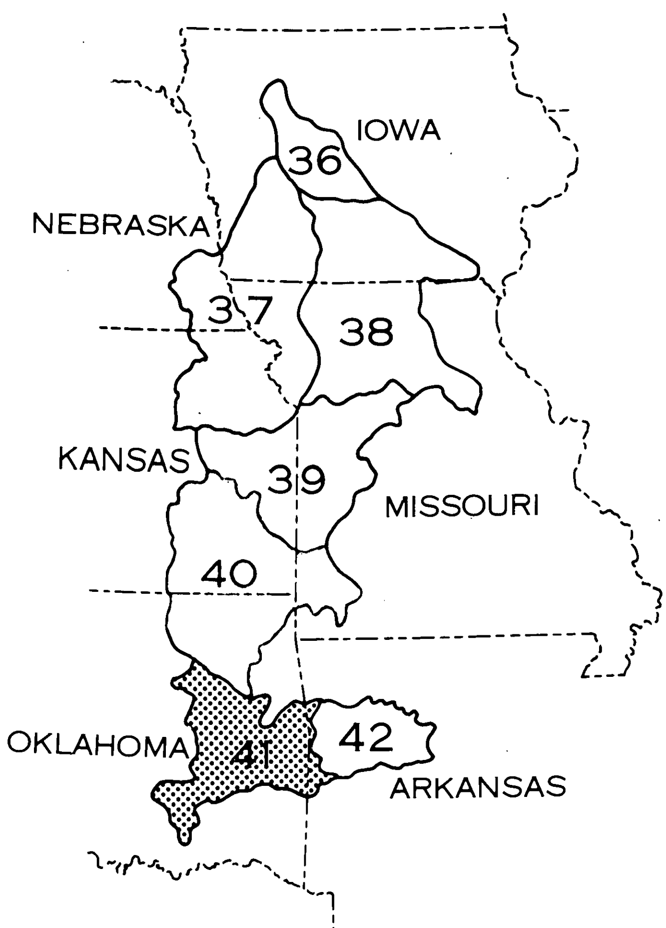
HYDROLOGY OF AREA 41, WESTERN REGION, INTERIOR COAL PROVINCE, OKLAHOMA AND ARKANSAS



- ARKANSAS RIVER
- CANADIAN RIVER
- POTEAU RIVER
- MUDDY BOGGY CREEK
- CLEAR BOGGY CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 84-129

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BY
MELVIN V. MARCHER, DE ROY L. BERGMAN, LARRY J. SLACK, STEPHEN P. BLUMER, AND ROBERT L. GOEMAAT

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OKLAHOMA CITY, OKLAHOMA
JANUARY 1987

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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CONTENTS

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) OF UNITS

For the convenience of readers who may want to use the International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inches (in.)	25.4	millimeters (mm)
inches per hour (in/h)	25.4 2.54	millimeters per hour (mm/h) centimeters per hour (cm/h)
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (mgal/d)	0.04381 3,785	cubic meters per second (m^3/s) cubic meters per day (m^3/d)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meters per second per square kilometer [$(m^3/s)/km^2$]
tons per square mile per year [$(ton/mi^2)/yr$]	0.3503	metric tons per square kilometer per year [$(t/km^2)/a$]
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(L/s)/m]
gallons (gal)	3.785	liters (L)
tons	0.9072	metric tons (t)
British thermal units per pound (Btu/lb)	2.326	kilojoules per kilogram (kJ/kg)
microhos per centimeter (μmho/cm)	1	microsiemens per centimeter (μS/cm)
acres	0.4047	square hectometers (hm^2)
acre-feet (acre-ft)	1,233	cubic meters (m^3)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

For purposes of reporting hydrologic and related land-resources data in coal areas of the Nation, the Western Region of the Interior Coal Province has been divided into seven hydrologic units. This report is for Area 41 in eastern Oklahoma and western Arkansas. The format of this report consists of a brief text accompanied by a map, graph, table, or other illustration for a series of topics which together portray the general geographic, geologic, and hydrologic environment.

Area 41 includes about 9,250 square miles in the Arkansas River basin and about 2,250 square miles in the Red River basin. Rocks of Pennsylvanian age are at or near the surface in approximately 95 percent of the area and contain 10 coal beds of economic importance. The remaining coal reserves in these beds have been estimated at nearly 8.2 billion tons of which about 10 percent are potentially strippable. The Pennsylvanian rocks consist of 60–80 percent shale and siltstone and 20–40 percent sandstone. Soils derived from these rocks are mostly sandy or clayey loams, are acidic, and have slow to moderate permeability. About one-half the area is woodlands; the remainder is about equally divided between pasture and crop lands.

Normal annual precipitation ranges from about 36 inches in the northwestern part of the area to about 50 inches in the southeastern part. In spite of the relatively large amount of precipitation, it is unevenly distributed throughout the year and, consequently, most streams have no flow about 20 percent of the time. Because the Pennsylvanian bedrock has minimal ability to absorb, store, or transmit water, the availability of ground water is extremely limited. Thus, most of the area depends on lakes and reservoirs for domestic, municipal, industrial, and irrigation supplies.

The U.S. Geological Survey has collected data at 118 surface-water stations in the area; 22 stations were active in 1983. Available data include records of stage, discharge, and water quality of streams and records of stage and contents of lakes and reservoirs. Records of chemical quality of stream water are available for 95 stations. Based on data from 86 stations, median dissolved-solids concentrations did not exceed 500 milligrams per liter in about 75 percent of the streams. Median sulfate concentrations of stream water ranged from 3 to 740 milligrams per liter; the greatest concentrations were in small streams draining areas that had been mined for coal. Coal mining has had little effect on the pH of stream water; median pH values ranged from 6.6 to 8.4.

Data on ground-water levels are available for 1,678 wells and water-quality data are available for 1,422 wells. Water types and concentrations of dissolved solids in water from Pennsylvanian rocks are extremely variable. No apparent relationship exists between the chemical quality of ground water and well depth, geographic distribution, or geologic formation.

Alluvium and some terrace deposits along the Arkansas River, alluvium along the Canadian River, and the Antlers Sandstone in the extreme southeastern part of the area are the only aquifers of significance. Most wells in Pennsylvanian rocks yield only a fraction of a gallon per minute. Consequently, much of the rural population relies on surface water provided by rural water systems.

Hydrologic data for Area 41 are stored in computer files accessible through the National Water Data Exchange (NAWDEX). Information on the kinds of computer-stored data and means of retrieval are given in this report. The extensive list of references included in the report will provide those interested with additional sources of information on the hydrology, geology, and geography of the area.

1.0 INTRODUCTION

1.1 Objective

Hydrology of Coal Area in Oklahoma and Arkansas Described

Existing hydrologic conditions and sources of information are identified to aid leasing decisions and preparation and appraisal of Environmental Impact studies and mine-permit applications.

Hydrologic information and analysis are needed to aid in decisions to lease Federally-owned coal and for the preparation of the necessary Environmental Assessment and Impact study reports. This need has become even more critical with the enactment of Public Law 95-87, the "Surface Mining Control and Reclamation Act of 1977." This act requires an appropriate regulatory agency to issue mining permits based on the review of permit application data to assess hydrologic impacts. This need is partly fulfilled by this report, which broadly characterizes the hydrology of Area 41 in Oklahoma and Arkansas, a part of the Western Region, Interior Coal Province (fig. 1.1–1). This report is one of a series that describes the hydrology of selected areas in coal provinces nationwide.

This report provides general hydrologic information by means of a brief text with accompanying map, chart, graph, or other illustration, for each of a series of topics related to water resources. Summation of the topical discussions provides a description of the hydrology of the area. The information contained herein will be useful to Federal agencies in the leasing and management of Federal coal and to surface-mine owners and operators, and others preparing permit applications and to regulatory authorities evaluating the adequacy of the applications.

The hydrologic information presented herein or available through sources identified in this report will be useful in describing the hydrology of the "general area" of any proposed mine. This information will be supplemented by the lease applicant's specific data as well as data from other sources. The purpose of the specific site data is to provide a detailed appraisal of the hydrology of the area in the immediate vicinity of the mine and the anticipated hydrologic consequences of mining.

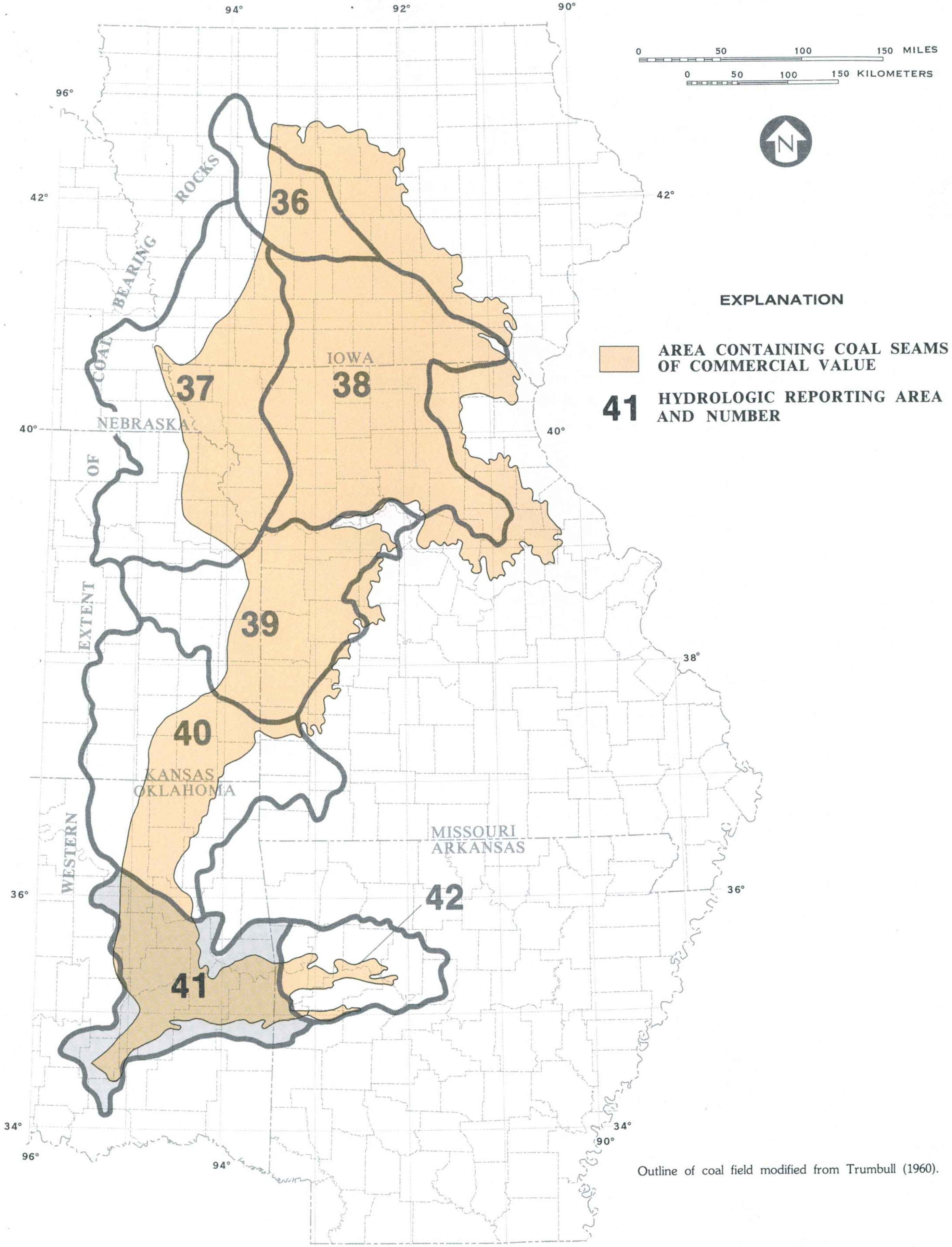


Figure 1.1-1 Hydrologic reporting areas within the Western Region, Interior Coal Province.

1.0 INTRODUCTION

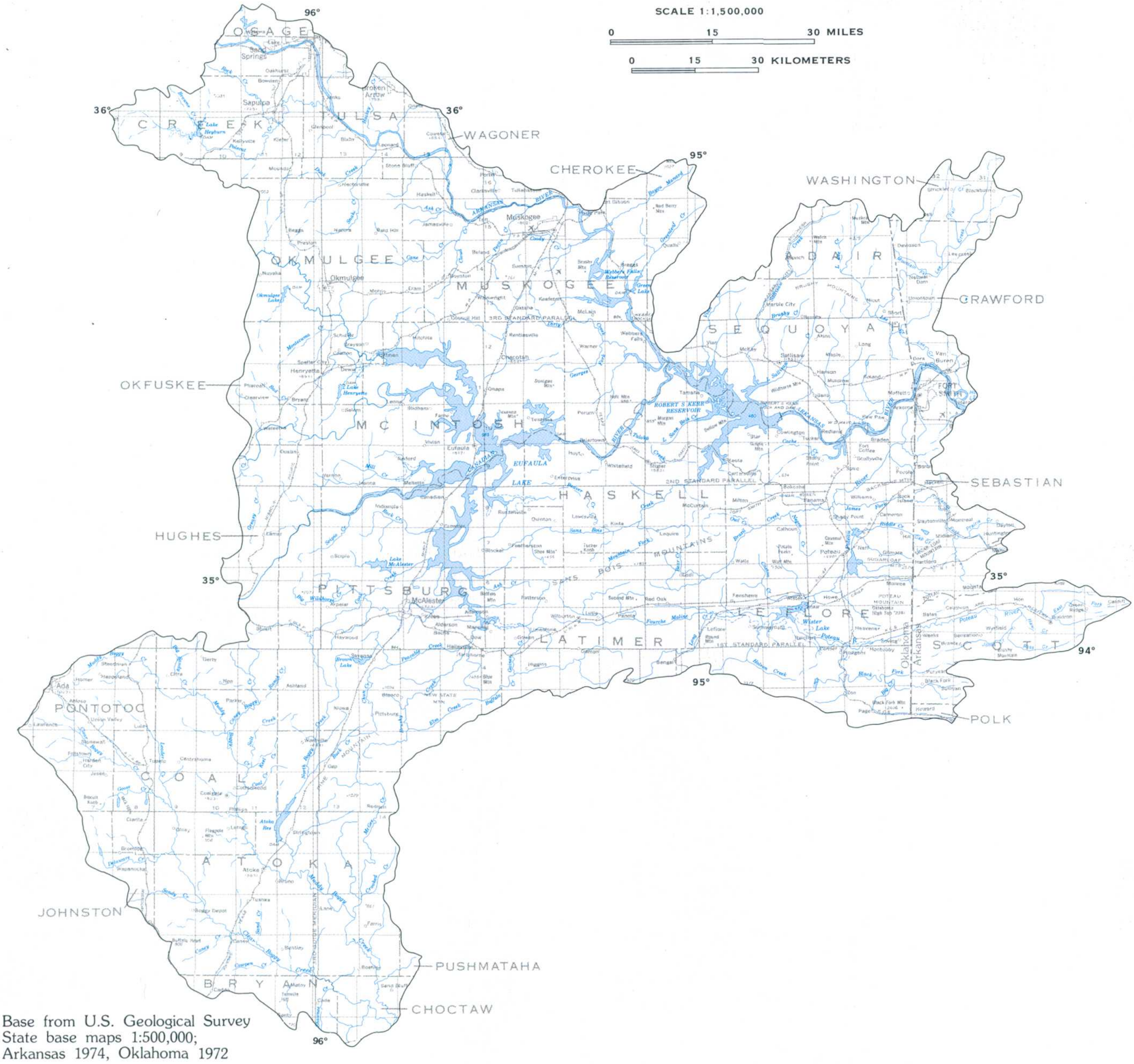
1.1 Objective

Area 41 Includes nearly 11,500 Square Miles in Oklahoma and Arkansas

The report area includes all or parts of 25 counties with a population of about 900,000.

Area 41, which encompasses nearly 11,500 square miles, includes all or parts of 21 counties in Oklahoma and parts of 4 counties in Arkansas (fig. 1.2–1). In 1980 the population of the area was approximately 900,000 of which about 70 percent lived in urban areas. Metropolitan areas and cities with populations exceeding 10,000 include the Tulsa metropolitan area (Tulsa, Broken Arrow, Sand Springs, and Sapulpa), 425,800; Fort Smith and Van Buren, 80,500; Muskogee, 40,000; McAlester, 17,300; Okmulgee, 16,300; and Ada, 15,900. Population trends from 1960 to 1980 show an increase in urban areas and a decrease in rural areas which is typical of much of the Nation.

Completion in 1970 of the McClellan-Kerr Arkansas River Navigation System which extends from the Port of Catoosa near Tulsa to the Mississippi River and provides ready access to the Gulf of Mexico, gave impetus to the growth of various industries that are major sources of income for the area. Other major income-producing activities are agriculture, cattle and horse ranching, and the production of fossil fuel (natural gas, oil, and coal).



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 1.2-1 Map of coal hydrology study Area 41.

Remaining Coal Reserves in 17 Counties Total Nearly 8.2 Billion Tons

Rocks of Pennsylvanian age contain 10 coal beds that are potentially mineable by surface methods.

Bituminous coal has been mined in Area 41 for more than a century. Early production was almost entirely from underground mines but as mining techniques advanced and the capabilities of earth-moving equipment improved, surface mining became increasingly important and since 1972 has accounted for nearly all coal mined. Total coal production in Oklahoma from 1873 to 1980 was approximately 230 million tons of which about 37 percent was surface mined. In Arkansas, total production from 1840 to 1977 was approximately 104 million tons of which about 13 percent was surface mined. Remaining coal reserves in counties wholly or partly in Area 41 amount to nearly 8.2 billion tons (table 1.3–2) of which about 10 percent are potentially strippable. The largest remaining reserves are in Le Flore, Haskell, and Pittsburg Counties, Oklahoma, where about 930,000 acres are underlain by nearly 80 percent of the total reserves.

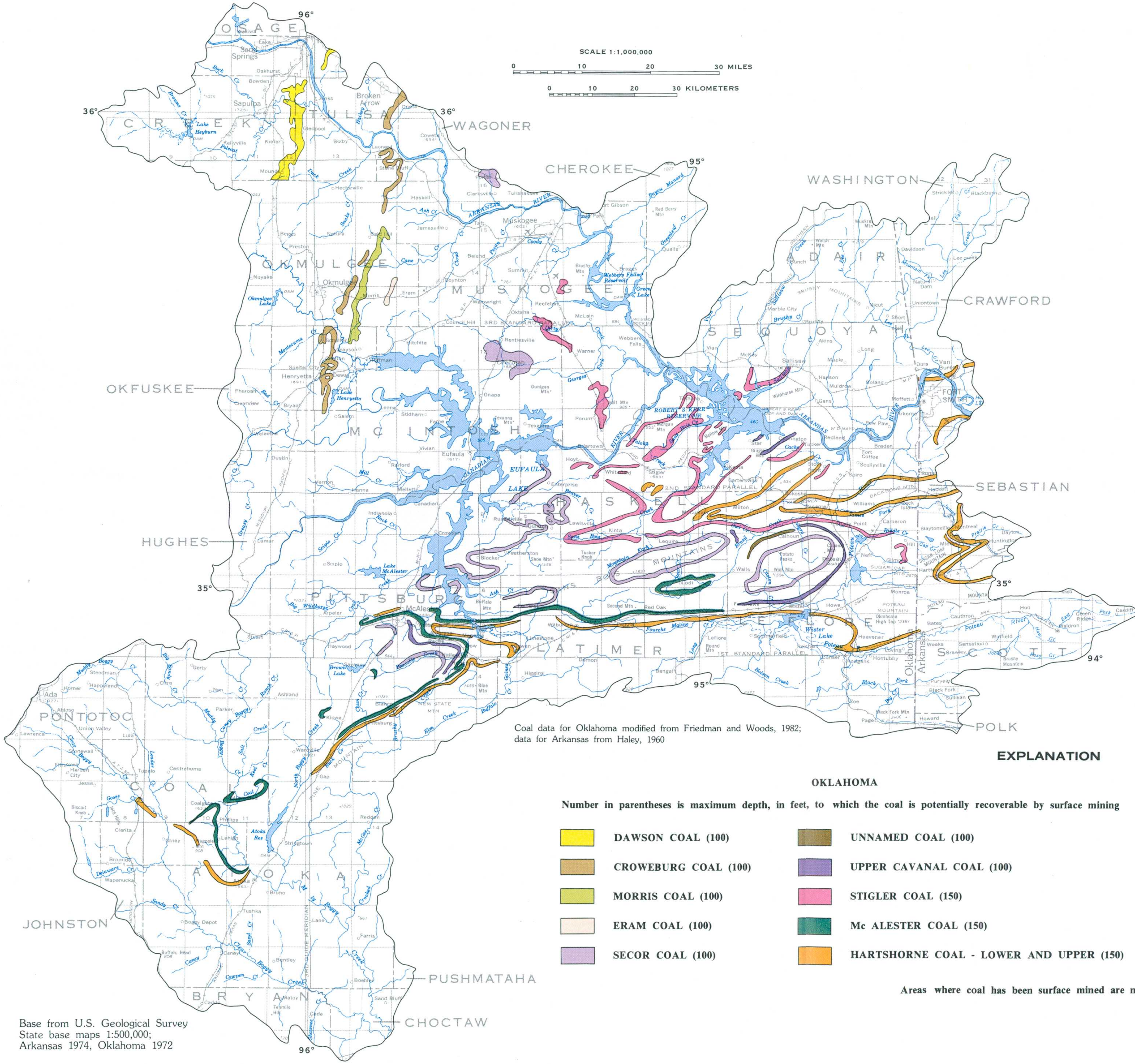
Coal recoverable by surface mining occurs in the Krebs, Cabaniss, Marmaton, and Skiatook Groups of Pennsylvanian age (table 1.3–1). The beds range in thickness from 12 to 42+ inches. The prinicipal coals are upper and lower Hartshone, McAlester, Stigler, and Secor which are most extensive in Le Flore, Haskell, and Pittsburg Counties (fig. 1.3–1). The depth to which these and other coals can be mined profitably by stripping depends largely on the geologic structure and thickness and quality of the coal. Most of the coals are ranked as medium to high volatile bituminous with heat values of 11,000–14,000 British thermal units per pound. Sulfur contents range from 0.4 to 6.6 percent. Detailed information on the distribution, reserves, quality, and other data on coal is given in reports by Friedman (1974) for Oklahoma and by Haley (1960) for Arkansas.

According to the U.S. Bureau of Land Management (1980), Federally-owned coal underlies about 372,000 acres in 38 tracts scattered throughout Atoka, Coal, Haskell, Latimer, Le Flore, and Pittsburg Counties, Oklahoma (fig. 1.3–2). However, less than 1,500 acres of the surface above the coal is Federally owned. About 10 percent of the Federal coal was considered economically strippable as of 1980.

The location and amount of coal that can be economically strip mined is significantly affected by the requirements of Federal and State laws relating to mining operations and reclamation. Although recent, current, and projected mining is subject to the requirements of reclamation laws, approximately 23,000 acres in counties wholly or partly in Area 41 and which were mined prior to passage of those laws, have not been reclaimed (Johnson, 1974, and Bush and Gilbreath, 1978). According to Friedman (1974), reclamation costs in 1973 in Oklahoma ranged from $380 to $6,600 per acre. The weighted average reclamation costs per ton of coal mined was $0.76 and the weighted average cost per acre was $1,450. These costs undoubtedly have increased significantly within the last 14 years.

Table 1.3–1—Remaining coal reserves. Values given for each county are the total for that county and not just the part included in Area 41. Data for Oklahoma from Friedman, 1974; data for Arkansas from Haley, 1960.

County	Acres	Short tons (in thousands)
	Oklahoma	
Atoka	6,200	29,600
Coal	40,500	292,900
Creek	3,500	14,000
Haskell	311,100	1,513,700
Latimer	167,900	842,000
Le Flore	361,900	1,973,400
McIntosh	13,400	46,800
Muskogee	29,900	61,200
Okfuskee	21,600	79,400
Okmulgee	78,900	370,700
Pittsburg	260,000	1,383,800
Sequoyah	11,400	27,100
Tulsa	36,600	138,400
Wagoner	23,900	63,500
Subtotal	1,366,800	6,836,500
	Arkansas	
Crawford	66,000	289,900
Scott	26,600	102,300
Sebastian	210,300	953,700
Subtotal	302,900	1,345,900
Total	1,669,700	8,182,400



EXPLANATION

OKLAHOMA

Number in parentheses is maximum depth, in feet, to which the coal is potentially recoverable by surface mining

- DAWSON COAL (100)
- CROWEBURG COAL (100)
- MORRIS COAL (100)
- ERAM COAL (100)
- SECOR COAL (100)
- UNNAMED COAL (100)
- UPPER CAVANAL COAL (100)
- STIGLER COAL (150)
- Mc ALESTER COAL (150)
- HARTSHORNE COAL - LOWER AND UPPER (150)

ARKANSAS

- HARTSHORNE COAL - LOWER AND UPPER Shown where overburden is 60 feet or less

Areas where coal has been surface mined are not shown

Figure 1.3-1 Coal deposits in Area 41.

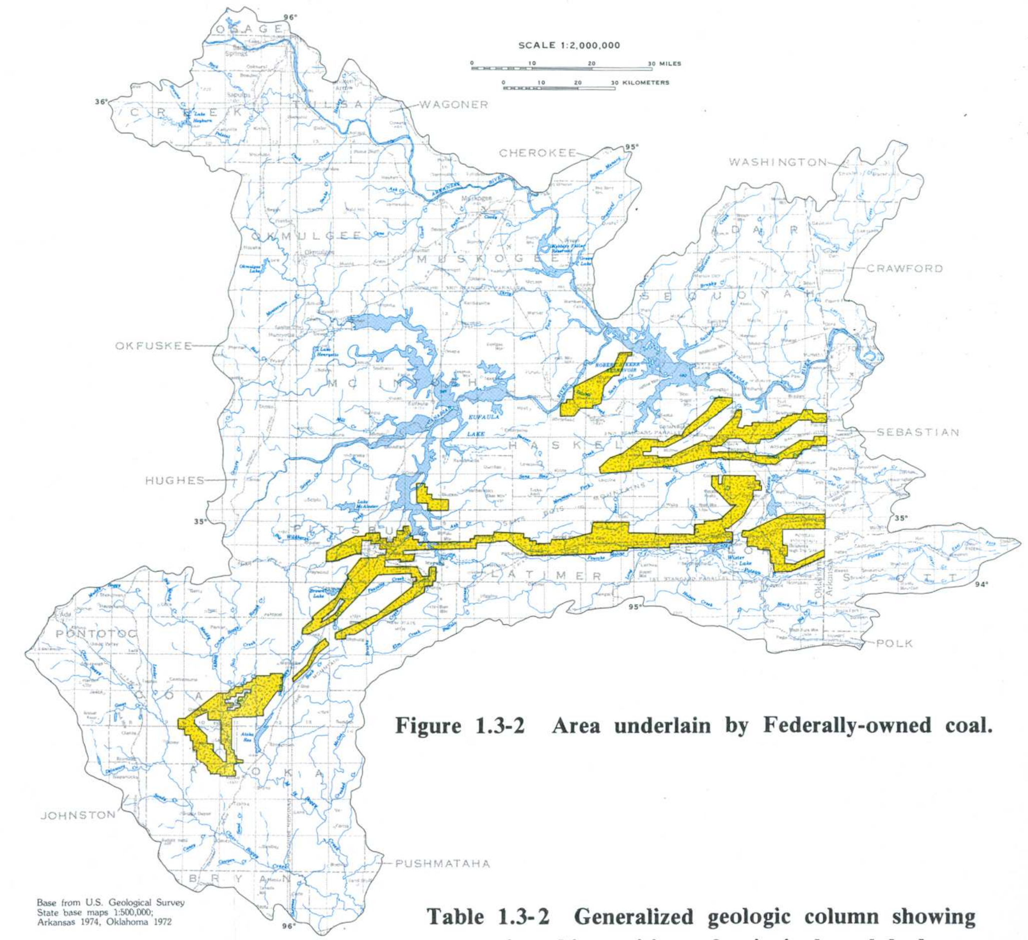


Figure 1.3-2 Area underlain by Federally-owned coal.

Table 1.3-2 Generalized geologic column showing stratigraphic position of principal coal beds.

SYSTEM	GROUP	FORMATION	COAL BED
PENNSYLVANIAN SYSTEM	Skiatook	Seminole	Dawson
		Holdenville	
	Marmaton	Nowata	
		Wewoka and Fort Scott	
	Cabaniss	Senora	Croweburg, Morris, Eram
	Krebs	Boggy	Secor
		Savanna	unnamed, upper Cavanal
		Mc Alester	Mc Alester / Stigler
		Hartshorne	Hartshorne--upper and lower

Vertical scale: 1 inch = 800 feet

1.0 INTRODUCTION--Continued

1.3 Coal in Area 41

Rocks at the Surface in Most of Area 41 are Pennsylvanian in Age

Pennsylvanian rocks are mainly shale, siltstone, and sandstone ranging in thickness from a few hundred to about 18,000 feet.

In Area 41 coal occurs only in the Arkoma basin and in the northeast Oklahoma platform. The Arkoma basin, the dominant tectonic feature, is an arcuate trough extending from south-central Oklahoma easterly into central Arkansas (fig. 2.1–1). Rocks in the basin have been moderately folded to form northeast- to east-trending synclines and anticlines. Dips on the limbs of these structures generally range from 10 to 40 degrees; the crests of some anticlines have been broken by thrust faults with displacements of several hundred feet. The geologic structure is particularly significant because the economically-important coal beds have been preserved in the synclines and the structure, in part, controls the depth to which the coal can be mined. In the eastern Oklahoma platform, the rocks dip toward the northwest at 40–60 feet per mile so that from their outcrop area coal beds become progressively deeper toward the northwest.

Rocks of Pennsylvanian age (fig. 2.1–2) in the Arkoma basin and the northeast Oklahoma platform consist of a sequence of interbedded shale, siltstone, fine to very fine grained sandstone, and a few thin beds of limestone and coal. The rocks range in thickness from a few hundred feet along the northern margin of the Arkoma basin to about 18,000 feet along the southern margin (fig. 2.1–3). Shale and siltstone are the predominant lithologies comprising 60–80 percent of the exposed part of the stratigraphic section. Sandstone units become more numerous and thicker toward the south. For example, in northern Haskell County, Oklahoma, the aggregate thickness of sandstone is about 600 feet but few individual beds are more than 5–10 feet thick. About 20 miles farther south, however, in the San Bois Mountains, the aggregate thickness of sandstone is about 2,000 feet with individual units attaining a maximum thickness of about 200 feet (Russell, 1960).

The Arkoma basin is flanked on the north by the Ozark uplift where the rocks are nearly flat-lying. In this area, the rocks are mostly shale and sandstone of Pennsylvanian age; shale, sandstone, limestone, and chert of Mississippi age; and a few local inliers of limestone of Silurian and Devonian age. In the Ouachita Mountains south of the Choctaw fault the rocks, mostly shale, siliceous shale, and sandstone of Pennsylvanian age, dip steeply to the south as a result of intense faulting and folding. Rocks in the Arbuckle Mountains range in age from Precambrian to Pennsylvanian and consist of limestone, dolomite, sandstone, and shale that have been greatly folded and faulted. In the Gulf Coastal Plain the rocks are of Cretaceous age and consist of sand or weakly cemented sandstone, with some beds of shale and limestone that dip toward the south at about 50 feet per mile.

Terrace deposits along the north side of the Arkansas River have a maximum thickness of about 60 feet and are mostly clayey silt overlying local beds of fine to medium sand. Elsewhere in the area, such as in the vicinity of Lake Eufaula, the terrace deposits consist almost entirely of clayey to sandy silt.

Alluvium along the larger streams, such as the Arkansas and Canadian Rivers, is as much as 60 feet thick and consists of clay, silt, and sand with a few local, thin layers of gravel at the base. Alluvium along the smaller, tributary streams generally is less than 20 feet thick and, because of the predominantly shale bedrock in the area, consists mainly of sandy and clayey silt. In the southern part of the area where sandstone units are thicker and more numerous, pebbles, cobbles, and boulder of that material are prominent components of the alluvium along such streams as the Fourche Maline.

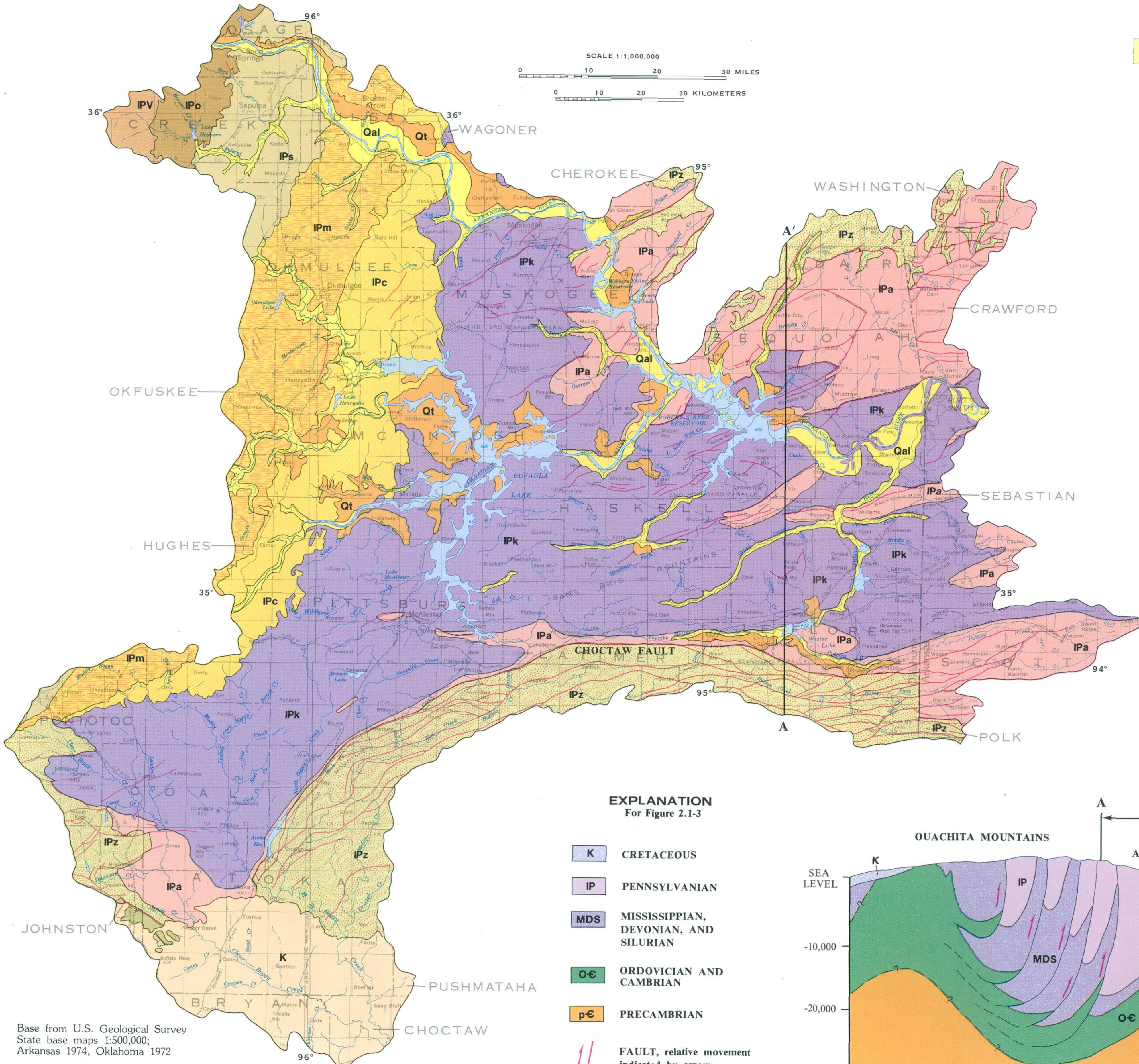


Figure 2.1-2 Generalized geology.

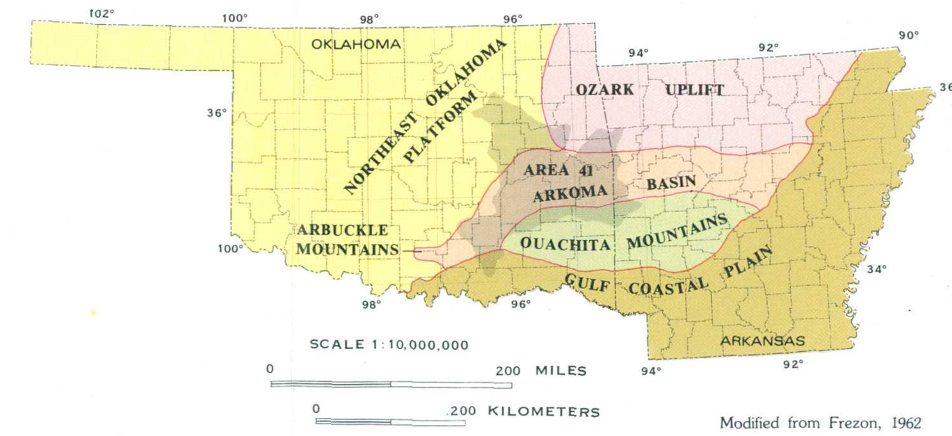


Figure 2.1-1 Tectonic provinces of eastern Oklahoma and Arkansas.

EXPLANATION
For Figure 2.1-2

PENNSYLVANIAN

- IPV VAMOOSA FORMATION
- IPo OCHELATA GROUP
- IPs SKIATOOK GROUP
- IPm MARMATON GROUP
- IPc CABANISS GROUP
- IPk KREBS GROUP
- IPa ATOKA FORMATION
- IPz PALEOZOIC, UNDIVIDED
- p€ PRECAMBRIAN

QUATERNARY

- Qal ALLUVIUM
- Qt TERRACE DEPOSITS
- K CRETACEOUS, UNDIVIDED
- GEOLOGIC CONTACT
- FAULT
- A′ – A LINE OF CROSS SECTION

Compiled from Arkansas Geological Commission, 1976; Bingham and Moore, 1975; Bingham and Bergman, 1980; Marcher, 1969; Marcher and Bingham, 1971; and Marcher and Bergman, 1983d

EXPLANATION
For Figure 2.1-3

- K CRETACEOUS
- IP PENNSYLVANIAN
- MDS MISSISSIPPIAN, DEVONIAN, AND SILURIAN
- O€ ORDOVICIAN AND CAMBRIAN
- p€ PRECAMBRIAN
- FAULT, relative movement indicated by arrow

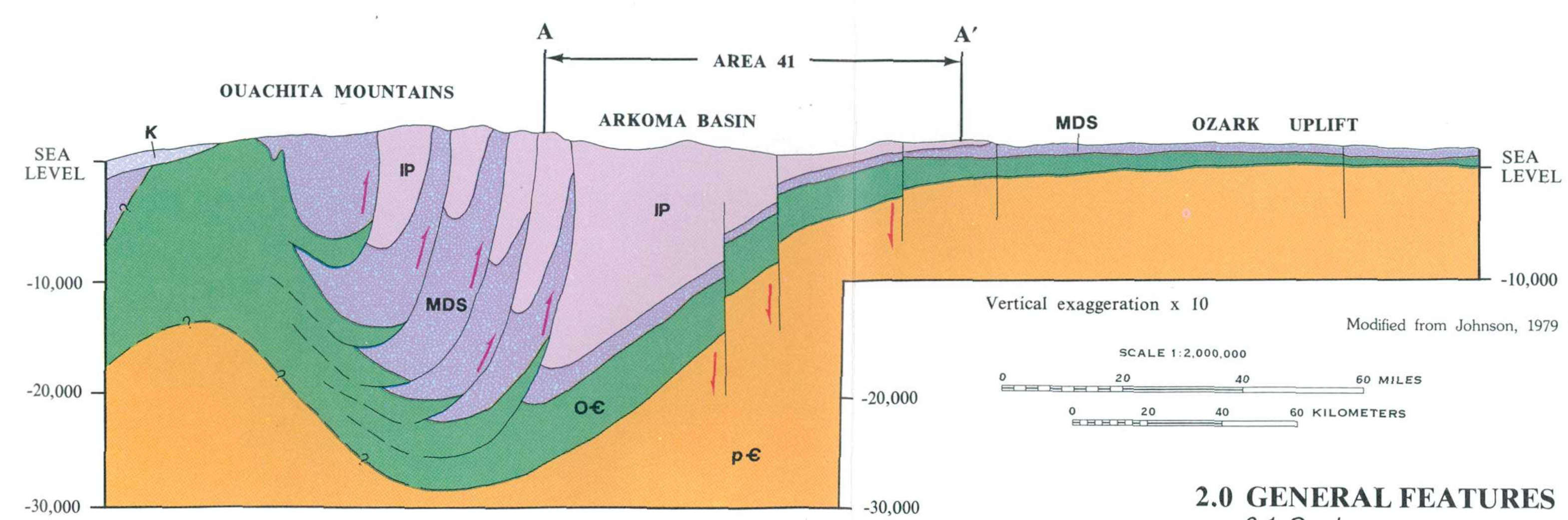


Figure 2.1-3 Generalized geologic section of eastern Oklahoma.

