DEVELOPMENT, DESCRIPTION, AND APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM DATA BASE FOR WATER RESOURCES IN KARST TERRANE IN GREENE COUNTY, MISSOURI

By Loyd A. Waite and Kenneth C. Thomson

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
cubic foot per second	0.2083	cubic meter per second
million gallons	3.785	cubic meter
million gallons per day	0.0438	cubic meter per second
mile	1.609	kilometer
square mile	2.590	square kilometer
inch	25.4	millimeter

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by using the following equation:

$$°C = 5/9\ °F - 32$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Loyd A. Waite[1] and Kenneth C. Thomson[2]

ABSTRACT

A geographic information system data base was developed for Greene County, Missouri, to provide data for use in the planning for the protection of water resources. The data base contains the following map layers: geology, cave entrances and passages, county and quadrangle boundary, dye traces, faults, geographic names, hypsography, hydrography, lineaments, Ozark aquifer potentiometric surface, public land survey system, sinkholes, soils, springs, and transportation.

Several incidents of ground-water contamination have been reported in the karst terrane developed in soluble carbonate rocks in Greene County. Karst terranes are environmentally sensitive because any contaminant carried by surface runoff has the potential for rapid transport through solution enlarged fractures to the ground-water system. In the karst terrane in Greene County, about 2,500 sinkholes have been located; these sinkholes are potential access points for contamination to the ground-water system. Recent examples of ground-water contamination by sewage, fertilizers, and hydrocarbon chemicals have demonstrated the sensitivity of ground water to degradation in the Greene County karst terrane. The ground-water system is a major source of drinking water for Greene County. The population in Greene County, which includes Springfield, the third largest city in Missouri, is rapidly increasing and the protection of the water resources of Greene County is an increasing concern.

INTRODUCTION

Greene County, in southwestern Missouri (fig. 1), has the third largest city in the State, Springfield, which has an annual population growth rate of about 5 percent and a rapidly increasing industrial base. The remaining area of the county is primarily agricultural with many dairy farms. Ground-water availability and quality is a major concern for residential and business expansion in the county.

The possibility of ground-water contamination from the effects of residential and business expansion and agricultural practices exists because of the fact that Greene County is underlain by rock (plate 1) that contains a well-developed and extensive karst terrane. Karst terrane is the product of chemical reactions that occur as slightly acidic water percolates through carbonate (limestone or dolostone) rock. Karst terrane is characterized by sinkholes, karst windows or unroofed caves, springs, caves, and losing, gaining, and underground streams. Sinkholes, caves, and associated solutional features provide virtually direct hydraulic connection between surface water and the underlying ground-water flow system. These hydraulic connections can allow contaminants originating from such diverse sources as septic tanks and industrial waste spills to enter the ground-water system (fig. 2) without undergoing the purification process that occurs in nonkarst areas, where solutions percolate slowly through the soil and into the ground water.

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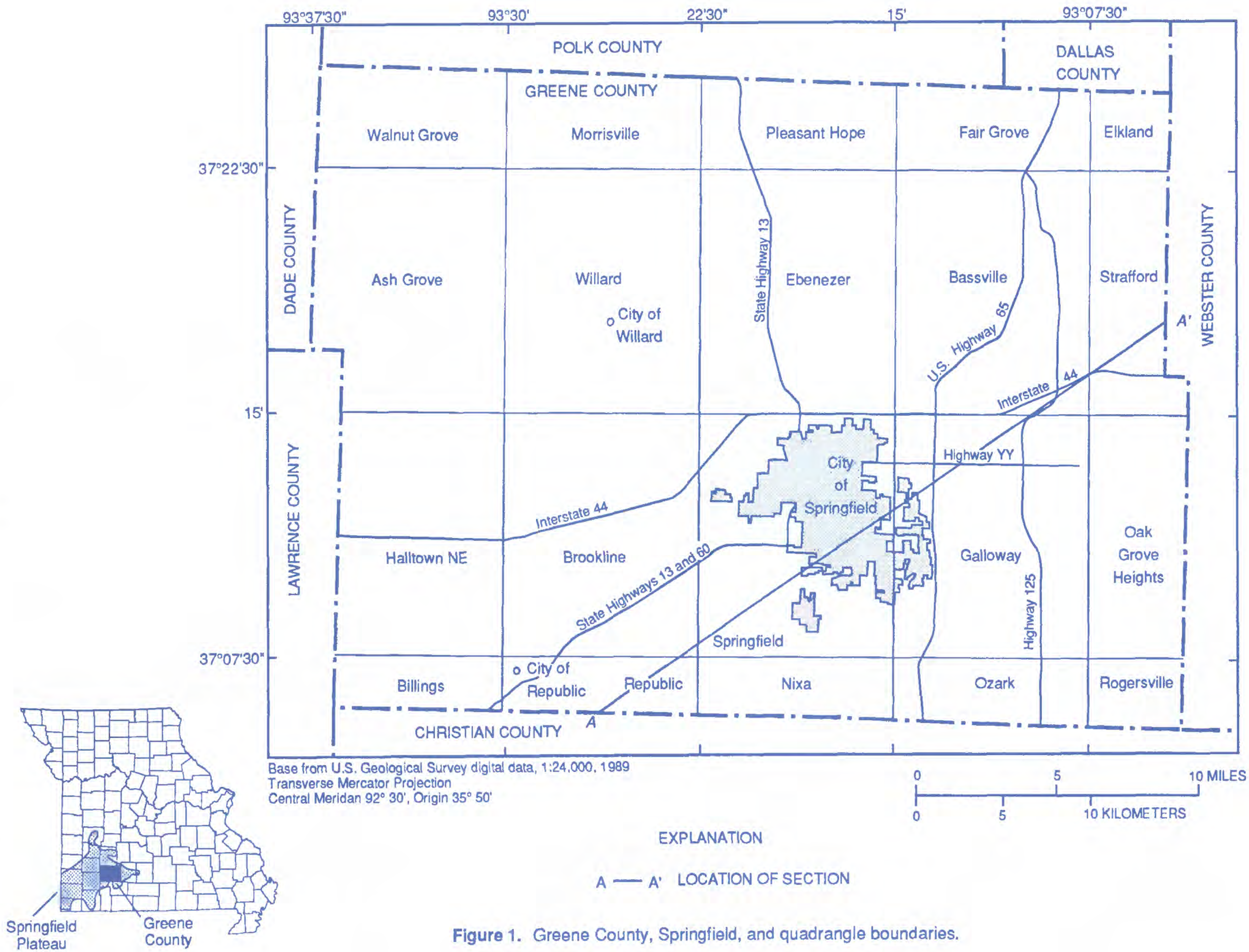

Figure 1. Greene County, Springfield, and quadrangle boundaries.

