6-30-1992

GIS Characterization of Beaver Watershed

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Publication No. 159
July 1, 1991 - June 30, 1992

Technical Completion Report Research
Project G-1549-06

Arkansas Water Resources Center
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AWRC

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The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research and Development Act of 1984 (P. L. 98-242)

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ABSTRACT

GIS CHARACTERIZATION OF THE BEAVER WATERSHED

Beaver Reservoir watershed is located in Northwest Arkansas including portions of Madison, Washington, Benton, Carroll, Franklin and Crawford counties. This watershed is important to the Northwest Arkansas region because it supplies most of the drinking water for the major towns and cities, and several rural water systems. The watershed consists of 308,971 ha with elevations ranging from approximately 341 m to 731 m above mean sea level. It includes the Springfield Plateau and the Boston Mountains provinces within the Ozark Plateau physiographic region. There are approximately 581 km of streams, 532 km of shore line, and 3712 km of roads in the watershed most of which are city streets and rural roads. The soils in the watershed vary extensively and are quite complex due to the differences in parent material, topography and time. Most parent material of the soils in the Springfield Plateau is limestone, whereas in the Boston Mountains the dominant parent material is sandstone and shale. The differences in soils have led to the differences in landuse and land cover. The near surface geology in the watershed is also divided by physiographic provinces. Most of the Springfield Plateau surface geology is limestone, whereas the Boston Mountains are primarily sandstone and shale. Spatial details of the streams, roads, soils and geology attributes in the watershed are presented in this report. The GIS database and characterization of the watershed offers an excellent beginning to future research and modeling of various water quality parameters in this and other watersheds.

D. SCOTT AND J. M. MCKIMMEY

pletion Report to the U. S. Department of Interior, Geological Survey Reston, July 1992

ords -- Geographical Information Systems, Soils, Geology, Groundwater, ry Litter.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Beaver Lake watershed is located primarily in northwestern Arkansas in portions of Washington, Madison, Carroll, and Benton counties (Figure 1). It serves as a source of drinking water for much of the population in these counties. The principal streams in the watershed include the White River, Middle Fork of the White River, West Fork of the White River, Richland Creek and War Eagle Creek. These streams originate in the Boston Mountains and generally flow northward toward the lake. Statistical summaries of water quality parameters taken by the Arkansas Department of Pollution Control and Ecology and U.S.G.S. have shown that some of these streams are experiencing several water quality problems including elevated concentrations of nitrogen, phosphorus, and bacteria (U.S.G.S., 1988). The sources of these pollution problems have been attributed to the effluent from the Fayetteville treatment plant, geology, agricultural operations such as the land application of poultry litter and other animal wastes, septic tank filter fields, and roadside management related to runoff from bare soil or gravel surfaces into surface and groundwater supplies (SCS, 1986). The water quality of Beaver Lake is of concern not only to the people in the area but also to those state and federal agencies which oversee the lake and watershed.

OBJECTIVE

The objective of this study was to develop a Geographical Information System (GIS) for the Beaver Lake Watershed. GIS is a technology widely used by many agencies to input, manage, manipulate, analyze, query, and display large collections of spatial data needed for informed resource management decisions. The GIS database was developed from several important spatial attributes of the watershed. Individual goals required to accomplish this objective included

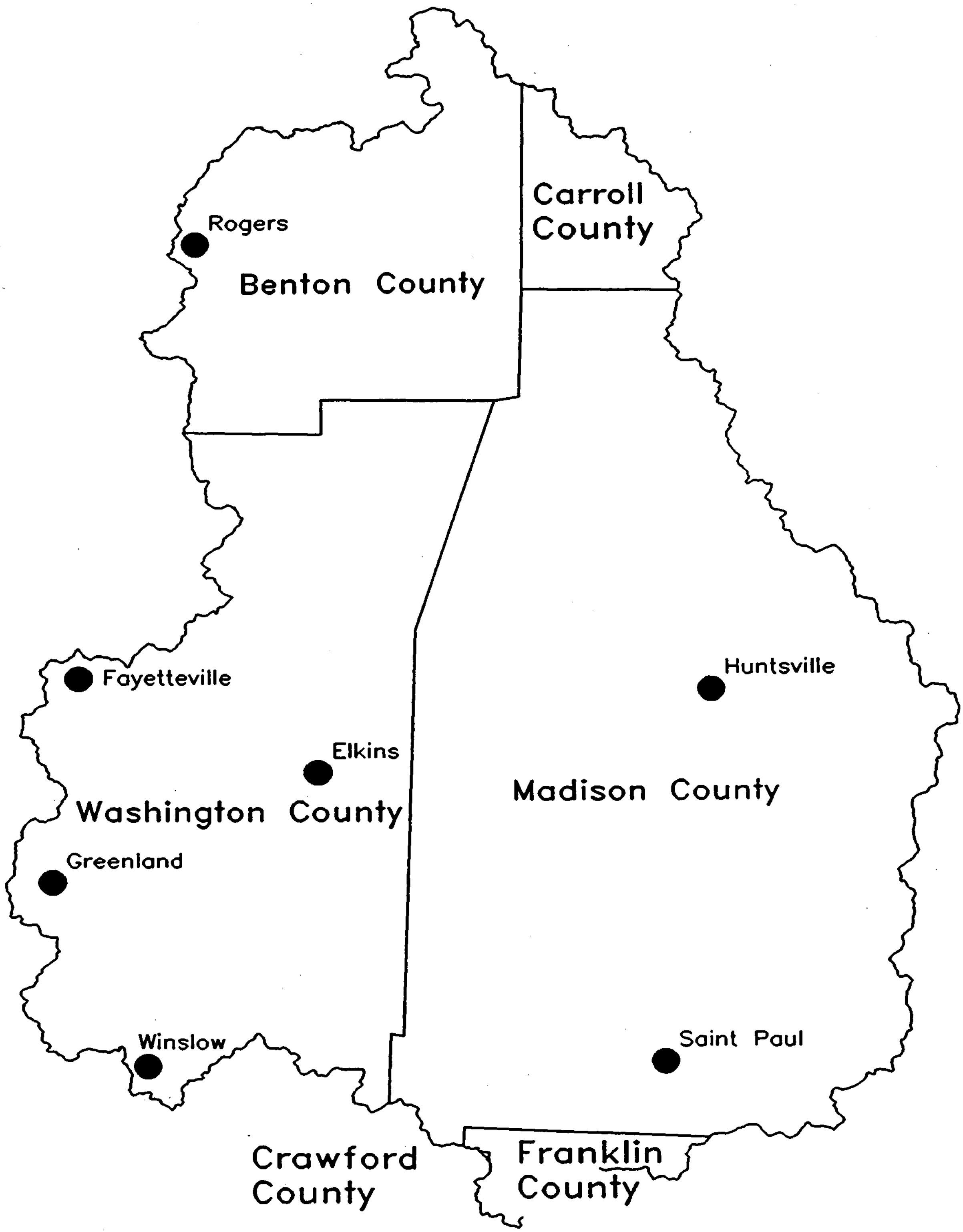

Figure 1. Spatial distribution of counties in the Beaver Reservoir watershed.

input, verification, and correction of each primary attribute selected to characterize the watershed.

LITERATURE REVIEW

Beaver Reservoir Watershed

Beaver Reservoir is located in Northwest Arkansas at the head waters of the White River. The reservoir is impounded by Beaver Dam located west of Eureka Springs in Carroll county. The watershed extends north to south, from just south of the Arkansas-Missouri state line to the northern edge of Franklin county. East-west extent of the watershed is from Fayetteville in Washington county to six miles east of Huntsville in Madison county. The watershed includes portions of Benton, Washington, Crawford, Franklin, Madison, and Carroll counties. The reservoir is also the main water source for the major municipalities in northwest Arkansas.

During the early 1960s the population of Northwest Arkansas was mostly rural with three small-to medium-size municipalities: Rogers, Springdale, and Fayetteville. Economic activity in the area was primarily agricultural and comprised mostly of small, individually owned farms. There was little industry associated with the three major communities. Water supplies for these three communities consisted of small reservoirs on the outskirts of the city limits. During the past 30 years, however, the area has more than doubled in population (Figure 2). Types of industry have diversified from small farms to a mixture of light industry and food processing, mainly located within cities, and large poultry and swine operations in rural areas. Much of the industrial growth within the cities can be attributed to a more than adequate water supply provided by Beaver Reservoir. With the rapid increase in population, industry, and agriculture, the problems of pollution have also increased. Until 1988, the

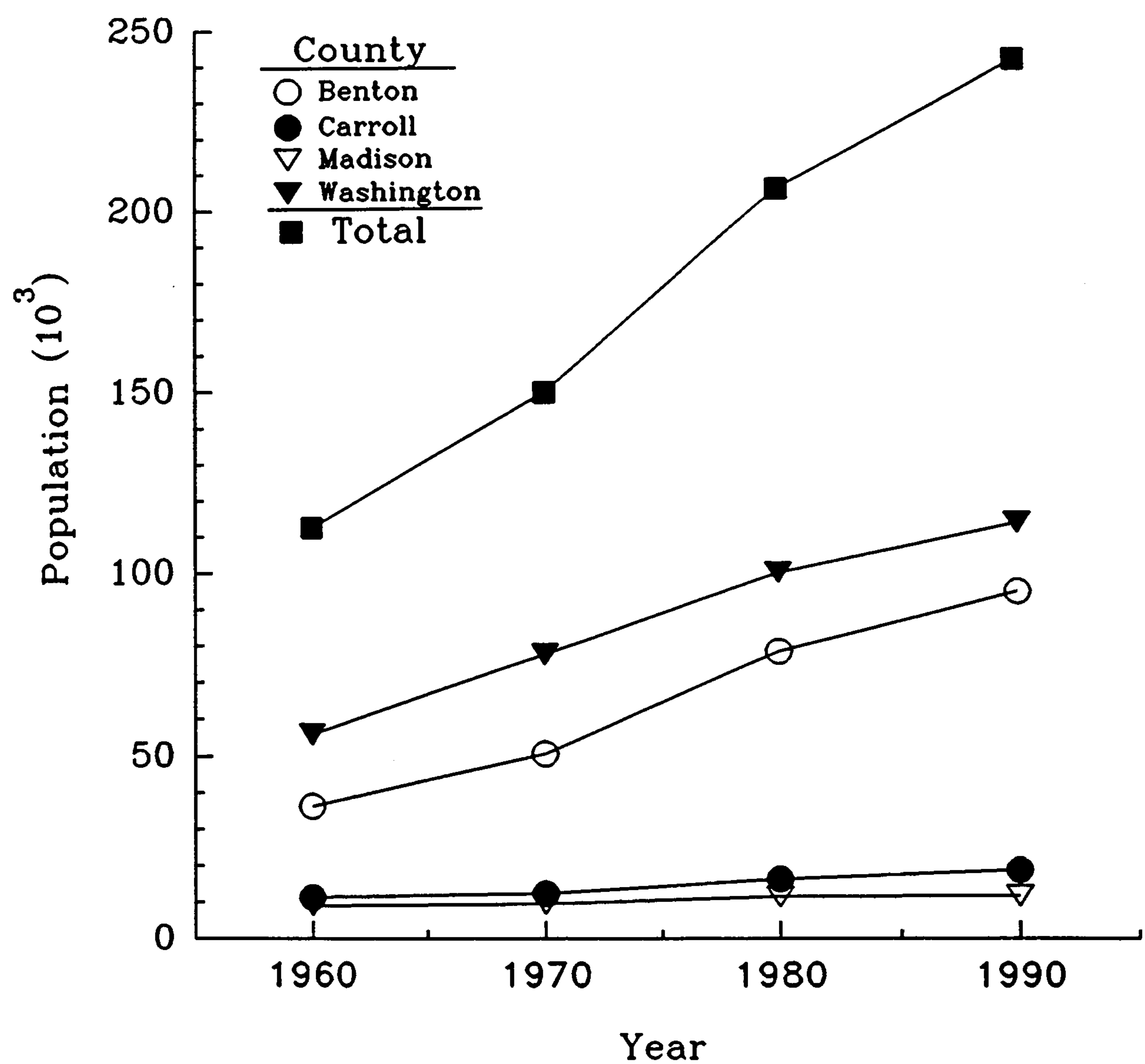

Figure 2. 30-year population change for Benton, Carroll, Madison and Washington counties in Northwest Arkansas (Source: U.S. Census Bureau 1960, 1970, 1980 and 1990).

