PHYSICAL AND HYDROLOGIC ENVIRONMENTS OF THE MULBERRY COAL RESERVES IN EASTERN KANSAS

By J. F. Kenny, H. E. Bevans, and A. M. Diaz

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JAMES G. WATT, Secretary

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Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
1950 Ave. A - Campus West
University of Kansas
Lawrence, Kansas 66044-3897
[Telephone: (913) 864-4321]

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CONVERSION FACTORS

Inch-pound units of measurement used in this report may be converted to International System of units (SI) using the following conversion factors:

To convert from	To	Multiply by
inch (in.)	centimeter (cm)	2.54
foot (ft)	meter (m)	0.3048
mile (mi)	kilometer (km)	1.609
square mile (mi^2)	square kilometer (km^2)	2.590
acre	hectare (ha)	0.4047
acre-foot	cubic meter	1,233
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	0.02832
gallon per minute (gal/min)	cubic meter per second (m^3/s)	0.00006309
short ton (2,000 pounds)	megagram (Mg)	0.9072
British thermal unit per pound (Btu/lb)	kilojoule per kilogram (kj/kg)	2.326
micromhos per centimeter (μmhos/cm)	microsiemens per centimeter (μS/cm)	1
degree Fahrenheit (°F)	degree Celsius (°C)	1/

1/ Temp °C = (temp °F -32)/1.8

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ABSTRACT

Strippable reserves of Mulberry coal underlie an area of approximately 300 square miles in Miami, Linn, and Bourbon Counties of eastern Kansas. Although subject to State reclamation law, current and projected strip mining of this relatively thin coal seam could alter the hydrologic environment of the study area. Drained by the Marais des Cygnes and Little Osage Rivers and their tributaries, this area is characterized by low relief and moderately impermeable soils. Streamflows are poorly sustained by ground-water discharge and fluctuate widely due to climatic extremes and usage of surface-water supplies. Because ground-water supplies are generally unreliable in quantity and quality, surface water is used to meet most water requirements in the study area. Primary uses of surface waters are for domestic supplies, maintenance of wildlife and recreational areas, and cooling needs at the LaCygne Power Plant. The prevailing chemical type of the natural streamflow is calcium bicarbonate, with concentrations of dissolved solids generally less than 500 milligrams per liter and pH near neutral. Additional streamflow and water-quality data are needed to evaluate pre-mining characteristics and any changes in the hydrologic environment as strip mining proceeds within the study area. A network of data-collection stations and a sampling scheme have been established to acquire this additional information.

INTRODUCTION

Purpose and Objectives

As the Nation turns to domestic energy sources to meet its needs, coal is being mined at an accelerating pace. Coal-mining activities can present both immediate and long-term hydrologic consequences. In order to protect the hydrologic environment, State and Federal regulatory agencies and coal-mining companies require information regarding pre-mining hydrologic characteristics and the effects of coal mining on these characteristics.

The U.S. Geological Survey is currently conducting a two-phase investigation designed to provide hydrologic information about the coal-producing area in Miami, Linn, and Bourbon Counties of eastern Kansas (fig. 1). This report presents information to satisfy the objectives

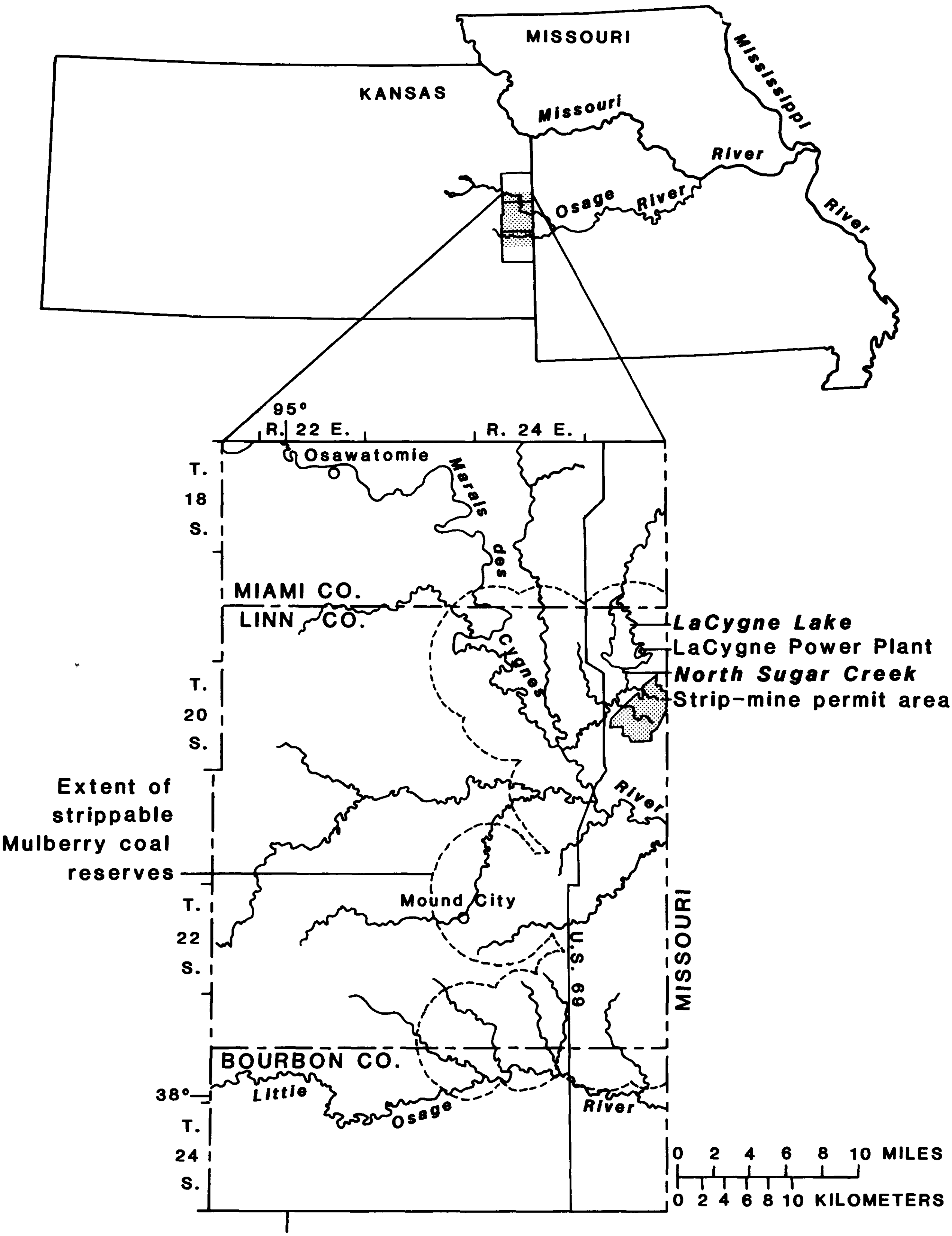


Figure 1.--Location of study area.

of the first phase of the investigation. These objectives are to:

(1) assemble and interpret existing hydrologic data;

(2) describe the physical and hydrologic environments based on existing data; and

(3) determine additional data needed to evaluate the impacts of coal mining on the hydrology of the study area.

Accomplishment of these objectives will provide background for the second phase of this investigation, which is to collect the additional hydrologic data needed to describe the pre-mining hydrologic environment and to determine the effects of coal mining on the hydrologic environment of the study area.

Strip-Mining Regulations

Since 1964, strip mining has been the only method used to recover coal in Kansas (Brady and others, 1976). Abatement of the adverse effects of strip mining is addressed by the Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87), hereafter referred to as the Act. The Act established a permitting process for all proposed mining activities, environmental protection performance standards for stripping and reclamation procedures, and the Office of Surface Mining Reclamation and Enforcement (OSM) to administer these regulatory functions. It is the responsibility of the Office of Surface Mining to assist individual States in enforcing State regulatory programs approved by the Secretary of the Interior, and to implement Federal programs in those States which do not have an approved State program. The State program for Kansas was approved in January 1981. Enforcement is now the jurisdiction of the Kansas Mined Land Conservation and Reclamation Board, headquartered in Pittsburg, Kans.

The Act prohibits disturbance of fragile, historic, and natural-hazard lands by surface mining. Among these lands are cemeteries, valuable wildlife habitats, archeological sites, listings on the State or National Register of Historic Places, and areas subject to faulting or frequent flooding.

The most pervasive mandate of the Act is the requirement that surface-mining activities be planned and conducted to minimize disturbances to the hydrologic environment in both the mine site and adjacent areas. Changes in water quality and quantity, in the depth to ground water, and in the location of surface-water drainage channels shall not adversely affect the post-mining land use. Specifications for monitoring of the quality and quantity of surface and ground waters are outlined in the Act. Detailed regulations may be found in chapter VII of the Permanent Regulatory Program (Office of Surface Mining Reclamation and Enforcement, 1979).

Mulberry Coal Reserves

The thickest and most extensive coal seam remaining in Kansas is the Mulberry coal. A study by Brady and others (1976) indicated that strippable reserves of 260 million short tons of Mulberry coal, ranging from 1 to 4 ft in thickness, underlie an area of approximately 300 mi^2 in Miami, Linn, and Bourbon Counties, of eastern Kansas (fig.1). This estimate is based on the extent of coal reserves that are at least 12 in. thick and have a stripping ratio (thickness of overburden to coal) of 30:1. The great thickness of overburden, approaching 100 ft, that must be removed to reach this relatively thin coal seam makes the stripping ratio one of the highest in the Nation.

The Mulberry coal is a high-volatile bituminous coal. Heat value on a dry, ash-free basis ranges from 13,750 to 15,120 Btu/lb. Moisture content ranges from 3 to 10 percent, ash content from 19 to 30 percent, and sulfur content from 4 to 6 percent. (See Brady and Dutcher, 1974.) Although the Mulberry coal is relatively free of clay and shale, it commonly contains thin layers or small nodules of pyrite; calcite and sphalerite also have been observed. The Mulberry coal contains relatively high concentrations of zinc, cadmium, and lead in comparison to crustal averages of these elements (Wedge and others, 1976).

Approximately 11 million short tons of Mulberry coal have been mined previously in Kansas. Currently (1982), Mulberry coal is being mined in northeast Linn County to supply the LaCygne Power Plant. Approximately 600 acres of the 3,848-acre permit area will be disturbed annually to mine a total of 30 million short tons of coal. The permit area for this mine is located in the drainage basin of North Sugar Creek, a tributary to the Marais des Cygnes River (fig. 1).

PHYSICAL ENVIRONMENT

Location and Extent

The study area is located in southeastern Miami, eastern Linn, and northeastern Bourbon Counties of eastern Kansas (fig. 1). The boundaries are determined to the north, west, and south by the extent of strippable reserves of Mulberry coal, as defined in the preceding section; the eastern boundary is the Kansas-Missouri State line.

Physiography

Topography

The study area is located within the physiographic unit known as the Osage Cuesta Plains (Frye and Schoewe, 1953, p. 248). The land surface slopes to the south and east and is composed of broad, level floodplains and gently rolling to hilly uplands. Local relief ranges from 100 to 300 ft. The regional topography is characterized by northeast-trending limestone escarpments formed by differential erosion of outcropping rocks of Pennsylvanian age.

U.S. Geological Survey 7.5-minute topographic maps, prepared at a scale of 1:24,000 from aerial photographs, delineate topographic contours at 10-foot intervals, surface drainage patterns, and cultural features. The names and locations of topographic maps available for the study area are shown in figure 2, along with the dates of publication, or most recent photo revision. These maps may be purchased at the Kansas Geological Survey publication sales office, 1930 Avenue A - Campus West, University of Kansas, Lawrence, Kans., 66045; or from the Western Branch Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colo. 80225.

Soils

Four major soil associations, shown in figure 3, are represented in the study area. These are the Verdigris-Osage-Lanton, the Woodson-Summit, the Catoosa-Clareson-Summit, and the Dennis-Parsons soil associations (Penner, 1981; Bell and Fortner, 1981). Upland soils, developed from underlying bedrock, cover approximately 87 percent of the area. About 1.5 percent of the area, consisting of terraces adjacent to stream valleys, is covered by soils derived from weathered and eroded bedrock outcrops. Bottom-land soils, formed from alluvium deposited adjacent to stream channels, cover the remaining 11.5 percent of the area (Kansas Water Resources Board, 1958).

About 30 different soil types, as identified by the U.S. Department of Agriculture, Soil Conservation Service, are found within the study area. These soil types are primarily silt and clay loams having moderate to very low permeabilities. The shrink-swell potential, or potential for volume changes with a loss or gain in moisture, ranges from moderate to very high. Infiltration rates of the soils in the study area are variable. Runoff from precipitation is inversely related to the infiltration rate of the soil. Soils consisting of sands and gravelly sands have high infiltration rates, or low runoff potentials. Soils that are moderately deep or deep, and are of moderately fine to moderately coarse texture, have moderate infiltration rates. Soils with fine textures or impeding layers have low infiltration rates. Soils consisting of clays with high shrink-swell potential, soils having a claypan near the surface, and shallow soils covering nearly impervious material have the lowest infiltration rates.

