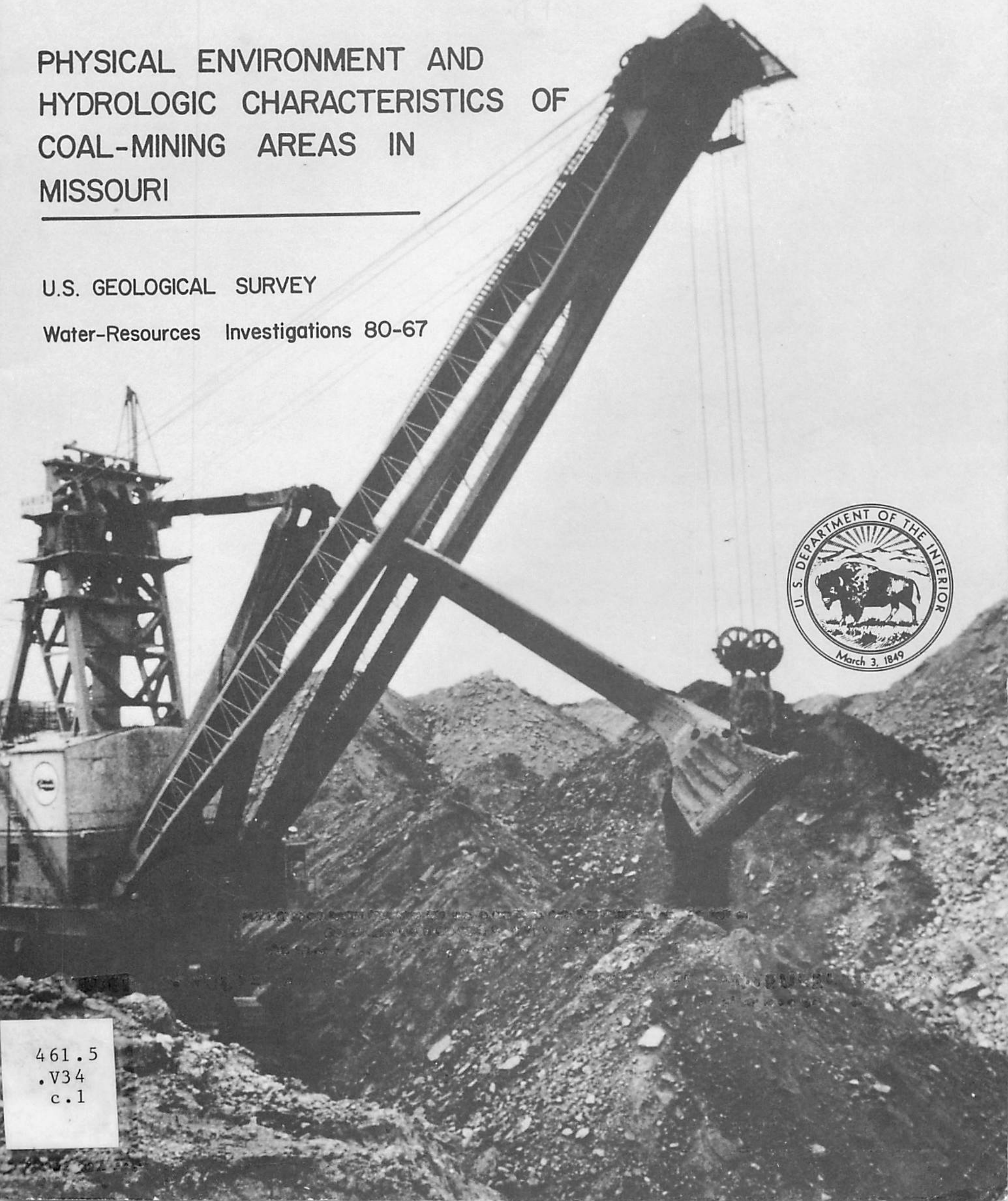
PHYSICAL ENVIRONMENT AND HYDROLOGIC CHARACTERISTICS OF COAL-MINING AREAS IN MISSOURI

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 80-67



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Streamflow in both mining regions is poorly sustained. Stream water quality generally varies with location and the magnitude of coal-mining activity in a watershed. Streams in non coal-mining areas generally have dissolved-solids concentrations less than 400 milligrams per liter. Acid-mine drainage has seriously affected some streams by reducing the pH to less than 4.0 and increasing the dissolved-solids concentrations to greater than 1,000 milligrams per liter. This has resulted in fish kills in some instances.

Ground-water movement is impeded both laterally and vertically in both mining regions, especially in western Missouri, because of the low hydraulic conductivity of the rocks of Pennsylvanian age. The quality of ground water varies widely depending on location and depth. Ground water commonly contains high concentrations of iron and sulfate, and dissolved-solids concentrations generally are greater than 1,000 milligrams per liter.

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By Jerry E. Vaill and James H. Barks

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Water-Resources Investigations 80-67

Rolla, Missouri

1980

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

For those readers who may prefer to use the International System of Units (SI) rather than the inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply inch-pound unit	By	To obtain SI units
acre	0.4047	hectare (ha)
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	6.31×10^{-5}	cubic meter per second (m^3/s)
inch (in.)	25.40	millimeter (mm)
micromho (μmho)	1.000	microsiemens (μS)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
ton (short)	0.9072	metric ton (t)
acre-foot (acre-ft)	0.00123	cubic hectometer (hm^3)
million gallons per day (Mgal/d)	0.044	cubic meter per second (m^3/s)

To convert temperature in °C (Celsius) to °F (Fahrenheit), multiply by 1.8 and add 32.