Fayetteville waste water treatment facility discharged effluent directly into the White River, the main tributary of Beaver reservoir, approximately 16 km upstream from the reservoir. Past research noted the high levels of nitrogen (N) and phosphorus (P) in the water below the treatment plant (U.S.G.S., 1988). A marked reduction of fish species diversity and population below the sewage discharge point was noted (Brown, 1983). The effluent from the treatment plant accounted for most of the point-source pollutants entering Beaver Reservoir (SCS, 1986). With the installation of the new waste disposal treatment plant, the levels of pollutants were supposedly dramatically reduced. Apparently, there is no research that has reported the effects of the new waste treatment facility on aquatic diversity and population below the discharge point. Although, data from water samples taken down stream suggests that P concentrations in the water have been reduced (Figure 3).

As the poultry and swine industry expanded in the area, the number of poultry and swine houses increased as well (Figure 4). These houses contain large populations of animals which result in a high density of animal waste. Waste from these houses is commonly applied broadcast to area pastures as a fertilizer. Subsequent runoff and infiltration of P from the applied animal waste has caused concern about the quality of surface runoff and groundwater. There have been few published studies on the Beaver watershed where small ponds, streams, and water wells have been sampled to evaluate water characteristics. Research has been conducted on the larger water bodies in the watershed with results generally showing a rise in P concentrations over time (SCS, 1986). Sources of P are from waste treatment facilities on the White River above Beaver Reservoir and an unknown source near Prairie Creek just east of Rogers. Before the Fayetteville treatment plant came on line in 1988, the input of P from the facility accounted for 62% of the P entering the reservoir (SCS, 1986). Therefore, it was estimated that non-point sources are responsible for 38% of total P entering the reservoir (SCS, 1986). These sources of P could result from agricultural practices, increased urban runoff, and a dramatic increase of septic tank filter fields along the shoreline due to recent development. It has been

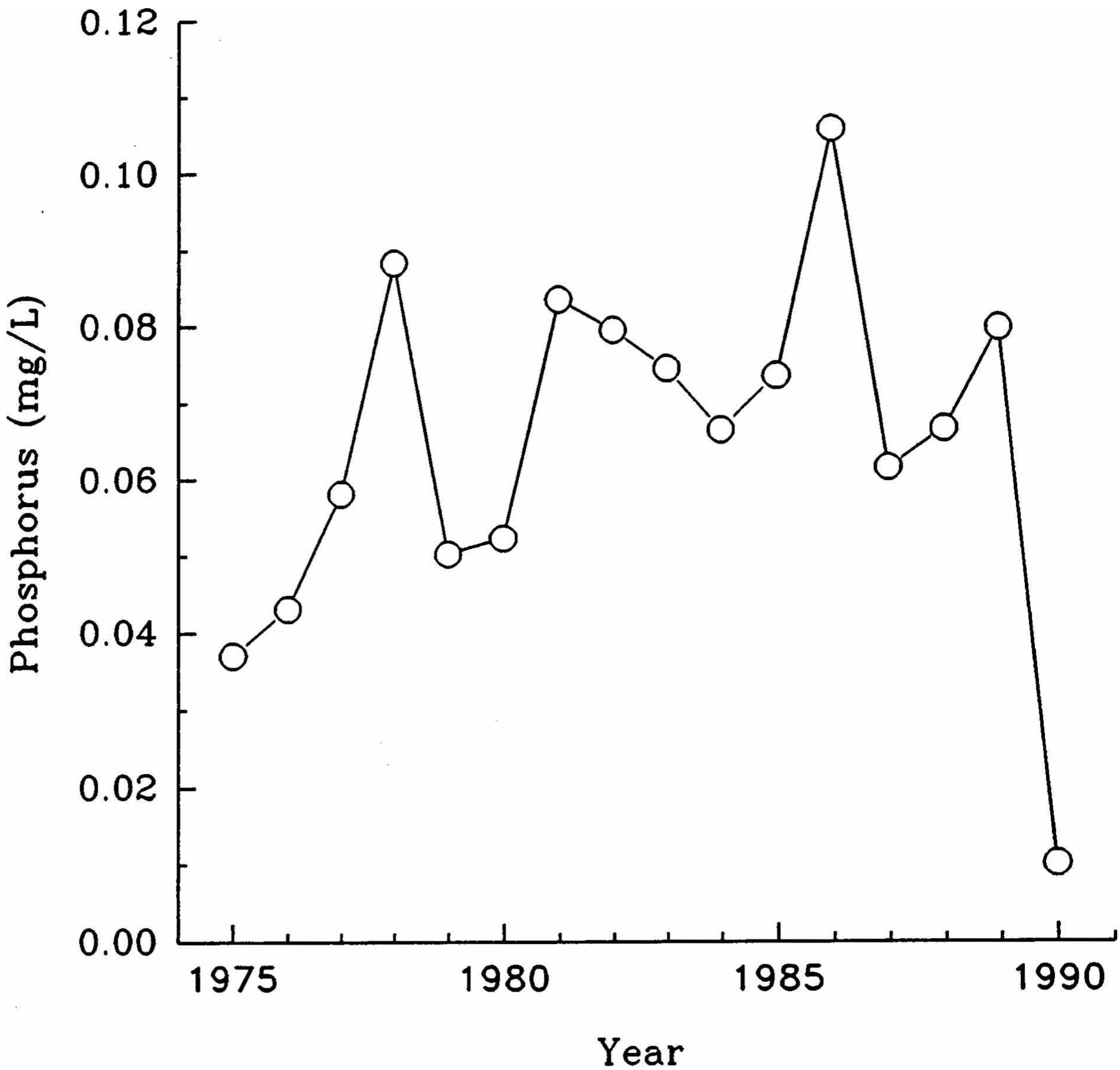

Figure 3. P concentration by year in the White River below the Fayetteville Waste Water Treatment facility (Source: USGS Water Resources Data 1975-1990).

a public consensus that the most important P sources are from animal waste sites such as poultry and swine houses as well as from the use of poultry and swine litter as a fertilizer. At this time, these suspicions have not been substantiated because of the lack of quantitative data.

The Soil Conservation Service (1986) reported on a study of animal waste, erosion and nutrient transport within the Beaver Reservoir watershed (SCS, 1986).

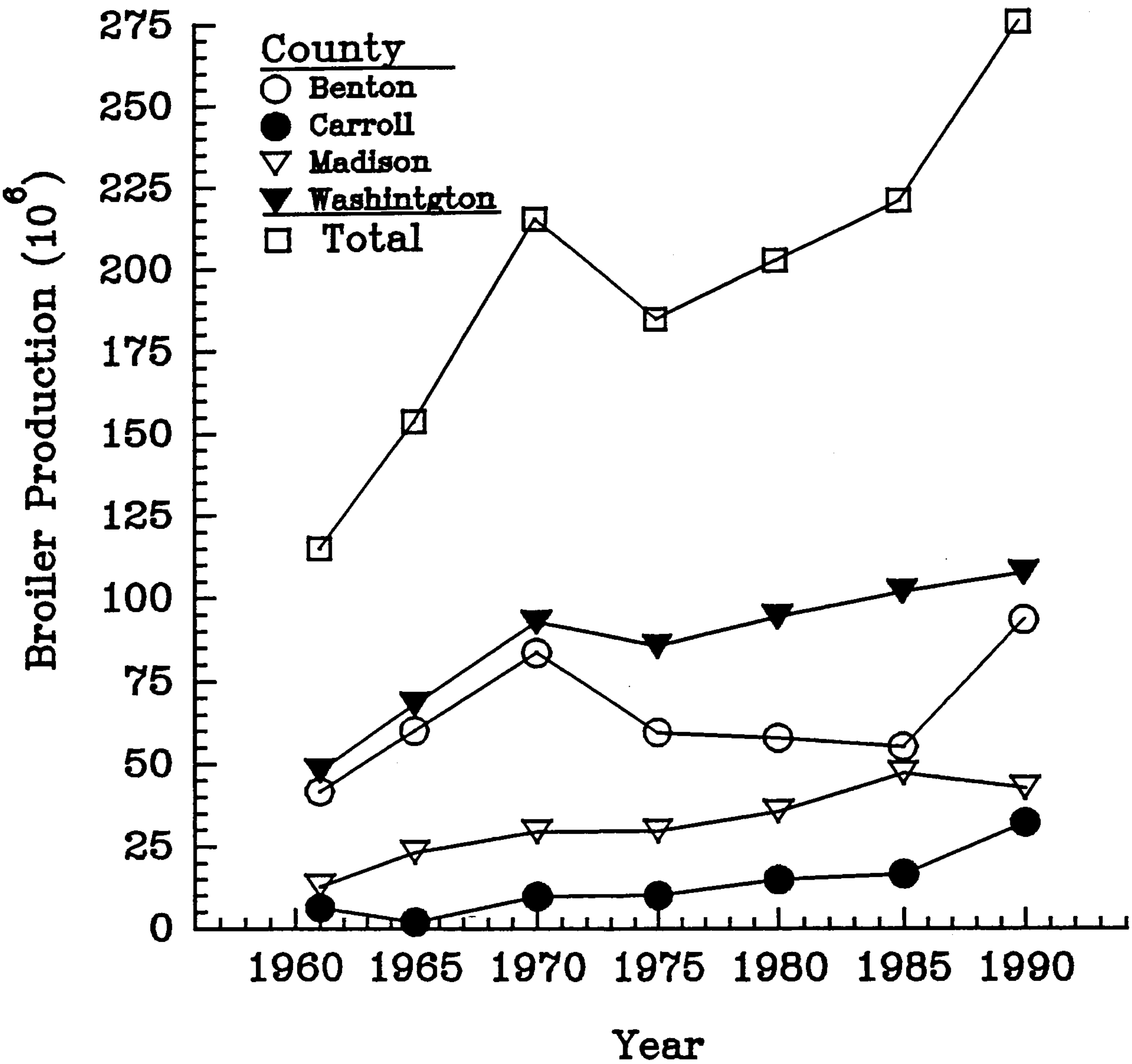

Figure 4. Broiler production since 1961 (Source: Arkansas Agricultural Statistics 1961, 1965, 1970, 1975, 1980, 1985 and 1990).

Results showed that many pollution problems encountered by the Beaver Lake Water District are caused by transported P and sediment. As of 1986, 417,000 tons per year of sediment enter the reservoir with road surfaces and drainage ditches responsible for 51% of the total sediment. Annual total P transported along with the sediments was estimated to be 243,000 lbs. Such a large mass of nutrients and sediments entering Beaver Reservoir occurs mainly in the upper reaches of the lake. The combination of high sediment and P concentrations gives this portion of the lake an eutrophic characteristic.

Geographic Information Systems

GIS software was designed to manipulate spatial data in the same manner as overlaying maps of differing themes to determine spatial relationships. While it is difficult for most individuals to comprehend more than three overlays at any one time, a GIS can allow many more overlays to be associated with each other at the same time. These overlays are called attributes and are a collection of data of the same theme. A GIS database is a collection of themes that can be envisioned by dividing a topographic map into separate layers. Topographic maps contain many types of information such as topography, hydrography, and transportation. In the GIS database a data file for each of these themes or attributes exists. Each attribute consists of information about that data layer. These attributes can be manipulated individually or with each other to create a new attribute.