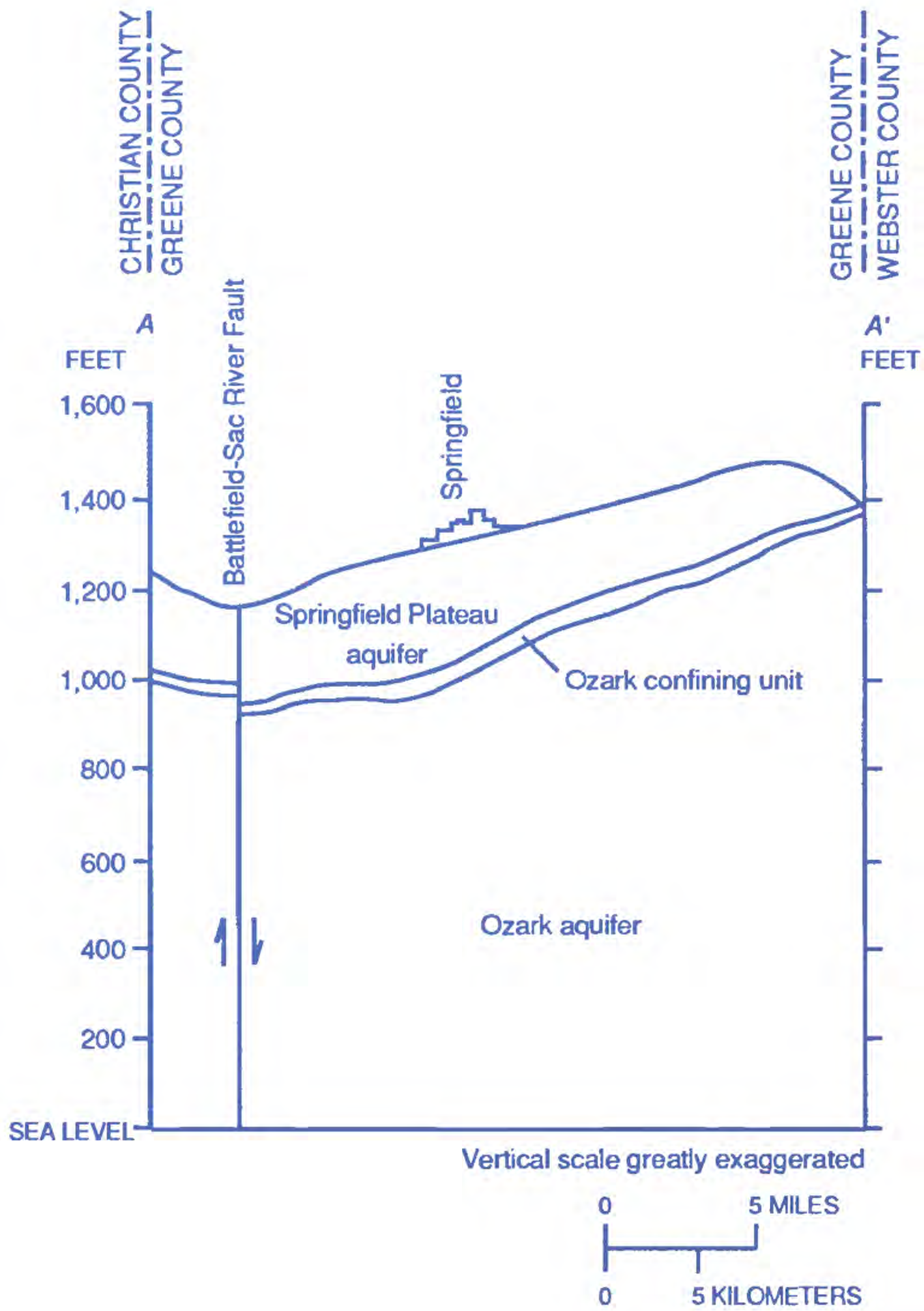

Figure 2. Regional geohydrologic units (location of section A-A' shown on figure 1; modified from Imes, 1989).

Historical accounts of ground-water contamination underscore the potential for serious degradation of the ground-water resources of Greene County. The following selected accounts are from the files of the Missouri Department of Natural Resources, Division of Environmental Quality (MDNR, DEQ) in Springfield, Missouri.

- On October 29, 1968, a catastrophic collapse of a sinkhole occurred under the municipal sewage lagoon in the city of Republic (fig. 1). Within 24 hours, an estimated 4 million gallons of sewage effluent had drained into cavernous rocks in the Springfield Plateau aquifer. Nearby springs and at least two domestic drinking water wells were contaminated.

- During 1973, a spring and pond were contaminated with wastewater from a leaking lagoon probably built over a sinkhole at an electroplating facility southeast of the city of Willard (fig. 1). Water in the spring and pond was reported to be blue, probably because of a high concentration of copper in the lagoon.

- During 1981, at least one shallow well and several springs may have been contaminated as a result of a leaking wastewater lagoon at an electroplating facility in northwest Springfield, in an area of intense sinkhole development. Samples collected at the shallow well contained 12 micrograms per liter of trichloroethylene (TCE), which is a solvent used in degreasing or dry cleaning. The lagoon was subsequently removed from service.

- During 1983, a public-water-supply well in Republic, an area of known sinkholes, was contaminated with as much as 140 micrograms per liter of TCE. Less than 1 block away, an electronics manufacturing plant had burned a few years earlier. An abandoned 500-foot deep well in the basement of the building contained more than 65,000 micrograms per liter of TCE. Ground-water remediation is now (1992) occurring at the site and probably will continue for at least 20 years.

- During 1983, gasoline additives were detected in seven wells clustered in the "U-Drive" area north of Springfield, an area with several sinkholes. One of the wells was a State-approved public-water-supply well serving a trailer park. A city water main was extended into the area and most of the domestic wells have been plugged.

- During 1987, a dairy in eastern Greene County was applying waste from a lagoon to pastureland in the upper Pearson Creek Basin east of Springfield. Because of equipment malfunction, waste had pooled in a "low" area, which was not readily discernible as a sinkhole. Within days, a spring located about 1.5 miles to the southeast was turbid and had a foul odor. Four wells in the vicinity also were affected and two of these wells had large fecal coliform densities, which is indicative of contamination from warm-blooded animals.

- During 1987, a petroleum taste was reported in water from individual wells in eastern Greene County and toluene (obtained mainly from tar oil and used in the manufacturing of explosives and dyes) was detected in well samples. Pooled oil was detected near a gasoline station and 3 storage tanks with diameters of 24, 67, and 100 feet located east of Highway 125 and 0.25 mile south of Highway 125 and YY (fig. 1). Benzene was detected in a spring 1 mile south of the site.

These contamination accounts, in addition to other accounts not described in this report, have caused concern about the water resources of Greene County. As a result, the U.S. Geological Survey (USGS), in cooperation with Springfield city planning agencies, constructed a detailed model of ground-water flow in two aquifers beneath the city (Imes, 1989). These aquifers are the shallow Springfield Plateau aquifer and the deep Ozark aquifer. The study indicated that the ground water withdrawn by municipal wells near Springfield originates as recharge in about a 500-square mile capture area that includes most of Greene County. The Ozark aquifer (figs. 2 and 3), the principal aquifer and source of municipal water supply in this area, is separated from the karstic surficial

Geohydrologic Unit	Stratigraphic Unit	Lithology
Western Interior Plains confining system	*Channel-sand deposits*	*Sand and clay*
Springfield Plateau aquifer	Warsaw Limestone Keokuk Limestone Burlington Limestone Elsey Formation Pierson Formation	Limestone, dolostone,and chert
Ozark confining unit	Northview Formation Compton Limestone Bachelor Formation	Shale, siltstone, limestone, and sandstone
Ozark aquifer	Cotter Dolomite Swan Creek Sandstone Jefferson City Formation Roubidoux Formation Gasconade Dolomite Gunter Sandstone Member of Gasconade Dolomite Eminence Dolomite Potosi Dolomite	Dolostone and sandstone
St. Francois confining unit	Derby-Doe Run Dolomites Davis Formation	Dolostone, silt, and shale
St. Francois aquifer	Bonneterre Dolomite Lamotte Sandstone	Dolostone and sandstone
Basement confining unit		Igneous and metamorphic rocks

Figure 3. Correlation of geohydrologic units and stratigraphic units in Greene County (modified from Thomson, 1986; Imes, 1989).

aquifer by a fractured, leaky confining unit insufficient to protect water quality in the Ozark aquifer from contaminated shallow water. Many non-municipal wells are open to both the shallow and deep aquifers.

Information necessary to define the hydrologic setting and karst terrane in Greene County was not available in a single data base. Therefore, during 1989 the USGS, in cooperation with the Watershed Committee of the Ozarks, Inc., City of Springfield, City Utilities of Springfield, Greene County, MDNR, Southwest Missouri State University (SMSU), and the U.S. Environmental Protection Agency (USEPA), began to assimilate data on sinkholes and other karst features in Greene County. A geographic information system (GIS) data base of karst-related information and cultural features was produced to correlate the location of karst features to man-made structures and to revise and update existing maps and data.

Purpose and Scope

The purpose of this report is to describe a GIS data base developed during a 3-year study (1989-92) for water resources planning in Greene County. Geology, caves, dye traces, faults, geographic names, hydrography, hypsography, lineaments, Ozark aquifer potentiometric surface, public land survey system, sinkholes, soils, springs, and transportation data were included in the data base. These data were organized by quadrangle map (fig. 1) and digitized or transferred into the GIS data base, which is stored using the software package ARC/INFO and is housed on the USGS Prime 9955[1] computer system. Selected maps in this report were produced from the data base to illustrate GIS capability.