Area Includes Parts of Four Major Physiographic Provinces

Approximately 80 percent of the area is about equally divided between the Central Lowlands and Ouachita Provinces; the remaining 20 percent is about equally divided between the Ozarks Plateaus and the Coastal Plain Provinces.

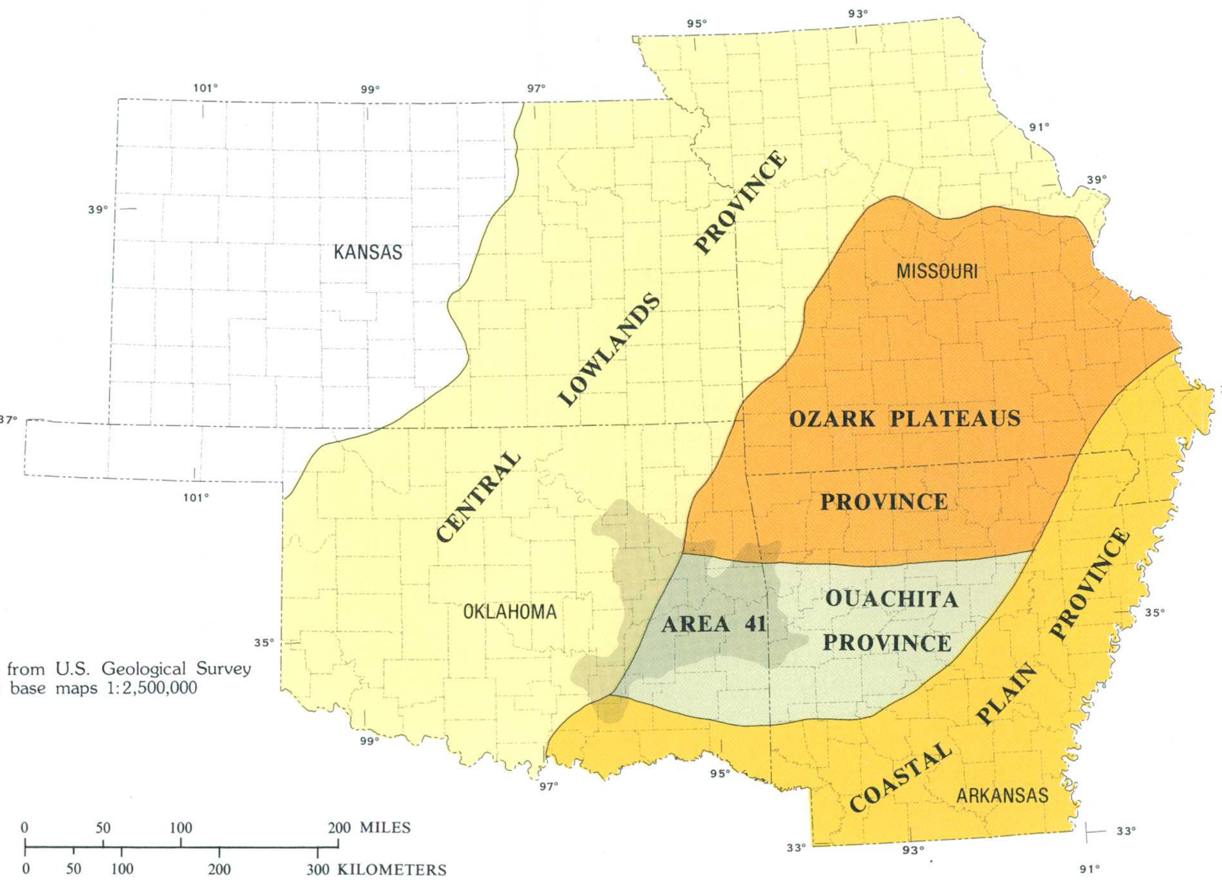
The topography of Area 41 ranges from gently rolling prairies in parts of the Central Lowlands Province (fig. 2.2–1) to rugged mountains with local relief as much as 2,000 feet in the Ouachita Province. These variations in topography reflect the geologic structure and the distribution of rock units of differing resistence to weathering and erosion.

Geomorphic subdivisions of Central Lowlands include the Claremore Cuesta Plains, the Eastern Sandstone Cuesta Plains, and the Arbuckle Plains (Johnson and others, 1979). The Claremore Cuesta Plains and the Eastern Sandstone Cuesta Plains do not differ greatly in topographic characteristics and, therefore, are shown as a single subdivision on figure 2.2–2. The Claremore and Eastern Sandstone Cuesta Plains are the product of unequal weathering of sandstone and shale of Pennsylvanian age that dip gently toward the west or northwest. Because of their superior resistance to erosion, the sandstone units form north-trending lines of irregular hills or east-facing cuestas rising 100–300 feet above the adjacent plain. The back slopes of the cuestas generally coincide with the regional dip of the rocks. The broad, plain-like valleys between the cuestas have been formed by weathering and erosion of thick, weakly resistant shales. The Arbuckle Plains in the extreme southwestern part of the area is characterized by smoothly rounded hills and rolling plains developed on limestone and dolomite, mostly of Ordovician age.

The Boston Mountains subdivision of the Ozark Plateaus Province is a deeply dissected plateau carved on sandstones and shales of Pennsylvanian age. The ridges typically are flat-crested and the valleys are deep and v-shaped; local relief ranges from 300 to 500 feet.

In the Ouachita Province, the Arkansas Hill and Valley Belt includes broad, gently-rolling plains and valleys with local hills and ridges capped with resistant sandstones of Pennsylvanian age. Rocks in the McAlester Marginal Hills Belt have been moderately folded to form west or southwest-trending anticlines and synclines; the crests of some anticlines have been broken by thrust faults. The landscape is characterized by sharp-crested ridges, such as Backbone Mountain, or masses of irregular hills, such as the Sans Bois Mountains. The ridges and hills are capped with thick, erosion-resistant sandstone and rise 300–2,000 feet above the adjacent shale-floored valleys. The Hogback Frontal Belt consists of sharp-crested ridges, trending west or southwest, that have been formed by thrust faulting of siliceous sandstones and shales mostly of Pennsylvanian age. The Ridge and Valley Belt is similar to the Hogback Frontal Belt but the topography is more rolling and the relief is less.

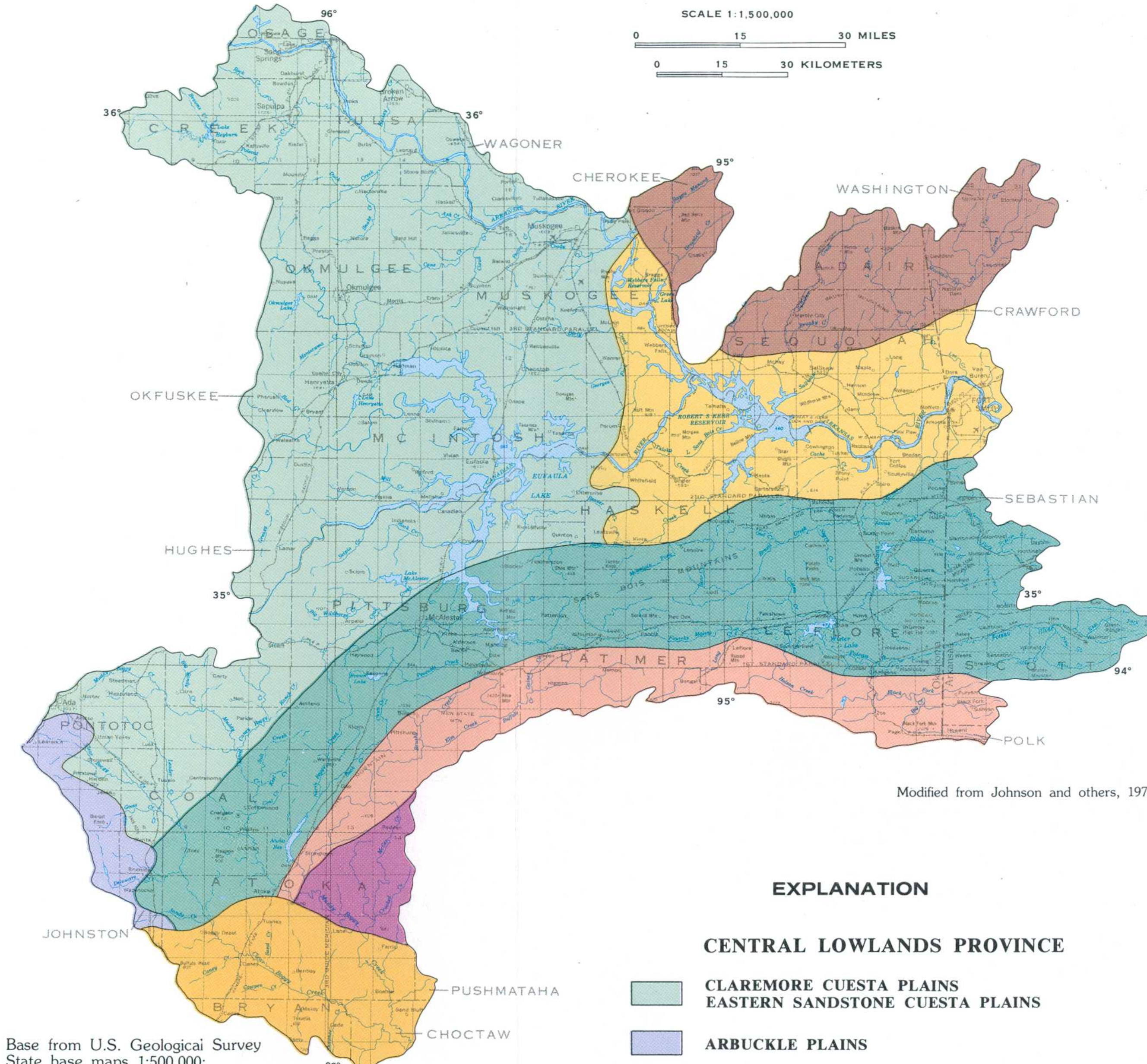
The Dissected Coastal Plain of the Coastal Plain Province in the extreme southern part of the area is a rolling plain of low relief. The area is underlain by sandstone, shale, clay, and thin limestones of Cretaceous age that dip gently toward the south.



Base from U.S. Geological Survey
State base maps 1:2,500,000

Modified from Fenneman and Johnson, 1946

Figure 2.2-1 Major physiographic provinces.



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Modified from Johnson and others, 1979

EXPLANATION

CENTRAL LOWLANDS PROVINCE

- CLAREMORE CUESTA PLAINS
  EASTERN SANDSTONE CUESTA PLAINS
- ARBUCKLE PLAINS

OZARK PLATEAUS PROVINCE

- BOSTON MOUNTAINS

OUACHITA PROVINCE

- ARKANSAS HILL AND VALLEY BELT
- McALESTER MARGINAL HILLS BELT
- HOGBACK FRONTAL BELT
- RIDGE AND VALLEY BELT

COASTAL PLAIN PROVINCE

- DISSECTED COASTAL PLAIN

Figure 2.2-2 Geomorphic subdivisions.

Area 41 Includes about 11,500 Square Miles Within the Basins of the Arkansas and Red Rivers

About 9,250 square miles are in the Arkansas River basin and about 2,250 square miles are in the Red River basin.

The Arkansas River (fig. 2.3–1) enters the area below Keystone Lake dam in northwest Tulsa County, Oklahoma, at mile 523.7[1] and flows in a general southeasterly direction to Arkansas River Lock and Dam No. 13 near Van Buren, Arkansas, where it leaves the area at mile 308.9. Streamflow in the Arkansas River is regulated by seven multipurpose lakes and reservoirs upstream from Area 41 and by three multipurpose lakes and four navigational locks and dams within the area. The reach of the river downstream from mile 460.2 near Muskogee, Oklahoma, is a segment of the McClellan-Kerr Arkansas River Navigation System to the Mississippi River which was opened to commercial traffic in 1970.

The principal tributary to the Arkansas River is the Canadian River which enters the area in eastern Hughes County, Oklahoma, and flows in a general east-northeasterly direction to its confluence with the Arkansas River at mile 422.7. The next largest tributary is the Poteau River which originates near Cardiff, Scott County, Arkansas, and flows westward into central Le Flore County, Oklahoma, where it curves northerly to flow into the Arkansas River at the Arkansas-Oklahoma State line.

About 20 percent of the area is drained by Clear Boggy and Muddy Boggy Creeks. These streams join at the southern boundary of the area and thence flow into the Red River.

[1] Mile refers to river mile or the distance upstream from the mouth of a river.

Figure 2.3-1 Drainage basins.

Soils Characteristics in Area Vary with Geology and Physiography

Most soils were developed from shale and sandstone and have low to moderate fertility, very slow to moderate permeability, and moderate potential for erosion.

Distribution of soil types varies with geologic and physiographic features. Soil characteristics are determined by the physical and mineral composition of the parent materials, relief of the land, climate, plant and animal life in and on the soil, and the length of time that soil-forming processes have been acting on the soil material. For general purposes, soils are grouped into soil associations (fig. 2.4–1) consisting of one or more major soils with generally similar characteristics. These soil associations were recognized by the different States in which they were mapped and thus differ in nomenclature even though some of them have similar characteristics and properties.

The most extensive soil association in Area 41 is the Hector-Pottsville (table 2.4–1) which is developed primarily on sandstone and shale. Due to the steep and hilly topography, low fertility, and general stoniness, these soils are mostly wooded with oak, hickory, and pine. Local areas of more level or rolling land, underlain mainly by shale, are well suited for pasture. The Parsons-Dennis-Bates association also is extensive and occurs principally in the prairies or savannah areas. These soils, developed mostly on shale, support tall grasses and provide some of the better pasture and cropland in the area.

Soil properties particularly significant to reclamation of surface-mined land include fertility, depth to bedrock, land slope, permeability, available water capacity, soil reaction, and erosion potential. Suitability rating of soils used as a plant growth medium in reclamation of surface-mined areas have been described by the U.S. Department of Interior (1977).

The depth to bedrock in the area ranges from zero or a few inches on the sandstone ridges and hills to 10–30 feet in the gently-floored valleys where soils are moderately deep (20–36 inches) to deep (more than 36 inches).

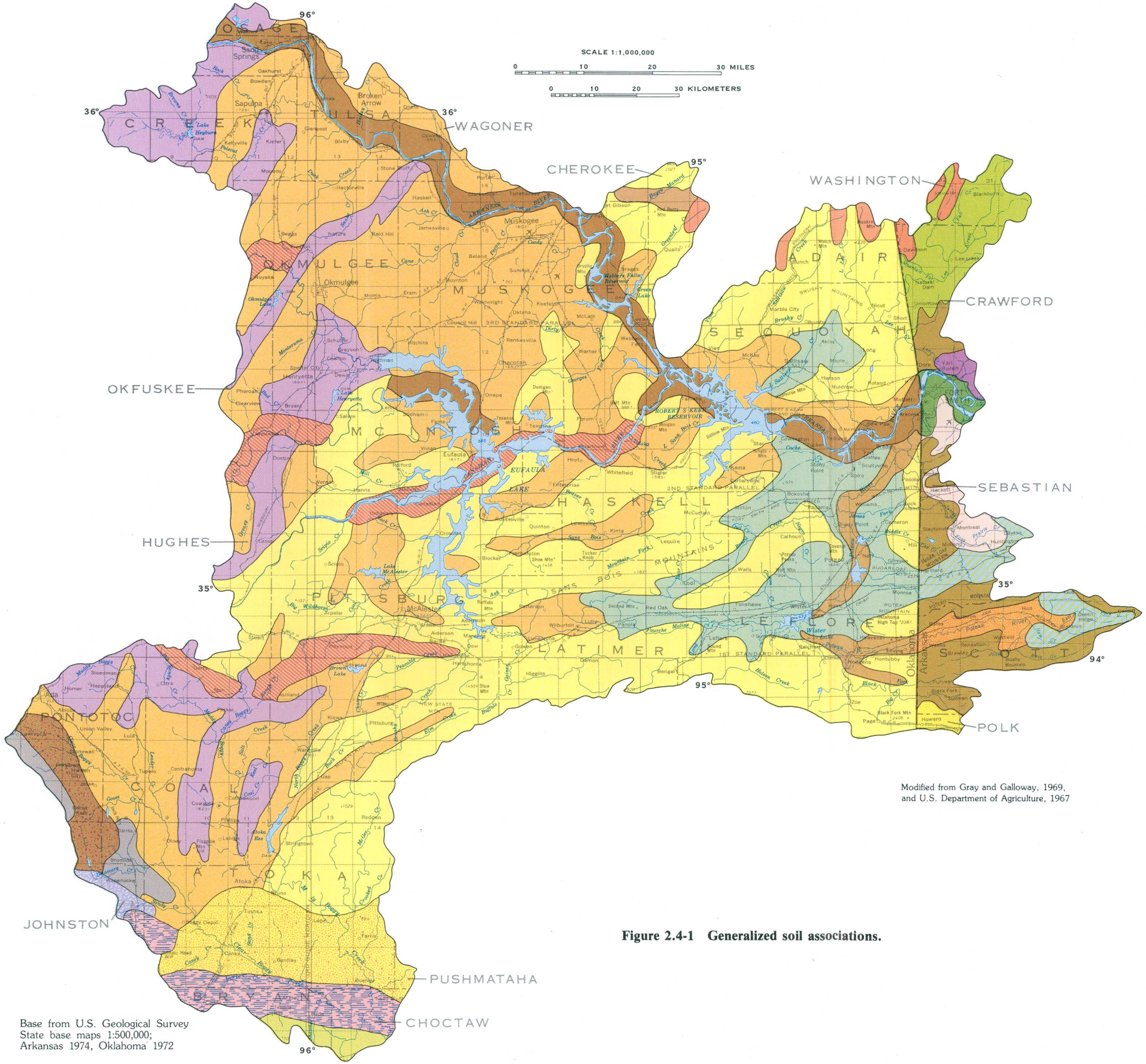
Soil permeability, which is the estimated rate of vertical transmission of water in saturated soil under unit head pressure, ranges from very slow (less than 0.06 inches per hour) to moderate (0.6 to 2 inches per hour). In general, permeabilities are lowest in soils developed from shale, clay, and alluvium and are moderate in soils developed from sandstone.

Available water capacity is the difference between the amount of water in the soil at saturation and the amount at the wilting point of most plants. In Area 41, available water capacity is high in the valley and alluvial soils because these deep, silty soils hold much water that the plants can extract and use. Available water capacity is moderate in loamy soils and is low in gravelly and stony soils of many upland areas. In some clay soils the water is held so tightly that the plants cannot extract it thus the available water capacity is low.

Soil reaction is a measure of acidity or alkalinity of the soil, expressed in pH units. Those soils formed from shale and sandstone tend to be acidic to neutral (pH 5.0 to 7). Locally in the northwestern part of the area where a few thin beds of limestone occur, the soils are neutral to mildly alkaline (pH 7.0 to 7.5) due to the release of bicarbonate ions during weathering of the limestone. Soil reactions in alluvial soils vary with composition of the material from which they were derived but in most of Area 41 they tend to be slightly acidic to slightly alkaline.

Erosion potential is affected by such soil conditions as permeability, texture and stability, depth, slope, and vegetative cover. Most soils in the area have moderate to severe erosion potential. Clay soils under native vegetation or carefully managed cropland and pasture have low erosion potential. Sandy soils, soils on steep slopes, or soils that have been denuded of plant growth by mining, fire, or overgrazing have a much higher erosion potential.

Detailed descriptions of soils and their various characteristics or properties as well as their potential for cropland, pasture, or woodland are given in publications of the U.S. Department of Agriculture, Soil Conservation Service. Most recent reports by the Soil Conservation Service show the distribution of soils on aerial photographs and provide information on management and utilization of various soils. Soil survey information is available from Soil Conservation Service offices in most county seats of Area 41 counties or from State offices in Stillwater, Oklahoma, and Little Rock, Arkansas.



Modified from Gray and Galloway, 1969, and U.S. Department of Agriculture, 1967

Base from U.S. Geological Survey State base maps 1:500,000; Arkansas 1974, Oklahoma 1972

Figure 2.4-1 Generalized soil associations.

Table 2.4-1 Soil associations.

Soil association		Description
	Oklahoma	
DST	Durrant-San Saba-Tarrant	Dark, loamy and clayey with clay subsoils, slowly to very slowly permeable, cropland and pasture
T	Tarrant	
TN	Tarrant-Newtonia	
DS	Darnell-Stephenville	Light-colored, sandy with reddish subsoils, very slowly permeable, pasture and cropland
DTY	Dougherty-Teller-Yohola	
LSS	Labette-Summit-Sogu	Dark-colored, clayey to sandy with clay subsoils, slowly permeable, pasture and cropland
PDB	Parsons-Dennis-Bates	
KCB	Kirvin-Cuthbert-Bowie	Light-colored, sandy with sandy clay loams to clay subsoils slowly to very slowly permeable, woodland and pasture
BCB	Bowie-Caddo-Boswell	
HP	Hector-Pottsville	Light-colored, sandy to loamy with heavier subsoils and shallow soils, slowly to moderately permeable, woodland and pasture
ECH	Enders-Conway-Hector	
BB	Bodine-Baxter	Brown and light-colored, silty with reddish clay subsoils, partly stony, moderately to rapidly permeable, woodland and pasture
AP	Atkins-Pope	Nearly level bottom lands, sandy to clayey, slowly to moderately permeable, cropland, pasture, and woodland
YPR	Yahola-Port-Reinach	
GT	Granitic Mountains-Tishomingo	Thin, stony, pasture and wildlife
	Arkansas	
EA	Enders-Alleghany	Grayish-brown or brown, loam or loamy, very slowly to moderately permeable, mostly woodland with some pasture
EH	Enders-Holston	
LTM	Leadvale-Taft-Montevallo	Dark brown and dark grayish-brown, loamy, slowly permeable, cropland and pasture
ME	Mountainburg-Enders	Brown and dark grayish-brown, partly gravelly or stony, rapid and very slowly permeable, mostly woodland with grassy areas
LMH	Linker-Mountainburg-Hartsells	Grayish-brown and brown, loam and clay loam, partly gravelly or stony, moderately and rapidly permeable, cropland, pasture, and woodland
PL	Pickwick-Leadvale	Grayish-brown and brown, sandy loam, moderately and slowly permeable, cropland and pasture
F	Falkner	Dark grayish-brown, silt loam, slowly permeable, hay and pasture
GR	Goldston-Rockland	Shallow, rough and stony, slowly and moderately permeable, woodland and wildlife
CN	Coushatta-Norwood	Deep, silt loam, rapidly permeable, cropland and woodland

Modified from Gray and Galloway, 1969, U.S. Department of Agriculture, 1967, and Oklahoma Water Resources Board, 1969, 1970, 1971a, and 1971b

Nearly One-Half the Area is Woodlands, the Remainder is About Equally Divided Between Pasture and Croplands

Woodlands predominate in the eastern part of the area; pasture and croplands predominate in the western part.

Land use varies with geology, topography, distribution of soils, and climate and coincides rather closely with geomorphic subdivisions described in section 2.2. As outlined by Austin (1972), the area includes three major land-resource regions distinguished by percentage of cropland, pastureland, and woodland (fig. 2.5–1). The eastern part of the area is included in the General Farming and Forest Region which includes three subregions—the Boston Mountains, the Arkansas Valley and Ridges, and the Ouachita Mountains. Most of the western part of the area is included in the Feed Grains and Livestock Region; a small part is included in the Crop, Forest, and Livestock Region.

In the Boston Mountains subregion, about 75 percent of the area is forested. The remaining 25 percent is about evenly divided between pasture and cropland. Pastures are mostly domestic grasses but native grasses are important in some parts of the area. Small grains and hay are the main crops.

In the Arkansas Valley and Ridges subregion, about 50 percent of the area is forested, about 30 percent is pastureland, and about 20 percent is cropland. Pastures are on the bottom lands along small streams and throughout cleared parts of the upland; they consist of a mixture of domestic and native grasses and some legumes. Most of the croplands are on the less sloping areas in the valleys but some are on the flat uplands. Hay and feed grains are the principal crops.

In the Ouachita Mountains subregion, about 80 percent of the area is forested. The southern half of Le Flore County, Oklahoma, and most of adjacent Scott County, Arkansas, are in the Ouachita Na tional Forest administered by the U.S. Forest Service. In this area, shortleaf pine is the major wood-producing tree but other commercially important trees in clude white oak, red oak, and gum. The principal forest products include lumber, paper pulp, posts, and poles. The remaining 20 percent of the subregion is about equally divided between pasture and croplands. Pastures are mainly mixtures of domestic grasses and legumes and the principal crops are hay and small grains. Because of the scenic terrain and the semi-wilderness aspect of the Ouachita Mountains, recreational uses are important.

The western part of the area is within the Feed Grains and Livestock Region. About 50 percent of this region is cropland with winter wheat, grain sorghum, soy beans, other feed grains, and hay as the principal crops. About 40 percent of the region is pasture mainly of domestic grasses and legumes with native grasses on the more sloping parts. Woodlands occupy about 10 percent of the area and are on the steeper slopes and wet bottomlands along larger streams.

The extreme southern part of the area is in the Crop, Forest, and Live-stock Region. About 70 percent of the region is woodland, about 20 percent cropland, and about 10 percent pasture land.

Additional land-use information is available as a result of the increasing accessibility of aerial photography and remote-sensing imagery. Detailed land-use and land-cover maps have been prepared by the U.S. Geological Survey from Landsat imagery. These maps are published at a scale of 1:250,000 with a minimum mapping unit of 4 hectares (about 10 acres). Land-use maps are available for parts of Area 41 (fig. 2.5–2); information concerning these maps can be obtained from:

Midcontinent Mapping Center
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
(314) 341-0851

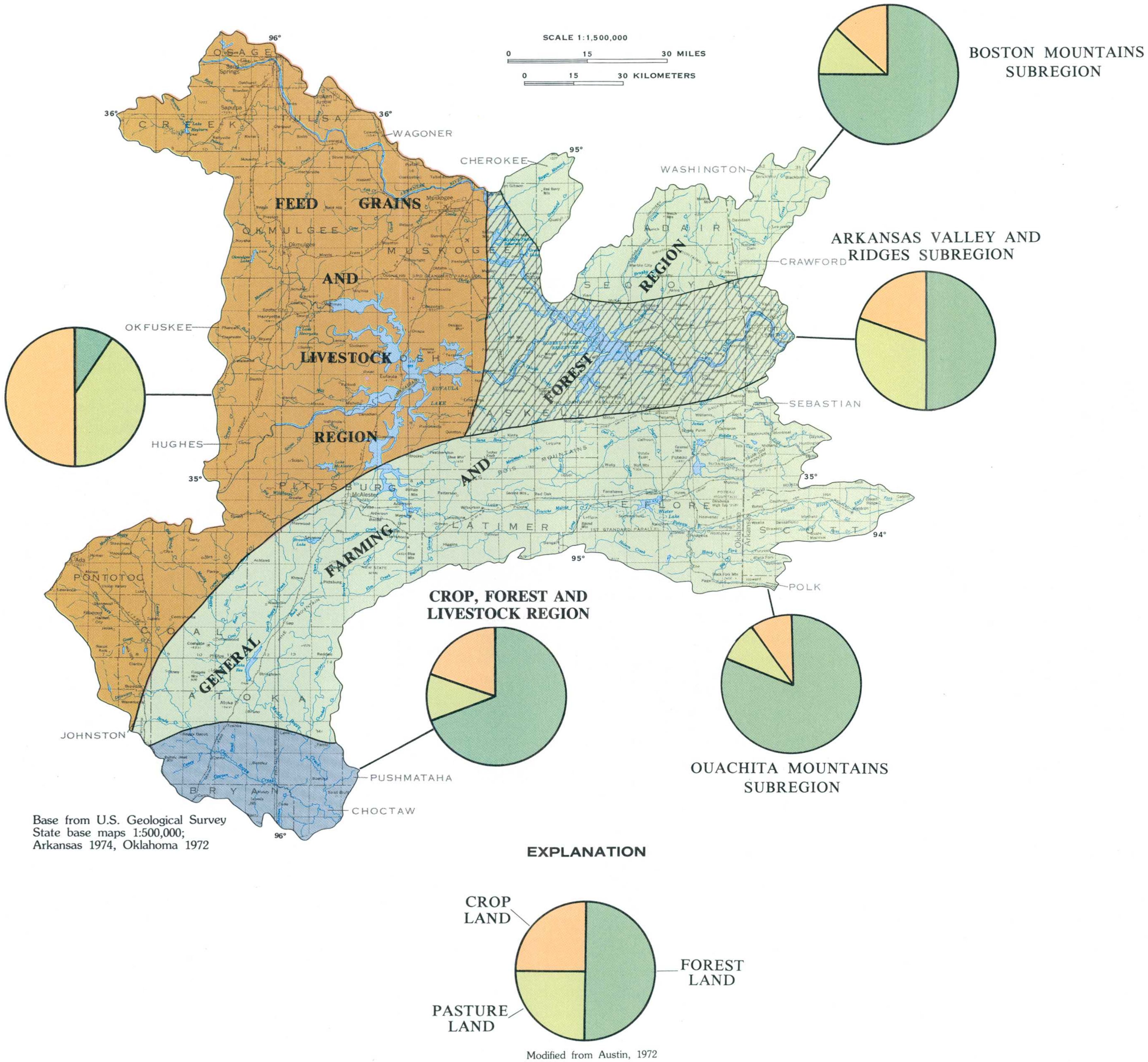


Figure 2.5-1 Land use.

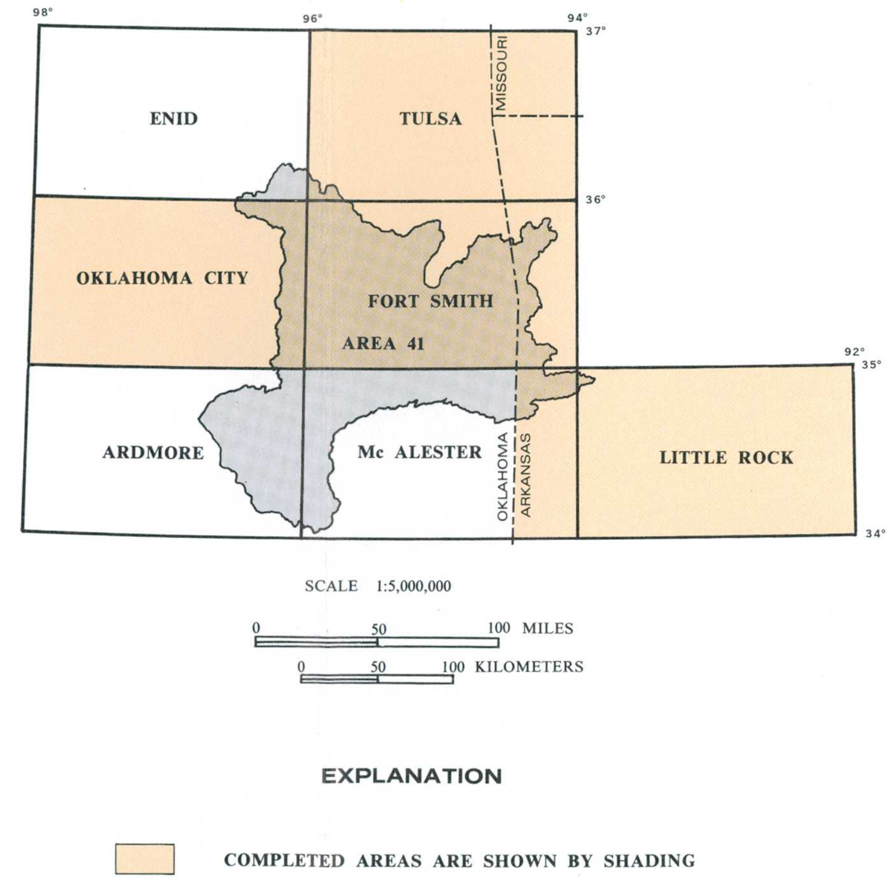


Figure 2.5-2 Land-use and land-cover maps available for Area 41.

Area has Warm, Temperate Climate

Normal annual precipitation ranges from 36 to 50 inches.

Area 41 has a warm, temperate climate and seasonal changes usually are gradual. Spring and autumn are mild and summers are hot and humid. Winters are comparatively mild although an occasional influx of cold air keeps the temperature below freezing several days in most years.

Normal annual precipitation ranges from about 36 inches in the northwestern part of the area to about 50 inches in the southeastern part (fig. 2.6–1). On the average, about 32 percent of the annual precipitation falls in the spring, 27 percent in the summer, 22 percent in the autumn, and 19 percent in the winter. The monthly and seasonal distribution of precipitation at Eufaula, Oklahoma, (fig. 2.6–2) is typical of the area. Much of the rainfall results from short-duration thunderstorms of varying intensity which are most common in April, May, and June, but can occur any month of the year. Such rainfall generally is very local in extent with several inches falling at one locality whereas none may fall a mile or two distant. Rainfall totals of as much as 10 inches in 24 hours have been recorded in the area. Precipitation is the winter typically is more widespread in area and more uniform in volume. Snowfall averages about 6 inches per year and falls mainly during January and February.

The National Oceanic and Atmospheric Administration (NOAA) maintains 22 precipitation stations, with 20 or more years of record, fairly well distributed across the area (fig. 2.6–1). In addition to these and other stations maintained by NOAA, the U.S. Geological Survey operates six stations (fig. 4.2–1) specifically intended to determine the relationship between annual and seasonal distribution of precipitation and ground-water levels in selected areas of current or potential coal mining. Data pro vided by these stations also will be useful in analysis of rainfall-runoff relationships.

The areal variation in mean annual temperature across the area is slight, normally averaging about 2 degrees. The graph of mean monthly temperature at Eufaula, Oklahoma, (fig. 2.6–3), which is typical of Area 41, shows that July and August are the warmest months and December and January are the coldest. Average daily maximum temperatures range from about 50 degrees in January to 95 degrees in July and August. Average daily minimum temperatures range from 28 degrees in January to 70 degrees in July and August.

Prevailing winds are southerly except in January and February when northerly winds are more common. Wind speeds range from 10 to 15 miles per hour with spring being the windiest season and summer the least windy. Winds of 30–40 miles per hour commonly are associated with thunderstorms during the passage of frontal systems.

Daily climatological data are published monthly for each state by the National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, North Carolina. Statistical analysis of historical climatic data are available in Technical Paper 40 entitled "Rainfall Frequency Atlas of the United States" by the U.S. Department of Commerce.

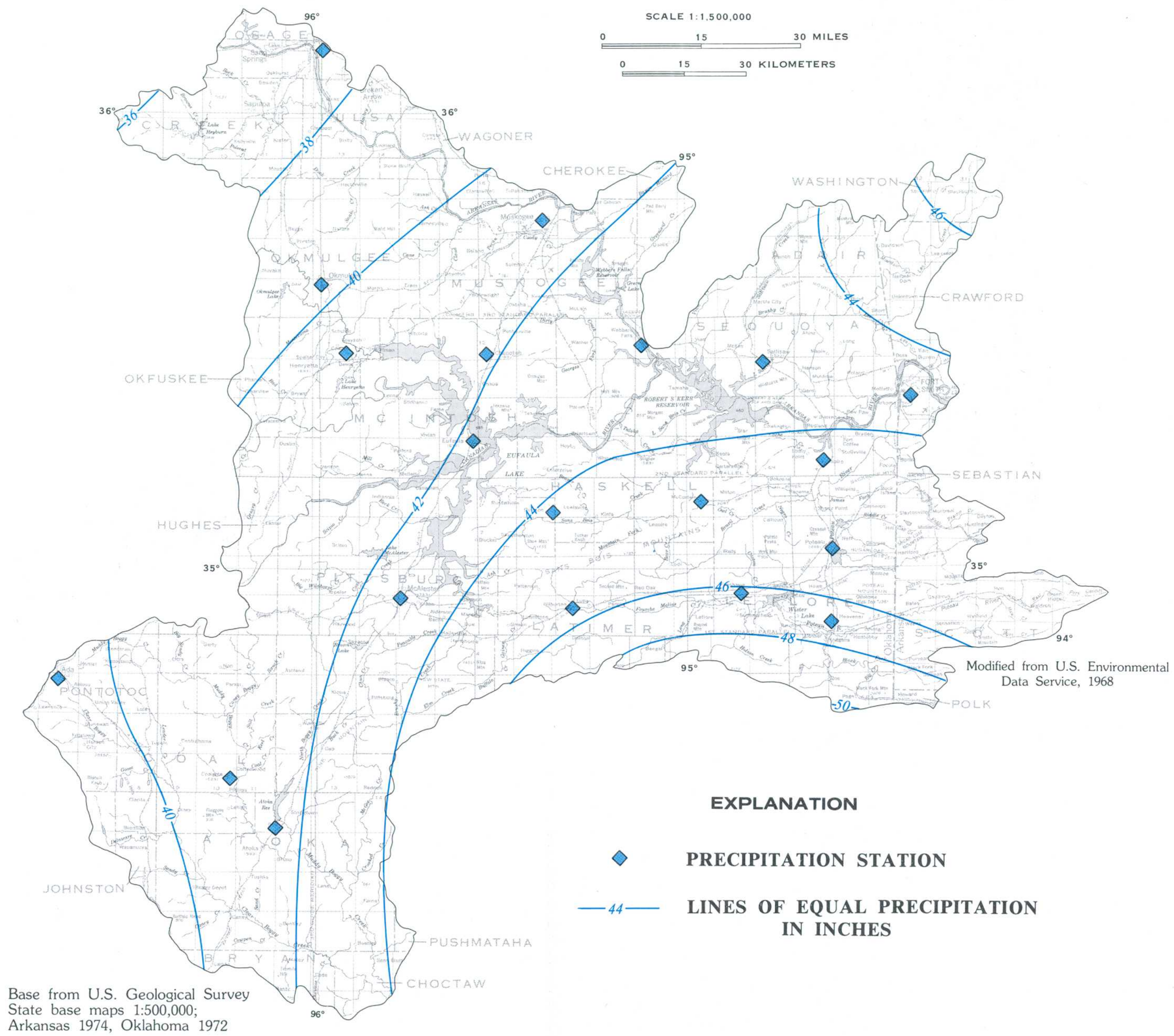


Figure 2.6-1 Location of precipitation stations with more than 20 years record and normal annual precipitation, in inches, 1931-60.

