2.42	2.82	2.8	0.07	0.06	0.05
October	25.76	27.89	27.87	0.27	0.53	0.49
November	2.58	0.46	0.45	0.05	0.01	0.01
December	0	0	0	0	0	0
January	4.77	0.14	0.12	0.04	0.02	0.01
February	7.01	0.95	0.92	0.06	0.09	0.08
March	0.80	0.59	0.58	0.02	0.05	0.05
April	0	0	0	0	0	0
May	3.82	4.87	4.84	0.04	0.39	0.38
June	0.04	0	0	0	0	0
July	0	0	0	0	0	0
August	0	0.02	0.01	0	0	0
September	1.98	0.86	0.84	0.06	0.08	0.07
October	3.37	1.06	1.04	0.04	0.09	0.08
November	6.31	1.37	1.34	0.08	0.12	0.11
Summation	59.82	41.05	40.82	0.74	1.44	1.33

Table 2.13. Regression parameters for runoff and total phosphorus loss for QOD using cell-by-cell and field simulations.

Parameter/Method	R^2	Slope	Intercept
Runoff:			
Observed v/s Cell by Cell	0.33	0.70	0.383
Observed v/s Field by Field	0.32	0.69	0.365
Field by Field v/s Cell by cell	0.99	0.990	-0.0203
Sediment:			
Observed v/s Cell by Cell	0.73	1.27	21.24

Observed v/s Field by Field	0.43	0.85	44.14
Field by Field v/s Cell by cell	0.76	0.761	19.24
Total Phosphorus Loading:			
Observed v/s Cell by Cell	0.32	0.190	0.056
Observed v/s Field by Field	0.22	0.157	0.062
Field by Field v/s Cell by cell	0.95	0.956	0.0042

Table 2.14. Observed and SIMPLE predicted cell by cell and field monthly runoff and total phosphorus yield for QOD watershed.

Month	Runoff (cm)			Sediment Yield (kg/ha)			Total Phosphorus (kg/ha)		
	Observed	Predicted Cell	Predicted Field	Observed	Predicted Cell	Predicted Field	Observed	Predicted Cell	Pred icted Field
January	1.7	2.05	1.96	18	88	60	0.1	0.08	0.08
February	4.08	1.14	1.1	20	56	49	0.43	0.05	0.052
March	0.57	0.06	0.05	1	9	10	0.01	0.01	0.007
April	6.21	3.17	3.06	19	97	203	0.26	0.13	0.18
May	0.57	0.05	0.03	8	5	0	0.02	0.01	0
June	0.15	0.11	0.09	1	41	18	0	0.03	0.015
July	0	0.01	0.01	0	0	0	0	0	0
August	0	0.03	0.03	0	2	0	0	0	0
September	2.96	9.84	9.73	211	561	469	0.25	0.53	0.5
October	0.1	0.27	0.24	1	39	23	0	0.03	0.02
November	7.09	5.58	5.52	444	537	332	1.79	0.36	0.3
December	1.86	0.43	0.39	64	42	25	0.18	0.04	0.03
January	3.1	1.28	1.26	20	61	41	0.03	0.06	0.056
February	2.1	0.28	0.24	163	33	24	0.11	0.03	0.02
March	0.6	0.19	0.16	9	16	17	0.02	0.02	0.015
April	0.4	1.39	1.37	8	34	53	0.01	0.06	0.078
May	1.6	4.14	4.11	62	157	380	0.05	0.19	0.28
June	0.1	0.03	0.03	1	2	0	0	0	0
Summation	33.39	30.05	29.47	1,050	1,780	1703	3.26	1.63	1.64

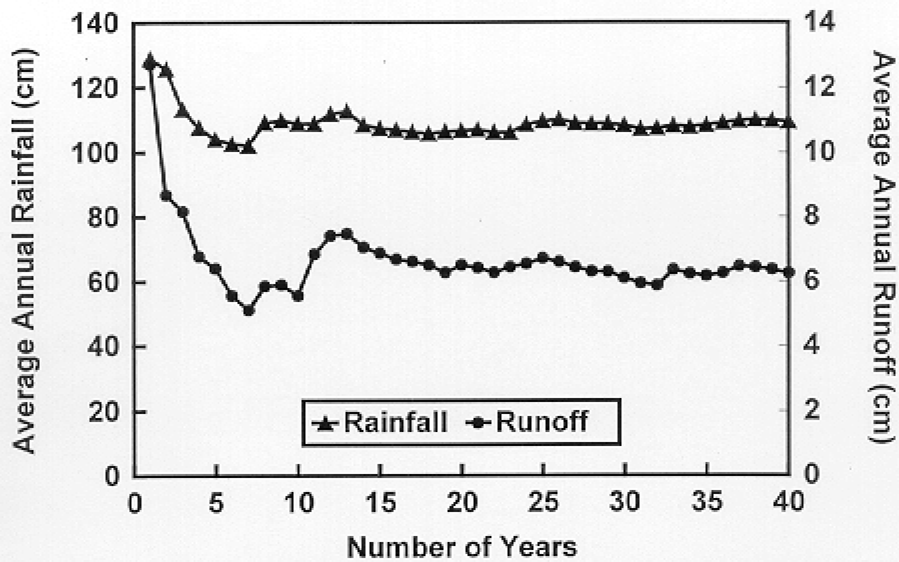


Figure 2.27. SIMPLE predicted running average annual runoff volume and rainfall for Battle Branch watershed.

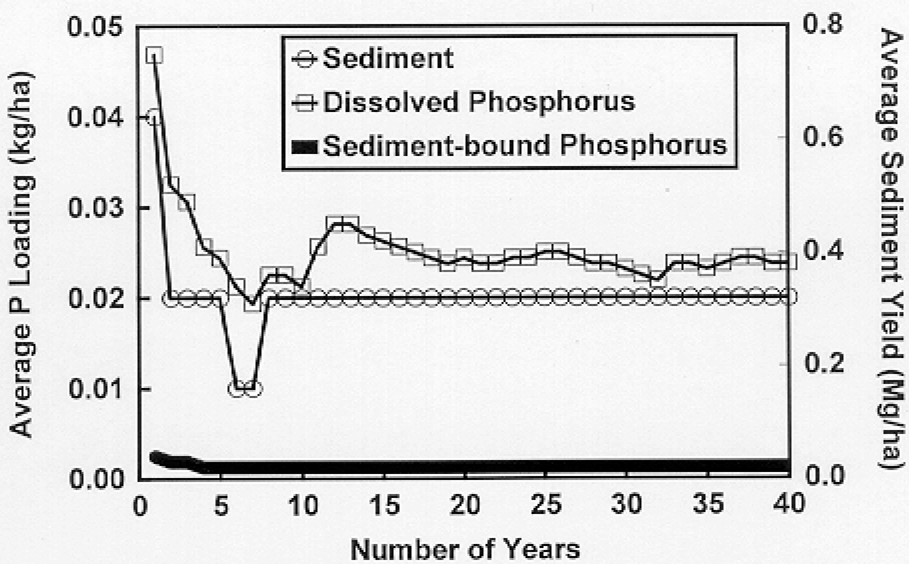


Figure 2.28. SIMPLE predicted running average annual sediment yield, and dissolved and sediment-bound phosphorus loading for Battle Branch watershed.

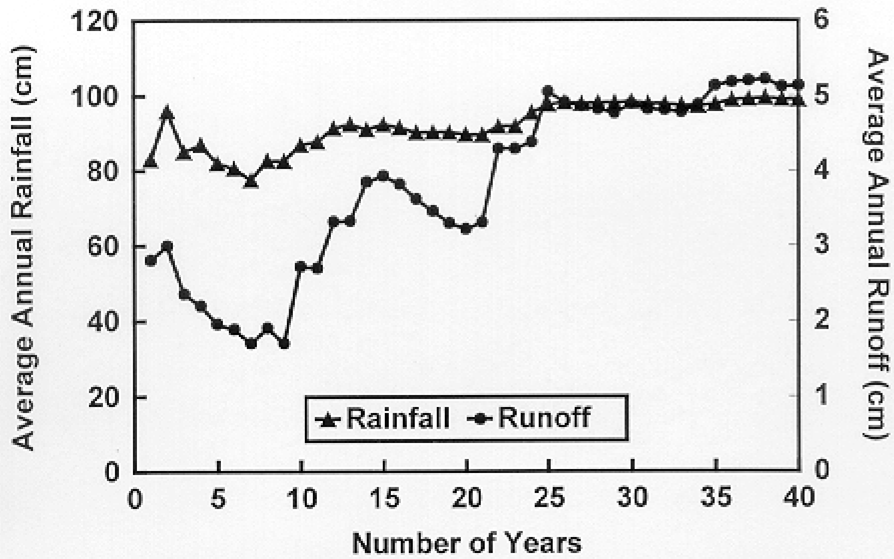


Figure 2.29. SIMPLE predicted running average annual runoff volume and rainfall for Peacheater Creek watershed.

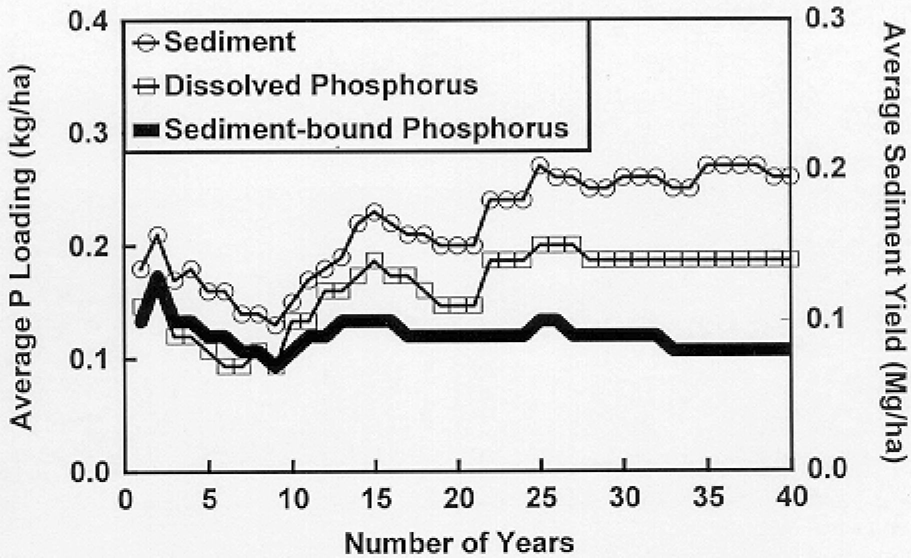


Figure 2.30. SIMPLE predicted running average annual sediment yield, and dissolved and sediment-bound phosphorus loading for Peacheater Creek watershed.

2.6 RESULTS

2.6.1 Independent Simulation Mode

For the independent simulation mode, Figures 2.31 through 2.35 give the average annual runoff volume, sediment yield, and the total, dissolved and sediment-bound phosphorus loads, respectively. Table 2.15 gives the mass loading predictions by year for the entire Upper Illinois River basin, and Table 2.16 give a summary of the average annual loading by land use. In addition, Tables 2.17 and 2.18 give the average annual mass loading and unit area loading by watershed, respectively, for the basin. Detailed average annual mass loading and unit area loading by watershed and land use are given in Tables 2.19 and 2.20, respectively. Figures 2.36 through 2.47 show the time series and relative frequency histograms for rainfall, runoff volume, sediment yield, and dissolved, sediment-bound and total phosphorus.

2.6.2 Continuous Simulation Mode

For the continuous simulation mode, Table 2.21 gives the mass loading predictions by year for the entire Upper Illinois River basin, and Table 2.22 give a summary of the average annual loading by land use. In addition, Tables 2.23 and 2.24 give the average annual mass loading and unit area loading by watershed, respectively, for the basin. Detailed average annual mass loading and unit area loading by watershed and land use are given in Tables 2.25 and 2.26, respectively.

Table 2.15. Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode.

Year	Rain Fall (cm)	Runoff (cm)	Sediment Yield (mg)	Soluble Phosphorus (kg)	Sediment-bound Phosphorus (kg)	Total Phosphorus (kg)
1962	96	8.8	3,294	189,294	430	191,005

1963	67	3.3	858	48,472	0	49,723
1964	97	8.4	2,124	156,565	0	157,820
1965	91	8.1	1,933	150,912	392	151,352
1966	80	5.5	1,575	84,596	0	85,561
1967	100	8.7	2,429	163,569	1,043	165,814
1968	107	8.7	2,347	163,063	1,043	164,398
1969	101	10.5	2,165	205,929	501	207,985
1970	100	13.1	3,681	281,318	1,043	283,703
1971	104	8.5	1,818	136,733	806	138,016
1972	96	12.4	2,580	257,775	1,252	259,240
1973	161	19.3	5,478	372,412	3,067	375,155
1974	131	23.0	4,874	463,487	2,648	465,789
1975	119	9.9	3,630	204,263	1,334	206,648
1976	83	5.9	1,355	89,882	0	90,894
1977	100	8.0	2,453	123,838	651	124,489
1978	99	8.7	2,956	157,000	413	158,649
1979	96	8.3	2,394	130,517	392	131,643
1980	65	4.2	988	62,033	0	63,491
1981	95	6.7	1,780	113,453	321	115,222
1982	97	11.8	4,515	283,638	601	285,105
1983	89	5.4	3,248	62,381	0	62,720
1984	115	11.1	3,660	225,018	2,346	226,460
1985	143	19.9	4,620	346,254	2,123	348,907
1986	133	25.4	7,571	454,943	3,078	458,473

Table 2.16. Unit area SIMPLE model average annual predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use.

Land Use	Runoff (cm/yr)	Sediment Yield (Mg/yr)	Soluble Phosphorus (kg/yr)	Sediment-Bound P (kg/yr)	Total Phosphorus (kg/yr)	Area (ha)
Urban	16	27	3813	4	3817	14446
Transportation & Utilities	19	3	87	0	88	1133
Crop	14	1081	1936	383	2319	3231
Pasture/Range	10	1261	185289	915	186236	202500
Orchards & Vineyards	4	229	79	48	127	1398
Nurseries	12	11	24	0	24	148
Forest	6	182	3168	51	3274	178391
Poultry Operations	112	0	0	0	0	1385
Dairy	112	0	0	0	0	67
Hog Operations	112	0	0	0	0	181
Water	112	0	0	0	0	6745

Table 2.17. Sub-basin mass loading SIMPLE model average annual predictions by land use for the Upper Illinois River Basin using the independent annual simulation mode.

Watershed Number	Watershed Name	Runoff (cm)	Sediment Yield (mg)	Soluble Phosphorus (kg)	Sediment-Bound P (kg)	Total Phosphorus (kg)	Total Area (ha)
1	Osage	9.6	470	42660	201	42861	57350
2	Clear	11.9	109	16713	60	16772	20897

3	Fork	11.1	124	33868	65	33958	41466
4	Flint	11.7	531	24098	235	24333	32109
5	Baron	12.3	333	27626	265	27890	39214
6	Caney	6	259	3750	109	3877	31447
7	Benton	9.8	164	24059	113	24172	37612
8	River	9.9	68	2646	29	2681	12563
9	Bord	8.5	240	4281	96	4410	32992
10	Tyner	9	133	3162	59	3227	10894
11	West	5.6	179	7467	127	7580	30452
12	Bbaron	6	46	1349	12	1374	31447
13	Bilin	6.3	38	1096	8	1104	13009
14	Lakeup	8.2	21	516	6	522	10155
15	Lake	9.5	82	1105	18	1123	5381

Table 2.18. Sub-basin unit area SIMPLE model average annual predictions by land use for the Upper Illinois River Basin using the independent annual simulation mode.

Watershed Number	Watershed Name	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble Phosphorus (kg/ha)	Sediment-Bound P (kg/ha)	Total Phosphorus (kg/ha)	Total Area (ha)
1	Osage	9.6	0.008	0.74	0.004	0.75	57350
2	Clear	11.9	0.005	0.80	0.003	0.80	20897
3	Fork	11.1	0.003	0.82	0.002	0.82	41466
4	Flint	11.7	0.017	0.75	0.007	0.76	32109
5	Baron	12.3	0.008	0.70	0.007	0.71	39214
6	Caney	6	0.008	0.12	0.003	0.12	31447
7	Benton	9.8	0.004	0.64	0.003	0.64	37612
8	River	9.9	0.005	0.21	0.002	0.21	12563
9	Bord	8.5	0.007	0.13	0.003	0.13	32992
10	Tyner	9	0.012	0.29	0.005	0.30	10894
11	West	5.6	0.006	0.25	0.004	0.25	30452
12	Bbaron	6	0.004	0.10	0.001	0.11	31447
13	Bilin	6.3	0.004	0.11	0.001	0.11	13009
14	Lakeup	8.2	0.004	0.10	0.001	0.10	10155
15	Lake	9.5	0.002	0.03	0.001	0.03	5381

Table 2.19. Area weighted SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Osage	Urban	14.2	0.002	0.24	0.00	0.24	5169
	Transportation & Utilities	17.7	0.000	0.07	0.00	0.07	271
	Crop	12.4	0.187	0.56	0.07	0.62	1653

	Pasture/Range	8.3	0.002	1.05	0.00	1.06	38244
	Orchards & Vineyards	3.3	0.093	0.05	0.03	0.08	679
	Nurseries	12	0.031	0.19	0.00	0.19	7
	Forest	4.5	0.001	0.01	0.00	0.01	10555
	Poultry Operations	112	0.000	0.00	0.00	0.00	480
	Dairy	112	0.000	0.00	0.00	0.00	42
	Hog Operations	112	0.000	0.00	0.00	0.00	73
	Water	112	0.000	0.00	0.00	0.00	177
Clear	Urban	18.5	0.000	0.31	0.00	0.31	4041
	Transportation & Utilities	19.7	0.000	0.08	0.00	0.08	182
	Crop	14.5	0.217	0.66	0.09	0.75	210
	Pasture/Range	10.2	0.003	1.33	0.00	1.34	11392
	Orchards & Vineyards	4.1	0.174	0.06	0.05	0.11	164
	Nurseries	13.8	0.070	0.18	0.00	0.18	13
	Forest	6.3	0.000	0.02	0.00	0.02	4701
	Poultry Operations	108.8	0.000	0.00	0.00	0.00	115
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	108.8	0.000	0.00	0.00	0.00	4
	Water	108.8	0.000	0.00	0.00	0.00	75
Fork	Urban	15.3	0.001	0.26	0.00	0.26	606
	Transportation & Utilities	23.3	0.002	0.10	0.00	0.10	26
	Crop	15.2	0.285	0.64	0.09	0.73	152
	Pasture/Range	10.7	0.003	1.31	0.00	1.31	25411
	Orchards & Vineyards	4	0.055	0.06	0.00	0.06	77
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	9	0.000	0.03	0.00	0.03	14784
	Poultry Operations	108.8	0.000	0.00	0.00	0.00	189
	Dairy	108.8	0.000	0.00	0.00	0.00	4
	Hog Operations	108.8	0.000	0.00	0.00	0.00	18
	Water	108.8	0.000	0.00	0.00	0.00	199
Flint	Urban	17.5	0.001	0.29	0.00	0.29	1508
	Transportation & Utilities	21.5	0.002	0.09	0.00	0.09	247
	Crop	16.3	0.718	0.71	0.24	0.95	518
	Pasture/Range	11.4	0.006	1.19	0.01	1.20	19362
	Orchards & Vineyards	4.7	0.145	0.07	0.03	0.10	143
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.5	0.002	0.02	0.00	0.02	9892
	Poultry Operations	115.4	0.000	0.00	0.00	0.00	197
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	115.4	0.000	0.00	0.00	0.00	37
	Water	115.4	0.000	0.00	0.00	0.00	205

Table 2.19 (continued). Area weighted SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Baron	Urban	19.6	0.002	0.33	0.00	0.33	169
	Transportation & Utilities	24.2	0.030	0.10	0.00	0.10	8
	Crop	18.2	1.209	0.75	0.45	1.20	108
	Pasture/Range	13.1	0.008	1.42	0.01	1.43	18976

	Orchards & Vineyards	5.8	0.240	0.08	0.05	0.14	126
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	10.5	0.001	0.03	0.00	0.03	19666
	Poultry Operations	123.7	0.000	0.00	0.00	0.00	148
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	123.7	0.000	0.00	0.00	0.00	6
	Water	123.7	0.000	0.00	0.00	0.00	7
Benton	Urban	15.7	0.004	0.26	0.00	0.26	278
	Transportation & Utilities	19.4	0.007	0.08	0.00	0.08	78
	Crop	14.2	0.120	0.63	0.03	0.65	284
	Pasture/Range	10.2	0.005	1.04	0.00	1.04	22703
	Orchards & Vineyards	4.2	0.098	0.05	0.00	0.05	7
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.2	0.001	0.02	0.00	0.02	13885
	Poultry Operations	113.3	0.000	0.00	0.00	0.00	123
	Dairy	113.3	0.000	0.00	0.00	0.00	18
	Hog Operations	113.3	0.000	0.00	0.00	0.00	29
	Water	113.3	0.000	0.00	0.00	0.00	207
River	Urban	17.5	0.001	0.29	0.00	0.29	101
	Transportation & Utilities	21.5	0.002	0.09	0.00	0.09	17
	Crop	16.4	0.065	0.72	0.00	0.72	49
	Pasture/Range	11.7	0.009	0.43	0.00	0.44	5669
	Orchards & Vineyards	0	0.000	0.00	0.00	0.00	0
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.6	0.002	0.02	0.00	0.02	6629
	Poultry Operations	115.4	0.000	0.00	0.00	0.00	11
	Dairy	115.4	0.000	0.00	0.00	0.00	3
	Hog Operations	115.4	0.000	0.00	0.00	0.00	5
	Water	115.4	0.000	0.00	0.00	0.00	79
Bord	Urban	15.8	0.090	0.26	0.05	0.31	96
	Transportation & Utilities	21.5	0.002	0.09	0.00	0.09	10
	Crop	18.4	0.394	0.60	0.00	0.60	13
	Pasture/Range	11.1	0.020	0.38	0.01	0.39	10172
	Orchards & Vineyards	0	0.000	0.00	0.00	0.00	0
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.1	0.001	0.02	0.00	0.02	22468
	Poultry Operations	115.4	0.000	0.00	0.00	0.00	38
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	115.4	0.000	0.00	0.00	0.00	5
	Water	115.4	0.000	0.00	0.00	0.00	190

Table 2.19 (continued). Area weighted SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Tyner	Urban	17.5	0.013	0.29	0.01	0.30	2
	Transportation & Utilities	21.5	0.002	0.09	0.00	0.09	20
	Crop	15	0.495	0.37	0.00	0.38	6
	Pasture/Range	11.1	0.022	0.57	0.01	0.58	5395
	Orchards & Vineyards	0	0.000	0.00	0.00	0.00	0

	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.6	0.002	0.02	0.00	0.02	5462
	Poultry Operations	115.4	0.000	0.00	0.00	0.00	7
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	115.4	0.000	0.00	0.00	0.00	2
	Water	115.4	0.000	0.00	0.00	0.00	0
West	Urban	12.7	0.000	0.22	0.00	0.22	174
	Transportation & Utilities	13.4	0.011	0.06	0.00	0.06	15
	Crop	9.7	0.456	0.47	0.24	0.70	96
	Pasture/Range	6.7	0.008	0.48	0.01	0.49	14911
	Orchards & Vineyards	4.1	0.015	0.06	0.00	0.06	11
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	3.8	0.001	0.01	0.00	0.01	15148
	Poultry Operations	84.2	0.000	0.00	0.00	0.00	51
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	84.2	0.000	0.00	0.00	0.00	1
	Water	84.2	0.000	0.00	0.00	0.00	45
Caney	Urban	12	0.002	0.20	0.00	0.20	415
	Transportation & Utilities	13.4	0.006	0.06	0.00	0.06	48
	Crop	9	1.077	0.43	0.50	0.92	77
	Pasture/Range	6.9	0.008	0.28	0.01	0.29	11988
	Orchards & Vineyards	2.5	1.519	0.04	0.26	0.30	40
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	4.3	0.001	0.01	0.00	0.01	18640
	Poultry Operations	84.2	0.000	0.00	0.00	0.00	16
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	84.2	0.000	0.00	0.00	0.00	1
	Water	84.2	0.000	0.00	0.00	0.00	222
Bbaron	Urban	11.7	0.003	0.20	0.00	0.20	41
	Transportation & Utilities	14.3	0.001	0.06	0.00	0.06	42
	Crop	10.7	0.271	0.43	0.08	0.51	28
	Pasture/Range	7.7	0.006	0.24	0.00	0.25	5077
	Orchards & Vineyards	0	0.000	0.00	0.00	0.00	0
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	4.3	0.001	0.01	0.00	0.01	7725
	Poultry Operations	83.9	0.000	0.00	0.00	0.00	9
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	0	0.000	0.00	0.00	0.00	0
	Water	83.9	0.000	0.00	0.00	0.00	87

Table 2.19 (continued). Area weighted SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Bilin	Urban	12.3	0.003	0.21	0.00	0.21	1260
	Transportation & Utilities	15	0.007	0.06	0.00	0.06	94
	Crop	12.5	0.016	0.59	0.00	0.59	19
	Pasture/Range	9	0.006	0.20	0.00	0.20	3777
	Orchards & Vineyards	0	0.000	0.00	0.00	0.00	0
	Nurseries	11.3	0.111	0.15	0.00	0.15	50

