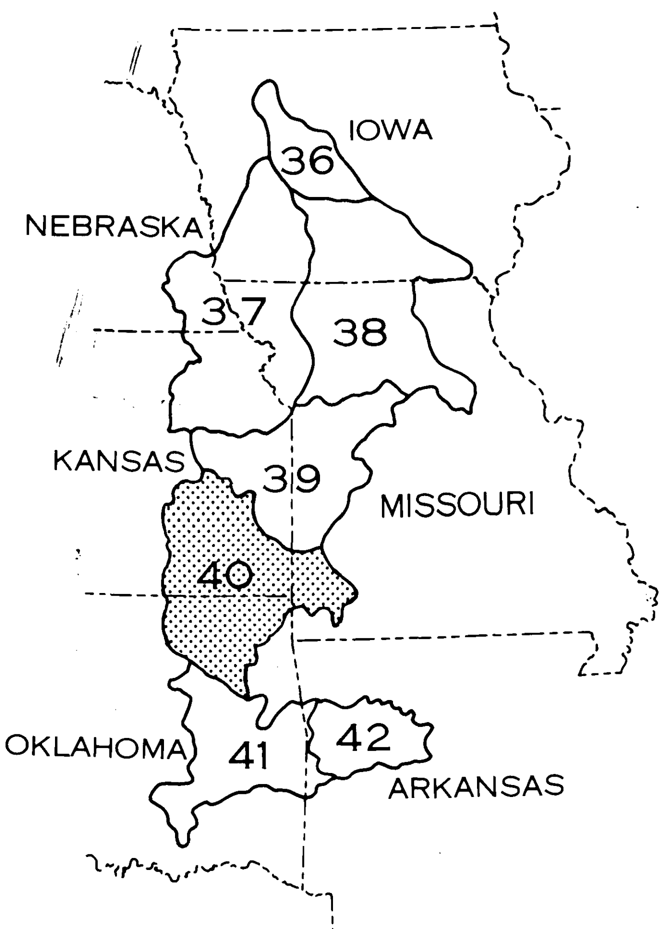
HYDROLOGY OF AREA 40, WESTERN REGION, INTERIOR COAL PROVINCE
KANSAS, OKLAHOMA AND MISSOURI



- NEOSHO RIVER
- VERDIGRIS RIVER
- CANEY RIVER
- SPRING RIVER
- BIRD CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-266

HYDROLOGY OF AREA 40, WESTERN REGION, INTERIOR COAL PROVINCE
KANSAS, OKLAHOMA AND MISSOURI

BY
M.V. MARCHER, J.F. KENNY AND OTHERS

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OPEN-FILE REPORT 83-266

OKLAHOMA CITY, OKLAHOMA
LAWRENCE, KANSAS
APRIL, 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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

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	By	To obtain
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	0.9072	metric tons (t)
tons per square mile per year [(ton/mi^2)/yr]	0.3503	metric tons per square kilometer per year [(t/km^2)/a]
gallons (gal)	3.785	liters (L)
gallons per minute per foot [(gal/min)/ft]	0.207	liters per second per meter [(L/s)/m]
British thermal units per pound (Btu/lb)	2.326	kilojoules per kilogram (kJ/kg)
micromhos per centimeter at 25° Celsius (μmhos/cm)	1	microsiemens per centimeter at 25° Celsius (μS/m)
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.

HYDROLOGY OF AREA 40, WESTERN REGION, INTERIOR COAL PROVINCE
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Abstract

For purposes of reporting hydrologic data available for 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 40 in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma. The stop-unit format consisting of a brief text accompanied by a map, graph, table, or other illustration has been used to portray the general geographic, geologic, and hydrologic environment of the area.

Area 40 encompasses about 16,300 square miles in the Arkansas River basin. Principal drainage systems within the area are the Verdigris and Neosho Rivers, which drain predominantly shale, sandstone, and limestone of Pennsylvanian age, and the Spring River, which drains mostly cherty limestone of Mississippian age. Pennsylvanian rocks in certain parts of Area 40 contain coal reserves of potential economic importance. Many of the smaller drainage basins have been affected by past and current coal mining, as well as petroleum production and zinc and lead mining. Land use and land cover are determined by the physiographic and soils characteristics of the area. In the Osage Plains where silt and clay loams predominate and relief is low, most of the land is nonirrigated cropland, managed pasture, or rangeland covered with native grasses. The steeper, stonier soils of the Springfield Plateau are covered with a greater proportion of woodlands.

Mean annual rainfall ranges from about 32 inches in the western part of the area to about 42 inches in the eastern. Because wells in most of the area yield only small quantities of water suitable for domestic and stock use, the sparse population relies principally on surface-water sources for public water supplies and industrial use. About 25 percent of the population is served by rural water systems. Lakes and reservoirs are an integral part of the surface-water drainage system in the area, minimizing floods and providing water supplies.

The U.S. Geological Survey has collected systematic data at 166 surface-water stations in Area 40, of which 72 are currently active. Available data include records of stage, discharge, and water quality of streams and records of stage and contents of lakes and reservoirs. Additional data have been collected at about 335 miscellaneous surface-water stations, many of which are in mined areas. Records from 91 stream-water-quality stations indicate great variability in pH and in concentrations of iron, manganese, and dissolved solids with the most mineralized water in areas previously disturbed by resource-recovery activities.

Water-level data are available for 438 wells in Area 40; water-quality data are available for 516 wells and springs. The greatest yields of useable ground water are obtained from wells in the unconsolidated deposits of stream valleys in Kansas and Oklahoma and from deeper rocks of the Cambrian and Ordovician Systems in the eastern part of the area.

Hydrologic data for Area 40 are stored in computer files accessible through the National Water Data Exchange (NAWDEX). Additional information is available from the references given in this report.

Area 40 Report Submitted in Response to Surface Mining Control and Reclamation Act of 1977

Existing hydrologic conditions and identification of sources of hydrologic information are presented for Area 40 of the Western Region, Interior Coal Province, in Kansas, Missouri, and Oklahoma.

A need for hydrologic information and analysis on a scale never before required nationally was initiated when the "Surface Mining Control and Reclamation Act of 1977" was signed into law as Public Law 95-87, August 3, 1977. In recognizing the potentially adverse impact that coal mining may have on water resources, Public Law 95-87 requires that: (1) Each mining-permit applicant make an analysis of the potential effects of the proposed mine on the hydrology of the mine site and adjacent area, (2) "an appropriate Federal or State agency" provide to each mining-permit applicant "hydrologic information on the general area prior to mining," and (3) measures be taken by mining permittees to control adverse effects of mining and reclamation on the "hydrologic balance."

The U.S. Geological Survey is helping to provide hydrologic data required by Public Law 95-87 through a series of reports covering the coal provinces nationwide. The Western Region of the Interior Coal Province is divided into seven hydrologic reporting areas, based on drainage boundaries, location, size, and mining activity (figure 1.1-1). This report broadly characterizes the hydrology of Area 40 in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma.

The report format consists of a brief text with an accompanying map, chart, graph, or other illustration for each of a number of water-resources related topics. These topics include general geographic, geologic, and hydrologic descriptions, information on available water data, and discussion of specific hydrologic problems in the area. The summation of the topical discussions provides a description of the hydrology of the entire area, which encompasses both coal-producing and non-coal-producing regions.

This information should be useful to surface-mine owners and operators and consulting engineers in the analysis of proposed mine sites and adjacent areas, and to regulatory authorities in appraising the adequacy of permit applications. The hydrologic information included in this report will be supplemented by the lease applicant's site-specific data as well as data from other sources to provide a more detailed description of the hydrology in the vicinity of the mine and to describe the anticipated consequences of the mining operation.

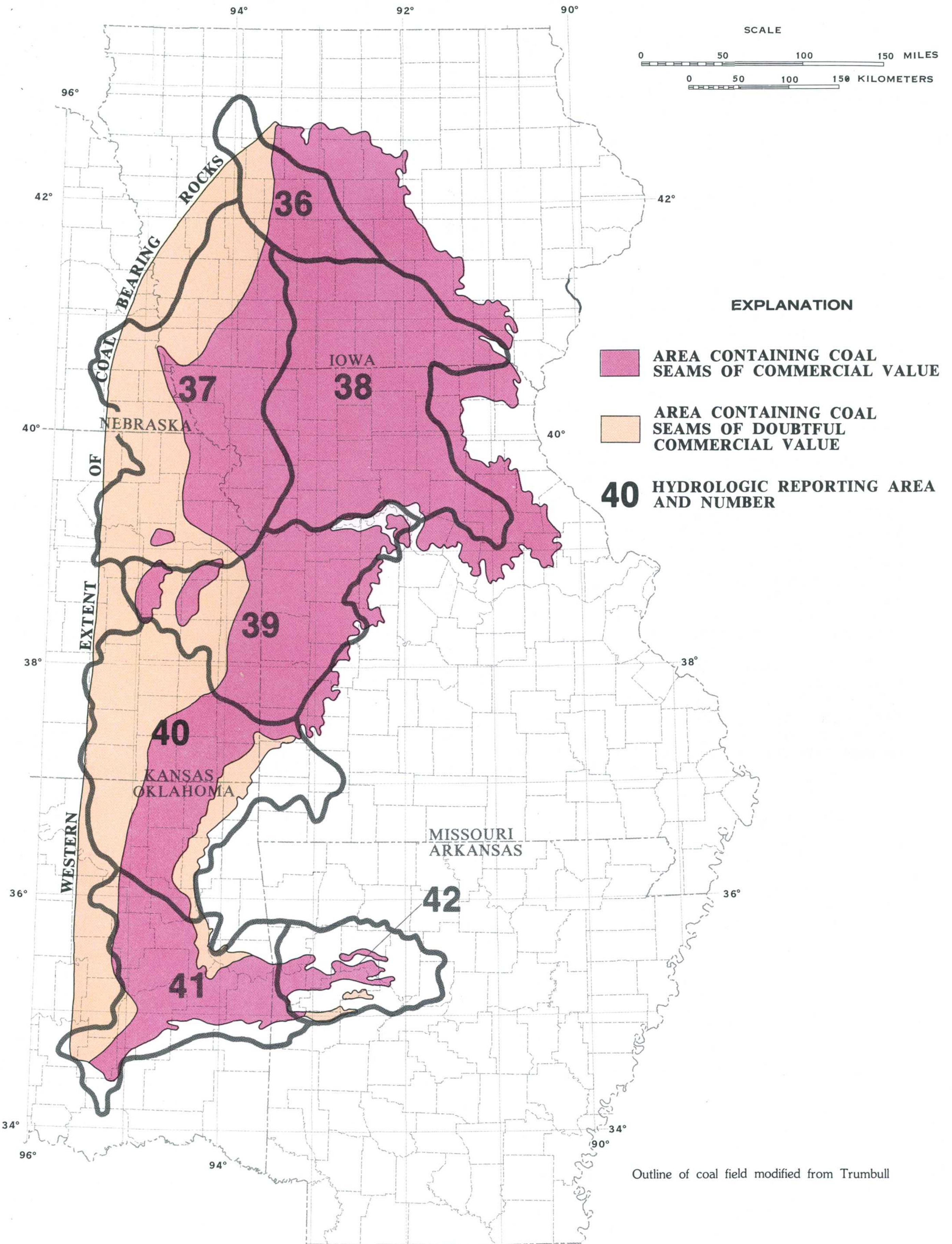


Figure 1.1-1 Hydrologic reporting areas within Western Region, Interior Coal Province.

Area 40 Encompasses About 16,300 Square Miles in Three States

All or parts of 36 counties and 3 major river basins are included in the report area.

Area 40 is one of the largest hydrologic reporting units within the Western Region, Interior Coal Province. It encompasses approximately 16,300 square miles in the Arkansas River basin, an area that includes all or parts of 18 counties in southeast Kansas, 7 counties in southwest Missouri, and 11 counties in northeast Oklahoma (figure 1.2-1).

Surface drainage in the area comprises three major river basins. The entire Verdigris River drains the western one-half of the area, which is underlain by shale, limestone, and sandstone of Pennsylvanian age. The Verdigris River flows into the Arkansas River in Muskogee County, Oklahoma, at the southern tip of the area. The eastern one-half is drained by the Neosho River and its major tributary, the Spring River. That part of the Neosho River basin in Area 40 (excluding the Spring River basin) is composed mainly of rocks of Pennsylvanian age in Kansas and Oklahoma. The Neosho River also flows into the Arkansas River at the southern tip of the area. The Spring River drains rocks of both Mississippian and Pennsylvanian age, most of which are in Missouri.

Pennsylvanian rocks in some parts of the area contain coal seams of economic importance. Many of the small drainage basins in the area are affected by past and current coal mining.

The population of the area is approximately 550,000. The area is predominately rural, with most of the land in farms and pasture. Few urban centers have populations greater than 10,000; major cities are Pittsburg, Kansas; Joplin, Missouri; and Tulsa, Oklahoma.

Figure 1.2-1 Location of report area.

Approximately 430 Million Tons of Coal Have Been Mined by Underground and Surface Methods in Area 40

Coal-mining operations have resulted in about 75,000 acres of unreclaimed land, most of which are not affected by reclamation laws.

Coal has been mined in parts of Area 40 for more than a century. Techniques for recovering this mineral resource have included underground mining through shafts, drifts, and slopes; and surface mining. Early production of coal was almost entirely from underground mines; however, since the 1940's strip mining has accounted for more than one-half of all production and in recent years has comprised virtually all of the coal production in the area.

The greatest quantities of coal have been produced from coal seams of the Cherokee Group (or Shale) in Cherokee and Crawford Counties, Kansas, and Barton County, Missouri, although some coal has been mined previously in nearly every county in Area 40. Past coal production by counties is indicated in figure 1.3.1-1. Estimates are for years through 1972 for counties in Kansas (Brady and Dutcher, 1974), 1970 for counties in Missouri (Robertson, 1971), and 1973 for counties in Oklahoma (Friedman, 1974).

Historical trends in coal production by State are illustrated in figure 1.3.1-2. Peak production in all three States occurred just prior to 1920. Coal production followed a general declining trend since that peak, with the exception of an increase during World War II, and a lesser increase since the mid-1960's. At that time, interest in coal mining was renewed due to the increased demand for fossil fuels and the development of more efficient equipment for strip mining the remaining thin coal seams.

However, added expense in coal mining after 1968 was incurred with the passage of State laws requiring reclamation of surface-mined lands. Within the following decade these State laws were strengthened, and the more comprehensive Federal Surface Mining Control and Reclamation Act of 1977 was enacted. The effects of this legislation have been both to initiate protection of land and water resources and to limit the quantity of coal that can be strip mined economically.

Although lands disturbed by recent, current, and projected strip mining are subject to the requirements of reclamation laws, much land in Area 40 remains disturbed due to pre-law mining, association with or proximity to mining operations, and surface effects of underground mining. The acreages of unreclaimed land resulting from coal mining in 12 counties in Area 40 are indicated in figure 1.3.1-3. No acreages were reported for six counties in Kansas where the small size, limited extent, or age of the coal mines has resulted in negligible acreages of of land needing reclamation. Of a total of about 75,000 acres of disturbed land in the counties for which acreages were reported, reclamation is required by law on only about 5,100 acres, or 7 percent.

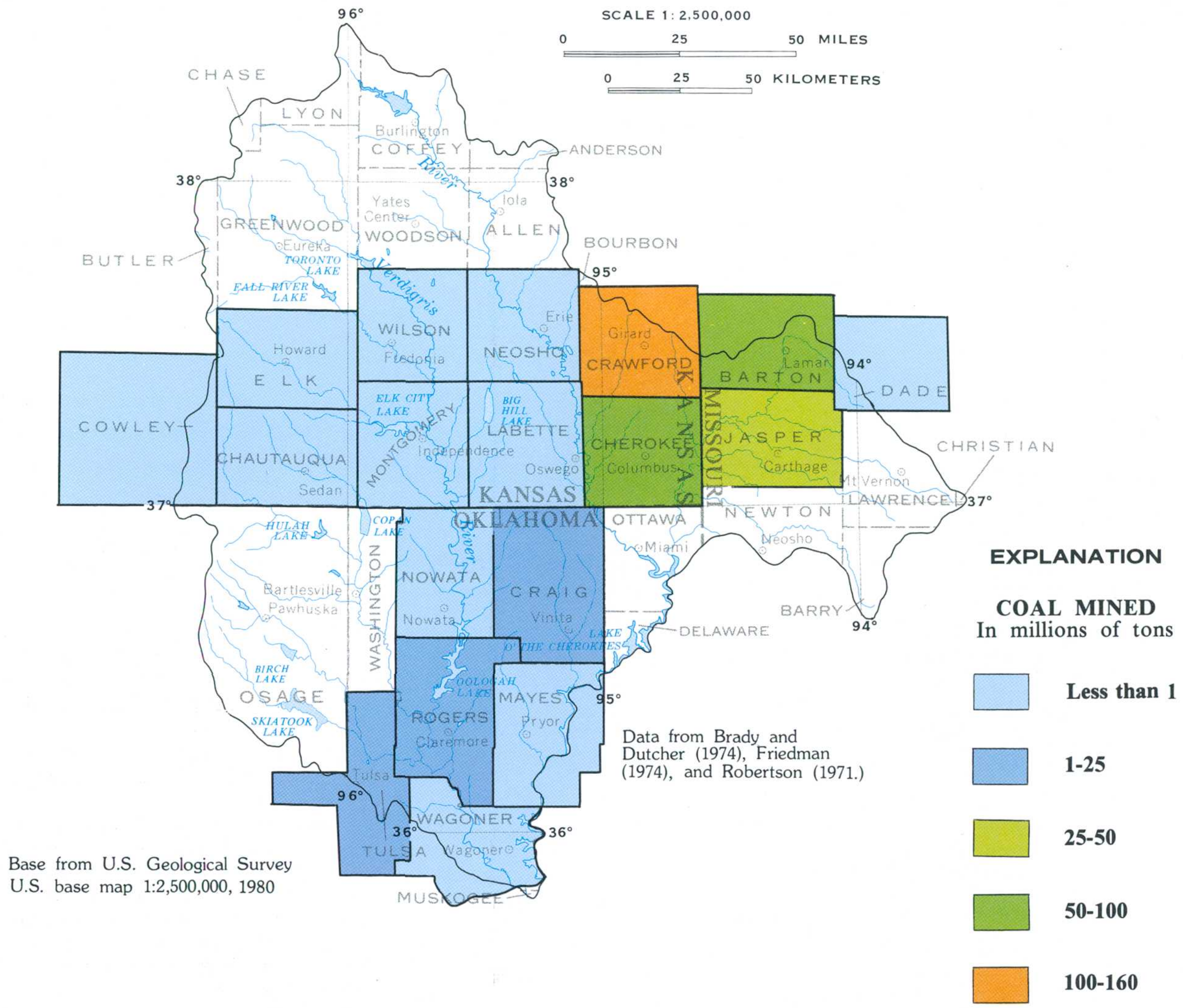


Figure 1.3.1-1 Previous coal mining in Area 40 counties.

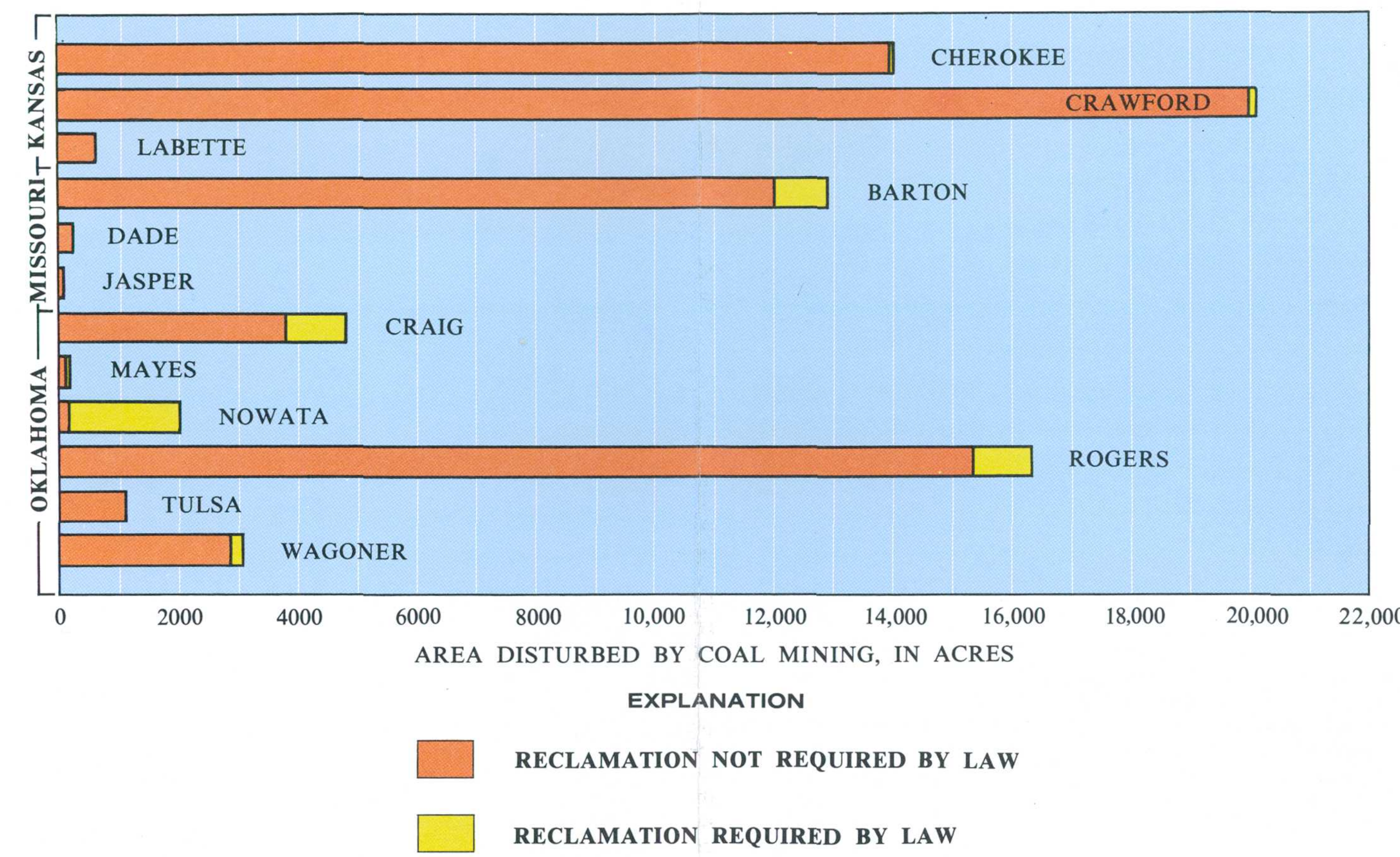


Figure 1.3.1-3 Acreages of unreclaimed land due to coal mining in Area 40 counties.

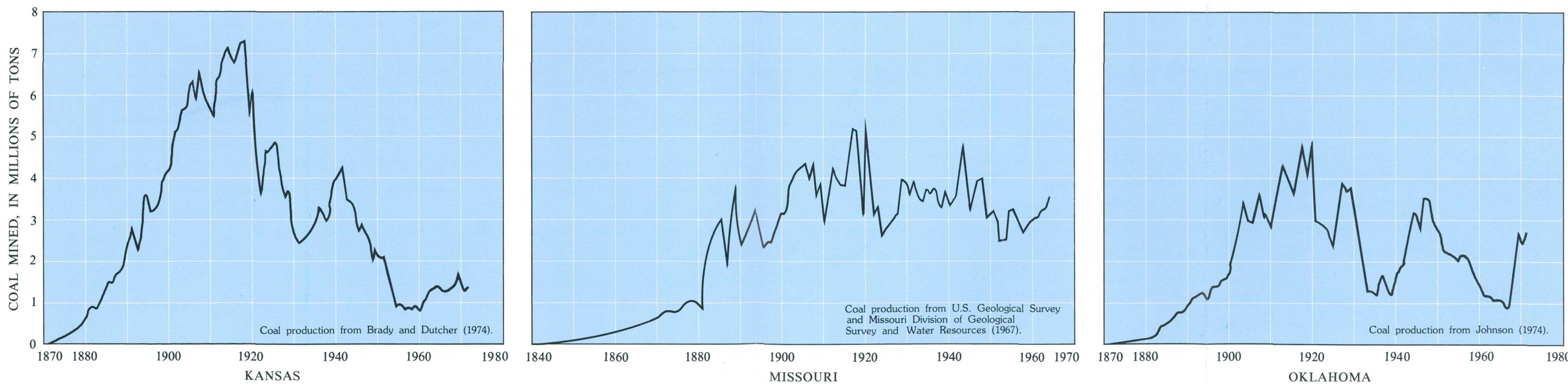


Figure 1.3.1-2 Historical trends in coal mining, by State.

Coal Reserves in 18 Counties Total Nearly 1.8 Billion Tons

Bituminous coals of Pennsylvanian age occur in seams from 1 to 4 feet thick and have relatively high sulfur contents and heat values.

Coal reserves considered in this report are those resources that have been proven to exist and which can be mined with current (1982) technology and under current economic conditions. For stripping operations, these are coals for which the ratio of overburden to coal thickness does not exceed 30:1. In Area 40, where coal seams generally are less than 4 feet thick, virtually all coal is and will continue to be produced by strip-mining methods. Maximum thickness of overburden for strippable reserves in the area is considered to be 100 feet.

Recent estimates by Brady and others (1976), Friedman (1974), and Robertson (1971), indicate that 18 counties within Area 40 have strippable coal reserves totaling about 1,764,000,000 tons. The reserves of strippable coal remaining in each county are shown in figure 1.3.2-1. Detailed information on the distribution of coal reserves by coal seam, county, and State is given in section 9.1.

Potentially strippable coal seams in the area occur in the Wabaunsee, Kansas City, Skiatook, Cabaniss, and Krebs Groups of Pennsylvanian age. The coals of the Cabaniss Group represent the majority of strippable reserves; these coals include the Weir-Pittsburg, Mineral, Croweburg, and Bevier seams. The Rowe coal of the Krebs Group also represents a significant reserve. The greatest reserves of these coals are located in Cherokee and Crawford Counties in Kansas, Craig and Rogers Counties in Oklahoma, and Barton County in Missouri.

Some physical and chemical characteristics of coals in Area 40 are presented in table 1.3.2-1. Coal reserves considered in this report range from 1 to 4 feet in thickness. Conditions affecting the use of various coal seams include their composition, sulfur content, and heat value. Proximate analyses of these coals on an as-received basis average about 5 percent moisture, 36 percent volatile matter, 48 percent fixed carbon, and 11 percent ash. Volatile matter tends to decrease and fixed carbon to increase in successively lower coals of the Cherokee Group (Pierce and Courtier, 1937). Most of the coals are classified as high volatile A bituminous, with heat values generally greater than 12,000 British thermal units per pound (BTU/lb.), except for the Nodaway and Rowe coals. Average sulfur contents range from 1.6 to 7.6 percent, generally decreasing with greater depth to the coal. Most of the sulfur in Area 40 coals occurs as the iron sulfide mineral, pyrite.

The primary use of coals mined in Area 40 is for electric-power generation. Although these bituminous coals produce more heat than equal volumes of subbituminous coals or lignite mined in thicker seams in the western United States, their greater sulfur contents necessitate the additional cost of pollution-control equipment to meet air-quality regulations for sulfur dioxide emissions.

Estimates of coal reserves include coals in three reliability classes--measured, indicated, and inferred--as agreed upon by the U.S. Bureau of Mines and the U.S. Geological Survey. Estimates of measured reserves are determined from closely spaced (no greater than ½ mile apart) observation points showing the thickness and extent of the coal seams so reliably that computed tonnages are considered to be accurate within 20 percent of the true tonnage. Estimates of indicated reserves are based on observation points as much as 1½ miles apart, from which the thickness and extent of the coal seams are projected using geologic evidence. Estimates of inferred reserves are based on observation points averaging about 2 miles apart, and on an assumed continuity of coal seams into areas surrounding those containing measured and indicated reserves.

Tonnages of coal produced from 1974 through 1979 in counties with coal reserves are shown in figure 1.3-2-2. The quantities shown are in net tons, or the actual tonnage of coal recovered after mining and processing. Coal production in Oklahoma has far surpassed that in Kansas and Missouri in recent years, although the greatest remaining reserves are in Kansas.

Further information concerning coals in the area can be obtained from the references listed in section 10.0. Stratigraphic, petrographic, and chemical information on coal-bearing rocks nationwide is stored in a U.S. Geological Survey data base known as the National Coal Resources Data System (NCRDS). Contact the U.S. Geological Survey, MS 956, Reston, VA 22092 for accessing procedures.

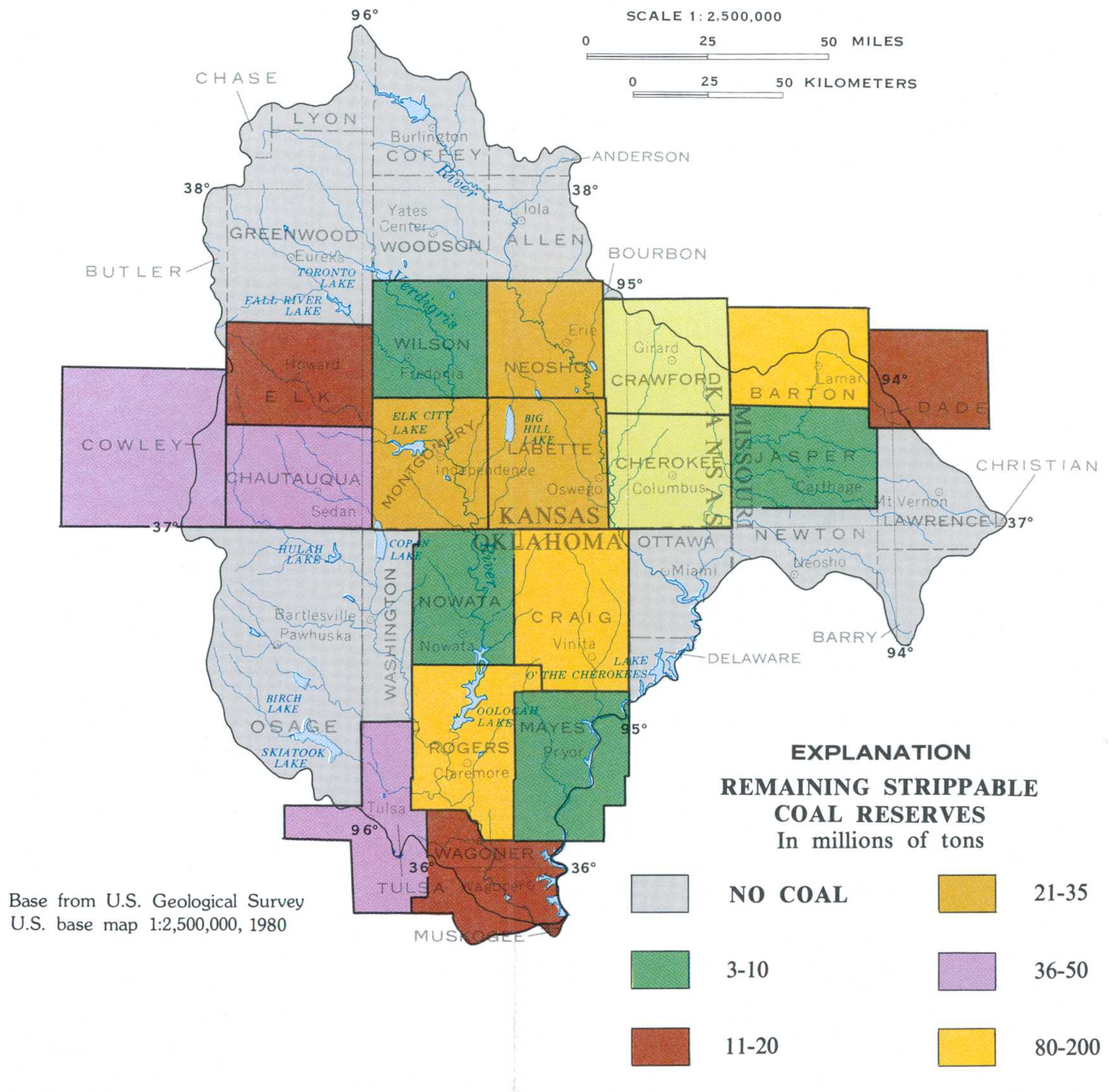


Figure 1.3.2-1 Strippable coal reserves in Area 40 counties.

Table 1.3.2-1 Physical and chemical characteristics of coals in Area 40 from Brady and Dutcher (1974), Friedman (1974), Pierce and Courtier (1937), Robertson (1971), Schoewe (1944), and Whitla (1940).

SYSTEM	GROUP	COAL SEAM	RANGE OF THICKNESS (INCHES)	PROXIMATE ANALYSIS, AS-RECEIVED BASIS					SULFUR CONTENT (PERCENT)	NUMBERS OF SAMPLES AVERAGED
				MOISTURE (PERCENT)	VOLATILE MATTER (PERCENT)	FIXED CARBON (PERCENT)	(PERCENT)	HEAT VALUE† (BTU/lb.)		
PENNSYLVANIAN	WABAUNSEE	NODAWAY	12-18	7	35	49	9	10,700	8	
	KANSAS CITY	THAYER	12-24	6	34	50	10	12,400	2	10
	SKIATOOK	DAWSON	18-37	6	36	49	9	12,500	4	6
	CABANISS*	IRON POST	12-17	3	45	45	7	13,400	4	1
		MULKY	12-15	3	40	47	10	13,300	4	3
		BEVIER	12-33	4	38	48	10	13,000	3	6
		CROWEBURG	12-41	7	35	52	6	12,800	2	17
		FLEMING	12-27	3	39	47	11	13,000	2	1
		MINERAL	12-24	4	34	49	13	12,500	4	9
		WEIR-PITTSBURG	12-48	6	33	51	10	12,600	4	8
	KREBS*	DRYWOOD	12-21	2	36	48	14	12,600	5	2
		ROWE	12-30	2	35	42	21	11,400	4	2

* Usage adopted for Oklahoma † British thermal units per pound

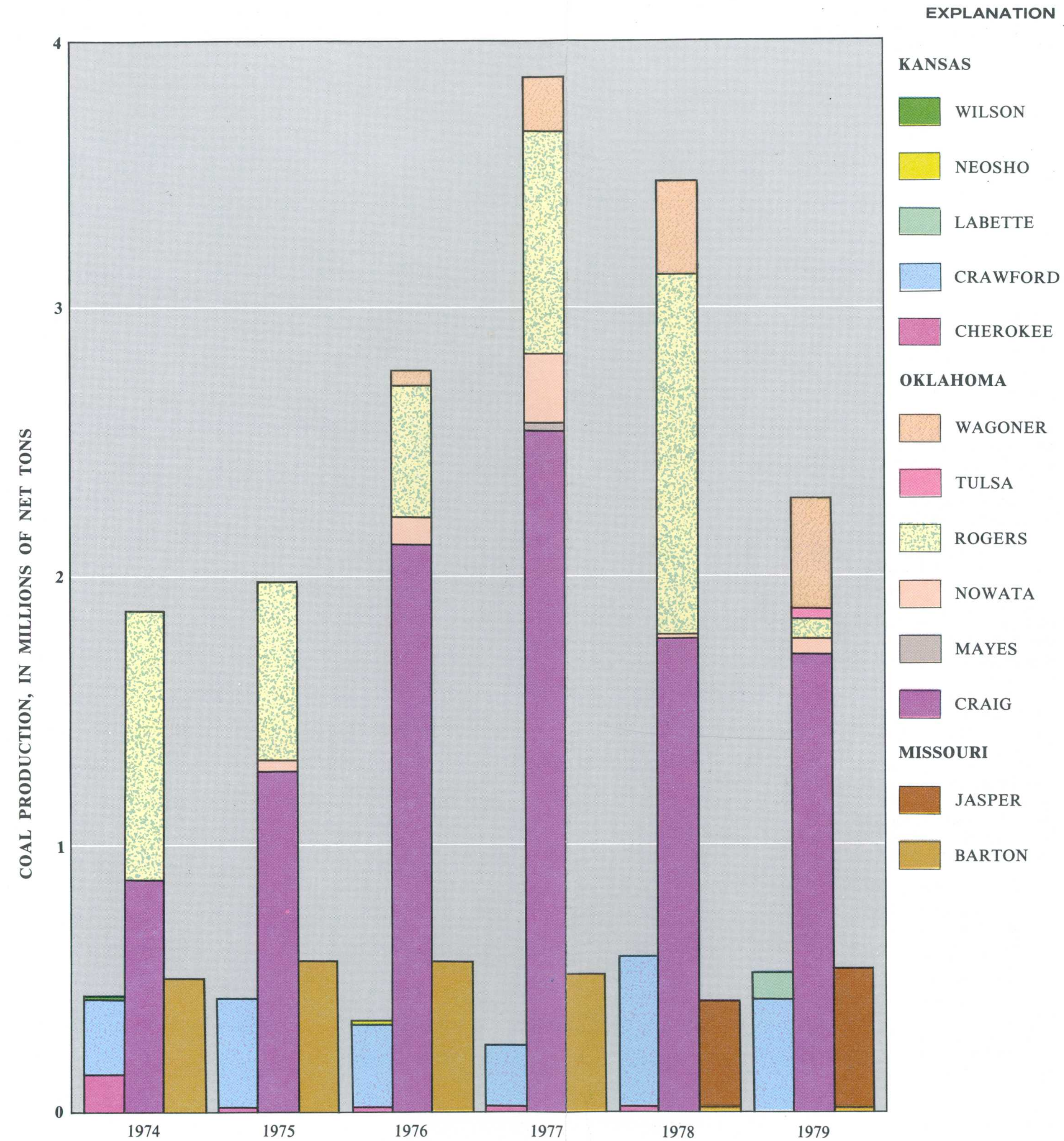


Figure 1.3.2-2 Recent coal production in Area 40 counties [from Mining Informational Services (1976-1981)]

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

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

A major change in the hydrologic environment that may result from surface mining of coal in Area 40 is the creation of additional surface-water storage in mine ponds. The following description of the coal-mining process (fig. 1.4.1-1), as practiced in the area, is summarized from Johnson (1974) to show how the 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 about 100 feet, that the coal can no longer be mined profitably. The final cut leaves an open trench bounded by the last spoil pile on one side and the undisturbed highwall on the other. The trench partly fills with water from surface runoff and ground-water seepage.

Reclamation of the spoil is required by law to keep pace with mining. Reclamation involves grading the spoil to a rolling topography, replacing the topsoil, adding lime or fertilizer as needed, and seeding with pasture grasses or legumes. The revegetated area usually is not grazed until the plants have become well established.

A readily apparent change in the hydrologic environment is the creation of additional water storage in the last mine cut shown in figure 1.4.1-1. A mine pond 0.5 mile long, 200 feet wide, and 30 feet deep has a volume of about 360 acre-feet or approximately 117 million gallons--a valuable resource in an area of limited ground-water supplies.

Mine ponds in Area 40 cover an estimated 6,165 acres (fig. 1.4.1-2). Assuming that the average depth of the ponds is 20 feet, they contain approximately 122,000 acre-feet or 40 billion gallons of water. The acreage estimates are based on data compiled in 1969 for Kansas, 1980 for Missouri, and 1973 for Oklahoma. Undoubtedly, the acreage has increased significantly, particularly in Kansas and Oklahoma. These mine ponds provide habitat for aquatic and semiaquatic wildlife and may contribute to the esthetics of the landscape; some have been stocked with fish (fig. 1.4.1-3). Also, water from the ponds may be used for stock, domestic, municipal, and irrigation supply if the quality is suitable (see section 6.7).

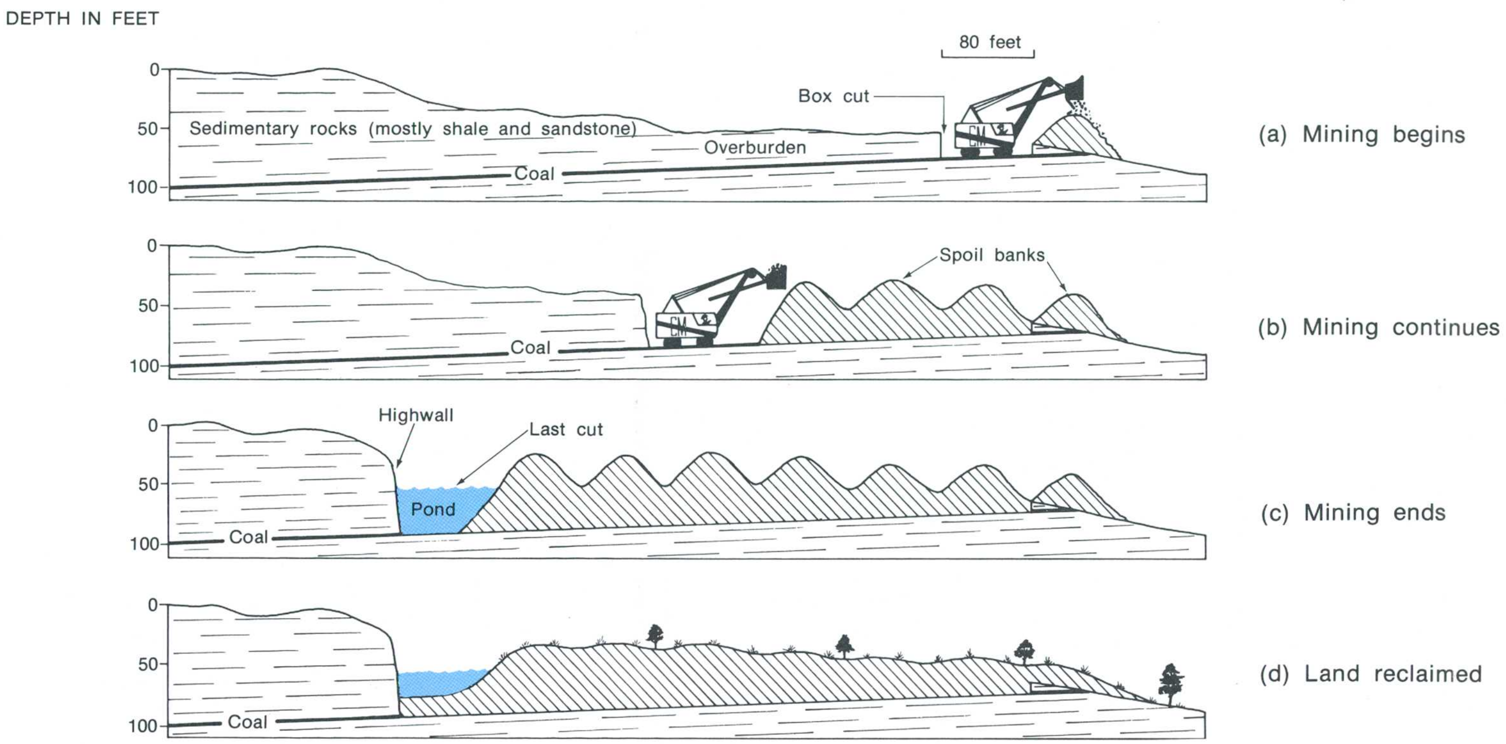


Figure 1.4.1-1 Schematic cross sections showing stages of surface mining for coal.

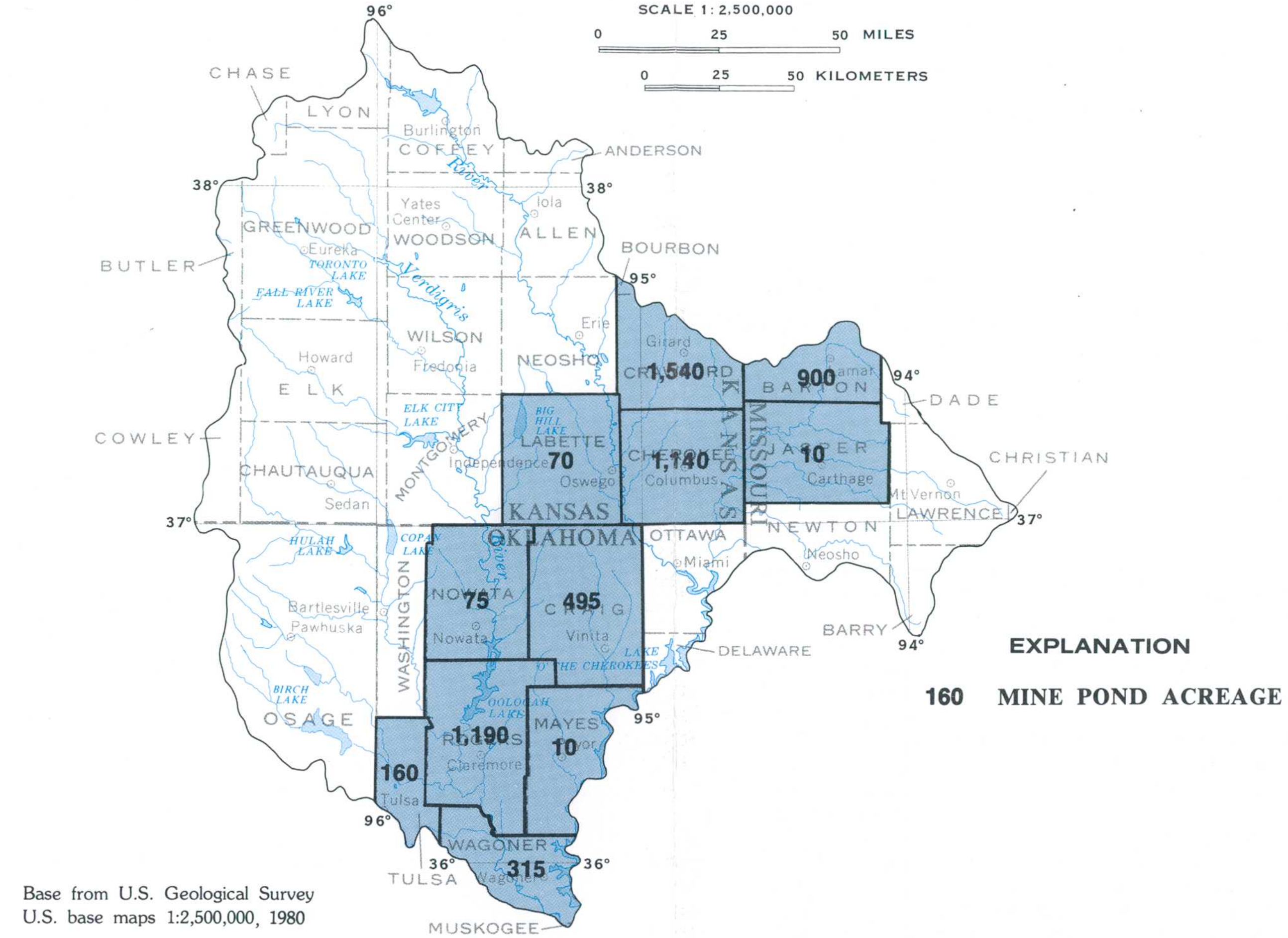


Figure 1.4.1-2 Estimated acreage of mine ponds based on data compiled in 1969 for Kansas, 1980 for Missouri, and 1973 for Oklahoma.