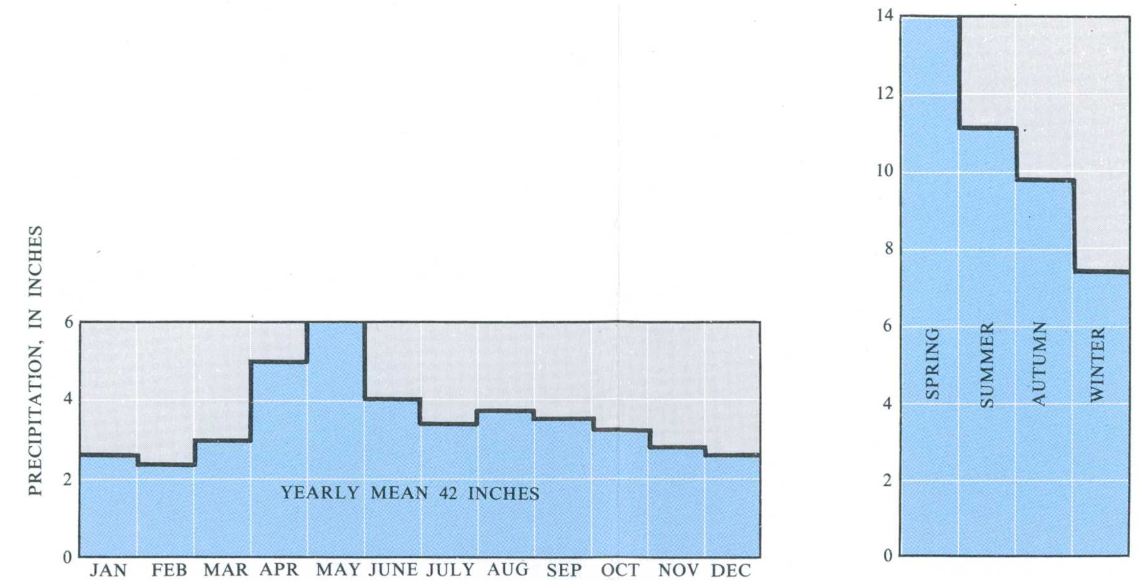


Figure 2.6-2 Mean monthly and mean seasonal precipitation at Eufaula, Oklahoma.

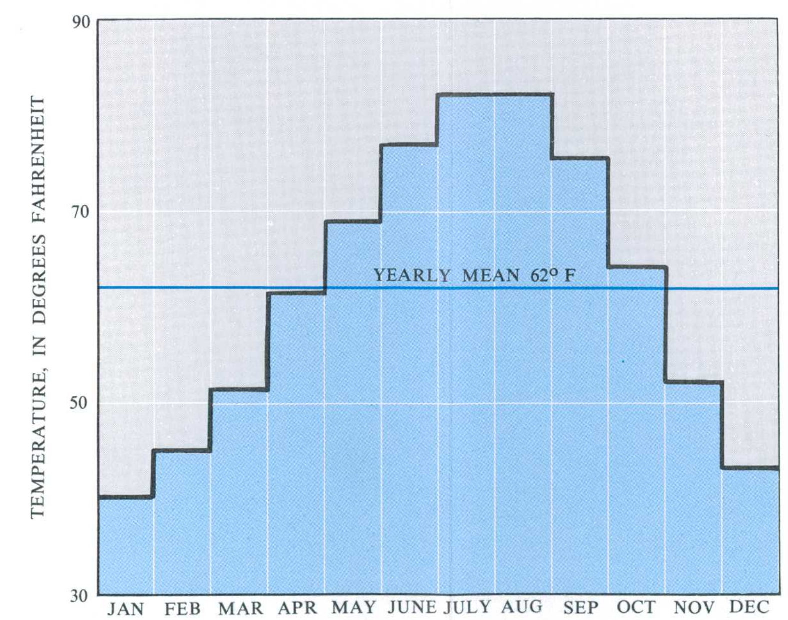


Figure 2.6-3 Mean monthly temperature at Eufaula, Oklahoma.

Principal Use of Water is for Public Supply

Approximately 93 percent of the water used is from surface-water sources.

Annual reported water use for irrigation, public supply, self-supplied industrial, power generation, and self-supplied rural domestic is given in the table 3.1–1. The data are for entire counties and not just that part in Area 41 thus the values are greater than the actual amount used in the area. Total water use in 1980 was about 402 million gallons per day. Of this amount, 214 million gallons per day, or 53 percent, was used for public supply and 120 million gallons per day, or 30 percent, was used for power generation (fig. 3.1–1). The greatest amount of water used, about 30 percent, was in the Tulsa area. Approximately 372 million gallons per day, or 93 percent, was derived from lakes and reservoirs (fig. 3.1–2) thus reflecting the lack of significant sources of ground water in the area.

Records of water use by county and purpose of use are available from the following agencies:

Oklahoma Water Resources Board
1000 NE 10th Street
P.O. Box 53585
Oklahoma City, OK 73153
(405) 271-2555

U.S. Geological Survey
Water Resources Division
2301 Federal Building
Little Rock, AR 72201
(501) 378-6391

The U.S. Geological Survey has published a report on estimated water use in the United States every 5 years since 1950. These reports rely on estimates derived from many sources to show water uses by States and by large river-basin regions. The need for more timely, consistent water-use data base for water policy and management by Federal, State, and local authorities led to the establishment of the National Water-Use Information Program in 1978. The program is designed to standardize the collection of water-use data, computerize storage and retrieval of these data, and improve methods of disseminating the information. Water withdrawal, return-flow, and usage data are compiled for 12 use categories and stored in a computerized system of State and National files. For each State, an automated State Water-Use Data System (SWUDS) will store site- and user-specific data. Aggregated information is available through the National Water-Use Data System (NWUDS). This data base can be accessed by all registered users of the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) and the National Water Data Exchange (NAWDEX). Information on these systems and on NAWDEX assistance centers is given in section 9.0.

Table 3.1-1 Water use in 1980 in million gallons per day.

[Data are for entire county and not just that part in Area 41]

County	Irrigation		Public supply		Industrial		Power		Rural domestic		Total	
	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water	Surface water	Ground water
OKLAHOMA												
Atoka	1.35	---	---	0.03	---	---	---	---	---	0.30	1.35	0.33
Bryan	6.73	0.76	0.02	.35	---	---	---	---	---	.36	6.75	1.47
Choctaw	4.56	.11	6.07	.19	---	---	---	---	---	.39	10.63	.69
Coal	.71	.03	.75	.05	---	---	---	---	---	.12	1.46	.20
Creek	.35	.02	4.17	.61	0.61	0.17	---	---	---	.68	5.13	1.48
Haskell	.04	---	.85	---	.09	---	---	---	---	.14	.98	.14
Hughes	3.92	1.77	.36	.09	---	---	---	---	---	.19	4.28	2.05
Johnston	1.79	.04	.42	1.16	.04	---	---	---	---	.09	2.25	1.29
Latimer	.15	---	1.79	---	---	---	---	---	---	.08	1.94	.08
Le Flore	.56	.18	5.95	---	---	---	---	---	---	.05	6.51	.23
McIntosh	---	---	2.76	---	.62	---	---	---	---	.16	3.38	.16
Muskogee	.45	2.07	5.72	---	8.63	---	102.04	---	---	.47	116.84	2.54
Okfuskee	.94	.06	.79	---	---	---	---	---	---	.09	1.73	.15
Okmulgee	.19	---	8.61	---	---	---	---	---	---	.16	8.80	.16
Pittsburg	.06	.06	1.86	---	.02	---	---	---	---	.11	1.94	.17
Pontotoc	.81	.65	2.57	1.99	---	.39	---	2.10	---	.30	3.38	5.43
Sequoyah	2.31	.76	2.74	---	7.33	---	---	---	---	.34	12.38	1.10
Tulsa	.04	.48	117.15	---	---	.02	15.78	---	---	1.05	132.97	1.55
Wagoner	.69	.06	6.77	---	---	---	---	---	---	.41	7.46	.47
Subtotal	25.65	7.05	169.35	4.47	17.34	.58	117.82	2.10	---	5.49	330.16	19.69
ARKANSAS												
Crawford	1.18	3.88	5.05	---	.18	.03	---	---	---	1.07	6.41	4.98
Scott	.01	---	.84	---	---	.01	---	---	---	.62	.85	.63
Sebastian	.02	.61	18.89	.09	.23	.05	---	---	---	.89	19.14	1.64
Washington	---	.80	14.98	.02	.07	.03	---	---	---	2.20	15.05	3.05
Subtotal	1.21	5.29	39.76	.11	.48	.12	---	---	---	4.78	41.45	10.30
TOTALS	26.86	12.34	209.11	4.58	17.82	.70	117.82	2.10	---	10.27	371.61	29.99

Data for Oklahoma from unpublished records by the Oklahoma Water Resources Board; data for Arkansas from Holland and Ludwig, 1981

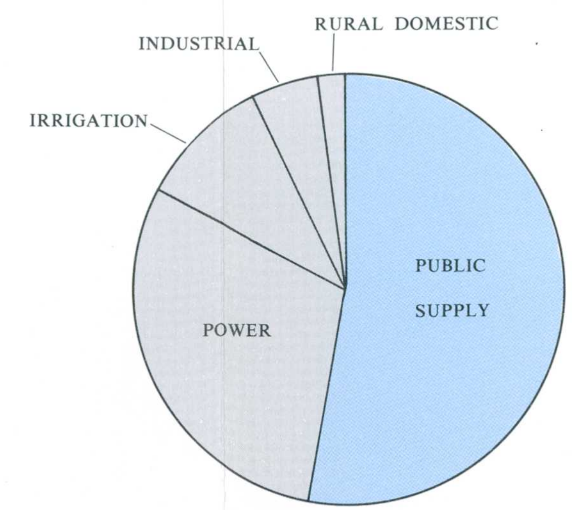


Figure 3.1-1 Uses of water.

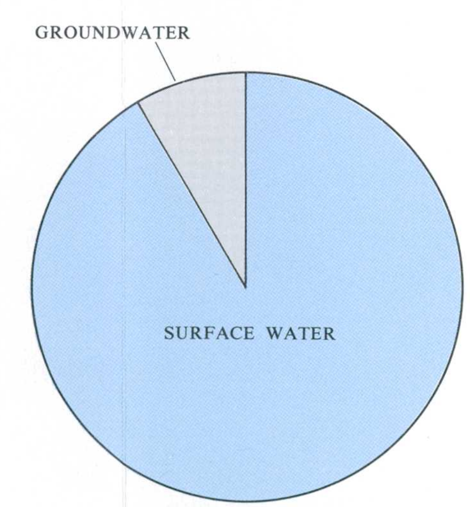


Figure 3.1-2 Sources of water.

About 15 Percent of the Population in Area Supplied by Rural Water Systems

Of 103 rural water systems in the area, 95 derive their supplies from surface-water sources.

In many parts of Area 41 adequate supplies of suitable ground water are not available or are expensive to obtain. Consequently, water districts have been established to meet the water-supply needs of the rural population. With funds from Federal and State agencies and local bonds or taxes, rural water districts are able to construct and maintain reservoirs, wells, pumping installations, pipe lines, and treatment and storage facilities.

Many of the areas served by rural water systems (fig. 3.2–1) include small communities and incorporated towns. As of 1978, 103 systems provided water to about 144,000 customers (table 3.2–1) or about 15 percent of the population of the area; the number of systems and customers probably have increased significantly since these data were compiled.

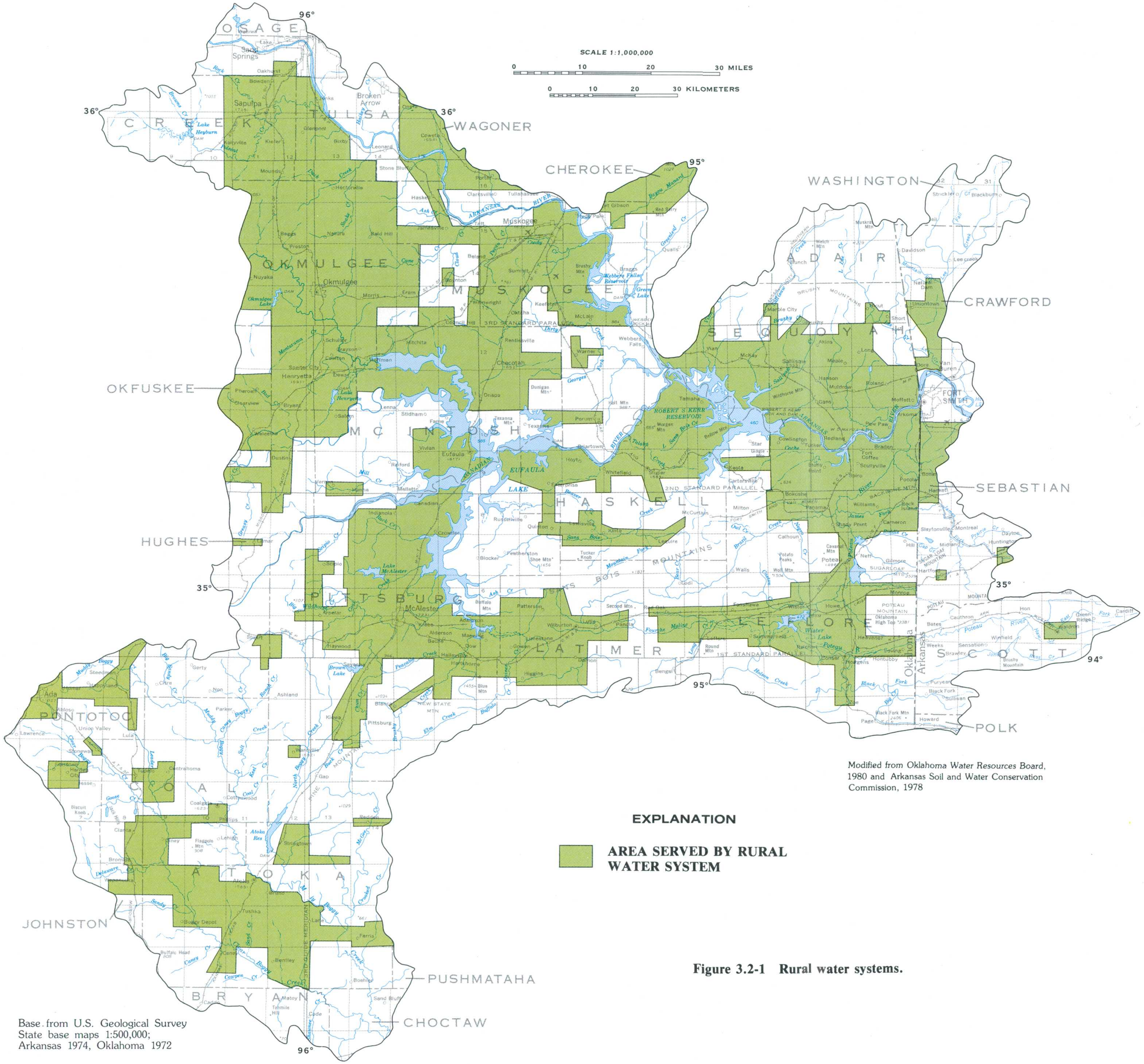


Figure 3.2-1 Rural water systems.

Table 3.2-1 Rural water systems in Area 41.

County	Number of systems	Population served	Source of water (number of systems) Ground water	Surface water
		Oklahoma		
Atoka	5	3,250	2	3
Bryan	---	---	---	---
Choctaw	---	---	---	---
Coal	3	920	3 1/	
Creek	6	18,775		6
Haskell	1	3,100		1
Hughes	3	550 2/	1	2
Johnston	1	805		1
Latimer	3	8,225		3
Le Flore	10	17,170		10
McIntosh	7	5,400	1	6
Muskogee	12	15,770		12
Okfuskee	2	2,300		2
Okmulgee	11	12,270		11
Pittsburg	14	18,915		14
Pontotoc	4	4,225		4
Sequoyah	8	13,420		8
Tulsa	1	500 3/		1
Wagoner	5	11,885		5
		Arkansas		
Crawford	2	1,770		2
Scott	1	2,500		1
Sebastian	4	2,285	1	3 4/
Washington	---	---	---	---
TOTALS	103	144,035	8	95

1/ Supplemented with surface water
2/ Part included with McIntosh County
3/ Part included with Okmulgee County
4/ One system uses both ground and surface water

Data Available for 118 Stations and Numerous Miscellaneous Sites

Surface-water data are published in Water-Supply Papers and in annual State water-data reports and are available from computer storage.

Information concerning streamflow, water quality, sediment, and reservoir or lake contents are essential to understanding the hydrology of an area. In order to assess the total water resources and to evaluate man's effects on those resources, both historic and current, site-specific data are needed. Surface-water data collected in Area 41 by the U.S. Geological Survey include records of stage, discharge, water quality, and suspended sediment of streams and records of stage and contents of reservoirs and lakes. Data have been collected at 118 stations (fig. 4.1–1) of which 22 were active in 1983. A detailed description of each station, types of data collected, and periods of record are summarized in section 10.1.

Additional streamflow and stream water-quality have been collected at numerous miscellaneous sites not shown on figure 4.1–1. These data, which can be used to supplement that collected systematically, were collected for site-specific or special studies primarily in areas that have been mined or have potential for mining. Most of the special studies are described in section 4.3.

Data from surface-water stations and miscellaneous sites in Area 41 are available from several sources. Records of discharge and stage of streams and stage and contents of reservoirs and lakes were published annually in the series of U.S. Geological Survey Water-Supply Papers entitled "Surface Water Supply of the United States" until 1861 and in a 5-year series for 1961–65 and 1966–70; records for Area 41 are in Part 7 of that series. Streamflow data also were published in annual water-data reports for each State from 1961–74. Records of chemical quality, water temperature, and suspended sediment were published for 1941–70 in an annual series of Water-Supply Papers entitled "Quality of Surface Waters of the United States"; data for Area 41 are in Part 7. Water-quality records also were released in annual water-data reports for 1964–74. Since 1975, data on streamflow, water quality, and reservoir contents have been published in annual data reports for each State entitled "Water Resources Data, Oklahoma, Water Year 1981" and "Water Resources Data, Arkansas, Water Year 1981".

Water-Supply Papers may be consulted in libraries of the principal cities or they may be purchased from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202. State annual-water data reports may be purchased from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161. Surface-water data also are available from computer storage through the National Water Data Exchange (NAWDEX) as described in section 9.2 of this report.

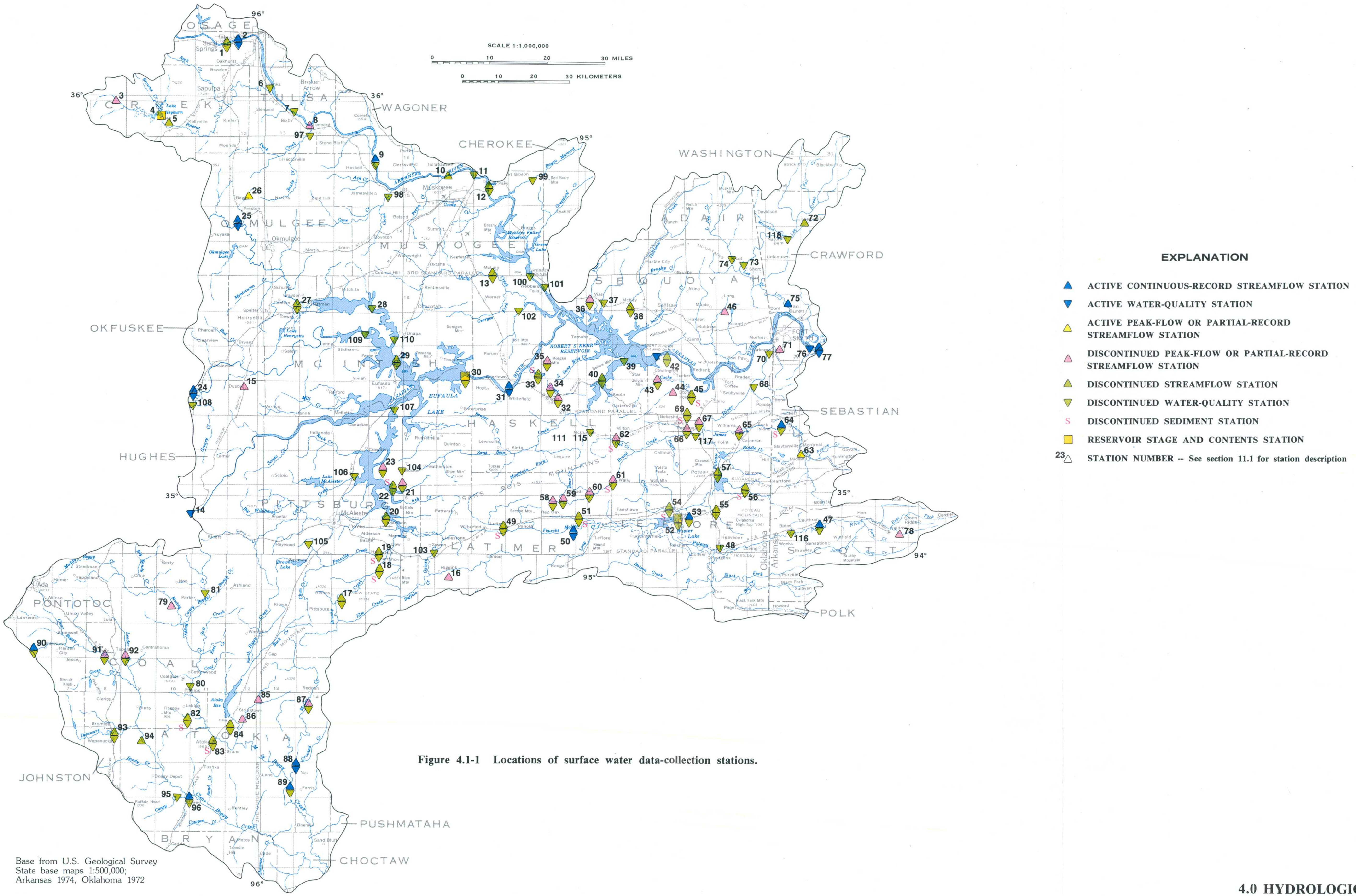


Figure 4.1-1 Locations of surface water data-collection stations.

Ground-Water Data Needed to Evaluate Effects of Mining and Reclamation

Water-level records exist for 1,707 wells and water-quality data are available for 1,422 wells.

Records of ground-water levels and water quality are needed to understand the hydrology of an area and to evaluate and manage the effects of mining on recharge-discharge characteristics and the quality of water in various local aquifers in the coal field. Water-level records consisting of five or more measurements over a period of at least one year are available for 29 wells (fig. 4.2–1); water levels in 19 of these wells are measured by the Oklahoma Water Resources Board. Water levels are measured either periodically (monthly, quarterly, or annually) or by means of continuous recorders. Information on the location, depth, aquifer, and period of record for each of the 29 wells are given in section 10.2. Water-level data also are available for an additional 1,678 wells measured fewer than five times or for less than one year (table 4.2–1); these records were collected primarily for short-term or site-specific studies.

As part of projects to appraise the hydrology of specific areas of active or potential mining, continuous recording precipitation gages have been installed adjacent to selected water-level observation wells. Data provided by these gages can be used to relate annual or seasonal changes in water levels to precipitation. Also, precipitation data, along with streamflow data, can be used to estimate volumes of ground-water recharge and discharge.

Water-quality data are available for 1,422 wells (table 4.2–1). For most of these wells, the data consist of onsite measurement of water temperature, specific conductance, and pH. Additional data for some wells include laboratory determinations of chloride, iron, manganese, and sulfate concentrations or determinations of the concentrations of other common constituents. For a few wells, detailed laboratory analysis, including trace elements, are available.

Information on water-level and water-quality sites, as well as the actual data available, may be obtained through the NAWDEX (National Water Data Exchange) system (section 9.2), from annual reports published by the U.S. Geological Survey, and from reports listed in section 11.0. In Oklahoma, additional information on municipal, industrial, irrigation, or waste-disposal wells requiring a permit may be obtained from:

Oklahoma Water Resources Board
1000 NE 10th St.
P.O. Box 53585
Oklahoma City, OK 73121
(405) 271-2555

In Arkansas, additional information on wells that provide water for muncipal supply is available from:

Arkansas Department of Health
Division of Engineering
4815 West Markham St.
Little Rock, AR 72201
(501) 661-2000

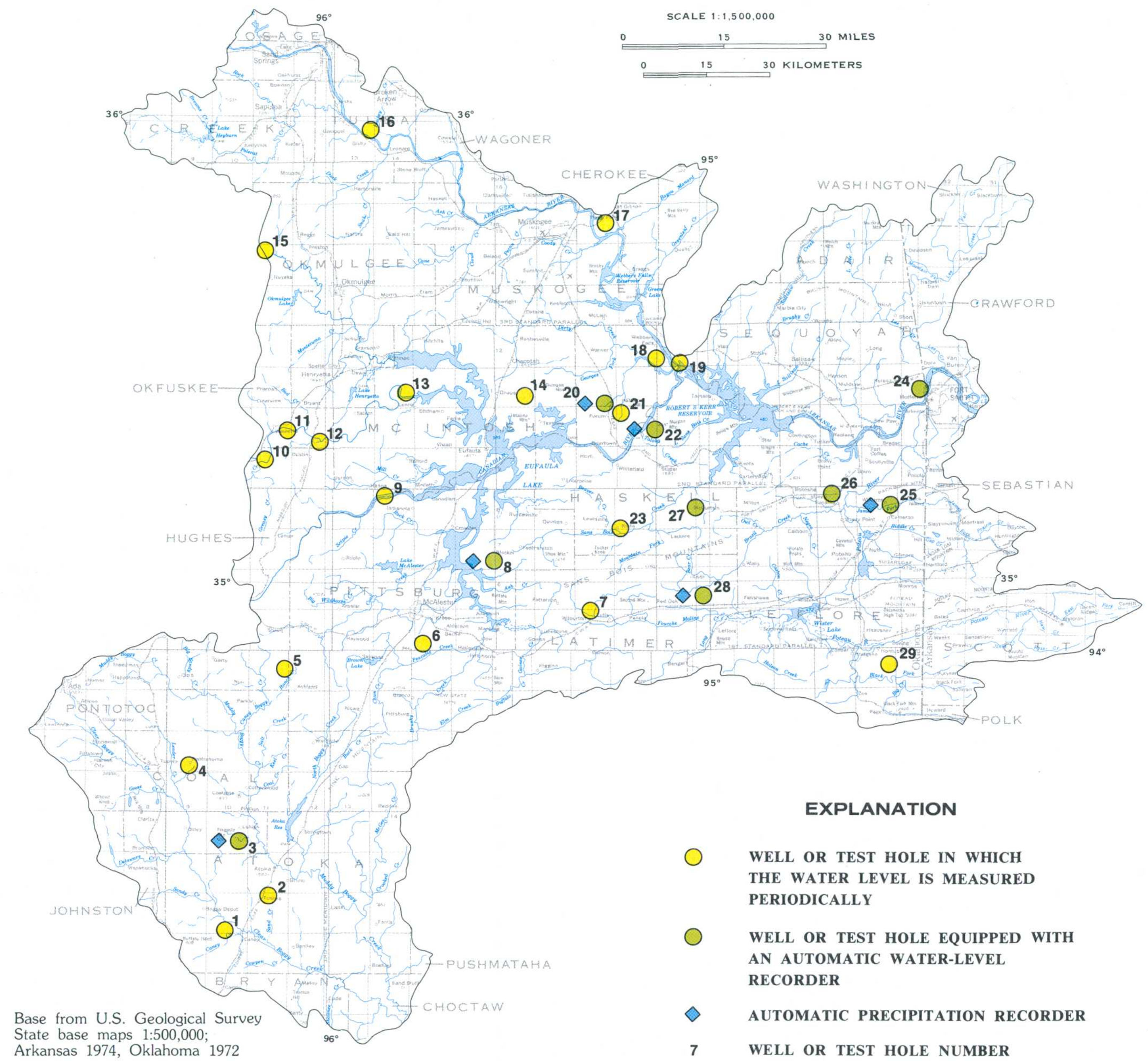


Figure 4.2-1 Ground-water-level sites.

Table 4.2-1 Number of wells in which water levels were measured fewer than five times or for less than one year as of 1983 and wells for which water-quality data were available as of 1983.

County	Number of wells: Water-level data	Number of wells: Water-quality data
	Arkansas	
Crawford	47	34
Scott	2	2
Sebastian	20	10
	Oklahoma	
Adair	23	0
Atoka	16	18
Bryan	0	0
Cherokee	11	0
Choctaw	7	0
Coal	63	80
Creek	33	1
Haskell	171	178
Hughes	19	17
Johnston	0	0
Latimer	173	133
Le Flore	267	289
McIntosh	144	69
Muskogee	121	141
Okfuskee	17	10
Okmulgee	139	55
Pittsburg	336	323
Pontotoc	26	8
Sequoyah	31	36
Tulsa	4	6
Wagoner	8	12
Totals	1,678	1,422

Special Studies Provide Hydrologic Data Throughout the Coal Field and in Specific Areas of Past, Present, or Potential Mining

Data on water quality, streamflow, and ground water are needed to assess the effects of coal mining on the hydrologic environment.

In the Oklahoma part of Area 41, special studies have been or are being made as part of the Survey's investigations of coal hydrology and in cooperation with the U.S. Bureau of Land Management and the Oklahoma Geological Survey (fig. 4.3–1). These studies are intended to provide general information on the hydrology of the coal field and to appraise the hydrology of specific areas of past, present, or potential coal mining.

As part of the Survey's studies of coal hydrology in Oklahoma, stations were established at 12 stream sites in areas of Federally-owned coal to collect data on streamflow and water quality; these stations are included in section 4.1 of this report. Also included in the Survey's program was a detailed study of an abandoned coal-mine area in Haskell County (Slack, 1983). Additionally, data on the chemical and biological quality of water in the Blue Creek arm of Lake Eufala have been collected; Blue Creek arm receives drainage from an area of potential coal mining near Blocker in Pittsburg County.

Beginning in 1978, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, began studies of selected areas in Oklahoma of Federally-owned coal under the EMRIA (Energy Minerals Rehabilitation and Inventory Analysis) program. These areas include the Blocker area in Pittsburg County, the Stigler area in Haskell County, the Rock Island area in Le Flore County, and the Red Oak area in Latimer County (Marcher and others, 1981, 1983a, 1983b, and 1983c). Also included in the EMRIA program is a rainfall-runoff model analysis of Coal Creek basin near Lehigh in Coal County. The cooperative program with the U.S. Bureau of Land Management included collection of sediment data at 15 sites.

As part of a cooperative program with the Oklahoma Geological Survey, hydrologic data have been collected throughout the Oklahoma part of the coal field since 1976. The emphasis of this cooperative program has been on the occurrence and chemical quality of ground water; however, some data also have been collected on selected streams and coal-mine ponds. Ground-water data include (1) Well depths and depths to water, (2) onsite determinations of temperature, specific conductance, and pH of well water, (3) laboratory determinations of chloride, iron, manganese, and sulfate concentrations in well water, and (4) detailed chemical analysis of water from selected wells. Surface-water data include one-time estimates of streamflow and onsite determinations of water temperature, specific conductance, and pH. Data for coal-mine ponds include profiles of specific conductance, pH, water temperature, and dissolved oxygen and laboratory determinations of concentrations of chloride, iron, manganese, and sulfate.

The regional data-collection program in cooperation with the Oklahoma Geological Survey is supplemented with more intensive study of South Fork basin, an area of past and present coal mining in southern Muskogee County. Data collected in this basin, in addition to that collected as part of the regional program, include: (1) Periodic measurement of stream discharge and collection of water samples for determinations of chemical constituents and sediment, (2) continuous measurement of ground water levels, and (3) continuous measurement of precipitation.

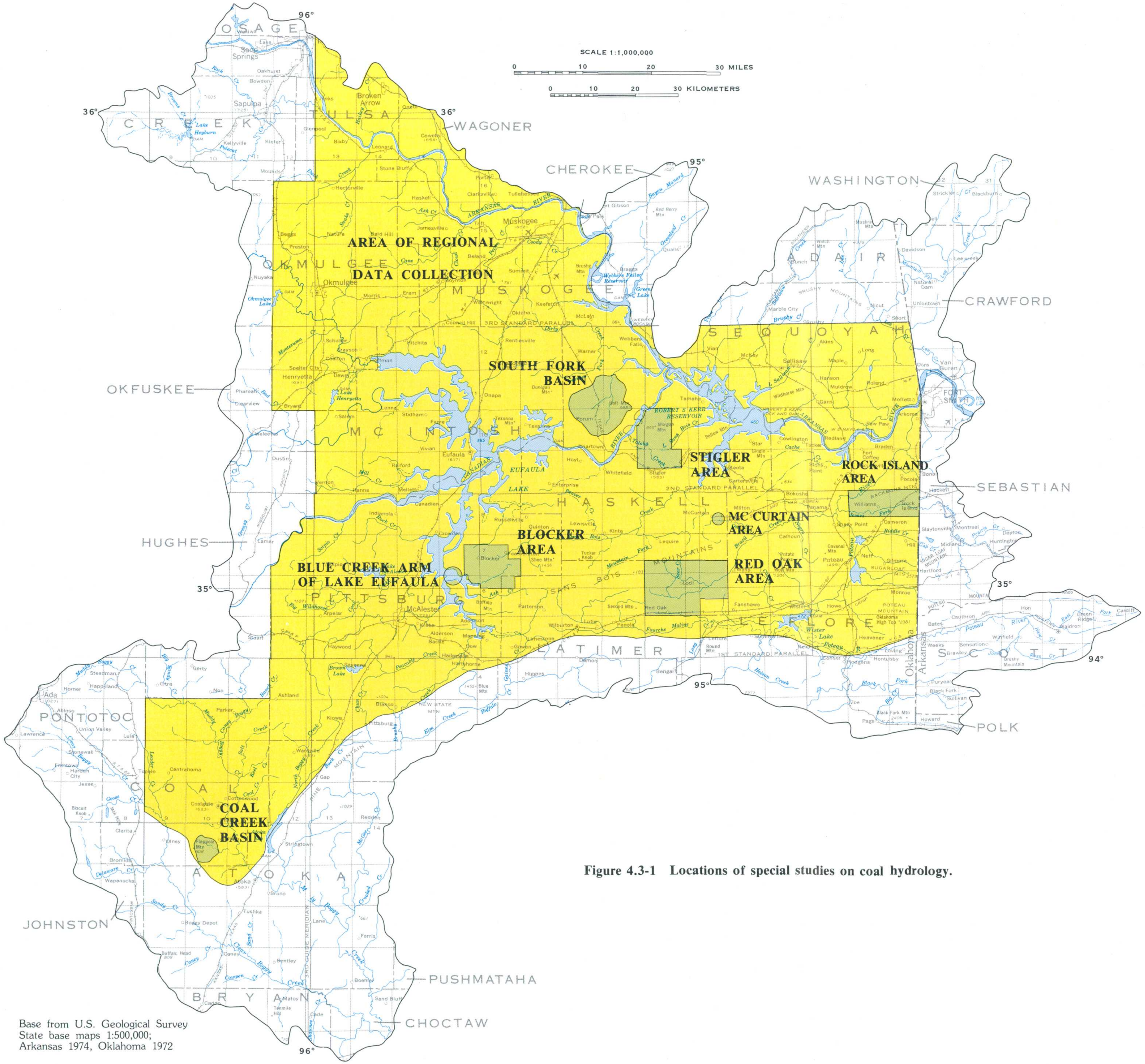


Figure 4.3-1 Locations of special studies on coal hydrology.

Streamflow Varies Seasonally

Streamflow can vary significantly from year to year and rapid changes in response to precipitation are common.

As described elsewhere in this report (sections 2.1 and 7.3), coal-bearing rocks underlying Area 41 have limited capacity to absorb, store, and transmit water. Consequently, ground water is not available to sustain streamflow during late summer and early autumn when rainfall generally is low and evapotranspiration is at or near its annual maximum. Due to the relatively impermeable nature of the bedrock and the thunderstorm type of rainfall, stream stages commonly rise and decline rapidly. Maximum streamflow typically occurs during spring and summer when about 60 percent of the annual rainfall occurs.

Blue Creek near Blocker (station 22) in Pittsburg County, Oklahoma, is representative of most small streams in the coal field and, with a drainage area of 12.1 square miles, is the size of stream that would most likely be affected by surface mining. The hydrograph of Blue Creek for the 1980–81 water years (fig. 5.1–1) shows that, except during summer and autumn, streamflow is closely related to precipitation falling on the basin. During summer when soil moisture is small and evapotranspiration is large, isolated thunderstorms of an inch or so may not result in any runoff. However, several smaller but successive thunderstorms may produce significant streamflow.

The mean discharge of 1.19 cubic feet per second for Blue Creek during the 1980 water year was well below the mean of 5.47 cubic feet per second for the 5-year period of record (1976–81); the mean discharge for the 1981 water year was slightly above the 5-year mean. About 21 inches of precipitation was recorded in 1980; however, there was no record for about 3 months. The 21 inches represents about one-half of the average annual value of 42 inches. Total streamflow for the same period (January through September) was 865 acre-feet or about 6 percent of the precipitation. In the 1981 water year, precipitation was nearly 37 inches and total streamflow was 4,750 acre-feet or 20 percent of the precipitation. These data show that streamflow from small basins, which are most likely to be affected by surface mining, can vary significantly from year to year. Thus, the effects of mining on streamflow would also vary and probably would be most pronounced in years of below-normal rainfall.

