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PREDICTION AND MANAGEMENT OF SEDIMENT LOAD AND PHOSPHORUS IN THE BEAVER RESERVOIR WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM

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Project

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ABSTRACT

PREDICTION AND MANAGEMENT OF SEDIMENT AND PHOSPHORUS IN THE BEAVER RESERVOIR WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM

A study was conducted to compile a GIS database for the Beaver Reservoir Watershed and then use the database to run the Universal Soil Loss Equation and the Phosphorus Index Model on the War Eagle Creek Watershed, a portion of the Beaver Reservoir Watershed database. Characterization of the spatial properties of the primary attributes compiled for the watershed were reported. In addition, water quality samples taken from War Eagle Creek were analyzed for relationships across the watershed. Erosion in the watershed was lower than expected with well vegetated and fertilized pastures contributing to the reduction of annual sediment yield. The Phosphorus Index Model results showed that pastures in the watershed become highly vulnerable to phosphorus transport with small amounts of phosphorus, but only a small fraction of the watershed was classified as excessively vulnerable to phosphorus transport with excessive fertilizer application rates. Aqueous total phosphorus concentrations within the watershed showed normal seasonal variability with the exception of high concentrations at one site. Aqueous ortho phosphorus concentrations also showed normal seasonal variations but few other conclusions could be drawn due to the overall low concentrations. There were few conclusive trends between phosphorus concentrations and attributes from the watershed database suggesting multiple sources contributed to the phosphorus in the War Eagle Creek.

H. D. SCOTT AND J. M MCKIMMEY

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Keywords -- Geographical Information Systems, Soils, Geology, Groundwater Poultry Litter.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (con't)

LIST OF TABLES

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INTRODUCTION

In recent years there had been much concern about the surface water quality in Northwest Arkansas. The general public opinion is that wastes from agricultural industries such as poultry and swine operations primarily responsible for most of any reduction in water quality wastes from these operations are commonly broadcast to area pastures as an organic fertilizers. The public assumption is that excessive quantities of nutrients from these mostly organic fertilizers are reaching surface waters; thus, increasing aqueous nutrient concentrations. Of the three major fertilizer elements, phosphorus seems to be the growth imiting factor for many aquatic microbiological populations. Much of the recent research was focused upon the fate of phosphorus in watersheds and reservoirs and has shown a direct relationship between algal population and aqueous phosphorus concentration, and an inverse relationships between algal population and other water quality parameters. Other studies have indicated that sediment from roads and ditches are major contributors to degradation of surface water quality. Sediment is transported from these bare surfaces to water sources during intense rains, particularly during the winter and spring increasing nutrient concentrations and turbidity in surface waters.

This study was conducted on the Beaver Reservoir Watershed and a sub-basin the War Eagle Watershed to locate areas susceptible to phosphorus transport by surface runoff and to estimate sediment loss within the watershed. A Geographical Information System and simulation models were used to estimate the spatial distribution of susceptible areas to sediment and phosphorus transport.

OBJECTIVES

The objectives of this study were to: (1) complete the GIS database characterization of the Beaver Reservoir Watershed, (2) estimate erosion from both the whole watershed and dirt roads only, and (3) investigate the spatial and temporal distribution of areas in the watershed susceptible to phosphorus transport via surface runoff.

LITERATURE REVIEW

The Beaver Reservoir Watershed (BRW) is located in Northwest Arkansas at the head waters of the White River. The reservoir is impounded by Beaver Dam west of Eureka Springs. The watershed consists of approximately 308,900 ha and includes portions of six counties with the largest portions in Benton, Carroll, Washington and Madison Counties. The reservoir serves as the primary source of drinking water for most of the major metropolitan areas both within and adjacent to the watershed. demands are being put on the reservoir by increased water usage from both expanding municipalities and new water systems designed to provide water to rural areas in the adjacent counties. The increased usage of reservoir for drinking water in recent years has enhanced the need to sustain water quality in the reservoir and the development of a management plan for the watershed. Additional information on the BRW has been published by Scott and McKimmey (1993).

Water Quality Investigations

In previous years water quality problems in Beaver Reservoir been linked either directly or indirectly to inflow of sediment phosphorus (USDA-SCS, 1986). These include (1) eutrophic nutrient loading, (2) depletion of oxygen in the lower levels of the reservoir, (3) formation of trihalomethanes, (4) high concentrations of algae affecting taste and odor of treated drinking water, and (5) excessive turbidity during winter months (USDA-SCS, 1986).

Bennett (1970) characterized the eutrophic state of Beaver Reservoir. He noted that the upper half of the lake exhibited characteristics of high nutrient loading whereas the lower portion of the reservoir exhibited characteristics of low nutrient loading observation was also noted by Larson (1983), who found an inverse relationship between phosphorus (P) and water transparency, and thus, suggested that Beaver Reservoir be classified in sections because of the unusually wide range of water quality parameters with respect to P concentration and transparency. In the lower reaches of the reservoir, P concentrations less than 0.01 mg l^{-1} resulted in much less algal activity than in the upper reaches where aqueous P concentrations may exceed 0.30 mg $^{-1}$ Larson noted that the reduction of P in the lower reaches may be due in part to one or more of the following: (1) a decrease in organic material from flooded soils; (2) the lake possesses an assimilative capacity due to the biomass and (3) a reduction in the rate of sedimentation. However, the upper reaches of the reservoir did not a reduction of P over the 13-year period. Feeny (1970) pointed out most of the sediments high in nutrients were located in the shallow upper portion of the reservoir. Annual accumulations of P in the reservoir have been estimated at 5,133 kg (Gearheart, 1973). This estimation assumed 42% accumulation of total P by inflow, but is much lower than the 110,223 kg of P yr reported by the UDSA-SCS (1986a).

The assumed reduction of P loadings from Fayetteville's new waste water treatment facility would mean that the majority of P entering Beaver Reservoir is from non-point sources. As the UDSA-SCS (1986a) reported, this P is mostly associated with sediment transport, 37% of which comes from dirt roads and drainage ditches. The SCS reported that reducing sediment runoff from dirt roads and drainage ditches is too expensive to be realistic.

The only known eutrophication model for Beaver Reservoir was based on phytoplankton production (Gearheart, 1973; Kirsch, 1973). The objectives of the model were to: (1) determine the rate of nutrient accumulation; (2) develop a eutrophication model to predict future eutrophication levels; and (3) identify and isolate the major nutrient sources. Source identification was achieved by classifying each tributary and drainage area by the type of predominant land use in the source area The major land use classifications were agricultural land, non-agricultural land, municipal waste treatment, and urban areas. Average rate of accumulation for P was estimated to be 14 kg day^{-1}, determined by comparing inflow and outflow nutrient concentrations. It should be noted that these calculations were based upon Eley's (1969) 70% nutrient retention calculated from a sampling period between October 1968 and April 1969. Eley did not take into consideration the patterns during the summer months when outflow exceeds inflow, yet, the model showed the expected cyclical pattern of high accumulations of nutrients during the wetter winter months and nutrient loss during the dryer summer months. This is not surprising given that sediment and P are transported mainly during larger rainfall events. Eley concluded that the majority of nutrient loading of BRW was from agricultural lands. However, since whole sub-basins in the watershed were classified as either forest or agricultural, the results were rather crude. Some of Gearheart's (1973) and Kirsch's (1973) conclusions were: (1) that there was an accumulation of nutrients in the reservoir; (2) major nutrient contributors were agricultural lands and municipal waste water; (3) nutrient inflow could be accurately predicted by rainfall; and (4) there was no significant relationship between concentrations of P and algal growth rates in the reservoir

Many of these research studies were conducted before the great expansion of the poultry industry in Northwest Arkansas and may not reflect the present conditions in the BRW. Since Fayetteville's new waste treatment plant came on line in 1988, there has been little published results of water quality studies down stream from this facility. An assumption that nutrient loading from Fayetteville's waste treatment facility will be drastically reduced means that the inflow of P to the reservoir will decrease However, an increase in septic filter fields, changes in urban influences, and changes in agricultural practices could affect the non-point sources of P. All these sources should now be the focus of both the public and researchers alike.

Phosphorus and Fertilization

Inorganic forms of P, in addition to nitrogen (N) and potassium (K) are commonly applied to agricultural lands to increase the fertility of the soils for crop production These elements exist in many different forms in soils, some of which are immediately available for plant use Other forms are considered to be fixed by soil components and not available for plant use. Fertilization recommendations are made according to plant-available forms of N, P and K. Commercial inorganic fertilizers are a mixture of N, P and K at varying ratios to meet specific soil requirements for plant growth.

Organic fertilizers are also available as soil amendments. These are similar to inorganic fertilizers with the exception that there is a relatively high concentration of organic carbon and other organic compounds. Many of the elements in the organic amendments gradually become available for plant uptake through a process called mineralization. Organic fertilizers are available in the form of animal wastes such as poultry litter or swine manure. These wastes differ from commercial inorganic and organic fertilizers in that the N:P:K ratios are not reflective of natural conditions or specific soil requirements. Ideal N:P ratios in nature are commonly 10 parts N to 1 part P and can be altered by crop production or improper fertilization. Nitrogen concentrations in soils will decrease more rapidly than P due to the needs of vegetation and microbial populations resulting in a nutrient imbalance. Such situations are quite common in agriculture particularly where poultry litter is frequently used as a fertilizer. Most poultry litter has a N:P ratio of between 2 and 3 (Scott et al., 1994).

In Arkansas, fertilizer recommendations are made by Cooperative Extension personnel based upon soil test samples taken from individual fields. In Northwest Arkansas these recommendations will call for additional applications of N but not P because of an imbalance in the N:P ratio. In such situations, inorganic forms of N without the addition of P are recommended. However, commercial fertilizers are expensive and may not be used. The farmer may achieve the recommended N level by applying increased amounts of poultry litter. Since the N:P ratio in the litter is approximately 3, the fields may receive several times more P than is required for plant growth. This additional P will exist both in the soil solution as dissolved P and as P adsorbed by soil components. Added P will replace other weaker bound minerals on the colloidal surface until a chemical concentration balance between the soils solution and soil colloidal surface is reached. The net effect is an increased concentration of P in the soil solution and on the colloidal surface P adsorbed by the soil colloidal surfaces is not readily redistributed in the soil profile. Transport of P bound to soil surfaces is initiated by erosion

Modeling in GIS

Many models used in a GIS environment consist of components require three primary data operations: input, manipulation and output. These models are a series of numerical computations that are incorporated into computer readable code that is simply an interface between the user, computer and the model computations. The most important component in this situation is the model computations because this component reflects the authors knowledge of the phenomena being modeled.

Modeling within a GIS environment often requires the user to know every detail of a model because the attributes within the database must reflect the necessary model parameters. Model parameters may be a digital map of a specific theme covering the entire study area. These digital maps are either primary attributes themselves or secondary attributes which are created from primary attributes. Primary attributes are data that are absolutely necessary in the database and can only be generated sources such as hard copy maps or tabular data by various methods. Common primary attributes include elevation, soils, geology, transportation, hydrography, land use and land cover, however, there can be others depending upon the parameters that a model requires. These data can be one of four different spatial characteristics: points, ines, areas or surfaces. Point or site data are specific locations described by a single x,y coordinate pair typically with an associated z value. In this study, point data were used to locate surface water sampling sites and poultry or swine houses. Primary attributes can also be line data. Lines are a collection of x,y coordinate pairs with a single z value describing the feature. Transportation and hydrography are represented as lines attributes are themes such as soils, geology, land use and and cover. Surface attributes can be almost any theme that is contiguous across an area such as elevation. A model may require one or more of these themes either in the original or some permutated form.

Permutations of the primary attributes are considered to be secondary attributes and are generated by a number of different methods from themes within a database. Methods of permutations can include classification, mathematical manipulation and primary attribute combinations. This does not mean that secondary attributes are important than primary attributes. In fact, secondary attributes are frequently more important because they re-define the primary attribute into a more useful form. One such example is classification of soil maps. In conjunction with the SCS's county soil survey publications, mapping units can be classified into, but not limited to, any of the following secondary attributes: (1) texture, (2) bulk density, (3) pH, (4 depth to bedrock, (5) permeability, (6) drainage, etc. Secondary attributes can be more important than the soil mapping unit since the soi mapping unit is simply a name associated with the previously named characteristics. Any of these secondary attributes are represented with numerical values that quantify the attribute. With respect to numerical modeling, these are much more important than a simple name

MATERIALS AND METHODS

Database Development

The hardware for our study consisted of a SUN SPARCstation operating on a UNIX platform, an Altek AC-30 digitizer, a Houston Instruments pen plotter with a scanning head, an AT&T 386i DOS/UNIX based workstation, and a Context FSSE8000 scanner. Software used in this research included the GIS software GRASS, SCAN-CAD, CADImage/SCAN, and Line Trace Plus (LTPlus). Maps were scanned either by a Houston Instruments plotter/scanner at 200 dpi or by a Contex scanner at 400 dpi. These files were transferred to another software package LTPlus. This software was designed by the U.S. Forest Service and modified by the SCS with the purpose of creating soil maps and Digital Elevation Models (DEM).

The GIS software used in the study is known as Geographic Resource Analysis Support System (GRASS). GRASS is a public domain, general propose, grid-cell based geographical modeling and analysis computer software package developed by environmental planners with the Army Corp of Engineers for environmental impact studies at military installations. GRASS databases are composed of three major data forms: (1 site or point, (2) vector or line, and (3) raster or grid data. Since GRASS is grid-cell based, most of the analyses and modeling were based upon raster data. Vector data are mostly an intermediate data format used in the production of raster information

Development of the GIS for the Beaver watershed was accomplished by several data input methods including digitizing and/or scanning hard copy maps, importing spatial data already in a digital format and keyboard entry of tabular data. The method used to input the data depended upon media availability of each primary attribute. Data such as roads, hydrography and digital elevation models were available in a digital format These attributes were imported into the database using appropriate commands. Soils, geology, and land use and and cover available only in a map format and were incorporated into the data base by several digitizing methods.

The boundary of the BRW was determined by manual interpolation of 7.5′ USGS topographic series maps. The interpolation was drawn on a mylar overlay and digitized by hand into the database. This boundary was to define the areal coverage of the watershed in the Northwest Arkansas area and also used as a mask to exclude characterizations and calculations of areas outside the watershed Al reports and characterizations were generated with this mask

Primary attributes in this study were elevation, soils, hydrography, transportation, land use and land cover (LULC) and geology. The sources of these data varied, but generally were the federal and state agencies that are responsible for these themes (Table 1) The Tennessee Valley Authority (TVA) was another source for land use, land cover and hydrography. Although the TVA and the USGS data had the same theme, there were large differences in detail and accuracy with the TVA data being much finer. These LULC data were obtained from the Army Corps of Engineers (ACoE) in Little Rock. They were produced for the ACoE by the TVA in an Intergraph DGN format. The TVA data were subsequently sent to Louisiana State University's CADGIS Laboratory for conversion to a DXF format, suitable for import to GRASS digit vector files.

Additional attributes included a sub-basin boundaries, roads,

Table 1. Primary attributes of the Beaver Reservoir Watershed database. Sources, scales and media materials varied depending upon source data availability. k = 1,000 LULC = land use/land cover

Attribute	Source	Media	Scale
Elevation	USGS	Digital	1:24k
Hydrography	TVA	Digital	1:24k
Transportation	USGS	Digital	1:24k
Soils	SCS	Mylar	1:20k/1:24k
Geology	AGC	Vellum	1:24k
LULC	TVA	Digital	1:24k

hydrography, LULC. Other attributes such as formation contacts, lineaments, linear seeps, and incorporated city boundaries were included, but coverage was limited to 11 quadrangles in the middle of the watershed

Digital Elevation Models

Digital elevation models (DEM) are maps arranged in an array of pixels or cells that portray the topography of an area by elevation above mean sea level in meters. Individual map areas were defined by the boundaries based upon the two national mapping grid systems provided by the USGS. The first format, produced by the Defense mapping Agency, is a 1° x 1° format generally published at a scale of 1:100,000. In Northern Arkansas each cell in the grid is approximately 80 m x 80 m with each cell containing an elevation value. The other format is the standard boundaries for the USGS 1:24,000 scale topographic series maps.

DEMs are divided into 30 m x 30 m cells. The datums of these two elevation files were significantly different, WGS-72 and NAD-27, respectively.