Previous Investigations

The surface- and ground-water quality in Greene County was adequate for most uses as determined by the results of a study by Emmett and others (1978). Existing ground-water contamination potential was noted because of the cavernous nature of the bedrock and the presence of many sinkholes and losing streams.

A report by Harvey (1980) summarized the hydrology of the aquifers in Cambrian and Ordovician rocks of southwest Missouri and northwest Arkansas. Hydrologic data include aquifer characteristics, stage and yield characteristics, recharge pathways, generalized directions of ground-water movement, use of ground water, quality of water in the aquifers, methods of waste disposal commonly used, projection of future water use, and feasibility of development of alternative water sources.

The "Missouri Water Atlas" (Missouri Department of Natural Resources, 1986) shows information on the hydrologic cycle, water quantity, water quality, and water use in Greene County and Missouri. Also included are maps showing drainage basins, losing streams, and other hydrologic features.

The geology of Greene County was mapped and described in a report by Thomson (1986). His report includes description of the bedrock units and structural features, with discussions of mineral potential, geologic hazards, and engineering properties.

The ground-water system and the effects of continued ground-water pumpage near Springfield are described in a report by Imes (1989). Pumpage from the Ozark aquifer for public supply and industrial use in Springfield and surrounding communities in southwestern Missouri has substantially altered ground-water flow patterns in the aquifer. A finite-difference model of ground-water flow in a 42- by 42-mile area centered on Springfield was calibrated with predevelopment and transient pumping conditions.

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[1]Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

The geohydrologic system in southern Missouri and parts of adjacent states was described in a report by Imes (1990a). This report includes maps of the altitude of the top, thickness, potentiometric surface, and percentage-of-shale content of individual geohydrologic units. Geohydrologic units and geologic formations that comprise the Springfield Plateau aquifer are described in a report by Imes (1990b).

Map reports by Imes and Davis (1990, 1991) list the water types and the concentrations of selected inorganic constituents for the Springfield Plateau and Ozark aquifers. The water type in the part of the Springfield Plateau aquifer that crops out in Greene County is a calcium bicarbonate. The dissolved solids concentration locally exceeded 400 milligrams per liter, but more commonly ranged from 100 to 300 milligrams per liter. The water type in the Ozark aquifer is a calcium bicarbonate or mixed calcium magnesium bicarbonate with calcium as the most prevalent cation. The dissolved solids concentration generally ranged from less than 200 to about 300 milligrams per liter.

The general geology, geologic structure, and mineral resources of the Springfield 1 x 2 degree quadrangle, which includes Greene County, were described in a report by Martin and Pratt (1991). The report discusses surficial geology, lithologic variations of the subsurface sedimentary rocks, and geochemistry of the subsurface carbonate rocks and the basal sandstones.

Acknowledgments

The authors thank Saul Nuccitelli, Barbara Becker, Russ Campbell, Ruth Johnson, Gary Pendergrass, and John Scheer of the Watershed Committee of the Ozarks, Inc., a volunteer organization, for their assistance in defining the data base. Thanks also to Loring Bullard of the Watershed Committee of the Ozarks, Inc. for contributing technical support to the project, residents in Greene County for providing access to land for the location of sinkholes, and the MDNR for their assistance and access to files.

DESCRIPTION OF THE STUDY AREA

Greene County is situated on the Springfield Plateau, which is part of the Ozark Plateaus Province (Fenneman, 1938). The land surface altitude in Greene County ranges from near 910 to more than 1,518 feet above sea level. The land surface consists of low rounded hills and rolling plains that contain numerous streams, springs, and sinkholes, especially northwest and south of Springfield. The Sac River, including Clear Creek and Little Sac River (fig. 4), drains the northern part of the county and flows into the Osage River (outside the study area), which flows into the Missouri River. The James River, including Wilsons and Pearson Creek, drains the southern part of the county and flows into the White River, which flows into the Mississippi River. Approximately one-half of Springfield is in each drainage basin. The Sac and James Rivers define the base level toward which much of the shallow ground water flows.

The climate of Greene County is humid with mild winters and warm summers. Annual rainfall averages 40 inches per year and the air temperature averages 55 degrees Fahrenheit (National Oceanic and Atmospheric Administration, 1985).

The soils in Greene County generally are moderately to well drained, and gently to moderately sloping. Water infiltrates through the soil at rates ranging from extremely low to high. One of the predominant soils in Greene County is the Pembroke Series (plate 2), consisting of deep, well-drained soils on uplands and stream terraces. Twenty-seven soils are identified in Greene County and shown on plate 2. A detailed discussion of soils is not presented in this report, but can be obtained from a report by Hughes (1982). In that report, soil properties are described by engineering index, by physical and chemical properties, and by series and association.

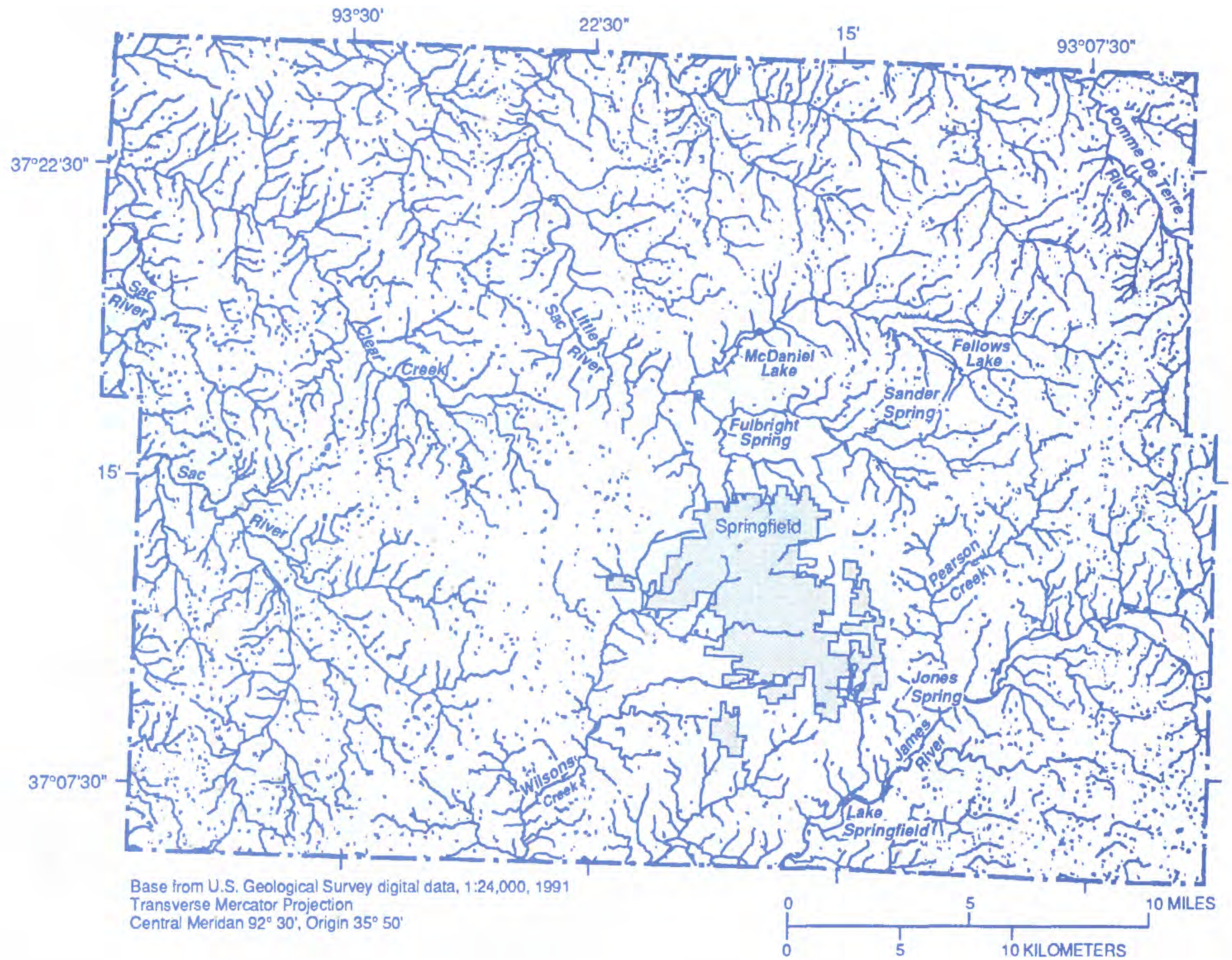


Figure 4. Hydrography map layer of Greene County containing lakes, streams, springs, and ponds.