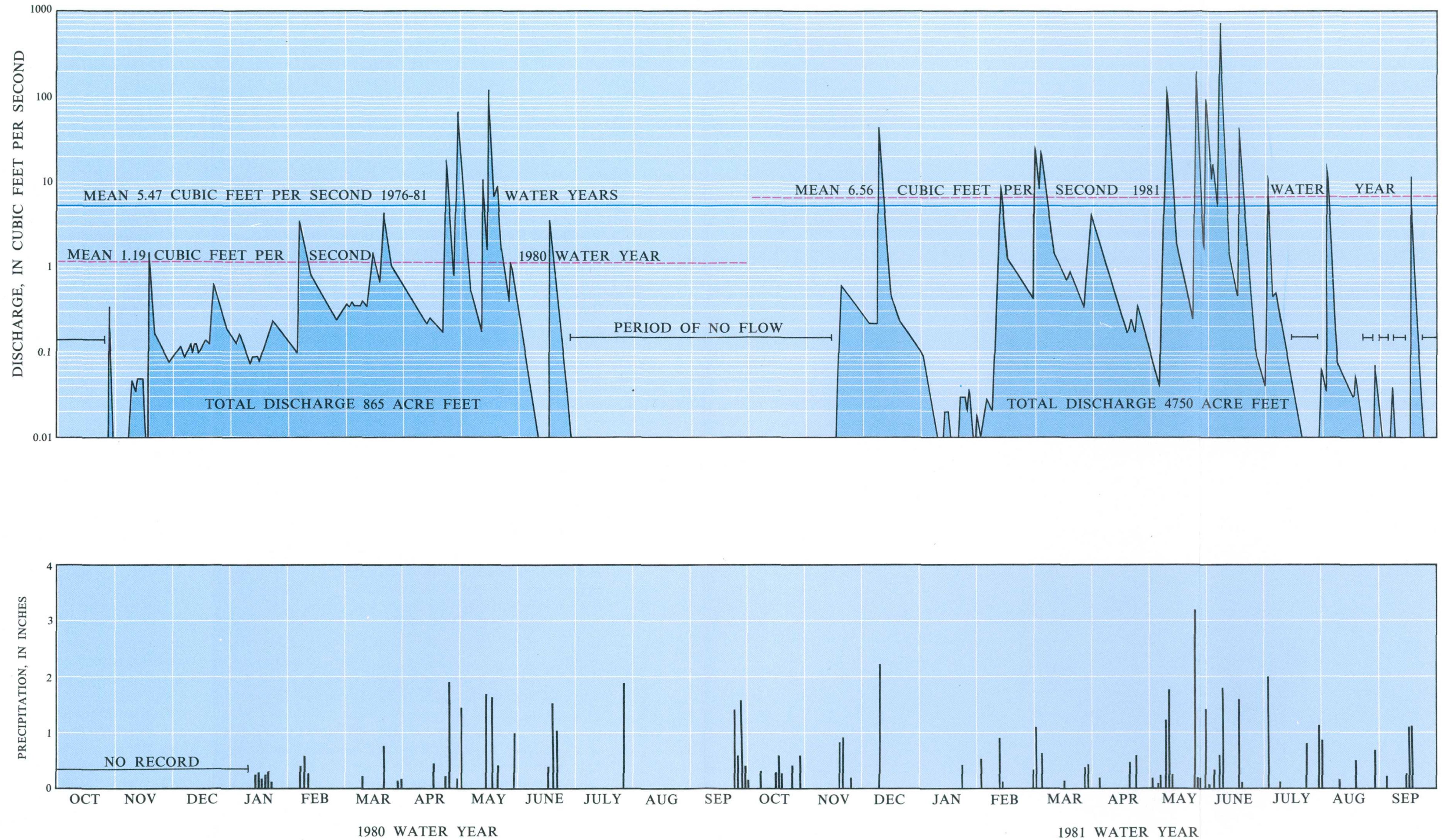


Figure 5.1-1 Streamflow hydrograph of Blue Creek (map number 22) and daily precipitation in Blue Creek basin.

Streamflow Not Sustained by Ground Water in Most of Area

Streams draining 500 square miles or less have periods of no flow most years.

Flow-duration curves[1] are useful for relating streamflow to the physical characteristics of a basin. The upper end of the curve reflects the direct runoff characteristics which are affected by climate, topography, and land use. The lower end of the curve shows the baseflow characteristics which largely depend on the ability of the rocks underlying a basin to absorb, store, and transmit water. A steep slope of the lower part of the curve indicates that ground water is not available to sustain streamflow during dry periods; a flat slope indicates that streamflow is sustained by ground water or by water from some other source during periods of no rainfall.

Flow-duration curves for four streams (fig. 5.2–1) with drainage areas of 35.3 to 1,087 square miles illustrate the typical time distribution of streamflow in Area 41. Peak flows, which relate mainly to basin size, range from 1,000 to 45,000 cubic feet per second. However, 50 percent of the time the discharge of Muddy Boggy and Lee Creeks was about 180 cubic feet per second or less even though the drainage area of Muddy Boggy Creek is about 2.5 times as large as that for Lee Creek. The curves also show that Lee Creek, Fourche Maline, and Cove Creek have no flow 8–10 percent of the time although the basin of Lee Creek is about 3.5 times as large as that of Fourche Maline and 12 times as large as that of Cove Creek. Thus, in spite of differences in drainage areas, all three streams have no flow about one month each year, on the average, usually in late summer or early autumn. The differences in flow duration for these streams may be caused by variations in geology, topography, land use, or land cover although such variations are not readily apparent.

The duration of streamflow can be affected by man's activities, such as mining, that significantly alter the physical characteristics of a basin. For example, overland flow may be intercepted by mine ponds or mine spoil before it reaches a stream or baseflow may be sustained by water stored in mine spoil (see section 8.2). Also, base flow may be increased by discharge of municipal or industrial waste waters or depleted by consumptive use. The volume of direct runoff may be increased by urbanization or decreased by impoundment. The curve for Fourche Maline near Red Oak, Oklahoma, (fig. 5.2–2) shows the variations in flow before and after construction of upstream impoundments. The principal changes are a decrease in peak flow and a slight increase in base flow.

The Arkansas River is regulated for flood control, hydroelectric power, and navigation upstream from and through Area 41 (section 2.3). Flow-duration curves (fig. 5.2–3) for the Arkansas River at Tulsa, Oklahoma, and at Lock and Dam 13 near Van Buren, Arkansas, show the uniform effects of regulation throughout this reach of the river. The curves also show the inflow from major tributaries including the Verdigris, Neosho, Illinois, Canadian, and Poteau Rivers which contribute substantially to streamflow near Van Buren.

Flow-duration data for gaged streams in Area 41 are given in reports by Mize (1975) for Oklahoma and by Hines (1975) for Arkansas. Flow-duration data also are available from computer storage through NAWDEX (National Water Data Exchange) (section 9.2).

[1]A cumulative frequency curve that shows the percentage of time that specified discharges are exceeded.

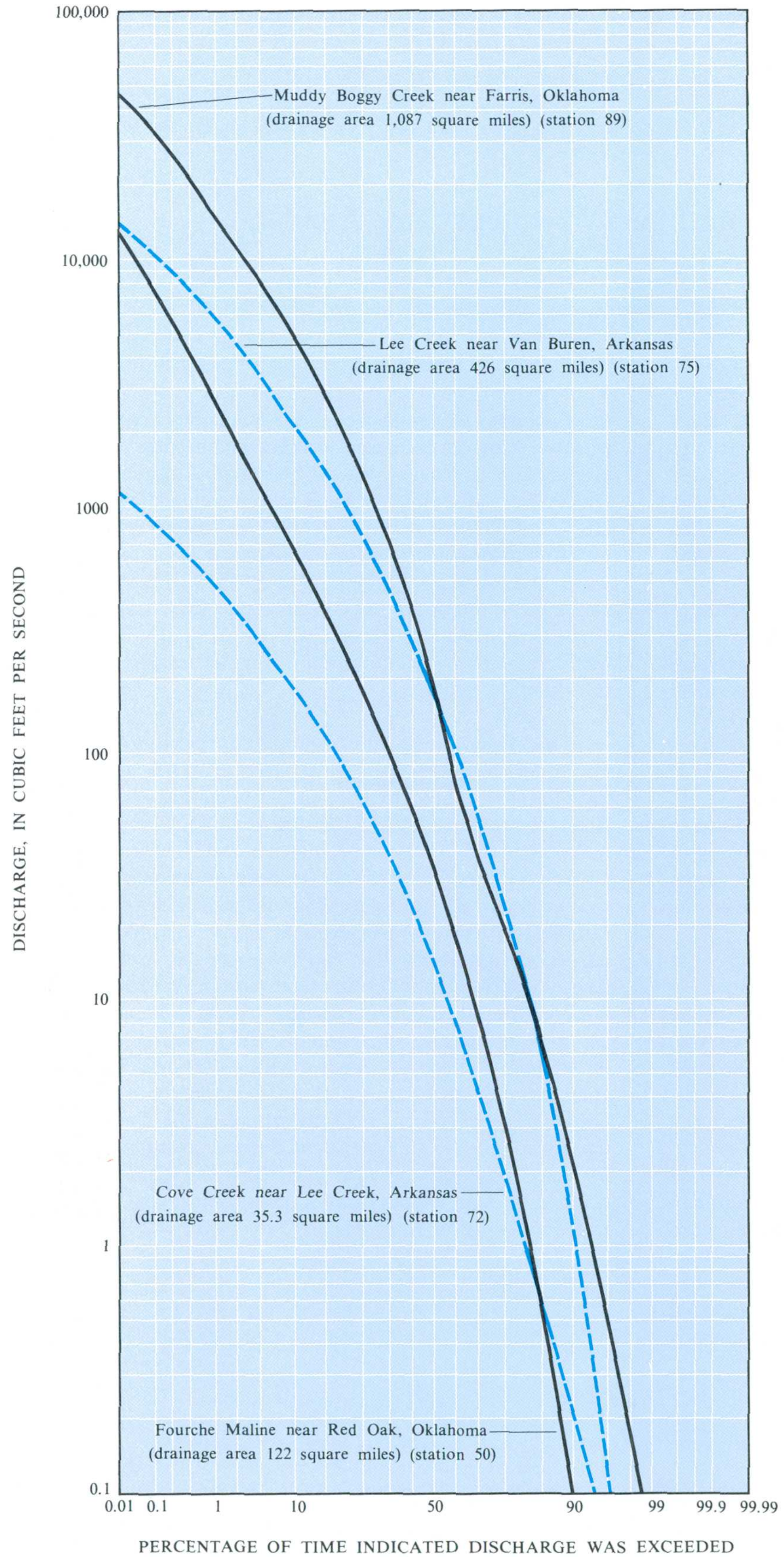


Figure 5.2-1 Streamflow-duration curves of typical streams in Area 41.

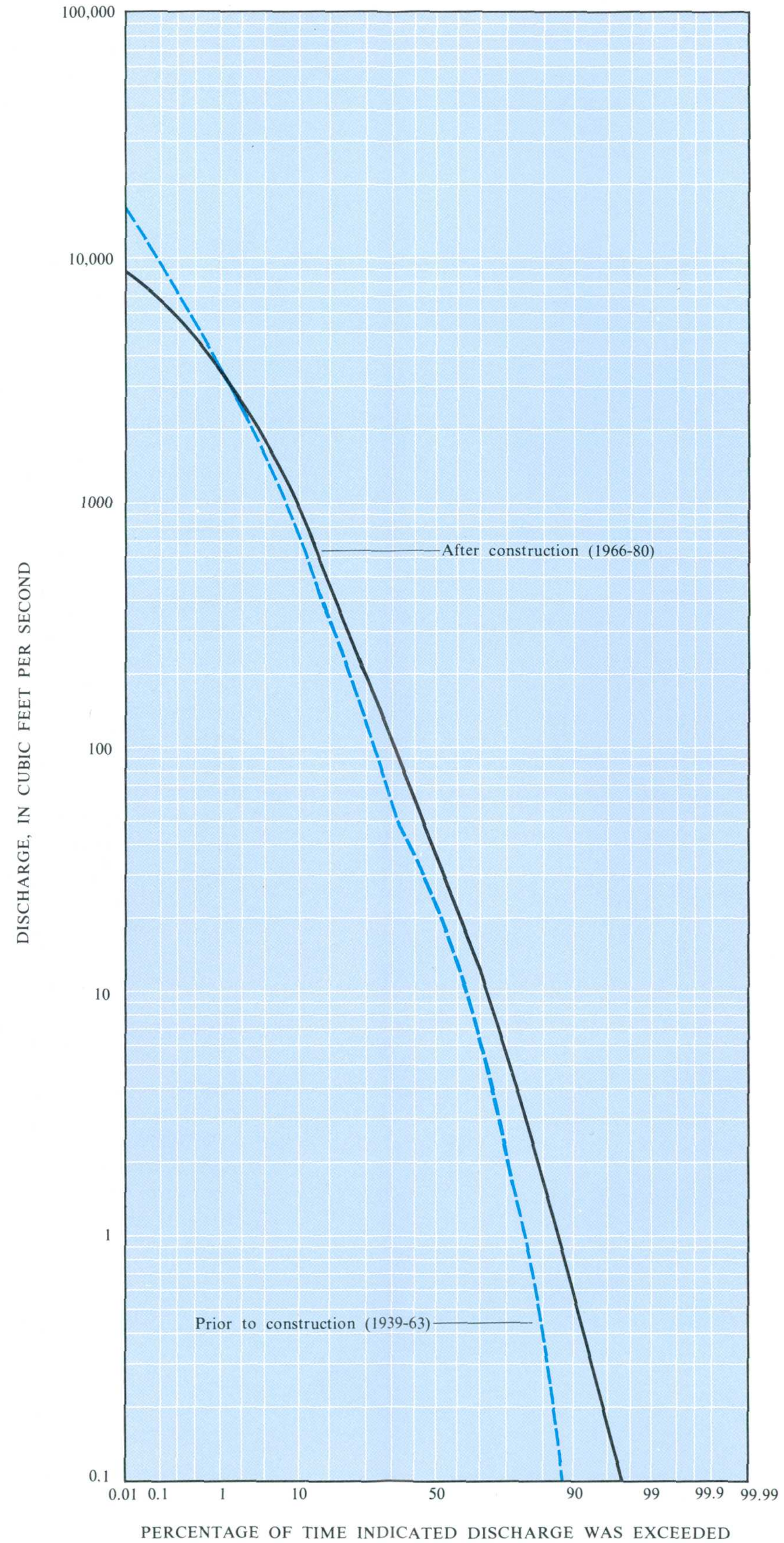


Figure 5.2-2 Streamflow-duration curves for Fourche Maline (station 50) before and after construction of upstream impoundments.

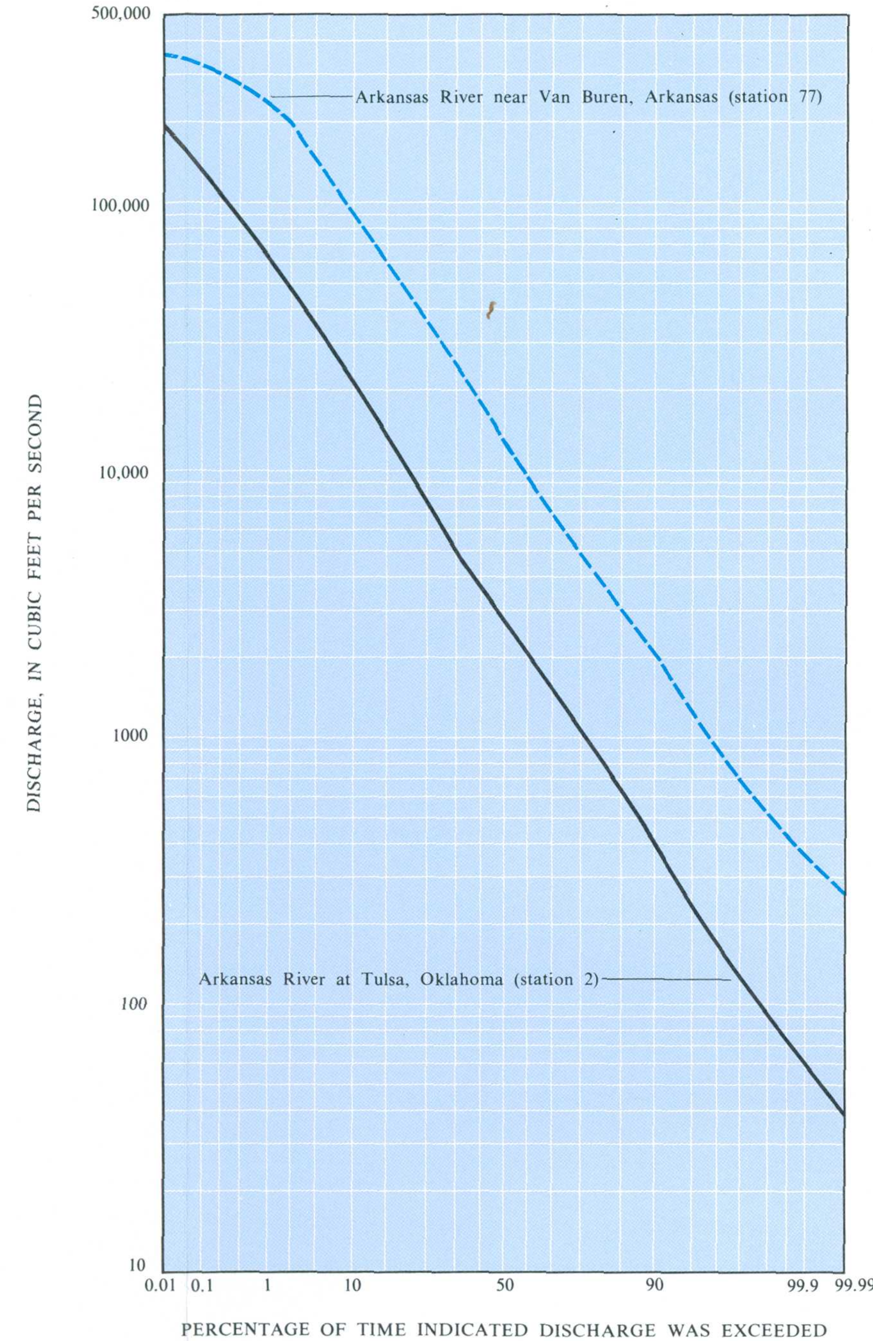


Figure 5.2-3 Comparison of streamflow-duration curves for the Arkansas River at Tulsa, Oklahoma and near Van Buren, Arkansas. Curves show effects of regulation and inflow between the two stations.

Methods for Estimating Flood Frequency are Available

The design of hydrologic structures requires data on the magnitude and frequency of floods.

Engineering design for safe and economical structures on and near streams such as bridges, culverts, embankments, dams, levees, and other structures requires information on the magnitude and frequency of floods. Regulations stemming from the Surface Mining Act (Public Law 95–87) refer in particular to floods caused by the 2-year, 24-hour, and the 10-year, 24-hour precipitation for the design of temporary and permanent structures, respectively. Although rainfall is the primary cause of floods, no exact correlation exists between rainfall amounts and resulting flood discharge as flood magnitude are also affected by the physiography of a basin including land slopes and drainage patterns. Furthermore, land use such as mining, farming, and urbanization affects flood magnitude. Man-made impoundments—lakes, reservoirs, and ponds—have a moderating effect on the magnitude and frequency of flooding along the Arkansas, Canadian, and lower Poteau Rivers and in some of the smaller drainage basins in the area.

Flood-frequency data for gaged streams, such as James Fork near Hackett, Arkansas (station 64), can be illustrated in the form of high-flow probability curves. Figure 5.3–1 shows that a peak discharge of 15,000 cubic feet per second for James Fork has a recurrence interval[1] of 10 years (line A) and that the probability that the average daily discharge for 15 consecutive days will exceed 200 cubic feet per second is 95 percent in any one year (line B). Flood-frequency data for gaged streams in Area 41 are available from computer storage through NAWDEX (National Water Data Exchange) (section 9.2).

Flood-frequency curves[2] for ungaged, unregulated streams can be estimated by use of regional equations developed for this purpose. These equations are not applicable to urbanized areas without modification (Huntzinger, 1978c). Flood-frequency equations applicable to Oklahoma and Arkansas have been developed by Sauer (1974) and Thomas and Corley (1977, p. 78) for Oklahoma and by Patterson (1971) for Arkansas. These equations were developed similarly; however, they differ in context and application. As an example, flood-frequency curves (fig. 5.3–2) for Brazil Creek (station 61) and Rock Creek (station 59) in Oklahoma were estimated by use of regional equations.

The flood-frequency equations developed for Oklahoma and Arkansas were based primarily on flood data for each State. No attempt has been made to define flood-frequency relations just for Area 41. Comparison of Arkansas and Oklahoma equations with actual gaging station frequency data show that computation of a particular flood will yield somewhat different values for the two States. However, differences do not exceed the accuracies stipulated in the reports noted above. Most of Area 41 is in Oklahoma and that part in Arkansas has similar rainfall-runoff characteristics. Consequently, the Thomas and Corley equations would be more suitable for estimating flood frequency for the entire area because they provide an estimate of flood magnitudes to the 500-year reccurrence interval whereas the Patterson equations provide an estimate of flood magnitudes to the 50-year reccurrence interval. Therefore, the relationships defined in the Thomas and Corley report are recommended for all of Area 41.

[1] Recurrence interval is the average interval of time within which a given flood will be equaled or exceeded once.

[2] Flood-frequency curve is a graph showing the number of times per year, on the average, that floods of a given magnitude are equaled or exceeded.

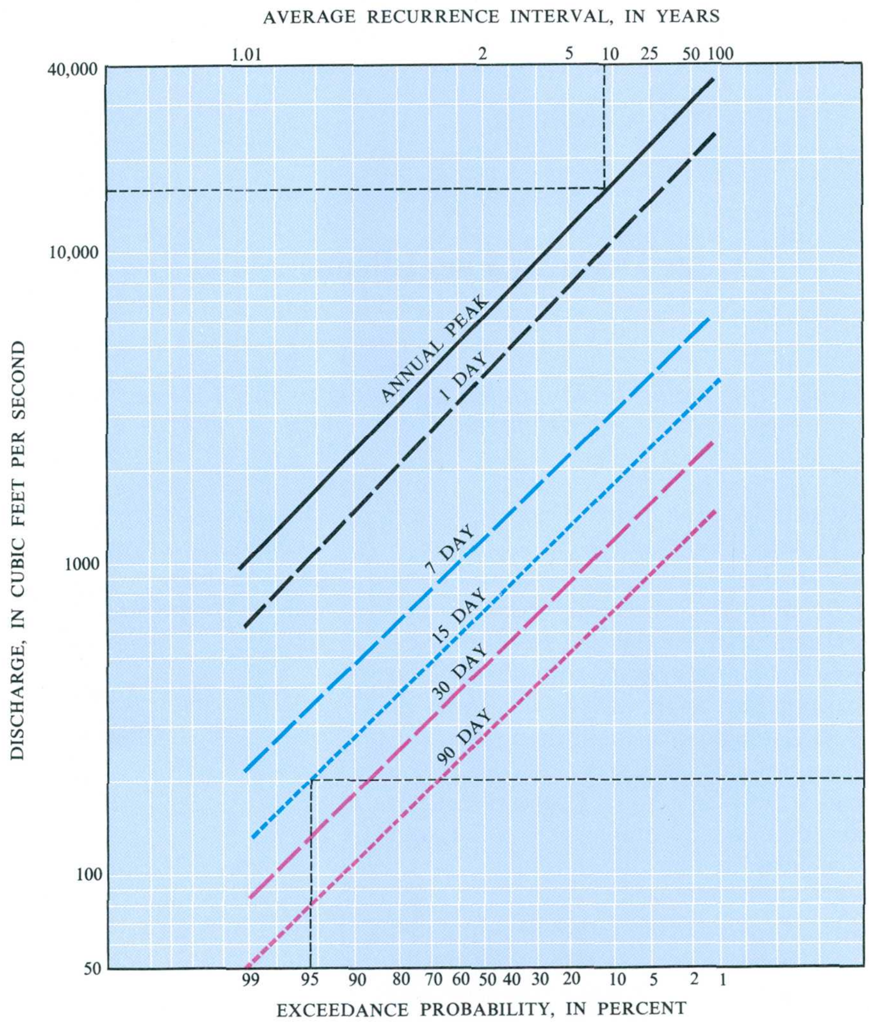


Figure 5.3-1 Annual peak and high-flow probability for James Fork near Hackett, Arkansas (station 64).

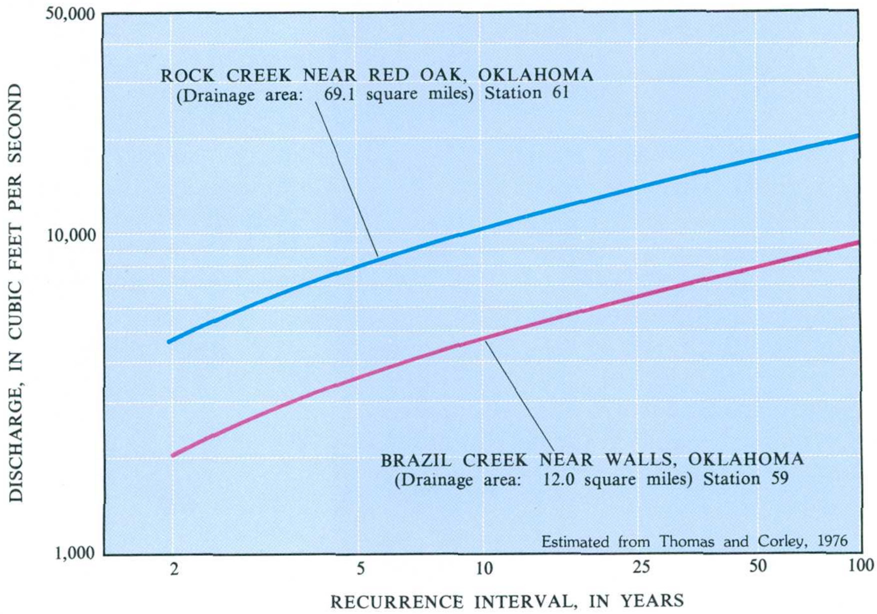


Figure 5.3-2 Flood frequency curves showing recurrence intervals.

Maps Defining Flood-Prone Areas are Available

Areas that would be inundated by floods with a 100-year reccurrence interval are delineated for many parts of Area 41.

The National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 established programs to investigate the extent and severity of flooding in urban and rural areas. Towns and stream valleys subject to flooding were identified, and flood-prone areas were outlined on topographic maps by approximate methods. In 1970, the U.S. Geological Survey, using existing information, began delineating boundaries of the 100-year flood—that which has a 1 percent chance of being exceeded in any one year—on 7½ and 15-minute topographic maps.

Those parts of Area 41 that would be inundated by the 100-year flood have been delineated on 116 7½ and 15-minute topographic maps. The locations of these maps and the names and locations of all available topographic maps in Area 41 are shown on figure 5.4–1. Flood-prone area maps for each State are available from the respective offices:

U.S. Geological Survey
Room 621
215 Dean A. McGee Street
Oklahoma City, OK 73102

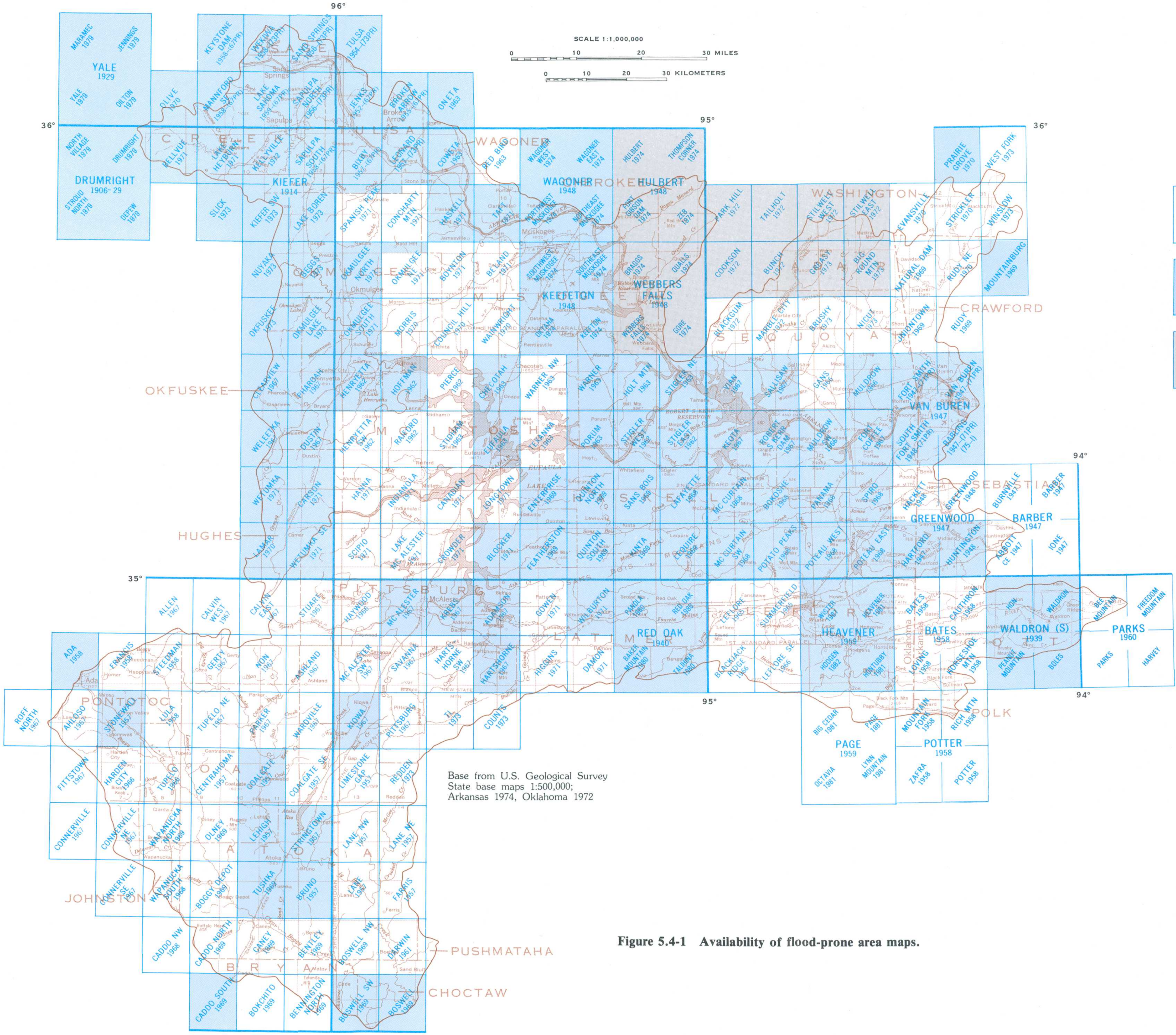
U.S. Geological Survey
Room 2301
Federal Office Building
Little Rock, AR 72201

Flood-prone maps for parts of Adair, Cherokee, Muskogee, Sequoyah, and Wagoner Counties, Oklahoma, were specially prepared by the U.S. Geological Survey for the Cherokee Indian Tribe; those maps are also identified on figure 5.4–1. Inquiries concerning these maps should be directed to:

Chief
Cherokee Indian Tribe
P.O. Box 948
Tahlequah, OK 74464

Since 1972, detailed flood insurance studies have been made for many incorporated cities and towns in Area 41. These studies define the 100-year and 500-year flood boundaries in great detail. A floodway boundary is delineated and flood insurance rates zones are shown. These detailed studies are administered by the Federal Emergency Management Agency (FEMA) and the Federal Insurance Administration (FIA) and were prepared by various U.S. Government agencies or private contractors. Communities participating in the National Flood Insurance Program and the dates of the current effective maps for those communities are listed in a bi-monthly publication "National Flood Insurance Program Community Status Book"; this publication and the FIA flood maps can be obtained from:

National Flood Insurance Program
P.O. Box 34294
Bethesda, MD 20034



Base from U.S. Geological Survey State base maps 1:500,000; Arkansas 1974, Oklahoma 1972

Figure 5.4-1 Availability of flood-prone area maps.

EXPLANATION

HIGGINS 1971	TOPOGRAPHIC MAP AND NAME
EUFAULA 1963	TOPOGRAPHIC MAP WITH APPROXIMATE 100-YEAR FLOOD BOUNDARIES DELINEATED (AVAILABLE FROM THE U.S. GEOLOGICAL SURVEY)
TAILHOLT 1972	TOPOGRAPHIC MAP WITH APPROXIMATE 100-YEAR FLOOD BOUNDARIES DELINEATED (AVAILABLE FROM THE CHEROKEE INDIAN TRIBE)

Surface-Water Storage Vital to Area

Variability of streamflow and limited ground-water resources make surface-water storage a necessity.

In most of Area 41, streamflow is so variable and the availability of ground water is so limited that surface-water storage is necessary to provide municipal, industrial, and irrigation water supply. For example, Lake Atoka in the southwestern part of the area (fig. 5.5–1) provides part of the water supply for Oklahoma City about 80 miles to the northwest. All cities and principal towns in the area, except Ada, Oklahoma, use lakes or reservoirs for water supply; Ada uses water from Byrds Mill Spring and has standby wells if needed. Many of the domestic water supplies in the area are furnished by rural water districts which obtain water from lakes and reservoirs. Most of the larger impoundments have been constructed by the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation.

In addition to water supply, 14 lakes and reservoirs in the area with maximum capacities of 4,000 acre-feet or more (table 5.5–1) provide flood control, hydroelectric power, navigation, recreation, and wildlife habitat. The McClellan-Kerr Arkansas River Navigation System includes four major locks and dams in the area and, of these, the Robert S. Kerr Lock and Dam (fig. 5.5–2) is the largest. Also in the area are many smaller municipal, industrial, and recreational lakes and thousands of farm and stock ponds. Additional flood control, conservation, and water supply is or will be provided by nearly 340 water-impounding structures constructed or under construction by the U.S. Department of Agriculture. These structures partially control runoff from 9 watersheds with a total area of about 1,600 square miles (fig. 5.5–1).

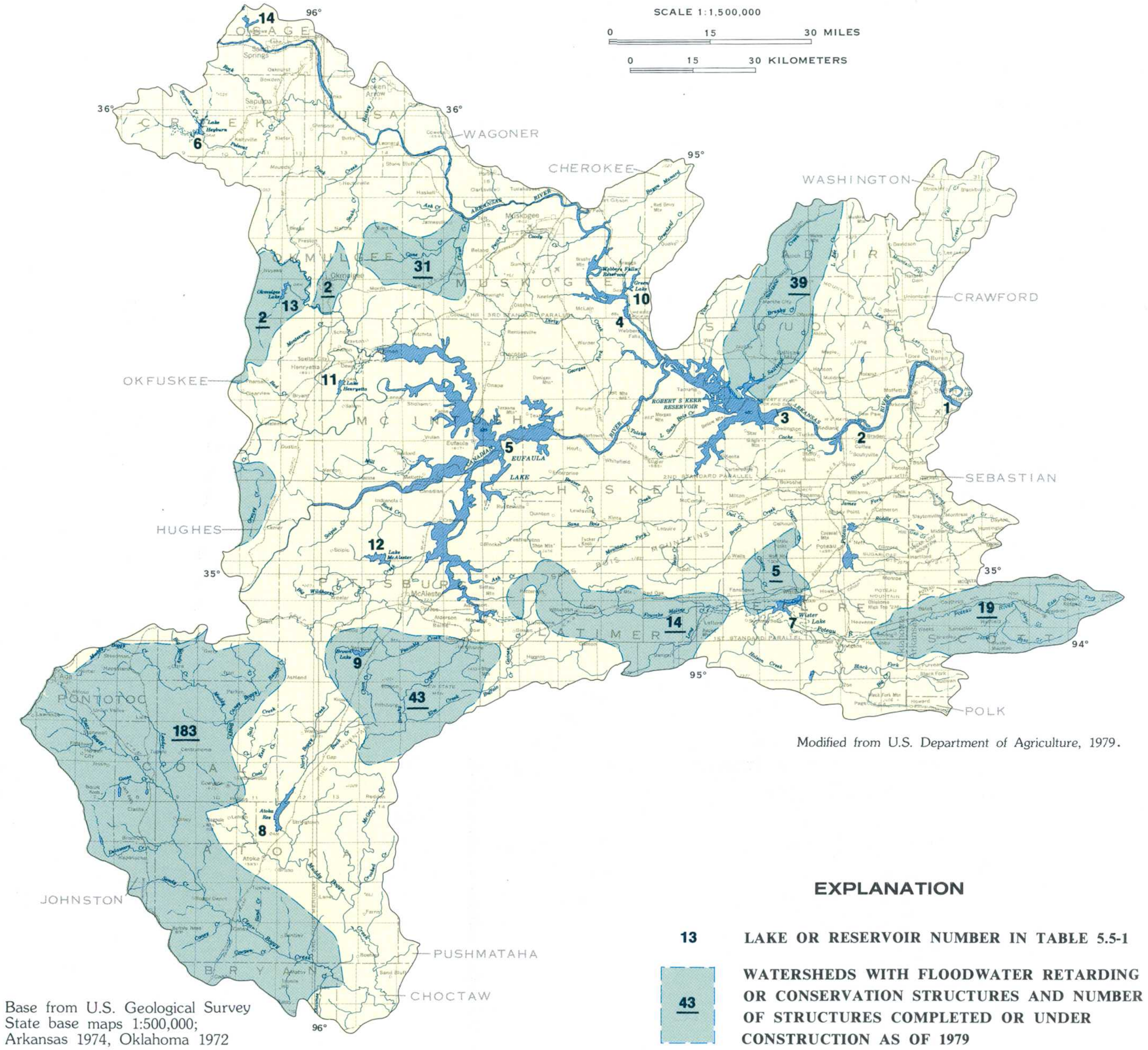


Figure 5.5-1 Lakes and reservoirs.

Table 5.5-1 Lakes and reservoirs with a maximum capacity of 4,000 acre-feet or more.

Map number	Name	Surface area (acres)	Maximum capacity (acre-feet)	Purpose *
	McClellan-Kerr Arkansas River Navigation System			
1	Lock and dam 13 at Van Buren, Ark.	---	Flow of river	N, H, R
2	W.D. Mayo lock and dam 14	---	Flow of river	N
3	Robert S. Kerr lock and dam 15 (Robert S. Kerr Reservoir)	42,000	493,600	N, H, R
4	Webbers Falls lock and dam 16 (Webbers Falls Reservoir)	10,900	165,200	N, H, R
	U.S. Army Corps of Engineers multi-purpose lakes			
5	Eufaula Lake	143,700	3,798,000	N, H, FC, M, R
6	Heyburn Lake	3,700	57,300	FC, C
7	Wister Lake	23,070	427,900	FC. M, R
	Municipal, industrial, and recreational lakes			
8	Atoka Reservoir	5,700	125,000	M, R
9	Brown Lake	550	4,000	I, R
10	Greenleaf Lake	920	14,720	R
11	Lake Henryetta	616	8,624	M, R
12	Lake McAlester	1,240	11,470	M, R
13	Lake Okmulgee	611	15,300	M, R
14	Shell Creek Lake	640	15,300	I, R

* N, navigation; H, hydroelectric power; FC, flood control; M, water supply; R, recreation; I, industrial; C, conservation

Photograph courtesy of the U.S. Army of Engineers.

Figure 5.5-2 The Robert S. Kerr Lock and Dam is a key element in the McClellan-Kerr Arkansas River Navigation System.