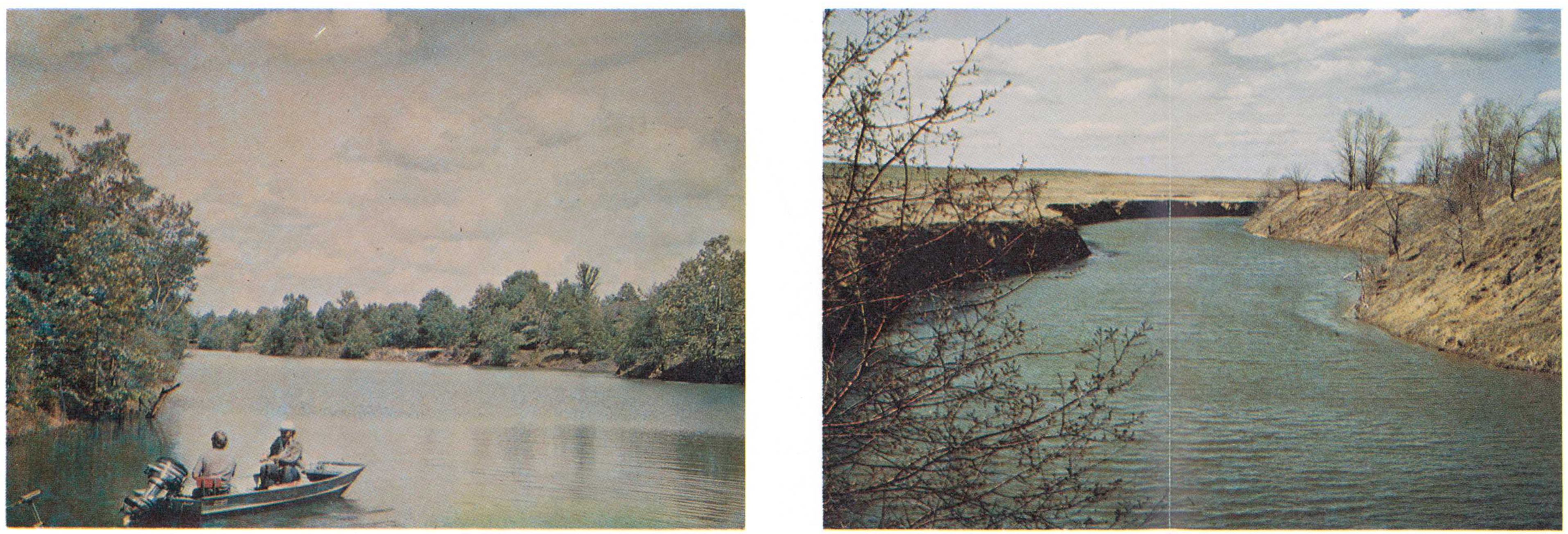


Figure 1.4.1-3 Mine ponds provide wildlife habitat and recreation and may be a source of water supply if the quality is suitable.

Mining May Increase Storage of Ground Water and Decrease Peak Discharges of Streams

Reclamation practices that improve the cover of vegetation on mine spoil may decrease the volume of precipitation that runs off quickly thereby allowing the water to infiltrate the spoil where it is stored and gradually discharged to streams.

Overburden in Area 40 consists principally of shale and siltstone with some sandstone and limestone. With the possible exception of some sandstones and limestones, these rocks have minimal porosity and permeability. During mining, however, the overburden is broken and shattered to form spoil with many openings that facilitate the entry, movement, and storage of water. The volume of water entering the spoil is partly controlled by the permeability of the surface and near-surface material. Where that material consists of silt and clay, openings may be plugged thus limiting the volume and rate of infiltration. Although the volume of void space, or porosity, in the spoil is unknown, it has been estimated to range from 15 to 25 percent in some areas (Cederstrom, 1971). If the porosity is conservatively estimated to be 5 percent, then a square mile of spoil with a saturated thickness of 50 feet would contain about 1,600 acre-feet or about 500 million gallons of water. Water stored in the spoil may (a) be slowly discharged to streams, (b) be used by plants, and (c) move into adjacent bedrock.

Observations in some parts of Area 40 show that if appropriate reclamation practices are used, grasses on the reclaimed spoil may be more lush and have a denser growth (fig. 1.4.2-1) than the original native vegetation. The denser plant growth tends to retard storm runoff so that it has more time to soak into the soil and, as a consequence, less water reaches the streams during times of normally high flow. Conversely, ground water stored in the spoil may be slowly released to streams thereby sustaining base-flow for a longer period of time following rainfall. The overall resulting changes in streamflow would be decreased peak discharges and augmented periods of low flow (fig. 1.4.2-2). These effects are enhanced by interception of runoff in mine ponds and depressions left in the reclaimed spoil.

Surface mining has resulted in changes in drainage patterns in some parts of the area (fig. 1.4.2-3). Such 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 proportion of the basin that has been disturbed by mining.

Figure 1.4.2-1 Thick growth of grasses on reclaimed coal-mine land in Cherokee County, Kansas, tends to retard overland flow of water.

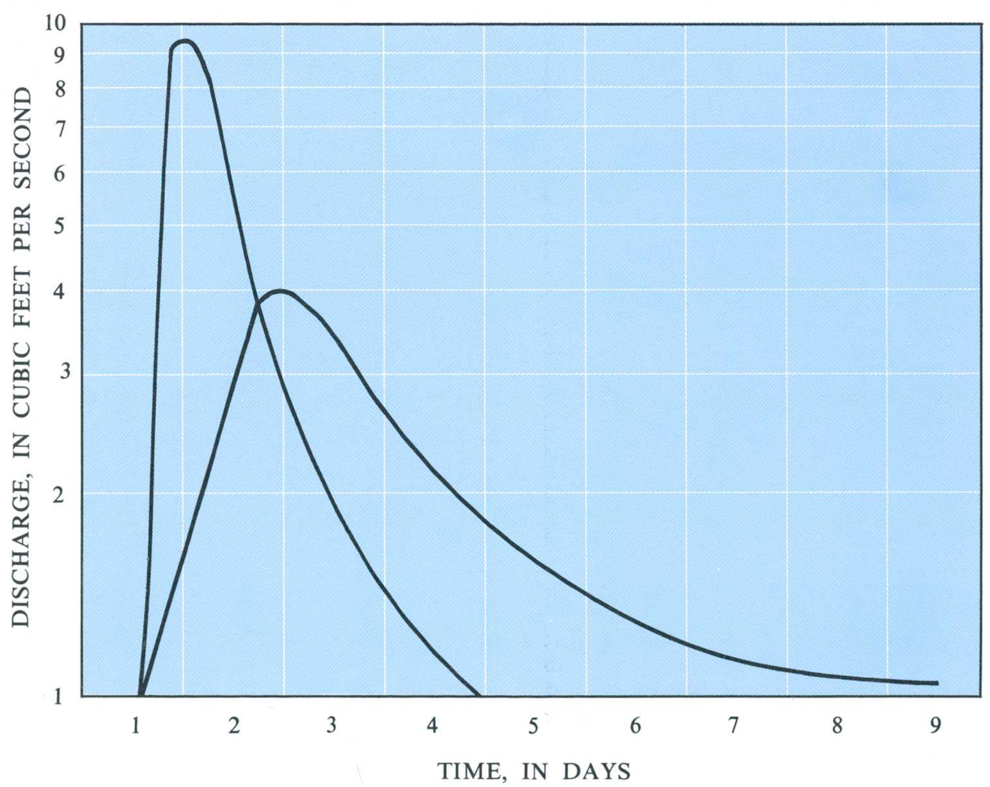


Figure 1.4.2-2 Hypothetical hydrographs of streams draining mined and unmined areas.

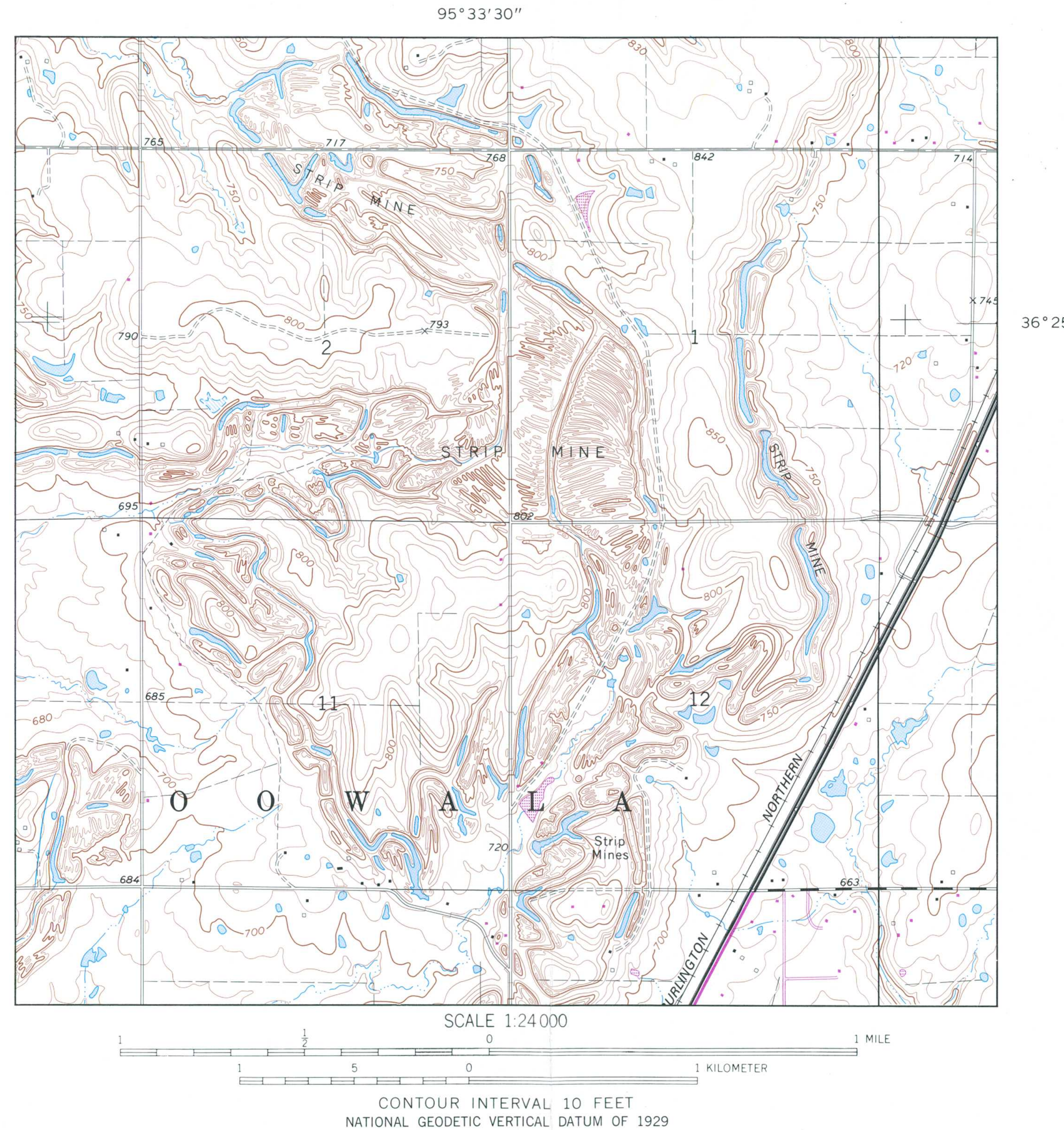


Figure 1.4.2-3 Segment of the Foyil 7½-minute quadrangle near Claremore, Oklahoma, showing changes in drainage patterns resulting from mining. Much of the runoff from the hills does not reach streams as overland flow because it is intercepted by mine ponds and spoil.

Surface Mining Coal May Cause Increases in the Dissolved-Solids Concentration and Sediment Loads of Streams

The most widespread effect of surface mining coal is an increase in sulfate concentrations in streams draining mined areas.

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 equilibrium by fracturing the rocks, causing changes in surface- and ground-water flow patterns, and exposing greater quantities of minerals to oxgyen and water (fig. 1.4.3-1). In particular, reactions between ground water moving through spoil, oxygen, and iron-sulfide minerals pyrite and marcasite, which commonly are associated with coal, introduce undesirable concentrations of iron, sulfate, and hydrogen ion into solution (Barnes and Clarke, 1964). Acidic, iron-bearing water commonly has a reddish or brownish hue due to the presence of ferric hydroxides (fig. 1.4.3-2) and is referred to as acid mine drainage. The acidity caused by excess hydrogen ion increases the solubility of potentially toxic trace metals such as aluminum, copper, lead, manganese, and zinc that may be present in the coal or overburden. However, limestone beds in the overburden in some parts of Area 40 contribute carbonate ions that buffer the excess acidity thus decreasing solubilities and preventing large concentrations of these trace elements from remaining in solution.

Concentrations of sulfate ion and, consequently, of dissolved solids are not affected by the buffering action of carbonate ions and are indicators of contamination of water by drainage from mine areas. Large concentrations of dissolved solids, principally sulfate, are present in streams during low streamflow when all or most of the flow is provided by ground-water seepage. The dilution of streamflow by overland runoff during intense rainfall results in a significant decrease in concentrations of dissolved solids (fig. 1.4.3-3). Studies in southeastern Kansas (Bevans, 1980) have shown that mean in-stream concentrations of dissolved solids and sulfate increase with increasing percentage of drainage area that has been disrupted by surface mining (figs. 1.4.3-4 and 1.4.3-5).

Disruption of the land surface during mining and before the spoil is fully reclaimed will increase the quantity of sediment available to streams (fig. 1.4.3-6). Trace metals absorbed to sediment particles can significantly increase total in-stream concentrations of these constituents. The quantity of sediment actually added to streams depends largely on the quantity and the intensity of rainfall, length and degree of slope, and surface characteristics of the spoil. The quantities of trace metals contributed to streams along with the sediment vary according to the geochemistry of the spoil. If appropriate mining practices are followed, such as the use of settling ponds, the quantities of sediment and contaminants added to the streams can be minimized. Likewise, the time available for transport of sediment can be shortened if the spoil is revegetated rapidly and effectively.

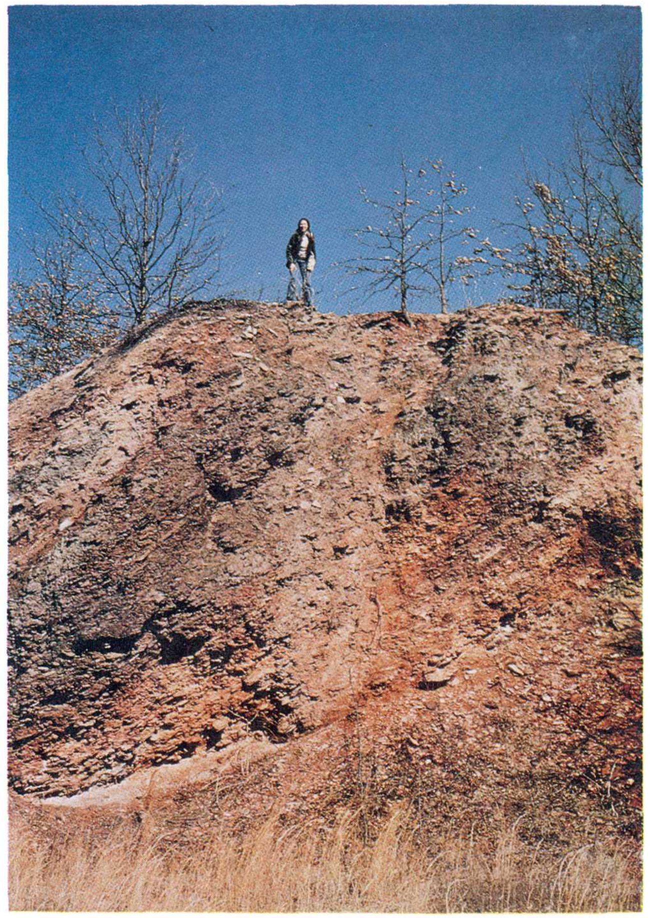


Figure 1.4.3-1 Waste pile in an unreclaimed strip-mined area in Cherokee County, Kansas.

Figure 1.4.3-2 Acid drainage from a gob pile in Rogers County, Oklahoma.

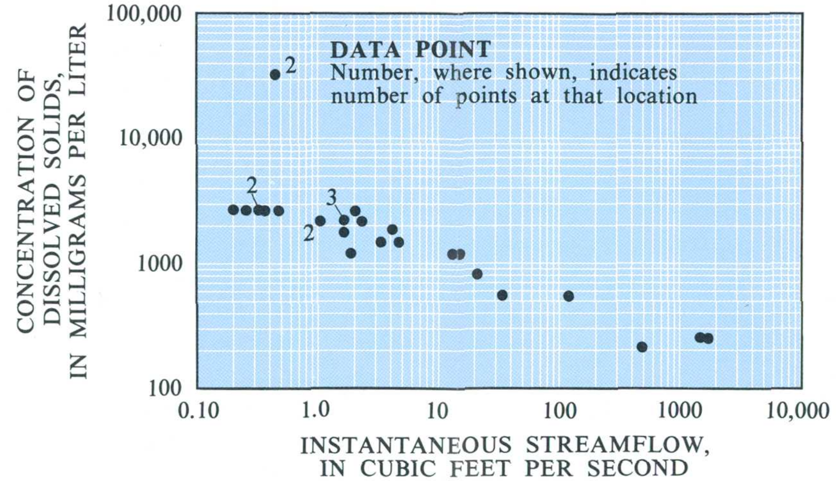


Figure 1.4.3-3 Relation of instantaneous streamflow to cutoff Cherry Creek near West Mineral, Kansas.

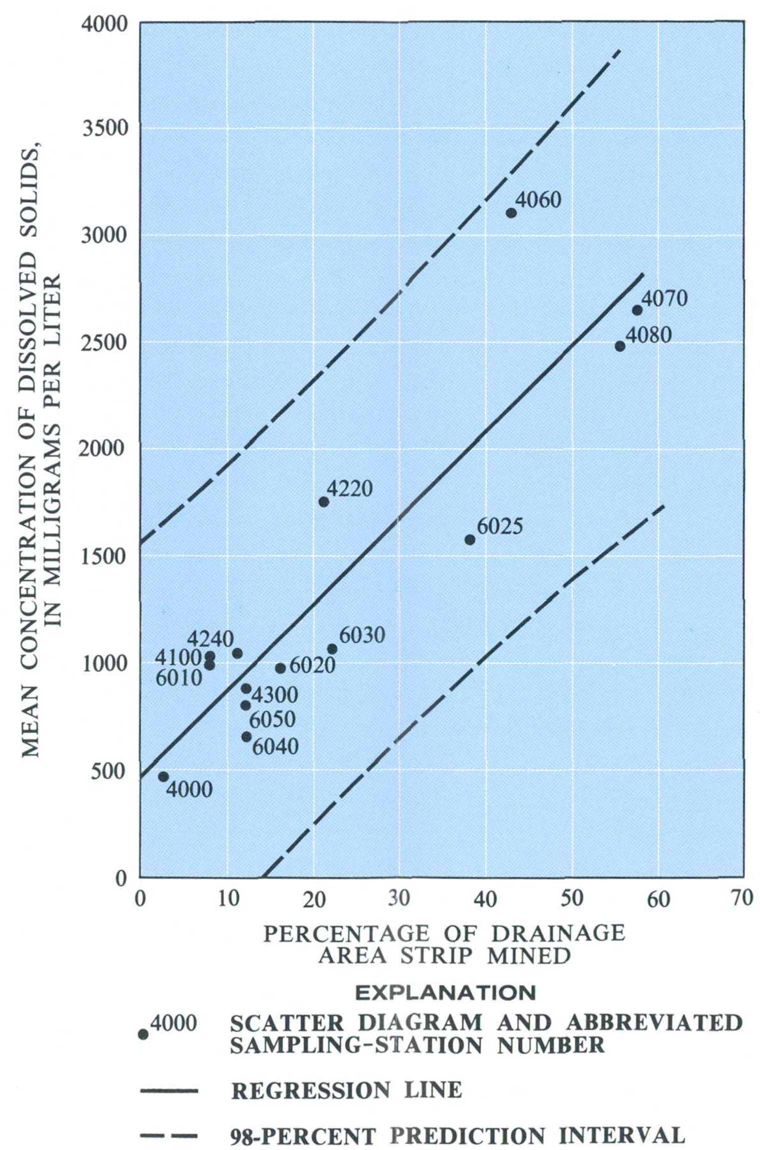


Figure 1.4.3-4 Relation of percentage of drainage area strip mined to concentration of dissolved solids.

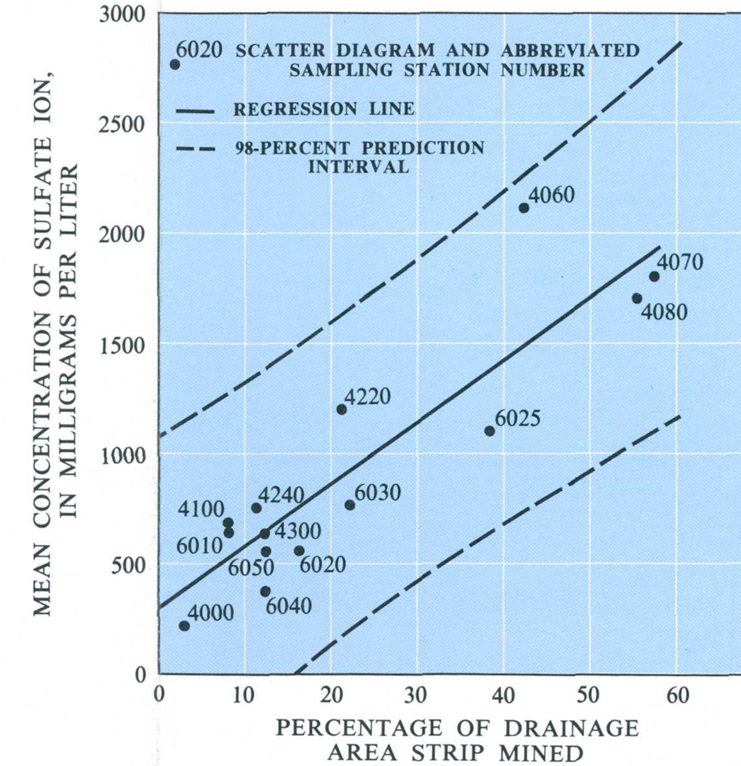


Figure 1.4.3-5 Relation of percentage of drainage area strip mined to concentration of dissolved sulfate.

Figure 1.4.3-6 Newly reclaimed but unvegetated spoil as a source of sediment to streams.

Some Parts of Area 40 Have Been Adversely Affected by Wastes from Oil Fields and Refineries

Large concentrations of dissolved solids, particularly chloride, are common in surface and ground waters degraded by disposal of brines and wastes.

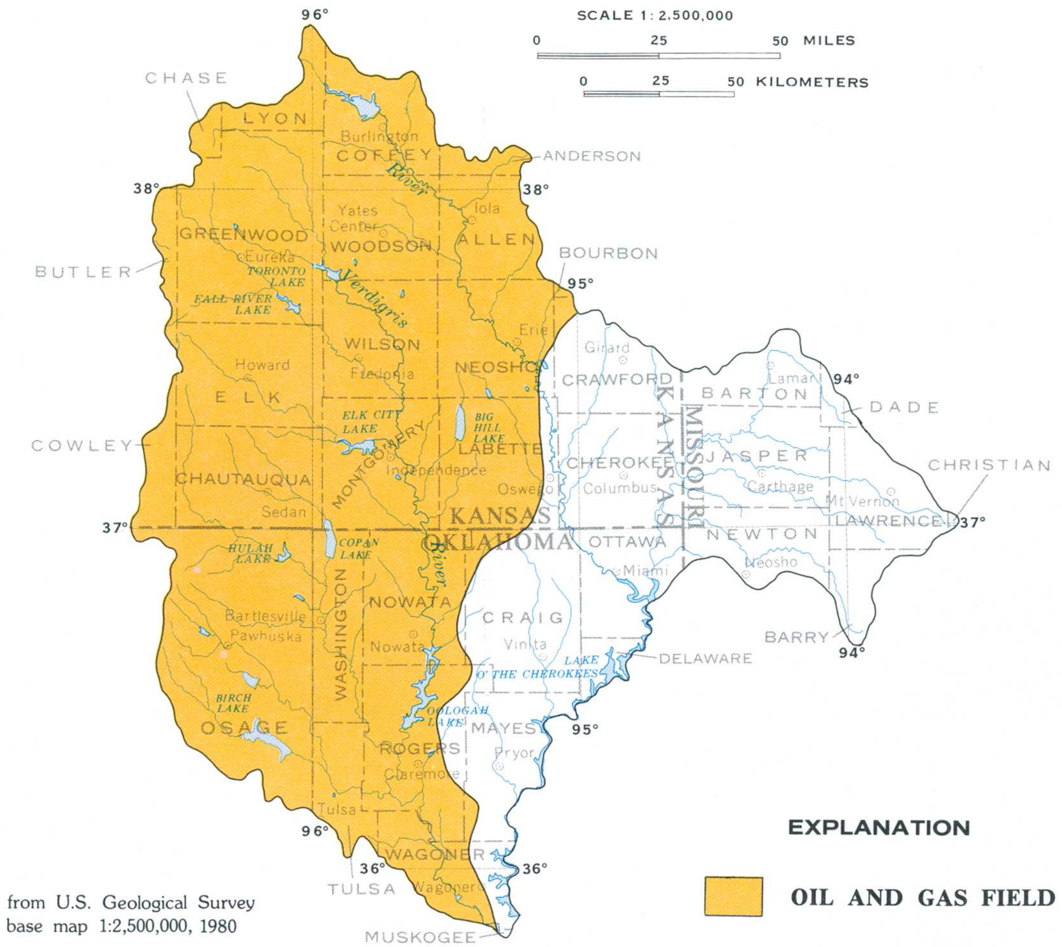
Any assessment of the effects of coal mining on the hydrologic environment needs to consider other resource-recovery activities, such as the production of petroleum, that have adversely affected the area. Brines and other wastes from production of petroleum have resulted in contamination of many parcels of land, streams, and local ground-water reservoirs in the western part of Area 40 (fig. 1.5-1). This area has been the scene of oil and gas production since the early 1900's and the activity continues. During 1979, about 875 oil and gas wells were completed in the Oklahoma part of the area (Prater, 1980) and, during 1980, about 500 oil and gas wells were drilled in the Kansas part (Paul and Bahnmaier, 1981).

Many of the problems related to contamination by oil-field wastes in Kansas have been caused by previous disposal practices. Until the mid-1960's, slush pits 50-60 feet wide and 100-200 feet long were used to hold brines and wastes before discharging them to streams or reinjecting into deep rock formations. Lands under and in the vicinity of these pits cannot support plant growth due to excessive soil salinity. In some places, salts have impregnated the soil causing it to become virtually impermeable so that little erosion occurs but in other areas erosion and gullying are severe. Recovery of the soil under and near the ponds may take 40-50 years or longer. The return of the soil to natural degrees of mineralization is particularly slow in rocks with little permeability because the salts are not flushed out readily. In Kansas, disposal of brines in slush pits is prohibited and above-ground tanks are used to hold brine; slush pits are still widely used in Oklahoma.

Salt-contaminated lands are particularly extensive in the Oklahoma part of Area 40. In Osage County alone, the number of oil and gas wells has been estimated at more than 25,000 and approximately 1,900 acres of land associated with these wells have been classed as oil-waste land (Bourlier and others, 1979). Individual parcels of oil-waste land, ranging from 0.5 to 150 acres, have been so severely contaminated that extensive reclamation would be needed before plant growth could be reestablished (fig. 1.5-2).

Streams are polluted by runoff from areas of salt-impregnated soil, accidental or intentional discharge of brines from slush pits and holding tanks, and leakage from defective well casings, pipes, and tanks. Seepage of brine from pits and infiltration of water through salt-impregnated soil into underlying or adjacent water-bearing formations has caused significant increases in dissolved-solid concentrations of underground water in some parts of the area (Bryson and others, 1966). Ground water also is contaminated by brines leaking through defective well casings or from improperly constructed wells used to repressure oil-bearing formations.

Chemical analyses of water from wells and streams in Osage County, Oklahoma, indicate contamination by oil-field brines (D'Lugosz and McClaflin, 1977). Bromide is considered as an indicator of such contamination because, in Area 40, brines are the only known source of that constituent in water in concentrations of 1 milligram per liter or more. Of 14 samples of water from wells for which bromide was determined, 8 had concentrations ranging from 1.8 to 10 milligrams per liter; concentrations of bromide in stream water ranged from 12 to 70 milligrams per liter.



Base from U.S. Geological Survey
U.S. base map 1:2,500,000, 1980

Figure 1.5-1 Area of oil and gas production (from Vlissides and Quirin, 1964).

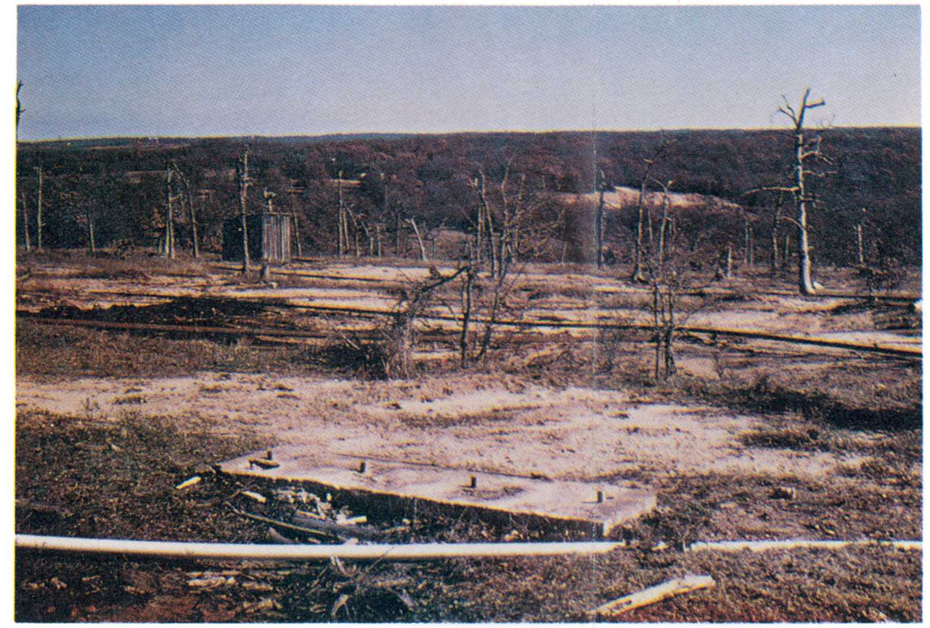


Figure 1.5-2 Typical waste lands in oil and gas producing areas in the western part of Area 40.

The Hydrologic Environment in Some Parts of Area 40 Has Been Affected by Metal Mining

Mining of zinc and lead has degraded the chemical quality of some surface and ground waters in the eastern part of Area 40.

Drainage from underground zinc and lead mines and associated mine waste, or tailings piles, is the source of mineralized water in the Tri-State Mining District of Missouri, Oklahoma, and Kansas (fig. 1.6-1). Mining in the Tri-State district began about 1850 but by 1950 most of the rich ores had been extracted and, by the late 1960's, mining and milling operations ceased. Throughout the mining era, water had to be pumped from the mines to keep the water level below the mine drifts. With cessation of mining, the mines filled with water; those in the vicinity of Picher, Ottawa County, Oklahoma, are estimated to contain 100,000 acre-feet (Playton and others, 1980). Through various chemical processes, water in the mines has become mineralized and is now discharging to Spring River and some of its tributaries in Missouri (Feder and others, 1969) and to Tar Creek, a small tributary of the Neosho River in Oklahoma. In addition to discharge directly from the mines, tailings piles also contribute mineralized water to some streams (Barks, 1977).

The most detailed information on the chemistry of the mine water (section 9.2) is provided by samples from mines in the Picher area (Playton and others, 1980). These data show that the water has large concentrations of aluminum, fluoride, iron, lead, manganese, nickel, sulfate, and zinc. Because of the large concentrations of toxic elements the water is unsuited for nearly all purposes. Water in the mines in the vicinity of Joplin, Missouri, is less mineralized than that from mines in the vicinity of Picher, Oklahoma. For example, the mean dissolved-solids concentrations in 16 samples from Missouri mines was 1,030 milligrams per liter whereas the mean of 74 samples from Oklahoma and Kansas mines was 4,000 milligrams per liter. The mean dissolved-solids concentration in water from eight tailings piles in Missouri was 414 milligrams per liter.

In addition to causing degradation of some stream waters, mineralized mine water might move into and contaminate water in shallow aquifers adjacent to the old mine workings; however, such movement does not appear to be widespread. Of greater significance, is the possible movement of mineralized water into the deep aquifers which are the principal source of supply for municipal and industrial use in the Tri-State district. The deep aquifers, such as the Roubidoux Formation (fig. 1.6-2), is separated from the water-filled mines by several hundred feet of relatively impermeable rocks. However, because the water level in the mines is higher than that in the deep aquifers, water could move downward through faults, fractures, solution openings, or unplugged wells and test holes. Such movement may have taken place in the Webb City and Carthage areas in Missouri (Barks, 1977).

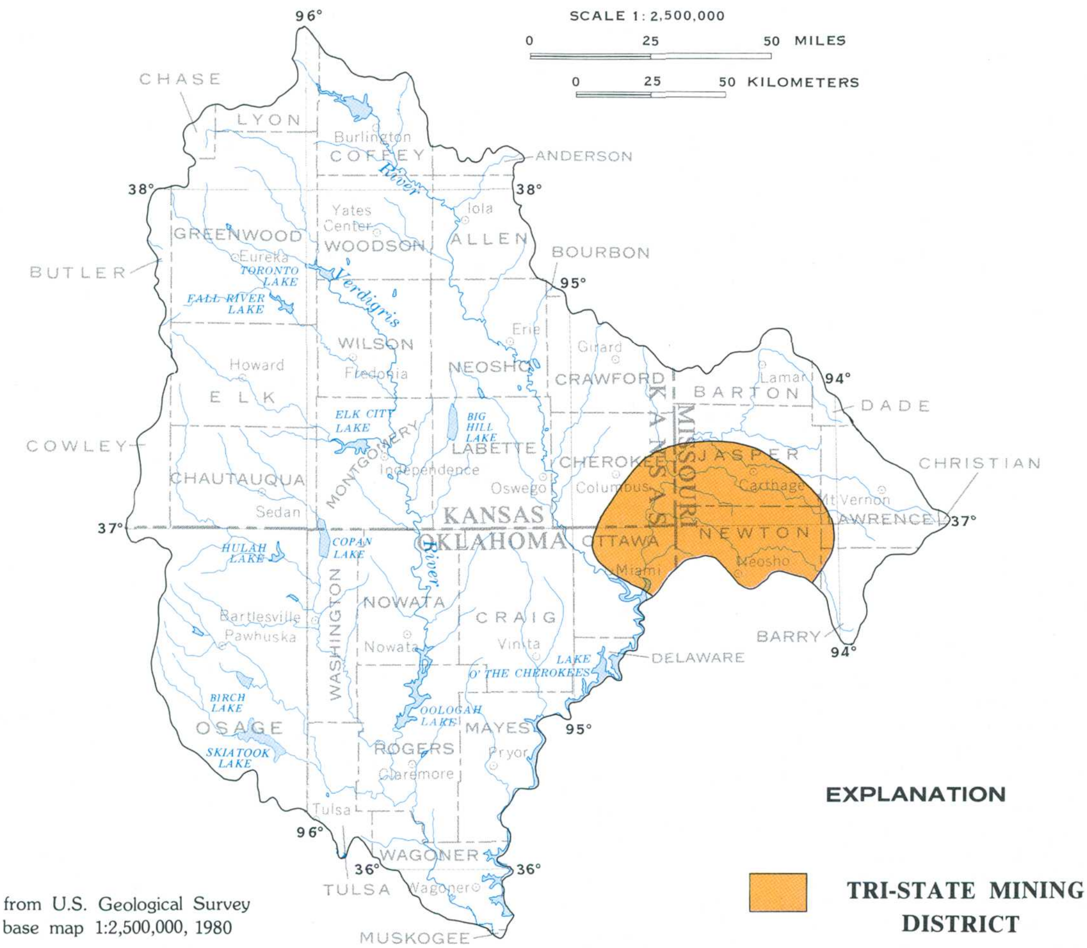


Figure 1.6-1 Location of the Tri-state zinc and lead mining district (modified from Feder and others, 1969).

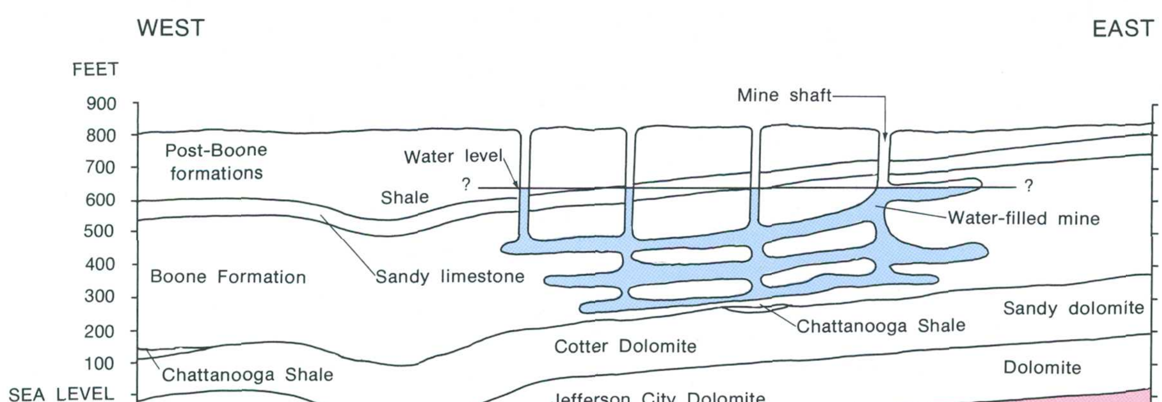


Figure 1.6-2 Schematic cross section showing relationship of mineralized water in the abandoned mines in the Picher area to the underlying Roubidoux Formation (modified from Playton and others, 1980).

Surface Bedrock is Mississippian or Pennsylvanian Age

Rocks of Mississippian age are mostly cherty limestone; rocks of Pennsylvanian age are mostly shale with some limestone, sandstone, and coal.

Structurally, Area 40 is dominated by the Ozark uplift, a broad dome centered in southern Missouri and extending into southeastern Kansas and northeastern Oklahoma. Because the area is on the western flank of this structural high, progressively younger rocks crop out from east to west. The regional dip of the rocks, which is toward the west-northwest about 30 feet per mile (fig. 2.1-1), is interrupted by local folds of small magnitude and minor faults with displacements of a few tens of feet. Along the southwestern flank of the uplift, in Mayes and Wagoner Countries, Oklahoma, the rocks have been broken by numerous faults with displacements of as much as several hundred feet.

Subsurface rocks of pre-Mississippian age, which consist of dolomite with a few sandy zones, lie at depths ranging from a few hundred feet in the eastern part of the area to about 3,000 feet in the western part. Rocks of Mississippian age (fig. 2.1-2) have a total thickness of about 400 feet and consist mainly of cherty limestone with a few thin shale units in the lower part. The cherty limestone is overlain by rocks of Pennsylvanian age that crop out in parallel bands extending north to northeast across the area. Pennsylvanian rocks, which have an aggregate thickness of about 2,500 feet, are subdivided into many geologic units. Nomenclature differs among the three States. For example, the Cabaniss and Krebs Groups are separate units in Oklahoma but are formations of the Cherokee Group in Kansas and in Missouri the Cherokee is considered a formation.

On the average, Pennsylvanian rocks in the area consist of about 70 percent shale, 20 percent sandstone, and 10 percent limestone. The percentage of shale decreases from south to north whereas the percentage of limestone increases. Shale units typically are 50-100 feet thick; limestone and sandstone units are 5-20 feet thick. Sandstone units become thicker and more numerous in the western part of the area.

Thin seams of coal are interbedded in the rocks of Pennsylvanian age. Strippable seams in Kansas occur in the Wabaunsee, Kansas City, and Cherokee Groups; in Missouri they occur in the Cherokee Shale; in Oklahoma they occur in the Skiatook, Cabaniss, and Krebs Groups.

Alluvium along some of the larger streams, such as the Neosho and Verdigris, may be as much as 60 feet thick but generally is less than 20 feet thick along the smaller, tributary streams. Because of the predominantly shale bedrock in most of the area, alluvium consists mainly of sandy and clayey silt with local thin beds of sand or fine gravel at the base. Bedrock in the Ozark Plateau includes much chert, thus fragments of that material are a prominent component of the alluvium along streams draining the Ozark areas.

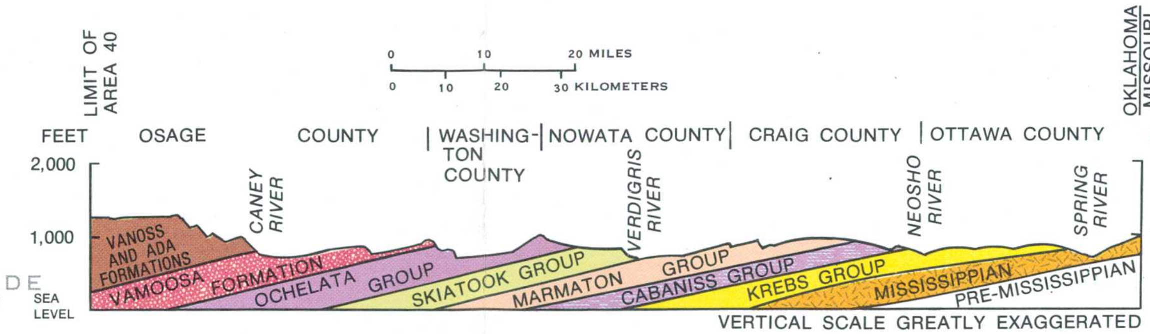
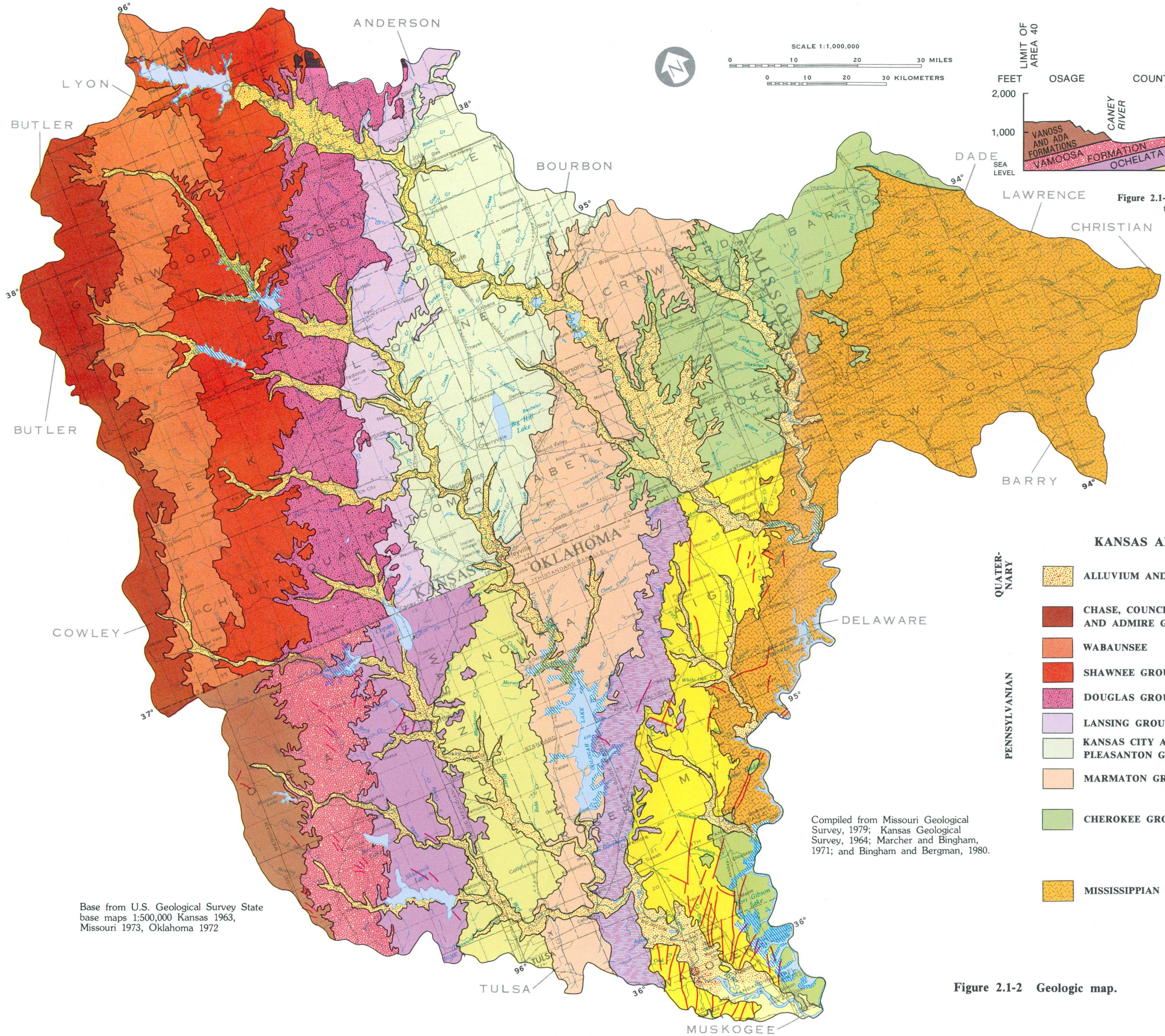


Figure 2.1-1 Generalized geologic section along the Oklahoma-Kansas line from the Oklahoma-Missouri line to the western limit of Area 40.



Base from U.S. Geological Survey State base maps 1:500,000 Kansas 1963, Missouri 1973, Oklahoma 1972

Compiled from Missouri Geological Survey, 1979; Kansas Geological Survey, 1964; Marcher and Bingham, 1971; and Bingham and Bergman, 1980.

EXPLANATION

	KANSAS AND MISSOURI	OKLAHOMA
QUATERNARY	ALLUVIUM AND TERRACE DEPOSITS	ALLUVIUM AND TERRACE DEPOSITS
PENNSYLVANIAN	CHASE, COUNCIL GROVE, AND ADMIRE GROUPS	VANOSS AND ADA FORMATIONS
	WABAUNSEE	VAMOOSA FORMATION
	SHAWNEE GROUP	OCHELATA GROUP
	DOUGLAS GROUP	SKIATOOK GROUP
	LANSING GROUP	MARMATON GROUP
	KANSAS CITY AND PLEASANTON GROUPS	CABANISS GROUP
	MARMATON GROUP	KREBS GROUP
	CHEROKEE GROUP OR SHALE	PENNSYLVANIAN AND MISSISSIPPIAN, UNDIVIDED
	MISSISSIPPIAN UNDIVIDED	MISSISSIPPIAN UNDIVIDED

GEOLOGIC CONTACT

FAULT

Figure 2.1-2 Geologic map.

Area 40 Includes Parts of Two Physiographic Provinces

Most of Area 40 Missouri is in the Springfield Plateau Section of the Ozark Plateaus Province; nearly all the area in Kansas and Oklahoma is in the Osage Plains Section of the Central Lowlands Province.

The Springfield Plateau in the eastern part of Area 40 (fig. 2.2-1) is carved on cherty limestones of Mississippian age which have relatively uniform resistance to erosion. Consequently, the land surface along the broad interstream divides is gently rolling with local relief of about 50 feet. Away from the divides and toward the streams, the topography becomes hilly to rugged with local relief ranging from 100 to 200 feet. The larger valleys have flat bottoms and steep walls; tributary valleys typically have sharp v-shaped cross sections.

The Springfield Plateau merges imperceptibly into the Osage Plains lying to the northwest. Immediately adjacent to the Plateau is a belt 20-25 miles wide underlain by shales of the Krebs and Cherokee Groups. These weakly resistant rocks have been weathered and eroded to form a broad, nearly featureless plain with maximum relief of about 50 feet.

Farther west, in the basin of the Verdigris River, the topography changes to a rolling prairie with average relief of about 50 feet. The landscape is interrupted at irregular intervals by east-facing cuestas and dotted with isolated mesas. These topographic features owe their existence to the presence of thin beds of sandstone and limestone that, because of their superior resistance, have prevented erosion of the underlying shale (fig. 2.2-2). The cuestas are characterized by steep faces rising 100-200 feet above the adjacent plain; their back slopes generally coincide with the regional dip of the rocks. The mesas are erosional remnants of the cuestas that, through time, have gradually retreated westward.

