

# ENVIRONMENTAL AND HYDROLOGIC SETTING OF THE OZARK PLATEAUS STUDY UNIT, ARKANSAS, KANSAS, MISSOURI, AND OKLAHOMA

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U.S. GEOLOGICAL SURVEY  
Water-Resources Investigations Report 94-4022



NATIONAL WATER-QUALITY ASSESSMENT PROGRAM



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*by* James C. Adamski, James C. Petersen, David A. Freiwald, *and* Jerri V. Davis

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Water-Resources Investigations Report 94-4022

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Little Rock, Arkansas  
1995



U.S. DEPARTMENT OF THE INTERIOR  
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY  
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## CONVERSION FACTORS AND VERTICAL DATUM

	<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
	inch (in.)	25.4	millimeter
	foot (ft)	0.3048	meter
	mile (mi)	1.609	kilometer
	acre	0.4047	hectare
	square mile (mi <sup>2</sup> )	2.590	square kilometer
	foot per day (ft/d)	0.3048	meter per day
	cubic foot per day (ft <sup>3</sup> /s)	0.02832	cubic meter per second
	gallon per minute (gal/min)	0.06308	liter per second
	million gallons per day (Mgal/d)	0.04381	cubic meter per second
	pound (lb)	0.4536	kilogram
	foot square per day (ft <sup>2</sup> /d)	0.09290	meter squared per day

Temperature in degrees Fahrenheit (° F) can be converted to degrees Celsius (° C) as follows:

$$^{\circ}\text{C} = 5/9 \times (^{\circ}\text{F} - 32)$$

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

# Environmental and Hydrologic Setting of the Ozark Plateaus Study Unit, Arkansas, Kansas, Missouri, and Oklahoma

By James C. Adamski, James C. Petersen, David A. Freiwald, and Jerri V. Davis

## ABSTRACT

The Ozark Plateaus study is 1 of 20 National Water-Quality Assessment (NAWQA) studies initiated by the U.S. Geological Survey in 1991 to describe the status and trends in the quality of the Nation's water resources. When the NAWQA program is fully implemented, a total of 60 study units in the United States will be investigated on a rotational basis. Study-unit investigations will include 5 years of intensive assessment activity followed by 5 years of low-level monitoring.

The environmental and hydrologic setting of the Ozark Plateaus National Water-Quality Assessment study unit and their factors that affect water quality are described in this report. The primary natural and cultural features that affect water-quality characteristics and the potential for future water-quality problems are described. These environmental features include physiography, climate, population, land use, water use, geology, soils, and surface- and ground-water flow systems.

The Ozark Plateaus study unit has an area of approximately 48,000 square miles and includes parts of Arkansas, Kansas, Missouri, and Oklahoma. The study unit contains most of the Ozark Plateaus Province and parts of the adjacent Osage Plains section of the Central Lowland Province and the Mississippi Alluvial Plain section of the Coastal Plain Province. The Ozark Plateaus Province consists of three sections--the Springfield Plateau, the Salem Plateau, and the Boston Mountains. Topography in the study unit is mostly gently rolling, except in the Boston Mountains and along the escarpment separating the Springfield and Salem Plateaus, where it is rugged. Karst fea-

tures such as springs, sinkholes, and caves are common in the Springfield Plateau and abundant in the Salem Plateau.

The study unit has a temperate climate with average annual precipitation ranging from about 38 to 48 inches and mean annual air temperature ranging from 56 to 60 degrees Fahrenheit. Population in the study unit was about 2.3 million people in 1990 and increased 28 percent between 1970 and 1990. Land use in the study unit is predominantly pasture and cropland in the northwestern part, and forest and pasture in the southeastern part. Poultry farming is a major industry in the southwestern part of the study unit. Mining, primarily in the four major lead-zinc mining districts, has been an important part of the local economy in the past. Total water use averaged 1,053 million gallons per day in the study unit in 1990. Ground water accounted for about 58 percent of the water withdrawn for all uses; surface water accounted for 42 percent.

Basement igneous rocks of Precambrian age are overlain by as much as 5,000 feet of gently dipping sedimentary rocks throughout much of the study unit. The igneous rocks, which include granite, rhyolite, and diabase, are exposed only in the St. Francois Mountains of southeastern Missouri. The sedimentary rocks include rocks of Cambrian through Ordovician age, which consist of dolomite, sandstone, and limestone with minor amounts of shale; rocks of Mississippian age, which are mostly cherty limestones; rocks of Pennsylvanian age, which consist mostly of shale, sandstone, and limestone; and Post-Paleozoic sediments, which consist of sands, gravels, and clays. The igneous and sedimentary rocks that underlie the study unit are extensively fractured and

faulted. Alfisol and ultisol soil types underlie most of the study unit. These soils are moderately to deeply weathered and have a wide range of hydraulic properties.

All or part of seven major river basins are within the study unit. These basins include the White, Neosho-Illinois, Osage, Gasconade, Meramec, St. Francis, and Black River Basins. Many of the rivers are impounded to form reservoirs. Stream gradients are steepest in the Boston and St. Francois Mountains and least steep in the Osage Plains and Mississippi Alluvial Plain. Streambed material ranges from clay and silt in the Osage Plains to sand, gravel, boulders, and bedrock in most of the Ozark Plateaus Province. Mean annual runoff ranges from 9 to 10 inches in the Osage Plains to 14 to 20 inches in the Boston Mountains. Minimum monthly streamflows generally occur from July through October, and maximum monthly streamflows occur from March through May. Surface- and ground-water interactions are greatest in the Springfield and Salem Plateaus and least in the Boston Mountains and Osage Plains. The ionic composition of surface water generally is calcium or calcium magnesium bicarbonate in the study unit. Dissolved-solids concentrations in water from streams range from about 40 milligrams per liter in the Boston Mountains to as much as 280 milligrams per liter in the Osage Plains, but generally are less than 200 milligrams per liter. Streams in the Boston Mountains generally are the least mineralized and those in the Osage Plains generally are the most mineralized in the study unit.

The study unit contains eight hydrogeologic units that consist of three major aquifers--the Springfield Plateau, Ozark, and St. Francois aquifers--interbedded with four confining units. The unconsolidated sediments of the Mississippi Alluvial Plain are a very productive aquifer, but are of limited areal extent in the study unit. The Springfield Plateau and Ozark aquifers are formed from thick sequences of limestones and dolomites. Rocks in both of these aquifers have secondary porosity as a result of fracturing and dissolution and these aquifers are used extensively for

sources of water supply. Where the Springfield Plateau aquifer is unconfined, it is extensively used as a source of water for domestic purposes. Well yields in this aquifer generally are less than 20 gallons per minute. The Ozark aquifer is used throughout much of the study unit as a source of water for public and domestic supply. Yields of wells completed in this aquifer commonly range from 50 to 100 gallons per minute but can be as much as 600 gallons per minute. The St. Francois aquifer consists of sandstones and dolomites of Cambrian age. Although well yields in this aquifer can be as much as 500 gallons per minute, the aquifer is rarely used except where it crops out. The ionic composition of ground water in most of the aquifers in the study unit is calcium or calcium magnesium bicarbonate, but locally it can be a calcium sulfate or sodium chloride where the aquifers are confined. Dissolved-solids concentrations generally range from 200 to 300 milligrams per liter, but can be as much as 10,000 milligrams per liter in the deeper aquifers along the western boundary. Ground water in the study unit has a pH of 5.2 to 8.3, locally can contain fecal bacteria, and in some areas has elevated concentrations of radionuclides and nitrates.

Factors that affect water quality in the study unit include geology, land use, and population density. The geochemical processes of mineral dissolution, ion exchange, and oxidation-reduction reactions are the dominant natural factors that affect water quality on a regional scale. Agricultural and mining land-use activities can increase the concentrations of nutrients, bacteria, dissolved solids, sulfate, and trace elements in the surface and ground water of the study unit. Increased population density can result in increased discharges of nutrients, trace elements, bacteria, suspended sediment, and organic compounds.

## INTRODUCTION

Nationally consistent information on the status and trends of the Nation's water quality is needed to determine the degree to which past investments in water-quality management are working and to provide a base

of knowledge for evaluating future decisions. In 1991, the U.S. Geological Survey (USGS) began to implement the full scale National Water-Quality Assessment (NAWQA) program to provide a nationally consistent description of water-quality conditions for a large part of the Nation's water resources. The long-term goals of the NAWQA program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and to provide a better understanding of the natural and human factors that affect the quality of these resources. Investigations will be conducted on a rotational basis in 60 river basins or aquifer systems (referred to as study units) throughout the Nation. Assessment activities began in 20 study units in 1991.

Regional and national synthesis of information from the study units will be the foundation for the comprehensive assessment of the Nation's water quality. Nationally consistent information on water quality, and factors such as climate, geology, hydrology, land use, and agricultural practices, will be integrated to focus on specific water-quality issues that affect large contiguous hydrologic regions. For example, an initial concern in the first 20 study units is the relation of the presence of pesticides in surface and ground water to application rates and cropping practices, and to climatic, geologic, and soil factors. Nutrients and sediment are also central problems to be addressed as part of the synthesis activities, which will contribute to answering fundamental national water-quality questions.

The study unit investigations will consist of 5 years (1991 to 1995) of intensive assessment activity, followed by 5 years (1996 to 2000) of low-level monitoring activity, and then the cycle is repeated. Within each 5-year intensive assessment activity period, there generally will be about 2 years of retrospective data analysis and planning, then 3 years of intensive-data collection (Leahy and others, 1990). The four main components of the intensive assessment activity and timeframe for the first 20 study units in the NAWQA Program are presented in table 1.

The retrospective analysis includes reviewing and analyzing existing hydrologic data to provide a historical perspective on water quality to aid in the design of the study unit intensive data-collection phase. The occurrence and distribution assessment will characterize the broad-scale geographic and seasonal distributions of water-quality conditions through sampling of surface- and ground-water resources and performing ecological surveys. Long-term monitoring will assess the

status and trends of selected aspects of water-quality conditions. Case studies of sources, transport, and effects will address specific questions about water-quality changes related to specific contaminants in selected areas.

In 1991, the Ozark Plateaus study unit was among the first 20 NAWQA study units selected for study under the full-scale implementation plan. The complex, mostly karst aquifer system of the Ozark Plateaus study unit coupled with the influx of people and probability of future growth makes this area extremely susceptible to water-resources contamination. Four major water-quality issues were identified jointly by USGS personnel and representatives of various Federal, State, and local agencies in Arkansas, Kansas, Missouri, and Oklahoma that served on a coordination committee, the Ozark Plateaus NAWQA Liaison Committee. The recurring local or regional water-quality issues identified in the Ozark Plateaus study unit include problems associated with nutrients and bacteria, trace elements and dissolved solids, radionuclides in ground water, and saline ground-water encroachment.

Elevated levels of nitrate, ammonia, and bacteria in surface and ground waters have resulted from the expanding poultry, cattle, and swine industry in northern Arkansas and southern Missouri. Arkansas is the leading poultry producer, and Missouri is the second leading producer of beef cattle in the United States.

Lead, zinc, and other trace elements are present in surface and ground waters in part of the Ozark Plateaus study unit, as a result of mining activities. Missouri has been a leading producer of lead and zinc ore in the United States since the 1800's. Numerous abandoned lead and zinc mines that are now flooded are located in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma. Water in these mines typically contains higher than normal concentrations of trace elements and dissolved solids. Lead mining of the Viburnum Trend or New Lead Belt of southeastern Missouri is expected to continue at present levels to the year 2000.

Naturally occurring radioactivity (radium-226 and -228) in ground water in excess of the maximum contaminant levels (MCL's) established for drinking water by the U.S. Environmental Protection Agency has been detected in the Ozark aquifer. Radionuclides are present primarily along the saline-freshwater transition zone on the western boundary of the Ozark Plateaus in Kansas, Missouri, and Oklahoma; St. Francois

**Table 1.** Timeframe of National Water-Quality Assessment program intensive assessment activity for the first 20 study units

Activity	Fiscal year (October through September)				
	1991	1992	1993	1994	1995
<u>Retrospective Analysis and Planning</u>					
Retrospective Data Analysis	-----				
Water-Quality Reconnaissance		-----			
<u>Occurrence and Distribution Assessment</u>					
SURFACE WATER					
Bed Sediment and Tissues					
Occurrence Survey		-----			
Spatial Distribution Survey			-----		
Water Column					
Basic Fixed Stations			-----		
Intensive Fixed Sites				-----	
Synoptic Studies			-----		
ECOLOGY					
Ecological Survey Prototype		---			
Ecological Survey			-----		
GROUND WATER					
Study-Unit Survey		-----			
Land-Use Studies			-----		
Flowpath Studies				-----	
<u>Long-term Monitoring</u>				----->	
<u>Case Studies of Sources, Transport, and Effects</u>			-----		
	1991	1992	1993	1994	1995

County in Missouri; and Newton and Searcy Counties in Arkansas.

The saline-freshwater transition zone lies along the entire western boundary of the study unit in the Ozark Plateaus aquifer system. The use of ground water near this transition zone has caused water levels to decline from 100 to 300 ft in places and has induced movement of highly saline ground water from the west into some well fields, resulting in ground water from these well fields that may be unsuitable for many uses.

### Purpose and Scope

The purpose of this report is to describe the environmental and hydrologic setting of the Ozark Plateaus study unit and the factors that affect water quality. This

report is the first in a series of NAWQA reports on the Ozark Plateaus study unit. It is intended to be used as a general reference for the environmental setting of the study unit and as background information for subsequent in-depth topical reports on water quality and aquatic biology.

The report describes the climate, physiography, geology, soils, population, land use, water use, and surface- and ground-water systems in the study area. Factors that affect surface- and ground-water quality are described for the primary natural and cultural environmental features of climate, physiography, geology, soils, population, land use, and water use. These environmental features largely determine water-quality characteristics and the potential for future water-quality issues in the area. Only a brief description of selected water-quality characteristics is included in this report.

## Location

The Ozark Plateaus study unit area is approximately 48,000 mi<sup>2</sup> and includes parts of four States: northern Arkansas, southeastern Kansas, southern Missouri, and northeastern Oklahoma (fig. 1). The study unit includes most of the about 40,000 mi<sup>2</sup> Ozark Plateaus Province as well as parts of the surrounding Central Lowland Province known as the Osage Plains section, and a small part of the Mississippi Alluvial Plain section of the Coastal Plain Province. The study-unit boundary approximates the natural flow boundaries of the Ozark Plateaus aquifer system (Imes and Emmett, 1994) but has been truncated on the north, east, and south to include only those major hydrologic units that exist in the core of the Ozark Plateaus Province. The western study-unit boundary extends beyond the Ozark Plateaus physiographic province to include the complex ground-water transition zone where fresh ground water from the Ozark Plateaus mixes with saline ground water from the Western Interior Plains aquifer system (Imes and Emmett, 1994). The northern boundary of the Ozark Plateaus study unit coincides with the northern boundaries of the Osage, Gasconade, and Meramec Rivers hydrologic unit boundary. The eastern boundary of the study unit coincides with the eastern boundaries of the Meramec and upper St. Francis River hydrologic unit boundary. The southeastern boundary of the study unit coincides with the eastern boundary of the Black River hydrologic unit boundary. The southern boundary of the study unit coincides with the drainage divide in the Boston Mountains.

## Previous Investigations

The NAWQA program concepts and plans are described in reports by Hirsch and others (1988) and Leahy and others (1990). The water-quality issues, objectives, and approach for this study have been described by Freiwald (1991).

Numerous hydrologic or environmental investigations of all or parts of the Ozark Plateaus region have been made in the past. Climatic information, mostly relating to precipitation in the study unit, has been described by Dugan and Peckenpaugh (1985) and Freiwald (1985). Information on temperature and potential evapotranspiration has been published by Dugan and Peckenpaugh (1985) and Hanson (1991). Physiography of the area has been described by Fenneman

(1938). Population data from the 1990 census have been published for individual states by the U.S. Department of Commerce, Bureau of Census (1990). Land use in the study unit has been described by Rafferty (1980) and Dugan and Peckenpaugh (1985). Geologic investigations in the study unit include those by Snider (1915) in northeastern Oklahoma; Howe and Koenig (1961) in Missouri; and Croneis (1930), Caplan (1957; 1960), and Frezon and Glick (1959) in northern Arkansas.

The Central Midwest Regional Aquifer-System Analysis (CM RASA) study completed in 1985 investigated the geohydrology of the Ozark Plateaus Province and adjacent areas, and provided much of the geologic and hydrogeologic foundation for this report (Jorgensen and Signor, 1981). In that study, Imes and Emmett (1994) identified the major geohydrologic units in the Ozark Plateaus, described the regional factors that control ground-water flow, and constructed a digital ground-water flow model of the Ozark Plateaus aquifer system. A series of map reports on the major aquifers and confining units in the Ozark Plateaus were produced by Imes (1990a-g). These reports describe the outcrop area, structure, thickness, potentiometric surface, and dissolved solids concentration of water in the aquifer, and percentage shale in the confining units. Also in this map series are reports by Imes and Davis (1990a, b; 1991), which describe water type, and concentration of dissolved solids, chloride, and sulfate in water from the St. Francois, Ozark, and Springfield Plateau aquifers.

A general summary of the hydrology of aquifers in the Springfield and Salem Plateaus of southern Missouri and northern Arkansas is presented in Harvey (1980). Christenson and others (1990) described the geology, hydrology, and water quality of the Roubidoux aquifer in northeastern Oklahoma. Lamonds (1972) described the occurrence, availability, and chemical quality of ground and surface water for the Ozark Plateaus of northern Arkansas. The hydrology and geochemistry of the lead-zinc mined areas of Cherokee County, Kansas, and adjacent areas are described by Spruill (1987).

Runoff and streamflow characteristics for Ozark Plateaus streams are presented in a report by Hedman and others (1987). Gann and others (1974; 1976) presented a general summary of information about the occurrence, availability, use, and quality of water in that part of Missouri south of the Missouri River. Information on major streams and reservoirs in Missouri have



EXPLANATION

———— STUDY-UNIT BOUNDARY

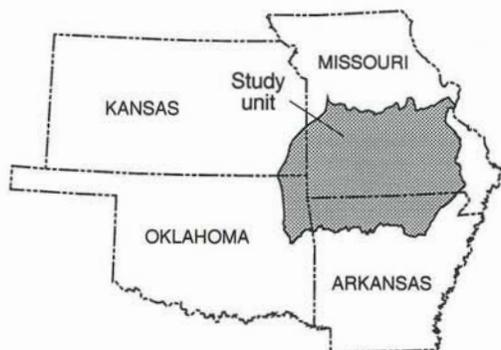


Figure 1. Ozark Plateaus National Water-Quality Assessment study unit location.

been described by Homyk and Jeffery (1967), U.S. Army Corps of Engineers (1967), Duchrow (1984), and Pflieger (1989). Information on surface-water quality has been presented in reports by Lamonds (1972), Gann and others (1974; 1976), Stoner (1981), Bennett and others (1987), Petersen (1988), Davis and Howland (1993), Petersen and others (1993), Kurklin and Jennings (1993), and Kenny and Snethen (1993).

## **ENVIRONMENTAL SETTING**

### **Climate**

The Ozark Plateaus study unit has a temperate climate because of its mid-latitude, interior-continent location. Major weather systems normally move from west to east during the fall, winter, and spring seasons. In early spring, the study unit receives moisture-laden air from the Gulf of Mexico, which often results in thunderstorms, tornadoes, and intense rainfall. Thunderstorms are responsible for most of the severe weather in the study unit. The severe weather season extends from March through June, although thunderstorms can occur throughout the year and occasionally cause flash floods.

Average annual precipitation generally increases toward the southeast from about 38 in/yr (inches per year) in the northern part of the study unit to about 48 in/yr near the southern boundary (fig. 2). Average seasonal precipitation during the cool season (October through March) ranges from around 12 in. in the northwestern part of the study unit to 24 in. in the southeastern part. Average precipitation during the warm season (April through September) ranges from 22 in. in the northeastern part of the study unit to 26 in. in the southwestern part (Dugan and Peckenpaugh, 1985). Average monthly precipitation indicates a seasonal pattern (fig. 3). Precipitation generally is greatest in the late spring (April to June) and least in late winter (December to February).

Mean annual air temperature ranges from 56 °F in the northeastern part of the study unit to 60 °F in the southwestern part (fig. 4). Mean monthly temperatures generally are lowest in January and highest in July. The mean temperature during January ranges from 30 °F in the northern part of the study unit to 38 °F in the southern part. The mean temperature during July ranges from 78 °F along the eastern boundary of the study unit

to about 82 °F along the southwestern boundary. The seasonal variation in mean temperatures is closely related to seasonal solar radiation with greater regional contrasts in winter than in summer. Also, the polar front and jet stream normally pass through the study unit in winter causing increased temperature contrasts within the study unit (Dugan and Peckenpaugh, 1985).

The estimated mean annual evapotranspiration rate in the study unit is 30 to 35 in/yr. Seasonal trends in evapotranspiration follow the seasonal trends in air temperature and solar radiation; the maximum rate occurs during the summer, and the minimum rate occurs during the winter. Evapotranspiration fluctuates daily as well as seasonally. In clear weather, the rate increases through the morning and reaches a maximum in early to midafternoon (Hanson, 1991).

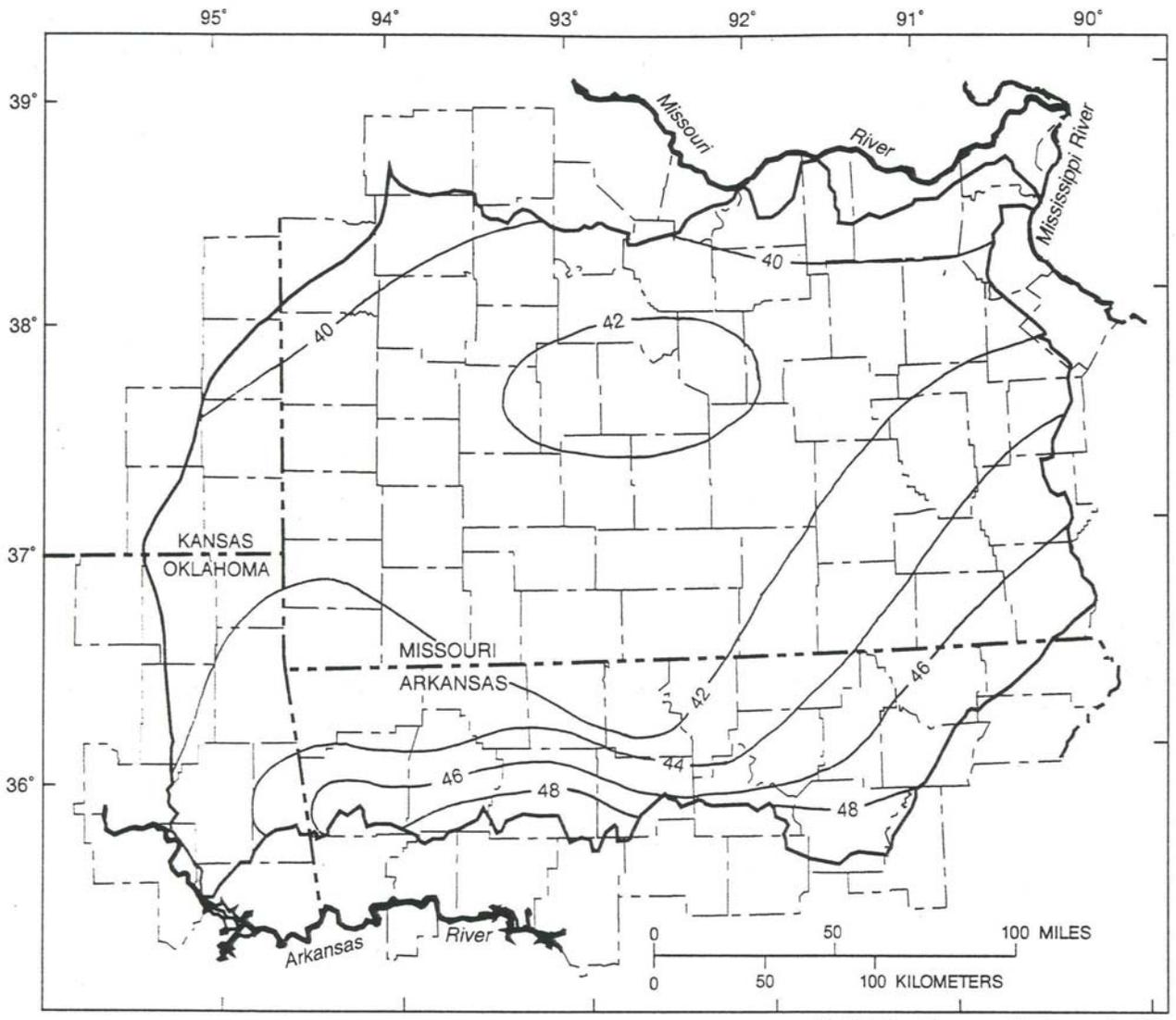
Precipitation in the study unit generally is acidic with low dissolved-solids concentrations. In 1990, the pH of precipitation ranged from about 4.6 to 5.0, and the sum of the major cations--calcium, magnesium, sodium, and potassium--was less than 0.5 mg/L (milligram per liter; National Atmospheric Deposition Program, 1991).

### **Physiography**

The Ozark Plateaus study unit includes most of the Ozark Plateaus Province and small parts of the Osage Plains and Mississippi Alluvial Plain of the Central Lowland and Coastal Plain Provinces, respectively (fig. 5). These three major physiographic provinces include a diverse range of topography and geomorphology, which greatly affects the hydrology of the area. Altitudes in these provinces range from greater than 200 ft in the Mississippi Alluvial Plain to more than 2,300 ft in the Boston Mountains.

#### **Ozark Plateaus Province**

The Ozark Plateaus Province has an area of about 40,000 mi<sup>2</sup> and includes parts of four states. The physiography of this province is largely controlled by the geology of the area; a structural dome underlies most of the province. Sedimentary rocks of Paleozoic age flank a core of igneous rocks at the center of the structural dome in southeastern Missouri. The igneous rocks form the St. Francois Mountains. The sedimentary rocks, which dip gently away from the center of the dome, form three distinct physiographic sections--the

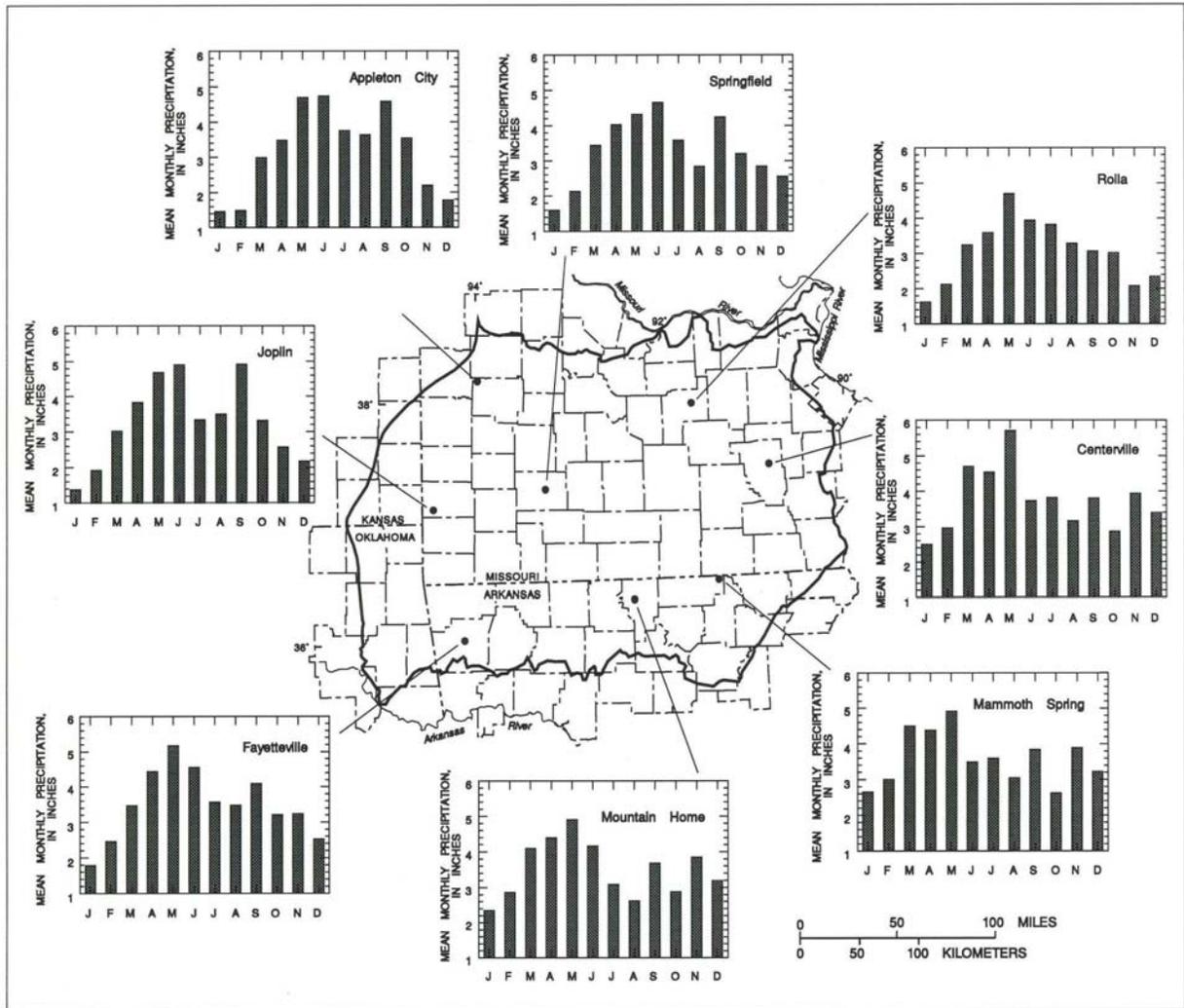


Modified from Dugan and Peckenpaugh, 1985

EXPLANATION

- 42 - LINE OF EQUAL MEAN ANNUAL PRECIPITATION—Interval 2 inches
- STUDY-UNIT BOUNDARY

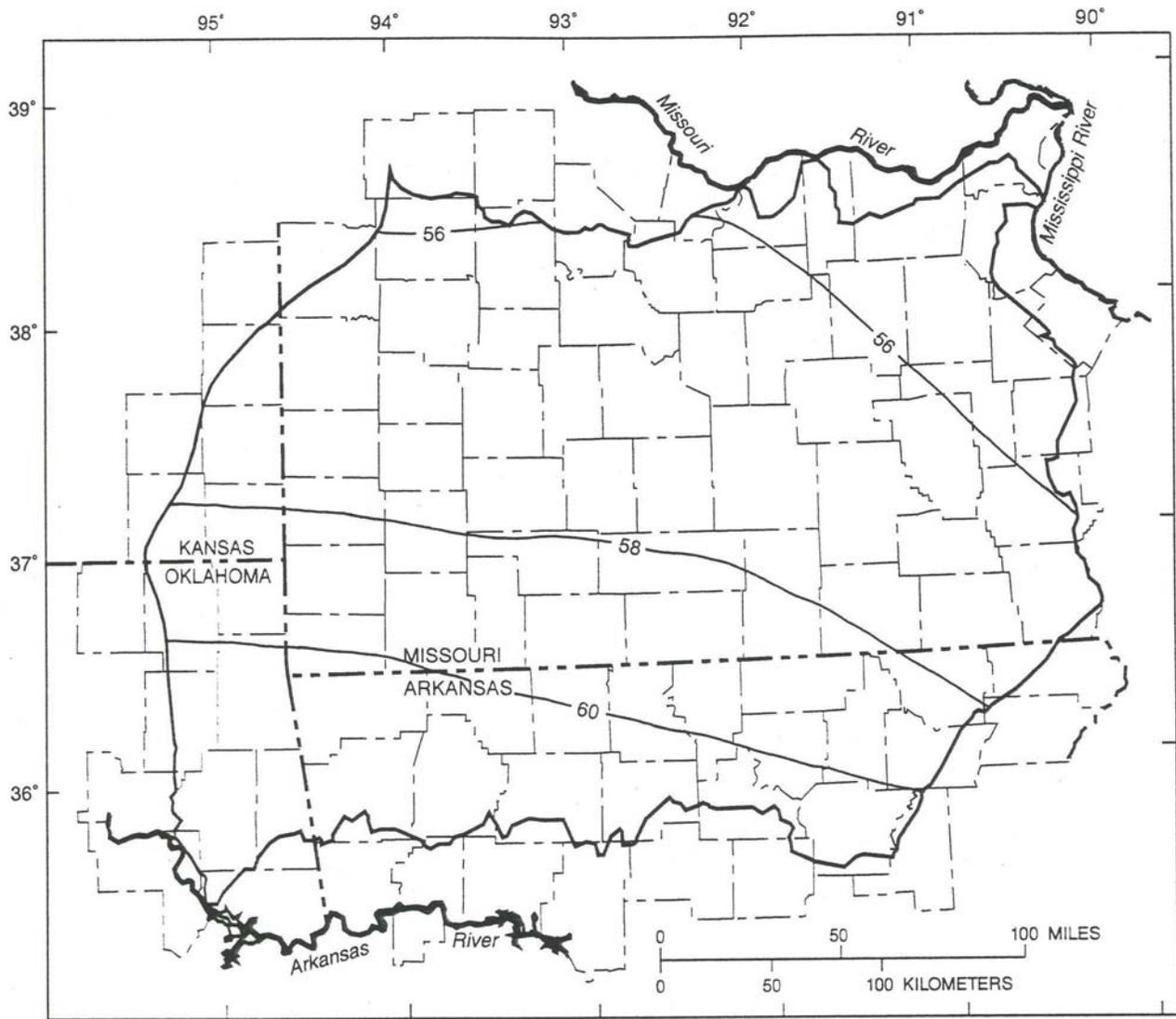
Figure 2. Mean annual precipitation in the Ozark Plateaus study unit, 1951-80.