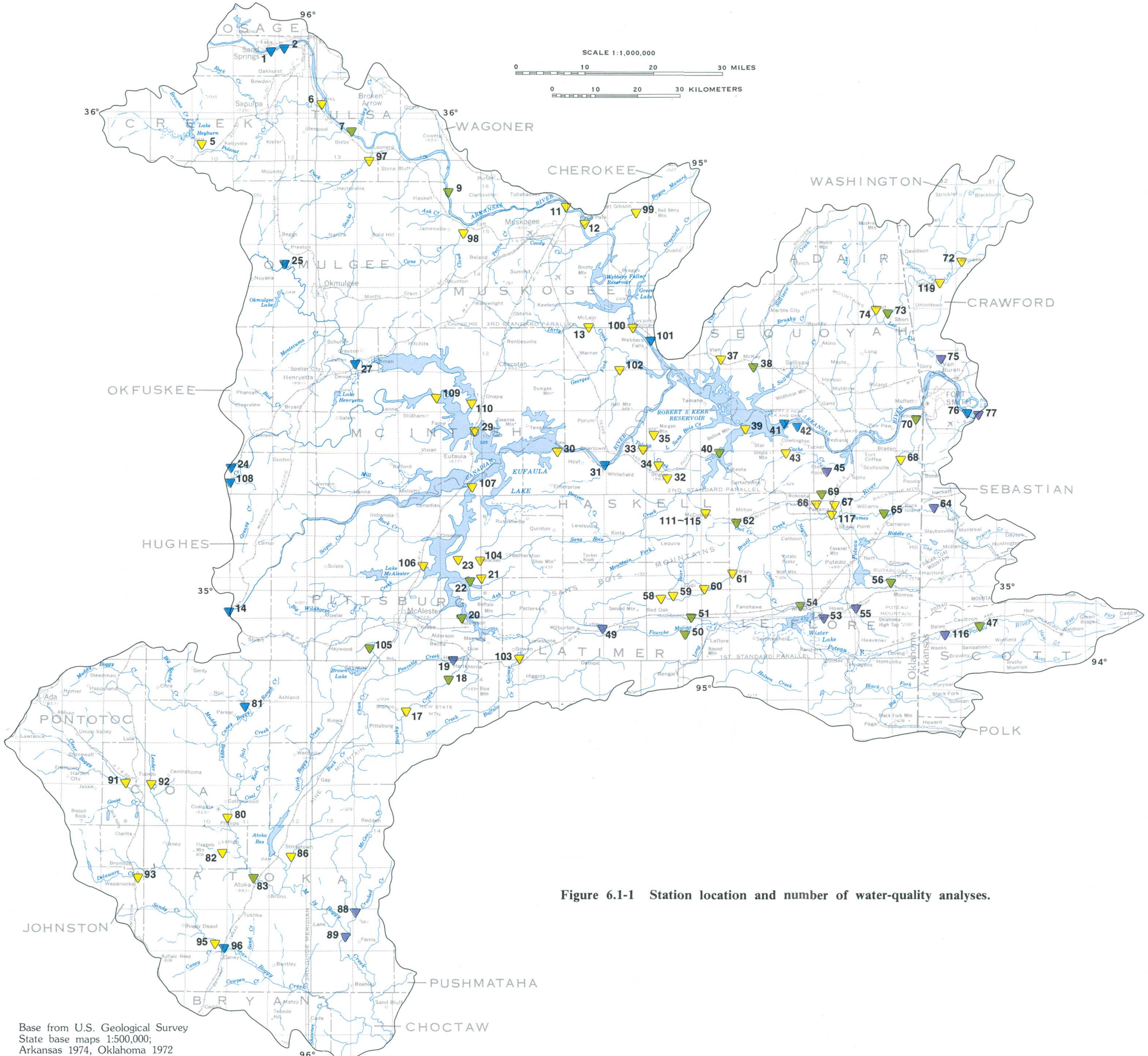
Water-Quality Data are Required for Coal-Mine Permit Applications

Data on dissolved- and suspended-solids, pH, iron, sulfate, and manganese are needed to assess the consequences of coal mining; some of these data are available for 95 stream locations in Area 41.

Drainage from surface-mined lands has seriously affected surface-water quality in many parts of the United States and its impact is well documented in the literature (Dyer and Curtis, 1977; Hoehn and Sizemore, 1977; King and others, 1974; and Letterman and Mitsch, 1978). The need for water-quality data has become critical since enactment of the Surface Mining Control and Reclamation Act of 1977. Section 507 (b) (11) of the Act requires that extensive information about the probable hydrologic consequences of mining and reclamation be included in permit applications so that the regulatory authority can determine the probable cumulative impact of mining on the hydrology of the area.

Water-quality data for the coal field in eastern Oklahoma and western Arkansas are available but few of these data are long term. The stream water-quality data available include that collected at 95 stations (fig. 6.1-1) where at least four determinations of specific conductance and pH have been made. More than 100 analyses are available from 25 stations. Station names, locations, and types of data collected are given in section 10.1. The data were collected for various purposes under a variety of cooperative programs with Federal, State, and local agencies. Therefore, the 95 stations do not represent a network designed to provide uniform data throughout the area that relate directly to coal mining or any other specific hydrologic problem.

Analysis of the available data provides a general summary of the chemical quality of the stream water in the area even though the data are not uniform as to quantity, type, or distribution. Those water-quality characteristics or constituents, described in the following sections, that relate directly to coal mining include dissolved solids, sulfate, pH, iron, and manganese. To avoid placing overemphasis on extreme values, median values were used to describe the chemical quality of stream water.



EXPLANATION

▽23 STATION LOCATION AND NUMBER

NUMBER OF WATER-QUALITY ANALYSIS

- 4-49
- 50-99
- 100-199
- 200-2609

Figure 6.1-1 Station location and number of water-quality analyses.

Dissolved-Solids Concentrations had No Areal Distribution that can be Related to Coal Mining

Median dissolved-solids concentrations in 74 percent of the streams sampled were less than EPA Drinking Water Standards.

The concentration of dissolved solids[1] is significant because water in streams draining some areas that have been mined for coal commonly contain greater concentrations of dissolved materials, with sulfate being the principal constituent. Also, water with large dissolved-solids concentrations may not be suitable for domestic supply, irrigation, livestock, or aquatic life.

The median dissolved-solids concentrations determined for 86 stream stations ranged from 44 to 1,910 milligrams per liter. Of these 86 stations, 64 had median concentrations of 500 milligrams per liter or less which is the limit for Secondary Drinking Water Regulations set by the U.S. Environmental Protection Agency (1979). Median dissolved-solids concentrations exceeded 500 milligrams per liter in all major river basins (fig. 6.2–1) but did not show any pattern of areal distribution that can be related to coal mining.

A major source of dissolved solids in the Arkansas River is the Salt Fork Arkansas River, about 100 river miles upstream from Area 41, which contributes about 1,200 tons of chloride per day to the river. Oil-field brines and wastes upstream from the area are a significant source of dissolved solids; other industrial and municipal wastes within the area also contribute. Although sulfate concentrations generally were larger for small streams draining coal-mining areas, increases in the dissolved solids were not as large, on a percent basis, as the sulfate increases nor were they they everywhere associated with coal mining.

Most substances dissolved in water are ionic, that is, they are atoms or groups of atoms that carry a positive or negative charge. Pie diagrams showing the proportion of total-ion concentration, in millie quivalents per liter, based on mean concentrations, are given for selected stations in figure 6.2–1. These diagrams show that the proportion of ion concentrations in stream water of the area vary considerably.

Stations 111–115 were part of a special study of the water quality of a small stream draining abandoned mine lands in the vicinity of McCurtain, Oklahoma. Mule Creek site D at McCurtain (station 115) had a median dissolved-solids concentration of 558 milligrams per liter. This relatively large concentration was due mostly to the large proportion of sulfate. The large dissolved-solids concentrations in the Arkansas River (station 77) primarily were due to large amounts of sodium chloride and were not related to coal mining. In contrast to stations 115 and 77, the water quality for Blue Creek tributary near Blocker (station 21) is unaffected by man's activities and is representative of natural water quality for Area 41 streams.

The concentration of dissolved solids generally can be estimated quickly and inexpensively by measuring the specific conductance of the water. Specific conductance is a measure of the ability of the water to conduct an electrical current and is directly proportional to the total concentration of ionized substances dissolved in the water. A mathematical relationship of the following form is used to estimate dissolved solids. The equation:

$$DS = M\ (SC) + B \qquad (1)$$

expresses the relationship between dissolved solids and specific conductance where:

DS = dissolved solids, in milligrams per liter;

M = slope of the regression line;

SC = specific conductance, in micromhos per centimeter at 25° Celsius; and

B = y-axis intercept value of dissolved solids, in milligrams per liter.

The regression relationship for all 86 stream stations with dissolved-solids data (14,127 data pairs) is expressed by the equation:

$$DS = 0.63\ (SC) - 59 \qquad (2)$$

This equation has an R square value of 0.98 which means that more than 98 percent of the variation in dissolved solids is accounted for by specific conductance according to the mathematically fitted straight-line equation. The slope (0.63) is within the range of 0.55 to 0.75 reported for most waters (Hem, 1970).

[1] Dissolved solids is the residue on evaporation at 180° Celsius and is a general indicator of the sum of inorganic and organic material dissolved in the water.

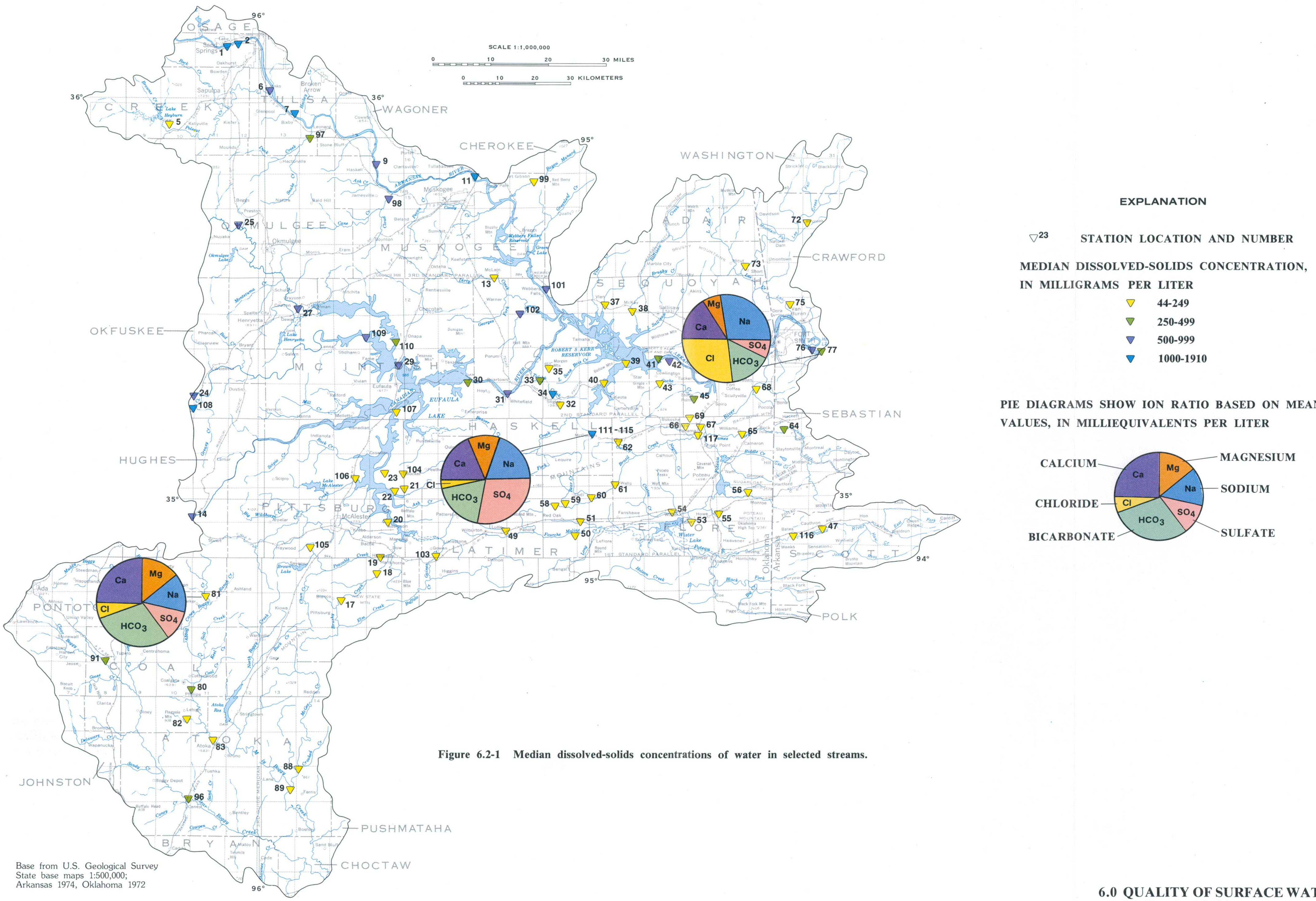


Figure 6.2-1 Median dissolved-solids concentrations of water in selected streams.

Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Largest Sulfate Concentrations are Associated with Coal Mines

Sulfate concentrations are largest where water draining from mine spoil constitutes a significant part of the streamflow.

Sulfate is the best indicator of coal-mine drainage in Area 41. The principal sources of sulfate are derived by solution of gypsum ($CaSO_4$) and oxidation of iron sulfides such as pyrite (FeS_2) and marcasite (FeS_2). Gypsum and pyrite occur naturally with the coal and along with other mining wastes is deposited in spoil piles adjacent to the mines. When exposed to oxygen and water, pyrite can be oxidized to sulfuric acid as follows:

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{+2} + 2H^{+} + 2SO_4^{-2}$$

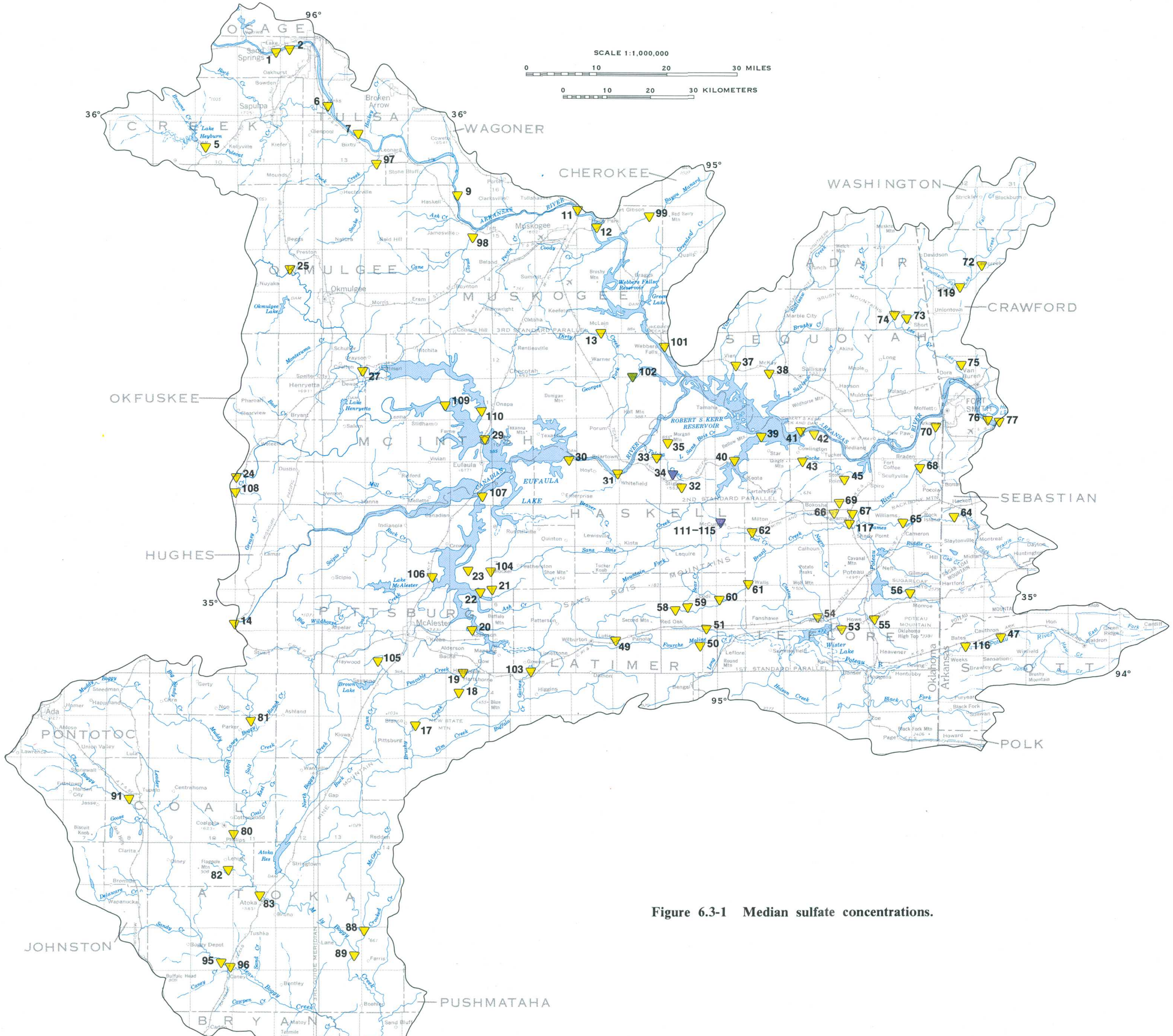
The same reaction occurs in the interior of active and abandoned mines and at the outcrop of coal seams.

Median sulfate concentrations in Area 41 streams ranged from 3 to 740 milligrams per liter (fig. 6.3–1). On the basis of taste and laxative effects, the recommended upper limit for sulfate is 250 milligrams per liter in waters intended for human consumption where sources of water with less sulfate concentrations are or can be made available (U.S. Environmental Protection Agency, 1979). Acclimation to sulfate is rapid and many people can drink water with as much as 600 milligrams per liter sulfate and not experience any laxative effects.

Sulfate concentrations are larger in the Arkansas and Canadian Rivers than in tributary streams. Where the Arkansas River enters the area (station 1) the median sulfate concentration was 155 milligrams per liter; where the river leaves the area (station 77) the median was 44 milligrams per liter indicating that the sulfate concentrations was diluted by inflow from tributary streams. Similarly, the median sulfate concentration was 69 milligrams per liter at station 14, where the Canadian River enters the area, and 39 milligrams per liter at station 31, near the confluence of the Arkansas and Canadian Rivers. For most streams in Area 41, the general trend is an increase in sulfate concentration with an increase in specific conductance.

The greatest median sulfate concentrations occur in small streams draining coal mine areas. For stations 34, 114, and 115, which had sulfate concentrations greater than 250 milligrams per liter, the maximum drainage area was 6.74 square miles. For example, median sulfate concentrations of water in Mule Creek (stations 111–115) ranged from 26 to 260 milligrams per liter and increased with greater percentage of unreclaimed mine area (Slack, 1983).

The variability of sulfate concentrations in streams draining mine areas is due primarily to the quantities of calcium sulfate and iron sulfide minerals in the spoil, the length of time these minerals are exposed to weathering, the length of time water is in contact with the spoil, and the quantity of water draining from mine areas. Sulfate concentrations are largest during low flow when contact time has been relatively long and drainage from spoil constitutes a significant part of the flow (fig. 6.3–2). Sulfate concentrations are less during high flow when contact time is short and dilution occurs.



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 6.3-1 Median sulfate concentrations.

EXPLANATION

▽1 **STATION LOCATION AND NUMBER**

MEDIAN SULFATE CONCENTRATION, IN MILLIGRAMS PER LITER

▽ 3-249

▽ 250-499

▽ 500-740

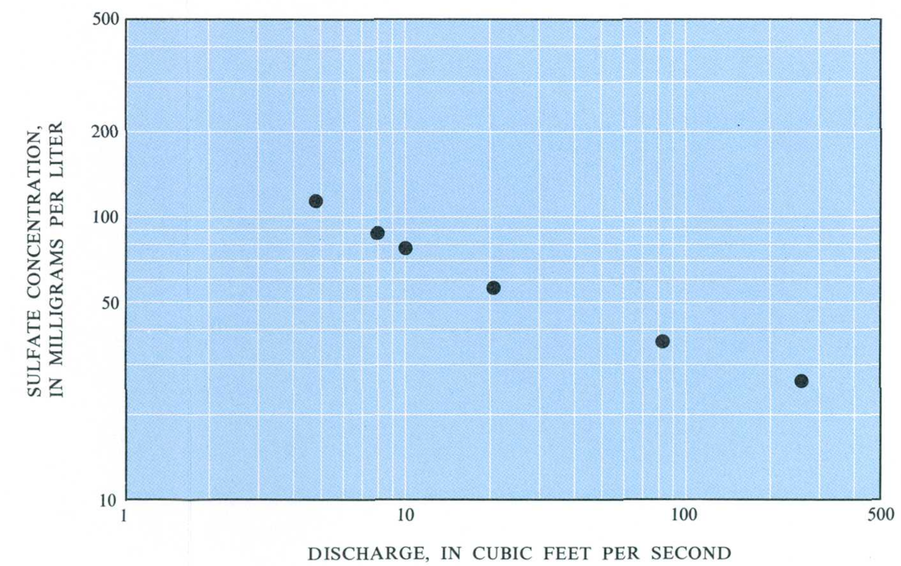


Figure 6.3-2 Relation between sulfate concentrations and discharge at Mule Creek near McCurtain (station 113).

Low pH is Not Common because of Natural Buffering

The median pH at 95 stations ranged from 6.6 to 8.4; pH is not a good indicator of coal-mine drainage in Area 41.

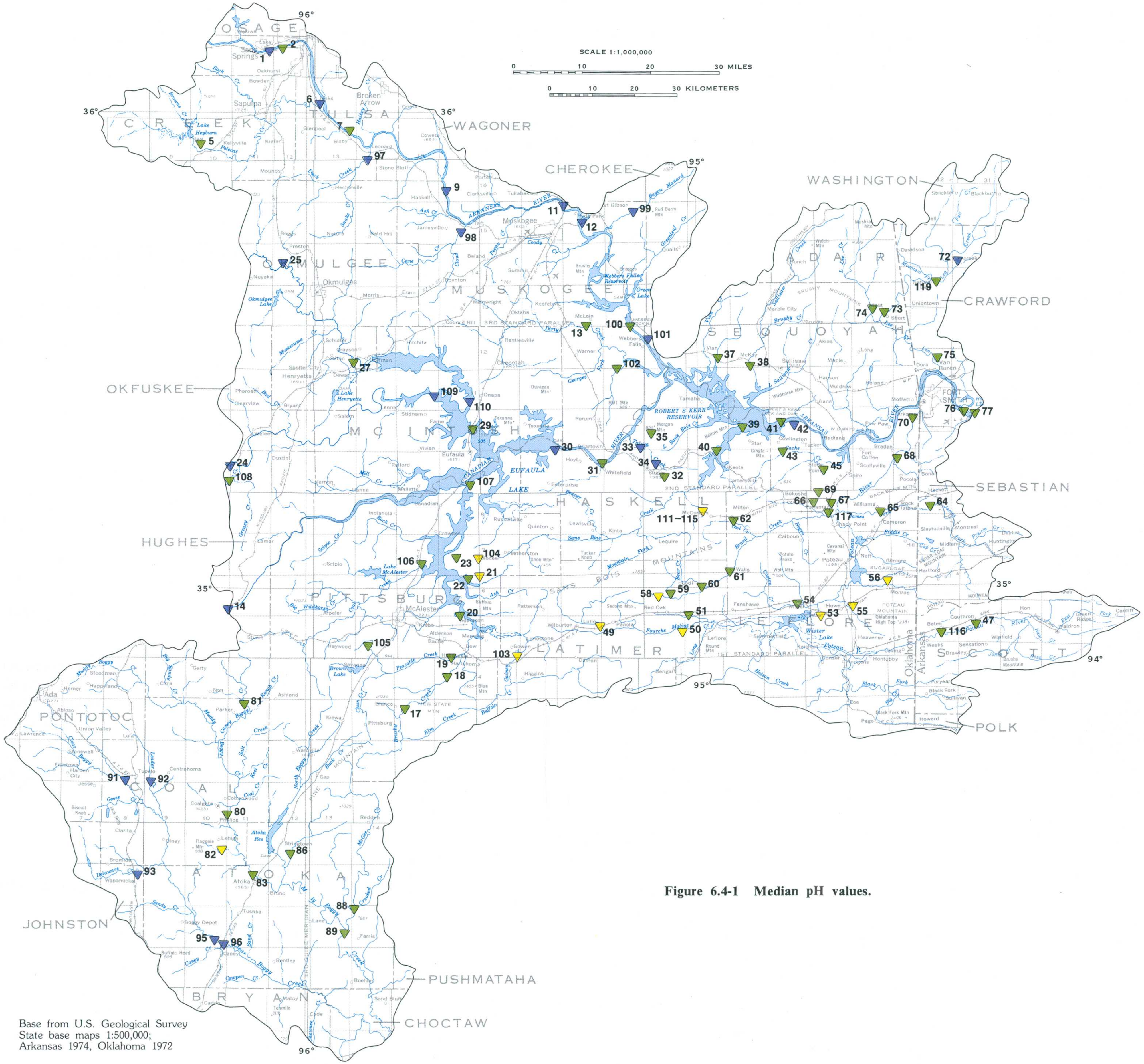
In natural waters, the pH[1] normally is within the range of 6.0 to 8.5, depending on the equilibrium between chemical species dissolved in the water (Hem, 1970). In coal-mine drainage, pH is governed by oxidation of sulfide minerals and subsequent buffering by carbonate minerals. Iron-sulfide minerals, usually pyrite (FeS_2) and marcasite (FeS_2), exposed in spoil piles and high walls of strip mines, react with oxygen (O_2) and water (H_2) to release sulfuric acid (H_2SO_4) and ferrous sulfate ($FeSO_4$), with a corresponding decrease in pH of the solution (or increase in H^+ ions):

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{+2} + 2H^+ + 2SO_4^{-2}$$

Subsequent oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) followed by hydrolosis of ferric iron results in further decrease in pH.

All of the streams for which determinations were made had a pH in the normal range, that is, between 6.0 and 8.5. The median pH at 84 of the 95 stations, or 88 percent, ranged from 7.0 to 8.4 (fig. 6.4–1). The smallest median pH was 6.6. In many parts of the area, carbonate-bearing materials such as siderite, calcite, and ankerite are common in the spoil and acidic mine drainage is thus neutralized. Consequently, pH is variable and in the normal range for most streams and is not a good indicator of acid mine drainage on an areal basis.

[1] The pH of a solution is an indicator of how acid or alkaline it is; a pH of 7 indicates a neutral solution. The greater the pH (more than 7.0), the more alkaline a solution is; the lesser the pH (less than 7.0), the more acidic.



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 6.4-1 Median pH values.

EXPLANATION

▽23 STATION LOCATION AND NUMBER

MEDIAN pH, IN STANDARD UNITS

- ▽ 6.6-6.9
- ▽ 7.0-7.9
- ▽ 8.0-8.4

Largest Total-Iron Concentrations were Associated with the McAlester, Stigler, and Hartshorne Coals South of the Canadian and Arkansas Rivers

Median total-manganese concentrations were much below OSM effluent standards and showed no pattern of areal distribution or relation to coal mines.

Total-iron[1] and total-manganese concentrations less than 1,000 micrograms per liter are not toxic to freshwater aquatic life (U.S. Environmental Protection Agency, 1976, and McKee and Wolf, 1963) and are essential to certain physiological functions of aquatic life. However, iron and manganese tend to stain clothing and plumbing fixtures and iron can impart a bittersweet astringent taste detectable by some persons at concentrations greater than 1,000 or 2,000 micrograms per liter (American Public Health Association and others, 1976).

Iron and manganese are common components of rocks and soils and, in water, may originate by leaching of these materials. Other sources of these elements in water include industrial and municipal wastes, corroded metals, and acid mine drainage.

Median total-iron concentrations at 63 stream stations in the area (fig. 6.5–1) ranged from 0 to 6,100 micrograms per liter. The largest median total-iron concentrations were south of the Canadian and Arkansas Rivers and generally were in streams associated with the McAlester, Stigler, or Hartshorne coals. Of 34 stations with median total-iron concentrations equal to or greater than 1,000 micrograms per liter, only 2 were north of the Canadian and Arkansas Rivers. Because of its significant pH dependancy, dissolved iron is not always a good indicator of mine drainage; however, total iron may be.

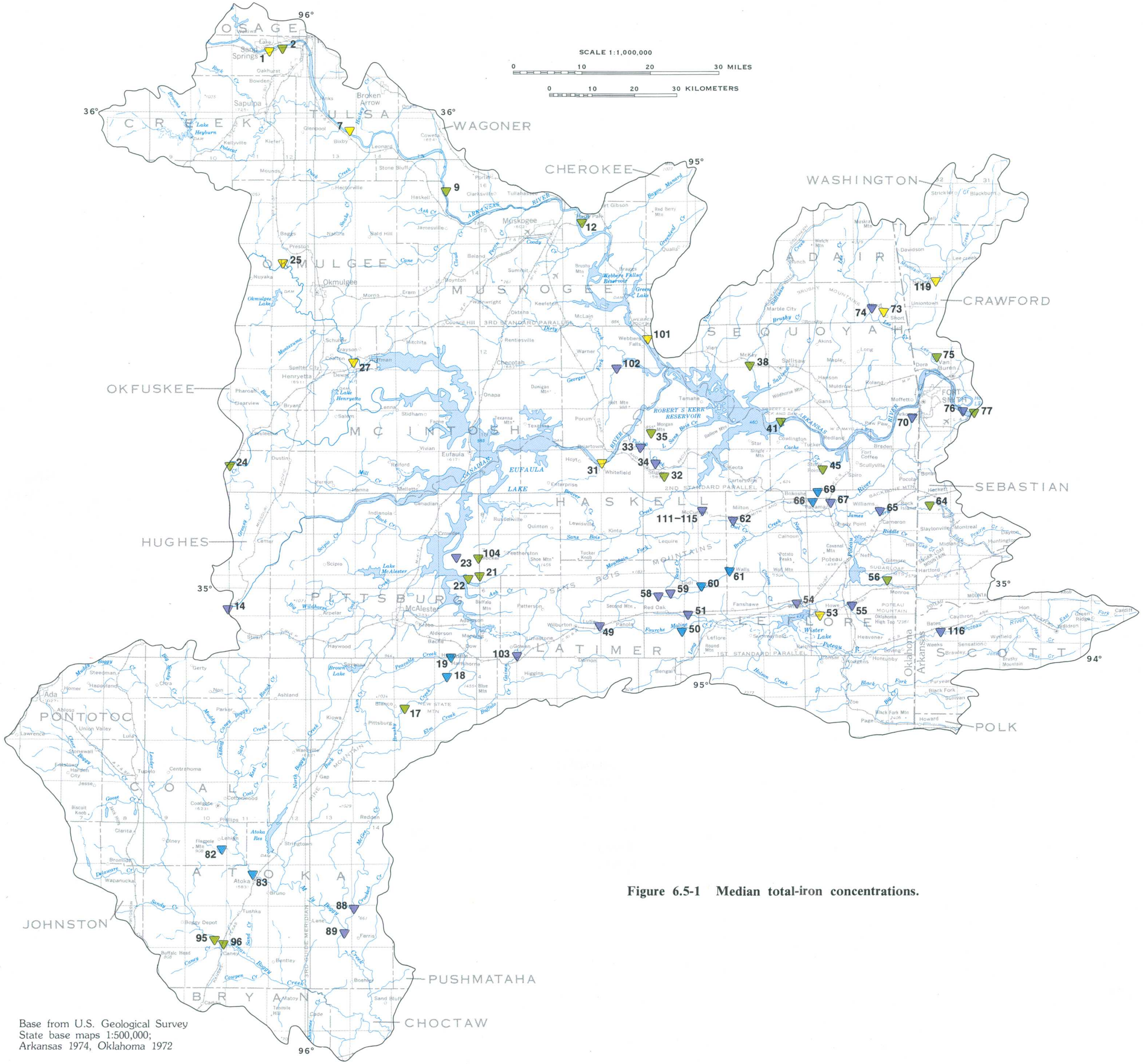
Total-iron concentrations during storm runoff for many small, unregulated streams is proportional to the concentration of suspended sediment in the water. For example, the regression equation between total-iron and suspended-sediment concentration for Coal Creek near Lehigh, Oklahoma (station 82) is:

total iron, in micrograms per liter = 16.1 suspended sediment, in milligrams per liter + 1,658.

This equation has a R square value of 0.86 which means that more than 86 percent of the variation in total-iron concentration is accounted for by suspended sediment according to the mathematically fitted straight-line equation.

Median total-manganese concentrations ranged from 0 to 400 micrograms per liter and were much below the 30-consecutive effluent standard of 2,000 micrograms per liter set by the U.S. Office of Surface Mining, Reclamation, and Enforcement (1979). Furthermore, the largest concentrations showed no pattern of areal distribution or relation to coal mines.

[1] Total iron and manganese are actually total recoverable measurements made on unfiltered samples following mild hot acid digestion and are not true total concentrations because the mineral lattice is not broken down.



EXPLANATION

▽23 STATION LOCATION AND NUMBER

MEDIAN TOTAL-IRON CONCENTRATION, IN MICROGRAMS PER LITER

- 0-299
- 300-999
- 1,000-1,999
- 2,000-6,100

Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 6.5-1 Median total-iron concentrations.

Sediment Yields Vary

Surface mining may cause some increase in sediment yields but the largest yields are from basins that have not been disturbed by mining.

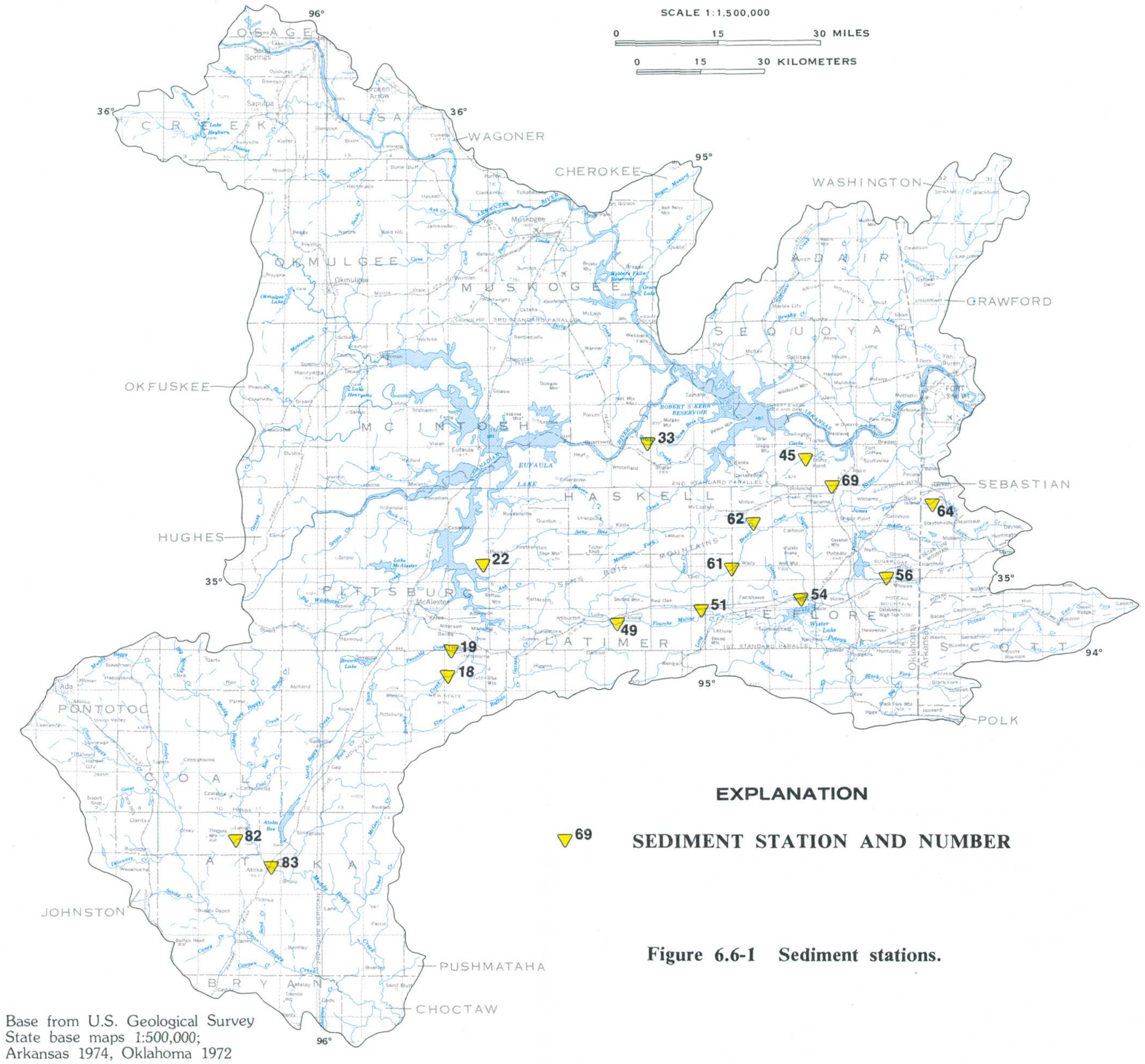
The quantity and characteristics of suspended sediment transported by a stream are affected by several environmental conditions, both natural and man-made. The principal conditions are volume and intensity of rainfall, soils, topography, vegetative cover, and land use. In Area 41 rainfall is particularly significant because a large percentage occurs as thunderstorms of varying intensity (section 2.6). During periods of little or no rainfall, which are common from late summer through winter, drying and weathering of the soil and rock materials produces an abundant supply of sand, silt, and clay particles. Thus, a subsequent thunderstorm would wash those particles into streams resulting in large concentrations of suspended sediment for varying periods of time.

As part of coal hydrology studies in cooperation with the U.S. Bureau of Land Management, suspended-sediment data have been collected for at least 3 years at 15 stations in the area (fig. 6.6–1). These data provide a means of estimating the suspended-sediment yield for the basin upstream from each station (table 6.6–1) by using the flow duration-suspended sediment transport curve procedure (Miller, 1951). Of the 15 basins, which range in size from 4.4 to 445 square miles, no surface mining has been done in 10, past mining has been done in 5, and 2 had active mining, as well as past mining, during the sediment-sampling period. Muddy Boggy Creek basin (station 83), with an area of 445 square miles, had the greatest suspended-sediment yield—215 tons per square mile per year. The cause for this disproportionate yield is not known; however, a relatively large percentage of the basin was formerly cultivated but now has largely reverted to pasture. Coal mining was not a probable source of sediment because the area disrupted by mining was only 690 acres (Johnson, 1974) or about 0.2 percent of the total area. Coal Creek near Lehigh (station 82) had the second largest yield. About one-half the basin is unmanaged pasture that appears heavily overgrazed; no mining has ever been done in the basin.

Excluding the basins of Muddy Boggy Creek and Coal Creek near Lehigh, the average sediment yield of the nine unmined basins was 42 tons per square mile per year. The average yield of the four mined basins was 66 tons per square mile per year. These data, although representing only a few basins and a sampling period of short duration, suggest that surface mining can result in some increase in sediment loads of streams. Such increases would be of short duration if reclamation is done rapidly and effectively. Other land uses, such as cultivation of the soil, overgrazing of pastures, and destruction of plant cover by use of herbicides or burning may be much more significant than mining in contributing sediment to streams generally because they affect much larger areas.

The flow duration-suspended sediment transport curve procedure was used to relate stream discharge to suspended-sediment concentration of Coal Creek near Lehigh (station 82) for specific thunderstorms (fig. 6.6–2). During the April 11, 1979, storm, both discharge and sediment concentrations showed a small peak at about 4 hours. These peaks represent very local inflow from a borrow ditch that reached the station before runoff from the main part of the basin. The local, short-term effect of the borrow ditch may be comparable to that from a small area of surface mining. The effect of runoff from the borrow ditch is masked during the May 21, 1979, storm by discharge from the main part of the basin; similar masking of sediment inflow from mined areas also may occur depending partly on the areal distribution of rainfall.