All DEMs were imported into GRASS as individual quadrangles and then patched together for a composite DEM map of the entire watershed. between quadrangles were filled on the full watershed coverage DEM using methods defined by McKimmey (1994). DEMs for the BRW had varying elevations for the reservoir level which resulted in strips across the reservoir surface with differences of approximately 1 m. This error was corrected by reclassifying all map values less than 341 m to 341 m (1,118 ft.). This was the final DEM from which all calculations and secondary attributes were made.

Soils

Soils data were provided by the SCS in Little Rock on stable Mylar media in one of two map formats. The first format was a 7.5′ x 7.5′, 1:24,000 scale hand-drafted Mylar. Some of the maps were redrawn from the previously published unrectified aerial photographs to fit the format. The second format was a 2.5′ x 7.5′, 1:20,000 scale orthophotographic reproduction. Both formats are based upon an Order II soil survey. The surveys were conducted by SCS soil scientists using both field sampling and aerial photograph interpretation according to Order II guidelines.

Soil surveys were conducted on a county basis at various times and by different personnel. As a result, mismatches were often present across county boundaries with regard to soil mapping units and aerial coverage Some of the mismatches were simply a name change with no change in soil properties and description; whereas, differences in the soil properties and description occurred with other mismatches. At this time, it is not possible to correct these problems across county boundaries because changes in soil mapping unit names and descriptions must be approved by the SCS. Correcting these adjoining areas would most likely require additional ground surveys and recompilation of the soils for several counties in Arkansas. The result of such work would require that changes in both soil mapping unit names and properties

Surface Geology

Geology maps were obtained from the AGC on a stable vellum media All but six of the quadrangles in the watershed were in the 7.5′ 1:24,000 scale format. The remaining six quadrangles were on two 15′ 1:62,500 scale. All of the source maps were originals for the state 1:500,000 scale map. Because of the reduction of scale on the state map, formations originally surveyed on the 7.5′ maps were either omitted combined with others, or given an exaggerated areal coverage The geology entered into the BRW database included formations at the same detail as mapped on the 1:24,000 scale originals. However, additional detail was added to several quadrangles to correct for mismatches between quadrangles and to achieve the same level of detail for all maps

Quadrangles around the reservoir were mapped by ground survey with much more detail than quadrangles in the southern portion of watershed. The southern portion of the BRW was mapped mainly by aerial photography with little delineation of individual rock units in formations. This resulted in areas in the south that were given a single formation classification, whereas around the reservoir the same formation was broken into separate members For example, on the Boston Mountain Escarpment there was an upper Mississippian formation named Mpfb which iincludes Pitkin Limestone, Wedington Sandstone, Fayetteville Shale and Batesville Sandstone. These formations were mapped as one unit along some of the Boston Mountain Escarpment, but in other quadrangles they were mapped as separate units. These conflicts in detail were resolved for this formation by ground surveys in conjunction with additional interpretation of infrared and black white aerial photographs. The quadrangles surveyed were Durham, Fayetteville, Forum, Goshen, Hartwell, Hindsville, Huntsville, Japton, Kingston, Sulphur City and West Fork. Additional surveys were not conducted on other formations because they were mapped at the same level of detail. This does not mean that these formations are uniform with respect to rock type. For example, the Atoka Formation is mapped as one unit but it contains alternating layers of shale and sandstone which are visible on aerial photography

All of the geology maps were digitized into the database by hand tracing the formation contacts with the same procedures and accuracy standards previously mentioned.

Land Use-Land Cover

The LULC was developed by the TVA from both infrared and black and white aerial photography. An infrared aerial photography mission was flown on March 25, 1988 at a scale of 1:24,000. This series was formatted to the standard 9" x 9" infrared color transparency format. The black and white photography was a mixture of high altitude photography missions flown in 1980, 1983, and 1985. Most of the data for the LULC was derived from the black and white photography. The infrared photography was used to identify several quality parameters of pastures within the watershed These data were drawn on a 7.5′ quadrangle formatted mylar and digitized using the Intergraph software. The data were then rectified to correct for the radial distortion inherent in aerial photography. Unlike the other TVA data, these data did not have any attributes associated with the work. These data were labeled in the GRASS using the same conventions and precautions established during development of the soils database (Scott and McKimmey, 1993).

The classification scheme of the LULC was derived by the TVA. It was more detailed than the USGS classification system (Table 2 and Table Where the USGS would classify an area as cropland and pasture, the TVA data separated cropland from pasture and gave additional information as to the quality of the pasture, good, fair or poor (Table 3). The additional description of pastures was interpreted from the infrared photography. The date of the mission, March 1988, allowed the classification of pastures by the intensity of reflected energy As pastures start to grow at during spring, differences in growth rate, and thus quality of a pasture, can be related to the intensity of the returned infrared energy. Good pastures returned a higher mount of infrared energy than fair or poor pastures. Patterns of uneven or unnatural growth can also be seen on the photographs. These irregularities were indicative of pasture fertilization. Terraced and gullied pastures were also noted on the photographs

In addition to the LULC provided by the TVA, all poultry and swine structures were digitized into the LULC as a separate attribute. These data were digitized in GRASS by overlaying the 1988 photographs over the corresponding quadrangle and digitizing each structure as a line that was approximately the same length as on the photograph. Radial distortion in

Table 2. Major similarities and differences in land use and land cover categories of the USGS and TVA classification system. This table reflects land use and land cover in the Beaver Reservoir Watershed only.

USGS level II	TVA Classification
Residential	Residential
Commercial	Commercial
Industrial	Industrial
Transportation	Transportation
Mixed Urban	Mixed Urban
Other Urban	Recreational
Deciduous Forest	Deciduous Forest
Evergreen Forest	Evergreen Forest
Mixed Forest	Mixed Forest
Streams	Streams
Lakes	Lakes
Reservoirs	Reservoirs
	Ponds
Transitional Areas	Transitional Areas
Cropland and Pasture	Cropland
	Pasture
Orchards, Vineyards, Nurseries	
Confined Feeding Operations	
Other Agriculture	

the photography was corrected by aligning the nearest ground features on the photograph to the corresponding map feature. Once the structures were digitized, they were converted to point or site data. Not all confined animal houses digitized from the photographs were in operation. The

Table 3. Additional descriptions provided with the Tennessee Valley Authority land use and land cover classification system.

Major Class	Minor Classes	Additional Classes
Cropland	Row Cropped	
	Double Cropped	
Pasture	Good	None
		Fertilized
		Terraced
		Gullied
		None
		Fertilized
		Terraced
		Gullied
		None
		Gullied
	Woodland	None
		Gullied
	Over Grazed	None

photographs showed evidence where houses had been destroyed, perhaps by ice storms. These were omitted from the data base. However, other houses were intact but in poor condition and were included in the database. It was not known what percentage of houses digitized were in operation. It should be noted, however, that these data as well as LULC in general are temporal and will change from year to year. Therefore; the number of confined animal operations in the database is applicable only to 1988, but can be useful in a broad sense.

Hydrography

The TVA data were selected as the source for the hydrography database. These data were more detailed and descriptive than the DLGs Another factor was the level of accuracy of the DLGs. DLGs for the BRW were available only in a 1:100,000 scale format. Upon comparison of data from the two sources, the TVA data fitted the 7.5′ DEM features with more accuracy. TVA data also included double line, perennial, ephemeral, and, intermediate streams classifications not on the USGS DLGs. Because of the scale of the USGS hydrography source material, 1:100,000, these features were omitted. In addition to the stated added categories, each of the TVA categories was further defined as streams with animal access Although these data were not used in this study, it could be of use for later studies. Length of streams in the watershed was estimated using methods defined by McKimmey (1994)

Transportation

The transportation selected for the database was from the Although these data were not compiled at a large enough scale, they were more complete than the TVA data, and had a more defined classification system. The classification system put each mapped road into a class that described its surface, amount and type of traffic and the passibility during wet weather conditions Class 1 roads were paved primary highways used by all traffic in any weather. Class 2 roads were paved secondary routes connecting towns and primary roads used by all traffic during all weather conditions Class 3 roads were either paved or unpaved roads that connected to secondary or primary routes used by local traffic and passible during all weather conditions. Class 4 roads were mostly unpaved roads used by local traffic and passible only in dry weather. Class 5 roads were trails that were used as service roads along power lines and trails that were passible only during dry weather. These data were available in a digital format from the USGS as DLG data. Distances were estimated using the same methods described by McKimmey (1994). Estimates were given according to U.S. Highways, State Highways, class 3, class 4 and class 5 roads

Water Quality Samples

One of the objectives was to investigate relationships between selected attributes of the BRW database and water quality samples taken within the BRW. The lack of full coverage of accurate DEMs and their secondary attributes, such as slope and aspect, prevented proper investigation into the relationships between aqueous P concentrations and selected attributes of the BRW database. Thus, analyses of the aqueous P concentrations and selected database attributes were conducted only on the WEW.

Water samples were taken by personnel of the ADPCE three times per year during May, August and December. The objective of the sampling was to sample at high, low and medium water flows, respectively. Flow values were qualitative judgements based upon the percent of stream filled at each sample point. Both total P and ortho P were determined for each sample and reported in mg L^{-1}. The minimum detection levels of P were 0.03 mg L^{-1} which is lower than what is considered high concentrations for streams, 0.1 mg L^{-1} (ADPCE, 1988). The sampling began in May, 1992 and ended in August, 1993. A total of seven sampling sites in the WEW were selected. Of these sites, six sites were on the War Eagle Creek with

WRE01 designated as the first upstream site and WRE06 the last down stream site. CLF01 was taken from Clifty Creek, a tributary of War Eagle Creek near WRE06. All samples were taken in the main stream of the creeks

Taking the samples in the middle of the creek between banks posed a question of whether these samples were statistically independent of each other. The data were graphed with the P concentration as the dependent variable and the sub-basin as the independent variable. If the samples were dependent, there would be trends reflecting the relationships. If the samples were dependent, there would not be any trends (McKimmey, 1994). In addition to plotting the samples by sub-basin, they also were plotted against selected attributes from the WEW database such as geology, LULC, slope, soil texture, soil permeability, soil test P and erosion.

Model Implementations

The USLE and PI models were used in this research. The USLE model was used to predict the rill and inter-rill erosion from both dirt roads and the whole BRW. Both models are empirical, and are either in use or will be used by the SCS and other government agencies to simulate field conditions. This was the premise for the selection and the implementation of these models in this study. Incorporation of these simulation models stands as a beginning point for further research using more complex models.

All DEMs were not available for the whole BRW and the data required to generate these DEMs could not be obtained in time to be included in this project. Therefore, all simulation modeling was performed on the War Eagle Watershed (WEW). Scripts used to generate the attributes and model parameters for the WEW can be easily adjusted to run on the BRW.

Universal Soil Loss Equation (USLE)

There are numerous models that predict erosion, some of which are empirical in that they estimate erosion based upon parameters that were determined in previous research. One of the most used empirical erosion models is the USLE (USDA 1978). The model is given in equation [1]

$$A = R * K * LS * C * P$$

where A is the soil loss (tons acre^{-1} year^{-1}), R is the rainfall index, K is the soil erodibility factor, LS is the slope and slope length factor C is the cropping factor, and P is the prevention factor. parameters are ratios derived by dividing calculated values of an area of interest by the volume of annual soil loss from a standard unit plot that is 72.6 ft long with a uniform slope of 9% and free of vegetation so that maximum erosion can occur. Ideally, a unit plot will exist for each soil mapping unit.

Most of the parameters for the USLE model were simple classifications of primary attributes. The rainfall index was a single value and was obtained from a isoerodent map. Soil erosivity was determined by reclassifying the soil mapping units to K factor values based upon data from the county soil surveys. Slope and slope length factors were derived using methods described by McKimmey (1994). Cover factors values, C, were produced by classifying LULC according to the USLE publication guidelines (Table 4). The cover factors associated with a particular LULC was chosen based upon general characteristics observed within the watershed. These values represented average conditions that best fit the general description of a particular LULC in the watershed It is highly unlikely that all good pastures actually had a cover factor

Table 4. Universal soil loss equation C factors derived from Tennessee Valley Authority land use and land cover. Data were classed according to the best description from the United States Department of Agriculture Soil Conservation Service manual.

Land Use Land Cover	Cover Factor value
Residential	0.003
Commercial	0.000
Industrial	0.000
Transportation, Communications and Utilities	0.039
Recreational Areas	0.003
Mixed or Built-up Land	0.042
Scrub and Brush Land	0.039
Deciduous Forest	0.001
Evergreen Forest	0.003
Mixed Forest	0.002
Strip mines, Quarries and Gravel Pits	1.000
Transitional Areas	1.000
Row Cropped	0.150
Double Cropped	0.140
Good Pasture	0.003
Fair Pasture	0.013
Poor Pasture	0.040
Woodland Pasture	0.085
Overgrazed Pasture	0.100
Confined Animal Operations	0.150

of 0.003 due to local variances within the watershed and this was particularly noticeable in woodland pastures where the cover factor selected represented an average canopy cover of 50 % with a 60 % ground

cover of grass like plants. The only solution to this dilemma would be to either conduct a ground survey or to interpret each individual area from aerial photography or satellite imagery. In this case, the former is nearly impossible while the latter is feasible given time, experienced personnel and sufficient resources. The P factors in the USLE model were not considered because of the relatively low concentration row crops. Most row crops in the watershed were small privately owned produce gardens.

Rill and inter-rill erosion from dirt roads was calculated by the same means as the whole watershed. A raster map representing the roads was used as a mask to exclude all areas other than roads during the calculation of the LS factor and the USLE. K factors were not changed because it was assumed that the road was composed of the same soil that the road traversed. C factors were given a value of 1, thus omitted, to represent no cover. The LS factor was recalculated using the roads as a mask. The routine was the same as with the whole watershed; however, the determination of slope lengths was based upon roads only. Although the LS for roads was based upon natural slope and aspect, the lengths estimated may not have been too far from reality. Generally, the slope of a road is related to the elevation gradient in the direction of travel. The aspect should reflect the cardinal direction of travel of the downhill portion of the road. This method assumes that there is no slope from side to side and that the road was not crowned; thus, water would run down the road and never leave until a stream or ditch is encountered, resulting in excessively long slope lengths. Using the natural slope and aspect would shed water off the road to the ditches within one cell in most cases rather than running water down the road. These considerations suggests that the majority of erosion in roads would be gully erosion and not and inter-rill erosion.

Phosphorus Index Model

The Phosphorus Index (PI) model is a qualitative weighted function that includes parameters such as soil erosion, irrigation erosion, runoff, soi P concentrations, P fertilization type, application and method (Table 5). Each of these parameters was given qualitative values or weights that portray their influence on the susceptibility of an area to P transport. The weights were summed for all parameters and then classified according to the range to which the sums correspond. The results of the model qualitative measures of the susceptibility of P transport and given as

Table 5. Tabular depiction of the Phosphorus Index Model. Values are multiplied by ratings, products are summed, and then classed into qualitative measures.

	Phosphorus Loss Rating (value)				
Parameter (weight)	None (0)	Low (1)	Medium (2)	High (4)	Very High (8)
Soil Erosion (1.5)	N/A	< 5 Tons Ac^{-1}	5 - 10 Tons Ac^{-1}	10-15 Tons Ac^{-}	> 15 Tons Ac^{-1}
Runoff Class (0.5)	Neg.	Very Low or low	Medium	High	Very High
Soil P Test (1.0)	N/A	Low	Medium	High	Excessive
Inorganic P (0.75)	None	1-30 lbs Ac^{-1} P_2O_5	31-90 lbs Ac^{-1} P_2O_5	91-150 lbs/Ac P_2O_5	> 150 lbs Ac^{-1} P_2O_5
Inorganic Method (0.5)	None	Planter	Incorp.	Incorp.	Surface
Organic P (1.0)	None	1-30 lbs Ac^{-1} P_2O_5	31-60 lbs Ac^{-1} P_2O_5	61-90 lbs Ac^{-1} P_2O_5	> 90 lbs Ac^{-1} P_2O_5
Organic Method (1.0)	None	Injected	Incorp.	Incorp.	Surface

low, medium, high and very high (Table 6). In this study, erosion due to irrigation was omitted because of the lack of irrigation in the BRW.

Table 6. A description of the PI indices and site vulnerability

P Indices	Site Vulnerability
< 8	Low
8 to 14	Medium
15 to 32	High
> 32	Very High

The PI model was run within the GRASS environment using the compiled WEW database. Analyses were conducted on the whole WEW and pasture areas only. Soil erosion was a classification of the USLE according to rating values in Table 5. Runoff class was a combination of slope soil permeability Table 7). Areas with slight slopes and rapid soil

Table 7. Surface runoff classification system for the PI model. system is based upon classification of slope and soil permeability.