Data from U.S. Department of Commerce, National Ocean and Atmospheric Administration, 1990

- EXPLANATION
- STUDY-UNIT BOUNDARY
  - LOCATION OF CITY

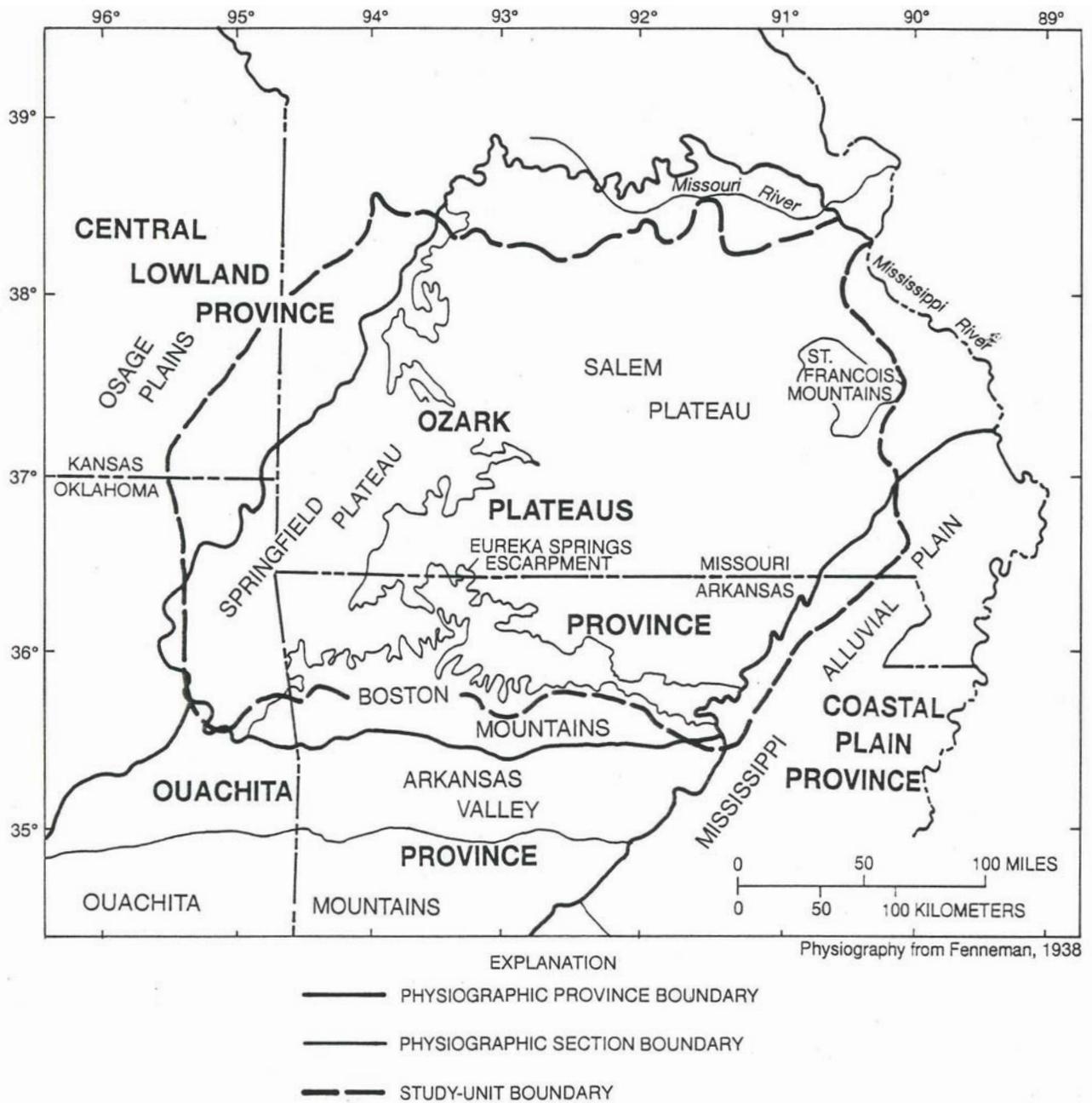
Figure 3. Mean monthly precipitation for selected cities in the Ozark Plateaus study unit, 1951-80.



Modified from Dugan and Peckenpaugh, 1985

- EXPLANATION
- 58 - LINE OF EQUAL MEAN ANNUAL AIR TEMPERATURE—Interval 2 degrees Fahrenheit
  - STUDY-UNIT BOUNDARY

Figure 4. Mean annual air temperature in the Ozark Plateaus study unit, 1951-80.



**Figure 5.** Physiographic subdivisions of the Ozark Plateaus study unit and adjacent areas.

Springfield Plateau, the Salem Plateau, and the Boston Mountains (Fenneman, 1938). In this report, each of these sections generally will be referred to without the physiographic section nomenclature. For example, the Salem Plateau section will be referred to as the "Salem Plateau."

The southeastern boundary of the Ozark Plateaus Province is marked by the contact between rocks of Paleozoic age of the Ozark Plateaus and younger, unconsolidated sediments of the Mississippi Alluvial Plain. The southern boundary is marked by faults on the southern flank of the Boston Mountains, although the southern boundary of the study unit is the east-west trending drainage divide formed by the Boston Mountains. The western boundary of the province is marked by the contact between rocks of Mississippian and Pennsylvanian age. The northern and eastern boundaries of the province generally follow the Missouri and Mississippi Rivers, respectively. However, an area containing rocks of Devonian age and older exposed in Illinois and structurally a part of the Ozark Plateaus Province (Fenneman, 1938) is not included as part of the study-unit area.

The highest land surface altitude in the study unit outside the Boston Mountains is 1,772 ft above sea level at Taum Sauk Mountain in the St. Francois Mountains. A ridge of locally high relief extends west-southwest from the St. Francois Mountains to the extreme southwestern corner of Missouri. Altitudes along this ridge range from 1,200 ft to more than 1,600 ft above sea level. Altitudes generally decrease to the northwest and south of this ridge (Fenneman, 1938).

Topography in the province ranges from nearly flat-lying to rugged. The boundaries between each plateau are characterized by escarpments where deeply incised valleys separate narrow divides or "mountains." The result is rugged topography with relatively high relief. Away from the escarpments, topography is nearly flat-lying to gently rolling hills with low relief. The exception is the Boston Mountains, which has rugged topography nearly everywhere (Fenneman, 1938).

Stream drainage patterns are radial, away from regional and local topographic highs. Drainage patterns can follow geologic features such as faults and joints in the rocks. Entrenched meanders, resulting from the downcutting of streams as the area was uplifted, are common in the larger stream valleys.

The Ozark Plateaus Province contains numerous distinctive geomorphic features. The development of these features generally is related to the geology and

hydrology of the area. For example, local topographic highs can form two distinct geomorphic features--mounds and bald mountains. Mounds are erosional remnants of outliers of rocks of Mississippian or Pennsylvanian age overlying older sedimentary rocks. Bald mountains, commonly called "balds," are predominantly tree-less hills present in south-central Missouri. Lines of trees on bald mountains can indicate water-bearing fractures in the rock (Beveridge and Vineyard, 1990).

Karst features are common in the Ozark Plateaus. Dissolution of carbonate rocks along fractures and faults has produced cave systems, sinkholes, and natural tunnels in the area (Beveridge and Vineyard, 1990). Missouri alone contains at least 5,000 caves, most of which are located in the Ozark Plateaus Province (Missouri Department of Natural Resources, 1980).

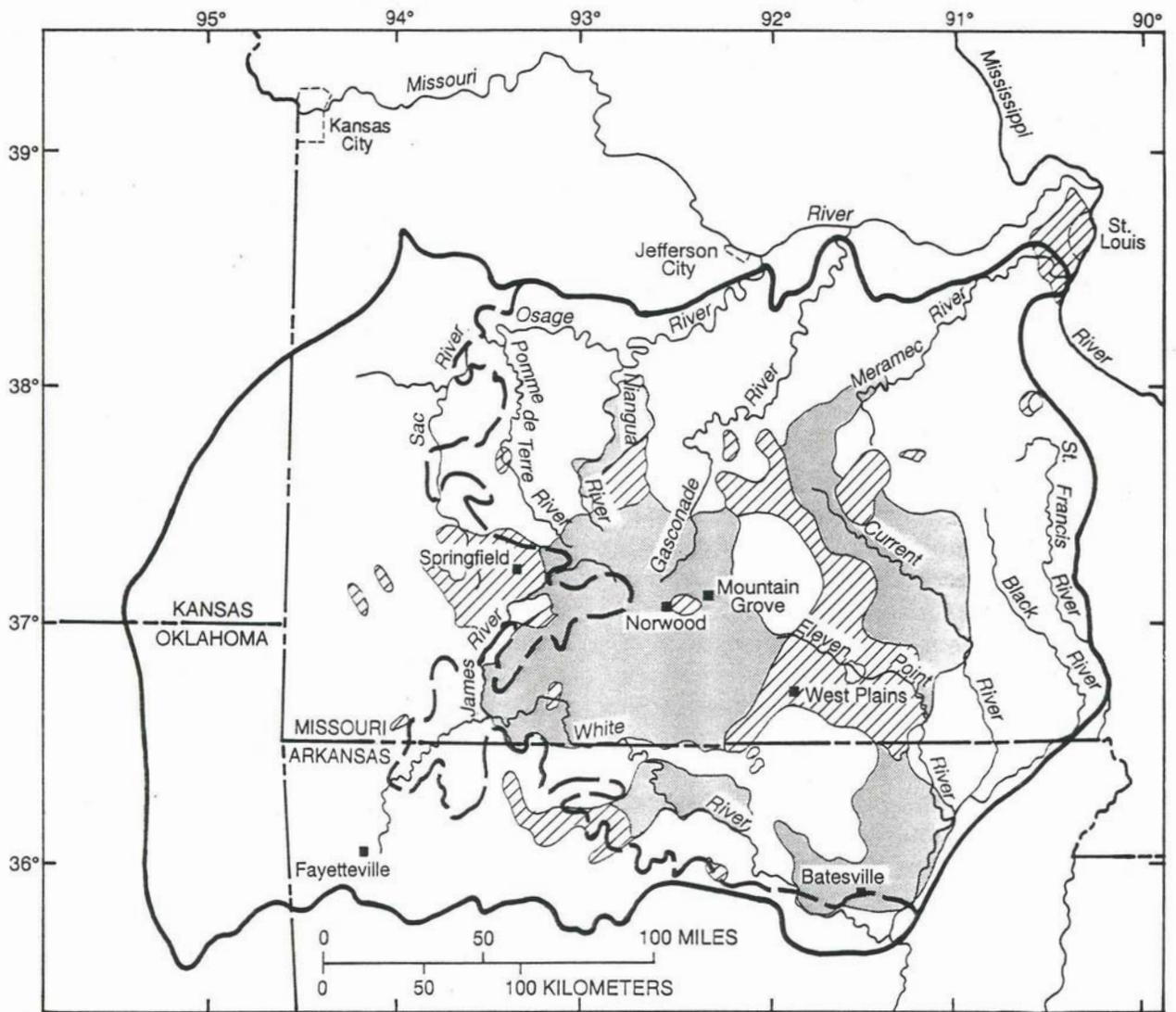
Filled paleo-sinkholes sometimes contain, and were mined for, iron, lead, and zinc ores. One of the largest of these filled sinkholes is the Oronogo Circle in Jasper County, Missouri. This sinkhole is 1,000 ft in diameter, and has been mined to depths as much as 190 ft deep (Beveridge and Vineyard, 1990).

#### **Salem Plateau**

The Salem Plateau includes a large part of the study unit (approximately 27,200 mi<sup>2</sup>) in Missouri and northern Arkansas (fig. 5). It is underlain by rocks of Cambrian and Ordovician age. The Salem Plateau contains a central upland area, which is present west of the St. Francois Mountains in Dallas, Laclede, Polk, Webster, and Wright Counties, Missouri (fig. 1). The upland generally is characterized by gently rolling hills. Local relief in the upland area is 50 to 100 ft (Fenneman, 1938).

Away from the upland area, the plateau is dissected by numerous streams, which results in increased relief. South and east of the upland, topography is rugged, and relief can be as much as 500 ft. North of the upland, topography is rugged, but relief rarely exceeds 350 ft (Fenneman, 1938).

Sinkholes and springs are abundant in the Salem Plateau. On average, the upland area has 1 to 10 sinkholes per 100 mi<sup>2</sup> (fig. 6). A north-south trending band in south-central Missouri contains more than 10 sinkholes per 100 mi<sup>2</sup> (Harvey, 1980). Large springs with discharges exceeding 100 ft<sup>3</sup>/s are common in some areas of the Salem Plateau (Imes and Smith, 1990).



Modified from Harvey, 1980

EXPLANATION

-  MORE THAN 10 SINKHOLES PER 100 SQUARE MILES
-  1 TO 10 SINKHOLES PER 100 SQUARE MILES
-  LESS THAN 1 SINKHOLE PER 100 SQUARE MILES
-  SPRINGFIELD-SALEM PLATEAUS BOUNDARY
-  STUDY-UNIT BOUNDARY
-  CITY

Figure 6. Distribution of sinkholes in southern Missouri and northern Arkansas.

The St. Francois Mountains are within the Salem Plateau and are formed from exposures of igneous rocks of Precambrian age associated with the structural dome in southeastern Missouri. The St. Francois Mountains are a series of resistant hills or knobs separated by valleys that are underlain by sedimentary rocks of Cambrian age. The St. Francois Mountains occupy an area of approximately 1,350 mi<sup>2</sup>, but the area in which predominantly igneous rocks are exposed is less than 100 mi<sup>2</sup> (Fenneman, 1938). Land surface altitudes range from 1,000 to more than 1,700 ft above sea level. Topography is rugged and relief ranges from 500 to 800 ft (Fenneman, 1938). The St. Francois Mountains are not a separate physiographic section as defined by Fenneman (1938), but will often be discussed in this report separately because of its unique geological features, which affect the hydrology of the area.

#### **Springfield Plateau**

The Springfield Plateau occupies an area of approximately 10,300 mi<sup>2</sup> in the study unit including parts of west-central and southwestern Missouri, southeastern Kansas, northeastern Oklahoma, and northern Arkansas (fig. 5). The Plateau is underlain by limestones and cherty limestones of Mississippian age (Fenneman, 1938).

Land-surface altitudes in the Springfield Plateau range from 1,000 to 1,700 ft, but locally topographic relief, which decreases from east to west, rarely exceeds 200 to 300 ft. Topography is mostly gently rolling hills, except at the Eureka Springs Escarpment (fig. 5), which separates the Springfield and Salem Plateaus, where deeply incised stream valleys separate narrow divides (Fenneman, 1938).

Sinkholes and springs are common in the Springfield Plateau, but generally are smaller and less abundant there than in the Salem Plateau. The number of sinkholes in the Springfield Plateau generally averages less than 1 per 100 mi<sup>2</sup> except near the city of Springfield, Missouri, where there are more than 10 sinkholes per 100 mi<sup>2</sup> (fig. 6).

#### **Boston Mountains**

The Boston Mountains occupy an area of approximately 2,400 mi<sup>2</sup> in a 200-mi wide band extending through northern Arkansas and northeastern Oklahoma (fig. 5). They are underlain by sandstones, shales, and limestones of late Mississippian to Pennsylvanian age.

Land-surface altitudes in the Boston Mountains range from 1,200 to more than 2,300 ft above sea level. Topographic relief is as much as 1,000 ft in some places. The topography is rugged, with narrow divides separating steep-sided valleys (Fenneman, 1938).

#### **Central Lowland and Coastal Plain Provinces**

The Central Lowland Province occupies a large area in the central United States extending from Texas to North Dakota and from Missouri to Colorado (Fenneman, 1938). The Osage Plains section of this province includes an area in the western and northwestern part of the study unit.

The Coastal Plain Province is another extensive province, extending along the Atlantic and Gulf Coasts from New England to Texas. It is a continuation of the Continental Shelf and has a very gentle slope. The Mississippi Alluvial Plain section of this province, which is an area of delta and bottomlands of the Mississippi River and tributaries (Fenneman, 1938), includes a small area in the southeastern part of the study unit.

#### **Osage Plains**

The Osage Plains occupies an area of approximately 6,700 mi<sup>2</sup> in the western and northwestern part of the study unit (fig. 5). The Osage Plains is underlain by soft shales with interbedded sandstones and limestones of late Mississippian to Pennsylvanian age. Land-surface altitudes in the part of the study unit in the Osage Plains range from 800 to 1,000 ft. In general, topography in this part of the study unit consists of gently rolling hills, but in some areas resistant beds of sandstones and limestones form rare east-facing escarpments (Fenneman, 1938).

#### **Mississippi Alluvial Plain**

The Mississippi Alluvial Plain includes a small area of approximately 1,100 mi<sup>2</sup> in the southeastern part of the study unit (fig. 5). The Mississippi Alluvial Plain is a flat to gently-rolling plain underlain by unconsolidated sediments of Cretaceous through Quaternary age. Land-surface altitudes in the part of the study unit in the Mississippi Alluvial Plain average just over 200 ft above sea level and topographic relief seldom exceeds 30 ft.

The formation of the plains is partially structural and partially erosional. The boundary between the un-

consolidated sediments of the Mississippi Alluvial Plain and sedimentary rocks of Paleozoic age is formed by normal faults. Faulting has resulted in subsidence of the older sedimentary rocks, allowing a thick sequence of unconsolidated sediments to be deposited on top. The Mississippi River and its tributaries have eroded the unconsolidated sediments in places, forming occasional bluffs and ridges in the section (Fenneman, 1938).

## Geologic Setting

The geology of the Ozark Plateaus study unit is diverse in lithology, mineralogy, and structure. Lithologies include igneous and sedimentary rocks. Secondary mineralization has occurred in many of the rock units, and uplifting has resulted in fracturing and faulting of the rock units.

## Stratigraphy

The stratigraphy of the Ozark Plateaus study unit is complex. The basement crystalline rocks in the study unit are overlain by a sequence of sedimentary rocks of Paleozoic age (fig. 7). The sedimentary-rock sequence consists predominantly of dolomites and limestones of Cambrian through Mississippian age in some areas and sandstones and shales of Pennsylvanian age in other areas. In addition, lateral changes in lithology, the absence of some geologic units in parts of the study unit, and nomenclature, which has evolved independently in the four states, result in different stratigraphic sequences over the study unit (Imes and Emmett, 1994). These units are briefly described in the following section.

### Precambrian Units

Igneous and metamorphic rocks of Precambrian age underlie the Ozark Plateaus and crop out in several places in the eastern part of the study unit (fig. 8). Elsewhere, these rocks are buried under as much as 5,000 ft of sedimentary rock. Structural relief of the rocks can be as much as 1,000 ft in a few miles (Imes and Emmett, 1994). These igneous rocks are mainly felsic (silica rich) rocks such as granite and rhyolite with mafic (silica poor) intrusions consisting of diabase and gabbro (Kisvarsanyi, 1981). Felsic rocks contain minerals such as quartz and potassium feldspar, which are resistant to weathering. In contrast, the mafic rocks contain

minerals such as pyroxene and calcium plagioclase, which weather easily.

The igneous rocks of Precambrian age also contain commercially important quantities of several trace elements, including iron, lead, manganese, and silver (Kisvarsanyi, 1981). In addition, uranium and thorium are present in some of these rocks (primarily the granites) in concentrations as large as 34 and 54 mg/kg (milligrams per kilogram), respectively (Kisvarsanyi, 1987).

### Cambrian and Ordovician Units

Rocks of Cambrian and Ordovician age in the study unit crop out mainly in the Salem Plateau (fig. 8). The geologic units of Cambrian and Ordovician age range in thickness from less than 50 ft to more than 4,000 ft; and average about 2,000 ft thick (Imes, 1990b, c, d). In general, the units consist predominantly of dolomites, cherty dolomites, sandstones, and limestones (Caplan, 1960), although shales are present in some areas mainly as discontinuous beds and thin partings.

The basal unit of the Cambrian and Ordovician rocks, the Lamotte Sandstone of Late Cambrian age, rests unconformably on igneous rocks of Precambrian age. It is a well-sorted quartz sandstone, which is arkosic and conglomeratic at its base. Its thickness ranges from less than 50 ft to nearly 500 ft. The Lamotte Sandstone grades upward into the Bonneterre Dolomite or equivalent, which is also of Cambrian age (Caplan, 1960).

The Bonneterre Dolomite is a fine- to medium-grained dolomite that crops out in the vicinity of the St. Francois Mountains. It contains glauconite and pyrite, and it can contain locally minor amounts of chert and shale. It is 200 to 300 ft in thickness near the St. Francois Mountains, but the thickness decreases southward to about 70 ft in northern Arkansas (Caplan, 1960). In southeastern Missouri, the Bonneterre Dolomite is extensively mineralized, containing abundant lead- and zinc-sulfide deposits. Other trace elements, such as cobalt, copper, nickel, and silver, are present in lower concentrations in the Bonneterre Dolomite (Wharton and others, 1975).

The Davis Formation and Derby-Doe Run Dolomite are shaly to silty, glauconitic dolomites that crop out in a roughly circular band around the St. Francois Mountains (Caplan, 1960). Thickness of the Davis Formation near its type locality is about 160 ft; thickness of the Derby-Doe Run Dolomite is about 115 ft (Howe

ERATHEM	SYSTEM	SOUTHERN MISSOURI	SOUTHEASTERN KANSAS	NORTHEASTERN OKLAHOMA	NORTHERN ARKANSAS	HYDROGEOLOGIC UNIT	HYDROGEOLOGIC SYSTEM
		Post-Paleozoic sediments					
PALEOZOIC	PENNSYLVANIAN	Kansas City Group Pleasanton Formation Marmaton Group Cherokee Shale	Kansas City Group Pleasanton Group Marmaton Group Cherokee Group	Marmaton Group Cabaniss Group Krebs Group Atoka Formation Bloyd Shale Hale Formation	Atoka Formation Bloyd Shale Hale Formation	Western Interior Plains confining system	
	MISSISSIPPIAN	Fayetteville Shale Batesville Sandstone Hindsville Limestone Carterville Formation		Pitkin Limestone  Fayetteville Shale Batesville Sandstone Hindsville Limestone	Pitkin Limestone  Fayetteville Shale Batesville Sandstone		
		St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone Eley Formation Reeds Spring Limestone Pierson Formation	St. Louis Limestone Salem Limestone Warsaw Limestone Keokuk Limestone Burlington Limestone  Fern Glen Limestone	Moorefield Formation  Keokuk Limestone  Boone Formation  St. Joe Limestone	Moorefield Formation   Boone Formation  St. Joe Limestone		

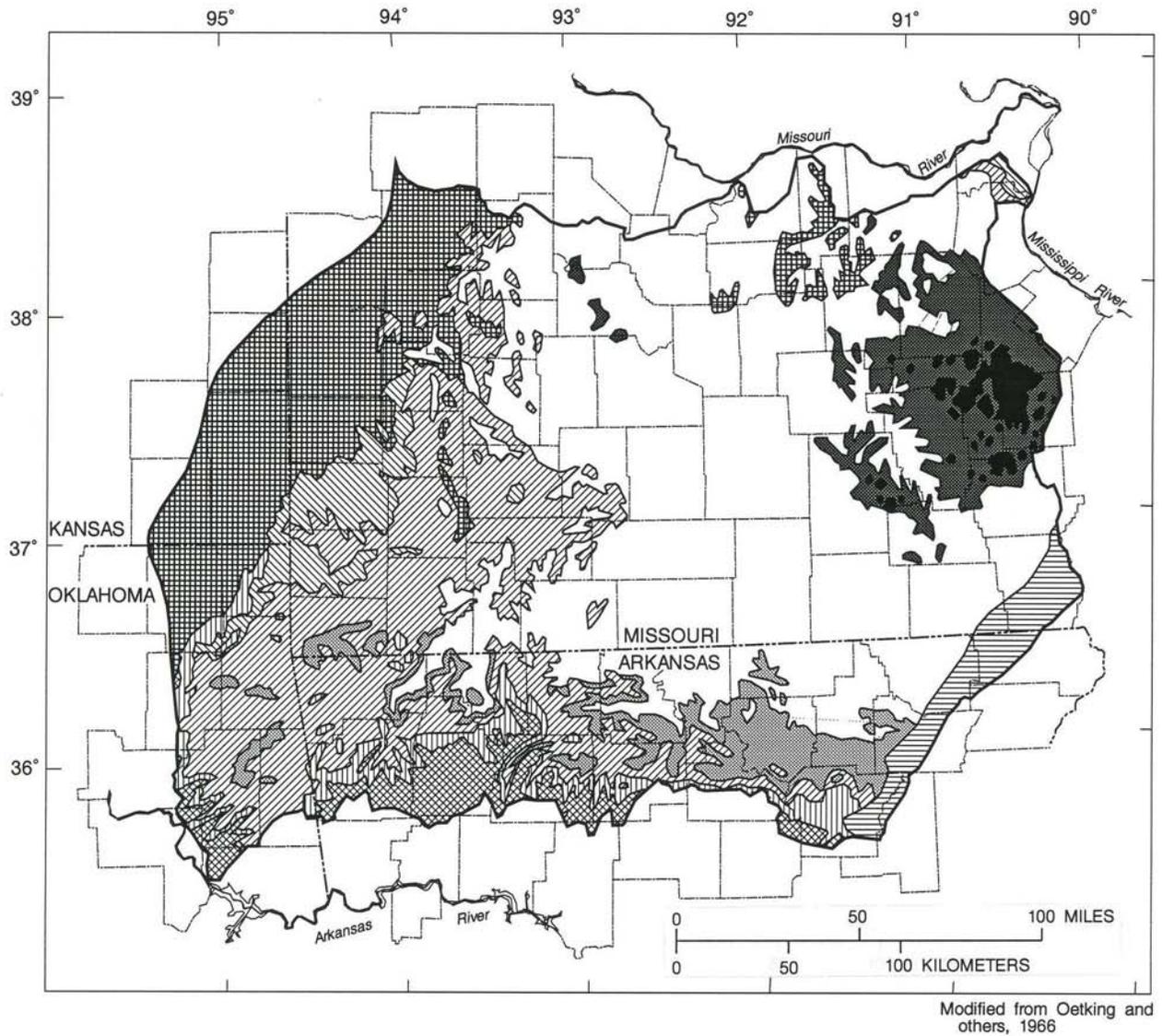
Figure 7. Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a).

PALEOZOIC	MISSISSIPPIAN	Northview Shale Sedalia Limestone Compton Limestone	Chouteau Limestone	Northview Equivalent  Compton Equivalent		Ozark confining unit
	DEVONIAN	Chattanooga Shale	Chattanooga Shale	Woodford Chert Chattanooga Shale	Chattanooga Shale	
		Callaway Formation Fortune Formation		Sallisaw Formation Frisco Limestone	Clifty Limestone Penters Chert	
	SILURIAN			St. Clair Limestone	Lafferty Limestone St. Clair Limestone Brassfield Limestone	Ozark aquifer
ORDOVICIAN	Kimmswick Limestone  Plattin Limestone  Joachim Dolomite  St. Peter Sandstone		Sylvan Shale  Fernvale Limestone  Viola Limestone  Fite Limestone  Tyner Formation   Burgen Sandstone	Cason Shale  Fernvale Limestone  Kimmswick Limestone  Plattin Limestone  Joachim Dolomite  St. Peter Sandstone	Ozark Plateaus aquifer system	

**Figure 7.** Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a)—Continued.

PALEOZOIC	ORDOVICIAN	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone	Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite  Van Buren Formation	Smithville Equivalent Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite  Van Buren Formation	Everton Formation Smithville Formation Powell Dolomite Cotter Dolomite Jefferson City Dolomite Roubidoux Formation Gasconade Dolomite Gunter Sandstone Van Buren Formation	Ozark aquifer	Ozark Plateaus aquifer system	
		Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite	Eminence Dolomite Potosi Dolomite			
	CAMBRIAN	Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	Derby-Doe Run Dolomite Davis Formation	St. Francois confining unit		
		Bonnerterre Dolomite Reagan Sandstone Lamotte Sandstone	Bonnerterre Equivalent Reagan Sandstone Lamotte Sandstone	Bonnerterre Equivalent Reagan Sandstone Lamotte Sandstone	Bonnerterre Dolomite Reagan Sandstone Lamotte Sandstone	St. Francois aquifer		
	PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS					Basement confining unit		

**Figure 7.** Geologic and hydrogeologic units in the Ozark Plateaus study unit and adjacent areas (modified from Imes, 1990a)—Continued.