GIS operates upon a world coordinate system such as Universal Trans Mercator, longitude/latitude grid, or State Plane coordinate system. Each bit of information will be tied to the coordinate system in a x,y,z format with the z value being some value for a given attribute.

There are three distinct types of data that a GIS can use. The first type is point or site information which consists of a single x,y coordinate pair and a z value. Point information is useful in describing sampling sites in a study area or some other point of interest. Concentrations of nitrate or fecal coliform at a specific sample site is an example of site data. The second type is line information that consists of a beginning and ending x,y coordinate pair describing the nodes and a single descriptive z value for the whole line.

Information such as roads is commonly found in this format. The third data type is area information which is described by a collection of lines that form a closed polygon. This data form consists of a collection of x,y values describing lines that outline an area with a single z value describing the area. These three types of information will describe any information that exist on most maps.

There are two general types of GIS software available. One is a raster or grid-cell based system while the other is a vector based system. These two types differ in the way that spatial data are stored and manipulated. Raster images are pixels or cells of a predetermined x,y dimension that collectively composes a study area that is defined by some boundary, such as a watershed. Each cell is assigned a value depicting something about that cell, such as elevation. Vector images are a collection of lines and points described by nodes and internodes with points along the internodes indicating direction change. Each line is given a value that describes something about that line. There are limits for each type of system. A grid-cell based GIS is best intended for analyzing area information, but cannot work with lines without first converting that line to a collection of pixels. Such a system will not be able to directly measure the distance of a line. A vector based GIS is intended to operate primarily upon line information. These systems are well suited for routing information, but are weak in area analysis (Burroughs, 1985).

The use of GIS as a land management system was recognized very early in its development. In fact, there are many land management systems throughout the United States. These systems are currently being used in areas that range from urban management and planning to natural resources monitoring. One such system called the Maryland Automated Geographic Information (MAGI) (MAGI, 1981) was developed for the state of Maryland by Environmental Systems Research Institute of Redlands California. MAGI was designed to serve as an efficient and accurate tool to address land use and natural resource planning. MAGI database is organized into two general categories physical data and cultural data. Physical data includes attributes such as soils, topographic information, geology, mineral resources, wetlands, vegetation cover, natural features, endangered species, and hydrology. Cultural attributes include land use/land cover for three different years, archaeological sites, sewage and water network, future planning, transportation, land ownership and outdoor recreation. A data structure such as this can be very extensive with multiple attributes in each of the categories mentioned above. With attributes in a single system, there is an unlimited number of applications that can be performed.

Dangermond and Smith (1988) stated that mankind has frequently recognized potential problems after it was too late to effectively correct them. Computer models offer hope for early warning systems for such potential problems. Such is the case with the Beaver Reservoir. By modeling the characteristics of P across the watershed, perhaps the P concentrations that actually enter the reservoir can be accurately predicted.

MacDonald et al (1973) made one such recommendation for modeling a potential problem. Their study showed that although chemical pollution in groundwater of Washington county was low, 80 % of the springs in his study area were polluted by bacteria. They recommended that a network of spring and well water be developed to monitor groundwater quality. This recommendation is ideally suited to GIS analysis because GIS provides a convenient place to store, manipulate, retrieve and update data with accuracy and efficiency. In fact, all of the recommendations by MacDonald et al are ideally suited for GIS.

METHODS

Use of the GIS

The GIS software used in the study is known as Geographic Resource Analysis Support System or by the acronym 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 are based upon raster data. Vector data are mostly an intermediate data production information. The data itself can be either point, line, or area information, but the format consists of beginning and ending nodes described by coordinate pairs. Attributes are digitized into this vector format and converted to the raster format.

In GRASS each vector file has a number of associated support files. The dig_att file is where the x,y label position of each point line and area are stored along with a numerical z value describing what is at that location. The dig_cat file is where a list of numerical z values is stored along with a legend describing each value. The dig_plus is the file where the topological structure is stored. A fully supported attribute will have a digit file where the vector information is stored long with one support file in each of these directories. A raster file will also have associated support files along with the cell file. The cats file is identical to the dig_cats file in structure and purpose but is associated with the raster file. In GRASS cellhd is a header file that contains pertinent information about the location, pixel size, and source of the cell file. The cell_misc contains information about the range of the z values in the raster data and is used in generating color tables. The colr file contains the color table for an attribute. Like the vector file, a fully supported attribute will have an entry in each of these directories. The last form of data is site information. The form of the data is in x,y coordinate pairs along with an associated z value. This z value can be a concentration, a count, or any numerical value associated with the point. The hardware for our study consisted of a SUN SPARCstation 1 operating on a UNIX platform, an Altek AC-30 digitizer, a Houston Instruments pen plotter with a scanning head, and an AT&T 386i DOS/UNIX based workstation. In addition to GRASS, other software used in this research included SCAN-CAD and Line Trace Plus (LTPlus).

Development of the Database

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 the media availability of each primary attribute. As an example, 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 suited to each data format. Several attributes were available only in a map format. These maps were digitized or optically scanned to create a digitized format of the map and then imported into the database. These processes were used in creating the soils and geology attributes, and are discussed later. This research included several types of tabular data such as water well logs and water quality parameters at a sample site.

Most attributes generated by these methods are primary attributes. Primary attributes are information that is absolutely necessary in the database. They cannot be generated from any other attributes. Attributes that are generated from the manipulation of one or more of the primary attributes are considered to be secondary. That is, they are products of other attributes. However, this does not mean that they are less important. One such example is reclassification of soils maps. In conjunction with the SCS's county soil survey publications, soil mapping units can be reclassified into, but not limited to, any of the following secondary attributes: 1) texture, 2) bulk density, 3) pH, 4) depth to bedrock, 5) drainage, etc. Combining primary and secondary data layers allows yet more possible attributes such as the combination of slopes, hydrology, and soil attributes to determine areas susceptible to erosion. Point data such as well logs can yield a database on depth of water producing formations as well as depth of geologic formations. Water sampling sites can reveal the concentrations and diversity of contaminants and microbiology. Site or point information could be linked with other area and line attributes to characterize conditions at a location in question. For example, information from such a query could determine elevation, slope, aspect, soil series, and/or proximity to a fault or animal waste production site.

Study Area

The study area was defined by the Beaver Reservoir watershed consisting of approximately 1,192 square miles. During the first portion of the study the watershed boundary was interpolated using USGS 1:24,000 topographic series maps and then digitized into the database. From the interpolated watershed a list of the USGS 1:24,000 scale topographic series maps were compiled (Table 1). Each 7.5 minute quadrangle existed as its own entity within the database as well as a portion of the total watershed. This scheme segregated areas into nationally accepted boundaries, allowed separate manipulation of a whole quadrangle, and

Table 1. USGS 1:24000 scale maps and year of publication for Beaver Reservoir Watershed.

Quadrangle Name	Date	Quadrangle Name	Date
Beaver	1976	Japton	1973
Bentonville South	1982	Kingston	1973
Bidville	1973	Pea Ridge	1976
Boston	1975	Pettigrew	1973
Brentwood	1983	Rockhouse	1972
Cass	1973	Rogers	1976
Delaney	1973	Sandstone Mtn.	1976
Durham	1973	Sonora	1976
Elkins	1976	Spring Valley	1976
Fayetteville	1982	St. Paul	1973
Forum	1973	Sulphur City	1973
Garfield	1976	War Eagle	1976
Goshen	1976	Weathers	1973
Hartwell	1973	West Fork	1982
Hindsville	1976	Winslow	1983
Huntsville	1973	Witter	1973

provided a detailed library of the acquired data attributes for each quadrangle. The choice of attributes to be input into the database was based primarily upon attributes affecting water quality (Table 2).

Table 2. Primary attributes, media type, scale or resolution, and source used as original data for the database.

Attribute	Type	Scale/Resolution	Source
Elevation	DEM	30m/80m	USGS/ESIC
Roads	DLG	1:100,000	USGS/ESIC
Hydrography	DLG	1:100,000	USGS/ESIC
Land Use/Land Cover	DLG	1:100,000	USGS/ESIC
Vegetation	IR imagery	30m	EOSat
Boundaries	Map	1:100,000	USGS/ESIC
Soils	Map	1:24,000	SCS/ARK
Geology	Map	1:24,000	AGC

Elevation

There were two forms of Digital Elevation Models (DEM) available from the Earth Science Information Center (ESIC). Both of these are distributed by the United States Geological Survey (USGS), but were produced by different government agencies. The first form is the 7.5′ DEM consisting of an array of elevations referenced to the UTM coordinate system with a datum of NAD27. The data are stored as discrete points 30m apart both north and south with a value depicting elevations for each point. Elevations are given in meters with a reference to mean sea level. 30m DEMs were produced from one of two sources: (1) digitized contour overlays, or (2) scanning aerial photography. From these sources one of four processes is used to generate the elevations: Gestalt Photo Mapper II (GPM2), (2) manual profiling from photogrammetric stereomodels, (3) stereomodel digitizing of contours, and (4) derivation from Digital Line Graphs (DLG) hypsography and hydrography categories. The different sources and processes resulted in three different levels of accuracy for a given DEM. The second DEM is produced by the Defense Mapping Agency and is distributed in a 1 degree x 1 degree format. These DEMs have a resolution of 80m x 80m with a datum of WGS72. Elevations are in meters relative to mean sea level. Elevations are produced from both cartographic sources like hypsographic features, such as contours and lakes, and photographic sources such as ridge and water elevations (USGS, 1986; USGS, 1987).

All 30m DEMs available from the USGS for the watershed were imported to GRASS. Each DEM had pixels that contained 0 values around portions of the quadrangle boundaries, a result of the processing of the DEMs. To fill these "holes", an averaging 3 x 3 filter was run over each quadrangle averaging elevations only for the holes and not changing other current values. This process will be run on the complete watershed once 30m DEMs for all quadrangles are produced. The 80m DEM also required an averaging 3 x 3 filter for the same reasons as the 30m DEMs. The watershed occurs in an area where four different 1 degree x 1 degree 80m DEMs were required for full coverage resulting in the same 0 values at the edge of the individual areas.

There was little hope that 30m DEMs for the remaining eight quadrangles would become available before the end of the project. Alternate methods of generating the 30m DEMs were considered. These methods include interpolations using various methods and equipment. One method involved scanning elevation contour lines of the eight quadrangles and interpolating values from the contours using LTPlus, the same software used in editing the soil maps. Another method was to sample known elevations within each quadrangle and interpolate values using a kriging routine available with SAS. As a measure of accuracy, a sample run would be made on areas with similar landscapes of which the 30m DEMs were available. As a further check, elevations at particular sites were checked.

Roads and Hydrography

Both roads and hydrography were obtained from the ESIC in a DLG3 format. This format consists of the lines, attributes, and the topology of the data. The data consist of points, lines, and area identifiers. Each of these map features are topological elements of a map. Topology is the relational structure or spatial relationships of each element in the file to other elements. Spatial relationships include concepts such as adjacency and connectivity between map features. Topology is necessary for plotting the line graphs and other advanced applications such as computations and analysis involving areas and lines and their spatial relationships. The DLG3 format includes these spatial relationships (USGS, 1989).

DLGs were produced by the USGS using 30′ X 60′ quadrangles at a scale of 1:100,000 based upon the UTM coordinate system. Procedures for production include manual digitizing, semiautomatic line-following method, and automated scanning and editing system. Data validation included checking for absolute positional accuracy from 0.003 to 0.005 of an inch for manually digitized products and 0.0013 of an inch for automated products, manual attribute verification, topological structure, and edge matching with adjacent maps. Both roads and hydrography were imported into GRASS and patched into one file for each attribute. These attributes were also divided into individual 7.5′ quadrangle maps.