	Soil Permeability				
	Very Rapid	Moderately Rapid to Rapid	Moderately Slow to Moderate	Slow	Very Slow
	> 20.00	2.00 - 20.00	0 20 - 2.00	0.06 - 0.20	< 0.06
Slope (%)	Runoff Class				
Concave	N	N	N	N	N
< 1	N	N	N	L	M
1 - 5	N	VL	L	M	H
5 - 10	VL	L	M	H	VH
10 - 20	VL	L	M	H	VH
> 20	L	M	H	VH	VH

Runoff Class: N = Negligible, VL = Very Low, L = Low, M = Medium, H = High, VH = Very High permeability were classed as negligible influence in P transport while steep slopes and low soil permeability were very influential in P transport. These data were derived by classification of the soil mapping units into permeability classes and slopes into appropriate classes (McKimmey, 1994). These attributes were combined according to Table 7 to produce the runoff class with 5 values ranging from 0 to 8 and changed on a log 2 basis (Table 5).

Soil test P (STP) data were obtained from county SCS offices Because of regulations governing the privacy of individuals, exact locations of these sampling sites were not provided. The only additional information available was the soil mapping unit from which each sample was taken. This allowed the estimation of a representative value for each mapping unit by using the median of all STP samples for each soil mapping unit Table 8). The soil mapping unit attribute was then reclassified according to these medians into values reflecting average STP for each mapping unit. Median STP was then reclassified according current SCS guidelines where 100 lbs acre^{-1} was considered as a high P concentration. In addition, concentrations greater than 200 lbs acre^{-1} were given the excessive description in the PI model. An additional set of maps were also created using 300 lbs acre^{-1} as the lower limit for the excessive category. Values assigned to these categories were the same as those given in the runoff and erosion categories with 1 being low and 8 being excessive.

Preliminary calculations of the PI model were made to determine what could be considered as the current status of P susceptibility to transport within the watershed. Like the STP, fertilization information was not

Table 8. Median soil test phosphorus concentrations (STP) in War Eagle Watershed. Data were supplied by the Cooperative Extension Office in Madison County.

Median STP	Taxonomic Unit	# Obs.	ha	% Cover
48	Leadvale	3	999	1.2
51	Elsah, Guin*	1	1,069	1.2
52	Arkana*, Arkana-Moko, Moko*, Sogn*, Hector-Mountainburg*, Summit Variant	4	396	0.5
72	Baxter*, Noark	2	7,631	8.8
78	Cleora	6	1,052	1.2
105	Tonti	1	1,874	2.2
120	Peridge	1	910	1.1
131	Steprock	2	2,927	3.4
140	Nella	1	467	0.5
150	Enders-Allegheny*, Enders-Leesburg	6	28,813	33.3
167	Apison*, Leesburg	1	1,027	1.2
173	Clarksville	4	8,179	9.5
178	Johnsburg, Cherokee*, Mayes*, Savannah*	19	469	0.5
197	Mountainburg	1	196	0.2
200	Fatima*, Healing, Razort*	4	1,059	1.2
201	Nella	2	964	1.1
209	Mountainburg	1	1,497	1.7
220	Ceda	4	2,358	2.7
230	Captina, Pembroke*, Pickwick*	10	1,614	1.9
238	Nixa	7	6,462	7.5
252	Nella-Steprock-Mountainburg	1	2,954	3.4
262	Britwater, Nella	2	626	0.7
273	Enders	2	646	0.8
286	Enders	2	481	0.6
292	Mountainburg	16	1,563	1.8
358	Linker	13	1,018	1.2
385	Enders	4	2,260	2.6
457	Nixa	1	5,134	6.0
466	Waben	1	120	0.1
487	Secesh	1	725	0.8
752	Allen	1	355	0.4
	Water and Rock		595	0.7
Total		124	86,440	100.0

*Correlated to another due to no data. Correlations were based on soil properties.

available. Therefore, realistic values of P fertilizer type, rate of application, and method of application were input into the PI model. These values were determined from SCS fertilization guidelines which estimate that there are 44.5 lb of P_2O_5 per ton poultry litter. Application rates in the WEW are commonly 2 tons acre^{-1} while some applications of 4 tons acre^{-1} also occur, both of which are used in these simulations. It should be noted that most fertilization recommendations and applications on area pastures are made on a N basis.

P Fertilizer application rates and types were set according to Table 9. Values used for organic fertilizer reflect actual estimates of P_2O_5 for each ton of litter. The map of PI indices were classified as to the site vulnerability (Table 6) and areal statistics were run on the results of all treatments.

Table 9. Weights and rating values of fertilizer source and method for the PI model used in the War Eagle Watershed. Application method rating value of 8, not shown, was used for all treatments.

P_2O_5 (lbs acre^{-1})	Application Method (wt)	Source Weight	Litter (tons acre^{-1})	P_2O_5 (lbs ton^{-1})	Rate Value	Quality
Inorganic						
1 - 30	0.50	0.75				Low
31 90	0.50	0.75			2	Medium
91 150	0.50	0.75			4	High
> 150	0.50	0.75			8	Very High
Organic						
1 - 30	1.00	1.00	0.5	22.25		Low
31 - 60	1.00	1.00	1	44.5	2	Medium
61 90	1.00	1.00	2	89	3	High
> 90	.00	1.00	4	178	8	Very High

RESULTS AND DISCUSSION

The characteristics of the BRW were developed by the compilation of the primary then the secondary attributes. Both types of attributes were developed according to the parameters required for the USLE and the PI models. Results of the model simulations, as well as the model parameters, were subsequently related to the water quality analyses of the streams. Reports of areal coverage for both primary and secondary attributes were generated for the watershed, thus characterizing the BRW watershed according to the chosen attributes

Characteristics of the Beaver Watershed

Characterization of the BRW was accomplished by using a mask to exclude all areas outside the watershed. Since most of the attributes were generated on a whole quadrangle basis, using a mask was necessary. In addition to the boundary mask, most attributes were characterized with the reservoir and some lakes as separate categories. This was necessary because most attributes were affected by the reservoir in one way or another. Attributes that specifically included the reservoir were soils, LULC and hydrography. Although transportation did not include a parameter of the reservoir, it was implied by the omission of roads before the impoundment of the reservoir waters. The elevation attribute reflected the reservoir by depicting the elevation of the water surface at the time the DEM was developed. Not all DEMs had the same reservoir level, but none of the various reservoir levels on the DEMs were above the 341 m 1,120 ft.), the normal reservoir elevation. This was the reasoning for setting a DEMs for the normal reservoir elevation. Geology was the only primary attribute that did not include the reservoir. All reports that follow with the exception of geology reflect all water bodies in the manner which they were mapped or classified. The exception to this is the elevation and its derivatives which reflect the reservoirs lakes categories from the TVA hydrography. These categories were used to portray the reservoir in all other secondary attributes.

Watershed Boundary

The BRW is bounded by the Illinois Watershed to the west, Little Sugar River Watershed to the northwest, and Kings River Watershed to the east. To the southeast and south is the Mulberry Watershed. West of the Mulberry Watershed is the Hurricane Creek, Frog Bayou, and Lee Creek watersheds bounding the southwest portion of the BRW.

The southeast portion of the watershed is unusual in that this is the location of the headwaters of the White River and War Eagle Creek, both within the BRW, as well as several major streams in northern Arkansas such as the Kings, Buffalo and Little Mulberry rivers. All of these rivers originate in a 12-square mile area near Boston, AR. Just east of this area near Fallsville, AR are the headwaters of the Big Piney River. The southern portion of the BRW s a section of a greater watershed boundary that divides the Arkansas River and the White River and their tributaries with the White, Buffalo and Kings rivers flowing north and east and the Mulberry and Big Piney rivers flowing generally west and south, respectively, to the Arkansas River

The BRW covers portions of six Northwest Arkansas counties (Table 10). Within Benton County, communities within the BRW include a portion of Rogers and Garfield. In Carroll County, there are no major communities within the watershed as this is the most isolated area around the

Table 10. Areal coverage of each county included in the Beaver Reservoir Watershed.

County	Hectares
Benton	46,891
Carroll	11,030
Crawford	18
Franklin	4,975
Madison	153,120
Washington	92,940

reservoir. Washington County is the most populated and major communities within the BRW include, Fayetteville, Elkins, West Fork, Winslow Goshen. The majority of the BRW is in Madison County and includes Huntsville, Clifty, Pettigrew and St. Paul. Neither Franklin nor Crawford counties have any significant communities within the BRW boundaries.

The BRW can be divided into eight major sub-basins (Figure 1) largest sub-basin is War Eagle Creek. This sub-basin is unique among the other sub-basins in that many of ts characteristics are proportionally similar to the BRW. The second largest sub-basin includes streams that drain directly into Beaver Reservoir without entering a major tributary Table 11). The total coverage of the White River above the reservoir was 148,926 ha or 48.21% of the total watershed. Richland Creek was included in the White River sub-basin.

Digital Elevation Models

A graphical portrayal of elevation within the BRW was produced by patching 80 m DEMs into the areas covered by the missing 30 m DEMs. Although this provided full coverage of elevations, the composite DEM could not be used in calculations of the USLE and the PI Model on the

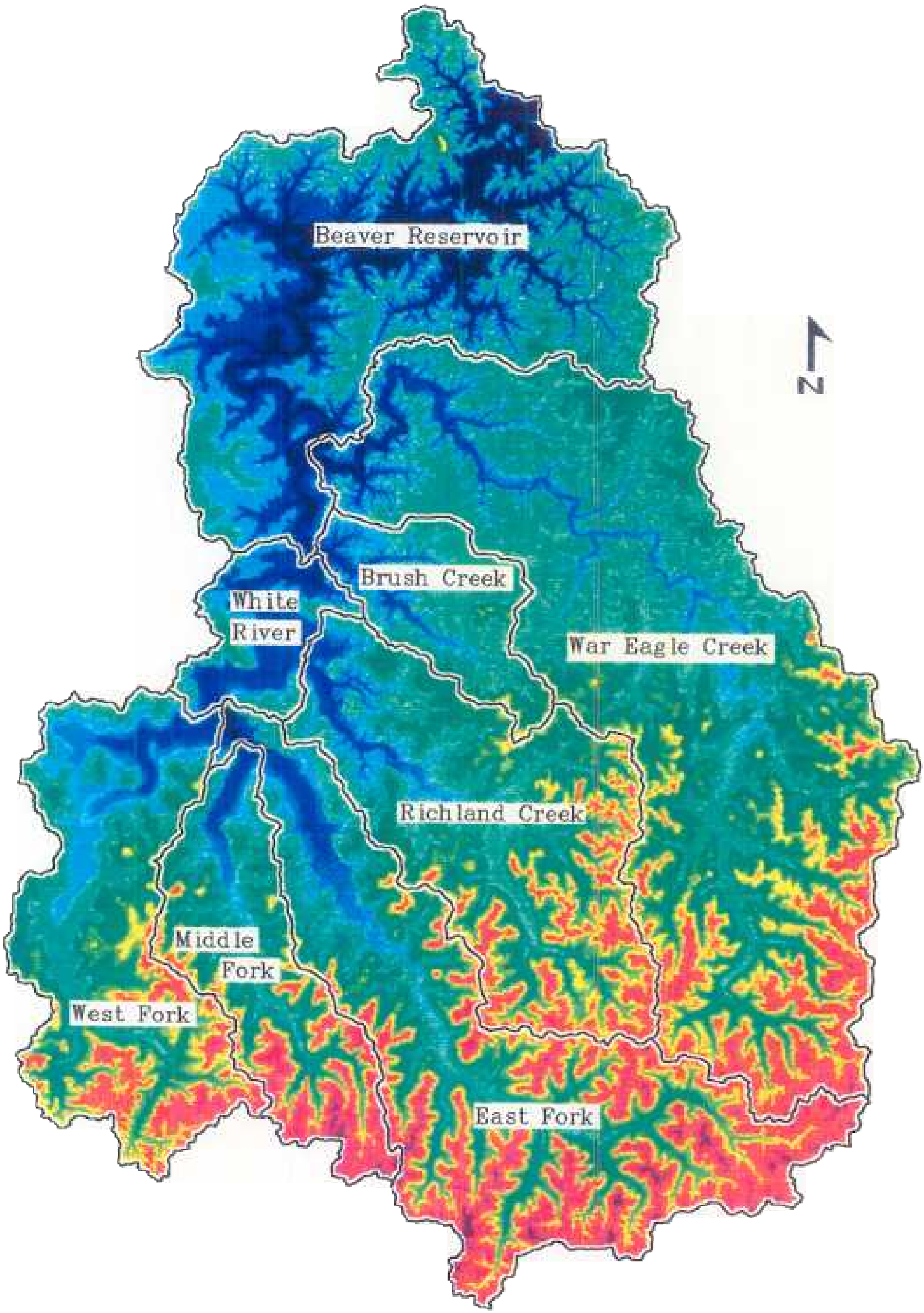

Figure 1. Major sub-basins in the Beaver Watershed overlaid on the DEM composite. Composite was constructed from 30 m and 80 m DEMs. Sub-basin data were obtained from the Tennessee Valley Authority.

whole BRW. Some positions on the 80 m DEMs were as much as 200 m displaced due to datum differences. Severe problems with banding in the coarser DEMs resulted in inaccurate slope and slope aspect calculations. These inaccuracies would result in gross errors in the USLE which uses both slope and aspect in the estimation of erosion. As a result both the and the PI models were run using the WEW portion of the database. Characterization of elevations, slope and aspect in the BRW was affected by the inclusion of the 80 m DEMS. When the elevations of the composite were plotted against the area covered by each elevation, some elevations had a much more areal extent than normal. The composite DEM was reclassified to show only these elevations with large areal coverage. The majority of these elevations fell within areas where the 80 m DEMs were substituted for the missing 30 m DEMs. This was further support for

Table 11. Distribution of the major sub-basins in the Beaver Reservoir Watershed. Data were interpreted by the Tennessee Valley Authority.

Sub-Basin	ha	% Cover
Beaver Reservoir	61,989	20.07
War Eagle Creek	86,480	27.99
Brush Creek	11,525	3.73
White River		
Lower White River	8,416	2.73
Richland Creek	37,383	12.10
East Fork	51,096	16.54
Middle Fork	19,900	6.44
West Fork	32,131	10.40
Total	308,920	100%

calculating models on the WEW only.

The BRW watershed is an erosional surface resulting in highly dissected areas depicted by steep slopes and narrow valleys and ridges. There were areas that could be portrayed as plateaus, but these were considered to be insignificant when related to the whole watershed. Elevations range from approximately 341 m to 761 m above sea level

Slopes were calculated as degrees from horizontal and in the watershed ranged from 0 to 77 degrees. The distribution of slopes was fairly even up to 13 degrees (Table 12). Beyond this slope the areal coverage of each slope was significantly reduced. The greater slopes are located in the southern portion of the watershed. The spatial distribution of the slopes in the database was strongly influenced by the presence of the 80 m DEMs. The majority of the slopes in these areas was portrayed as 0 degrees when in reality, the distribution should be more complex. Since there were vast areas with the same elevation, the results from slope calculation would be 0 degrees. Slopes in the BRW actually ranged to 90 degrees, as in the case of cliffs and bluffs. It was not possible for slopes to reach 90 degrees in the database because the slopes were calculated using raster data with a 30 m resolution.