EXPLANATION

- |   |  |   |  |
|---|--|---|--|
|  | POST-PALEOZOIC SEDIMENTS   |  | MIDDLE ORDOVICIAN THROUGH DEVONIAN--<br>Everton, Burgen, St. Peter,<br>Joachim, Tyner, Platin, Viola,<br>Kimmswick, Fernvale, Sylvan,<br>Carson, and Chattanooga |
|  | PENNSYLVANIAN--Cherokee, Marmaton,<br>Pleasanton, and Kansas City Groups   |  | LOWER ORDOVICIAN--Gunter, Gasconade,<br>Roubidoux, Jefferson City, Cotter,<br>Powell, and Smithville   |
|  | PENNSYLVANIAN (MORROWAN-ATOKAN)--<br>Hale, Bloyd, and Atoka  |  | CAMBRIAN--Lamotte, Reagan, Bonnetterre,<br>Davis, Derby-Doe Run, Potosi, and<br>Eminence   |
|  | MISSISSIPPIAN (CHESTERIAN)--<br>Cartersville, Hindsville,<br>Batesville, Fayetteville, and Pitkin  |  | PRECAMBRIAN IGNEOUS ROCKS  |
|  | MISSISSIPPIAN (MERAMECIAN)--Warsaw,<br>Salem, St. Louis, and Moorefield  |  | STUDY UNIT BOUNDARY  |
|  | MISSISSIPPIAN (KINDERHOOKIAN-OSAGEAN)<br>Compton, Sedalia, Northview, Chouteau,<br>Pierson, Fern Glen, St. Joe, Boone,<br>Reeds Spring, Elsey, Burlington, and<br>Keokuk |   |  |

Figure 8. Geology of the Ozark Plateaus study unit.

and others, 1972). These dolomites are relatively impermeable compared to the other units of Cambrian and Ordovician age (Imes and Emmett, 1994).

The Potosi and Eminence Dolomites, which represent the top of the Cambrian section, are fine- to coarse-grained dolomites with dense chert, drusy quartz, and, in northern Arkansas, glauconitic green shale (Caplan, 1960). These units are exposed in south-eastern Missouri. Thicknesses of the Potosi and Eminence Dolomites in Missouri average about 300 to 350 ft each (Howe and others, 1972), but total thickness for the two formations combined diminishes to 300 ft in northern Arkansas (Caplan, 1960). Both units contain barite, which has been mined in southeastern Missouri (Wharton and others, 1975).

The Gasconade Dolomite consists of a basal sandstone member, the Gunter Sandstone, and upper and lower dolomite members (MacDonald and others, 1975). It crops out extensively in southeastern Missouri. The Gunter Sandstone Member is a fine- to coarse-grained quartz sandstone, which can be dolomitic (Caplan, 1960). Thickness ranges from 30 to 120 ft. Chert is present in both dolomite members and can constitute more than 50 percent of the lower member. The upper dolomite member contains much less chert than does the lower member. Thickness of the Gasconade Dolomite ranges from 300 ft in central Missouri to more than 700 ft in northern Arkansas (MacDonald and others, 1975).

The Roubidoux Formation consists of sandstones, dolomites, and cherty dolomites (Thompson, 1991). It crops out extensively in central, south-central, and southeastern Missouri. The dolomites are fine to medium grained, and the sandstones are loosely cemented. In northern Arkansas, it can contain a few pyritic black shales. Thickness generally increases to the south-southeast and ranges from 100 to 450 ft (Caplan, 1960; Thompson, 1991).

The Jefferson City, Cotter, and Powell Dolomites, and the Smithville Formation consist of dolomite with chert, sandstone lenses, and a few shale beds. These units are pyritic, and the Smithville Formation contains lead and zinc ore. The units are exposed in southern Missouri and northern Arkansas (Caplan, 1960). Thickness of each unit averages about 200 ft (MacDonald and others, 1975).

The Everton Formation contains sandy dolomite and sandstone members, which crop out extensively in northern Arkansas. It contains a few shale beds, none of

which are laterally continuous. It can exceed 1,000 ft in thickness (Frezon and Glick, 1959).

The St. Peter Sandstone unconformably overlies the Everton Formation and crops out mainly in northern Arkansas. It is a loosely cemented, well-rounded quartz sandstone that can be as much as 300 ft thick (McFarland and others, 1979). Its contact with the overlying Joachim Dolomite is lithologically gradational (Frezon and Glick, 1959).

#### **Silurian and Devonian Units**

Rocks of Silurian and Devonian age are thin, and most are not laterally continuous in the study unit. Most of the units in this interval exist only in northern Arkansas and parts of Missouri. The most significant unit is the black, pyritic, thinly bedded Chattanooga Shale. This shale ranges in thickness from less than 10 to 100 ft, but averages about 70 ft in thickness (Wise and Caplan, 1979). It contains phosphate, glauconite (Frezon and Glick, 1959), and minor amounts of uranium (Nuelle, 1987).

#### **Mississippian Units**

Rocks of Mississippian age in the study unit are predominantly fine- to coarse-grained limestones and cherty limestones. These units have a total thickness of about 200 to 500 ft (McFarland and others, 1979) and crop out extensively in the Springfield Plateau (fig. 8).

Because of lateral facies changes and independent geologic studies in different states, the same sequence of rocks has different nomenclature throughout the study unit. For example, the St. Joe Limestone and the Boone Formation in northern Arkansas are equivalent to the entire sequence from the Compton Limestone to the Keokuk Limestone in southern Missouri.

As with the underlying rocks of Cambrian and Ordovician age, secondary mineralization is extensive in the limestones of Mississippian age. Lead- and zinc-sulfide deposits are present in southwestern Missouri, southeastern Kansas, and northeastern Oklahoma. Pyrite, lead and zinc carbonates, and zinc silicates are also present in these deposits (Kiilsgaard and others, 1967).

Rocks of late Mississippian age overlie the Boone Formation and equivalent units and crop out on the northern flank of the Boston Mountains. These units include the relatively permeable Hindsville and Pitkin Limestones, which are separated by the thick, impermeable Fayetteville Shale. The Fayetteville Shale is a

fissile, pyritic, and carbonaceous shale with abundant iron concretions. In north-central Arkansas, the shale is interbedded with thin layers of finely crystalline limestones (McFarland and others, 1979).

#### **Pennsylvanian Units**

Rocks of Pennsylvanian age crop out in the Boston Mountains of northern Arkansas, and in the Osage Plains of western Missouri, southeastern Kansas, and northeastern Oklahoma (fig. 8). In general, rocks of Pennsylvanian age rest unconformably on rocks of Mississippian age; however, in the north-central part of the study unit, rocks of Mississippian age are missing, and rocks of Pennsylvanian age directly overlie rocks of Ordovician age (fig. 8).

In northern Arkansas, three geologic units--the Hale Formation, the Bloyd Shale, and the Atoka Formation--are of Pennsylvanian age. The Hale Formation and Bloyd Shale are massive sandstones with limestone, shale, and coal beds. The Atoka Formation is mostly dark shales with sandstones and sandy limestones (Caplan, 1957). Total thickness of the section in the southern part of the study unit ranges from 1,000 to 2,000 ft (Imes, 1990g).

Rocks of Pennsylvanian age in western Missouri, southeastern Kansas, and northeastern Oklahoma consist of four groups--Cherokee, Marmaton, Pleasanton, and Kansas City--and have a combined thickness that ranges from 40 to 700 ft. Lithologies are mostly shales and sandstones with some limestones. Black shales in the section can be uranium-bearing (Coveney and others, 1987). Bituminous coal beds are present in the Cherokee and Marmaton Groups (Robertson and Smith, 1981). In places, these same units produce oil and gas (Anderson and Wells, 1967).

#### **Post-Paleozoic Units**

Sediments of Cretaceous through Quaternary age in the study unit consist of unconsolidated sands, gravels, and clays. These sediments crop out in the Mississippi Alluvial Plain and as thin alluvial deposits in some of the major stream valleys (fig. 8; Fenneman, 1938).

#### **Structural Geology**

The Ozark Plateaus Province is underlain by a structural dome formed by a series of uplifts that has

occurred since Precambrian time. Total uplift is approximately 5,000 ft (McCracken, 1967).

The dome is asymmetrical; the dip of sedimentary rocks is greater to the east-southeast than it is to the south, west, or north (McCracken, 1967). For example, regional dip east of the St. Francois Mountains is 150 ft/mi (feet per mile; Tikrity, 1968), whereas regional dip in southwestern Missouri is about 10 ft/mi. The dip to the south increases to 200 ft/mi on the southern flank of the Boston Mountains as a result of faulting in the area (Frezon and Glick, 1959).

Extensive fracturing, jointing, and faulting of the rocks has resulted from the uplifting. Photo-lineament analyses of the Boone Formation in northwestern Arkansas indicate that fractures generally trend northwest, northeast, and east-west (Ogden, 1980; Adamski, 1987; Leidy and Morris, 1990). Joints are present in many of the rocks of Paleozoic age. Joints trend east-west, north-south, northwest-southeast, and northeast-southwest. Dip of these joints generally is vertical (McCracken, 1971).

Major faults in the Ozark Plateaus trend northwest (McCracken, 1967). Displacement can be as much as 1,000 ft. Some of the major faults form escarpments visible for several miles (Beveridge and Vineyard, 1990).

Several distinct ring-shaped fault systems exist in the Ozark Plateaus of Missouri. One such structure, the Decaturville Structure in Camden County, Missouri, is about 4 mi in diameter. It consists of a pegmatite of Precambrian age exposed in the center and surrounded by rocks of Ordovician age (Offield and Pohn, 1979).

#### **Geological History**

Granite and rhyolite rocks of Precambrian age crystallized about 1.2 to 1.5 billion years ago in the Ozark Plateaus and adjacent areas (Tikrity, 1968). These igneous rocks form the basement complex of the study unit. After igneous activity ceased, the landscape was eroded prior to Late Cambrian time when the Lamotte Sandstone and Bonnetterre Dolomite were deposited (McCracken, 1971). Deposition of marine carbonates was nearly continuous, with brief periods of erosion and deposition of clastic sediments, from Late Cambrian to Middle Ordovician time (Frezon and Glick, 1959). The area was extensively eroded prior to the deposition of the Everton Formation (C.E. Robertson, Missouri Division of Geology and Land Survey, written commun., 1992).

After deposition of the Everton Formation, the Ozark Plateaus area was uplifted and the sediments were extensively eroded. Geologic units from the St. Peter Sandstone through Fernvale Limestone were subsequently deposited, but uplifting limited sediment deposition from Middle Ordovician to Early Devonian time. After the Early Devonian time, the Ozark Plateaus area was uplifted again and eroded (McCracken, 1971).

Sediments of Middle Devonian and Mississippian age were subsequently deposited in the study unit. Limestones of Mississippian age were deposited in shallow seas that inundated the Ozark Plateaus area. After Mississippian time, the northern part of the Ozark Plateaus area was uplifted and tilted. Rocks of Devonian and Mississippian age were beveled, exposing rocks of Ordovician age over much of the area (Frezon and Glick, 1959; McCracken, 1971).

Sediments of Pennsylvanian age were deposited by transgressing seas and by riverine systems, in places, directly on the exposed rocks of Ordovician age. Periodic uplifts formed unconformities in the rocks of Pennsylvanian age. The Ozark Plateaus area was uplifted and extensively eroded after Pennsylvanian time (McCracken, 1971).

The fluvial and marine sediments were deposited in Late Cretaceous and early Tertiary time. Subsequent uplifting exposed the area to erosion, generating the current topography (McCracken, 1971).

## Soils

Three types of soils--mollisols, alfisols, and ultisols--underlie most of the study unit (fig. 9). Mollisols, which are the dominant soil in the Osage Plains, form under prairies on sandstones, limestones, and shales (Persinger, 1977). These soils are agriculturally productive, having thick, dark upper horizons that are dominated by divalent cations. This horizon has a crumbly or granular texture (Brady, 1984).

Alfisols and ultisols are the dominant soil types underlying the Ozark Plateaus and the Mississippi Alluvial Plain (Allgood and Persinger, 1979). These soil types, which generally form under deciduous forests in warm, humid climates, are moderately to strongly weathered. These soils commonly contain an abundance of kaolinite, illite, and iron and aluminum oxides, are depleted in organic matter, and can be acidic (Brady, 1984).

Soil series in the study unit are extremely diverse; therefore, it is difficult to generalize hydrologic characteristics. In Boone County, Arkansas, for example, parts of which lie in the Boston Mountains, Springfield Plateau, and Salem Plateau, 19 soil series have been identified. Soil thickness for these series ranges from 0 to 84 in., permeability ranges from 0.06 to 6.00 in/hr (inches per hour), and pH ranges from 3.6 to 8.4 (Harper and others, 1981). In Benton, Fulton, Izard, and Newton Counties, Arkansas, organic matter constitutes from 0.2 to 6 percent of the soil (Phillips and Harper, 1977; Ward and Rowlett, 1984; Fowlkes and others, 1988).

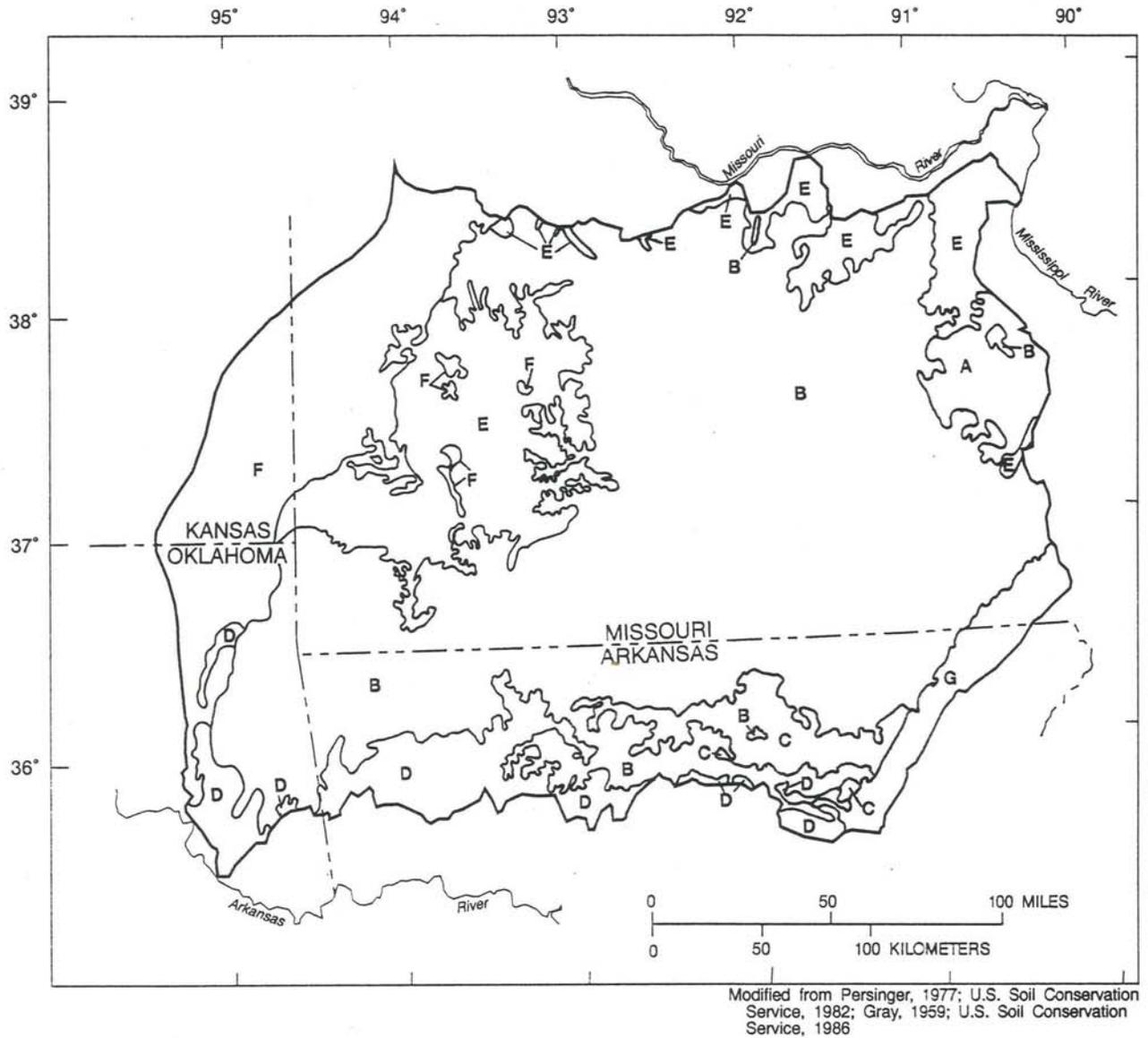
In general, most of the soils in the study unit have a high potential for nutrients and other dissolved constituents to be leached to the ground water and have a high potential for runoff to surface water systems. Leaching potential is high for 65 percent of the soils in Boone County, Arkansas; runoff potential is severe for 38 percent of the soils (Rick Fielder, U.S. Soil Conservation Service, written commun., 1992). In addition, erosion potential is moderate to high for soils in the Ozark Plateaus. Erosion factors range from 0.10 to 0.49 in Boone, Fulton, Izard, and Newton Counties, Arkansas (Harper and others, 1981; Ward and Rowlett, 1984; Fowlkes and others, 1988). Erosion factors greater than 0.40 are considered high (Rick Fielder, oral commun., 1992).

In places, several diverse soil series are closely associated and, therefore, difficult to map separately. Arkana and Moko soil series account for nearly 22 percent of the soils in Boone County, Arkansas. Arkana soils have a low leaching potential and a moderate runoff potential. Moko soils have a high leaching potential and a severe runoff potential. In 91 percent of the total area of distribution, Arkana and Moko soils are closely associated, forming a combined soil with diverse hydrologic characteristics (Harper and others, 1981).

## Population

The 1990 population within the Ozark Plateaus study unit was approximately 2.3 million people. In the study unit, the population distribution was about 1.6 million in Missouri, 420,000 in Arkansas, 150,000 in Oklahoma, and 81,000 in Kansas (fig. 10; U.S. Department of Commerce, Bureau of Census, 1990).

Population in the study unit increased about 28 percent between 1970 and 1990. Counties having pop-



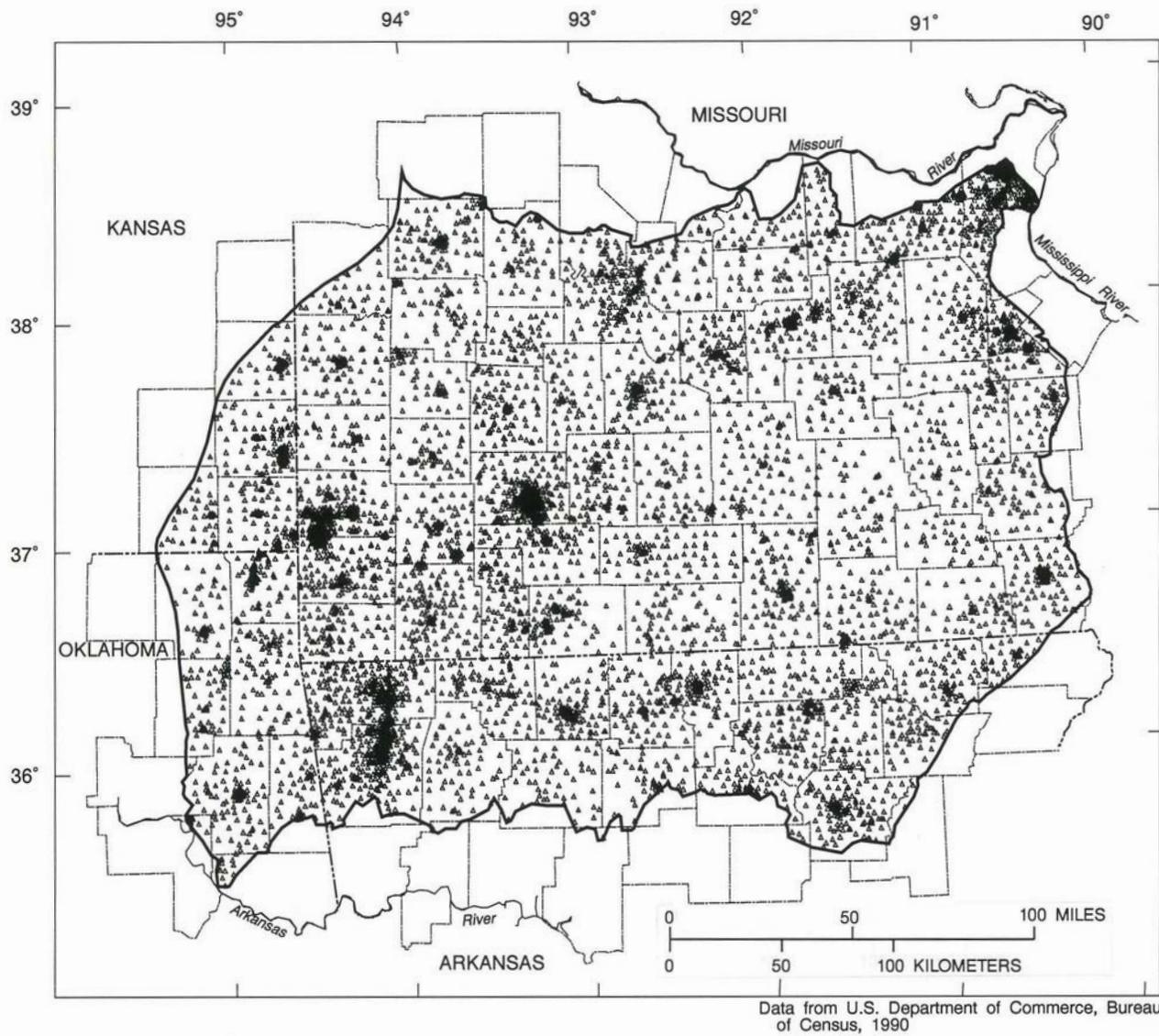
#### EXPLANATION

##### SOIL TYPES

- A** OZARK DOME—Alfisols and Ultisols
- B** OZARK HIGHLANDS (DOLOMITES)—Alfisol and Ultisols
- C** OZARK HIGHLANDS (SANDSTONES AND LIMESTONES)—Ultisols, Alfisols, and Mollisols
- D** BOSTON MOUNTAINS—Ultisols and Alfisols
- E** OZARK BORDER—Ultisols and Alfisols
- F** OZARK PLAINS—Mollisols and Alfisols
- G** MISSISSIPPI ALLUVIAL PLAIN—Alfisols and Ultisols

— STUDY UNIT BOUNDARY

**Figure 9.** Major soil types of the Ozark Plateaus study unit.



EXPLANATION

- STUDY-UNIT BOUNDARY
- ▲ 1,000 PEOPLE WITHIN A CENSUS TRACT

**Figure 10.** Population distribution in the Ozark Plateaus study unit, 1990.

ulation increases of 25, 50, 75, and 90 percent since 1970 are shown in figure 11. The largest percentage increases in population within the study unit were in southern Missouri and northern Arkansas. The population of some counties in northern Arkansas has increased more than 50 percent, and the population of several counties in southern Missouri has increased 90 percent in the last two decades.

Recreational activities attract many tourists to southern Missouri and northern Arkansas during the spring, summer, and fall. For example, Branson, Missouri (fig. 11), which has a resident population of only 3,700 people, was visited by an estimated 4.2 million tourists in 1991 (U.S. Department of Commerce, Bureau of Census, 1990).

Large urban areas are not common in the study unit. Springfield, Missouri, is the only city in the study unit with a population exceeding 100,000 people. The only urban areas in the study unit having populations exceeding 20,000 residents are Joplin, Missouri, and Fayetteville, Rogers, and Springdale, Arkansas (fig. 11; table 2; U.S. Department of Commerce, Bureau of Census, 1990).

**Table 2.** Population of the largest cities within the Ozark Plateaus study unit

[Source: U.S. Department of Commerce, Bureau of Census, 1990]

City	Population, 1990
Springfield, Missouri	140,494
Fayetteville, Arkansas	42,099
Joplin, Missouri	40,961
Springdale, Arkansas	29,941
Rogers, Arkansas	24,692

## Land Use

Land use in the Ozark Plateaus and adjacent areas prior to European settlements was primarily oak-hickory forests on the hilly regions and bluestem prairie on the undissected plateaus. The upland forests generally consisted of old-growth oak-hickory or oak-hickory-shortleaf pine stands. Lowland forests had a greater variety of species than upland forests and included sycamores, cottonwoods, maple, black walnut, butternut, hackberry, poplar, and bur oaks. Prairies were common

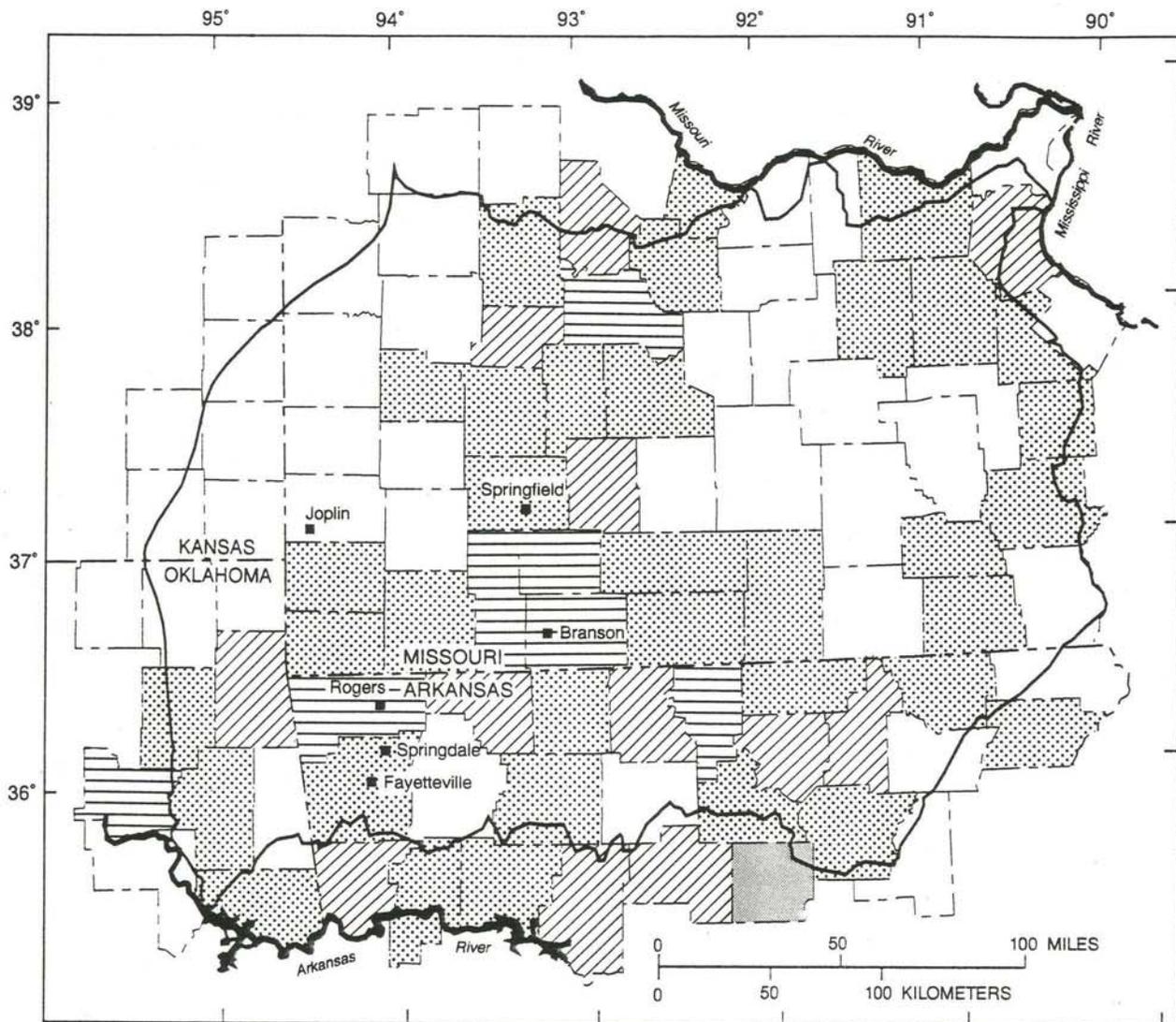
only in small patches in the eastern part of the Ozark Plateaus but about 50 percent of the western part was in prairie grasslands. The prairie vegetation was primarily composed of bluestem grasses. Trees were not well established in these prairies because Native Americans periodically burned the vegetation to drive game. Early settlers continued the practice of burning to provide pastureland; after the Civil War, however, many of the prairies were allowed to revert to forests (Rafferty, 1980).

A majority of the woodlands of the Ozarks Plateaus study unit are now second or third growth due to intense logging through the years. However, tree species in the woodlands are similar to those of the old-growth forests.

Currently (1993) land use in the Ozark Plateaus study unit consists primarily of forest, pasture, and some cropland (fig. 12). Deciduous forestland, mostly oak and hickory trees, predominate in the Salem Plateau and Boston Mountains, which often is mixed with pine trees in the White River Basin. Pastureland, which is mostly fescue (used as hay) and Kentucky blue grass, is grown in the river bottoms and gentle to steep slopes of the uplands in the Springfield Plateau. Cropland is the predominant land use in the Osage Plains and Mississippi Alluvial Plain. Soybeans and sorghum with some corn, wheat, grains, and other field crops are grown in the Osage Plains, with rice dominating in the Mississippi Alluvial Plain.