Physical Environment and Hydrologic Characteristics of

Coal-Mining Areas in Missouri

By Jerry E. Vaill and James H. Barks

ABSTRACT

Hydrologic information for the north-central and western coal-mining regions of Missouri is needed to define the hydrologic system in these areas of major historic and planned coal development. This report describes the physical setting, climate, coal-mining practices, general hydrologic system, and the current (1980) hydrologic data base in these two coal-mining regions.

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INTRODUCTION

This report presents information compiled during the first phase of a project designed to provide general hydrologic information for coal provinces in Missouri. The report contains a discussion of the history of coal mining and coal-mining regulations in Missouri and a description of the physical setting, climate, coal-mining practices, hydrology, and the current (1980) hydrologic data base. The report provides background for the second phase of the study that will include collection of hydrologic data required to increase the data base, and provide the general hydrologic information needed for State and Federal regulatory authorities and mine-permit applicants.

The energy crisis of the 1970's is rapidly increasing the demand for the abundant coal resources of the United States, including those in Missouri. Most of the northwestern part of the State is in the Western Interior Coal Basin (fig. 1). Missouri ranks fifth among the states with coal resources (all coal beds 12 or more in. thick, which can be reasonably assumed to exist) and has an estimated 50 billion tons (Robertson, 1973). Of this, 32 billion tons have been located by mapping and drilling, and 12.3 billion tons are considered reserves (proven to exist and can be mined with existing technology and under existing economic conditions). Only about 350 million tons have been recovered since commercial coal mining began in Missouri in the 1840's (Wedge and others, 1976).

The major coal-mining regions of Missouri are in the western and north-central parts of the State (Missouri Land Reclamation Commission, 1979, written commun.), although mining has not been limited to these areas (fig. 2). The two regions selected for this study based on past, present (1980), and predicted future mining are outlined in figure 3. According to a report by the Missouri Department of Natural Resources (1978), a total of 76,158 acres have been disturbed by coal-mining activities in Missouri. Of this, 67,440 acres are abandoned (unreclaimed) and 8,718 acres are active (totally reclaimed, in some stage of reclamation, or being actively mined). Sixty-five percent of the abandoned land is in the western region and 27 percent is in the north-central region as outlined in figure 3. The remaining 8 percent is scattered in several other counties. Fifty-eight percent of the active land is in the western region and 42 percent is in the north-central region as outlined in figure 3. Nearly all of the disturbed land in the western region is in the Osage River basin and most of the disturbed land in the north-central region is in the Chariton River basin.

The history of coal mining in Missouri dates back to the early 1840's when coal mining began at several locations in the western part of the State. Most of the early mines were local-trade wagon mines that consisted of drifts that began at outcrops and proceeded into the coal seam a few hundred feet, or as far as natural ventilation permitted.

Coal production reached a peak in Missouri in 1917 when 6 million tons were mined. Production fluctuated between 3 and 6 million tons per year from 1917 until 1948 when a general decline began because of increasing dependence on less expensive, cleaner energy sources. Production declined steadily to a minimum of 2.5 million tons during 1958. By the mid-1960's, underground mining had all but ceased and strip mining became the accepted coal-mining method (Robertson, 1973). From 1967 to 1976, coal production in Missouri increased from 3.7 to 6.8 million tons per year. During the same 10-year period, the State's coal consumption increased from 9.5 to 23 million tons per year.

Coal in Missouri has a relatively high sulfur content. Robertson (1971) estimates that of the remaining coal reserves in the State, one-fourth contains 2 to 3 percent sulfur, one-half contains 4 to 5 percent sulfur, and most of the remaining one-fourth contains greater than 5 percent sulfur.