The curves for the May 21, 1979, storm graphically show the difference in suspended-sediment concentration during rising and falling stream stages. For example, at a discharge of 70 cubic feet per second during the rising stage, the suspended-sediment concentrations was 660 milligrams per liter (line A). At the same discharge during the falling stage, the suspended-sediment concentrations was only 170 milligrams per liter (line B).



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 6.6-1 Sediment stations.

Table 6.6-1 *Sediment yields.*

Map number	Sediment station	Period of sediment record	Drainage area (square miles)	Sediment yield (tons per square mile per year)	Surface mining
18	Brushy Creek near Haileyville	10/78 - 9/81	139	40	No mining
19	Peaceable Creek near Haileyville	10/78 - 9/81	134	43	No mining
22	Blue Creek near Blocker	10/76 - 9/81	12.1	20	No significant mining
33	Taloka Creek near Stigler	10/78 - 9/81	20.1	58	Past and active mining
45	Coal Creek near Spiro	10/78 - 9/81	18.1	85	Past mining
49	Fourche Maline near Wilburton	10/78 - 9/81	56.2	38	Past mining
51	Red Oak Creek near Red Oak	10/78 - 9/81	13.2	50	No mining
54	Caston Creek at Wister	10/78 - 9/81	72.9	44	No mining
56	Sugarloaf Creek near Monroe	10/78 - 9/81	53.6	39	No mining
61	Brazil Creek near Walls	10/78 - 9/81	69.1	83	Past and active mining
62	Owl Creek near McCurtain	10/78 - 9/81	27.9	50	No mining
64	James Fork near Hackett	10/78 - 9/81	147	44	No mining
69	Holi-Tuska Creek near Panama	10/78 - 9/81	4.4	49	No mining
82	Coal Creek near Lehigh	5/78 - 1/82	8.5	91	No mining
83	Muddy Boggy Creek at Atoka	10/78 - 9/81	445	215	Past mining

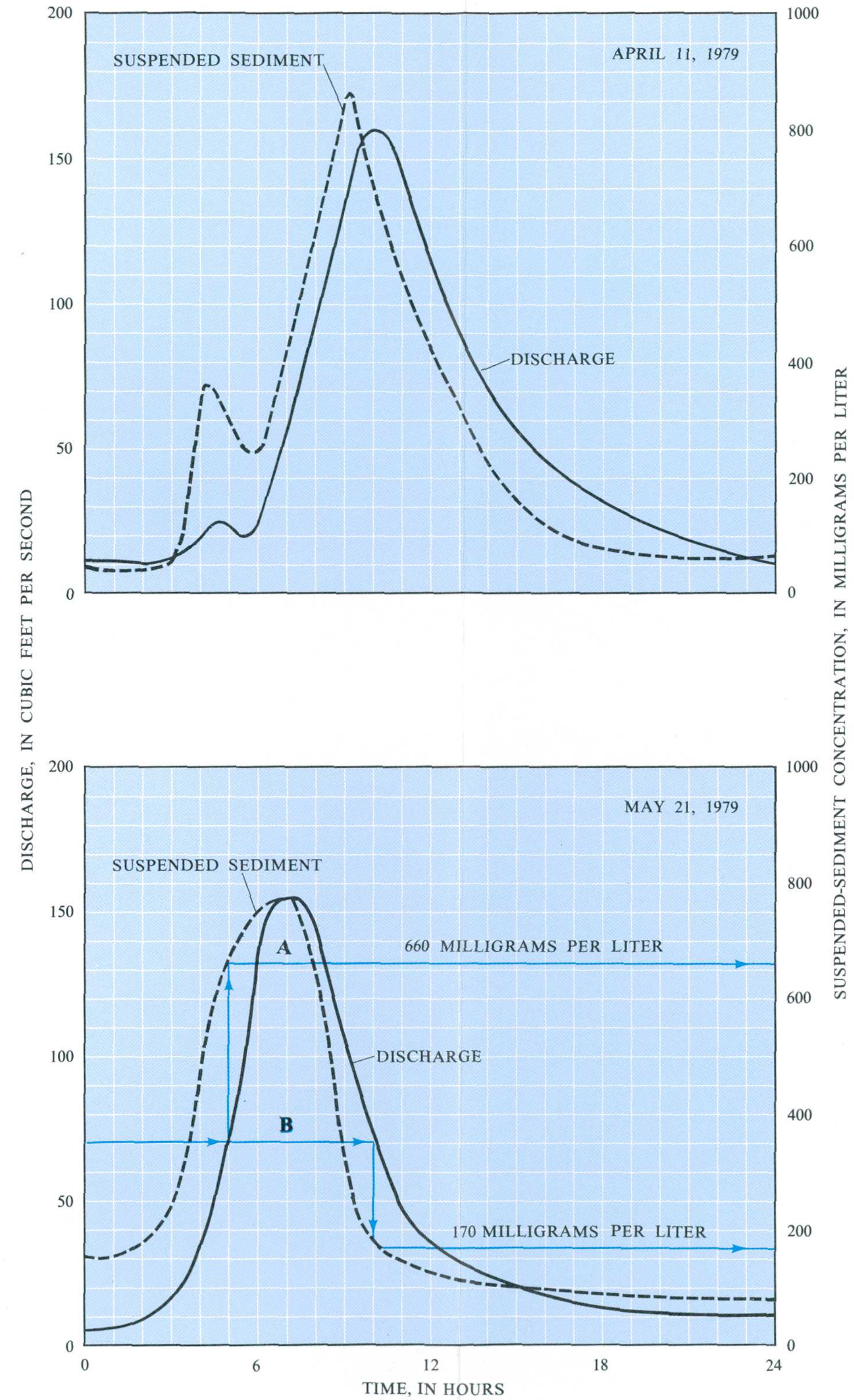


Figure 6.6-2 Stream discharge and suspended-sediment concentration for Coal Creek near Lehigh (station 82).

Selected Chemical-Quality Data are Available for 69 Coal-Mine Ponds in Area 41

The pH of mine-pond water generally is in the normal range but water from some ponds has large concentrations of sulfate, iron, and manganese.

From 1976 to 1981, water-quality samples were collected from 69 randomly-selected coal-mine ponds in Area 41 (fig. 6.7–1). The ponds were created when surface mining ceased in an area and the last mine cut was partly filled with water from surface runoff, direct precipitation, and ground-water seepage (see section 8.1).

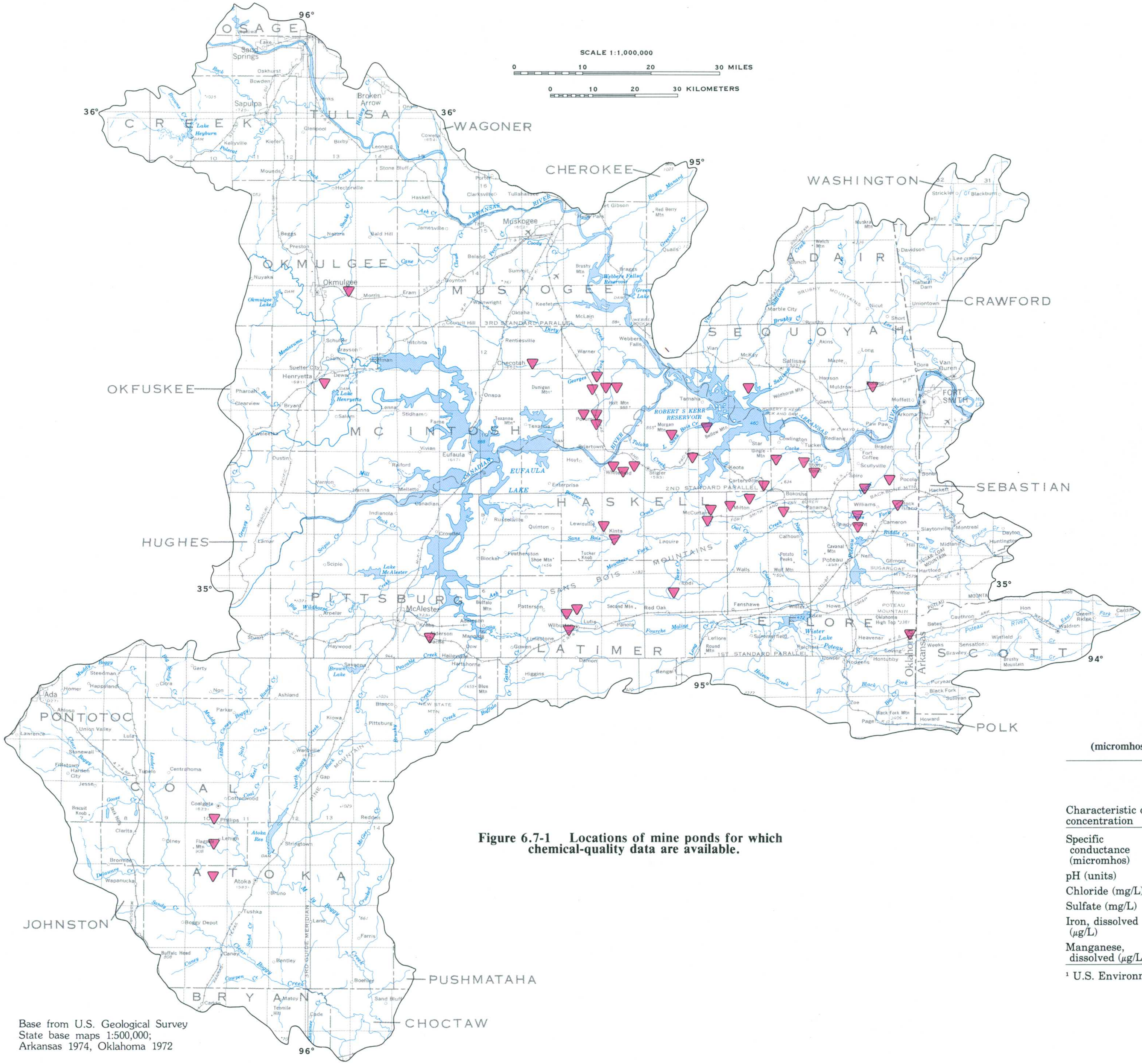
The use of water from some mine ponds may be limited by large concentrations of iron, manganese, and sulfate. Iron and manganese are objectionable because they stain fixtures and clothing, accumulate in plumbing, and give the water an unpleasant taste. However, both are readily removed by aeration or filtration and neither have any significant effect on most irrigated crops. Sulfate affects the taste of the water and may produce laxative effects but acclimation to the substance usually is rapid. Waters with large concentrations of sulfate used to irrigate crops on some soils may decrease soil permeability but the sulfate itself has little effect on most plants. Concentrations of iron and manganese, and to some extent, sulfate differ from pond to pond; these differences presumably are related to differences in mineralogy of the spoil and possibly to the age of the ponds.

The pH of mine pond water generally was in the normal range; less than 5 percent of the determinations were below the minimum allowable effluent limit of pH 6.0 (U.S. Office of Surface Mining, Reclamation, and Enforcement, 1979). More that 50 percent of the sulfate concentrations, more than 75 percent of the iron concentrations, and nearly 50 percent of the manganese concentrations of samples from mine ponds (table 6.7–1) were less than the maximum level recommended in the Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1979). In general, mine-pond water was a sodium sulfate type, very hard, and alkaline.

Detailed studies of two mine ponds near McCurtain, Oklahoma, (Slack, 1983) showed that all determinations of both dissolved and total recoverable arsenic, cadmium, lead, mercury, and selenium were less than the Primary Drinking Water maximum contaminant levels set by the U.S. Environmental Protection Agency (1976). For both ponds, chloride, dissolved iron, and dissolved and total recoverable copper and zinc concentrations were below the Secondary Drinking Water Regulations maximum levels. However, more than 50 percent of sulfate and dissolved solids concentrations exceeded the secondary limits.

Vertical profiles of specific conductance, temperature, dissolved oxygen, and pH in mine ponds in Oklahoma show that water in most ponds more than 30 feet deep is stratified. In general, specific conductance increases with depth indicating increasing mineralization of the water; both dissolved oxygen and pH decrease with depth. Mine ponds less than 30 feet deep usually are not stratified probably because of mixing resulting from winds blowing over the pond surface.

In 1983, Red Oak was the only community in Area 41 that used water from a mine pond as a source of supply. Formerly, several other communities used mine pond water but no longer do so because of the ready availability of water from rural water systems and because of inconsistent quality of the water.



Base from U.S. Geological Survey
State base maps 1:500,000;
Arkansas 1974, Oklahoma 1972

Figure 6.7-1 Locations of mine ponds for which chemical-quality data are available.

EXPLANATION

▽ **COAL-MINE POND; WATER-QUALITY SITE**
Some symbols represent more than one site

Table 6.7-1 Summary of water-quality data for coal-mine ponds.

(micromhos, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter)

Characteristic or concentration	Recommended drinking water limit[1]	Number of analyses	Standard deviation	Percentile: Minimum 0	10th	25th	Median 50th	75th	90th	Maximum 100th
Specific conductance (micromhos)	—	895	767	93	210	380	678	1,045	1,400	4,800
pH (units)	—	877	0.8	3.2	6.7	7.1	7.5	8.1	8.0	9.4
Chloride (mg/L)	250	259	9	0.1	1.9	2.8	4.0	7.0	12	85
Sulfate (mg/L)	250	259	403	3.7	20	48	190	440	691	2,200
Iron, dissolved (µg/L)	300	246	1,243	10	10	20	40	80	810	8,100
Manganese, dissolved (µg/L)	50	200	8,764	5	10	20	60	1,600	4,390	56,000

[1] U.S. Environmental Protection Agency, 1979.

Alluvium Along the Arkansas River is the Principal Aquifer in Area

Wells 40-60 feet deep may yield as much as 1,000 gallons per minute; the water is very hard but is suitable for most uses.

Unconsolidated deposits—alluvium and terrace deposits—are present along many of the streams in Area 41 (fig. 2.1–1). However, only the alluvium along the Arkansas and Canadian Rivers and terrace deposits along the north side of the Arkansas River between Tulsa and Muskogee, Oklahoma, are significant sources of water. Alluvium along the smaller streams and terrace deposits in the vicinity of Lake Eufaula are too thin and too fine grained to yield more than a few gallons per minute and wells in these deposits generally go dry during periods of little rainfall.

Alluvium along the Arkansas River ranges in thickness from 20 to 60 feet and averages about 40 feet. The upper part is mostly clay, silt, and very fine to fine sand which overlies medium to very coarse sand (fig. 7.1–1); a few thin lenses of fine gravel occur locally. The saturated thickness averages about 25 feet. Well yields are greatest in areas where the lower sands are coarse grained, thick, and fully saturated. Measured yields from four aquifer tests ranged from 130 to 860 gallons per minute (Tanaka and Hollowell, 1966); reported yields of irrigation wells ranged from 200 to 1,000 gallons per minute.

Recharge to the unconsolidated deposits is mainly from precipitation although some may be derived by seepage from adjacent bedrock and streams or by infiltration of irrigation water. The volume of recharge depends on the permeability of the surface and near surface materials and the volume and rate of rainfall. Recharge to Arkansas River alluvium has been estimated at 10 percent of the annual rainfall which averages about 42 inches per year (Tanaka and Hollowell, 1966). Most discharge is by evapotranspiration and by seepage into streams; a very small amount is used for irrigation or industrial use along the Arkansas River. No irrigation or industrial wells are known in the Canadian River alluvium or terrace deposits in the area.

The principal direction of ground-water movement is down the valley with a secondary component of movement toward the river. Water-levels, which reflect the volume of water in storage, generally fluctuate in response to evapotranspiration and rainfall. Prior to construction of the McClellan-Kerr Arkansas River Navigation System, changes in stage of the Arkansas River resulted in water-level changes in wells near the river. Far ther away from the river, changes in river stage had negligible effect on the ground-water level. Since completion of the navigation system, the series of locks and dams maintain the river stage at a near-uniform level.

Water in the Arkansas River alluvium is a calcium magnesium bicarbonate type with dissolved-solids concentrations ranging from about 150 to 700 milligrams per liter (table 7.1–1). Calcium and magnesium hardness, expressed as calcium carbonate, ranged from 64 to 640 milligrams per liter; all but a few samples were classed as very hard, that is, hardness more than 180 milligrams per liter (Hem, 1970). Intense or prolonged pumping of wells close to the river may degrade the water quality in the alluvium by inducing inflow of river water which has a mean chloride concentration of about 330 milligrams per liter at Webber Falls, Oklahoma (Stoner, 1981).

Terrace deposits along the north side of the Arkansas River (fig. 2.1–1) between Tulsa and Muskogee, Oklahoma, are as much as 60 feet thick and consist of very fine to fine sand with local areas of coarse sand. Wells in these deposits reportedly yield as much as 125 gallons per minute in a few areas. Few data are available on the chemical quality of water in the terrace deposits but the concentrations of dissolved solids probably are less than 500 milligrams per liter.

Water in alluvium and terrace deposits along the Arkansas River and alluvium along the Canadian River is not likely to be affected by coal mining. However, water in the Arkansas River is not suitable for many uses; therefore, the alluvium is a potential source of water for coal-related industries.

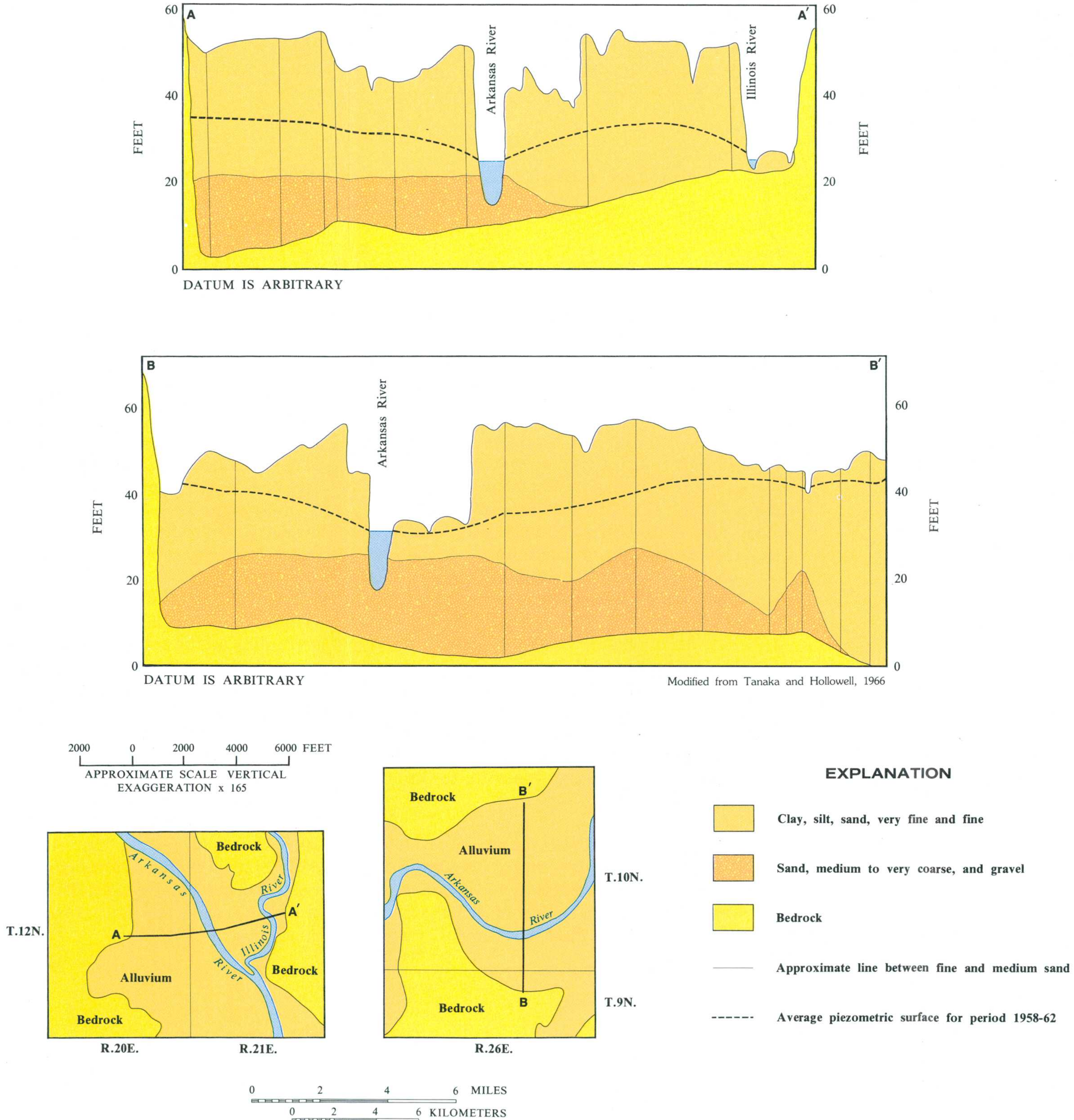


Figure 7.1-1 Geologic sections of alluvium along the Arkansas River.

Table 7.1-1 Selected chemical and physical characteristics of water from alluvium along the Arkansas River.

[mg/L, milligrams per liter; ROE, residue on evaporations at 180° Celsius; umho, micromhos per centimeter at 25° Celsius]

	Number of samples	Minimum	Mean	Maximum
Calcium (mg/L)	62	18	66	148
Magnesium (mg/L)	62	1.3	21	48
Sodium (mg/L)	121	5.3	17.5	87
Bicarbonate (mg/L)	138	70	289	618
Carbonate (mg/L)	137	0	0.9	16
Sulfate (mg/L)	153	0	40	363
Chloride (mg/L)	154	0.8	18	68
Dissolved solids (ROE)(mg/L)	47	148	338	702
Specific conductance (umho)	153	160	451	1,070
pH (units)	183	7.1	---	8.6

The Antlers Aquifer is a Significant Source of Water in the Extreme Southern Part of Area

Wells fully penetrating the confined part of the aquifer may yield 2,500 gallons per minute; the water is suitable for most uses.

The Antlers aquifer, which consists primarily of the Antlers Sandstone in the extreme southern part of the area (fig. 7.2–1), is several miles from any potential mining and, therefore, not likely to be affected by that activity. However, the aquifer is a potential source of water for coal-related industry. The aquifer consists of weakly to moderately indurated sandstone, clay, and conglomerate which has a maximum thickness of about 400 feet at the southern edge of the area. The rocks dip toward the south or southeast at 30–80 feet per mile.

In the outcrop area of the aquifer the water is unconfined but where it is overlain by less permeable rocks the water is confined. A few wells in the confined part of the aquifer and that are at topographically low elevations flow at times. The general direction of water movement is toward the south or southeast.

Recharge to the aquifer is mainly by precipitation falling directly on the outcrop area but some is derived by seepage from lakes and streams and from overlying or adjacent rocks. Most recharge occurs in April, May, and June, the time of greatest precipitation. Recharge has been estimated at about 6 inches per year which is approximately 15 percent of the average annual precipitation (Hart and Davis, 1981). Most discharge is by evapotranspiration, springs, and seepage to streams. For example, low-flow measurements of a small stream at Caney, Oklahoma, show that discharge from the aquifer to the stream ranges from about 300 to 800 acre-feet per year.

Wells in the unconfined part of the aquifer generally yield 20–100 gallons per minute depending on the saturated thickness and method of well construction. Properly constructed wells that fully penetrate the confined part of the aquifer where the percentage of sand is greatest may yield as much as 2,500 gallons per minute.

In the outcrop area or unconfined part of the aquifer, the water is typically a sodium bicarbonate type and has a dissolved-solids concentration of 100–300 milligrams per liter. As the water moves downdip, however, it changes to a sodium chloride type and the dissolved-solids concentrations increases to about 500 milligrams per liter.

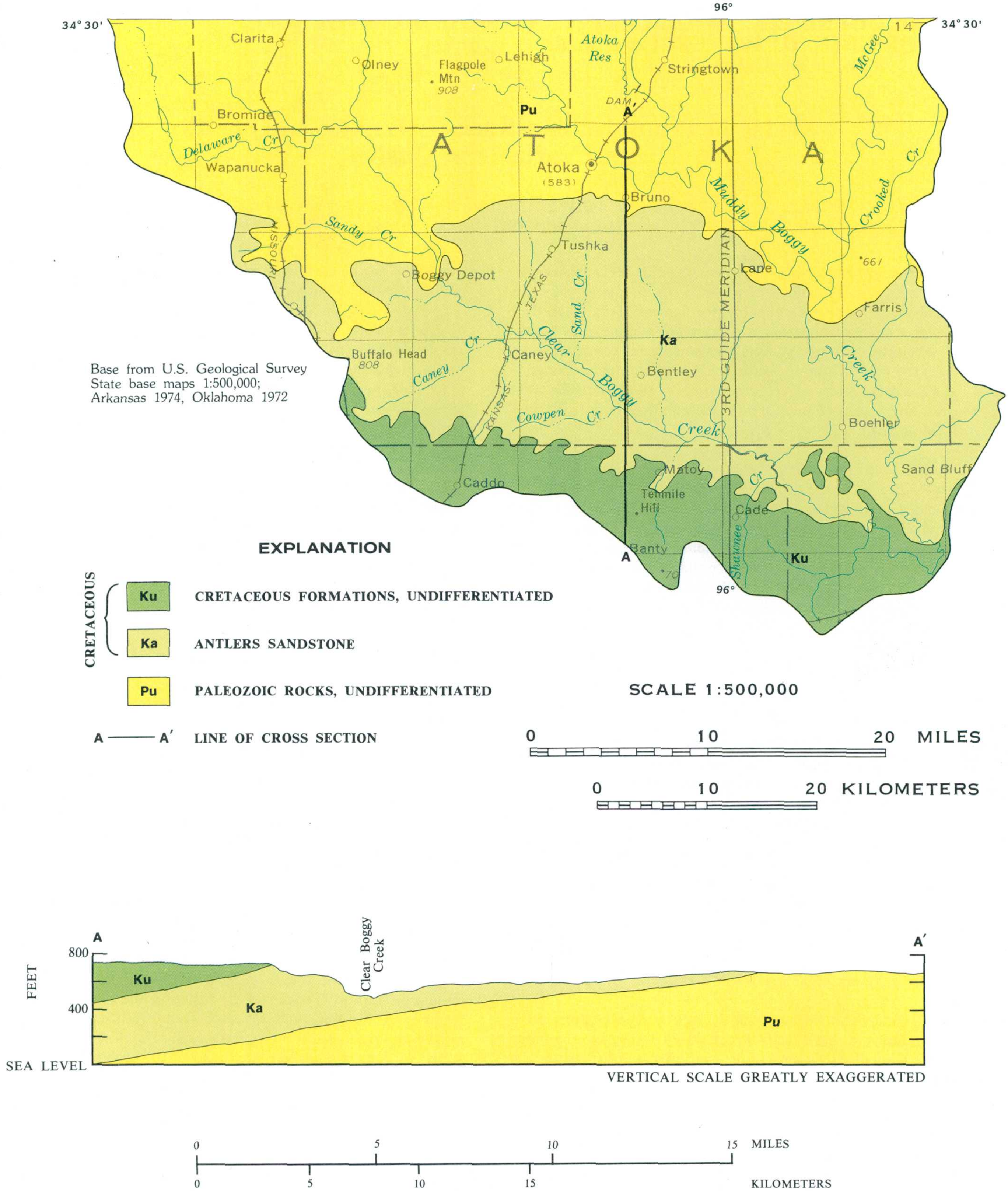


Figure 7.2-1 Map and cross section of the Antlers aquifer.

Water in Pennsylvanian Rocks is Limited in Quantity and Variable in Quality

Yields of most wells are very small and the water is generally suitable for domestic and stock supply.

Although the coal-bearing Pennsylvanian rocks in Area 41 yield only small amounts of water, wells in these rocks are widely used to provide supplies for domestic and stock use. Under some conditions, surface mining of coal may have some effect on the recharge, storage, movement, and chemical quality of the water. However, because of the geologic characteristics and the areal distribution of rock units in relation to the locations and depths of surface mines, such effects would be very local in extent.

The occurrence, storage, and movement of water in the Pennsylvanian rocks are largely controlled by the lateral and vertical distribution of rock units and their physical characteristics, particularly permeability, and by the geologic structure. The Pennsylvanian rocks consist principally of shale and siltstone with widely separated sandstone units. The broad valleys and prairie areas are floored with shale and siltstone that commonly are weathered to depths of 10–30 feet. The sandstone units, which comprise 20–40 percent of the total thickness of exposed rocks, are thicker and more numerous in the southern part of the area (see section 2.1). The sandstones are fine to very fine grained and usually are well cemented with silica and iron oxides.

Because of the geologic structure, the rocks are tilted at the surface exposing bedding plane openings between the layers of sandstone and partings between laminae of shale; these openings are the principal avenues of water entry and movement. Other openings for water movement are fractures and joints formed during folding of the brittle rocks. Faults, where they are present, also may be water conduits but if the rocks are so greatly crushed that the openings are sealed, the faults may act as water barriers. The number and distribution of bedding planes, fractures, and joints differ both areally and with depth so that a well of given depth may yield enough water for household use whereas a nearby well of the same depth, or even deeper, may not yield any water.

Ground-water recharge is derived almost entirely from precipitation falling directly on the area. Locally, some recharge may be provided by seepage from overlying terrace deposits and alluvium or from streams during periods of high water stage. Water levels, which reflect the amount of water in storage, typically are highest in spring or early summer because most recharge occurs at that time. Due to the lack of recharge and high rates of evapotranspiration during the hot summer months, water levels decline and usually are lowest in the autumn or winter. Occasional rains of 1–2 inches during the summer when evapotranspiration is at or near its peak do not have any significant effect on the downward trend of the water level. The annual fluctuation of the water level generally is less than 10 feet.

Analysis of hydrologic data for the Blocker area in northeastern Pittsburg County, Oklahoma, (see section 4.3 for location) which is geologically and hydrologically typical of most of Area 41, provides an estimate of annual recharge of about 3 acre-feet per square mile or about 0.1 percent of the annual precipitation of about 42 inches (Marcher and others, 1981). The amount of recharge varies from year to year depending on climatic conditions and from place to place depending on local soil, geologic, and physiographic characteristics. Evapotranspiration in the Blocker area has been estimated at 75–85 percent of the annual precipitation.

Ground water in the zone of weathered rock generally is unconfined whereas water bedrock is confined. Because of the confining pressure, water rises in wells and in most of the coal field is less than 20 feet below the land surface; a few wells flow at times. The movement of water in bedrock is governed by the location and altitude of areas of recharge and discharge. Consequently, the slope of the potentiometric surface[1] is in the same direction as the land surface and geologic structure has little effect on the regional movement of the water. As illustrated by the schematic geohydrologic sections (fig. 7.3–1) the slope of the potentiometric surface, which indicates the direction of water movement, may parallel the geologic structure in some areas but may cut across the structure in others. This relationship is significant in selecting sites for observation wells to monitor ground-water conditions in the vicinity of a surface mine.

The yields of most wells in Pennsylvanian rocks as measured onsite (Marcher, 1969, and Marcher and Bingham, 1971) and reported by well drillers and homeowners generally are less than 5 gallons per minute and many yield only a fraction of gallon per minute. Locally, a few wells penetrating thick units of fractured sandstone have been reported to yield as much as 25 gallons per minute. Because of the difficulty and expense of obtaining an adequate water supply from wells in the Pennsylvanian rocks, rural water districts are relied on to provide water for domestic use in many parts of the area (see section 3.2) and thousands of farm ponds have been constructed for stock water.

The chemical quality of water in the Pennsylvanian rocks is extremely variable. No relationship between variations in ground-water chemistry and well depth, geographic distribution, or geologic formation is apparent. Typically, ground water is a sodium bicarbonate type although many variations in water type occur (fig. 7.3-2). Concentrations of dissolved solids typically range from 300 to 2,000 milligrams per liter and pH ranges from 6 to 8 (table 7.3-1). In most of the area the water is hard to very hard (more than 120 milligrams per liter). Of 25 samples of ground water analyzed for trace elements—arsenic, cadmium, chromium, lead, and mercury—only one sample exceeded the maximum contaminant level of 50 micrograms per liter for lead in drinking water as established by the U.S. Environmental Protection Agency (1976). The maximum contaminant levels of the other trace elements were not exceeded in any of the samples. None of the data available on the chemical quality of ground water indicate that it has been affected by surface mining.

[1] Potentiometric surface is an imaginary surface connecting points to which water would rise in tightly cased wells from a given point in an aquifer; it may be above or below the land surface.

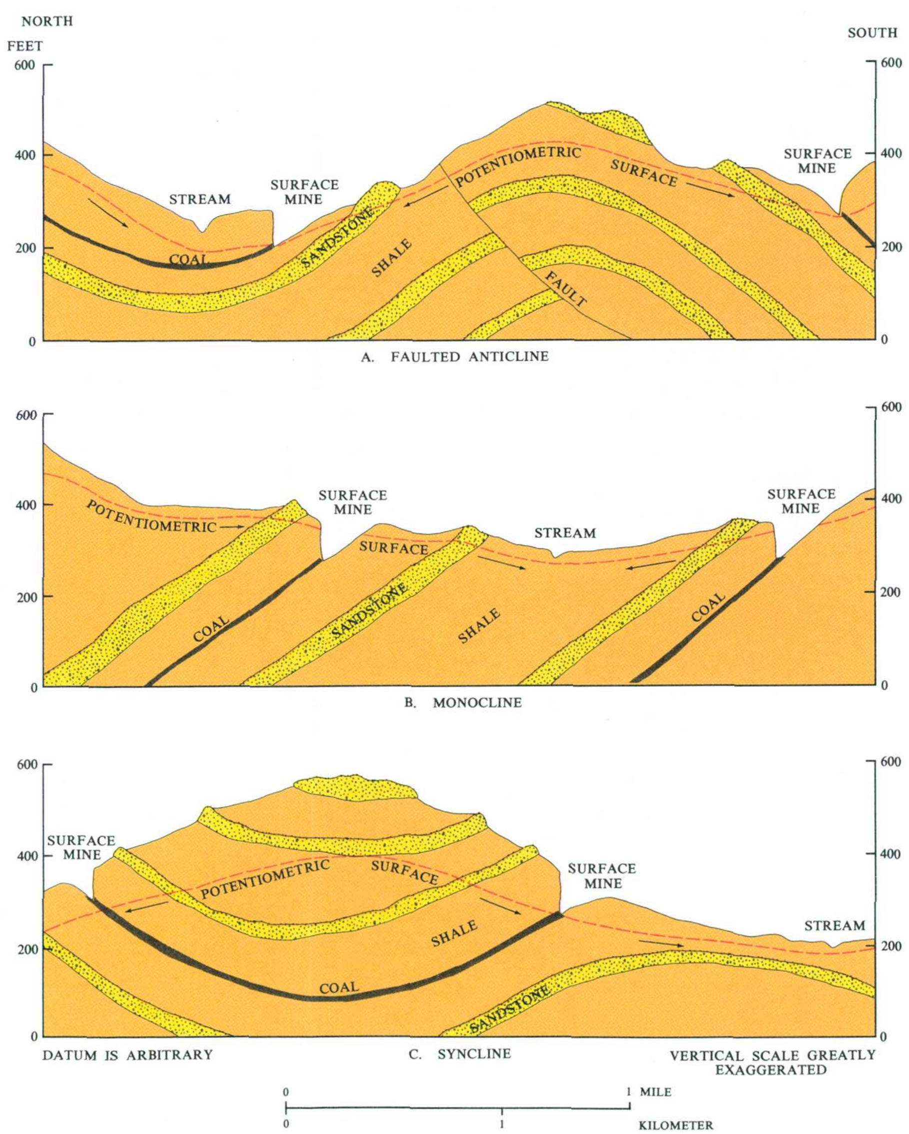


Figure 7.3-1 ***Schematic geohydrologic sections showing the direction of ground-water movement (arrows) in relation to geologic structure typical of Area 41 and locations of surface mines.***

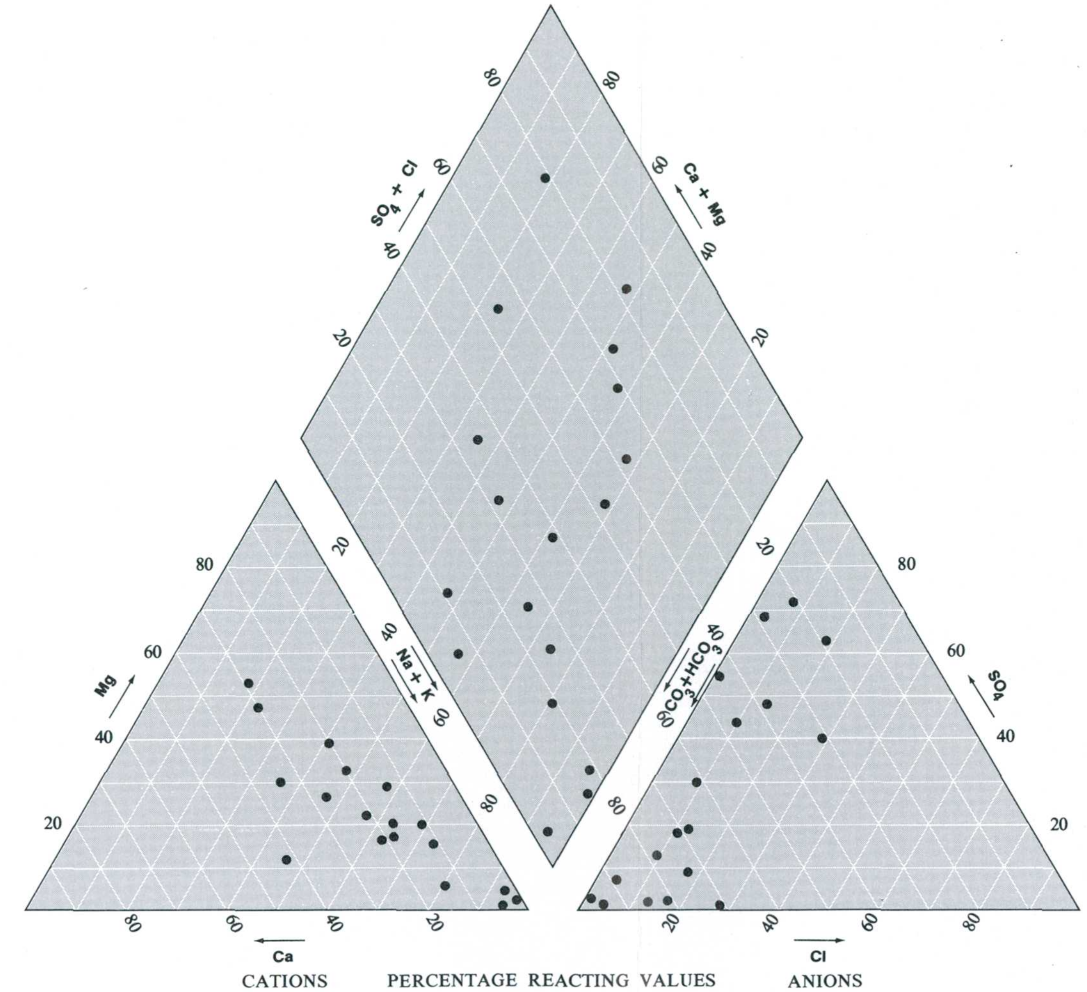


Figure 7.3-2 Trilinear diagram of ground-water samples showing variations in water type.