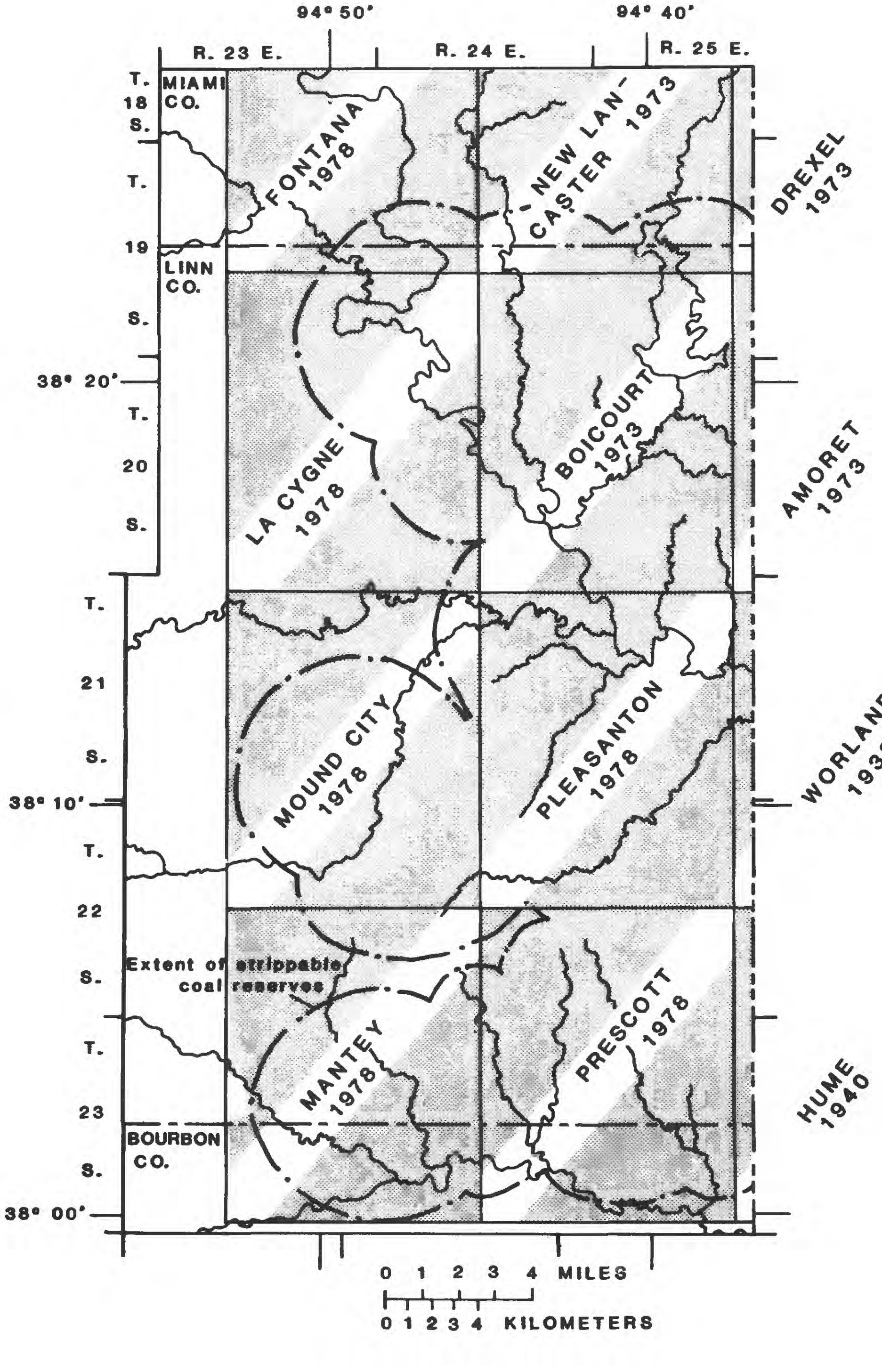


Figure 2.--Available U.S. Geological Survey 7.5-minute topographic maps.

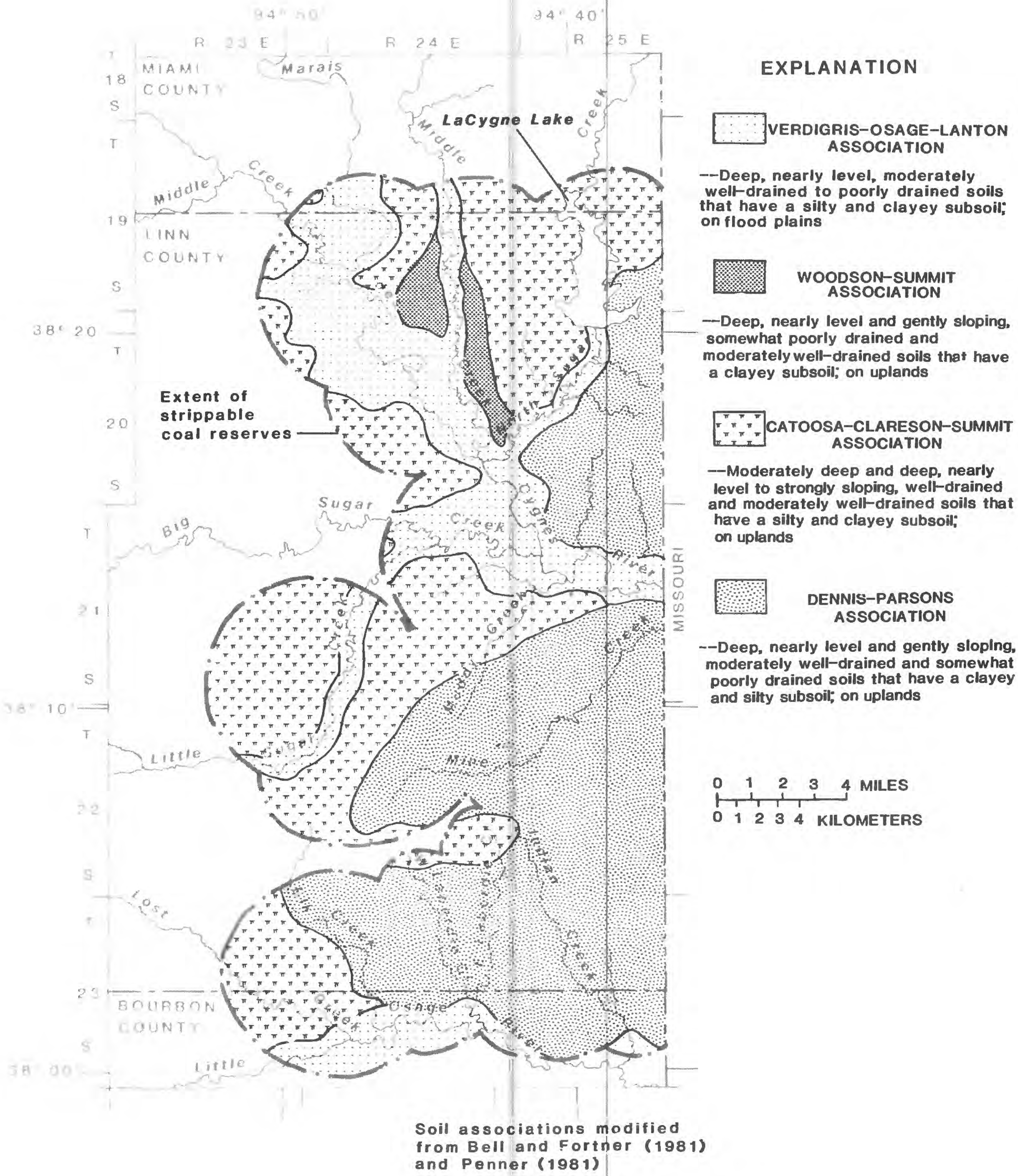


Figure 3.--General soil associations.

Soil erosion by wind and water is not generally a problem provided that proper preventive measures are taken. Severe erosion is most likely on steep upland claypans not covered by perennial vegetation and on unprotected cultivated areas. Land left in pasture or native vegetation, even when covered by a thin soil mantle over bedrock, has been only slightly eroded.

Detailed information on individual soil properties, productivities, and management is available for Bourbon County (Bell and Fortner, 1981) and for Linn and Miami Counties (Penner, 1981).

Land Use

Land use in the study area is illustrated in figure 4. The area is predominately rural. Three distinct land-use categories are identified within the rural sector: agricultural, forested, and barren lands. Also shown in figure 4 are major surface-water bodies and streams, managed wildlife areas, towns, transportation routes, and the LaCygne Power Plant complex.

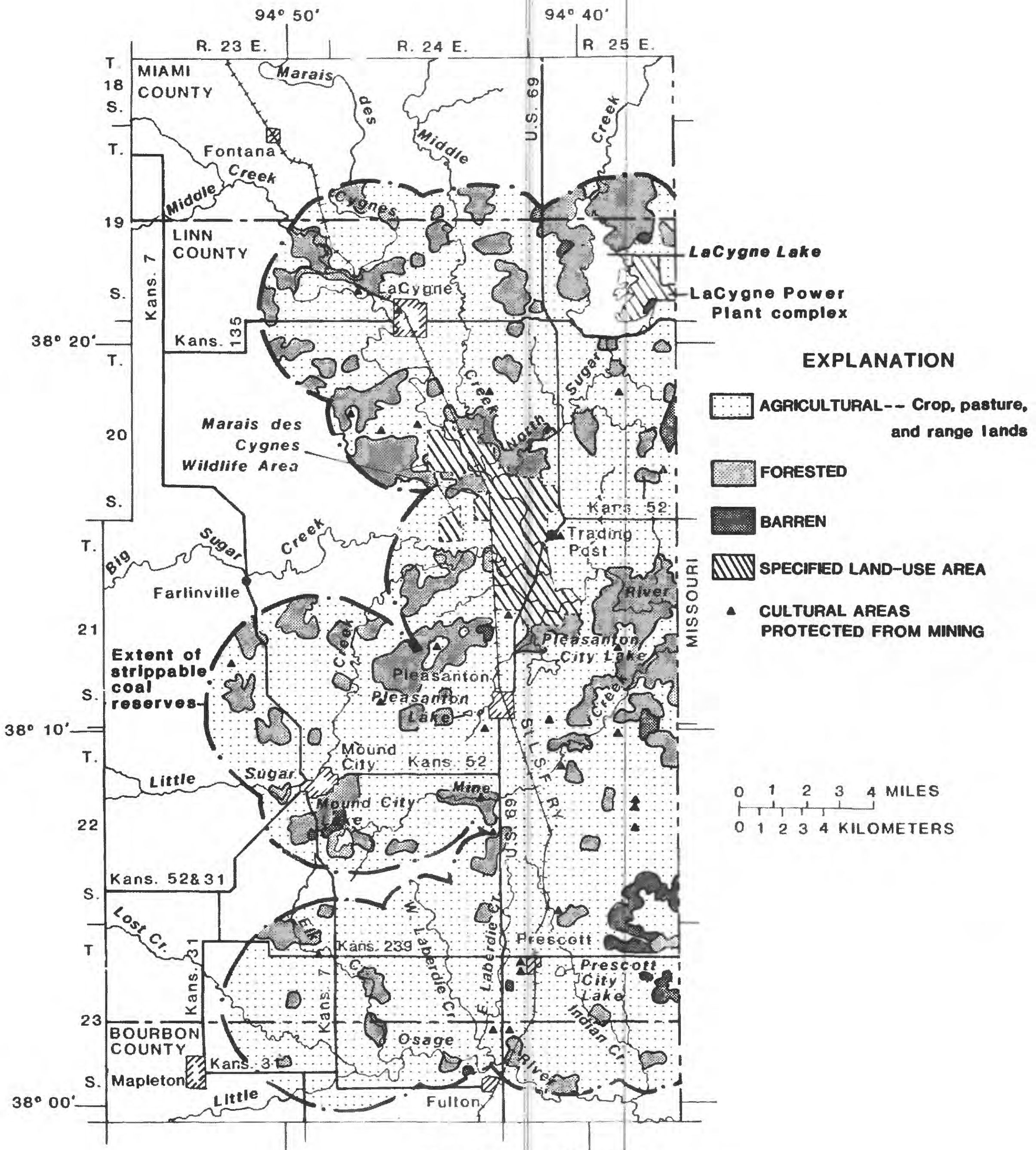
The majority of the land is classified as agricultural. Approximately equal percentages of cropland and pasture comprise this category. Important crops include corn, wheat, oats, soybeans, grain sorghum, and alfalfa. Cattle, sheep, hogs, and poultry are raised. Rangeland, or area covered by indigenous grasses, shrubs, and brush, is very scarce in the study area. Because the few parcels of rangeland are used for grazing, they are included in the agricultural category. Land used for facilities in support of farming or grazing operations is also designated agricultural.

Forested land represents the second most extensive land-use category. Oak and hickory are the dominant tree species on uplands and valley sides, while hackberry, cottonwood, willow, and elm are the major components of riparian and floodplain woods. Many of the older strip-mined areas are forested.

Barren lands identified in the study area consist primarily of unvegetated strip-mined lands. Quarries, pits, and transitional areas also are included in the barren land-use category.

Surface-water bodies and wetlands are quite numerous within the study area, although few are shown in figure 4 due to their relatively small sizes. Surface waters serve many municipal, industrial, agricultural, and recreational uses. Wetlands provide wildlife habitat and hunting opportunities.

Wildlife areas managed by the Kansas Fish and Game Commission include lands classified as agricultural and forested, as well as surface-water bodies and wetlands. The Marais Des Cygnes Wildlife Area covers 7,145 acres and is approximately 17 percent agricultural land, 42 percent forest, 39 percent wetland, and 2 percent water. LaCygne Lake and adjacent forested and agricultural lands are also used for wildlife management.



Land use modified from U. S. Geological Survey (1979) and U. S. Geological Survey 7.5-minute topographic quadrangles, 1:24,000

Figure 4.--Land use.

Urban areas are small in both number and size, none having a population greater than 1,500. Very little industry is located within the study area. The LaCygne Power Plant, located on the east side of LaCygne Lake, is the major industrial complex in the study area. The power-plant complex includes power-generating facilities, coal piles and unloading areas, scrubber-limestone facilities, solid-waste disposal sites, and wet-scrubber waste-disposal ponds. These facilities are needed to accommodate the operations of two coal-fired units. Unit 1 has an 800-MW (megawatt) capacity and began commercial operation in 1973. It annually burns 1.5 to 1.6 million short tons of Mulberry coal from Kansas and Missouri, contracted through the year 2002. The high sulfur and ash content of the Mulberry coal necessitates the hauling of limestone from a quarry north of the site for use in the wet scrubber and two large waste ponds to dispose of the flue-gas-desulfurization sludge. Unit 2 has a 650-MW capacity and was completed in 1977. This unit burns 1.8 to 2.2 million short tons of low-sulfur Wyoming coal per year, contracted through the year 1997. U.S. Environmental Protection Agency emission standards are met by use of an electrostatic precipitator, which removes smoke particles as the Wyoming coal is burned.

Also indicated in figure 4 are cultural areas protected by law from surface-mining activities. These areas include 22 cemeteries, 4 schools, 1 church, and two sites listed on the National Register of Historic Places. These are the Marais Des Cygnes Massacre Site, 4 miles northeast of Trading Post, and the Mine Creek Battlefield, 2.5 miles southwest of Pleasanton. Exact locations of archeological sites are not available; however, most sites with archeological potential are located in stream valleys. The Little Osage River in Bourbon County has been almost completely surveyed for archeological sites, but very little work has been done on the other streams within the project area. Additional archeological information on proposed mine sites may be obtained from the Kansas State Historical Society, Topeka, Kans.