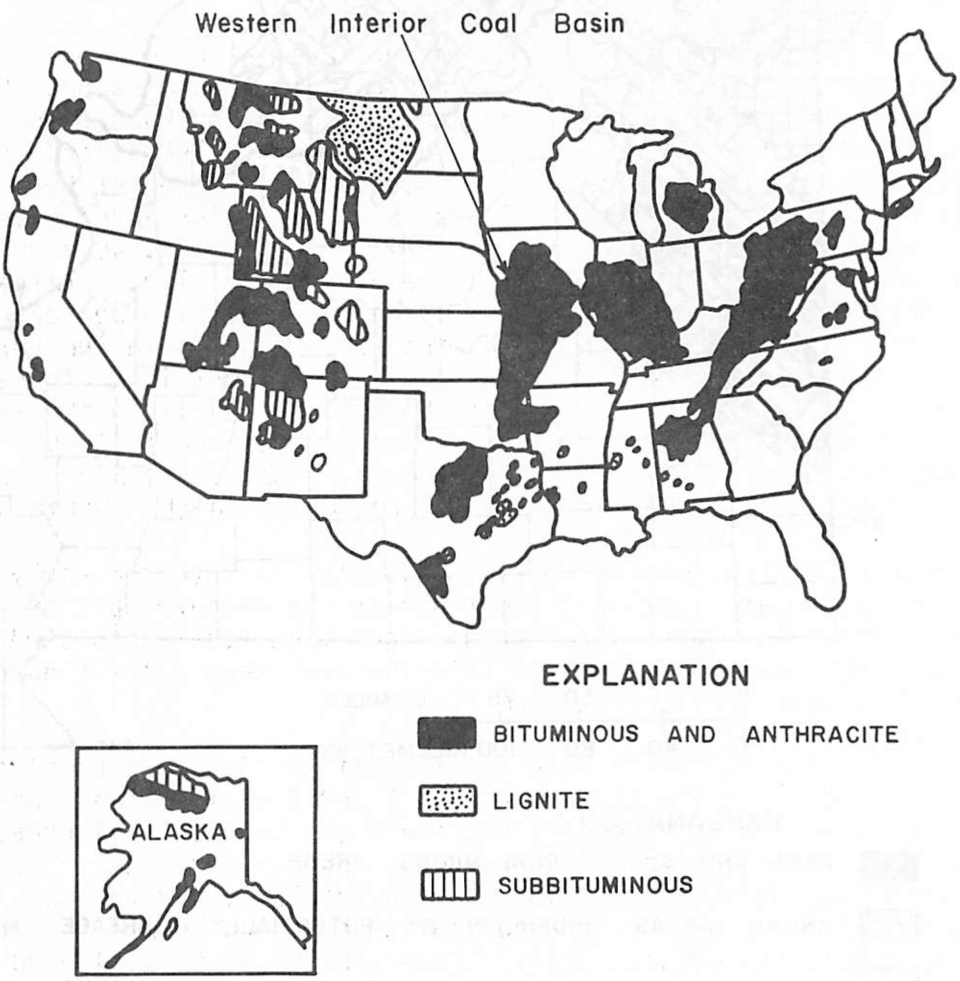


Figure I.-- Coal and lignite fields in the United States (modified from Robertson, 1973).

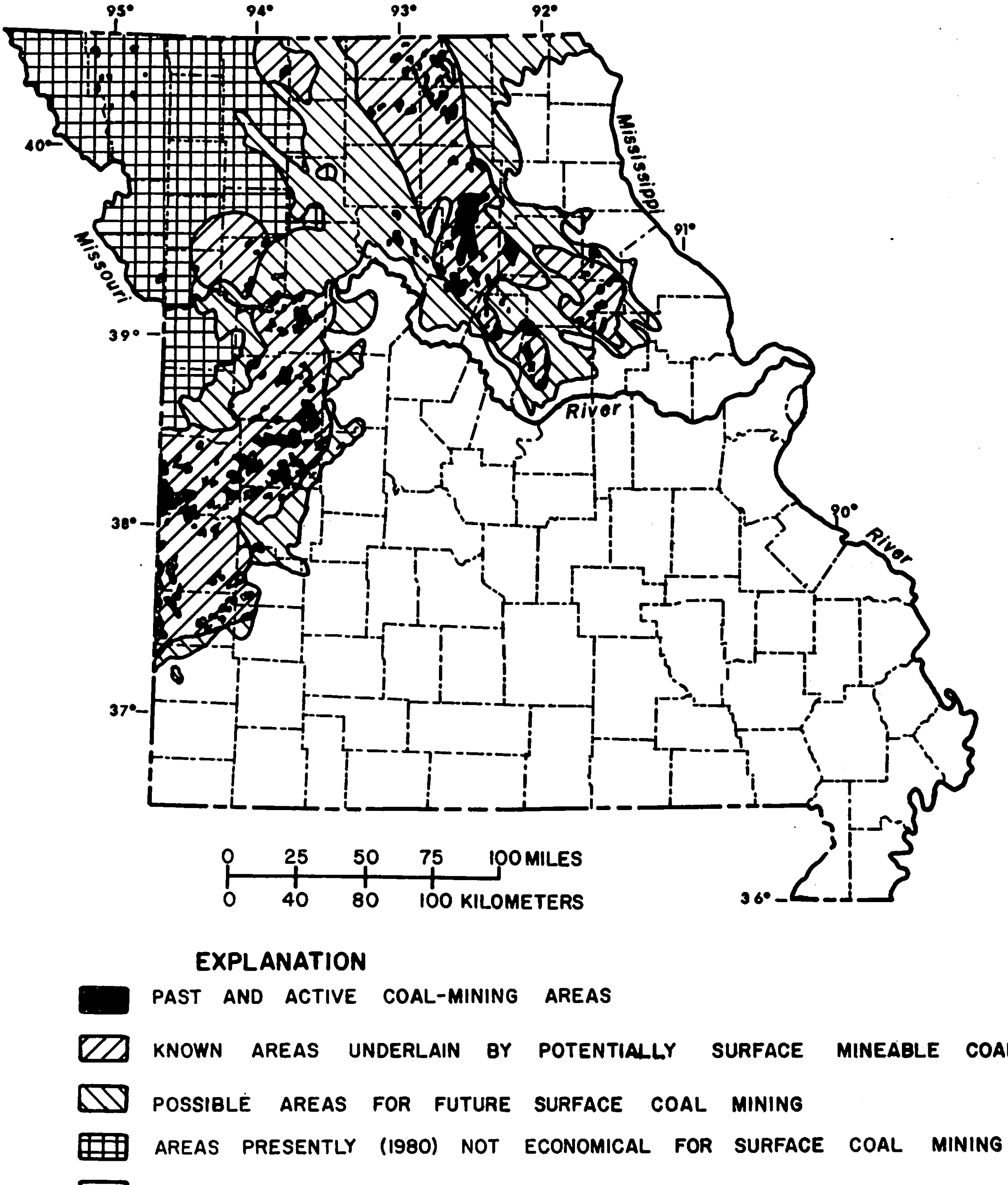


Figure 2.--Coal resources and coal-mining areas in Missouri (from Missouri Land Reclamation Commission, 1979, written commun.).