Table 7.3-1 Summary of selected physical properties and chemical constituents in water from 25 wells completed in rocks of Pennsylvanian age.

[µmhos, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ROE, residue on evaporation at 180° Celsius]

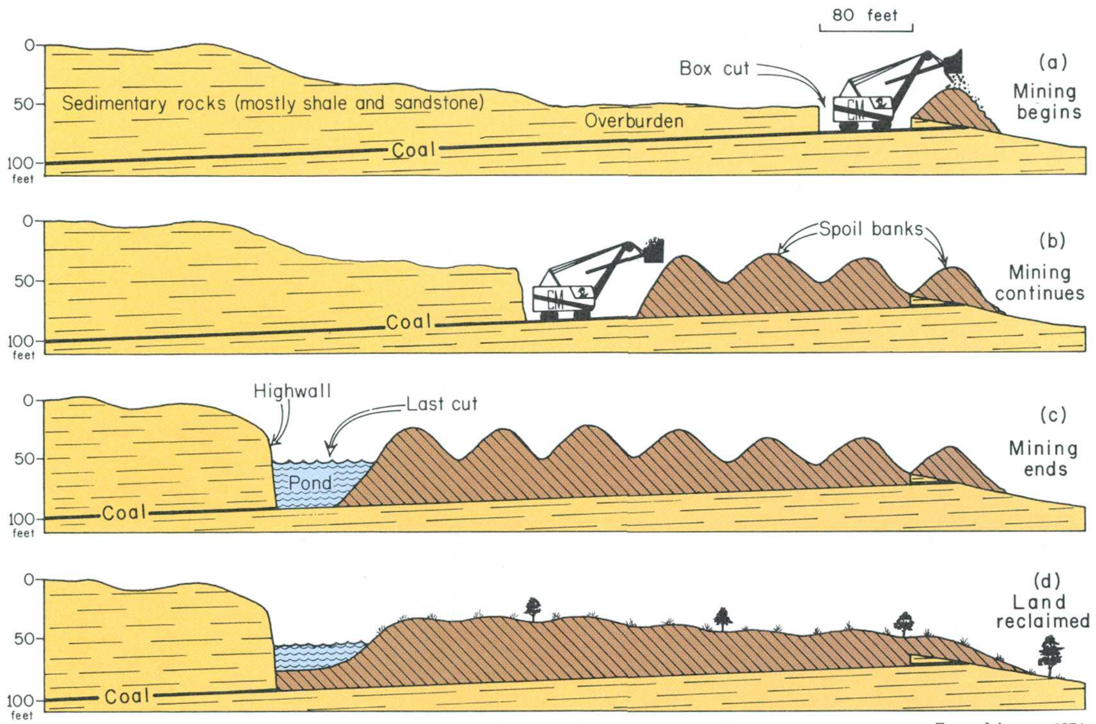
	Mimimum	Mean	Median	Maximum
Well depth (feet)	21	81	78	233
Specific conductance (µmho)	460	964	800	2,690
pH (units)	6.2	---	7.3	8.8
Hardness (Ca plus Mg)(mg/L)	5	204	140	790
Calcium (mg/L)	1.8	36	24	120
Magnesium (mg/L)	0.1	27	19	120
Sodium (mg/L)	49	144	120	330
Chloride (mg/L)	3.4	46	30	190
Sulfate (mg/L)	4.3	151	56	870
Iron (µg/L)	20	995	110	17,000
Manganese (µg/L)	8	195	50	1,000
Dissolved solids (ROE)	294	603	520	2,010

Ponds Left When Mining is Completed Provide Valuable Surface-Water Storage

Mine ponds provide habitat for wildlife and can be a water-supply source if the quality is suitable.

A significant change in the hydrologic environment that results from surface mining coal in Area 41 is the creation of additional surface-water storage in mine ponds. The following description of the coal-mining process (fig. 8.1–1), as practiced in the area, is summarized from Johnson (1974) to show how these ponds are formed. The first step in a surface-mining operation is to remove and stockpile the topsoil. Next, a trench is dug through the overburden to expose the coal which is then removed. As each succeeding cut is made, the overburden or spoil is placed in the cut previously excavated. Successive cuts are mined until the overburden thickness becomes so great, usually 100–150 feet, that the coal can no longer be mined profitable. The final cut leaves an open trench bounded by the last spoil on one side and the undisturbed highwall on the other. The trench partly fills with water from surface runoff, direct precipitation, and ground-water seepage. A mine pond 0.5 mile long, 200 feet wide and 30 feet deep has a volume of 360 acre-feet—a valuable resource in an area of limited ground-water supply.

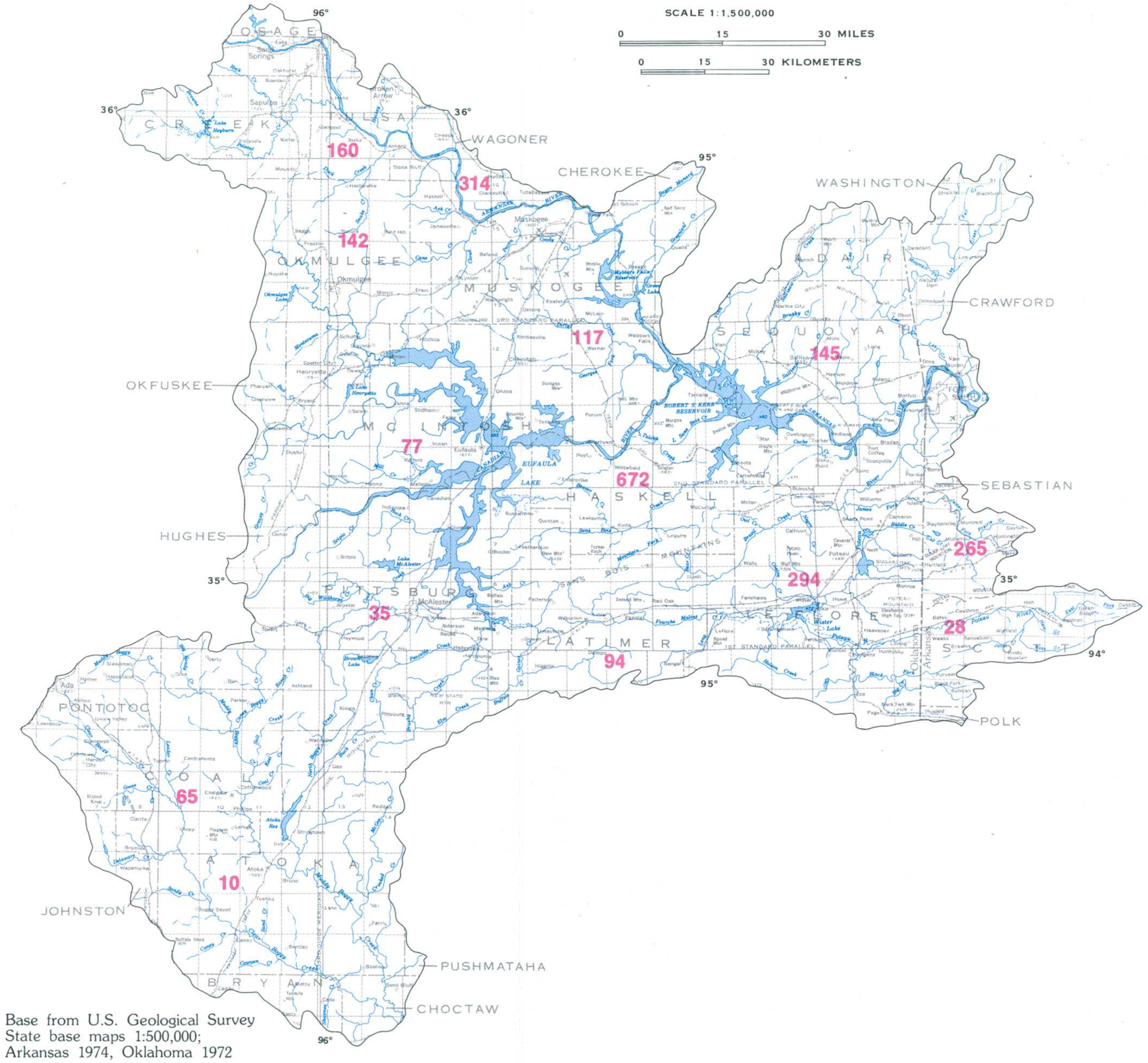
Mine ponds in Area 41 cover approximately 2,400 acres (fig. 8.1–3) and with an average depth of 25 feet, they contain approximately 60,000 acre-feet or more than 19 billion gallons of water. The acreage estimates are based on data compiled in 1973 for Oklahoma and 1977 for Arkansas. Undoubtedly, the acreage has increased significantly since the data were compiled, particularly in Oklahoma. These mine ponds provide habitat for aquatic and semiaquatic wildlife and may contribute to the aesthetics of the landscape; some have been stocked with fish (fig. 8.1–2). Also, water from the ponds can be used for stock, domestic, municipal, and irrigation supply if the quality is suitable (see section 6.7).



From Johnson, 1974

Figure 8.1-1 Schematic cross sections showing stages of surface mining for coal.

Figure 8.1-2 Mine ponds provide wildlife habitat and recreation and may be water-supply sources if the water quality is suitable.



Base from U.S. Geological Survey State base maps 1:500,000; Arkansas 1974, Oklahoma 1972

Figure 8.1-3 Estimated acreage of mine ponds based on data compiled in 1973 for Oklahoma (Johnson, 1974) and 1977 for Arkansas (Bush and Gilbreath, 1978). Acreages shown are for the entire county and not just that part included in Area 41.

Mining May Increase Ground-Water Storage

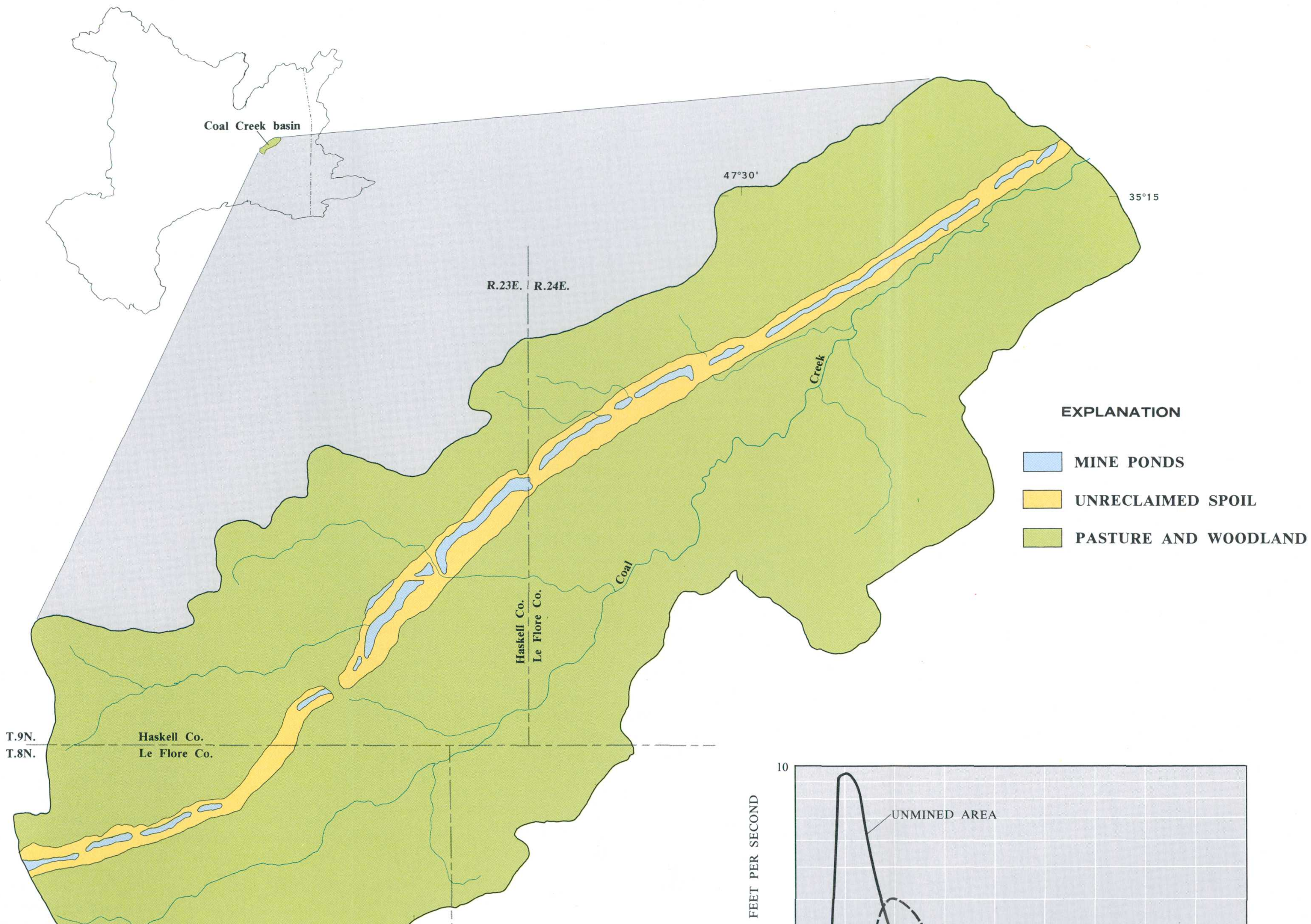
Surface runoff intercepted by mine spoil may provide baseflow during periods of no rainfall and may reduce peak flows of small streams.

Overburden in Area 41 consists principally of shale and siltstone which have very limited porosity and permeability. During mining, however, the rocks are broken and shattered to form spoil with many openings that facilitate the entry, movement, and storage of water. The volume of water that enters the spoil is partly controlled by the permeability of the surface and near-surface material. Where that material consists principally of silt and clay, openings may be plugged thus limiting the rate and volume of infiltration. Although the volume of void space or porosity is not known, it has been estimated to range from 15 to 25 percent (Cederstrom, 1971). If the porosity is estimated at 15 percent, then a square mile of spoil with a saturated thickness of 50 feet would contain about 4,800 acre-feet or nearly 1.5 billion gallons of water. Water stored in the spoil may (a) move into the adjacent bedrock, (b) be used by plants, and (c) gradually discharged to nearby streams. Water discharged to streams can provide a supply for livestock and wildlife and may be used for other purposes if the quality is suitable.

Surface mining has changed drainage patterns in some parts of the area. These changes have resulted from (a) filling natural drainageways with spoil, (b) mining across drainageways, and (c) diversions necessary to keep runoff from entering active mines. The effect of these changes on the hydrologic system in a given basin would depend largely on the locations of the mines and on the proportion of the basin that has been disrupted by mining.

Coal Creek basin (station 45) in northwestern Le Flore and eastern Haskell Counties, Oklahoma, is an example of how surface mining can affect drainage patterns, ground-water storage, and streamflow. The geology, topography, and land cover in Coal Creek basin is typical of most of the coal field in Area 41. The basin has an area of 18.1 square miles or which nearly 1 square mile, or about 5 percent of the basin, is unreclaimed spoil and mine ponds (fig. 8.2–1). The rest of the basin is mostly native pasture with trees and bruch on the steeper slopes and along the creek. Mining across several small drainage-ways on the north side of the basin has altered their normal pattern so that they no longer flow directly into the creek. Runoff in these drainageways and over the land surface is intercepted by the spoil and mine ponds and gradually discharged to Coal Creek. During the 1979–81 water years, Coal Creek had no flow for only 6 days. During the same period, Fourche Maline (station 50) with a drainage area of 122 square miles and Brazil Creek (station 61) with a drainage area of 69.1 square miles, had no flow for 87 and 112 days, respectively. Both streams are about 30 miles southwest of Coal Creek basin (see fig. 4.1–1 for locations). The flow duration curve (fig. 8.2–2) for Coal Creek shows that for 99 percent of the 1979–81 water years, discharge exceeded 0.06 cubic feet per second whereas for 90 percent of the same period the discharge of Taloka and Morris Creeks (stations 33 and 55), which are comparable in size, was 0.01 cubic feet per second or less. About 5 percent of Taloka Creek basin has been mined and mostly reclaimed but much of the mined area has interior drainage and does not contribute to the flow of the creek; no mining has ever been done in Morris Creek basin.

Most surface mines in Area 41 are in valleys where the land is used mainly for unmanaged pastures of native grasses. Appropriate reclamation practices after mining include replacing the topsoil, adding fertilizer, and reseeding with tame grasses and legumes for pasture. Where these practices are followed and the new pastures are properly managed, the new vegetation generally is more lush and has a denser growth than the original native vegetation. The denser plant growth tends to retard storm runoff so that it has more time to soak into the spoil and, as a consequence, less water reaches the streams during times of normally peak flow. Converserly, as in Coal Creek basin, water stored in the spoil is slowly released to streams thereby sustaining baseflow for a longer period of time following rainfall. The overall resulting changes in streamflow would be decreased peak discharges and augmented periods of baseflow (fig. 8.2–3).



Base from U.S. Geological Survey; Bokoshe 1:24,000, 1968, and Roberts S. Kerr Dam 1:24,000, 1967

Figure 8.2-1 Mine ponds, unreclaimed spoil, and drainage patterns in Coal Creek basin.

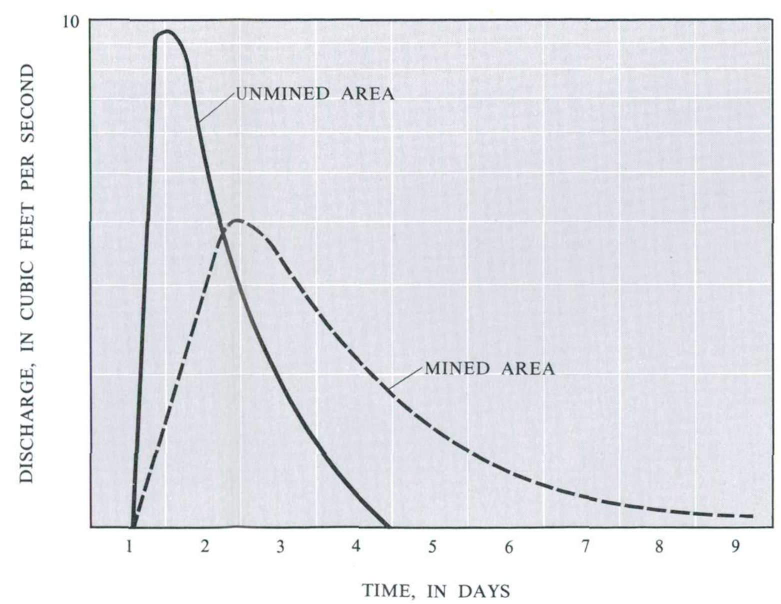


Figure 8.2-3 Hypothetical hydrographs of streams draining mined and unmined areas.

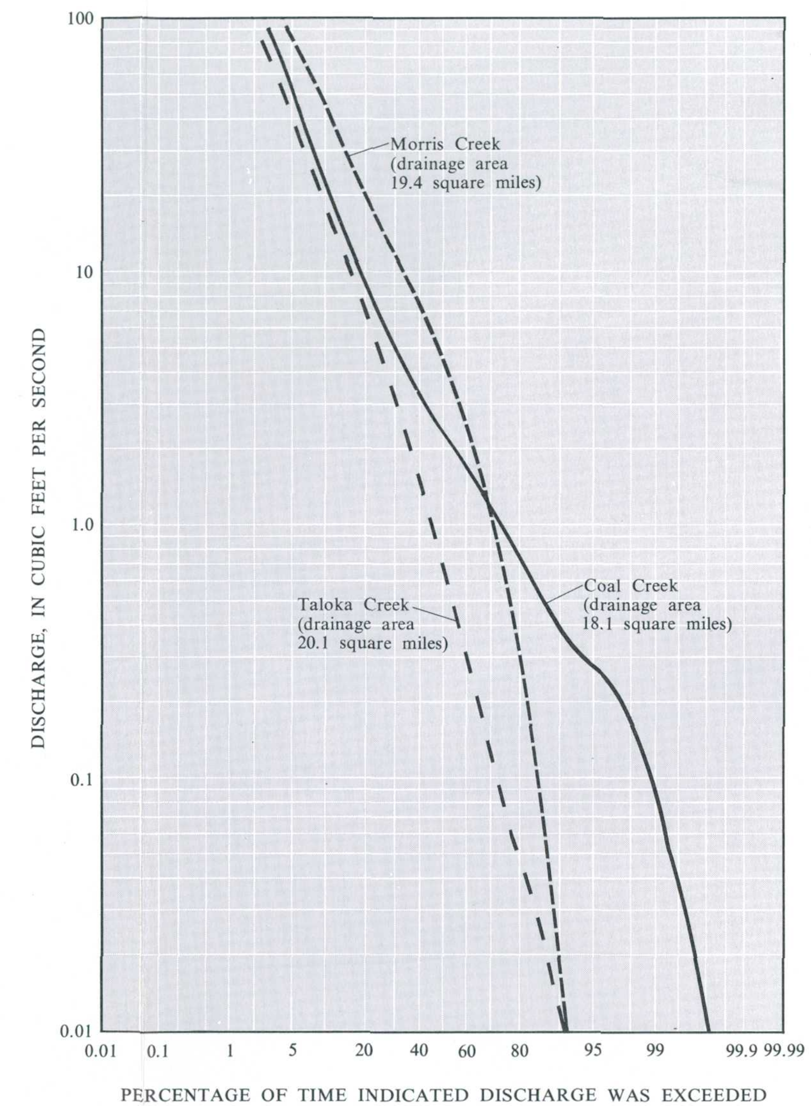


Figure 8.2-2 Comparison of flow-duration curves of streams draining mined (Coal Creek and Taloka Creek) and unmined (Morris Creek) areas, 1979-81 water years.

Surface Mining May Increase the Dissolved-Solids Concentrations and Sediment Loads of Streams

The most common effect of surface mining coal is an increase in sulfate concentrations in streams; mining has little or no effect on pH of stream water.

Minerals in the overburden and coal are in equilibrium with their environment as long as that environment is not changed. Surface mining, however, disturbs that environment by fracturing the rocks thus exposing greater quantities of minerals to water and oxygen. In particular, reactions between water moving through spoil, oxygen, and the iron-sulfide minerals pyrite and marcasite commonly associated with coal may introduce undesirable concentrations of iron and sulfate and increase the water's acidity by adding hydrogen ions. Acidic, iron-bearing water commonly has a reddish or brownish hue due to the presence of ferric hydroxides and is referred to as acid mine drainage (fig. 8.3–1). The acidity caused by the excess hydrogen ion increases the solubility of trace metals such as aluminum, copper, lead, and zinc that may be present in the coal or overburden. However, if calcium carbonate is present in the overburden, it buffers the excess acidity.

Selected physical and chemical characteristics of water from Blue Creek (station 22), Brazil Creek (station 61), Coal Creek (station 45), and Taloka Creek (station 33) (fig. 8.3–2), which are typical of small streams in the area, are compared in table 8.3–1; mean values are given to avoid overemphasis on extremes. All four basins are rural and although the geologic formations underlying each may differ, the rocks consist primarily of shale and siltstone with some sandstone. Other than mining, none of the basins have been significantly affected by man's activities. Characteristics of each basin are summarized as follows:

1. Blue Creek drains an area of 12.1 square miles and is underlain by the Boggy and Savannah Formations. Land cover consists of pasture and woodland. Prior to 1938, a small area (40 acres) was surface mined and a few small slope mine were operated.

2. Brazil Creek drains an area of 69.1 square miles and is underlain by the McAlester and Savannah Formations. Land cover is mostly woodland but with extensive areas of pasture in the valleys. The basin includes about 1 square mile of unreclaimed old spoil and mine ponds, reclaimed recent spoil, and mines that were in operation during the sampling period.

3. Coal Creek drains an area of 18.1 square miles and is underlain by the Atoka, Hartshone, and McAlester Formations. Land cover is mostly pasture with some woodlands. About 1 square mile is unreclaimed old spoil and mine ponds.

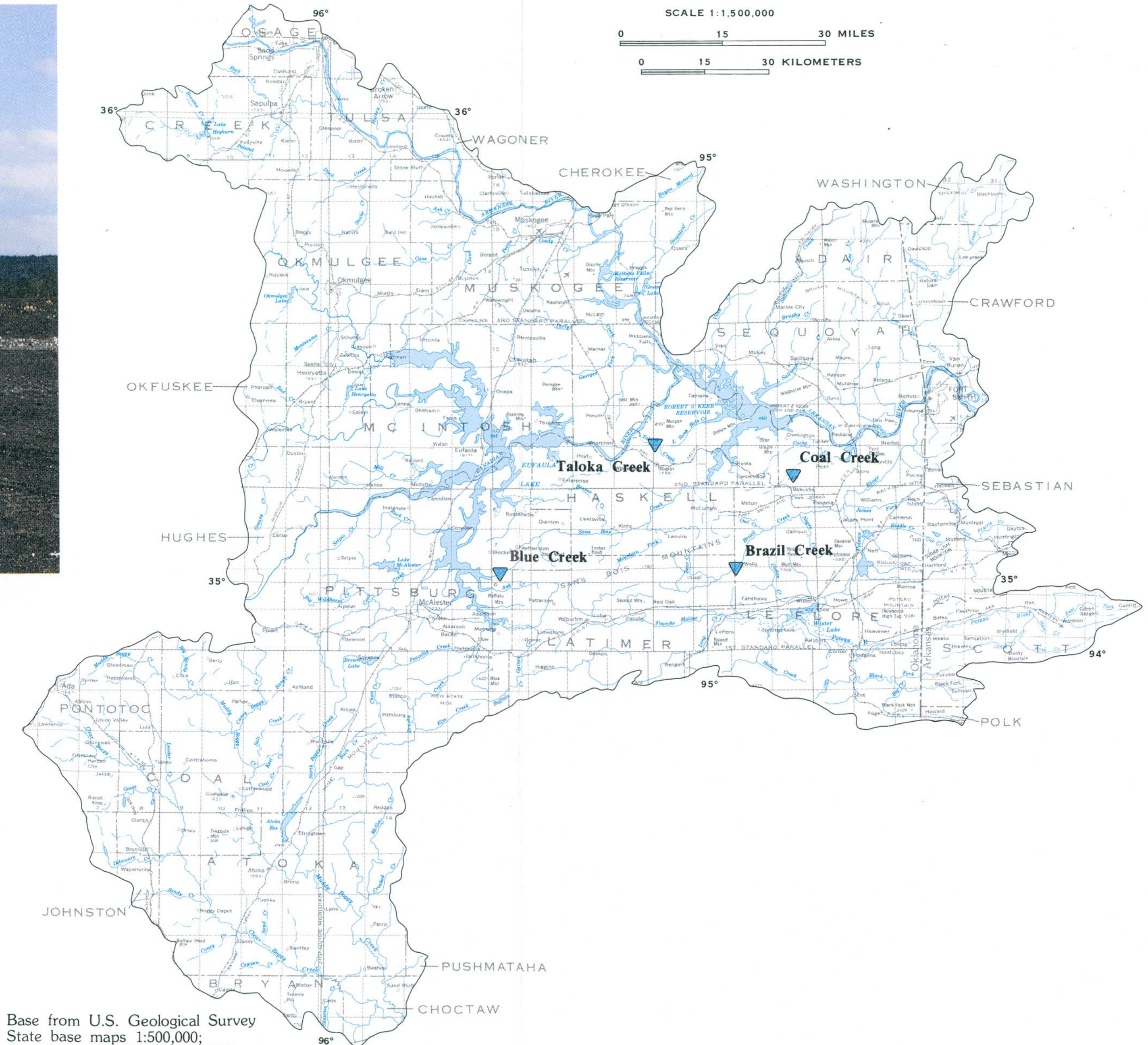
4. Taloka Creek drains an area of 20.1 square miles and is underlain by the McAlester, Savannah, and Boggy Formations with some local terrace deposits. Land cover is pasture and woodland. The basin includes about 150 acres of unreclaimed old spoil, about 1 square mile of reclaimed old spoil, and about 0.5 square mile of reclaimed recent spoil. Mining was active in the basin until October, 1980. During part of the time when mining was active, water was pumped from the mine into a settling pond from which it flowed into Taloka Creek. Seven samples of water were analyzed in the laboratory after mining ceased.

The data for the four streams show that pH was not significantly affected by mining. The large concentrations of dissolved solids and sulfate in Taloka Creek during active mining was due to water being pumped from the mine and when pumping stopped, concentrations of these constituents returned to normal. The larger concentrations of dissolved solids and sulfate in Coal Creek as compared to Brazil Creek and Taloka Creek aafter mining ceased may be due to differences in mineralogy of the overburden. In summary, mining in the basins of Brazil and Taloka Creek has not had any apparent long-term effect on the pH and concentrations of dissolved solids or sulfate; however, mining has resulted in increased concentrations of these constituents in water from Coal Creek.

Data presented in section 6.6 show that the average sediment yield of nine unmined basins and four mined basins was 42 and 66 tons per square mile per year, respectively, thus suggesting that mining may increase sediment loads of streams. Obviously, disruption of the land surface during mining and before the spoil is fully reclaimed will increase the quantity of sediment available to streams (fig. 8.3–3). Trace metals adsorbed to sediment particles may increase total in-stream concentration of these constituents. However, the increase in the volume of sediment and adsorbed metals depends largely on the proximity of the stream and the mined area, topography, climate, percentage of the basin disturbed, mining techniques, and reclamation practices. Of these, mining techniques and reclamation practices are particularly significant. If appropiate mining techniques are followed, such as the construction and maintenance of adequate settling ponds, the volume of sediment reaching a stream can be reduced. Likewise, if reclamation is done quickly and effectively, the source of the sediment and the time available for it to be added to the stream also can be reduced. Other land uses, such as cultivation of the soil, overgrazing of pastures, and destruction of vegetative cover by burning or herbicides may be more significant than mining in contributing sediment to streams.

Figure 8.3-1 Acid mine drainage discharging from an abandoned underground mine.

Figure 8.3-3 Partly reclaimed but unvegetated spoil is a source of sediment to streams.



Base from U.S. Geological Survey State base maps 1:500,000; Arkansas 1974, Oklahoma 1972

Figure 8.3-2 Location of sampling sites of streams draining mined and unmined areas.

Table 8.3-1 Comparison of selected physical properties and chemical constituents of water from streams draining mined and unmined areas.

(ROE, residue on evaporation at 180° Celsius; N, number of determinations; µmho, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter)

Stream	Property or constituent									
			Mean values							
	pH Range in values		Specific conductance		Dissolved solids (ROE)		Sulfate		Iron, dissolved	
	N	units	N	µmho	N	mg/L	N	mg/L	N	µg/L
Blue Creek - no mining	18	6.0-8.0	19	117	19	79	19	21	16	178
Brazil Creek - old and recent mining	47	6.7-8.5	48	190	29	132	28	36	42	216
Coal Creek - old mining	109	7.0-8.3	108	575	36	414	36	209	24	95
Taloka Creek - active mining	36	6.8-8.6	36	1,845	19	1,323	19	543	32	89
Taloka Creek - mining ended	9	6.9-7.7	9	224	7	118	7	29	7	270

NAWDEX, WATSTORE, OWDC, and STORET have Water-Data Information

Water data are collected in coal areas by a large number of organizations in response to a wide variety of missions and needs.

Three activities within the U.S. Geological Survey help identify and improve access to the vast amount of existing water data.

(1) The National Water-Data Exchange (NAWDEX) indexes the water data available from more than 400 organizations and serves as a central focal point to help those in need of water data to determine what information already is available.

(2) The National Water-Data Storage and Retrieval System (WATSTORE) serves as the central repository of water data collected by the U.S. Geological Survey and contains large volumes of data on the quantity and quality of both surface and ground waters.

(3) The Office of Water-Data Coordination (OWDC) coordinates Federal water-data acquisition activities and maintains a "Catalog of Information on Water Data." To assist in identifying available water-data activities in coal provinces of the United States, special indexes to the catalog are being printed and made available to the public.

The U.S. Environmental Protection Agency operates a Water Quality Control Information System which includes a data base called STORET. This data base is used for the STOrage and RETrieval of data relating to the quality of water in waterways within and contiguous to the United States.

More detailed explanations of these four activities are given in sections 9.2, 9.3, 9.4, and 9.5.

NAWDEX Simplifies Access to Water Data

The National Water-Data Exchange (NAWDEX) is a nationwide program managed by the U.S. Geological Survey to assist users of water data or water-related data in identifying, locating, and acquiring needed data.

NAWDEX is a national confederation of water-oriented organizations working together to make their data more readily accessible and to facilitate a more efficient exchange of water data.

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities (see fig. 9.2–1). A directory (Edwards, 1980) is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations.

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requestor to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water-Data Index (fig. 9.2–2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A Water Data Sources Directory (fig. 9.2–3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In all instances, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and in all instances where costs are anticipated to be substantial.

For additional information concerning the NAWDEX program or its services contact:

Program Office
National Water-Data Exchange (NAWDEX)
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 860-6031
or FTS 928-6031
Hours: 7:45 to 4:15 EST

NAWDEX ASSISTANCE CENTER
OKLAHOMA
U.S. Geological Survey
Water Resources Division
Room 621, 215 Dean A. McGee
Oklahoma City, OK 73102
Telephone (405) 231-4256
FTS 736-4256
Hours: 8:00 to 4:45 CST

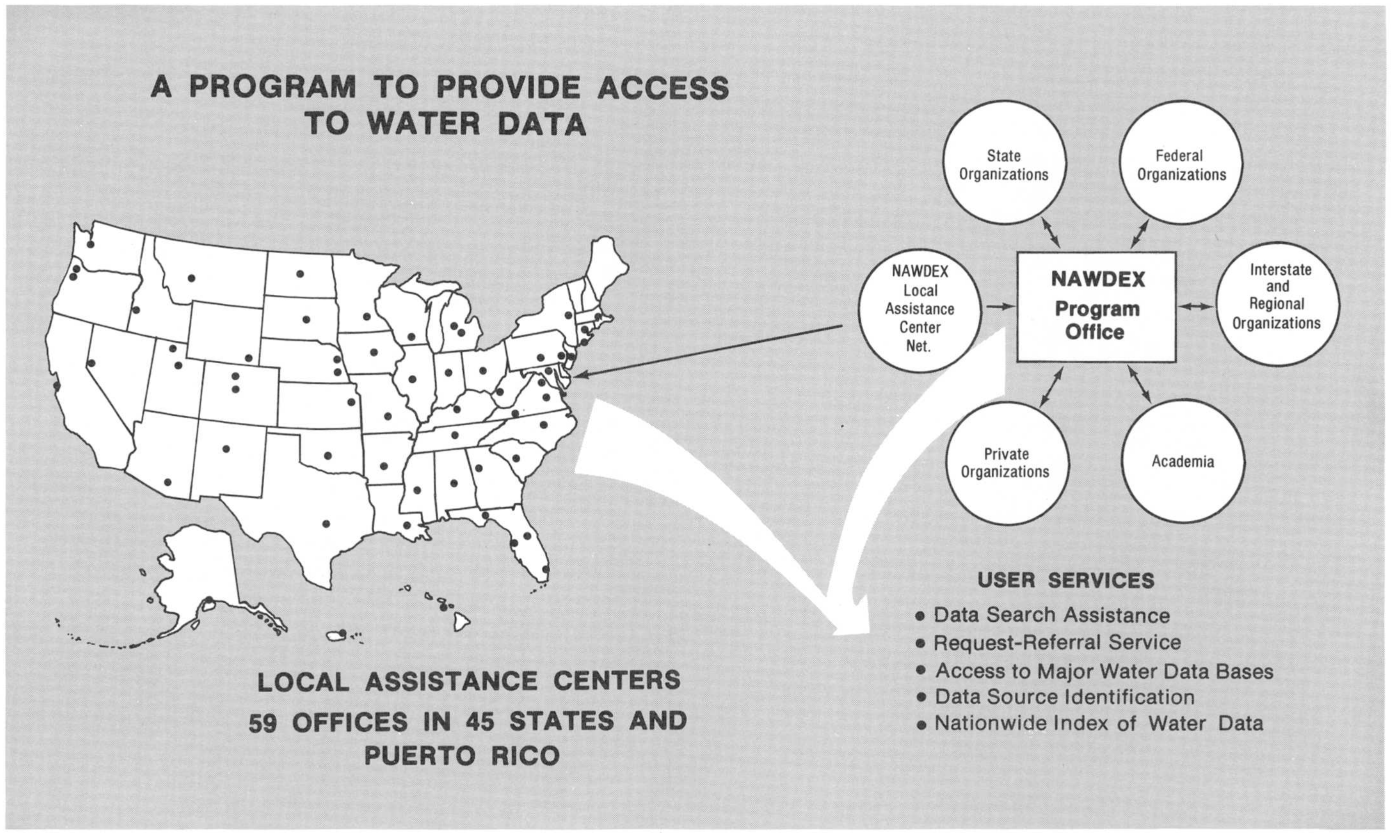


Figure 9.2-1 Access to water data.

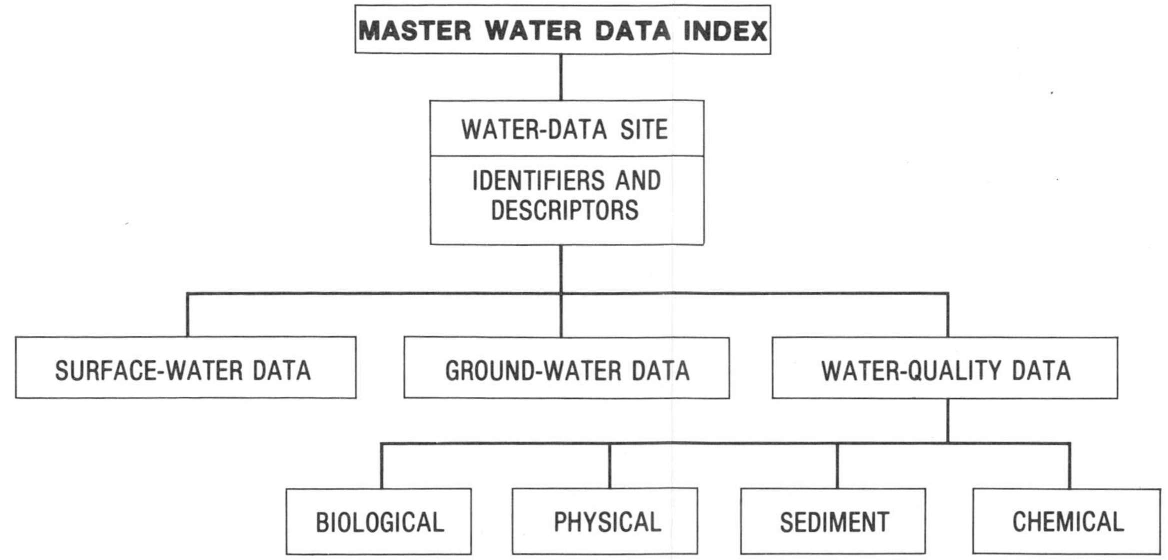


Figure 9.2-2 Master water-data index.