Wildlife

Within the study area are four general types of wildlife habitat: open areas, woodlands, riparian areas, and water. Open areas are those which were originally native tallgrass prairie but are now primarily cropland and pasture. Representative species of open areas include bobwhite quail, prairie chicken, cottontail rabbit, coyote, raccoon, opossum, and striped skunk, as well as a variety of non-game mammals and birds, furbearers, and reptiles.

The study area contains a relatively high percentage of woodland for Kansas. Representative wildlife of the woodlands include whitetail deer, eastern turkey, fox, and squirrels. Non-game animals and birds are plentiful in wooded areas and adjacent transitional zones.

Wildlife in riparian areas is quite diverse. Inhabitants of stream-associated woodlands consist of raccoon, mink, muskrat, and beaver, as well as the above-mentioned woodland species. Sandpipers, killdeer, and herons are also part of this community. Bald eagles, included on both the National and State lists of endangered species, are found near reservoirs and marshes during the winter.

Lakes and streams provide habitat for many fish species, including flathead and channel catfish, large-mouth and white bass, and bluegill. Stream survey data on fish species inhabiting the Marais des Cygnes River basin have been collected by the Kansas Fish and Game Commission. These data are summarized by the Kansas Department of Health and Environment and the Kansas Fish and Game Commission (1978).

All four types of wildlife habitat are found within the Marais des Cygnes Wildlife Area (shown in figure 4). Ten different units within this area are managed by the Kansas Fish and Game Commission to provide a resting and feeding place for migratory waterfowl, as well as public hunting and fishing opportunities.

Wildlife populations are dependent upon the stability of the land, water, and associated vegetation for their survival. Because wildlife habitats must be restored after mining, the Kansas Fish and Game Commission and the Kansas Mined Land Conservation and Reclamation Board have prepared a package of information on wildlife resources for use by the mining companies. This information may be obtained from the Kansas Fish and Game Commission.

Climate

The continental climate of eastern Kansas is affected primarily by warm, moist air masses from the Gulf of Mexico and cold, dry air masses from the polar regions. Consequently, weather patterns in the study area are subject to large variations.

The average annual temperature for the study area is 58.1°F. Average monthly temperatures recorded at Mound City, shown in figure 5, range from a low of 31.7°F in January to a high of 80.7°F in August (from records of the National Weather Service, formerly the U.S. Weather Bureau, 1950-78). The average length of the growing season, April through October, is 181 days (Seevers, 1969).

Prevailing winds are from the south except during January, February, and March when they are from the north. Windspeed averages 10.4 miles per hour and is greatest in March and April.

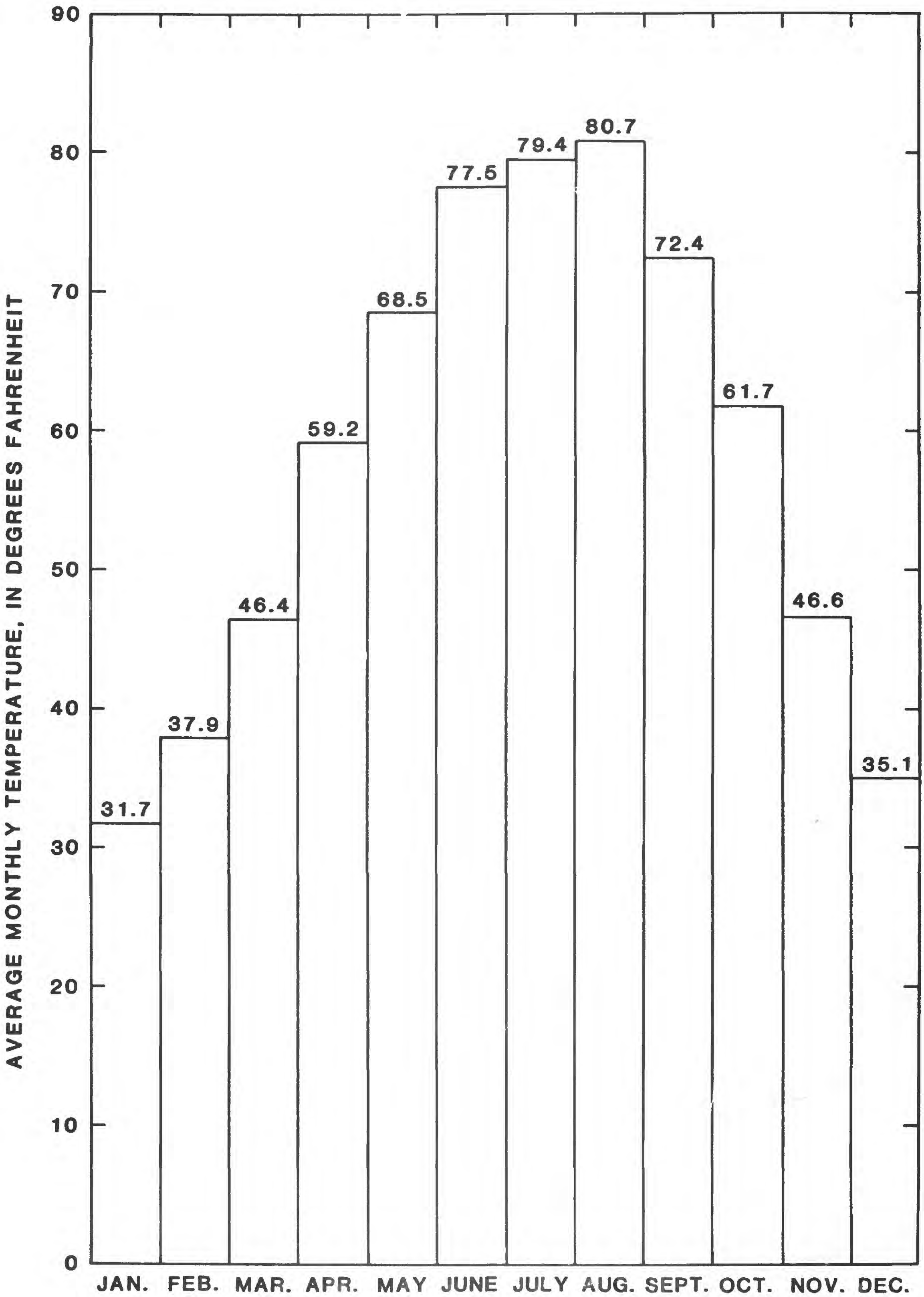


Figure 5.--Average monthly temperatures recorded at Mound City, 1950-78 (from records of the National Weather Service, 1950-78).

Annual precipitation recorded at Mound City averages 40 in. (from records of the National Weather Service, 1950-78). The distribution of this precipitation in percentage by month is shown in figure 6. Relatively little precipitation falls during the winter months (December through February), and the ground is generally covered by snow for less than 1 month per year. About 70 percent of the annual precipitation occurs during the growing season, although distribution can be erratic. Two general types of rainstorms occur, intense local thunderstorms of short duration and longer storms of great areal extent. Periods of little or no precipitation can occur at any time of the year and last for several consecutive months. Drought conditions during July and August are particularly severe when high temperatures cause high evapotranspiration. Maximum annual evaporation from an open water surface may exceed 5 ft, though the average amount for the study area is about 3.5 ft per year (Kansas Water Resources Board, 1958).

Precipitation, temperature, and wind velocity data for Kansas weather weather stations are published monthly by the National Oceanic and Atmospheric Administration in "Climatological Data for Kansas" and "Hourly Precipitation Data for Kansas."

Geology

Surface Rocks and Stratigraphy

Surface rocks in the study area are of Pennsylvanian and Quaternary age, as illustrated in figure 7. The Pennsylvanian rocks that crop out, in order of most common occurrence, are shale, limestone, sandstone, and small amounts of coal and underclay. Progressively older rocks of the Kansas City, Pleasanton, Marmaton, and Cherokee Groups are exposed from northwest to southeast. Unconsolidated terrace and alluvial deposits of Quaternary age fill the major stream valleys. These deposits are primarily chert and limestone gravel, clay, and shale.

The stratigraphic succession, thickness, and lithology of the various rock units of Pennsylvanian and Quaternary age are summarized in table 1. These rock formations and members are described in detail by Zeller (1968) and Seevers (1969).

Structure

Subsidence in eastern Kansas during earliest Pennsylvanian deposition formed the Forest City Basin, marked by a thickening of the Cherokee Group to the northwest in Linn County. The southern boundary of this basin, a positive structural element known as the Bourbon Arch, underlies southern Linn County. A subsequent tectonic event produced the Prairie Plains Monocline, establishing the present 20 ft/mi northwest dip of the rock units in eastern Kansas (Seevers, 1969).

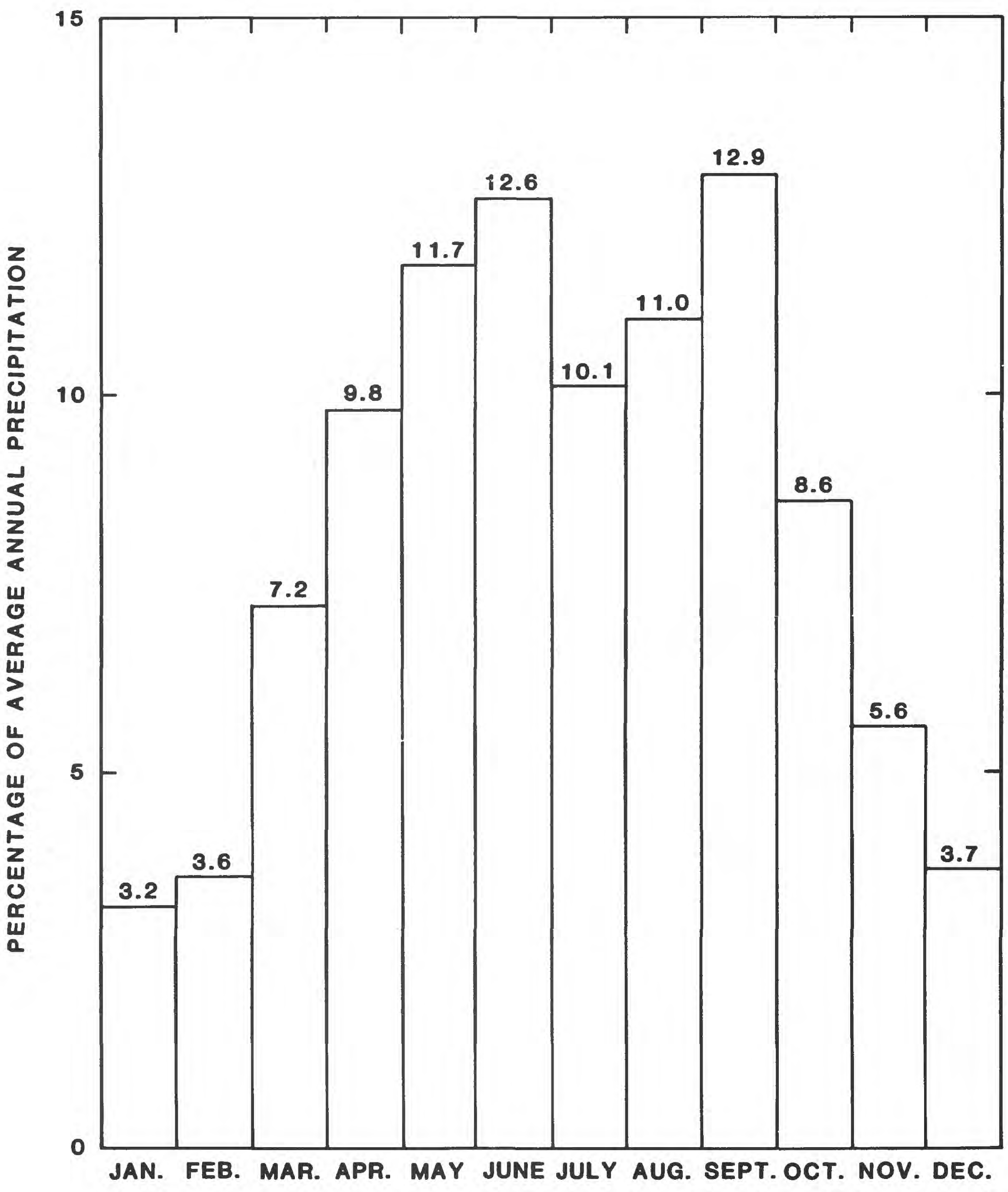


Figure 6.--Percentage of average annual precipitation by month, recorded at Mound City, 1950-78 (from records of the National Weather Service, 1950-78).