Land Use and Land Cover

There are two Land use and Land Cover (LULC) files used in the database. The first was the USGS 1:250,000 scale and 1:100,000 scales. The second was obtained from the Tennessee Valley Authority (TVA) and will be discussed later. As of 1 July 1992, the USGS data was in hand on a Mylar base, while the same data had been ordered in a digital format. Since the initial proposal, USGS LULC had become available in digital format. The time delay of ordering these data was less than the required time for manual digitizing.

LULC provides what is known as Level II categories of the classification system. The classification system is given in Table 3. Source data were from NASA high altitude aerial photographs normally at scales smaller than 1:60,000. The data structure is similar to that of the roads and hydrography in that there are areas described by polygons composed of lines. LULC differs from roads and hydrography in that it consists of polygons only. The minimum aerial coverage varies depending upon the category. For categories 11-17, 51-54, 23, 24, 75, 76 the smallest area depicted was 4 hectares (ha). The minimum width for these

Table 3. Land Use/Land Cover Level II Classification System. (Source: Land Use and Land Cover Digital Data Users Guide 1990)

LEVEL I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetlands	61 Forested Wetland
	62 Non-forested Wetland
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas Other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrubs and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

categories is 200m except for double line streams and access highways. All other categories are 16 ha with a minimum width of 400m (USGS, 1990).

LULC data were obtained from ESIC in both digital and Mylar map formats. The watershed encompasses portions of four 1′ x 1′ quadrangles requiring the files to be patched. The map covering the southeast portion of the watershed was at a scale of 1:100,000, while the remainder was at a scale of 1:250,000. There was no difference in the detail between scales.

Soils

Soils data were provided by the Soil Conservation Service 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. These maps were redrawn from the previously published unrectified aerial photographs to fit the 7.5′ 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.

County soil surveys were conducted by SCS soil scientists using both field sampling and aerial photograph interpretation according to Order II guidelines. In each county, SCS soil scientists conducted detailed studies of soil profiles within a landscape. The site selection of each profile sample was determined by 1) steepness, length, and shape of slopes, 2) general drainage patterns, 3) crops and native vegetation, and 4) near surface geology (SCS, 1986). The SCS found that each soil mapping unit was associated with landscape segments described by the previously stated factors. This allowed placement of a soil mapping unit in a specific landscape segment. In this manner, the SCS soil scientists determined the significant natural bodies of soils in a county and their position as related to a landscape. At this point the landscape was divided into landscape segments by aerial photographic interpretation with each segment assigned a specific soil mapping unit.

A soil mapping unit represents an area on a map that is dominated by one or several soil series. These mapping units are named according to taxonomic classification of the dominate soil series. Each taxonomic classification has a set of defined limits for the properties of the named soil. This does not mean that a soil mapping unit has uniform properties, since each soil mapping unit has inclusions of other mapping units that may or may not have the same defined limits. These inclusions can be non-contrasting or similar or they may be dissimilar. An inclusion is dissimilar when differences in limits affect the management or recommended use. Dissimilar inclusions cover small areas and cannot be mapped because of scale limitations. In an Order II survey, dissimilar inclusions comprise no more than 15 percent of the total mapping unit area, while similar inclusions occupy no more than 25 percent of the total mapping unit area. In addition, 2.02 ha (5 acres) is the minimum area a mapping unit can cover at a scale of 1:24,000.

Soil surveys were conducted by county at various times and by different personnel. Mismatches were often found across county boundaries with regard to soil mapping units and area edges. Some of the mismatches were simply a name change with no change in soil properties. There were several areas that matched others where the soil properties changed. At this time, it is not possible to correct these problems across county boundaries. Changes of this nature must be approved by the SCS and would most likely require recompilation of the soils for several counties in Arkansas.

This research will not change soil mapping units across county boundaries but use the properties and limits already stated by the SCS. Another solution to this dilemma would be to name the soils to the family level only omitting the series names. With this scheme, soil mapping units with the same properties would have the same name. However, this solution still would not solve mismatches with soil properties.

Two processes were used to digitize the soils. The first method was digitizing the map by hand on an ALTEK digitizing table. This process involved registering the map to a position on the earth by entering the UTM coordinates of the four corners of the map along with four interior positions into the GIS. The coordinates were determined by converting longitude and latitude of each point to UTM with the GRASS module m.ll2u using the projection clark66 or NAD27 datum. The location of these eight points was then registered by positioning the digitizing puck over each of the eight points and digitizing them. The GRASS module v.digit then checked the geometry of the points registered from the map against the geometry of the coordinates previously entered. Residual error for each point and mean residual error for the quadrangle map were then reported. In all the maps digitized, the mean residual error remained below 2.0m with no single point greater than 2.6m. These are USGS standards for 7.5′ quadrangles at a scale of 1:24,000. Once the residuals were within tolerances, the soil boundaries were ready to be digitized.

After the map was properly registered, a neat line or map boundary was drawn by GRASS based upon the four corners of the map. This line was used to close areas at map edges. All lines were traced with the digitizing puck using a digitizing threshold of 0.01 map inches or 6.1 m ground distance. The digitizing threshold determined the side to side distance that must be traveled by the puck in order to create a point in a line indicating a change of direction. Smaller thresholds were used to create smoother line work in the digital map. Once all soil boundaries were traced, the neat line was broken at soil boundary intersections. The soil boundaries were snapped to the breakpoints of the neat line to complete closed areas. Any other open areas within the map body were closed as well. At this point the map was ready to label.

Labeling is the process where each area outlined by the soil boundaries is given an identifying number that corresponds to a soil mapping unit. This soil mapping unit consists of the predominate soil series within the area with some additional description usually the slope range of the area. To label an area, a category number was entered. A point within an area and one of the boundary lines were selected. The v.digit then completed the labeling process for that area. To avoid missing or mislabeling an area, a scheme of bookkeeping was devised. Before any work proceeded on a map, a blue line copy was made of each soil map. This map included both the line work and the assigned numerical values for each area. During the labeling process the assigned value for each area was marked off the blue line copy after it was labeled. This served two purposes: 1) it assured that an area was labeled and 2) it assured that the area received the proper category value. This process continued until the map was completed. The map was then again checked for any unlabeled or open areas and corrected if necessary. At this time, the vector soil map was complete and ready for conversion to a raster map.

The second method of digitizing soils was by scanning the line work. This is the method that was used for most of the soil maps because of the greater speed of data processing. Since most of the soil maps in the watershed were provided on a stable Mylar base and were of known heights and widths, scanning was possible. If map height and widths could not be determined, the map was digitized by hand. Most of these maps covered small areas and were inserts on other soil maps. The maps were scanned by a Houston Instruments plotter/scanner. This hardware is a pen plotter with an attachable scanning head. A soil map was placed in the plotter and scanned by the optical head. The result was a binary raster image consisting of 0's for blank areas and 1's for dark areas with a resolution of 200 dots per inch. This file was transferred to another software package called LTPlus or Line Trace Plus. This software was designed for the SCS with the purpose of creating soil maps. The first process in LTPlus was to import and reference the image to a coordinate system. LTPlus operates on longitude/latitude coordinates rather than UTM. Registration involved giving the coordinates for one of the four corners of the image then pointing to the four corners to fix the map scale to the height and width of the map. The editing process was ready to begin.

Editing the image was necessary for several reasons. Some soil map Mylars were provided as single sheets with roads, streams, and labels as additional information. These had to be removed or separated from the soil boundaries. During the scanning process some soil boundaries would coalesce. These had to be separated also. Once all unwanted lines were separated from the soil boundaries, LTPlus thinned the soil lines to a one pixel width and removed any lines that were not part of a closed polygon. Only the neat line and the soil boundaries remained. The image was converted to a vector file format that was suitable for import into GRASS.

Maps that were 7.5′ x 7.5′ did not need any additional editing and were labeled as previously described. Some of the soil maps were provided in a 2.5′ x 7.5′ format. These had to be patched together using the GRASS module v.patch. The patched file was then edited in v.digit to remove adjacent neat lines and snap soil boundaries. The map was then labeled as previously mentioned. At this time the map was converted to a raster format with a 30m x 30m resolution using the GRASS module v.to.rast. Once necessary support files were generated, the map was complete.

Geology

Geology maps were obtained from the Arkansas Geological Commission (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. These maps are the originals for the state 1:500,000 scale map. Because of the reduction of scale on the state map, some formations originally surveyed on the 7.5′ maps were omitted, combined with others, or given an exaggerated areal coverage. The geology entered into the Beaver Reservoir watershed includes formations in the detail as originally mapped.

As with the soil surveys, geology surveys of the watershed were conducted at different times by different geologists using different techniques. Quadrangles around the reservoir were mapped by ground survey with much more detail than quadrangles in the southern portion of the watershed. The southern portion of the Beaver watershed was mapped mainly with aerial photography. Very few ground surveys were done in this area. Currently, the detail in the watershed reflects the original maps. The net result is that there were 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 is a formation named Mpfb which is a mixture of Pitkin Limestone, Fayetteville Shale, Batesville Sandstone. These formations are mapped as one unit along some of the Boston Mountain Escarpment, but in other quadrangles they were mapped as separate units along with the Wedington Sandstone, a member of the Fayetteville Shale. These conflicts in detail were temporally resolved by reducing the detail to the least accurate level in the database. In the future the detail will be increased by ground surveying the quadrangles with the least detail. These data will be entered into the database after final approval from the AGC.

All of the geology maps were digitized into the database by hand tracing the formation contacts with the same procedures used with the soils. The 15′

maps were digitized as a whole and later divided into 7.5′ quadrangles.

Additional Primary Attributes

Additional attributes included in the database were obtained from the Army Corps of Engineers (ACoE). These data are products produced for the ACoE by the TVA in an Intergraph DGN format. The TVA data were sent to Louisiana State University's CADGIS Laboratory for conversion to a DXF format, suitable for import to GRASS digit vector files. Data were imported into GRASS using the v.in.dxf command. The TVA coordinate system had the point of origin at the center of the watershed. This resulted in an egocentric system with no reference to a real world position. These files were converted to UTM grid using the GRASS command v.transform. One result of this process is a mean residual average of error similar to the one in registering a map in v.digit. Mean residuals for the data imported to this data have been within acceptable limits. Additional attributes included a subwatershed interpretation, roads, hydrography, land use/land cover, formation contacts, lineaments, linear seeps, and incorporated city boundaries. Unfortunately, coverage for some of these attributes coverage is limited to 11 quadrangles. These include lineaments, linear seeps, and formation contacts. It is unclear whether these will be used in the database.

TVA land use/land cover was converted into a format suitable for import into GRASS. Although this and the USGS data have the same theme, there is a large difference in detail with the TVA data being much finer. In addition to the USGS roads and hydrography, TVA roads and hydrography were to be added. These attributes were included because of the additional information they provided. Both TVA roads and hydrography have been converted to a format suitable for import to GRASS. Currently, the hydrography has been entered, but the roads have not been imported to GRASS.

Watershed Characterization

Characterization of the watershed was accomplished by determining area statistics using the GRASS module r.report. This module operates upon the raster file of a selected attribute. Statistics reported include cell count, percent coverage, acres, hectares, square miles, and square kilometers. This report was run on all of the primary attributes that had complete aerial coverage of the watershed. In addition to primary attributes, some statistics were done on secondary attributes. These secondary attributes include slope and aspect. Secondary soil attributes were not created because of the incomplete soils data.

Areal statistics for line attributes such as roads were handled differently. Since GRASS is a grid-cell based GIS, the line attributes were converted to a raster file making these line data areal data. The statistics generated on the converted line data are given as area data. In this case all line data were converted to raster data at a resolution of 30m x 30m. The statistics generated would report these as areas. The distance of line data were obtained by taking the square root of the reported aerial coverage, thus removing one of the dimensions, then conversion to the proper units of measure (Equation 1).

$$L = \left(\frac{\sqrt{A}}{r}\right) * \sqrt{A} \qquad [1]$$

where L = distance (km), A = aerial coverage (km^2) and r = grid cell resolution.