Geology

Formations that crop out in Greene County are composed of limestone, shale, sandstone, and dolostone (fig. 3). The aggregate thickness of these rock units is as much as 1,000 feet. An additional 1,700 feet of sedimentary rock overlie the igneous and metamorphic rocks (fig. 3), but these rock units will not be discussed in this report because they do not crop out in Greene County.

Structure

Greene County lies on the western side of the Ozark Uplift, where the strata have a regional dip of 15 to 20 feet per mile to the west-southwest. This general attitude has been modified by several northwest trending faults and folds. Two major northwest trending fault zones outside of Greene County affect the rocks in the county; the Bolivar-Mansfield Fault System to the northeast of the county and the Chesapeake-Ten O'Clock Run Fault Zone, which is west of the southwest corner of Greene County.

Faults within Greene County generally trend northwest to southeast (fig. 5). Asher Fault, Walnut Grove Fault, Steel Bridge Fault, Danforth Graben, Sawyer Fault, and probably the Pearson Creek Fault parallel the northwest-southeast trending Graydon Springs Fault. The northwest-southeast trending faults on the southwest part of the county include the Sac River-Battlefield Fault. Faults between the Graydon Springs Fault and the Sac River-Battlefield Fault are normal and, in most cases, the south side is the downthrown side. The throw of some of the faults reverses direction, creating a scissors fault of which the Fassnight-Kinser Bridge Fault is an example.

Lineaments are straight or gently curved features that are structurally controlled and appear on aerial photography as lines. Much of the drainage pattern in the county has developed along and reflects these zones of structural weakness. Lineaments give probable joint structure and fracture patterns that may be related to the development of karst terrane. The lineament pattern in Greene County indicates a strong northwest to southeast and northeast to southwest orientation. The lineaments and faults range from less than 1 mile to as much as 10 to 15 miles across the county.

Major Geohydrologic Units

This section describes the major geohydrologic units that crop out in Greene County. These include the Springifeld Plateau aquifer, the Ozark confining unit, and the Ozark aquifer. The youngest rock units that occur in the county are terrace deposits and alluvium along the larger streams and rivers. The Western Interior Plains confining system is represented by channel-sand deposits of sandstone, conglomeratic sandstone, and conglomerates. These deposits occur as cap rocks and ridges that have been resistant to erosion and valley fill in stream channels mainly in the western part of the county.

Springfield Plateau aquifer

The Springfield Plateau aquifer consists of limestone, dolostone, and chert (fig. 3). This includes the Warsaw, Keokuk, and Burlington Limestones, and the Elsey and Pierson Formations (plate 1). The aquifer crops out over most of Greene County, except for the northern and northeastern parts of the county.

The Warsaw Limestone, the uppermost formation in the aquifer, is a medium-bedded, bluish-gray to light brown crystalline limestone with minor quantities of chert. It crops out in three generalized locations in the western and southern parts of the county, where as much as 50 feet remain exposed after erosion.

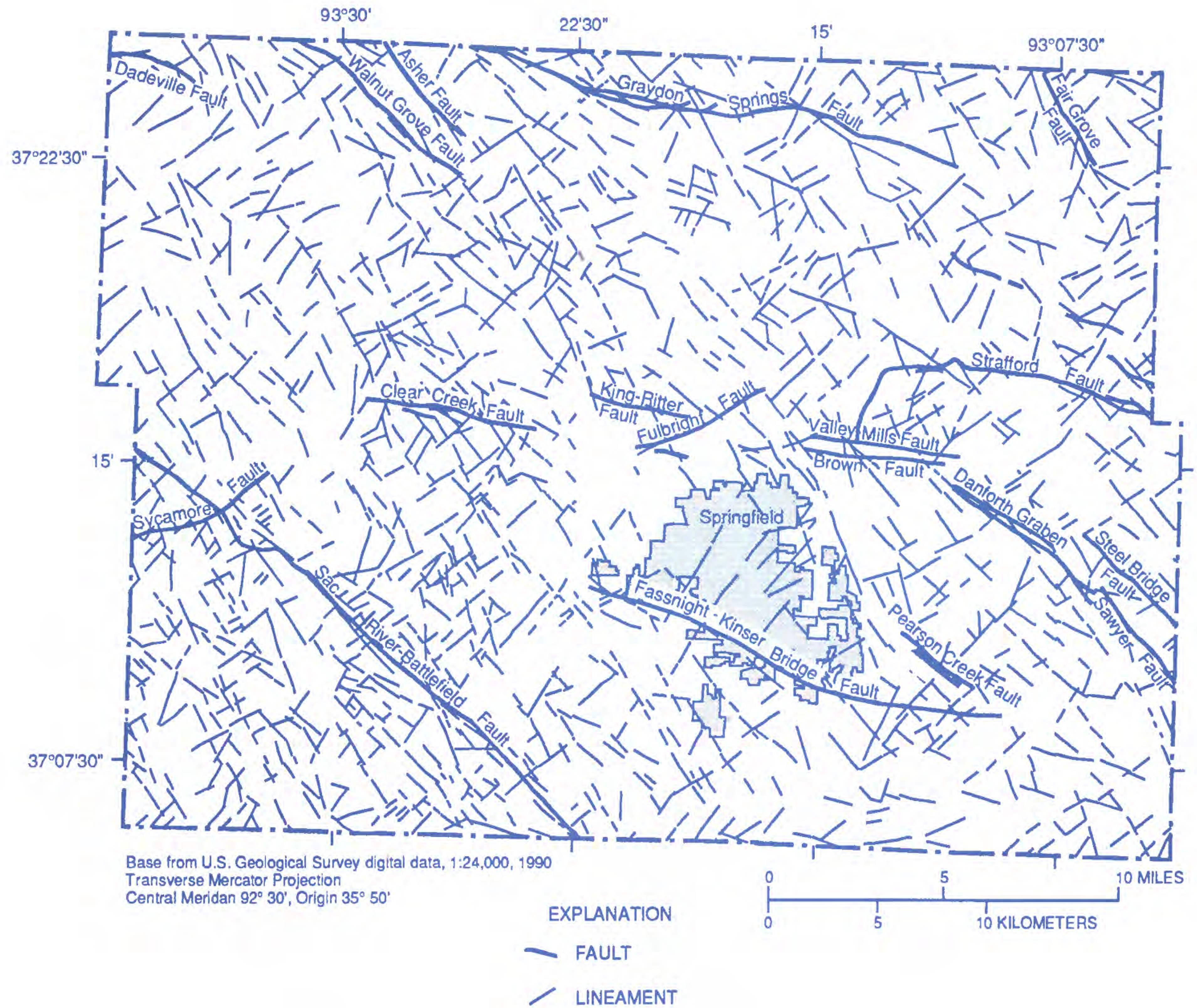


Figure 5. Faults and lineaments in Greene County (Thomson, 1986).

The Burlington and Keokuk Limestones are exposed over the largest part of the county and host most of the sinkholes and other karst features. These limestones are light gray, crystalline, and crinoidal. Chert nodules and beds occur mainly in the lower part of the unit. The Burlington and Keokuk Limestones can be 200 feet thick in Greene County.

The Elsey Formation is a dense, light gray, fine-grained limestone that contains from 25 to 50 percent chert, either as nodules or beds throughout the formation. This unit weathers extensively so that outcrops are rare and chert-strewn hillsides are the most common evidence for the unit. The formation ranges from 50 to 80 feet thick.

The Pierson Formation is a light brown to gray silty dolostone or dolomitic cherty limestone. It is exposed in the eastern and northern parts of the county where it ranges from 10 to 50 feet thick.

Ozark confining unit

The Ozark confining unit consists of shale, siltstone, limestone, and sandstone (fig. 3). The Northview Formation, Compton Limestone, and Bachelor Formation are included in this unit. This unit crops out along the east side of the county and in the northeastern parts of the county. The unit crops out as a narrow band at the edge of the Springfield Plateau aquifer and along some of the larger rivers.