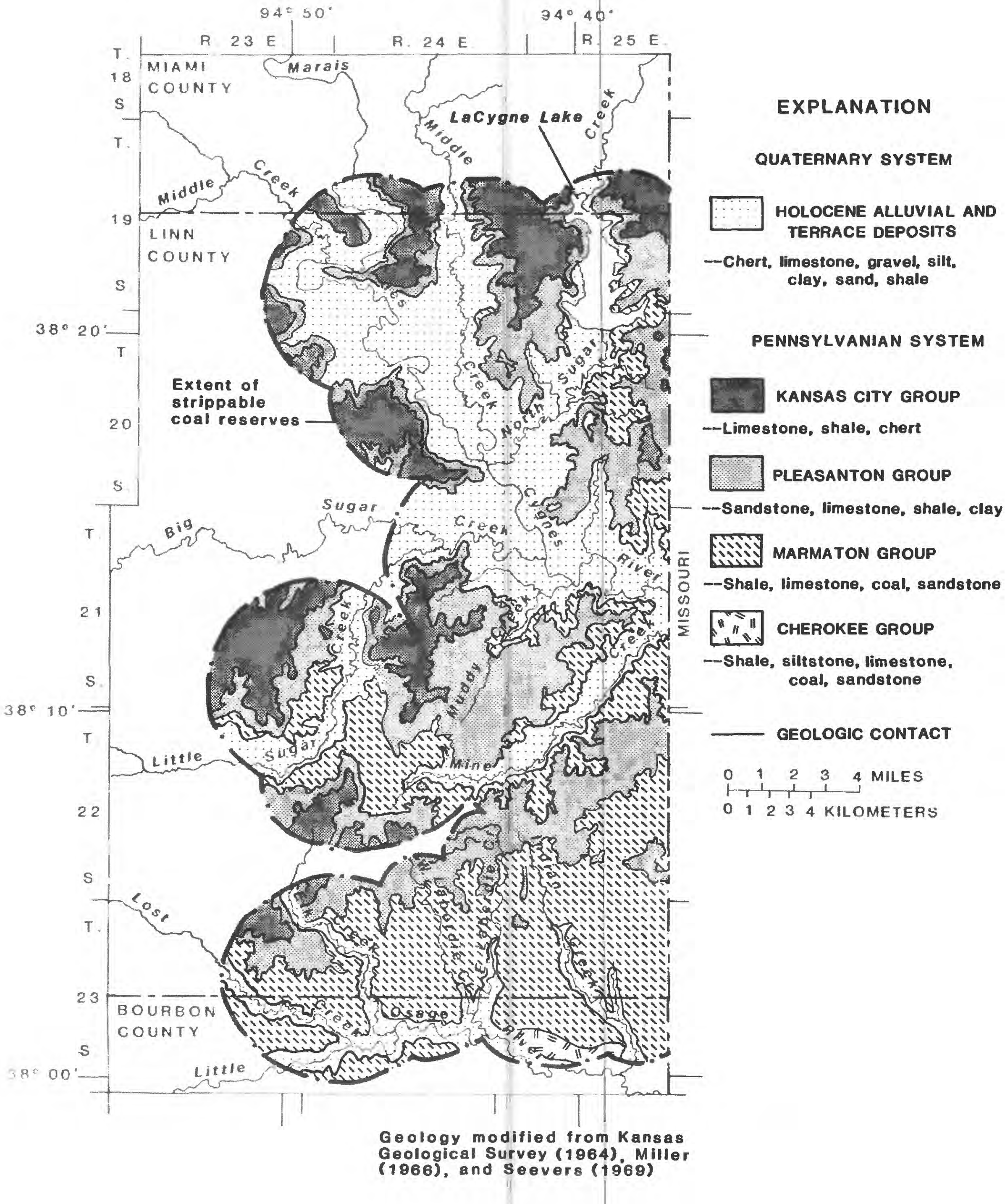


Figure 7.--Surface geology.

Local structures include a prominent dome 1 mi northeast of Mound City and several smaller domes near Pleasanton, Trading Post, and Prescott. Faulting in the study area is not extensive, and the known faults have relatively small displacements.

Mineral Resources

The rock units potentially disturbed by strip mining the Mulberry coal include all formations above the Pawnee Limestone. These alternating beds of limestone, sandstone, and shale contain valuable raw materials.

The Laberdie, Bethany Falls, and Winterset Limestones have been quarried for construction aggregate and agricultural lime. Locations of existing quarries are indicated on the mineral-resource map (fig. 8).

Chert gravel has been obtained from terrace deposits of Kansan age, which occur only in eastern Linn County directly south of the Marais des Cygnes River in T. 21 S., R. 25 E., as shown in figure 8 (Kansas Geological Survey, 1964). These deposits consist of 1 to 4 feet of coarse to medium clay-bound chert gravel and are found about 40 to 50 feet above the present floodplain of the river (Seevers, 1969).

Shallow rocks of the Marmaton Group yield oil and gas in several fields within the study area. The locations of these fields and of existing oil and gas pipelines have been mapped by Oros and others (1974; 1975) and are shown in figure 8. As with any resource, the status of these fields is subject to economic circumstances. Limited information on producing and abandoned wells has been published by the Kansas Geological Survey (Beene, 1979). Additional figures on oil production by fields are published semiannually by the Petroleum Information Corporation, headquartered in Denver, Colo.

Rocks of the Marmaton Group have been mined for lead and zinc south of Pleasanton where the Bandera Shale and underlying beds have been mineralized with lead and zinc sulfides (Seevers, 1969). The Bandera Shale is also a source of sandstone for flagstone (Jewett, 1941) and contains the Mulberry coal bed.

The Mulberry coal generally occurs as a single seam about 3 ft above the base of the Bandera Shale. The contact rock above and below the coal is gray to dark-gray shale. Coal thickness ranges from 1 to 4 ft, increasing towards the northwest from outcrop areas in southern Linn and northern Bourbon Counties. Natural outcrops are scarce due to earlier mining and erosion. Depth to the Mulberry coal, ranging from 15 to 100 ft, is quite variable due to the northwesterly dip of rock units and local variation in topographic relief. Past production of Mulberry coal occurred primarily in coal-mining districts near LaCygne, Pleasanton, Prescott, and in the drainage basin of North Sugar Creek. The earliest mining techniques were drift or slope mining of shallow coal and under-

Table 1.--Stratigraphic succession of Pennsylvanian and Quaternary rock units (from Zeller, 1968; and Seevers, 1969)1/

System	Series	Group	Formation	Member	Average thickness (feet)	Lithology
Quaternary	Pleistocene		Alluvial deposits		40-50	Dark-gray and grayish-brown silt- and clay-sized material, coarse and medium subrounded chert and limestone gravel
			Terrace deposits		20-35	Light-gray and brown clay, sand, chert, and shale
Pennsylvanian	Upper Pennsylvanian	Kansas City	Cherryvale Shale	Block Limestone	1-7	Blue-gray fine-grained limestone
				Fontana Shale	5-7	Gray clay shale
			Dennis Limestone	Winterset Limestone	30-40	Light-gray cherty limestone with thin shale partings
				Stark Shale	4	Soft gray blocky shale in upper part, black platy shale in lower part
				Canville Limestone	0-2	Dense blue massive limestone with dark calcareous shale and nodular limestone along outcrop
			Galesburg Shale		2	Gray shale with thin micaceous sandstone near base
			Swope Limestone	Bethany Falls Limestone	11-21	Light-gray to light-yellow cherty limestone with shale near bottom
				Hushpuckney Shale	5	Brown clay shale in upper part, black fissile shale in lower part
				Middle Creek Limestone	2	Medium- to bluish-gray limestone
			Ladore Shale		5-13	Brown-weathering calcareous shale with local beds of argillaceous limestone
			Hertha Limestone	Sniabar Limestone	2-6	Medium-gray, rust-brown weathering, fine-grained massive limestone
				Mound City Shale	3-20	Medium- to dark-gray calcareous shale with limestone nodules and thin coal smut
				Critzer Limestone	1-10	Brownish-gray fine-grained limestone with yellowish-brown silty nodules near LaCygne; gray thin wavy-bedded cherty limestone south of Mound City
		Pleasanton	Tacket Formation	Knobtown Sandstone	9-35	Buff to light-gray fine-grained massive sandstone that occurs north of Mound City
				Bourbon Flags	3-35	Dense bluish-gray limestone flags with alternating beds of dark-gray to black shale that occur south of Mound City
			Seminole Formation	Hepler Sandstone	1-30	Brown and gray sandstone beds separated by thin weathered yellow clay, position occupied by maroon shale near Mound City

Pennsyl-vanian	Middle Pennsyl-vanian	Marmaton	Holdenville Shale		0-30	Yellow-weathering gray clay shale with coal, black fissile shale, and nodular limestone occurring locally near base
			Lenapah Limestone	Idenbro Limestone	1-9	Brownish-gray to dark-gray mostly crystalline limestone
				Perry Farm Shale	1-10	Light- to dark-gray clay shale co taining limestone nodules
				Norfleet Limestone	0.5-4.5	Dark brownish-gray massive to bluish-gray slabby limestone
			Nowata Shale		3-24	Gray to yellow clay shale, sandy shale, and sandstone
			Altamount Limestone	Worland Limestone	3-5	Light-gray homogenous-textured limestone
				Lake Neosho Shale	0-5	Gray to black shale with abundant phosphatic concretions
				Amoret Limestone	1-2	Light-gray sandy limestone
			Bandera Shale	Bandera Quarry Sandstone	0-30	Gray and brown thin-bedded sandstone
				Mulberry Coal	1-4	Persistent coal seam, underlain by light to dark carbonaceous shale, overlain by thin dark-gray limestone
			Pawnee Limestone	Laberdie Limestone	6	Light-gray crystalline limestone that occurs in thin wavy beds, contains chert in easternmost Linn County
				Mine Creek Shale	0-16	Light-gray to black fissile shale containing thin limestone beds
				Myrick Station Limestone	2-8	Dark-gray, brown, and light-gray massive limestone
				Anna Shale	2-5	Black fissile and gray calcareous shale containing phosphatic con-cretions
			Labette Shale		30-100	Gray and yellow clay shale, sandy shale, black shale, and sand-stone, coal, and limestone beds
			Fort Scott Limestone		20	Massive limestone beds separated by black shale
		Cherokee	Cabaniss Formation		75-150	Black platy shale, light- and dark-gray shale, sandy siltstone, limestone, sandstone, and coal

1/ The stratigraphic nomenclature used in this report is that of the Kansas Geological Survey and does not necessarily follow the usage of the U.S. Geological Survey.

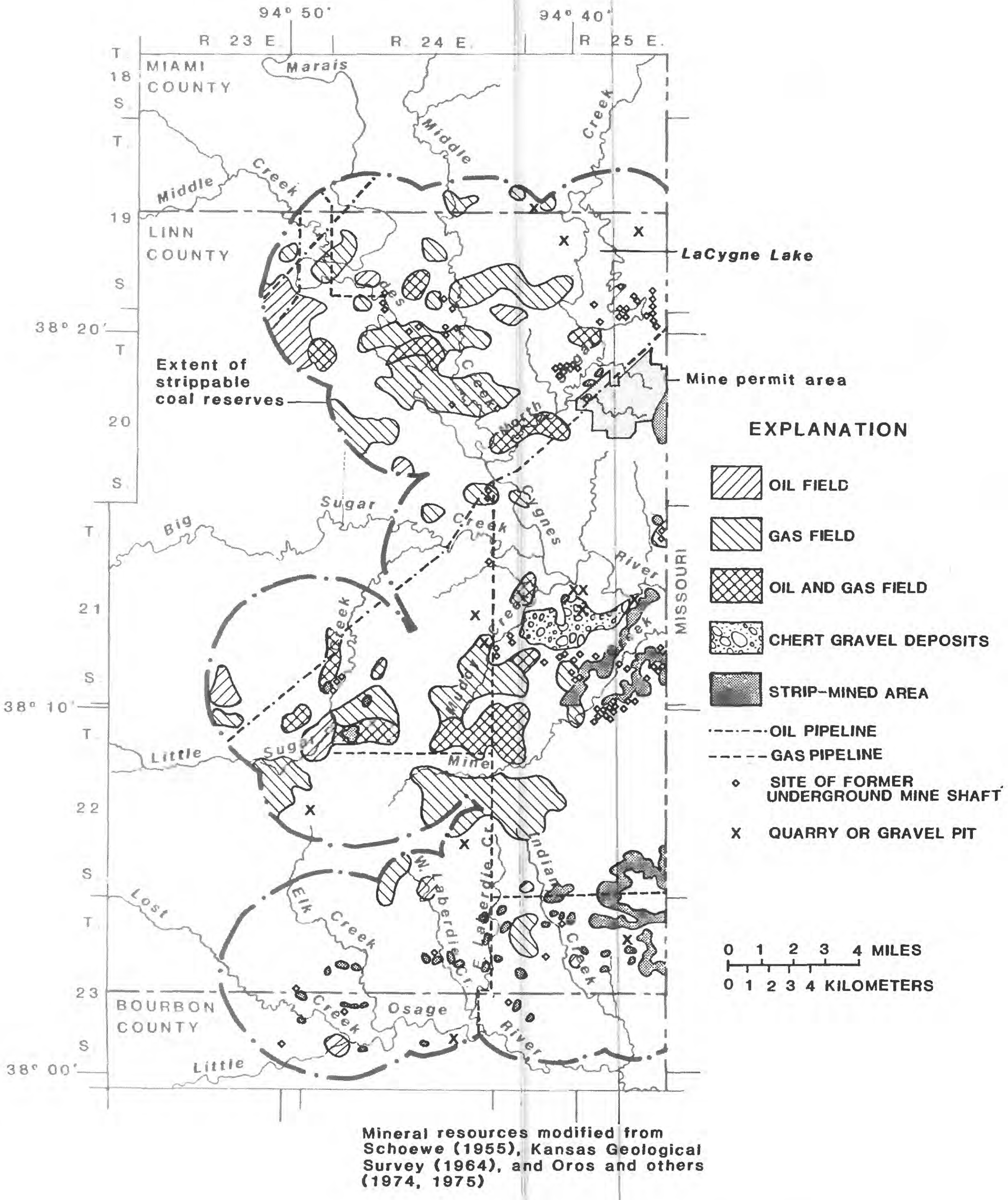


Figure 8.--Mineral resources.

ground mining of deep coal. As strip mining became the predominant method of obtaining coal, these older mines often were engulfed. The known locations of shafts for former underground mines and the areas that have been strip mined (from Schoewe, 1955) are mapped in figure 8. Also shown is the permit area for current coal-mining operations in the North Sugar Creek drainage basin.

HYDROLOGIC ENVIRONMENT

Surface Water

Drainage Patterns

The study area is drained by the Marais des Cygnes River, the Little Osage River, and their tributaries. These streams are well developed dendritically due to their shallow slopes. The gradient of the Marais des Cygnes River is about 1.1 ft/mi in Linn County, and its floodplain width averages about 4 mi (Seevers, 1969, p. 4). The drainage basin of the Little Osage River is narrower and steeper than that of the Marais des Cygnes River. Floodplain width of this river ranges from one-fourth to three-fourths of a mile (Kansas Water Resources Board, 1958, p. 120). Stream channels of both the Marais des Cygnes and the Little Osage Rivers are relatively stable, with pools and riffles commonly present. Streambeds of these rivers are composed of bedrock, gravel, clay, and silt. The bed of the Marais des Cygnes River also contains some sand. Major tributaries of the Marais des Cygnes River within the study area are, in downstream order of confluence with the main channel, (1) Middle Creek (confluence 2 mi northwest of LaCygne), (2) Middle Creek (confluence near Boicourt), (3) North Sugar Creek, (4) Big Sugar Creek and its major tributary Little Sugar Creek, (5) Muddy Creek, (6) two unnamed tributaries east of Trading Post, and (7) Mine Creek. Major tributaries of the Little Osage River within the study area are (1) Lost Creek, (2) Elk Creek, (3) Laberdie Creek, and (4) Indian Creek.