The spatial distribution of slope aspect was fairly evenly distributed throughout the watershed (Table 12). The only values that are abnormal are the east and west facing slopes and the slopes with no aspect. This higher coverage was related to the 80 m DEM inclusions. When these areas were excluded, the aspect trends were more noticeable There was a higher concentration of slopes that range from west to southwest. The expected general trend would be toward the north given

Table 12. Spatial distribution of slope and aspect. Masked column indicates percent cover of areas represented by 30 m DEMs

Slope				Aspect			
Slope	ha	% Cover	Masked	Aspect	ha	% Cover	Masked
0°	19,351	6.26	0.65	East	16,742	5.42	4.27
1°	14,931	4.83	2.89	15° N of E	11,465	3.71	
2°	17,110	5.54	4.82	30° N of E	11,111	3.60	4.09
3°	17,829	5.77	5.59	Northeast	11,675	3.78	4.08
4°	18,300	5.92	6.12	30° E of N	10,599	3.43	
5°	19,182	6.21	6.60	15° E of N	10,486	3.39	3.76
6°	19,466	6.30	6.87	North	14,498	4.69	3.91
7°	18,914	6.12	6.80	15° W of N	10,820	3.50	3.94
8°	20,232	6.55	7.34	30° W of N	11,202	3.63	4.11
9°	19,898	6.44	7.17	Northwest	12,458	4.03	4.49
10°	18,918	6.12	7.03	30° N of W	12,108	3.92	4.53
11°	16,544	5.36	6.16	15° N of W	12,005	3.89	
12°	14,674	4.75	5.50	West	16,011	5.18	
13°	12,362	4.00	4.63	15° S of W	11,572	3.75	
14°	10,155	3.29	3.79	30° S of W	11,212	3.63	
15°	8,387	2.72	3.14	Southwest	11,355	3.68	4.14
16°	6,732	2.18	2.53	30° W of S	10,085	3.26	3.76
17°	5,335	1.73	2.01	15° W of S	9,995	3.24	3.66
18°	4,352	1.41	1.62	South	12,889	4.17	3.61
19°	3,515	1.14	1.32	15° E of S	9,620	3.11	3.44
20°	2,842	0.92	1.07	30° E of S	9,888	3.20	3.61
21°	2,262	0.73	0.84	Southeast	10,997	3.56	3.90
22°	1,820	0.59	0.68	30° S of E	10,815	3.50	4.00
23°	1,387	0.45	0.52	15° S of E	11,237	3.64	4.12
>23°	3,972	1.29	1.48	No Aspect	17,625	5.71	0.18
Water	10,450	3.38	2.83	Water	10,450	3.38	2.83
Total		100%	100%	Total	308,920	100%	100%

that general stream flows are also in that direction. The omission of the four quadrangles may be a factor in this case. These quadrangles should have the majority of aspects either toward the east because they are located on the western boundary of the BRW or no aspect due to the presents of the larger flood plains in the Lower White River and West Fork of the White River valleys. Since elevations below lake level were not available, the distribution of aspect, as well as slope was not truly representative of the BRW. By assuming general trends of no aspect in river valleys and the northward trend of the river, north and no aspect might be predominant in the watershed.

Soils

The distribution of soils within the BRW was based on two primary factors: parent material and geomorphological processes. The parent material in the watershed was limestone, sandstone or shale Geomorphological processes forming soils include: formed in place (residuum), transported by gravity (colluvium), and transported by water (alluvium). The color scheme in Figure 2 was developed to portray these influences. Magenta-colored soils in the northern portion of the watershed are residuum soils derived from limestone. Blues and cyans depict soils formed from alluvial parent materials. Greens are colluviums derived from either sandstone or shale. Yellows are a mixture of colluviums and residuums derived from sandstone and shale. Reds are residuums derived from sandstone and shale. This color scheme shows that soils in the northern portion of the watershed are residuum soils derived primarily from limestone. An unusual aspect in this portion of the BRW is that there are very few colluvial soils from limestone parent material.

The lack of colluvial soils in the northern portion of the watershed may suggest that the residuum soils are fairly stable and are not affected by gravity. There are alluvial soils in the narrow valleys of northern portion of the watershed, but these do not have the coverage as in the southern portion. The most common soil series in this northern area are Clarksville, Nixa and Noark also known as Baxter. These three soil series cover nearly 25% of the total watershed (Table 13).

One major difference between the northern and southern portions of the watershed is that there are more soil complexes mapped in the southern portion of the watershed. Complexes are combinations of two or more soils that cannot be differentiated from each other at the scale of the soil survey. Normally, this is the case when individual soils occupy areas too small to map. It is possible to have a mixture of residual and colluvial soils in these complexes as is the case with the yellow colored areas in Figure 2. These areas were mostly mapped as Allen and Allen complex soils. The darker green areas were mapped as Enders soils mixed with both Allegheny and Leesburg soils. These soils cover 29% of the watershed

The other group of soils that have extensive coverage in the BRW are the Mountainburg, Nella and Steprock soils. Areal coverage for combinations of these soils was nearly 14%. By combining Clarksville Nixa, Noark, Enders, Leesburg, Allegheny, Mountainburg, Nella and Steprock soil series, the total watershed coverage was nearly 68%. These soils are mostly colluviums and residuums. Since alluvial soils occur mainly in stream valleys, their distribution was much more limited.

Enders soils are classified as clayey and cover 16% of the BRW Noark (Baxter) soils are clayey-skeletal and cover 4% of the

Table 13. Spatial distribution of the soil series. Lines divide MLRA categories 116, 117 and 118 consecutively. Data were a reclassification of soil mapping units.

Soil Series	ha	%	Soil Series	ha	%
Arkana	16	>0.01	Ceda	5,658	1.83
Arkana-Eldon[1]	37	0.01	Cherokee[1]	507	0.16
Arkana-Moko[1]	2,052	0.66	Cleora	4,733	1.53
Baxter	2,755	0.89	Enders	9,887	3.20
Britwater	751	0.24	Enders-Allegheny[1]	29,922	9.69
Captina	3,693	1.20	Enders-Leesburg[1]	59,819	19.36
Clarksville	38,073	12.32	Fayetteville	1,641	0.53
Elash	4,475	1.45	Fayetteville-Hector[1]	566	0.18
Fatima	4	>0.01	Hector-Mountainburg[1]	6,990	2.26
Guin	209	0.07	Leadvale	2,184	0.71
Healing	1,678	0.54	Leesburg	3,743	1.21
Jay	159	0.05	Linker	6,501	2.10
Johnsburg	2,651	0.86	Linker-Mountainburg[1]	5	>0.01
Leaf	347	0.11	Mountainburg	7,532	2.44
Mayes	167	0.05	Nella	5,963	1.93
Moko	224	0.07	Nella-Steprock-Mountainburg	16,296	5.28
Nixa	24,001	7.77	Samba	414	0.13
Noark	10,476	3.39	Savannah	4,647	1.50
Pembroke	830	0.27	Steprock	5,069	1.64
Peridge	2,176	0.70	Allen-Enders[2]	919	0.30
Pickwick	1,536	0.50	Allen-Holston[2]	754	0.24
Ramsey-Lily[1]	43	0.01	Allen-Mountainburg[2]	307	0.08
Razort	1,970	0.64	Bruno	1	>0.01
Secesh	1,028	0.33	Enders-Mountainburg[2]	206	0.07
Sloan	886	0.29	Guthrie	5	>0.01
Sogn	287	0.09	Hartsell	204	0.07
Sogn-Clarison[1]	605	0.20	Holston	403	0.13
Summit	2,243	0.73	Holston-Enders[2]	750	0.24
Taloka	364	0.12	Linker-Mountainburg[2]	61	0.02
Tonti	3,444	1.11	Montevallo	520	0.17
Ventris	2,137	0.69	Montevallo-Mountainburg[1]	20	0.01
Waben	298	0.09	Mountainburg-Enders[2]	9	>0.01
Allegheny	2,903	0.94	Mountainburg-Rock Land[2]	48	0.01
Allen	2,487	0.81	Nella-Enders[2]	15	>0.01
Allen-Hector[1]	4,767	1.54	Rock Land	586	0.19
Apison	1,344	0.44	Water	10,876	3.52
Cane	43	0.01	Total	308,920	100%

[1] Complex; [2] Soil association

Leesburg and Allegheny soils are fine-loamy textured soils and cover 16% of the BRW. Clarksville, Mountainburg and Nixa soils are loamy-skeletal textured soils with a coverage of 33%. The importance of texture with these major soils is that the clayey soils, Enders and Noark, have reduced water infiltration and permeability and are classed as very slow and slow, respectively. The loamy soils, Clarksville, Mountainburg and Nixa soils are classified as moderately slow permeability and Leesburg and Allegheny soils are classified as slow permeability. Permeability will affect runoff from a soil which in turn may affect the chemical or nutrient concentrations of the runoff water. There are other factors to consider in water quality but soil permeability is highly significant.

Surface Geology

entire BRW is located within the Ozark Plateau which is a portion of the Ozark dome centered in southeastern Missouri. The lithology of the Ozark Plateau is characterized mostly by horizontal bedding of the lithologic units with minor folding and faulting. The Ozark Plateau is divided into three different regions that are defined by topographic boundaries. The upper-most and youngest region is known as the Boston Mountains and is bounded to the north by the Boston Mountain Escarpment. It is mainly composed of Pennsylvanian age sandstones, siltstones, limestones and shales. The middle region is the Springfield Plateau and is also the mid-point in geologic age of the watershed. It is bounded by the Boston Mountain Escarpment to the south and the Eureka Springs Escarpment to the north. It is composed of mostly Mississippian sandstones, limestones and shales. The lower and oldest region is the Salem Plateau which is bounded to the south by the Eureka Springs Escarpment. The Salem Plateau is a mixture of Devonian sandstones and shales and Ordovician sandstones and dolomites (Figure 3).

The highest portions of the watershed are composed mostly of the Pennsylvanian age Atoka Formation (Table 14). This formation is the thickest and has the greatest relief. It composed of alternating rock units of mostly shale and sandstone (Lonsinger 1980). These rock units extend across the southern half of the watershed and cap the higher

Table 14. Spatial distribution of surface geology. Formations and members listed were based upon the classification system used when mapped.

Formation		ha	% Cover
Pa	- Atoka Formation	102,145	33.07
	Bloyd Shale of the Hale	46,813	15.15
	Cane Hill of the Hale	3,533	1.14
Mp	- Pitkin Limestone	3,734	1.21
	- Wedington Sandstone	10,585	3.43
Mf	- Fayetteville Shale	24,376	7.89
	- Batesville Sandstone	4,065	1.32
	Boone Formation	98,323	31.83
	Chattanooga Shale	4,670	1.51
	Clifty Sandstone	170	0.06
Oe	- Everton Formation	781	0.25
	Powell Dolomite	2,327	0.75
Oc	- Cotter Dolomite	7,398	2.39
Total		308,920	100%

outlier mountains on the Springfield Plateau (Figure 3). The formation terminates at the top of the Boston Mountain Escarpment which enters the study area near West Fork then zig-zags to the east along major streams to Huntsville and continues to the eastern portion of the watershed west of Kingston.

Below the Atoka Formation is the Bloyd Formation. It is composed of several members which were not mapped. The unmapped members are a mixture of limestones, shales, and sandstones (Branch, 1966). The Bloyd Formation is contiguous south of the Boston Mountains Escarpment while it also

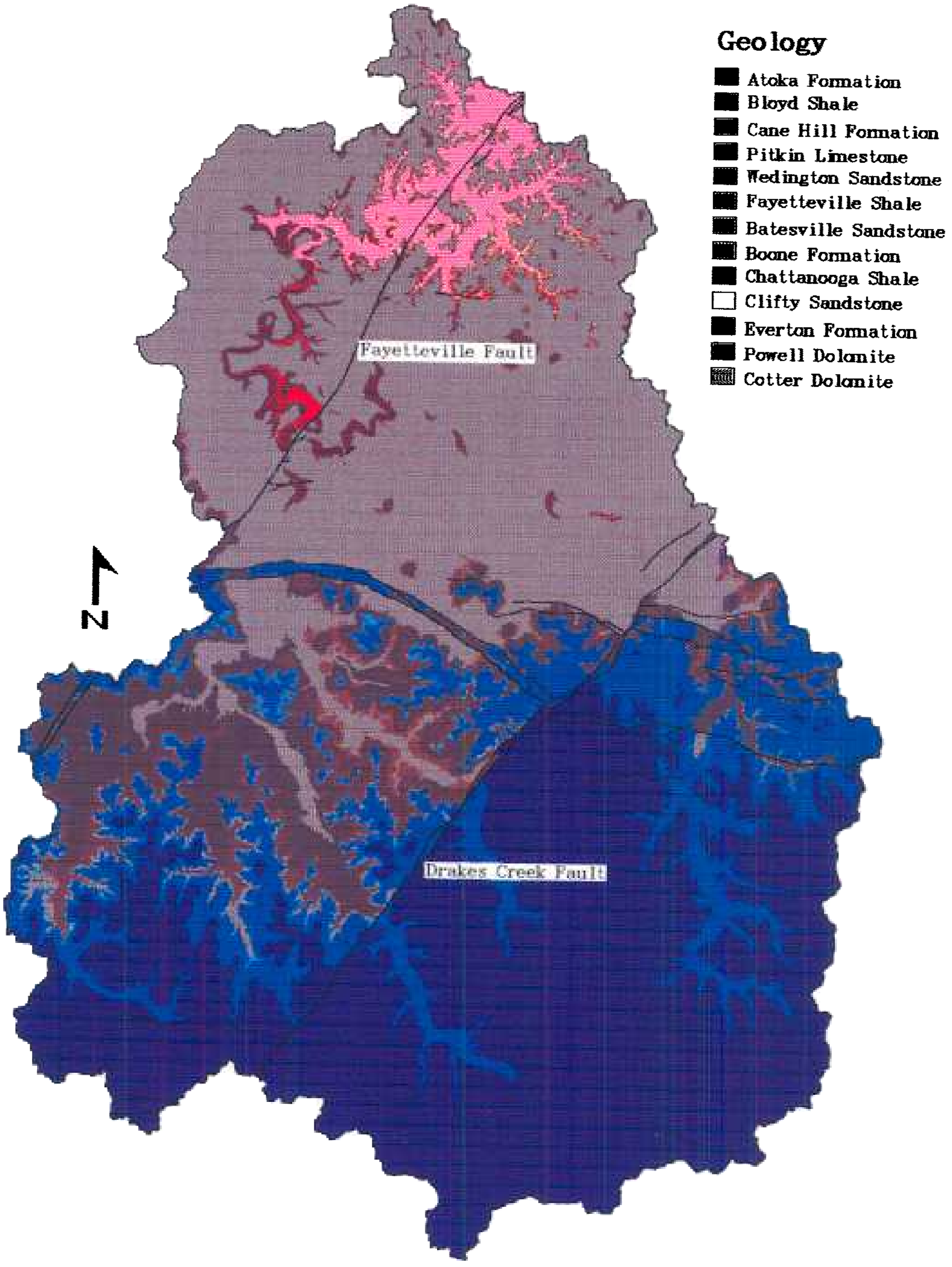

Figure 3. Surface geology based upon the original master maps of the state geology. Data were obtained from the Arkansas Geological Commission on 1:24,000 and 1:62,500 scale maps.

occurs on the outliers of the Boston Mountains on the Springfield Plateau.

The Hale Formation is exposed at the lower portion of the Boston Mountains Escarpment and is the basal formation of the Pennsylvanian age rocks. Members include the Prairie Grove Limestone and the Cane Hill Member. The Cane Hill Member of the Hale Formation is the lowest oldest member of the Pennsylvanian rocks. It consists of alternating layers of sandstone and shale with the thickest unit of shale occurring at the base of the member (Branch, 1966)

The source data from which the geology was compiled included Prairie Grove Limestone as the basil member Bloyd Formation (Haley, et al., 1976). This division differs from the normal classification scheme which groups the Prairie Grove Limestone with Cane Hill Member to form the Hale Formation (Hawkins, 1980). In the database and on the state geology map, the Cane Hill Member is mapped as a formation, but since its mapped coverage did not include the Prairie Grove Limestone, the total coverage of the Hale Formation may be roughly two times thicker than the database shows

The upper portion of the Mississippian rocks is a mixture of limestone, sandstone and shales. The top most member is the Pitkin Limestone. It is found on and along the Boston Mountain Escarpment as well as the sides and tops of outlier mountains on the Springfield Plateau (Mollison, 1983). The Pitkin Limestone truncates north of a line extending from Fayetteville through just south of Goshen to just south of Huntsville. The member thickens to the south and is most prominent in the Sulphur City area.

Below the Pitkin Limestone is the Fayetteville Formation. It is composed an upper shale member, a middle sandstone member, and a shale member. The Fayetteville Formation is very prominent across the region ranging in thickness from 3 to 133 m. The Lower Fayetteville Shale is often the thickest and most prominent of the three. It is marked by the gentler slopes on the mountain sides particularly on the outliers on the Springfield Plateau. The Wedington Sandstone overlays the Lower Fayetteville Shale. It is prominent along the Boston Mountain Escarpment and on the outliers on the Springfield Plateau It often forms low bluffs on hill sides, although this sandstone can be very thick in other areas This member becomes thinner and non-conformal to the east existing only in isolated areas in the eastern portion of the watershed. The upper Fayetteville Shale was not mapped in the database due to limited coverage This formation is mostly absent in the presence of thick Wedington Sandstone (Price, 1979).

The Batesville Sandstone lies below the lower shale of the Fayetteville Formation. This formation is very thin in the watershed and was not mapped in many places, but may exist as a thin layer near the contact of the Springfield Plateau and the Boston Mountain Escarpment and as a sandstone cap on the Boone Formation near the escarpment. formation grades and intertongues with the Hindsville Formation (Cochran 1989) It was unclear form the source data whether the mapped Batesville Formation included the Hindsville Formation.