The Northview Formation includes an upper bluish to greenish gray shale with interbedded light brown siltstone and a lower siltstone with interbedded shale. The formation ranges from 5 feet thick in the southwest part of the county to as much as 80 feet in the northeastern part of the county where it crops out.

The Compton Limestone is a light to dark greenish to bluish gray, finely crystalline limestone that becomes dolomitic in some areas in the county. The Compton is easily recognized because of the green shale partings in the limestone. This rock unit averages 20 feet thick in Greene County.

The Bachelor Formation is a poorly sorted, pale green quartz sandstone or green sandy shale that, in some areas, contains rounded black phosphate nodules. This formation is extremely thin (2 inches to 2 feet thick) in Greene County and, therefore, is difficult to find in outcrop.

Ozark aquifer

The Ozark aquifer consists of dolostone and sandstone. The stratigraphic units contained in the Ozark aquifer are listed in figure 3. The aquifer crops out along the eastern boundary and in the northern and northeastern parts of the county.

The Cotter Dolomite is a light gray to light brown, fine-grained saccharoidal dolostone. Chert layers and some thin beds of sandstone commonly occur in the formation. The Swan Creek Sandstone Member of the Cotter Dolomite is a source of domestic water supply in a large part of the county. The Cotter Dolomite ranges from 50 to 175 feet thick and crops out in the northeastern part of the county.

The Jefferson City Formation often is mapped as a single unit with the Cotter Dolomite because of similarities between the two formations. The Jefferson City Formation is a light brown to brown, medium to finely crystalline dolostone and argillaceous dolostone with layers of chert and sandstone. The unit is from 190 to 220 feet thick and crops out in the northeastern part of the county.

The Roubidoux Formation crops out along the Pomme de Terre River in the northeastern corner of Greene County. It is mainly a fine- to medium-grained white to light brown quartz sandstone. Well data on file at the MDNR, Division of Geology and Land Survey (DGLS) in Rolla, Missouri, indicate that the unit is from 140 to 180 feet thick in the county.

Karst Features

Greene County, located on the Springfield Plateau of the southwestern part of the Ozarks Plateaus Province, is in an area with many karst features. The topography in the county is a result of a period of erosion that formed a gently rolling land surface. The carbonate bedrock land surface is covered by a veneer of residuum. Cracks, crevices, and other openings along bedding planes are solutionally enlarged by surface precipitation infiltrating through the residuum and into the bedrock. The general uplift of the Ozarks Plateaus caused an increase in stream gradient and accelerated the erosional processes of the land surface. The valleys that were formed and intersected the solutional channels in the bedrock were further deepened and in some cases created cave entrances. Subsidence and collapse of the surface residuum into subsurface channels formed sinkholes or dolines, which allowed interior drainage throughout much of the Greene County area. Karst or solutional processes are most effective on a relatively thick bed of limestone with well-defined joints and distinct bedding planes. Sufficient relief for vertical water movement through the rock is needed in addition to a climate with sufficient rainfall to maintain a proper quantity of ground water.

Karren Features

The solvent action of water on exposed soluble carbonate rocks causes solution grooves called karren features (fig. 6) that can occur over large areas as distinct geomorphic features. Karren features include pinnacles, bands, ridges, and ledges of limestone that range from a few inches up to 6

Figure 6. Karren features along State Highway 13 north of Springfield.

feet across. Enlargement along joints beneath the residual soils creates solutional features known as cutters, which are separated by residual limestone masses or pinnacles. Cutters and pinnacles that are present in the subsurface have no topographic expressions and can be identified only in excavations or in areas in which the soil has washed away. Cutters and pinnacles can be observed along many of the roadcuts throughout Greene County (Fellows, 1965), such as State Highway 13 north of Springfield, Interstate Highway 44, and U.S. Highway 65 on the east side of Springfield.

Sinkholes

Sinkholes (fig. 7) are the most obvious karst features in Greene County (fig. 8). As rainwater percolates through the soil into fractures and along bedding planes in the limestone, the rock is dissolved and the soil moves downward into the enlarged fractures and fracture intersections and is washed away through underground channels. The result of this solutional process is subsidence of the ground surface and the formation of a sinkhole. Therefore, most sinkholes have a shallow alluvial cover. Many sinkholes form after intense rain in the fall and spring of each year. In Greene County, about 2,500 sinkholes have been recorded during the course of this study. Of these sinkholes, 958 are shown on published topographic maps by closed hachured contours and most of these sinkholes are in the Burlington Limestone. Sinkholes throughout the county range from more than 10 feet in diameter to as large as 180 acres and from less than 10 feet to more than 60 feet deep.

Figure 7. Sinkhole on South Kansas Avenue in Springfield.

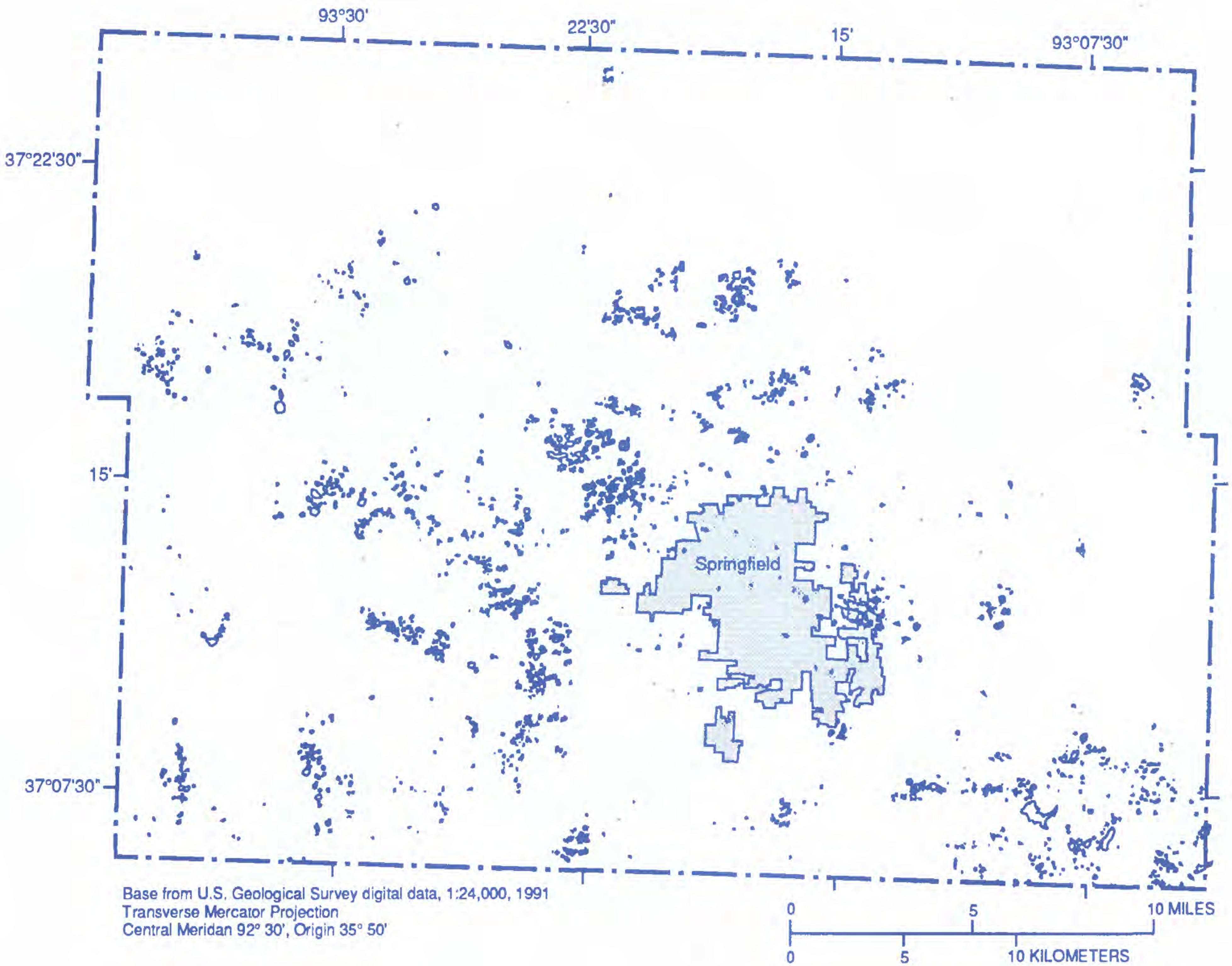


Figure 8. Location of sinkholes in Greene County, 1992.