Poultry, beef and dairy cattle, and swine are the dominant livestock raised in the pasturelands of the Ozark Plateaus study unit. Large concentrations of poultry farms are in the southwestern part of the study unit and in a small area around Miller County, Missouri. Intensive poultry farming started mainly around northwestern Arkansas in the 1930's and has expanded greatly into southwestern Missouri and northeastern Oklahoma in recent years (Rafferty, 1980). Dairy cattle farming is a major land use in the central part of the study unit. Commercial dairy farming grew rapidly from the early through the mid-1900's in southwestern Missouri and northwestern Arkansas. In recent years, dairy farming in the study unit has declined slightly. Beef cattle and hogs are raised throughout most of the study unit (Rafferty, 1980).

Throughout much of the early and mid-1900's, mining was a major land use in parts of the Ozark Plateaus study unit. The study unit contains major deposits of lead, zinc, iron, barite, coal, and minor deposits of copper, silver, manganese, and tungsten and has a long



Data from U.S. Department of Commerce, Bureau of Census, 1990

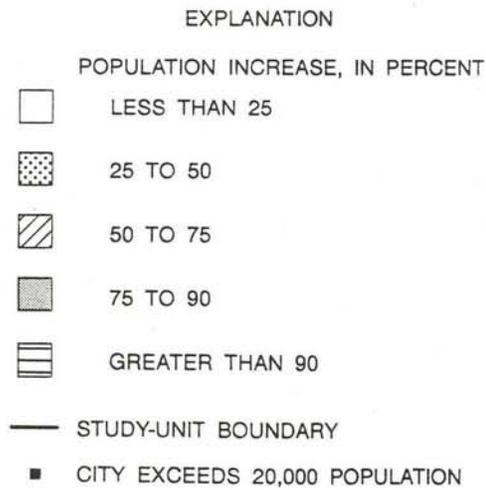
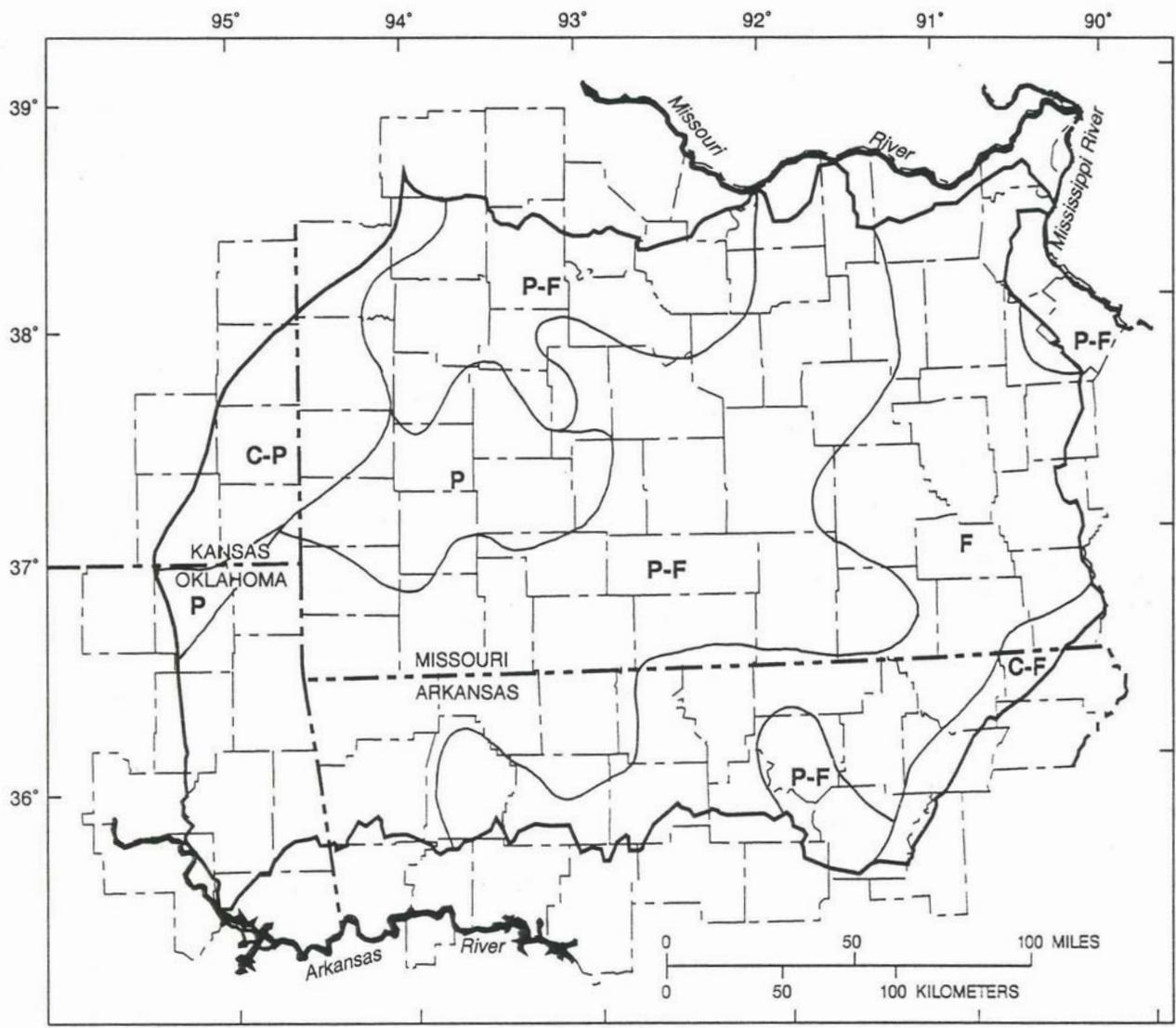


Figure 11. Percentage increase in population by county, 1970-90, and location of cities with 1990 population exceeding 20,000.



Modified from Dugan and Peckenpough, 1985

- EXPLANATION
- C** CROPLAND
  - F** FOREST
  - P** PASTURE
  - LAND-USE BOUNDARY
  - STUDY-UNIT BOUNDARY

Figure 12. Generalized land use in the Ozark Plateaus study unit.

history as a major producer of lead and zinc. Mining activities in the study unit have occurred primarily in four main lead-zinc mining districts--the Southeastern District (Old Lead Belt, Viburnum Trend, and the Fredericktown subdistricts), the Tri-State District, the Central District, and the North Arkansas District (fig. 13). By far, the most important ore deposits were in the Tri-State District and the Southeastern District (Wharton and others, 1975). The Southeastern District was primarily a lead producer, and the Tri-State District was primarily a lead and zinc producer (Wharton and others, 1975). The Central and the North Arkansas Districts contained relatively small, scattered ore deposits that were not mined as actively as were deposits in the two major lead-zinc mining districts (Rafferty, 1980). The Viburnum Trend subdistrict is the only area still actively mined for lead and zinc (Wharton and others, 1975).

Bituminous coal deposits underlie the northwestern part of the study unit. The coal is present in numerous beds, all associated with rocks of Pennsylvanian age (Robertson and Smith, 1981). Historically, coal production in this area has fluctuated with national and international economic conditions. Until 1925, most of the coal was mined underground. Approximately two-thirds of the coal mined is used to produce electricity (Searight, 1967).

### Water Use

Freshwater withdrawals or use from both surface- and ground-water sources within the Ozark Plateaus study unit averaged about 1,053 Mgal/d in 1990. A summary of water use for parts of Arkansas, Kansas, Missouri, and Oklahoma that are within the study unit

is presented in table 3. Nonconsumptive withdrawals, such as water withdrawn by power generating plants, are not included in the data given in this table. Water use by county in the Ozark Plateaus study unit is shown in figure 14. Withdrawals within the study unit for counties only partly within the study unit were estimated from county totals and the percentage of the county within the study unit. Of the total water used in the study unit in 1990, approximately 58 percent was withdrawn from ground-water sources and 42 percent from surface-water sources. Ground-water use for irrigation accounted for 39 percent of the total, primarily for rice production from counties in the Mississippi Alluvial Plain. Surface-water use for public supply, primarily from reservoir systems in northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma, accounted for 20 percent of the total water used in the study unit. Withdrawals for agriculture, commercial, domestic, industrial, and mining use categories were each less than 100 Mgal/d in 1990.

### SURFACE WATER

Surface-water resources are abundant in the Ozark Plateaus study unit. Several major rivers and large reservoirs are located within the study unit. Most rivers flow radially away from the central part of the Springfield-Salem Plateaus or the Boston Mountains.

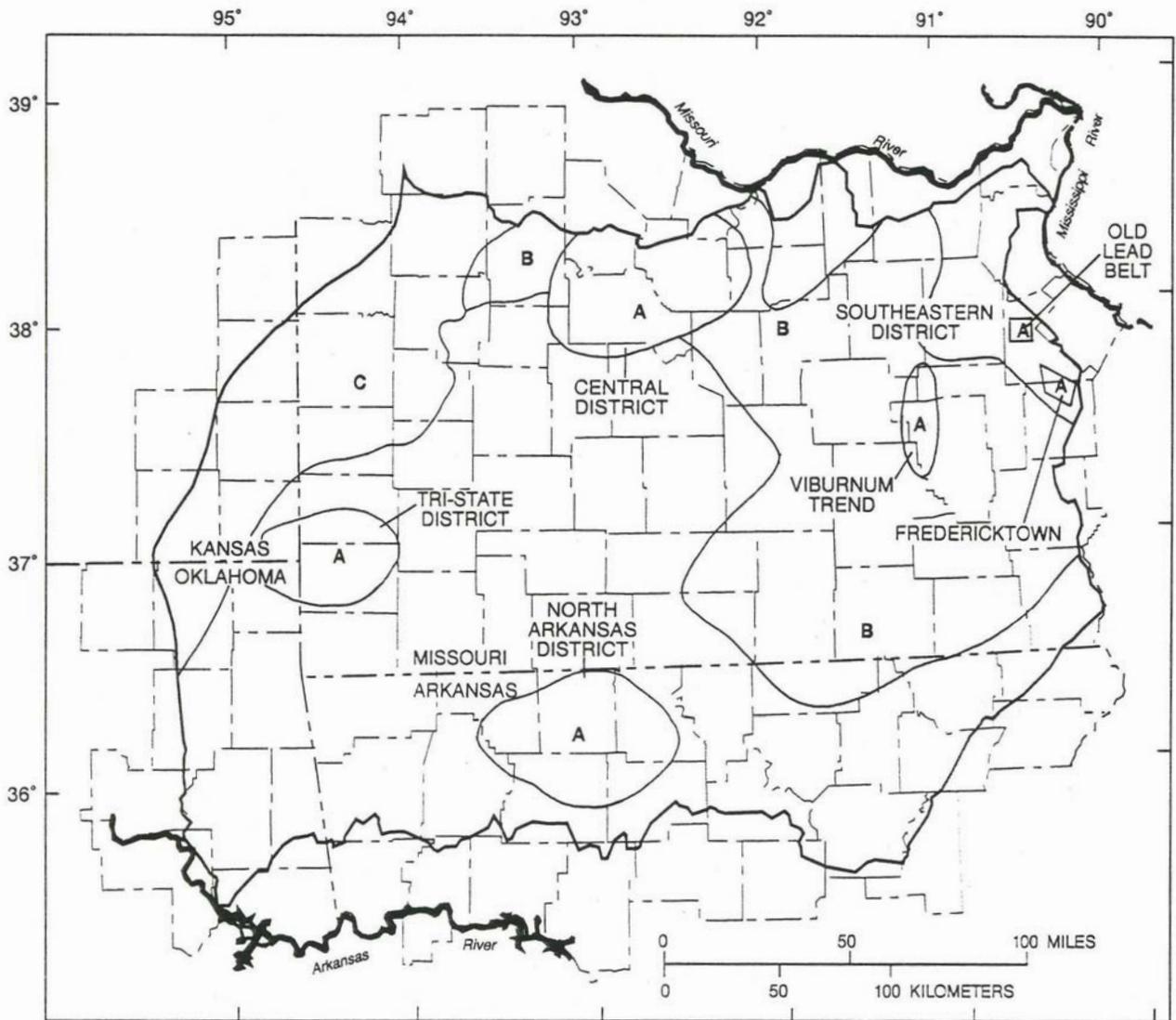
### Major Rivers, Tributaries, and Reservoirs

The Ozark Plateaus study unit is drained by seven major river basins--the White, Neosho-Illinois, Osage, Gasconade, Meramec, Black, and St. Francis Rivers

**Table 3.** Water use within the Ozark Plateaus study unit, 1990

[SW, surface water; GW, ground water; units are million gallons per day. Source: Aggregated Water Use Data System (AWUDS) data base maintained by U.S. Geological Survey office in each state]

State	Agriculture		Commercial		Domestic		Industrial		Irrigation		Mining		Public supply		Total		Total water use
	SW	GW	SW	GW	SW	GW	SW	G W	SW	GW	SW	GW	SW	GW	SW	GW	
Arkansas	18	7	85	0	0	11	19	0	27	272	0	0	51	12	200	302	502
Kansas	2	1	0	0	0	0	4	0	1	0	0	0	4	6	11	7	18
Missouri	17	6	0	10	0	32	21	18	24	140	0	25	96	65	158	296	454
Oklahoma	9	1	0	0	0	4	0	0	4	0	0	0	57	4	70	9	79
	46	15	85	10	0	47	44	18	56	412	0	25	208	87	439	614	1,053

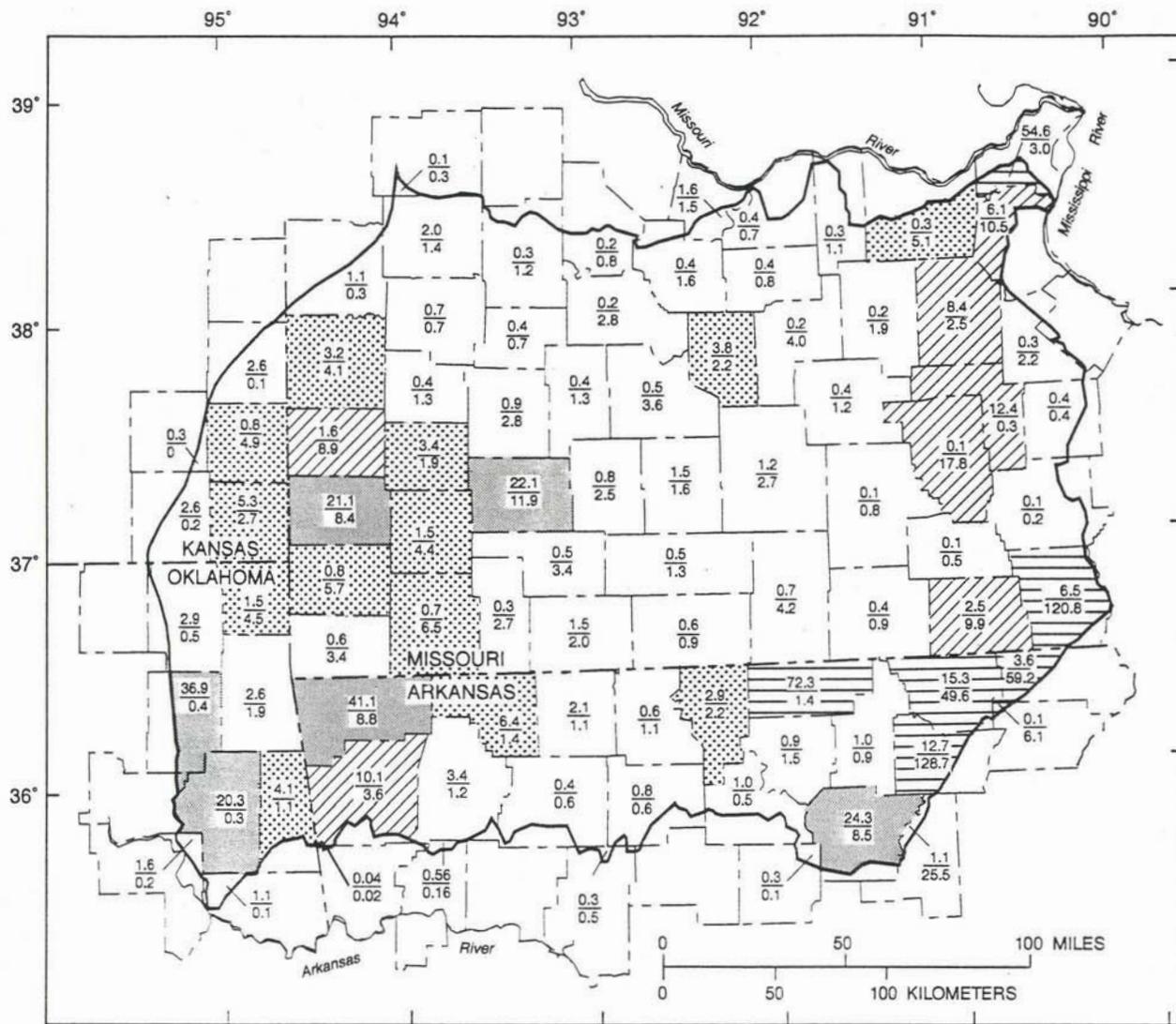


Modified from Smith, 1988; Rafferty, 1980; Rueff, 1990

EXPLANATION

- A LEAD-ZINC DEPOSITS
- B IRON DEPOSITS
- C COAL DEPOSITS
- MINERAL RESOURCE BOUNDARY
- STUDY-UNIT BOUNDARY

Figure 13. Mineral resources in the Ozark Plateaus study unit.



Data from U.S. Geological Survey

EXPLANATION

WATER USE, IN MILLION GALLONS PER DAY

2.1 SURFACE WATER  
1.1 GROUND WATER

TOTAL SURFACE- PLUS GROUND-WATER USE,  
IN MILLION GALLONS PER DAY

- LESS THAN 5
- ▤ 5 TO 10
- ▨ 10 TO 20
- 20 TO 50
- ▬ GREATER THAN 50

— STUDY-UNIT BOUNDARY

Figure 14. Water use by county in the Ozark Plateaus study unit, 1990.

(fig. 15; table 4)--that either directly or indirectly flow into the Mississippi River. The Black River is a tributary of the White River, which flows directly into the Mississippi River, as do the Meramec and St. Francis Rivers. The Neosho and Illinois Rivers are tributaries to the Arkansas River, which flows into the Mississippi River. The Osage and Gasconade Rivers flow into the Missouri River, which is the largest of the Mississippi River tributaries.

### **White River**

The White River originates in the rugged terrain of the Boston Mountains of northwestern Arkansas, generally flows northward to the Arkansas-Missouri State line, then eastward through southern Missouri for about 115 mi where it intersects the State line again (fig. 15). The river meanders along the Arkansas-Missouri boundary for about 30 mi, flows southeastward into Arkansas to the mouth of the Black River (fig. 16), and then south to its confluence with the Mississippi River. The total drainage area of the White River is 27,800 mi<sup>2</sup>, with about 10,600 mi<sup>2</sup> in southern Missouri and 17,200 mi<sup>2</sup> in northern and eastern Arkansas. About 11,300 mi<sup>2</sup> (not including the Black River Basin) are in the Ozark Plateaus study unit (Sullivan, 1974). The reach of the White River near the Arkansas-Missouri State line is a series of reservoirs, beginning with Beaver Reservoir in northwestern Arkansas and then proceeding downstream to Table Rock Lake, Lake Taneycomo, and Bull Shoals Lake. Norfolk Lake is on a tributary to the White River downstream from Bull Shoals Lake. With the completion of Powersite Dam on the White River in 1912, Lake Taneycomo was the first major impoundment of water for power production in Missouri (U.S. Army Corps of Engineers, 1967). The areas near these lakes in both Arkansas and Missouri are increasingly popular recreational attractions and retirement areas.

Major tributaries to the White River in Arkansas are War Eagle Creek, Kings River, Crooked Creek, and Buffalo River. In 1972, the Buffalo River was designated the Buffalo National River by Congress (Public Law 92-237) "for the purposes of conserving and interpreting an area containing unique scenic and scientific features, and preserving as a free-flowing stream an important segment of the Buffalo River..." (Mott, 1991). Headwaters of War Eagle Creek, Kings River, and Buffalo River are in the Boston Mountains, but most of these basins lie within the Springfield Plateau

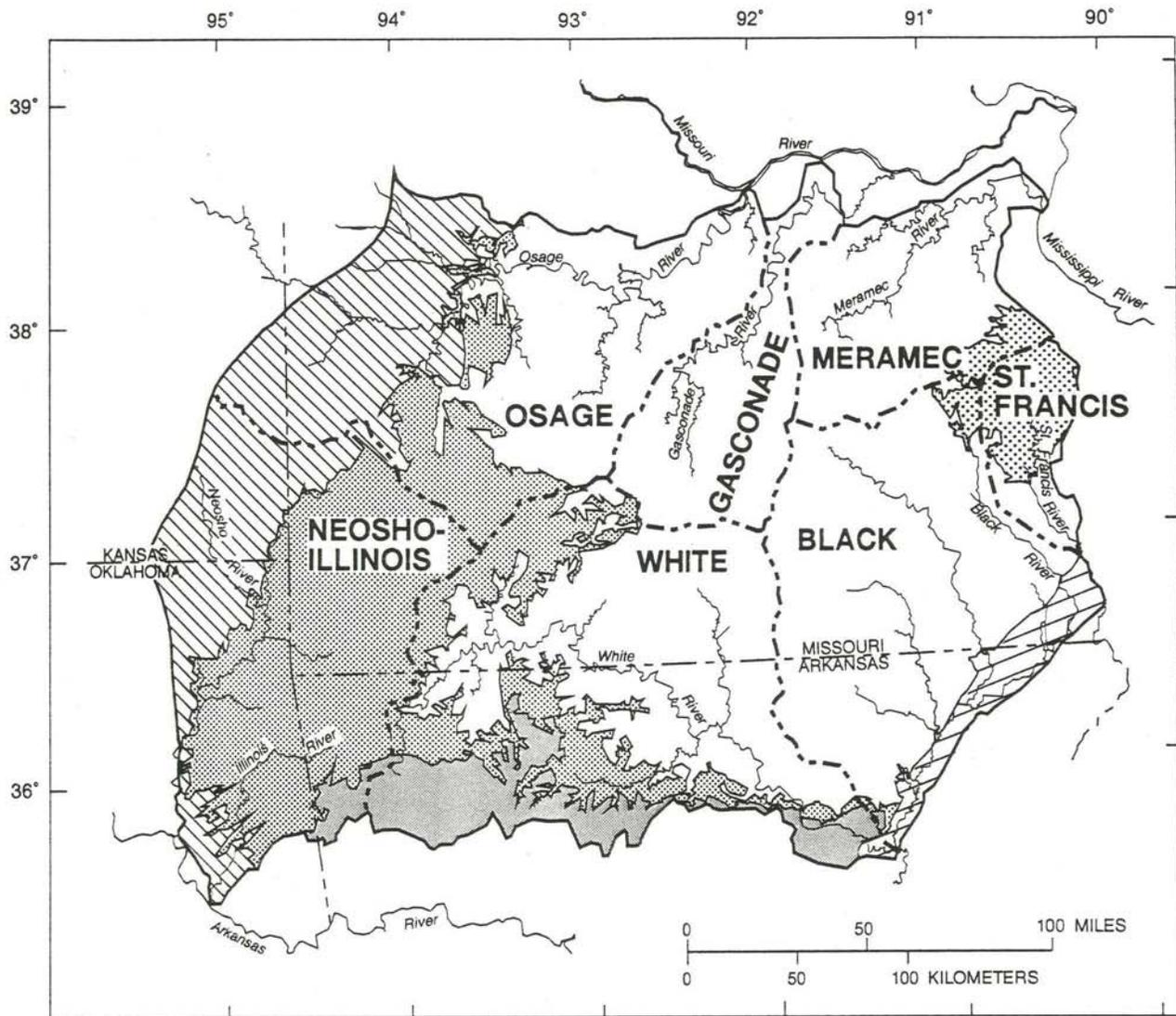
(War Eagle Creek) or the Springfield and Salem Plateaus (Kings River and Buffalo River). Crooked Creek lies mainly in the Salem Plateau, but its headwaters are in the Springfield Plateau. Land use in this part of the White River Basin is primarily forest with pasture and some cropland.

The James and North Fork White Rivers are major tributaries to the White River in Missouri. Most of the James River Basin lies within the Springfield Plateau with the exception of the lower part of the basin where the James River or tributaries have incised rocks of Ordovician age in the Salem Plateau. The lower part of the basin is primarily forested, whereas the upper part is predominately pasture and cropland agriculture. Springfield, Missouri, the largest urban area in the study unit, lies within the James River Basin. The North Fork White River Basin lies entirely in the Salem Plateau and is about 70 percent forested. The lower part of the river has been impounded to form Norfolk Lake.

### **Neosho-Illinois Rivers**

The Neosho River originates in east-central Kansas in the gently rolling hills of the Osage Plains (fig. 15). Land in this part of the basin is used principally for cropland and pasture, although coal and lead-zinc mining has occurred in the basin. The river flows toward the southeast through Kansas into Oklahoma. Below the confluence with the Spring River, a major tributary, the river then follows a winding course through a chain of reservoirs before entering the Arkansas River (fig. 17). These reservoirs are popular recreational attractions. The lower part of the basin, which is predominantly in Missouri and Oklahoma, lies in the Springfield Plateau. The total drainage area of the Neosho River Basin is about 12,500 mi<sup>2</sup>, but only about 60 percent of the drainage area (7,600 mi<sup>2</sup>) is in the study unit. The largest urban area in the basin within the study unit is Joplin, Missouri. A major tributary to the Neosho River, the Elk River, lies entirely in the Springfield Plateau and drains pasture and forest in northern Arkansas and southwestern Missouri.

The Illinois River originates in northwestern Arkansas, flows generally to the north and then to the southwest into Oklahoma where it flows into the Arkansas River (fig. 17). The lower part of the river is impounded to form Tenkiller Ferry Lake. The basin (about 1,630 mi<sup>2</sup>) lies entirely within the study unit and is mostly in the Springfield Plateau. The headwaters of the basin are in the Boston Mountains. From the Arkan-



EXPLANATION

- |   |                            |   |  |
|---|----------------------------|---|--|
|  | OSAGE PLAINS               |  | PHYSIOGRAPHIC SECTION OR AREA BOUNDARY |
|  | SPRINGFIELD PLATEAU        |  | BASIN BOUNDARY                         |
|  | SALEM PLATEAU              |  | STUDY-UNIT BOUNDARY                    |
|  | BOSTON MOUNTAINS           |   |  |
|  | MISSISSIPPI ALLUVIAL PLAIN |   |  |
|  | ST. FRANCOIS MOUNTAINS     |   |  |

Figure 15. Major river basins and physiographic sections or areas in the Ozark Plateaus study unit.

**Table 4.** Summary of major tributaries, reservoirs, and land use in the major river basins in the Ozark Plateaus study unit

[Land use codes: F, forest; P, pasture; C, cropland; U, urban; M, mining; NA, not applicable]

River basin	Drainage area, in square miles		Land use, in order of importance	Principal tributaries and drainage areas, in square miles		Principal reservoirs in the river basin
	Total	Study unit				
White River <sup>1</sup>	27,800	11,300	F, P, C, U	War Eagle Creek	332	Beaver Reservoir
				Kings River	565	Table Rock Lake
				Crooked Creek	462	Lake Taneycomo
				Buffalo River	1,340	Bull Shoals Lake
				James River	1,460	Norfolk Lake
				North Fork White River	1,830	
Neosho-Illinois Rivers <sup>2</sup>	14,100	9,230	C, P, F, M	Spring River	2,510	Lake O' the Cherokees
				Elk River	872	Lake Hudson
				Big Cabin Creek	450	Fort Gibson Lake
				Osage Creek	206	Tenkiller Ferry Lake
				Baron Fork	307	
Osage River <sup>3</sup>	15,300	10,500	C, P, F, M	Little Osage River	570	Truman Reservoir
				Marmaton River	1,150	Lake of the Ozarks
				South Grand River	2,040	Stockton Lake
				Sac River	1,970	Pomme de Terre Lake
				Pomme de Terre River	828	
				Niangua River	1,040	
Gasconade River <sup>4</sup>	3,600	3,600	F, P	Big Piney River	760	None
				Osage Fork	520	
				Roubidoux Creek	300	
				Little Piney Creek	272	
Meramec River <sup>5</sup>	3,980	3,980	F, P, M	Bourbeuse River	841	None
				Big River	964	
St. Francis River <sup>6</sup>	6,480	1,310	F, P, M	NA	NA	Lake Wappapello
Black River <sup>7</sup>	8,560	8,560	F, P, M	Current River	2,610	Clearwater Lake
				Spring River	1,230	
				Eleven Point River	1,220	
				Strawberry River	792	

<sup>1</sup> Does not include the Black River Basin, which is the largest tributary of the White River. Drainage area for James River from Homyk and Jeffery (1967); all other drainage areas from Sullavan (1974). The drainage area for the Kings River does not include the small part of the basin in Missouri.

<sup>2</sup> Drainage areas for the Neosho River Basin determined at the following U.S. Geological Survey stations: (1) Neosho River below Fort Gibson Lake, near Fort Gibson, Oklahoma (07193500), (2) Spring River near Quapaw, Oklahoma (07188000), (3) Elk River near Tiff City, Missouri (07189000), and (4) Big Cabin Creek near Big Cabin, Oklahoma (07191000). Drainage area for Osage Creek from Terry and others (1984). Drainage areas for Baron Fork and Illinois River Basins determined at the following U.S. Geological Survey stations: (1) Illinois River near Gore, Oklahoma (07198000) and (2) Baron Fork at Eldon, Oklahoma (07197000).

<sup>3</sup> Drainage areas from Homyk and Jeffery (1967). About 960 mi<sup>2</sup> of the South Grand River Basin, 1,000 mi<sup>2</sup> of the Marmaton River Basin, and 270 mi<sup>2</sup> of the Little Osage River Basin are in the study unit. Drainage area for Little Osage River does not include the Marmaton River.

<sup>4</sup> Drainage areas from Homyk and Jeffery (1967).

<sup>5</sup> Drainage area for Meramec River Basin from Homyk and Jeffery (1967); drainage areas for Bourbeuse and Big Rivers from Missouri Department of Natural Resources (1984).

<sup>6</sup> Drainage area for the St. Francis River Basin from U.S. Geological Survey annual Water-Data Report; drainage area in the study unit determined at U.S. Geological Survey station St. Francis River at Wappapello, Missouri (07039500).

<sup>7</sup> Drainage areas from Sullavan (1974). Drainage area for Spring River does not include the Eleven Point River.