The oldest formation of Mississippian age in the watershed is the Boone Formation. The Boone Formation is composed of limestone intermixed layers of chert and an overlying regolith of chert intermixed with red clay (Liner, 1980). This portion of the Boone Formation caps most of the surface west of the watershed as wel as a small portion within the watershed on mountain tops, but in these areas there is little if any red clay leaving only chert with little covering soil. This characteristic is noticed mainly in the northeastern portion of the watershed east of the reservoir in the vicinity of Big Clifty Creek west of Highway 23 and north of highway 12. Below the chert is an unmapped formation called the St. Joe Limestone which bounds approximately half of the Beaver Reservoir shoreline. It ranges in thickness from 2 to 28 m with and average of 15 m. The St. Joe is continuous over most of the Springfield Plateau. Most of the water wells in Northwest Arkansas draw water from the aquifer within these two rock layers.

Below the Mississippian age formations are the Devonian age formations. The most prominent member of this age in the watershed is the Chattanooga Shale. It is exposed in a few areas along the shoreline in the upper portions of the reservoir, and is mostly continuous along or near the shoreline in the lower portions of the reservoir. Included in this age is the Clifty Sandstone. It occurs only in a small area along the lake shore north of the town of Clifty

Below the Devonian Formations are the formations of the Ordovician age. These formations occur along the shoreline only in the lower portions of the reservoir marking the Eureka Springs Escarpment. There are three primary formations of Ordovician age present in the watershed: Everton Formation, Powell Dolomite and the Cotter Dolomite. The Everton consists of a mixture of mostly dolomites and sandstones (Frezon and Glick, 1959), but in the BRW the distribution is very limited and consists mostly of sandstone. It is mostly submerged in the southern portions the reservoir, and occurs in the main river channel from near Prairie Creek south of the confluence of War Eagle Creek and White River. The Everton also occurs along the shoreline in the northern portion of the reservoir is less contiguous. The Powell Dolomite underlies the Everton Formation and is located near lake level in the northern half of the reservoir. This dolomite is relatively thin in the watershed but is contiguous. The majority of the surface geology of the inundated area of the northern half of the reservoir is the Cotter Dolomite

From Figure 3 it is evident that the whole BRW watershed is strongly influenced by faults or joints. The most striking feature is the Drakes Creek Fault that extends from the southwestern corner to the middle eastern boundary of the watershed. Southeast of this line the geology appears to be less complex and dominated by mostly Pennsylvanian rocks (depicted in blues). This may be due in part to the grouping of several rocks members into single formations. The map could look more complex these rock members as individual formations, but the Drakes Creek would still be highly visible. Another evident feature is the curvilinear structure in the middle western portion of the watershed. is a grabben that extends from west of Springdale to south of Hindsville. The rocks in the grabben are younger than the surrounding rocks. There are many other linear features that do not stand out as well as these two. These lesser features are more evident on the soil series map mainly due to the greater complexity of the soil series attribute features include the Fayetteville Fault that extends from Fayetteville to south of Beaver Dam. Because of the uniformity of the Boone Formation, this fault does not present itself very well on the geology map without the aid of lines. Both the Fayetteville fault, previously mentioned faults, and several others all trend from southwest to northeast, but there are others that trend from south of northwest to north of southeast. These faults often truncate formations, e.g. south of Huntsville in the War Eagle Creek valley and on the Boone Formation southeast of the Reservoir. There is another set of linear features on the Boone Formation that trend nearly east to west, but these are obvious except by the alignment of valleys and ridges near the reservoir.

Land Use-Land Cover

Land use and land cover used in analysis was a product of source data (Figure 4). The data indicate that the majority of the watershed was rural with over 63% of the area covered by forests, colored with greens (Table 15). Over 30% of the watershed is covered by pasture, colored in yellow and red These two major categories comprise 93% of the total land cover in the watershed. The coverage of reservoirs is not only Beaver Reservoir. Lake Atalanta and Lake Sequoia add to the total coverage of reservoirs. Other major lakes in the watershed also include Wilson and Hindsville. Urban and recreational land uses were mapped as grays and black and have an area of about 1%. There also are several quarries and gravel pits in the watershed which are mapped in orange. The largest occurs near West Fork with smaller operations north of Rogers east of Wesley on Highway 74. Transitional areas, mapped in red, may not reflect current conditions within the watershed because of the date of the source material Transitional areas are normally exposed ground associated with construction and will vary with time. Quarries, transitional areas, and pastures with evidence of fertilization, poor

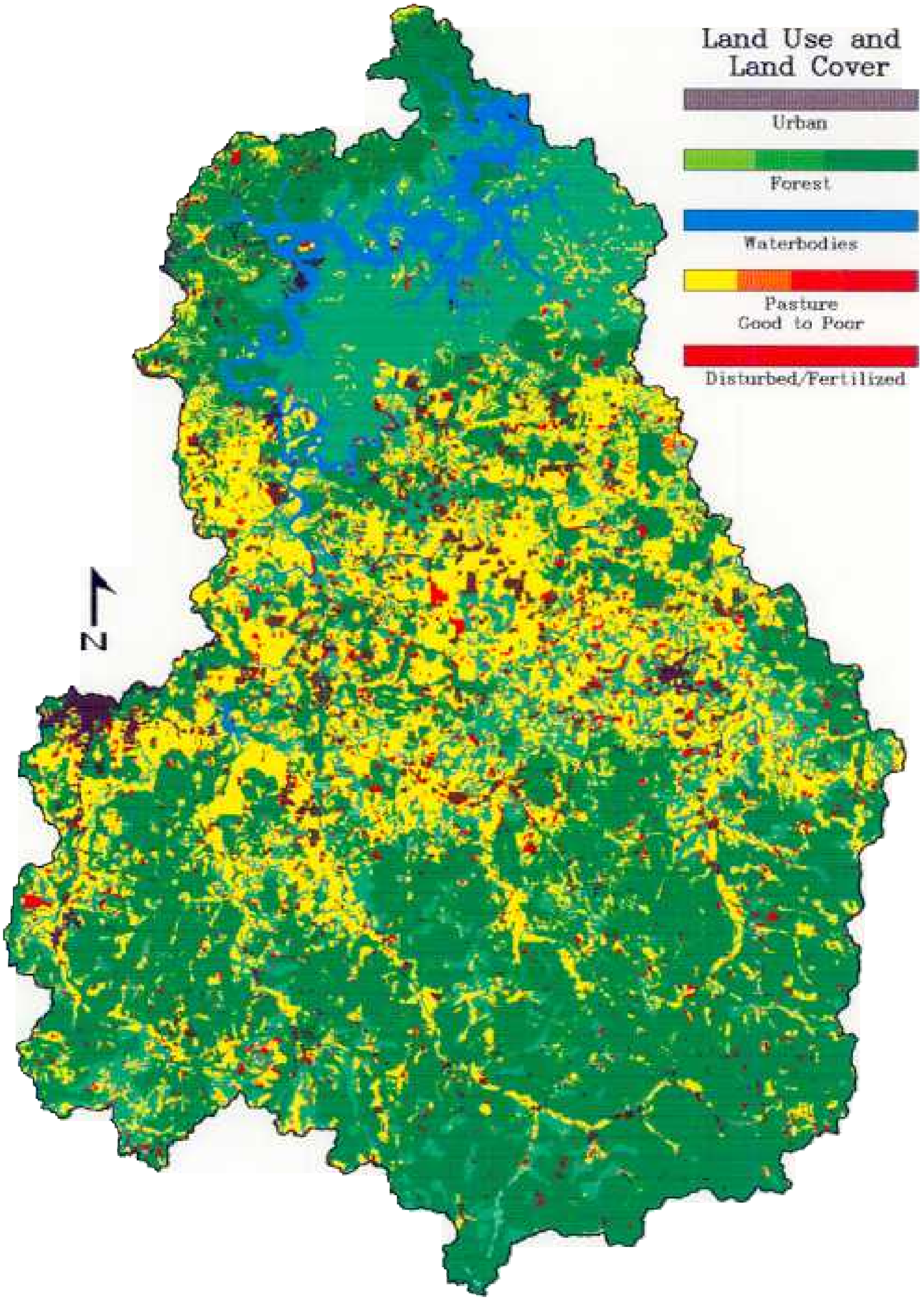

Figure 4. Land use and land cover based upon the Tennessee Valley Authority interpretation. Data were interpreted from black and white and infrared areal photographs ranging in date from 1980 to 1988.

Table 15. Spatial distribution of land use and land cover. Source data were produced by the Tennessee Valley Authority from black and white and infrared aerial photography.

Land Use / Land Cover	ha	%
Residential	704	0.23
Commercial	38	0.01
Industrial	1	>0.01
Transportation, Communications, and Utilities	94	0.03
Recreational	120	0.04
Mixed or Built-up Areas	2,217	0.72
Scrub and Brush Land	4,073	1.32
Deciduous Forest	120,130	38.89
Evergreen Forest	1,070	0.35
Mixed Forest	73,779	23.88
Ponds	59	0.02
Streams	338	0.11
Lakes	23	0.01
Reservoirs	10,490	3.40
Quarries and Gravel Pits	183	0.06
Transitional Areas (Bare Soil)	133	0.04
Row Cropped	984	0.32
Double Cropped	912	0.30
Good Pasture	53,520	17.32
Fertilized	6,116	1.98
Terraced	258	0.08
Gullied	456	0.15
Fair Pastures	29,030	9.40
Fertilized	70	0.02
Terraced	81	0.03
Gullied	449	0.15
Poor Pastures	982	0.32
Gullied	7	>0.01
Woodland Pastures	1,184	0.38
Gullied	24	0.01
Over Grazed Pasture (Feeding Areas)	724	0.23
Confined Animal Structures	671	0.22
Total	308,920	100%

pastures, and overgrazed pastures were all colored in red. Quarries and transitional areas were considered significant in the outcome of the USLE The PI model used in the WEW data depended upon fertilization of pastures Therefore, these areas were colored with reds and oranges

Pastures with evidence of fertilization covered 2% of the BRW most of which was classified as good pasture. This category is not based on actual fertilizer applications to these pastures, but rather, on evidence of such practices as indicated by the uneven growth of grasses reflecting the spreading pattern. Pastures were further divided into quality assessments of good, fair, poor, woodland and overgrazed pastures pastures were located in the central portion of the watershed on the more level areas of the Springfield Plateau and in the river bottoms. were few pastures located on steeper slopes and mountain tops.

An additional attribute of confined animal structures was interpreted in the Soil Physics Laboratory. These data were interpreted from the aerial photographs provided with the TVA data base In 1988, there was a total of 2,043 individual structures in the watershed (Figure 5) and these structures were either poultry or swine houses. A distinction between the two types of confined animal structures was not possible. It is recognized that this count of confined animal structures will change from year to year depending on destructive weather and poultry and swine production rates for each year The spatial distribution of the poultry houses was unique in that the area near Beaver Reservoir was devoid of structures with the exception of the upper reaches of the reservoir. Otherwise, the confined animal structures were mostly located in pastures along the river valleys and on the Springfield Plateau

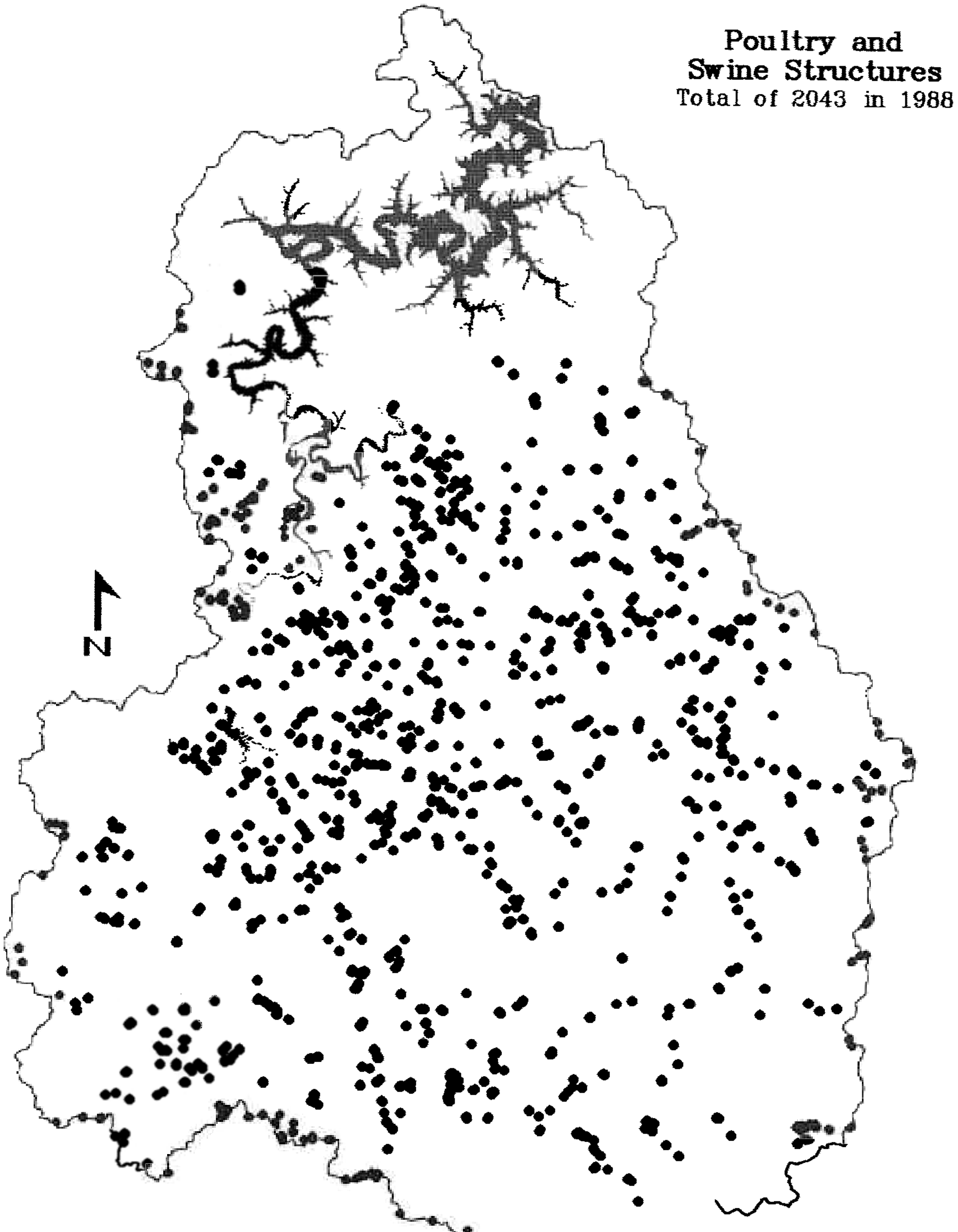

Figure 5. Poultry and swine production structures interpreted from 1988 1:24,000 scale infrared aerial photography. Data were interpreted by the Soil Physics Laboratory.

Hydrography

The total areal coverage of all water features in the BRW was over 6.5% Table 16; Figure 6). This coverage included streams that were mapped as single lines Double line streams are sections on rivers where slow pools exist in the stream year round. These streams only occur on major tributaries of Beaver Reservoir, such as the White River and War Eagle Creek. There were very few double line streams on the West Fork and Middle Fork of the White River

The density of the streams mapped was greater in the middle portion of the watershed. The middle 11 quadrangles were interpreted more intensely than in the northern or southern portions of the watershed Included in this central area are streams with animal access. Had these data been interpreted at the same intensity throughout the watershed,

Table 16. Spatial distribution of surface hydrography. Source data were based upon Tennessee Valley Authority interpretations.