	Forest	4.3	0.001	0.01	0.00	0.01	4827
	Poultry Operations	83.9	0.000	0.00	0.00	0.00	1
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	0	0.000	0.00	0.00	0.00	0
	Water	83.9	0.000	0.00	0.00	0.00	127
Lakeup	Urban	13.6	0.000	0.23	0.00	0.23	167
	Transportation & Utilities	17.6	0.002	0.07	0.00	0.07	14
	Crop	15.8	0.160	0.76	0.06	0.81	2
	Pasture/Range	10.5	0.003	0.12	0.00	0.12	3667
	Orchards & Vineyards	7.5	0.103	0.12	0.04	0.15	25
	Nurseries	11.7	0.057	0.17	0.00	0.17	78
	Forest	5.8	0.002	0.02	0.00	0.02	1418
	Poultry Operations	0	0.000	0.00	0.00	0.00	0
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	0	0.000	0.00	0.00	0.00	0
	Water	83.9	0.000	0.00	0.00	0.00	10
Lake	Urban	13.2	0.000	0.22	0.00	0.22	419
	Transportation & Utilities	16.4	0.009	0.07	0.00	0.07	61
	Crop	13.2	0.002	0.61	0.00	0.61	16
	Pasture/Range	9.4	0.007	0.10	0.00	0.10	5756
	Orchards & Vineyards	3.3	0.145	0.04	0.01	0.04	126
	Nurseries	0	0.000	0.00	0.00	0.00	0
	Forest	6.7	0.001	0.02	0.00	0.02	22591
	Poultry Operations	0	0.000	0.00	0.00	0.00	0
	Dairy	0	0.000	0.00	0.00	0.00	0
	Hog Operations	0	0.000	0.00	0.00	0.00	0
	Water	93.2	0.000	0.00	0.00	0.00	5115

Table 2.20. Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Osage	Urban	14.2	10.3	1241	0	1241	5169
	Transportation & Utilities	17.7	0.0	20	0	20	271
	Crop	12.4	309.1	917	107	1025	1653
	Pasture/Range	8.3	76.5	40309	76	40386	38244
	Orchards & Vineyards	3.3	63.1	35	17	52	679
	Nurseries	12	0.2	1	0	1	7
	Forest	4.5	10.6	137	0	137	10555

	Poultry Operations	112	0.0	0	0	0	480
	Dairy	112	0.0	0	0	0	42
	Hog Operations	112	0.0	0	0	0	73
	Water	112	0.0	0	0	0	177
Clear	Urban	18.5	0.0	1265	0	1265	4041
	Transportation & Utilities	19.7	0.0	15	0	15	182
	Crop	14.5	45.6	139	18	157	210
	Pasture/Range	10.2	34.2	15197	34	15231	11392
	Orchards & Vineyards	4.1	28.5	10	8	18	164
	Nurseries	13.8	0.9	2	0	2	13
	Forest	6.3	0.0	85	0	85	4701
	Poultry Operations	108.8	0.0	0	0	0	115
	Dairy	0	0.0	0	0	0	0
	Hog Operations	108.8	0.0	0	0	0	4
	Water	108.8	0.0	0	0	0	75
Fork	Urban	15.3	0.6	156	0	156	606
	Transportation & Utilities	23.3	0.1	2	0	2	26
	Crop	15.2	43.3	98	14	111	152
	Pasture/Range	10.7	76.2	33238	51	33314	25411
	Orchards & Vineyards	4	4.2	5	0	5	77
	Nurseries	0	0.0	0	0	0	0
	Forest	9	0.0	370	0	370	14784
	Poultry Operations	108.8	0.0	0	0	0	189
	Dairy	108.8	0.0	0	0	0	4
	Hog Operations	108.8	0.0	0	0	0	18
	Water	108.8	0.0	0	0	0	199
Flint	Urban	17.5	1.5	443	0	443	1508
	Transportation & Utilities	21.5	0.5	22	0	22	247
	Crop	16.3	371.9	366	124	490	518
	Pasture/Range	11.4	116.2	23080	97	23176	19362
	Orchards & Vineyards	4.7	20.7	9	4	14	143
	Nurseries	0	0.0	0	0	0	0
	Forest	6.5	19.8	178	10	188	9892
	Poultry Operations	115.4	0.0	0	0	0	197
	Dairy	0	0.0	0	0	0	0
	Hog Operations	115.4	0.0	0	0	0	37
	Water	115.4	0.0	0	0	0	205

Table 2.20 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Baron	Urban	19.6	0.3	56	0	56	169
	Transportation & Utilities	24.2	0.2	1	0	1	8
	Crop	18.2	130.6	81	48	129	108
	Pasture/Range	13.1	151.8	26908	190	27098	18976
	Orchards & Vineyards	5.8	30.2	10	7	17	126
	Nurseries	0	0.0	0	0	0	0
	Forest	10.5	19.7	570	20	590	19666
	Poultry Operations	123.7	0.0	0	0	0	148

	Dairy	0	0.0	0	0	0	0
	Hog Operations	123.7	0.0	0	0	0	6
	Water	123.7	0.0	0	0	0	7
Benton	Urban	15.7	1.1	73	0	73	278
	Transportation & Utilities	19.4	0.5	6	0	6	78
	Crop	14.2	34.1	178	8	186	284
	Pasture/Range	10.2	113.5	23566	91	23657	22703
	Orchards & Vineyards	4.2	0.7	0	0	0	7
	Nurseries	0	0.0	0	0	0	0
	Forest	6.2	13.9	236	14	250	13885
	Poultry Operations	113.3	0.0	0	0	0	123
	Dairy	113.3	0.0	0	0	0	18
	Hog Operations	113.3	0.0	0	0	0	29
	Water	113.3	0.0	0	0	0	207
River	Urban	17.5	0.1	30	0	30	101
	Transportation & Utilities	21.5	0.0	1	0	1	17
	Crop	16.4	3.2	35	0	35	49
	Pasture/Range	11.7	51.0	2460	23	2489	5669
	Orchards & Vineyards	0	0.0	0	0	0	0
	Nurseries	0	0.0	0	0	0	0
	Forest	6.6	13.3	119	7	126	6629
	Poultry Operations	115.4	0.0	0	0	0	11
	Dairy	115.4	0.0	0	0	0	3
	Hog Operations	115.4	0.0	0	0	0	5
	Water	115.4	0.0	0	0	0	79
Bord	Urban	15.8	8.6	25	4	30	96
	Transportation & Utilities	21.5	0.0	1	0	1	10
	Crop	18.4	5.1	8	0	8	13
	Pasture/Range	11.1	203.4	3865	92	3967	10172
	Orchards & Vineyards	0	0.0	0	0	0	0
	Nurseries	0	0.0	0	0	0	0
	Forest	6.1	22.5	382	0	404	22468
	Poultry Operations	115.4	0.0	0	0	0	38
	Dairy 0	0.0	0	0	0	0	
	Hog Operations 115.4	0.0	0	0	0	5	
	Water	115.4	0.0	0	0	0	190

Table 2.20 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Tyner	Urban	17.5	0.0	1	0	1	2
	Transportation & Utilities	21.5	0.0	2	0	2	20
	Crop	15	3.0	2	0	2	6
	Pasture/Range	11.1	118.7	3059	59	3118	5395
	Orchards & Vineyards	0	0.0	0	0	0	0
	Nurseries	0	0.0	0	0	0	0
	Forest	6.6	10.9	98	0	104	5462
	Poultry Operations	115.4	0.0	0	0	0	7
	Dairy	0	0.0	0	0	0	0

	Hog Operations	115.4	0.0	0	0	0	2
	Water	115.4	0.0	0	0	0	0
West	Urban	12.7	0.0	38	0	38	174
	Transportation & Utilities	13.4	0.2	1	0	1	15
	Crop	9.7	43.8	45	23	68	96
	Pasture/Range	6.7	119.3	7217	104	7306	14911
	Orchards & Vineyards	4.1	0.2	1	0	1	11
	Nurseries	0	0.0	0	0	0	0
	Forest	3.8	15.1	167	0	167	15148
	Poultry Operations	84.2	0.0	0	0	0	51
	Dairy	0	0.0	0	0	0	0
	Hog Operations	84.2	0.0	0	0	0	1
	Water	84.2	0.0	0	0	0	45
Caney	Urban	12	0.8	85	0	85	415
	Transportation & Utilities	13.4	0.3	3	0	3	48
	Crop	9	82.9	33	38	71	77
	Pasture/Range	6.9	95.9	3405	60	3465	11988
	Orchards & Vineyards	2.5	60.8	1	11	12	40
	Nurseries	0	0.0	0	0	0	0
	Forest	4.3	18.6	224	0	242	18640
	Poultry Operations	84.2	0.0	0	0	0	16
	Dairy	0	0.0	0	0	0	0
	Hog Operations	84.2	0.0	0	0	0	1
	Water	84.2	0.0	0	0	0	222
Bbaron	Urban	11.7	0.1	8	0	8	41
	Transportation & Utilities	14.3	0.0	2	0	2	42
	Crop	10.7	7.6	12	2	14	28
	Pasture/Range	7.7	30.5	1234	10	1249	5077
	Orchards & Vineyards	0	0.0	0	0	0	0
	Nurseries	0	0.0	0	0	0	0
	Forest	4.3	7.7	93	0	100	7725
	Poultry Operations	83.9	0.0	0	0	0	9
	Dairy	0	0	0	0	0	0
	Hog Operations	0	0.0	0	0	0	0
	Water	83.9	0.0	0	0	0	87

Table 2.20 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the independent annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Bilin	Urban	12.3	3.8	262	0	262	1260
	Transportation & Utilities	15	0.7	6	0	6	94
	Crop	12.5	0.3	11	0	11	19
	Pasture/Range	9	22.7	752	8	759	3777
	Orchards & Vineyards	0	0.0	0	0	0	0
	Nurseries	11.3	5.6	8	0	8	50
	Forest	4.3	4.8	58	0	58	4827
	Poultry Operations	83.9	0.0	0	0	0	1
	Dairy	0	0.0	0	0	0	0
	Hog Operations	0	0.0	0	0	0	0

	Water	83.9	0.0	0	0	0	127
Lakeup	Urban	13.6	0.0	38	0	38	167
	Transportation & Utilities	17.6	0.0	1	0	1	14
	Crop	15.8	0.3	2	0	2	2
	Pasture/Range	10.5	11.0	436	4	440	3667
	Orchards & Vineyards	7.5	2.6	3	1	4	25
	Nurseries	11.7	4.4	13	0	13	78
	Forest	5.8	2.8	23	1	24	1418
	Poultry Operations	0	0.0	0	0	0	0
	Dairy	0	0.0	0	0	0	0
	Hog Operations	0	0.0	0	0	0	0
	Water	83.9	0.0	0	0	0	10
Lake	Urban	13.2	0.0	93	0	93	419
	Transportation & Utilities	16.4	0.5	4	0	4	61
	Crop	13.2	0.0	10	0	10	16
	Pasture/Range	9.4	40.3	564	17	581	5756
	Orchards & Vineyards	3.3	18.3	5	1	6	126
	Nurseries	0	0.0	0	0	0	0
	Forest	6.7	22.6	429	0	429	22591
	Poultry Operations	0	0.0	0	0	0	0
	Dairy	0	0.0	0	0	0	0
	Hog Operations	0	0.0	0	0	0	0
	Water	93.2	0.0	0	0	0	5115

Table 2.21. SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode.

Year	Rain Fall (cm)	Runoff (cm)	Sediment Yield (mg)	Soluble Phosphorus (kg)	Sediment-bound Phosphorus (kg)	Total Phosphorus (kg)
1962	96	8.8	3,294	189,294	430	191,005
1963	67	3.3	858	66,328	392	66,720
1964	97	8.4	2,124	266,545	1,700	269,404
1965	91	8.1	1,933	326,557	1,396	328,588
1966	80	5.5	1,575	254,023	922	255,275
1967	100	8.7	2,429	439,164	2,778	441,626
1968	107	8.7	2,347	526,927	2,964	529,805
1969	101	10.5	2,165	728,721	3,362	732,513
1970	100	13.1	3,681	1,000,644	4,090	1,004,828
1971	104	8.5	1,818	510,551	2,517	513,393
1972	96	12.4	2,580	1,023,429	4,510	1,028,979

1973	161	19.3	5,478	1,615,105	7,681	1,622,936
1974	131	23.0	4,874	1,996,918	7,281	2,004,203
1975	119	9.9	3,630	945,421	4,677	950,060
1976	83	5.9	1,355	456,119	2,042	457,638
1977	100	8.0	2,453	638,776	3,099	642,964
1978	99	8.7	2,956	880,982	4,020	884,816
1979	96	8.3	2,394	719,771	3,321	723,825
1980	65	4.2	988	370,498	2,201	372,717
1981	95	6.7	1,780	648,583	3,742	652,772
1982	97	11.8	4,515	1,938,113	5,761	1,943,335
1983	89	5.4	3,248	398,184	2,744	400,856
1984	115	11.1	3,660	1,557,299	7,405	1,565,396
1985	143	19.9	4,620	2,501,837	9,351	2,511,812
1986	133	25.4	7,571	3,115,154	10,146	3,125,075

Table 2.22. Unit area SIMPLE model average annual predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use.

Land Use	Runoff (cm/yr)	Sediment Yield (Mg/yr)	Soluble Phosphorus (kg/yr)	Sediment-Bound P (kg/yr)	Total Phosphorus (kg/yr)	Area (ha)
Urban	16	27	6031	5	6035	14447
Transportation & Utilities	19	3	109	0	109	1133
Crop	14	1081	9110	820	9930	3231
Pasture/Range	10	1261	990815	3524	994332	202499
Orchards & Vineyards	4	230	66	22	88	1397
Nurseries	12	11	2	0	2	148
Forest	6	182	5527	68	5629	178390
Poultry Operations	112	0	0	0	0	1385
Dairy	112	0	0	0	0	67
Hog Operations	113	0	0	0	0	180
Water	96	0	0	0	0	6744
Total	10	2795	1011659	4437	1016125	409621

Table 2.23. Sub-basin mass loading SIMPLE model average annual predictions by land use for the Upper Illinois River Basin using the continuous annual simulation mode.

Watershed Number	Watershed Name	Runoff (cm)	Sediment Yield (mg)	Soluble Phosphorus (kg)	Sediment-Bound P (kg)	Total P (kg)	Total Area (ha)
1	Osage	9.6	470	248959	761	249720	57350
2	Clear	11.9	109	86479	185	86665	20897
3	Fork	11.1	125	180664	262	180940	'41466
4	Flint	11.7	531	124603	733	125317	32109
5	Baron	12.3	333	166959	963	167922	39214
6	Caney	6.0	259	14802	247	15080	31447
7	Benton	9.8	164	110848	373	111207	37612
8	River	9.9	68	9350	58	9407	12563
9	Bord	8.5	240	17513	269	17805	32992
10	Tyner	9.0	132	9218	130	9342	10894
11	West	5.6	178	32352	387	32739	30452
12	Bbaron	6.0	259	14802	247	15080	31447

13	Bilin	6.3	46	2662	23	2685	13009
14	Lakeup	8.2	38	1700	11	1711	10155
15	Lake	9.5	21	1391	6	1395	5381

Table 2.24. Sub-basin unit area SIMPLE model average annual predictions by land use for the Upper Illinois River Basin using the continuous annual simulation mode.

Watershed Number	Watershed Name	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble Phosphorus (kg/ha)	Sediment-Bound P (kg/ha)	Total P (kg/ha)	Total Area (ha)
1	Osage	9.6	0.0082	4.34	0.0133	4.35	57350
2	Clear	11.9	0.0052	4.14	0.0089	4.15	20897
3	Fork	11.1	0.0030	4.36	0.0063	4.36	41466
4	Flint	11.7	0.0165	3.88	0.0228	3.90	32109
5	Baron	12.3	0.0085	4.26	0.0246	4.28	39214
6	Caney	6.0	0.0082	0.47	0.0078	0.48	31447
7	Benton	9.8	0.0044	2.95	0.0099	2.96	37612
8	River	9.9	0.0054	0.74	0.0046	0.75	12563
9	Bord	8.5	0.0073	0.53	0.0082	0.54	32992
10	Tyner	9.0	0.0122	0.85	0.0119	0.86	10894
11	West	5.6	0.0059	1.06	0.0127	1.08	30452
12	Bbaron	6.0	0.0082	0.47	0.0078	0.48	31447
13	Bilin	6.3	0.0035	0.20	0.0018	0.21	13009
14	Lakeup	8.2	0.0037	0.17	0.0011	0.17	10155
15	Lake	9.5	0.0039	0.26	0.0011	0.26	5381

Table 2.25. SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff	Sediment Yield (cm)	Soluble P (Mg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (kg/ha)
(ha)							
Osage	Urban	14.2	0.002	0.25	0.00	0.25	5169
	Transportation & Utilities	17.7	0	0.07	0.00	0.07	271
	Crop	12.4	0.187	2.89	0.17	3.06	1653
	Pasture/Range	8.3	0.002	5.76	0.01	5.77	38244
	Orchards & Vineyards	3.3	0.093	0.03	0.01	0.04	679
	Nurseries	12.0	0.031	0.08	0.00	0.08	7
	Forest	4.5	0.001	0.02	0.00	0.02	10555
	Poultry Operations	112.0	0	0.00	0.00	0.00	480
	Dairy	112.0	0	0.00	0.00	0.00	42
	Hog Operations	112.0	0	0.00	0.00	0.00	73
	Water	112.0	0	0.00	0.00	0.00	177

Clear	Urban	18.5	0	0.32	0.00	0.32	4041
	Transportation & Utilities	19.7	0	0.07	0.00	0.07	182
	Crop	14.5	0.217	3.08	0.16	3.24	210
	Pasture/Range	10.2	0.003	6.66	0.01	6.67	11392
	Orchards & Vineyards	4.1	0.174	0.04	0.02	0.06	164
	Nurseries	13.8	0.07	0.03	0.00	0.03	13
	Forest	6.3	0	0.02	0.00	0.02	4701
	Poultry Operations	108.8	0	0.00	0.00	0.00	115
	Hog Operations	108.8	0	0.00	0.00	0.00	4
	Water	108.8	0	0.00	0.00	0.00	75
Fork	Urban	15.3	0.001	0.26	0.00	0.26	606
	Transportation & Utilities	23.3	0.002	0.07	0.00	0.07	26
	Crop	15.2	0.285	2.34	0.21	2.55	152
	Pasture/Range	10.7	0.003	6.42	0.01	6.42	25411
	Orchards & Vineyards	4.0	0.055	0.04	0.00	0.04	77
	Forest	9.0	0	0.03	0.00	0.03	14784
	Poultry Operations	108.8	0	0.00	0.00	0.00	189
	Dairy	108.8	0	0.00	0.00	0.00	4
	Hog Operations	108.8	0	0.00	0.00	0.00	18
	Water	108.8	0	0.00	0.00	0.00	199
Flint	Urban	17.5	0.001	0.28	0.00	0.28	1508
	Transportation & Utilities	21.5	0.002	0.07	0.00	0.07	247
	Crop	16.3	0.718	2.86	0.45	3.31	518
	Pasture/Range	11.4	0.006	5.70	0.02	5.73	19362
	Orchards & Vineyards	4.7	0.145	0.03	0.01	0.03	143
	Forest	6.5	0.002	0.02	0.00	0.02	9892
	Poultry Operations	115.4	0	0.00	0.00	0.00	197
	Hog Operations	115.4	0	0.00	0.00	0.00	37
	Water	115.4	0	0.00	0.00	0.00	205

Table 2.25 (continued). SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Baron	Urban	19.6	0.002	0.30	0.00	0.30	169
	Transportation & Utilities	24.2	0.03	0.06	0.00	0.06	8
	Crop	18.2	1.209	2.67	0.79	3.46	108
	Pasture/Range	13.1	0.008	8.19	0.04	8.24	18976
	Orchards & Vineyards	5.8	0.24	0.03	0.01	0.05	126
	Forest	10.5	0.001	0.03	0.00	0.03	19666
	Poultry Operations	123.7	0	0.00	0.00	0.00	148
	Hog Operations	123.7	0	0.00	0.00	0.00	6
	Water	123.7	0	0.00	0.00	0.00	7
Benton	Urban	15.7	0.004	0.24	0.00	0.24	278
	Transportation & Utilities	19.4	0.007	0.06	0.00	0.06	78
	Crop	14.2	0.12	2.40	0.07	2.46	284

	Pasture/Range	10.2	0.005	4.28	0.01	4.29	22703
	Orchards & Vineyards	4.2	0.098	0.02	0.00	0.02	7
	Forest	6.2	0.001	0.02	0.00	0.02	13885
	Poultry Operations	113.3	0	0.00	0.00	0.00	123
	Dairy	113.3	0	0.00	0.00	0.00	18
	Hog Operations	113.3	0	0.00	0.00	0.00	29
	Water	113.3	0	0.00	0.00	0.00	207
River	Urban	17.5	0.001	0.28	0.00	0.28	101
	Transportation & Utilities	21.5	0.002	0.05	0.00	0.05	17
	Crop	16.4	0.065	3.58	0.00	3.58	49
	Pasture/Range	11.7	0.009	1.32	0.01	1.33	5669
	Forest	6.6	0.002	0.02	0.00	0.02	6629
	Poultry Operations	115.4	0	0.00	0.00	0.00	11
	Dairy	115.4	0	0.00	0.00	0.00	3
	Hog Operations	115.4	0	0.00	0.00	0.00	5
	Water	115.4	0	0.00	0.00	0.00	79
Bord	Urban	15.8	0.09	0.24	0.04	0.28	96
	Transportation & Utilities	21.5	0.002	0.05	0.00	0.05	10
	Crop	18.4	0.394	1.57	0.00	1.57	13
	Pasture/Range	11.1	0.02	1.46	0.02	1.48	10172
	Forest	6.1	0.001	0.02	0.00	0.02	22468
	Poultry Operations	115.4	0	0.00	0.00	0.00	38
	Hog Operations	115.4	0	0.00	0.00	0.00	5
	Water	115.4	0	0.00	0.00	0.00	190

Table 2.25 (continued). SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Tyner	Urban	17.5	0.013	0.28	0.01	0.29	2
	Transportation & Utilities	21.5	0.002	0.05	0.00	0.05	20
	Crop	15.0	0.495	0.49	0.00	0.49	6
	Pasture/Range	11.1	0.022	1.34	0.02	1.36	5395
	Forest	6.6	0.002	0.02	0.00	0.02	5462
	Poultry Operations	115.4	0	0.00	0.00	0.00	7
	Hog Operations	115.4	0	0.00	0.00	0.00	2
	Water	115.4	0	0.00	0.00	0.00	0
West	Urban	12.7	0	0.23	0.00	0.23	174
	Transportation & Utilities	13.4	0.011	0.04	0.00	0.04	15
	Crop	9.7	0.456	2.12	0.47	2.59	96
	Pasture/Range	6.7	0.008	2.34	0.03	2.36	14911
	Orchards & Vineyards	4.1	0.015	0.03	0.00	0.03	11
	Forest	3.8	0.001	0.01	0.00	0.01	15148

	Poultry Operations	84.2	0	0.00	0.00	0.00	51
	Hog Operations	84.2	0	0.00	0.00	0.00	1
	Water	84.2	0	0.00	0.00	0.00	45
Caney	Urban	12.0	0.002	0.21	0.00	0.21	415
	Transportation & Utilities	13.4	0.006	0.05	0.00	0.05	48
	Crop	9.0	1.077	1.59	0.94	2.53	77
	Pasture/Range	6.9	0.008	1.00	0.01	1.01	11988
	Orchards & Vineyards	2.5	1.519	0.02	0.10	0.11	40
	Forest	4.3	0.001	0.01	0.00	0.01	18640
	Poultry Operations	84.2	0	0.00	0.00	0.00	16
	Hog Operations	84.2	0	0.00	0.00	0.00	1
	Water	84.2	0	0.00	0.00	0.00	222
Bbaron	Urban	11.7	0.003	0.21	0.00	0.21	41
	Transportation & Utilities	14.3	0.001	0.05	0.00	0.05	42
	Crop	10.7	0.271	1.41	0.28	1.69	28
	Pasture/Range	7.7	0.006	0.67	0.00	0.67	5077
	Forest	4.3	0.001	0.01	0.00	0.01	7725
	Poultry Operations	83.9	0	0.00	0.00	0.00	9
	Water	83.9	0	0.00	0.00	0.00	87
Bilin	Urban	12.3	0.003	0.22	0.00	0.22	1260
	Transportation & Utilities	15.0	0.007	0.06	0.00	0.06	94
	Crop	12.5	0.016	3.20	0.00	3.20	19
	Pasture/Range	9.0	0.006	0.53	0.00	0.53	3777
	Nurseries	11.3	0.111	0.04	0.00	0.04	50
	Forest	4.3	0.001	0.01	0.00	0.01	4827
	Poultry Operations	83.9	0	0.00	0.00	0.00	1
	Water	83.9	0	0.00	0.00	0.00	127

Table 2.25 (continued). SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (Mg/ha)	Soluble P (kg/ha)	Sediment-bound P (kg/ha)	Total P (kg/ha)	Area (ha)
Lakeup	Urban	13.6	0	0.24	0.00	0.24	167
	Transportation & Utilities	17.6	0.002	0.06	0.00	0.06	14
	Crop	15.8	0.16	4.08	0.24	4.32	2
	Pasture/Range	10.5	0.003	0.44	0.00	0.44	3667
	Orchards & Vineyards	7.5	0.103	0.08	0.02	0.10	25
	Nurseries	11.7	0.057	0.04	0.00	0.04	78
	Forest	5.8	0.002	0.02	0.00	0.02	1418
	Water	83.9	0	0.00	0.00	0.00	10
Lake	Urban	13.2	0	0.24	0.00	0.24	419
	Transportation & Utilities	16.4	0.009	0.06	0.00	0.06	61
	Crop	13.2	0.002	4.16	0.00	4.16	16
	Pasture/Range	9.4	0.007	0.48	0.01	0.49	5756
	Orchards & Vineyards	3.3	0.145	0.01	0.00	0.01	126
	Forest	6.7	0.001	0.02	0.00	0.02	22591