Still farther west, in Osage County, Oklahoma, and adjacent Chautauqua County, Kansas, erosion of the thicker and more numerous sandstone beds has produced a rugged topography with local relief of 150-200 feet. Much of this area is characterized by cuesta escarpments that have been deeply dissected to form narrow, sinuous ridges separated by even narrower v-shaped valleys.

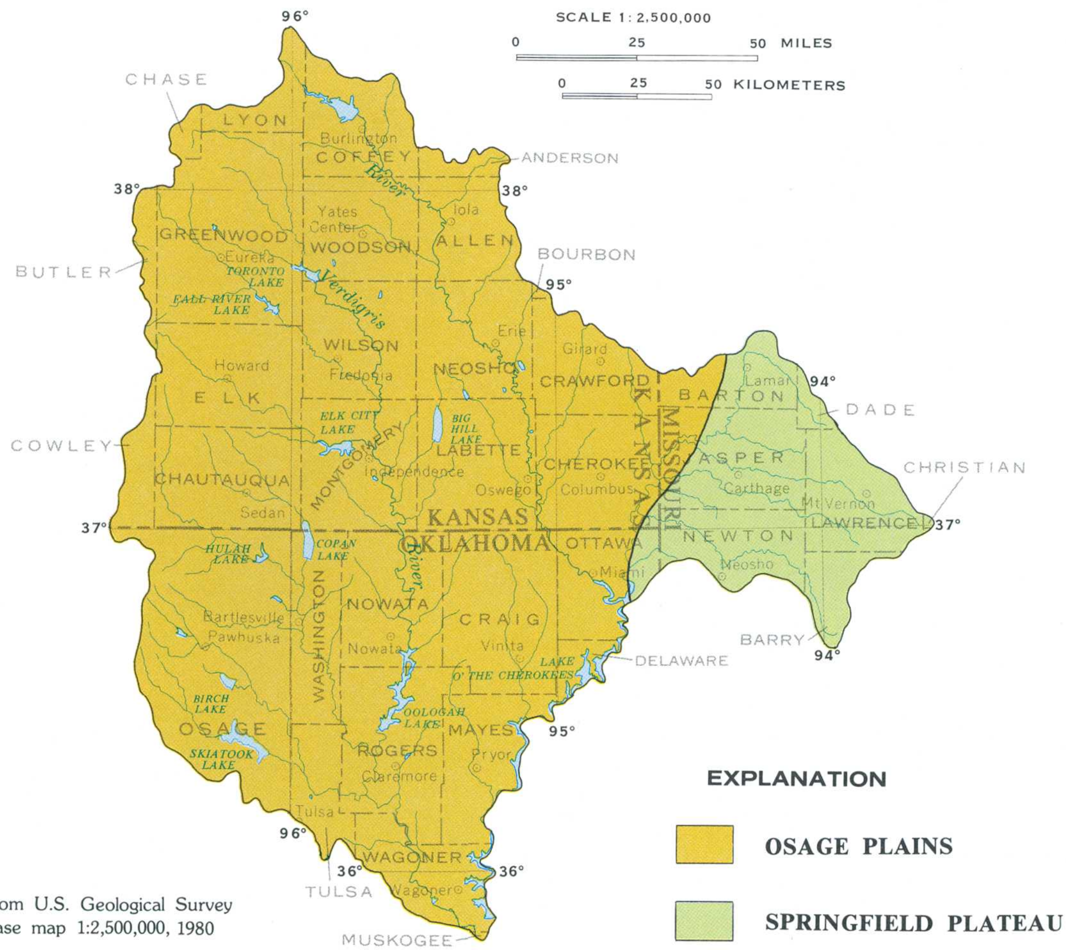


Figure 2.2-1 Physiographic divisions.

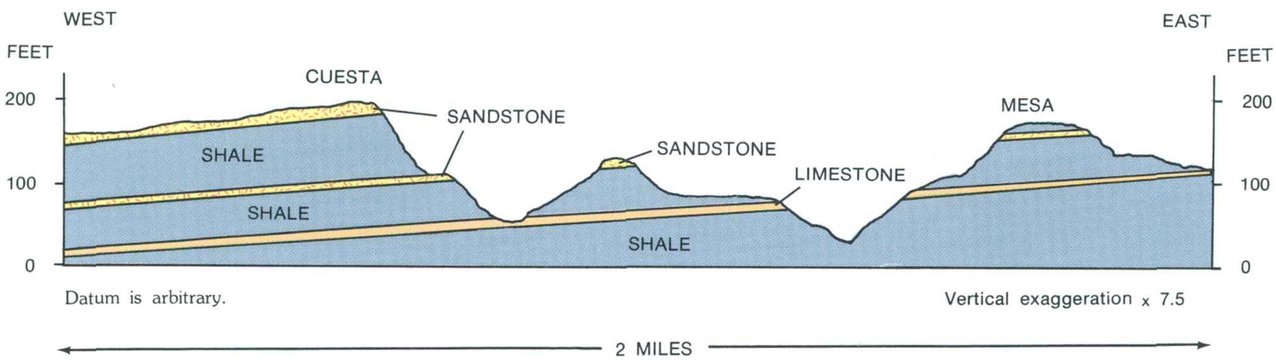


Figure 2.2-2 Generalized section showing relationship of topographic features to geology in the Osage Plains.

Three Rivers Drain Area 40

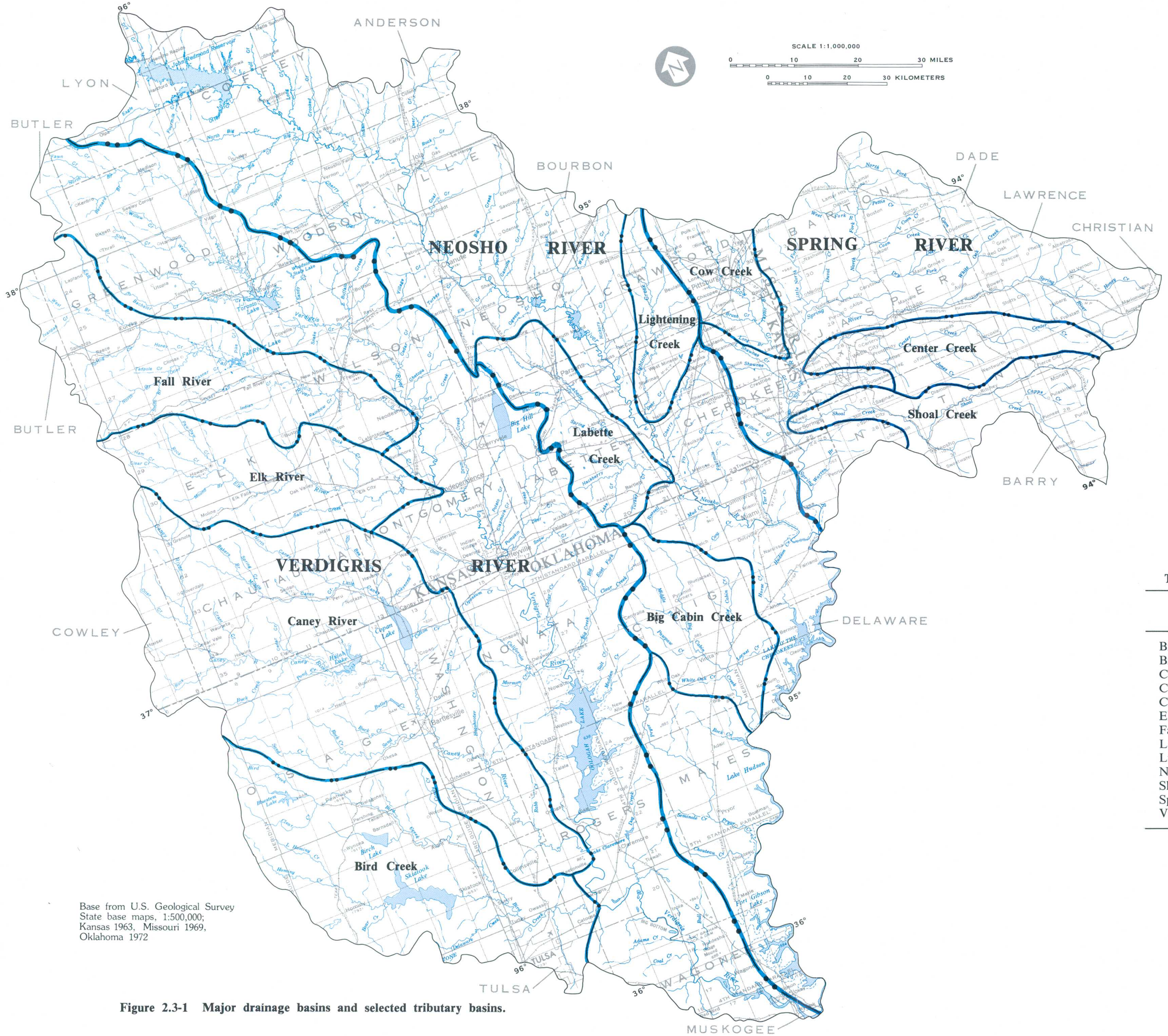
Major streams are the Verdigris, Neosho, and Spring Rivers.

Area 40, which encompasses about 16,300 square miles, is drained by the Verdigris, Neosho, and Spring Rivers (fig. 2.3-1). The area includes the entire basins of the Verdigris and Spring Rivers and about 65 percent of the Neosho River basin. Drainage-area data for these streams and their tributaries have been published by the U.S. Army Corps of Engineers (1954).

The Verdigris River, which drains about 8,300 square miles (table 2.3-1), has its headwaters in the southeastern corner of Chase County, Kansas, and flows generally south to the Arkansas River. Principal tributaries are Fall River, Elk River, Caney River, and Bird Creek. The lower 65 miles of the Verdigris River downstream from Catoosa, Oklahoma, is the upstream end of the McClellan-Kerr Arkansas River Navigation System to the Mississippi River.

The Neosho River drains a total area of about 9,950 square miles of which approximately 5,400 square miles are within Area 40. The Neosho River begins in Morris County, Kansas, and flows south-southeasterly to the Arkansas River. Principal tributaries are Lightning Creek, Labette Creek, and Big Cabin Creek.

Spring River, which drains about 2,500 squares miles, begins in eastern Lawrence County, Missouri, and flows west to the Missouri-Kansas State line thence generally south to the Neosho River. Principal tributaries are Center Creek, Cow Creek, and Shoal Creek.



EXPLANATION

BOUNDARY OF MAJOR RIVER BASINS

BOUNDARY OF SELECTED TRIBUTARY BASINS

Base from U.S. Geological Survey
State base maps, 1:500,000;
Kansas 1963, Missouri 1969,
Oklahoma 1972

Figure 2.3-1 Major drainage basins and selected tributary basins.

Table 2.3-1 Approximate area of selected basins.

Basin	Approximate area (square miles)
Big Cabin Creek	450
Bird Creek	1,100
Caney River	2,000
Center Creek	230
Cow Creek	170
Elk River	630
Fall River	830
Labette Creek	200
Lightning Creek	250
Neosho River	5,400
Shoal Creek	430
Spring River	2,500
Verdigris River	8,300

Soil Characteristics in Area Vary with Geology and Physiography

Most soils were developed from shales, are acidic, and have low to moderate fertility, very slow to moderate permeability, and moderate erosion potential.

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 length of time that soil formation processes have been acting on the soil material. For general purposes, soils are grouped into soil associations consisting of one or more major soil series and at least one minor soil series. Fifteen major soil associations are shown in figure 2.4-1. These soil associations are those recognized by the individual states in which they were mapped and thus differ somewhat in nomenclature.

Soils in the Springfield Plateau region were formed from cherty limestones and dolomite on steep to hilly topography. A thin loess mantle is present on nearly level areas and ridgetops. These soils, developed under hardwood forests, are used primarily for woodland due to stoniness, steep topography, low fertility, and low available water capacity. Some of the more level, fertile areas are suitable for cropland, forage, and pasture.

In general, soils in the Osage Plains region were formed from weathered shales, limestones, alluvium, and sandstones. These soils were developed on rolling uplands, nearly level prairie, stream terraces, or floodplains, primarily under tall grasses or oak-hickory forests. They have low to moderate fertility and are used for cropland, forage, and pasture.

Soil-engineering properties significant to mining and reclamation operations include depth to bedrock, slope, permeability, available water capacity, soil reaction, and erosion potential. Suitability ratings of soil used as a plant-growth medium in the reclamation of drastically disturbed lands are published by the U.S. Department of the Interior (1977).

Most soils in Area 40 are moderately deep to deep: although depth to bedrock ranges from less than 20 inches for the Sogn and Darnell series, it is greater than 5 feet for about one-half of the soils represented in the area. Slopes range from virtually zero for some of the alluvial soils to 60 percent for soils on sharply dissected uplands.

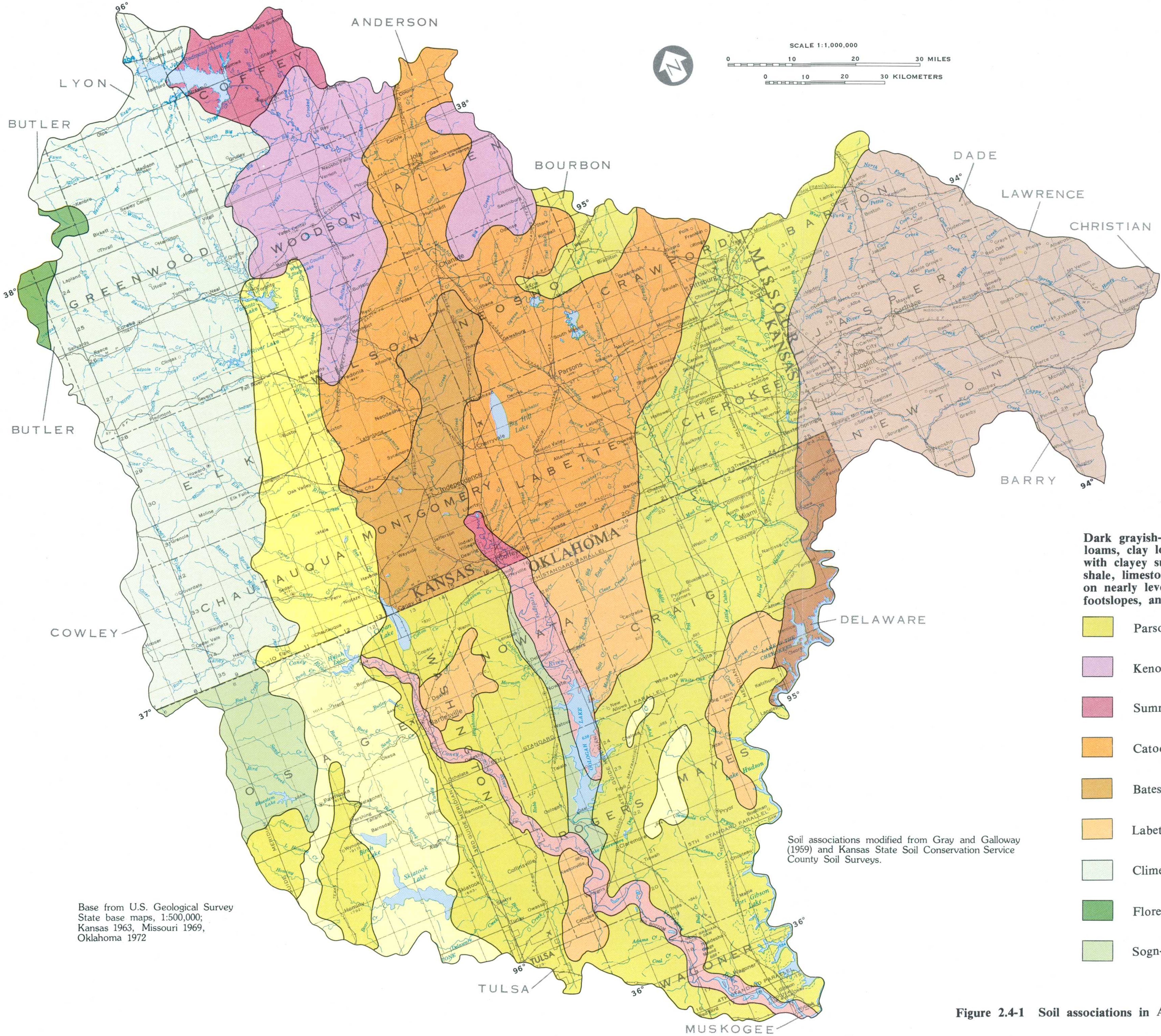
Soil permeability, defined as the estimated rate of vertical transmission of water in saturated soil under unit pressure head, ranges from very slow (less than 0.06 inch per hour) to moderate (0.6 to 2.0 inches per hour). In general, permeabilities are lowest in soils developed from shale, clay shale, and alluvium, and are moderate in soils developed from sandstone and limestone.

Available water capacity is defined as the difference between the volume of water in the soil at field capacity and the volume at the wilting point of most plants. In Area 40, available water capacity is significant in the valley and alluvial soils: these deep, silty soils hold much water that plants can extract. Available water capacity is moderate in soils that are greater than 40 percent clay, and is least in gravelly soils, such as those in many parts of the Springfield Plateau, and in shallow soils. Available water capacity also is low in some clay soils, which hold water so tightly that plants are unable to extract it.

Soil reaction, the acidity or alkalinity of the soil expressed in pH units, ranges from strongly acid to mildly alkaline (pH 5.0 to 7.5). Those soils formed from sandstone and shale tend to be strongly acidic to neutral (pH 5.0 to 7). Those soils formed on material weathered from shale with interbedded limestone may be slightly acid to mildly alkaline (pH 6.0 to 7.5) due to release of calcium carbonate from the limestone. Soil reactions in alluvial soils vary with the composition of the material from which they were derived.

Erosion potential is affected by such factors as permeability rates, soil texture and stability, soil depth, slope, and vegetative cover. Most soils in Area 40 have moderate erosion potential. Clayey soils under native vegetation or carefully managed cropland and pasture undergo very little erosion. Sandy soils, soils on steep slopes, or soils that have been denuded are more likely to be eroded.

Discussion of these and other important soil properties, as well as more detailed maps and descriptions of individual soil series and associations, are available in publications of the U.S. Department of Agriculture, Soil Conservation Service. For information on Soil Surveys for individual counties and Soil Interpretations Records for each soil series, contact the Soil Conservation Service offices in Salina, Kans., Columbia, Mo., or Stillwater, Okla.



Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Soil associations modified from Gray and Galloway (1959) and Kansas State Soil Conservation Service County Soil Surveys.

EXPLANATION

SOIL ASSOCIATIONS OF THE SPRINGFIELD PLATEAU

Light to dark-brown silty soils and dark prairie soils with red cherty clay subsoils, developed from cherty limestone and dolomite on nearly level to steep uplands and hills

- Clarksville-Nixa-Baxter
- Bodine-Baxter

SOIL ASSOCIATIONS OF THE OSAGE PLAINS

Dark grayish-brown and black silt loams, clay loams, and silty clays with clayey subsoils, developed from shale, limestone, and sandstone on nearly level to steep uplands, footslopes, and terraces

- Parsons-Dennis-Bates
- Kenoma-Woodson-Dennis
- Summit-Kenoma-Lula
- Catoosa-Kenoma-Zaar
- Bates-Dennis-Collinsville
- Labette-Summit-Sogn
- Clime-Martin-Sogn
- Florence-Irwin-Sogn
- Sogn-Summit

Light- and dark-brown fine sandy soils with reddish silty clay and sandy clay loam subsoils, developed from sandstone and shale on nearly level to moderately sloping uplands

- Steedman-Stephenville-Darnell
- Darnell-Stephenville

Alluvial soils

- Verdigris-Osage-Lanton
- Verdigris-Osage

Figure 2.4-1 Soil associations in Area 40.

Most of Area Consists of Farms and Rangelands

Land-use and land-cover maps and resource evaluation using remote-sensing techniques provide detailed information for many applications.

Land use varies with the geology, soils distribution, climate, and topography of an area. Area 40 includes land in four major land-resource regions, as defined by Austin (1965). These four regions are distinguished by percentage distribution of cropland, rangeland or pasture, and woodland, as shown in figure 2.5-1. Those land-use types that constitute a relatively minor percentage of the total area - such as urban and industrial areas, strip-mined lands, and barren lands - are not differentiated but are designated "other".

The westernmost part of the area lies within the Central Great Plains Winter Wheat and Range Region and consists primarily of rangeland or pasture covered with native grasses and grazed by beef cattle. About one-fifth of this region is cropland used for raising wheat, grain sorghum, and alfalfa. Scattered parcels of woodland are present. Population density in this part is very sparse and there are no incorporated towns of 10,000 or more.

Part of Osage County, Okla., lies within the Southwestern Prairies Forage Region in which rangeland or pasture, covered by shrubs and grasses and used for grazing, is the predominant land-use category. Open woodlands with grass understory, also used for grazing, are the next most common land-use type in this region. Croplands, covering about 20 percent of the area, are used for growing small grains, grain sorghum, soybeans, and alfalfa. Population density is sparce and urban centers are small.

The largest part of Area 40 lies within the Central Feed Grains and Livestock Region. About one-half of this land is cropland, with wheat, soybeans, corn, grain sorghum, and other feed grains being the major crops. Rangelands and pastures are covered with both native grasses and tame grasses and legumes. About 10 percent of this land-use region, particularly in Missouri and Oklahoma, is woodland. Coal-mined lands, which may be barren, forested, or in pasture, also are present in this part of the area. Major urban centers include Chanute, Coffeyville, Independence, Iola, Parsons, and Pittsburg, Kansas; and Bartlesville, Miami, and Tulsa, Oklahoma.

The eastern part of Area 40 lies within the East and Central General Farming and Forest Region. This area approximately corresponds with the Springfield Plateau physiographic section, and is about 60 percent forest or woodland in either farm woodlots or large holdings. The remaining 40 percent is about equally divided between cropland and pasture. Principal crops include corn, feed grains, and hay for dairy cattle and other livestock. Some cropland is in orchards and vineyards. Pastures are covered primarily by tame grasses and legumes. Some parts of this land-resource region are barren due to previous mining for zinc and lead ores and coal. Joplin and Carthage, Mo., are the largest urban areas; much of the rest of this region is sparsely populated.

Additional land-use information is available as a result of the increasing accessibility of aerial photography and other 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 and show two levels of classification (Anderson and others, 1976) using a minimum mapping unit of 4 hectares (about 10 acres). Land-use maps available for Area 40 are shown in figure 2.5-2. Information on ordering these maps may be obtained from:

Mid-Continent Mapping Center (NCIC-M)
U.S. Geological Survey
1400 Independence Road
Rolla, Missouri 65401
Phone: (314) 341-0851

Kansas land-use patterns also are delineated on a map at a scale of 1:1,000,000 (Williams and Barker, 1973). The Kansas Applied Remote Sensing (KARS) Program, located in the University of Kansas Space Technology Center, provides assistance to local, regional, State, and Federal agencies in the design, interpretation, and application of remote-sensing data systems. Major areas of KARS Program Research and applications are:

- Land-use and land-cover inventory, change detection and mapping
- Irrigated-lands inventories
- Water-resources management
- Wildlife-habitat evaluation
- Strip-mined-lands assessment
- Crop- and rangeland-resource inventory and evaluation
- Integrated natural-resources inventories
- Geographic-information-system design, construction, and application
- Thematic mapping
- Technology transfer and remote-sensing education

For additional information contact:

Kansas Applied Remote Sensing (KARS) Program
University of Kansas
Space Technology Center
2291 Irving Hill Road
Lawrence, Kansas 66045
Phone (913) 864-4775

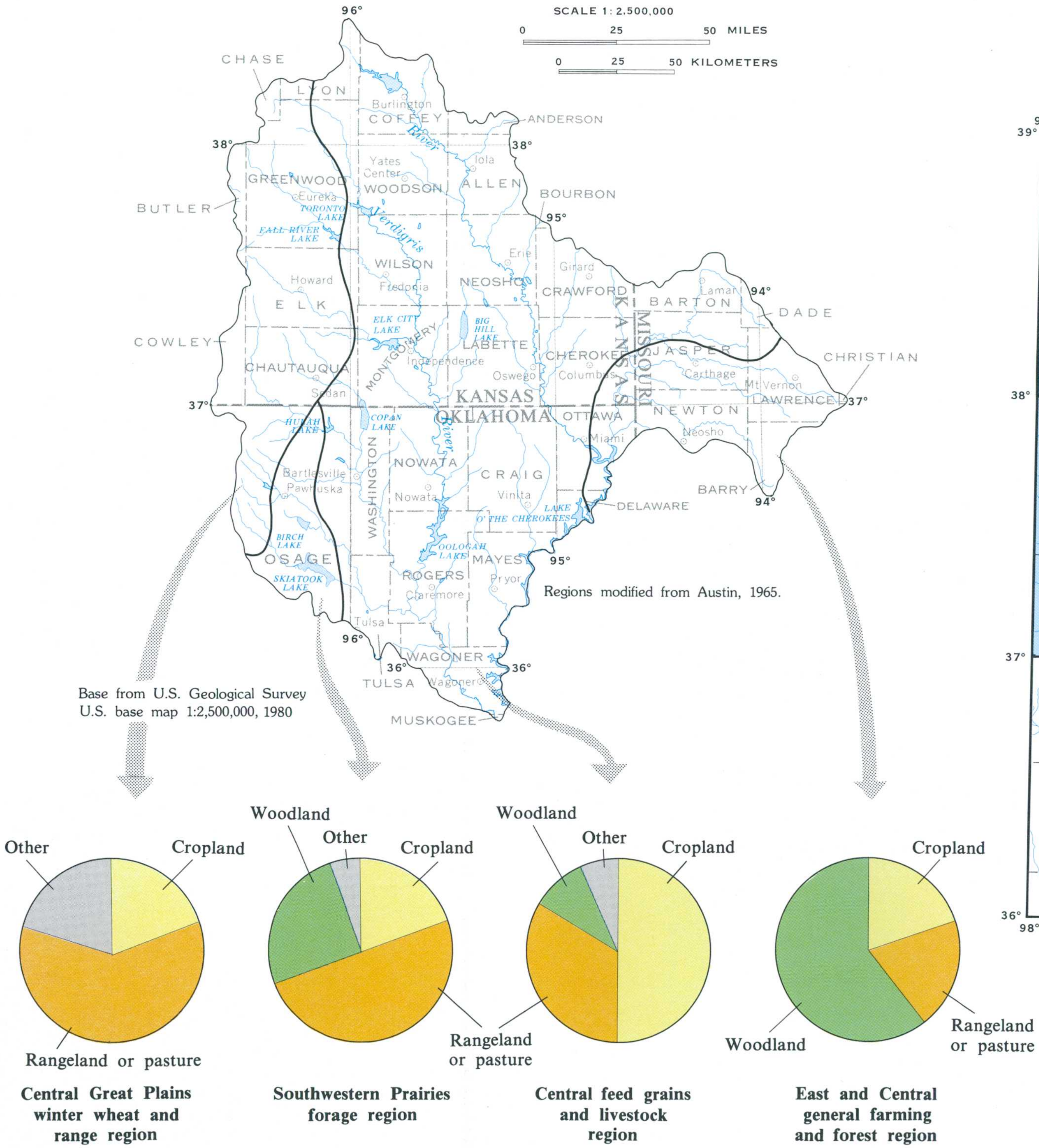
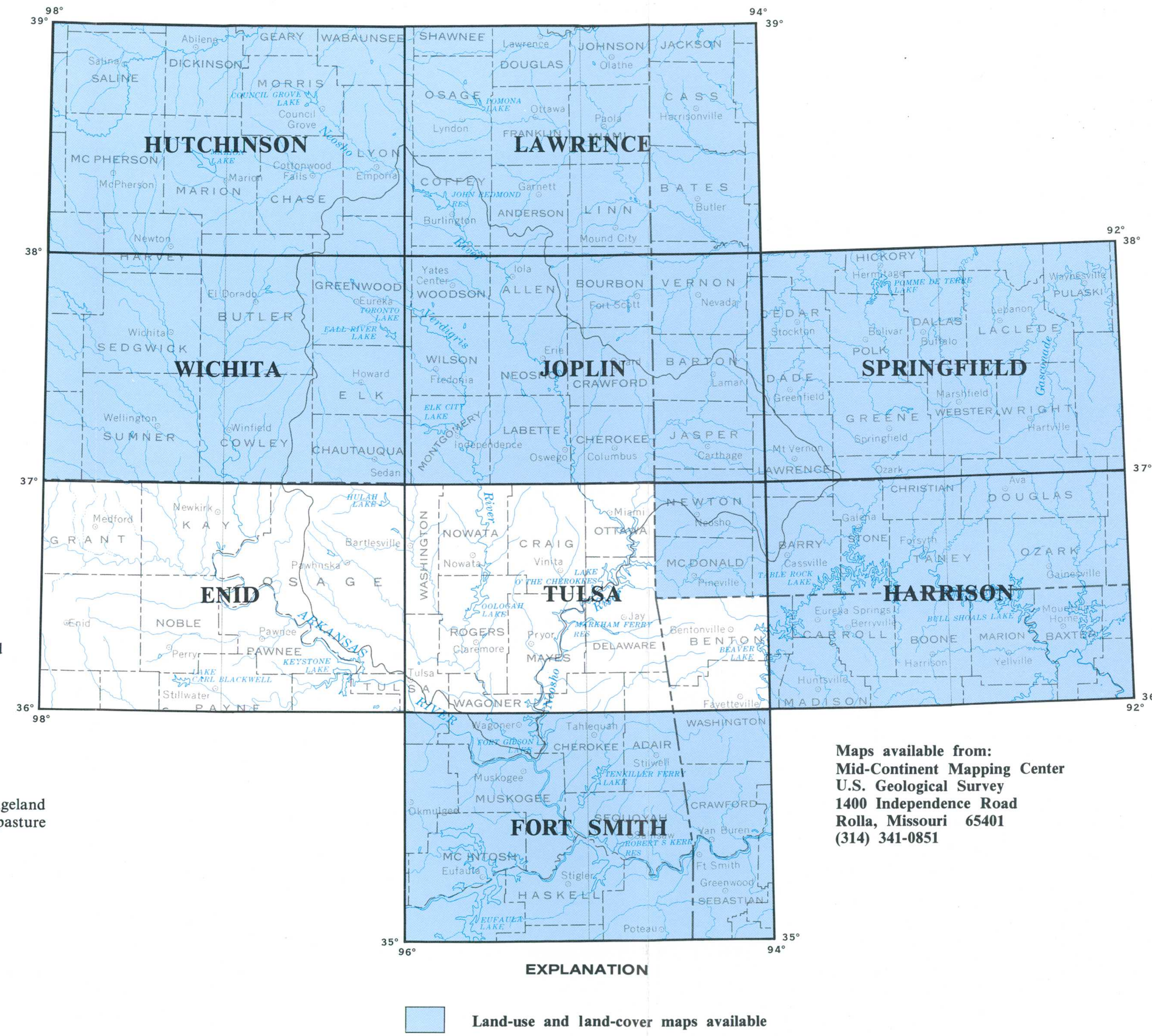


Figure 2.5-1 Distribution of land uses in four major land-resource regions.



Maps available from:
Mid-Continent Mapping Center
U.S. Geological Survey
1400 Independence Road
Rolla, Missouri 65401
(314) 341-0851

Figure 2.5-2 Land-use and Land-cover maps available for Area 40.

Area 40 Characterized by Humid, Continental Climate

Average annual precipitations ranges from about 32 to 42 inches; late summer to early winter is the driest period and spring is the wettest.

Area 40 has a humid, continental climate; summer generally is hot and spring and autumn are mild with warm days and cool nights. Winters usually are mild except for brief periods of cold weather associated with arctic fronts.

Mean annual temperatures range from 56° Fahrenheit in the north to 61° Fahrenheit in the south. Average temperature extremes from north to south across the area have a minimum range of 30° to 38° Fahrenheit during January to a maximum range of 79° to 82° Fahrenheit in July. The growing season ranges from 190 days in the north to 210 days in the south.

Average annual precipitation ranges from about 32 inches along the western edge of the area to about 42 inches along the eastern edge (fig. 2.6-1). Precipitation varies seasonally with the driest period in late summer to early winter and the wettest period in the spring. A large percentage of rainfall occurs during short, intense thunderstorms associated with squall lines ahead of frontal systems during spring and summer; about 75 percent of the annual precipitation falls during this period (fig. 2.6-2). Precipitation is less intense and more widespread during autumn and winter. Some winter precipitation falls as snow; average annual snowfall ranges from 15 inches in the north to 8 inches in the south.

Yearly percentage frequency for wind direction and velocity is fairly uniform (fig. 2.6-3). Prevailing winds are southerly during all months except January and February when northerly winds are predominant. Average yearly wind speeds are 10-12 miles per hour. Winds of 30-40 miles per hour are not uncommon when storm centers move across the area. Strong, gusty winds commonly are associated with thunderstorms in the summer and behind cold fronts in the winter.

Because of the warm temperatures and windy conditions, evaporation is significant. Average pan evaporation ranges from about 60 to 75 inches (fig. 2.6-4).

Climatological data are useful for developing correlations and statistical analyses. The results of an analysis of rainfall data to compute the 10-year, 24-hour rainfall intensity are shown in figure 2.6-5.

Daily climatological data are published monthly for each State by the National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, North Carolina. Statistical information based on analysis of historical rainfall frequency are presented in a report by the U.S. Department of Commerce (1961).

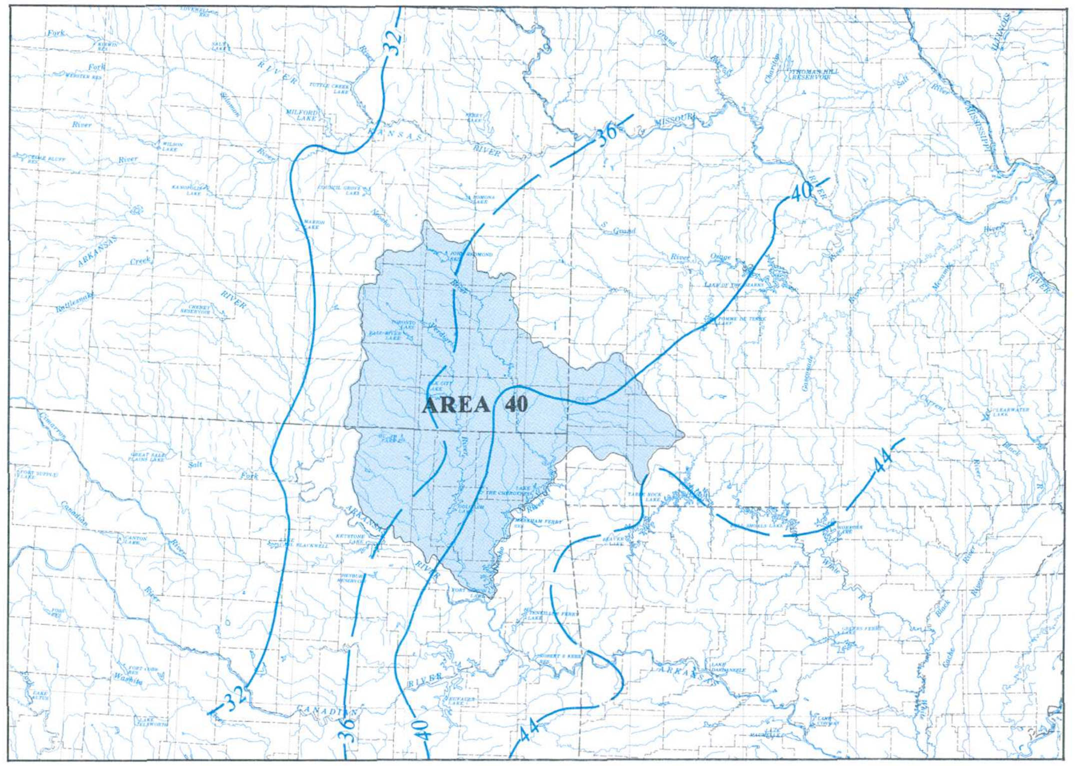


Figure 2.6-1 Normal annual total precipitation, in inches, 1931-1960 (from U.S. Environmental Data Service, 1968).

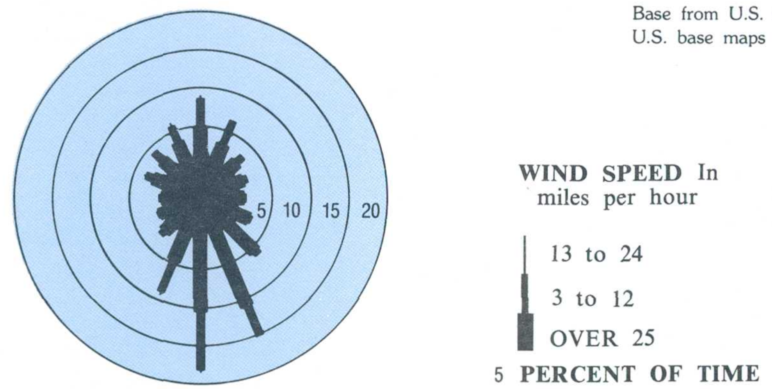


Figure 2.6-3 Yearly percentage frequency of occurrence for wind direction at Tulsa, Oklahoma (from Oklahoma Water Resources Board, 1971).

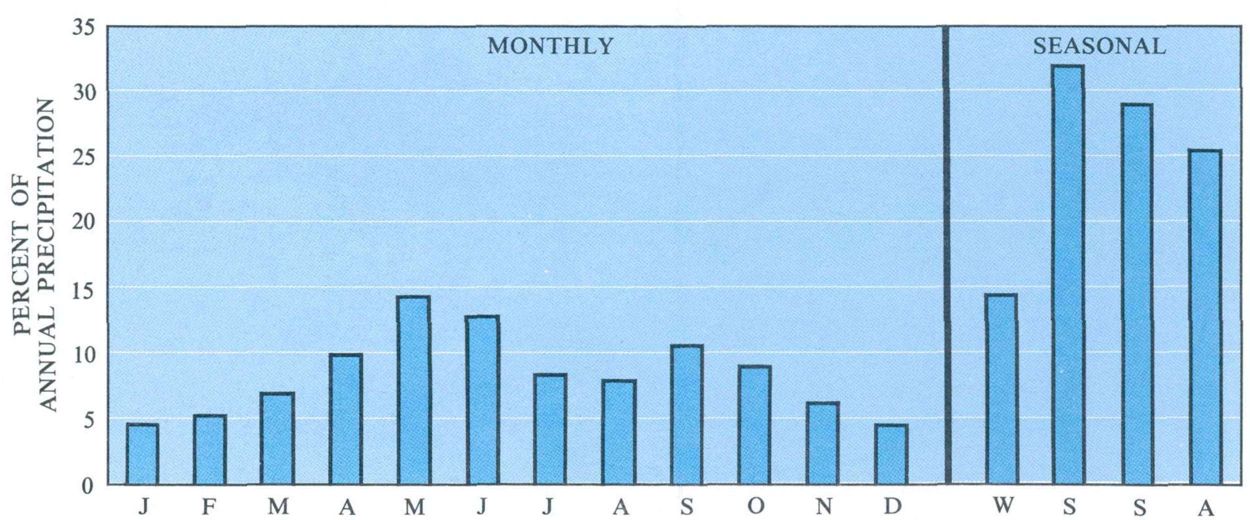
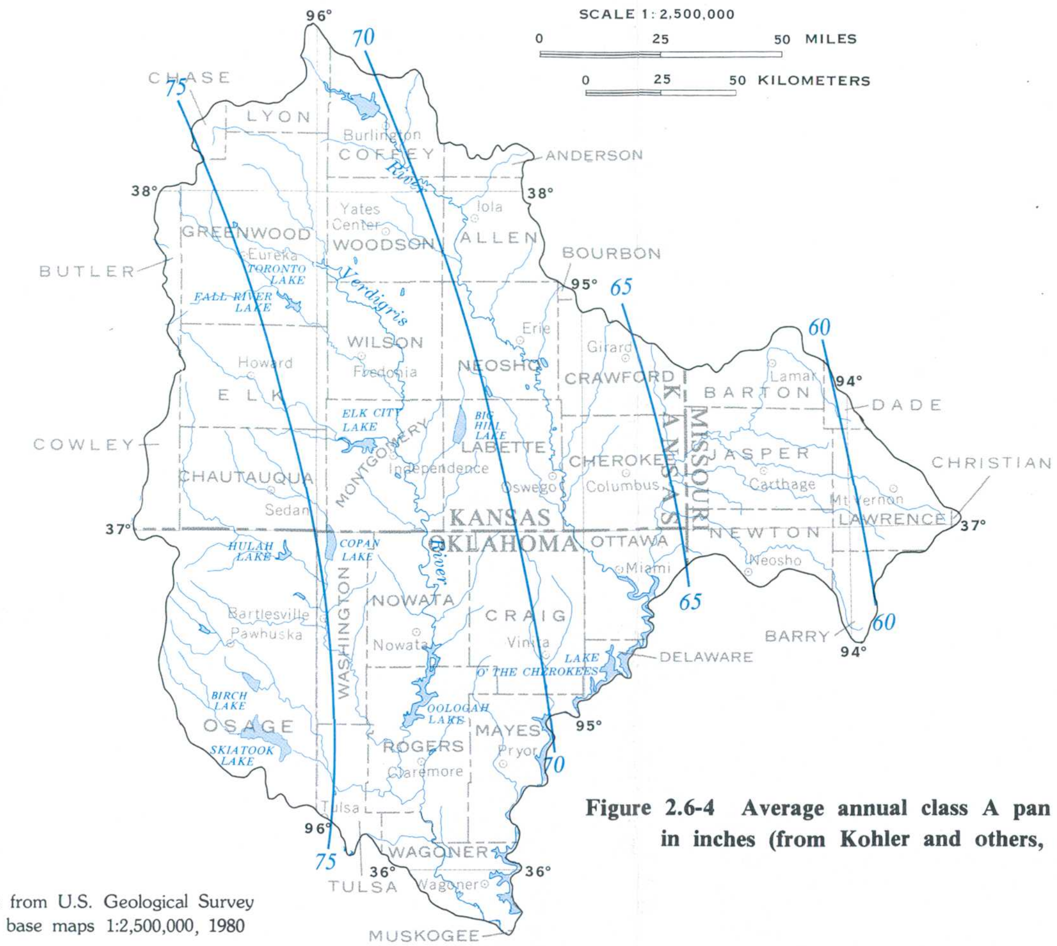


Figure 2.6-2 Monthly and seasonal distribution of annual precipitation at Tulsa, Oklahoma (from Oklahoma Water Resources Board, 1971).



Base from U.S. Geological Survey
U.S. base maps 1:2,500,000, 1980

Figure 2.6-4 Average annual class A pan evaporation, in inches (from Kohler and others, 1959).

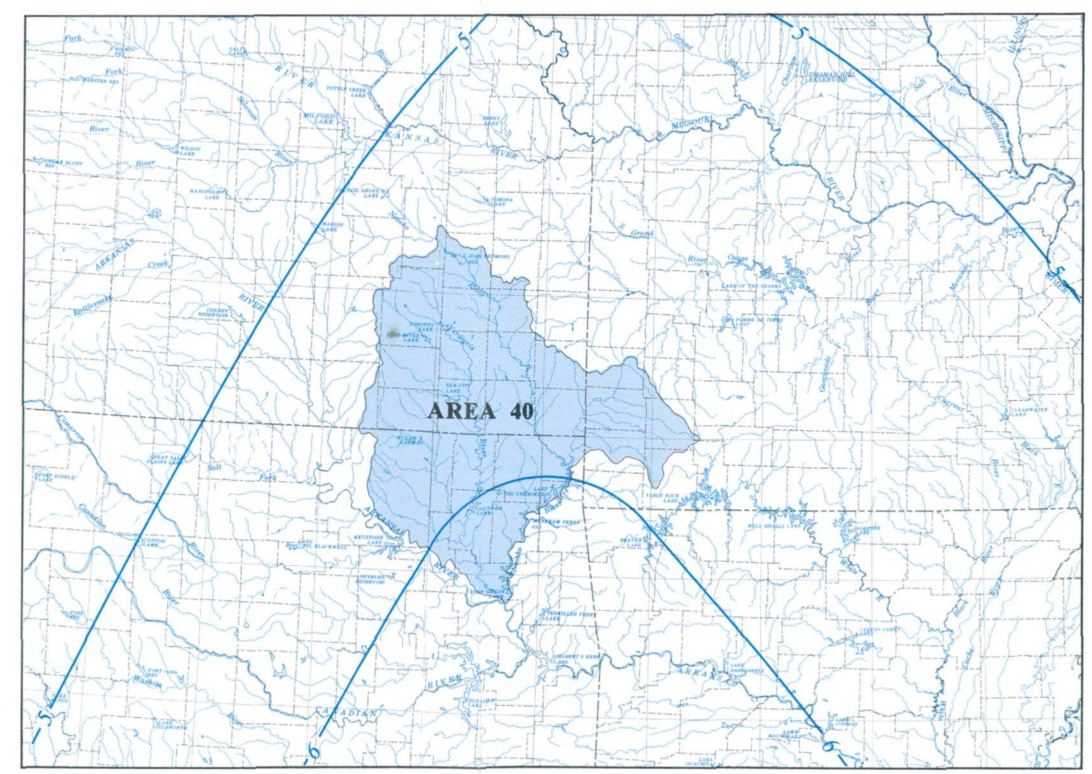


Figure 2.6-5 10-year, 24-hour rainfall, in inches (from U.S. Department of Commerce, 1961).

Principal Use of Water in Area is for Public Supply

Most of the water used in Kansas and Oklahoma during 1980 was derived from surface-water sources, while in Missouri approximately equal volumes of surface and ground water were used.

Annual reported water use for irrigation, industry, and public supply in Area 40 by county is illustrated in figure 3.1-1. For counties in Missouri and Oklahoma, 1980 was used as a representative year; for counties in Kansas, 1981 data were considered more reliable than the 1980 figures. Volumes shown in fig. 3.1-1 represent those reported to the respective collecting agencies and may not necessarily have been recorded on similar bases.

Counties in the Osage Plains region of Kansas and Oklahoma rely primarily on surface water from reservoirs and streams to meet irrigation, industrial, and public-supply needs. In the Springfield Plateau region of Missouri and adjacent parts of Kansas and Oklahoma, the use of surface and ground water is more nearly equal due to the greater availability of ground water. The largest use of both surface and ground water is for public supply, which includes water delivered through both municipal and rural water systems. The large volumes of surface water used for public supply in Tulsa County, Oklahoma, are consumed mainly by the city of Tulsa and are derived from Lake Spavinaw and Lake Eucha, two reservoirs east of Area 40 in Delaware County, Oklahoma.

Records of water use by counties are maintained by various State agencies. Data are available through computer storage or in publications of these agencies. For further information on water use in counties of Area 40 contact:

Division of Water Resources
State Board of Agriculture
901 Kansas Avenue, 2nd Floor
Topeka, Kansas 66612
(913) 296-3717
or

Missouri Division of Geology and Land Survey
111 Fairground Road
P. O. Box 250
Rolla, Missouri 65401
(314) 364-1752
or

Oklahoma Water Resources Board
1000 N. E. 10th St.
P. O. Box 53585
Oklahoma City, Oklahoma 73152
(405) 271-2555

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 a more timely, consistent water-use data base that can be used for water policy and management by Federal, State, and local water 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 the storage and retrieval of these data, and improve the methods of disseminating the information (Mann and others, 1982). Water withdrawal, return-flow, and the use data are compiled for 12 use catgories 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 information. Aggregated information will be available throught the National Water-Use Data System (NWUDS). This water-use 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 8.0.