Description	km	ha	% Cover
No Water		298,088	96.50
Reservoirs		10,450	3.38
Double Line Streams		382	0.12
Perennial Streams	1,405		
Animal Access	34		
Ephemeral Streams	441		
Animal Access	57		
Intermittent Streams	1,478		
Animal Access	60		
Total	3,475	308,920	100

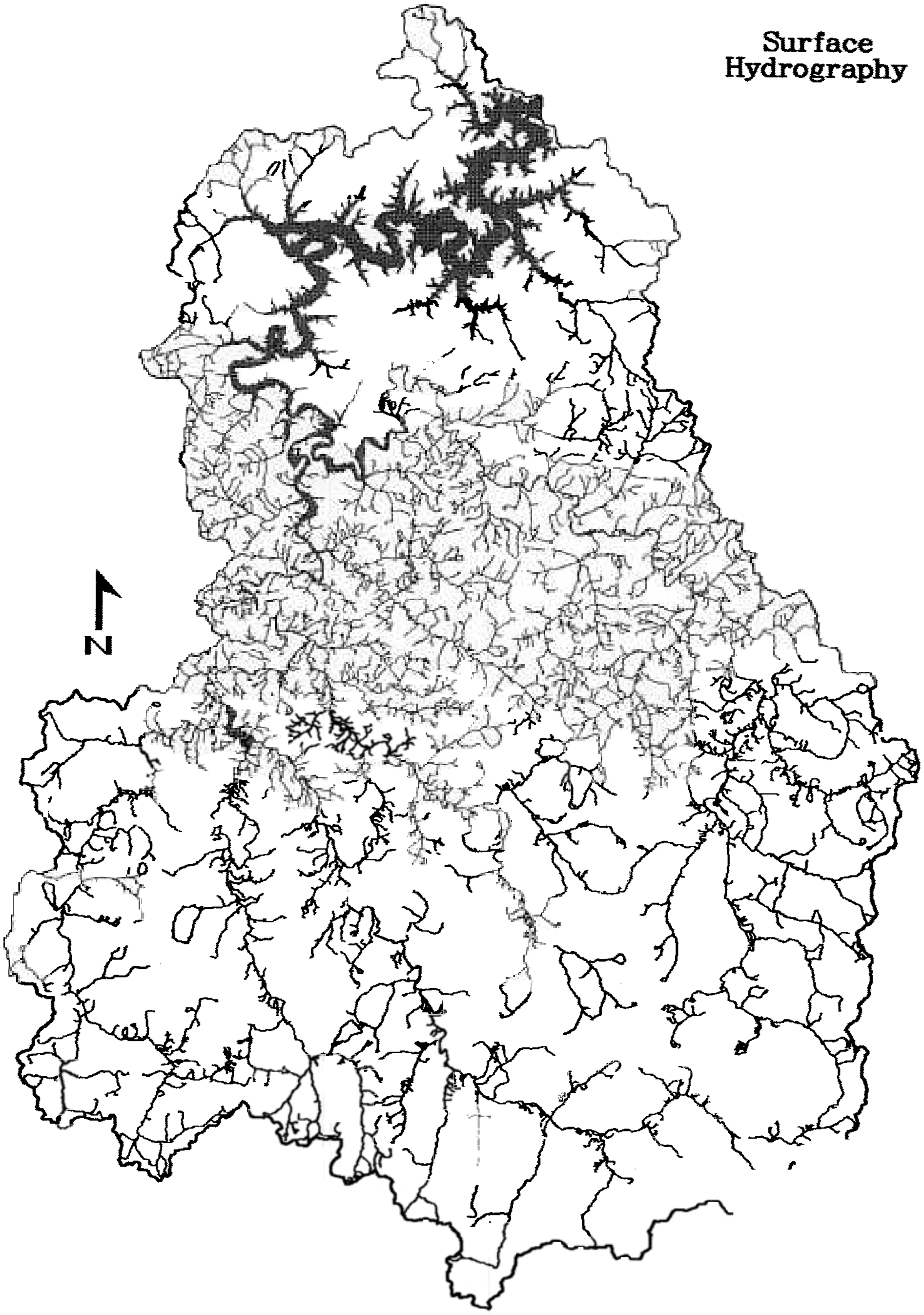

Figure 6. Surface hydrography based upon the Tennessee Valley Authority interpretation. Interpretations were more intense in center portions of the watershed.

these data would have been used in analyses of the PI model and water quality data on WEW. There also are a number of smaller lakes within the watershed and their area is presented in Table 17.

Table 17. Spatial distribution of lakes and reservoirs. Elevations and cover are both averages based upon approximate water surface elevations.

	Elevation		Cover
Water Body	m	ft	ha
Beaver Reservoir	341	1,120	10,233
Lake Sequoia	357	1,170	154
Lake Wilson	390	1,280	13
Lake Atalanta	366	1,200	12
Lake Hindsville	402	1,320	7

Transportation

The source data for the roads were the USGS 1:100,000 scale DLGs Table 18; Figure 7). These were chosen over the TVA interpretation because of the lack of unimproved roads mapped in the TVA data. The positional discrepancies in the USGS data were deemed to be less important and were also classified with more detail than the TVA interpretation. The data were classified either by the highway number or by the class of road. All U. S. highways are considered as class one or primary roads. These are paved highways that are state maintained. State highways can be either class 1 or class 2 depending upon whether the highway is a primary route or not. Most unpaved state highways in the BRW are considered as class 2 or secondary highways. The last three categories in Table 18 are classes 3, 4 and 5. Class 3 or all weather roads include both paved and

Table 18. Approximate total distances of roadways. Source data were compiled from 1979 data by United States Geological Survey. These data may not reflect current totals due to the date of compilation and scale of interpretation.

Description	Class	Km	Miles
U.S Highway	1		
62		2	2
71		41	25
412		51	9
Business Route	1	15	32
State Highway	2		
12		47	29
16		72	45
23		76	47
45		34	21
74		49	30
94		13	8
112		2	1
		27	17
		8	5
170		4	2
187		6	4
		8	5
		8	5
		71	44
		28	17
All Weather Roads	3	1,606	998
Dry Weather Roads	4	1,964	1,220
Single Track Roads	5	120	74
Totals		4,251	2,641

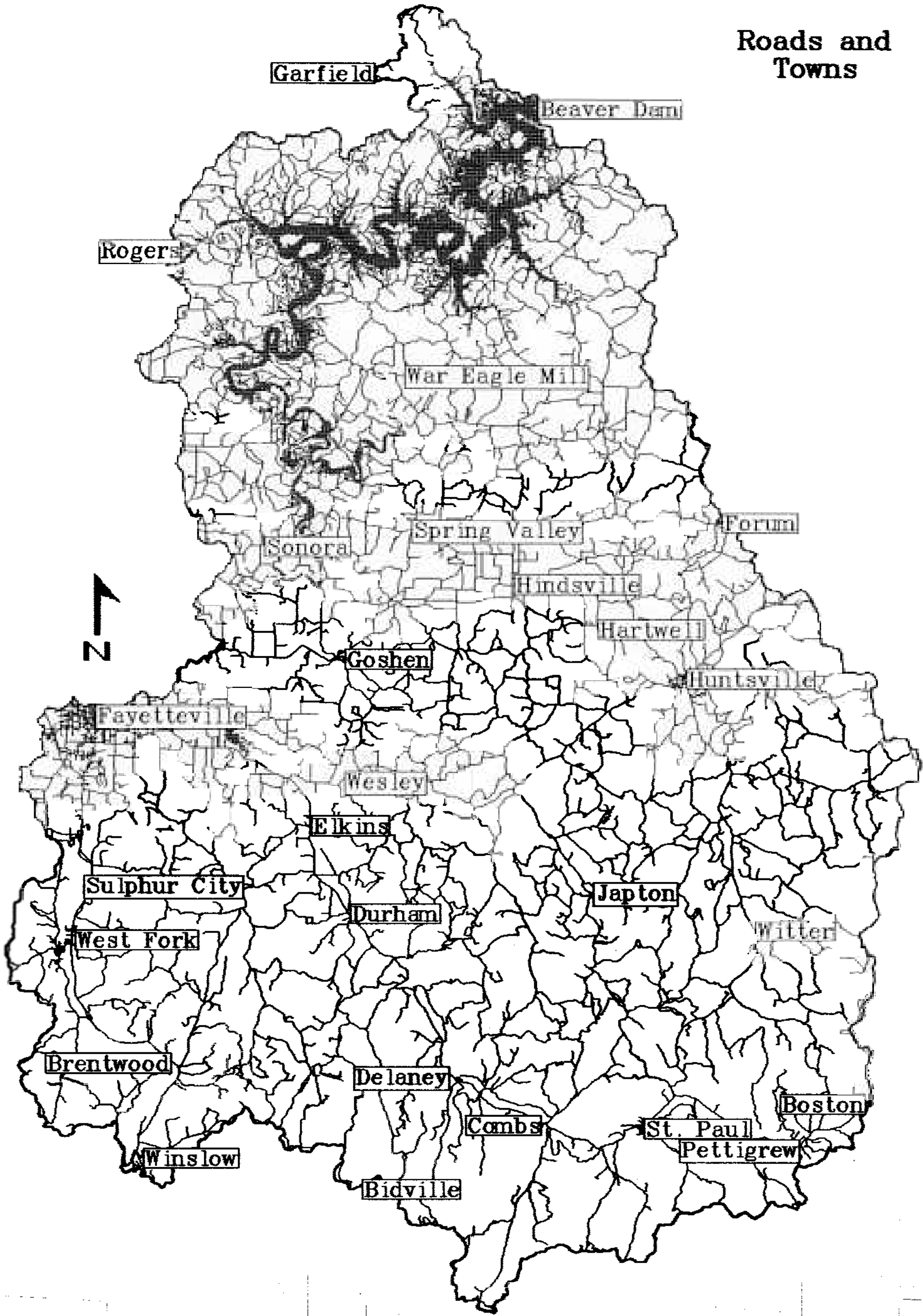

Figure 7. Roads in the watershed as interpreted by the United States Geological Survey from 1979 data. Data were interpreted at a scale of 1:250,000.

unpaved city and county maintained roads and are used mostly for local traffic. Class 4 or dry weather roads are mostly double track dirt roads with unimproved surfaces, or are city streets that are not considered to be primary local traffic routes. Many Class 5 trails in the BRW are old logging roads that are now foot trails, bicycle trails or power service roads. It is possible that there are many more class 5 trails in the BRW, but these were not mapped by the USGS because of the limitations of the scale in interpretation. Approximate distances of various roadways in the BRW.

The roads are concentrated around the towns in the watershed as well as around the reservoir itself. Roads around the reservoir are mostly recreational areas or lake side property development. Since these data were compiled in 1979, it is most likely that there are more roads around the reservoir as well as in and around Fayetteville, Rogers Springdale, not shown on map. As with LULC, the distribution of this attribute is highly time dependent and should be updated periodically.

Aqueous P Samples

The data gathered by ADPCE (1992 and 1993) showed that there was great variability in the aqueous P concentrations in the creek. This variability was due to several factors of different origins. The most obvious variability was observed with the sample taken at the WRE03 sub-basin (Figure 8). Included in this sample site sub-basin is Holman Creek which flows from Huntsville north to War Eagle Creek. Along this creek is the Huntsville sewage treatment facility. The high P concentrations from this sub-basin sample site may be from a poultry processing facility located in Huntsville. A published report by the ADPCE stated that at

Figure 8. Location of sample sites collected by the Arkansas Department of Pollution Control and Ecology in the War Eagle Watershed. WRE01 was the southern most sample while WRE06 was the northern most sample.

times waste products from the poultry processing facility sometimes overruns the Huntsville sewage treatment facility resulting in release of improperly or untreated effluent into Holman Creek. The largest concentration total P noted from the ADPCE study was nearly 63 mg L^{-1}, but varied greatly with time and distance down stream from the outflow of the treatment facility. The lowest P concentrations were noted at the farthest down stream sample site, 6 mg L^{-1}, but this value also greatly exceeded what is considered high total P concentrations for streams, i.e. 0.1 mg L^{-1}. With such high P concentrations at periodic times, it is possible that with the exception of May 1993 sampling, the samples taken from the WRE03 site were influenced by the problems in Holman Creek. Few definite conclusions could be made by including the WRE03 samples, so they were deleted from further analyses.

By excluding the WRE03 data, a better view of the distribution of P concentrations in the War Eagle Creek was found (Figure 9). Despite the exclusion of the WRE03 data, there was still much variability between both sample dates and location. It was expected that there would be variability from one season to the next due to the changing flow of water in the creek. In high flow conditions, ortho P was expected to make up a smaller fraction of the total P concentration with the majority of P being associated with sediment. Conversely, during low flow, ortho P was a larger fraction of the total P due to the lesser amount of sediment P. Figure 9 supports this expectation as with the difference in the May and August dates. The differences in May 1992 and May 1993 were related to the flow at the time of sampling. The measurements taken during 1992 had lower flow than 1993, thus the amount of sediment P should be arger for

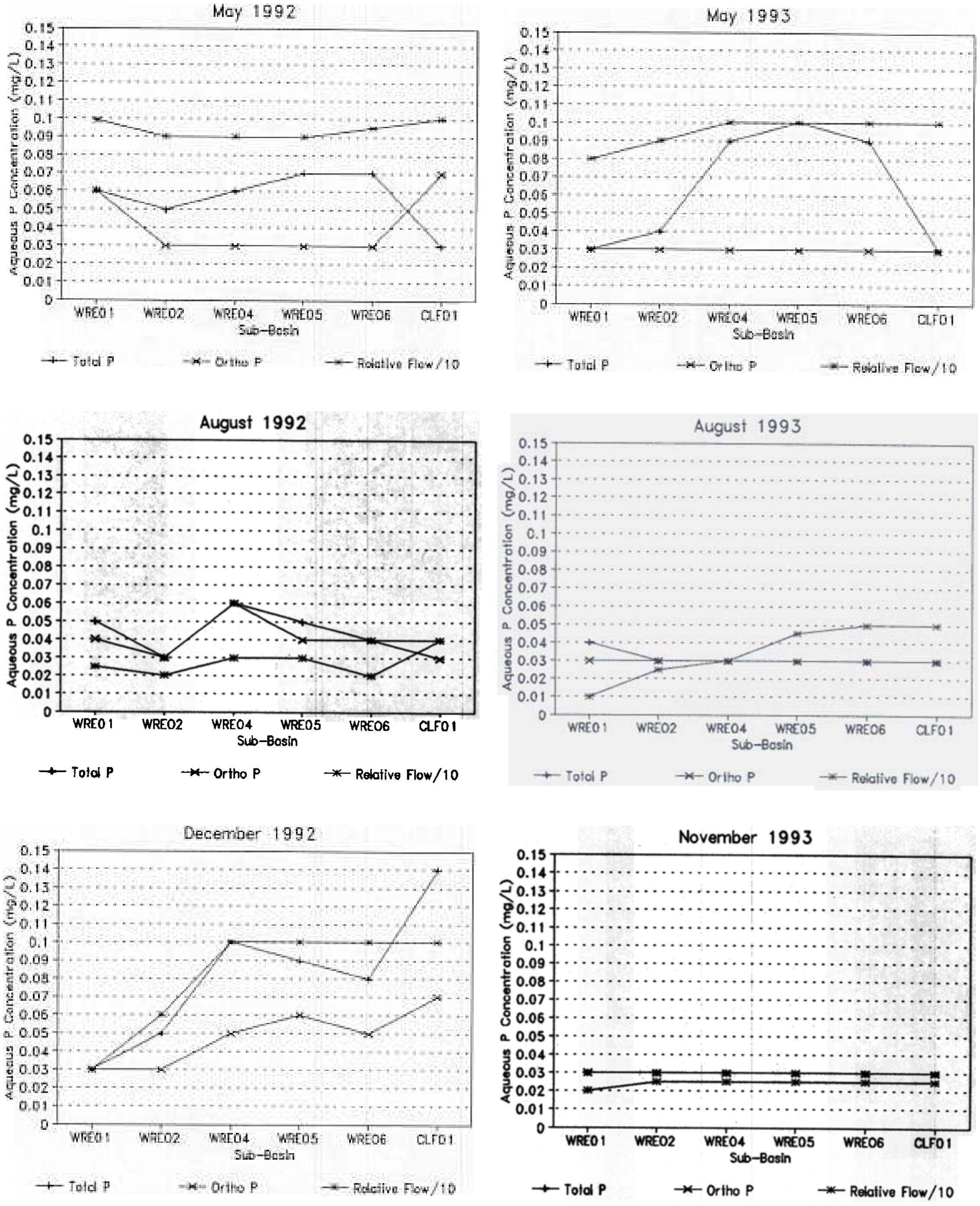

Figure 9. Aqueous P concentrations taken from War Eagle Creek and Clifty Creek. The data for WRE03 were omitted due to extreme values. Flow is represented as 1/10 of actual value.

1993. Ortho P for both years were at or below detectable levels with the exception of WRE01 in 1992. In samples taken during August, ortho P comprised more of the total P concentrations. The data obtained in 1993 were less supportive because both ortho- and total-P were at or below detectable limits. The December data were apparently taken under high flow conditions because of high sediment P. High ortho P is due to the low biological consumption

One enigma is CLF01 which at times showed high P concentrations The fluctuations do not seem to fit any discernable pattern. It is possible that the high ortho P reported in May 1992 is in error since it is a higher concentration than the total P for the sample and date Although CLF01 does not seem to fit with the War Eagle Creek data is not unusual. The fact that it often differs may suggest that the WRE samples may not be statistically independent. Lack of independence could be noted in high flow periods, i.e. during May and December.