RESULTS AND DISCUSSION

In this study, characterization of the Beaver Watershed was accomplished by development of the computerized databases. The results of the accomplishments as of 1 July 1992 are reported below.

Watershed Boundary and Areal Extent

The Beaver watershed consists of approximately 308,974 ha. Coverage of the watershed in each county is given in Table 4. The spatial distribution of USGS 7.5′ quadrangles is presented in Figure 5. It is essentially a rural watershed with several small towns scattered throughout. Larger communities include all or portions of Fayetteville, Rogers, and Huntsville.

Table 4. Areal coverage of each county of the Beaver watershed.

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

Topography

The watershed is within two of the Ozark Highland Provinces: the Boston Mountains and the Springfield Plateau. These two provinces are divided by the Boston Mountain Escarpment. The Springfield Plateau consists of mainly rolling hills with areas of steeper topography in river valleys. The Boston Mountains are a series of ridge tops and river valleys separated by relatively steep slopes that are in turn divided by benches. Elevations range from approximately 341m in the north at lake level to 731m in the south. Base elevations will vary depending upon the elevation of Beaver Reservoir. GRASS generated slopes from the 80m DEM ranged from 0 degrees to 34 degrees (Table 5). Table 5 reports a maximum slope of 34 degrees based upon the 80m DEM. The majority of the steeper slopes are in the Boston Mountains, whereas the lesser slopes are predominant in the Springfield Plateau. These data do not, however, reflect the true slope

Table 5. Slope distribution within the Beaver watershed.

Slope Range	Hectares
0 degrees	56,690
1 thru 2 degrees	62,219
3 thru 4 degrees	49,306
5 thru 6 degrees	44,705
7 thru 8 degrees	36,782
9 thru 10 degrees	25,789
11 thru 12 degrees	15,544
13 thru 14 degrees	8,108
15 thru 18 degrees	7,316
19 thru 34 degrees	2,459

range in the watershed. Generated slopes are averages of each cell thus, the larger aerial coverage of each cell, the more inaccurate the generated data. As an example, analysis of some 30m DEM in the watershed has computed slopes upwards of 60 degrees.

The differences in calculated slopes is a direct result of the resolution of the elevation data. As the resolution of the DEM is increased, the description of the topography is also increased. The top diagram in Figure 6 shows how topographic features can be lost or hidden in the resolution of the data. The bottom diagram shows a finer resolution where the slope range increases as well as the detail of the topography. With an 80m resolution DEM the landscape is divided into 80 x 80 increments. Each cell has an assigned value that is the elevation at the center of the cell. Slopes are calculated as degrees from horizontal by taking the tangent of the rise in elevation divided by the horizontal distance (80m) of the run. Equation [2] shows the one dimensional formula for slope calculation where S is the slope in degrees, ΔY is

$$S^{\circ} = TAN\left(\frac{\Delta\ Y}{\Delta\ X}\right) \qquad [2]$$

the elevation gain, and ΔX is the resolution of the DEM. The y dimension is the difference in elevation of the adjacent cell at the beginning of the x dimension

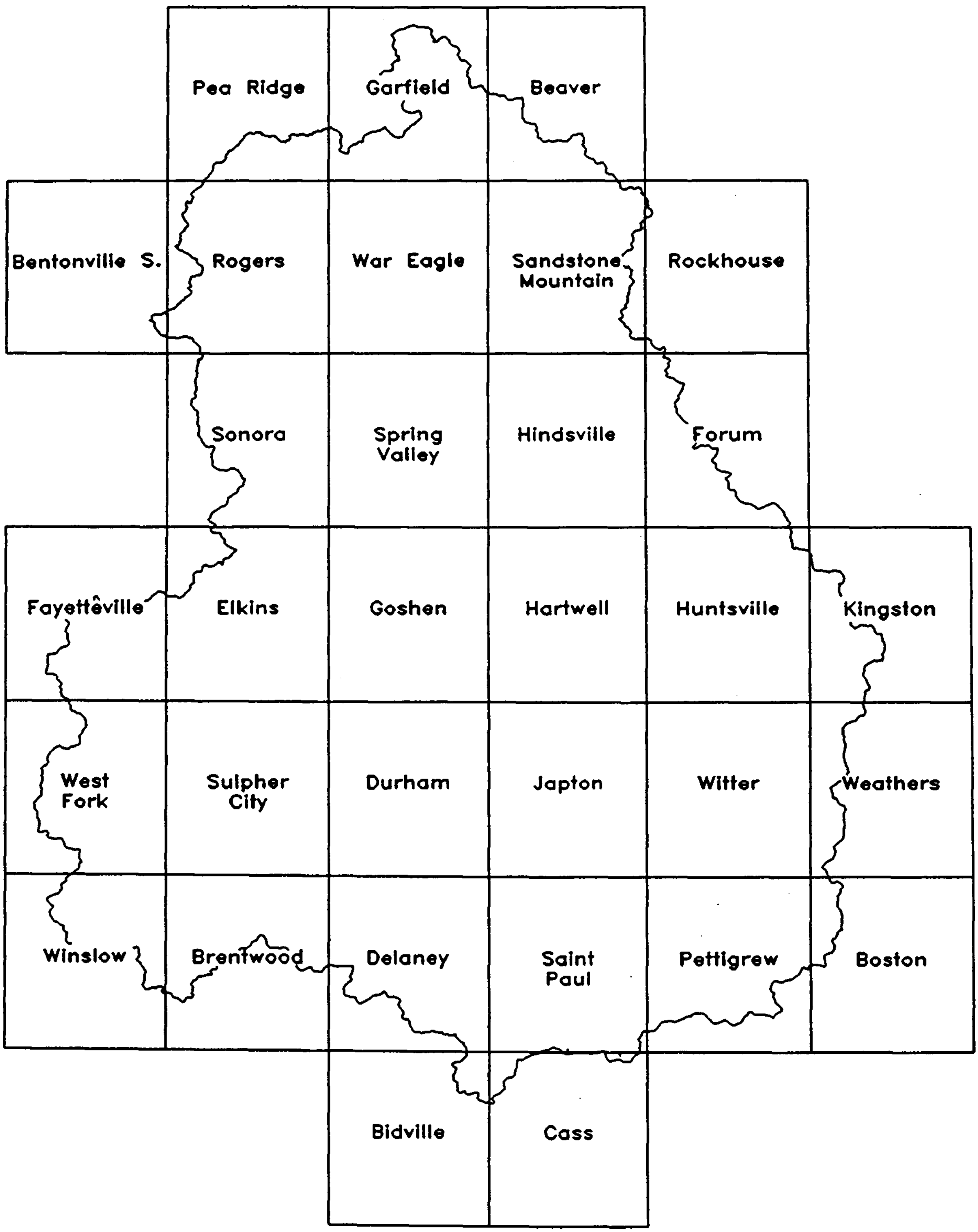

Figure 5. Spatial distribution of USGS 7.5′ quadrangles in the Beaver Reservoir watershed.

and the adjacent cell at the end. Actually, GRASS uses a 3 x 3 matrix averaging filter where the y value is the average change in elevation of all 8 adjacent cells across the center cell.

The implications of slope and DEM resolution upon the database is that the coarser resolution data could reduce the quality of analyses using these attributes. One such example is the prediction of soil erosion. Analysis using coarse data would not use small areas of high erosion. Individually, these areas may not be significant, but they may be very significant when missed as a group. Using 30m DEMs will increase the aerial description, thus calculating a more accurate analysis.

Roads

As of 1 July 1992, roads from the USGS data were in the watershed database (Figure 7). These data included both primary and secondary roadways. The categories of this attribute were reclassed to reflect U.S. and state highway numbers. Other streets, roads, and trails retained the original category numbers (Table 6). Categories of roads and streets were divided into class 3 and class 4 by the USGS, but the differences between these two classes were not known. This will be corrected later. These differences are important because of the predominance of these categories. Only 9.15 km of trails were reported. There are most likely more trails in the watershed given the amount of logging that has occurred in the past. As with class 3 and class 4 roads, the definition of trails needs determining. If the data can be acquired, another category describing these logging roads may need to be compiled. Sources of logging roads could include satellite imagery and possibly land use and land cover. Another problem with these digital data is that many of the secondary roads and trails are not contiguous. There are roads that do not connect to any other roads.

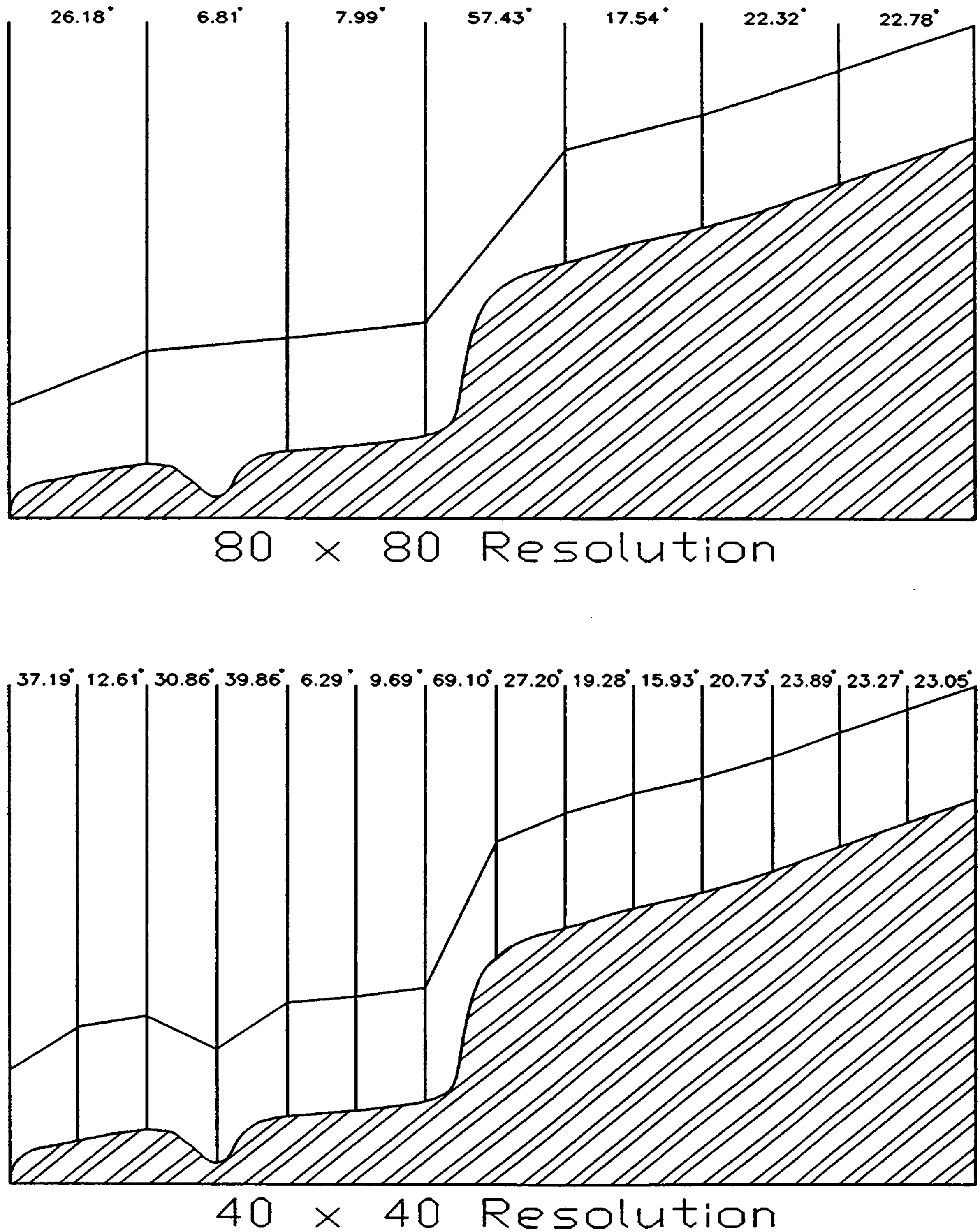

Figure 6. Differences in generated slope data resulting from changing resolution.