Streamflow variability

Streamflow variability is determined by many factors, including the physical characteristics of a drainage basin, climatic conditions, and management of water supplies. Streams within the study area exhibit great variation in the magnitude of flow. Ground-water discharge, or that portion of streamflow known as base flow, is not appreciable in these streams due to the lack of aquifers capable of storing large amounts of water. Prolonged droughts cause serious depletion of streamflows. Streamflows tend to reflect rainfall events, reservoir release, and usage of surface-water supplies. Storm runoff, or that part of the precipitation that flows across the land surface into drainage channels, provides most of the streamflow in the study area. Intense storms can cause flooding in this area of low soil-infiltration rates.

Flow in the Marais des Cygnes River is regulated by two federal reservoirs on upstream reaches in Osage County, Kans. Pomona Lake, which impounds drainage from 322 mi^2, began storage in October 1963. Melvern Lake, which impounds water from 349 mi^2, began storage in the summer of 1972. A minimum of 15 ft^3/s is released from Pomona Lake; a minimum of 20 ft^3/s from Melvern Lake. However, no minimum streamflow requirements exist for the Marais des Cygnes River at downstream municipalities or at the Kansas-Missouri State line. Flows in other streams in the project area are not affected by any major reservoirs with the exception of North Sugar Creek, which is regulated downstream of LaCygne Lake.

Quantitative measurements of streamflow variability require continuous streamflow records of sufficient duration to represent historical fluctuations. Streamflow records from four stream-gaging stations operated by the U.S. Geological Survey can be used to illustrate flow characteristics in the three largest streams--the Marais des Cygnes River, Big Sugar Creek, and the Little Osage River. Locations of the four stream-gaging stations are shown in figure 9. Station descriptions and streamflow characteristics for the period of record maintained at these stations are available from computer storage through the National Water Data Exchange (NAWDEX). Station information for periods of record through September 1980 is summarized in table 2, along with low-flow and flood-frequency data for these stream-gaging stations.

Low-flow frequency analyses were computed from annual records of the lowest average discharge for 7-consecutive days. The 7-day low-flow discharges occurring at 2-year and 10-year recurrence intervals indicate the tendency of streams in the study area to experience severe streamflow deficiencies. Flood-frequency analyses were computed using a Log-Pearson type-III analysis. Peak discharges expected at 2-year and 10-year recurrence intervals are listed in table 2. Curves showing flood magnitude for recurrence intervals from 1 to 100 years are presented in figure 10. These curves were prepared using available data from all periods of record through 1980 for all the stream-gaging stations except the Marais des Cygnes River near State line, for which only data from the period that flow has been regulated (1964-80) were used.

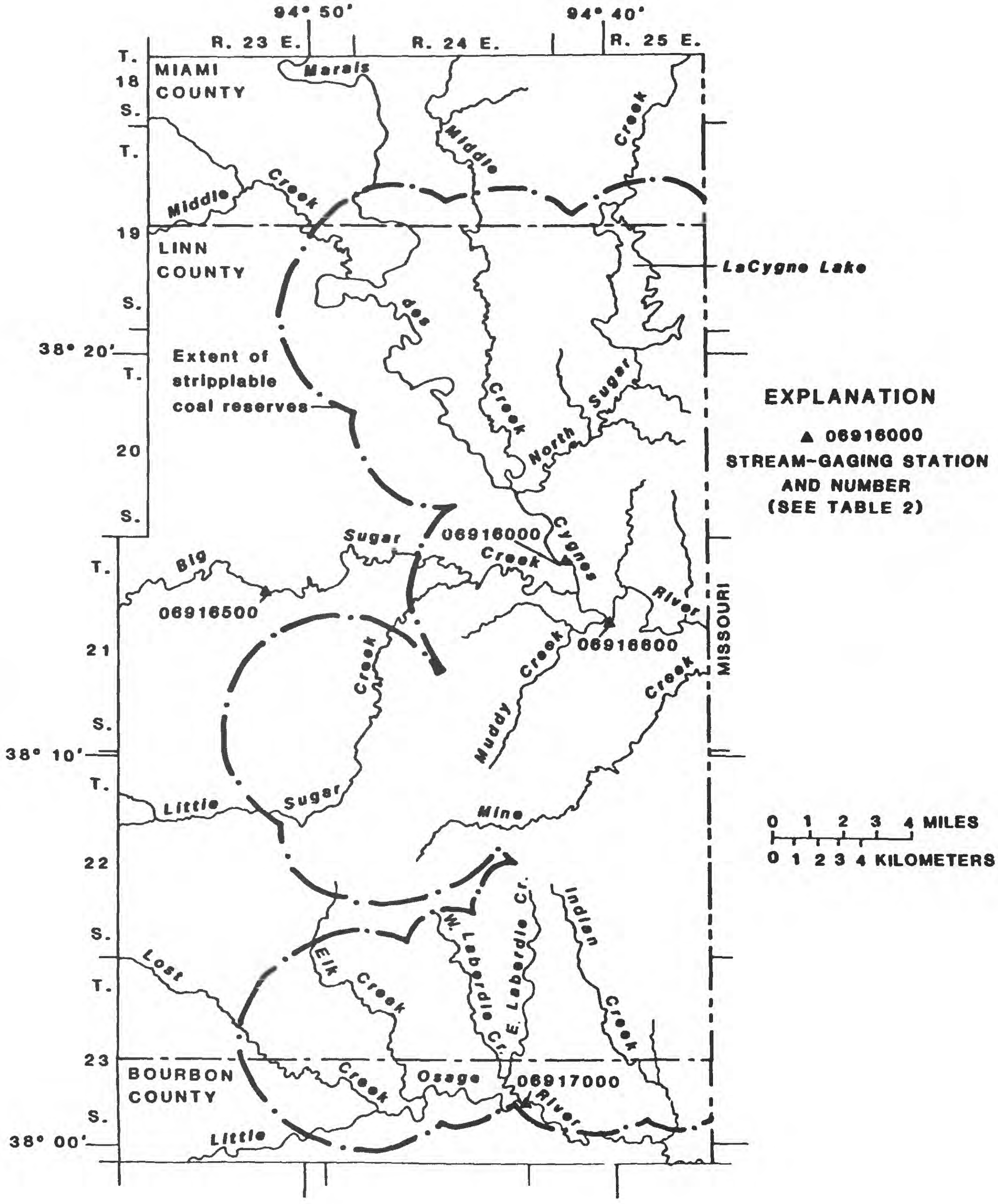


Figure 9.--Locations of selected U.S. Geological Survey stream-gaging stations.

Table 2.--Station descriptions and streamflow characteristics for selected U.S. Geological Survey stream-gaging stations

Station number	Station name	Land-line location (township-range-section)	Drainage area (square miles)	Period of record	Average discharge (cubic feet per second)	Peak discharge (cubic feet per second) and year of occurrence		Low-flow frequency data: 7-day low flow (cubic feet per second) for indicated recurrence interval		Flood-frequency data: Peak discharge (cubic feet per second) for indicated recurrence interval [1]	
								2-year	10-year	2-year	10-year
06916000	Marais des Cygnes River at Trading Post	21S-25E-5	2,880	October 1928-September 1958	1,686	148,000	1951	2.30	0	20,850	55,600
06916500	Big Sugar Creek at Farlinville	21S-23E-11	198	February 1929-June 1932, November 1948-September 1958, July 1959-September 1970	129	41,000	1967	0.30	0	6,880	18,400
06916600	Marais des Cygnes River near Kansas-Missouri State line	21S-25E-16	3,230	October 1958-September 1980	1,920	57,400	1961	26.0	2.00	20,000	52,000
				October 1963-September 1980[2]	1,918	49,300	1977	23.0	2.00	21,700	43,500
06917000	Little Osage River at Fulton	23S-24E-25	295	November 1948-September 1980	203	26,300	1969	0.17	0	7,380	18,400

1 As defined by Log-Pearson type-III analysis.
2 Indicates period of record for which flow has been regulated.

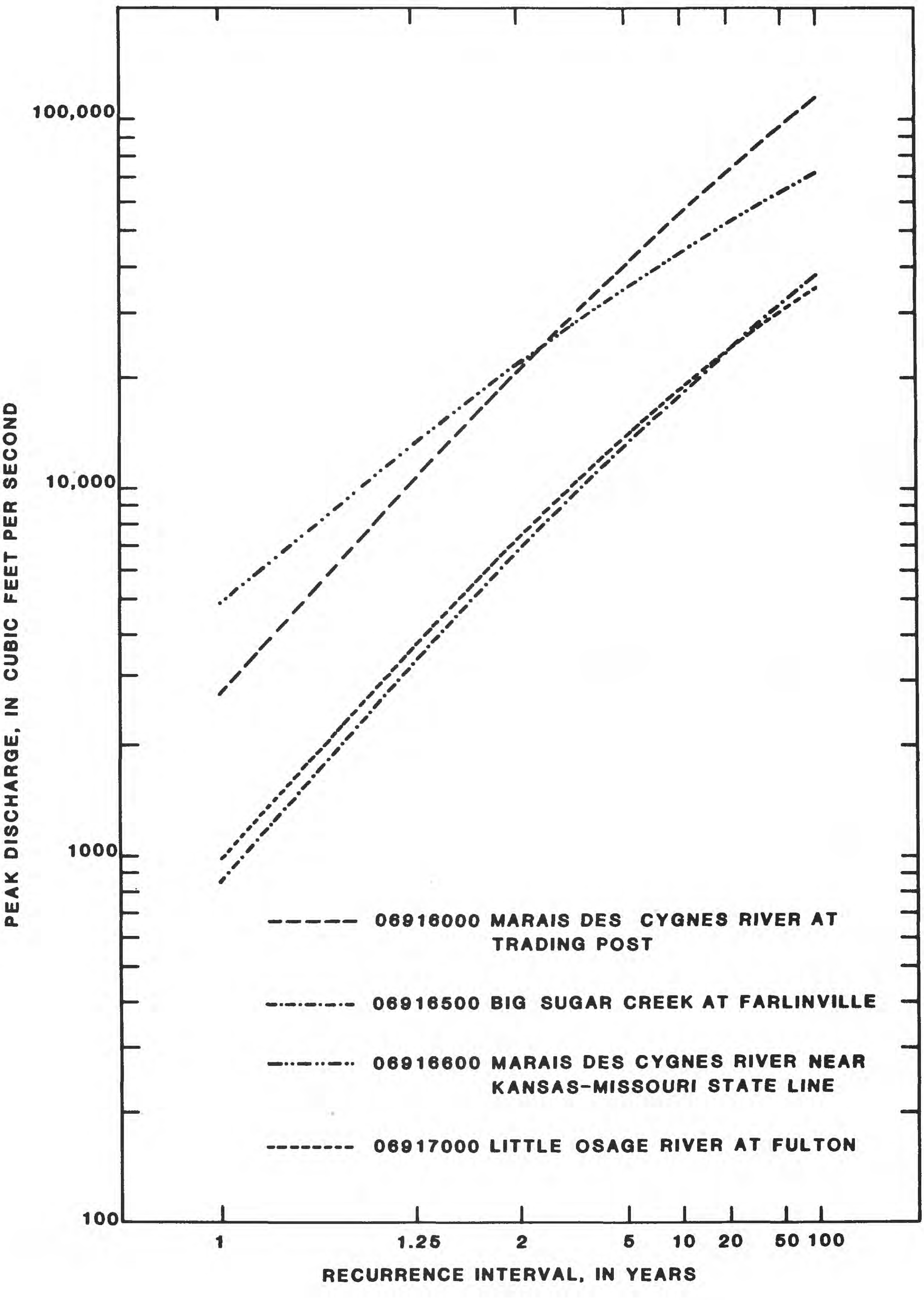


Figure 10.--Flood-frequency curves for selected U.S. Geological Survey stream-gaging stations.

Flow-duration curves, a means of illustrating variability in streamflow magnitude and frequency for the four stream-gaging stations, are shown in figure 11. Because each curve was computed with data from a different period of record, the differences in the curves reflect climatic fluctuations and water usage during these periods, as well as the storage and runoff characteristics of the drainage basins. All four curves have steep slopes indicative of streams that receive little or no ground-water discharge during periods of no surface runoff. Curves for the Little Osage River at Fulton and Big Sugar Creek at Farlinville are typical of streams with relatively small drainage areas, in that for about 10 percent of the periods of record, streamflows did not equal or exceed 0.01 ft^3/s. Curves for the Marais des Cygnes River lie farther to the right than those of the two smaller streams due to the greater area drained by this stream and the resultant higher streamflows. Flow-duration curves for the Marias des Cygnes River at Trading Post and near State line reflect differences in drainage basin characteristics and in periods of record. Thirty years of record were used to define the flow-duration curve for the Marais des Cygnes River at Trading Post. This time period included the peak-of-record flood of 1951 and the drought of 1952-56, but did not include data since 1964 when streamflow became regulated by the reservoirs at Pomona and Melvern. Consequently, the upper left part of the curve indicates very high peak flows, while the lower right part shows that flow in the Marais des Cygnes River at Trading Post dropped below 0.01 ft^3/s about 4 percent of the time. The curve for the Marais des Cygnes River near State line represents the years during which flow has been regulated (1964-80). This curve has a flatter slope due to fewer intense storms during that period of record, supplementary flow from Big Sugar Creek, and the regulating effects of the reservoirs. However, flow has occasionally dropped below 0.01 ft^3/s because of prolonged drought conditions and increased usage of river water in recent years.

U.S. Geological Survey flood-prone maps completed in 1970 (scale = 1:24,000), which show the boundaries of the 100-year flood elevations, are available for the Fontana, LaCygne, Boicourt, and Pleasanton quadrangles. Maps showing 100-year flood-elevation boundaries are available for Bourbon County (scale= 1:2,000) and Mound City (scale = 1:500) from the U.S. Department of Housing and Urban Development - Federal Insurance Administration. The areas that would be inundated by the 100-year flood, approximated from available flood-prone maps and streamflow records, are shown in figure 12.

Water Quality

Water-quality data are available for three U.S. Geological Survey stream-gaging stations located on the two major streams within the study area. The Marais des Cygnes River has been sampled at Trading Post from October 1968 to September 1972 and at the Kansas-Missouri State line from October 1968 to September 1973. The Little Osage River at Fulton has been sampled from October 1968 to September 1975. Statistical summaries of these water-quality data are presented in table 3. Examination of these summaries indicates that the chemical quality of waters in the Marais des Cygnes and Little Osage Rivers is roughly equivalent.