If subsidence takes place over an area of solutional enlargement, such as a cave system, the land surface may break through the cave ceiling and create a collapsed sinkhole (fig. 9). The underlying cave passage can be observed in the sinkhole, which generally will have vertical or near vertical sides. In most cases, the sinkhole walls are formed of limestone or surface residuum. The sinkhole begins initially in soils or residuum that sloughs off to form a bowl shape that leads to a limestone-walled pit. Most collapsed sinkholes in the county are small, generally 5 to 10 feet in diameter and from 10 to 20 feet deep. The larger sinkholes are 10 to 20 feet in diameter and as deep as 75 feet. Collapsed sinkhole entrances are connected directly to at least 46 cave systems in the county. Several sinkhole collapses occur within the county each year (Hayes and Russel, 1977). Many collapses are reported to local authorities, and the sinkholes often are filled to keep the ground-water system open to rainwater percolation.

Figure 9. *Sinkhole in residuum near Fremont and Primrose Streets in Springfield.*

Sinkholes provide direct pathways for water and possible contaminants to enter the Springfield Plateau aquifer (fig. 3). Fertilizer, pesticides, and livestock wastes can wash into sinkholes in agricultural areas (fig. 10). Runoff from urban areas can contain trace elements and hydrocarbon compounds, in addition to any chemicals that have spilled or leaked on the land surface. Sinkholes can become plugged with debris when used as trash dumps (fig. 11) and become inactive for long periods. However, the sinkholes can become unplugged without warning or can be cleaned out and become reactivated as direct point of entry into the shallow aquifer.

Figure 10. Sinkhole depression in an agricultural area in the Brookline quadrangle west of Springfield.

Figure 11. Sinkhole used as a trash dump near Springfield.

Because sinkholes are a part of the surface drainage system in karst terrane, water from intense rains collects in large and small sinkholes, and drains into the shallow ground-water system. When water flows through the sinkhole into the ground-water system, the flood potential is relatively small. However, if the sinkhole becomes clogged or filled, it can become a flood hazard (fig. 12). During intense rain, even those sinkholes that drain fairly well will collect and retain water.

Caves

Greene County is one of the more cavernous areas in the State. More than 320 known caves ranging from 10 feet to more than 5,000 feet long have been identified in Greene County (figs. 13 and 14). Sixteen caves are more than 1,000 feet long and the longest cave in the county is Fantastic Caverns (more than 6,500 feet). These caves can be the conduits for springs and provide storage for shallow ground water so many of the springs flow even during times of drought.

Figure 12. Flooded sinkhole near Monroe Terrace Avenue in Springfield.

Figure 13. Entrance to Sequiota Cave in southeast Springfield.

Figure 14. Entrance to Doling Cave in north Springfield.

Most of the caves in the county are formed in the Burlington Limestone or the Pierson Formation. A few caves, which are unstable and susceptible to collapse, are in the extremely cherty Elsey Formation. Five caves are at the contact between the Burlington Limestone and the Elsey Formation. The major opening of 136 caves is horizontal and the major opening of about 70 caves is though a sinkhole or vertical crevice in the limestone. The caves that are accessible by a sinkhole or vertical crevice range from a few feet to 75 feet deep. About 30 of the known caves in the county have been filled by human activities.

Springs

Springs are abundant in Greene County. The water from the springs generally is adequate for most uses, but the presence of a solution channel that can rapidly transport contaminants makes the springs susceptible to contamination. Most of the spring openings are in rocks of the Springfield Plateau aquifer. Although springs are abundant in the county, they are small--generally with flow less than 20 cubic feet per second (Vineyard and Feder, 1982; Imes and Smith, 1990). Even with the small flows, a considerable quantity of water is discharged through the springs. For example, Fulbright Spring (fig. 4), north of Springfield, Sander Spring, northeast of Springfield, and Jones Spring, east of Springfield, have a combined discharge of 4 million gallons per day (Vineyard and Feder, 1982).

Surface-Water Hydrology

The smaller streams in Greene County usually are dry in their headwaters because the streambed is higher than the water table. These streams usually have no or low flows during rainfall because of the large capacity of the ground-water system to store and transport infiltrated water. One result of rapid flow through the solution-enlarged joints and fractures in karst areas is the convergence of ground water into the larger channels and emergence of the water as springs where these channels intersect the land surface.

Springfield is located on a ridge that is the surface-water divide for the Sac River and the James River basins (fig. 4). The major tributaries to the Sac River--the Pomme de Terre River, the Little Sac River, and Clear Creek--flow to the northwest. The James River and its major tributary, Wilsons Creek, flow to the southwest. Three major reservoirs on the Sac and James River are located near Springfield: McDaniel and Fellows Lakes, north of Springfield on the Little Sac River, and Lake Springfield, south of Springfield on the James River.

Surface impoundments, including lakes and ponds, have been constructed to be detention or retention areas that receive runoff. They can be subject to failure because of sinkholes that develop within them. However, in a karst area, construction of impoundments often removes a substantial quantity of overburden and can accelerate the natural process of sinkhole formation. The impoundments cause runoff to be concentrated in a much smaller area than with natural conditions. Some impoundments are constructed to receive stormwater runoff and to allow the runoff to seep slowly into the ground, thereby allowing time for potential contaminants to settle or chemically alter.

GEOGRAPHIC INFORMATION SYSTEM DATA BASE

The GIS data base is stored using the software package ARC/INFO and is housed on the USGS Prime 9955 computer system. The ARC/INFO package processes geographic data in a digital form, displays data graphically for efficient data management and analysis, and translates these data into maps. Each map constitutes a layer in the GIS data base that can be used interactively with other maps in the data base.

Development of Data Base

The GIS data base was developed to include karst-related hydrologic and geologic data and cultural features necessary for evaluation, modeling, and planning of ground-water use and development in a karst terrane. The GIS data base contains these data in digital map layers compiled from original maps and digital data produced by private organizations, universities, and other State and Federal agencies (table 1). These data were collected, checked for accuracy, combined in a common map projection available for all layers and stored in the GIS data base. All layers contained in this data base are organized by 7 1/2' quadrangle map sheets (fig. 1) of the source data. Each map layer, map scale, memory used, and data source are listed in table 1.

Table 1.--*Map layer, map scale, memory required, and source of data for the geographic information system data base*

[mb, megabytes; SMSU, Southwest Missouri State University; MSS, Missouri Speleological Survey, Inc.; USGS, U.S. Geological Survey; MDNR, Missouri Department of Natural Resources; PLSS, Public Land Survey System; SCS, Soil Conservation Service]

Map layer	Map scale	Memory required (mb)	Source of data
Geology	1:24,000	2.61	SMSU
Cave entrances and passages	1:24,000	.12	MSS
County and quandrangle			
boundary	1:24,000	.01	USGS
Dye traces	1:24,000	.12	MDNR, SMSU
Faults	1:24,000	.07	SMSU
Geographic names	1:24,000	.05	USGS
Hydrography	1:24,000	3.00	USGS
Hypsography	1:24,000	8.00	USGS
Lineaments	1:24,000	.39	SMSU
Ozark aquifer potentiometric surface			
1900	1:126,720	.06	USGS
1974	1:126,720	.10	USGS
1987	1:126,720	.08	USGS
PLSS	1:24,000	.35	USGS
Sinkholes	1:24,000	2.00	SMSU
Soils	1:24,000	5.00	SCS
Springs	1:24,000	.02	SMSU
Transportation	1:100,000	3.50	USGS

Description of Data Base Map Layers

The following sections describe the 15 map layers included in the GIS data base. The source and accuracy of the data, where applicable, and the steps used to compile these data into the data base also are described. The source of several of the map layers are 7 1/2' quadrangle maps at a scale of 1:24,000 from the USGS, National Mapping Division (NMD). The accuracy of the horizontal control for each quadrangle map is plus or minus 2 feet.