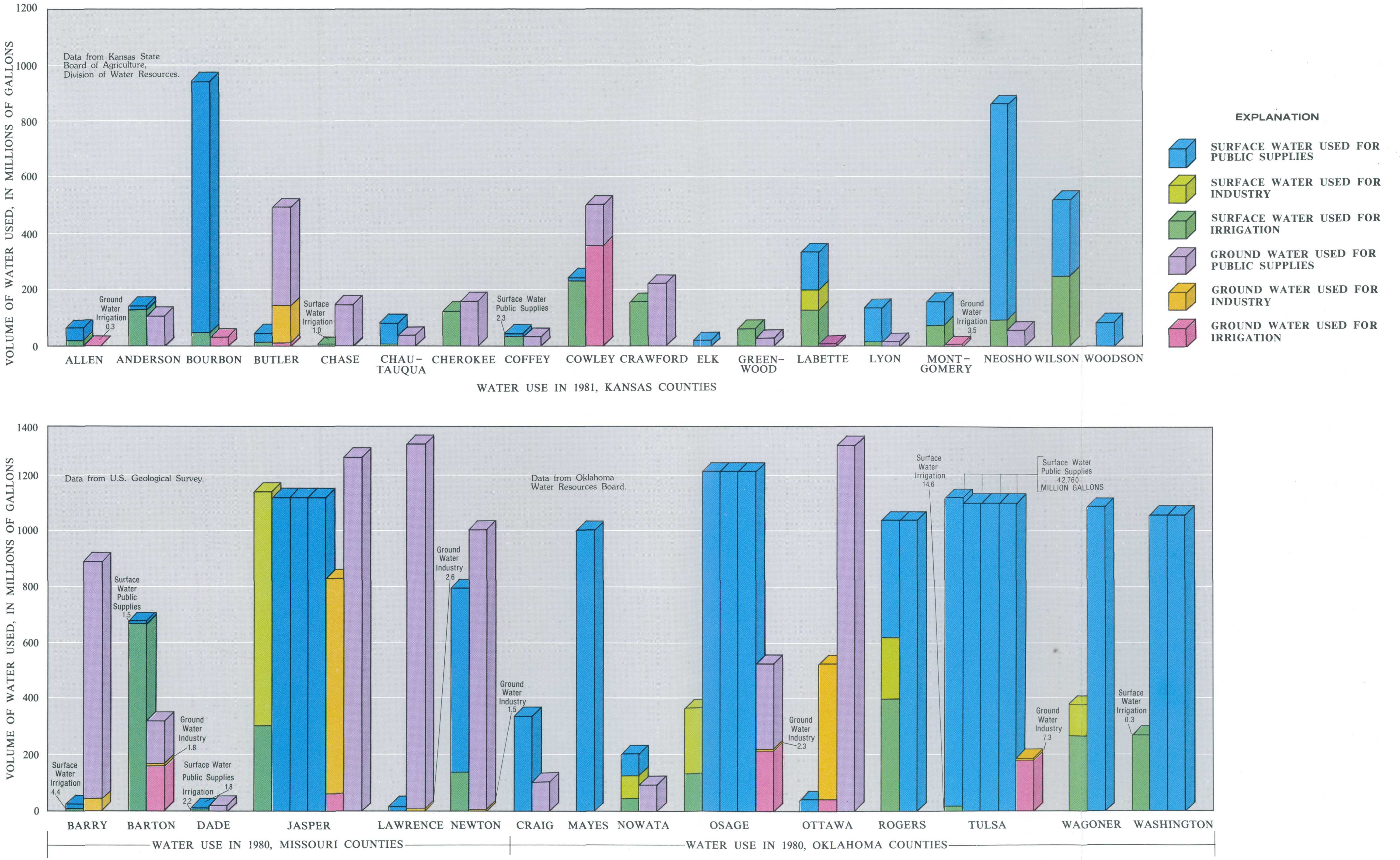


Figure 3.1-1 Annual reported water use in Area 40 by county.

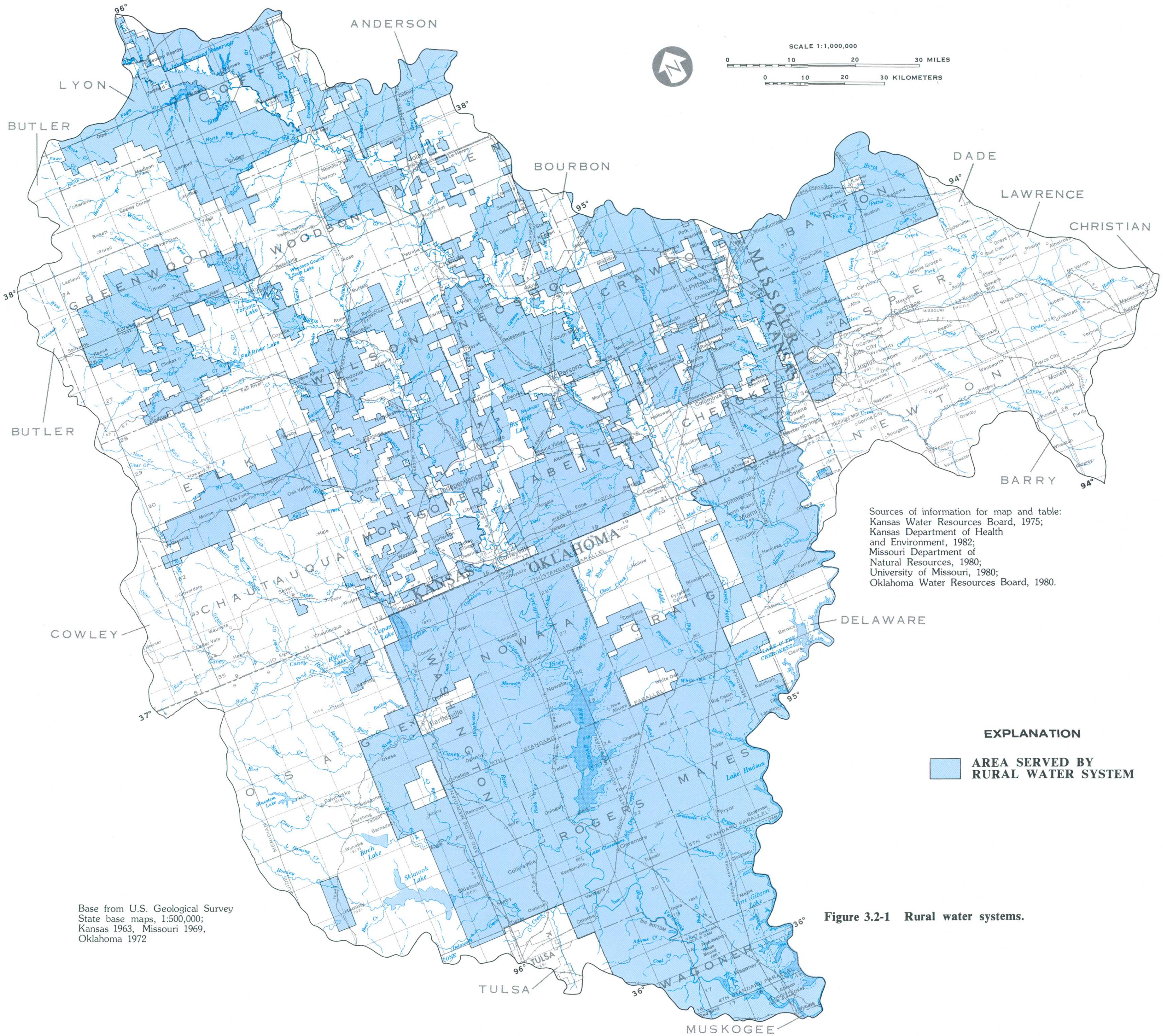
About One-Fourth of Population Supplied with Water from Rural Water Systems

Of 140 Rural water districts in the area, 118 derive supplies from surface-water sources.

Rural water districts are organizations formed to meet the water-supply needs of specific rural areas that otherwise would have no dependable source of water. With funds made available by the Farmers Home Administration and State grants, rural water districts are able to construct and maintain ponds, reservoirs, wells, pipelines, pumping installations, and storage facilities for their water systems.

The areas served by rural water systems are shown in figure 3.2-1. Many rural water districts include small communities and incorporated towns. The number and type of systems in each county, as well as the populations served, are given in table 3.2-1. A total of 140 systems serves about 130,000 people, or about one-fourth of the population of Area 40.

Most of the rural water systems use surface-water sources. Throughout much of the area, wells supply only small quantities of water suitable for domestic and stock uses, and commonly go dry during prolonged droughts. The exceptions are some water districts in the eastern counties that use water from deep wells completed in the Roubidoux Formation of Ordovician age.



Sources of information for map and table: Kansas Water Resources Board, 1975; Kansas Department of Health and Environment, 1982; Missouri Department of Natural Resources, 1980; University of Missouri, 1980; Oklahoma Water Resources Board, 1980.

Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Figure 3.2-1 Rural water systems.

Table 3.2-1 Rural water systems.

STATE AND COUNTY	NUMBER OF SYSTEMS	POPULATION SERVED	SOURCE OF WATER (NUMBER OF SYSTEMS)	
			SURFACE WATER	GROUND WATER
KANSAS				
Allen	10	744	10	--
Anderson	1	1,525	1	--
Bourbon	1	900	1	--
Chautauqua	1	168	1	--
Cherokee	7	4,090	--	7
Coffey	2	2,461	2	--
Crawford	7	6,380	1	6
Elk	1	380	1	--
Greenwood	2	1,879	2	--
Labette	8	3,255	8	--
Lyon	3	1,587	3	--
Montgomery	12	4,978	12	--
Neosho	12	4,585	12	--
Wilson	12	3,045	12	--
Woodson	1	1,150	1	--
MISSOURI				
Barton	1	4,000	--	1
Jasper	2	3,750	1	1
OKLAHOMA				
Craig	7	5,017	5	2
Mayes	7	11,860	7	--
Nowata	7	2,829	7	--
Osage	6	6,793	6	--
Ottawa	5	4,313	--	5
Rogers	9	21,436	9	--
Tulsa*				
Wagoner	9	19,802	9	--
Washington	7	12,928	7	--
TOTAL	140	129,855	118	22

*Rural parts of northern Tulsa County are supplied by systems in Osage, Rogers, and Washington Counties.

Data Available for 166 Network Stations and Numerous Miscellaneous Sites

Data are published in U.S. Geological Survey Water-Supply Papers and annual State water-data reports, and are accessible through computer storage.

Records of streamflow, water quality, and reservoir contents are essential to an understanding of the surface-water hydrology of an area and to any evaluation of the effects of mining and reclamation on this system. Both historic data and current, site-specific data are needed. Surface-water data collected in Area 40 by the U.S. Geological Survey include records of stage, discharge, and water quality of streams and records of stage and contents of reservoirs. Systematic data have been collected at 166 stations, of which 72 are currently active. Location of both active and discontinued stations are shown in figure 4.1-1. More detailed descriptions of these stations, as well as the periods of record and types of data available, are given in section 9.3.

Records of stage, or water-surface elevation above an arbitrary datum, are obtained either from direct readings on a non-recording gage or from a continuous water-stage recorder. Stage records, when combined with direct measurements of streamflow (discharge) to derive stage-discharge relations, are used to compute discharge for any given stage. For stations with continuous recorders, daily values for streamflow are available; for other stations only limited data are collected. Crest-stage gages register the peak stage occurring between inspections and provide records of peak discharges for determining flood-frequency characteristics. Direct measurements at low-flow stations, made during dry periods when streamflow is derived primarily from ground-water storage, can be correlated with continuous-discharge records from nearby streams to indicate low-flow characteristics.

For reservoir stations, capacity tables are prepared relating contents to stage. Application of stage readings to capacity tables gives the contents, from which daily, monthly, and yearly changes can be computed.

Water-quality data commonly are collected at stream-gaging stations in order to provide relationships between streamflows and concentrations or loads of constituents. Several types of data are collected, but not necessarily at each station. Temperature and specific conductance commonly are recorded by means of automatic monitors. Temperature, specific conductance, pH, and dissolved oxygen usually are measured when water-quality samples for chemical analyses are collected.

Sediment data may include determinations of suspended-sediment concentrations as well as particle-size analyses of suspended sediment and bed material. These data are used to establish relations between sediment yields and streamflow, and to predict long-term sediment characteristics of streams. Particle-size data are useful in identifying the character of the sediment in transport and deposited on the streambed.

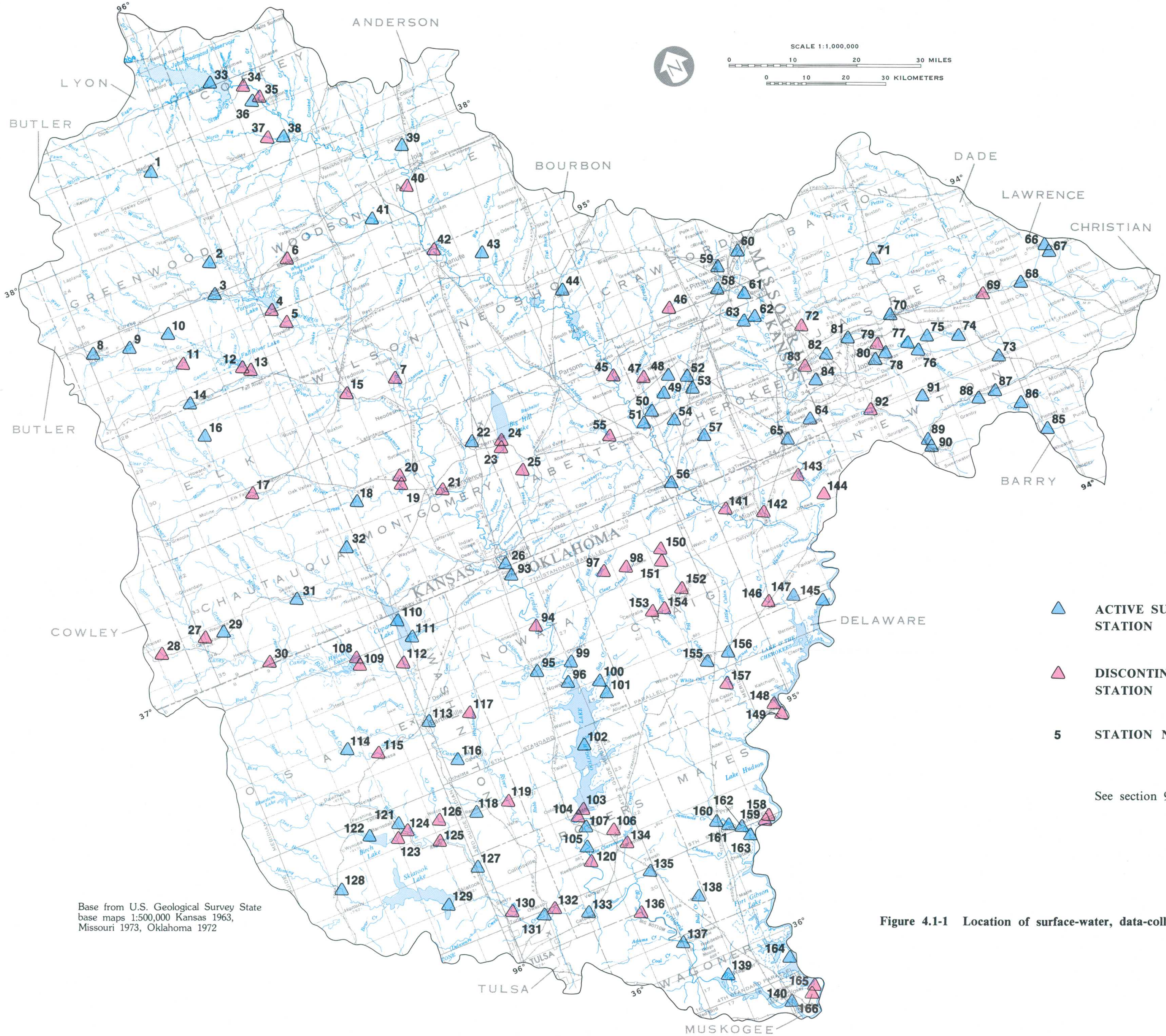
The National stream-quality accounting network (NASQAN) is a national data-collection network designed by the U.S. Geological Survey to depict areal variability in streamflow and water quality on a year-to-year basis and to detect and assess any long-term changes (Ficke and Hawkinson, 1975). Data collected at NASQAN stations include discharge measurements and samples for chemical-quality, suspended-sediment, and phytoplankton analyses. The Area 40 surface-water network includes three NASQAN stations: Neosho River near Parsons, Kansas (station 45), Verdigris River near Iola, Oklahoma (station 136), and Neosho River below Fort Gibson Lake near Fort Gibson, Oklahoma (station 166).

Additional surface-water data are available for about 335 sites not shown in figure 4.1-1. These sites generally were established for site-specific or special-purpose studies, primarily in areas previously mined for coal, lead, or zinc. These studies are discussed in section 4.3. The data collected at streams, lakes, and strip pits for these projects can be used to supplement data from the estabished network in certain areas.

Surface-water data from network stations and miscellaneous sites in Area 40 are available from several sources. Records of discharge or stage of streams and contents or stage of lakes and reservoirs were published in the series of U.S. Geological Survey Water-Supply Papers entitled "Surface Water Supply of the United States" on an annual basis until 1961 and in a 5-year series for 1961-65 and 1965-79. Records for Area 40 are in part 7 of the series. Streamflow data also were released in annual water-data reports for each State from 1961-74. Records of chemical quality, water temperatures and suspended sediment were published from 1941-70 in an annual series of water-supply papers entitled "Quality of Surface Waters of the United States" (part 7). Water-quality records also were released in annual water-data reports for each State from 1964-74. Since 1975, data on streamflow, reservoir contents, and water quality have been published in annual water-data reports for each State.

Water-supply papers may be consulted in the libraries of the principal cities in the United States or may be purchased from 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 8.2.



EXPLANATION

ACTIVE SURFACE-WATER, DATA-COLLECTION STATION

DISCONTINUED SURFACE-WATER, DATA-COLLECTION STATION

5 STATION NUMBER

See section 9.3 for station description

Base from U.S. Geological Survey State base maps 1:500,000 Kansas 1963, Missouri 1973, Oklahoma 1972

Figure 4.1-1 Location of surface-water, data-collection stations.

Water-Level and Water-Quality Data Available

Water-level records exist for 438 wells in Area 40; water-quality data are available for 516 wells and springs.

Records of ground-water levels and ground-water quality in Area 40 provide a data base necessary to evaluate the effects of mining and reclamation on the recharge-discharge characteristics and chemical quality of the various aquifer systems. Long-term water-level and water-quality data are essential for proper management of ground-water resources for present and future generations.

Water-level records consisting of five or more measurements during a period of at least 1 year are available for 50 wells (fig. 4.2-1). Information on the location, depth, principal aquifer, and period of record for each of these water-level sites is given in section 9.4. Each well is identified by a 15-digit site-identification number based on latitude and longitude and by a local well number. Many of these wells were established as part of a network designed to provide the most significant data from the fewest wells in the most important aquifers. Water levels are measured either on a periodic basis or by means of continuous recorders. Fifteen wells, including two (sites 26 and 27) maintained by the Missouri Division of Geology and Land Survey, are currently (1982) being measured.

Additional water-level data are available for wells measured fewer than five times or for less than 1 year. These data have been collected primarily for short-term or site-specific studies. There are 388 such wells in Area 40; the number of wells in each county is given in table 4.2.1.

Water-quality data are available for 516 wells and springs. The number of sites in each county is given in table 4.2-2. The exact location of these wells and springs may be found by consulting published reports from each State (section 10.0). Many of these sites were established for various water-quality investigations in problem areas, particularly in areas mined for coal (section 4.3), and are not routinely sampled. Sites in Kansas are part of a continuing ground-water-quality monitoring network established in 1976 to provide broad-based information on the chemical quality of ground water throughout the State.

Information on water-level and water-quality sites, as well as the actual data collected, are available from the National Water Data Exchange (NAWDEX) and from the annual Water Resources Data reports published for each State by the U.S. Geological Survey. Additional information on ground-water resources may be obtained from the State agencies listed below:

Kansas Geological Survey
1950 Constant Avenue, Campus West
University of Kansas
Lawrence, Kansas 66045
(913) 864-3965

Missouri Division of Geology and Land Survey
111 Fairgrounds Road
P.O. Box 250
Rolla, Missouri 65401
(314) 364-1752

Oklahoma Water Resources Board
1000 N.E. 10th St.
P.O. Box 53585
Oklahoma City, Oklahoma 73152
(405) 271-2555

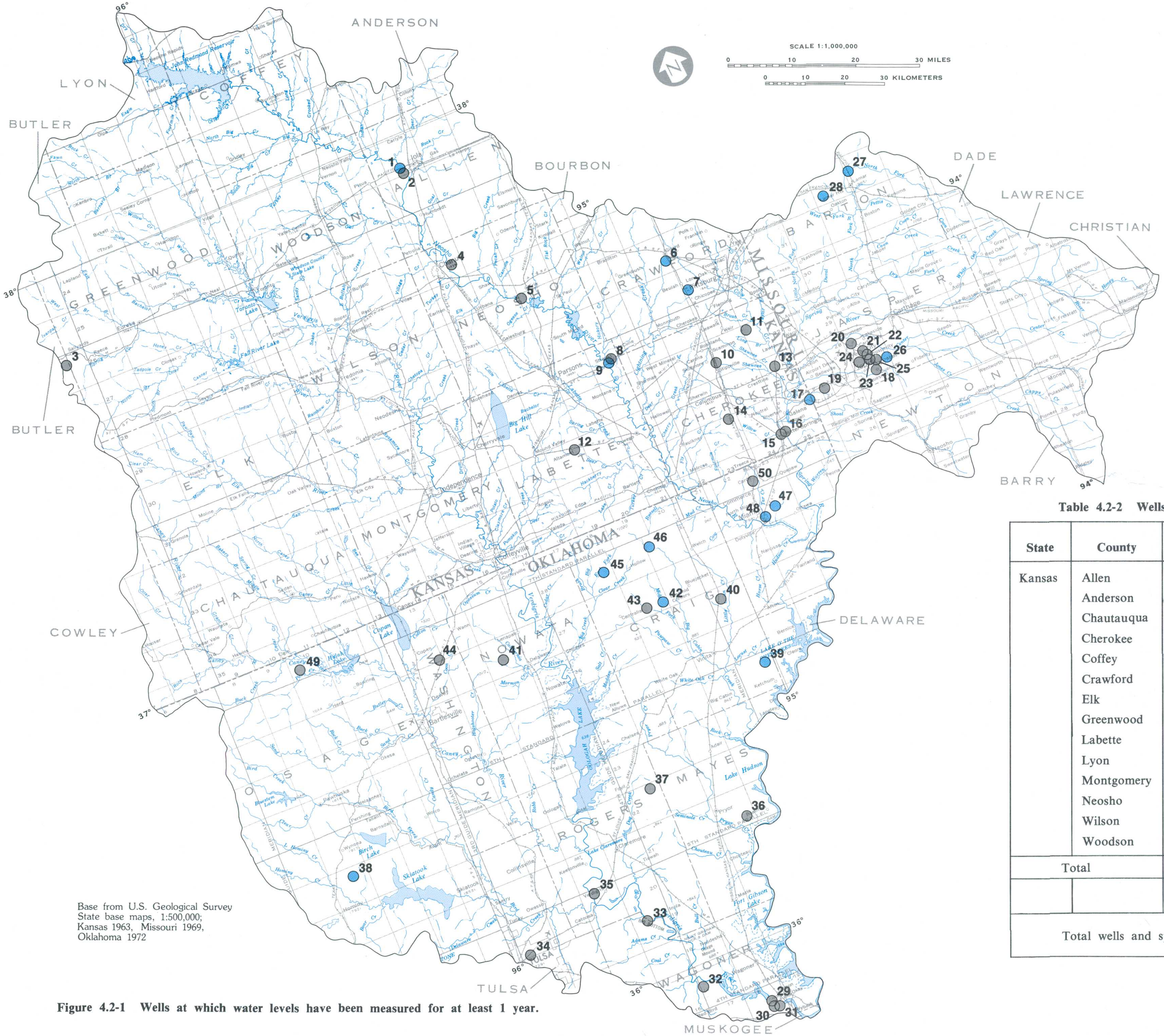


Figure 4.2-1 Wells at which water levels have been measured for at least 1 year.

EXPLANATION

- ACTIVE SITE
- DISCONTINUED SITE
- **23** SITE NUMBER

Table 4.2-1 Additional numbers of wells, at which water levels have been measured fewer than five times or for less than 1 year.

State	County	Number of wells
Kansas	Crawford	2
	Labette	1
Missouri	Barry	6
	Barton	37
	Dade	1
	Jasper	304
	Lawrence	17
	Newton	19
Oklahoma	Ottawa	1
Total		388

Table 4.2-2 Wells and springs for which water-quality data are available.

State	County	Number of wells	State	County	Number of wells	Number of springs
Kansas	Allen	5	Missouri	Barry	7	5
	Anderson	1		Barton	14	
	Chautauqua	4		Jasper	90	7
	Cherokee	10		Lawrence	16	7
	Coffey	4		Newton	23	14
	Crawford	4	Total		150	33
	Elk	6	Oklahoma	Craig	41	
	Greenwood	4		Delaware	3	
	Labette	4		Mayes	22	
	Lyon	2		Nowata	5	
	Montgomery	5		Osage	21	2
	Neosho	4		Ottawa	70	2
	Wilson	4		Rogers	83	
	Woodson	4		Tulsa	5	
Total		61		Wagoner	12	
				Washington	6	
			Total		268	4
Total wells and springs, Area 40 -- 516						

Special Studies Provide Hydrologic Data in Selected Areas of Coal Mining

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

As discussed in section 1.4 of this report, surface mining of coal may have detrimental effects on the hydrologic environment. In order to assess the extent, intensity, and duration of these effects, a variety of hydrologic data are needed. To meet this need, special studies have been or are being made in Area 40.

In the Oklahoma part of Area 40, hydrologic data have been collected on a regional basis as part of a cooperative program with the Oklahoma Geological Survey since 1976. Although the emphasis of this program has been on ground water, 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 determination of specific conductance and pH of well water, (3) laboratory determinations of chloride, iron, manganese, and sulfate in water from most wells inventoried, and (4) detailed chemical analyses of water from selected wells. Surface-water data include stream discharge and onsite determination of specific conductance and pH. Data for coal-mine ponds include profiles of specific conductance, pH, water temperature, and dissolved oxygen and laboratory determinations of chloride, iron, manganese, and sulfate.

The regional data-collection program in Oklahoma is supplemented with more intensive studies in the basins of Big Cabin Creek, East Fork Big Creek, Middle Fork Big Cabin Creek, and West Fork Big Cabin Creek in Craig County and the basin of Sweetwater Creek in Rogers County (fig. 4.3-1). Data collected in these basins, in addition to that collected as part of the regional program, include; (1) Periodic measurement of stream discharge and collection of stream-water samples for laboratory determinations of chemical quality and sediment, (2) continuous measurement of water levels in selected wells, and (3) continuous measurement of precipitation.

In the Kansas part of Area 40, a 4-year study was conducted in cooperation with the Kansas Department of Health and Environment to investigate streamflow and water-quality characteristics of streams draining coal-mined areas in Cherokee and Crawford Counties. From 1976 through 1980, data were collected for streamflow and the physical, chemical, and suspended-sediment characteristics of surface waters in the basins of Cherry, Cow, Deer, and Lightning Creeks (fig. 4.3-1). These data provide information on existing conditions (Bevans and Diaz, 1980), and can be used to develop and interpret relations between streamflow, water quality, and coal-mining and reclamation activities (Bevans, 1980). Cherry Creek basin subsequently was studied in more detail to determine the effects of mining and reclamation on hydrology (Kenny and McCauley, 1982). This study involved the use of aerial photography in conjunction with surface-water-quality data to indentify areal changes in vegetative type and vigor and to locate point sources of acid mine drainage.

Data for the water quality of 42 selected coal-mine ponds in Crawford and Cherokee Counties, Kansas, (fig. 4.3-1) were collected as part of a cooperative study with the U.S. Office of Surface Mining, Region IV, Kansas City. Selection of the ponds and timing of sampling were closely coordinated with remote-sensing activities of the Center for Public Affairs and the Space Technology Center at the University of Kansas. The resulting data base for the physical and chemical quality of mine-pond water could be useful in determining the potential for contamination of surface and ground waters from mine spoils in southeastern Kansas. Descriptive statistics and linear regressions relating selected chemical constituents to specific conductance, dissolved solids, and acidity have been published (Pope and Diaz, 1982).

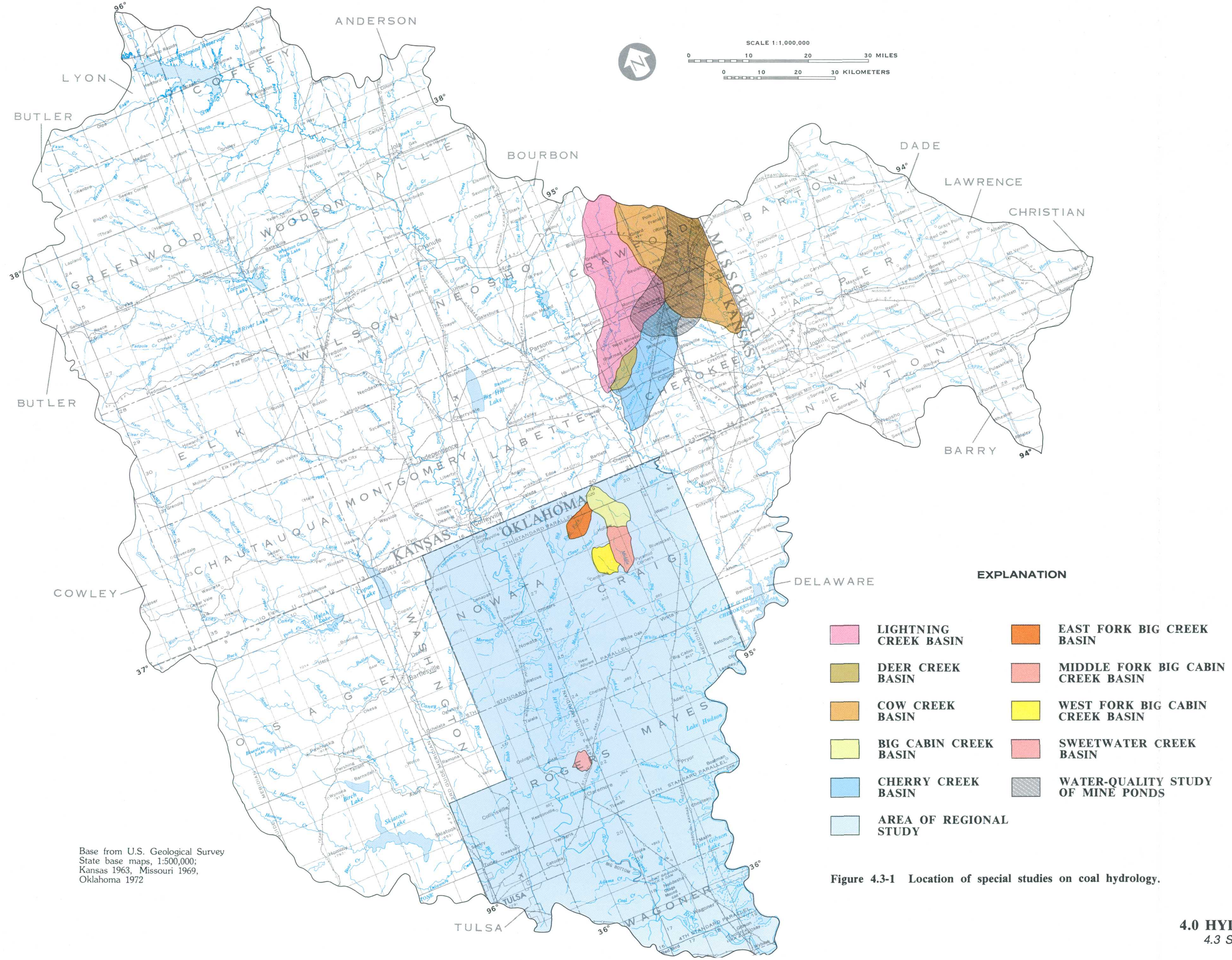


Figure 4.3-1 Location of special studies on coal hydrology.

Streamflow Varies Seasonally

Minimum streamflow occurs in later summer and autumn and many streams cease flowing during this period.

Seasonal changes in streamflow largely reflect the volume of rainfall and evapotranspiration. Minimum streamflow typically occurs in late summer and autumn when rainfall is least and evaporation is greatest. Many streams draining less than 250 square miles can be expected to cease flowing during this period. Maximum streamflow normally occurs in the spring when rainfall is greater and before evaporation reaches a summer peak. The streamflow pattern of Lightning Creek (fig. 5.1-1), which is typical for the area, is representative of most streams in the Osage Plains section of Area 40 (fig. 2.2-1). Streamflow is more sustained in the Ozark Plateaus section. For example, Shoal Creek above Joplin, Missouri (station 92), has flow of about 40 cubic feet per second 98 percent of the time (Feder and others, 1969).

Streamflow data from gaging stations having 20 or more years record show an average annual water yield of 0.57 cubic foot per second per square mile for streams in the Verdigris and Neosho River basins and an average annual water yield of 0.79 cubic foot per second per square mile in the Spring River basin (fig. 5.1-2). These differences largely reflect the water-storing characteristics of rocks underlying the respective basins. The Verdigris and Neosho basins are underlain mainly by shale and sandstone that have limited capacity to store water. The basin of Spring River is underlain by weathered chert and limestone that can store a large volume of water that is released slowly to the river and its tributaries.

Mean annual runoff and flood-discharge characteristics with selected recurrence intervals can be estimated for perennial, intermittent, and ephemeral streams where gaged streamflows are not available by use of equations developed for this purpose (Hedman and Osterkamp, 1982). These empirical equations permit the use of channel-geometry measurements as an alternative method of quickly estimating streamflow characteristics for ungaged streams.

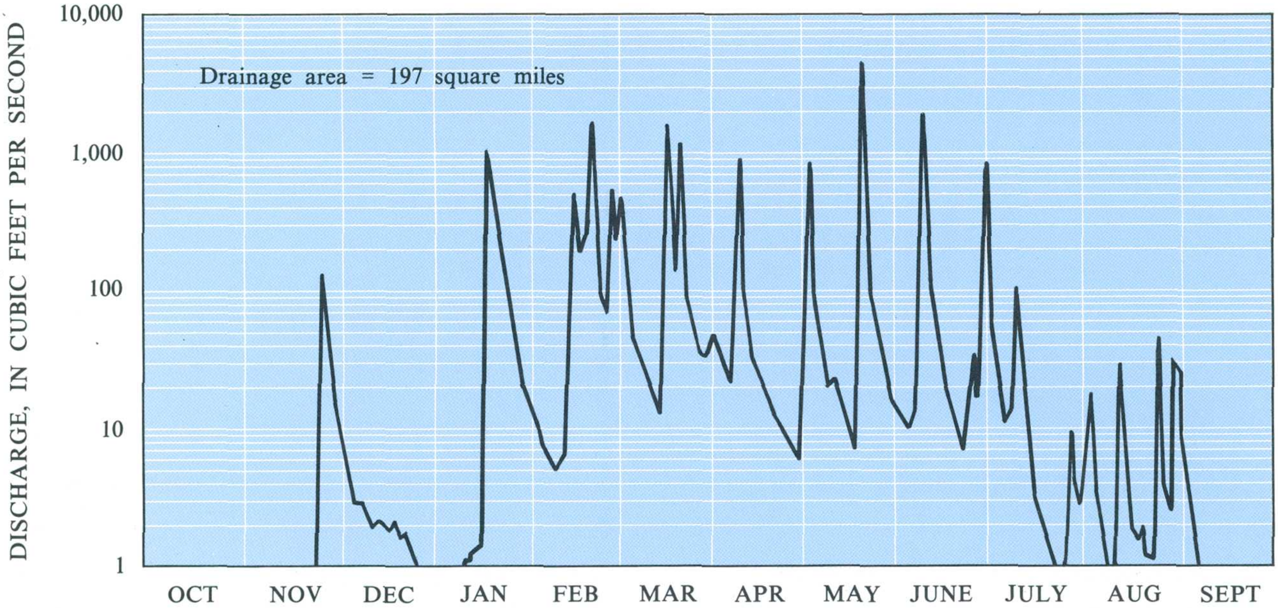


Figure 5.1-1 Hydrograph of mean daily discharge of Lightning Creek for water year 1979.

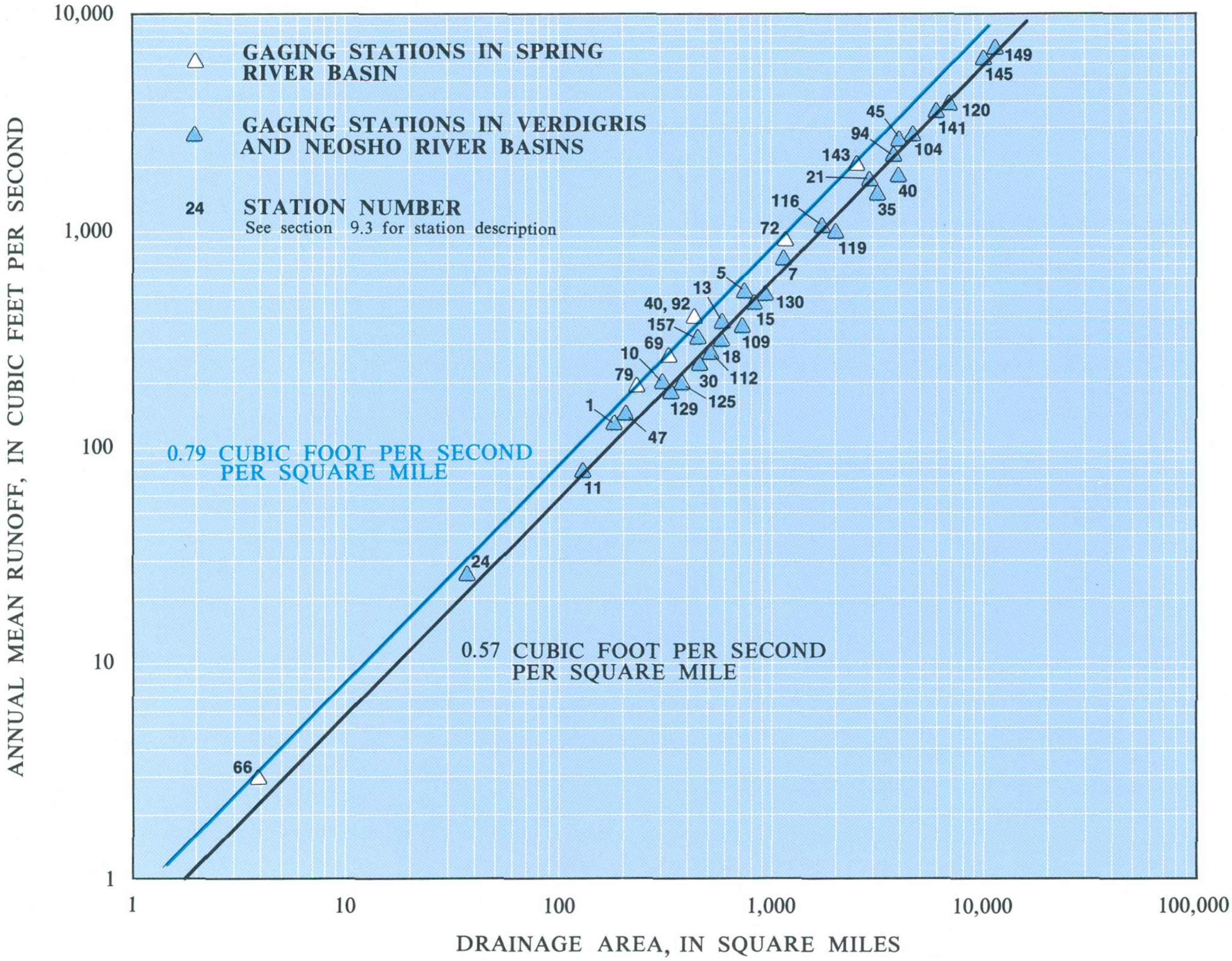


Figure 5.1-2 Comparison of average annual runoff to drainage-basin size for gaging stations having 20 or more years record.

Duration of Streamflow is Affected by Basin Characteristics and Man's Activities

Streams in the Neosho and Verdigris basins flow about 80 percent of the time; streams in the Spring River basin flow all or nearly all the time.

Information on the duration of flow, which is the distribution of stream discharge with time, is useful for various hydrologic analyses such as determining the yield of a stream or its ability to assimilate waste. Duration of flow can be determined from flow-duration curves showing the percentage of time that a specific discharge at a given point is equaled or exceeded. For example, the discharge of Shoal Creek above Joplin, Missouri, equaled or exceeded 0.62 cubic foot per second per square mile 40 percent of the time (fig. 5.2-1). Multiplying the unit discharge value (0.62) by the area of the drainage basin (410 square miles) shows that Shoal Creek discharged 254 cubic feet per second or more 40 percent of the time.

Flow-duration curves are useful for relating streamflow to the physical characteristics of a basin. The upper end of the curve shows the direct-runoff characteristics, which are affected by climate, topography, and land use. The lower end of the curve shows the base-flow characteristics, which usually depend on the capacity of rock underlying the basin to store and transmit water. A steep slope of the lower part of the curve indicates that the volume of ground water available to sustain streamflow during dry weather is limited. A flat slope of the lower part of the curve indicates that streamflow is sustained during dry weather by ground-water discharge, addition of municipal or industrial wastes, or reservoir regulation.

Streams in the Neosho and Verdigris basins, which include about 85 percent of Area 40, flow about 80 percent of the time whereas most streams in Spring River basin flow all or nearly all the time. The variations in duration of flow are shown by differences in slopes of curves for small streams, such as Big Cabin and Shoal Creeks (fig. 5.2-1), and large streams, such as Neosho and Spring Rivers (fig. 5.2-2). Differences in duration of flow are a consequence of differences in geology. Pennsylvanian rocks underlying the basins of Neosho and Verdigris Rivers (fig. 5.2-3) are mostly shale and sandstone that have little capacity to store and transmit water. In contrast, Mississippian rocks underlying the basin of Spring River store and transmit water to the streams thereby maintaining flow during dry weather.

The duration of flow can be altered significantly by man's activities. For example, the volume of direct runoff may be increased by urbanization or decreased by impoundment. Additionally, base flow may be augmented by discharge of municipal or industrial wastes or depleted by consumptive use. If such changes are great enough, they will be reflected by the shape of the flow-duration curve. The flow-duration curves for the Verdigris River near Claremore, Oklahoma (fig. 5.2-4) shows the variations in streamflow before and after impoundment; the principal change is a decrease in peak flow.

Flow-duration data for gaged streams in Area 40 are given in reports by Furness (1959) for Kansas, Skelton (1976) for Missouri, and Mize (1975) for Oklahoma. Flow-duration data also are available from computer storage through NAWDEX (National Water Data Exchange).

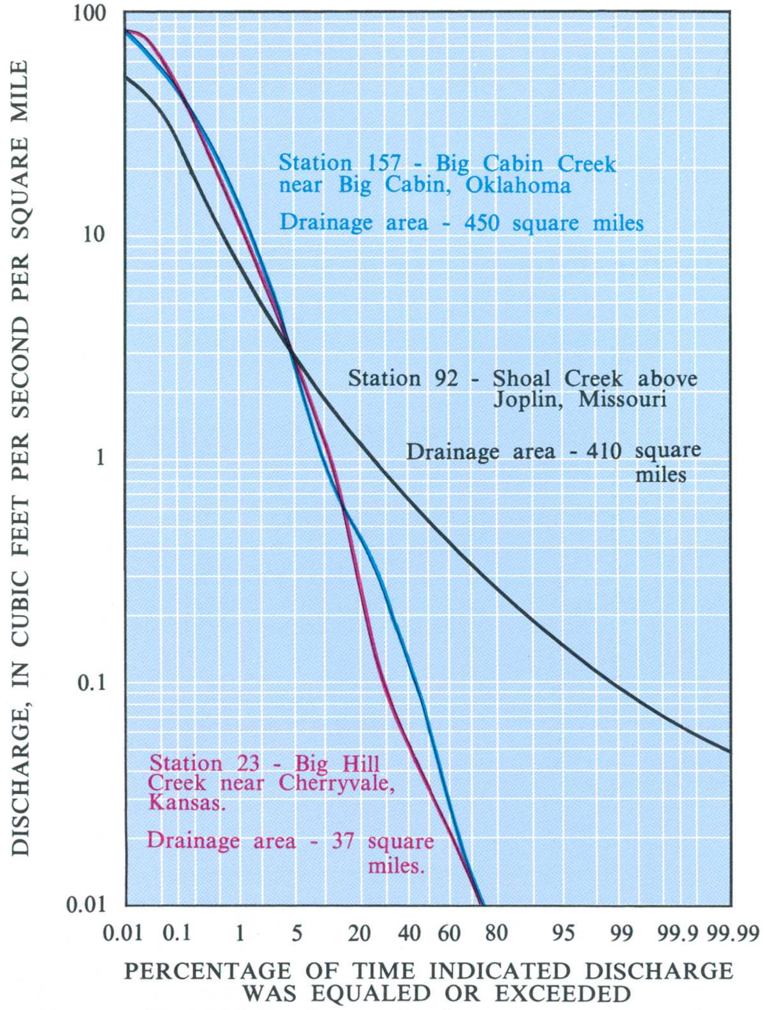


Figure 5.2-1 Low-flow potential of streams draining Pennsylvanian rocks (stations 23 and 157) contrasted with a stream draining Mississippian rocks (station 92).

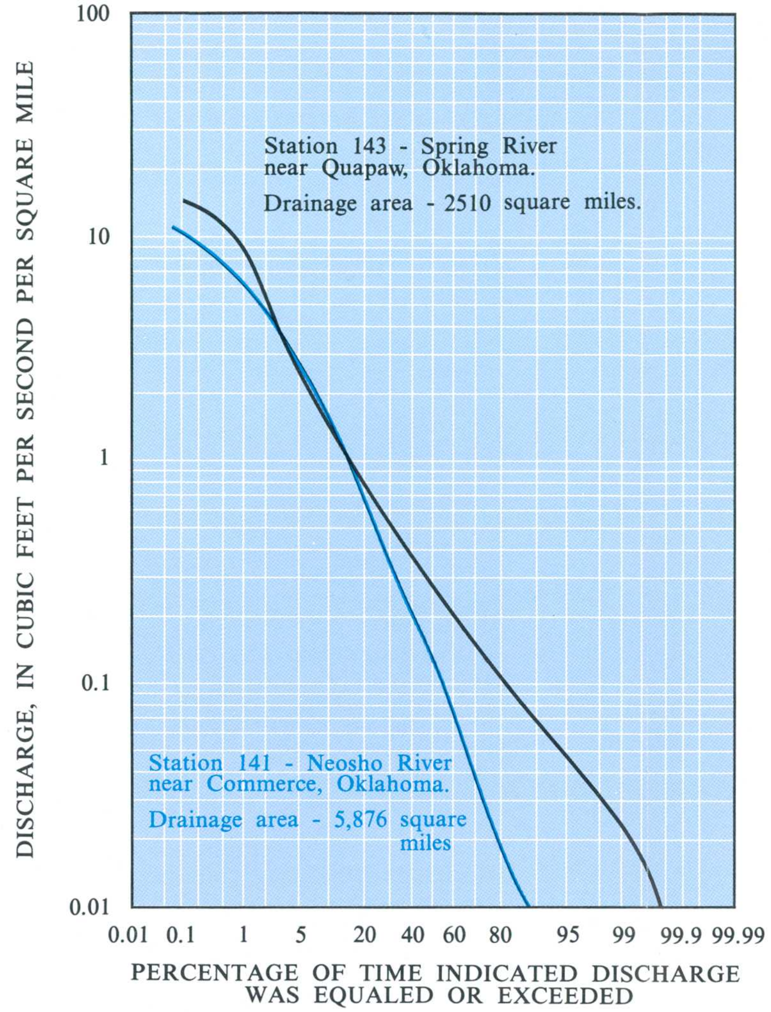


Figure 5.2-2 Flow-duration curves comparing streamflow variability of the Neosho River with that of Spring River.