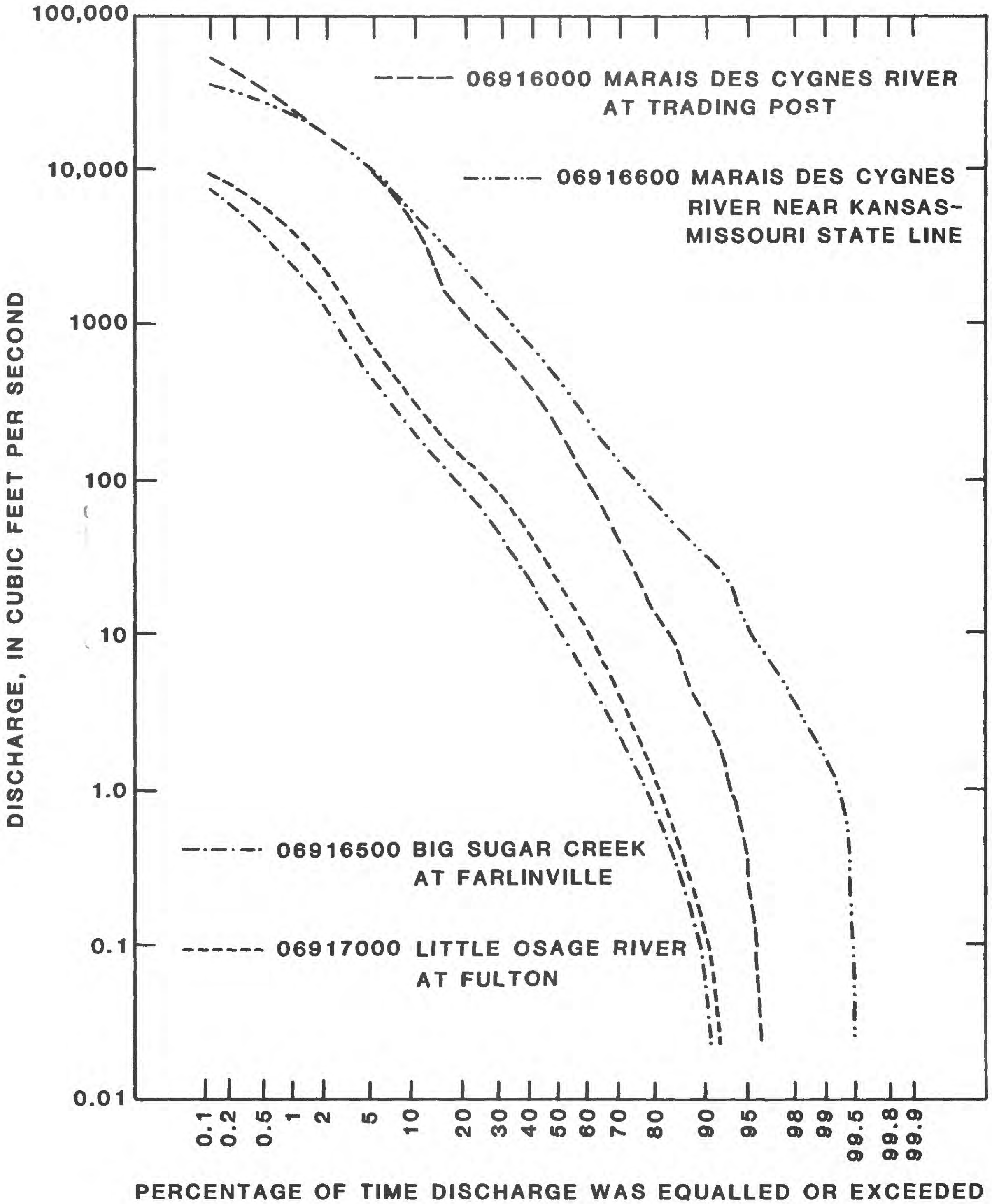


Figure 11.--Flow-duration curves for selected U.S. Geological Survey stream-gaging stations.

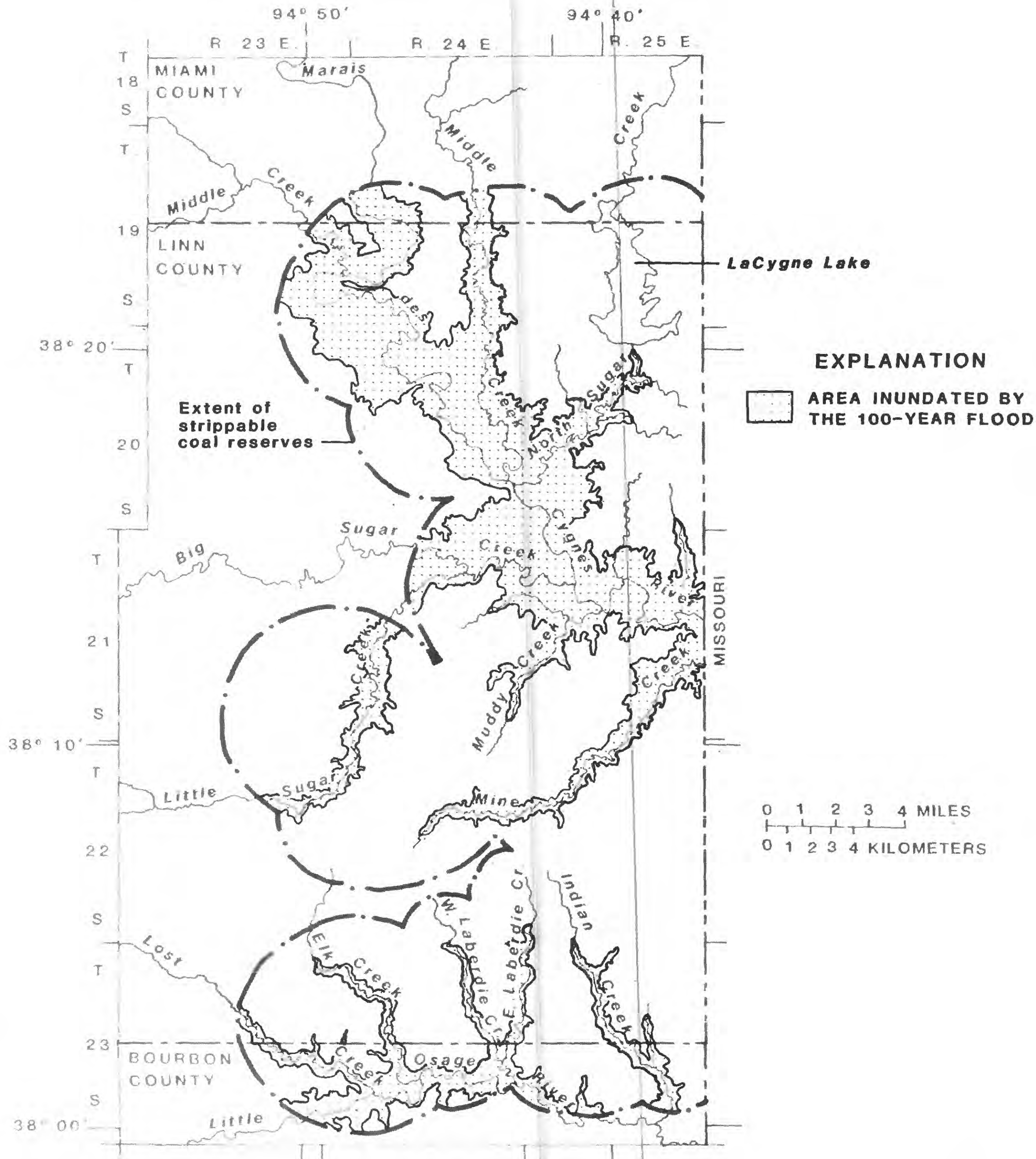


Figure 12.--Areas inundated by the 100-year flood.

Table 3.--Statistical summaries of water-quality data from selected U.S. Geological Survey stream-gaging stations

[Analyses by U.S. Geological Survey. Streamflow is in cubic feet per second (ft^3/s); specific conductance in micromhos per centimeter at 25°C (micromhos); and chemical constituents in milligrams per liter (mg/L) or micrograms per liter (μg/L)]

Station name and period of record	Parameter	Number of samples	Mean	Minimum	Maximum	Standard deviation
Marais des Cygnes	Streamflow (ft^3/s)	21	1,320	33	11,600	2,720
River at Trading	Specific conductance (micromhos)	21	468	265	610	105
Post	pH (standard units)	21	7.9	7.4	8.3	0.2
	Hardness as $CaCO_3$ (mg/L)	21	220	120	330	55
	Hardness, noncarbonate as $CaCO_3$ (mg/L)	21	28	15	62	12
	Alkalinity as $CaCO_3$ (mg/L)	21	190	100	270	48
(October 6, 1968-	Magnesium, dissolved (mg/L)	21	9.3	4.0	13	2.3
September 1972)	Sodium, dissolved (mg/L)	21	15	7.5	21	3.6
	Potassium, dissolved (mg/L)	21	4	2	6	1
	Sulfate, dissolved (mg/L)	21	41	20	65	12
	Chloride, dissolved (mg/L)	21	14	5.0	22	5.0
	Fluoride, dissolved (mg/L)	21	0.4	0.0	1.1	.4
	Solids, dissolved (mg/L)	21	287	161	418	64
	Iron, dissolved (μg/L)	18	60	<10	360	90
	Manganese, dissolved (μg/L)	18	54	5	260	63

Table 3.--Statistical summaries of water-quality data from selected U.S. Geological Survey stream-gaging stations--Continued

Station name and period of record	Parameter	Number of samples	Mean	Minimum	Maximum	Standard deviation
Marais des Cygnes River near Kansas-Missouri State line	Streamflow (ft^3/s)	24	3,950	74	16,300	5,180
	Specific conductance (micromhos)	23	419	150	659	140
	pH (standard units)	24	7.7	6.9	8.2	0.4
	Hardness as $CaCO_3$ (mg/L)	24	190	65	330	76
	Hardness, noncarbonate (mg/L)	18	27	7	48	14
(October 1968-September 1973)	Alkalinity as $CaCO_3$ (mg/L)	18	180	57	290	69
	Calcium, dissolved (mg/L)	13	55	21	91	24
	Magnesium, dissolved (mg/L)	13	7.6	3.0	12	2.7
	Sodium, dissolved (mg/L)	14	12	4.9	19	4.9
	Potassium, dissolved (mg/L)	6	4	3	5	1
	Sulfate, dissolved (mg/L)	24	37	14	63	15
	Chloride, dissolved (mg/L)	24	12	4.5	27	5.5
	Fluoride, dissolved (mg/L)	13	0.4	0.1	1.3	.3
	Solids, dissolved (mg/L)	24	264	118	413	78
	Iron, dissolved (μg/L)	--	--	--	--	--
	Manganese, dissolved (μg/L)	8	100	10	530	180
Little Osage River at Fulton	Streamflow (ft^3/s)	38	300	0.22	3,680	775
	Specific conductance (micromhos)	38	451	202	640	106
	pH (standard units)	38	7.9	7.2	8.3	0.2
	Hardness as $CaCO_3$ (mg/L)	38	220	93	330	60
(October 1968 - September 1975)	Hardness, noncarbonate (mg/L)	38	23	<1	52	13
	Alkalinity as $CaCO_3$ (mg/L)	38	200	79	290	51
	Calcium, dissolved (mg/L)	38	79	32	120	22
	Magnesium, dissolved (mg/L)	38	6.1	2.9	8.4	1.8
	Sodium, dissolved (mg/L)	38	8.0	4.0	12	1.9
	Potassium, dissolved (mg/L)	38	2	1	5	1
	Sulfate, dissolved (mg/L)	38	34	11	54	12
	Chloride, dissolved (mg/L)	38	8.0	3.1	18	5.6
	Fluoride, dissolved (mg/L)	38	0.2	.0	0.4	.1
	Solids, dissolved (mg/L)	38	274	132	380	64
	Iron, dissolved (μg/L)	33	40	<10	170	40
	Manganese, dissolved (μg/L)	34	64	<1	300	75

The waters are calcium bicarbonate type at all stages of streamflow and range from moderately hard to very hard. The pH values range from neutral to slightly basic. Concentrations of dissolved solids are less than 500 mg/L (milligrams per liter). Concentrations of dissolved sulfate, a principal indicator of stream contamination by drainage from coal-mined areas (Bevans, 1980), do not exceed 65 milligrams per liter. These low concentrations of dissolved sulfate indicate that the quality of water in the Marias des Cygnes and Little Osage Rivers has not been impaired by coal-mine drainage. The waters are generally acceptable for use as municipal, industrial, and agricultural supplies.

Water Use

Surface waters within the study area provide water supplies for domestic, agricultural, industrial, and recreational uses. Impoundments, such as reservoirs, channel dams, diked depressions, and farm ponds, are the chief sources of surface water. However, impoundments have historically been inadequate during periods of prolonged drought due to inadequate storage capacity, insufficient streamflows, and the increased demand for water (U.S. Department of Agriculture and Kansas Water Resources Board, 1980). Major streams also have failed as reliable water sources during droughts, and many of the smaller streams cease flowing entirely.

Insufficient streamflows in the study area could result in critical water shortages. Four municipalities and three rural water districts are supplied by water from streams and impoundments. Information on domestic surface-water supplies, including sources, populations served, and present and projected future usage for towns and rural water districts in the study area is presented in table 4. The Marais des Cygnes River, which provides the greatest volume of water used for domestic supplies in the study area, is also used upstream at Osawatomie and Ottawa, Kans. The Little Osage River is not used for domestic water supplies either within the project area or at upstream locations.

Another important function of streams within the study area is for disposal of sewage effluent from four municipalities. Sewage lagoons at LaCygne, Pleasanton, and Mound City discharge into the Marais des Cygnes River, Muddy Creek, and Little Sugar Creek, respectively. The Little Osage River receives sewage effluents indirectly from the secondary waste-treatment plant at Prescott, which discharges into East Fork Laberdie Creek, and from small municipalities located near upstream tributaries of the river. The town of Fulton presently (1982) disposes of sewage through septic tanks but has plans for a sewer system.