Geology

The geology (plate 1) layer contains linework that represents contacts between geologic formations that crop out in Greene County. Geologic maps originally were compiled from 1:20,000 scale aerial photographs and 1:24,000 scale topographic maps based on onsite investigations. Geologic contacts were digitized from each 7 1/2' quadrangle in Greene County. Computer plots were made of each quadrangle and checked against the original maps. Adjacent quadrangles were checked for continuity of linework along quadrangle borders. After exact matchups along all the quadrangle borders were established, the data were combined into one map layer for the entire county.

Cave Entrances and Passages

The cave entrances and passages map layer contains linework that represents the entrances and passages of caves. The cave information was obtained from the files of the Missouri Speleological Survey, Inc. Maps originally were compiled at scales of 1:240 and 1:480 by members of the Missouri Speleological Survey, Inc. The passages of about 135 mapped caves and the entrances of an additional 185 unmapped caves are included in the data base. A location point in degrees latitude and longitude represents the major opening of the cave and straight lines represent cave passages. The cave passages were digitized from the original field maps.

County and Quadrangle Boundary

The county and quadrangle boundary map layer contains the political boundary that defines Greene County and the 7 1/2' quadrangle boundaries layer (fig. 1) for all quadrangles within Greene County. The data were at a 1:24,000 scale and were furnished by the USGS, NMD.

Dye Traces

The dye traces map layer contains lines with arrows that represent dye trace location and direction of ground-water flow. The input and recovery locations for the dye traces originally were recorded to the nearest second of latitude and longitude or to the nearest township, range, and quarter quarter quarter section of the Public Land Survey System (PLSS) on the 7 1/2' quadrangle maps (fig. 1). Each input and recovery location was entered into the data base as two points, identified by latitude and longitude. Data were furnished by MDNR, DGLS.

Faults

The faults map layer contains lines representing the surface traces of faults in Greene County. The data define approximate locations of fault lines and fault zones with respect to each other and other mapped features (fig. 5). The fault locations are from Thomson (1986) and were digitized from each 7 1/2' quadrangle (fig. 1).

Geographic Names

The geographic names map layer contains geographic features such as cities, towns, and schools. The digital data were furnished by the USGS, NMD for each 7 1/2' quadrangle map (fig. 1).

Hydrography

The hydrography map layer (fig. 4) contains streams and water bodies. Data were furnished by the USGS, NMD by 7 1/2' quadrangle. Data were combined into one county map.

Hypsography

The hypsography map layer contains altitude data consisting of contour lines with 10- and 20-feet contour intervals and "spot elevations" (altitudes determined for roads, fences, and similar features) and was furnished by USGS, NMD. Contours and altitudes were digitally scanned from 1:24,000 maps. Data were obtained from 7 1/2' quadrangle maps and were combined into one county map.

Lineaments

The lineaments map layer (fig. 5) contains linework that represents linear features selected from 1:20,000 and 1:60,000 scale aerial photos and USGS, NMD 7 1/2' quadrangle maps (Thomson, 1986). The location of lineaments is subjective and approximate.

Ozark Aquifer Potentiometric Surface

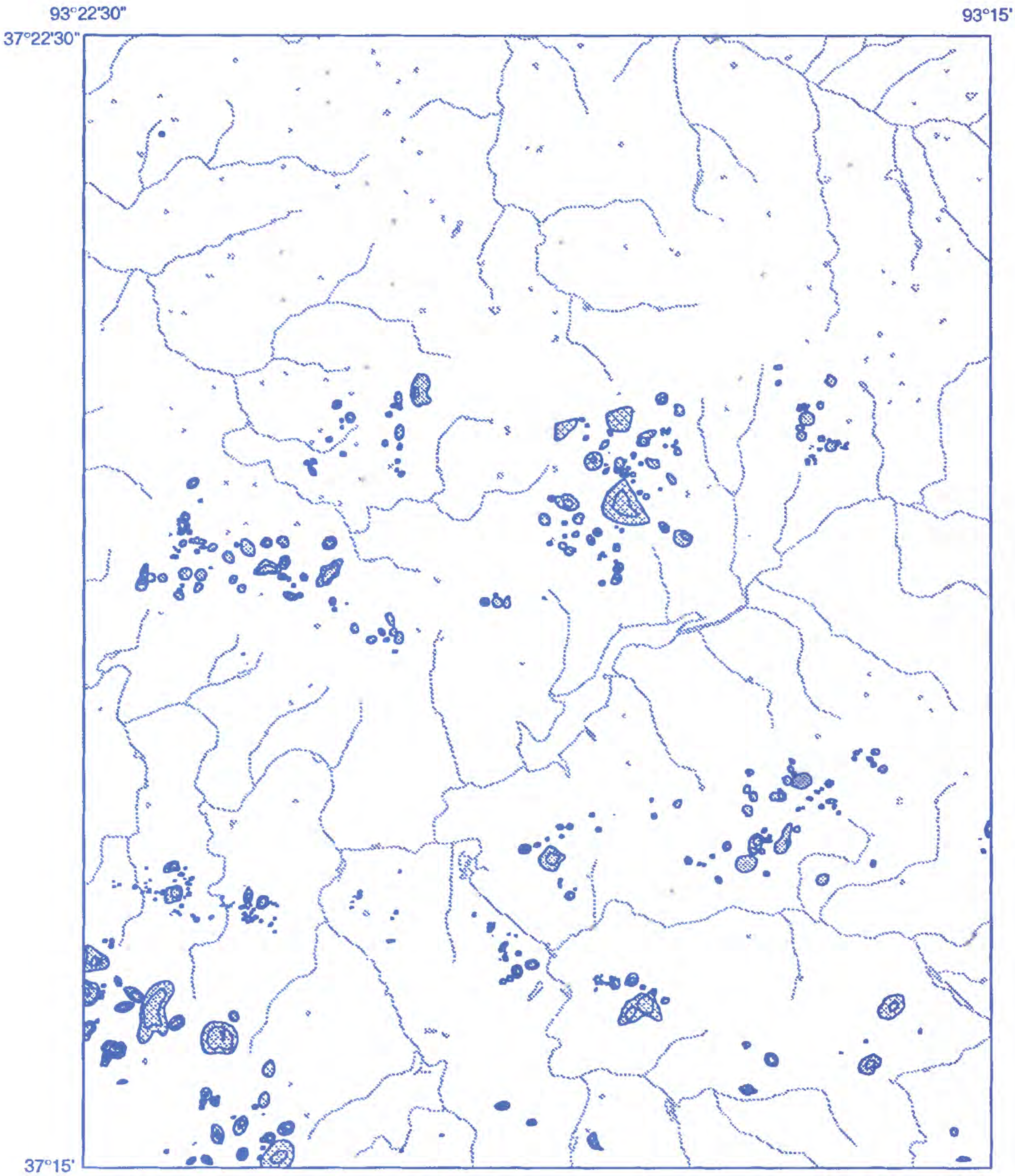
The Ozark aquifer potentiometric surface map layer contains the potentiometric surface of the Ozark aquifer for Greene County for 1900, 1974, and 1987. The potentiometric surface for 1900 was drawn from water-level measurements obtained from published reports and well logs on file at the MDNR, DGLS office in Rolla. The potentiometric surfaces for 1974 and 1987 were drawn from water-level measurements made by the USGS and also from well log information on file at the MDNR, DGLS. All water-level measurements were plotted on 1:126,270 scale county maps, and potentiometric surface contours were interpolated from the water-level measurements and topographic contours. The potentiometric surface for each year is accessed separately.

Public Land Survey System

The PLSS map layer contains the rectangular system of land surveys that is administered by the U.S. Bureau of Land Management. The PLSS subdivides the public domain and represents property boundaries or references to property boundaries. The PLSS includes only township, range, and section data. Data were furnished by USGS, NMD in 7 1/2' quadrangles. Data were combined into one county map layer.