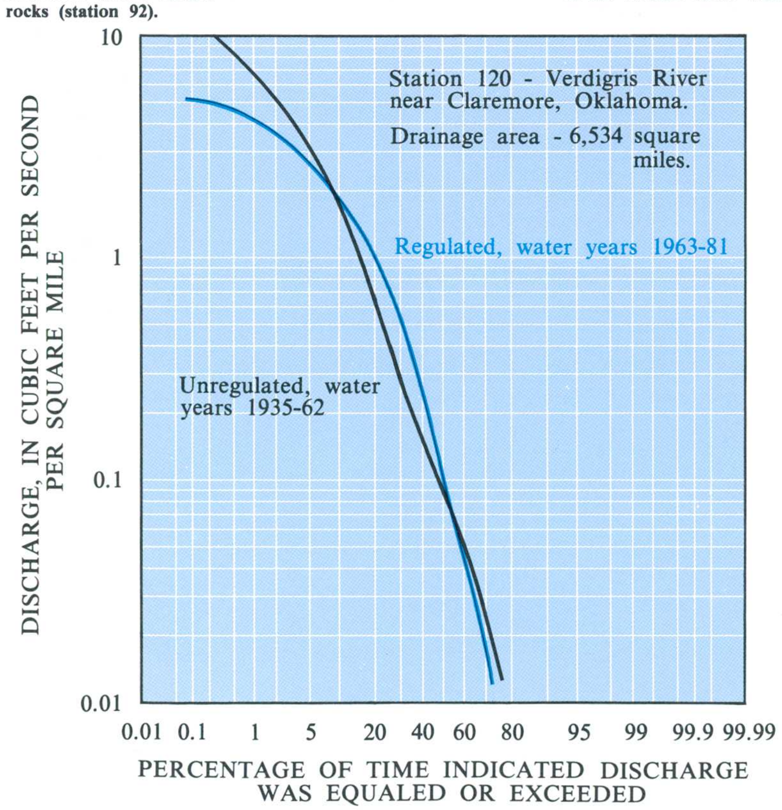


Figure 5.2-4 Flow-duration curve showing effects of regulation on time distribution of streamflow.

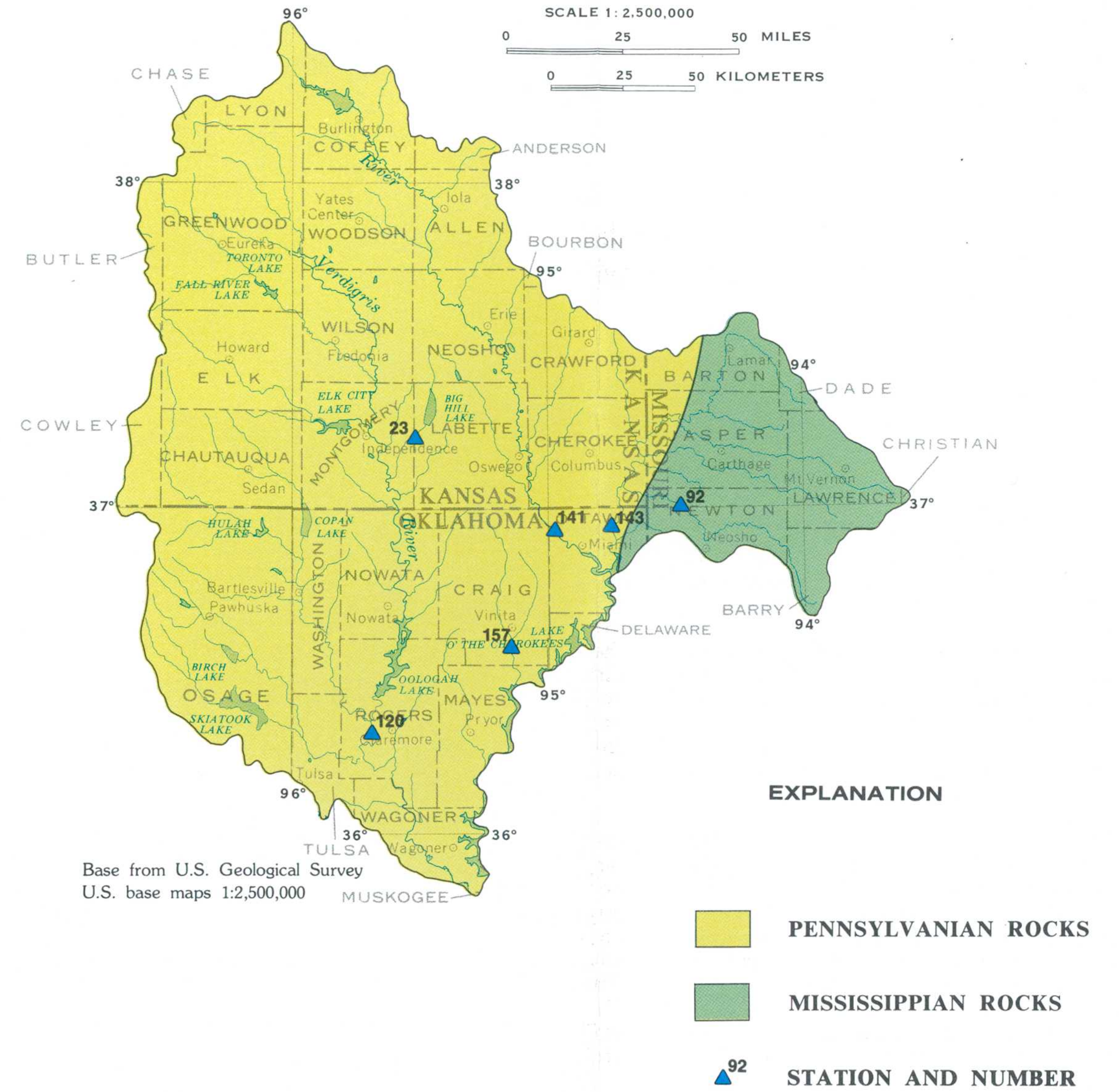


Figure 5.2-3 Generalized geology and location of selected streamflow measurement sites

Flooding is Most Likely to Occur Between March and July and is Least Likely to Occur Between November and February

Flooding of small streams is most frequent although floods on larger streams generally affect more extensive areas.

Flooding along small streams, which is most frequent in Area 40, usually is caused by rainfall associated with local, intense thunderstorms in spring or summer. The maximum known flood along the Verdigris and Spring Rivers occurred in May, 1943. Peak discharges were 182,000 cubic feet per second on the Verdigris river near Claremore, Oklahoma (station 120), and 190,000 cubic feet per second on the Spring River near Quapaw, Oklahoma (station 143). The maximum known flood along the Neosho River was on July 13, 1951, when a peak discharge of 436,000 cubic feet per second occurred near Iola, Kansas (station 40). The probability of severe flooding along the Neosho and Verdigris Rivers has been decreased by main-stem and tributary reservoirs. Peak flood flows that are the maximum known at gaging stations that have 20 or more years record are related to drainage basin size and compared to an envelope curve developed by Jordan and Irza (1975) for the eastern one-third of Kansas (fig. 5.3-1). This curve cannot be assigned any particular recurrence interval but indicates magnitude of peak flows that could occur or even be exceeded.

Engineering design for safe and economical structures such as bridges, culverts, embankments, dams, and levees, requires data on the magnitude and frequency of floods. Regulations stemming from the Surface Mining Act (Public Law 95-87) refer in particular to the 2-year, 24-hour, and the 10-year, 24-hour, precipitation for design of temporary and permanent structures, respectively. Although rainfall is the primary cause of floods, no exact correlation exists between rainfall quantities and resulting flood discharge. Flood magnitudes also are related to the physiography of a basin, including land slopes and drainage patterns. Furthermore, land use such as mining, farming, and urbanization also affect flood magnitudes. Most significant are man-made regulating structures, which are common in Area 40, particularly in Kansas.

The relation between flood-peak magnitude to probability of occurrence, or recurrence interval, generally is referred to as a flood-frequency relation. The flood-frequency relation for a stream where gaging-station records are available is defined by fitting logarithms of annual peak discharges to log-Pearson Type III distribution (U.S. Water Resources Council, 1981). The flood-frequency curves (fig. 5.3-2). For example, on Big Cabin Creek (station 157) a peak discharge of 71,000 cubic feet per second has a 2 percent chance of being exceeded in any given year (a 50-year recurrence interval). Flood-frequency data for gaged streams are available from computer storage through NAWDEX (National Water Data Exchange).

Flood-frequency curves for ungaged, unregulated streams in Area 40 can be estimated by use of regional equations developed for this purpose. These equations are not applicable for urbanized basins without modification (Huntzinger, 1978a). Flood-frequency equations applicable to those parts of each State included in Area 40 have been developed independently for Kansas (Jordan and Irza, 1975), Missouri (Sandhaus and Skelton, 1968, and Hauth, 1974), and Oklahoma (Sauer, 1974, and Thomas and Corley, 1977). These equations were developed similarly; however, they differ in context and application.

The flood-frequency reports listed in the preceeding paragraph provide information in the forms of equations, curves, and nomographs to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The regional flood frequencies provided in these reports are based primarily on flood data for each particular State. No attempt has been made to optimize flood-frequency relationships only for Area 40. Comparisons of Kansas, Missouri, and Oklahoma flood-frequency equations with actual gaging-station-frequency data show that computation of a particular flood will yield different values for the three different States. For sites in Area 40, flood discharges need to be computed using the relationships for each particular State except for drainage areas less than 10 square miles in Missouri. For sites in Missouri with drainage areas less than 10 square miles, values need to be based on the average of values computed using Kansas and Oklahoma relationships. Similarly, estimates for sites in Missouri that are on or very near the Kansas and Oklahoma State lines need to be based on the average values computed from the Kansas and Oklahoma relations.

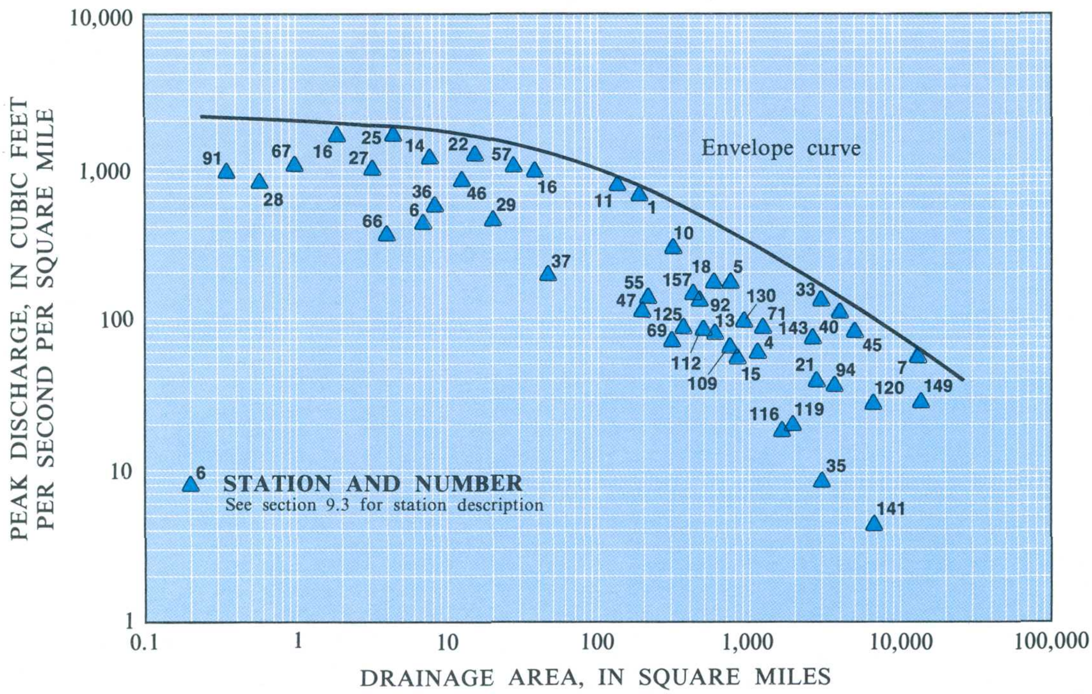


Figure 5.3-1 Maximum known floods at gaging stations with 20 or more years record.

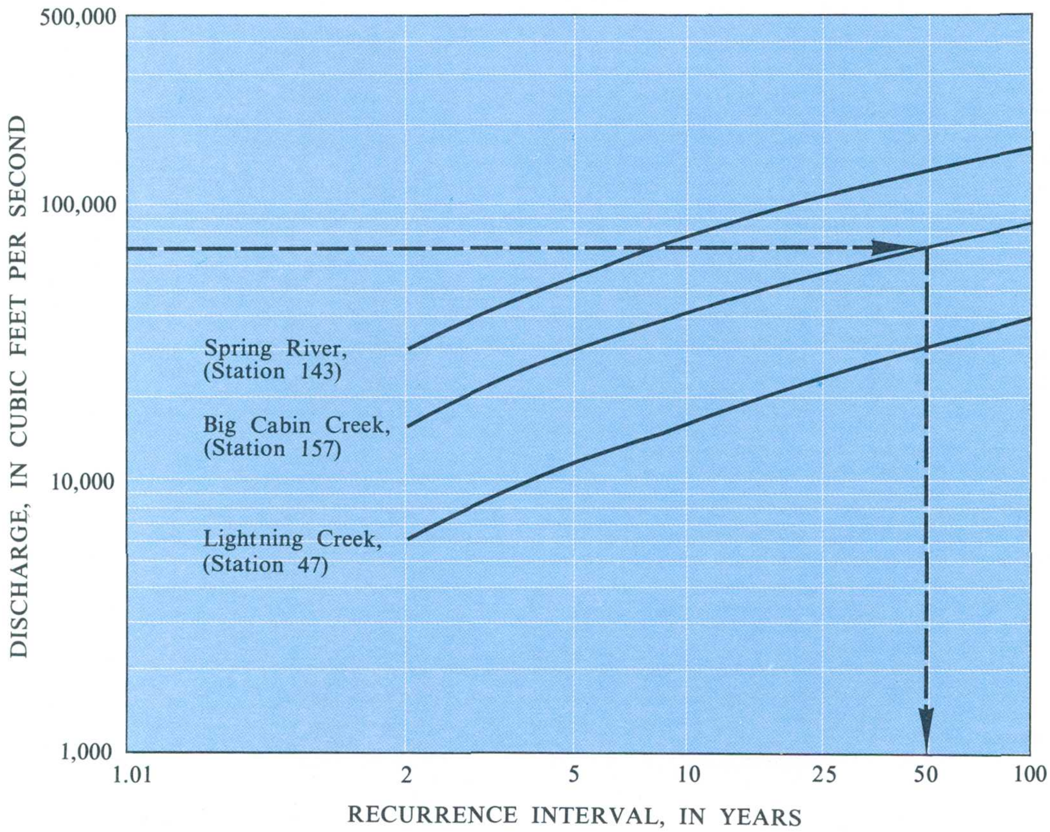


Figure 5.3-2 Typical flood frequency curves for unregulated streams.

Maps Defining Flood-Prone Areas Are Available

Areas that would be inundated by floods with a 100-year recurrence interval are delineated for many parts of Area 40.

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 streams subject to flooding were identified and flood-prone areas 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 quadrangle maps.

Areas inundated by the 100-year flood have been delineated on 75 7½-minute and 6 15-minute topographic maps. Figure 5.4-1 shows the locations of these maps and the names and locations of all available topographic quadrangle maps in Area 40. The flood-prone maps for each state are available from the respective offices:

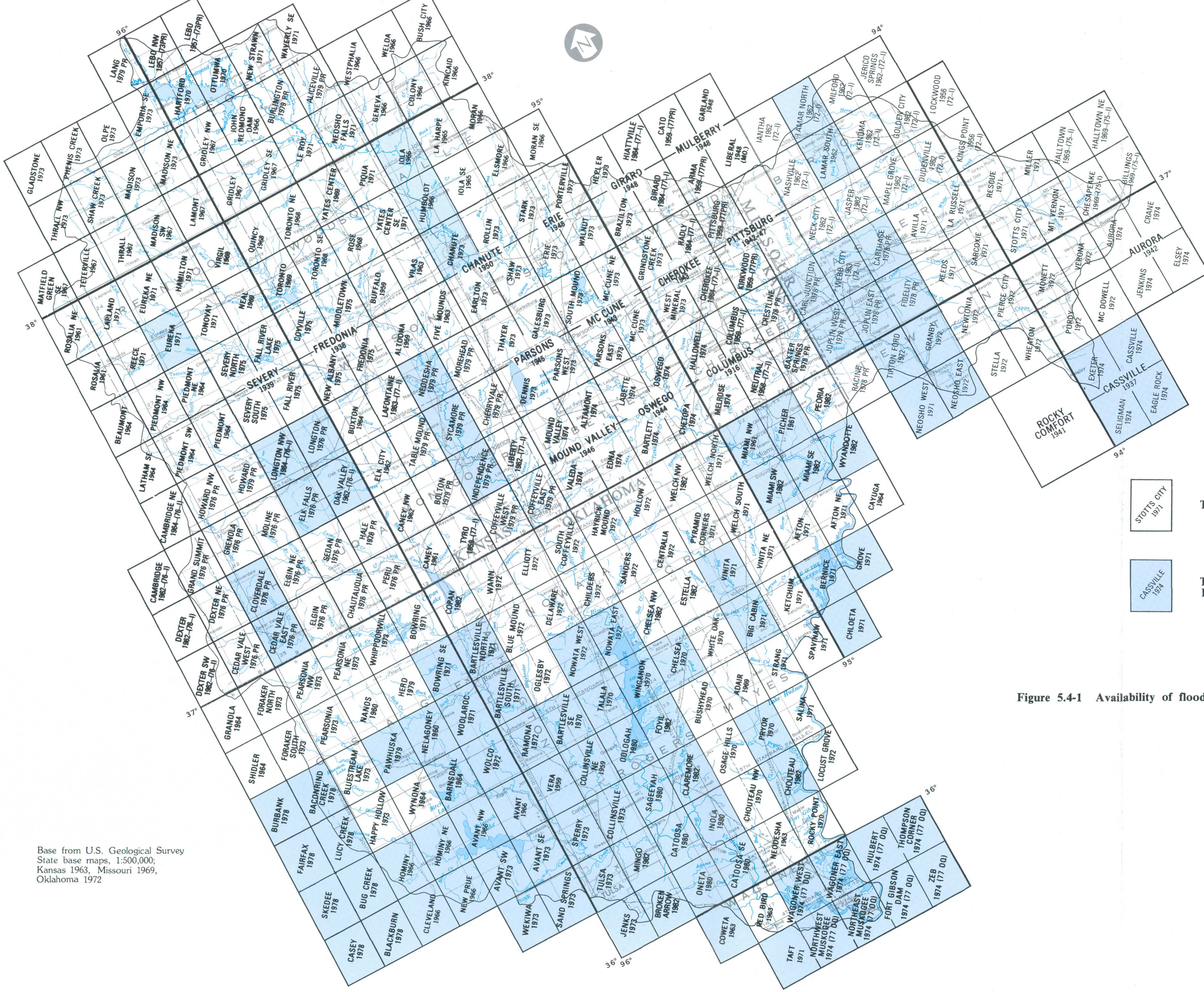
U.S. Geological Survey
1950 Avenue A, Campus West
University of Kansas
Lawrence, KS 66045

U.S. Geological Survey
1400 Independence Road
Mail Stop 200
Rolla, MO 65401

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

Since 1972, detailed flood insurance studies have been made for many incorporated cities and towns in Area 40. These studies define the 100-year and 500-year flood boundaries in great detail. A floodway boundary is delineated and flood insurance rate 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 book and the FIA flood maps can be obtained from:

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



SCALE 1:1,000,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

EXPLANATION

STOTTS CITY 1971 — TOPOGRAPHIC MAP

CASSVILLE 1974 — TOPOGRAPHIC MAP WITH 100-YEAR FLOOD BOUNDARIES DELINEATED

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

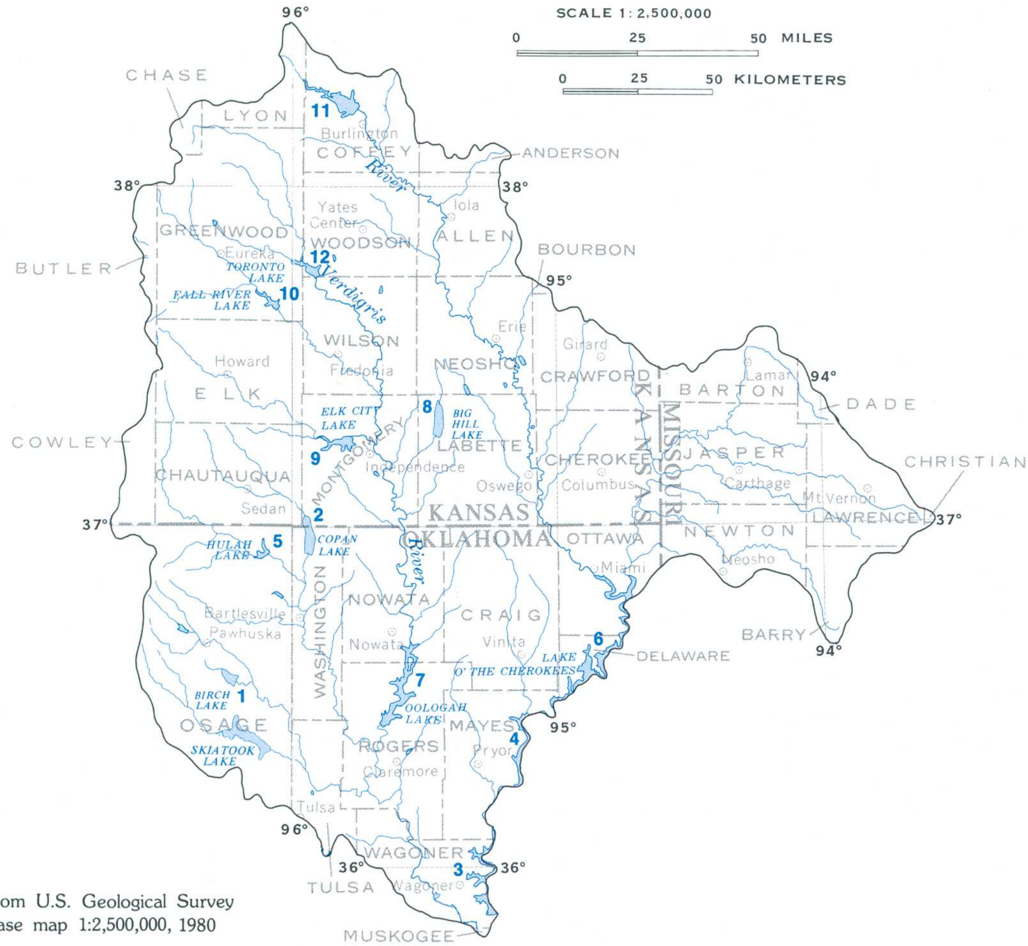
Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Surface-Water Storage Vital to Area 40

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

In most of Area 40, streamflow is so variable and the availability of ground water is so limited that surface-water storage is a necessity to provide municipal, industrial, irrigation, and domestic water supplies. To meet these needs, 12 large multi-purpose lakes that regulate runoff from about 45,000 square miles of the Neosho and Verdigris basins have been constructed (fig. 5.5-1 and table 5.5-1). In addition, more than 100 flood-detention ponds that partly regulate runoff from about 4,300 square miles, many small municipal lakes, and thousands of farm ponds with a surface area less than 10 acres have been built. These projects have been developed through programs of the U.S. Army Corps of Engineers, U.S. Department of Agriculture, Grand River Dam Authority, and a number of cities and towns in the area. Additional management of lake areas is provided by State agencies such as the Kansas Park and Resources Authority and the Kansas Fish and Game Commission.

In addition to insuring an adequate water supply for various uses, lakes provide flood control, hydroelectric power, water-quality control, navigation, fish and wildlife habitat, and recreational opportunities that substantially benefit the environment and economy of the area.



Base from U.S. Geological Survey
U.S. base map 1:2,500,000, 1980

Figure 5.5-1 Location of principal lakes.

Table 5.5-1 Data on principal lakes.

Lake number	Lake	Stream	Drainage area (square miles)	Conservation and sediment storage (acre-feet)	Flood control storage (acre-feet)	Maximum storage (acre-feet)	Purpose[1]
				Oklahoma			
1	Birch	Birch Creek	66	19,200	39,000	58,200	FC-WS-R-FW-WQC
2	Copan	Little Caney River	505	46,000	184,300	230,300	FC-WS-R-FW-WQC
3	Fort Gibson	Neosho River	12,492	--	919,200	1,284,400	FC-P-R-FW
4	Hudson	Neosho River	11,533	--	244,200	444,500	FC-P-R-FW
5	Hulah	Caney River	732	34,700	257,900	292,600	FC-WS-R-FW-WQC
6	Lake O' the Cherokees	Neosho River	10,298	--	523,000	2,197,000	FC-P-R-FW
7	Oologah	Verdigris River	4,399	553,400	965,500	1,519,000	FC-WS-R-FW-N
				Kansas			
8	Big Hill	Big Hill Creek	37	27,500	13,100	40,600	FC-WS-R-FW
9	Elk City	Elk River	634	44,450	239,500	284,300	FC-WS-WQC-R-FW
10	Fall River	Fall River	585	21,900	234,500	256,400	FC-C-R-FW-WQC
11	John Redmond	Neosho River	3,015	71,285	558,965	630,250	FC-WS-WQC-R-FW
12	Toronto	Verdigris River	730	21,900	177,800	199,800	FC-C-R-FW

[1] FC, flood control; C, conservation; WS, water supply; R, recreation; FW, fish and wild life; P, hydroelectric; N, navigation; WQC, water-quality control

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

Data needed to assess the probable hydrologic consequences of surface mining of coal are available at 91 stream locations in Area 40.

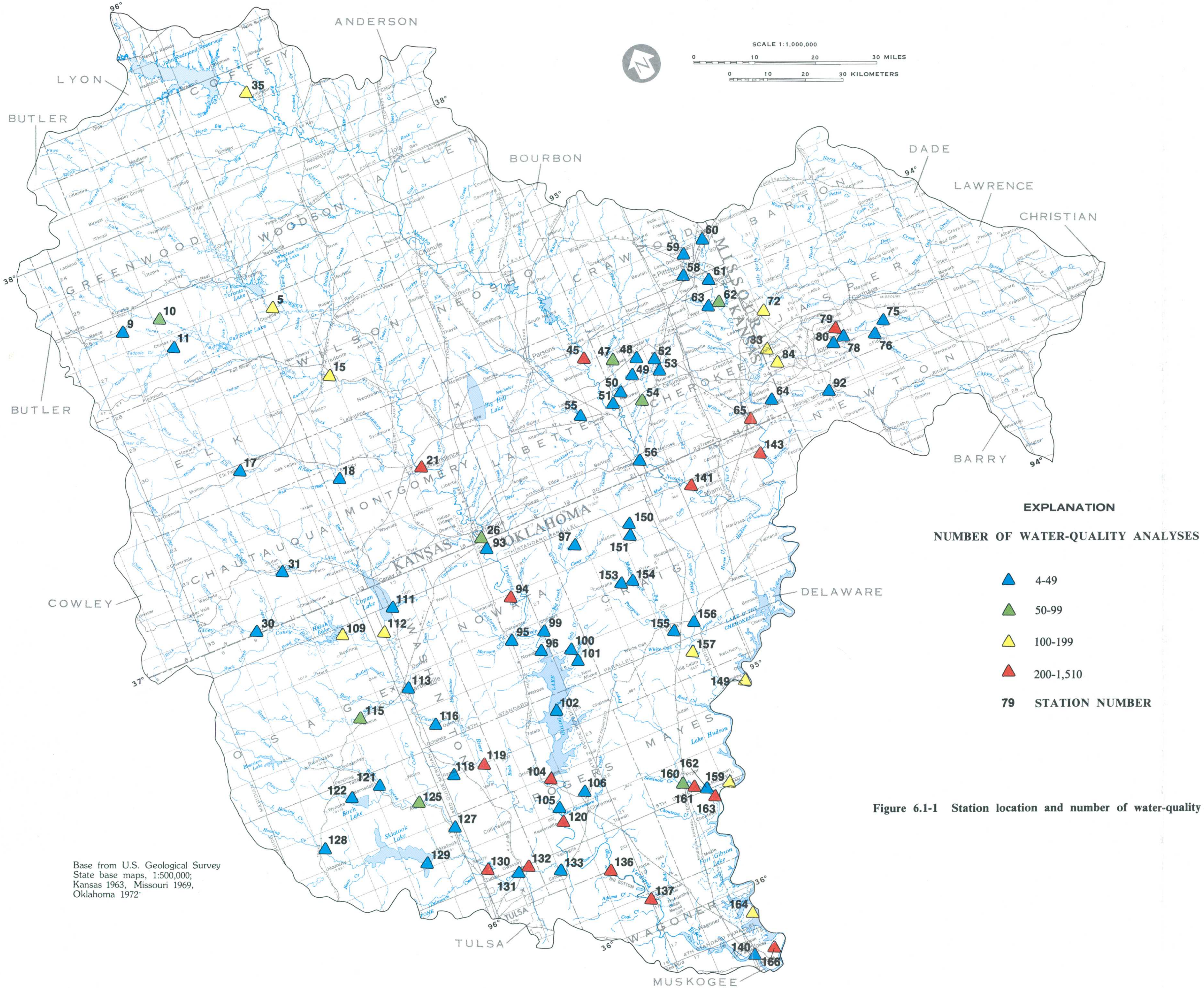
Acid mine drainage caused by surface mining and reclamation has seriously affected surface-water quality in many parts of the United States, and its impact, especially in coal-mining areas, is well documented in the literature (Dyer and Curtis, 1977; Hoehn and Sizemore, 1977; King and others, 1974; and Letterman and Mitsch, 1978). Acid mine drainage results from the oxidation of pyrite and marcasite when these minerals are exposed to the atmosphere (see section 6.4). In Area 40, some areas were mined prior to Oklahoma's Open Cut Land Reclamation Act (1968) and Mining Lands Reclamation Act (1971), the Kansas Mined Land and Conservation Act (1968, amended 1975), and the Missouri Land Reclamation Law (1972), which mandate that spoil piles be graded and a cover vegetation established.

Acid mine drainage is not the only water-quality problem. Concentrations of many dissolved and suspended constituents, including iron and manganese, are greater in both old and new mining areas than in streams unaffected by mining. Erosion from unreclaimed or unvegetated areas can substantially increase suspended-sediment concentration in streams (Dyer and Curtis, 1977).

Water-quality data for the coal-mining region of eastern Oklahoma and Kansas and western Missouri are available but few long-term data exist. The need for these data has become critial 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 cumultive impact of mining on the hydrology of the area. Hydrologic information on the general area is to be made available to applicants for mining permits from an appropriate Federal or State agency before those permits are issued. The Act provides little information on water-quality constituents that should monitored. Paragraph 779.16 of the Federal regulations concerning reclamation (U.S. Office of Surface Mining Reclamation and Enforcement, 1979) states that, in general, local water-quality standards are applicable, but, as a minimum, impact determinations should consider the following: dissolved solids, suspended solids, acidity, pH, total and dissolved iron, and total manganese. Other water-quality properties or constituents that might be affected by surface mining include specific conductance, alkalinity, sulfate, and aluminum.

The stream water-quality data available include that collected at 91 stations (fig. 6.1-1) where at least four determinations of specific conductance and pH have been made. Only 29 stations had more than 100 analyses available. Station name and location are given in section 9.3. The water-quality data were collected for various purposes under a variety of cooperative programs with Federal, State, and local agencies. Therefore, the 91 stations do not represent a network designed to provide uniform data throughout the area that relate directly to coal mining or other specific hydrologic problems.

Analysis of the available data provides a general summary of the chemical quality of 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, and iron and manganese. To avoid placing overemphasis on extreme values, median values were used to describe the chemical quality of the stream water.



Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972.

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

Dissolved-Solids Concentrations Show No Areal Distribution

Median dissolved-solids concentrations in area streams range from 122 to 3,100 milligrams per liter.

Dissolved solids, which is the residue on evaporation at 180° Celsius, is a general indicator of the sum of the inorganic and organic material dissolved in the water. The concentration of dissolved solids is significant because water in streams draining areas that have been mined for coal commonly contain increased concentrations of dissolved materials, with sulfate being the principal constituent. Also, water with large dissolved-solids concentrations may be unsuitable for domestic supply, irrigation, livestock, and aquatic life.

Greater dissolved-solids concentrations might be expected in streams draining the principal areas of past and present coal mining which are in Crawford and Cherokee Counties, Kansas, and Craig and Rogers Counties, Oklahoma. However, median dissolved solids concentrations exceeding 500 milligrams per liter occur in all major river basins (fig. 6.2-1) and do not show any pattern of areal distribution that can be related to coal mining except in Cherokee County, Kansas. In general, the largest median concentrations are in water of small streams. Median concentrations in large streams, such as the Neosho and Verdigris Rivers, are less than 500 milligrams per liter. Some streams have increased concentrations of dissolved solids derived from sources unrelated to coal mining. For example, the Verdigris River upstream from Oologah Lake and Caney River upstream from the confluence with Double Creek near Ramona, Oklahoma, have greater than normal concentrations of chloride indicating contamination by oil-field brines (Marcher and Bingham, 1971).

The median dissolved-solids concentrations determined for 85 stream stations ranged from 122 to 3,100 milligrams per liter. Of these 85 stations, 63 have median concentrations of 500 milligrams per liter or less which is the maximum contaminant level set for Secondary Drinking Water Regulations by the U.S. Environmental Protectional Agency (1977a). Only 2 of the 85 stations had median concentrations greater than 1,000 milligrams per liter. Water containing as much as 1,000 milligrams per liter of dissolved solids is considered suitable from growing all non-sensitive and many sensitive crops and also is suitable for most industrial uses, barring objectional concentrations of specific substances.

Most substances dissolved in water are ionic, that is, they are atoms or groups of atoms that carry a positive (cations) or negative (anions) charge. Pie diagrams showing the proportion of total-ion concentration, in milliequivalents per liter, based on mean concentrations are given for selected stations in figure 6.2-1. These diagrams show that there is considerable variation in the proportion of ion concentrations in stream waters in different parts of the area. For example, compare the diagram for station 94 with that for station 63.

Dissolved-solids concentrations in even a single stream vary considerably during low or base flow and are least during high flow. This is especially true for small, unregulated streams such as Center Creek near Smithfield, Missouri (station 83, fig. 6.2-1) as shown by the graph relating dissolved-solids concentrations to discharge (fig. 6.2-2). For larger, regulated streams, dilution effects of storm runoff on base flow generally is less pronounced but usually is apparent.

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 proportional to the total concentration of ionized substances dissolved in the water. A mathematical relationship (regression equation) 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.

The regression relationship for all 85 stream stations (8,861 data pairs) is expressed by the equation:

$$DS = 0.58(SC) + 12 \qquad (2)$$

This equation explains that more than 98 percent of the variation in dissolved solids is accounted for by specific conductance according to the mathematically fitted straight-line equations (fig. 6.2-3). The slope (0.58) is within the range of 0.55 to 0.75 reported for most waters (Hem, 1970).

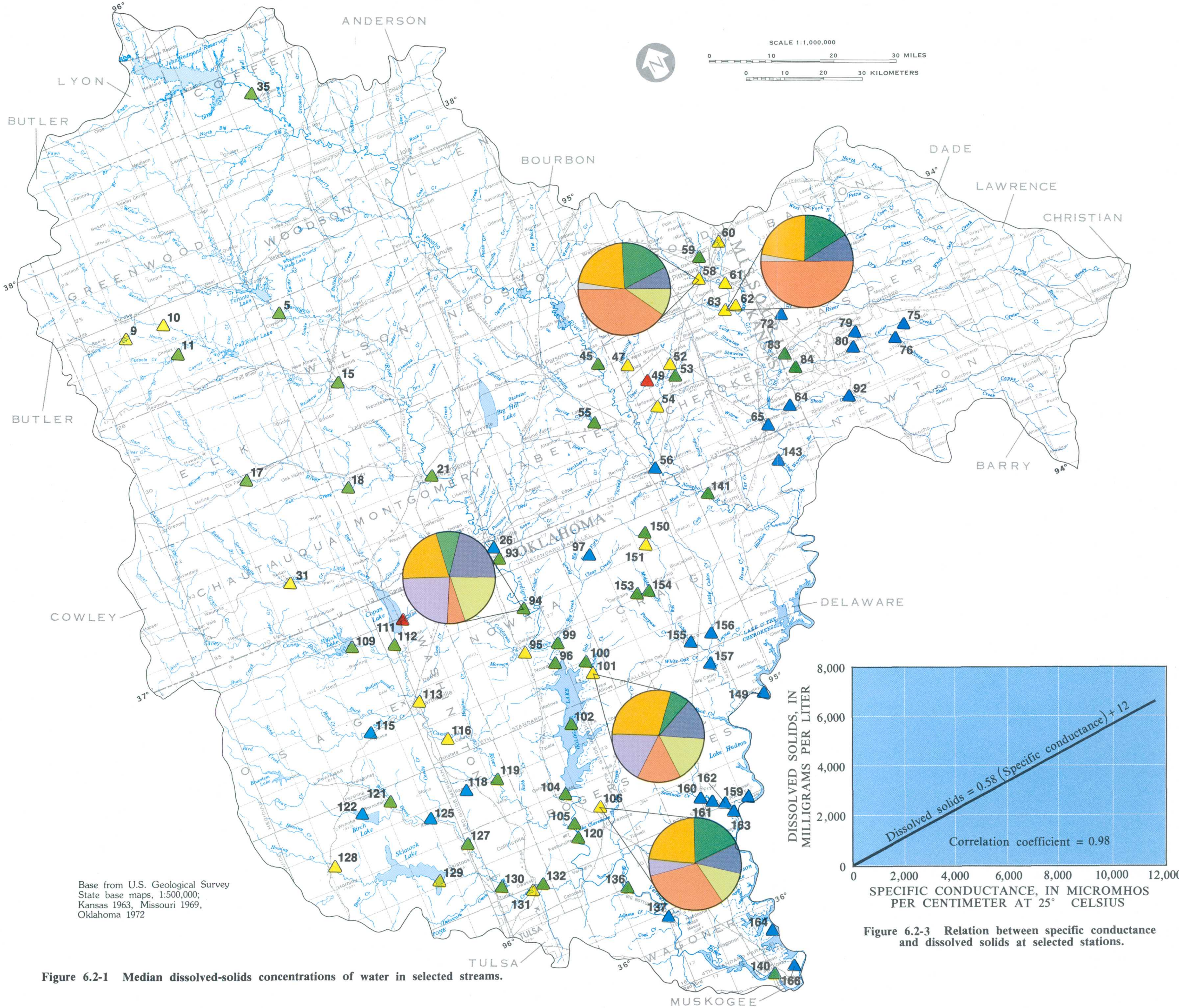


Figure 6.2-1 Median dissolved-solids concentrations of water in selected streams.

EXPLANATION

MEDIAN DISSOLVED-SOLIDS CONCENTRATION, IN MILLIGRAMS PER LITER

- 122-249 (blue triangle)
- 250-499 (green triangle)
- 500-999 (yellow triangle)
- 1,000-3,100 (red triangle)

79 STATION NUMBER

PIE DIAGRAMS SHOW ION RATIO BASED ON MEAN VALUES, IN MILLIEQUIVALENTS PER LITER

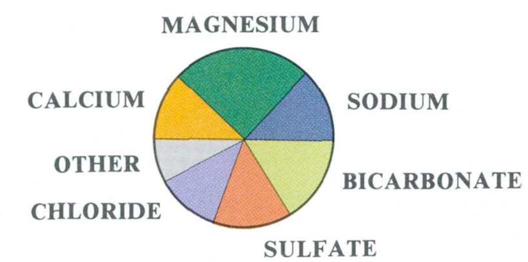


Figure 6.2-3 Relation between specific conductance and dissolved solids at selected stations.

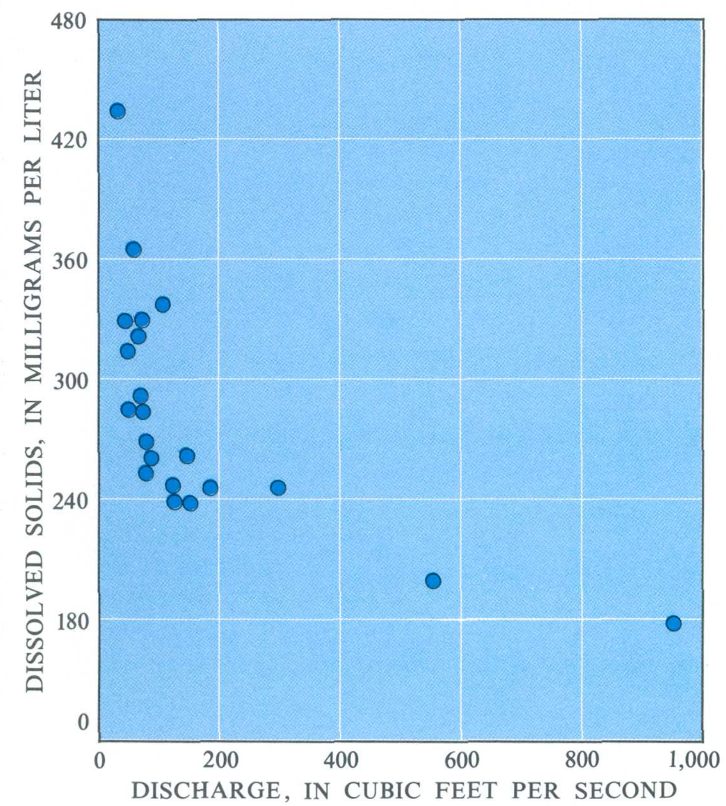


Figure 6.2-2 Relation of dissolved solids and discharge of Center Creek near Smithfield, Missouri (station 83).

Greatest Sulfate Concentrations are Associated with Coal Mines

Median sulfate concentrations in Area 40 streams range from 6 to 2,050 milligrams per liter; greatest median concentrations occur in small streams draining coal-mining areas.

Sulfate is the best indicator of coal-mine drainage in Area 40. The principal sources of sulfate include the weathering of gypsum ($CaSO_4$) and the oxidation of various iron sulfides such as pyrite (FeS_2) and marcasite (FeS_2). Iron pyrite, FeS_2, occurs naturally with coal and along with other mining wastes is deposited in spoil piles near mining activities. Once exposed to oxygen and water, pyrite can oxidize to sulfuric acid as follows:

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

The same reaction occurs in the interior of active and abandoned coal mines, and where coal seams crop out.

The greatest median-sulfate concentrations occur in small streams draining coal-mining areas. For stations with median-sulfate concentrations greater than 1,000 milligrams per liter, the maximum drainage area is 27 square miles. Bevans (1980, p. 14) reported that for stations in southeast, Kansas, the following relationship exists:

$$Y_p = 308 + 28.07\,X_i \qquad (1)$$

with the correlation coefficient, $r = 0.90$ and a standard error of estimate of 260 milligrams per liter where Y_p = mean sulfate concentration, in milligrams per liter; and X_i = the percentage of the drainage area strip mined. More than 80 percent of the variance in sulfate concentration is explained by the percentage of the basin that has been strip mined. However, this relationship describes only a small part of Area 40 and is not valid for the whole area.

The variability of sulfate concentrations in streams draining mined areas primarily is due to the quantities of iron sulfide and calcium sulfate minerals in spoil material, the length of time of exposure of these materials to weathering, the length of time water is in contact with the spoil, and the quantity of water leaving the mined areas. Sulfate concentrations are greatest during low flow, when contact time with spoil has been fairly long, and water draining from spoil material may constitute a significant part of the flow. Sulfate concentrations are less during high flow when contact time is short and dilution occurs.

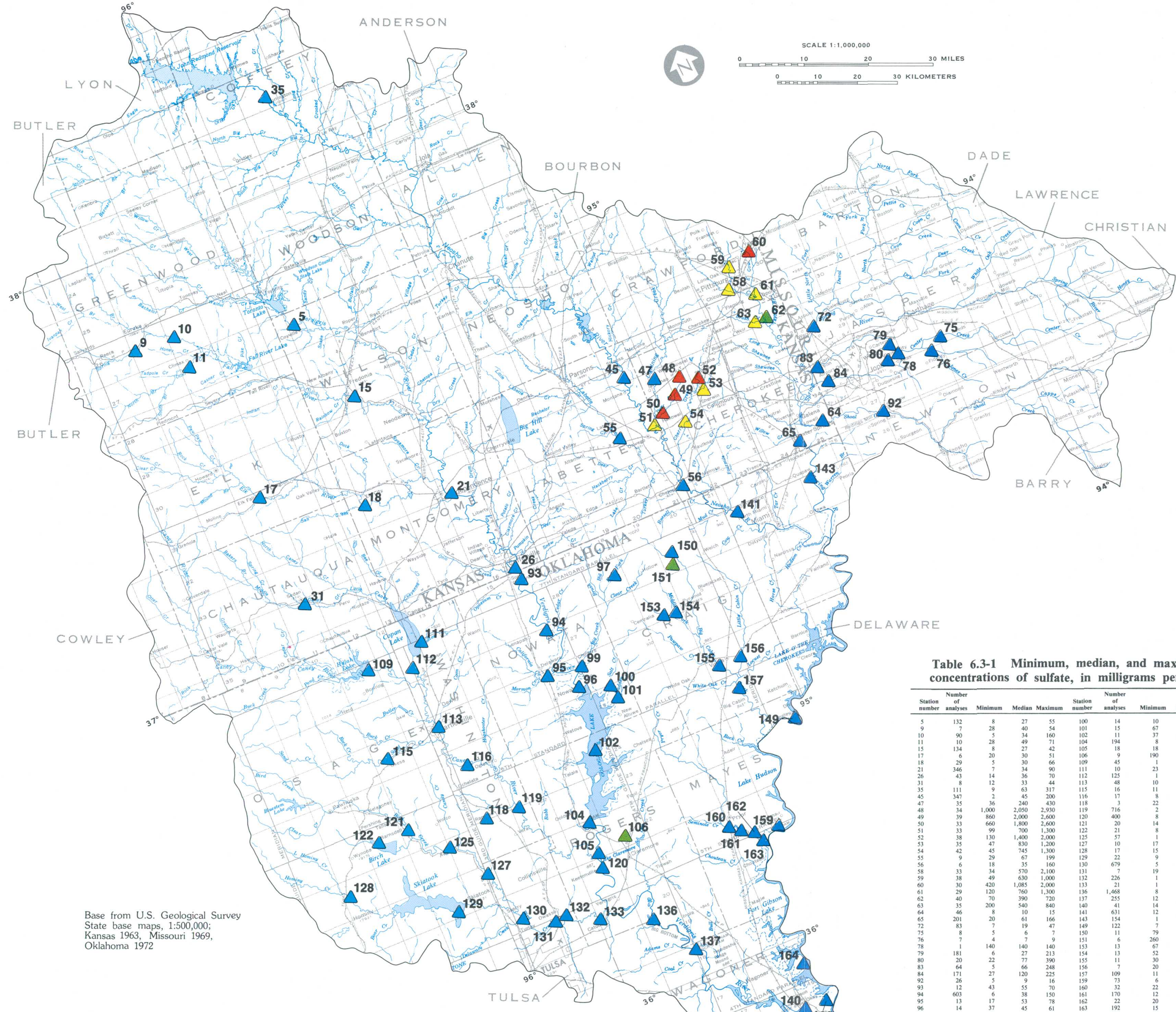
Median sulfate concentrations in the area range from 6 to 2,050 milligrams per liter (table 6.3-1). On the basis of taste and laxative effects, the recommended upper limit is 250 milligrams per liter in waters intended for human consumption in areas where sources with less sulfate concentrations are or can be made available (U.S. Environmental Protection Agency, 1977a). Acclimation to sulfate is rapid and many people can drink water with as much as 600 milligrams per liter of sulfate and not experience any laxative effects (Peterson, 1951). Only 23 of 90 stations had maximum sulfate concentrations greater than 250 milligrams per liter (table 6.3-1).