Table 6. Total length of roads by category in the Beaver watershed.

Road Classification	Distance (km)
US Hwy. 62	2
US Hwy. 71	34
US Hwy. 412 (old State Hwy. 62)	45
State Hwy. 12	41
State Hwy. 16	61
State Hwy. 23	68
State Hwy. 45	30
State Hwy. 74	42
State Hwy. 94	11
State Hwy. 112	2
State Hwy. 127	23
State Hwy. 156	7
State Hwy. 170	3
State Hwy. 187	5
State Hwy. 264	7
State Hwy. 265	7
State Hwy. 295	61
State Hwy. 303	24
Primary Route	3
Secondary Route	1,414
Road or Street, Class 3	1,729
Road or Street, Class 4	105
Trail, Class 5	7
Interchange	1
Business Route	9
Total	3,741

Correction of these roads would involve digitizing omitted roads using USGS 7.5′, 1:24,000 scale topographic series maps. This could prove to be a lengthy process and could possibly be bypassed with the addition of other sources of digital road data.

An additional roads dataset was obtained from the TVA. Preliminary inspection of the data revealed that not much additional data were to be gained from this data layer. However, roads in this database seem more contiguous than in the USGS DLGs. The TVA roads could be use to augment the USGS DLG roads data. The TVA data also separates the data into three classifications of primary, secondary, and light duty. Another source of roads is now available. The TIGER data, provided by the US Census Bureau, are available on CDROM and could also be used to augment the USGS DLG road data.

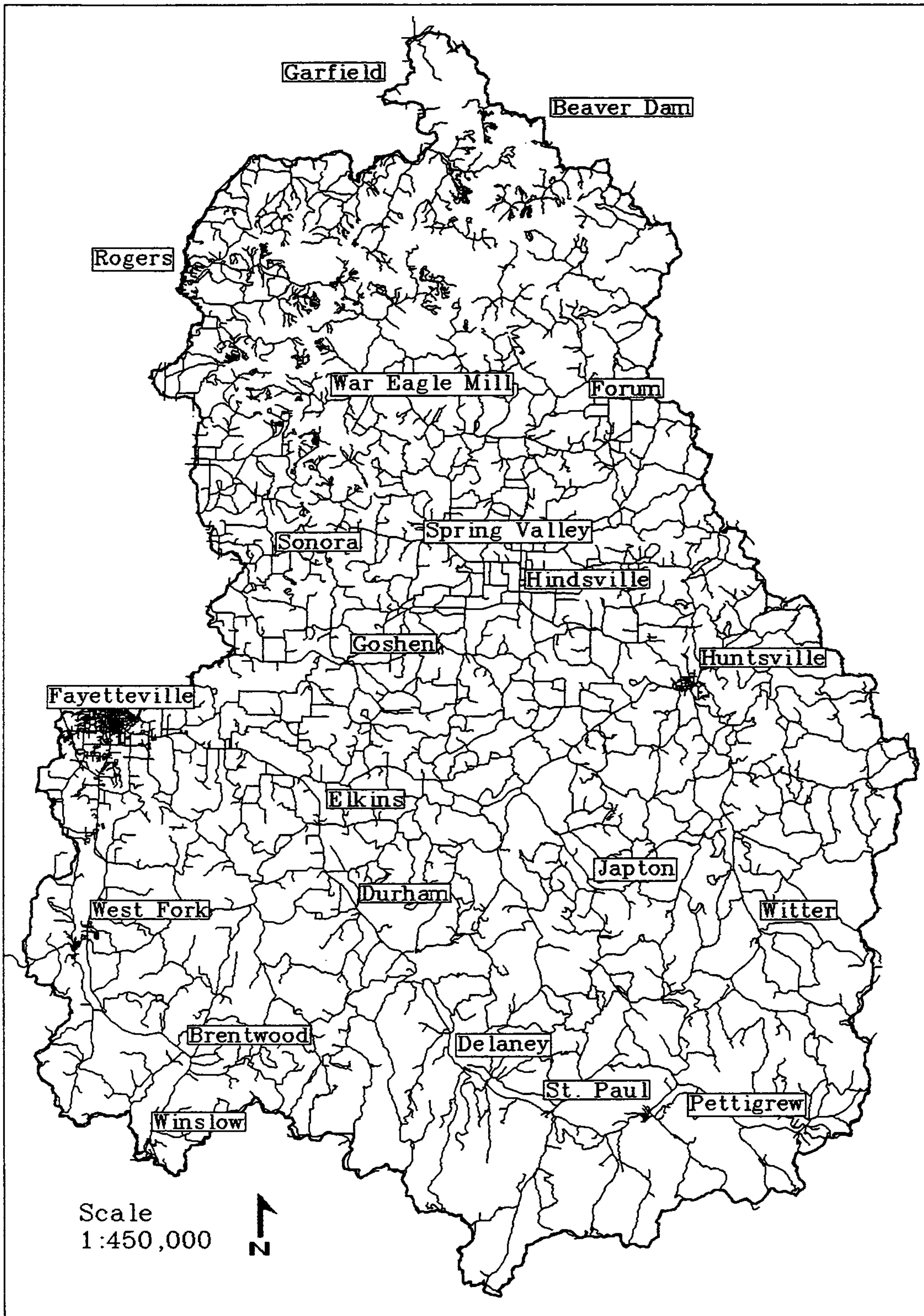

Figure 7. Spatial distribution of roads in the Beaver Reservoir watershed.

Hydrology

As of 1 July 1992, the USGS hydrography was in the database (Figure 8). All of the categories reported were the original values provided by the USGS (Table 7). An additional category was added for the double line streams. These are areas where long slow flowing holes occur year round. Double line streams

Table 7. USGS hydrologic features in the Beaver watershed.

Hydrologic Feature	Coverage
Shore line	534.12 km
Man Made Shore Line	1.05 km
Dam	0.33 km
Streams	580.74 km
Fish Hatchery	12.23 ha
Lake or Pond	966.733 ha
Double Line Streams	119.23 ha

were labeled and reported as areas. Like the base elevation of the watershed, the area coverage of lakes and ponds varies depending upon the lake elevation at the time of the data collection. Reservoir elevation can be determined for a point in time by manipulating the DEMs. At a later date, the primary streams will be reclassified into individual categories allowing a more detailed characterization of the hydrography.

The TVA hydrology was also in the database. These digital data are unique in that the information is much more detailed. In addition to a more detailed classification system of perennial, intermittent, and ephemeral streams, the data also includes more streams, ponds, and double line streams. These data can be use in conjunction with the USGS data.

Soils

As of 1 July 1992, 18 of the 32 soils quadrangles in the watershed have been entered into the database. Three quadrangles were partially complete.

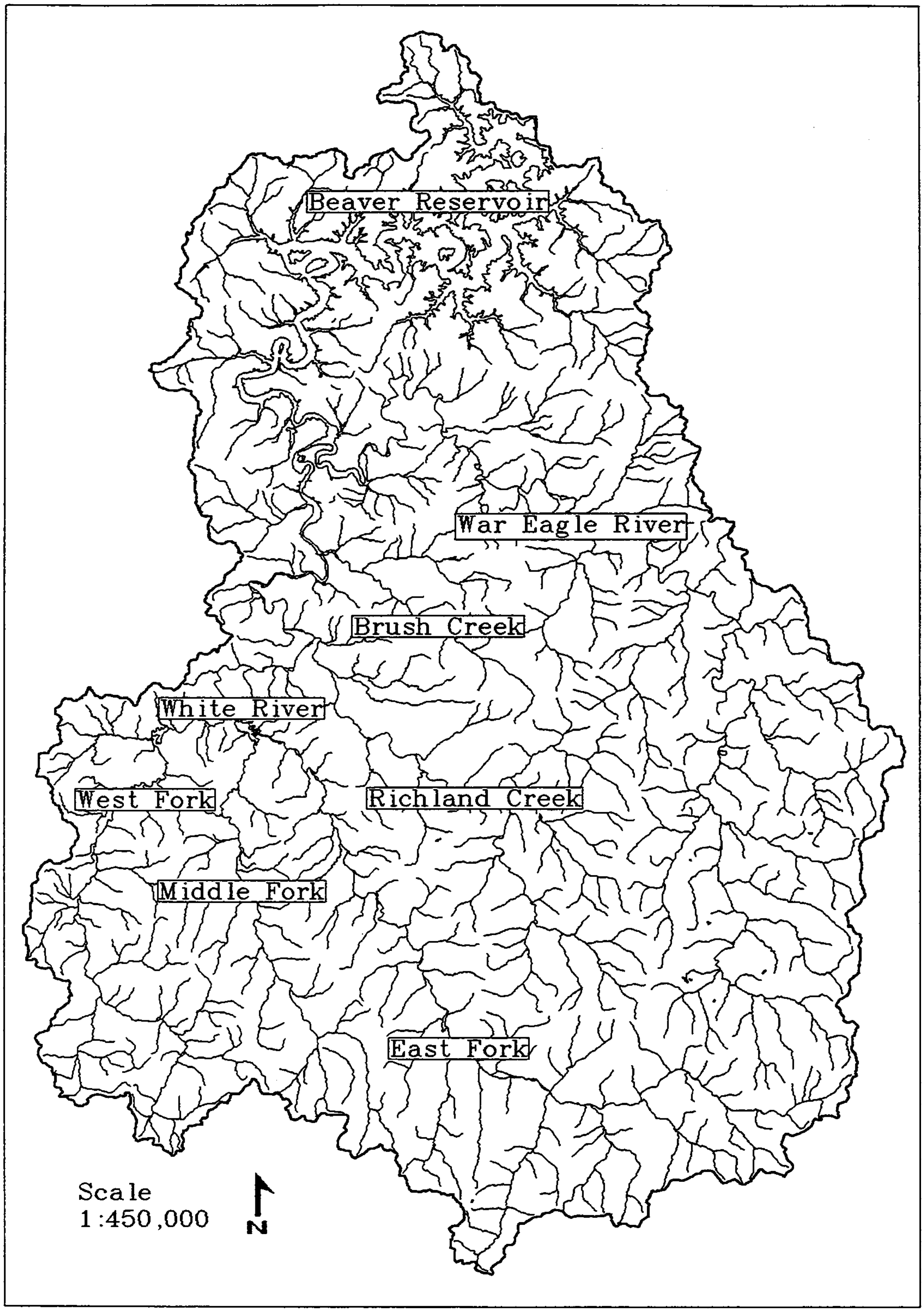

Figure 8. Spatial distribution of water bodies in the Beaver Reservoir watershed.

These partially complete quadrangles are located at county boundaries and will be completed as they become available. Thus, 11 quadrangles of soils are yet to be done. Of these 11 quadrangles, six are fully or partially recompiled and in final editing by the SCS. Once the editing is finished, work will continue on the remaining quadrangles. The remaining tasks to be done include the entry of the remaining 11 quadrangles and edge matching soils boundaries between quadrangles and counties.