Sinkholes

The sinkhole map layer (sinkholes for Ebenezer quadrangle are shown in figure 15) contains linework that represents sinkhole boundaries in Greene County as of 1992. The sinkhole and the hydrography map layers for the Ebenezer quadrangle are shown in figure 15. Sinkholes were initially located using 1:24,000 and 1:100,000 scale topographic maps. Aerial photographs flown for the Greene County Assessors Office at 3,000; 6,000; and 12,000 feet during 1980 also were used to locate sinkholes. The precise location and morphology of sinkholes were determined by examining topographic maps and aerial photographs and interviews with local residents. Ownership of a sinkhole was determined by interviewing local residents or using the county real estate ownership plat maps or the Greene



Base from U.S. Geological Survey digital data, 1:24,000, 1991
Transverse Mercator Projection
Central Meridan 92° 30', Origin 35° 50'

0 0.5 1 MILE
0 0.5 1 KILOMETER

EXPLANATION

SINKHOLE--Outer line indicates shape of the sinkhole at land surface; inner line indicates the shape of the bottom of the sinkhole

LAKE

STREAM

Figure 15. Sinkhole and hydrography map layers, 1992, Ebenezer quadrangle.

County Court records. Any historical information about the sinkhole was obtained, such as past containment of water or identification of any material placed in the sinkhole. The following physical characteristics of each sinkhole were determined:

1. Length, width, and depth;
2. Degree of slope of the sides or degree of collapse;
3. Orientation of the long direction of the sinkhole;
4. The lowest altitude within the sinkhole;
5. Location of any eyes or openings within the sinkholes;
6. Description of vegetation in and near the sinkhole;
7. Any outcrops in the walls of the sinkhole; and
8. Ability of the sinkhole to hold water.

Sinkholes were mapped at scales of 1:60 to 1:2,400 and sorted by 7 1/2' quadrangle (table 2). The sinkhole boundary, an identification code, the scale, a north arrow, and a location point were digitized. The boundary lines for sinkholes greater than 10 feet in diameter on the map layer do not represent the altitude of the land surface, but the lines define shape based on onsite investigation. For example, in the larger sinkholes shown in figure 15, the outside line defines the shape of the sinkhole at the land surface and the inner line defines the shape of the bottom of the sinkhole. Other sinkholes were defined as a point if the sinkhole was less than 10 feet in diameter, the location was known but access was not possible, or the location was known but the sinkhole was covered with vegetation and definition was impossible.

Table 2.--*Quadrangle name and number of sinkholes, 1992*

Quadrangle name (fig. 1)	Number of sinkholes	Quadrangle name (fig. 1)	Number of sinkholes
Ash Grove	177	Bassville	84
Billings	38	Brookline	635
Ebenezer	513	Elkland	0
Fair Grove	2	Galloway	284
Halltown NE	125	Morrisville	2
Nixa	31	Oak Grove Heights	70
Ozark	93	Pleasant Hope	18
Republic	55	Rogersville	112
Springfield	102	Strafford	11
Walnut Grove	2	Willard	141

Total sinkholes mapped in Greene County -- 2,495

Soils

The soils map layer contains soil map units consisting of soil series and slope classes. Soils for the Springfield 7 1/2' quadrangle are shown on plate 2. These data originally were mapped by the Soil Conservation Service (SCS) at a 1:20,000 scale (Hughes, 1982) and were joined and edited by MDNR, DGLS to cover the county. These data were converted to data layers by quadrangle and were checked for continuity of linework along quadrangle borders by the USGS. After checking, the quadrangle maps were combined into one county map layer. The soil codes contained in the map layer are the standard codes used by the SCS.

Springs

The springs map layer contains the location of springs in Greene County. Data were obtained from 7 1/2' topographic maps and SMSU personnel, who plotted spring locations onsite on 1:24,000 scale maps.

Transportation

The transportation map layer contains transportation systems in three separate overlays: (1) roads and trails, (2) railroads, and (3) pipelines, transmission lines, and miscellaneous transportation features. Data were furnished by USGS, NMD in 7 1/2' quadrangles and combined into one county map.

Application of the Data Base

The GIS data base described in this report can be used to increase the understanding of the factors affecting the hydrology in Greene County. For example, the concept of ground-water protection involves determining areas on the land surface from which contaminants or hazardous materials can migrate into the capture area of water-supply wells and then excluding certain practices or land uses and excluding disposal of potential contaminants from these areas (fig. 16). The GIS data base described here provides a means to delineate sensitive areas, evaluate potential contaminant pathways, and plan for mitigation responses.

Also, the GIS data base can be used to analyze the relation between sinkholes and associated karst features, such as caves and springs, to identify characteristics of sinkholes, and to assess the significance of various factors, such as geologic structures, soils, and bedrock lithology that may control the development and growth of sinkholes. Combinations of map layers at any scale can be selected by the user for statistical analysis, graphic display, or model analysis. The GIS data base provides planners and managers immediate access to a variety of information relevant to issues such as ground-water contamination, emergency response to chemical and hazardous product spills, and residential, industrial, and commercial-development planning and zoning. The GIS data base also provides a foundation on which new map layers, such as location of underground storage tanks, chemical warehouses, landfills, lagoons, artificial lakes, septic tanks, and other potential sources of ground-water contaminants, could be added.

POTENTIAL ADDITIONAL MAP LAYERS

Because of the increasing population and industry in Greene County, the quality of the water resources will continue to be a concern. Although water-quality data are available for selected areas of the county (Emmett and others, 1978; Imes, 1989; Imes and Davis, 1990, 1991), an updated county-wide assessment of the water quality, which was beyond the scope of this study, could assist in decisions affecting the protection and use of the water resources. The location of existing and future water-quality sampling sites could be added to the GIS data base.

Figure 16. Ground-water protection program sign on Interstate Highway 44 in southwest Missouri.

The potential for ground-water contamination in Greene County exists because the karst terrane provides direct conduits to the ground water. For example, map layers of the location of underground storage tanks, landfills, lagoons, artificial lakes, and septic tanks could be added to the GIS data base. Underground storage tanks, which usually store gasoline or fuel oil, can pose a significant threat as a source of potential ground-water contamination. An estimated 20 to 40 percent of all underground storage tanks leak, and 40 percent of the tanks dug up because of leaks had more than five holes (data on file at the MDNR, DGLS in Rolla, Missouri).

Similarly, chemical products or by-products of manufacturing, cleaning, or degreasing procedures can become the source of ground-water contamination. A map layer containing the location of manufacturing plants, chemical warehouses, or major chemical users could be added to the GIS data base. The location of sites where wastewater is used for irrigation or is released into surface water could be added to the data base to help assess the risk of increased concentration of nutrients, bacteria, and viruses in ground water.

SUMMARY

Greene County is located in a karst terrane where about 2,500 sinkholes have been located. These sinkholes are potential access points for contamination to the ground-water system. Karst terranes are environmentally sensitive because any contaminant carried by surface runoff has the potential for rapid transit through solution-enlarged fractures to the ground-water system. Some of the most serious incidents of ground-water contamination have been reported in karst terranes developed in soluble carbonate rocks.

The population in Greene County, which includes Springfield, the third largest city in Missouri, is rapidly increasing, and the protection of water resources of Greene County is an increasing concern. The possibility of ground-water contamination from residential and business expansion and agricultural practices exists in Greene County. Recent examples of ground-water contamination by sewage, fertilizers, and hydrocarbon chemicals have demonstrated the sensitivity of ground water in the Greene County karst terrane to degradation. The ground-water system is a major source of drinking water for the county.

A GIS data base was developed for Greene County to increase understanding of the nature of karst terrane and provide information on how development can best be tailored to protect water resources. The GIS data base contains 15 map layers: geology, cave entrances and passages, county and quadrangle boundary, dye traces, faults, geographic names, hydrography, hypsography, lineaments, Ozark aquifer potentiometric surface, public land survey system, sinkholes, soils, springs, and transportation. The data base was designed so updates or additions of map layers could be added easily.

The GIS data base gives planners and managers immediate and easy access to a wide variety of information relevant to such issues as ground-water contamination, emergency response to chemical and hazardous product spills, and residential, industrial, and commercial development planning and zoning. The GIS data base provides a foundation on which new GIS map layers, such as the location of underground storage tanks, chemical warehouses, landfills, lagoons, artificial lakes, septic tanks, and other potential sources of ground-water contamination, can be added to increase the value of the data base as an instrument by which water resources can be protected.

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