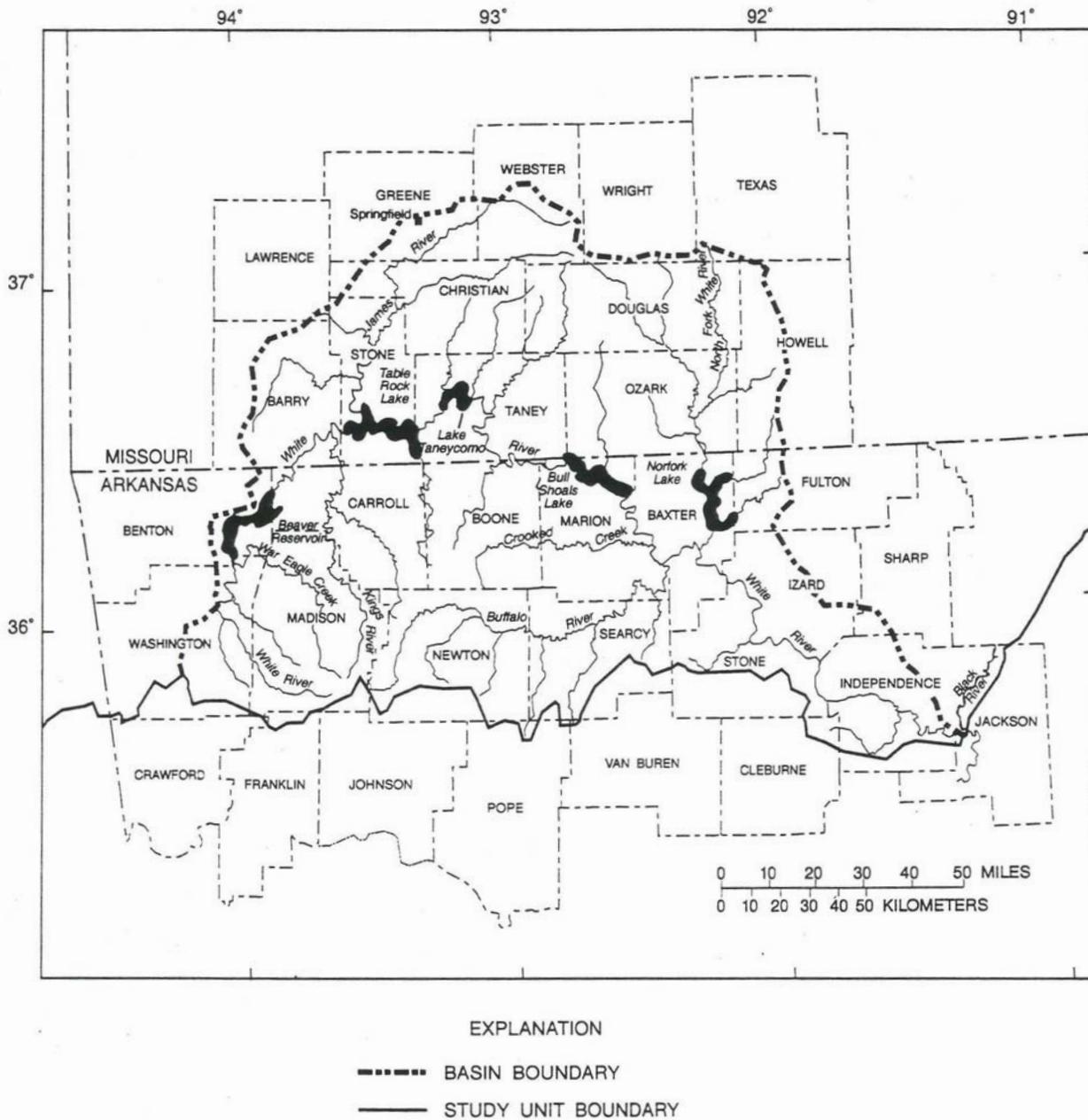


Figure 16. White River Basin with major tributaries and reservoirs.

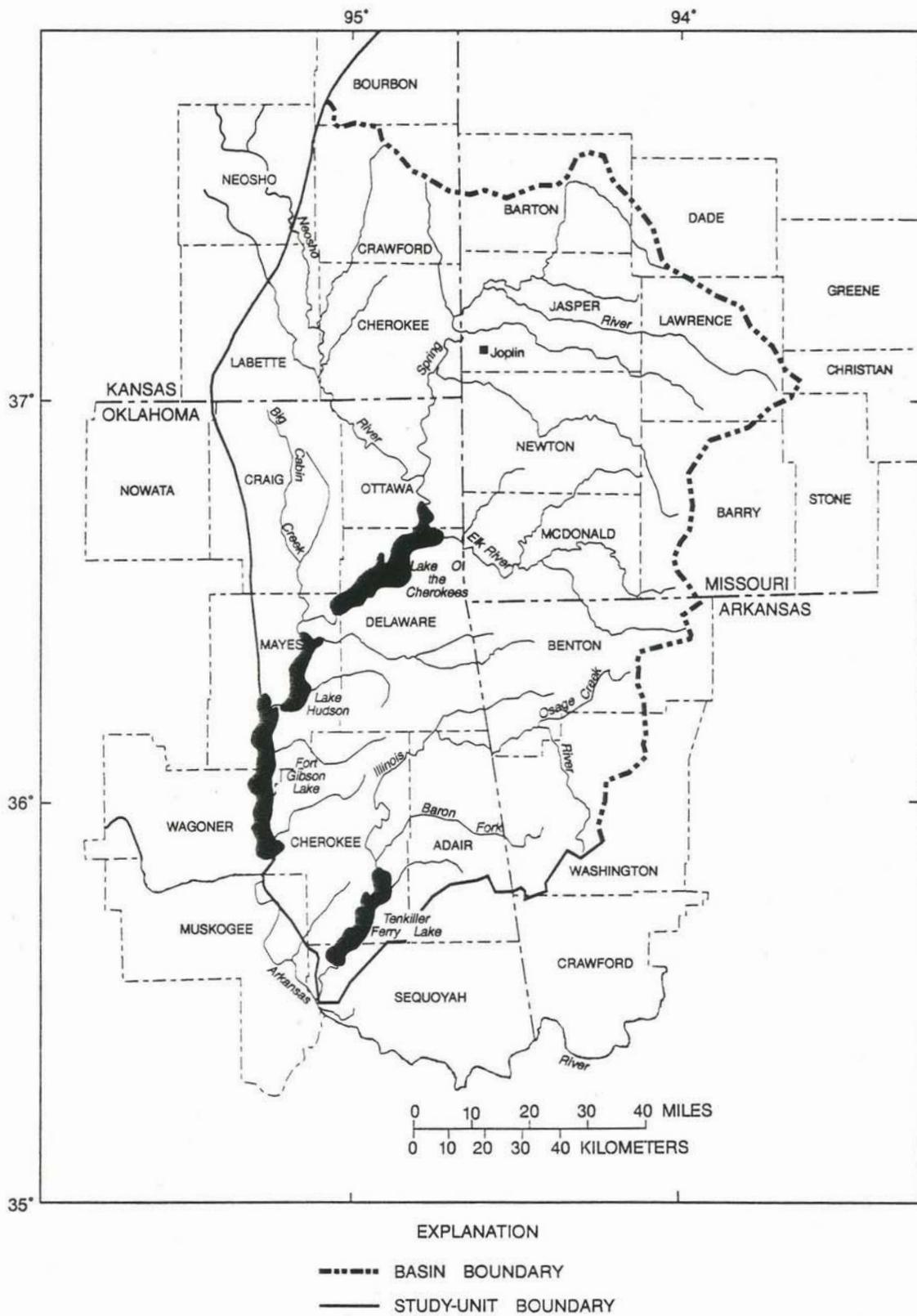


Figure 17. Neosho-Illinois River Basin with major tributaries and reservoirs.

sas-Oklahoma State line to the upper end of Tenkiller Ferry Lake, the Illinois River has been designated by the Oklahoma State Legislature as a scenic river and is the only river with this designation in Oklahoma.

### **Osage River**

The Osage River originates in east-central Kansas and generally flows eastward into Missouri (fig. 15). In Kansas, the Osage River is called the Marais des Cygnes. The upper two-thirds of the Osage River system, including the Little Osage, Marmaton, and South Grand Rivers, drain the gently rolling prairie land of the Osage Plains (figs. 15 and 18). The South Grand River is the largest tributary to the Osage River and is the only major south-flowing tributary. Land use in this part of the basin is primarily cropland and pasture, although coal has been mined along the western study unit boundary.

The Osage River continues flowing eastward across the Springfield and Salem Plateaus to the Missouri River. About 602 mi of river have been inundated by the construction of four major reservoirs, including Truman Reservoir and Lake of the Ozarks on the main stem (Duchrow, 1984). As in the White and Neosho-Illinois River Basins, the lakes are popular recreational attractions and retirement areas. The total drainage area of the basin is 15,300 mi<sup>2</sup>, with 10,700 mi<sup>2</sup> in Missouri and the remainder in Kansas. The drainage area for that part of the basin that lies in the study unit is about 10,500 mi<sup>2</sup>.

The Sac River is the only tributary to the Osage River that lies entirely within the Springfield Plateau. Stockton Lake, the third major reservoir in the Osage River Basin, is on the Sac River. About one-half of the Sac River Basin is forested with the remaining land used primarily for cropland or pasture. A small part of this basin is urban. Withdrawals from two small public water-supply lakes and a spring in the Sac River Basin supply much of the drinking water for Springfield, Missouri, which lies on the drainage divide between the James and Sac River Basins.

The Pomme de Terre and Niangua Rivers are the two main Osage River tributaries that lie entirely within the Salem Plateau. Pomme de Terre Lake on the lower Pomme de Terre River is the fourth major reservoir in the Osage River Basin. The resident and tourist populations are not as large at Pomme de Terre Lake as at some of the other recreational reservoirs. Land use in

nearly 50 percent of these two basins is agricultural, centered primarily around livestock production.

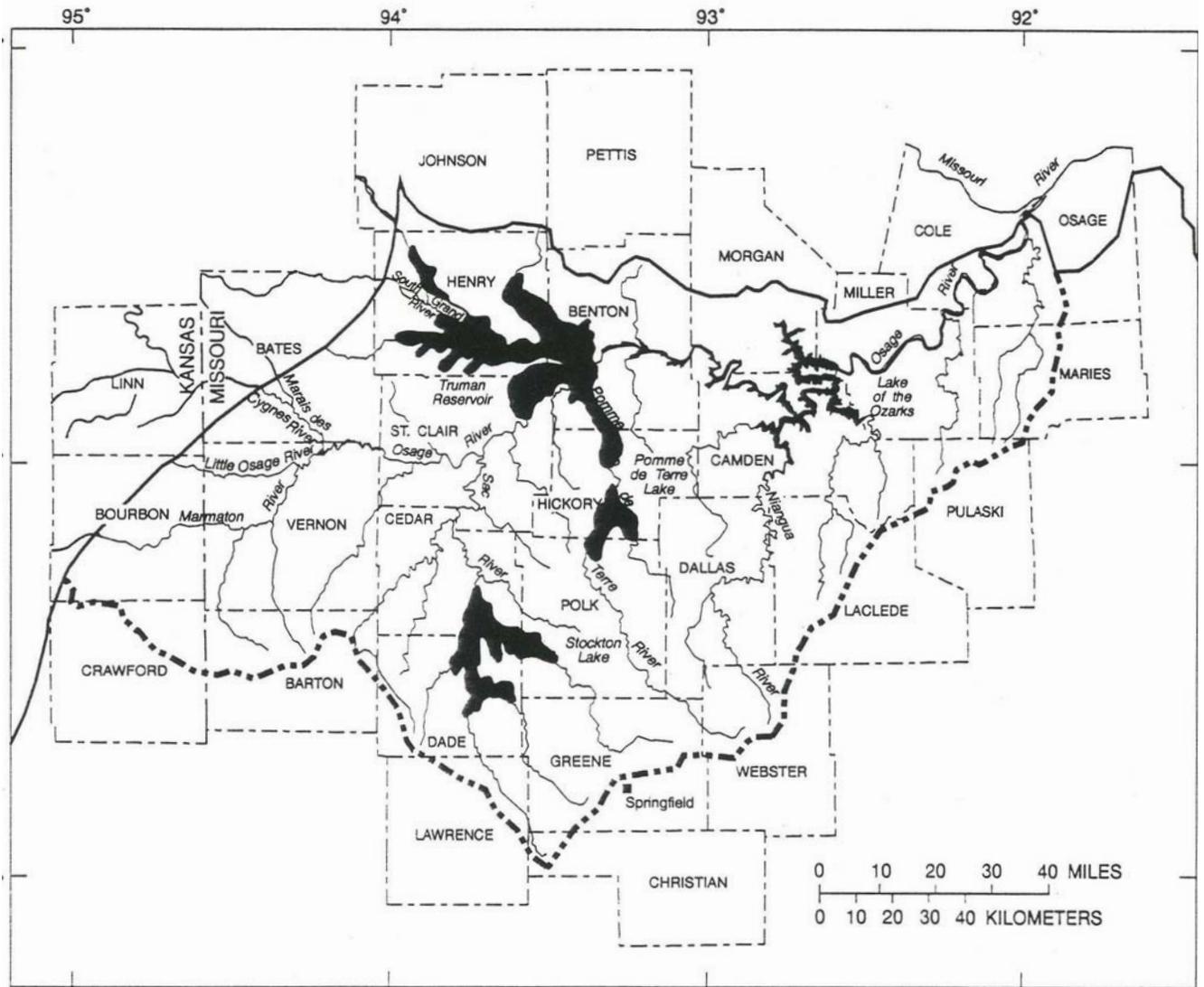
### **Gasconade River**

The Gasconade River and its major tributary, the Big Piney River, generally flow toward the northeast through the rough terrain of the Salem Plateau to the Missouri River (figs. 15 and 19). No reservoirs or urban areas of any size are located in the basin, which is entirely within the study unit. The total drainage area of the Gasconade River Basin is 3,600 mi<sup>2</sup>. At one time, parts of the Gasconade and Big Piney Rivers were considered for inclusion in the Wild and Scenic River System, but because of shoreline development, agricultural activities, and transportation corridors, some segments of the rivers did not meet the eligibility criteria (Bureau of Outdoor Recreation, 1973). The basin is about 75 percent forested; however, livestock and crop production are important land uses in the basin, particularly in the stream valleys.

### **Meramec River**

The Meramec River Basin originates in the Salem Plateau in the northeastern part of the study unit and flows toward the northeast to the Mississippi River just south of St. Louis, Missouri (figs. 15 and 20). Meramec Spring, the seventh largest spring in Missouri, more than doubles the flow of the Meramec River in the upper part of the basin. The entire basin (3,980 mi<sup>2</sup>) is in the study unit, with the exception of a small part in the St. Louis metropolitan area. The upper part of the basin is primarily forested with some cropland and pasture. Small tributaries to the upper Meramec River drain part of the Viburnum Trend mining area.

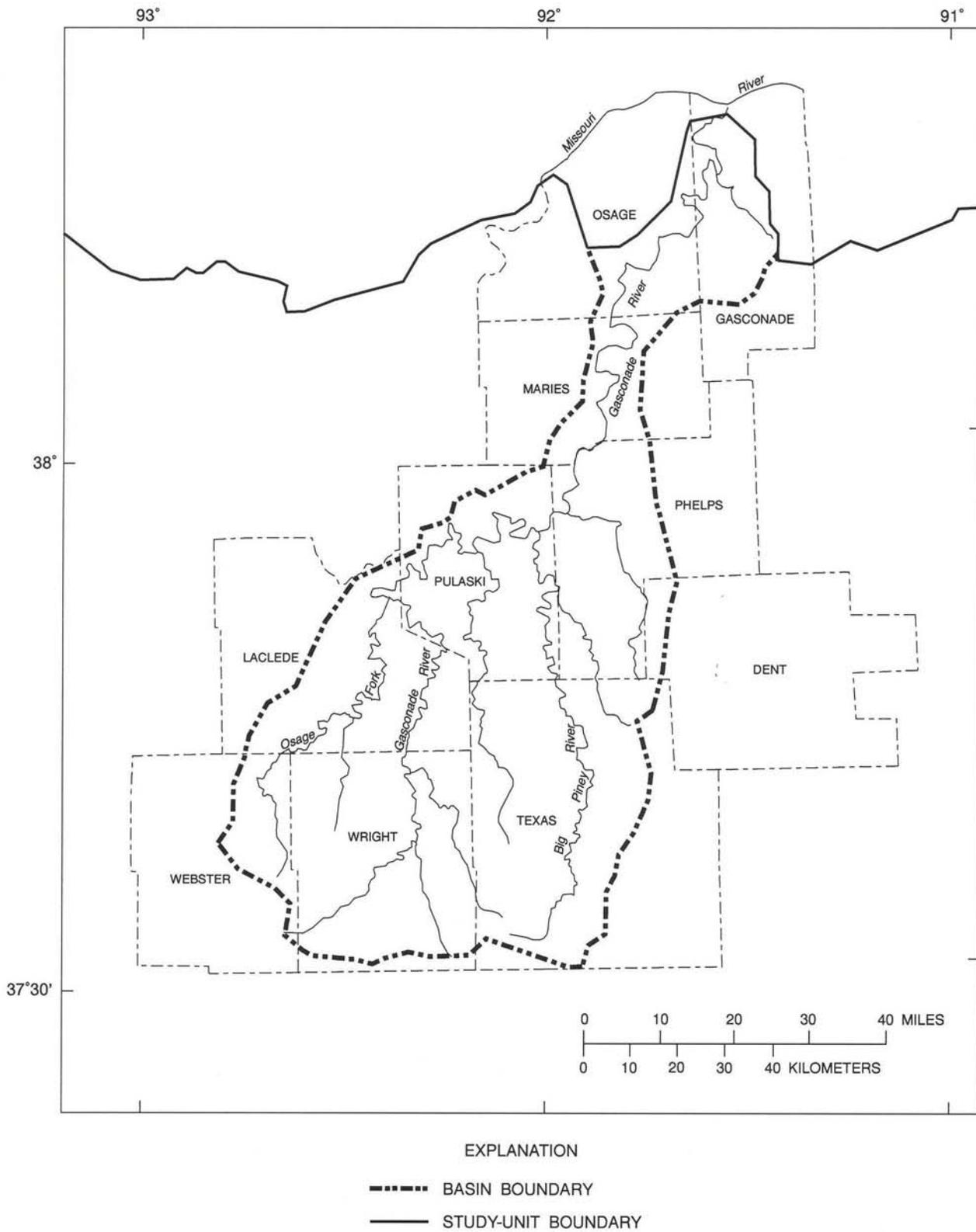
The Meramec River has two major tributaries, the Bourbeuse River on the north and the Big River on the east. Much of the basin of the Bourbeuse River, which flows from west to east along the northern part of the Meramec River Basin, is underlain by undifferentiated deposits of Pennsylvanian age, which overlie and sometimes fill depressions in an ancient karst topography developed in deposits of Ordovician age (Vineyard and Feder, 1974). The gently rolling terrain is suitable for agricultural land uses, and the Bourbeuse River Basin has more pasture and tilled lands than other parts of the Meramec River Basin. The Big River originates in the St. Francois Mountains and flows northward through the Salem Plateau to the Meramec River. The



EXPLANATION

- BASIN BOUNDARY
- STUDY-UNIT BOUNDARY

Figure 18. Osage River Basin with major tributaries and reservoirs.



**Figure 19.** Gasconade River Basin with major tributaries.

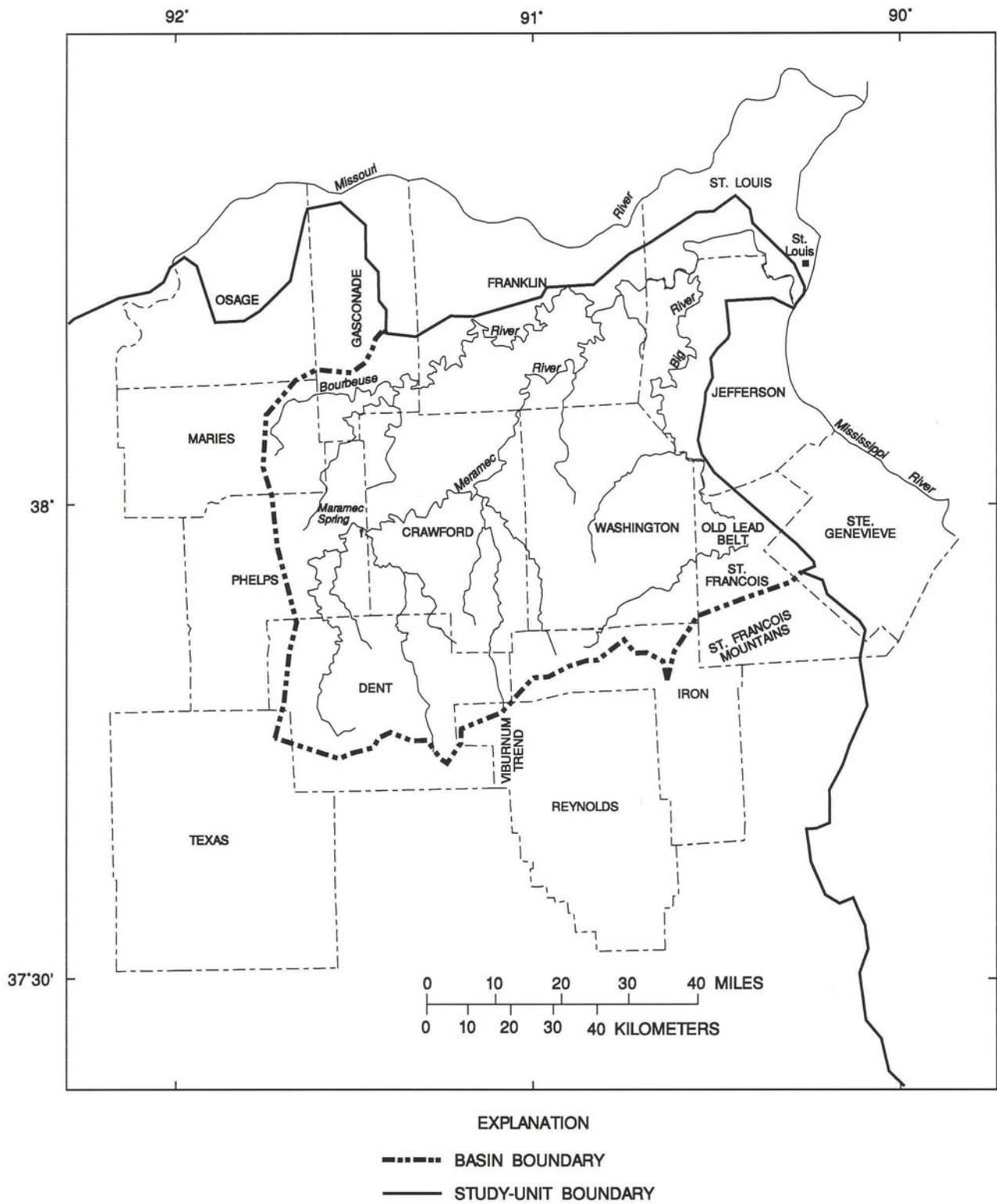


Figure 20. Meramec River Basin with major tributaries and spring.

Big River Basin encompasses much of the Old Lead Belt mining area and most of the area of past and present barite mining.

### **St. Francis River**

The St. Francis River originates in the southern flank of the rugged St. Francois Mountains of southeastern Missouri and flows toward the south through the Salem Plateau out of the study unit into Arkansas to the Mississippi River (figs. 15 and 21). The total drainage area of the basin is about 6,480 mi<sup>2</sup>, with only about 1,310 mi<sup>2</sup> in the study unit. Lake Wappapello, located at the southeastern extent of the basin in the study unit, is a major recreation area. Like other basins in the Salem Plateau, the basin is predominantly forested with some pasture, although some lead and zinc have been mined in the upper part of the basin.

### **Black River**

The Black River is the largest tributary (8,560 mi<sup>2</sup>) to the White River system. Major tributaries to the Black River include the Current, Eleven Point, Spring, and Strawberry Rivers. The Strawberry River Basin lies wholly in north-central Arkansas, but the headwaters and much of the drainage area of the other major tributaries of the Black River are in southern Missouri. Like the St. Francis River, the Black River originates on the southern flank of the St. Francois Mountains and flows southward through the Salem Plateau into Arkansas to the White River (figs. 15 and 22). On the eastern side of the river, a small part of the drainage area is in the Mississippi Alluvial Plain. The other tributaries lie entirely in the Salem Plateau. The only major reservoir in the basin, Clearwater Lake, is on the Black River in Missouri. At least 50 percent of the land is forested in all of the basins with the remainder used primarily for pasture and cropland; no major urban areas are in the Black River Basin. Small tributaries to the upper Black River drain the southern end of the Viburnum Trend mining area.

The Black River Basin is characterized by rugged, hilly countryside, numerous springs, and clear, fast-flowing streams. The three largest springs in the study unit are in the Black River Basin: Greer Spring (average flow of 289 ft<sup>3</sup>/s) on the Eleven Point River, Mammoth Spring (measured flows ranged from 240 to 431 ft<sup>3</sup>/s) on the Spring River, and Big Spring (average flow of 428 ft<sup>3</sup>/s; Vineyard and Feder, 1974) on the

Current River. In 1974, 134 mi of the Current River and its principal tributary, Jacks Fork, and about 65,000 acres of adjoining land were designated as the Ozark National Scenic Riverways (Barks, 1978) to preserve the natural conditions of the Current River Basin and to increase recreational opportunities for fishermen, canoeists, and campers. A part of the Eleven Point River in Missouri also has been designated as a National Scenic River.

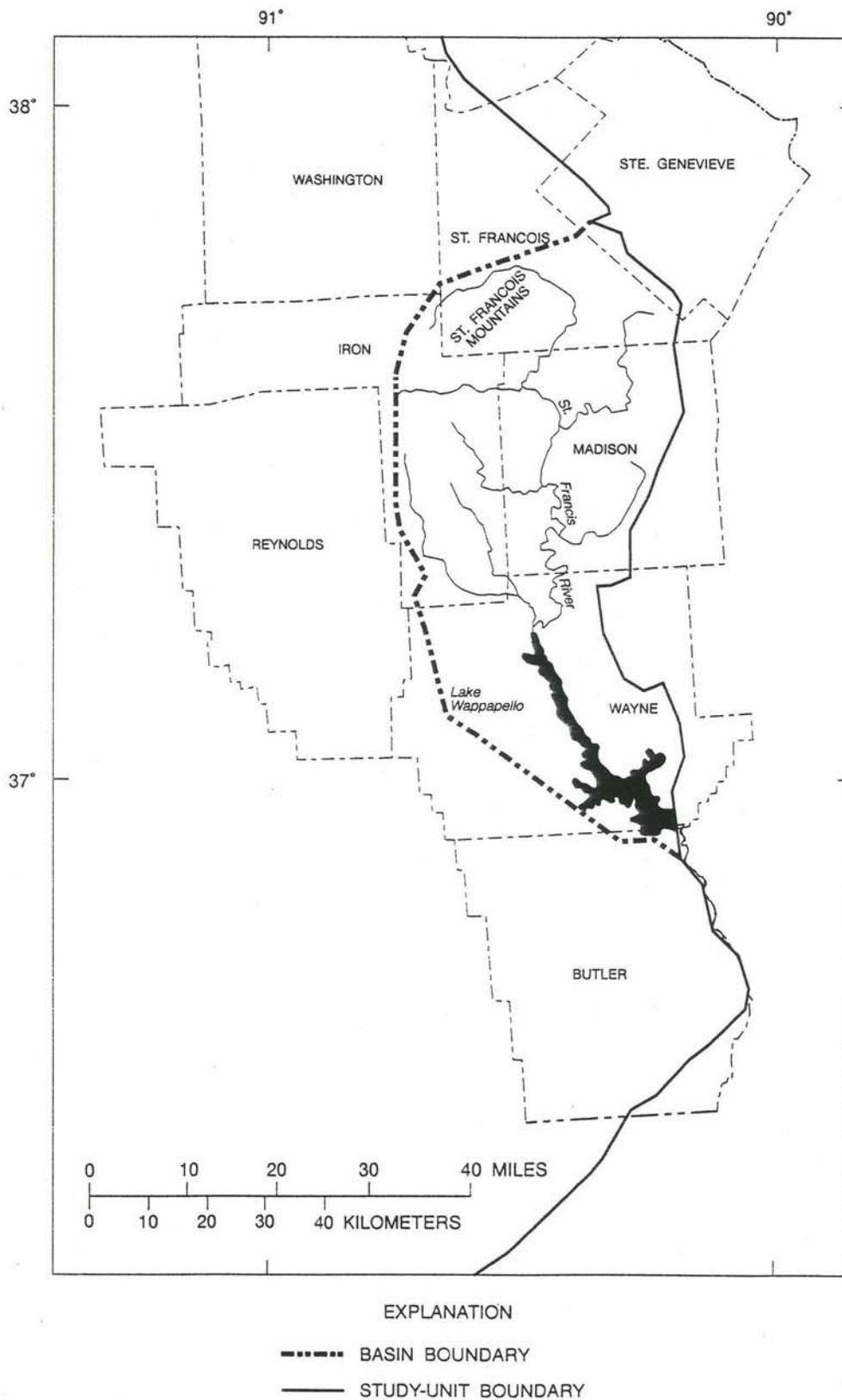
### **Stream Morphology**

Some of the major rivers and their tributaries lie totally within a single physiographic section; however, more typically, a large stream will flow through two or more physiographic sections and, as it does, the stream morphology changes. Descriptions of typical stream morphology for each of the physiographic sections or areas follow.