Table 8 reports aerial coverage of the soil mapping units in the portion of the Beaver watershed in Madison County. Because of the complexity of the soil maps and the small scale, only the soil mapping in the units Huntsville quadrangle is shown (Figure, 9). Mapping by landscape resulted in an image that portrayed several aspects about the study area including geology, geomorphology and topography. The geology is portrayed by the parent material of a soil mapping unit. Geomorphology is depicted by the origin of the parent material. Each of the mapping units is described as residuum, colluvium, or alluvium. Residuum is soil that was formed over the parent material. Colluvium is soil that was formed from parent material that has been move down slope by gravity. Alluvium is soil that was formed from parent material transported by water. Topography was emphasized by the position upon the landscape with residuum soils on hill tops and plateaus, colluvium located on slopes and benches, and alluvium located in past or current river bottoms and terraces.

In the southern half of the study area, most of the parent material is Pennsylvanian age sandstones and shales, although there were a few soils with Pennsylvanian age limestone parent material. Soils from sandstone and shales are residuum, colluvium, and aluvium. Soils from limestone were mostly residuum. These soils occurr in small areas of limestone in the Boston Mountains. Parent

Table 8. Aerial coverage for the soil mapping units of Madison County in the Beaver watershed.

Soil Mapping Unit	Hectares
Arkana very cherty silt loam, 8-15% slopes	15
Arkana-Moko Complex, 20-40% slopes	56
Arkana-Moko Complex, 8-20% slopes	99
Britwater gravelly silt loam, 3-8% slopes	261
Captina silt loam, 1-3% slopes	1057
Clarksville very cherty silt loam, 20-50% slopes	6897
Elsah very cherty silt loam, occasionally flooded	926
Guin cherty silt loam, 3-8% slopes	1
Healing silt loam, 1-3% slopes	1423
Johnsburg silt loam, 1-3% slopes	668
Moko very stony silt loam, very rocky, 12-40 % slopes	194
Nixa very cherty silt loam, 3-8% slopes	5869
Nixa very cherty silt loam, 8-12 slopes	2
Nixa very cherty silt loam, 8-15% slopes	4790
Noark very cherty silt loam, 12-20% slopes	831
Noark very cherty silt loam, 20-45% slopes	6285
Noark very cherty silt loam, 8-12% slopes	166
Peridge silt loam, 1-3% slopes	630
Peridge silt loam, 3-8% slopes	1124
Secesh gravelly silt loam, occasionally flooded	936
Tonti cherty silt loam, 3-8% slopes	2344
Waben very cherty silt loam, 3-12% slopes	135
Allen loam, 3-8% slopes	467
Ceda cobbly fine sandy loam, frequently flooded	3558
Ceda gravelly fine sandy loam, occasionally flooded	2101
Cleora fine sandy loam, occasionally flooded	1499
Enders gravelly loam, 3-8% slopes	1338
Enders gravelly loam, 8-12% slopes	744
Enders stony loam, 3-12% slopes	4509
Enders-Leesburg stony loams, 20-40% slopes	29,146
Enders-Leesburg stony loams, 8-20% slopes	30,618
Hector-Mountainburg gravelly fine sandy loams, 8-12% slopes	64
Leadvale loam, 3-8% slopes	2146
Leesburg gravelly loam, 3-8% slopes	1020
Leesburg gravelly loam, 8-12% slopes	328
Leesburg stony loam, 8-20% slopes	2330
Linker loam, 3-8% slopes	2699
Linker loam, 3-8% slopes, eroded	1
Mayes silty clay loam, 0-1% slopes	160
Mountainburg gravelly loam, 3-12% slopes	350
Mountainburg stony loam, 3-20% slopes	3452
Mountainburg very stony loam, 20-50% slopes	3103
Nella gravelly loam, 12-20% slopes	1440
Nella gravelly loam, 3-8% slopes	512
Nella gravelly loam, 8-12% slopes	449
Nella stony loam, 8-20% slopes	3,567
Nella-Steprock-Mountainburg very stony loams, 20-40% slopes	11,620
Nella-Steprock-Mountainburg very stony loams, 40-60% slopes	4,576
Steprock gravelly loam, 3-8% slopes	3,756
Steprock stony loam, 3-12% slopes	1,301
Summit Variant silty clay loam, 3-12% slopes	90
Summit Variant silty clay loam, 12-25% slopes	324
water	230

material in the northern portion of the watershed is mostly limestone residuum. The majority of these soils were derived from the limestone residuum of the

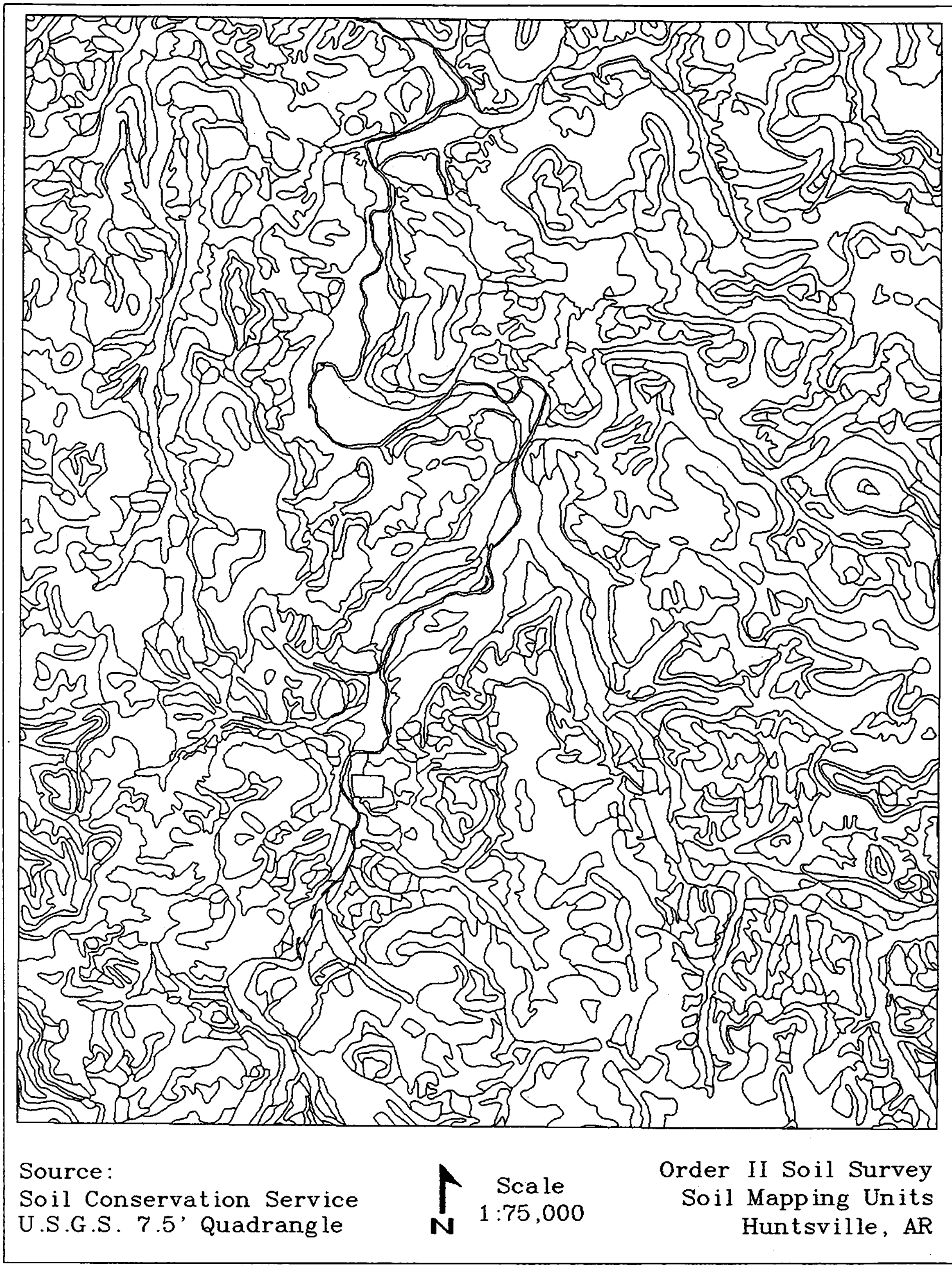

Figure 9. Spatial distribution of soil mapping units in the Huntsville, Ark quadrangle in the Beaver Reservoir watershed.

Mississippian age Boone Formation. Sandstone alluvium soils are common along the river valleys as well as limestone alluvium. There are areas in the northern portion that include sandstone and shale parent material. These areas are on the outlyers and remnants of the Boston Mountains and in the deeper river valleys where older sandstones had been exposed. The northern and southern portions are divided by the Boston Mountain Escarpment. The greatest diversity of soils occurs in this transition area resulting in some soil associations that are not shown in Table 8. The diversity of soils in this area is the result of the variety of geomorphic processes and surface geology.

There are several dominant soil mapping units in Madison County. Combining slopes of like soil mapping units reveal that the complex mapping units cover more area than the single taxa. Two Enders-Leesburg soils complexes have the largest aerial coverage of all soil mapping units, 59,764 ha. The slopes of these two mapping units, 8 to 20% and 20 to 40%, indicate that the watershed in Madison County is very steep. Another major soil complex is the Nella-Steprock-Mountainburg mapping units. These mapping units cover 16,186 ha in Madison county and include some of the steepest slopes in the watershed, 20 to 60%. There are mapping units for each of the soil series named in these complexes, but these single taxa have far less aerial coverage. The slopes of the single taxa also tend to be more gentle than the complex mapping units. All these soil mapping units would naturally support native hardwood, but some of areas have been cleared for pasture, resulting in a higher erosion potential. All of the afore mentioned mapping units are located in the Boston Mountains. Most are acid soils due to the parent material.

There are less complex soil mapping units in the Springfield Plateau. Nixa soil mapping units have the largest aerial coverage in the Springfield Plateau with slopes ranging from 3 to 20%. The next most common is the Clarksville mapping unit, 6,896 ha. Clarksville soils occupy most of the steeper slopes in the plateau, 20 to 50%. Noark mapping units cover 6,383 ha with slopes ranging from 8 to 45%. Most of these soils are neutral or basic indicating the limestone parent material.

The completion of soil maps for the remaining counties in the watershed will produce more varied results since a different series name was often used to classify like soils across county boundaries. The net effect is that the characteristics presented here will not change to any large extent, but rather, increase the reported number of categories. These categories can later be grouped to reflect soil classification down to the family level allowing the combination of different soil series without the loss of detail in the database.

Geology

The geology in the database is as a composite of the whole watershed (Figure 10). A few minor corrections remain to be done to the data layer. These changes include areas of formation mismatch across map boundaries, addition of several formation boundaries, and the addition of several faults. All these changes were approved by the AGC. Unlike the soils data, the geology of the impoundment area of the lake is included.