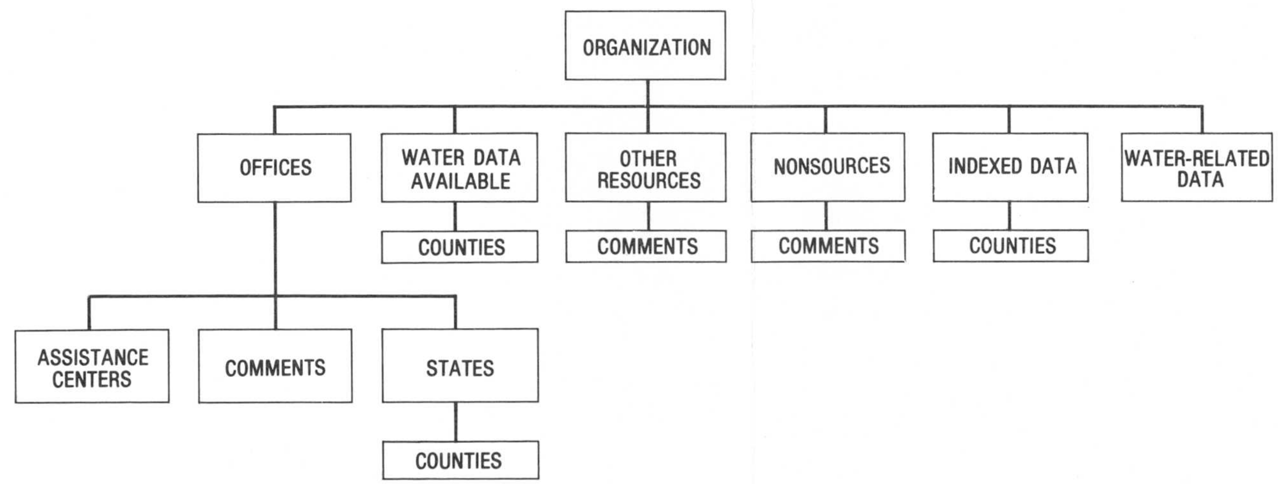


Figure 9.2-3 Water-data sources directory.

WATSTORE Automated Data System

The National Water-Data Storage and Retrieval System (WATSTORE) of the U.S. Geological Survey provides computerized procedures and techniques for processing water data and provides effective and efficient management of data-releasing activities.

WATSTORE was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Virginia. Data may be obtained from WATSTORE through the Water Resources Division's 43 district offices. General inquiries about WATSTORE may be directed to:

Chief Hydrologist
U.S. Geological Survey
437 National Center
Reston, VA 22092

U.S. Geological Survey
Water Resources Division
Room 621, 215 Dean A. McGee
Oklahoma City, OK 73102

U.S. Geological Survey
Water Resources Division
Room 2301 Federal Office Building
700 West Capitol Ave.
Little Rock, AR 72201

The Geological Survey currently (1983) collects data at approximately 17,000 stage- or discharge-gaging stations, 5,200 surface-water quality stations, 27,000 water-level observation wells, and 7,400 ground-water quality wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to allow for the inclusion of additional data daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 9.3–1). A brief description of each file is as follows.

Station Header File: Information pertinent to the identification, location, and physical description of nearly 220,000 sites are contained in this file. All sites for which data are stored in the Daily Values, Peak Flow, Water Quality, and Unit Values files of WATSTORE are indexed in this file.

Daily-Values File: All water-data parameters measured or observed either on a daily or on a continuous basis and numerically reduced to daily values are stored in this file. Instantaneous measurements at fixed-time intervals, daily mean values, and statistics such as daily maximum and minimum values also may be stored. This file currently contains more than 200 million daily values including data on streamflow, river stages, reservoir contents, water temperatures, specific conductance, sediment concentrations, sediment discharges, and ground-water levels.

Peak-Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values at surface-water sites comprise this file, which currently contains more than 400,000 peak observations.

Water-Quality File: Results of more than 1.4 million analyses of water samples are contained in this file. These analyses contain data for as many as 185 different constituents and physical properties that describe the chemical, physical, biological, and radiochemical characteristics of both surface and ground waters.

Unit-Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and temperature data are examples of the types of data stored in the Unit Values File.

Ground-Water Site-Inventory File: This file is maintained within WATSTORE independent of the files discussed above, but it is cross-referenced to the Water-

Quality File and the Daily-Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic chracteristics, well-construction history, and one-time onsite measurements such as water temperature. The file is designed to accommodate 225 data elements and currently contains data for nearly 700,000 sites.

All data files of the WATSTORE system are maintained and managed on the central computer facilities of the Geological Survey at its National Center. However, data may be entered into and retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

Remote-Job Entry Sites: Almost all Water Resources Division's district offices are equipped with high-speed computer terminals for remote access to the WATSTORE system. These terminals allow each site to enter data into or retrieve data from the system within an interval of several minutes to overnight, depending upon the priority placed on the request. The number of remote job-entry sites is increased as the need arises.

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chloride concentration. Data are recorded on 16-channel paper tape; the tape is removed from the recorder, and the data are transmitted over telephone lines to the receiver at Reston, Va. The data are re-recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for transmitting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 500 data-relay stations are being operated currently (1983) by the Water Resources Division.

Central Laboratory System: The Water Resources Division's two water-quality laboratories, in Denver, Colo., and Atlanta, Ga., analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic substances, such as chloride, to complex organic compounds, such as pesticides. As each analysis is completed, the results are verified by laboratory personnel and transmitted via a computer terminal to the central computer facilities to be stored in the Water Quality File of WATSTORE.

Water data are used in many ways by decision-makers for the management, development, and monitoring of our water resources. In addition to its data processing, storage, and retrieval capabilities, WATSTORE can provide a variety of useful products ranging from simple tables of data to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requestor.

Computer-Printed Tables: Users most often request data from WATSTORE in the form of tables printed by the computer. These tables may contain lists of actual data or condensed indexes that indicate the availability of data stored in the files. A variety of formats is available to display the many types of data.

Computer-Printed Graphs: Computer-printed graphs for the rapid analysis or display of data are another capability of WATSTORE. Computer programs are available to produce bar graphs (histograms), line graphs, frequency-distribution curves, X-Y point plots, site-location map plots, and other similar items by means of line printers.

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package called SAS (Statistical Analysis System, 1976) to provide extensive analyses of data such as regression analyses, analysis of variance, transformations, and correlations.

Digital Plotting: WATSTORE also makes use of software systems that prepare data for digital plotting on peripheral offline plotters available at the central computer site. Plots that can be obtained include hydrographs, frequency-distribution curves, X-Y point plots, contour plots, and three-dimensional plots.

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable form for use on other computers or for use as input to user-written computer programs. These data are available in the standard format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

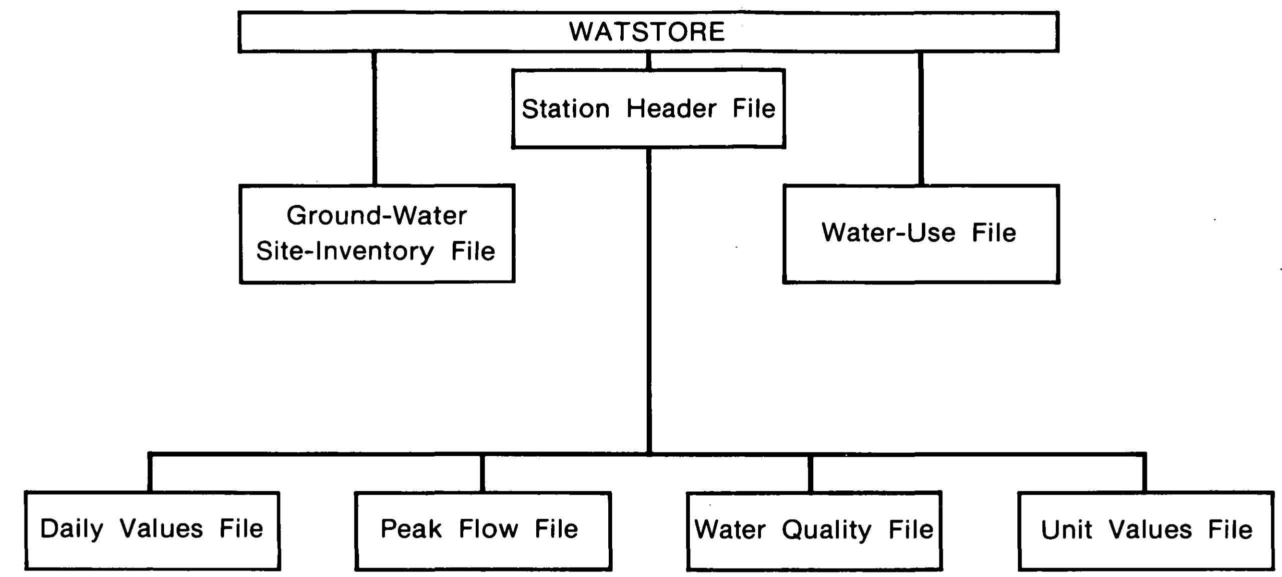


Figure 9.3-1 Index file stored data.

Water Data Indexed for Coal Provinces

A special index, "Index to Water-Data Activities in Coal Provinces of the United States," has been published by the U.S. Geological Survey's Office of Water Data Coordination (OWDC).

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information on the availability of water-resources data in the major coal provinces of the United States. It is derived from the "Catalog of Information on Water Data," which is a computerized information file about water-data acquisition activities in the United States, and its territories and possessions, with some international activities included.

This special index consists of five volumes (fig. 9.4-1): Volume 1, Eastern Coal Province; Volume II, Interior Coal Province; Volume III, Northern Great Plains and Rocky Mountain Coal Provinces; Volume IV, Gulf Coast Coal Province; and Volume V, Pacific Coast and Alaska Coal Provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A–C includes: (1) The identifiecation and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are listed in a table.

Those who need additional information from the Catalog file or who need assistance in obtaining water data can contact the National Water-Data Exchange (NAWDEX) (See section 9.2).

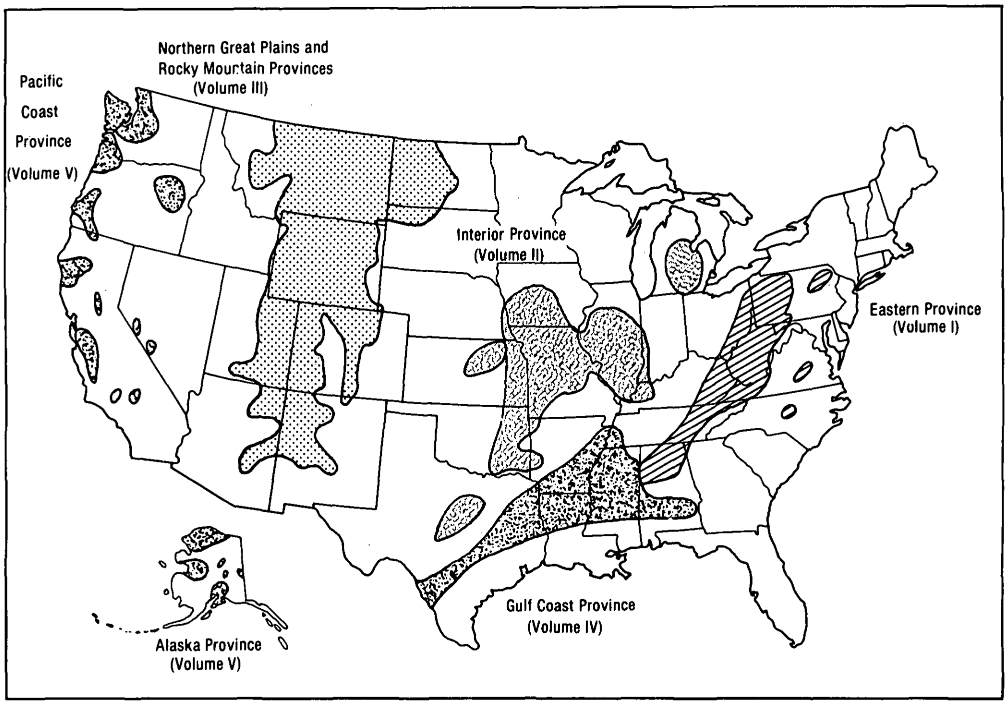


Figure 9.4-1 Index volumes and related provinces.

STORET is U.S. Environmental Protection Agency Computerized Water-Data System

STORET is the computerized water-data system that is maintained by the U.S. Environmental Protection Agency; the system is used to store many kinds of water-quality data.

STORET is a computerized water-data system maintained by the U.S. Environmental Protection Agency for the STOrage and RETreival of data relating to the quality of water in waterways within and contiguous to the United States. The system is used to store data on water quality, water-quality standards, point sources of pollution, pollution-caused fish kills, waste-abatement needs, implementation schedules, and other water-quality related information. The Water Quality File is the most widely used file in the STORET data base.

The data in the Water Quality File is collected through cooperative programs involving the Environmental Protection Agency, State water pollution control authorities, and other governmental agencies. The U.S. Forest Service, the U.S. Army Corps of Engineers, the U.S. Bureau of Reclamation, and the Tennessee Valley Authority all use STORET's Water Quality File to store and retrieve data collected through their water-quality monitoring programs. Data from the U.S. Geological Survey's water-quality file in WATSTORE are automatically copied into STORET on a periodic basis.

There are 1,800 water-quality parameters defined within STORET's Water Quality File. In 1976 data from more than 200,000 unique collection points in the United States were stored in the system. The groups of parameters and number of observations that are in the Water Quality File are shown in figure 9.5–1.

State, Federal, interstate, and local government agencies can become STORET users. Information on becoming a user of the system can be obtained by contacting the Environmental Protection Agency. The contact for Region VI is:

Director
Surveillance and Analysis Division
Environmental Protection Agency
1201 Elm Street
Dallas, TX 75270

Source: Handbook, Water Quality Control Information System (STORET), U.S. Environmental Protection Agency, Office of Water and Hazardous Materials, Washington, D.C. 20460.

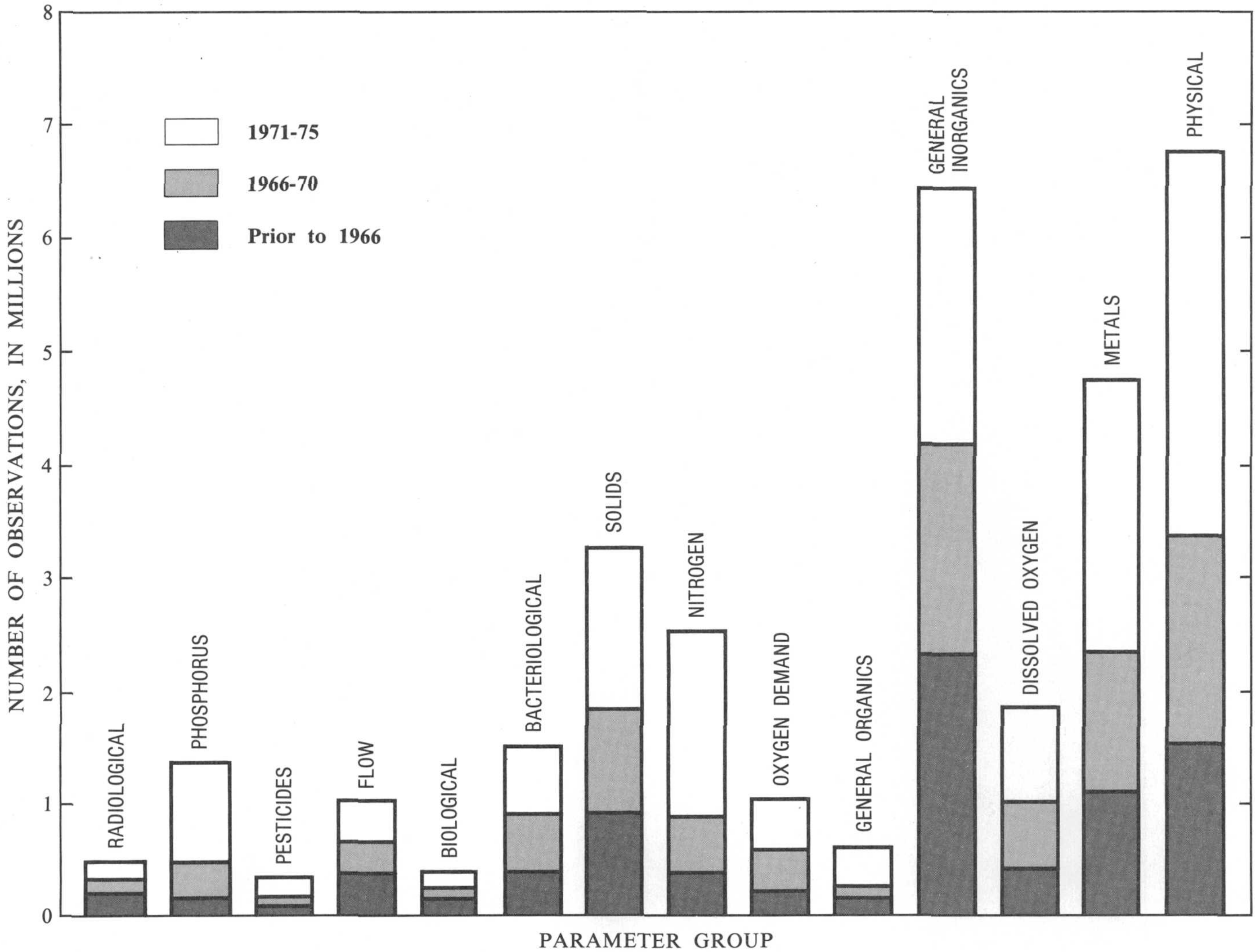


Figure 9.5-1 Parameter groups and number of observations in the Water Quality File.

Report station number	U.S. Geological Survey station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
1	07164400	Arkansas River at Sand Springs bridge near Tulsa, OK	36°07'22"	96°07'23"	74,350	Water quality	1946-53, 1975-77
						Sediment	1946-53, 1975-77
2	07164500	Arkansas River at Tulsa, OK	36°08'37"	96°00'13"	74,615	Daily streamflow	1925-83
						Water quality	1960-61, 1977-83
						Sediment	1931, 1939-83
3	07164940	Deep Creek near Olive, OK			3.25	Peak stage	1967-72
4	07165000	Heyburn Lake near Heyburn, OK	35°56'51"	96°17'55"	123	Reservoir	1950-83
						Water quality	1961
5	07165500	Polecat Creek below Heyburn reservoir near Heyburn, OK	35°56'42"	96°17'39"	123	Daily streamflow	1943-79
						Sediment	1943-51, 1953-78, 1980
6	07165510	Polecat Creek near Jenks, OK	36°00'58"	96°00'42"	-----	Water quality	1960-63
7	07165520	Arkansas River at Bixby, OK	35°57'26"	95°53'10"	-----	Water quality	1949
8	07165550	Snake Creek near Bixby, OK	35°49'08"	95°53'18"	50.0	Peak stage	1951-70, 1970-76
9	07165570	Ark. River near Haskell, OK	35°49'23"	95°38'39"	75,473	Daily streamflow	1972-83
						Water quality	1974-79
						Sediment	1972-78, 1980-81
10	07165600	Ark. River near Tullahassee, OK	35°48'15"	95°24'10"	75,815	Daily streamflow	1971-72
						Sediment	1969-72
11	07165610	Arkansas River at Muskogee,OK	35°47'50"	95°20'00"	-----	Water quality	1957, 1962, 1963
12	07194500	Arkansas River near Muskogee, OK	35°46'10"	95°17'55"	96,674	Daily streamflow	1926-70
						Water quality	1957, 1963, 1973-79
						Sediment	1943-71
13	07198500	Dirty Creek near Warner, OK	35°33'18"	95°18'28"	227	Daily streamflow	1940-46
						Water quality	1960-61
						Sediment	1940-46
14	07231500	Canadian River near Calvin, OK	34°58'32"	96°14'24"	27,952	Daily streamflow	1905-08, 1939-42, 1944-83
						Water quality	1950-53, 1960-61, 1965-77
						Sediment	1975-83
15	07231560	Middle Creek near Carson, OK	35°11'10"	96°04'20"	7.40	Peak stage	1964-74
16	07231950	Pine Creek near Higgins, OK	34°47'40"	95°50'20"	9.99	Peak stage	1964-82
17	07231965	Ti Creek near Blanco, OK	34°55'44"	95°44'59"	4.82	Daily streamflow	1980-82
						Water quality	1980-82
						Sediment	1980-82

Report station number	U.S. Geological Survey station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
18	07231975	Brushy Creek near Haileyville, OK	34°48'05"	95°39'16"	139	Daily streamflow Water quality Sediment	1979-82 1978-82 1978-82
19	07231990	Peaceable Creek near Hailyville, OK	34°51'07"	95°39'15"	134	Daily streamflow Water quality Sediment	1978-82 1978-82 1978-82
20	07232000	Gaines Creek near Krebs, OK	34°59'00"	95°37'00"	588	Daily streamflow Water quality Sediment	1943-63 1946-47, 1950-51, 1960-62 1944-46, 1949-55
21	07232008	Blue Creek tributary near Blocker, OK	34°02'25"	95°34'15"	4.60	Periodic stream- flow Water quality Sediment	 1979-82 1979-82 1979-82
22	07232010	Blue Creek near Blocker, OK	34°02'26"	95°34'21"	12.1	Daily streamflow Water quality Sediment	1976-82 1976-82 1976-82
23	07232029	Mathuldy Creek near Crowder, OK	33°04'17"	95°36'47"	5.41	Periodic stream- flow Water quality Sediment	 1976-81 1976-81 1976-81
24	07242000	North Canadian River near Wetumka, OK	35°15'53"	96°12'25"	14,290	Daily streamflow Water quality Sediment	1938-83 1952, 1954-83 1977-83
25	07243500	Deep Fork near Beggs, OK	35°40'31"	96°03'55"	2,018	Daily streamflow Water quality Sediment	1938-83 1952-83 1939-50, 1953, 1955-56, 1968, 1978-83
26	07243550	Adams Creek near Beggs, OK	35°44'55"	96°02'15"	5.90	Peak stage	1965-81
27	07244000	Deep Fork near Dewar, OK	35°28'43"	95°52'57"	2,307	Daily streamflow Water quality Sediment	1937-50 1949-51 1937-50, 1961-65
28	07244550	Deep Fork near Pierce, OK	35°23'35"	95°35'07"	-----	Water quality	1949-51
29	07244500	North Canadian River near Eufaula, OK	35°19'00"	95°34'20"	17,657	Daily streamflow Water quality	1960-62 1952-53, 1960, 1961
30	07244800	Eufaula Lake near Brooken, OK	35°18'25"	95°21'45"	47,522	Reservoir Water quality	1964-83 1965-67
31	07245000	Canadian River near Whitefield, OK	35°15'45"	95°14'19"	47,576	Daily streamflow Water quality Sediment	1938-83 1944-64, 1967-83 1938-83
32	07245020	Taloka Creek at Stigler, OK	35°16'09"	95°05'49"	3.98	Periodic stream- flow Water quality Sediment	 1978-83 1978-83 1978-81
33	07245030	Taloka Creek near Stigler, OK	35°17'46"	95°07'56"	20.1	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81
34	07245025	Taloka Creek tributary near Stigler, OK	35°16'09"	95°05'49"	-----	Periodic stream- flow Water quality Sediment	 1978-81 1978-81 1978-81
35	07245040	Jackson Creek near Stigler, OK	35°20'22"	95°07'52"	-----	Periodic stream- flow	 1979-81
36	07245090	Vian Creek near Vian, OK	35°32'30"	94°48'05"	19.6	Peak stage Water quality	1966-72 1958-59
37	07245119	Little Vian Creek near Vian, OK	35°29'30"	94°57'10"	-----	Water quality	1960
38	07245500	Sallisaw Creek near Sallisaw, OK	35°27'52"	94°51'43"	182	Daily streamflow Water quality	1942-76 1952-63, 1977
39	07245703	Sans Bois Creek near Kinta, OK	35°06'00"	95°12'40"	-----	Water quality	1961
40	07246000	San Bois Creek near Keota, OK	35°15'37"	94°57'56"	346	Daily streamflow Water quality Sediment	1938-42 1958-63 1938-42
41	07246400	Robert S. Kerr Lock and Dam (Arkansas River) near Sallisaw, OK	35°20'57"	94°46'43"	147,756	Water quality	1970-83

10.1 Surface-Water Quantity and Quality Stations

Report station number	U.S. Geological Survey station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
42	07246500	Arkansas River near Sallisaw, OK	35°20'58"	94°48'16"	147,757	Daily streamflow	1947-70
						Water quality	1957, 1959-63
						Sediment	1943-72
43	07246600	Cache Creek near Cowlington, OK	35°17'10"	94°45'35"	20.6	Peak stage	1964-72
						Water quality	1959-61
44	07246610	Pecan Creek near Spiro, OK	35°14'40"	94°44'35"	0.90	Peak stage	1964-76
45	07246615	Coal Creek near Spiro, OK	35°15'11"	94°45'17"	18.1	Daily streamflow	1978-81
						Water quality	1978-81
						Sediment	1979-81
46	07246630	Big Black Fox Creek near Long, OK	35°31'15"	94°37'10"	5.32	Peak stage	1964-79
47	07247000	Poteau River near Cauthron, AR	34°55'08"	94°17'55"	203	Daily streamflow	1939-83
						Water quality	1973-75
						Sediment	1939-50, 1964, 1968
48	07247350	Poteau River near Heavener, OK	34°51'29"	94°37'42"	-----	Water quality	1976-79
49	07247450	Fourche Maline near Wilburton, OK	34°55'25"	94°15'10"	56.2	Daily streamflow	1978-81
						Water quality	1978-81
						Sediment	1979-81
50	07247500	Fourche Maline near Red Oak, OK	34°54'44"	95°09'20"	122	Daily streamflow	1938-83
						Water quality	1952, 1954, 1956-60, 1963, 1978-79
						Sediment	1940-42, 1944-45 1947-48, 1951
51	07247550	Red Oak Creek near Red Oak, OK	34°56'23"	95°01'58"	12.8	Daily streamflow	1978-81
						Water quality	1978-81
						Sediment	1978-81
52	07248000	Wister Lake near Wister, OK	34°56'10"	94°43'10"	993	Reservoir	1949-83
						Water quality	1960-64
53	07248500	Poteau River near Wister, OK	34°56'15"	94°42'54"	933	Daily streamflow	1938-83
						Water quality	1938, 1952, 1955-59, 1973-79
						Sediment	1938-50

Report station number	U.S. Geological Survey station number	Station name	Location		Drainage area (square miles)	Type of record	Period of record
			Latitude	Longitude			
54	07248500	Caston Creek at Wister, OK	34°57'27"	94°44'18"	72.9	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81
55	07248620	Morris Creek at Howe, OK	34°57'34"	94°37'45"	19.4	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81
56	07248700	Sugarloaf Creek near Monroe, OK	35°00'00'	94°31'21"	53.6	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81
57	07249000	Poteau River near Poteau, OK	35°03'35"	94°36'10"	1,240	Daily streamflow Water quality	1938-45 1944-45
58	07249060	Brazil Creek near Red Oak, OK	34°59'03"	95°07'06"	2.74	Periodic stream- flow Water quality Sediment	 1978-81 1978-81 1978-81
59	07249070	Rock Creek near Red Oak, OK	34°59'30"	95°04'56"	12.0	Periodic stream- flow Water quality Sediment	 1978-81 1978-81 1978-81
60	07249073	Brazil Creek near Lodi, OK	34°59'28"	95°00'24"	-----	Periodic stream- flow Water quality Sediment	 1980-81 1980-81 1980-81
61	07249080	Brazil Creek near Walls, OK	35°01'21"	94°56'39"	69.1	Periodic stream- flow Water quality Sediment	 1978-81 1978-81 1978-81
62	07249100	Owl Creek near McCurtain, OK	34°07'40"	94°53'03"	27.9	Periodic stream- flow Water quality Sediment	 1978-81 1978-81 1978-81
63	07249300	James Fork near Midland, AR	35°04'27"	94°20'20"	44.0	Peak stage	1963-83
64	07249400	James Fork near Hackett, AR	35°09'45"	94°24'25"	147	Daily streamflow Water quality Sediment	1958-83 1960-61, 1969-81 1977-81
65	07249410	James Fork near Williams, OK	35°09'30"	94°36'01"	198	Periodic stream- flow Water quality Sediment	 1976-81 1976-81 1976-81
66	07249415	Coal Creek tributary near Bokoshe, OK	35°11'30"	94°43'19"	1.26	Periodic stream- flow Water quality Sediment	 1976-79 1976-79 1976-79
67	07249419	Coal Creek near Panama, OK	35°11'08"	94°40'23"	6.67	Periodic stream- flow Water quality Sediment	 1976-79 1976-79 1976-79
68	07249438	Poteau River near Braden, OK	35°15'20"	94°30'00"	-----	Water quality	1958-59, 1962-63
69	07249422	Holi-Tuska Creek near Panama, OK	35°12'46"	94°40'21"	4.39	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81
70	07249440	Poteau River near Fort Smith, AR	35°20'43"	94°27'09"	-----	Water quality	1975-79
71	07249450	Mill Creek at Fort Smith, AR	35°26'34"	94°05'41"	10.4	Peak stage	1952, 1960-63
72	07249500	Cove Creek near Lee Creek, AR	35°43'20"	94°24'28"	35.3	Daily streamflow Peak stage	1951-70 1971-80
73	07249800	Lee Creek near Short, OK	35°33'45"	94°32'00"	-----	Water quality	1958-61, 1976-77
74	07249900	Little Lee Creek near Short, OK	35°34'41"	94°33'20"	-----	Water quality	1978-79
75	07250000	Lee Creek near Van Buren, AR	35°29'40"	94°26'58"	426	Daily streamflow	1931-37, 1951-83
76	07250500	Arkansas River at Van Buren, AR	35°25'42"	94°21'37"	150,482	Water quality	1945-70, 1974-83
77	07250550	Arkansas River at Dam 13 near Van Buren, AR	35°20'56"	94°17'54"	150,547	Daily streamflow Water quality	1928-83 1928-83
78	07258200	Pack Saddle Creek tributary near Waldron, AR	34°58'18"	94°05'42"	0.92	Peak stage	1961-80
79	07332700	Muddy Boggy Creek near Parker, OK	34°44'28"	96°15'51"	174	Periodic low flow	1958-73
80	07332750	Muddy Boggy Creek near Coalgate, OK	34°32'00"	96°12'00"	-----	Water quality	1962
81	07332800	Caney Boggy Creek near Ashaland, OK	34°45'11"	96°08'52"	49.0	Water quality	1972-75
82	07332900	Coal Creek near Lehigh, OK	34°27'06"	96°13'56"	8.5	Daily streamflow Water quality Sediment	1978-81 1978-81 1978-81

Report station number	U.S. Geological Survey station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
83	07332950	Muddy Boggy Creek at Atoka, OK	34°23'23"	96°07'12"	445	Daily streamflow Water quality Sediment	1978-83 1978-81 1978-81
84	07333000	North Boggy Creek near Stringtown, OK	34°31'08"	96°03'38"	136	Daily streamflow Water quality	1956-59 1956-59
85	07333330	Chickasaw Creek tributary near Stringtown, OK	34°29'34"	95°56'39"	3.19	Peak stage	1965-72
86	07333500	Chickasaw Creek near Stringtown, OK	34°27'41"	96°01'36"	32.7	Peak stage	1955-68, 1969-75
87	07333800	McGee Creek near Stringtown, OK	34°26'33"	95°52'10"	86.6	Peak stage Water quality	1956-68, 1969-75 1956-58
88	07333910	McGee Creek near Farris, OK	34°18'54"	95°52'30"	176	Daily streamflow Water quality Sediment	1978-83 1976-83 1978-81
89	07334000	Muddy Boggy Creek near Farris, OK	34°16'17"	95°54'43"	1,087	Daily streamflow Water quality Sediment	1938-83 1976 1938-77
90	07334200	Byrds Mill Spring near Fittstown, OK	34°35'45"	96°39'55"	6.86	Daily streamflow Water quality	1959-83 1953, 1955-56
91	07334400	Clear Boggy Creek near Tupelo, OK	34°32'45"	96°24'30"	248	Periodic low flow Water quality	1958-73 1958, 1960, 1962
92	07334420	Leader Creek near Tupelo, OK	34°35'55"	96°23'45"	64.3	Periodic low flow Water quality	1958-73 1958, 1960
93	07334440	Delaware Creek near Wapanucka, OK	34°24'20"	96°25'15"	45.8	Daily streamflow Water quality	1958-73 1958, 1960
94	07334500	Clear Boggy Creek near Wapanucka, OK	34°22'00"	96°19'00"	516	Daily streamflow Sediment	1940-43 1940-42
95	07334800	Clear Boggy Creek above Caney Creek near Caney, OK	34°15'18"	96°12'45"	-----	Water quality	1975-78
96	07335000	Clear Boggy Creek near Caney, OK	34°15'09"	96°12'19"	720	Daily streamflow Water quality Sediment	1943-83 1975-79 1943-77

10.2 SUPPLEMENTARY INFORMATION FOR AREA 41--Continued

10.2 Water-Level Observation Wells

Report well number	Site identification number	Local well number	County	Well depth (feet)	Aquifer	Period of record	Frequency of measurement
1	341508096150201	03S-10E-33 ADD 1	Atoka	78	Antlers Formation	1979-80	Periodic
2	341938096090001	03S-11E-04 ACA 1	Atoka	73	Antlers Formation	1976-83	Periodic
3	342619096144201	01S-10E-27 BAB 1	Coal	32	Krebs Group	1978-83	Recorder
4	343634096204901	02N-09E-27 CDD 1	Coal	23	Krebs Group	1981-83	Periodic
5	344929096053501	04N-11E-13 AAA 1	Hughes	--	Krebs Group	1976-83	Periodic
6	345128095441501	05N-15E-32 DDA 1	Pittsburg	110	Krebs Group	1976-83	Periodic
7	345509095184901	05N-19E-09 CBB 1	Latimer	--	Krebs Group	1976-83	Periodic
8	350241095341101	07N-16E-25 CDC 1	Pittsburg	148	Krebs Group	1980-83	Recorder
9	351206095504201	08N-14E-05 AAB 1	McIntosh	14	Terrace deposits	1977-83	Periodic
10	351142096145301	08N-10E-04 DAA 1	Hughes	21	Marmaton Group	1982-83	Periodic
11	352016096061901	10N-11E-14 DAD 1	Okfuskee	19	Marmaton Group	1982-83	Periodic
12	351817096020301	10N-12E-24 CCC 1	Okfuskee	16	Terrace deposits	1982-83	Recorder
13	352420095472601	11N-14E-26 ABB 1	McIntosh	32	Cabaniss Group	1982-83	Periodic
14	352512095285701	11N-17E-23 BBB 1	McIntosh	115	Krebs Group	1980-83	Periodic
15	354302096102101	14N-11E-06 DAA 1	Okmulgee	36	Seminole Group	1976-83	Periodic
16	355828095531501	17N-13E-02 DDC 1	Tulsa	25	Alluvium	1980-83	Periodic
17	354613095161001	15N-19E-15 DDD 1	Muskogee	29	Alluvium	1974-83	Periodic
18	353025095082701	12N-20E-24 BAA 1	Muskogee	15	Alluvium	1960-80	Periodic
19	353117095065201	12N-21E-18 AAA 1	Sequoyah	15	Alluvium	1977-83	Periodic
20	351833095155401	11N-19E-35 BBB 1	Muskogee	25	Krebs Group	1981-83	Recorder
21	352143095131301	10N-20E-07 AAA 1	Muskogee	30	Alluvium	1981-83	Periodic
22	352006095080101	10N-20E-13 DDD 1	Haskell	148	Krebs Group	1980-83	Recorder
23	350700095142801	08N-20E-31 CCD 1	Haskell	75	Krebs Group	1983	Periodic
24	352419094270501	11N-27E-21 CDD 1	Sequoyah	48	Alluvium	1960-83	Recorder
25	351002094314401	08N-26E-14 ACC 1	Le Flore	276	Krebs Group	1980-83	Recorder
26	351122094403901	08N-25E-04 CDC 1	Le Flore	135	Krebs Group	1980-83	Recorder
27	350938094591201	08N-22E-16 DCD 1	Haskell	112	Krebs Group	1981-83	Recorder
28	345908095013001	06N-22E-18 DCC 1	Latimer	137	Krebs Group	1980-83	Recorder
29	345021094320801	04N-26E-11 BBD 1	Le Flore	215	Pennsylvanian	1980-83	Periodic

10.2 SUPPLEMENTARY INFORMATION FOR AREA 41--Continued

10.2 Water-Level Observation Wells

Report station number	U.S. Geological Survey station number	Station name	Location		Drainage area (square miles)	Type of record	Period of record
			Latitude	Longitude			
97	07165559	Snake Creek near Leonard, OK	35°54'53"	95°50'00"	-----	Water quality	1960-61
98	07165581	Cane Creek near Jamesville, OK	35°45'25"	95°36'45"	-----	Water quality	1960-61
99	07194512	Bayou Manard near Fort Gibson, OK	35°47'35"	95°09'00"	-----	Water quality	1961
100	07194545	Greenleaf Creek near Braggs, OK	35°36'57"	95°10'06"	-----	Water quality	1952-55
101	07194550	Arkansas River at Webbers Falls, OK	35°31'10"	95°07'30"	97,049	Water quality	1944-45, 1949, 1957-63
102	07198800	South Fork near Porum, OK	35°27'01"	95°13'00"	-----	Water quality	1980-81
103	07231980	Gaines Creek near Higgins, OK	34°48'57"	95°28'46"	-----	Water quality	1978-80
104	07232009	Blue Creek tributary near Blocker, OK	35°02'24"	95°34'19"	0.22	Water quality	1975-78
105	07232024	Deer Creek near McAlester, OK	34°56'58"	95°51'00"	38.3	Water quality	1978-80
106	07232027	Coal Creek near McAlester, OK	35°02'07"	95°42'00"	-----	Water quality	1960-61
107	07232050	Gaines Creek near Canadian, OK	35°12'10"	95°35'30"	-----	Water quality	1960-62
108	07242100	Wewoka Creek near Wetumka, OK	35°13'15"	96°13'10"	396	Water quality	1961-64
109	07242190	North Canadian River near Pierce, OK	35°25'30"	95°41'45"	17,712	Water quality	1960-63
110	07244200	Deep Fork near Pierce, OK	35°23'35"	95°35'07"	-----	Water quality	1960-63
111	07245580	Mule Creek site A at McCurtain, OK	35°09'06"	94°59'43"	3.64	Water quality	1981-82
112	07245590	Mule Creek site B at McCurtain, OK	35°09'35"	94°59'03"	6.45	Water quality	1981-83
113	07245591	East Pond outlet to Mule Creek at McCurtain, OK	35°09'38"	94°59'05"	-----	Water quality	1981-83
114	07245592	Mule Creek site C at McCurtain, OK	35°09'37"	94°59'05"	6.49	Water quality	1981-83
115	07245594	Mule Creek site D at McCurtain, OK	35°09'44"	94°59'02"	6.74	Water quality	1981-83
116	07247012	Poteau River south of Bates, AR	34°53'44"	94°23'35"	-----	Water quality	1973-80
117	07249200	Brazil Creek near Panama, OK	35°08'15"	94°40'20"	-----	Water quality	1960-61
118	07244703	Lee Creek near Natural Dam, AR	35°38'03"	94°24'18"	-----	Water quality	1973-74

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