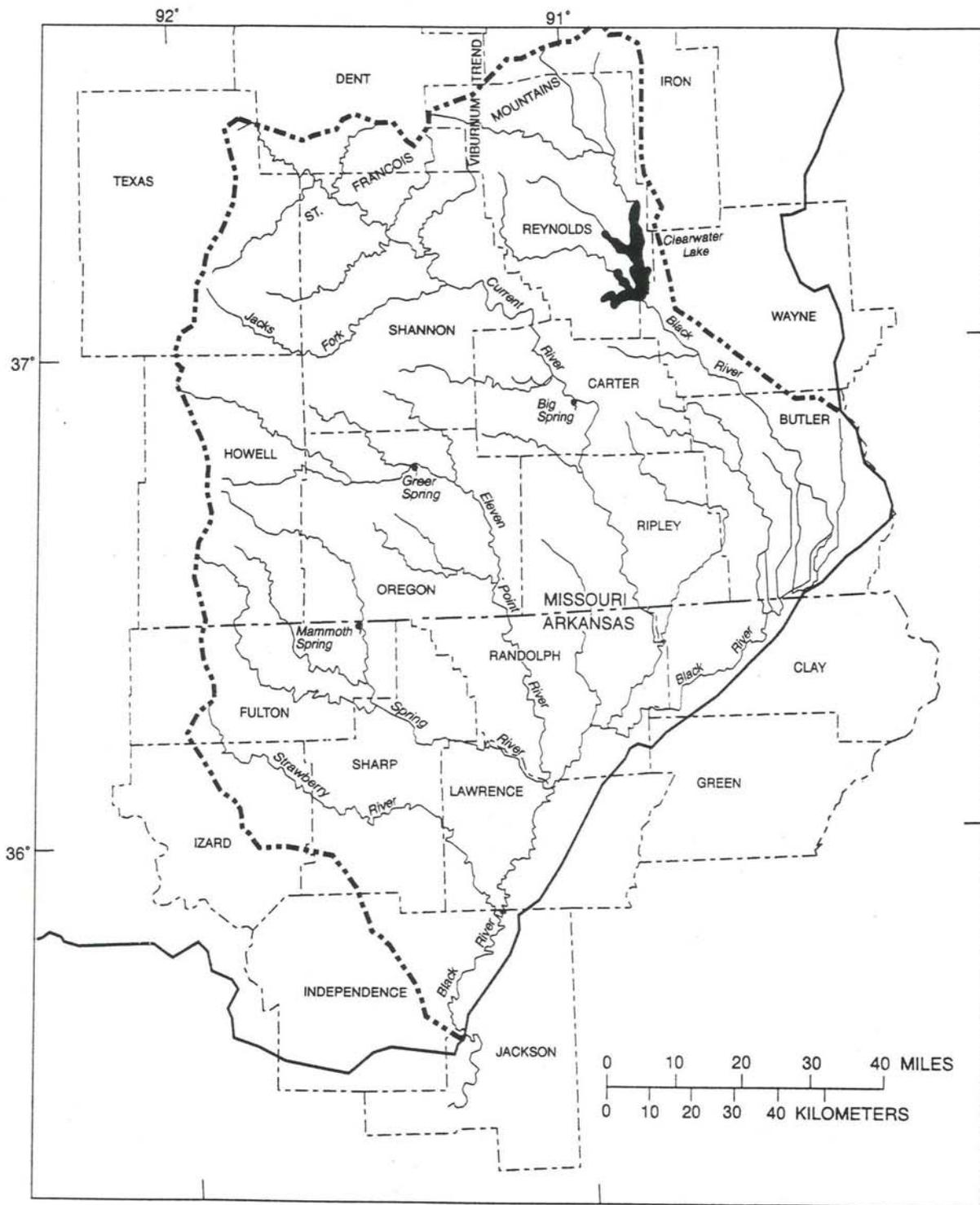
The terrain in the Boston Mountains is exceptionally steep and rugged with local relief as much as 1,000 ft in places (Bennett and others, 1987). Because of the rugged terrain and steep slopes, streams have high gradients, averaging about 20 ft/mi (Giese and others, 1987). Stream beds consist predominantly of bedrock and rubble with smaller amounts of boulders, gravel, and sand.

Relief in the Springfield and Salem Plateaus generally is less than that in the Boston Mountains. Valleys generally are deeper and narrower and the ridges sharper in the Salem Plateau than in the Springfield Plateau. Local relief along the major streams often exceeds 300 ft (Pflieger, 1989) and is as much as 500 ft in some areas. Stream channels in the Springfield and Salem Plateaus consist of a series of well-defined riffles and pools, and channel beds consist predominantly of coarse gravel, rubble, boulders, and bedrock. Stream gradients generally exceed 3 ft/mi even in the larger streams and are as much as 50 ft/mi in some headwater areas (Pflieger, 1989). The water usually is quite clear. In some areas of the Springfield and Salem Plateaus, forests have been cleared to develop land for agricultural purposes resulting in a reduction in the tree canopy overhanging streams. This reduction allows more sunlight to reach the stream, which can increase water temperatures and the growth of aquatic vegetation.

Streams in the St. Francois Mountains within the Salem Plateau have high stream gradients. Pflieger (1989) does not differentiate between the morphology



**Figure 21.** St. Francis River Basin with major tributaries and reservoir.



**Figure 22.** Black River Basin with major tributaries, reservoir, and springs.

of the St. Francois Mountains and the rest of the Salem Plateau. Therefore, the morphology of streams in the St. Francois Mountains probably is similar to that of streams in other parts of the Salem Plateau; however, stream gradients are as much as 200 ft/mi in some headwater stream reaches. A distinctive valley form, called a shut-in, is formed where streams erode resistant igneous rocks in the St. Francois Mountains. The results are steeply sided valleys and cascading waterfalls (Beveridge and Vineyard, 1990).

Streams in the Osage Plains occupy broad, shallow valleys and, if unchannelized, follow meandering courses. Gradients average about 26 ft/mi in headwater areas but average less than 2 ft/mi in the larger streams (Pflieger, 1989). Channels consist of long pools, and riffles are often nonexistent or poorly defined. Sand and silt channel beds are dominant in the pools; shale and sandstone gravel and pebbles are dominant in the riffles.

Streams in the Mississippi Alluvial Plain meander through a broad alluvial plain. Oxbow lakes are common along the lower reach of the Black and Current Rivers. Many of the streams have been channelized. Maximum relief is only a few feet per mile (Bennett and others, 1987). Stream gradients generally are less than 1 ft/mi. The channel bed in swifter areas of streams and ditches is mostly sand and gravel; in areas of less velocity, the channel bed is usually silt (Pflieger, 1989).

## **Runoff and Streamflow**

Runoff can be defined as the water that drains from the land into stream or river channels after precipitation and is a function of precipitation amounts, topography, geology, soil moisture, and other factors. Mean annual runoff per square mile of basin, which can be computed by dividing the mean annual volume of water leaving the basin (measured as streamflow at a gaging station) by the area of that basin, is often used for purposes of comparing runoff characteristics between basins.

Mean annual runoff within the Ozark Plateaus study unit is shown in figure 23 (Gebert and others, 1987). Mean annual runoff generally is least in the Osage Plains where it ranges from about 9 to 10 in. Mean annual runoff in the Springfield and Salem Plateaus, and St. Francois Mountains generally ranges from 10 to 15 in., although values are more variable in the eastern

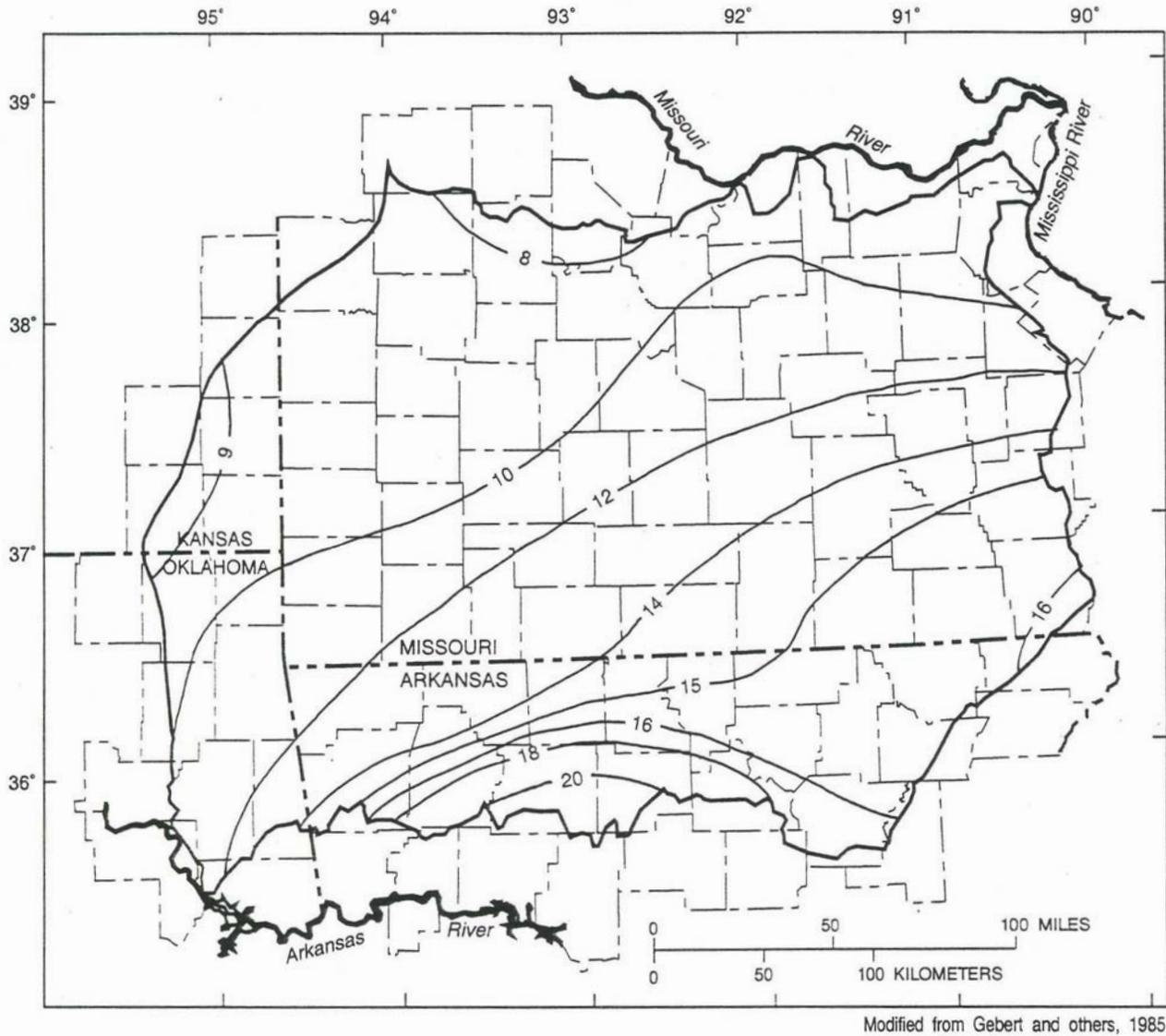
Salem Plateau where they range from about 4 to 30 in. (Hedman and others, 1987). Mean annual runoff is about 16 in. in the Mississippi Alluvial Plain within the study unit (Neely, 1986). The mean annual runoff generally is greatest in the Boston Mountains where it ranges from 14 to 20 in.

Magnitude, frequency, and duration of floods and high streamflows are affected by many factors, including drainage area, basin and channel slope, channel length, precipitation amount and intensity, vegetation, season, and flow-regulation activities or structures. Flood-frequency and flood-magnitude information for streams in the study unit are available in reports for Arkansas (Neely, 1987), Kansas (Jordan and Irza, 1975), Missouri (Sandhaus and Skelton, 1968; Hauth, 1974), and Oklahoma (Sauer, 1974; Thomas and Corley, 1977).

Duration of high streamflows (and the time lag between onset of precipitation and the peak flow) generally will be shortest in small, steep basins. The location of streamflow stations and hydrographs that exemplify this type of response for the Neosho River and Lightning Creek in the Osage Plains, and the Current River and Jacks Fork in the Salem Plateau are shown in figures 24 and 25. Streamflow is elevated for longer periods of time in the Osage Plains streams and in the streams with larger drainage areas. Although these examples are typical, the duration and magnitude of streamflow peaks at a specific location are strongly dependent on antecedent precipitation and precipitation intensity, duration, and distribution.

Annual mean streamflow of individual streams within the Ozark Plateaus study unit can vary substantially from year to year (fig. 26). Between 1951 and 1990, there were periods of low flows in the mid-1950's, mid-1960's, and early 1980's, and periods of generally high flows in the early 1950's, early and late 1960's, mid-1970's, and mid-1980's. Annual mean streamflows for water year 1981 were extremely low throughout the study unit but annual mean streamflows just 4 years later, in 1985, were among the highest for the period of record. Although, these patterns generally are regionally consistent, local climatological differences also affect annual mean streamflows.

Runoff and streamflow also vary seasonally. Minimum monthly streamflows typically occur in summer and fall, July through October (fig. 27). Maximum monthly streamflows typically occur in spring, March through May (fig. 27). These seasonal variations in streamflow primarily are the result of seasonal differ-

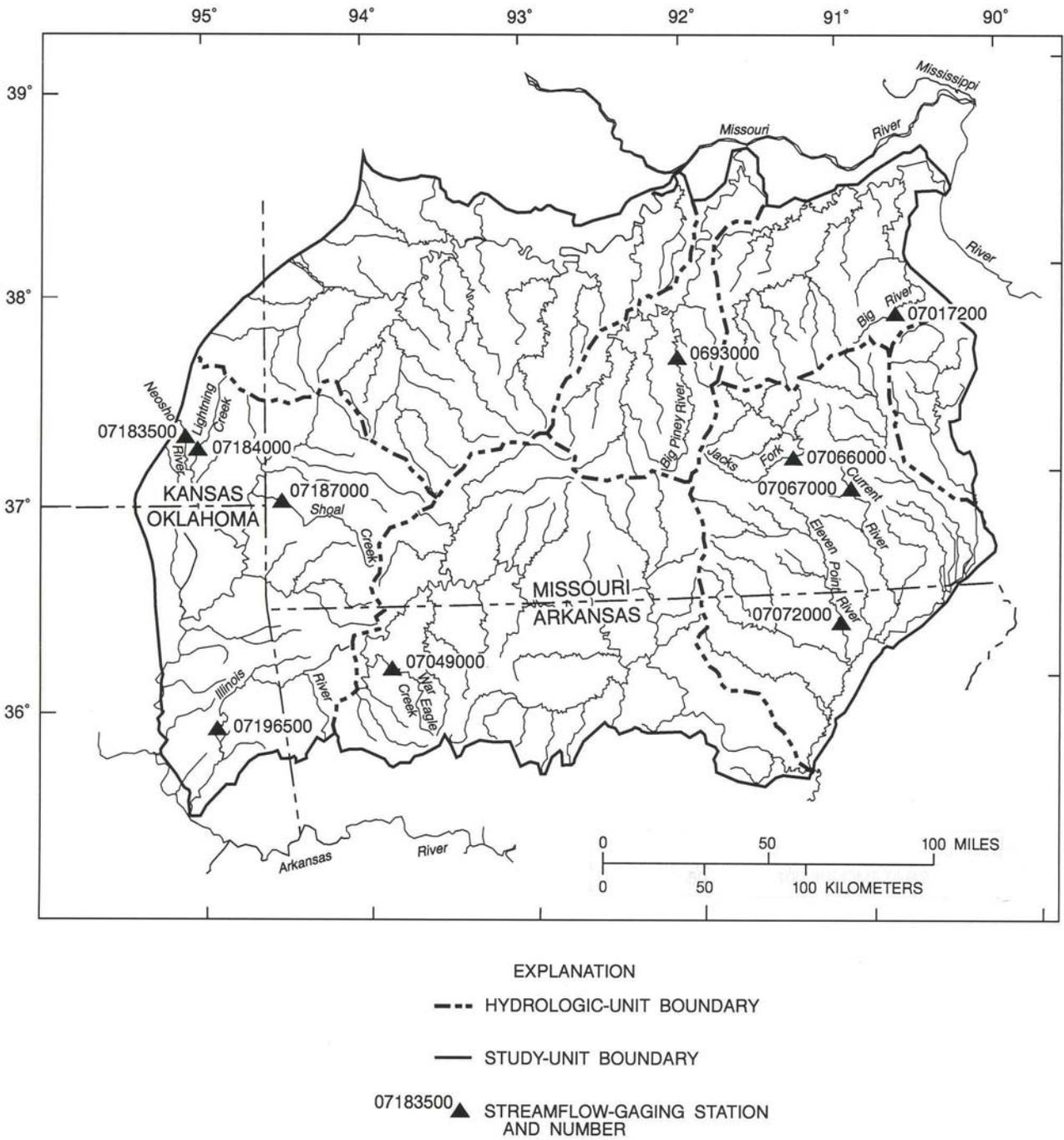


Modified from Gebert and others, 1985

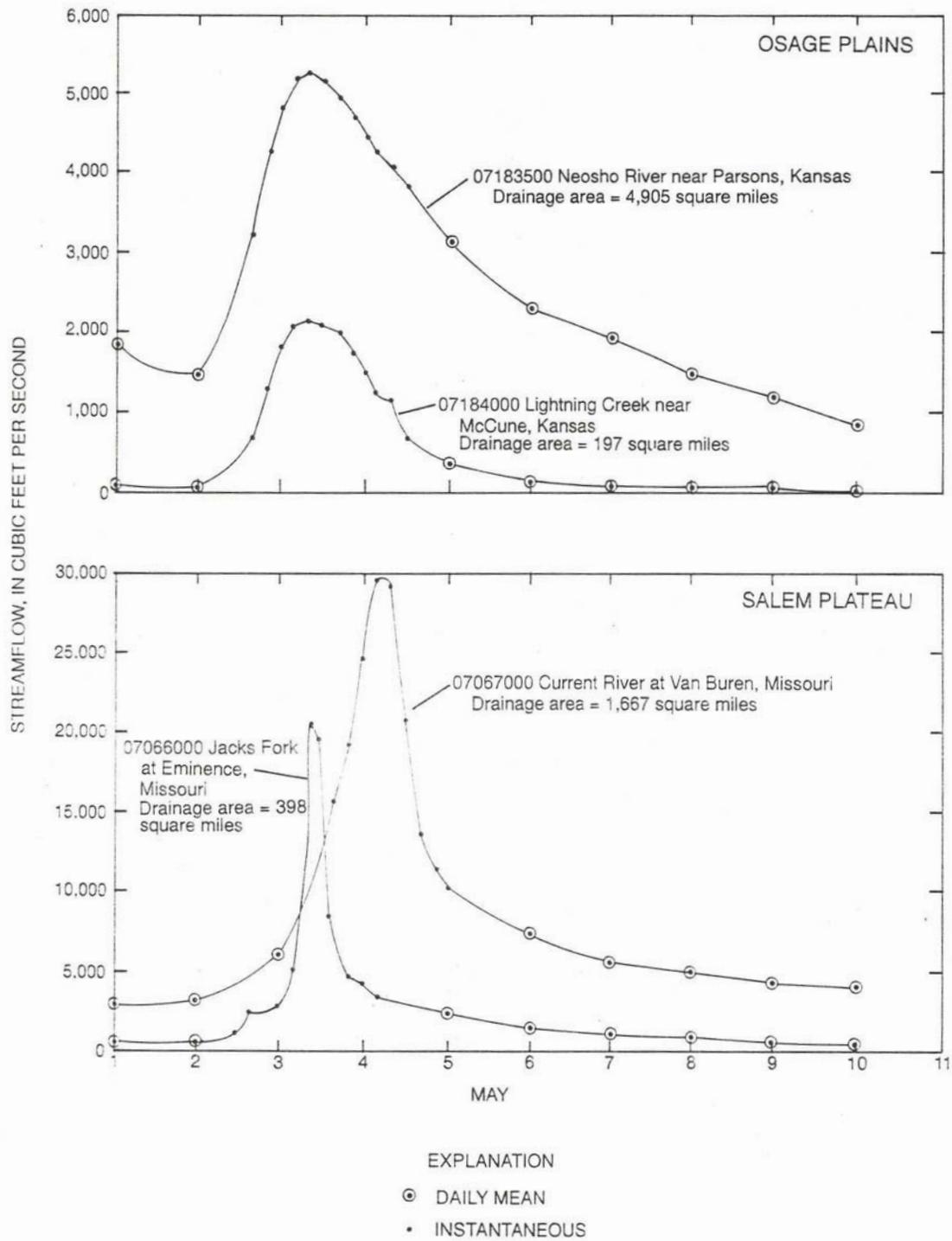
EXPLANATION

- 14 - LINE OF EQUAL RUNOFF—Interval 1 and 2 inches
- STUDY-UNIT BOUNDARY

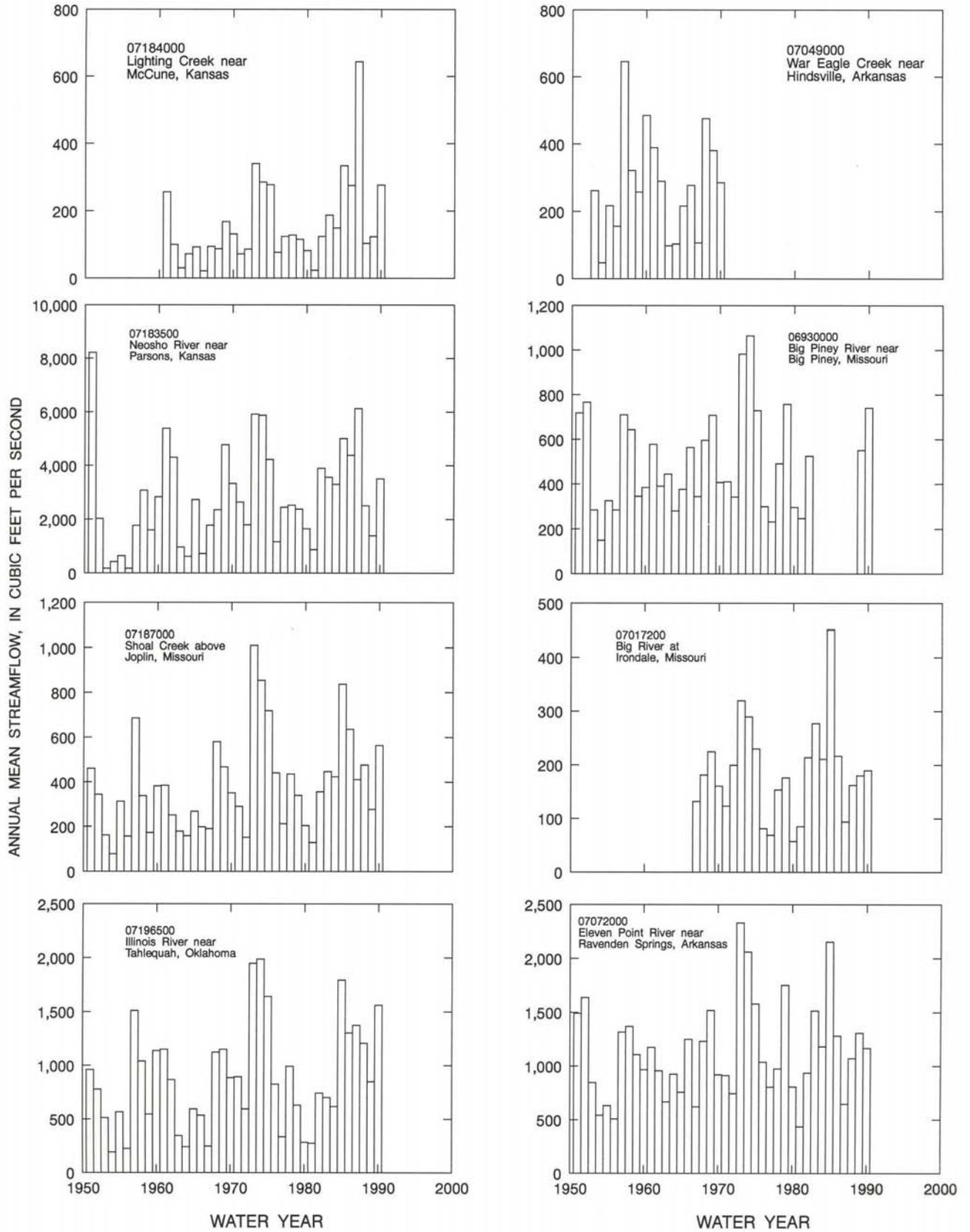
Figure 23. Mean annual runoff in the Ozark Plateaus study unit, 1951-80.



**Figure 24.** Location of selected streamflow-gaging stations in the Ozark Plateaus study unit.



**Figure 25.** Streamflow at Neosho River near Parsons, Lightning Creek near McCune, Current River at Van Buren, and Jacks Fork at Eminence, May 1-10, 1990.



**Figure 26.** Annual mean streamflow for selected stations in the Ozark Plateaus study unit.

ences in evapotranspiration and precipitation. Potential evapotranspiration is much lower during October through March (about 6 to 10 in.) than in April through September (about 37 to 42 in.; Dugan and Peckenpough, 1985). Evapotranspiration probably has a greater effect than precipitation on low flow. For example, in northwestern Arkansas, January and February generally are the driest months (Freiwald, 1985), but streamflows generally are lowest in August and September when evapotranspiration rates are higher (fig. 27). Maximum monthly precipitation and streamflow in this area generally occurs in March through May.

The interaction between surface- and ground-water flow systems is a function of factors such as geology, soil type, and topography and can differ substantially between basins and between physiographic sections or areas. In general, interaction is less in the Osage Plains, Boston Mountains, and St. Francois Mountains and greater in the Springfield Plateau, Salem Plateau, and Mississippi Alluvial Plain. The amount of interaction generally can be characterized by flow-duration curves, dye-tracing and seepage-run studies, and ground-water level information. Streams with sustained dry-season flow (base flow) have a large ground-water contribution to streamflow and streams with little or no dry-season flow receive relatively little ground water and in some instances lose water to the ground-water system.

Interaction between the surface- and ground-water flow systems in the Osage Plains is rather limited and streams in the area have little base flow. Flow-duration curves for streams in the Osage Plains have relatively steep slopes, indicating extremely variable streamflow largely from surface runoff (Hedman and others, 1987). These streams are not well-sustained by ground-water discharge during periods of little rainfall because they are underlain by relatively impermeable shales and sandstones. Ground-water levels in the Osage Plains generally do not fluctuate substantially with season (except where affected by pumping), which indicates that vertical recharge of the ground water is limited (Gann and others, 1974).

Interaction between the surface- and ground-water flow systems also is limited in the Boston Mountains. Flow-duration curves for streams in the Boston Mountains indicate extremely variable streamflow, largely from surface runoff (Hedman and others, 1987). No streams in the Boston Mountains are perennial (Hunrichs, 1983) and few springs exist.

Surface- and ground-water flow system interaction also is limited in the St. Francois Mountains. Flow-duration curves (Hedman and others, 1987) for gaging stations on some streams in this area are similar to flow-duration curves for stations on streams in the Osage Plains and Boston Mountain; curves for stations on other streams are intermediate between the Osage Plains and Boston Mountain curves and curves typical of the Springfield and Salem Plateaus. Few springs exist in areas in the St. Francois Mountains underlain by igneous rocks.

Interaction between the surface- and ground-water flow systems is much greater in the Springfield and Salem Plateaus than in the Osage Plains, Boston Mountains, and St. Francois Mountains. Flow-duration curves for streams in these areas have relatively flat slopes, indicating a well-sustained flow from surface- or ground-water storage (Hedman and others, 1987). Streams in the Salem Plateau north of the Osage River generally have less base flow than streams south of the Osage River. Seasonal ground-water level fluctuations typically are greater in the Springfield and Salem Plateaus than in the Osage Plains, indicating that solution openings are well developed and that recharge occurs locally (Gann and others, 1974). Freiwald (1987), in a study of streamflow gain and loss for several streams in northern Arkansas, determined that for most of the length of the studied streams in the Springfield and Salem Plateaus, these streams were gaining streamflow through ground-water contributions. Short reaches where the streams recharge the ground-water system through losing stream channels also were identified. In Missouri, many basins or stream reaches exist where substantial quantities of flow are known to be lost to the subsurface drainage, particularly in the Eleven Point, Current, and Meramec River Basins (Gann and others, 1976). Dye-tracing studies indicate that interbasin transfers are common.

A moderate amount of interaction occurs between the surface- and ground-water flow systems in the Mississippi Alluvial Plain. Flow-duration curves for streams in this area of the study unit have relatively flat slopes, indicating a well-sustained flow from surface- or ground-water storage (Hedman and others, 1987). Model simulations indicate that the Black River is a losing river in southern Missouri and northern Arkansas but is a gaining river in most of its length downstream from the mouth of the Current River (Ackerman, 1989, p. 66). Water levels at some locations in the alluvial aquifer are known to fluctuate with

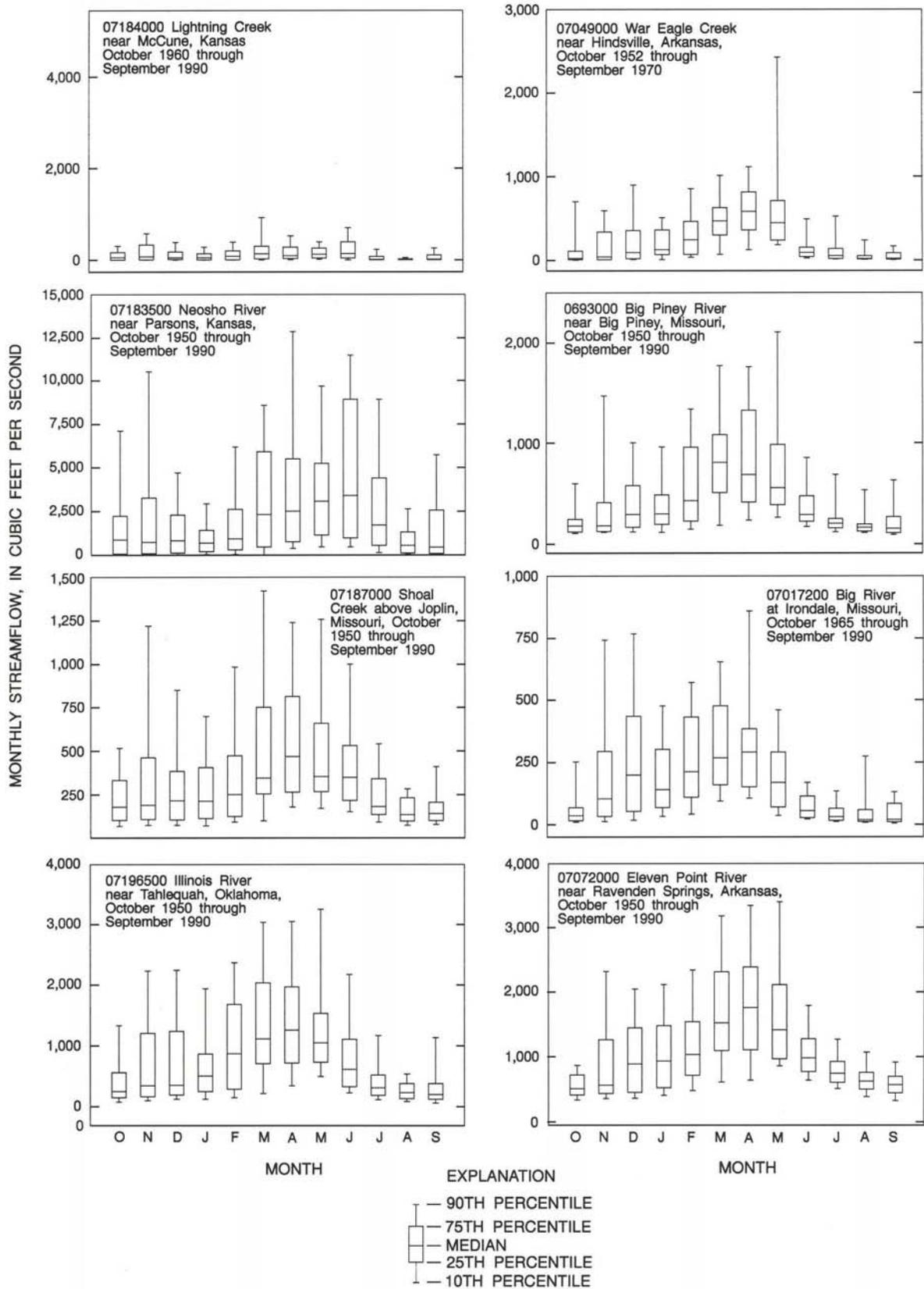


Figure 27. Monthly streamflow variations for selected stations in the Ozark Plateaus study unit.

streamflow (Albin and others, 1967; Lamonds and others, 1969).