Table 4--Domestic surface-water supply sources and usage
[Information from U.S. Department of Agriculture and Kansas Water Resources Board, 1980, appendix c]

Water-supply source	Drainage area (square miles)	City or rural water district (RWD) served	Population served	Water use (millions of gallons per year) 1976-77	Water use (millions of gallons per year) Projected (2000)
Marais des Cygnes River at LaCygne	2,731	LaCygne	1,070	31.02	38.66
		RWD 1	527	10.88	13.53
		RWD 3	525	20.08	25.01
Little Sugar Creek (overflow dam)	57	Mound City	859	23.72	29.55
Pleasanton Lake (Muddy Creek reservoir)	1.1	Pleasanton	1,360	47.45	59.11
		RWD 2	380	14.60	18.20
Prescott City Lake (Indian Creek tributary reservoir)	0.25	Prescott	229	9.12	11.35
Total			4,950	156.87	195.41

Most industries within the study area use municipal water supplies. However, cooling water for the LaCygne Power Plant, which is the largest industrial user of water, is obtained from the Marais des Cygnes River and from LaCygne Lake. The power plant has rights to divert an amount of water not to exceed 35,000 acre-feet per year from the Marais des Cygnes River at the SW 1/4 NW 1/4 sec. 10, T. 20 S., R. 24 E. This water is piped into LaCygne Lake, where it supplements the natural streamflow from North Sugar Creek. A maximum amount of 40,000 acre-feet may be stored in LaCygne Lake. Water is recycled into the lake after being used for cooling. None is released to the lower reaches of North Sugar Creek until the lake level exceeds an elevation of 840 ft above sea level.

Water-related recreational activities are a major use of surface-water supplies in the study area. Maintenance of marshy areas, located on the Marais des Cygnes River floodplain, for fishing and hunting activities requires sufficient streamflow in this stream as well as water pumped from tributaries such as Big Sugar, Middle, and North Sugar Creeks. Other recreational activities share the same surface-water supplies used for municipal, agricultural, and industrial purposes. LaCygne Lake, for example, is available for fishing, sailing, and canoeing through an agreement between the power companies, Linn County, and the Kansas Fish and Game Commission. However, sports such as water skiing and swimming are prohibited. Similar restrictions apply to the Marais des Cygnes Wildlife Area. City lakes, farm ponds, and intermittent streams also may have recreational value.

The social and economic future of this eastern Kansas area is heavily dependent on the available supplies of surface water for domestic, industrial, and recreational purposes. Alternative plans for developing small- to intermediate-sized watershed reservoirs to meet present and future needs are discussed by the U.S. Department of Agriculture and the Kansas Water Resources Board (1980).

Ground Water

Sources

Ground-water aquifers yielding large quantities of usable water are generally lacking in the study area. Records compiled by the Kansas Geological Survey show that about 170 wells have been dug, augered, or drilled within the study area. Detailed descriptions and logs of wells in the study area have been published (Seevers, 1969).

The greatest number of wells draw from aquifers of Pennsylvanian age. The thick limestone members of the Kansas City Group are the most productive, followed by the sandstone, shale, and siltstone units in the Pleasanton and Marmaton Groups. Yields obtained from wells in Pennsylvanian formations are generally small and undependable. Dug wells normally yield less than 10 gal/min and often go dry during droughts.

The greatest yields are obtained from wells constructed in the unconsolidated terrace deposits of Illinoisan and Wisconsinan age, and in recent alluvial deposits of Quaternary age. Wells penetrating sand and gravel of these terrace and alluvial deposits often yield up to 100 gal/min.

Recharge

Ground-water recharge to water-bearing formations in the study area varies with the climate, topography, and rock and soil textures. Recharge is greatest during the spring months when rainfall is highest and evapotranspiration losses are low. Very little recharge occurs on steep, well-drained slopes or where the land surface is underlain by impermeable shales or well-developed claypans. Gentle slopes of the thicker limestone units collect moderate amounts of water. Recharge is greatest on the alluvium developed on valley fill and terrace surfaces where the soil zone is most permeable. Overland runoff and discharge from the valley sides recharge the alluvial aquifers. Floodwater from streams also provides an occasional source of recharge. However, only limited amounts of water are stored by the relatively thin alluvial aquifers.

Movement

Ground-water movement is in the direction of the hydraulic gradient, at a rate that is proportional to this gradient and to the permeability of the aquifer. Direction of movement in alluvial sands and gravels is both downstream and towards streams, while the hydraulic gradient in upland areas follows the northwest regional dip. Small areas of anomalous structure exist where the gradient is not in this direction. Estimates of the rate of ground-water movement range from 0.34 foot per day in the unconsolidated valley-fill deposits of the Marais des Cygnes River and its tributaries, to 0.03 foot per day in the upland bedrock aquifers (Seevers, 1969, p. 23-25).

Water Quality

The chemical types and concentrations of dissolved constituents in ground waters are dependent primarily on the mineralogical compositions of the soils and rocks and the length of time the ground water has been in contact with them. The results of chemical analyses for ground water from wells in and adjacent to the study area are presented in table 5. The locations of these wells are shown in figure 13. Examination of water-quality data in table 5 indicates that the ground waters sampled are moderately to very hard and exhibit a wide range of chemical characteristics.

Alluvial and terrace deposits of Quaternary age normally produce calcium bicarbonate type waters, reflecting the predominantly limestone terrain. Alluvial well 2 produces water with high concentrations of sodium and chloride ions. If the concentrations of sodium and chloride ions were due to the dissolution of sodium chloride salt, the theoretical ratio of the concentrations of sodium to chloride would be 0.65 (Hem,

Table 5--Results of chemical analyses of ground water from selected wells

[Specific conductance in micromhos per centimeter at 25°C (micromhos) and chemical constituents in milligrams per liter (mg/L)]

Map index number	Location (township-range-section)	Geologic source (System)	Formation	Well depth (feet)	Specific conductance (micromhos)	Hardness as $CaCO_3$ (mg/L)		Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, as $CaCO_3$ (mg/L)	Sulfate, dissolved as SO_4	Chloride, dissolved (mg/L)	Solids, dissolved, residue at 180°C (mg/L)	Nitrate, dissolved as NO_3	Iron, total (mg/L)	Manganese, dissolved (mg/L)
						Carbonate	Noncarbonate										
1	20S-23E-36	Quaternary	Alluvium	18	580	270	60	99	5.1	9.7	210	52	14	331	8.9	0.05	<0.005
2	20S-24E- 3		Alluvium	21	4,050	1,100	740	320	69	330	330	4.1	1,030	1,970	8.0	.04	< .005
3	21S-23E- 6		Alluvium	24	900	450	82	160	13	12	370	70	16	522	17	.01	< .005
4	21S-24E-29		Alluvium	25	480	220	28	65	15	9.4	200	30	8.0	264	6.2	.15	< .005
5	18S-23E-36		Terrace deposit[1]	50	660	330	9	110	11	20	320	24	12	396	1.4	4.1	.400
6	22S-23E-12		Terrace deposit	43	1,350	500	86	140	37	88	410	44	160	728	0.4	1.1	< .005
7	19S-23E-30	Pennsylvanian	Cherryvale Shale	18	2,070	970	610	290	63	85	360	610	110	1,400	15	.25	.380
8	21S-23E-31		Dennis Limestone	30	630	280	19	88	14	22	250	51	13	351	6.2	.37	< .005
9	21S-24E- 8		Dennis Limestone	125	640	300	60	110	7.4	16	240	81	7.0	374	.4	2.9	< .005
10	22S-23E-27		Dennis Limestone	48	1,830	600	28	140	58	160	570	74	170	1,030	66	1.6	.470
11	18S-25E-33		Dennis Limestone	18	1,860	890	640	290	42	33	250	320	130	1,230	240	1.4	.360
12	19S-24E- 4		Dennis Limestone	27	1,020	500	240	120	46	30	260	240	39	664	4.2	3.1	.040
13	19S-25E- 7		Dennis Limestone	26	820	410	87	140	12	5.5	320	37	12	464	49	.22	.020
14	20S-24E-19		Dennis and Swope Limestones	20	650	310	54	110	5.7	9.9	250	30	6.0	370	44	.24	< .005
15	21S-23E-26		Dennis and Swope Limestones	100	530	90	8	48	17	35	180	62	12	296	2.2	.30	< .005
16	19S-23E-15		Swope Limestone	52	690	370	68	130	12	6.4	300	44	10	431	27	.13	< .005
17	22S-25E-16		Seminole Formation	55	780	270	30	62	29	56	240	80	36	436	19	.07	< .005
18	19S-25E-31		Seminole Formation	31	380	160	57	43	13	12	100	62	5.0	222	12	.18	< .005
19	22S-24E-20		Holdenville Shale	87	2,030	140	0	38	10	390	490	52	300	1,100	6.2	.08	< .005
20	23S-24E- 8		Pawnee Limestone	53	2,150	950	740	320	39	46	220	320	150	1,380	360	3.6	< .005
21	23S-25E- 7		Pawnee Limestone	32	660	150	16	40	13	74	140	74	42	382	49	.12	< .005
22	22S-24E-14		Fort Scott Limestone	228	7,960	260	0	53	30	1,600	980	34	2,000	4,300	.4	.96	< .005
23	21S-23E- 6	Mississippian		705	25,300	850	490	190	89	5,200	360	8.6	8,300	14,000	3.5	3.1	.18

1 Average of seven analyses.

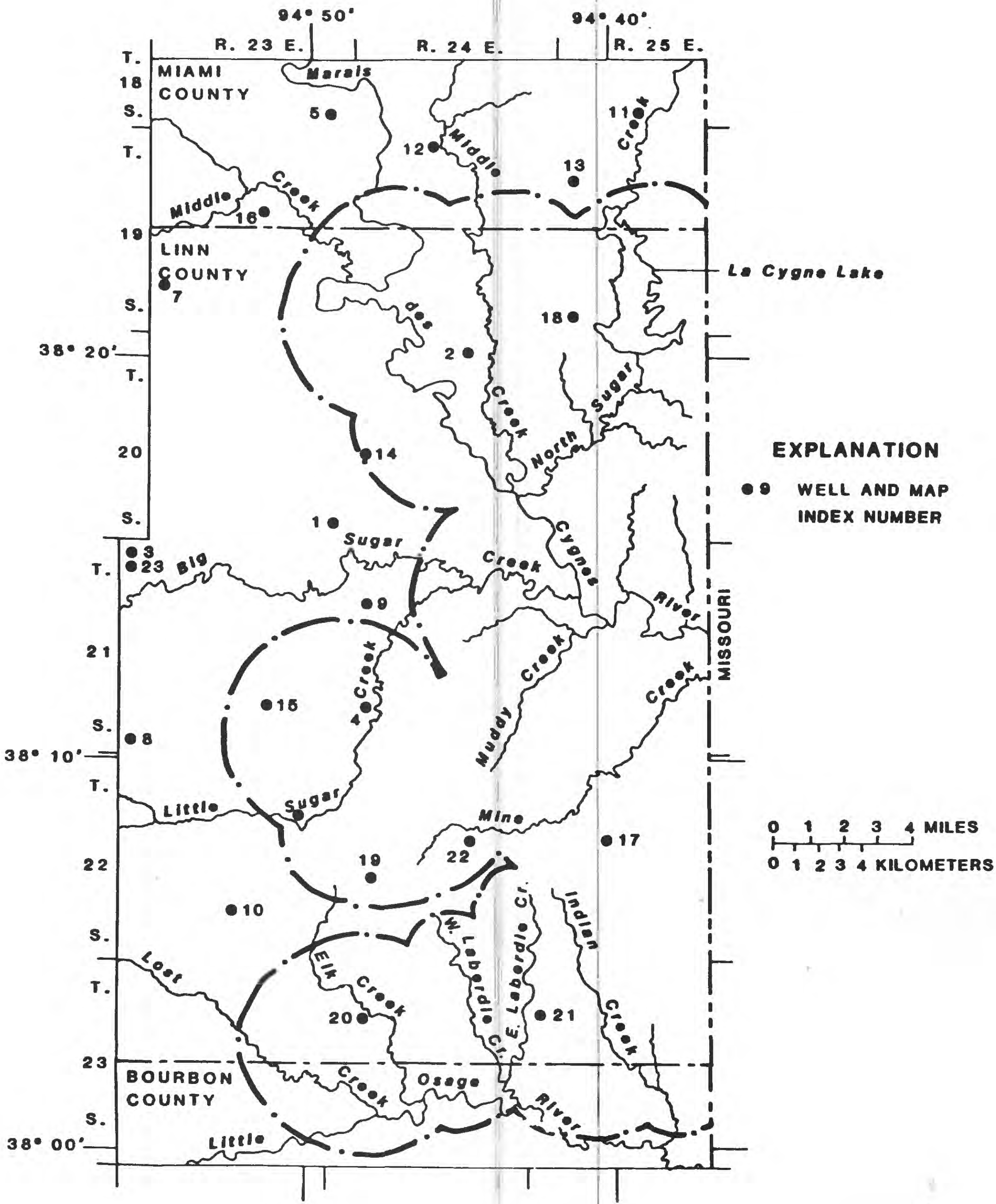


Figure 13.--Locations of wells for which results of chemical analyses are presented in table 5.

1970). The ratio of the concentration of sodium to chloride in water from well 2 is 0.32 which, combined with the fact that the well is located in an oil and gas field, may indicate contamination from oilfield activities. Terrace-deposit well 6 produces water with relatively high concentrations of sodium and chloride ions. Water from well 6 has a ratio of the concentration of sodium to chloride of 0.54. Since this ratio is close to the theoretical ratio and the well is located in a predominantly shale terrain, it is likely that the sodium and chloride ions are derived from residual salt held in the adjacent fine-grained marine shales.

The chemical characteristics of waters produced from wells completed in rocks of the Pennsylvanian System reflect the chemical characteristics of the rock units that function as aquifers. Wells completed in limestone units typically produce calcium bicarbonate type waters. Wells 8, 9, 13, 14, and 16 are examples of wells tapping limestone units. Wells completed in shale units often produce waters with relatively high concentrations of sulfate, sodium, and chloride ions. Wells 7 and 19 are examples of wells producing water from shale units. Water from wells drawing from both shale and limestone units is a mixed-ion type; wells 12 and 15 are examples. Wells 17 and 18 produce water from a predominantly sandstone unit. Water from these wells is relatively low in dissolved solids. Some of the wells completed in rocks of the Pennsylvanian System produce water with concentrations of constituents that indicate contamination: wells 10, 11, 20, and 21 contain high concentrations of chloride and nitrate ions.