	Water	93.2	0	0.00	0.00	0.00	5115

Table 2.26. Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Osage	Urban	14.2	10	2187	0	2187	5169
	Transportation & Utilities	17.7	0	31	0	31	271
	Crop	12.4	309	4882	283	5165	1653
	Pasture/Range	8.3	76	241548	459	242007	38244
	Orchards & Vineyards	3.3	63	35	9	44	679
	Nurseries	12	0	1	0	1	7
	Forest	4.5	11	274	11	285	10555
	Poultry Operations	112	0	0	0	0	480
	Dairy	112	0	0	0	0	42
	Hog Operations	112	0	0	0	0	73
	Water	112	0	0	0	0	177
Clear	Urban	18.5	0	2134	0	2134	4041
	Transportation & Utilities	19.7	0	21	0	21	182
	Crop	14.5	46	660	33	694	210
	Pasture/Range	10.2	34	83489	148	83637	11392
	Orchards & Vineyards	4.1	29	9	4	13	164

	Nurseries	13.8	1	1	0	1	13
	Forest	6.3	0	165	0	165	4701
	Poultry Operations	108.8	0	0	0	0	115
	Dairy	0	0	0	0	0	0
	Hog Operations	108.8	0	0	0	0	4
	Water	108.8	0	0	0	0	75
Fork	Urban	15.3	1	264	0	264	606
	Transportation & Utilities	23.3	0	3	0	3	26
	Crop	15.2	43	364	33	397	152
	Pasture/Range	10.7	76	179349	229	179577	25411
	Orchards & Vineyards	4	4	4	0	4	77
	Nurseries	0	0	0	0	0	0
	Forest	9	0	680	0	695	14784
	Poultry Operations	108.8	0	0	0	0	189
	Dairy	108.8	0	0	0	0	4
	Hog Operations	108.8	0	0	0	0	18
	Water	108.8	0	0	0	0	199

Table 2.26 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Flint	Urban	17.5	2	709	0	709	1508
	Transportation & Utilities	21.5	0	28	0	28	247
	Crop	16.3	372	1512	238	1750	518
	Pasture/Range	11.4	116	122001	484	122466	19362
	Orchards & Vineyards	4.7	21	6	1	7	143
	Nurseries	0	0	0	0	0	0
	Forest	6.5	20	346	10	356	9892
	Poultry Operations	115.4	0	0	0	0	197
	Dairy	0	0	0	0	0	0
	Hog Operations	115.4	0	0	0	0	37
	Water	115.4	0	0	0	0	205
Baron	Urban	19.6	0	85	0	85	169
	Transportation & Utilities	24.2	0	1	0	1	8
	Crop	18.2	131	295	88	382	108
	Pasture/Range	13.1	152	165568	854	166422	18976
	Orchards & Vineyards	5.8	30	7	2	9	126
	Nurseries	0	0	0	0	0	0

	Forest	10.5	20	1003	20	1023	19666
	Poultry Operations	123.7	0	0	0	0	148
	Dairy	0	0	0	0	0	0
	Hog Operations	123.7	0	0	0	0	6
	Water	123.7	0	0	0	0	7
Benton	Urban	15.7	1	110	0	110	278
	Transportation & Utilities	19.4	1	7	0	7	78
	Crop	14.2	34	695	19	714	284
	Pasture/Range	10.2	114	109562	341	109903	22703
	Orchards & Vineyards	4.2	1	0	0	0	7
	Nurseries	0	0	0	0	0	0
	Forest	6.2	14	472	14	472	13885
	Poultry Operations	113.3	0	0	0	0	123
	Dairy	113.3	0	0	0	0	18
	Hog Operations	113.3	0	0	0	0	29
	Water	113.3	0	0	0	0	207

Table 2.26 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
River	Urban	17.5	0	47	0	47	101
	Transportation & Utilities	21.5	0	2	0	2	17
	Crop	16.4	3	181	0	181	49
	Pasture/Range	11.7	51	8889	51	8940	5669
	Orchards & Vineyards	0	0	0	0	0	0
	Nurseries	0	0	0	0	0	0
	Forest	6.6	13	232	7	239	6629
	Poultry Operations	115.4	0	0	0	0	11
	Dairy	115.4	0	0	0	0	3
	Hog Operations	115.4	0	0	0	0	5
	Water	115.4	0	0	0	0	79
Bord	Urban	15.8	9	38	4	42	96
	Transportation & Utilities	21.5	0	1	0	1	10
	Crop	18.4	5	21	0	21	13
	Pasture/Range	11.1	203	16712	264	16976	10172
	Orchards & Vineyards	0	0	0	0	0	0
	Nurseries	0	0	0	0	0	0
	Forest	6.1	22	741	0	764	22468

	Poultry Operations	115.4	0	0	0	0	38
	Dairy	0	0	0	0	0	0
	Hog Operations	115.4	0	0	0	0	5
	Water	115.4	0	0	0	0	190
Tyner	Urban	17.5	0	1	0	1	2
	Transportation & Utilities	21.5	0	2	0	2	20
	Crop	15	3	3	0	3	6
	Pasture/Range	11.1	119	9015	124	9139	5395
	Orchards & Vineyards	0	0	0	0	0	0
	Nurseries	0	0	0	0	0	0
	Forest	6.6	11	197	5	197	5462
	Poultry Operations	115.4	0	0	0	0	7
	Dairy	0	0	0	0	0	0
	Hog Operations 115.4	0	0	0	0	2	
	Water	115.4	0	0	0	0	0

Table 2.26 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

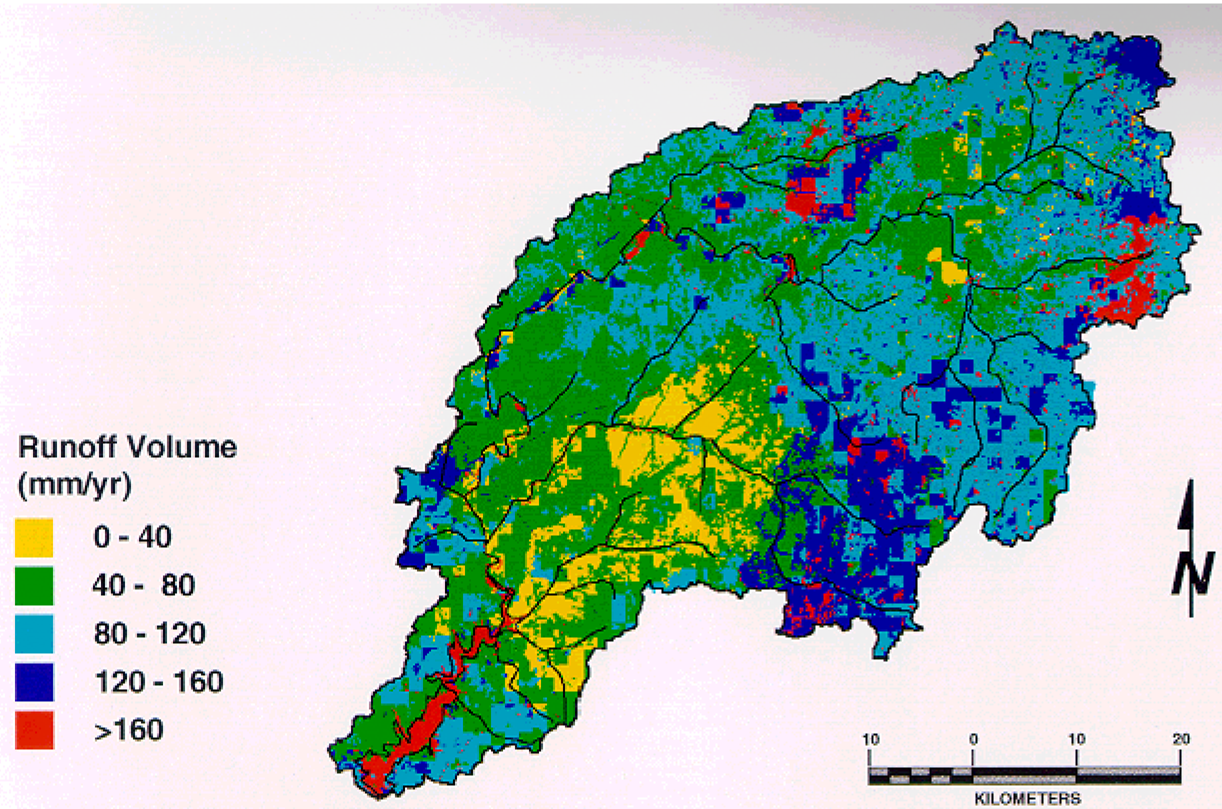
Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
West	Urban	12.7	0	19	0	19	174
	Transportation & Utilities	13.4	0	0	0	0	15
	Crop	9.7	44	199	44	243	96
	Pasture/Range	6.7	119	32058	343	32401	14911
	Orchards & Vineyards	4.1	0	0	0	0	11
	Nurseries	0	0	0	0	0	0
	Forest	3.8	15	76	0	76	15148
	Poultry Operations	84.2	0	0	0	0	51
	Dairy	0	0	0	0	0	0
	Hog Operations	84.2	0	0	0	0	1
	Water	84.2	0	0	0	0	45
Caney	Urban	12	0	151	0	151	415
	Transportation & Utilities	13.4	0	4	0	4	48
	Crop	9	83	125	74	199	77
	Pasture/Range	6.9	96	14074	168	14254	11988
	Orchards & Vineyards	2.5	61	1	5	6	40
	Nurseries	0	0	0	0	0	0
	Forest	4.3	19	447	0	466	18640

	Poultry Operations	84.2	0	0	0	0	16
	Dairy	0	0	0	0	0	0
	Hog Operations	84.2	0	0	0	0	1
	Water	84.2	0	0	0	0	222
Bbaron	Urban	11.7	0	3	0	3	41
	Transportation & Utilities	14.3	0	1	0	1	42
	Crop	10.7	7	38	8	46	28
	Pasture/Range	7.7	30	2589	15	2605	5077
	Orchards & Vineyards	0	0	0	0	0	0
	Nurseries	0	0	0	0	0	0
	Forest	4.3	8	31	0	31	7725
	Poultry Operations	83.9	0	0	0	0	9
	Dairy	0	0	0	0	0	0
	Hog Operations	0	0	0	0	0	0
	Water	83.9	0	0	0	0	87

Table 2.26 (continued). Mass loading SIMPLE model predictions for the Upper Illinois River Basin using the continuous annual simulation mode by land use for each watershed.

Watershed	Land Use	Runoff (cm)	Sediment Yield (mg)	Soluble P (kg)	Sediment-bound P (kg)	Total P (kg)	Area (ha)
Bilin	Urban	12.3	4	103	0	103	1260
	Transportation & Utilities	15	1	2	0	2	94
	Crop	12.5	0	61	0	61	19
	Pasture/Range	9	23	1515	11	1526	3777
	Orchards & Vineyards	0	0	0	0	0	0
	Nurseries	11.3	6	0	0	0	50
	Forest	4.3	5	19	0	19	4827
	Poultry Operations	83.9	0	0	0	0	1
	Dairy	0	0	0	0	0	0
	Hog Operations	0	0	0	0	0	0
	Water	83.9	0	0	0	0	127
Lakeup	Urban	13.6	0	15	0	15	167
	Transportation & Utilities	17.6	0	0	0	0	14
	Crop	15.8	0	7	0	8	2
	Pasture/Range	10.5	11	1360	4	1364	3667
	Orchards & Vineyards	7.5	3	1	0	1	25
	Nurseries	11.7	4	0	0	0	78
	Forest	5.8	3	7	1	7	1418
	Poultry Operations	0	0	0	0	0	0
	Dairy	0	0	0	0	0	0

	Hog Operations	0	0	0	0	0	0
	Water	83.9	0	0	0	0	10
Lake	Urban	13.2	0	165	0	165	419
	Transportation & Utilities	16.4	1	6	0	6	61
	Crop	13.2	0	66	0	66	16
	Pasture/Range	9.4	40	3085	29	3114	5756
	Orchards & Vineyards	3.3	18	2	0	3	126
	Nurseries	0	0	0	0	0	0
	Forest	6.7	23	836	0	836	22591
	Poultry Operations	0	0	0	0	0	0
	Dairy	0	0	0	0	0	0
	Hog Operations	0	0	0	0	0	0
	Water	93.2	0	0	0	0	5115



.Figure 2.31. SIMPLE predicted average annual runoff volume to the Upper Illinois River basin using the independent simulation mode.

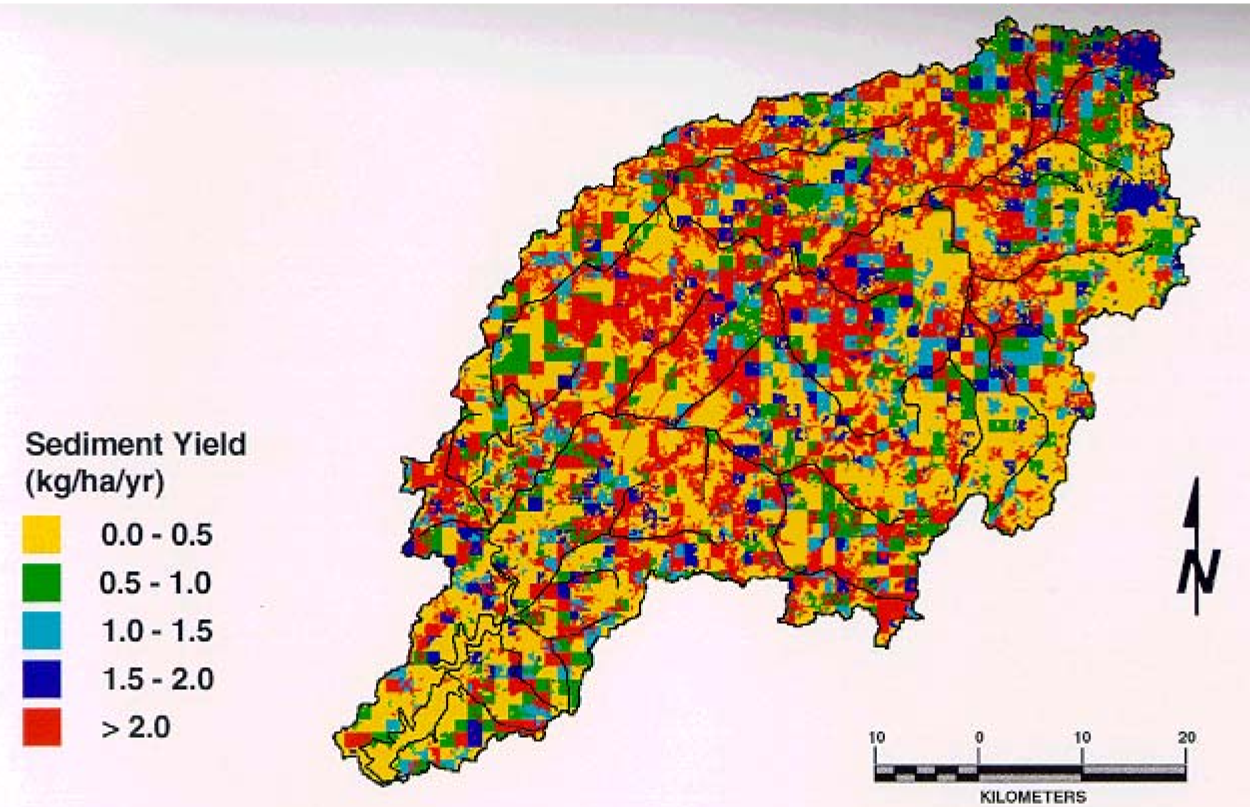


Figure 2.32. SIMPLE predicted average annual sediment load to the Upper Illinois River basin using the independent simulation mode.

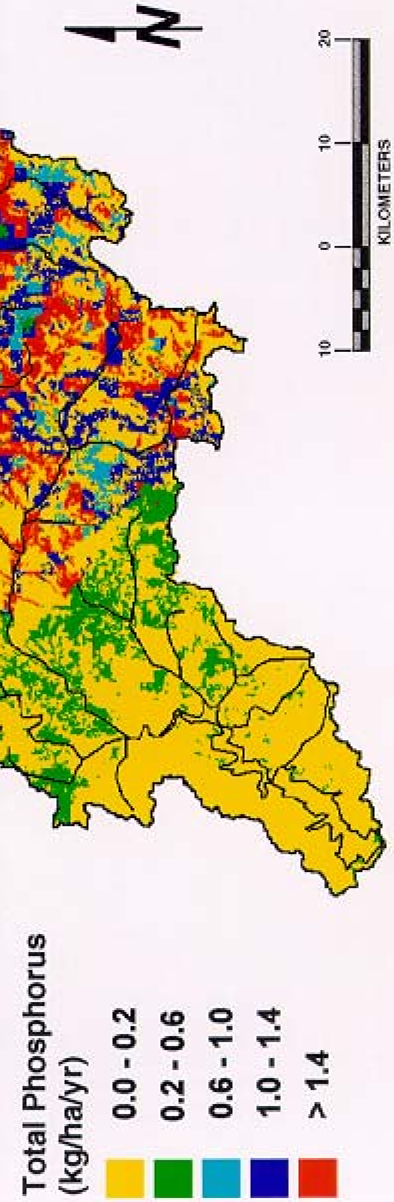


Figure 2.33. SIMPLE predicted average annual total phosphorus load to the Upper Illinois River basin using the independent simulation mode.

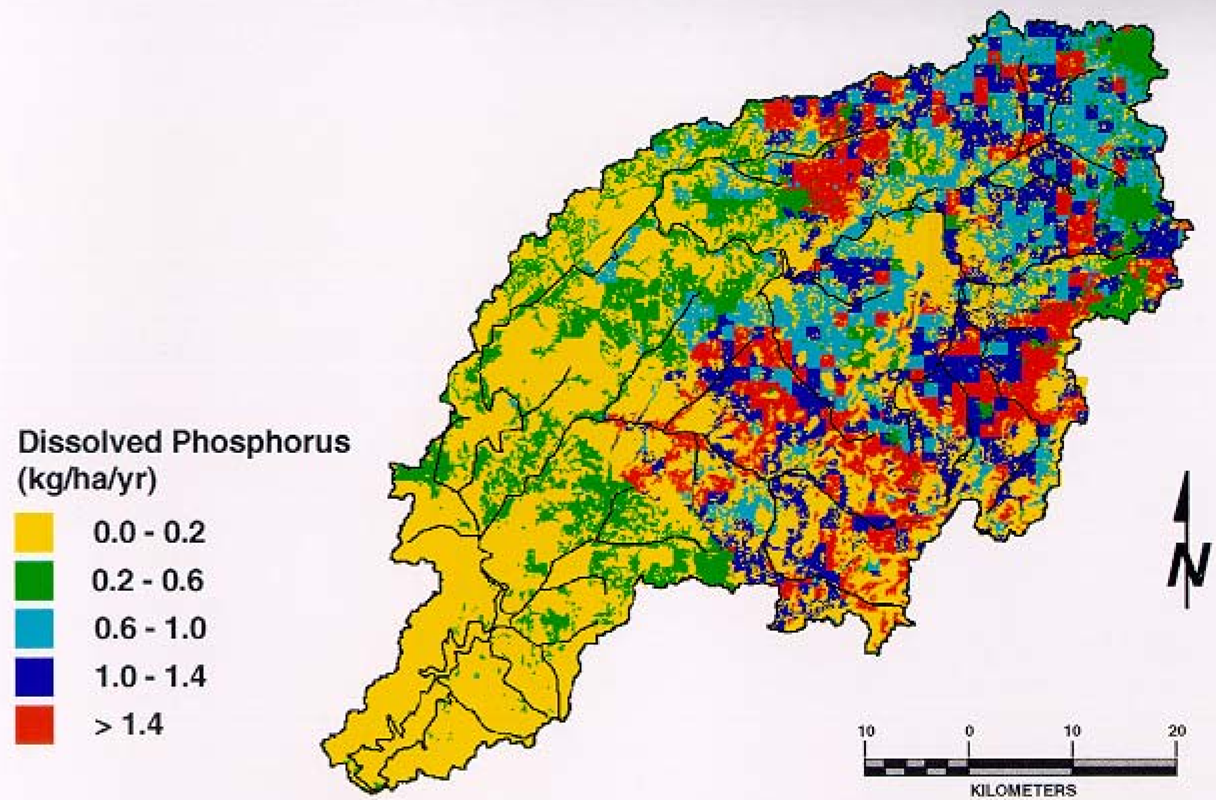


Figure 2.34. SIMPLE predicted average annual dissolved phosphorus load to the Upper Illinois River basin using the independent simulation mode.

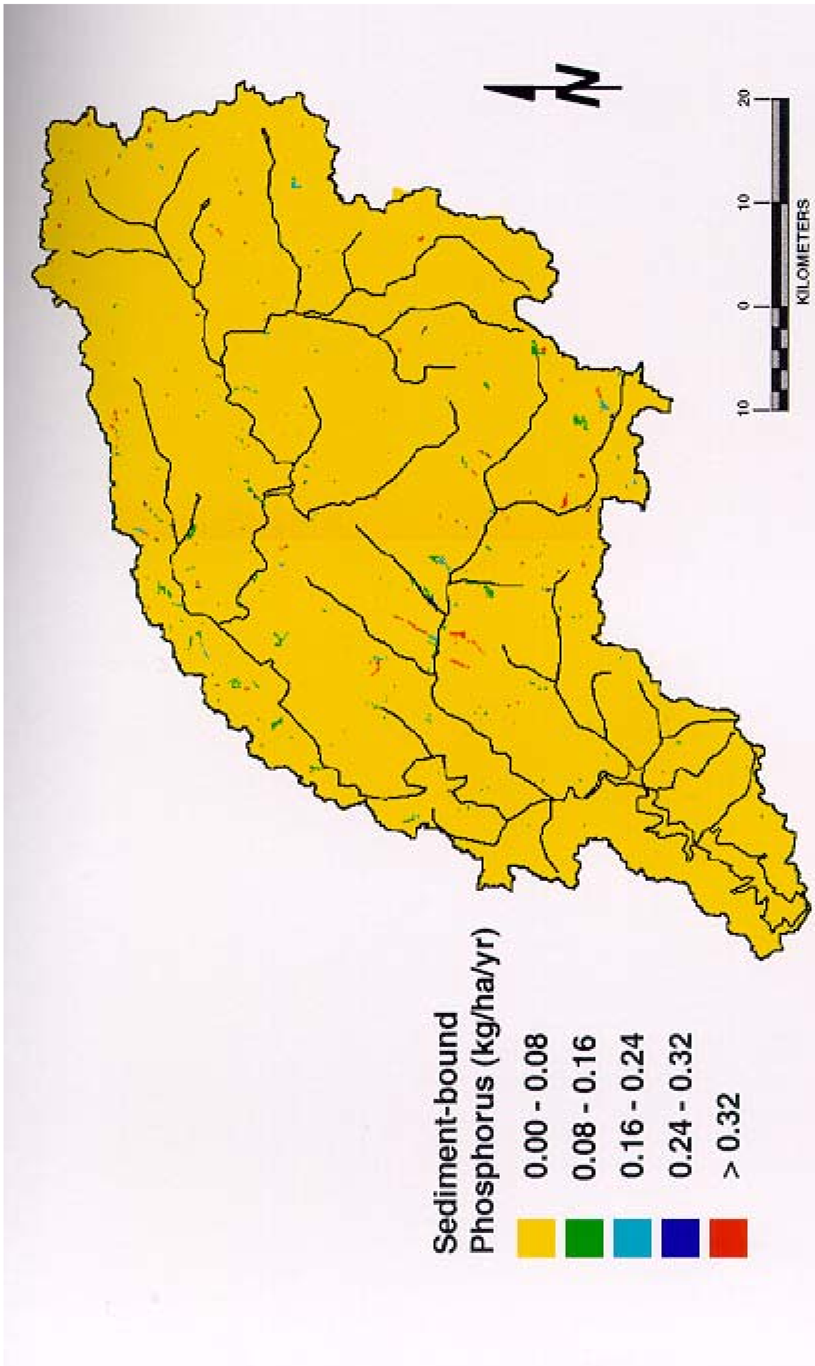


Figure 2.35. SIMPLE predicted average annual sediment-bound phosphorus load to the Upper Illinois River basin using the independent simulation mode.

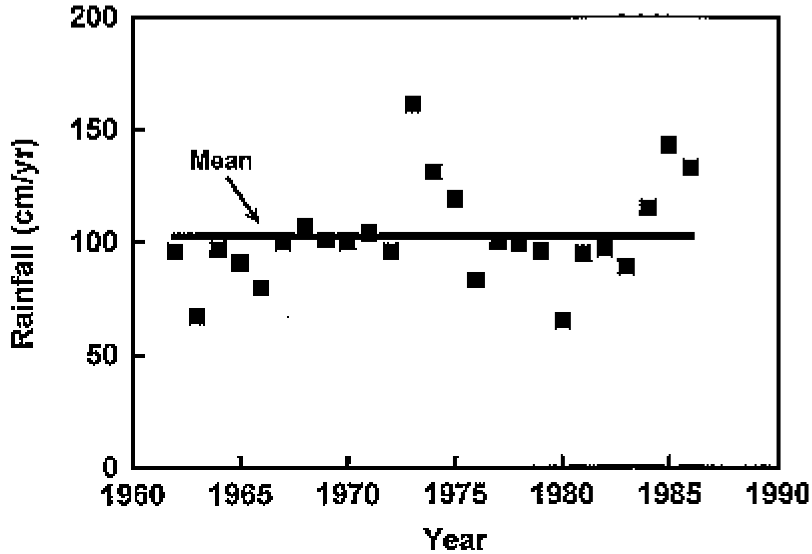


Figure 2.36. Time series of observed annual rainfall at Tahlequah, Oklahoma.