## Water Quality

The ambient or natural water quality of streams and rivers in the study unit differ as a result of differences in geology and physiography in the basins and differences in the amount of surface- and ground-water interaction. Typical ranges of selected water-quality characteristics of streams in the study unit are listed by physiographic section or area in table 5. These data have been compiled from reports by Lamonds (1972), Gann and others (1974; 1976), Stoner (1981), Bennett and others (1987), and Petersen (1988) and from USGS water-quality computer files. These ranges are typical of characteristics in relatively large streams and rivers during periods of near average flow. Water-quality characteristics during periods of low or high flow would likely be substantially different from those presented in table 5. Only water-quality data for streams and rivers “relatively unaffected” by human activities were used to calculate these ranges. Because of agricultural activities and higher population density in the Osage Plains and Springfield Plateau, a “relatively unaffected” stream in these two areas probably is more affected by human activities than streams in other areas.

Streams in the Osage Plains generally are the most mineralized streams in the study unit. Water in Osage Plains streams typically is a calcium bicarbonate type with substantial amounts of sodium, magnesium, and sulfate. Sulfate concentrations in Osage Plains streams and rivers generally are 5 to 10 times higher than those in most other streams and rivers in the study unit; chloride concentrations are about 2 times higher than concentrations in most other streams.

Streams in the Boston Mountains generally are the least mineralized streams in the study unit; dissolved-solids concentrations in water in those streams commonly are one-fifth to one-half of the dissolved-solids concentrations in water from streams in other areas. Water in these streams generally is a calcium bicarbonate type and commonly is more acidic and has lower buffering capacity (lower alkalinity) than water in streams from other areas. Nutrient concentrations (for example, nitrite plus nitrate) are relatively low. Nutrient concentrations in water from streams in the Boston Mountains generally are among the lowest nutrient concentrations for Arkansas streams (Petersen, 1988).

Water-quality values for streams and rivers in the Springfield and Salem Plateaus typically are quite similar. However, dissolved-solids concentrations and alkalinity are somewhat lower in water from some streams in the Springfield Plateau than in water from streams in the Salem Plateau. Most of the streams with relatively low dissolved-solids concentrations in water flow from the Boston Mountains into the Springfield

**Table 5.** Typical ranges of selected physical and chemical characteristics of surface water in the Ozark Plateaus study unit

[Ranges shown represent median values for individual stations. Water quality of small streams might not be reflected by these data. Individual medians that were considered to be outliers are not included in these ranges; mg/L, milligrams per liter; CaCO<sub>3</sub>, calcium carbonate]

Physiographic section or area	Dissolved solids (mg/L)	pH (units)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Alkalinity <sup>1</sup> (mg/L as CaCO <sub>3</sub> )	Nitrite plus nitrate, total as nitrogen (mg/L)
Osage Plains	220-280	7.4-7.8	8-20	20-45	140-210	0.1 -0.9
Boston Mountains	40-60	6.8-7.3	3-5	5-10	15-20	.05-.2
Springfield Plateau	100-200	7.5-8.0	4-10	5-10	100-175	.2-1.5
Salem Plateau <sup>2</sup>	150-210	7.5-8.1	2-8	3-12	150-200	.2-.8
St. Francois Mountains	110-130	7.5-8.0	2-5	8-17	75-110	.1-.3
Mississippi Alluvial Plain	140-170	7.9-8.0	3-5	4-8	110-150	.1-.3

<sup>1</sup> Alkalinity as CaCO<sub>3</sub> can be converted to bicarbonate (HCO<sub>3</sub>) by multiplying by 1.22.

<sup>2</sup> Values not included for streams in the St. Francois Mountains.

Plateau. Water in most streams in the Springfield Plateau is a calcium bicarbonate type, and water in most streams in the Salem Plateau is a calcium magnesium bicarbonate type. Nitrite plus nitrate nitrogen concentrations in some Springfield Plateau streams that are relatively unaffected by human activities are higher than concentrations in most Salem Plateau streams. Population and land-use differences between the Springfield and Salem Plateaus indicate that the water quality of streams in the Springfield Plateau is more likely to be affected by human activities than is water quality of streams in the Salem Plateau.

Streams in the St. Francois Mountains are more mineralized than streams in the Boston Mountains but less mineralized than many streams in the rest of the study unit. Dissolved-solids concentrations of water from the southward-flowing streams draining the St. Francois Mountains commonly are about 120 mg/L and dissolved sulfate concentrations commonly range from about 8 to 17 mg/L. Water in streams in the St. Francois Mountains typically is a calcium magnesium bicarbonate type. Nitrite plus nitrate nitrogen concentrations in streams in the St. Francois Mountains are the lowest in the study unit with the exception of streams in the Boston Mountains and Mississippi Alluvial Plain.

The quality of the water in the larger streams in the part of the study unit in the Mississippi Alluvial Plain is similar to the quality of water in streams in the Salem Plateau because a large part of the drainage area of these streams is within the Salem Plateau. Streams in this area generally contain a calcium magnesium bicarbonate water with dissolved-solids concentrations commonly between 140 and 170 mg/L.

## **GROUND WATER**

Ground water is an abundant resource in most of the Ozark Plateaus study unit. Ground water is present in intergranular pore spaces and in fractures of the sandstones, limestones, and dolomites (Imes and Emmett, 1994).

Ground-water divides in the shallow aquifers generally coincide with topographic divides. Ground-water level altitudes are highest in the Boston Mountains and along the major topographic ridge extending across southern Missouri, which form regional ground-water divides. Ground water flows away from these regional divides; water flowing in the deep part of the aquifer system discharges into the major rivers of the

area (fig. 28). Ground water moving through the shallow part of the aquifer system follows short (usually less than 10 mi), local flow paths that terminate at nearby streams (Imes and Emmett, 1994).

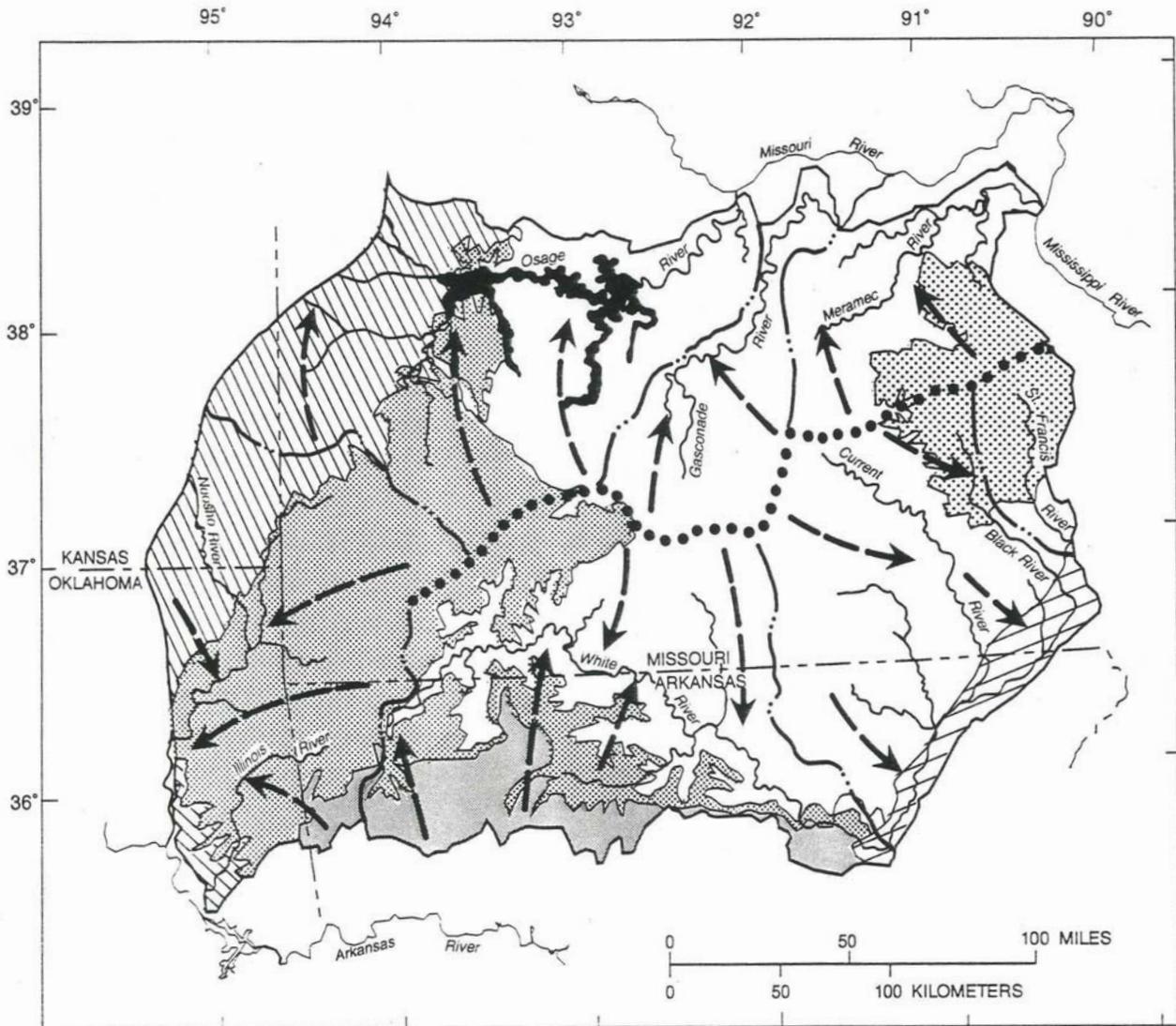
Regional boundaries for the ground-water flow system in the Ozark Plateaus study unit and adjacent areas include the Missouri and Mississippi Rivers to the north and northeast, respectively. To the southeast, ground water discharges into the unconsolidated sediments of the Mississippi Alluvial Plain. The topographic divide along the crest of the Boston Mountains forms the southern boundary. The western boundary is formed by a broad, topographically low area where freshwater mixes with saline water along the transition zone between the Ozark Plateaus aquifer system and the Western Interior Plains aquifer system (Imes and Emmett, 1994).

## **Hydrogeology**

The ground-water system in the Ozarks Plateaus study unit can be divided into seven major regional hydrogeologic units based on relative rock permeabilities and well yield. The hydrogeologic units consist of three main aquifers and four confining units that coincide with the major geologic units and physiographic sections of the study unit (fig. 7). These units include the Western Interior Plains confining system, the Springfield Plateau aquifer, the Ozark confining unit, the Ozark aquifer, the St. Francois confining unit, the St. Francois aquifer, and the Basement confining unit (fig. 29). The middle five units comprise the Ozark Plateaus aquifer system, and are confined above and below by the Western Interior Plains confining system and the Basement confining unit, respectively (fig. 30; Imes and Emmett, 1994). The unconsolidated sediments of Post-Paleozoic age in the Mississippi Alluvial Plain are productive aquifers in a small part of the study unit, but the ground-water resources of these sediments will not be discussed in this report.

### **Western Interior Plains Confining System**

The Western Interior Plains confining system coincides with parts of two physiographic sections--the Boston Mountains in the southern part of the study unit and the Osage Plains in the western part of the study unit (fig. 29). Rocks of late Mississippian to Pennsylvanian age form the confining system (fig. 7). Equivalent,

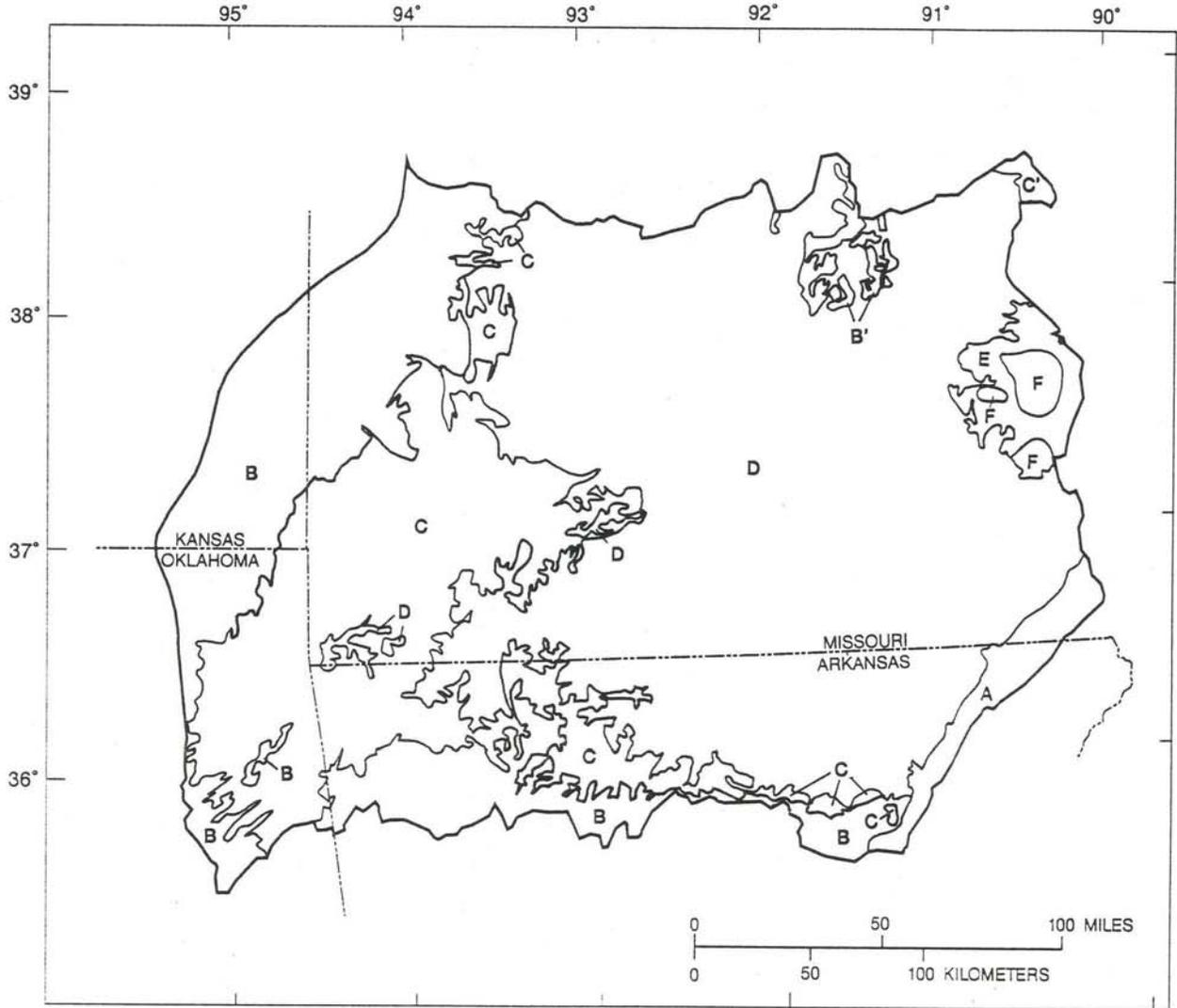


Modified from Imes and Emmett, 1994

EXPLANATION

- |  |   |
|--|---|
|  OSAGE PLAINS               |  GENERALIZED DIRECTION OF REGIONAL GROUND-WATER FLOW |
|  BOSTON MOUNTAINS           |  GROUND-WATER DIVIDE                                 |
|  SPRINGFIELD PLATEAU        |  RIVER BASIN BOUNDARY                                |
|  SALEM PLATEAU              |  STUDY-UNIT BOUNDARY                                 |
|  ST. FRANCOIS MOUNTAINS     |   |
|  MISSISSIPPI ALLUVIAL PLAIN |   |

Figure 28. Generalized regional ground-water flow directions in the Ozark Plateaus study unit.

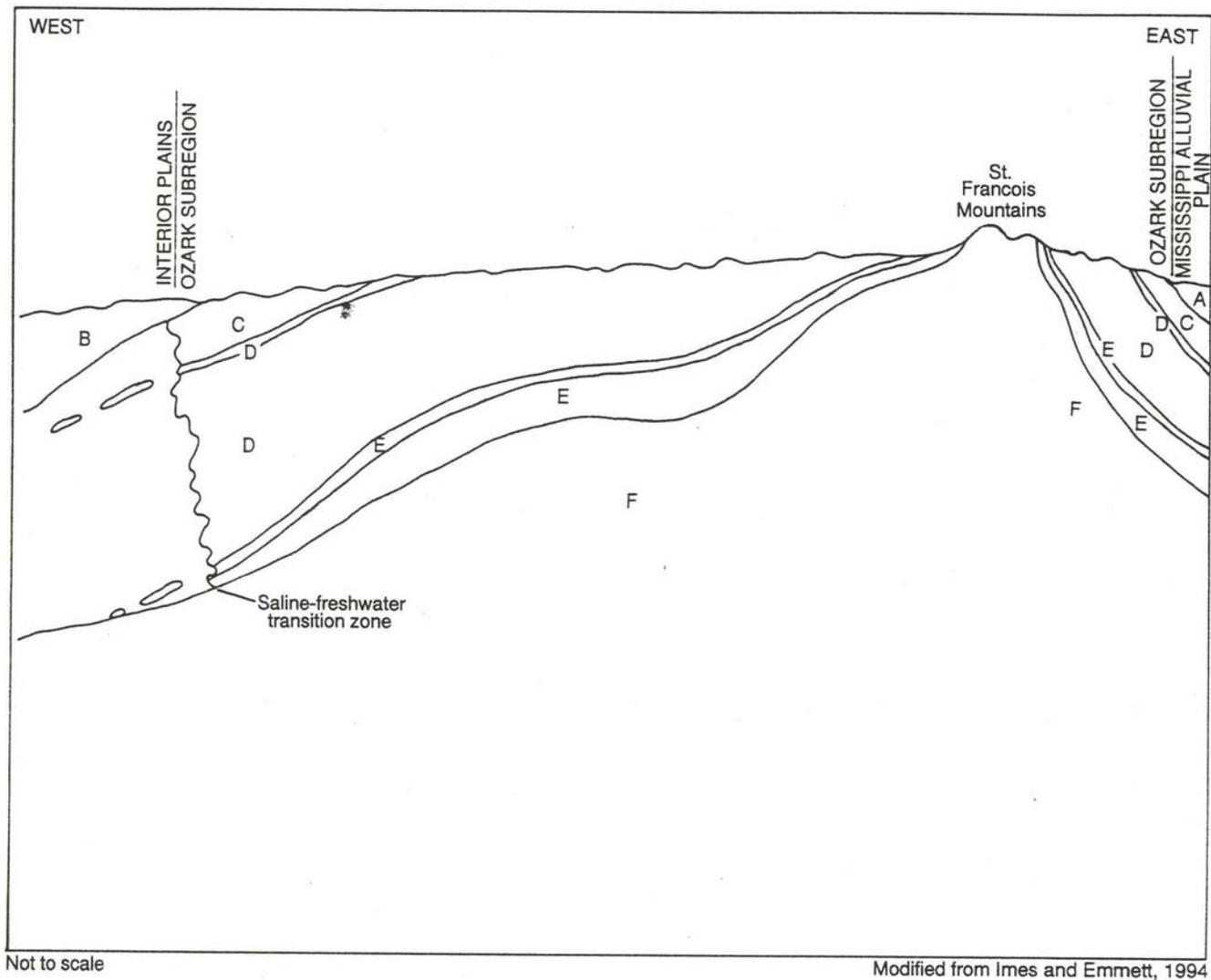


Modified from Imes, 1990a

EXPLANATION

- |   |  |
|---|--|
| <p><b>A</b> UNCONSOLIDATED SEDIMENTS (MISSISSIPPI ALLUVIAL PLAIN)</p> <p><b>B</b> WESTERN INTERIOR PLAINS CONFINING SYSTEM</p> <p><b>B'</b> ROCKS OF PENNSYLVANIAN AGE—Geologically similar to, but hydraulically separate from the Western Interior Plains confining system</p> <p><b>C</b> SPRINGFIELD PLATEAU AQUIFER</p> <p><b>C'</b> ROCKS OF MISSISSIPPIAN AGE—Geologically similar to, but hydraulically separate from the Springfield Plateau aquifer</p> | <p><b>D</b> OZARK AQUIFER AND CONFINING UNIT</p> <p><b>E</b> ST. FRANCOIS AQUIFER AND CONFINING UNIT</p> <p><b>F</b> BASEMENT CONFINING UNIT</p> <p>— HYDROGEOLOGIC-UNIT BOUNDARY</p> <p>— STUDY-UNIT BOUNDARY</p> |
|---|--|

Figure 29. Location of hydrogeologic units in the Ozark Plateaus study unit.



- EXPLANATION
- A UNCONSOLIDATED SEDIMENTS  
(MISSISSIPPI ALLUVIAL PLAIN)
  - B WESTERN INTERIOR PLAINS  
CONFINING SYSTEM
  - C SPRINGFIELD PLATEAU AQUIFER
  - D OZARK AQUIFER AND CONFINING UNIT
  - E ST. FRANCOIS AQUIFER AND CONFINING  
UNIT
  - F BASEMENT CONFINING UNIT

**Figure 30.** Generalized hydrogeologic section showing stratigraphic relations of regional hydrogeologic units in the Ozark Plateaus study unit.

but hydraulically unconnected, rocks are present in the north-central part of the study unit (Imes and Emmett, 1994).

Altitude of the top of the confining system ranges from 800 to 1,000 ft above sea level in the Osage Plains, and from 1,000 to more than 2,000 ft above sea level in the Boston Mountains. The system is from 40 to 800 ft thick in the Osage Plains, but averages between 1,500 and 2,000 ft in thickness in the Boston Mountains (Imes, 1990g).

Lithologies in this regional confining system include relatively permeable sandstone and limestone beds separated by thick layers of impermeable shale that result in an overall low permeability. Hydraulic conductivities generally range from 0.001 to 0.01 ft/d depending upon thickness and shale content (Imes and Emmett, 1994).

Yields of wells in western Missouri range from 1 to 40 gal/min. Specific capacities of these wells range from 0.1 to 3 gal/min/ft (gallons per minute per foot; Kleeschulte and others, 1985). Yields of 16 wells completed in this confining system in northwestern Arkansas range from 2.5 to 19 gal/min (Imes and Emmett, 1994).

### **Springfield Plateau Aquifer**

The Springfield Plateau aquifer, where it is unconfined, coincides with the Springfield Plateau (fig. 29). It consists of limestones and cherty limestones of Mississippian age (fig. 7). In northeastern Oklahoma, the aquifer includes the Moorefield Formation, which elsewhere is shaly. The aquifer is confined by the Western Interior Plains confining system where it underlies the Boston Mountains and Osage Plains (Imes and Emmett, 1994).

Altitude of the top of the aquifer ranges from about 200 ft to 1,600 ft above sea level where the aquifer crops out and is unconfined. Dip of the beds generally is about 11 ft/mi. Thickness of the aquifer ranges from about 100 ft in south-central Missouri to about 400 ft in southeastern Kansas (Imes, 1990f).

The configuration of the potentiometric surface of the unconfined Springfield Plateau aquifer generally reflects the overlying topography. Ground-water levels range from 700 ft above sea level in west-central Missouri to more than 1,400 ft above sea level in southwestern Missouri. The unconfined Springfield Plateau aquifer is recharged nearly everywhere by precipitation. Ground water flows mostly laterally and then dis-

charges in springs and seeps along streams. Where the aquifer is confined, it is recharged by lateral flow from the outcrop areas, and by seepage from the overlying Western Interior Plains confining system (Imes and Emmett, 1994).

Fracturing and dissolution of the limestone units in the Springfield Plateau results in karst features, such as sinkholes and caves, and the aquifer is characterized by high secondary porosity and relatively high permeability. Karst features and springs are more abundant in the nonchert-bearing limestones, such as the St. Joe Member of the Boone Formation, than in the chert-bearing limestones.

The Springfield Plateau aquifer is anisotropic and heterogenous, but average horizontal hydraulic conductivity is estimated to be about 22 ft/d. Horizontal hydraulic conductivity is about an order of magnitude greater than vertical hydraulic conductivity. Average transmissivity ranges from about 1,700 to 8,600 ft<sup>2</sup>/d and increases with aquifer thickness (Imes and Emmett, 1994).

Wells drilled into the Springfield Plateau aquifer generally have yields of less than 20 gal/min; therefore, most wells are used primarily for domestic water supply and for watering livestock. However, several industrial wells completed in this aquifer in southwestern Missouri yield 300 to 400 gal/min (Imes and Emmett, 1994).

### **Ozark Confining Unit**

The Ozark confining unit consists of rocks of Devonian and Mississippian age from the Chattanooga Shale through the Northview Shale and Chouteau Limestone (fig. 7). The confining unit consists mostly of shales and dense limestones that crop out along the Eureka Springs Escarpment in southwestern Missouri and northwestern Arkansas and underlie much of the Springfield Plateau aquifer (fig. 29). The Ozark confining unit averages about 60 to 80 ft in thickness, but locally is as much as 120 ft thick in southeastern Kansas (Imes, 1990e).

Shales and dense limestones in the Ozark confining unit hydraulically separate the overlying Springfield Plateau aquifer from the underlying Ozark aquifer. Shale content ranges from about 10 to 100 percent in much of northwestern Arkansas. Shale is missing from the unit in parts of southwestern Missouri, northeastern Oklahoma, and southeastern Kansas (Imes, 1990e). Differences in water levels of about 50

ft between the Springfield Plateau and the Ozark aquifers indicate that, even where the shale is missing, low vertical hydraulic conductivity of the dense limestones effectively separates the two hydrogeologic units (Imes and Emmett, 1994).

### **Ozark Aquifer**

The Ozark aquifer, which consists of a thick sequence of dolomites, sandstones, limestones, and shales (fig. 7), crops out in the Salem Plateau in south-central Missouri and northern Arkansas (fig. 29). The highest altitude of the top of the aquifer is about 1,500 ft above sea level in south-central Missouri. Altitudes of the top of the aquifer decrease to 300 ft above sea level near the eastern boundary of the study unit, to about sea level near the western boundary, and to nearly 2,000 ft below sea level near the southern boundary (Imes, 1990d).

Aquifer thickness ranges from about 300 ft in northeastern Oklahoma to nearly 4,000 ft in northern Arkansas. However, aquifer thickness averages between 1,500 and 2,000 ft throughout much of the study unit (Imes, 1990d).

The configuration of the potentiometric surface of the unconfined Ozark aquifer generally mimics the overlying topography. Ground-water levels in wells completed in this aquifer average about 700 to 1,000 ft above sea level over much of the Salem Plateau, but are as much as 1,400 ft above sea level in south-central Missouri (Imes, 1990d). Precipitation recharges the unconfined Ozark aquifer nearly everywhere. Ground water flows mostly laterally from the higher altitudes to points of discharge in springs and seeps along streams. The confined part of the Ozark aquifer is recharged by lateral ground-water flow from the unconfined area, and, in places, by seepage from the overlying confining unit (Imes and Emmett, 1994).

The Ozark aquifer is subdivided into five zones based on lithology and permeability. Stratigraphically, the lowest zone is also the thickest, most permeable, and most areally extensive. The lowermost zone includes the highly permeable Potosi and Gasconade Dolomites and the Roubidoux Formation (fig. 7). The second and third permeable zones above the base of the aquifer include units from the Everton Formation through the Plattin Limestone and the Kimmswick and Fernvale Limestones, respectively. The next highest zone is a local confining unit consisting of the Cason and Sylvan Shales. The uppermost permeable zone in-

cludes the Brassfield Limestone through Clifty Limestone and the Callaway Limestone and Sallisaw Formation (Imes and Emmett, 1994).

As with the Springfield Plateau aquifer, fracturing and dissolution of the rock units comprising the aquifer have resulted in a high degree of secondary porosity and permeability. Hydraulic properties of the aquifer are anisotropic and heterogeneous, but horizontal hydraulic conductivity commonly ranges from 0.001 to 86 ft/d. Yields of wells tapping most of the units range from 50 to 100 gal/min, but can be as much as 500 or 600 gal/min in the Roubidoux Formation or the Potosi Dolomite (Imes and Emmett, 1994).

Perched aquifers exist locally where permeable layers are interbedded with impermeable layers. Ground water in these perched aquifers overlies the regional aquifer and sometimes flows through separate cave and fracture systems, making it difficult to determine local ground-water flow directions (Imes and Emmett, 1994).

Losing streams are common in areas overlying the Ozark aquifer. These streams are sources of recharge to the ground-water system. Results from ground-water dye-tracing studies indicate that water recharging the aquifer from the losing streams can discharge in springs in adjacent drainage basins. This is possible because, on a local scale, ground-water divides do not always coincide with surface-water divides (Harvey and others, 1983).

Dissolution of rocks resulting in increased secondary porosity is greater in the Ozark aquifer than in the Springfield Plateau aquifer. The rocks of the Ozark aquifer consist primarily of the mineral dolomite and those of the Springfield Plateau aquifer consist primarily of the mineral calcite. Although the dissolution kinetics of dolomite are slower than those of calcite (Hess and White, 1989), the dolomites of the Salem Plateau have dissolved faster than the calcite limestones of the Springfield Plateau, as evidenced by the numerous sinkholes (fig. 6) and losing streams in the Salem Plateau.

Dissolution of the rocks which comprise the Ozark aquifer allows deep circulation of the ground water. In south-central Missouri, municipal wells are from 1,300 to 1,500 ft deep and commonly are cased to depths of 950 to 1,000 ft. Despite the depth of these wells, water in some of the wells becomes turbid after a rainstorm, indicating that surface-recharged water rapidly circulates deep within the aquifer (Harvey, 1980).

### **St. Francois Confining Unit**

The St. Francois confining unit hydraulically separates the Ozark aquifer from the underlying St. Francois aquifer (fig. 7; fig. 30). It consists of shales, siltstones, and dolomites of Late Cambrian age, which crop out around the St. Francois Mountains. The unit dips quaquaversally away from its outcrop area. It attains a maximum thickness of 750 ft in parts of Missouri and northern Arkansas. This confining unit is missing in parts of northwestern Arkansas, west-central Missouri, and northeastern Oklahoma (Imes, 1990c).