Total P concentrations tended to increase downstream with the exception of WRE06 where in some cases the total P concentrations decreased. This could be an affect caused by an impoundment at this location, War Eagle Mill. The samples taken at WRE04 and WRE05 may also be influenced by the high concentrations from WRE03. The time that WRE03 samples were not high was during May 1993. This was also the only time WRE04 had a higher P concentration than WRE03. WRE04 could have been lower for the remainder of the samples due to a dilution effect caused by War Eagle Creek. This could not be investigated because actual flow rates were not taken, thus, the mass of P could not be determined. Sub-basin WRE03 could affect the downstream sites during low flow periods as evidenced by an influx of P at WRE04 and a gradual decrease in concentration downstream. This situation suggests consumption of ortho P with little or no additional input. Under these conditions ortho P would be consumed by algal populations in the creek while total P concentrations would also decrease due to settling of sediment or with organic materials. Both ortho and total P concentrations decreased downstream as did the flow of water

The overall trends in the data reflect a normal variance due to seasonal influence such as flow and biological activity. The higher concentrations in the northern portion of the watershed may be due to the influences from point source pollution in the WRE03 sub-basin. The effects from this source masked any non-point source influence. This suggests that there is not much evidence that poultry and swine litter used as fertilizer on area pastures are affecting nutrient balance of War Eagle Creek in a negative manner. In fact results of the USLE suggest that the use of these animal wastes as fertilizer may reduce the aqueous P concentrations by inducing vegetative growth in pastures which in turn would reduce the total sediment load to the creek. There was little to be gained from the ortho P data because of the high minimum detectable limits.

Erosion in the War Eagle Watershed

Erosion estimates for the whole WEW came to a total of 111,244 tons year Of the total watershed, over 30 % yielded less than 1 ton acre^{-1} year^{-1} (Figure 10 and Table 19). Nearly 90 % of the watershed yielded less than 5 tons acre $^{-1}$ year^{-1} Only 0.5 % of the watershed yielded greater than 40 tons acre $^{-1}$ year^{-1} From these results, it is evident that there

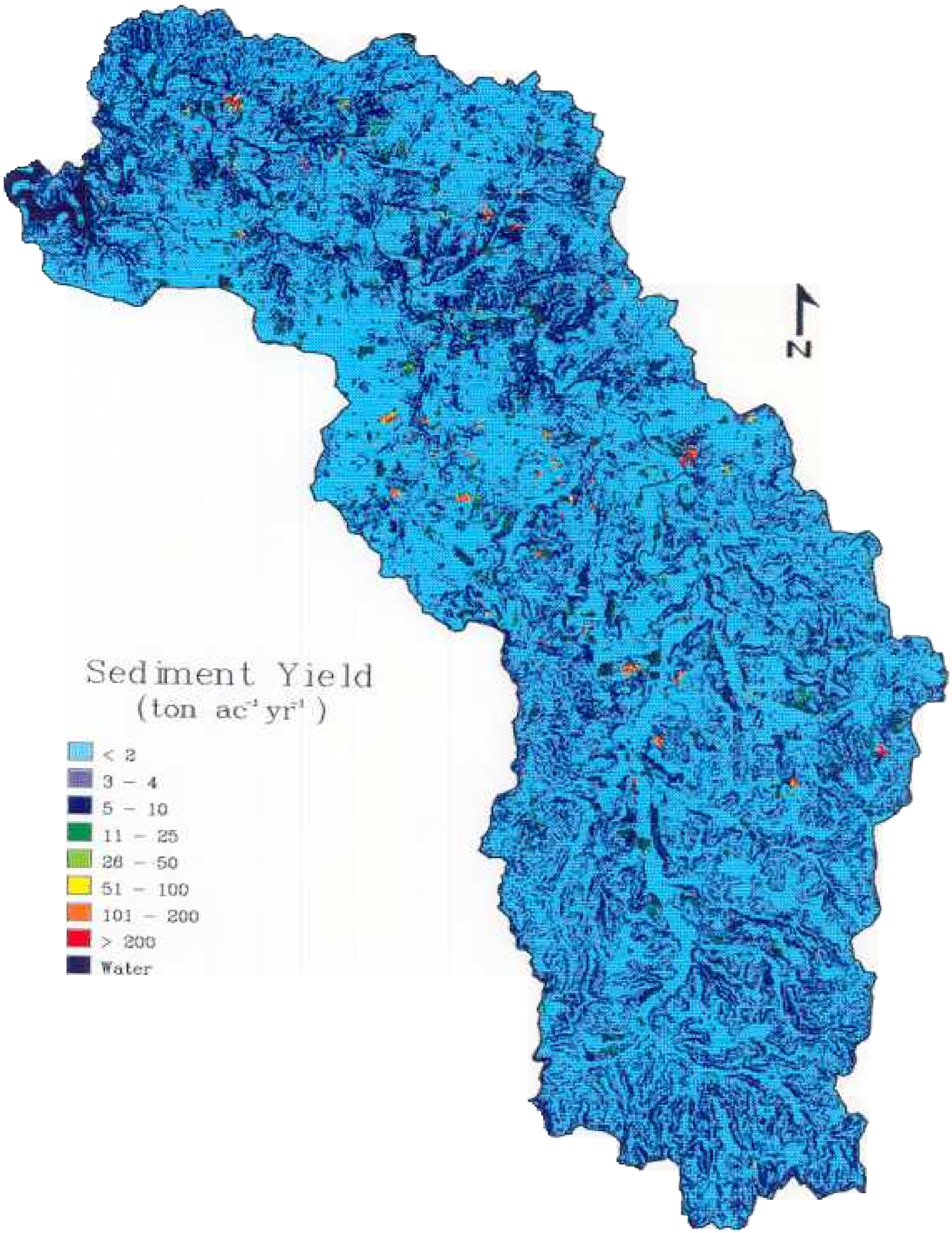

Figure 10. Estimated annual sediment yield in the War Eagle Watershed. Results were calculated with the USLE.

Table 19. Spatial distribution of erosion for the War Eagle Watershed. Erosion from roads was not used in the totals calculated from the whole watershed.

Sediment yield	Area	Cover
tons acre^{-1} year^{-1}	ha	%
1	26,312	30.44
2	31,276	36.18
3	13,339	15.43
4	6,195	7.17
	6,695	7.75
1-20	1,107	1.28
21-40	502	0.58
41-80	229	0.26
81-150	117	0.13
151-300	75	0.09
301-600	19	0.02
	2	0.01
Water	572	0.66
Total	86,440	100

is not a severe erosion problem within the watershed.

Of the major soil series, the series that contributed most to the sediment yield was Clarksville and Noark. As the yield increased the areal coverage of these two series also increased. Noark coverage increased gradually with sediment yield, while greatest coverage of Clarksville was in the middle ranges of sediment yield. The most stable soil was the Ceda series. As the area coverage of Ceda deceased sediment yield increased. The Enders-Leesburg complex was predominate throughout all but the highest sediment yields. This was mainly due to the fact that this complex is also the most extensive one in the watershed. Enders-Leesburg complex had a greater than normal distribution in the low yield ranges and a lower distribution in the higher yields. Nixa was predominant in the lower sediment yields but was less influential in the middle yields. It also had a higher than normal distribution in high yields. This is mostly due to the fact that much of the steeper slopes in the northern portion of the watershed are covered by Nixa soils The series that had a higher distribution in the low yields were Ceda, Steprock, Mountainburg, Leesburg, and Enders. All these appear to be less erosive than Clarksville and Noark series.

LULC influence on sediment yield reflected the assigned values for cover factor. The largest contributing category was transitional or bare areas. These areas had a higher than normal distribution in high sediment yield areas. Poor pastures were also predominate in the high yield areas This was expected, but not to the extent that was reported. Poor pastures were significant in yields ranging from 20 to 600 tons acre^{-1} year^{-1} Good, fair, and fertilized pastures had a higher than normal distribution in the low sediment yield areas. All forested areas had a higher distribution in the medium sediment yield areas. These results indicated that sufficient ground cover was significant in the reduction of sediment yield. This conclusion is consistent with the use of poultry litter as a fertilizer to reduce sediment yield

Shorter slope lengths had a higher than normal distributed in the low sediment yield areas while most of the longer length were in yields greater than 40 tons acre^{-1} year^{-1} Most of the WEW had slope lengths less than 30 m which made up over 80 % of the low yield area. It was unusual that all of the longest slope lengths were in the low sediment yield areas. This may be due to good ground cover or shorter slopes despite the longer lengths.

Rill and inter-rill erosion on roads only resulted in 17,451 tons year^{-1} of sediment. This is nearly 16 % of the total erosion estimated for the watershed which is significantly less than the 51 % that the SCS had estimated for the BRW. The differences were most likely due to the fact that this research did not estimate gully erosion on roads. The value for rill and inter-rill erosion is most likely high given the conditions stated in the methods. Therefore, if the 51 % of total sediment estimated by the SCS is accurate, most of the sediment yield from dirt roads would be due to gully erosion. This would support the implementation of a gully erosion model within a GIS environment

Phosphorus Index Model

With excessive STP set to > 200 lb acre^{-1} (STP 200), more than 50% of the watershed had STP values in excess of 100 lb acre^{-1} and nearly 35 % of the area was in the excessive category. With high STP set to 300 lb acre^{-1} (STP 300), the excessive coverage dropped to 11% but the high category increased to over 75% coverage. In either of these scenarios the coverage of high STP is significant, but in the PI results, coverage of areas highly susceptible to P transport did not reflect the value of STP in the WEW (Tables 20 and 21, Figure 11). Although there were areas with excessive STP, there were no very high categories in the PI with no litter application. This suggest that either STP is not the most determinant factor in the PI model or other factors such as erosion class and runoff class had more influence on the results of the no fertilizer treatment

Table 20. Spatial distribution of P transport vulnerability for inorganic fertilizer application on the entire War Eagle Watershed.

Susceptibility to P Transport	Excessive STP > 200 lb acre^{-1} ha	Excessive STP > 200 lb acre^{-1} % Cover	Excessive STP > 300 lb acre^{-1} ha	Excessive STP > 300 lb acre^{-1} % Cover
	No Fertilizer Application			
	46,840	54.19	62,796	72.65
Medium	37,250	43.09	21,517	24.89
High	1,755	2.03	1,532	1.77
	Inorganic 1-30 lb acre^{-1}			
	9,613	11.12	9,613	11.12
Medium	68,153	78.84	71,771	83.03
	8,079	9.35	4,461	5.16
	Inorganic 31 to 90 lb acre^{-1}			
	3,546	4.10	3,546	4.10
Medium	67,949	78.61	76,272	88.24
High	14,350	16.60	6,027	6.97
	Inorganic 91-150 lb acre^{-1}			
Low	151	0.17	151	0.17
Medium	57,940	67.03	75,449	87.28
	27,754	32.11	10,245	11.85
	Inorganic > 150 lb acre^{-1}			
Medium	23,660	27.37	34,946	40.43
High	62,093	71.83	50,858	58.84
Very High	93	0.11	40	0.05

Scenario STP 200 classed excessive STP to > 200 lb acre^{-1} and scenario STP 300 classed excessive STP to > 300 lb acre^{-1}.

Table 21. P transport vulnerability calculated for organic fertilizer on the entire War Eagle Watershed. Tons acre^{-1} is fertilizer application rates with an average P concentration of 44.5 lb ton^{-1} (USDA-SCS, 1992).

Susceptibility to	Excessive STP > 200 lb acre^{-1}		Excessive STP > 300 lb acre^{-1}	
P Transport	ha	% Cover	ha	% Cover
	No Fertilizer Application			
	46,840	54.19	62,796	72.65
Medium	37,250	43.09	21,517	24.89
High	1,755	2.03	1,532	1.77
	Organic 1-30 lb acre (½ ton acre^{-1})			
Medium	10,100	11.68	12,256	14.18
	75,653	87.52	73,549	85.09
Very High	93	0.11	40	0.05
	Organic 31-60 lb acre^{-1} (1 ton acre^{-1})			
Medium	9,561	11.06	9,561	11.06
High	76,119	88.06	76,236	88.19
Very High	164	0.19	48	0.06
	Organic 61-90 lb acre^{-1} (2 tons acre^{-1})			
Medium	151	0.17	151	0.17
	85,155	98.51	85,399	98.80
Very High	539	0.62	295	0.34
	Organic > 90 lb acre^{-1} (> 4 tons acre^{-1})			
Medium	0	0	0	0
High	84,622	97.90	84,696	97.98
Very High	1,223	1.41	1,149	1.33

Scenario STP 200 classed excessive STP to > 200 lb acre^{-1} and scenario STP 300 classed excessive STP to > 300 lb acre^{-1}.

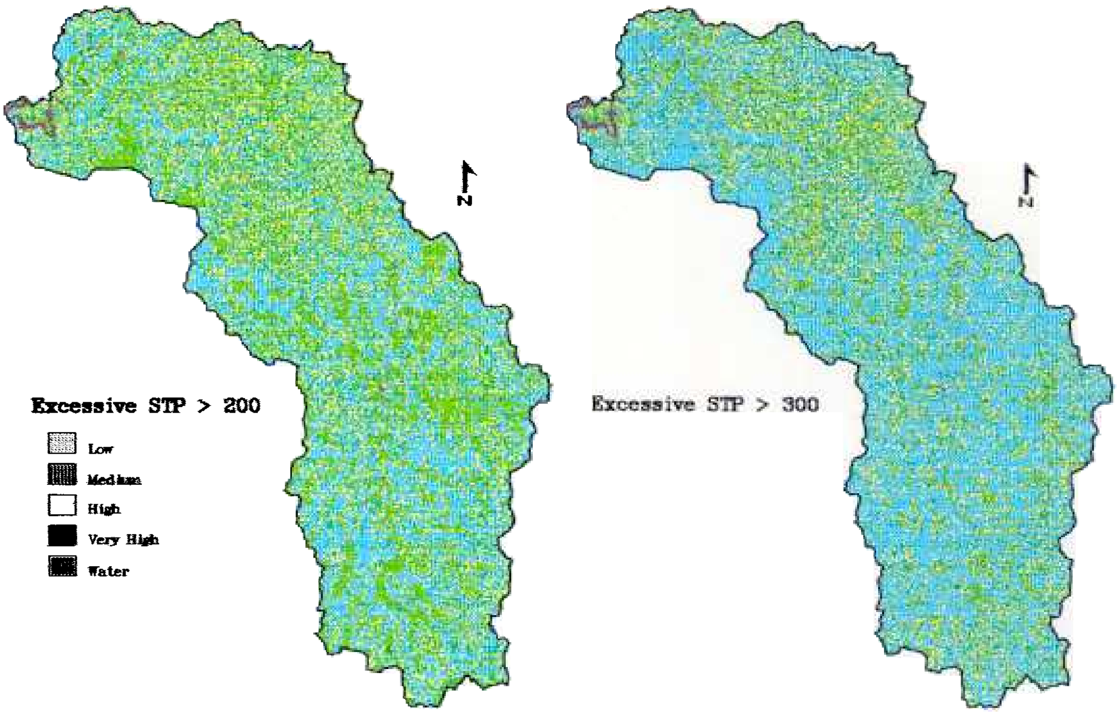

Figure 11. PI Model results without fertilizer treatments. The left figure is excessive STP > 200 lbs acre^{-1} while the right figure is excessive STP > 300 lbs acre^{-1}.

Presented in Tables 20 and 21 and Figure 11 are the PI model results for the total WEW watershed, but it is unlikely that fertilizer would be used on any area other than pastures. Therefore, the following results concern the PI model results on pastures only. The pasture data were derived by the TVA based upon 1988 aerial photography with the same pasture characterization as previously discussed.

No fertilizer application on pastures only responded differently than on the total watershed (Tables 22 and 23; Figures 13 and 14). In the STP 200 scenario, the distribution of the susceptibility was more evenly split between low and medium susceptibility. In the STP 300 scenario, the low category covered over 75 % of the total pastures. The differences mostly due to the shift of high STP to the low category in the STP

Table 22. Spatial distribution of P transport vulnerability calculated for inorganic fertilizer on pastures only.