Deep wells completed near the bottom of the Pennsylvanian System and in the Mississippian System produce sodium chloride type water that is essentially connate brine. Wells 22 and 23 are examples of deep wells producing sodium chloride brines.

In general, wells in shallow alluvium, terrace deposits, and Pennsylvanian rocks produce water with the best quality in the study area. However, these shallow wells are very susceptible to contamination.

Water Use

Wells completed in terrace and alluvial deposits of Quaternary age yield quantities of water suitable for municipal supplies at LaCygne and Fulton; elsewhere they serve domestic and stock-watering purposes.

Wells completed in Pennsylvanian formations yield only small quantities of water and normally go dry during drought conditions. The primary use of water from wells in these formations is for stock watering. Some of these wells are used for domestic purposes, but most of them are too unreliable.

Wells in the Mississippian and deeper formations produce sodium chloride type water that is too highly mineralized for domestic, municipal, or industrial purposes.

HYDROLOGIC IMPACTS OF STRIP MINING

Surface Water

Strip-mining activities in the study area may affect streamflow quantities both in the short and long term. Clearing of land for strip mining and compaction of soil layers by heavy equipment may increase runoff volumes, resulting in increased flood volumes and frequencies. Recently reclaimed land will experience similar conditions at least until vegetation is well established. In the long term, base flows in streams draining reclaimed areas may increase because of increased porosities and transmissivities of disturbed subsurface strata.

Erosion of cleared, actively mined, and recently reclaimed land may increase sediment yields to streams, causing increased instream concentrations and loads of suspended sediment. Concentrations of suspended trace metals (such as iron, manganese, lead, and zinc) that are adsorbed to suspended sediment may increase during runoff events. Base flow from reclaimed areas usually contains high concentrations of dissolved solids, principally sulfate (Bevans, 1980).

Ground Water

Disturbance of bedrock aquifers during strip-mining operations initially disrupts their continuity and may dewater them locally. Recharge capabilities are impaired due to compaction of soil layers by heavy equipment. However, in the long term, the fractured and heterogeneous reclaimed overburden probably will have greater porosities and transmissivities than adjacent bedrock aquifers.

Rock units in the study area include many shales that contain sulfide minerals (pyrite, marcasite, sphalerite, and galena) and large quantities of limestone that are sources of calcium, magnesium, and bicarbonate. When ground water contacts rock units disturbed by strip mining, it dissolves the sulfide minerals, releasing trace metals (iron, zinc, and lead), sulfate ions, and hydrogen ions. The hydrogen ions increase the acidity of the ground water and react with the limestone to release calcium, magnesium, and bicarbonate ions into solution. The bicarbonate ions buffer the remaining acidity, which causes most of the trace metals to precipitate. The net result is that ground waters in strip-mined areas tend to have near-neutral pH and contain high concentrations of calcium, magnesium, bicarbonate, and sulfate ions.

HYDROLOGIC DATA

Evaluation of Existing Hydrologic Data Base

Adequate hydrologic data currently exist to describe the streamflow and water-quality characteristics of the major streams draining the study area. However, major streams usually are not affected by strip-mining activities until significant percentages of their drainage areas have been mined. The smaller tributary streams are first to show alterations in streamflow and water quality because a single mine-permit area can be a significant percentage of their drainage areas. There are no hydrologic data available to describe streamflow and water-quality characteristics of small tributary streams in the study area. There is a need for hydrologic data collected from small streams draining mine-permit areas prior to, during, and after strip mining to quantify changes in streamflow and water-quality characteristics.

Adequate hydrologic data currently exist to describe aquifer and water-quality characteristics of ground-water sources in the study area. The lack of hydrologic data concerning aquifer and water-quality characteristics of reclaimed strip mines constitutes a major inadequacy in the data base. However, unless additional drilling occurs, the number of wells that can be used for aquifer tests, water-level measurements, and water-quality sampling is insufficient for such determinations.

Collection of Additional Hydrologic Data

In order to assess the hydrologic impacts of strip mining the Mulberry coal, adequate data to describe both background and changing conditions are needed. A project stream-sampling network to acquire data on streamflow and water quality has been established to supplement the existing data base outlined in this report. Locations of the 24 stations in this network are shown in figure 14. Station descriptions are presented in table 6. Reference stations are located upstream of stream reaches likely to be affected by mining activities in order to define background conditions in those streams. Trend stations are situated downstream of reference stations and mining operations in order to monitor changes resulting from those activities. Synoptic stations are established throughout the study area to provide data on background conditions and to identify specific problem areas.

Hydrologic instrumentation in the network is confined to the 10 reference and trend stations. Wire-weight gages attached to bridge guardrails are used to measure stream stage when samples are collected. Continuously recording streamflow gages are located at previously established sites on the Marais des Cygnes River near the Kansas-Missouri State line (station 16) and the Little Osage River at Fulton (station 23). Continuously recording streamflow gages also are located on North Sugar Creek just downstream from LaCygne Lake (station 4) and near Trading Post (station 9). High-streamflow recorders are located on three tributaries

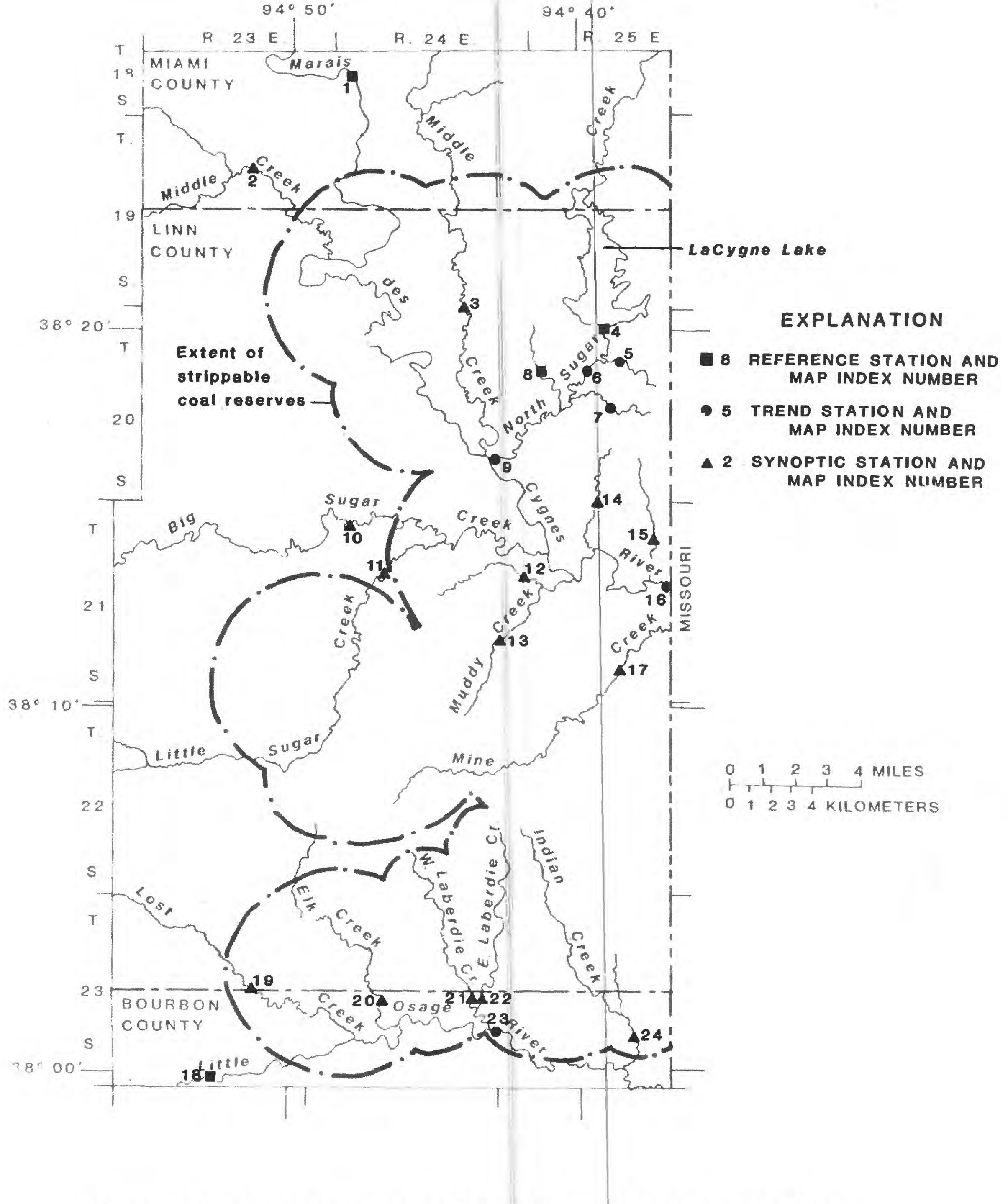


Figure 14.--Locations of project data-collection stations.

Table 6.--Descriptions of project data-collection stations

Map index number	Station name	Station number	Land-line location (township-range-section)	Drainage area (square miles)	Station type
1	Marais des Cygnes River near Fontana	382651094474500	18S-24E-30	2,600	Reference
2	Middle Creek near Fontana	382423094512100	19S-23E-10	63.3	Synoptic
3	Middle Creek 4 miles west of LaCygne Lake	382046094430800	19S-24E-35	58.5	Synoptic
4	North Sugar Creek below LaCygne Lake	06915977	20S-25E-4	57.6	Reference
5	North Sugar Creek tributary 1 below LaCygne Lake	381919094380900	20S-25E-9	2.06	Trend
6	North Sugar Creek 2 miles below LaCygne Lake	381916904391200	20S-25E-9	59.3	Trend
7	North Sugar Creek tributary 2 below LaCygne Lake	381807094382400	20S-25E-16	1.91	Trend
8	North Sugar Creek tributary 3 below LaCygne Lake	381856094403800	20S-25E-18	1.96	Reference
9	North Sugar Creek near Trading Post	06195988	20S-25E-25	73.0	Trend
10	Big Sugar Creek 4 miles east of Farlinville	381459094475900	21S-24E-5	306	Synoptic
11	Little Sugar Creek 5 miles east of Farlinville	381354094463700	21S-24E-9	73.6	Synoptic
12	Muddy Creek tributary 2 miles southwest of Trading Post	381334094415600	21S-25E-18	4.72	Synoptic
13	Muddy Creek near Pleasanton	381155094424500	21S-25E-30	6.49	Synoptic
14	Marais des Cygnes River tributary 2 miles northeast of Trading Post	381525094392100	21S-25E-3	2.11	Synoptic
15	Marais des Cygnes River tributary 4 miles east of Trading Post	381432094372600	21S-25E-11	6.04	Synoptic
16	Marais des Cygnes River near Kansas-Missouri State line	06916600	21S-25E-16	3,250	Trend
17	Mine Creek near Pleasanton	381109094383900	21S-25E-27	28.7	Synoptic
18	Little Osage River near Mapleton	380006094524600	23S-23E-33	204	Reference
19	Lost Creek near Mapleton	380217094511500	23S-23E-23	14.3	Synoptic
20	Elk Creek near Fulton	380143094465200	23S-25E-21	20.3	Synoptic
21	West Laberdie Creek near Fulton	380150094435000	23S-24E-24	6.96	Synoptic
22	East Laberdie Creek near Fulton	380150094431700	23S-24E-24	10.1	Synoptic
23	Little Osage River at Fulton	06917000	23S-24E-25	295	Trend
24	Indian Creek near Fulton	380057094381400	23S-25E-26	21.9	Synoptic

of North Sugar Creek. Two of these tributaries drain land that is currently being strip mined (stations 5 and 7); the other, which functions as a control site, drains land that will not be mined (station 8). All three tributary stations are equipped with monitors which periodically record the temperature and specific conductance in those streams. A rain gage has been installed at station 5 to record local amounts of precipitation.

Reference and trend sites are visited monthly to measure streamflow and physical characterstics and to collect water samples for chemical analysis. Physical characteristics include pH, specific conductance, temperature, and observations noted at the time of sampling. Additional water samples are obtained at these stations during runoff events for determination of physical, chemical, and suspended-sediment characteristics. The greatest data-collection emphasis is on those stations in the drainage basin of North Sugar Creek, as this stream currently is being affected by strip-mining activities.

The 14 synoptic sites are visited quarterly to measure streamflow and physical characteristics and to collect water samples for chemical analysis. During high flows, samples for suspended-sediment determinations are collected.

Data collected for this network are stored in computer files that can be accessed through WATSTORE (the National Water Data Storage and Retrieval System), the central repository of U.S. Geological Survey water data.

Well sites for the collection of additional ground-water data concerning aquifer characteristics in strip-mined areas have not been established. Such a network is beyond the scope of this project.

SUMMARY

An area of approximately 300 mi^2 in eastern Kansas is underlain by strippable reserves of Mulberry coal. This coal ranges from 1 to 4 ft in thickness and occurs beneath limestone and shale layers ranging from 15 to 100 ft in thickness, making the ratio of overburden to coal thickness one of the highest in the country. In addition to mineral resources of coal, oil, and gas, the study area contains much prime farmland, pastureland, extensive wildlife habitat, and many recreational opportunities.

Because ground-water supplies are generally unreliable in quantity and quality, most water requirements in the study area are met by surface-water sources. Streamflows are extremely variable due to erratic precipitation, reservoir releases, and water-use patterns. Streamflow in the Marais des Cygnes River is supplemented by releases from two reservoirs upstream in Osage County but is heavily used for domestic supplies and power-plant cooling in the study area. Flow in North Sugar Creek is regulated by release of water from LaCygne Lake, which is used for cooling at the coal-fired LaCygne Power Plant.

Available data concerning the quantity and quality of surface and ground water in the study area are limited. A major inadequacy in the existing data base is the lack of information concerning pre-mining streamflow and water-quality characteristics and the effects of strip mining on small streams in the study area. Because these data are essential to an interpretive assessment of the impact of strip mining on the hydrologic environment, a network of 24 stream data-collection stations has been established. Streamflow measurements and water-quality samples are obtained in order to define existing hydrologic conditions and detect changes resulting from strip mining the Mulberry coal. Another major inadequacy is the lack of information concerning aquifer and water-quality characteristics of reclaimed strip mines. However, drilling of test wells to determine these characteristics is beyond the scope of this project.

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