For most stations in Area 40, sulfate concentrations generally increase with increasing specific conductance. However, for many stations the plot of sulfate versus specific conductance shows much more variance or scatter than the plot shown in figure 6.3-2 for Second Cow Creek at Pittsburg, Kansas (station 58).

EXPLANATION

MEDIAN SULFATE CONCENTRATION, IN MILLIGRAMS PER LITER

- ▲ 6-249 (blue)
- ▲ 250-499 (green)
- ▲ 500-999 (yellow)
- ▲ 1,000-2,500 (red)
- **24** STATION NUMBER



Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Figure 6.3-1 Median sulfate concentrations.

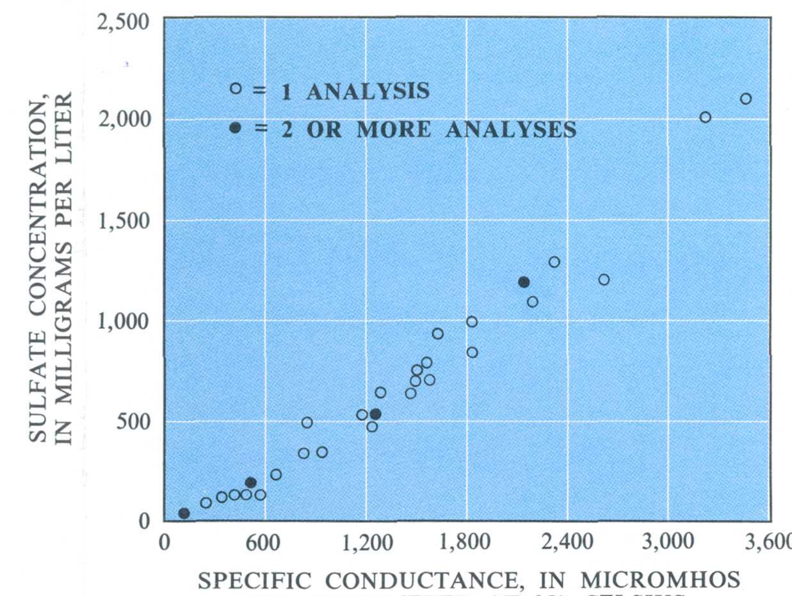


Figure 6.3-2 Relation of sulfate to specific conductance, Second Cow Creek at Pittsburg, Kansas (station 58).

Table 6.3-1 Minimum, median, and maximum concentrations of sulfate, in milligrams per liter.

Station number	Number of analyses	Minimum	Median	Maximum	Station number	Number of analyses	Minimum	Median	Maximum
5	132	8	27	55	100	14	10	26	34
9	7	28	40	54	101	15	67	96	155
10	90	5	34	160	102	11	37	44	55
11	10	28	49	71	104	194	8	36	730
15	134	8	27	42	105	18	18	45	58
17	6	20	30	51	106	9	190	280	380
18	29	5	30	66	109	45	1	24	34
21	346	7	34	90	111	10	23	60	89
26	43	14	36	70	112	125	1	23	83
31	8	12	33	44	113	48	10	33	89
35	111	9	63	317	115	16	11	24	39
45	347	2	45	200	116	17	8	34	67
47	35	36	240	430	118	3	22	23	25
48	34	1,000	2,050	2,930	119	716	2	30	112
49	39	860	2,000	2,600	120	400	8	32	87
50	33	660	1,800	2,600	121	20	14	28	182
51	33	99	700	1,300	122	21	8	20	45
52	38	130	1,400	2,000	125	57	1	19	49
53	35	47	830	1,200	127	10	17	27	49
54	42	45	745	1,300	128	17	15	25	45
55	9	29	67	199	129	22	9	17	53
56	6	18	35	160	130	679	5	22	67
58	33	34	570	2,100	131	7	19	28	43
59	38	49	630	1,000	132	226	1	40	135
60	30	420	1,085	2,000	133	21	1	48	63
61	29	120	760	1,300	136	1,468	8	32	116
62	40	70	390	720	137	255	12	37	120
63	35	200	540	840	140	41	14	34	76
64	46	8	10	15	141	631	12	67	238
65	201	20	61	166	143	154	1	72	188
72	83	7	19	47	149	122	7	39	88
75	8	5	6	7	150	11	79	160	680
76	7	4	7	9	151	6	260	315	360
78	1	140	140	140	153	13	67	130	260
79	181	6	27	213	154	13	52	120	620
80	20	22	77	390	155	11	30	78	115
83	64	5	66	248	156	7	20	32	123
84	171	27	120	225	157	109	11	73	275
92	26	5	9	16	159	73	6	28	140
93	12	43	55	70	160	32	22	60	82
94	603	6	38	150	161	170	12	57	129
95	13	17	53	78	162	22	20	66	104
96	14	37	45	61	163	192	15	76	228
97	7	15	29	33	164	124	13	36	51
99	15	19	33	60	166	408	8	39	65

Stream Water pH is in Normal Range

The median pH at 87 of 90 stations ranged from 6.9 to 8.4; pH is not a good indicator of stream contamination by coal-mine drainage in Area 40.

The pH of a solution is an indicator of how acidic or alkaline that solution is. A pH of 7.0 indicates neutral water. 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. In natural water, the pH usually is within the range of 6.0 to 8.5, depending upon 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 from pyrite (FeS_2) and marcasite (FeS_2), exposed in spoil piles and high walls of strip pits, react with oxygen (O_2) and water (H_2O) 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):

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

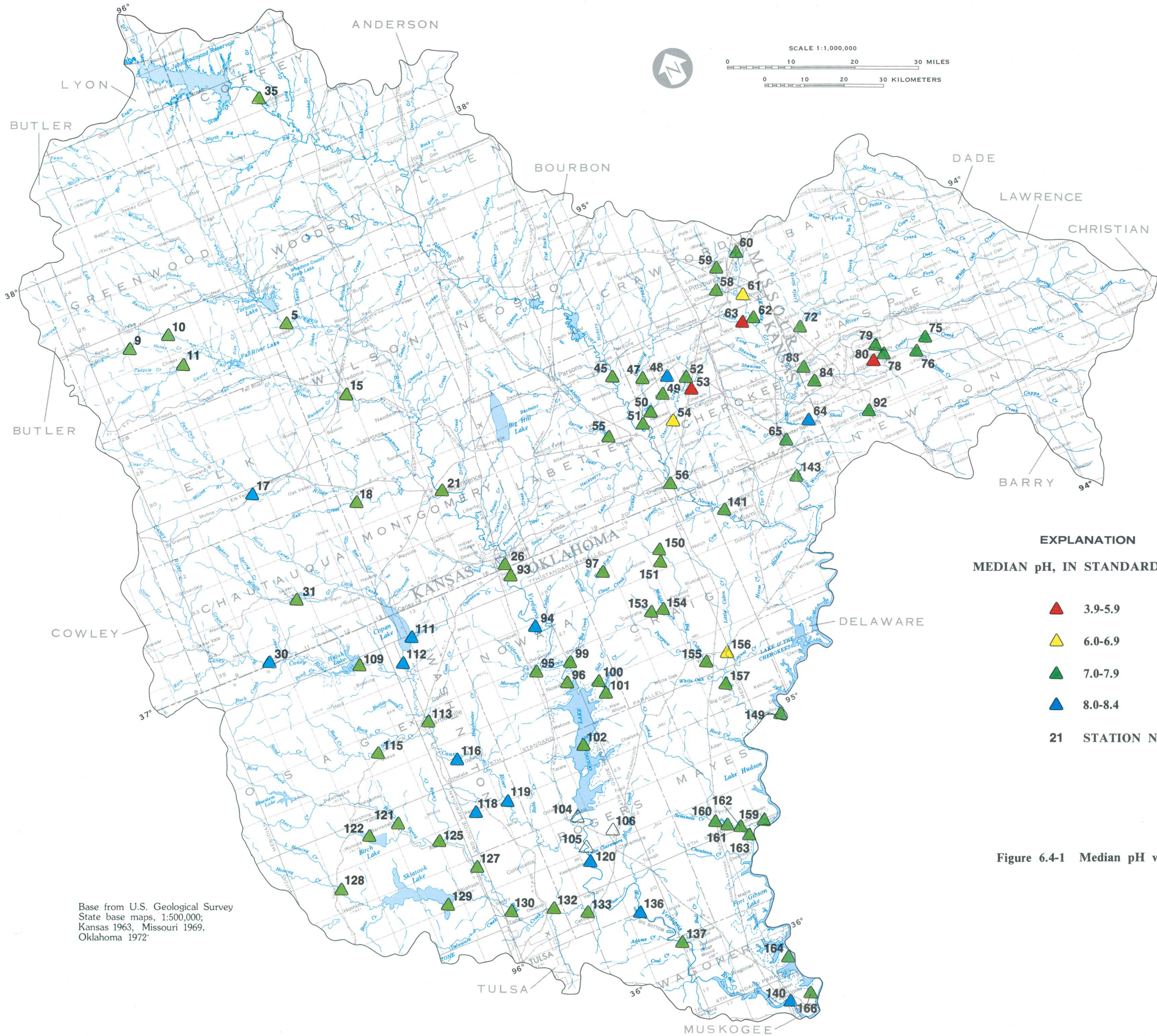
Subsequent oxidation of ferrous iron (Fe^{+2}) to ferric iron (Fe^{+3}) followed by hydrolysis of ferric iron results in a further decrease in pH:

$$4\,Fe^{+2} + O_2 + 10\,H_2O \rightarrow 4\,Fe(OH)_3 + 8\,H^+$$

However, water in most of the streams has a pH greater than 7.0 (alkaline) because of the buffering or neutralizing effect of the carbonate-bearing sedimentary rocks: $CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2CO_3$. The median pH at 87 of 90 stations ranged from 6.9 to 8.4 (fig. 6.4-1). Consequently, whereas pH is variable but generally in the normal range for most streams, pH is not a good indicator of acid mine drainage on an areal basis.

The median pH for 3 stations is less than the minimum allowable effluent limit of pH 6.0 (U.S. Office of Surface Mining Reclamation and Enforcement, 1979). All three of these stations are on small streams directly draining strip-mine areas:

Station number	Station name	Drainage area (square miles)	Median pH
53	Little Cherry Creek near West Mineral, Kansas	34.0	3.9
63	Brush Creek near Weir, Kansas	29.0	3.9
80	Zinc Mine tailings area storm runoff near Joplin, Missouri	0.01	4.1



EXPLANATION

MEDIAN pH, IN STANDARD UNITS

- (red triangle) 3.9-5.9
- (yellow triangle) 6.0-6.9
- (green triangle) 7.0-7.9
- (blue triangle) 8.0-8.4
- 21 STATION NUMBER

Figure 6.4-1 Median pH values.

Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Greatest Total-Iron and Total-Manganese Concentrations Associated with Coal Mines

The greatest median total-iron and total-manganese concentrations occur in small streams draining coal-mining areas; median total-iron concentrations ranged from 0 to 8,550 micrograms per liter and median total-manganese concentrations ranged from 0 to 8,300 micrograms per liter.

Total-iron and total-manganese concentrations less than 1,000 micrograms per liter are nontoxic to freshwater aquatic life (U.S. Environmental Protection Agency, 1976b, p. 80, and McKee and Wolf, 1963, p. 215) and are essential to certain physiological functions of aquatic life. The maximum dissolved-iron and dissolved-manganese concentration limits, 300 and 50 micrograms per liter, respectively, recommended for drinking water by the U.S. Environmental Protection Agency (1977a and 1977b) are based on the tendency of these elements to stain clothing and plumbing. In addition, 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. p. 207).

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

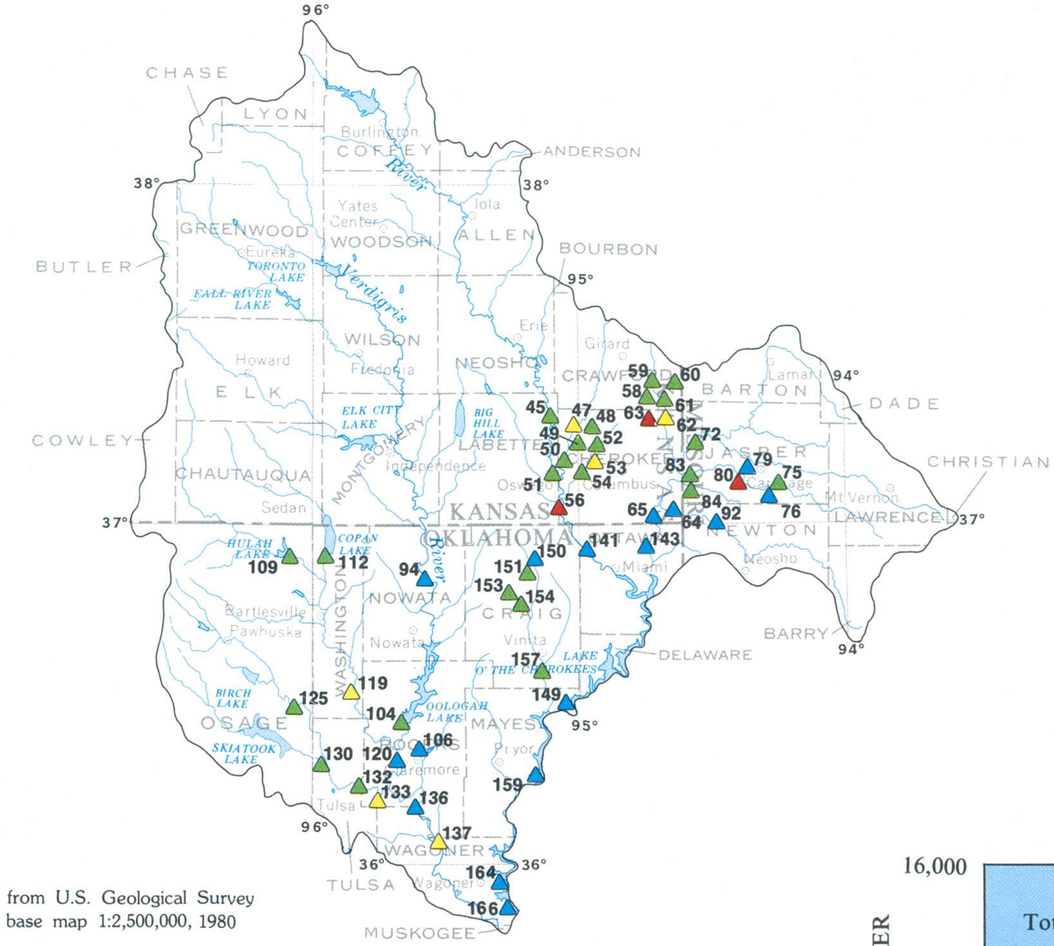
Median total-iron concentrations (fig. 6.5-1) ranged from 0 to 8,550 micrograms per liter. The median for 1,804 analyses at 52 stream stations is 300 micrograms per liter. The largest median total-iron concentration occurred at station 80, a small stream (drainage area = 0.01 square mile) receiving storm runoff from zinc and lead mine tailings. Although dissolved iron, because of its significant pH dependency, is not always a good indicator of surface-mine drainage, total iron may be. Total-iron concentration during storm runoff for some small, unregulated streams is proportional to the concentration of suspended sediment in the water. For example, for Second Cow Creek at Pittsburg, Kansas, station 58, (fig. 6.5-2) the regression equation between total-iron and suspended sediment concentrations is:

total-iron, in micrograms per liter = *9.03 (suspended sediment, in* milligrams per liter) + 2,100. (1)

Although this equation has a correlation coefficient of 0.97, it is based on only 6 data pairs and describes only 1 station at high flow.

Median total-manganese concentrations ranged from 0 to 8,300 micrograms per liter (fig. 6.5-3). The median of all 1,301 analyses at 55 stream stations was 216 micrograms per liter. The median concentrations at 4 stations (stations 53, 61, 62, and 63) exceed the U.S. Office of Surface Mining Reclamation and Enforcement (1979) 30-consecutive day average effluent standard of 2,000 micrograms per liter. All 4 stations are on small streams (drainage areas of 29 to 170 square miles) draining strip-mined areas in Kansas and have large median sulfate concentrations (390 to 830 milligrams per liter) and large median total-iron concentrations (595 to 3,600 micrograms per liter).

Although no direct relationship is apparent between total-iron concentrations and total-manganese concentrations, median concentrations of both generally are greater for small streams draining strip-mined areas than for large streams or streams draining non-mining areas. Because manganese is less readily oxidized than iron, manganese usually remains in solution in river water for greater distances downstream from the source than the iron contained in mine-drainage inflows (Hem, 1970, p. 130). The rates of oxidation of dissolved iron and manganese are especially slow when pH is less than 6 for iron or 9 for manganese (Sawyer and McCarty, 1978). The manganous ion (Mn^{+2}) is not as noticeably affected by slight changes in pH as the ferrous ion (Fe^{+2}); consequently, manganese remains in solution until most of the iron has been precipitated (Musser and Whetstone, 1964).



Base from U.S. Geological Survey
U.S. base map 1:2,500,000, 1980

SCALE 1: 2,500,000

0 25 50 MILES

0 25 50 KILOMETERS

EXPLANATION

MEDIAN TOTAL-IRON CONCENTRATION, IN MICROGRAMS PER LITER

- ▲ 0-299
- ▲ 300-999
- ▲ 1,000-1,999
- ▲ 2,000-8,550
- 14 STATION NUMBER

Figure 6.5-1 Median total-iron concentrations.

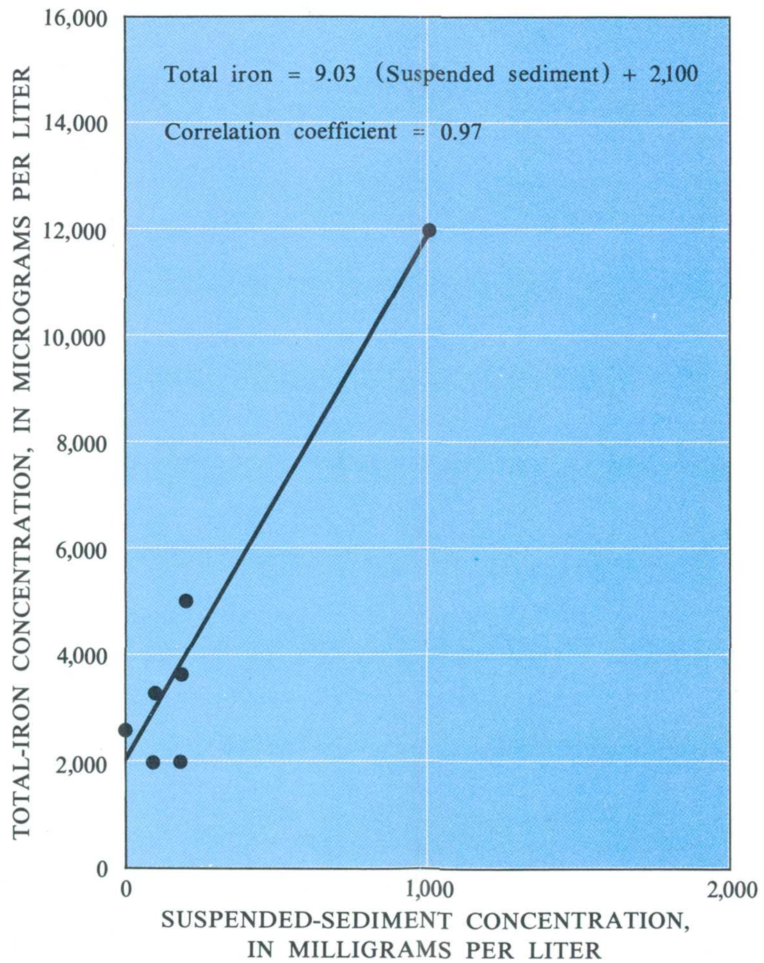
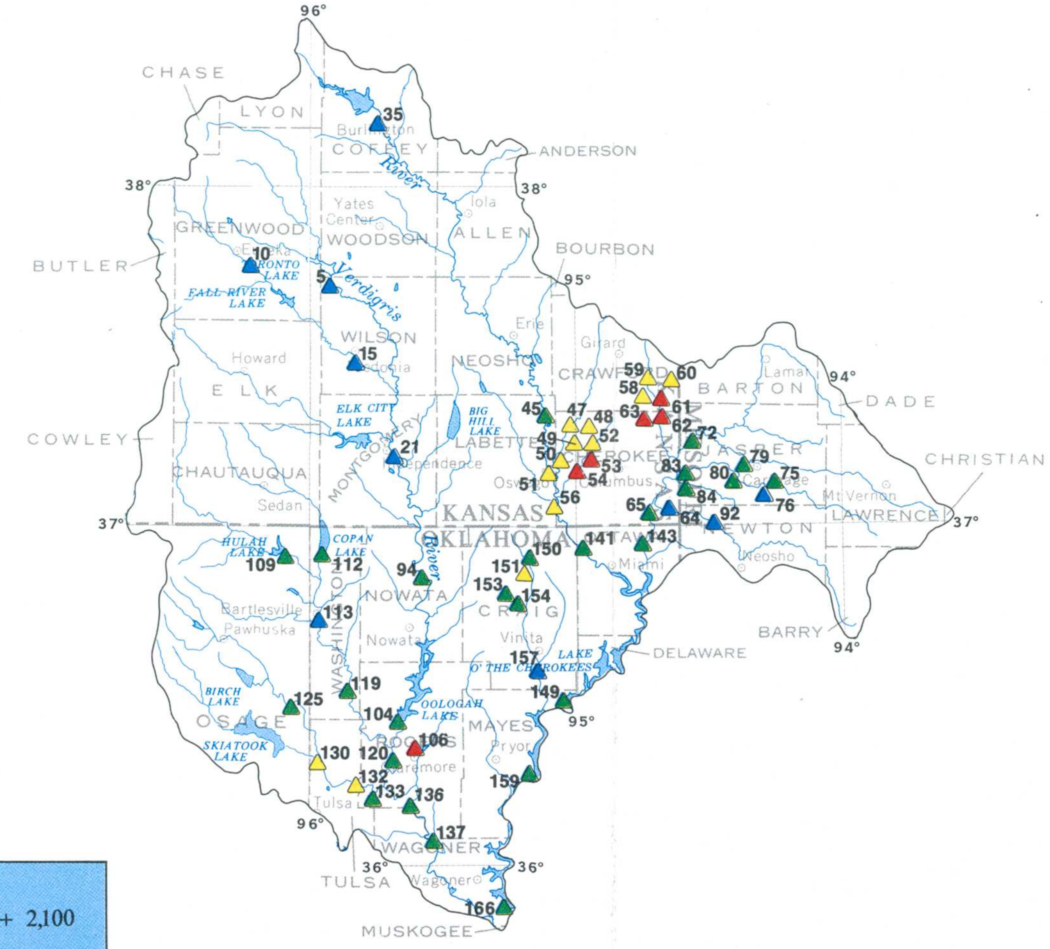


Figure 6.5-2 ***Relation between total-iron concentration and suspended-sediment concentration, Second Cow Creek, at Pittsburg, Kansas (station 58).***



EXPLANATION

MEDIAN TOTAL-MANGANESE CONCENTRATION, IN MICROGRAMS PER LITER

- ▲ 0-49
- ▲ 50-299
- ▲ 300-999
- ▲ 1,000-8,300
- 14 STATION NUMBER

Figure 6.5-3 Median total-manganese concentrations.

Sediment Yields Vary in Area 40

Average annual sediment yields range from 50 to 600 tons per square mile of drainage area.

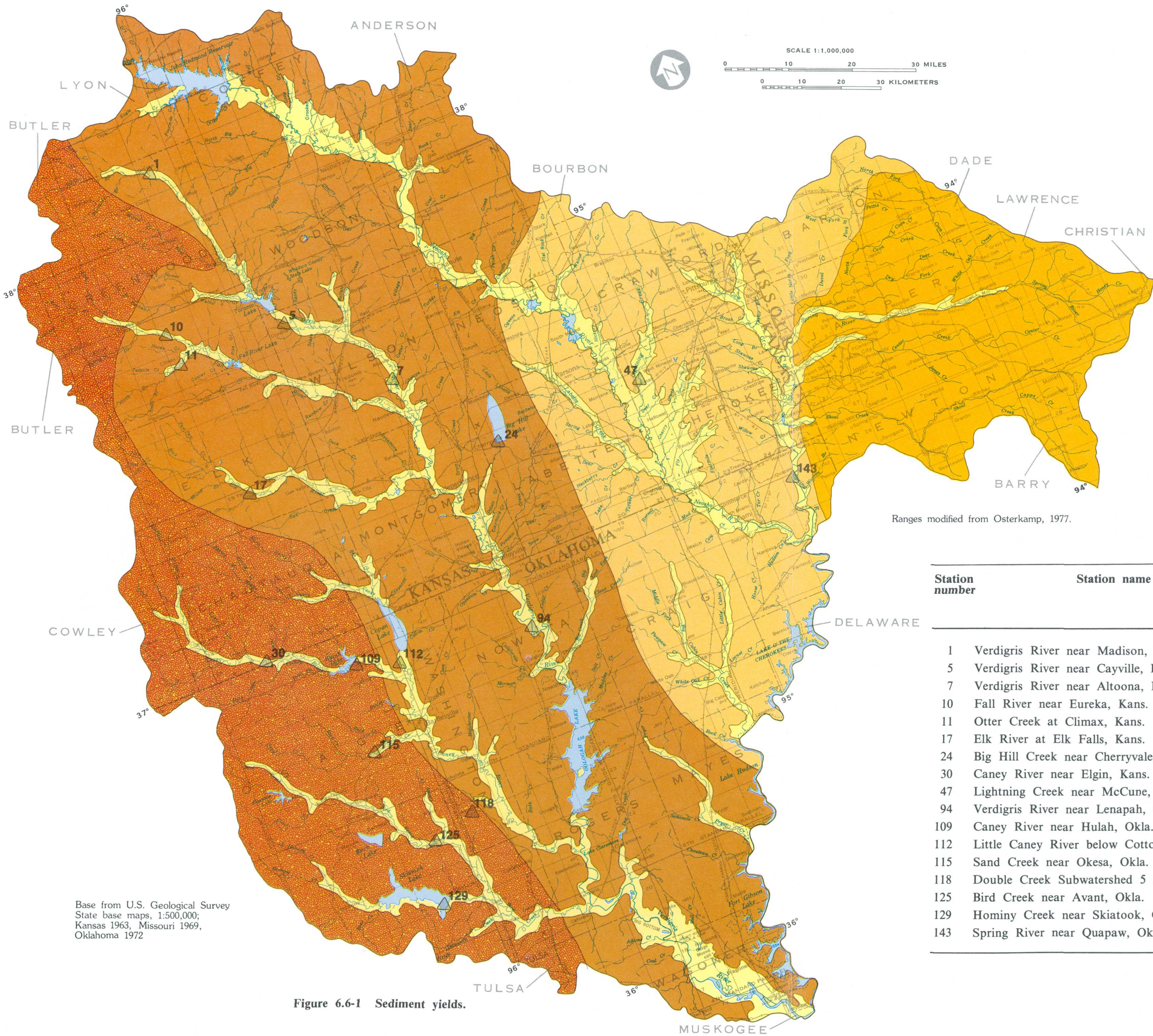
Most of the sediment transported in Area 40 accompanies runoff resulting from thunderstorms of varying intensity during spring and early summer. Runoff as a direct result of precipitation from any particular basin represents the integrated effect of several interrelated conditions including precipitation, geology, soils, topography, vegetation, and land use. This runoff controls the amount and particle size of suspended sediment transported. The instantaneous concentrations of suspended sediment in transport is also dependent on the availability of transportable materials. Agricultural activities, which are a major land use type in the area (section 2.5), is the most areally significant condition.

The total amount of sediment passing a station per unit area and time is expressed as sediment yield. Sediment yields in the area are lowest on floodplains, where the reduction in average slope and runoff velocity decreases the erosive capacity of water. In bedrock areas, sediment yields range from about 50 to over 600 tons per square mile per year (fig. 6.6-1). Yields generally increase in a westerly direction from the Kansas-Missouri state boundary. The Spring River basin in Missouri is estimated to yield between 100 and 200 tons per square mile per year.

For a given basin, the average sediment yield necessarily generalizes the area sediment discharge; significant variations from the average occur in upstream subbasins. Several ranges of estimated sediment yield (fig. 6.6-1) encompass this natural variation. Several important contributing conditions used in the areal delineation are discussed in detail by Osterkamp (1977). Data used to develop the sediment yields are given in table 6.6-1; additional data on sediment collection stations are tabulated in section 9.3.

Most of the sediment samples were collected weekly, bi-weekly, or monthly irrespective of stream stage; that is, the data are a mixture of rising, peak, and falling stage samples. Stations with sufficient samples over the expected flow regime were used to develop a rating curve showing the relationship between stream discharge and suspended-sediment discharge. Rising-stage discharge would be expected to transport significantly greater quantities of suspended sediment. Some of the scatter of the data is attributed to plotting rising and falling-stage data on the same graph.

Most of the sediment yields for Area 40 streams were calculated using the flow-duration/sediment-rating curve procedure. A flow-duration curve (section 5.2) was developed from mean daily discharge for each station with an adequate sediment-rating curve. The procedure, simply stated, combines a flow-duration curve with a sediment rating curve and mathematically weights the products over discrete time and stream discharge intervals. The result is an estimate of the average annual amount of sediment which passed the station during the period of data collection. This approach is the simplest and most practical procedure for analyzing the type of data currently available. Sediment yields calculated in this manner have comparable accuracy with yields based on data collected daily or more frequently (Osterkamp, 1977).



Ranges modified from Osterkamp, 1977.

Base from U.S. Geological Survey State base maps, 1:500,000; Kansas 1963, Missouri 1969, Oklahoma 1972

Figure 6.6-1 Sediment yields.

Table 6.6-1 Sediment-yield data.

Station number	Station name	Period of sediment record	Drainage area (square miles)	Total sediment yield (tons per square mile per year)
1	Verdigris River near Madison, Kans.	1956-73	181	397
5	Verdigris River near Cayville, Kans.	1954-60	747	752
7	Verdigris River near Altoona, Kans.	1940-59	1140	673
10	Fall River near Eureka, Kans.	1954-73	307	395
11	Otter Creek at Climax, Kans.	1953-73	129	342
17	Elk River at Elk Falls, Kans.	1967-73	220	332
24	Big Hill Creek near Cherryvale, Kans.	1958-73	37	292
30	Caney River near Elgin, Kans.	1940-78	445	432
47	Lightning Creek near McCune, Kans.	1940-46	197	538
94	Verdigris River near Lenapah, Okla.	1962-73	3640	831
109	Caney River near Hulah, Okla.	1938-78	733	452
112	Little Caney River below Cotton Creek near Copan, Okla.	1944-78	502	319
115	Sand Creek near Okesa, Okla.	1960-78	139	301
118	Double Creek Subwatershed 5 near Ramona, Okla.	1957-69	2.39	607
125	Bird Creek near Avant, Okla.	1945-78	364	453
129	Hominy Creek near Skiatook, Okla.	1944-71	340	597
143	Spring River near Quapaw, Okla.	1944-50	2510	252

Selected Chemical-Quality Data are Available for 35 Coal-Mine Ponds in Kansas and for 33 Coal-Mine Ponds in Oklahoma

Water in coal-mine ponds commonly contained large concentrations of dissolved sulfate and total and dissolved iron and manganese, and was acidic.

From April, 1978, to October, 1980, water quality samples were collected from 35 coal-mine ponds in Cherokee and Crawford Counties, Kansas. These samples were collected as part of a sampling program designed to obtain water-quality data for the most severe conditions created by acid mine drainage; therefore, values for specific conductance and pH, and concentrations of sulfate, iron, and manganese may be the maximum that would occur in these ponds. Data provided by these samples (table 6.7-1) show that concentrations of sulfate exceeded 250 milligrams per liter in about 75 percent of the samples, concentrations of total iron exceeded 300 micrograms per liter in about 50 percent, and concentrations of total manganese exceeded 50 micrograms per liter in about 90 percent.

From May, 1976, to November, 1981, water-quality samples were collected at 33 randomly-selected, coal-mine ponds in Oklahoma. In these samples, concentrations of sulfate exceeded 250 milligrams per liter in about 50 percent, dissolved iron exceeded 300 micrograms per liter in about 10 percent, and concentrations of dissolved manganese exceeded 50 micrograms per liter in about 50 percent. Because the Kansas and Oklahoma samples were collected for completely different studies, the reader is cautioned against comparing the data for the two States.

Iron and manganese cause staining of sinks and other fixtures, accumulation of deposits in water distribution systems, and an objectionable taste. However, both constituents are readily removed by aeration or filtering and neither have any significant effect on most irrigated crops.

Sulfate affects the taste of water and may produce laxative effects on some people but acclimation to the substance generally is rapid. Waters with large concentrations of sulfate used to irrigate crops grown on clayey soils may decrease soil permeability but the sulfate itself has little effect on most plants.

Vertical profiles of specific conductance, temperature, dissolved oxygen, and pH in the 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; both dissolved oxygen and pH decrease with depth. 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. Mine ponds less than 30 feet deep usually are not stratified probably because of mixing caused by winds blowing over the pond surface.

Table 6.7-1 Summary of water-quality data for coal-mine ponds.
(µmho – micromhos per centimeter at 25° Celsius; mg/L – milligrams per liter; µg/L – micrograms per liter)

Constituent or property	Recommended drinking water limit*	Number of analyses	Standard deviation	Minimum 0	10th	25th	Percentile Median 50th	75th	90th	Maximum 100th
			Kansas							
Specific conductance (µmho)	--	43	898	73	293	877	1,610	1,990	2,670	3,620
pH (units)	--	46	2.07	2	2.6	3.3	6.4	7.5	7.7	8.5
Chloride (mg/L)	250	45	5.43	0.8	1.7	2.7	4.5	6.4	12	33
Sulfate (mg/L)	250	45	633	17	71	430	980	1,400	1,800	2,200
Iron, total (µg/L)	300	45	8,202	80	140	200	440	2,200	9,100	42,000
Manganese, total (µg/L)	50	45	15,865	30	60	160	350	5,800	18,000	74,000
			Oklahoma							
Specific conductance (µmho)	--	377	897	329	420	541	755	1,600	2,700	3,730
pH (units)	--	336	0.49	6.3	7.2	7.4	7.8	8.1	8.3	9.1
Chloride (mg/L)	250	102	52	0.7	3.1	4.0	5.1	7.3	15	240
Sulfate (mg/L)	250	105	553	61	74	150	260	790	1,100	2,300
Iron, dissolved (µg/L)	300	93	1,471	10	20	30	40	100	460	10,000
Manganese, dissolved (µg/L)	50	93	3,337	5	20	30	270	1,300	3,200	16,000

*U.S. Environmental Protection Agency, 1977b

Unconsolidated Deposits in Most of Area 40 Yield Only Limited Quantities of Water

Wells in unconsolidated deposits may yield as much as 100 gallons per minute locally but most wells yield less than 10 gallons per minute; concentrations of dissolved solid in water from unconsolidated deposits usually are less than 1,000 milligrams per liter.

Unconsolidated deposits--alluvium and terrace deposits--are present along most of the streams in Area 40 (fig. 2.1-2). These deposits consist of variable proportions of silt, clay, and sand with minor amounts of fine gravel. The deposits are as much as 60 feet thick along the larger streams, such as the Verdigris and Neosho (fig. 7.1-1), but are 20 feet thick or less along the smaller, tributary streams.

Recharge to the unconsolidated deposits is derived mainly from precipitation; some recharge is provided by seepage from bedrock and the adjacent stream during periods of high flow. The quantity of recharge has not been determined but is estimated at 1-2 inches per year. Most discharge is by evapotranspiration and by flow into the nearby stream. The principal direction of ground-water movement is toward the streams but a secondary component is downvalley.

The unconsolidated deposits are capable of storing large quantities of water. However, the water-bearing pores in the silt and clay are so small that most of the water is retained by capillary action. Consequently, only in areas where the deposits consist largely of sand will they yield more than a few gallons per minute to wells. The saturated thickness in the unconsolidated deposits generally is less than 10 feet although it may be as much as 30 feet locally (fig. 7.1-1). Because of the limited saturated thickness, the drawdown available to wells is likewise limited. In areas where the saturated thickness is 20 feet or more, yields of 100 gallons per minute may be available from individual wells. Appropriately spaced batteries of wells or infiltration galleries probably are the best methods of developing water supplies from the unconsolidated deposits.

Water-level fluctuations, which reflect the volume of water in storage, generally respond to annual evapotranspiration, intense rains, and changes in river stage. The hydrograph of a well in alluvium along the Verdigris River (fig. 7.1-2) does not show an annual cycle because the frequency of measurement was twice yearly. However, this hydrograph shows longer-term trends in response to precipitation. For example, the high water level during 1962-63 followed several years of greater than normal rainfall and the low water level during 1965-66 coincided with a period of less than normal rainfall.

Data on the chemical quality of water from unconsolidated deposits in Area 40 are summarized in table 7.1-1. Water from these deposits in the larger river valleys is dominated by calcium and bicarbonate ions and generally has dissolved-solids concentrations of less than 500 milligrams per liter. Large concentrations of sodium, chloride, and particularly sulfate may be present in unconsolidated deposits in the smaller valleys. Sulfate is a major component of ground water in stream valleys draining shale of Pennsylvanian age. Water with a pH of less than 6.5, sulfate concentrations greater than 250-300 milligrams per liter, and dissolved iron and manganese concentrations of more than 100-200 milligrams per liter may indicate mineralization from pyritic materials associated with coal or metal mines.

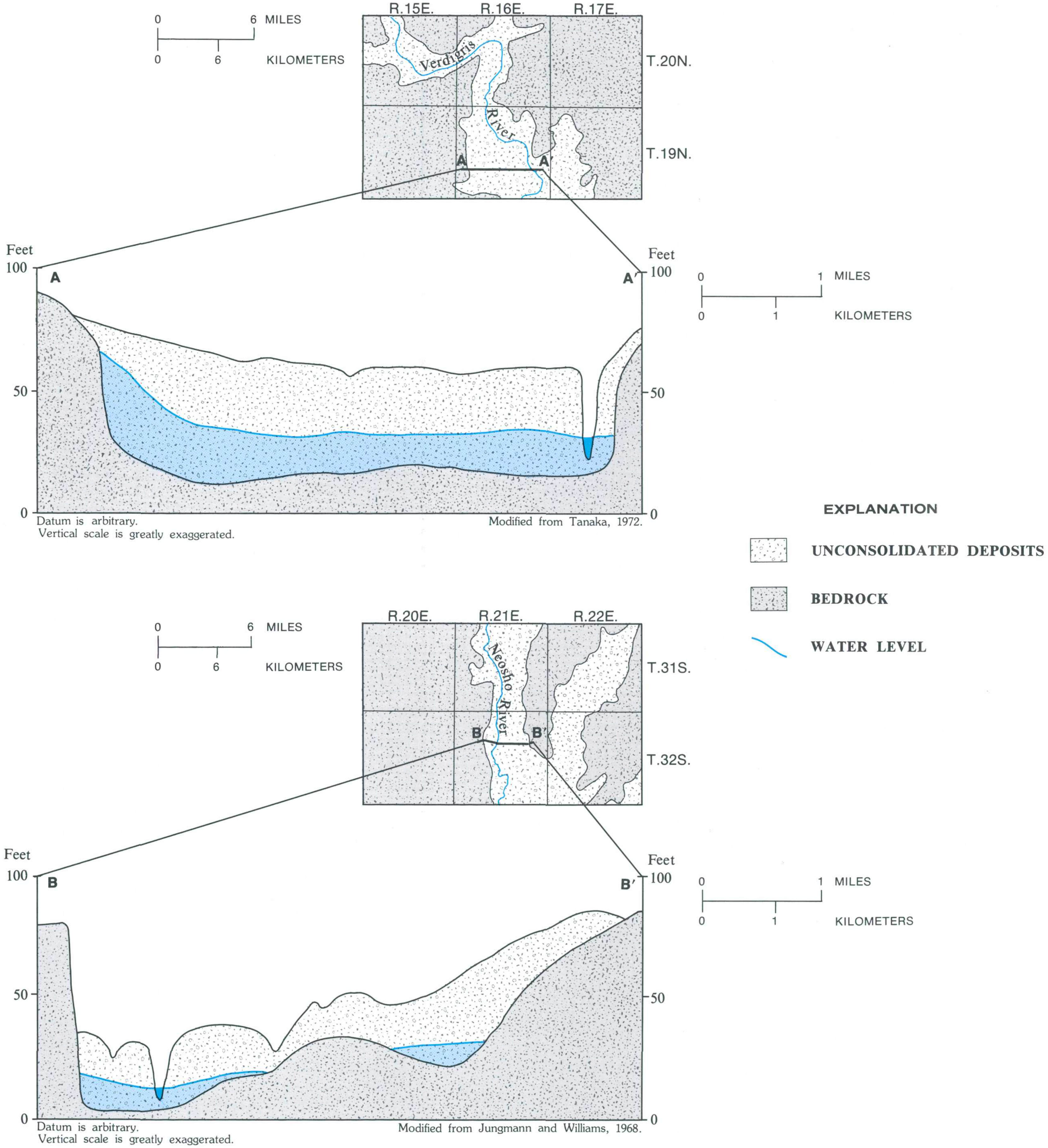


Figure 7.1-1 Geologic sections of the unconsolidated deposits along the Verdigris River (A-A′), Rogers County, Oklahoma, and the Neosho River (B-B′), Labette County, Kansas.

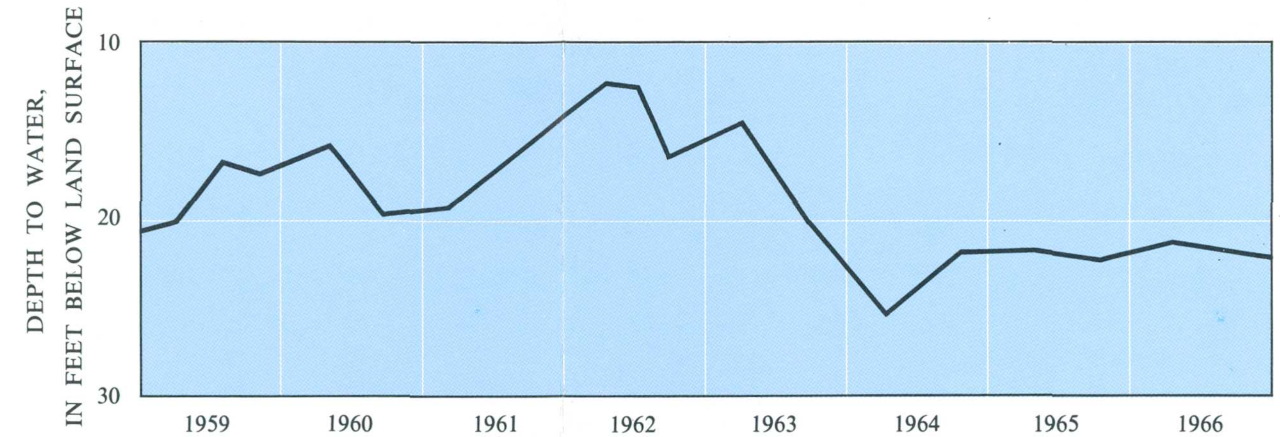


Figure 7.1-2 Water-level fluctuations in unconsolidated deposits along the Verdigris River.

Table 7.1-1 Minimum, median and maximum concentrations of selected dissolved constituents and similar values for pH in water from unconsolidated deposits.
(mg/L – milligrams per liter; μg/L – micrograms per liter)

Constituent or property	Minimum	Median	Maximum	Number of analyses
Bicarbonate (mg/L)	130	340	470	10
Calcium (mg/L)	37	115	170	10
Chloride (mg/L)	7	38	454	19
Dissolved solids (mg/L)	240	410	889	10
Iron (μg/L)	10	70	34,000	17
Magnesium (mg/L)	5	14	87	10
Manganese (μg/L)	10	32	1,750	10
pH (units)	6.0	7.1	7.7	18
Potassium (mg/L)	0	1	3	9
Sodium (mg/L)	10	22	250	9
Sulfate (mg/L)	2	47	3,970	19

Rocks of Pennsylvanian Age Generally Yield Only Small Amounts of Water

Wells in rocks of Pennysylvanian age, other than those in sandstones of the Ada and Vamoosa Formations and the Douglas Group, generally yield less than 5 gallons per minute; concentrations of dissolved solids in water from these wells range from about 100 to 5,000 milligrams per liter.

Rocks of Pennsylvanian age, which are present in about 80 percent of Area 40 (fig. 2.1-2), consist of a sequence of interbedded shale, sandstone, and limestone; the sandstone beds become more numerous and thicker toward the west. Shale units typically are 50-100 feet thick; sandstone and limestone units generally are 5-20 feet thick. Excluding sandstones in the Ada and Vamoosa Formations and the Douglas Group, the Pennsylvanian rocks have little primary porosity and their ability to store and transmit water is extremely limited. Consequently, few wells in these rocks yield more than 5 gallons per minute and many yield much less. Deeper wells might yield more water by intercepting more bedding planes or fractures, but below depths of 200-250 feet the water is likely to be too mineralized for most uses. In the western part of the area, thick sandstones in the Ada and Vamoosa Formations and the Douglas Group may yield as much as 100 gallons per minute.

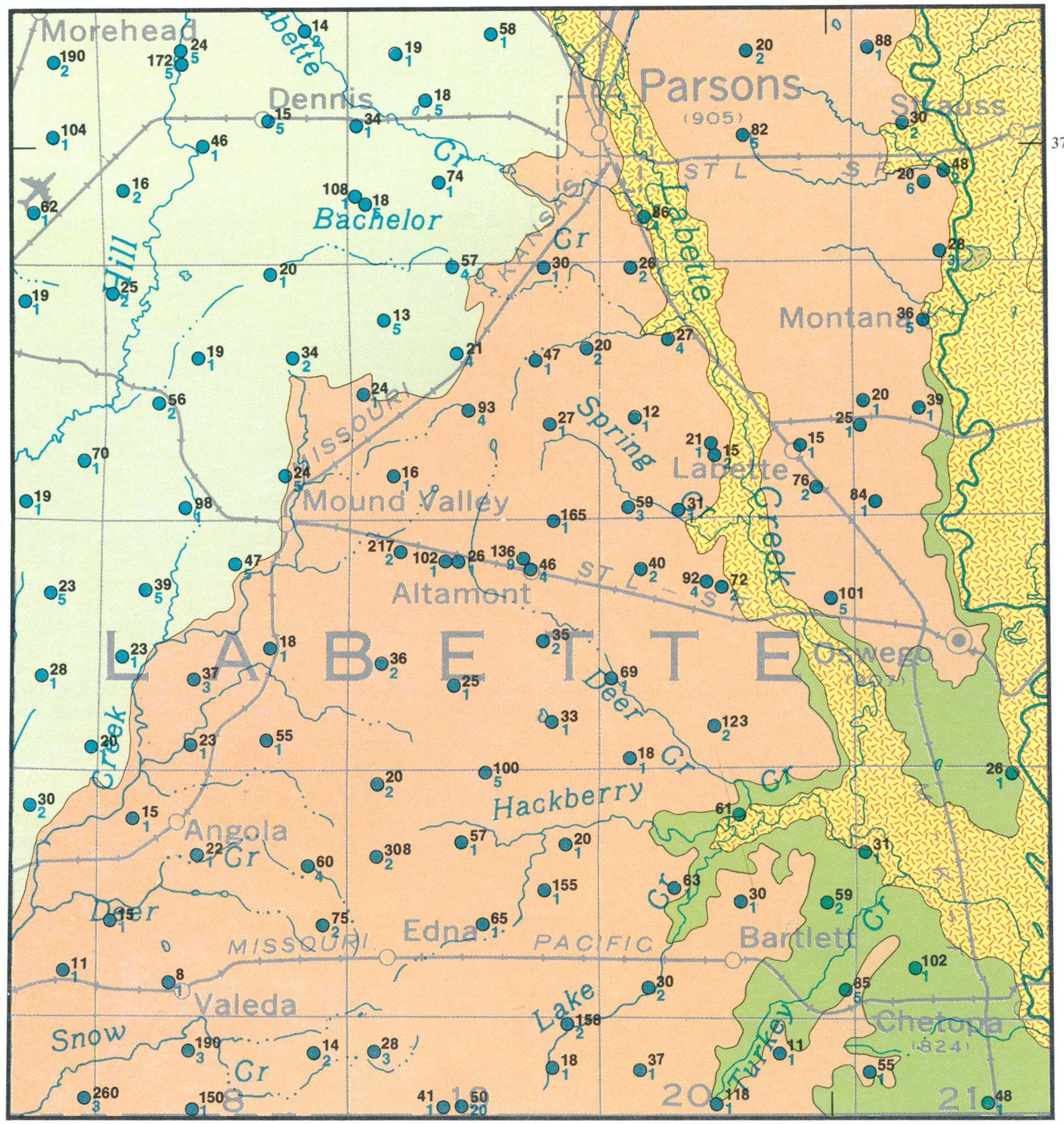
Because of the geologic structure, the Pennsylvanian rocks are slightly tilted at the surface exposing bedding planes between the rock layers. These bedding planes are the principal avenues or openings for water entry and movement although joints and fractures may be important in some places. Recharge entering the rocks is derived mainly from precipitation falling on the outcrop; small quantities may be derived by seepage from overlying unconsolidated deposits or from streams. Most discharge is by evapotranspiration, although some water is discharged to streams during periods of high water levels. A very small quantity of water is discharged by pumping wells.