Maximum shale content of the unit is about 30 percent in the study unit (Imes, 1990c). In places where shale units are thin or missing, impermeable siltstones and dolomites confine the St. Francois aquifer (Imes and Emmett, 1994).

### **St. Francois Aquifer**

The St. Francois aquifer consists of the Lamotte and Reagan Sandstones and the Bonneterre Dolomite of Late Cambrian age, which crop out in the St. Francois Mountains (fig. 7; fig. 29). These units are used as a ground-water resource where they are unconfined, but are rarely used where overlain by the thicker Ozark aquifer. Thickness of the St. Francois aquifer is as much as 900 ft in Missouri and as much as 500 ft in northern Arkansas. Yields of wells completed in this aquifer commonly range from 100 to 500 gal/min (Imes, 1990b).

Permeability of the aquifer is due somewhat to intergranular porosity (primary porosity) in the loosely cemented sandstones, but is due mostly to secondary porosity in the dolomites as a result of fracturing and dissolution. Permeability data are sparse because the aquifer is rarely used, but the few available data indicate that horizontal hydraulic conductivity ranges from 0.1 to 8.6 ft/d. Transmissivity ranges from 8.6 to 860 ft<sup>2</sup>/d (Imes and Emmett, 1994).

### **Basement Confining Unit**

The Basement confining unit consists mostly of igneous rocks of Precambrian age, which underlie the study unit and crop out in the core of the St. Francois Mountains (fig. 7; fig. 29). These rocks are locally used as a ground-water resource where they crop out. The igneous rocks are relatively impermeable; however, some secondary permeability is generated from frac-

tures in the rocks. Yields of wells completed in this confining unit are as large as 70 gal/min in some wells, but generally are less than 10 gal/min (Imes and Emmett, 1994).

### **Water Quality**

Differences in ground-water quality exist not only between different aquifers, but also within the same aquifer (table 6). Water type and concentrations of dissolved solids and various chemical constituents can differ among the aquifers, and between confined and unconfined parts of the same aquifer. In general, the predominant water type in the Springfield Plateau, Ozark, and St. Francois aquifers, where they are unconfined, is calcium bicarbonate or calcium magnesium bicarbonate (Imes and Davis, 1990a, b; 1991). Calcium is the dominant cation in the ground water of limestone aquifers, whereas, calcium and magnesium are the dominant cations in the ground water of dolomite aquifers. Bicarbonate generally is the dominant anion in water from all three carbonate aquifers; however, sulfate is the dominant anion in water from these aquifers in some areas (Imes and Davis, 1990a, b; 1991). Where the Springfield Plateau and Ozark aquifers are confined near the western boundary of the study unit the predominant water type in these aquifers generally is sodium chloride. No data are available to indicate the water type of the St. Francois aquifer near the western boundary (Imes and Davis, 1990a). The predominant water type in the Western Interior Plains confining system in the Boston Mountains is calcium sodium bicarbonate (Lamonds, 1972). Water type in the Osage Plains section of this confining system is sodium chloride (Klee-schulte and others, 1985).

Dissolved-solids and chloride concentrations in ground water in the study unit can vary by several orders of magnitude (table 6). In water from the Springfield Plateau and Ozark aquifers, dissolved-solids concentrations generally ranged from 200 to 300 mg/L, and chloride concentrations generally ranged from 5 to 10 mg/L. Concentrations of dissolved solids and chloride in water from these aquifers generally increased where the aquifers are confined, particularly along the western boundary. Dissolved-solids concentrations in ground water in the Western Interior Plains confining system ranged from about 20 to 200 mg/L in the Boston Mountains (Lamonds, 1972) but are much higher in other areas. Ground-water samples from 10 wells com-

**Table 6.** Water type and typical ranges of selected physical and chemical characteristics of ground water in the Ozark Plateaus study unit [Water type, cationic and anionic species that each contribute 50 percent or more of total cation or anion concentrations, respectively; mg/L, milligrams per liter; Ca, calcium; Na, sodium; HCO<sub>3</sub>, bicarbonate; Cl, chloride; SO<sub>4</sub>, sulfate; Mg, magnesium; --, no data; all data from Imes and Davis (1990a; b; 1991) unless otherwise indicated]

Hydrogeologic unit	Water type	pH <sup>1</sup>	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Bicarbonate <sup>2</sup> , dissolved (mg/L)	Dissolved solids (mg/L)
Western Interior Plains confining system <sup>3</sup>	CaNaHCO <sub>3</sub> , NaCl	5.2-8.0	--	--	--	20-30,000
Springfield Plateau aquifer	CaHCO <sub>3</sub> , CaSO <sub>4</sub> , NaCl	5.2-8.3	<1-1,000	<1-1,000	110-320	<200-5,000
Ozark aquifer	CaMgHCO <sub>3</sub> , NaCl	7.0-7.2	<1-1,000	<1-500	166-352	<200-10,000
St. Francois aquifer	CaMgHCO <sub>3</sub> , CaSO <sub>4</sub>	--	<5-60	<5-100	--	<100-500

<sup>1</sup>From Adamski (1987), Harvey (1980), and Smith and Steele (1990).

<sup>2</sup>From Feder (1979).

<sup>3</sup>From Kleeschulte and others (1985), Lamonds (1972), and Steele (1983).

pleted in the Osage Plains section of this confining system in west-central Missouri had dissolved-solids concentrations that ranged from 1,000 to 3,000 mg/L (Kleeschulte and others, 1985). The pH of ground water in the study unit ranged from 5.2 to 8.3.

Sulfate concentrations in water in the Springfield Plateau, Ozark, and St. Francois aquifers can vary by several orders of magnitude (table 6), but typically are 5.0 to 20.0 mg/L. The highest sulfate concentrations in ground water in the Springfield Plateau aquifer generally are present in southwestern Missouri and southeastern Kansas. The highest sulfate concentrations in water in the Ozark aquifer generally are in the area just north of the St. Francois Mountains and where the aquifer is confined by shales of Pennsylvanian age (Imes and Davis, 1991). Sulfate concentrations of as much as 120 mg/L were present in water from the Ozark aquifer in southwestern Missouri and southeastern Kansas where the aquifer is confined (Imes and Davis, 1990b). The area of elevated sulfate concentrations in water from the Ozark aquifer approximately coincides with the area of elevated sulfate concentration in water from the Springfield Plateau aquifer and could indicate seepage between the aquifers through the Ozark confining unit.

Elevated nitrate concentrations are present in ground water from the unconfined Springfield Plateau

and Ozark aquifers in some areas of the study unit (Harvey, 1980; Harvey and others, 1983; Leidy and Morris, 1990). The geometric means of nitrate concentrations in water from the Springfield Plateau and Ozark aquifers in southern Missouri are about 2.4 and 3.4 mg/L, respectively (Feder, 1979). Nitrate concentrations in water from the Springfield Plateau aquifer where it is unconfined ranged from about 0.01 to 46 mg/L. Nitrate concentrations in water from the Ozark aquifer where it is unconfined ranged from about 0.3 to 14 mg/L (Feder, 1979).

Data indicate that water in parts of the unconfined Springfield Plateau aquifer in northwestern Arkansas contains fecal bacteria. Of 70 water samples collected from wells in this area, analyses indicate that 67 percent contained coliform bacteria in concentrations of 1 colony per 100 mL (milliliters) of sample or greater and 51 percent contained fecal streptococcus bacteria in concentrations of 1 colony per 100 mL of sample or greater (Ogden, 1980).

Radionuclides are present in water from the Ozark aquifer in some areas within the study unit. Gross alpha radioactivity ranged from 1.2 to 7.1 pCi/L (picocuries per liter) in eight water samples collected from the confined Ozark aquifer in southwestern Missouri (Feder, 1979). Gross alpha activity exceeded the U.S. Environmental Protection Agency's MCL for

drinking water of 15 pCi/L in 11 of 26 water samples from the Roubidoux Formation (Ozark aquifer) in northeastern Oklahoma. Radium-226 concentrations ranged from 0.5 to 11.0 pCi/L in 58 wells completed in the Ozark aquifer (Imes and Emmett, 1994). The combined radium-226 and -228 activity ranged from 5.1 to 13.9 pCi/L in 18 water samples from public-supply wells in Missouri in 1983, and from 4.9 to 12.8 pCi/L in samples from several public-supply wells in northern Arkansas in 1987-89. Depths of these wells ranged from 250 to more than 1,700 ft below land surface. The MCL for combined radium-226 and -228 is 5 pCi/L (U.S. Environmental Protection Agency, 1988).

## **FACTORS THAT AFFECT WATER QUALITY**

Water quality in the Ozark Plateaus study unit is affected by various environmental factors. Climate, physiography, geology, soil type, population, land use, and water use directly and indirectly affect the water quality of the study unit. Additionally, these factors are not independent. This section will briefly describe how these factors interact to effect a geochemical evolution of the water as it flows in the streams and aquifers of the study unit.

### **Climate**

Several climatic factors interact with physiographic, geologic, land use, and population factors to affect water quality in the Ozark Plateaus study unit. Streamflow is strongly affected by precipitation and evapotranspiration; seasonal patterns in precipitation and evapotranspiration cause seasonal variations in streamflow, which cause seasonal variations in quality of surface water and some ground water. Air temperature affects water temperature, which in turn affects reaeration rates, dissolved oxygen and carbon dioxide equilibria, and biochemical reaction rates.

Concentrations of dissolved and suspended constituents in surface waters vary with flow. Concentrations of dissolved constituents in surface water generally are highest during low flows because of the larger relative contribution of ground water, and lowest during high flows because of dilution. Concentrations of suspended constituents in surface water generally are highest during high flows because of runoff from

upland areas and resuspension of stream bottom materials. A large percentage of the annual load of suspended sediment or other constituents can be transported in a stream during one or two high-flow periods.

The water quality in streams differs depending on the amount of point-source contamination entering the stream as well as streamflow conditions. For example, the quality of water in streams that receive point-source contaminant discharges will be most affected during low-flow periods because of lower volumes of streamflow to dilute the wastewater from the point source. Wastes with high biochemical oxygen demands will have the most serious effects during these periods because of reduced reaeration and, usually, high water temperatures in the stream. Stream segments that do not receive point-source wastewater discharges generally will have the highest concentrations of constituents from nonpoint sources during high-flow periods. During these high-flow periods, suspended materials can be transported into the streams where they can settle to the streambed and affect the water quality for long periods of time.

Shallow ground water can be expected to show seasonal patterns in dissolved constituent concentrations because of reduced recharge and longer residence times during periods of dry weather. Springs that are rapidly recharged from precipitation and streamflow can be expected to respond to rainstorms with increased discharge, decreased concentrations of some constituents because of dilution, and elevated concentrations of some constituents (primarily nutrients, bacteria, and suspended materials) because of the movement of these constituents from the surface into the spring system (Steele and others, 1985; Leidy and Morris, 1990).

The chemical quality of precipitation also affects the quality of surface and ground water. Precipitation that is relatively dilute and slightly acidic decreases the dissolved-solids concentration and the pH of surface water, particularly during storms and in areas such as the Boston Mountains where alkalinity is naturally low. Carbonic acid, formed by the reaction of precipitation with carbon dioxide in the atmosphere and soil, also reacts with calcite, resulting in elevated concentrations of calcium and bicarbonate ions. Precipitation contributes a substantial percentage of the sulfate in streamwater, where the natural sulfate concentrations are low and human contributions are small (Smith and Alexander, 1983).

## Physiography

Physiography affects water quality to the extent that it controls the volume and intensity of runoff during a rainstorm. In places with steep slopes and rugged topography, such as in the Boston Mountains or the Eureka Springs Escarpment, runoff after a rainstorm is greater as compared to runoff in places with relatively gentle slopes and flat topography. Increased runoff can cause erosion and increased sediment loads in nearby streams. Other surface contaminants are also more likely to be flushed into streams during rainstorms in areas with steep slopes than in areas with gentle slopes.

The karst topography throughout much of the study unit affects ground-water quality. The numerous sinkholes present in the Springfield and Salem Plateaus allow surface water to rapidly infiltrate into the subsurface and recharge the underlying shallow aquifers. Contaminants on the land surface are readily flushed into the aquifer, particularly during rainstorms. The soils that often line the bottom of sinkholes commonly are too thin to remove contaminants from water recharging the aquifer through ion adsorption or filtering (Harvey, 1980).

## Geology

Geology affects water quality through physical and geochemical processes. Ground water in the fractures and cave systems in the rocks of the study unit flows faster and generally has less interaction with the rock matrix than water in the intergranular pores spaces of the rocks. Where secondary porosity is substantial, dissolved and particulate contaminants are rapidly transported through the aquifer with minimal removal by adsorption or filtering. Furthermore, fractures and cave systems allow ground water to flow under surface-drainage divides into adjacent drainage basins, which makes determining the contaminant source or direction of migration difficult.

Geochemical processes probably are the most important natural factors that directly affect water quality on a regional scale in the study unit. The minerals and rocks of the region are the source of most dissolved constituents in the water (Harvey, 1980). Even for most streams and rivers, geochemical processes directly affect water quality during periods of low flow, when the ground-water contribution to streamflow is relatively large. These processes include, but are not limited to,

mineral dissolution, ion exchange, and oxidation-reduction reactions.

Clearly, the most important of these processes is the dissolution of carbonate minerals, such as calcite and dolomite, which causes the water type over most of the region to be calcium or calcium magnesium bicarbonate. Carbon dioxide, which is present in the atmosphere and forms in the soil from the oxidation of organic matter, mixes with water to form carbonic acid. The acid reacts with (dissolves) calcite to generate calcium and bicarbonate ions. The dissolution forms openings that eventually can develop into cave systems or sinkholes.

Ion exchange along a ground-water flow path can cause the dominant cation to change from calcium or magnesium to sodium (Drever, 1988). Divalent cations such as calcium and magnesium readily exchange for sodium sorbed onto clays in the aquifer media.

Other important geochemical reactions include oxidation and dissolution of sulfide minerals--pyrite, sphalerite, and galena--and uranium-bearing minerals. Dissolution of these minerals increases the trace-element, sulfate, and radionuclide concentrations in the water.

## Soils

Water quality is affected by the leaching and runoff potentials of soil, which are a result of physical and chemical properties of the soil. These physical and chemical properties include soil thickness and permeability and ionic adsorption capacity.

A wide range of soil thicknesses and permeabilities is present in the Ozark Plateaus study unit. A thick, low permeability soil, particularly one with a clay fragipan, will prevent leaching and allow runoff. In areas underlain by these soils, contaminants and sediments on the land surface can be flushed into nearby streams, whereas areas underlain by a thin, permeable soil will allow water to readily infiltrate into the ground-water system. Contaminants and sediments on the land surface are less likely to be flushed into streams in areas underlain by these soils but can be transported into the unconfined aquifers.

In general, the ionic adsorption capacity of the alfisols and ultisols of the Ozark Plateaus Province is minimal. Kaolinite, illite, and hydroxide clays, which constitute the soil types of the Ozark Plateaus Province, are relatively low in ionic adsorption capacity com-

pared to expandable clays and organic matter, which constitute the soil types of the Osage Plains (Brady, 1984, p. 170). Hence, ionic constituents in infiltrating water will not be readily adsorbed by most soils in the Ozark Plateaus Province.

Soil particles and ions that are adsorbed onto these particles can, in places where runoff potential is high, be flushed into nearby streams or into the shallow aquifer. For example, potassium, nitrate, and orthophosphate concentrations increased in water samples from three springs in northern Arkansas after a rainstorm (Leidy and Morris, 1990). Concentrations of these constituents probably increased when these ions were desorbed from soil particles that were flushed into the springs.

## Population

The distribution of the population within the study unit affects the quality of surface and ground waters. Urban areas, in addition to having larger populations, typically have more industries and produce larger quantities of municipal and industrial wastewater. Industrial areas, residential areas, streets and other paved areas, golf courses, and construction areas are nonpoint sources of nutrients, trace elements, suspended sediments, pesticides, and other synthetic organic compounds to streams draining the area (Missouri Department of Natural Resources, 1990, p. 27, 46-48). In rural areas that are not served by municipal sewers, septic systems can be nonpoint sources of nutrients and bacteria to surface and ground water, if the systems do not adequately treat the wastewater.

Concentrations of nutrients and bacteria in water in the streams and rivers in much of the Springfield Plateau are higher than those in water in the streams in the rest of the study unit (Petersen, 1988; J.C. Petersen, J.V. Davis, and J.F. Kenny, U.S. Geological Survey, written commun., 1991). The largest cities in the study unit and many of the most densely populated nonurban areas are located in the Springfield Plateau. Municipal and industrial wastewater (Missouri Department of Natural Resources, 1990, p. 32) and leachate from septic systems all probably affect water in the Springfield Plateau. However, in Arkansas most streams and rivers that do not support their designated use are considered to be affected primarily by nonpoint sources resulting from agricultural activity (Giese and others, 1990, p. 232, 281, 286) rather than by municipal wastewaters,

industrial wastewaters, or septic system leachate. Other concerns for areas in the Springfield Plateau include the effect of increased population, recreation, tourism, and related development upon water quality in the White, Neosho, and Osage River lakes areas.

## Land Use

Land use is an important factor that affects the quality of surface and ground water throughout the study unit. Two land uses in the Ozark Plateaus study unit, agriculture and mining, affect water quality over large areas. Agricultural land use, which includes poultry, cattle, and swine production on pastureland, and row crops on cropland, can result in elevated concentrations of ionic constituents, including sodium, potassium, chloride, nitrate, and phosphate, and fecal bacteria in surface and ground water (Feder, 1979; Harvey and others, 1983; Leidy and Morris, 1990). Fertilizers, particularly animal wastes, spread across pasture and cropland in the study unit are a major source of these ions and bacteria. Production of large numbers of poultry, cattle, and swine in northwestern Arkansas, and increasingly in southwestern Missouri and northeastern Oklahoma, is contributing to elevated nutrient and bacteria concentrations in streams (Giese and others, 1990; Missouri Department of Natural Resources, 1990; Kurklin and Jennings, 1993). Some of the highest nutrient and fecal-coliform bacteria concentrations in surface water in Arkansas are present in this area (Petersen, 1988). Concerns about existing or potential animal-waste problems have prompted studies in a number of areas, including Boone County, Arkansas (Leidy and Morris, 1990), the Buffalo River Basin (Mott, 1991; Mott and Steele, 1991), and the Niangua River Basin (Harvey and others, 1983).

Substantial amounts of soybeans, sorghum, corn, and wheat are produced within the study unit in the Osage Plains and the Mississippi Alluvial Plain. Substantial amounts of rice also are produced in the Mississippi Alluvial Plain. Past and potential future application of fertilizers and pesticides to these crops could affect water quality in these areas.

Mining activities increase the dissolution rate of sulfide minerals by exposing the minerals to oxidizing conditions. The dissolution of sulfide minerals results in decreased pH and increased suspended sediment and concentrations of dissolved solids, sulfate, and trace el-

ements in the surface and ground water of the study unit.

Surface coal-mining activities in the Spring River Basin, Osage River Basin, and the Lightning and Cherry Creek Basins (small tributaries to the Neosho River in Kansas) have adversely affected water quality, principally by causing elevated concentrations of dissolved solids, sulfate, iron, and manganese in waters draining the mined areas (Bevans and others, 1984; Marcher and others, 1984). In places, mining activity could be the cause of sulfate being the dominant anion in ground water (Imes and Davis, 1990a, b; 1991).

Lead, zinc, and barite mining activities have affected water quality in several areas. Water quality in the Tar Creek Basin (a small tributary to the Neosho River in Oklahoma) and the Spring River Basin has been adversely affected by lead-zinc mining activities (Parkhurst, 1987; Spruill, 1987; Davis and Schumacher, 1992). Discharges from flooded underground lead-zinc mines and runoff from tailings piles contribute large amounts of calcium, sulfate, dissolved solids, and zinc to receiving streams.

The Big River Basin encompasses much of the Old Lead Belt mining area and much of the area of past and present barite mining. About 15 mi of streams in the basin do not support or only partially support the designated beneficial uses because of mining activities (Missouri Department of Natural Resources, 1990). The potential failure of tailings pond dams also is of concern (Missouri Department of Natural Resources, 1984). In the Viburnum Trend, inactive iron, lead-zinc, and barite mines are located in the upper Meramec River Basin. Lead and zinc ores are actively mined, milled, and smelted in the upper Meramec River, upper Black River, and upper St. Francis River Basins. Local water-quality problems and concerns regarding potential failure of tailings pond dams and trace-element deposition in Clearwater Lake have resulted from these mining activities (Missouri Department of Natural Resources, 1984; Smith, 1988).

## Water Use

Water use also affects water quality. The quality of the water can be impaired by some uses; consumptive uses can reduce the volume of water available for dilution of wastewaters, and some uses, such as reservoir storage and releases, can change natural stream-flow characteristics that can affect water quality.

Some water uses can impair the quality of water. For example, water that is withdrawn for public supply systems, used for domestic uses, and then discharged from wastewater-treatment plants often will contain elevated concentrations of nutrients, dissolved solids, suspended solids, and trace elements (Hem, 1989). Similarly, industrial, agricultural, mining, or aquacultural uses of water can impair the quality of water.

The withdrawal of water from a stream or aquifer reduces the volume of water in that stream or aquifer. Withdrawal of water from streams can reduce the amount of water available for dilution, lower water velocities and depths, and reduce reaeration. In aquifers, substantial withdrawals of water can change the direction of water movement and induce the encroachment of water with impaired quality. For example, groundwater withdrawals from areas in the northwestern part of the study unit along the transition zone between freshwater and saline water have caused declines in water levels. The declines have resulted in the eastward encroachment of saline ground water into freshwater areas (Kleeschulte and others, 1985).

Dams substantially alter the downstream water quality. Chemical and physical characteristics of the stream, such as water temperature and concentrations of dissolved oxygen, suspended sediment, nutrients, and trace elements, commonly are altered (for examples see Walburg and others, 1981). The direction and magnitude of this alteration is dependent on factors such as reservoir size, reservoir release depth, and season. The volume of water released also affects water quality; for example, low release volumes can decrease dilution, velocity, depth, and reaeration. High release volumes can resuspend streambed materials.

## SUMMARY

The Ozark Plateaus study is 1 of 20 National Water-Quality Assessment (NAWQA) studies initiated by the U.S. Geological Survey in 1991. When the NAWQA program is fully implemented, a total of 60 study units in the United States will be investigated on a rotational basis. Study-unit investigations will include 5 years of intensive assessment activity followed by 5 years of low-level monitoring.

The Ozark Plateaus study unit has an area of approximately 48,000 mi<sup>2</sup> and includes parts of Arkansas, Kansas, Missouri, and Oklahoma. Major water-quality concerns in the study unit include elevated con-

centrations of nutrients in surface and ground waters; elevated concentrations of bacteria, trace elements, dissolved solids, and radionuclides in ground water, and saline ground-water encroachment.

The study unit has a temperate climate with average annual precipitation ranging from about 38 to 48 in., and mean annual air temperature ranging from 56 to 60 °F. Evapotranspiration rates range from 30 to 35 in/yr.

The study unit contains most of the Ozark Plateaus Province and parts of the adjacent Osage Plains section of the Central Lowland Province and Mississippi Alluvial Plain section of the Coastal Plain Province. The Ozark Plateaus Province consists of three sections—the Springfield Plateau, the Salem Plateau, and the Boston Mountains. Topography in the study unit is mostly gently rolling, except in the Boston Mountains and along the escarpment separating the Springfield and Salem Plateaus, where it is rugged. Land-surface altitudes range from just over 200 ft to more than 2,300 ft above sea level with local relief of as much as 1,000 ft. Karst features such as sinkholes and caves are common in the Springfield Plateau and abundant in the Salem Plateau. Springs are abundant and several large springs (discharge greater than 100 ft<sup>3</sup>/s) are located in the Salem Plateau.

Basement igneous rocks of Precambrian age crop out in the St. Francois Mountains in southeastern Missouri. These basement rocks are overlain by as much as 5,000 ft of gently dipping younger sedimentary rocks throughout much of the study unit. Dip of the sedimentary rocks is greatest to the east-southeast relative to other directions. The igneous rocks include granite, rhyolite, and diabase. The sedimentary rocks include rocks of Cambrian through Ordovician age, which consist of dolomite, sandstone, and limestone with minor amounts of shale; rocks of Mississippian age, which consist mostly of cherty limestones; and rocks of Pennsylvanian age, which consist mostly of shale, sandstone, and limestone. In some areas, rocks of Cambrian through Mississippian age contain commercially important deposits of lead and zinc minerals. Also, rocks of Pennsylvanian age contain coal deposits in some parts of the study unit. The igneous and sedimentary rocks underlying the study unit have been extensively fractured and faulted.

Alfisol and ultisol soil types underlie most of the study unit. These soils are moderately to deeply weathered and have a wide range of hydraulic properties. Mollisols, which underlie most of the Osage Plains,

contain more organic matter and expandable clays than alfisols or ultisols and are not as weathered.

Population in the study unit was approximately 2.3 million people in 1990 and increased 28 percent between 1970 and 1990. Northwestern Arkansas and southwestern Missouri are the fastest growing areas in the study unit. Springfield, Missouri, with a 1990 population of 140,494, is the largest city in the study unit.

Land use in the study unit is predominantly pasture and cropland in the northwestern part of the study unit, and forest and pasture in the southeastern part. Forests consist mostly of oak and hickory trees mixed with some pine trees. Pasture is mostly fescue and Kentucky blue grass. Poultry farming is a major industry in the southwestern part of the study unit. Mining, primarily in the four major lead-zinc mining districts, has been an important part of the local economy in the past. Coal has also been mined in the northwestern part of the study unit.

Total water use averaged 1,053 Mgal/d in the study unit in 1990. Approximately 58 percent was withdrawn from ground-water sources and 42 percent from surface-water sources. Ground-water use for irrigation accounted for 39 percent and surface-water use for public supply accounted for 20 percent of total withdrawals. The surface-water use was primarily from the reservoirs in northwestern Arkansas and southwestern Missouri; ground-water use was mostly for rice production in the southeastern part of the study unit.

All or part of seven major river basins are located within the study unit. These basins include the White, Neosho-Illinois, Osage, Gasconade, Meramec, St. Francis, and Black River Basins. Many of the rivers have been impounded to form reservoirs. The White River Basin alone has five major reservoirs. Several of the rivers have been designated for protection from future development. The Buffalo River has been designated as the Buffalo National River; and the Current, Eleven Point, and Jacks Fork Rivers have been designated as National Scenic Rivers. The Illinois River is designated as a scenic river by the State of Oklahoma.

Stream gradients are steepest in the Boston and St. Francois Mountains and least in the Osage Plains and Mississippi Alluvial Plain. Streambed material ranges from clay and silt in the Osage Plains to sand, gravel, boulders, and bedrock in most of the Ozark Plateaus Province. Streams in the Osage Plains are turbid, with long pools separated by poorly defined riffles. Streams in the Ozarks Plateaus Province are mostly

clear, with pools separated by riffles, and in places, cascading waterfalls.

Mean annual runoff ranges from 9 to 10 in. in the Osage Plains to 14 to 20 in. in the Boston Mountains. Minimum monthly streamflows generally occur from July through October, and maximum monthly streamflows occur from March through May. Surface- and ground-water interactions are greatest in the Springfield and Salem Plateaus and least in the Boston Mountains and Osage Plains. Ground water discharging through springs contributes significantly to low flows in the Springfield and Salem Plateaus.

Surface water in the study unit generally is a calcium or calcium magnesium bicarbonate type water. Dissolved-solids concentrations in water from streams ranged from about 40 mg/L in the Boston Mountains to as much as 280 mg/L in the Osage Plains, but generally were less than 200 mg/L. Streams in the Boston Mountains generally are the least mineralized and those in the Osage Plains generally are the most mineralized in the study unit.

The study unit is divided into seven hydrogeologic units consisting of three major aquifers interbedded with four confining units. These units, from youngest to oldest, are as follows: the Western Interior Plains confining system, the Springfield Plateau aquifer, the Ozark confining unit, the Ozark aquifer, the St. Francois confining unit, the St. Francois aquifer, and the Basement confining unit. The unconsolidated sediments of the Mississippi Alluvial Plain, which constitute a productive aquifer in a small part of the study unit, are not discussed in this report.

The Western Interior Plains confining system consists of relatively permeable sandstone and limestone beds separated by thick layers of impermeable shales. The system is used locally as a source of water for domestic supplies. Overall, the confining system has low permeability and well yields generally are less than 40 gal/min.

The Springfield Plateau and Ozark aquifers are formed from thick sequences of limestones and dolomites that have secondary porosity as a result of fracturing and dissolution. Where the Springfield Plateau aquifer is unconfined, it is extensively used as a source of domestic water. Yields of wells completed in this aquifer generally are less than 20 gal/min. The Ozark aquifer is used throughout much of the area for public supply and domestic use. Well yields commonly

range from 50 to 100 gal/min but are as much as 600 gal/min in some areas.

The St. Francois aquifer consists of sandstones and dolomites of Cambrian age. Well yields in the aquifer can be as much as 500 gal/min. The aquifer is little used except where it crops out.

The Ozark and St. Francois confining units consist mostly of shales and dense limestones or dolomites. These confining units hydraulically separate the overlying and underlying aquifers. The Basement confining unit underlies the study unit and consists of mostly igneous rocks.

Ground water in most of the aquifers in the study unit is a calcium or calcium magnesium bicarbonate type water, but locally it can be calcium sulfate or sodium chloride water where the aquifers are confined. Dissolved-solids concentrations generally ranged from 200 to 300 mg/L, but can be as much as 10,000 mg/L where the aquifers are confined along the western boundary. The pH of ground water in the study unit ranged from 5.2 to 8.3. The Springfield Plateau aquifer locally can contain fecal bacteria. The Ozark aquifer has elevated concentrations of radionuclides in some areas where it is confined. Elevated nitrate concentrations are present in ground water from unconfined parts of the Springfield Plateau and Ozark aquifer in some areas.

Factors that affect water quality in the study unit include climate, physiography, geology, soils, population, land use, and water use. The geochemical processes of mineral dissolution, ion exchange, and oxidation-reduction reactions are the dominant natural factors affecting water quality on a regional scale. Land use and population density can affect the potential for the introduction of contaminants into the water from human sources. Agricultural and mining land-use activities can increase the concentrations of nutrients, bacteria, dissolved solids, sulfate, and trace elements in surface and ground water. The population density can affect point and non-point sources of nutrients, trace elements, suspended sediment, and organic compounds in runoff and wastewater discharges. Climate, physiography, soils, and water use affect water quality by affecting the quantity and movement of water in the study unit.

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