Susceptibility to P Transport	Excessive STP > 200 lb acre^{-1}		Excessive STP > 300 lb acre^{-1}	
	ha	% Cover	ha	% Cover
No Fertilizer Application				
	16,066	48.20	23,973	71.92
Medium	16,319	48.96	8,507	25.52
	915	2.75	820	2.46
Inorganic 1-30 lb acre^{-1}				
	4,807	14.42	4,807	14.42
Medium	24,183	72.55	26,329	78.99
	4,311	12.93	2,165	6.50
Inorganic 31-90 lb acre				
	2,102	6.31	2,102	6.31
Medium	24,179	72.54	28,335	85.01
High	7,020	21.06	2,865	8.59
Inorganic 91-150 lb acre^{-1}				
Low	51	0.15	51	0.15
Medium	19,355	58.07	28,170	84.52
High	13,895	41.69	5,080	15.24
Inorganic > 150 lb acre				
Medium	11,317	33.95	17,059	51.18
High	21,920	65.76	16,215	48.65
Very High	64	0.19	27	0.08

Scenario STP 200 classed excessive STP to > 200 lb acre^{-1} and scenario STP 300 classed excessive STP to > 300 lb acre^{-1}.

Table 23. P transport vulnerability calculated for organic fertilizer on pastures only. Tons acre^{-1} is poultry litter application rates based upon an average P concentration of 44.5 lb ton^{-1} (USDA-SCS, 1992).

Susceptibility to P Transport	Excessive STP > 200 lb acre^{-1} ha	Excessive STP > 200 lb acre^{-1} % Cover	Excessive STP > 300 lb acre^{-1} ha	Excessive STP > 300 lb acre^{-1} % Cover
No Fertilizer Application				
	16,066	48.20	23,973	71.92
Medium	16,319	48.96	8,507	25.52
High	915	2.75	820	2.46
Organic 1-30 lb acre (½ ton acre^{-1})				
Medium	5,023	15.07	6,270	18.81
	28,214	84.65	27,004	81.02
Very High	64	0.19	30	0.09
Organic 31-60 lb acre^{-1} (1 ton acre^{-1})				
Medium	4,787	14.36	4,787	14.36
	28,424	85.28	28,480	85.45
Very High	90	0.27	35	0.10
Organic 61-90 lb acre^{-1} (2 tons acre^{-1})				
Medium	51	0.15	51	0.15
High	32,970	98.91	33,088	99.27
Very High	280	0.84	162	0.49
Organic > 90 lbs acre^{-1} (> 4 tons acre^{-1})				
Medium	0	0	0	0
High	32,589	97.77	32,632	97.90
Very High	711	2.13	669	2.01

Scenario STP 200 classed excessive STP to > 200 lb acre^{1} and scenario STP 300 classed excessive STP to > 300 lb acre^{-1}.

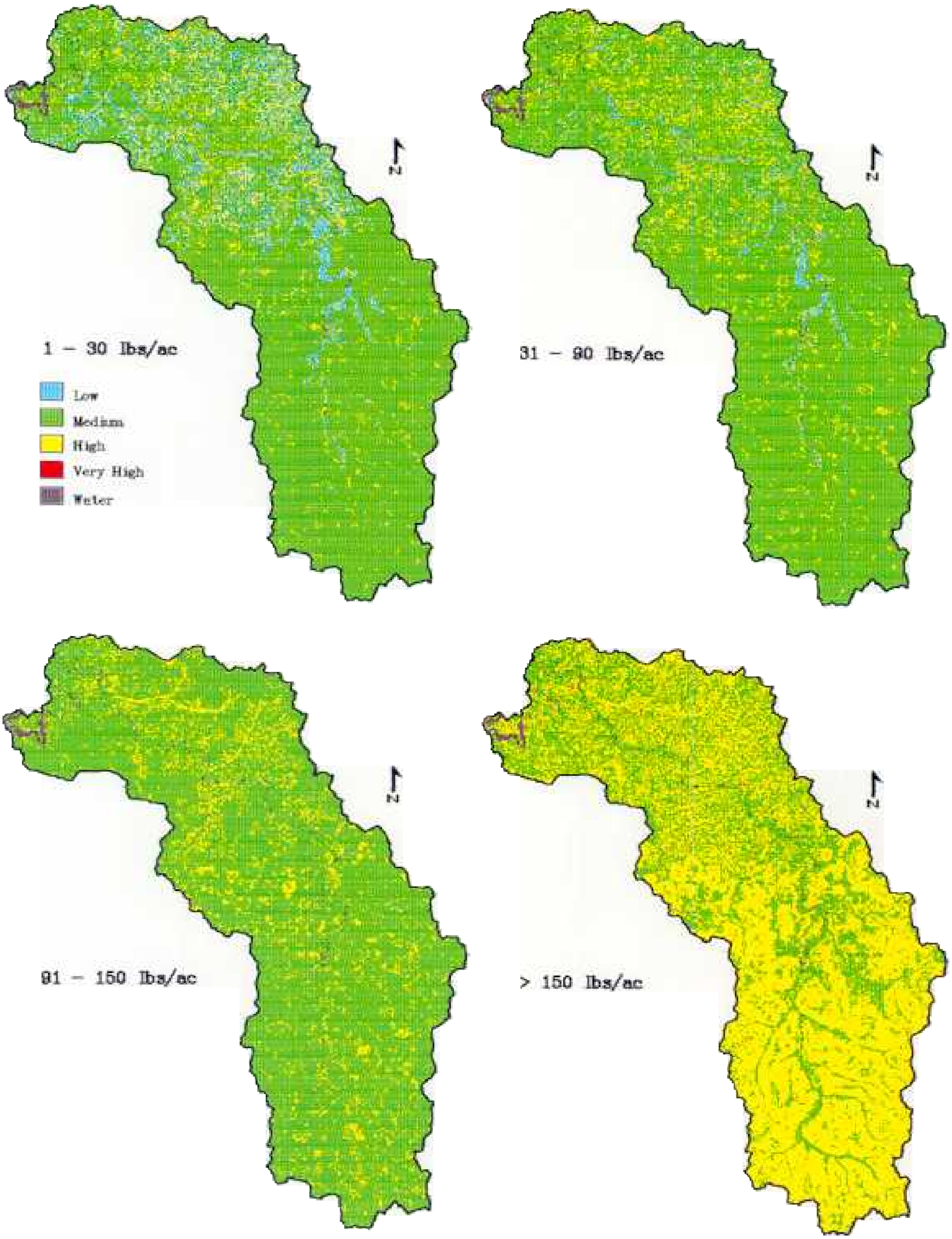

Figure 12. Results of the PI Model on the War Eagle Watershed. These figures show treatments of inorganic fertilizer of 1-30, 31-90. 91-150 and >150 lbs acre^{-1}, from left to right and top to bottom, respectively.

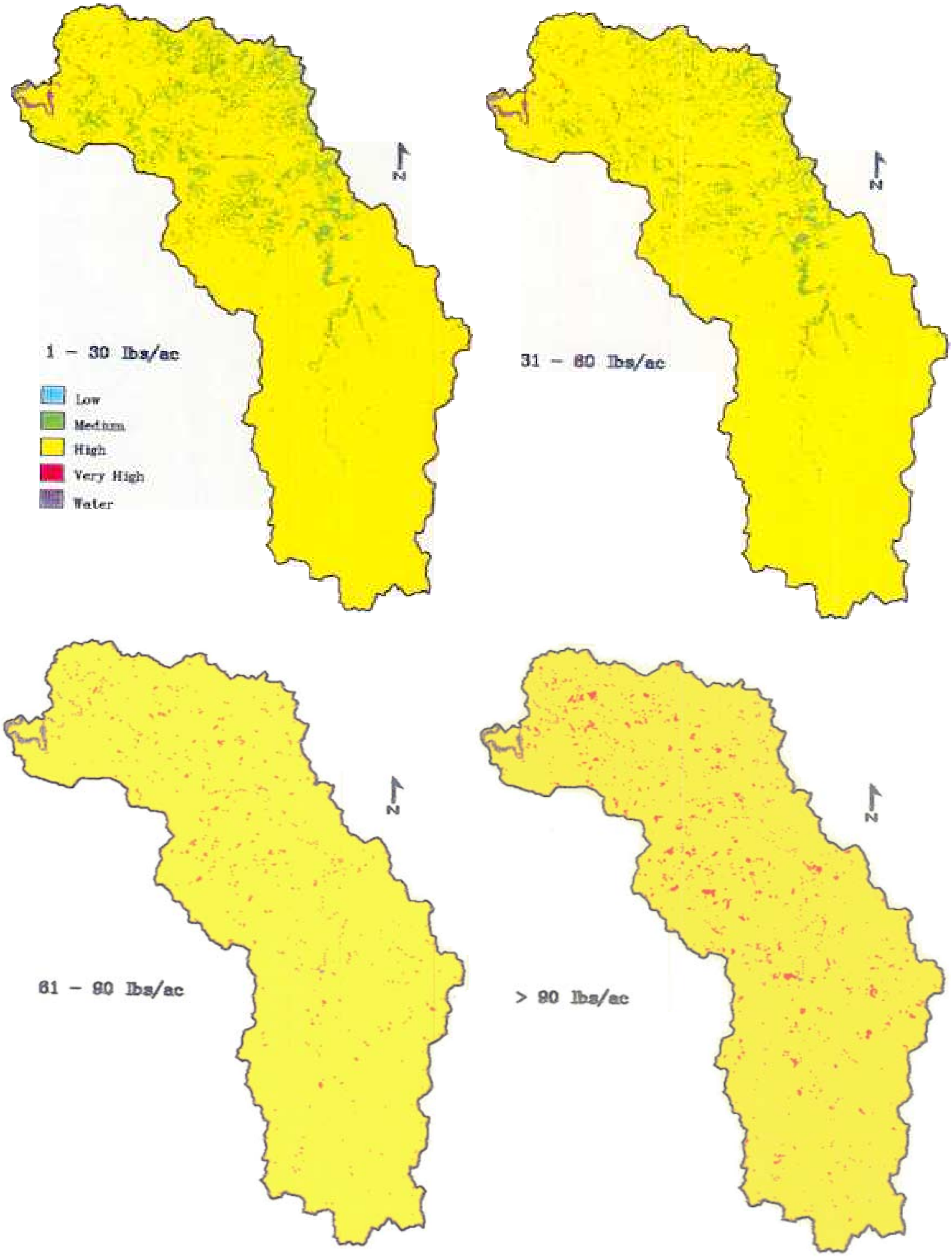

Figure 13. Results of the PI Model on the War Eagle Watershed. These figures show treatments of organic fertilizer of 1-30, 31-60. 61-90 and >90 lbs acre^{-1}, from left to right and top to bottom, respectively.

scenario. This reflects the lack of influence of STP on the no fertilizer application

At the first application of both inorganic and organic fertilizer, there was an increase in the coverage of the medium categories coinciding with a decrease in the low categories. The response to the inorganic fertilizer showed that coverage of the high category increased dramatically with a large reduction in the low category. The response to the organic fertilizer was dramatic with the first treatment. The category was dropped all together, while the medium category had nearly the same coverage as the low category in the inorganic treatment. response was mainly due to the difference in weights given to inorganic (0.75), and organic (1.00) fertilizers in the PI model. The difference between the STP 200 and STP 300 excessive categories for both fertilizers was almost double with STP 300 being the lowest. The difference between the two scenarios were not significantly different in the low and medium categories.

With the second simulated application of fertilizer, the rates differed between inorganic and organic (Tables 22 and 23). Not only were the weights different between the two fertilizers, but also, the inorganic fertilizer classes covered a wider range of rates than the organic suggesting that organic fertilizer is more unstable. Inorganic responses for the second treatment showed that the low category coverage was reduced by one half, coinciding with a doubling in the high category for the STP 200 scenario. The high category for the STP 300 scenario response was much less than the STP 200 scenario. The medium category did not significantly change. Application of organic P responses showed that the rate of increase in susceptibility was not as rapid as the inorganic P, although the susceptibility to P transport was more than the inorganic treatments. It is important to note that the coverage for the very high category (> 32) for organic did not increase rapidly. Differences between STP 200 and STP 300 scenarios were similar to the inorganic differences.

The third simulated application of inorganic fertilizer showed a significant loss in the low category, a smaller loss in the medium category and nearly a doubling in the high category. Again differences between the STP 200 and STP 300 scenarios were noted in the high category although both increased by the same rate. Organic P response to the third treatment was markedly different than the inorganic. The response was noted only where the medium category coverage was reduced dramatically, but the increase in the very high category was not as much as the inorganic. Responses between the STP 200 and STP 300 scenarios were the same as the inorganic treatment.

The final application was intended to overload the watershed with fertilizer. Responses for inorganic showed the loss of the low category, a reduction in the medium category, an increase in the high category and the inclusion of the very high category with limited coverage. Differences between the STP 200 and STP 300 scenarios remained about the same, but the rate of increase of the STP 300 scenario high category was much higher. Organic response to the final treatment was not as much as expected. The areal coverage for both scenarios in the medium category did not change significantly. While there was an increase in the very high category coverage, the change was not significant when related to the total WEW area. This response suggests that there may be a threshold limit within the model. This threshold is most ikely related to the range of indices for the high susceptibility category (15 to 32). Low and medium susceptibility categories have a range of only 8 while the high susceptibility category has a range of 16.

Of the 4 variables (fertilizer application rate, erosion, runoff and STP), the most influential with no fertilizer applied was erosion, although STP also had some effect. General trends for organic fertilizers showed that of the 3 variables (erosion, runoff and STP), the most influential STP. Its influence decreased with an increase in fertilizer application rate. Erosion was also influential, but its significance also decreased with fertilizer application rate. Runoff was the least significant, but its influence increased with fertilizer application rate

As inorganic fertilizer was applied, the most influential variable was STP, but the influence of STP decreased with an increase in application rate. The next most influential variable was erosion. As fertilization application rates increased, its influence also decreased The least influential was runoff, and this variable became less significant with an increased in fertilizer application rates.

The class values assigned to the two highest organic fertilization rates, 4 and 8, tended to mask the influence of the other three variables. Although there were changes in the effects of the three variables, they were very hard to discern for organic fertilizer. Conversely, at all application rates of inorganic fertilizer, the influence of each variable was decernable. This was mostly due to less weight (0.75) assigned to inorganic fertilizer.

CONCLUSIONS

Characterization of the Beaver Reservoir Watershed using compiled database showed that the watershed is a highly dissected region with steep slopes and narrow valleys and ridges. Soils differ depending upon surface geology (parent material) and geomorphic processes. There are ten predominant soil series that comprise over 75 % of the total watershed. Geology data suggest that the area is level bedded sandstones, siltstones, shales and limestones. The whole region has many lineaments that characterize the jointing and faulting in the region. predominant LULC is forested areas followed by pasture land indicating a mostly rural watershed. There are six major tributaries that flow into Beaver Reservoir, three of which are forks of the White River. The largest single sub-basin is War Eagle Creek. Most of the streams are either perennial or intermittent comprising nearly 3,000 km of streams There is an estimated total distance of 4,251 km of roads in the BRW. weather and dry weather cover the most distance, 3,600 km. Many more characteristics can be generated by interrelating the primary attributes. These characteristics can be tailored to specific uses and needs.

Based upon the ADPCE data, a general assumption can be made that with the exception of P from point sources, there were few problems with excessive P loading into War Eagle Creek. Relationships between the database and the aqueous P samples suggested that sub-basins with lower P concentrations had a higher than normal distribution of forest pastures, particularly good and fair pastures both with and without evidence of fertilization. The data varied by season particularly with respect to flow and state of vegetative growth. The difference between total P and ortho P also varied by season

Results from the USLE calculations suggest that the WEW was not experiencing any severe problems with erosion in 1988. There were several areas with high annual sediment yields but these areas were a very small percentage of the total watershed area. Annual sediment yield from dirt roads and drainage ditches were significantly less than expected. This was due mainly to a lack of an appropriate gully erosion model. Given the conditions under which erosion from dirt roads occur in these areas, rill and inter-rill erosion would constitute a minor fraction of the total sediment yield.

According to the PI model results, a significant portion of the War Eagle Creek Watershed is vulnerable to P transport by over land flow. STP was not the only determining factor in vulnerability to P transport. Erosion and runoff were also influencial. The two scenarios used for classifying STP reflected the possible impact of management practices or regulations on the application of fertilizer.

The future holds a greater role for GIS in the arena of mathematical modeling and watershed monitoring. This is true in light of the development of more complex process based models that require a large number of input parameters. The concept of parameters as maps make development and input of these parameters easier and quicker. GIS can also provide a means to transfer models from the development arena to the real world; thus, making the concept of a total watershed management system more of a reality rather than a possibility

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