Water in the zone of weathered rock, which may be as much as 30 feet thick in some areas, generally is unconfined. Water in bedrock below the weathered zone is confined and some wells may flow at times of high water levels. In shallow, unconfined aquifers the slope of the potentiometric surface coincides with the slope of the land surface so the local direction of water movement is toward the streams and downvalley.

Ground-water conditions in Labette County, Kansas, as described by Jungmann and Williams (1968), are typical of Pennsylvanian rocks in most of Area 40. In Labette County, wells for which yields were reported by their owners ranged in depth from 8 to 308 feet (fig. 7.2-1); about 60 percent were less than 60 feet deep. Reported yields ranged from 1 to 20 gallons per minute; about 75 percent yielded 2 gallons per minute or less.

Water levels in the shallow, weathered part of the Pennsylvanian rocks generally fluctuate in response to annual weather cycles (fig. 7.2-2). Water levels typically are highest during spring and early summer and are lowest during late fall or winter. Intermittent rains of an inch or so during summer when evapotranspiration is greatest may produce sharp but only temporary rises in the water level and have litte or no effect on the seasonal downward trend.

The chemical quality of water from Pennsylvanian rocks varies depending on lithology, location in the local or regional flow system, and depth. Chemical analyses of water from wells in the Pennsylvanian rocks are summarized in table 7.2-1. In general, water from wells less than 100 feet deep in sandstone and limestone near the outcrop is dominated by calcium and bicarbonate ions with dissolved-solids concentrations between 500 and 1,000 milligrams per liter. Deeper wells in sandstone and limestone may produce water with greater concentrations of sodium, sulfate, chloride, and dissolved solids. Such mineralization is typical of water in the western part of Area 40. Water from shale commonly has the greatest concentrations of dissolved solids, principally due to calcium, sodium, sulfate, and chloride. However, shallow wells in shale may yield water with concentrations of dissolved solids less than 500 milligrams per liter and with calcium and bicarbonate as the predominant ions. Concentrations of dissolved iron and dissolved manganese generally are less the 100 micrograms per liter in water from sandstone and limestone but typically are much greater in water from shale. The pH of water from all lithologic types usually ranges from 6 to 8.



Base from U.S. Geological Survey
Kansas state base map, 1:500,000, 1963

Geology from Kansas Geological Survey, 1964.
Hydrology modified from Jungmann and Williams, 1968.

SCALE 1:250,000

0 5 10 MILES

0 5 10 KILOMETERS

Figure 7.2-1 Geohydrologic map of Labette County, Kansas, showng location, depth, and reported yields of wells in rocks of Pennsylvanian age.

EXPLANATION

ALLUVIUM AND TERRACE DEPOSITS

KANSAS CITY AND PLEASANTON GROUPS

MARMATON GROUP

CHEROKEE GROUP

CONTACT

81/2 WELL Upper number is well depth, in feet; lower number is reported yield, in gallons per minute.

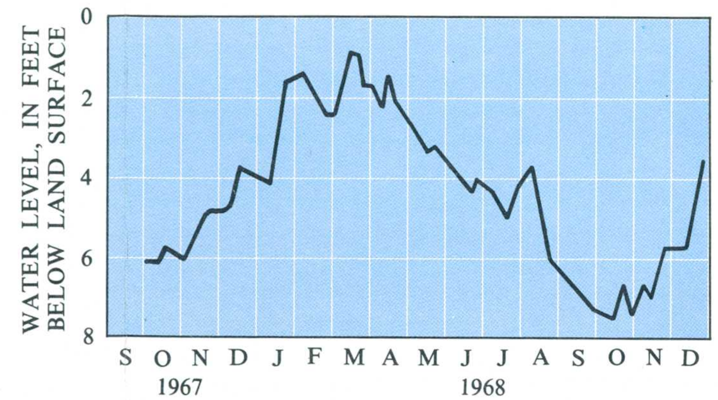


Figure 7.2-2 Water level fluctuations in a well penetrating rocks of Pennsylvanian age near Vinita, Oklahoma.

Table 7.2-1 Minimum, median, and maximum concentrations of selected dissolved constituents and similar values of water from rocks of Pennsylvanian age.

(mg/L – milligrams per liter; μg/L – micrograms per liter)

Constituent or property	Minimum	Median	Maximum	Number of analyses
Bicarbonate (mg/L)	11.5	320	1,170	52
Calcium (mg/L)	2	60	550	52
Chloride (mg/L)	1	39	3,240	149
Dissolved solids (mg/L)	83	527	5,110	50
Iron (μg/L)	10	80	10,000	139
Magnesium (mg/L)	0	10	130	52
Manganese (μg/L)	10	20	61,000	53
pH (units)	4.5	7.3	9.0	143
Potassium (mg/L)	0	2	46	45
Sodium (mg/L)	4.5	76	1,900	52
Sulfate (mg/L)	1	54	2,300	150

The Vamoosa-Ada Aquifer in the Western Part of Area 40 is a Potential Source of Moderate Quantities of Water

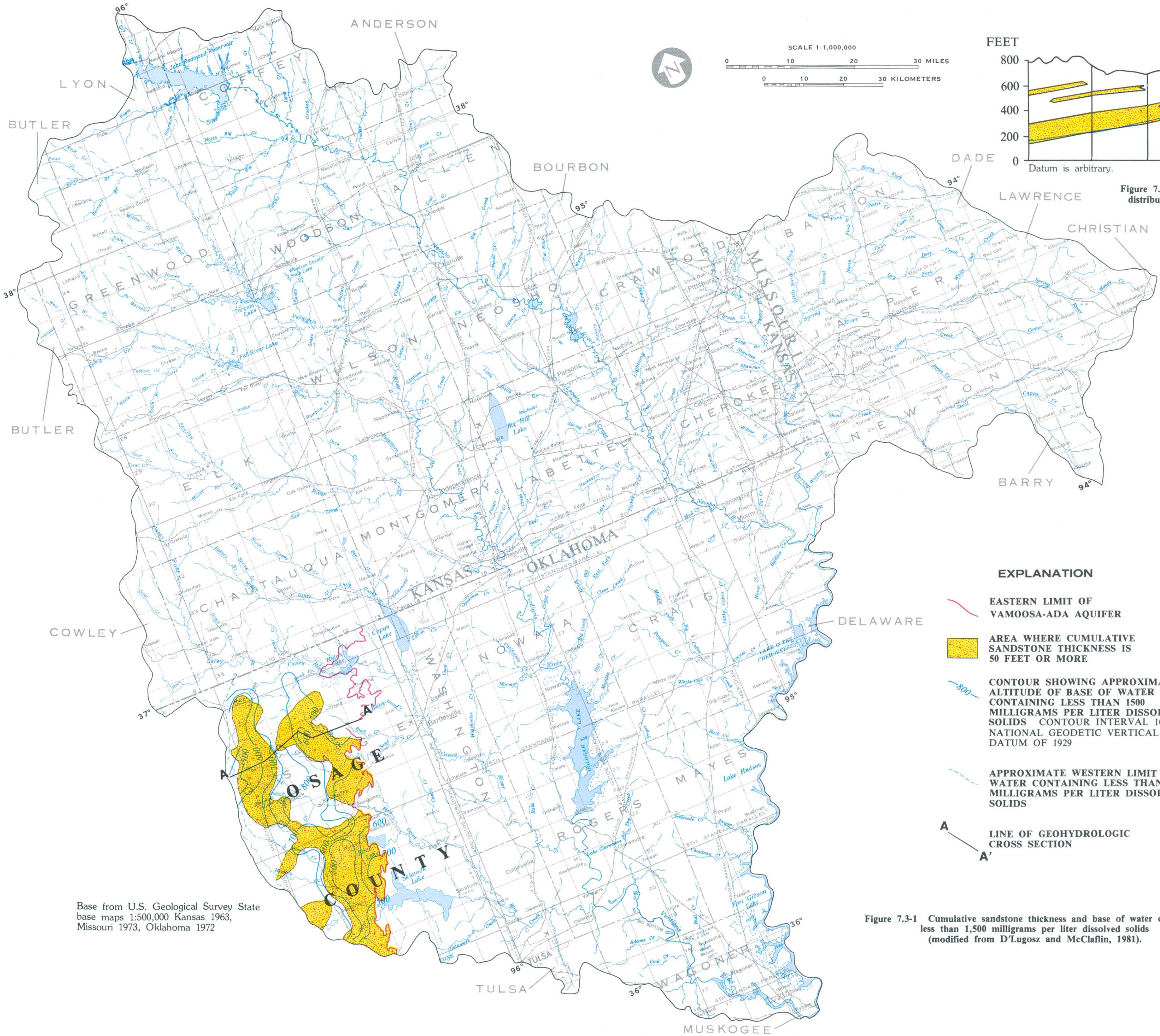
Wells in thick sequences of sandstone in the Vamoosa-Ada aquifer may yield 100 gallons per minute; concentration of dissolved solids in water from the aquifer generally are less than 1,000 milligrams per liter but locally the water has been contaminated by oil-field brines.

The Vamoosa-Ada aquifer (fig. 7.3-1) consists of the Vamoosa Formation and parts of the overlying Ada Formation (D'Lugosz and McClaflin, 1981). The aquifer is a complexly interbedded sequence of fine to very fine grained sandstone, siltstone, shale, and conglomerate with a few thin limestone beds of local extent. Most of these rocks were deposited in a near-shore environment ranging from marine on the west to nonmarine on the east. The variable and shifting nature of the depositional environment is reflected by abrupt changes in lithology and thickness of individual units, particularly sandstone, within short distances (fig. 7.3-2). Individual sandstone units typically are 1-30 feet thick. The thin units (1-5 feet) are laterally extensive whereas the thick units (5-30 feet) are of limited extent. Cumulative sandstone thicknesses are as much as 225 feet. The more favorable areas for development of ground-water supplies are where the cumulative thickness of sandstone beds is at least 50 feet (fig. 7.3-1).

Because of vertical and lateral variations in lithology and, consequently, hydraulic characteristics, water in the Vamoosa-Ada aquifer occurs under both confined and unconfined conditions. Unconfined conditions generally exist in the outcrop area and probably for a short distance westward from the point where the sandstone is overlain by impermeable shale. Confined conditions exist farther west and in the more deeply buried sandstone beds. Recharge, which is derived principally from precipitation falling directly on or near the outcrop area, is estimated to be about 1 inch per year (D'Lugosz and McClaflin, 1981). Discharge is equal to recharge. An estimated 80 percent of the discharge is by evapotranspiration; nearly all the remaining 20 percent is by streamflow. Water levels in the aquifer fluctuate annually (fig. 7.3-3) and under natural conditions this fluctuation generally is less than 10 feet.

The chemical type of water in the aquifer is variable; of the analyses complete enough to classify the water, about 75 percent were sodium bicarbonate or sodium calcium bicarbonate. The remaining 25 percent were sodium sulfate, calcium sulfate, sodium chloride or mixed types. Dissolved-solids concentrations were less than 1,000 milligrams per liter in about 80 percent of the samples analyzed. Concentrations of chloride, which may indicate invasion of parts of the aquifer by brines or oilfield waste, were less than 250 milligrams per liter in about 90 percent of the samples analyzed. Hôwever, concentrations of bromide in excess of 1 milligram per liter, which indicates contamination by brines (see section 1.5), was present in 8 of 14 samples analyzed for that constituent (D'Lugosz and McClaflin, 1977).

Water with dissolved-solids concentrations of less than 1,500 milligrams per liter, described as potable water by D'Lugosz and McClaflin (1981), in the Vamoosa-Ada aquifer is everywhere underlain by more mineralized water that becomes brine with depth. The contact between the potable and nonpotable water generally is abrupt. The position of the base of potable water (fig. 7.3-1) is significant because wells completed below that base will yield water unsuitable for drinking. In addition, local overpumping of wells completed near the base of potable water may induce upward movement of the more mineralized water thus contaminating part of the aquifer.



Base from U.S. Geological Survey State base maps 1:500,000 Kansas 1963, Missouri 1973, Oklahoma 1972

EXPLANATION

EASTERN LIMIT OF VAMOOSA-ADA AQUIFER

AREA WHERE CUMULATIVE SANDSTONE THICKNESS IS 50 FEET OR MORE

800 — CONTOUR SHOWING APPROXIMATE ALTITUDE OF BASE OF WATER CONTAINING LESS THAN 1500 MILLIGRAMS PER LITER DISSOLVED SOLIDS CONTOUR INTERVAL 100 FEET NATIONAL GEODETIC VERTICAL DATUM OF 1929

APPROXIMATE WESTERN LIMIT OF WATER CONTAINING LESS THAN 1500 MILLIGRAMS PER LITER DISSOLVED SOLIDS

A—A′ LINE OF GEOHYDROLOGIC CROSS SECTION

Figure 7.3-1 Cumulative sandstone thickness and base of water containing less than 1,500 milligrams per liter dissolved solids (modified from D'Lugosz and McClaflin, 1981).

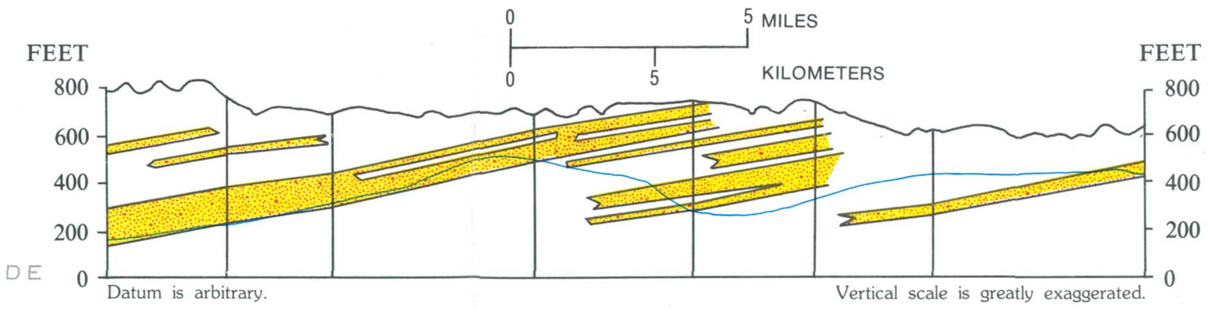


Figure 7.3-2 Typical geohydrologic section of the Vamoosa-Ada aquifer showing distribution of sandstone units (color) and base of water containing less than 1,500 milligrams per liter dissolved solids (blue line).

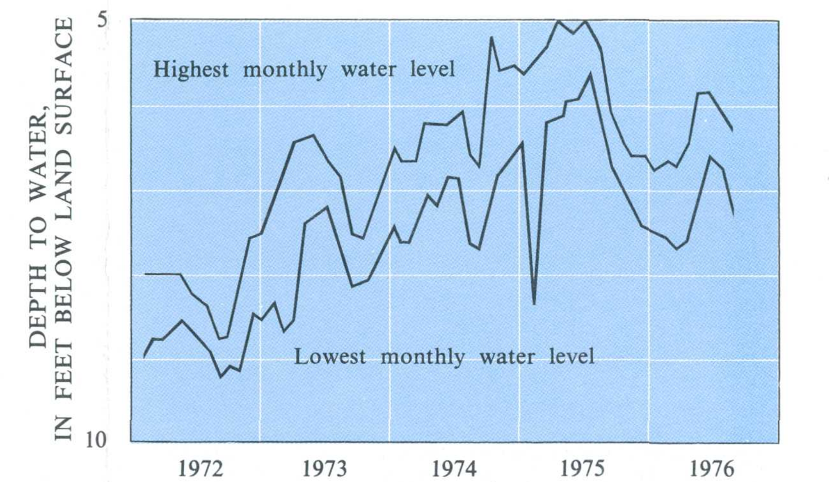


Figure 7.3-3 Water-level fluctuations in the Vamoosa-Ada aquifer.

Table 7.3-1 Minimum, median and maximum concentrations of selected dissolved constituents in water from the Vamoosa-Ada aquifer.
(mg/L – milligrams per liter)

Constituent	Minimum	Median	Maximum	Number of analyses
Bicarbonate (mg/L)	37	376	590	25
Bromide (mg/L)	0.3	1.9	10	14
Calcium (mg/L)	1.8	30	1,400	23
Chloride (mg/L)	7.8	110	9,400	27
Dissolved solids (mg/L)	192	637	14,300	25
Magnesium (mg/L)	.1	14	200	23
Nitrate (mg/L)	.4	7.2	58	12
Sodium (mg/L)	13	140	2,500	26
Sulfate (mg/L)	6	45	220	25

Water-Yielding Rocks of Mississippian Age are At or Near the Surface in the Ozark Plateau Section of Area 40

Some wells in the Mississippian aquifer may yield 300 gallons per minute but most yield less than 10 gallons per minute; the water typically is a calcium bicarbonate type and is hard to very hard.

Water-yielding rocks of Mississippian age in Oklahoma include the "St. Joe", "Reeds Spring", "Keokuk" Formations referred to as the "Boone" Group by Fay and others (1979) or "Boone Chert" by Marcher and Bingham (1971). Approximately equivalent rocks in Kansas include the Burlington and Keokuk Limestones (Eubanks and others, 1979) and in Missouri they include the Reeds Spring Formation, Elsey Formation, Burlington Limestone, and Keokuk Limestone (Thompson, 1979, and Feder and others, 1969). These formations, which have an aggregate thickness of 300-400 feet, consist prinicipally of cherty to very cherty limestone with a few thin sandy or shaly zones. For convenience in this report, these rocks are collectively referred to as the Mississippian aquifer.

In most of its area of outcrop (fig. 7.4-1) the Mississippian aquifer has been intensely weathered to a residual rubble of fractured chert. Weathering and resultant slumping is important because the fractures thus formed provide openings for the entry, movement, and storage of water. Localized areas of very intensely weathered rocks, referred to as breccia areas (Feder and others, 1969), have been mapped in some detail in the vicinity of Joplin, Missouri. These breccia areas may yield as much as 300 gallons per minute to individual wells whereas wells in nearby, less weathered rocks may yield only 5-10 gallons per minute. Breccia areas were the sites of mineralization by zinc and lead ores which have been mined leaving extensive underground openings now filled with water.

Because of vertical and lateral variations in hydraulic characteristics, water in the Mississippian aquifer occurs under confined and unconfined conditions. Generally unconfined conditions occur in the upper 50-100 feet of the aquifer. However, there is little difference in water levels--commonly no more than 5 feet--in adjacent wells that are completed in confined and unconfined zones. In the outcrop area the static water level commonly is less than 30 feet below the surface. Where the aquifer is overlain by impermeable shale of Pennsylvanian age, the static level may be 50-100 feet below the surface depending on local hydrologic conditions.

Recharge to the Mississippian aquifer is derived mainly from precipitation falling directly on the outcrop. Average annual precipitation in Spring River basin, where the aquifer is widely exposed at the surface, is about 40 inches. According to Feder and others (1969), about 5 percent of the precipitation recharges the aquifer, 20 percent runs off as streamflow, and 75 percent is lost by evaporation.

Springs in the Ozark Plateau section of Area 40 are a very significant part of the hydrologic system. At least 50 springs discharging more than 100 gallons per minute are known in the basin of Spring River (Vineyard and Feder, 1974) and many smaller springs and seeps undoubtedly are present. Springs discharge approximately 300 cubic feet per second (194 million gallons per day) to Spring River and its tributaries thereby maintaining flow of these streams during times of no rainfall (see section 5.2). Because of its uniform temperature (14-16° Celsius), spring water is well suited for propagation of fish. Springs also supply water for domestic, stock, industrial, and recreation use.

Water from the Mississippian aquifer typically is a calcium bicarbonate type and commonly is hard to very hard (more than 121 milligrams per liter as calcium carbonate). The chemical quality of water from wells and springs is summarized in table 7.4-1. Because water in the Mississippian aquifer moves through fractures and solution openings, it is subject to contamination from various surface sources.

In the vicinity of Joplin, Missouri, abandoned mines are a source of water supply for various uses (Feder and others, 1969). Concentrations of dissolved solids in water from 23 mine shafts and open-pit ponds in the Joplin area ranged from 329 to 2,200 milligrams per liter. Water from abandoned mines in Oklahoma and Kansas contains large concentrations of dissolved solids and toxic metals and, therefore, is unsuited for most uses without extensive treatment (Playton and others, 1980). The inability of current (1982) domestic water-treatment practices to remove toxic metals, such as cadmium and lead (see section 9.2), precludes use of the mine water for public supply.

Depending on local hydrologic conditions, excessively mineralized water from mines may move into adjacent Mississippian aquifer. However, such movement apparently is not widespread in the Joplin area (Barks, 1977).

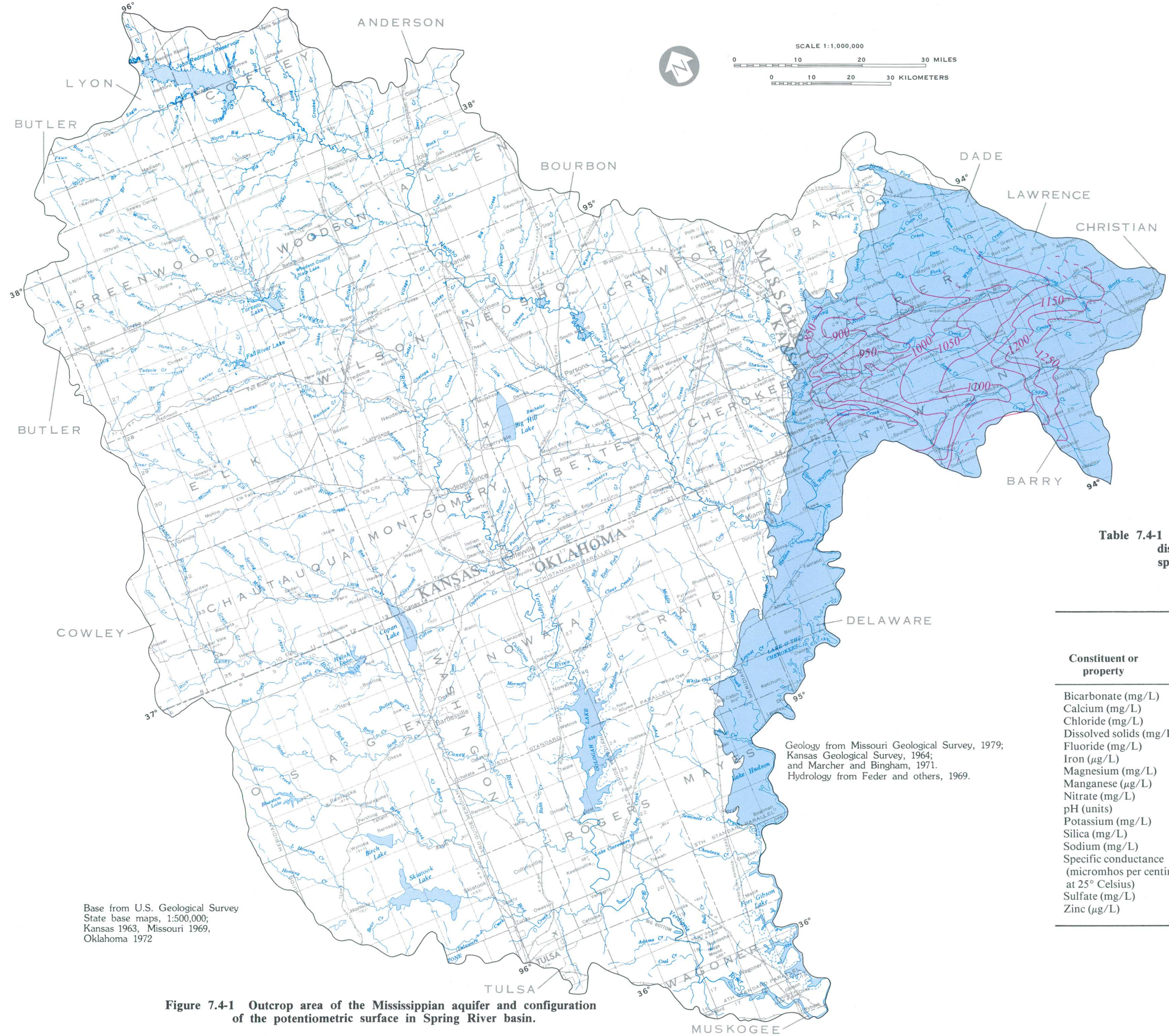


Figure 7.4-1 Outcrop area of the Mississippian aquifer and configuration of the potentiometric surface in Spring River basin.

EXPLANATION

OUTCROP OF MISSISSIPPIAN AQUIFER

–900– **POTENTIOMETRIC CONTOUR** Shows altitude at which water level would have stood in tightly cased wells (1966). Dashed where approximately located.
Contour interval 50 feet.
National Geodetic Vertical Datum of 1929

Table 7.4-1 Minimum, median, and maximum concentrations of selected dissolved constituents and similar values for pH and specific conductance of water from wells and springs in the Mississippian aquifer, Spring River basin, Missouri (from Feder and others, 1969).

(mg/L – milligrams per liter; µg/L – micrograms per liter)

Constituent or property	Wells				Springs			
	Minimum	Median	Maximum	Number of analyses	Minimum	Median	Maximum	Number of analyses
Bicarbonate (mg/L)	72	225	339	37	90	167	253	27
Calcium (mg/L)	33	80	221	39	31	55	147	29
Chloride (mg/L)	0.2	4.1	130	39	2.9	6.2	13	29
Dissolved solids (mg/L)	162	228	981	39	123	186	520	29
Fluoride (mg/L)	.0	0.2	0.8	39	.0	.0	4.1	29
Iron (µg/L)	.0	240	2,400	36	.0	20	770	29
Magnesium (mg/L)	.5	6.8	36	39	.4	2.4	7.3	29
Manganese (µg/L)	.0	.0	200	39	.0	.0	100	27
Nitrate (mg/L)	.0	4.2	277	39	1.1	9.3	18	29
pH (units)	6.1	7.9	8.3	39	7.0	7.5	8.3	27
Potassium (mg/L)	.4	1.4	43	39	.2	.9	1.8	21
Silica (mg/L)	7.2	9.0	22	39	5.0	9.8	27	29
Sodium (mg/L)	3.0	7.6	106	39	1.1	4.3	10	21
Specific conductance (micromhos per centimeter at 25° Celsius)	285	470	1,390	39	201	301	741	26
Sulfate (mg/L)	1.6	43	446	39	1.2	6.6	192	29
Zinc (µg/L)	50	900	6,700	38	--	--	--	--

The Cambrian-Ordovician Aquifer is an Important Source of Water in the Eastern Part of Area 40

Yields of wells in the Cambrian-Ordovician aquifer range from 50 to 1,000 gallons per minute and average about 200 gallons per minute; the water is typically a calcium magnesium bicarbonate type and is moderately hard to very hard.

Rocks of Cambrian and Ordovician age are present in the sub-surface throughout Area 40. However, these rocks are a source of water having a dissolved-solids concentrations of 1,000 milligrams per liter or less only in southwestern Missouri and adjacent parts of Kansas and Oklahoma (fig. 7.5-1). Farther west in Area 40, the Cambrian and Ordovician formations are the source of oil and gas and are used to dispose of oil-field brines and various industrial wastes.

The Cambrian-Ordovician formations consist principally of cherty dolomite with some sandstone, siltstone, and shale (table 7.5-1). These rocks were deposited on an irregular surface with local relief of as much as 800 feet (Ireland and Warren, 1946) so that units below the Roubidoux Formation or Gasconade Dolomite may be missing in some areas. Where all formations are present, their aggregate thickness is about 1,400 feet.

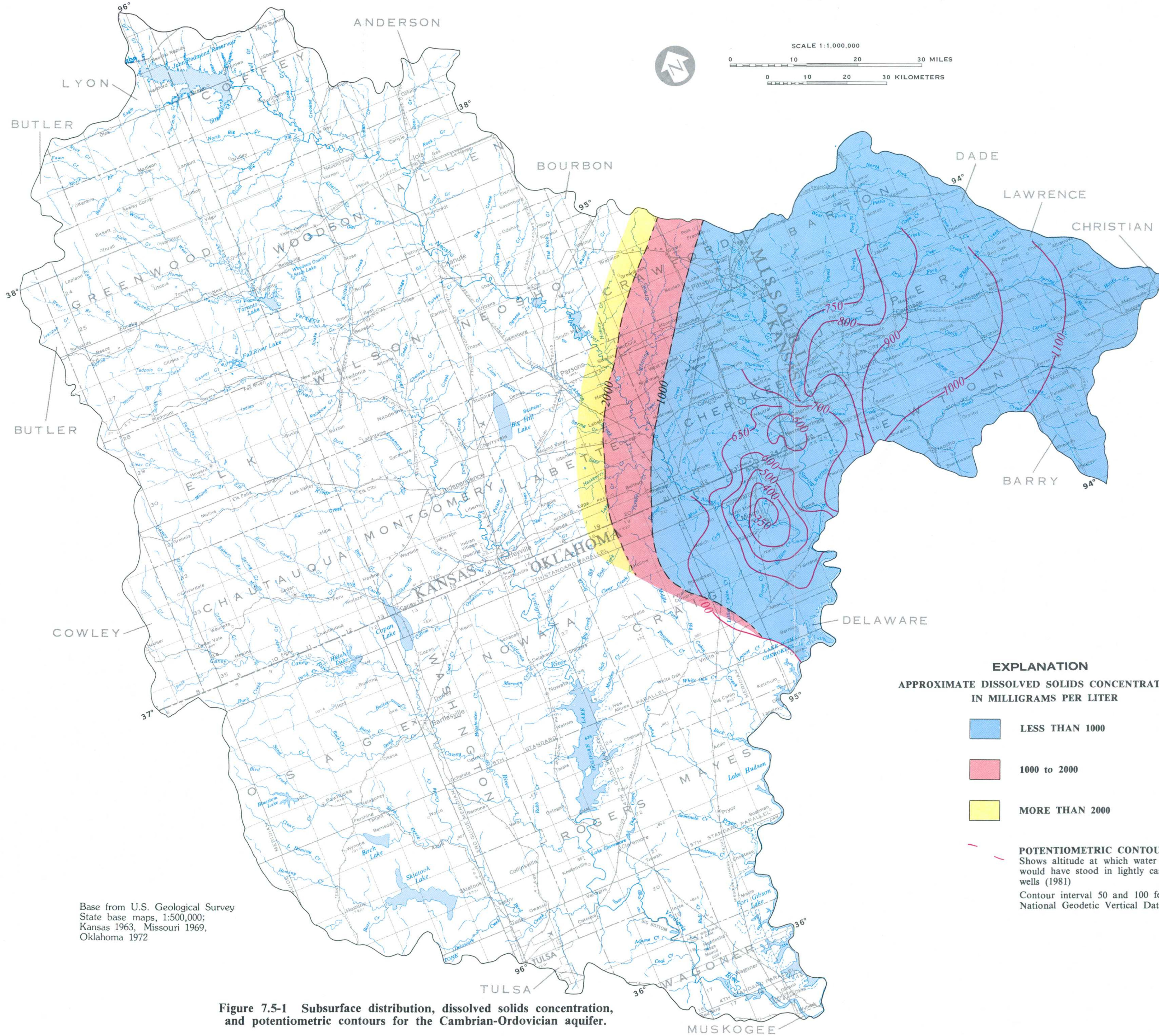
Water in the Cambrian-Ordovician aquifer is confined. Wells in these rocks generally are not cased below the top of the Cotter Dolomite so that all formations penetrated may yield some water. Consequently, the water level in a given well is a composite of all uncased formations. In Oklahoma and Kansas, the main water-yielding zones are sandstone or sandy dolomite in the Roubidoux Formation. In Missouri, the Eminence and Potosi Dolomites, as well as the Roubidoux, yield water to wells. The specific capacities of wells in the Cambrian-Ordovician aquifer in Spring River basin range from 1 to 20 gallons per minute per foot of drawdown (Feder and others, 1969).

The principal source of recharge to the Cambrian-Ordovician aquifer is in its outcrop area 10-30 miles east of Spring River basin. According to Harvey (1980), recharge is variable and occurs through sinkholes, by infiltration in permeable uplands, and by infiltration through streambeds. A secondary source of recharge is downward seepage from the overlying Mississippian aquifer. Water-level measurements in Spring River basin show that the potentiometric surface in the Cambrian-Ordovician aquifer generally is 50-100 feet below that in the Mississippian aquifer. Thus, if fractures or solution openings are present, water in the Mississippian aquifer will move downward. Such movement could result in the degradation of water in the Cambrian-Ordovician aquifer, particularly in areas where it is overlain by abandoned zinc and lead mines filled with excessively mineralized water (Fairchild and Christenson, 1982).

The potentiometric surface in the Cambrian-Ordovician aquifer is highest in the eastern part of Spring River basin (fig. 7.5-1) near the areas of recharge. The slope of the surface and, consequently, the direction of water movement, is toward the west or northwest. Irregularities in the surface are the result of pumping. Pumping for municipal and industrial supply in the vicinity of Miami, Oklahoma, has produced a cone of depression with an area of about 500 square miles; a smaller cone has been developed in the vicinity of Baxter Springs, Kansas. During the early 1900's, the water level at Miami was near the land surface at an altitude of about 800 feet; a few wells reportedly flowed. However, long-continued and ever-increasing pumping has caused the water level to decline about 500 feet (fig. 7.5-2).

Water from the Cambrian-Ordovician aquifer in Spring River basin and Ottawa and Delaware Counties, Oklahoma, is a calcium magnesium bicarbonate type. Farther west, in Craig County, Oklahoma, the water type changes to sodium chloride; still farther west the water is brine. The water is moderately hard to hard (more than 61 milligrams per liter as calcium carbonate). Data for the chemical quality from the Cambrian-Ordovician aquifer in Spring River basin are summarized in table 7.5-2. These data also are representative of water from the aquifer in Ottawa and Craig Counties, Oklahoma. Water from some wells contains hydrogen sulfide, which gives it an unpleasant odor; however, the odor is readily eliminated by aeration.

The supposed presence of radium in water from the Cambrian-Ordovician rocks at Claremore and Nowata, Oklahoma, led to the development of "radium water" spas that were popular during the early part of the century (Siebenthal, 1908, and Smith and others, 1942). Although none of the early chemical analyses of the waters showed the presence of radium, the supposition that it was present was correct (Oklahoma State Department of Health, 1980). As part of a study of the Cambrian-Ordovician aquifer in northeastern Oklahoma, 61 water samples, mostly from Ottawa, Craig, and Delaware Counties, were analyzed by the U.S. Geological Survey in 1982. In 7 of these samples, or 11 percent, radium-226 ranged from 5.2 to 14 picocuries per liter thus exceeding the contaminant level for drinking water of 5 picocuries established by the U.S. Environmental Protection Agency (1976a). Although the radioactivity occurs naturally, its source is unknown. However, Totten and Fay (1982) report that radioactive minerals are common in the Chattanooga Shale, which immediately overlies the Cotter Dolomite in most of the area, and that sand grains from the Roubidoux Formation penetrated by a well in Delaware County, Oklahoma, were coated with a uranium mineral resembling carnotite. The possibility also exists that the radioactivity is derived from Precambrian granite and rhyolite underlying the Cambrian-Ordovician rocks.



EXPLANATION

APPROXIMATE DISSOLVED SOLIDS CONCENTRATIONS, IN MILLIGRAMS PER LITER

LESS THAN 1000

1000 to 2000

MORE THAN 2000

POTENTIOMETRIC CONTOUR
Shows altitude at which water level would have stood in lightly cased wells (1981)

Contour interval 50 and 100 feet.
National Geodetic Vertical Datum of 1929.

Base from U.S. Geological Survey
State base maps, 1:500,000;
Kansas 1963, Missouri 1969,
Oklahoma 1972

Figure 7.5-1 Subsurface distribution, dissolved solids concentration, and potentiometric contours for the Cambrian-Ordovician aquifer.

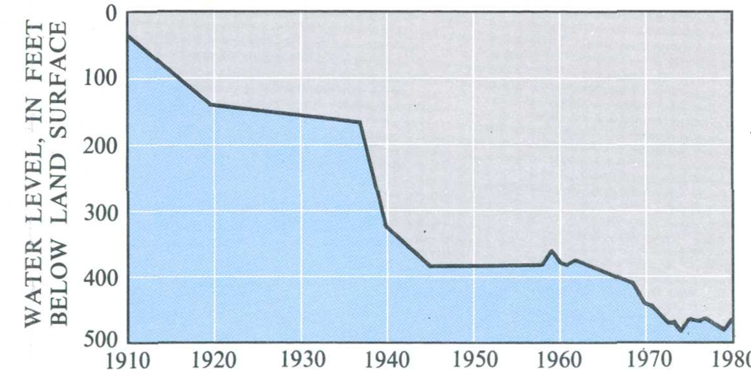


Figure 7.5-2 Water-level fluctuations in the Cambrian-Ordovician aquifer at Miami, Oklahoma.

Table 7.5-1 Generalized geologic section of Cambrian and Ordovician rocks in southwestern Missouri and adjacent parts of Oklahoma and Kansas (modified from Feder and others, 1969, and Reed and others, 1955).

Formation	Thickness (feet)	Lithology	Water-yielding characteristics
Cotter Dolomite	200		Yields small quantities of water
Jefferson City Dolomite	350	Cherty dolomite	
Roubidoux Formation	200	with some beds	Yields 50-1,000 gallons per minute
Gasconade Dolomite	0-300	of sandstone	Yields small quantities of water
Eminence and Potosi Dolomites	0-200		Yields 50-400 gallons per minute
Derby-Doerun, Davis, and Bonneterre Formations	0-200	Silty dolomite, siltstone, and shale	Yields small quantities of water
Lamotte Sandstone	0-150	Sandstone	Yields vary considerably

Table 7.5-2 Minimum, median, and maximum concentrations of selected dissolved constituents and similar values for pH and specific conductance of water from the Cambrian-Ordovician aquifer, Spring River basin, Missouri (from Feder and others, 1969).
(mg/L – milligrams per liter; µg/L – micrograms per liter)

Constituent or property	Minimum	Median	Maximum	Number of analyses
Bicarbonate (mg/L)	120	206	257	38
Calcium (mg/L)	25	40	74	38
Chloride (mg/L)	1.7	5.2	22	38
Dissolved solids (mg/L)	140	227	290	37
Fluoride (mg/L)	0.1	0.1	0.5	25
Iron (µg/L)	.0	700	1,700	37
Magnesium (mg/L)	11	18	22	38
Nitrate (mg/L)	.0	.0	12	36
pH (units)	7.3	7.6	8.4	35
Potassium (mg/L)	.6	1.5	2.0	17
Silica (mg/L)	5.0	8.0	12	37
Sodium (mg/L)	1.6	5.4	30	17
Specific conductance micromhos per centimeter at 25° Celsius	347	369	474	5
Sulfate (mg/L)	3.7	13	68	37

NAWDEX, WATSTORE, and OWDC Have Water Data Information

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

Within the U.S. Geological Survey there are three activities that help to identify and improve access to the vast amount of existing water data. These activities are:

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

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

(3) The Office of Water Data Coordination (OWDC), which 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.

A more detailed explanation of these three activities are given in sections 8.2, 8.3, and 8.4.

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 aquiring 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 (fig. 8.2-1). A directory is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations [Directory of Assistance Centers of the National Water Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 79-423 (revised)].

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water Data Index (fig. 8.2-2), 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. 8.2-3) 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 cases, 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 cases 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)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 860-6031
FTS 928-6031

NAWDEX ASSISTANCE CENTER
KANSAS
U.S. Geological Survey
Water Resources Division
1950 Constant Avenue - Campus West
University of Kansas
Lawrence, KS 66045
Telephone: (913) 864-4321
FTS 752-2300, 2301, 2302
Hours: 8:00 - 4:30 CST

MISSOURI
U.S. Geological Survey
Water Resources Division
1400 Independence Road
Mail Stop 200
Rolla, MO 65401
Telephone: (314) 341-0824
FTS 277-0824
Hours: 7:30 - 4:00 CST

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

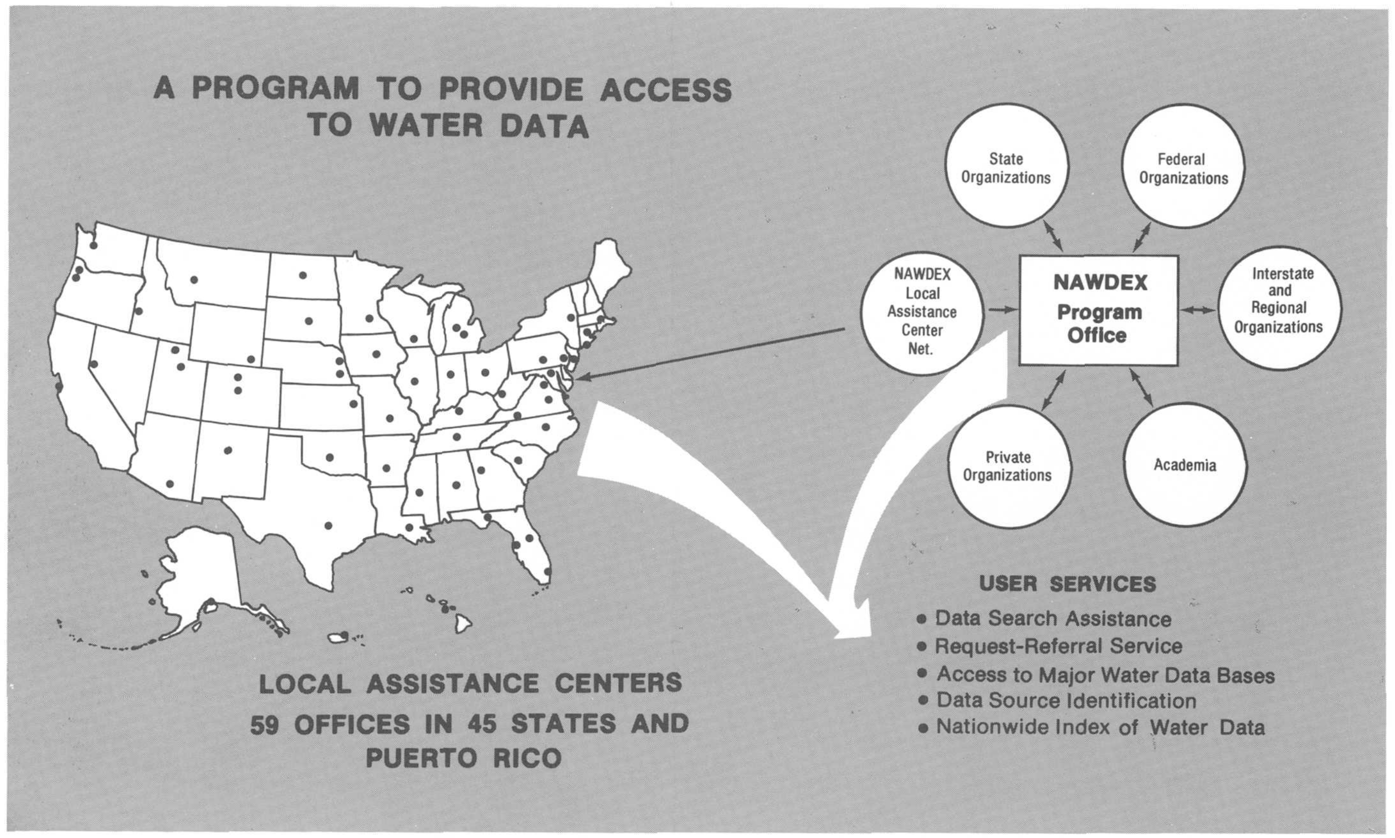


Figure 8.2-1 Access to water data.

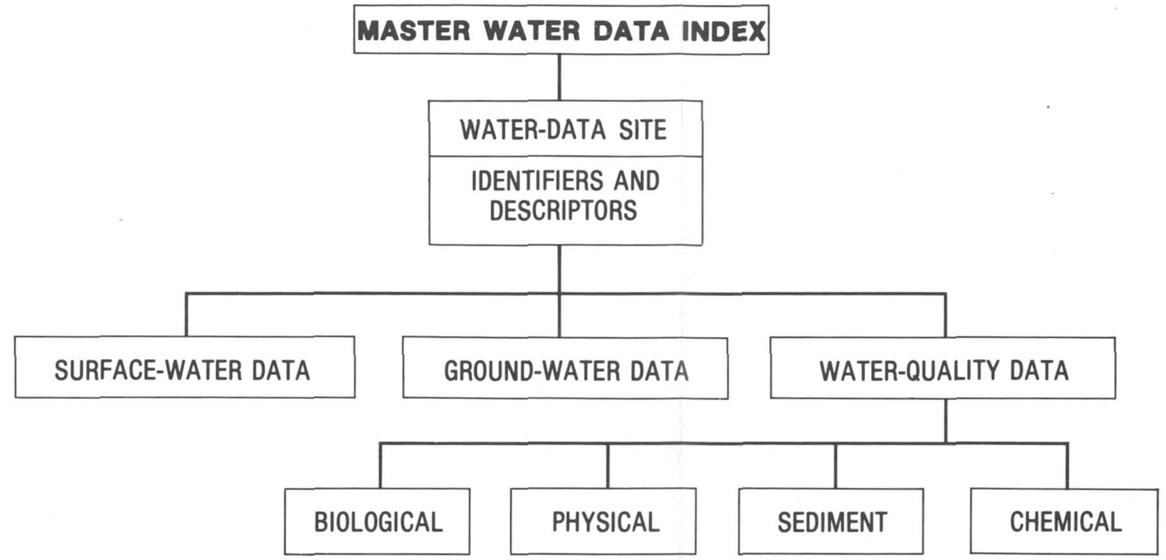


Figure 8.2-2 Master water-data index.