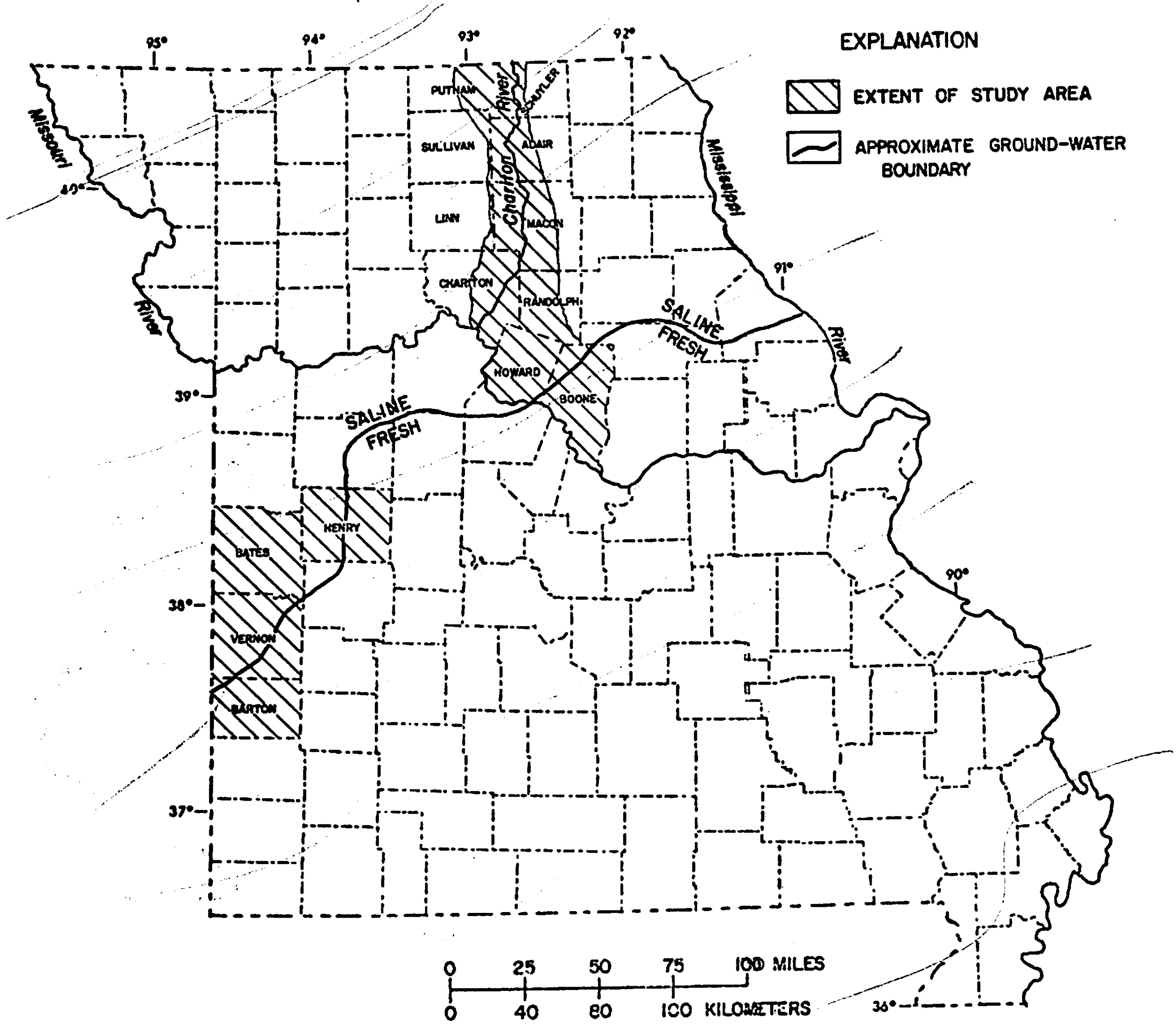


Figure 3.--Major coal-mining regions in Missouri.

Government standards controlling the emission of oxides of sulfur from the stacks of coal-burning facilities presently limits the use of coal containing more than about 3 to 4 percent sulfur. Development of methods to remove the sulfur before burning or from the stack gases could increase the demand for Missouri coal.

Other disadvantages resulting from the high sulfur content of Missouri coal are the solution of iron sulfide minerals, the production of sulfuric acid, and subsequent breakdown of clays and other minerals in earth materials disturbed by mining activities. These minerals are present in strip pits, spoil piles, and waste materials from coal washing (gob piles). Streams draining coal-mine areas commonly have concentrations of dissolved solids exceeding 1,000 mg/L (milligrams per liter). Numerous fish kills have been documented as a result of acid-mine drainage from strip mines in Missouri.

No legal requirements existed for reclamation of mined land in Missouri before March 28, 1972, the effective date of the Missouri Land Reclamation Law. Reclamation of mined lands prior to implementation of the Reclamation Law by the Missouri Land Reclamation Commission was very limited.