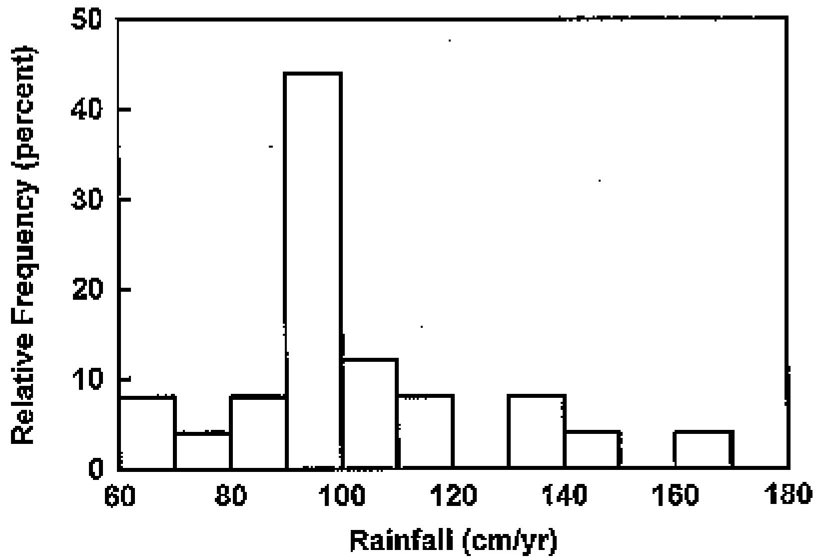


Figure 2.37. Histogram of annual observed rainfall at Tahlequah, Oklahoma.

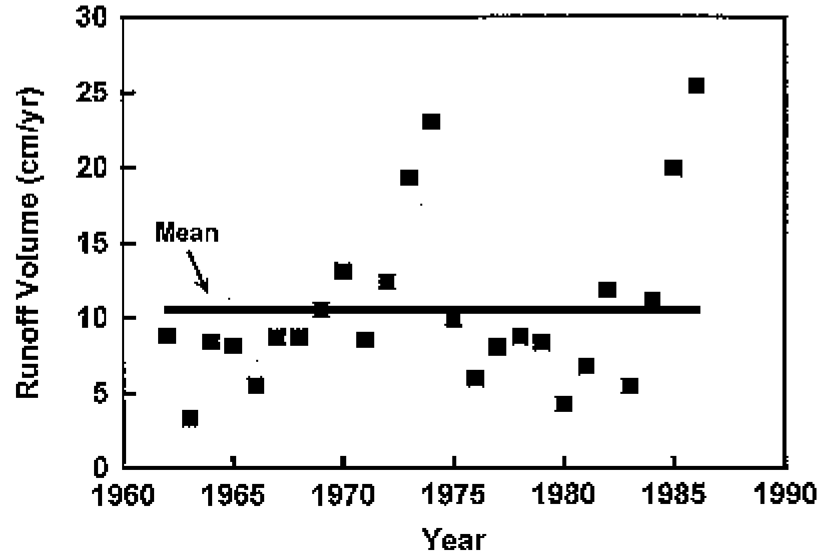


Figure 2.38. Time series of SIMPLE predicted annual runoff volume to the Upper Illinois River Basin.

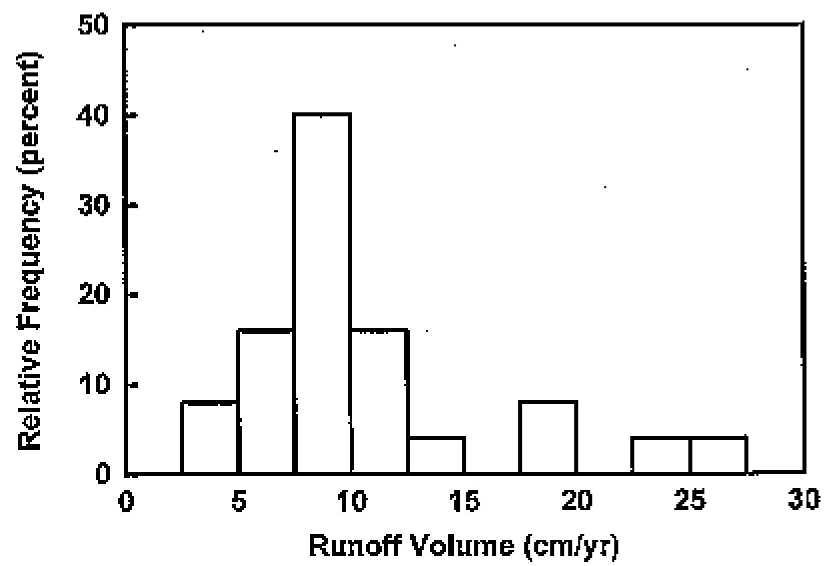


Figure 2.39. Histogram of SIMPLE predicted annual runoff volume to the Upper Illinois River Basin.

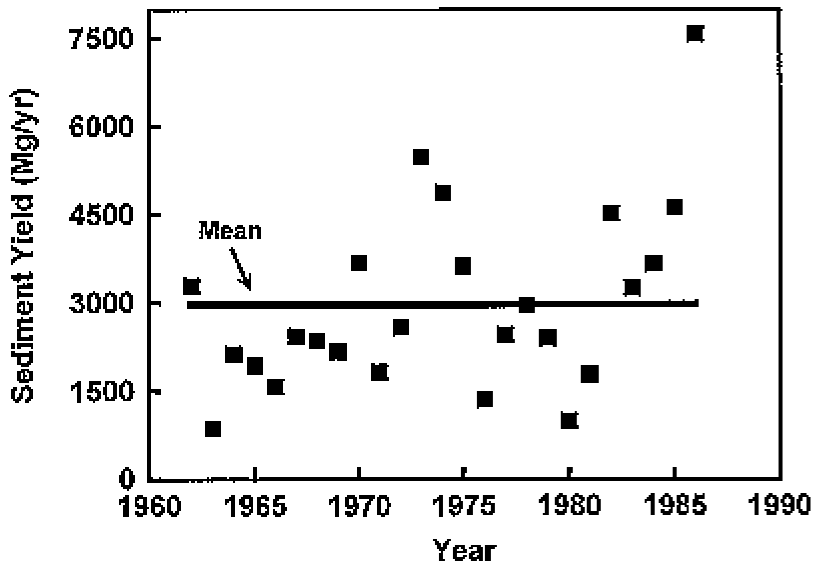


Figure 2.40. Time series of SIMPLE predicted annual sediment yield to the Upper Illinois River Basin.

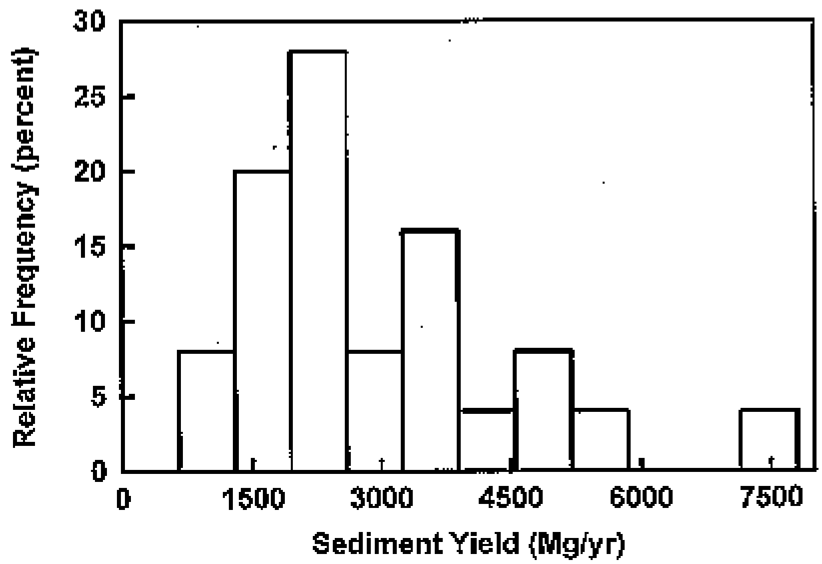


Figure 2.41. Histogram of SIMPLE predicted annual sediment yield to the Upper Illinois River Basin.

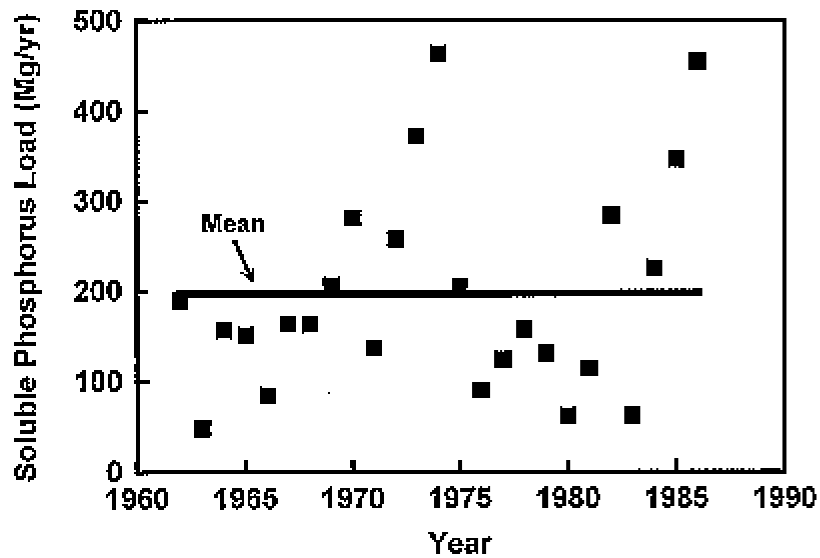


Figure 2.42. Time series of SIMPLE predicted annual soluble phosphorus load to the Upper Illinois River Basin.

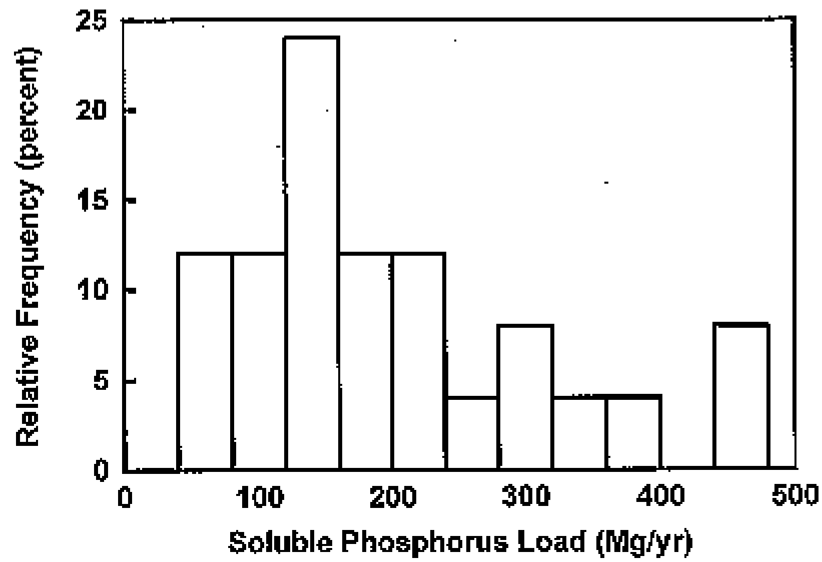


Figure 2.43. Histogram of SIMPLE predicted annual soluble phosphorus load to the Upper Illinois River Basin.

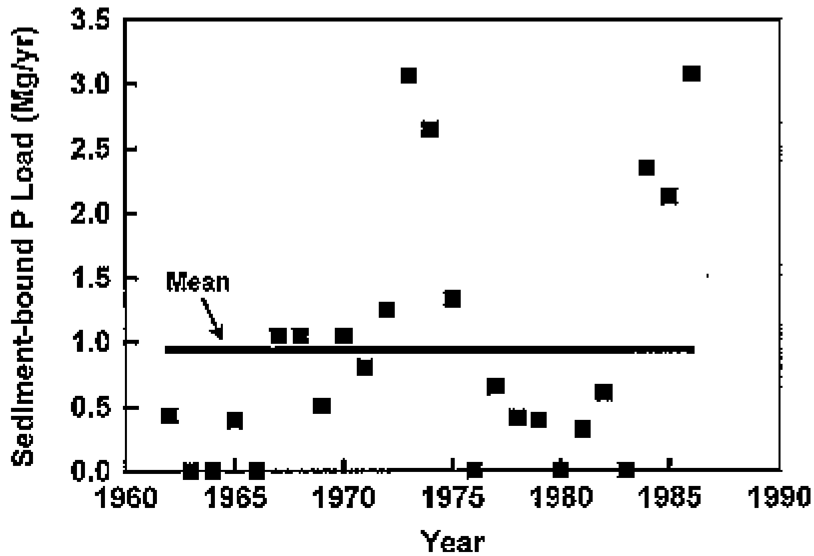


Figure 2.44. Time series of SIMPLE predicted annual sediment-bound phosphorus load to the Upper Illinois River Basin.

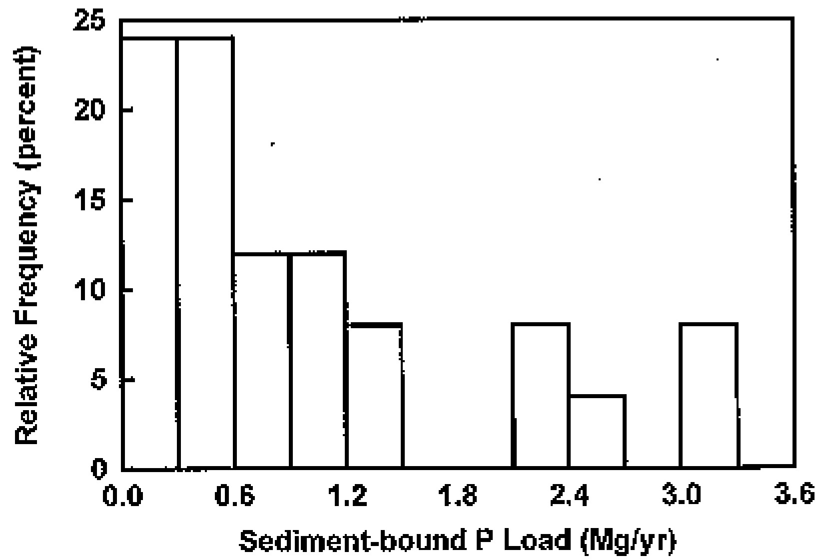


Figure 2.45. Histogram of SIMPLE predicted annual sediment-bound phosphorus load to the Upper Illinois River Basin.

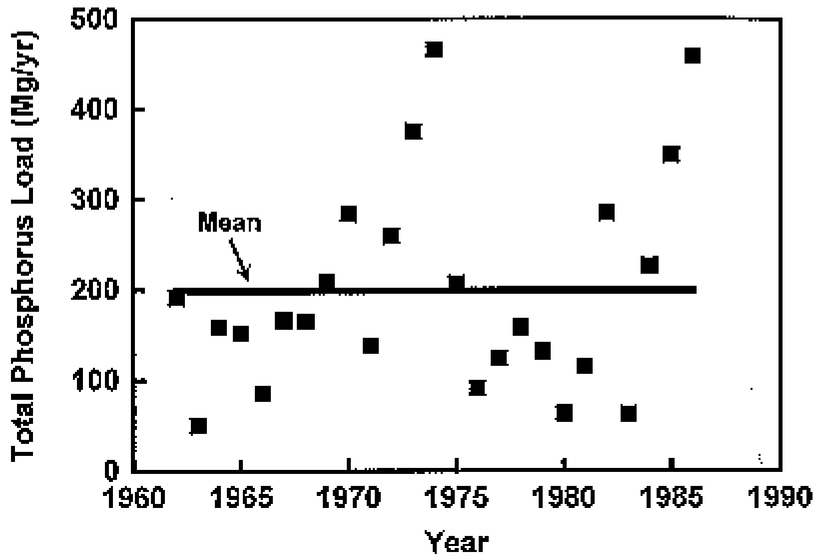


Figure 2.46. Time series of SIMPLE predicted annual total phosphorus load to the Upper Illinois River Basin.

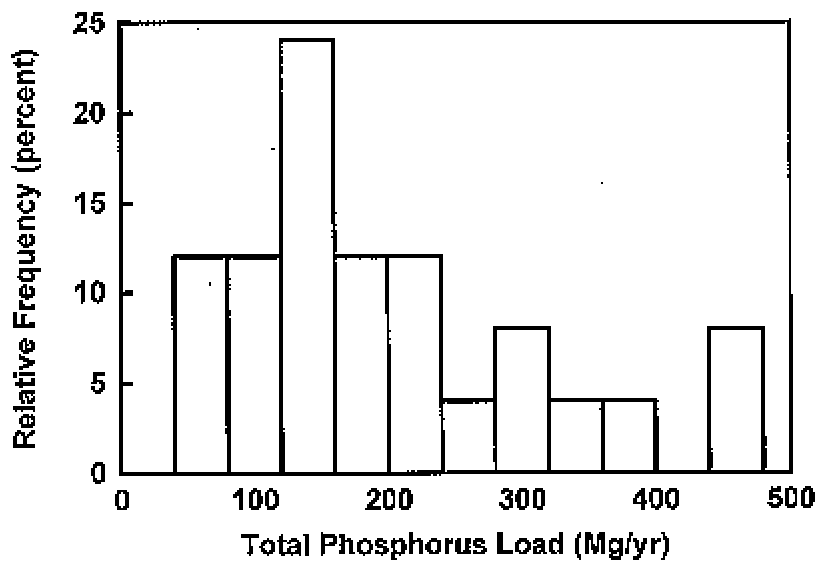


Figure 2.47. Histogram of SIMPLE predicted annual total phosphorus load to the Upper Illinois River Basin.

CHAPTER 3. POINT SOURCE LOADING

Point source nutrient loading estimates of Lake Tenkiller are presented below. The loading estimates are extracted directly from the Cleans Lakes Project Phase I Diagnostic and Feasibility Study on Tenkiller Lake, Oklahoma. There were ten permitted point sources discharge upstream of Lake Tenkiller at Horseshoe Bend (Prairie Grove, Rogers, Fayetteville, Springdale, Lincoln, Gentry, Siloam Springs, Watts, Westville, and Midwestern Nursery), which is considered to be the beginning of the lake and represents approximately 75 percent of the Illinois River basin. There are two remaining permitted point sources that discharge downstream of Horseshoe Bend: Tahlequah, and Cherokee Nation. The estimated point source loadings to the stream are given in Table 3.l. The combined total loading to the lake is estimated to be 93,000 kg P per year.

Table 3.1. Estimates of Point Source Discharge Quantities of Total Phosphorus to the Horseshoe Bend Area of Lake Tenkiller (1991 to 1993 data).

Discharger	Estimated Load at Source (kg P/yr)
Prairie Grove	1,200
Rogers	21,600
Fayetteville	4,500
Springdale	43,150
Lincoln	1,200
Gentry	1,700
Siloam Springs	10,000
Wafts	500
Westville	2,900
Midwestern Nursery	600
Tahlequah	4,700
Cherokee Nation	530
Total	92,580

CHAPTER 4. DISCUSSION AND CONCLUSIONS

4.1 INDEPENDENT AND CONTINUOUS NONPOINT SIMULATION MODES

Figure 4.1 shows the difference between independent simulation and continuous simulation of years in a twenty-five year historical sequence. Results are expressed as a cumulative distribution of total phosphorus loading. Both curves are continually increasing because the previous year's loadings are added to those of the year before. The difference between the two curves after 25 years of simulation, however, is significant.

The independent simulation mode (lower curve in Figure 4.1) represents the best estimator of phosphorus loading to the Illinois River based on existing conditions. Each simulation in this mode is equivalent except for weather conditions, so they reflect the weather variability of the system. Since the continuous simulation mode (upper curve in Figure 4.1) does not re-initialize parameters at the beginning of each year, accumulation of phosphorus in soils can occur. The phosphorus accumulation allows increased diffusion when there is sufficient runoff. The continuous mode, therefore, simulates the effect of continuing current management, continuing the same level of poultry production, and continuing litter application to the same fields throughout the twenty-five year period. Because the phosphorus diffusion process is not linear, the sequence of wet years and dry years can influence the loading rate. Caution must be taken when interpreting the continuous simulation results because poultry litter may not be continually spread at the same locations, and the sequence of wet and dry years may not be typical. It should be noted that the predicted runoff volumes and sediment yields are identical for both modes.

As shown in Table 4.1, the continuous simulation mode estimates a 420 percent area-weighted average increase in total phosphorus loading over the 25 year simulation period, which corresponds to an area-weighted total phosphorus loading of 0.49 and 2.59 kg/ha/yr for the independent and continuous simulation modes, respectively. Over the 25 year simulation period, the continuous simulation mode predicts a total phosphorus load 4.7 times higher than the independent simulation mode (Figure 4.1). This increase in phosphorus loading results from the continued import of nutrients into the basin in the form of feed. Since only a portion of the nutrients leave the basin in the form of finished products, such as meat, eggs and milk, there is a net accumulation of nutrients into the basin. These concepts are more thoroughly discussed by Smolen et al. (1994, 1995).

Long-term reductions of phosphorus loading can only be accomplished by exporting animal manure from the basin. Short-term solutions, however, could focus on the proper or uniform distribution of poultry litter. If permanent pasture, the predominant agricultural land use in the basin, is fertilized exclusively with poultry litter based on crop needs for nitrogen, excess phosphorus is applied. Therefore, the model predicts if this practice continues over an extended period of time soil phosphorus levels will build to excessive levels and increased phosphorus loading to surface waters will result. To prevent excessive build up of soil phosphorus, litter should be diverted to fields deficient in soil phosphorus, and those fields with excessive soil phosphorus levels should discontinue use of poultry litter and receive nitrogen from commercial fertilizers.

4.2 POINT AND NONPOINT LOADING

Table 4.2 gives a summary of the nonpoint source mass loading from the independent simulation mode. Presented in Table 4.2 are the mean, and 25, 50 and 75 percent quartiles for total, dissolved and sediment-bound phosphorus, sediment yield, rainfall (Tahlequah, Oklahoma), and runoff volume. These quartile distributions represent the expected stochasticity of loading caused by variation in rainfall only. It does not account for parameter uncertainty. It should be noted that virtually all the predicted phosphorus loads are in the dissolved form, because upland erosion rates are low the model does not account for stream bank contributions, and in-stream biological and chemical processing of the phosphorus. The loading estimates in Table 4.2 are nonpoint source loading to the stream, and are not the loading to Lake Tenkiller since in-stream assimilation processes are neglected.

Table 4.3 presents a summary of the total loading to the Upper Illinois River basin from anthropogenic and background nonpoint sources, and point sources. Background nonpoint source loadings were estimated from SIMPLE assuming the basin was 100 percent forested. It should be noted that these background loadings are low, because they do not account for stream bank contributions and neglect contributions from the forest system other than phosphorus diffusion from soils. Anthropogenic nonpoint sources are the SIMPLE model predictions minus background loading. As shown in Table 4.3, anthropogenic and background nonpoint sources, and point sources account for 66, 2 and 32 percent of the total phosphorus loading, respectively, to the Upper Illinois River basin. Figure 4.2 shows the total phosphorus loading by pastures using the independent simulation mode.

Total phosphorus loadings are given in Table 4.1 and Figure 4.3 by sub-basin for the independent and continuous simulation modes. Based on the independent simulation mode, 76 percent of the total phosphorus load comes from six subwatersheds, Flint, Benton, Baron, Osage, Clear and Fork, although these watersheds only contain 56 percent of the basin area. The next highest unit-area total phosphorus loading is the Tyner watershed. According to these simulations, the pasture/range land use accounts for 95 percent of the total nonpoint source phosphorus loading to the basin.

4.3 NONPOINT SOURCE LOADING ASSUMPTIONS AND DATA LIMITATIONS

There are a number of assumptions that must be considered when interpreting our sediment and phosphorus loading predictions from nonpoint sources. Probably the most important and sensitive parameter in the model is the initial soil phosphorus level. Due to the lack of available data, there are several limitations to our current estimates. The soil phosphorus estimates are based on county or watershed level data, some of which were obtained outside the watersheds. Consistent site-specific data across the basin would improve the reliability of our loading estimates. In addition, it was assumed that the available soil test data accurately represented the soil phosphorus status for pastures. This assumption has not been validated, and requires additional soil testing to specifically evaluate this assumption. Our choice of minimum and maximum soil phosphorus levels and arbitrary soil phosphorus levels for all land uses except pasture and range could also be a source of error, although these were selected through professional judgment of County Extension Agents and soil scientists. Probably the most important untested assumption was that soil phosphorus levels decreased linearly with distance from poultry houses.

Another limitations of our study was the lack of current land use data. We used 1985 land use and poultry house inventories, with soil test data were from 1991 to 1995. The poultry house inventory determined the amount of litter applied to pastures in the model every April. Due to the poultry expansion since 1985 in Oklahoma, we would expect a higher density of poultry in Oklahoma increasing long-term phosphorus loadings. This would likely increase the contribution from the Oklahoma portion of the watershed. Other limitations include neglecting commercial fertilizer use, dairy, layer, pullets and turkey manure application, and human recreation inputs, all of which may be substantial.

Our current model predictions estimate sediment and phosphorus loading to the stream. We have arbitrarily defined streams to be the blue line stream from the USGS 1:24,000 Digital Line Graphs. The selection of the stream density affects the delivery ratio of sediment and sediment-bound phosphorus. It should also be noted that the delivery ratio function is an unvalidated equation, thus adding to the uncertainty of our predictions.

Another very important assumption was to neglect in-stream assimilation of nutrients and stream bank erosion, which may significantly affect our loading predictions to Lake Tenkiller. In addition, our loading estimates do not account for parameter uncertainty. They only account for weather variability, and thus caution should be taken when utilizing our loading predictions. The expected overall accuracy of the absolute sediment and phosphorus loading is relatively low due to parameter uncertainty. However, we have relatively high accuracy with the relative differences of the loadings throughout the basin.

Table 4.1 Average annual total phosphorus loading by sub-basin for independent and continuous simulation modes with percent difference calculations.