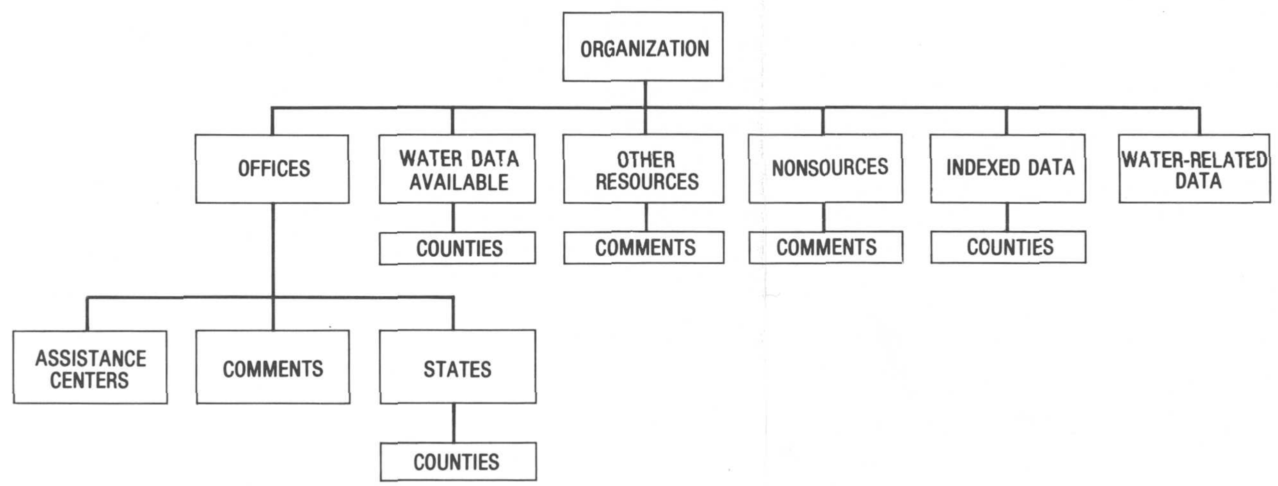


Figure 8.2-3 Water-data sources directory.

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.

The National Water Data Storage and Retrieval System (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 46 district offices. General inquiries about WATSTORE may be directed to:

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

KANSAS
U.S. Geological Survey
Water Resources Division
1950 Constant Avenue - Campus West
University of Kansas
Lawrence, KS 66045

Missouri
U.S. Geological Survey
Water Resources Division
1400 Independence Road
Mail Stop 200
Rolla, MO 65401

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

The Geological Survey currently (1983) collects data at approximately 16,000 streamgaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,020 sediment stations, 30,000 water-level observation wells, and 12,500 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 is also designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a 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. 8.3-1). A brief description of each file is as follows:

Station Header 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. It contains information pertinent to the identification, location, and physical description of nearly 220,000 sites.

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 over 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 over 400,000 peak observations.

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

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 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 characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 70,000 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 or retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

Remote Job Entry Sites: Almost all of the 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 put data into or retrieve data from the system within 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 chlorides. Data are recorded on 16-channel paper tape, which is removed from the recorder and transmitted over telephone lines to the receiver at Reston, Virginia. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data collection platforms indicates their feasibility for collecting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data relay stations are being operated currently (1983).

Central Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colorado, and Atlanta, Georgia, analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic compounds, such as chlorides, 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 decisionmakers 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 data tables to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

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 (SAS) to provide extensive analyses of data such as regression analyses, the 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 storage format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

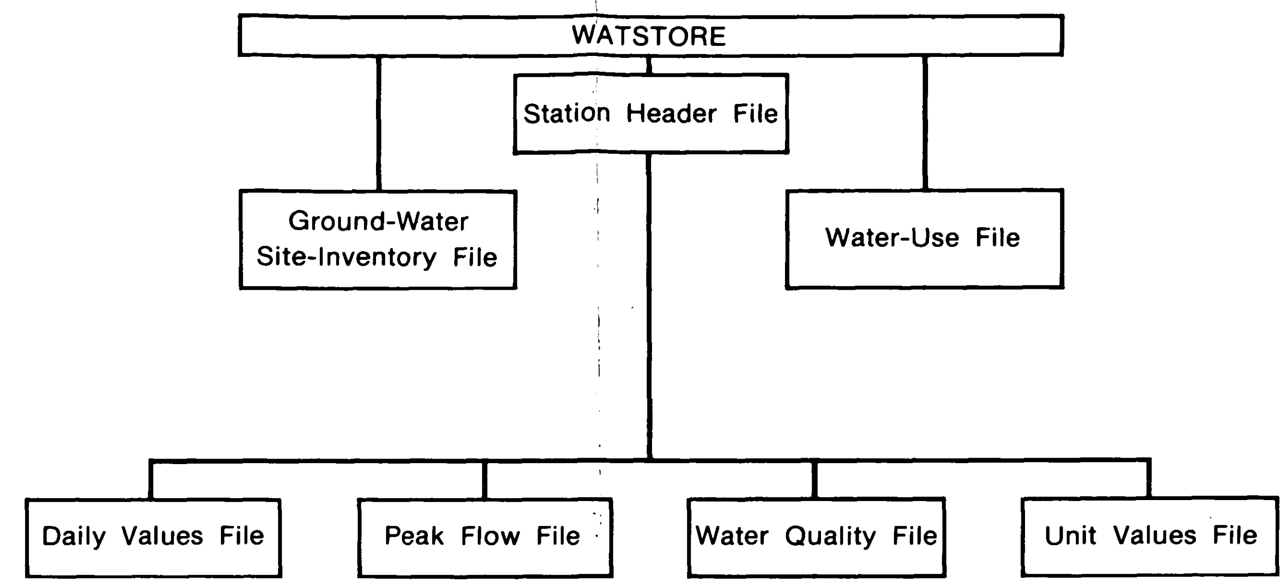


Figure 8.3-1 Index file stored data.

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. 8.4-1): volume I, 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 and 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 identification 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 shown in a table.

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water Data Exchange (NAWDEX) or NAWDEX Assistance Centers (see section 8.2).

Further information on the index volumes and their availability may be obtained from:

Office of Surface Mining
U.S. Department of the Interior
818 Grande Avenue, Scarritt Building
Kansas City, MO 64106
Telephone: (816) 374-3920
FTS 758-5162

KANSAS
U.S. Geological Survey
Water Resources Division
1950 Constant Avenue - Campus West
University of Kansas
Lawrence, KS 66045
Telephone: (913) 864-4321
FTS 752-2300, 2301, 2302
Hours: 8:00 - 4:30 CST

MISSOURI
U.S. Geological Survey
Water Resources Division
1400 Independence Road
Mail Stop 200
Rolla, MO 65401
Telephone: (314) 341-0824
FTS 277-0824
Hours: 7:30 - 4:00 CST

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

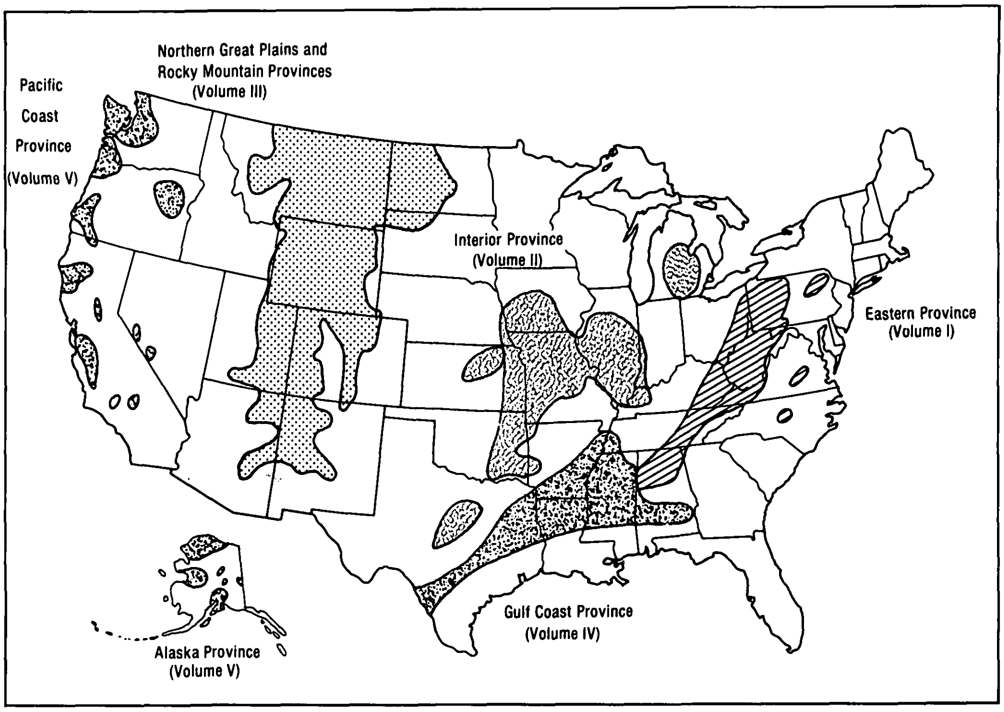


Figure 8.4-1 Index volumes and related provinces.

9.0 SUPPLEMENTARY INFORMATION FOR AREA 40

9.1 Coal Reserves

Remaining coal reserves in Area 40 counties

[Figures in millions of tons. Information compiled from Brady and others (1976), Friedman (1974) and Robertson (1974).]

State and County	COAL SEAM													Percentage of total coal reserves
	Nodaway	Thayer	Dawson	Iron Post	Mulky	Bevier	Croweburg	Fleming	Mineral	Weir-Pittsburg	Drywood	Rowe	Total	
KANSAS														
Cherokee	--	--	--	--	--	62.6	47.5	23.5	241.7	122.7	27.2	83.6	608.8	34.5
Chautaugua	44.1	--	--	--	--	--	--	--	--	--	--	--	44.1	2.5
Cowley	40.0	--	--	--	--	--	--	--	--	--	--	--	40.0	2.3
Crawford	--	--	--	--	13.2	162.6	63.7	28.6	192.4	18.0	6.0	19.3	503.8	28.6
Elk	11.6	--	--	--	--	--	--	--	--	--	--	--	11.6	0.6
Labette	--	--	--	--	--	10.7	--	--	21.1	--	--	--	31.8	1.8
Montgomery	--	29.8	--	--	--	--	--	--	--	--	--	--	29.8	1.7
Neosho	--	26.8	--	--	--	--	--	--	--	--	--	--	26.8	1.5
Wilson	--	7.9	--	--	--	--	--	--	--	--	--	--	7.9	0.4
Total, Kansas	95.7	64.5	--	--	13.2	235.9	111.2	52.1	455.2	140.7	33.2	102.9	1304.6	74.0
MISSOURI														
Barton	--	--	--	--	--	--	--	--	--	59.4	--	92.4	151.8	8.6
Dade	--	--	--	--	--	--	--	--	--	--	--	17.6	17.6	0.9
Jasper	--	--	--	--	--	--	--	--	--	--	--	5.8	5.8	0.3
Total, Missouri	--	--	--	--	--	--	--	--	--	59.4	--	115.8	175.2	9.8
OKLAHOMA														
Craig	--	--	--	21.2	--	--	48.2	--	18.0	--	--	--	87.4	5.0
Mayes	--	--	--	--	--	--	--	--	--	3.2	--	--	3.2	0.2
Nowata	--	--	--	4.8	--	--	--	--	--	--	--	--	4.8	0.3
Rogers	--	--	21.6	18.5	--	--	77.9	--	0.8	7.3	--	7.3	133.4	7.6
Tulsa	--	--	28.4	--	--	--	8.8	--	--	--	--	--	37.2	2.1
Wagoner	--	--	--	--	--	--	18.1	--	--	--	--	--	18.1	1.0
Total, Oklahoma	--	--	50.0	44.5	--	--	153.0	--	18.8	10.5	--	7.3	284.1	16.2
Grand total	95.7	64.5	50.0	44.5	13.2	235.9	264.2	52.1	474.0	210.6	33.2	226.0	1763.9	100
Percentage of total coal reserves	5.4	3.6	2.8	2.5	0.7	13.4	15.0	3.0	26.9	11.9	1.9	12.8	100	

Summary of physical and chemical characteristics of water from abandoned zinc and lead mines in the Picher area, Oklahoma and Kansas (from Playton and others, 1980).

Chemical or physical property	Number of analyses	Values			
		Minimum	Mean	50th Percentile	Maximum
Acidity (as $CaCO_3$)(mg/L)	66	0	465	320	1,340
Alkalinity (as $CaCO_3$)(mg/L)	77	0	61	23	308
Aluminum, dissolved (µg/L)	77	0	4,880	460	42,000
Aluminum, total (µg/L)	77	10	9,040	1,700	280,000
Arsenic, dissolved (µg/L)	44	0	2.2	1.0	11
Arsenic, total (µg/L)	44	0	2.8	1.6	14
Barium, dissolved (µg/L)	44	0	55	0	600
Barium, total (µg/L)	44	0	50	0	600
Bicarbonate (mg/L)	77	0	75	33	375
Boron, dissolved (µg/L)	77	30	150	140	560
Boron, total (µg/L)	77	50	280	200	1,700
Cadmium, dissolved (µg/L)	77	1	240	80	1,200
Cadmium, total (µg/L)	77	10	310	180	1,100
Calcium, dissolved (mg/L)	77	120	395	480	600
Carbon, total organic (mg/L)	44	.0	2.6	2.1	8.0
Carbonate (mg/L)	77	0	0	0	0
Chloride, dissolved (mg/L)	77	.5	11.8	6.3	85
Chromium, dissolved (µg/L)	44	0	20	16	140
Chromium, total (µg/L)	44	0	22	17	150
Cobalt, dissolved (µg/L)	44	0	160	50	800
Cobalt, total (µg/L)	44	50	340	200	850
Copper, dissolved (µg/L)	44	1	40	8	260
Copper, total (µg/L)	44	10	45	20	240
Dissolved solids, residue at 180°Celsius (mg/L)	74	622	4,000	3,410	5,920
Fluoride, dissolved (mg/L)	77	.1	3.3	1.9	15
Hardness, noncarbonate (mg/L)	77	250	1,480	1,800	2,500
Hardness, total (mg/L)	77	410	1,540	1,800	2,500
Iron, dissolved (µg/L)	77	0	88,000	39,000	330,000
Iron, total (µg/L)	77	0	110,000	52,000	150,000
Lead, dissolved (µg/L)	77	0	135	63	500
Lead, total (µg/L)	77	0	220	310	500
Lithium, dissolved (µg/L)	77	20	123	130	300
Magnesium, dissolved (mg/L)	77	13	133	134	290
Manganese, dissolved (µg/L)	77	10	3,000	1,870	14,000
Manganese, total (µg/L)	77	10	3,370	2,400	15,000
Mercury, dissolved (µg/L)	44	.0	.31	.22	1.30
Mercury, total (µg/L)	44	.0	.33	.20	1.40
Molybdenum, dissolved (µg/L)	44	0	0	0	2
Molybdenum, total (µg/L)	44	0	0	0	3
Nickel, dissolved (µg/L)	77	3	1,510	600	5,000
Nickel, total (µg/L)	77	50	1,800	1,000	8,000
Nitrate, dissolved (as N)(mg/L)	44	0.00	0.08	0.04	0.42
Nitrite, dissolved (as N)(mg/L)	44	.00	.00	.00	.04
pH , measured onsite (units)	147	3.4	--	6.4	8.6
Potassium, dissolved (mg/L)	77	1.3	4.0	3.8	9.2
Selenium, dissolved (µg/L)	44	0	1	1	3
Selenium, total (µg/L)	44	0	1	1	3
Silica, dissolved (mg/L)	77	4.9	11.7	11.7	22
Sodium, dissolved (mg.L)	77	7.1	54	44	200
Specific conductance, measured onsite (µmho)	139	740	2,680	2,800	4,950
Sulfate, dissolved (mg/L)	77	320	1,950	2,070	3,500
Vanadium, dissolved (µg/L)	74	.0	34	1.0	200
Water temperature, measured onsite (degrees Celsius)	149	13.0	15.5	15.0	18.0
Zinc, dissolved (µg/L)	77	640	175,000	103,000	490,000
Zinc, total (µg/L)	74	730	108,000	106,000	490,000

9.3 Surface-Water Stations

Number used in report	U.S. Geological Survey Station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
1	07165700	Verdigris River near Madison, Kans.	38°08'15"	096°06'05"	181	Daily streamflow	1955-76
						Sediment	1956-76
2	07165800	Willow Creek near Quincy, Kans.	37°53'40"	096°02'40"	120	Low flow	1960-70
3	07165850	Walnut Creek at Neal, Kans.	37°49'20"	096°04'00"	130	Low flow	1960-70
4	07165900	Toronto Lake near Toronto, Kans.	37°44'30"	095°56'00"	730	Reservoir	1960-83
5	07166000	Verdigris River near Coyville, Kans.	37°42'20"	095°54'20"	747	Daily streamflow	1939-83
						Water quality	1963-75
						Sediment	1940-78
6	07166200	Sandy Creek near Yates Center, Kans.	37°50'47"	095°50'07"	6.80	Peak stage and discharge	1957-83
7	07166500	Verdigris River near Altoona, Kans.	37°29'26"	095°40'49"	1,138	Daily streamflow	1939-83
						Sediment	1940-78
8	07166700	Burnt Creek at Reece, Kans.	37°48'20"	096°26'50"	8.85	Peak stage and discharge	1957-69
9	07166800	Spring Creek near Eureka, Kans.	37°47'17"	096°20'40"	69.0	Low flow	1955-70
						Water quality	1963, 1966-70
10	07167000	Fall River near Eureka, Kans.	37°47'07"	096°13'52"	307	Daily streamflow	1946-76
						Water quality	1963-70
						Sediment	1947-76
11	07167500	Otter Creek at Climax, Kans.	37°42'30"	096°13'30"	129	Daily streamflow	1946-83
						Water quality	1964-66
						Sediment	1947-83
12	07168000	Fall River Lake near Fall River, Kans.	37°38'48"	096°04'39"	585	Reservoir	1957-83
13	07168500	Fall River near Fall River, Kans.	37°38'34"	096°03'33"	585	Daily streamflow	1904-05, 1939-83
						Sediment	1940-48, 1963-73
14	07169200	Salt Creek near Severy, Kans.	37°37'12"	096°15'07"	7.59	Peak stage and discharge	1957-77
15	07169500	Fall River at Fredonia, Kans.	37°30'30"	095°50'00"	827	Daily streamflow	1938-83
						Water quality	1963-81
16	07169700	Snake Creek near Howard, Kans.	37°32'28"	096°14'24"	1.84	Peak stage and discharge	1957-77
17	07169800	Elk River at Elk Falls, Kans.	37°22'32"	096°11'07"	220	Daily streamflow	1967-83
						Water quality	1973-83
						Sediment	1967-83
18	07170000	Elk River near Elk City, Kans.	37°15'59"	095°55'04"	575	Daily streamflow	1938-69
						Water quality	1963-65
19	07170050	Elk City Lake near Independence, Kans.	37°16'39"	095°46'37"	634	Reservoir	1966-83
20	07170060	Elk River below Elk City Lake, Kans.	37°16'46"	095°46'53"	634	Daily streamflow	1965-83
21	07170500	Verdigris River at Independence, Kans.	37°13'26"	095°40'43"	2,892	Daily streamflow	1895-1904, 1921-83
						Water quality	1961-75
22	07170600	Cherry Creek near Cherryvale, Kans.	37°17'46"	095°32'51"	15.0	Peak stage and discharge	1957-77
23	07170695	Big Hill Lake near Cherryvale, Kans.	37°16'12"	095°28'12"	37.0	Reservoir	1980-83
24	07170700	Big Hill Creek near Cherryvale, Kans.	37°16'00"	095°28'05"	37.0	Daily streamflow	1957-83
						Sediment	1958-83
25	07170800	Mud Creek near Mound Valley, Kans.	37°11'38"	095°26'52"	4.22	Peak stage and discharge	1957-83
26	07170990	Verdigris River near Coffeyville, Kans.	37°00'20"	095°35'32"		Water quality	1969-1973
27	07171700	Spring Branch near Cedar Vale, Kans.	37°06'48"	096°27'29"	3.10	Peak stage and discharge	1957-83
28	07171800	Cedar Creek tributary near Hooser, Kans.	37°06'27"	096°34'27"	0.56	Peak stage and discharge	1957-83
29	07171900	Grant Creek near Wauneta, Kans.	37°06'34"	096°23'55"	20.0	Peak stage and discharge	1957-77
30	07172000	Caney River near Elgin, Kans.	37°00'13"	096°18'54"	445	Daily streamflow	1938-83
						Water quality	1973-75
						Sediment	1940-78
31	07173300	Middle Caney Creek at Sedan, Kans.	37°07'04"	096°10'53"	120	Low flow	1961-69
						Water quality	1962-67

Number used in report	U.S. Geological Survey Station number	Station name	Location		Drainage area (square miles)	Type of record	Period of record
			Latitude	Longitude			
32	07173500	Bee Creek near Havana, Kans.	37°10'50"	095°59'30"	11.0	Daily streamflow	1953-58
33	07182400	Neosho River at Strawn, Kans.	38°16'00"	095°52'00"	2,933	Daily streamflow	1948-63
						Sediment	1946-63
34	07182450	John Redmond Reservoir near Burlington, Kans.	38°14'15"	095°46'05"	3,015	Reservoir	1963-83
						Sediment	1965-83
35	07182510	Neosho River at Burlington, Kans.	38°11'40"	095°44'10"	3,042	Daily streamflow	1961-83
						Water quality	1961-64, 1965-83
						Sediment	1944-45, 1961-78
36	07182520	Rock Creek at Burlington, Kans.	38°11'46"	095°45'24"	8.27	Peak stage and discharge	1957-77
37	07182600	North Big Creek near Burlington, Kans.	38°06'37"	095°45'26"	46.0	Peak stage and discharge	1957-83
38	07182700	Big Creek near Leroy, Kans.	38°06'00"	095°43'00"	128	Low flow	1954-70
39	07182900	Deer Creek near Iola, Kans.	37°58'00"	095°24'00"	105	Low flow	1954-70
40	07183000	Neosho River near Iola, Kans.	37°53'27"	095°25'50"	3,818	Daily streamflow	1895-1903, 1917-83
						Sediment	1940-61
41	07183100	Owl Creek near Piqua, Kans.	37°51'00"	095°34'30"	177	Daily streamflow	1959-70
42	07183200	Neosho River near Chanute, Kans.	37°43'49"	095°26'26"	4,195	Daily streamflow	1962-74
						Daily stage	1974-83
43	07183300	Big Creek near Chanute, Kans.			95	Low flow	1960-70
44	07183400	Flat Rock Creek near St. Paul, Kans.	37°32'00"	095°09'00"	139	Low flow	1960-70
						Sediment	1940-41
45	07183500	Neosho River near Parsons, Kans.	37°18'39"	095°06'37"	4,905	Daily streamflow	1921-83
						Water quality	1961-83
						Sediment	1975-83
						Biological	1979-83
46	07183800	Limestone Creek near Beulah, Kans.	37°24'12"	094°53'16"	12.0	Peak stage and discharge	1957-83
47	07184000	Lightning Creek near McCune, Kans.	37°16'54"	095°01'56"	197	Daily streamflow	1938-46, 1959-83
						Water quality	1976-83
						Sediment	1940-46, 1976-83
48	07184060	Deer Creek near West Mineral, Kans.	37°15'37"	094°57'31"	1.50	Partial streamflow	1976-80
						Water quality	1976-80
49	07184070	Deer Creek near Hallowell, Kans.	37°13'50"	094°59'41"	7.00	Partial streamflow	1976-80
						Water quality	1976-80
50	07184080	Deer Creek near Oswego, Kans.	37°12'03"	095°02'59"	12.0	Partial streamflow	1976-80
						Water quality	1976-80
51	07184100	Lightning Creek near Oswego, Kans.	37°10'49"	095°04'11"	250	Partial streamflow	1976-80
						Water quality	1976-80
52	07184220	Cherry Creek near West Mineral, Kans.	37°14'14"	095°55'04"	27.0	Partial streamflow	1976-80
						Water quality	1976-80
						Sediment	1977-79
53	07184240	Little Cherry Creek near West Mineral, Kans.	37°13'31"	094°50'13"	34.0	Partial streamflow	1976-80
						Water quality	1976-80
54	07184300	Cherry Creek near Hallowell, Kans.	37°09'46"	094°59'43"	90.0	Daily streamflow	1976-82
						Water quality	1976-81
						Sediment	1976-80
55	07184500	Labette Creek near Oswego, Kans.	37°11'30"	095°11'30"	211	Daily streamflow	1938-45
						Low flow	1954-70
						Peak stage and discharge	1961-83
						Water quality	1962-70
56	07184590	Neosho River at Chetopa, Kans.	37°02'10"	095°04'50"		Partial streamflow	1976

Number used in report	U.S. Geological Survey Station number	Station name	Location Latitude	Location Longitude	Drainage area (square miles)	Type of record	Period of record
						Water quality	1972-73, 1976, 1978
57	07184600	Fly Creek near Faulkner, Kans.	37°06'15"	094°56'21"	27.0	Peak stage and discharge	1957-77
58	07186010	Second Cow Creek at Pittsburg, Kans.	37°23'49"	094°44'30"	60.0	Partial streamflow	1976-80
						Peak stage and discharge	1977-79
						Water quality	1976-80
						Sediment	1977-79
59	07186020	First Cow Creek at Frontenac, Kans.	37°26'25"	094°42'54"	30.0	Partial streamflow	1976-80
						Water quality	1976-80
60	07186025	East Cow Creek at Frontenac, Kans.	37°27'18"	094°38'48"	7.50	Partial streamflow	1976-80
						Water quality	1976-80
61	07186030	East Cow Creek near Pittsburg, Kans.	37°22'04"	094°40'30"	43.0	Partial streamflow	1976-80
						Water quality	1976-80
62	07186040	Cow Creek near Weir, Kans.	37°18'35"	094°40'48"	170	Daily streamflow	1976-82
						Water quality	1976-81
						Sediment	1977-80
63	07186050	Brush Creek near Weir, Kans.	37°18'32"	094°42'19"	30.0	Partial streamflow	1976-80
						Peak stage and discharge	1977-79
						Water quality	1976-80
64	07187560	Shoal Creek near Galena, Kans.	37°02'31"	094°38'34"		Partial streamflow	1976-79
						Water quality	1976-79
65	07187600	Spring River near Baxter Springs, Kans.	37°01'25"	094°43'15"		Partial streamflow	1978-79
						Water quality	1978-79
66	07185500	Stahl Creek near Miller, Mo.	37°11'42"	093°50'37"	3.86	Daily streamflow	1950-76
67	07185600	South Fork Stahl Creek near Miller, Mo.	37°11'15"	093°50'25"	0.94	Peak stage and discharge	1950-79
68	07185650	Spring River near Stotts City, Mo.	37°08'13"	093°56'52"		Low flow	1962-65, 1967
69	07185700	Spring River at LaRussell, Mo.	37°09'13"	094°03'21"	306	Daily streamflow	1957-83
70	07185765	Spring River at Carthage, Mo.	37°11'11"	094°18'56"	425	Daily streamflow	1966-82
71	07186000	Opossum Creek at Jasper, Mo.	37°19'20"	094°18'09"	9.67	Peak stage and discharge	1954-77
72	07186000	Spring River near Waco, Mo.	37°14'45"	094°33'55"	1,164	Daily streamflow	1924-83
						Water quality	1965-83
73	07186080	Center Creek near Wentworth, Mo.	37°02'36"	094°05'27"		Low flow	1968, 1970, 1972
74	07186100	Center Creek near Sarcoxie, Mo.	37°04'53"	094°10'00"		Low flow	1954, 1962-65, 1967
75	07186180	Center Creek above Fidelity, Mo.	37°07'07"	094°15'28"		Water quality	1977-78
76	07186195	Jones Creek near Fidelity, Mo.	37°05'49"	094°17'11"		Water quality	1977-78
77	07186200	Center Creek near Fidelity, Mo.	37°06'18"	094°18'40		Low flow	1962-64, 1967, 1969-70
78	07186250	Grove Creek near Scotland, Mo.	37°06'54"	094°22'33"		Water quality	1976
79	07186400	Center Creek near Carterville, Mo.	37°08'26"	094°22'57"	232	Daily streamflow	1962-83
80	01786405	Tailings area storm runoff	37°06'41"	094°24'44"	0.01	Water quality	1976
81	07186420	Center Creek near Webb City, Mo.	37°10'31"	094°27'17"		Low flow	1962-66, 1970-71
82	07186460	Center Creek near Carl Junction, Mo.	37°10'00"	094°32'05"		Low flow	1943, 1946, 1949, 1952, 1954, 1956, 1962-70
83	07186480	Center Creek near Smithfield, Mo.	37°09'20"	094°36'10"	33.0	Water quality	1968-83
84	07186600	Turkey Creek near Joplin, Mo.	37°07'15"	094°34'55"	41.8	Daily streamflow	1963-72
						Water quality	1963-73
85	01786700	Shoal Creek near Fairview, Mo.	37°49'10"	094°02'58"		Low flow	1954, 1962-67
86	07186800	Capps Creek near Berwick, Mo.	36°53'14"	094°05'15"		Low flow	1962-67, 1968, 1970
87	07186850	Clear Creek near Ritchey, Mo.	36°56'03"	094°08'34"		Low flow	1954, 1962-67

Number used in report	U.S. Geological Survey Station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
88	07186880	Shoal Creek at Ritchey, Mo.	36°56'20"	094°11'20"		Low flow	1954, 1962-67, 1968, 1970
89	07186890	Shoal Creek at Neosho, Mo.	36°53'44"	094°22'10"		Low flow	1941-43, 1945-46, 1949, 1952, 1954, 1962-65, 1967
90	07186900	Hickory Creek at Neosho, Mo.	36°53'01"	094°22'13"		Low flow	1941, 1962-65, 1967, 1968, 1970
91	07186950	North Fork Carver Creek at Diamond, Mo.	36°59'45"	094°19'50"	0.33	Peak stage and discharge	1955-79
92	07187000	Shoal Creek above Joplin, Mo.	37°01'25"	094°31'00"	427	Daily streamflow	1941-83
						Water quality	1962, 1963, 1966, 1968, 1980, 1983
93	07170950	Verdigris River near South Coffeyville, Okla.	36°59'18"	095°35'45"	4,339	Water quality	1952-53
94	07171000	Verdigris River near Lenapah, Okla.	36°51'05"	095°35'06"	3,639	Daily streamflow	1938-83
						Water quality	1945, 1952-64, 1973-79
						Sediment	1940-78
95	07171080	California Creek near Nowata, Okla.	36°45'15"	095°37'30"		Water quality	1952-53, 1959
96	07171100	Verdigris River near Nowata, Okla.	36°42'48"	095°37'20"		Water quality	1952-53
97	07171105	East Fork Big Creek near Hollow, Okla.	36°54'06"	095°21'34"	14.4	Partial streamflow	1980-83
						Water quality	1980-83
98	07171120	Clear Creek tributary near Hollow, Okla.	36°52'50"	095°16'00"	2.19	Peak stage and discharge	1966-75, 1979-83
99	07171220	Big Creek near Nowata, Okla.	36°45'00"	095°31'50"		Water quality	1952-53, 1959
100	07171230	Salt Creek near Alluwe, Okla.	36°40'44"	095°29'12"		Water quality	1952-53, 1959
101	07171240	Lightning Creek near Alluwe, Okla.	36°58'54"	095°29'06"		Water quality	1952-53, 1959
102	07171260	Verdigris River near Talala, Okla.	36°31'30"	095°42'45"		Water quality	1952-53
103	07171300	Oologah Lake near Oologah, Okla.	36°25'19"	095°40'43"	4,339	Reservoir	1963-83
104	07171400	Verdigris River near Oologah, Okla.	36°25'17"	095°41'01"	4,339	Daily streamflow	1961-83
						Water quality	1962-63, 1965-83
						Sediment	1961-78
105	07171405	Verdigris River above Caney River near Claremore, Okla.	36°25'14"	095°40'36"		Water quality	1952-53, 1959
106	07171409	Sweetwater Creek near Claremore, Okla.	36°23'29"	095°36'51"		Periodic streamflow	1980-83
						Water quality	1980-83
107	07171500	Verdigris River near Sageeyah, Okla.	36°23'30"	095°40'15"	4,402	Daily streamflow	1939-45
108	07172500	Hulah Lake near Hulah, Okla.	36°55'44"	096°05'08"	732	Reservoir	1950-83
109	07173000	Caney River near Hulah, Okla.	36°55'06"	096°04'15"	733	Daily streamflow	1937-83
						Water quality	1952-53, 1956, 1958, 1960, 1963, 1964, 1976-83
						Sediment	1938-78
110	07177400	Caney Creek near Copan, Okla.	36°58'15"	095°56'05"	424	Daily streamflow	1944-58
111	07174150	Cotton Creek near Copan, Okla.	36°56'20"	095°55'00"		Water quality	1952-53, 1967-68
112	07174200	Little Caney River below Cotton Creek near Copan, Okla.	36°53'42"	095°58'09"	502	Daily streamflow	1958-83
						Water quality	1967-68, 1976-80
						Sediment	1944-78
113	07174500	Caney River at Bartlesville, Okla.	36°44'42"	095°57'36"	1,465	Daily streamflow	1950-56
						Water quality	1952-53, 1967-68
						Sediment	1955-51
114	07174570	Dry Hollow near Pawhuska, Okla.	36°45'30"	096°12'30"	1.67	Peak stage and discharge	1965-72

Number used in report	U.S. Geological Survey Station number	Station name	Location: Latitude	Location: Longitude	Drainage area (square miles)	Type of record	Period of record
115	07174600	Sand Creek at Okesa, Okla.	36°43'16"	096°07'56"	139	Daily streamflow	1957-83
						Water quality	1952-55, 1960-62
						Sediment	1960-78
116	07174700	Caney River near Ochelata, Okla.	36°38'26"	095°56'02"	1,753	Daily streamflow	1956-76
						Water quality	1960-61, 1973-75
117	07174720	Hogshooter Creek tributary near Bartlesville, Okla.	36°43'40"	095°50'52"	0.94	Peak stage and discharge	1965-83
118	07175000	Double Creek subwatershed 5 near Ramona, Okla.	36°30'50"	095°56'25"	2.39	Daily streamflow	1955-65
						Water quality	1965, 1967-69
						Sediment	1957-69
119	07175500	Caney River near Ramona, Okla. (Published as "near Collinsville" Oct., 1935 to Feb., 1939).	36°30'31"	095°50'36"	1,955	Daily streamflow	1935-39, 1945-83
						Water quality	1952-53, 1965-83
						Sediment	1944-57, 1968
120	07176000	Verdigris River near Claremore, Okla.	36°18'26"	095°41'52"	6,534	Daily streamflow	1935-83
						Water quality	1948-54, 1959, 1978-83
						Sediment	1947-49
121	07176350	Bird Creek near Barnsdall, Okla.	36°33'20"	096°09'22"		Water quality	1949-53
122	07176455	Birch Creek near Barnsdall, Okla.	36°33'13"	096°14'45"		Water quality	1965-66
123	07176460	Birch Lake near Barnsdall, Okla.	36°32'05"	096°09'45"	66	Reservoir	1977-83
124	07176465	Birch Creek below Birch Lake near Barnsdall, Okla.	36°32'08"	096°09'38"	66	Daily streamflow	1977-83
125	07176500	Bird Creek near Avant, Okla.	36°29'11"	096°03'45"	364	Daily streamflow	1945-83
						Water quality	1965-66, 1976-79
						Sediment	1945-78
126	07176800	Candy Creek near Wolco, Okla.	36°34'06"	096°02'54"	30.6	Daily streamflow	1969-83
127	07176910	Bird Creek near Skiatook, Okla.	36°23'45"	095°59'30"		Water quality	1948-53
128	07176950	Hominy Creek near Hominy, Okla.	36°27'20"	096°22'45"		Water quality	1950-53, 1956
129	07177000	Hominy Creek near Skiatook, Okla.	36°20'55"	096°06'35"	340	Daily streamflow	1944-80
						Water quality	1948-53, 1965-66
						Sediment	1944-78
130	07177500	Bird Creek near Sperry, Okla.	36°16'42"	095°57'14"	905	Daily streamflow	1938-83
						Water quality	1952-53, 1964-77
						Sediment	1978
131	07178000	Bird Creek near Owasso, Okla.	36°14'25"	095°50'50"	1,022	Daily streamflow	1936-39
						Water quality	1948-53
132	07178050	Bird Creek near Catoosa, Okla.	36°13'51"	095°49'55"	1,080	Water quality	1963, 1965-83
133	07178400	Bird Creek at Catoosa, Okla.	36°12'14"	095°45'41"		Water quality	1978-80
134	07178500	Dog Creek near Claremore, Okla.				Partial streamflow	1979-83
135	07178580	Otter Creek near Tiawah, Okla.	36°14'32"	095°33'21"	15.2	Peak stage and discharge	1966-72
136	07178600	Verdigris River near Inola, Okla. (Published as Newt Graham Lock and Dam prior to Oct., 1976).	36°09'43"	095°37'07"	7,911	Daily streamflow	1972-83
						Water quality	1948-72, 1977-83
						Sediment	1976-83
137	07178620	Newt Graham Lock and Dam near Inola, Okla.	36°03'29"	095°32'06"	8,030	Water quality	1972-76
						Sediment	1940-75
138	07178640	Bull Creek near Inola, Okla.	36°08'55"	095°27'20"	10.7	Peak stage and discharge	1965-75
139	07178650	Billy Creek tributary near Wagoner, Okla.	35°57'31"	095°27'41"	5.71	Peak stage and discharge	1966-72
140	07178670	Verdigris River near Okay, Okla.	35°50'50"	095°19'25"	8,296	Water quality	1952-53, 1960-63

Number used in report	U.S. Geological Survey Station number	Station name	Location		Drainage area (square miles)	Type of record	Period of record
			Latitude	Longitude			
141	07185000	Neosho River near Commerce, Okla.	36°55'43"	094°57'26"	5,876	Daily streamflow	1939-83
						Water quality	1948-54, 1960-73, 1976-83
						Sediment	1944-50, 1978-83
142	07185100	Tar Creek at Miami, Okla.	36°52'56"	094°51'43"		Daily discharge	1981-83
143	07188000	Spring River near Quapaw, Okla.	36°56'04"	094°44'45"	2,510	Daily streamflow	1939-83
						Water quality	1948-58, 1960-63, 1976-79
						Sediment	1944-50
144	07188140	Flint Branch near Peoria, Okla.	36°52'25"	094°41'35"	4.90	Peak stage and discharge	1964-83
145	07189500	Neosho River near Grove, Okla.	36°33'25"	094°44'45"	9,965	Daily streamflow	1925-39
146	07189700	Horse Creek at Afton, Okla.	36°41'50"	094°57'20"	21.9	Peak stage and discharge	1966-83
147	07189720	Horse Creek tributary near Afton, Okla.	36°41'00"	094°52'50"	0.81	Peak stage and discharge	1966-72
148	07190000	Lake O'Cherokees at Langley, Okla.	36°28'17"	095°02'19"	10,298	Reservoir	1940-83
149	07190500	Neosho River near Langley, Okla.	36°26'15"	095°02'44"	10,335	Daily streamflow	1939-83
						Water quality	1950-59, 1976-83
150	07190595	Big Cabin Creek near Welch, Okla.	36°54'09"	095°10'33"	28.1	Periodic streamflow	1980-83
						Water quality	1980-83
151	07190597	Big Cabin Creek tributary near Welch, Okla.	36°53'04"	095°10'47"		Periodic streamflow	1980-83
						Water quality	1980-83
152	07190600	Big Cabin Creek near Pyramid Corners, Okla.	36°48'06"	095°09'48"	71.1	Daily streamflow	1963-72
						Peak stage and discharge	1973-83
153	07190620	West Fork Big Cabin Creek near Centralia, Okla.	36°47'11"	095°16'11"	13.1	Periodic streamflow	1980-83
						Water quality	1980-83
154	07190625	Middle Fork Big Cabin Creek near Pyramid Corners, Okla.	36°48'18"	095°14'25"	13.4	Periodic streamflow	1980-83
						Water quality	1980-83
155	07190650	Big Cabin Creek near Vinita, Okla.	36°37'40"	095°10'25"		Water quality	1949-51
156	07190850	Little Cabin Creek near Vinita, Okla.	36°37'35"	095°07'05"		Water quality	1948-51
157	07191000	Big Cabin Creek near Big Cabin, Okla.	36°34'06"	095°09'07"	450	Daily streamflow	1947-83
						Water quality	1951-60, 1964-71, 1975-77
158	07191400	Lake Hudson near Locust Grove, Okla.	36°13'54"	095°11'36"	11,534	Reservoir	1964-83
159	07191500	Neosho River near Chouteau, Okla.	36°14'13"	095°13'35"	11,546	Daily streamflow	1937-50, 1963-83
						Water quality	1951-58, 1960, 1976-83
160	07192000	Pryor Creek near Pryor, Okla.	36°16'52"	095°19'32"	229	Daily streamflow	1948-64
						Water quality	1948-63
161	07192030	Pryor Creek at Elliot St. Bridge near Pryor, Okla.	36°16'10"	095°18'30"		Water quality	1966-71
162	07192050	Pryor Creek at Highway 69A bridge near Pryor, Okla.				Water quality	1958, 1962-63
163	07192060	Pryor Creek below Sulphur Creek near Pryor, Okla.	36°13'20"	095°15'20"		Water quality	1966-75
164	07192500	Neosho River near Wagoner, Okla.	36°55'54"	095°16'08"	12,307	Daily streamflow	1924-49
						Water quality	1948-50
165	07193000	Fort Gibson Lake near Fort Gibson, Okla.	35°51'16"	095°13'43"	12,492	Reservoir	1949-83
166	07193500	Neosho River below Fort Gibson Lake near Fort Gibson, Okla.	35°51'15"	095°13'45"	12,495	Daily streamflow	1950-83
						Water quality	1952-83

Number used in report	Site-identification number	Location (Township-Range-Section Well number)	County and State	Well depth (feet)	Principal aquifer system (age of rocks)	Period of record	Frequency of measurement[1]
1	375528095263701	24S-18E-28CDD 01	Allen, Kans.	23	Pleistocene	1964-83	P
2	375521095263701	24S-18E-33BAA 01	Allen, Kans.	18.6	Pennsylvanian	1948-57	P
3	374809096315301	26S-08E-09DBB 01	Butler, Kans.	99.7	--[2]	1963-70	P
4	374100095244801	27S-18E-23BCC 01	Neosho, Kans.	26	Pleistocene	1960-78	P
5	373241095154601	29S-20E-06CDC 01	Neosho, Kans.	35	Pleistocene	1960-71	P
6	373020094501801	29S-23E-24DBA 01	Crawford,Kans.	1,212	Ordovician	1977-83	P
7	372509094485501	30S-24E-19ADD 01	Crawford, Kans.	955	Ordovician	1977-83	P
8	372026095060701	31S-21E-15CCC 01	Labette, Kans.	18	Pleistocene	1960-72	P
9	372026095060702	31S-21E-15CCC 02	Labette, Kans.	17	--	1967-83	P
10	371428094493801	32S-24E-19CBD 01	Cherokee, Kans.	850	--	1943-65	P
11	371704094422601	32S-25E-06DAD 01	Cherokee, Kans.	25	Pennsylvanian	1951-64	P
12	371133095171501	33S-19E-11AA 01	Labette, Kans.	--	--	1963-65	P
13	371055094401701	33S-25E-09DAD 01	Cherokee, Kans.	1,015	--	1964-79	P
14	37078094511201	34S-23E-02ABA 01	Cherokee, Kans.	26	Pennsylvanian	1942-65	P
15	370205094443301	34S-24E-36CDB 01	Cherokee, Kans.	1,016	--	1926-75	P
16	370215094443001	34S-24E-36DB 01	Cherokee, Kans.	1,094	Ordovician	1956-65	P
17	370514094373901	34S-25E-13BAC 01	Cherokee, Kans.	1,150	Ordovician	1975-83	P
18	370516094245501	27N-32W-03CAD 1	Jasper, Mo.	210	Mississippian	1965-78	P
19	370527094340901	27N-33W-06DAC 1	Jasper, Mo.	186	Mississippian	1964-76	P
20	370933094270001	28N-32W-08CCD 1	Jasper, Mo.	139	Mississippian	1964-65	P
21	370752094261501	28N-32W-21CBC 1	Jasper, Mo.	173	Mississippian	1964-78	P
22	370730094260001	28N-32W-28BBA 1	Jasper, Mo.	--	Mississippian	1964-65	P
23	370716094255801	28N-32W-28BDC 1	Jasper, Mo.	201	--	1964-76	P
24	370647094272401	28N-32W-29CCC	Jasper, Mo.	234	Mississippian	1964-78	P
25	370623094244501	28N-32W-34ACC 1	Jasper, Mo.	173	Mississippian	1963-78	P

Number used in report	Site-identification number	Location (Township-Range-Section Well number)	County and State	Well depth (feet)	Principal aquifer system (age of rocks)	Period of record	Frequency of measurement[1]
26	370600094223501	28N-32W-36DCB 1	Jasper, Mo.	1,750	Cambrian	1956-83	R
27	373115094161501	32N-30W-18BDD 1	Barton, Mo.	981	Mississippian, Ordovician	1968-83	R
28	372915094211501	32N-31W-29DBD 1	Barton, Mo.	1,040	Ordovician	1967-83	P
29	355129095224401	16N-18E-15DDC 1	Wagoner, Okla.	34	Pleistocene	1960-74	P
30	355122095223602	16N-18E-22AAA 2	Wagoner, Okla.	32	Pleistocene	1958-74	P
31	355122095222001	16N-18E-23BBA 1	Wagoner, Okla.	42	Pleistocene	1960-74	P
32	355728095315101	17N-17E-18AAB 1	Wagoner, Okla.	42	Pleistocene	1963-74	P
33	360802095365401	19N-16E-09CCC 1	Wagoner, Okla.	41	Pleistocene	1963-74	P
34	361027095572801	20N-13E-32BBC 1	Tulsa, Okla.	154	Pennsylvanian	1970-74	R
35	361408095431001	20N-15E-04CDD 1	Rogers, Okla.	43	Pleistocene	1959-74	P
36	361618095142301	21N-19E-26ADD 1	Mayes, Okla.	25	Mississippian	1967-68	R
37	362454095281701	22N-17E-02CBB 1	Rogers, Okla.	68	Pennsylvanian	1967-68	R
38	362935096291501	23N-09E-10AAD 1	Osage, Okla.	55	Pennsylvanian	1971-83	R
39	363439095020901	24N-21E-11BDB 1	Craig, Okla.	1,924	Ordovician	1981-83	R
40	364438095042501	26N-21E-08DDD 1	Craig, Okla.	91	Pennsylvanian	1967-68	R
41	364840095421001	27N-15E-21ADB	Nowata, Okla.	65	Pennsylvanian	1967-68	R
42	364705095135302	27N-19E-25CBB 2	Craig, Okla.	103	Pennsylvanian	1980-83	R
43	364723095161301	27N-19E-28DAA 1	Craig, Okla.	156	Pennsylvanian	1980-81	R
44	365147095525401	28N-13E-36CBC 1	Washington, Okla.	22	Pennsylvanian	1967-68	R
45	365413095213201	28N-18E-14CCB 1	Craig, Okla.	200	Pennsylvanian	1980-83	R
46	365502095121801	28N-20E-07DCC 1	Craig, Okla.	133	Pennsylvanian	1980-83	R
47	365309094494701	28N-23E-21DCD 1	Ottawa, Okla.	343	Mississippian	1980-83	R
48	365229094520201	28N-23E-30DCC 1	Ottawa, Okla.	1,410	Ordovician	1980-83	R
49	365749096145701	29N-10E-29BDC 1	Osage, Okla.	65	Pennsylvanian	1971-75	R
50	365732094513201	29N-23E-30CDD 1	Ottawa, Okla.	220	Mississippian	1980-81	R

[1] P = Periodic
R = Recorded

[2] -- Principal aquifer system not known

10.0 SELECTED REFERENCES

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