A 1977 federal law, the Surface Mining Control and Reclamation Act, Public Law 95-87, requires that the Secretary of the Interior publicly announce and promote permanent regulatory procedures for surface coal mining and reclamation operations. The Director, Office of Surface Mining Reclamation and Enforcement, implements the regulations. Public Law 95-87 provides for the states, if they choose, to prepare, maintain, and enforce the regulations under the individual state programs. Each state's program will become effective after review and approval by the Secretary of the Interior. The Office of Surface Mining Reclamation and Enforcement maintains a limited role in a state with an approved program. Missouri expects to receive regulatory primacy by late 1980 or early 1981.

According to the Office of Surface Mining Reclamation and Enforcement (1979), some of the stated purposes of Public Law 95-87 are:

1. To establish a national program to protect society and the environment from the adverse effects of coal mining.

2. To prohibit mining where reclamation, as required by the Law, is not feasible.

3. To assure that reclamation occurs as concurrently as possible with the mining.

4. To achieve a balance between protection of the environment and agricultural productivity and the assurance of adequate coal production.

5. To assist the states in developing, administering, and enforcing regulatory programs which achieve the purpose of the Law.

6. To achieve reclamation of areas previously mined.

7. To provide appropriate procedures for public participation in the development of regulations, standards, and programs under the Law.

Public Law 95-87 requires that proposed mining areas and adjacent areas must be reclaimable to pre-mine hydrologic conditions such as surface-flow regimes, ground-water movement and recharge, ground-water to surface-water relationships, and water quality. All applications for permits to mine must contain a description of the geology, hydrology, and water quality and quantity of all lands within the proposed mine plan area, the adjacent area, and the general area. This information will be provided by the regulatory authority to the extent that it is available from an appropriate federal or state agency. Otherwise, it must be provided by the applicant.

PHYSICAL SETTING

Geology and Physiography

Missouri, bounded on the east by the Mississippi River and bisected by the Missouri River, has a varied geologic and physiographic character (Fenneman, 1938). Missouri is of interest to structural geologists because it contains the Ozark Dome, the result of intermittent, long-continued mild uplift in the Ozark region. Exposed rocks range in age from Precambrian through Pennsylvanian. Igneous rocks of early to middle Precambrian are the oldest rocks in the State and are found mainly exposed in the St. Francois Mountains. Sediments were deposited in Missouri throughout much of the Paleozoic era, when relatively shallow seas repeatedly covered part and at times all of the State. Much of Missouri remained submerged under a shallow sea at the end of the Cambrian, and sedimentation continued with only minor interruption into Early Ordovician time. Silurian and Devonian rocks in the State are relatively thin, restricted in occurrence, and are separated above, below, and internally by unconformities. Widespread structural deformation at the end of Early Devonian time resulted in so much erosion and beveling of beds that the original extent of sedimentation cannot be determined. Remnants of sedimentary rocks in downdropped blocks on the Ozark uplands indicate that their extent was greater than that now preserved. At the close of Mississippian time, the Ozark region was uplifted again; the resultant widespread erosion stripped nearly all of the Mississippian rocks from the uplift and beveled them over much of the rest of the State. During Pennsylvanian time, deposition was renewed in shallow seas and contiguous swamps and deltas. About 2,000 ft of sand, silt, clay, and carbonates were deposited, and numerous coal seams formed from decaying forest growth. Post-Pennsylvanian uplift again raised Missouri above sea level. The exposure of these rocks has made strip mining of the coal possible.

During the Pleistocene, Nebraskan, and Kansan glaciations of northern Missouri, thick deposits of outwash (sand and gravel), till (clay and gravel), and loess (windblown silt) buried a surface of moderate relief severely restricting exposures of sedimentary rocks of Mississippian and Pennsylvanian age. Postglacial erosion of these deposits has carved new streams and formed the Dissected Till Plains now present in northern Missouri (fig. 4). Relief is greatest along the Mississippi and Missouri Rivers and where principal tributary streams have dissected the more abundant and easily eroded loess deposits. Most streams have eroded their channels through the loess and into the drift and some have eroded to bedrock.

Nearly all of the region north of the Missouri River is underlain by northwestward-dipping bedrock formations of Mississippian and Pennsylvanian age. The Pennsylvanian bedrock becomes progressively younger toward the northwest and is composed principally of shale, limestone, and sandstone. In the north-central coal region, Pennsylvanian rocks crop out in some areas, especially along streams, and are covered by as much as 300 ft of glacial till and 5 ft of loess in others. Coal in this region is confined to the rocks of the Pennsylvanian System with most of the economic deposits found in the Des Moinesian Series (see fig. 5).

The western coal region is situated on the Osage Plains (fig. 4). The Osage Plains are rolling plains with little relief that occur along the western border of the State, south of the glaciated area. They are underlain by Pennsylvanian sedimentary strata that dip gently westward. The relief is more subdued than that of the Dissected Till Plains of northern Missouri. Coal is confined to the Pennsylvanian System, Des Moinesian Series in this region as well.

Structural Geology

The coal-mining regions of Missouri contain only a few major structural features. These features are outlined on a map by McCracken (1971). Three features are found in the north-central mining region, the most important being the Kirksville-Mendota anticline. This fold is mapped as an anticlinal structure with 50 to 100 ft of closure. Coal from the Lexington bed is at the surface on the crest of the structure from which it has been strip mined extensively. The College Mound-Bucklin (Randolph-Macon Counties) and Brown's Station (Boone County) anticlines are the other major features found in the region. Both follow the general pattern of such flexures in northern Missouri. They are structures with a little topographic expression and a gentle northeast limb and a slightly steeper southwest limb. The strike is northwest with a gentle northwest plunge.