Watershed	Independent Simulation Mode		Continuous Simulation Mode		Difference Independent vs Continuous (%)
	Total Phosphorus (kg/yr)	Total Phosphorus (kg/ha/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/ha/yr)	

Fork	33958	0.82	180940	4.36	433
Clear	16772	0.80	86665	4.15	417
Flint	24333	0.76	125317	3.90	415
Osage	42861	0.75	249720	4.35	483
Baron	27890	0.71	167922	4.28	502
Benton	24172	0.64	111207	2.96	360
Tyner	3227	0.30	9342	0.86	190
West	7580	0.25	32739	1.08	332
Caney	3877	0.12	15080	0.48	289
River	2681	0.21	9407	0.75	251
Bord	4410	0.13	17805	0.54	304
Bbaron	1374	0.11	15080	1.16	997
Bilin	1104	0.11	2685	0.26	143
Lakeup	522	0.10	1711	0.32	228
Lake	1123	0.03	1395	0.04	24
Total	199,000		1,030,000		
Area Weighted Average		0.49		2.59	420

Table 4.2. SIMPLE predicted quartile and mean estimates of total, dissolved and sediment-bound phosphorus, sediment yield, rainfall and runoff for independent simulation mode. Note: these estimates only account for rainfall stochasticity and do not account for parameter uncertainty.

Parameter	Mean	Quartile (percent)		
		25	50	75
Total Phosphorus (kg/yr)	199,000	115,000	164,000	284,000

Dissolved Phosphorus (kg/yr)	198,000	114,000	163,000	282,000
Sediment-bound Phosphorus (kg/yr)	1,000	300	600	1,300
Sediment Yield (Mg/yr)	3,000	1,800	2,500	3,700
Rainfall (cm)	103	91	99	115
Runoff (cm)	10.5	6.7	8.7	12.4

Table 4.3. Average annual total phosphorus summary of anthropogenic and background nonpoint source loading using the independent simulation mode, and point source loading to the Upper Illinois River basin.

Source	Total Phosphorus (%)	Total Phosphorus (kg/yr)	Dissolved Phosphorus (kg/yr)	Sediment-bound Phosphorus (kg/yr)	Sediment Yield (Mg/yr)
Anthropogenic Nonpoint	66	191,000	190,000	1,000	2,600
Background	2	7,500	7,300	200	400
Point	32	93,000	-	-	-
Total	100	292,000	191,000	1,200	3,000

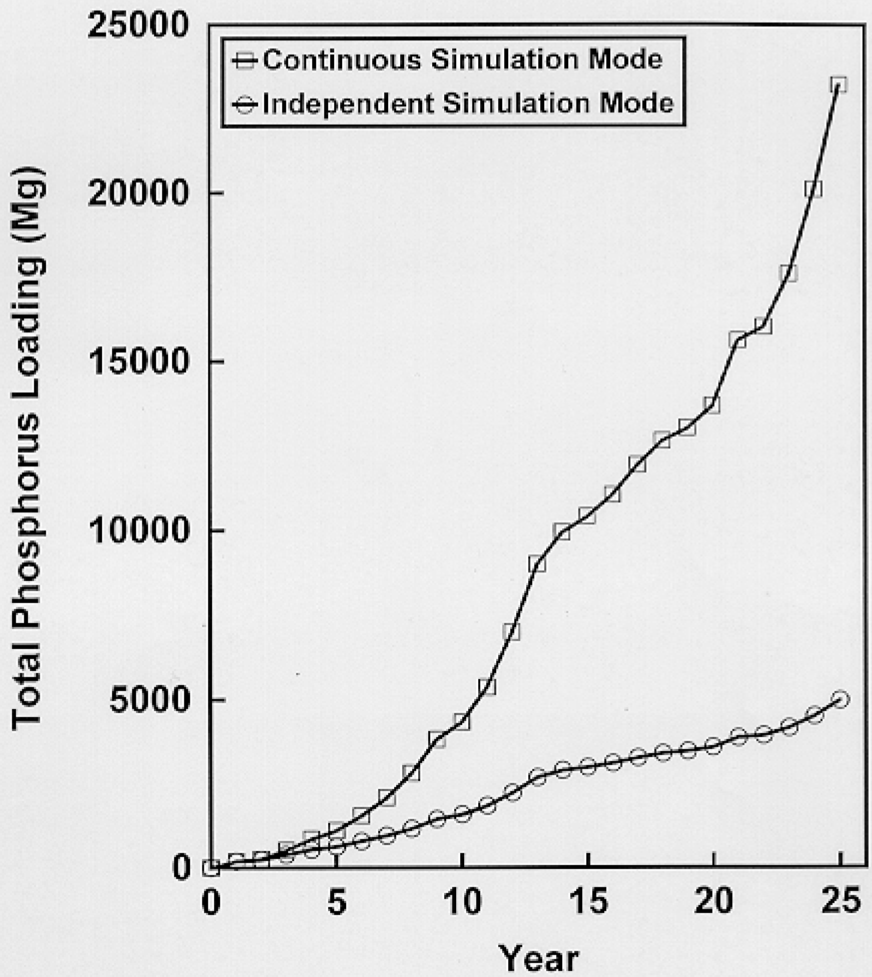


Figure 4.1. Cumulative total phosphorus loading for continuous and independent simulation modes to the Upper Illinois River basin.

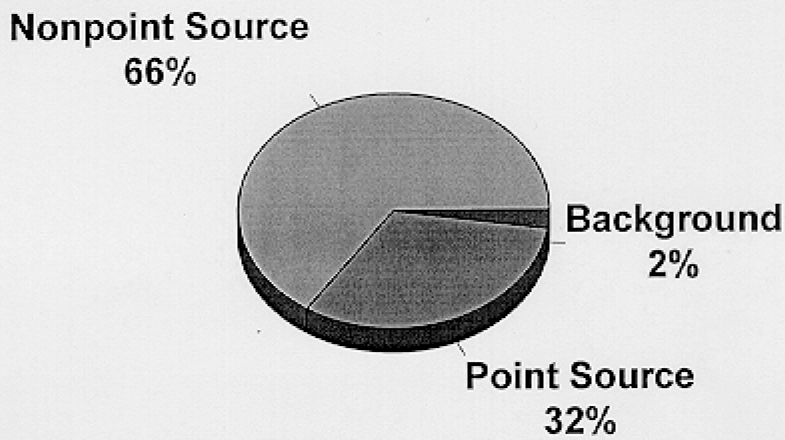


Figure 4.2. Total phosphorus summary of anthropogenic nonpoint source, background nonpoint source and point source loading to the Upper Illinois River basin.

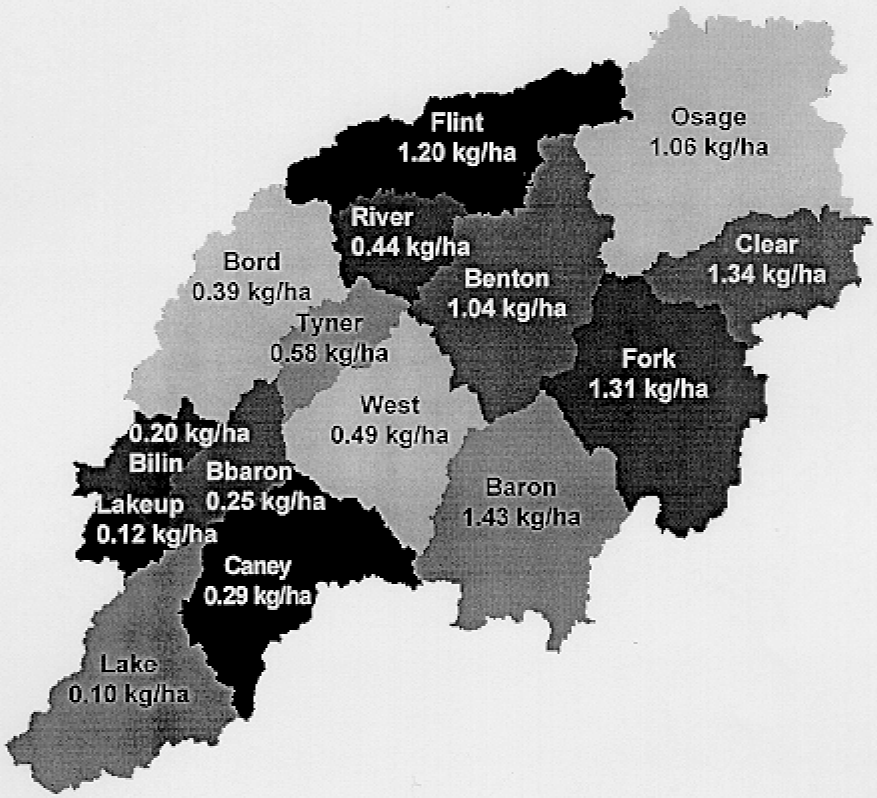


Figure 4.3. Sub-basin Average annual total phosphorus loading for pasture using the independant simulation mode for the Upper Illinois River Basin.

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APPENDIX A

PROCEDURE TO GENERATE FIELD BOUNDARY MAPS

A field boundary map was generated for each watershed independently. The steps and commands used to generate these maps are described in this section. Also, the source codes of the Fortran utility programs used here are included at the end of this section.

<u>a. Dividing the watershed into 225 ha grids:</u>
This step creates an ASCII map that divides the watershed into 1500xl500 cells and then imports the map into GRASS. The ASCII map is created with the program “gensect.x” (the source code is “gensect.f”). This program reads the ASCII file “landuse.asc” and creates another ASCII file called “section.grd”. This file is then imported into GRASS under the name “section.grd”:

Commands: gensect.x
r.in.ascii input=section.grd output=section.grd

<u>b. Generate a polygon map from the land use map:</u>
The r.clump command was applied to the land use map. A new map was created where each area of contiguous cells with the same land use values was given a unique category value. The new map was called: “tmp.clump”:

Commands: r.clump input=irt_$l.land use output=tmp.clump

note: $1 = name of the watershed
irb_$l.land use = the name of the land use map for watershed $1

<u>c. Limit the size of the polygons to 225 ha:</u>
The maps “tmp.clump” and “section.grd” were intersected to create a new map with maximum polygon areas of 225 ha. This new layer was called “tmp.1”:

Commands: r.mapcalc
tmp.1 = if(tmp.clump, tmp.clump + section.grd * 10000)

note: The value 10000 was used for enumeration purposes, since the number of polygons may exceed 1000.

<u>d. Create the field boundary map:</u>
This part was done in two steps: (1) create an ASCII representation of the file “tmp.1”, and (2) re-enumerate the polygons by giving them a value from 1 to N, with N being the total number of polygons. The second step is accomplished by running the program “genfield.x”. This program also allocates the same unit value to polygons that the user wants to treat as I field (for example, water or urban). In this study, we combined all polygons under urban were given 1 field number. The same was done for polygons under water, poultry house, hog houses and transportation.

Commands: r.out.ascii map=tmp.1 > polygons.asc
genfield.x

note:
genfield.x creates an ASCII representation of the field map called “field.asc”. This program also creates a file called “fl_lu.rep”. This file includes a list of the field numbers and their corresponding land use numbers. “genfield.x” requires two input files: “genfield.fil” and “polygons.asc”.

A.1 FORTRAN PROGRAM "GENSECT.F"

```
c
c       Divides a region into sections with dimensions defined by the user.
c       Reads the boundaries (north, south, ..) defined in the file landuse.asc
c       and creates the file section.grd, which can be imported into GRASS and
c       in generating the polygons needed to create the field.asc file from the
c       land use data.
```

```
c
c
                        integer luf(5000)
                        integer*4 North,south,east,west
                        open(l5,file='landuse.asc',status='old')
                        open(l6,file='section.grd',status='unknown')
c
c..    initialize luf
                        totnb=5000
                        do 5 i=l,totnb
                        luf(i)=0
5                       continue
c
c..    read headers from the ASCII files and create headers for field.asc
                        read(15,7) north
                        read(l5,7) south
                        read(l5,8) east
                        read(15,8) west
7                       format(t7,i8)
8                       format(t6,i7)
c
c..    read the size of the section grid (dx,dy)
                        write(*,*) 'define the height of the section grid (dy)'
                        read(*,*) dy
                        write(*,*) 'define the width of the section grid (dx)'
                        read(*,*) dx
c
c..    determine the number of sections in each row and the number of rows,
c      and adjust the SOUTH and EAST boundary values.
                        nsect = (north-south)/dy
                        dsect = (north-south)/dy
                        diff = nsect - dsect
                        if (diff.ge.0) nrow=nsect
                        if (diff.it.0) nrow=nsect+l
                        south = north - nrow*dy
                        nsect = (east-west)/dx
                        dsect = (east-west)ldx
                        diff = nsect - dsect
                        if (diff.ge.0) ncol=nsect
                        if (diffft.0) ncol=nsect+l
                        east = west + ncol*dx
c
c      Write the headers for the file section.grd
                        write(16,15) north
                        write(16,16) south
                        write(l 6,1 7) east
                        write(16,18) west
                        write(16,19) nrow
                        write(16,20) ncol
15                      format('north:',i8)
16                      format('south:',i8)
17                      format('east:',i7)
18                      format(lwest:',i7)
19                      format('rows:',i4)
20                      format('cols:',i4)
c
c ..   Write the number of each section
```



```
                        ni=O
                        do 100 i=l,nrow
                        id=ni*ncol
                        write(16,30) (id+k, k=l,ncol)
30                      FORMAT(1500l5)
100                     CONTINUE
                        stop
                        end
```

A.2 FORTRAN PROGRAM "GENFIELD.F"

```
cc
c      program to create the ASCII file field.asc from two ASCII files
c      landuse.asc and polygons.asc (where polygons.asc is a cross of
c      the clumped file and the section file.
c
                 integer luf(5000),nids(5000),idf(5000),ids(5000),luc(5000)
                 integer idl(5000), maxluid
                 character*40 head, lutype(20)
                 character lin1*8,lin2*113,lin3*104,lin4*62,lin5*62,lin6*64
c
                 open(11,file='genfield.fil',status='old')
                 open(15,file='landuse.asc',status='old')
                 open(16,file='polygons.asc',status='old')
                 open(17,file='field.asc',status='unknown')
                 open(18,file='fl_lu.rep',status='unknown')
                 open(19,file='fieldname.str',status='unknown')
                 open(20,file='dat.dat.fid.asc',status='unknown')
c
c..     initialize luf and nids
c ----           luf(m) = land use number corresponding to field m
c ----           nids(n) = the polygon id # identified by n
                 totnb=5000
                 do 5 i=l,totnb
                 luf(i)=0
                 nids(i)=0
5                continue
c
c      read headers from the ASCII files and create headers for field.asc
                do 10 i=1,4
                read(15,7) head
                read(16,*)
                write(l7,7) head
7               format(a15)
10              continue
                read(15,13) head,nrow
                read(16,*)
                write(17,13) head,nrow
                read(15,13) head,ncol
                read(16,*)
                write(17,13) head,ncol
13              format(a5,i6)
c
c..       read the land uses that need to be grouped and give them field numbers
c ---- nluc = # of land uses to be grouped
c ---- luc(m) = the land use number referenced in m
                 read(11,*) nluc
                 read(11,*) (luc(k),k=l,nluc)
                 do 20 i=l,nluc
                 luf(i)=luc(i)
20         continue
c
c.. read the name of the land use type and the associated land use #
c ---- maxluid = the highest land use # value
c ---- luidn = the land use id number
c ---- lutype (luidn) = the land use type associated with the land use number luidn
```



```
                 maxluid=0
                 do 30 i=1,20
                 read(11,27,end=33) luidn,lutype(luidn)
27               format(14,a40)
                 if(luidn.gt.maxluid) maxluid=luidn
30               continue
33               continue
c
c
c..     process the information 1 row at a time
```

```
                    nsec =l
                    write(*,*) '.. .. .. .. .. .. .. processing'
                    do 500 j=l,nrow
c ---- idl(k) = the land use id # in column k
c ---- idf(k) = the field # in column k
c ---- ids(k) = the polygon # in column k
                    do 110 k=l,ncol
                    idl(k)=0
                    idf(k)=0
                    ids(k)=0
110                 continue
                    read(15,*) (idl(k),k=l,ncol)
                    read(16,*) (ids(k),k=l,ncol)
c……..process each column at a time
                    do 300 k=l,ncol
                    if(idl(k).eq.0) go to 300
c……..check if the column is a land use to be grouped
                      do 210 m=l,niuc
                      if(idl(k).eq.luc(m)) then
                      idf(k)=m
                      go to 300
                      endif
210                   continue
c……..check if the polygon number has been processed before
                      do 220 m=l,nsec
                      if(ids(k).eq.nids(m)) then
                      idf(k)=m+nluc
                      go to 300
                      endif
220                   continue
c……..process the new polygon number
                    if(nids(nsec).gt.0) nsec--nsec+l
                    nids(nsec) = ids(k)
                    idf(k)=nsec+nluc
                    luf(nsec+nluc)=idl(k)
300                 continue
c……..write the fields in field.asc
                    write(17,310) (idf(k),k=l,ncol)
310                 format(5000i5)
500                 continue
c
c..                 generate the fieldname.str file
                    write(*,*) '… …generate the fieldname.str file'
                    write(19,*)'begin|'
                    write(19,*)'0:no data'
                    do 510 i=l,nluc+nsec
                    write(19,505) i,lutype(luf(i))
505                 format(i4,':',a40)
510                 continue
                    write(19,*)'end|'
c
c..                 write the land use id # corresponding to each field
                    write(*,*) generate the file fl_lu.rep'

                    write(18,*)'land use# field#'
                    do 520 m=l,maxluid
```



```
                    do 520 i=l,nluc+nsec
                    if(luf(i).eq.m) write(18,515) m,i, lutype(m)
515                 format(i5,6x,i5,3x,a20)
520                 continue
c
c..                 generate the dat.dat.fld.asc --
                    write(*,*) ' .. .. generate the file dat.dat.fld.asc'
                    linl ='RECORD #'
                    lin2=' 0.00 0.00 0 0 0 0 0 0 0 0 0 0 0 0 0 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
                    0.00 0.00'
                    lin3=' 1.00 0.00 0.00 0.00 0.00 0 0.00 0.00 0.00 0 0.00 0.00 0.00 0 0.00'
```

```
      lin4='.............................. 0 0 0 0 0.00 0.00'
      lin5=' 1.00 0 0 1.00 0.00 0.0161 0.6000 16.1000 0.0570'
      lin6=' 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00'
      write(20,531) linl
      write(20,532) lin2
      write(20,533) lin3
      write(20,534) lin4
      write(20,535) lin5
      write(20,536) lin6
531   format(a8,'0')
532   format(al13)
533   format(al04)
534   format(a62)
535   format(a62)
536   format(a64)
      do 550 i=l,nluc+nsec
      if(i.lt.10) write(20,541) lin1,i
      if(i.ge.10.and.i.lt.100) write(20,542) lin1,i
      if(i.ge.100.and.i.lt.1000) write(20,543) lin1,i
      if(i.ge.1000) write(20,544) lin1,i
c     write(20,nfot) lin1,i
      write(20,532) lin2
      write(20,533) lin3
      write(20,534) lin4
      write(20,535) lin5
      write(20,536) lin6
541   format(a8,il)
542   format(a8,i2)
543   format(a8,i3)
544   format(a8,i4)
550   continue
      write(20,*)
c
      stop
      end
```

A.3 EXAMPLE for the file "GENFIELD.FIL"

```
6
1  2 8 9 10 11
  1 Urban
  2 Transportation, Communication, Utilities
  3 Crop
  4 Pasture/Range
  5 Orchards, Groves, and Vineyards
  6 Nurseries
  7 Forest
  8 Poultry Operations
  9 Dairy
  10 Hog Operations
  1l Water
```


APPENDIX B
SUMMARIZATION OF INPUT DATA AT FIELD SCALE

To run SIMPLE at field scale, the input data needed to be compiled and summarized for each field. Four programs were developed to accomplish this task. These programs create files that can be imported directly into SIMPLE. These programs are described in this section. Also, a listing of their source codes and examples on the required input data files are provided in this section.

a. genveget.x:
This program creates the files describing the vegetation data sets. It requires two input data files: “genveget.fil” and 'fl_lu.rep". The program generates two output files:

1. "grow_per.inp" = the dates of the growing period for each land use
2. "uslecfac.inp" = the USLE C factors associated with each land use type.

b. genpappl.x:
Creates the file that includes the data on P management. It requires two input files: “genpappl.fil” and "fl_lu.rep". This program creates the file "p_applic.inp"

c. gentopof.x:
It reads the ascii maps describing the topographic characteristics (dist.asc, slp.asc, and sipstrm.asc) developed by DTM, and creates the file "topofile. inp"

d. gensoilf.x:
It reads the soil characteristics related ASCII files (cn.asc, ph.asc, clay.asc, orgc.asc, initp.asc, den.asc, and k.asc) generated with the SIMPLE DATA BASE MANAGER, and generates the file "soilfile.inp".

B.1 FORTRAN PROGRAM "GENVEGET.F"

```
cc - 7/13/95 - George J. Sabbagh
c
c     Program to generate the vegetation related data sets.
c
c     It reads the USLE C factors and growing period associated with
c     each land use (from file genveget.fil) and generates two files
c     (grow_per.inp & uslecfac.inp) that can be imported into SIMPLE.
c
c     The program requires the file fl_lu.rep (land use and the associated
c     field number); this file can be generated by the program genfield.x
c
      dimension ism(20),isd(20),iem(20),ied(20),pf(20)
      dimension iyr(20,60),id(20,60),c(20,60), luidf(3000)
c
      open(15,file='genveget.fil',status='old')
      open(16,file='fl_lu.rep',status='old')
      open(l7,file='grow_per.inp',status='unknown')
      open(l8,file='uslecfac.inp',status='unknown')
c
c     ism(i) = starting month of the growing period for landuse I
c     isd(i) = starting day of the growing period for landuse i
c     ied(i) = ending month of the growing period for landuse i
c     ied(i) = ending day of the growing period for landuse i
c     pf(i)         USLE practice factor for landuse I
c
c     iyr(i,j) = the year associated with landuse i
c     id(i,j) = the day associated with landuse i
c     c(i,j) = the USLE C factor for year iyr and day id for land use i.
```



```
c                there can be 60 different
c
      do 20 i=1,20
      ism(i)=0
      isd(i)=0
      iem(i)=0
      ied(i)=0
      pf(i)=0
      do 20 j= 1,60
      iyr(i,j)=0
      id(i,j)=0
      c(i,j)=0
20    continue
```

```
c
c                       nlu = the number of landuse types
                        read(15,*) nlu
c..   read the data associated with the growing period
                        do 30 i=l,nlu
                        read(15,*) lu,ism(lu),isd(lu),iem(lu),ied(lu),pf(lu)
30                      continue
c..     read the data associated with the C factor
                        do 70 i=l,nlu
                        nnl=l
35                      read(15,*,end=71) lu,iyrt,idt,ct
                        if(lu.eq.i) then
                        iyr(i,nnl) = iyrt
                        id(i,nnl) = idt
                        c(i,nni) = ct
                        nnl     =   nnl+l
                        go to 35
                        endif
                        backspace (15)
70                      continue
71                      continue
c
                        read(16,*)
c                       idf = field number
c                       luidf(idf) = landuse number associated with idf
                        do 73 i=1,3000
                        luidf(i)=0
73                      continue
                        nfl = 0
                        do 75 i=l, 3000
                        read(16,*,end=76) lu,idf
                        luidf(idf) = lu
                        if(idf.gt.nfl) nfl=idf
75                      continue
76                      continue
                        do 100 i=l,nfl
                        lu = luidf(i)
                        if(lu.gt.0) write(17,81) i,ism(lu),isd(lu),iem(lu),ied(lu),pf(lu)
81                      format(5(i5,1x),f4.2)
82                      do 90 j=1,60
                        if(iyr(lu,j).eq.0) go to 91
                        write(18,85) i,iyr(lu,j),id(lu,j),c(lu,j)
85                      format(3(i5,lx),f6.4)
90                      continue
91                      continue
100                     continue
101                     continue
                        stop
                        end
```

B.2 FORTRAN PROGRAM "GENTOPOF.F"


```
cc-- 7/13/95 --......... George J. Sabbagh
cc
c   program to take cell values and generate average field values.
c   it reads field.asc, and the parameter cell by cell data from the ASCII files
c   slp.asc, slen.asc,dist.asc and slpstrm.asc, and generates the file
c   topofile.inp which can be imported directly into SIMPLE.
c NOTE: the area of the cell is taken as 0.09 ha (30m X 30m)
c
                        dimension fact(20)
                        integer*4 idf(3000),ncell(3000,20)
                        real avg(3000,20),sum(3000,20), par(3000,20)
                        character*30 filname(20)
                        open(12, file='topofile.inp', status='unknown')
                        open(15, file='field.asc', status='old')
c
```

```
                read(15,*)
                read(l5,*)
                read(l5,*)
                read(15,*)
                read(15,5) nrow
                read(15,5) ncol
5               format(t6,11 0)
                write(*,*) 'nrow and ncol ',nrow,ncol
c
c    nbf = # of parameter fields
c    filname = name of the ASCII files
c    fact(m) = the factor by which to multiply the values for parameter m
c    cellarea = area of a cell
                cellarea=0.09
                nbf=4
                filname(l)='slp.asc'
                filname(2)='slen.asc'
                filname(3)='dist.asc'
                filname(4)='slpstrm.asc'
                fact(l)=l
                fact(2)=0.01
                fact(3)=l
                fact(4)=l
c
                do 100 l=1, nbf
                iop=i+20
                open(iop,File=filname(i), status='old')
                read(iop,*)
                read(iop,*)
                read(iop,*)
                read(iop,*)
                read(iop,*)
                read(iop,*)
100             continue
                do 20 J=l. 3000
                idf(J)=0
                do 20 mmj=1,20
                sum(J,mmj)=0
                par(J,mmj)=0
                avg(J,mmj)=0
                ncell(J,mmj)=0
20              continue
                do 60 J=l, nrow
                read(15,*) (idf(k), k=l, ncol)
                do 60 i=l,nbf
                iop=i+20
                read(iop,*) (par(k,i), k=l, ncol)
                do 50 k=l, ncol
                if(idf(k).GT.0) then
                sum(idf(k),i)=sum(idf(k),i)+par(k,i)*fact(i)
                ncell(idf(k),i)=ncell(idf(k),i)+l
```



```
                endif
50              continue
60              continue
                do 70 i=l,nbf
                do 70 k=1,3000
                if(sum(k,i).GT.0) avg(k,i)=sum(k,i)/ncell(k,i)
70              continue
                do 150 k=1,3000
                if(ncell(k,l).GT.0) then
                fielda = ncell(k,l) * cellarea
                write(12,65) k,fielda,(avg(k,mm),mm=l,nbf)
65              format(14,20(lx,f7.2))
                endif
150             continue
                stop
                end
```