The geology of the watershed is dominated by nearly horizontal-bedded, marine sedimentary rock with minor deformation. There is a average 3 degree tilt to the south. The type of rock is related to the conditios at the time of deposition. Limestones were derived from marine animal remains indicating that the area was once a shallow sea. Shale is composed of very fine particles deposited in calm waters. Siltstone and sandstone indicate that the area was submerged intermittently with siltstone being deposited under more turbulent

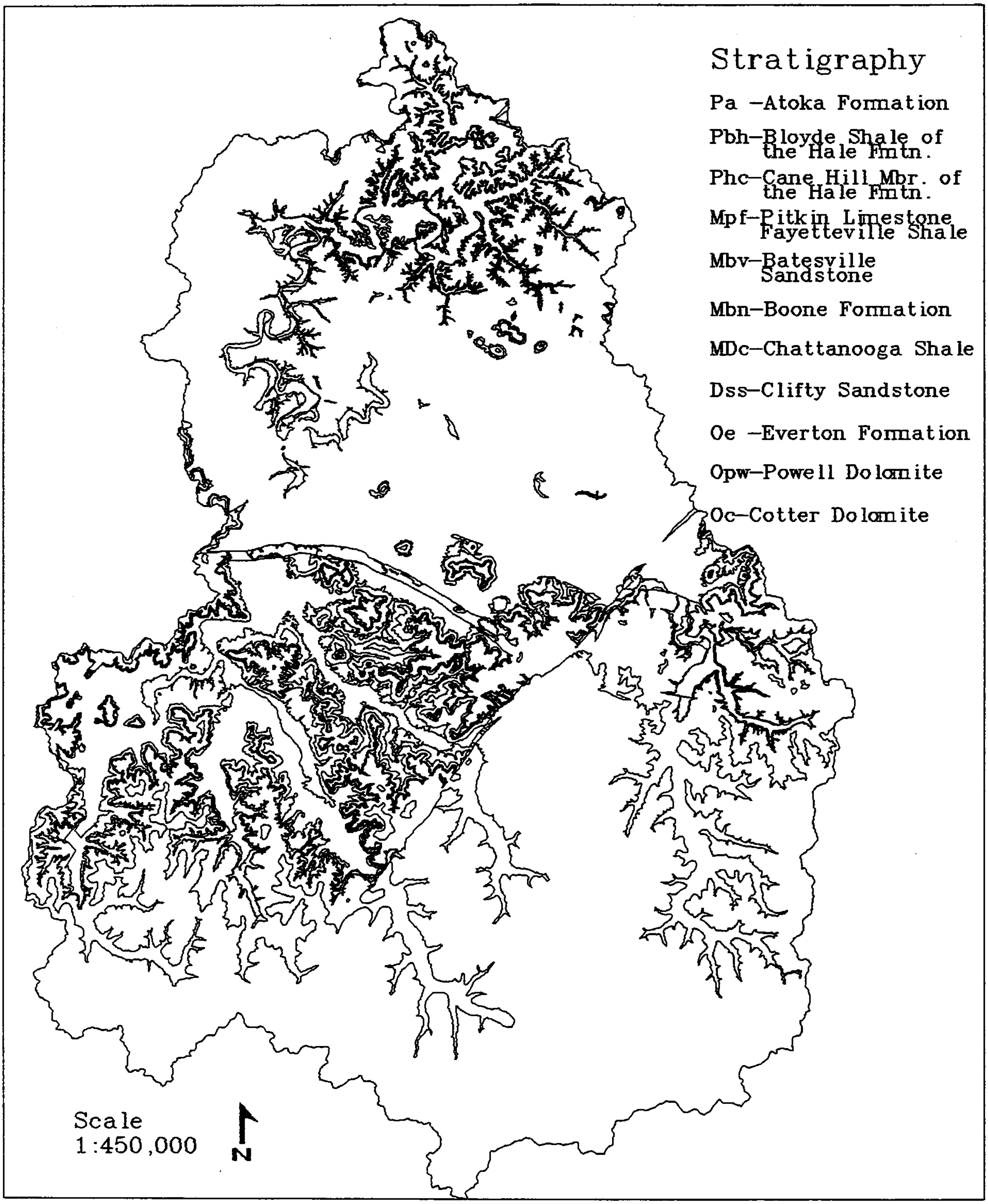

Figure 10. Spatial distribution of surface geology in the Beaver Reservoir watershed.

conditions.

The Boston Mountains consists primarily of sandstones, siltstones, and shales of Pennsylvanian age, whereas the Springfield Plateau is dominated by chert and carbonate rocks of Mississippian age (Figure 11). Some lower elevations in the northern portion of the watershed are on the Eureka Springs Escarpment particularly along the lake shoreline. Geological formations in this

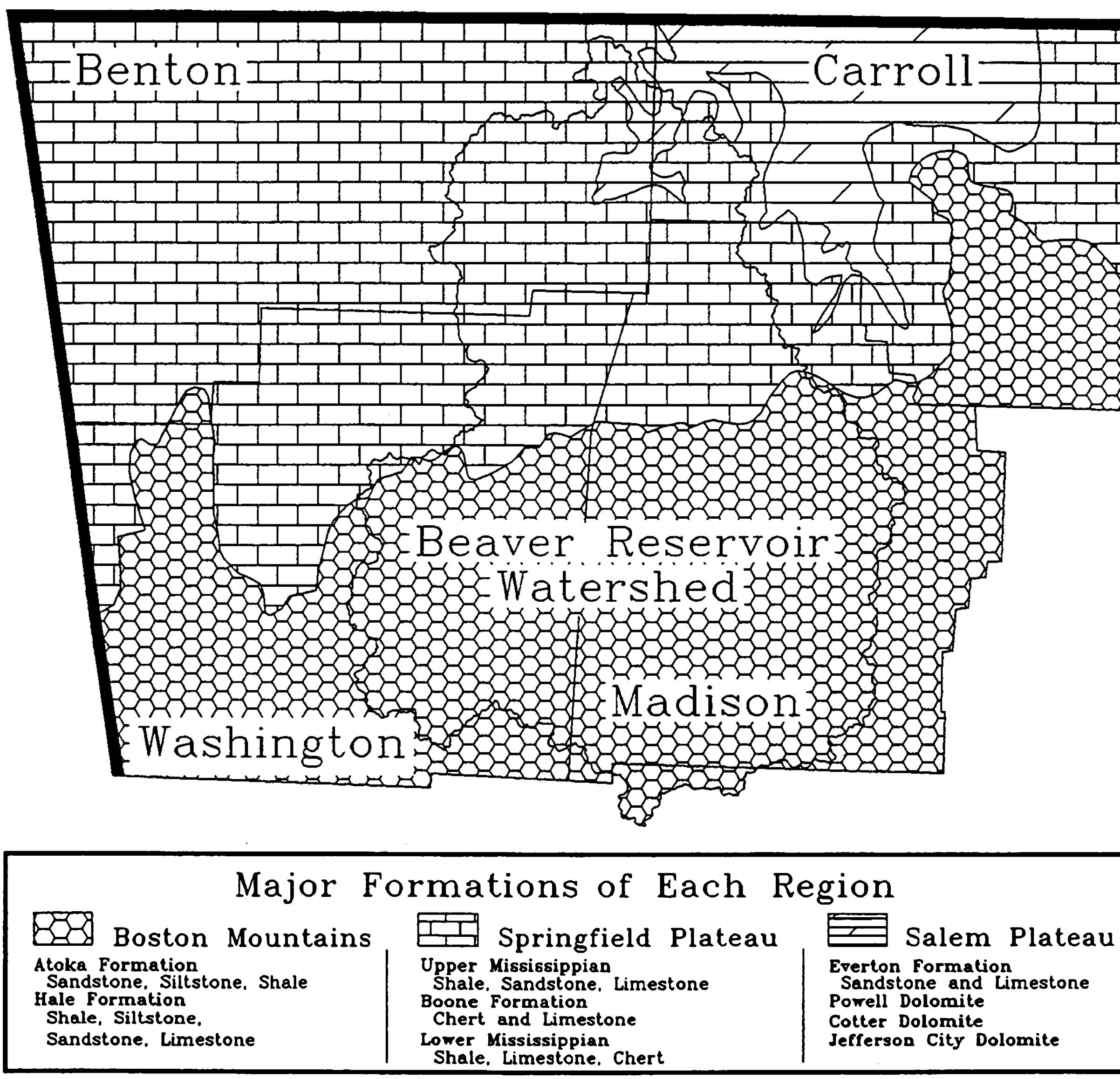

Figure 11. Physiographic regions and associated formations of the Ozark Plateau.

area are mostly Devonian and Ordovician age. Table 9 presents the aerial extent of the primary geologic formations in the Beaver Reservoir watershed. Like the soils, the surface geology is most diverse at the Boston Mountain Escarpment. This area is a mixture of older Pennsylvanian age and younger Mississippian age formations. Most of the formations in this area do not extend beyond the escarpment except for minor aerial coverage on outlyers of the Boston Mountains. Some formations are not contiguous across the watershed. For example, the Wedington Sandstone does not extend to the east much beyond Goshen, and the Pitkin Limestone does not extend to the east beyond Huntsville.

The primary formations are composed of other formations and members. Many of these are included in part or whole for the watershed. There were also many other geologic members that were not included on the original maps because of limited aerial coverage and lack of mapping information. Many of these are members of the Atoka Formation and the Hale Formation that are both mixtures of sandstones, siltstones, limestones, and shales. Some of these members are the Kessler Limestone and the Prairie Grove Limestone. Similar omissions are associated with the Boone Formation. The Boone Formation is a mixture of regolith that overlays the St. Joe Limestone, also a member of the Boone Formation. Most of these omissions will not prove to be a problem as they do not have much aerial coverage in the watershed.

Lineament data accompanied the surface geology data, and was input simultaneously with the geology. One of the most significant lineaments in the watershed extends from Fayetteville to the northeastward exiting the watershed near the dam site. Another significant lineament begins east of Winslow and continues northeastward exiting the watershed near Forum. There are many splinters originating from these two lineaments in near perpendicular angles.

Table 9. Aerial extent of near surface geology.

Geological Formation	Hectares
Atoka Formation	102,340
Bloyd Shale of the Hale Formation	46,964
Cane Hill of the Hale Formation	3,429
Fayetteville Shale-Pitkin Limestone Batesville Sandstone	42,586
Boone Formation	98,323
Chattanooga Shale	4,771
Everton Formation	852
Powell Dolomite	2,295
Cotter Dolomite	7,407

The majority of these occur near the Boston Mountain Escarpment. Most of the lineaments in the watershed are regional fractures or jointing that run parallel to the axis of the Ozark Dome. To the trained eye, these lineaments and others not mapped are indicated by other attributes such as geology, soils, hydrography, and elevation.

Land Use and Land Cover

The LULC from the USGS was on order from the USGS. Expected delivery date was 1 August 1992. The data will need to be converted to a media readable by GRASS and imported into GRASS. These data will be imported along with the corresponding attributes. Little editing will need to be done since the format will be in DLG3. LULC line work from the TVA was in the database, but the associated attribute file was not with the data. These data have been ordered.

SUMMARY

As of 1 July 1992, insertion of most of the primary attributes into the database were either completed or in progress. Transportation and hydrography provided by the USGS were in the database. There remains several minor tasks to be done on these two attributes including a more detailed classification system and clarification of some of the supplied category descriptions before these attributes can be used. Digitizing is continuing on the soils attribute with 18 of the 32 quadrangles completed. All soils in the Beaver watershed located in Madison and Carroll counties were complete. Digitizing portions of soils in Washington county was complete. Source maps for Benton, Franklin and Crawford counties were not yet available. Digitizing the remaining quadrangles is continuing as the soil maps become available. Edge matching between quadrangles is also proceeding. Surface geology is complete and in the database. Several lineament and formation contact corrections recommended by the AGC remain to be done. LULC data was on order with an expected delivery date of 1 August, 1992. Area statistics were generated for each attribute as they completed.

Future work to be done included completion of the soils attributes, input of the LULC, and updates and corrections to existing attributes. Once the primary attributes are complete, secondary attributes will be generated. These additional data will be generated by various GIS methods. The themes of the secondary attributes will be dictated by parameters required in water quality management.

Other work remaining to be done includes converting the TVA database to a format suitable to GRASS. Some of these data could provide additional data for themes such as hydrography and LULC as long as the conversion process is not too tedious.

ACKNOWLEDGEMENTS

We would like to express our appreciation to several individuals who greatly aided this work. Pam Smith of the Agronomy Department was very helpful in suggesting innovative ways of digitizing and scanning the various databases and importing into GRASS. Charles Fultz and Marcella Callahan of the Soil Conservation Service supplied the soils data. Jerry Dillion worked part time on scanning the soils data and patching the quads together. We also would like to thank Fred Limp, Director of the Center for Advanced Spatial Technology, Jim Farley, and Bob Harris for their continued support of GIS and the application to GIS techniques to water resources, and Becky Jolly and Bruce Rolland of the TVA for their help with the TVA database.

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