The western coal-mining region of Missouri is virtually a featureless rolling plain of few major geological structures. One major feature is the Chesapeake fault, which is best developed in eastern Lawrence County. By projecting the trend of the fault to the northwest it would extend into Barton and Vernon Counties. Evidence for the fault in Barton and Vernon Counties is meager, but is inferred in part through well logs, by abrupt changes in topography, and by residual cherts and soil patterns. Another major feature is the Schell City-Rich Hill (Vernon-Bates Counties) anticline. This is one of the larger anticlinal structures in Pennsylvanian rocks in western Missouri. It is asymmetrical with a steep southwest limb; closure is 150 ft. Gentile (1976) pointed out the probability that this anticline is a fault in the more brittle limestones and dolomite of the pre-Pennsylvanian Paleozic rocks and that the anticline may be an extension of the Eldorado Springs fault. If so, it would then be a part of one of the larger fault zones of the State.

Drainage Patterns

Streams in northern Missouri, including the Chariton River that drains most of the north-central mining region, flow in a southerly direction. The existence of these south-flowing streams is probably due to the initial slope of the drift surface, as most streams of northern Missouri appear to be postglacial (Fenneman, 1938). The flood plains are wide and the bluffs low where the streams are eroding through drift. Steep bluffs on the south and gentle slopes on the north are characteristic of stream valleys in this part of the State. This feature is attributed to the disintegration and loosening of material on the south-facing slopes by frequent alternations of freezing and thawing. Streams of this part of the State form a dendritic drainage pattern, which is typical in areas having homogeneous materials that are easily eroded.

In western Missouri, streams flow generally eastward and stream valleys are of two types that grade into each other. In the prairie country, the streams meander widely and tributaries form a dendritic pattern. The valleys are broad and shallow with low bluffs where the underlying shale has been eroded. Next to the Ozark region, these same valleys are deep and narrow and the meanders are incised into the limestone outcrops. Streambanks of smaller streams in western Missouri are high and steep and the channels are of even width for long reaches.

Soils

Glacial deposits are the parent soil-forming material in the north-central mining region. Some of the more fertile soils were developed from loess, a windblown silt that was deposited mainly during glacial times. Soils formed from glacial outwash (sand and gravel) and till (clay and gravel) are less fertile.