B.3 FORTRAN PROGRAM "GENTSOILF.F"

```
cc          -- 7/13/95 --......... George J. Sabbagh
cc
c       program to take cell values and generate average field values.
c       it reads field.asc, and the parameter cell by cell data from the ASCII files
c       cn.asc, k.asc, initp.asc, den.asc, orgc.asc clay.asc, and ph.asc, and
c       generates the file soilfile.inp which can be imported directly into SIMPLE.
c       NOTE: the area of the cell is taken as 0.09 ha (30m X 30m)
c
                    dimension fact(20)
                    integer*4 idf(3000),ncell(3000,20)
                    real avg(3000,20),sum(3000,20), par(3000,20)
                    character*30 filname(20)
                    open(12, file='soilfile.inp', status='unknown')
                    open(15, fiie='field.asc', status='old')
c
                    read(15,*)
                    read(15,*)
                    read(l 5,*)
                    read(l 5,*)
                    read(15,5) nrow
                    read(15,5) nool
5                   format(t6,l10)
                    write(*,*)'nrow and ncol',nrow,ncol
c
c                   nbf = # of parameter fields
c                   filname = name of the ASCII files
c                   fact(m) = the factor by which to multiply the values for parameter m
c                   cellarea = area of a cell
c                   lan = langmuir's option value (0 or 1)
c                   lin = linear option value (0 or 1)
c                   skd = the kd value associated with the linear option
                    cellarea=0.09
                    nbf=7
                    filname(l)='cn.asc'
                    filname(2)='k.asc'
                    filname(3)='initp.asc'
                    filname(4)='den.asc'
                    filname(5)='orgc.asc'
                    filname(6)='clay.asc'
                    filname(7)='ph.asc'
                    fact(l)=0.01
                    fact(2)= 0.01
                    fact(3)=0.01
                    fact(4)=0.01
                    fact(5)=0.0l
                    fact(6)=0.0l
```



```
                    fact(7)=0.0l
                    lan=0
                    lin=l
                    skd=175
c
                    do 100 l=1, nbf
                    iop=i+20
                    open(iop,File=filname(i), status='old')
                    read(iop,*)
                    read(iop,*)
                    read(iop,*)
                    read(iop,*)
                    read(iop,*)
                    read(iop,*)
100                 continue
                    do 20 J=1, 3000
                    idf(J)=0
                    do 20 mmj=1,20
```

```
                 sum(J,mmj)=0
                 par(J,mmj)=0
                 avg(J,mmj)=0
                 ncell(J,mmj)=0
20               continue
                 do 60 J=l, nrow
                 read(15,*) (idf(k), k=l, ncol)
                 do 60 i=l,nbf
                 iop=i+20
                 read(iop,*) (par(k,i), k=l, ncol)
                 do 50 k=l, ncol
                 if(idf(k).GT.0) then
                 sum(idf(k),i)=sum(idf(k),i)+par(k,i)*fact(i)
                 ncell(idf(k),i)=ncell(idf(k),i)+l
                 endif
50               continue
60               continue
                 do 70 i=l,nbf
                 do 70 k=1,3000
                 if(sum(k,i).GT.0) avg(k,i)=sum(k,i)/ncell(k,i)
70               continue
                 do 150 k=1,3000
                 if(ncell(k,l).GT.0) then
                 ncn=avg(k,l)
                 write(12,65) k,ncn,(avg(k,mm),mm=2,4),lan,(avg(k,mm),mm=5,7),
                 *          lin,skd
65               format(l4,i4,3(1x,f7.2),i3,3(1x,f7.2),i4,1x,f7.2)
                 endif
150              continue
                 stop
                 end
```


APPENDIX C SUMMARIZING OUTPUT DATA

SIMPLE simulation runs generate sets of output files. The number and type of files generated is dependent on the method (cell by cell or field by field) used for conducting the simulation runs. In this project the simulations were conducted based on field by field option. The simulation results are compiled and saved in a file in "tabular' format. There are 6 output parameters in the file: runoff volume (cm), sediment loss (metric tons/ha), dissolved P (kg/ha), sediment bound P (kg/ha), and total P (kg/ha). This file includes two sets of data one for the entire watershed, and another for each field. The watershed data sets are presented by month and by year. They also summarize for the entire simulation period. The field data sets represent the total loading for the entire simulation period only.

Two types of simulation runs were conducted one in continuous mode and the other one in independent mode (see chapter 1 and 2 for definition). The SIMPLE output files for the continuous simulation were saved as *1.ann, where * represent the watershed name. For the independent runs, they were saved as *2.ann.

For this project, we needed to summarize the simulation results by land use, and to develop maps describing spatially the loadings. The Fortran program 'sumlumap.f' and a set of shell files were written for that purpose. The shell files are mainly GRASS commands used to import the ASCII files generated by "sumlumap.f"into GRASS, and to combine the various watershed maps into 1 map for the entire basin. The program "sumlumap.fil" is presented below:

SUMLUMAP.FOR: This program reads the "tabular" output file generated by SIMPLE and summarize the results by land use. This program also reads the file "field.asc" and uses the field data from the simple "tabular" output file to generate 5 ASCII files representing the 5 output parameters defined above. These files describe spatially the predicted loadings associated with each of the parameters. The 5 files are: roff_field.asc, sed_field.asc, proff_field.asc, psed_field.asc and ptotal_field.asc. It is important to note that the values presented in these ASCII filed are the predicted values for the entire simulation period * 1000. The 1000 factor was used to make these values integer so these files can be imported into GRASS. Thus, if average annual values are needed, the values in these ASCII files need to be divided by 1000*number of years of simulation.

C.1 FORTRAN PROGRAM "SUMLUMAP.F"

```
cc SUMLUMAP.F          9/14/95        George J. Sabbagh
c
c    Program to summarize SIMPLE output such as the results are provided
c    by land use.  This program also reads the file field.asc and generates
c    ASCII files showing the spatial distribution of the simulated results
c
              Dimension areaf(2000),arealu(30),par(6,30)
              integer*2 lu(2000)
              integer*4 val(6,2000)
              character*40 strid(6),outf,fllu,flarea,lusum
              character*40 lunam(30),ascfil(6)
c
              open(l,file='field.sum',status='unknown')
              open(l0,file='sumlu.fil',status='old')
              read(10,*) filu,flarea,outf,lusum
              read(10,*) ntlu
              do 10 i=l,ntlu
              read(10,7) ilu,lunam(ilu)
  7           format(i4,a40)
  10          continue
              ascfil(l)='roff-field.asc'
              ascfil(2)='sed-field.asc'
              ascfil(3)='proff-field.asc'
```



```
              ascfil(4)='psed-field.asc'
              ascfil(5)='panimal field.asd
              ascfil(6)='ptotal-field.asc'
c
              open(l l,file=fllu,status='old')
              open(l 2,file=flarea,status='old')
              open(l 3,file=outf,status='old')
              open(l 4,file=lusum,status='unknown')
c
              write(14,15)
              write(14,16)
              write(14,17)
              write(14,18)
              write(14,*)
15            format('LANDUSE',7x,'RUN',7x,'SED',11x,'PLOADING',15x,'area')
16            format(T10,'          -----------------)
17            format(T10,'          RUN      SED      TOTAL')
18            format(T15,'cm m ton/ha  kg P/ha  kg P/ha  kg P/ha     ha')
c
              DO 20 l=1,2000
```

```
                LU(l)=0
                AREAF(l)=0
                do 20 k=1,6
                val(k,i)=0
20              CONTINUE
c
                DO 30 l=1,30
                AREALU(l)=0
                DO 30 J=1,6
                PAR(J,l)=0
30              CONTINUE
                READ(11,*)
                DO 100 l=1,2000
                READ(11,*,END=l 01) LANDU,IFL
                LU(IFL)=LANDU
100             CONTINUE
101             CONTINUE
                do 105 i=1,2000
                READ(12,*,err=106) IFL,AREAF(IFL)
                LUN=LU(IFL)
                AREALU(LUN)=AREALU(LUN)+AREAF(IFL)
105                     continue
106                     continue
c
c
c               DO 200 l= 1, 10000
                READ(13,110,ERR=999) STRID(1)
110             FORMAT(T25,A20)
                IF(STRID(l).EQ.'FIELD SUMMARY REPORT') GO TO 205
200             CONTINUE
205             READ(13,*)
                READ(13,*)
                READ(13,210) NBYR
210             FORMAT(T30,l3)
                DO 220 K=1,8
                READ(13,*)
220             CONTINUE
c
                DO 250 J=1,2000
                READ(13,*,END=251) l,Q,S,PQ,PS,PA,PT
                LUN=LU(l)
                q =q*AREAF(l)
                s =s*AREAF(l)
                pq=pq*AREAF(l)
                ps=ps*AREAF(l)
```



```
                pa=pa*AREAF(l)
                pt=pt*AREAF(l)
                val(i,j)=val(1,j)+q*1000
                val(2,j)=val(2,j)+s*1000
                val(3,j)=val(3,j)+pq*1000
                val(4,j)=val(4,j)+ps*1000
                val(5,j)=val(5,j)+pa*1000
                val(6,j)=val(6,j)+pt*1000
                PAR(1,LUN)=PAR(1,LUN)+Q/nbyr
                PAR(2,LUN)=PAR(2,LUN)+S/nbyr
                PAR(3,LUN)=PAR(3,LUN)+PQ/nbyr
                PAR(4,LUN)=PAR(4,LUN)+PS/nbyr
                PAR(5,LUN)=PAR(5,LUN)+PA/nbyr
                PAR(6,LUN)=PAR(6,LUN)+PT/nbyr
c               write(1,245) i,lu(i),areaf(i),q,s,pq,ps,pt
c 245           format(2i5,6(1x,f10.2))
250             CONTINUE
251             CONTINUE
c
                DO 300 M=1,30
                IF(AREALU(M).GT.0) THEN
```

```
                        DO 290 J=1,6
                        PAR(J,M)=PAR(J,M)/AREALU(M)
290                     CONTINUE
                        WRITE(14,295) LUNAM(M),(PAR(J,M),J=1,4),PAR(6,M),arealu(m)
295                     FORMAT(A10,2X,F6.2,4(2X,F8.3),2x,f8.1)
                        ENDIF
300                     CONTINUE
c
                        close(11)
                        close(12)
                        close(13)
                        close(14)

                        open(11,file='field.asc',status='old')
                        open(12,file=ascfil(1),status='unknown')
                        open(13,file=asefil(2),status='unknown')
                        open(14,file=ascfil(3),status='unknown')
                        open(15,file=ascfil(4),status='unknown')
                        open(16,file=ascfil(5),status='unknown')
                        open(17,file=ascfil(6),status='unknown')
c
                        read(11,330) strid(1)
                        read(11,330) strid(2)
                        read(11,330) strid(3)
                        read(11,330) strid(4)
330                     format(al5)
                        read(11,331) strid(5),nrow
                        read(11,331) strid(6),ncol
331                     format(a6,i3)
c
                        do 340 m=1,6
                        write(m+11,330) strid(1)
                        write(m+ 11,330) strid(2)
                        write(m+ 11, 330) strid(3)
                        write(m+11,330) strid(4)
                        write(m+11,331) strid(5),nrow
                        write(m+11,331) strid(6),ncol
340                     continue
c
                        do 350 m=1,3000
                        lu(m)=0
350                     continue
                        do 400 i=l,nrow
                        read(11,*) (lu(m),m=1,ncol)
```



```
                        do 370 j=1,6
                        write(j+11,365) (val(j,lu(k)),k=l,ncol)
365                     format(3000i10)
370                     continue
400                     continue
c
999                     CONTINUE
                        STOP
                        END
```

C.2 EXAMPLE for the file SUMLU.FIL

11	number of landuses
l urban	landuse id number and description
2 Transportation, Communication, Utilities	
3 Crop	
4 Pasture/Range	
5 Orchards, Groves, and Vineyards	

6 Nurseries
7 Forest
8 Poultry Operations
9 Dairy
10 Hog Operations
11 Water

15,'land2a.sum'	Number of watersheds, output file name
'osage.rep','osage.inp','osage2.ann' 'clear.rep','clear.inp','clear2.ann' 'fork.rep','fork.inp','fork2.ann' 'flint.rep','flint.inp','flint2.ann' 'baron.rep','baron.inp','baron2.ann' 'benton.rep','benton.inp','benton2.ann' 'river.rep','river.inp','river2.ann' 'bord.rep','bord.inp','bord2.ann' 'tyner.rep','tyner.inp','tyner2.ann' 'west.rep','west.inp','west2.ann' 'caney.rep','caney.inp','caney2.ann'	file names where to read the data from; *.rep & *.inp are described in Appendix A.1 and A.2; *.ann is generated by SIMPLE

APPENDIX D
LTPLUS PROCEDURES FOR DEM DEVELOPMENT

A. Scanning in Data

1. On pc next to the scanner, create a directory by using the command mkdir name.
2. Change directories to your newly created directory by using cd \new name.
3. Type ascan and press enter.
4. Set the following parameters on the screen:
    a. Name the map. We have been using the format of three letters for the map followed by an underscore followed by the threshold setting followed by .rlc. For instance, cha_64.rlc would tell us the name of the map, chance, the threshold setting, 64, and the output of rlc. Any naming system is acceptable.
    b. Set density to 600 dpi.
    c. Set output to rlc.
    d. Set speed to 75/100.
    e. Set X (in) to 11.0 and 22.5. These numbers are used because the scanner blurs the first couple inches of the left hand side of the scan. I moved the scanning area over 10 inches to avoid this

problem. When the map is inserted into the scanner make sure that the printed part is even with the 12 inch mark. If the scanner is ever fixed, the normal numbers used is 2.0 and 21.5. Insert the map all the way over on the left hand side.

f. Set Y (in) to 1.0 and 28.0. The numbers used in steps e and f are for scanning in mylar quad sheets, different numbers will have to be determined for different size sheets.

g. To set the threshold, it will have to be determined what is the best for map you have. On the mylar maps I used 61 or 64. This will give you a starting point. A good rule of thumb to use is, the more detail you have the lower the threshold setting will have to be. What you are looking for is the point where you have the highest threshold setting and still maintain the integrity of the lines being scanned in. If the threshold setting is set to low then the lines will become intermittent. If it is set to low there will be to much interference on the map and the number of errors will increase dramatically.

h. Set the hysteresis to 5.

i. Set the dynamic to 0.

5. Insert the map. If using mylar maps, a second sheet of mylar will have to be taped to the map to prevent from scratching the original map. The orientation of the map doesn't matter because the map can be rotated any direction in LTPlus. If a sheet of mylar is used it must be down.
6. Use the mouse to click on scan.
7. After the scanner quits, click on exit.
8. Type ftp 139.78.2.48. This is biosun.
9. Type bin. This sends the information in binary.
10. Type cd /gis/u/lbryce/scan_data/import. This will send the data to biosun. The data can be found in biosun by following this path.
11. Type put map name given in step 4a. Example: cha-64.ric.
12. Type bye
13. Type del *.* It is critically important that you are in your own directory before you type this command. You could erase everything on the computer if not.

B. Creating a Map (in 117)

1. Start LTPlus by:

a. Type newgrp scan. This puts you in the group scan.

b. Type umask 002. This sets up the correct permissions. Steps a and b must be typed every time LTPlus is started up or no one else will have access to the maps and the system administrator will have to set up the correct permissions.

c. Type ltp. This starts up the LTPlus program.

2. Click on create with the mouse.
3. Name map. This step renames the map. The map should be given its full name.
4. Click on scan input.
5. Click on import.
6. Here is a list of ways of importing data. Click on rlc.
7. Here it is asking for a reduction factor. Enter 2. This just allows the map to fit on the screen.
8. Here it is asking for the threshold. You have a choice of 1 to 4. 1 found that 4 worked better for me. This is another area where you will have to experiment. It is the same situation as in step 4g.
9. This is where the orientation of the map needs to be checked. If the map is backwards or upside down, use the reflect-h or reflect-v as needed to correct the orientation of the map.
10. Click on regis raster. This command is used to register the map. The corners of the map should be marked. Click on these corners with the middle mouse button in the order indicated by the program. This will automatically register the map.
11. Click on save.
12. Click on margin. Enter 150. This sets the margins around the map at 150 pixels.

13. Click on save.

C. Getting Ready to Edit

1. Click on edit0.
2. Click on contour clean 0.
3. Click on batch edit.
4. Click on thin_lines, then type 0 and press enter, type 0 and press enter again.
5. Click on fill holes.
6. Click on thin_lines, then type 0 and press enter, type 0 and press enter again.
7 Click on delete_points.
8. Click on delete_spurs, thin type 5 and press enter.
9. Click on thin-lines, then type 0 and press enter, type 0 and press enter again.
10. Click on save.

D. Editing

Now that we have created a map in the LTPlus program, it has to be edited. The computer has done most of the editing, but somebody has to personally complete the editing process. The purpose of editing is to have all of the lines on the contour map to be continuous and have no intersections or junctions. The job of the editor is to go to each and every junction on the map and correct the problem. Another very important function of the editor is to maintain the integrity of the map. What this means is that it is very important to keep the lines on the map exactly where they were scanned in at. Some little part of a line may have to be moved due to the inaccuracies of the scanning and creating process, but this must kept to an absolute minimum. If a line is lost during the editing process, and it will eventually happen if you edit long enough, we have a process to recover the line and put it exactly where it belongs. Do not try to put it back by drawing it in. This process will be described in detail later.

1. Click on edit0.
2. Type log clear and press enter.
3. Type log junc and press enter.
4. Click on start search and click on the map anywhere. This zooms in on the map.

5. Click on go to log +. This will take you to the first junction. There are several options depending on what is wrong with this junction. These are the most common commands used when editing:
    a. wink - turns on or off one pixel at a time.
    b. connect - draws a line from a starting point to a finishing point indicated by the mouse. It also turns off all the pixels next to the drawn line.
    c. erase_seg - this erases the line segment that is clicked on all the way to the next junction or break in the line. Be careful!
    d. undo - this command is both a blessing and a curse at the same time. It will return the last thing that was erased but, in order to do this it makes a block around the line and it returns everything inside the block since the last time you saved.
    e. separate - separates lines by putting a blank space between the lines and turning on the pixels around the blank space.
    f. bridge_gap - used to connect lines that have a small gap in them. Especially useful for connecting lines to along the edge of the map to the border when the map has been framed.
    g. draw line - same as connect except it doesn't turn any pixels off.
6. Keep clicking on go to log + until all the junctions are gone. Now all the spurs have to be removed.
7. Type frame_map d r. This will put a frame around the map.
8. Go along the edges of the map and ensure that all the lines are connected to the frame.
9. Type del_spurs 25. This removes all spurs that are 25 pixels in length.
10. Type log clear.
11. Type log spurs.

12. Click on go to log +. This will take you to each of the spurs. Correct all spurs in the same manner as_the junctions.
13. Click on save.
14. Type frame_ map e r. This will remove the frame around the map.
15. Click on save.

E. Attributing

The purpose of attributing a map is to assign elevations to the contour lines on the map. This procedure isn't hard, but some experience is recommended. It is very important that the person attributing the maps be very sure of the direction that the slopes are running. The hardest part to determine is the islands. If there are any questions ask Mark or even better leave them for Mark to determine.

1. Click on special_bl
2. Click on assemble. This converts the raster map to a vector map.
3. Click on save.
4. Click on graph_setup. This highlights all unattributed contour lines.
5. Click on graphics_b. This shows the vector map overlaid on the raster map.
6. Click on get_att_keys.
7. Now to attribute there are 3 different functions that are used:
   a.atr_context1 - this command allows the user to drag the mouse across the contours to label them from lower to higher elevations.
   b. atr_contour1 - this command allows the user to label one line at a time. This is mostly used to provide a place to start attributing from.
   c. line_query - this command shows the elevation of the line that is clicked on with the mouse.
8. Click on save.

F. Registering a Map

1. Click on scan_input.
2. Click on regis_geo.

3. The program is now asking if the maps are rectangular. Type yes.
4. Type width of 7.5.
5. Type height of 7.5.
6. Enter the number of the corner for which you have coordinates. Usually I had the Northeast corner coordinates which is 3.
7. Enter the numbers in this fashion.
   LAT LON
   36/00/00 , 94/50/00
8. Sometimes the some of the information is automatically entered. Then only enter the information starting from step 6.

G. Restoring Data Lost in the Editing Process

1. Always back up the map and work with the back up only.
2. Change directory to the map directory.
3. Type ~/exchange.
4. Start LTPlus.
5. Acquire the map.
6. Type check. This is a program that shows the differences between the original scanned in map and the edited map. There will be obvious differences between the scanned map and the edited map. What you are looking for is big lines. This is usually the missing line or lines. This is also a good technique for just checking maps to see if all the lines are there.

7. Edit around the line or lines you want to keep.
8. Click on save.
9. Exit LTPlus.
10. Change to map directory.
11. Type ~/exchange2.
12. Start LTPlus.
13. Acquire map.
14. Type disprstr_get a.
15. Type disprstr_put.
16. Type disprstr_get c.
17. Type disprstr_mrg.
18. Click on save.
19. Exit LTPlus.
20. Change to map directory.
21. Type ~/exchange3.
22. Start LTPlus.
23. Acquire map.
24. Click on assemble.
25. Click on save. All lines should be back.

H. Comments

I have written this procedure as if a person could do it from beginning to end in one sifting. This is impossible to do. Anytime during this procedure a person can stop and save their work. All that needs to be done is to click on save and then click on exit. This takes you out of LTPlus and into the windows environment.

To pick up where you left off, all that is needed is the following:

a. Type newgrp (name of your group). Our group was scan.
b. Type umask 002. This sets your correct permissions.
c. Type ltp. This starts up the LTPlus program.
d. Click on acquire.
e. A list of maps will show up that belongs to you. Click on the map name that you want and the program will bring it up. Just pick up where you left off.

The next thing I want to talk about is the importance of saving your work often. Anything could happen and you could lose a lot of work. Their are several commands that you could hit that will lock up the program and the only way to stop it is to kill the process. This means that all work that was done since the last time the work was saved is lost. All work should be saved at least every hour. More often if the work is complex.

The way LTPlus works is when a map is acquired it makes a copy of the original and puts it on the screen to work on. Anything can be done to this map without affecting the original map. This means that if a big mistake was made on the map on the screen everything is all right because the original is unaffected. The map can be reacquired and started on again. If the map was saved, then the LTPlus program has replaced the original map with the map on the screen and the mistake is saved forever. On the flip side, if the work is not saved often enough then work could be lost.

BASIN-WIDE POLLUTION INVENTORY FOR THE ILLINOIS RIVER COMPREHENSIVE BASIN MANAGEMENT PROGRAM

FINAL REPORT

VOLUMEII

Monitoring Stream Periphyton for Nutrient Limitation

by

Dale Toetz
Professor

Submitted
to the
Oklahoma Conservation Commission
for the
U.S. Environmental Protection Agency

Department of
Zoology
Oklahoma State University

August 1996

FINAL REPORT

BASIN-WIDE POLLUTANT FNVENTORY FOR THE ILLINOIS RIVER COMPREHENSIVE BASIN MANAGEMENT PROGRAM

Subproject: Monitoring stream periphyton for nutrient limitation

Submitted to:

Oklahoma Conservation Commission
Oklahoma City, Oklahoma

From:

Dale W. Toetz,
Zoology Department
Oklahoma State University
Stillwater, OK 74078

ABSTRACT

The problem of non-point source pollution was attacked in the Oklahoma portion of the Illinois River watershed by a two-step process of using animal inventory to estimate P loadings from 62 sub-basins and biological monitoring of streams in eight of the sub-basins. The streams were selected to represent a wide spectrum of potential P loading. Alkaline phosphatase activity (APA), surplus P and chlorophyll a biomass of biofilms were observed during February, June and August, 1993. Ancillary data were also obtained on water chemistry, stream habitat suitability and the composition of the macroinvertebrate and fish populations at each sampling site.

Biofilms in streams in sub-basins with loading > 10-20 kg P ha^{-1} exhibited greatest stress for P as measured by APA and surplus P. These streams also tended to have highest chl. a biomass and nuisance blooms of periphytic filamentous cyanobacteria. These same streams shared similar communities of macroinvertebrates and fish. Stream habitat suitability was not related to P in animal inventory. Nutrients and physical attributes of streams were not closely coupled.

It is suggested that sub-basins with loadings > 10-20 kg P ha^{-1} deserve priority in management efforts to reduce nutrients in the Illinois River.

INTRODUCTION

Non-point source pollution by nutrients from agriculture is a significant national problem (NRC, 1992). It is manifested in eastern Oklahoma and western Arkansas where poultry production has expanded (NASS, 1989). This fact coupled with urban development in northwestern Arkansas has led to the perception that adverse environmental impacts to streams and lakes might occur. One of the first steps in control of nutrients is a comprehensive basin-wide inventory of pollutant loadings. Here we show how such an inventory was developed and sub-basins prioritized using biological indicators, for the Illinois River watershed, which lies in Arkansas and Oklahoma (Figure 1).

The purpose of this paper is to describe three empirical biologically-based models to prioritize sub-basins given an initial coarse grained prioritization supplied by animal inventory of P nutrients. These empirical models were representative of stream conditions in a subset of sub-basins over a range of predicted nutrient contamination in the Oklahoma portion of the Illinois River watershed. The objective of one model is to predict the degree of P stress of the biofilms as measured by an enzyme, alkaline phosphatase. Alkaline phosphatase tends to increase on cell surfaces during P limitation and apparently is adaptive in that it hydrolyzes phosphomonoesters, releasing P04 for uptake (Perry, 1972; Jansson et al., 1988; McComb et al. 1979). We developed a model predicting alkaline phosphatase activity (APA) as a function of P in animal inventory. Another model predicts stored P (surplus P) as a function of P in animal inventory. Stored P increases when algae are replete with P (Fitzgerald and Nelson, 1966). Another model predicts maximum chlorophyll a biomass, as a function of P in animal inventory.