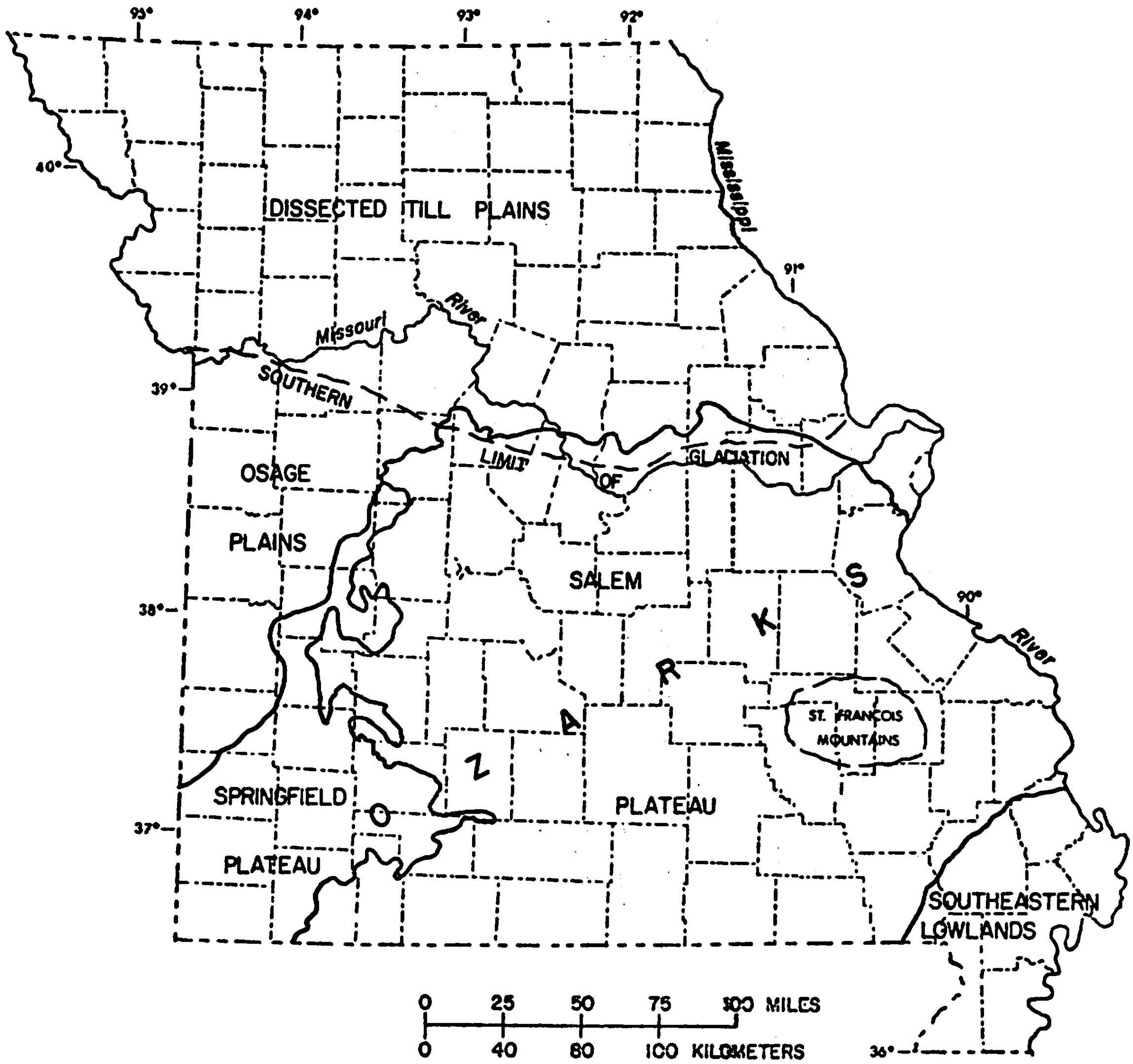


Figure 4.--Major physiographic divisions of Missouri (modified from Skelton, 1976).

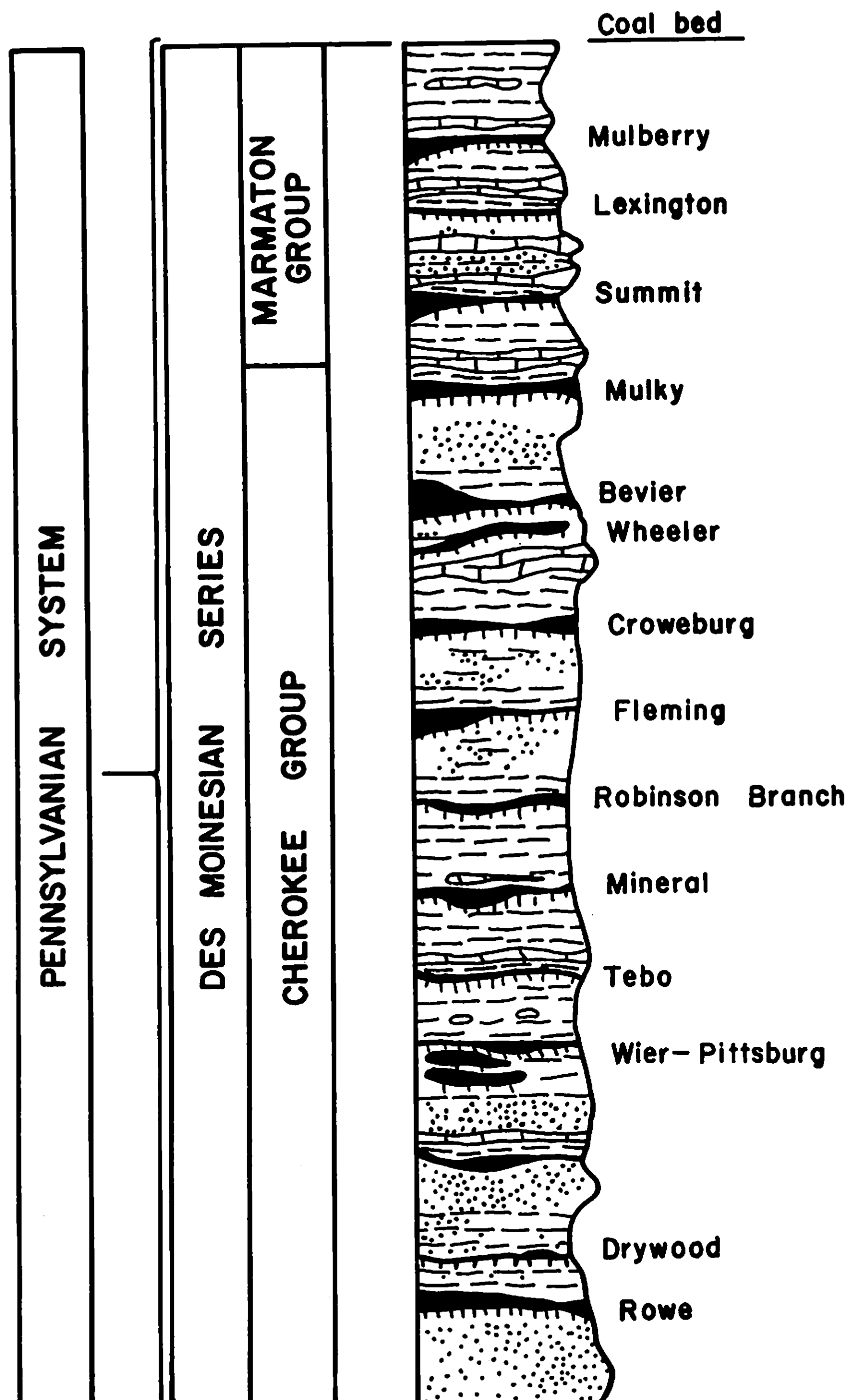


Figure 5.--Stratigraphy of the principal coal beds of Missouri (modified from Robertson, 1971).