Although the eight streams were selected on the basis of P in animal inventory in sub-basins, we also describe in the nature of the stream habitat and the fish and invertebrate community structure at each site as background information.

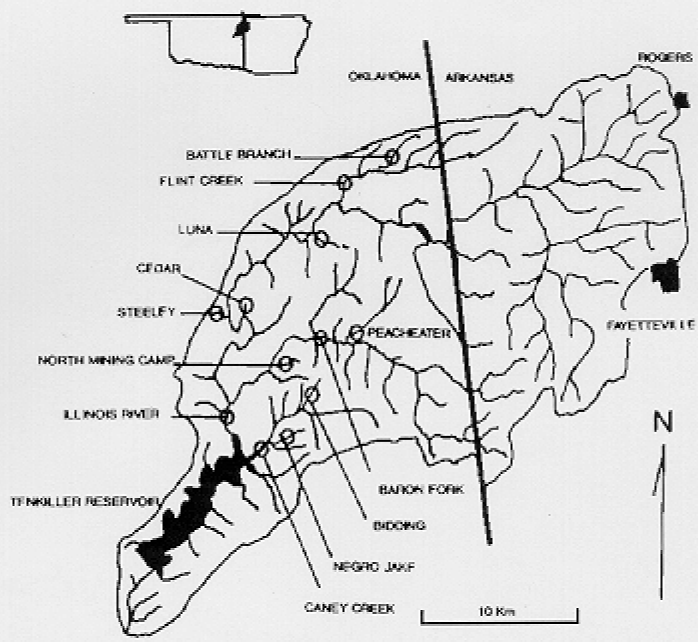

Figure 1. Location map of the Illinois River watershed showing streams sampled.

SITE DESCRIPTION

The Illinois River watershed (500,000 ha) is in the Ozark Plateau province of northwestern Arkansas and eastern Oklahoma (Figure 1). This research was restricted to the Oklahoma portion of the watershed. In eastern

Oklahoma bedrock is cherty limestone, shale and sandstones (Terry, et al., 1984). Topography and stratigraphy are chert-dominated hills. Hills are rough and steep (70-680 m elevation) (Omernik, 1987). Soils are thin and weathered. Land-use is a mosaic of cropland, forests and pasture. Natural vegetation is oak/hickory/pine (Omernik, 1987). Only 3-4% of the land is in poultry production. Precipitation and evaporation are roughly 132 and 86 cm per year, respectively.

The Illinois River has its headwaters in the vicinity of a rapidly developing urban area in the vicinity of Fayetteville, Arkansas. The river flows west and then south into Oklahoma. It is impounded as Tenkiller Lake near its confluence with the Arkansas River.

Eight sub-basins were selected for study to represent a range of P in animal inventory, total P delivered to the sub-basin per annum (Table 1). The areas of sub-basins were 2880 - 6560 ha (Table 1). Average annual P concentrations measured in stream water were 10 - 330 mg m^{-3}; N concentrations were 750 - 3240 mg m^{-3} (Oklahoma Conservation Commission, unpublished).

Table 1. Nutrients from animal inventory for Upper Illinois River sub-basins.

HU	Site Name	Area	Nutrients	
			P	N
		(acres)	(lbs P/ac)	(lbs N/ac)
204	Linder Bend	5416	0.76	1.96

207	Burnt Cabia	7878	0.09	0.24
209	Cato & Snake	7304	0.29	0.75
212	Pine	3272	0.65	1.67
213	Terrapia	11149	0.11	0.29
215	Sizemore	4467	0.11	0.27
216	Petit	9924	0.39	1.02
218	Elk	13857	0.16	0.41
219	Bolin & Dry	17593	3.53	3.17
225	Mining Camp South	5031	0.17	0.43
226	Dripping Spring Hollow	7512	0.04	0.11
227	Parkhill	12246	0.27	0.71
302	Ross & Town Branch	11742	0.05	0.13
307	North Briggs Hollow	5782	12.13	10.71
309	Pumpkin	11940	6.45	4.10
310	Cedar & Tully	7116	6.15	5.23
312	Steeley	11900	8.14	5.29
314	Dog & Telemay	7917	0.01	0.04
315	Mollyfield	7700	31.09	19.86
319	Kirk Spring/Sawmill	5841	0.07	0.18
321	Falls Branch	6998	11.60	7.93
323	Black Fox & Winset	14668	10.23	7.93
325	Falls Branch (east)	5515	14.68	10.39
326	Luna	9480	0.81	0.74
330	Kill, Rock & Tahlequah	5308	62.17	47.97
331	Dripping Springs Branch	7265	5.02	4.741
333	Tate Parrish	10675	19.60	14.30
334	Beaver	9281	8.10	6.22
337	Ballary (1)	9281	53.99	46.72
402	Negro Jake	10863	9.73	7.32
403	Tailhot	11871	1.93	1.77
404	Bidding	11169	17.20	14.92
407	Smith	8076	3.94	3.28
408	Goat	8.65	2.70	2.75
409	Mulberry	10210	5030	4.93
502	Mining Camp North	4418	3.35	2.87
503	Welling Camp	3193	0.03	0.07

Table 1 (cont'd.)

HU	Site Name	Area	Nutrients	
			P	N
		(acres)	(lbs P/ac)	(lbs N/ac)
504	Field	4250	7.69	6.64

506	South Briggs Hollow	4853	32.59	20.95
507	Walltrip Branch	6375	3.22	2.83
508	Proctor Mts.	6425	0.08	0.20
509	Tyner (L & U)	27300	37.30	31.14
510	South Proctor (E & W)	9360	0.59	0.53
511	Dennison	5051	0.03	0.07
512	Peacheater	16210	472.82	35.17
513	Scraper	5970	34.12	22.43
514	England	6049	28.34	22.85
515	Green	9983	44.63	36.99
518	Shell	11248	26.87	21.27
519	Peavine (E & W)	10329	19.60	27.92
520	Evansville (L & U)	31046	11.22	9.22
521	West	472	26.14	20.23
602	Five Mile	7186	9.45	7.21
603	Galunchety	4448	13.27	11.29
604	Battle Branch	5970	49.77	42.16
605	Bluespring Branch	3380	22.03	19.67
606	Hazelnut	2896	26.36	22.50
607	Crazy	6019	13.22	12.49
609	Sager	5268	23.11	16.52
610	Fagan	2382	24.77	21.08

MATERIALS AND METHODS

N and P Inventory of Nutrients

Animal inventory data provided estimates of N and P nutrients in 62 sub-basins in the Illinois River watershed in Oklahoma (Table 1). The U.S. Soil Conservation Service provided animal inventory data used in this paper (Ron Treat, Pers. Comm. 1994). Area and land use in each of the 62 sub-basins was calculated and estimated using GIS data. An inventory was conducted in each sub-basin to estimate human, livestock, and poultry populations. The total waste generated annually by each category was determined (USDA, 1992). The weight of N and P in waste was determined using known % N and P in each type of waste. Not all N was assumed to be applied in a sub-basin; a constant 47.6% was estimated to be lost by volatilization and de-nitrification (Ronald Treat, Pers. Comm, 1994). It was assumed that all P was applied to a sub-basin with no such losses. Thus, the N:P ratios in the data are less than N:P ratios normally associated with animal wastes.

Samples were collected near the exit of the stream from its watershed during February 5-7, June 16-18, and August 16-18, 1993, supplemented by observations on water chemistry only on October 5. During February the canopy was entirely open. In other seasons the section of the stream sampled was entirely in full sunlight except for North Mining Camp and Luna Creek where the cover was about 35% and 25%, respectively. Sampling was done between 0830 and 1700 hours CST or CDT. Water temperature was measured with a hand-held thermometer.
Five-six flat limestone rocks measuring no greater than 14 x 16 cm diameter were collected in the middle of each stream in moving water. An attempt was made to select rocks in riffles or ends of pools where water depth was 10-20 cm. Further, rocks having apparent biofilms were selected against those that were barren. The flat area was vigorously scraped with a brush to remove periphyton. The sample was diluted to known volume with stream water after being passed through a 250 μm sieve to remove large invertebrates and debris. Each sample (n = 5) was vigorously shaken in a plastic cylinder before subsamples were taken for chlorophyll a (chl. a), alkaline phosphatase activity (APA) and surplus P.

Known volumes of subsamples for chl. a and surplus P were harvested onto 0.8 μm Millipore membrane acetate filters and stored in coin envelopes in the dark at 5°C while in transit to the laboratory where they were

stored at -10°C until analysis for chl. a and surplus P (n = 3-5, respectively). Subsamples of known volume (n = 3) were also harvested onto 0.8 μm Millipore filters and stored in coin envelopes on solid $C0_2$ in the field and at -20°C in the laboratory before analysis for APA. Known volumes of subsamples were preserved with 10% gluteraldehyde for algal identification.

The area of each rock scraped was estimated by pressing freezer paper to the area and drawing an outline of the circumference of the area of rock that had been scraped. This area was then determined in the laboratory by planimetry. Sometimes several rocks were scraped to obtain one sample. The areas obtained were used to normalize chl. a, APA and surplus P measurements to an areal basis.

A grab sample of stream-water was obtained by submerging an acid-washed polypropylene bottle below the surface. Such bottles were cleaned with a solution of potassium-dichromate sulfuric acid and rinsed with copious volumes of tap water and deionized water 3-5 times. The sample was stored on ice in the field. The hydrogen ion concentration was determined in the field with a LaMotte model HA pH meter and probe. Immediately upon return to the laboratory 2-3 days later the sample was filtered through a 0.8 µm Millipore filter. The filtrate was split into three subsamples, which were stored in polypropylene bottles, which had been cleaned as described above. One subsample for ammonia (NH3 + NH4+) analysis was stabilized to pH 2 with H_2SO_4 and frozen at -50°C. Samples for NO_3 and soluble reactive phosphorus (SRP) were frozen at -5°C. Unfiltered samples for alkalinity, turbidity and conductivity were held at 5°'C and analyzed 2-3 days after collection.

Alkaline phosphatase activity (APA) was measured by the hydrolysis of 3-0-methylfluorescein phosphate (MFP) following the method of Bothwell (1988). A 5.0 ml of thawed periphyton sample was placed in a fluorometer tube with 0.5 ml of 100 µM MFP in 10 µm tris buffer. Then, the fluorescence of the mixture was measured immediately and one hour later in a Turner model 10-005R fluorometer. During the one-hour interval, the tube was sealed with parafilm and inverted twice. A standard curve for fluorescence was prepared with 3-0-methylfluorescein (MF). The increase of fluorescence is proportional to the mass of MF released by enzymes in the sample. The rate was normalized to the chl. a in the sample, which had been determined separately. APA was expressed as the increase of MF as nM MF (chlorophyll a • hr)$^{-1}$.

Surplus P

Analysis of surplus P followed the method of Wynne and Berman (1980). Periphyton samples were rinsed with distilled deionized water. Each sample was placed in 50 ml distilled deionized water, -then boiled for I hour to extract surplus P. The extract was filtered through a 1.2 µm Whatman glass fiber filter. Then P in the extract was measured using the molydate blue/ascorbic acid method of EPA (1979). The mass of P (surplus-P) and was normalized to chl..a as described above.

Chlorophyll a

Chlorophyll a analyses followed the method of APHA (1990). Aliquots of 150 - 250 ml were filtered onto 0.8 µm Millipore AA filters (n = 2). Samples were stored in coin envelopes at -10° C in the dark until analysis 2-4 weeks later. The filters were then dissolved in 90% acetone. After grinding and centrifugation, absorbance was measured in a Shimadzu model UV-120-02 spectrophotometer. The absorbances of the extract were measured at 665 and 750 nm before, and at 665 and 750 nm after adding one drop of I N HCI.

Chemical Methods

Alkalinity was measured by titration with 0. I N HCI to pH 4.5 (EPA, 1979). Turbidity was measured with a Hach turbidimeter (Model 16800) and conductivity with a YSI model 22 S-C-T- probe and meter.

Soluble reactive P (SRP) was measured spectrophotometrically on filtered samples using the molydate blue/ascorbic acid for color development (EPA, 1979). Total P was measured on unfiltered samples following persulfate digestion and development of color as for SRP as above (EPA, 1979).

Detection limits for SRP were 3x the value of the mean blank (n = 2-3) or 5, 3, 14, and 10 mg m-3 for samples collected in February, June, August, and October, respectively.

Ammonia (hereafter called NH_4^+ - N) was measured spectrophotometrically on filtered samples after raising pH to 7, using phenol-sodium citrate method of Solorzano (Wetzel and Likens, 1991). Nitrate plus nitrite (hereafter

called NO_3^- - N) was measured spectrophotometrically after passage of filtered water through a cadmium column and color development with sulfanilamide (Wetzel and Likens, 1991). Total N was measured on unfiltered samples using persulfate digestion and second derivative spectrometry (Crumpton et al., 1992).

Periphytic algae were examined microscopically and identified to genera using keys in Smith (1950), and enumerated in Sedgwick-Rafter cells according to the method described by Lind (1985). For each sample at least 500 algal individuals were counted.

Stream Habitat, Fish and Invertebrates

During August 16-18, 1993, strearn habitat at each site was characterized by a weighting system using 12 parameters: bottom cover, pool substrate, pool variability, shading, channel alteration and sinuosity, deposition, lower bank channel capacity, upper bank stability, bank vegetation and cover, streamside cover, grazing and riparian vegetative zone (Plafkin, et al., 1989). A composite score was obtained for each site.

In addition, during October 5-6, 1993, fish were sampled with a 10 m minnow sieve (mesh size 10 mm) and invertebrates were kick-sampled. Samples were preserved in 10% formalin and identified to lowest taxon possible using keys in Merritt and Cummins (1984), Pennack, (1989), and Miller and Robison (1973). A community similarity matrix was created using Sorenson's coefficient of community similarity.

RESULTS

Biomass, alkaline phosphatase activity (APA) and stored P are given for all dates in Table 2. The ranges of biomass, APA an surplus P, respectively, was widely different between sampling dates. Hence, plots of these parameters as dependent variables and P loadings as independent variables result in curves that could not be readily compared. As a solution to this problem, we calculated values as a percentage of the maximum observed on that date in all subbasins and then averaged values for the three dates. The mean values for all three dates for % max. chl. a % max. APA, and % max. surplus P, respectively, were plotted against P loading (Figures 2-4).

Percent maximum APA decreased and percent maximum chl. a increased asymptotically as P loadings increased. The inflection point of the curves is roughly where P loadings are 10-20 kg ha-'. The implication is that watersheds producing P loadings in excess of 10-20 kg ha -1 are good sites in which to implement nutrient control techniques. Percent maximum surplus P also increased as P loadings increased, but no asymptote resulted. Attempts were made to fit the data to linear regression models. The best fit was found using regressions of the arcsine of the square root of the average percent of a parameter (y) against P loadings (x) (Sokal and Rohlf, 1981). At base flow P and N inventory, respectively, in eight subbasins in three seasons was related linearly to algal biomass, alkaline phosphatase activity, and surplus P as follows:

$$\text{P inventory} = 0.69\,[\text{chl. a}] + 31.3,\ r = 0.68 \quad (1)$$
$$\text{P inventory} = -0.23\,[\text{APA}] + 30.5,\ r = 0.43 \quad (2)$$
$$\text{P inventory} = 1.1\,[\text{surplus P}] + 32.8,\ r = 0.81 \quad (3)$$

$$\text{N inventory} = 0.76\,[\text{chl. a}] + 29.7,\ r = 0.64 \quad (4)$$
$$\text{N inventory} = -0.76\,[\text{APA}] + 49.6,\ r = 0.52 \quad (5)$$
$$\text{N inventory} = 1.0\,[\text{surplus P}] + 42.1,\ r = 0.86 \quad (6)$$

The brackets indicate transformation to the arcsine of the square root of the average percent of the parameter as a percentage of the maximum observed in the entire sample. Also the following relationships for stream water quality were found, where TP and TN are in units of mg m^{-3} .

$$\text{TP}\ 0.52\ \text{P inventory} + 12.88,\ r = 0.90$$
$$\text{TN}\ 35.4\ \text{N inventory} + 551.9,\ r = 0.86$$

Table 2. Biomass as µg chlorophyl a (chl.a) cm^{-2}, alkaline phosphatase activity (APA), nM MF (µg chl.a • $hr)^{-1}$, and stored P, (µg $chl.a)^{-1}$ during 1993. Standard error in parentheses.

	February 5-7			June 16-18			August 16-18		
	chl.a	APA	Stored P	chl.a	APA	Stored P	chl.a	APA	Stored P
Battle Branch	9.86	1.73	1065	1.55	5.26	531	10.57	7.67	553
	(1.90	(0.30)	(84)	(0.29)	(1.44)	(19)	(2.15)	(1.31)	(60)
Bidding	12.61	2.32	505	0.87	7.26	379	0.65	11.99	273
	(2.28)	(0.13)	(54)	0.09	0.93	(18)	(0.22)	(1.82)	(33)
Cedar Hollow	0.35	6.45	731	0.61	35.77	455	0.98	55.09	319
	(0.21)	(1.95)	(154)	(0.10)	(4.97)	(67)	(0.19)	(4.24)	(31)
Luna Hollow	4.80	6.52	558	2.38	8.20	265	3.71	4.64	190
	(0.33)	(0.80)	(93)	(0.27)	(0.85)	(23)	(0.58)	(1.27)	(14)
Negro Jake Hollow	2.46	2.46	397	7.18	4.10	379	1.05	5.99	227
	(0.98)	(0.98)	(57)	(1.20)	(0.63)	(67)	(0.28)	(1.47)	(35)
North Mining Camp	7.23	8.59	398	2.03	10.30	231	1.00	17.06	179
	(0.15)	(1.05)	(101)	(0.19)	(1.59)	(7)	(0.26)	(1.64)	(20)
Peacheater	10.20	2.42	518	6.92	6.76	543	3.68	8.77	450
	(2.07)	(0.50)	(34)	(0.78)	(1.22)	(53)	(0.25)	(0.81)	(36)
Steeley Hollow	6.33	3.10	426	7.26	6.52	284	4.69	12.70	328
	(0.48)	(0.91)	(38)	(2.67)	(1.46)	(51)	(0.77)	(2.09)	(29)

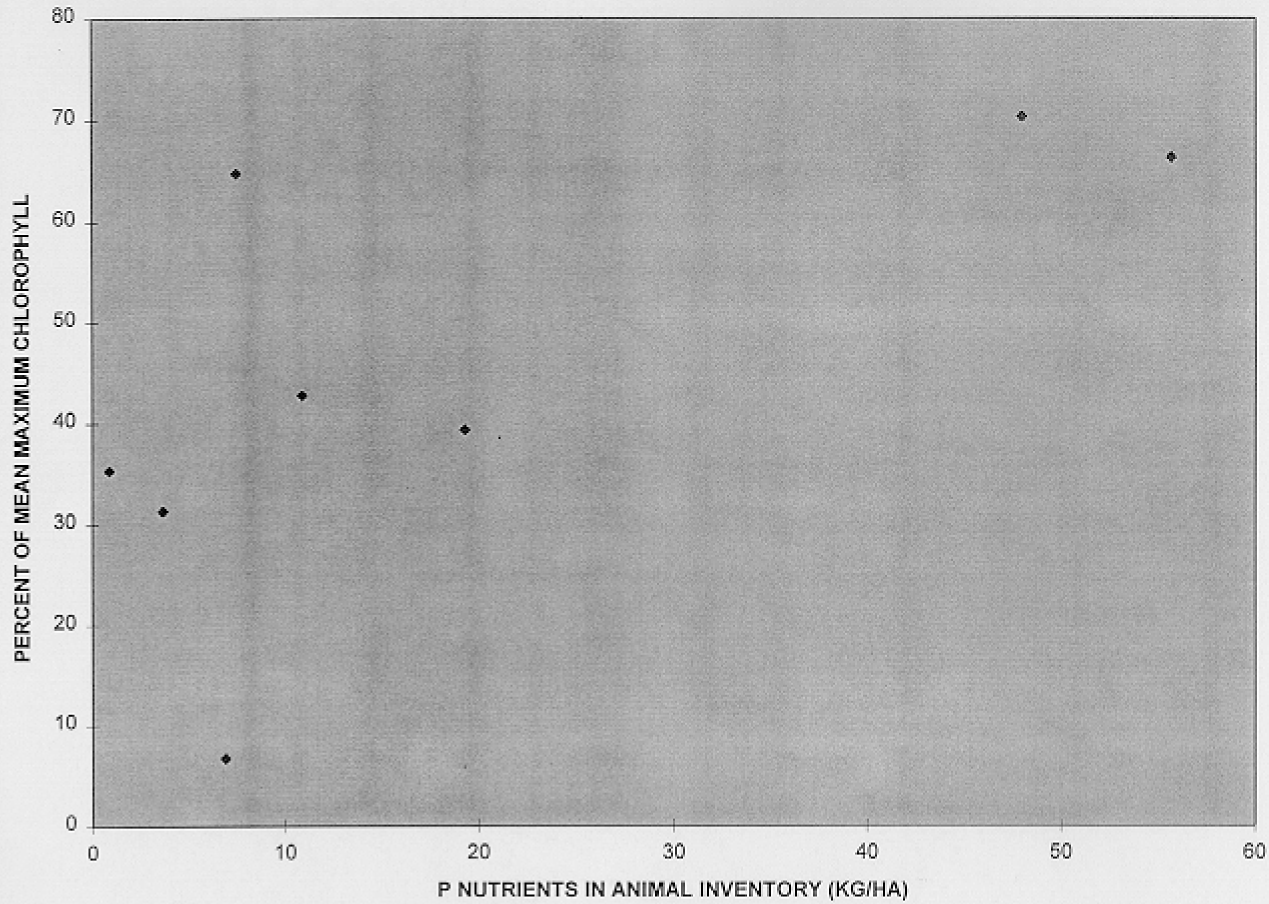

Figure 2. Mean percent chlorophyll a vs P inventory. Values were calculated for each sampling date (n = 3) as a percentage of the maximum observed in the entire sample and then averaged to produce each data point in this Figure. Each data point represents three sampling dates, and five samples. Coefficient of variation of each of the five samples was 10-20-%.

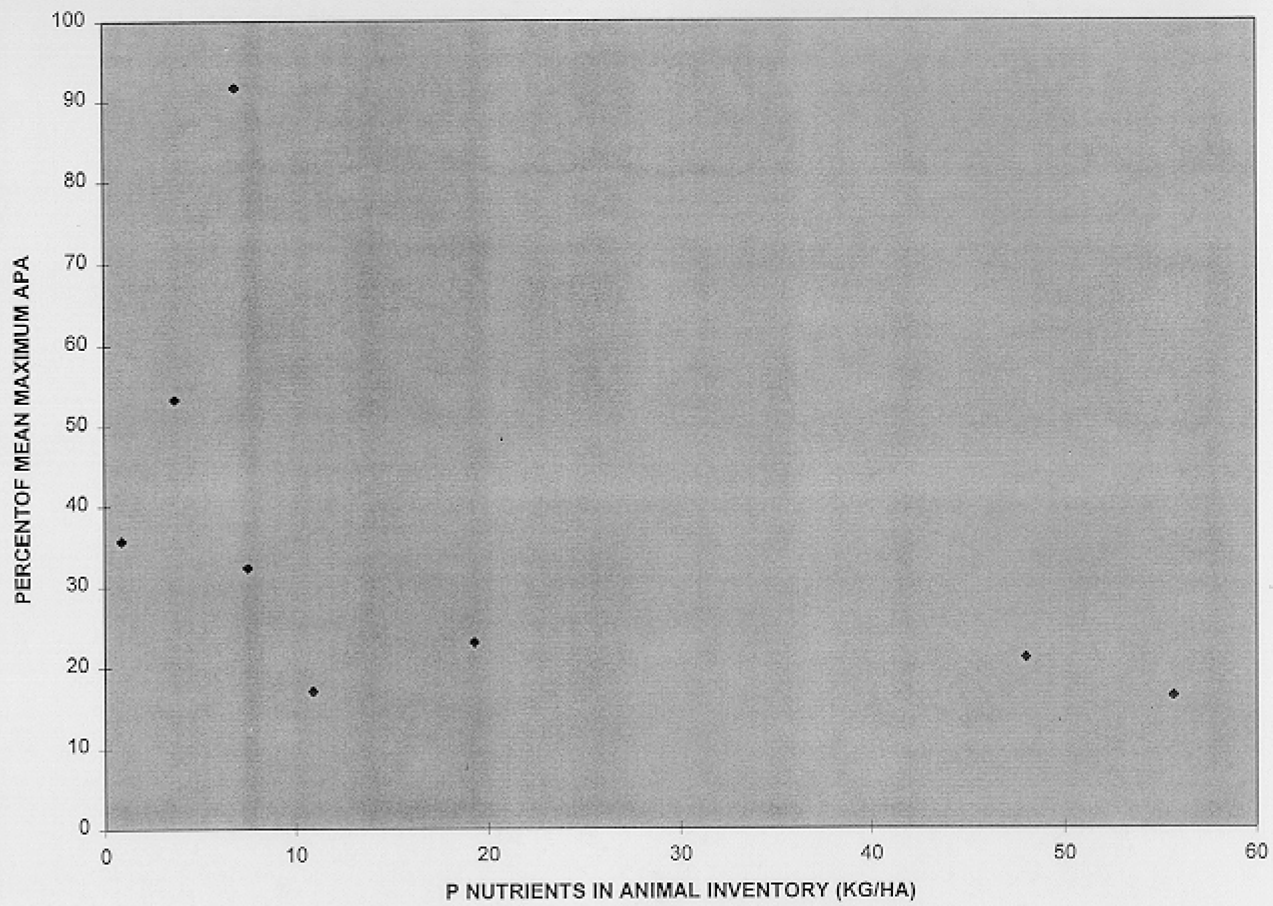

Figure 3. Mean percent alkaline phosphatase activity (APA) vs P inventory. Values were caculated for each sample date (n = 3) as a percentage of the maximum observed in the entire sample and then averaged to produce each data point in this figure. Each data point represents three sampling dates, and five samples. Coefficient of variation of each of the five samples was 10-20%.

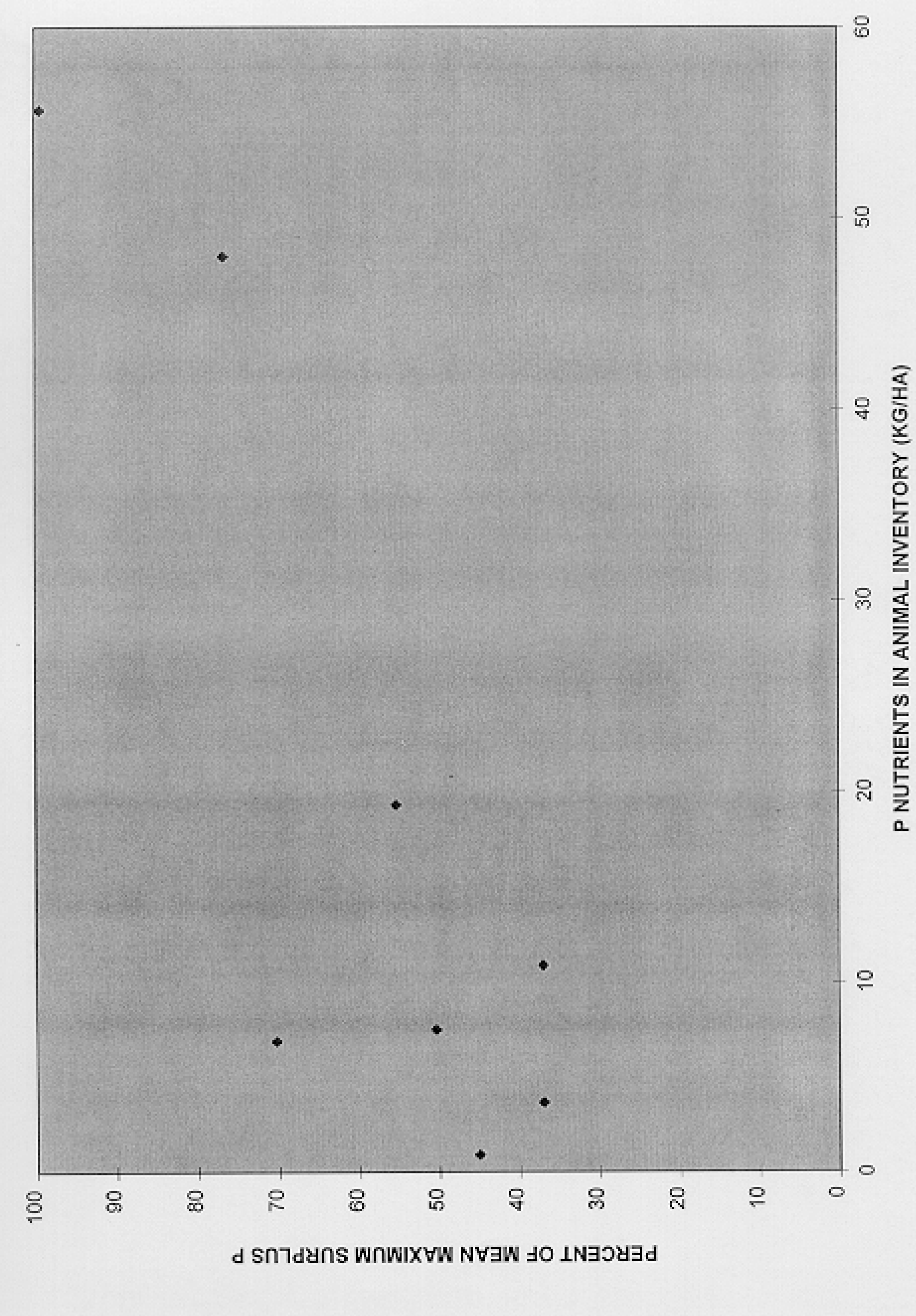

Figure 4. Mean percent surplus P vs P inventory. Values were calculated for each sampling date (n = 3) as a percentage of the maximum observed in the entire sample and then averaged to produce each data point in this figure. Each data point represents three sampling dates, and five samples. Coefficient of variation of each of the five samples was 10-20%.

These equations can be used to predict P in animal inventory at 90%, 50% and 10% of the maximum of the mean of parameters chl. a, APA and surplus P, respectively. For example, Model 1 predicted 90, 50 and 10% maximum chl. a occurred at animal inventories of 35, 37 and 44 kg P ha^{-1}, respectively. Model 2 predicted 90, 50 and 10% maximum APA occurred at animal inventories of 29, 29 and 26 kg P ha^{-1}. respectively. Model 3 predicted that 90, 50 and 10% maximum surplus occurred at animal inventories of 39, 42 and 53 kg P ha^{-1}, respectively. These data can be used to predict animal inventory in a sub-basin necessary to achieve a given biofilm biomass or its metabolism. For example, it would be necessary to reduce animal inventory in sub-basins below >37 kg P ha^{-1} in order to achieve a reduction of chl. a biomass to 50% of the observed maximum.

Physical/chemical properties of river water are summarized in Table 3. Generally, water temperatures were about 16-18°C, pH circumneutral and turbidity was low.

Nutrients were high in Battle Branch and Peacheater Creek, as expected. SRP in stream water was above detection limits in Cedar Hollow and North Mining Camp only in June. The SRP in all streams was below the detection limit of 10 mg m^{-3}, except for Battle Branch, Bidding and Peacheater. Nitrate was always detectable. However, in February NO_3--N was 4 and 33 mg m^{-3} in Battle Branch and Bidding, respectively. We calculated the N:P supply ratio as NO_3--N + NH_4^+ - N/SRP. Mean N:P supply ratios (by atoms) were 55 - 347 indicating a potential for P limitation.

When stream habitat was plotted against P output, two streams in nutrient impacted and two streams in non-impacted sub-basins were almost identical (Figure 5). This demonstrates that prioritization for nutrient control might begin with measures of nutrients and not habitat suitability, no matter how related habitat degradation and nutrient pollution may be in theory. However, the habitat suitability values given here are only for the one site on each stream, not the entire reach.

Mean density of all algae in the study was 10^{-5} cells ml^{-1}. Biovolume was not determined. Cyanobacteria were most important, constituting 78-96% of all cells (Table 4). Diatoms were next in importance, 2 - 20% of all cells. The relative importance of cyanobacteria increased, while that of diatoms decreased between February and August. Green algae were usually a small percentage of total cell density.

Table 3. Physical/Chemical parameters of study streams, temperature as °C, turbidity as NTU, conductivity as µs cm^{-1} anions and cations as gm^{-3}, nutrients as mg m^{-3} N or P standard errors in parentheses. n=4, Bicar. = bicarbonate. Carbonate was not detected. SRP = soluble reactive P. Mean SRP values include some that were below detection limits.

Stream	Temp	pH	Turb.	Cond	Na	K	Ca	Mg	Cl	SO_4	Bicar.	TP	SRP	NO_3	NH_4	TN	N:P
Battle Branch	17.7	7.5	2.1	148	5	1.3	21.7	2	6	4.7	67	37	29	805	32	2059	62.8
	(3.1)	(0.2)	(0.4)	(16.5)	(1)	(0.6)	(3.7)	(1)	(1)	(1.1)	(18)	(10.1)	(11.4)	(537.9)	(22.0)	(383)	(48.2
Bidding	17.0	7.4	3.5	152	4.7	1	23	1.3	1.7	3.3	82	25	17	806	35	1366	101.9
	(4.6)	(0.1)	(1.2)	(20.1)	(1.5)	(0)	(4.3)	(0.6)	(0.6)	(2.9)	(16.7	(16.7)	(5.8)	(518.0)	(13.8)	(393)	(70.2
Cedar Hollow	17.3	7.3	2.2	227	4	1.3	30	8.7	2.7	8	142	11.5	3	251	23	155	347.1
	(8.6)	(2.3)	(1.5)	(36.1)	(2.1)	(0.6)	(4.7)	(3.0)	(2.3)	(7)	(27.7	(9.7)	(1.5)	(665.6)	(21.0)	(92)	(748.6
Luna Branch	17.3	7.6	1.9	133	5	1.7	20	1	3.7	5	64.7	15	8	863	30	716	208.2
	(7.6)	(0.2)	(0.4)	(3.8)	(1.7)	(0.6)	(1.7)	(0)	(3.2)	(1)	(6.6)	(13.9)	(2.9)	(256.1)	(21.4)	(372)	(194.2
Negro Jake Hollow	18.3	7.7	2.1	215	5	1.7	37.3	1.7	4.3	7.7	118	28	14	977	27	1229	229.1
	(9.3)	(4.3)	(1.1)	(66.2)	(1.7)	(0.6)	(16.0)	(0.6)	(3.8)	(0.6)	(58.6)	(10.1)	(8.4)	(284.4)	(23.5)	(397)	(136.9
North Mining Camp	16.3	7.3	2.4	131	5.3	1.0	18.7	1	5.3	4.7	67	11	5	884	28.0	457	530.0
	(5.7)	(2.3)	(1.5)	(11.5)	(2.1)	(0)	(3.8)	(0)	(4.7)	(0.6)	(10.7)	(7.9)	(3.1)	(650.1)	(20.3)	(67)	(443.0
Peacheater	18.0	7.3	2.2	143	5.7	2.7	19.3	1	6.7	5	66	42	23	853	25	1926	55.0
	(7.2)	(2.1)	(1.3)	(4.9)	(1.5)	(0.6)	(0.6)	(0)	(2.3)	(1.7)	(2.5)	(3.1)	(4.8)	(378.7)	(24.6)	(486)	(42.4
Steeley	18.0	7.2	3.5	137	6	1	19	1	1	7	63	13	10	448	28	613	125.9
	(9.6)	(0.6)	(0.9)	(4.6)	(1.7)	(1)	(1.7)	(0)	(0)	(2.1)	(8.2)	(8.2)	(4.6)	(146.8)	(13.8)	(237)	(58.1

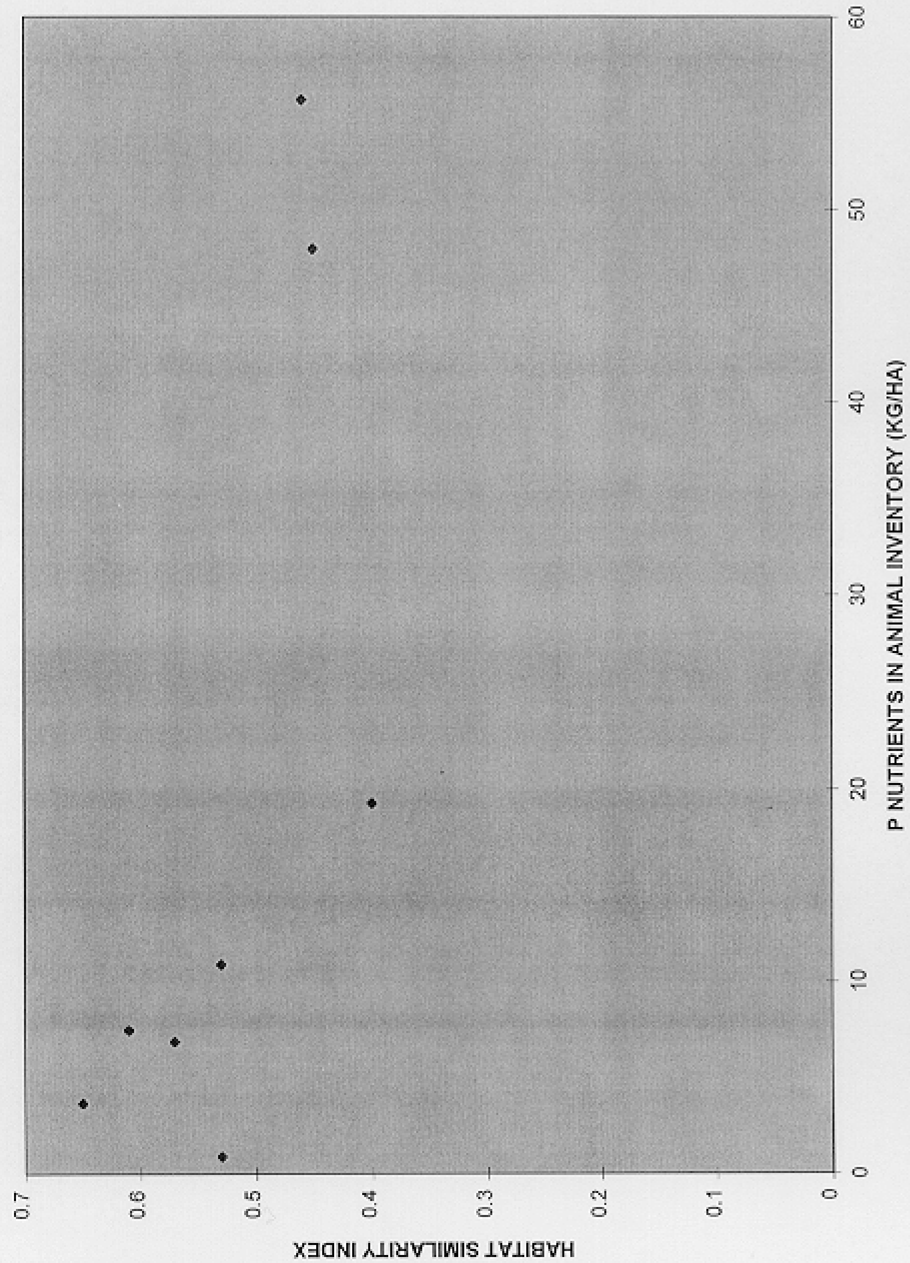

Figure 5. Stream habitat suitability vs P nutrients in animal inventory.

Table 4. Percentages of cyanobacteria, green algae and diatoms in 8 stream samples in February, June and August 1993. Standard deviations are in parentheses.

Time	Percent of Total Cells		
	Cyanobacteria	Diatoms	Green algae
February	78.2 (32.17)	19.6 (19.72)	2.2 (2.84)
June	84.7 (19.70)	14.2 (19.25)	1.3 (1.43)
August	96.3 (1.57),	2.1 (1.23)	1.5 (1.20)

Table 5. Streams with high percentages of diatoms and green algae (as % of total cells).

Month	Stream	% diatoms	Stream	% green algae
February				
	North Mining Camp	57.7	North Mining Camp	8.8
	Luna	36.9	Peacheater	2.9
	Negro Jake	27.1	Steeley	2.4
	Steeley	12.8		
June				
	Negro Jake	51.0	Battle Branch	4.2
	Steeley	37.3	Steeley	3.0
	Battle Branch	13.3	Negro Jake	1.1
August				
	Battle Branch	3.4	Negro Jake	3.5
	Peacheater	3.4	Luna	2.6
	Negro Jake	3.3	Cedar	2.5

Diatoms were relatively important only in certain streams such as Steeley, Negro Jake and Battle Branch (Table 5). Diatoms and green algae were 57.7 and 8.8 % of total cells, respectively, in February in North Mining Carnp.

Cyanobacteria observed were either filamentous *(Lygnbya* sp. and *Oscillatoria* spp.) or non-filamentous. *Capisora* spp., a non-filamentous cyanobacterium was small and consequently not included in estimations of density. However, it was present in all streams during June and August, but only in Steeley and Battle Branch in February.

The relative density of filamentous cyanobacterial cells as a percent of total cyanobacterial cells is shown in Table 6. During February the % filamentous cyanobacteria were either very high (Battle Branch, Bidding, and Luna) or very low (e.g. Cedar, Negro Jake and North Mining Camp). In June, Battle Branch had 3% filamentous cyanobacteria; all other streams had % filamentous cyanobacteria >25%. In August Negro Jake had 8% filamentous cyanobacteria; all other streams had higher % filamentous cyanobacteria.

Regression of % filamentous cyanobacteria on respective values of biomass as chl. a/cm^{-2} yielded correlation coefficients of 0.60, 0.76 and 0.68, for February, June and August, respectively.

A community similarity matrix (Table 7) shows that streams in watersheds with P loadings > 10-20 kg ha^{-1} (Battle Branch, Peacheater and Bidding) were clustered together and had similar coefficients of community similarity.

When community similarity is plotted versus inventory P, the response was more or less linear yet the results suggest a similar threshold (10-20 kg P ha^{-1}) (Figure 6). Maximum numbers of fish and invertebrates were found in Bidding Creek (Watershed 404).

Table 6. Percent filamentous cyanobacteria of total cyanobacterial cell density.

Stream	February	June	August
Battle Branch	78	3	71
Bidding	85	55	42

Cedar	6	30	53
Luna	100	53	17
Negro Jake	8	29	8
North Mining Camp	6	25	63
Peacheater	60	100	57
Steeley	28	87	73

Table 7. Community similarity matrix (values are Sorenson's coefficient of community)

	Cedar Hollow	Steeley	Negro Jake	N. Mining Camp	Luna Branch	Battle	Peacheater	Bidding
Cedar Hollow	1.00	0.56	0.43	0.53	0.36	0.29	0.24	0.18
Steeley	0.56	1.00	0.44	0.61	0.44	0.56	0.48	0.38
Negro Jake	0.43	0.44	1.00	0.53	0.26	0.38	0.47	0.27
N. Mining Camp	0.53	0.61	0.53	1.00	0.57	0.62	0.55	0.67
Luna	0.36	0.44	0.26	0.57	1.00	0.47	0.54	0.52
Battle Branch	0.29	0.56	0.38	0.62	0.47	1.00	0.42	0.48
Peacheater	0.24	0.48	0.47	0.55	0.54	0.42	1.00	0.48
Bidding	0.18	0.38	0.27	0.67	0.52	0.48	0.48	1.00
Mean	0.57	0.61	0.53	0.65	0.53	0.46	0.45	0.40

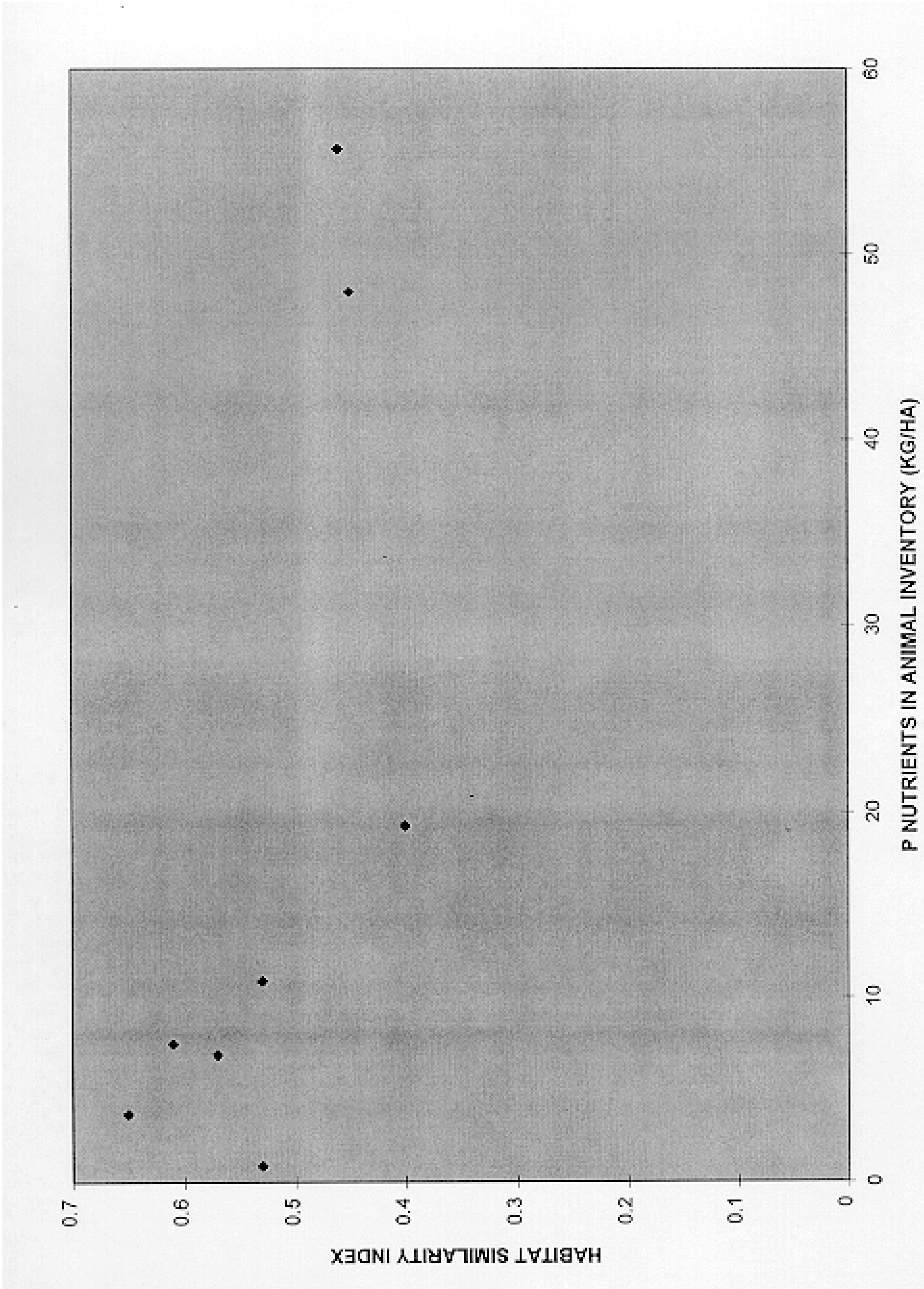

Figure 6. Invertebrate and fish community similarity vs P nutrients in animal inventory.

CONCLUSIONS

Biofilms in streams in sub-basins where animal inventory was > 10-20 kg P ha^{-1} exhibited highest stress for P and generally highest chlorophyll a biomass and nuisance algal blooms. Cyanobacteria were the dominant algal taxon in most streams. Stream habitat suitability was not related to P in animal inventory. Streams in sub-basins with animal inventory > 10-20 kg P ha^{-1} shared similar benthic invertebrate and fish communities. This conclusion is based upon only one sample and seasonal changes are to be expected. But, the data on animals show the same trend as the periphyton data.

DISCUSSION

Four measures of stream trophic status may be applied to the data. Nuisance blooms of periphytic filamentous algae occur at densities of 10 - 15 µg chl. a cm^{-2} (Welch, et al., 1988). According to this criterion, nuisance blooms occurred in Battle Branch, Peacheater, and Bidding Creeks, but not at all times. The lowest P in animal inventory that was associated with nuisance blooms was 19.3 kg ha^{-1} (Bidding). These results corroborate the view that sub-basins having P inventories > 10 - 20 kg ha^{-1} deserve management.

Simple inspection of Figures 2 and 3 is sufficient to conclude which sub-basins deserve treatment. Thresholds are always arbitrarily defined, but in this case both chl.a biomass and APA thresholds were the same. Still another criterion for P limitation is the N:P supply ratio. When such ratios are greater than 13:1 - 18:1 by atoms there exists a potential for P limitation (Rhee and Gotham, 1980). We observed N:P supply ratios of 55-347 by atoms. These ratios indicate a potential for P limitation, but only a potential. If P is available at sufficient concentrations, it is unlikely periphyton will be limited by P in spite of the magnitude of the ratio. Bothwell (1989) demonstrated that as little as I mg P M-3 was sufficient to allow growth of periphyton. Welch et al. (1988) suggest higher concentrations, circa 10 mg m^{-1}, for thick biofilms. Ambient SRP was always above detection limits in Battle Branch, Bidding and Peacheater and below detection limits in most cases in North Mining Camp and Cedar Hollow.

Cyanobacteria tended to be a dominant species of the periphyton, especially in August, but considerable differences were observed between streams. The cause of these differences is impossible to determine, but

herbivory by algivorous fish may be one. Gilwick and Matthews (1992) report that *Campostoma anomalum* selectively consumed diatoms when both cyanobacteria and diatoms were present. This implies cyanobacteria are poor competitors with diatoms and only flourish when diatom density is reduced. C. *anomalum* was observed in Negro Jake and Peacheater on October 5, 1993, and could have been present in other streams as well, especially in the Baron Fork River and Bidding which is a tributary to the Baron Fork. *C. anomalum* is a common species in streams in the Ozark highlands (Rohm, et al., 1987). Absence of herbivory by this fish could explain the relatively high diatom density in Negro Jake and also in Battle Branch in June and August and in Peacheater during August. During June chl. a biomass in Battle Branch was only about 20% of its value in February or August and this unexpectedly small value might be explained by fish herbivory, although other explanations cannot be excluded.

Power, et al. (1988) attribute the persistence of cyanobacterial mats in Ozark streams to their resistance to grazing caused by prostrate filaments, copious mucilage and the capacity to regenerate quickly from basal filaments. However, the major blue-green genus involved in their observations, *Calothrix,* was not observed in this study. *Calothrix* fixes nitrogen and is apparently dominant under conditions of low inorganic N nutrients. It is not known if the non N fixing cyanobacteria, which were observed in this study, would also be poor competitors with diatoms.

It is unlikely that in this study the chl. a data reflect maximum biomass that could be attained if only nutrients were limiting. Consequently, chl a vs P in animal inventory models, which were developed from single sampling events, were not always useful to determine the priority of sub-basins needing nutrient abatement. However, clear trends were established using all of the chl. data, which suggested P loadings > 10-20 kg P ha-I increased P stress of biofilms. Moreover, APA and surplus P data could also be interpreted similarity. In addition, the streams so identified (Battle Branch, Bidding and Peacheater) were also shown to have similar community composition values for animals.

RECOMMENDATIONS

Sub-basins with annual loadings > 10-20 kg P ha^{-1} should have priority in implementation of management tactics (BMPs) to reduce total maximum daily loadings (TMDL) of nutrients in the Oklahoma portion of the Illinois River watershed.

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