There are five major soil associations in the north-central mining region (fig. 6). They include:

1. The Adair-Shelby-Seymour-Edina and Armstrong-Gara-Pershing Soil Associations (AS).

2. Lindley-Keswick-Hatton Soil Association (LK).

3. Putnam-Mexico-Gara Soil Association (PM).

4. Menfro-Winfield-Weldon Soil Association (MW).

5. Sarpy-Haynie-Onowa-Wabash Soil Association (S).

The Adair, Edina, Armstrong, Putman, and Mexico soils that occur in the upland plains are underlain by clayey subsoils and have only moderate to very low permeabilities. Low permeabilities combined with the level topography of much of the upland areas results in drainage problems during rainy seasons. The water-storage potential of these soils is only moderate and crop yields may be reduced during moderately dry seasons because of water shortages. The Lindley, Keswick, and Hatton soils generally occupy the steeply sloping areas between the upland plains and the river bluffs. These soils generally are less fertile and normally support either forest or pasture. The Menfro, Winfield, and Weldon soils occupy the bluff area along the Mississippi and Missouri Rivers and generally have high water-storage capacities. The fertility of these soils varies, but steep slopes with resulting erosion limit the agricultural use of the land. The Sarpy and associated soils are bottomland soils composed of either loamy sand, silt, or clay. The good to rapid permeability and fertility of these soils make the land valuable as cropland.

Topography of the north-central mining region varies from steep slopes and bluffs (9-14 percent slope) along the major streams to nearly level areas (2-5 percent slope) on broad ridgetops and wide valley plains.

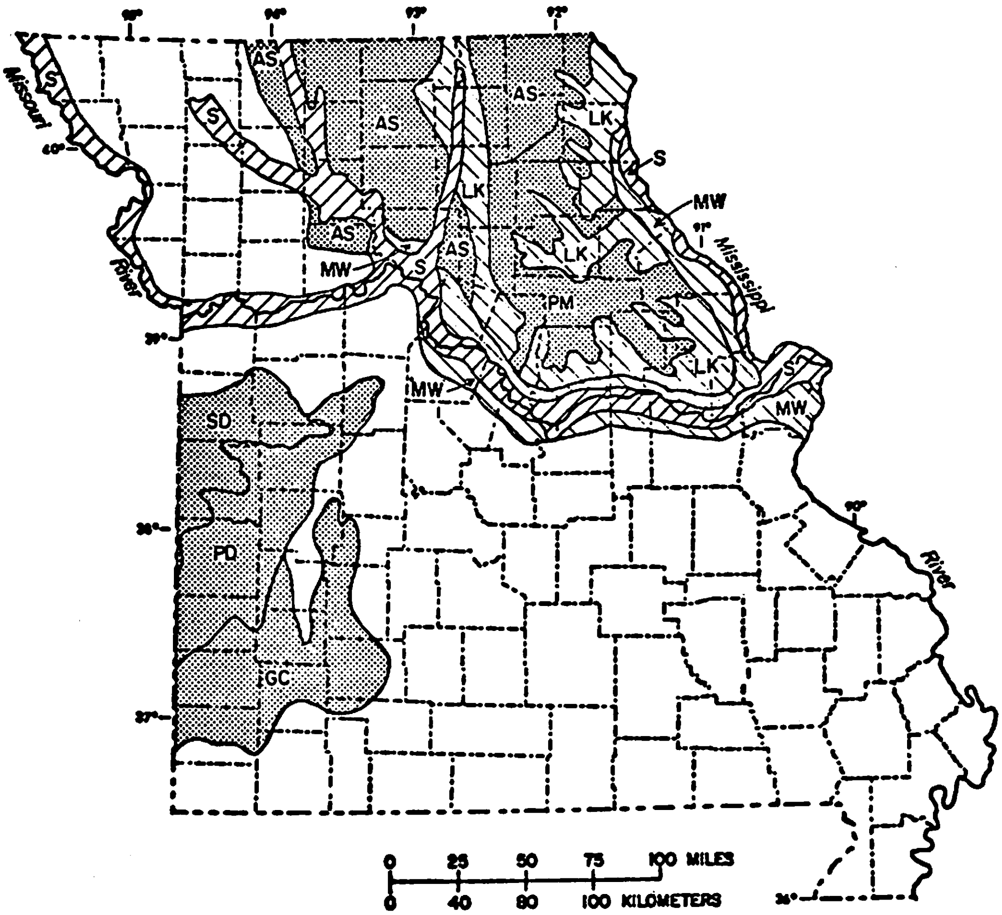
The southern limit of glaciation did not reach western Missouri. As a result, the soils of the western mining region were almost entirely formed from weathered Pennsylvanian rocks. There are a few scattered areas in the northern extremes of the western mining region in which thin (0-2 ft) layers of loess were deposited. However, the climatic conditions together with the thin nature of the deposits have resulted in highly weathered soils that are not suitable as croplands.

There are three major soil associations commonly found in the western mining region. These associations are:

1. Summit-Newtonia-Parsons-Dennis Soil Association (SD).

2. Parsons-Dennis-Bates Soil Association (PD).

3. The Gerald-Craig-Eldon and Newtonia-Baxter Soil Associations (GC).



EXPLANATION

PRAIRIE AND PRAIRIE-FOREST TRANSITION NATURAL VEGETATION

SD: SUMMIT-NEWTONIA-PARSON-DENNIS SOIL ASSOCIATION

PD: PARSONS-DENNIS-BATES SOIL ASSOCIATION

GC: GERALD-CRAIG-ELDON AND NEWTONIA-BAXTER SOIL ASSOCIATIONS

AS: ADAIR-SHELBY-SEYMOUR-EDINA AND ARMSTRONG-GARA-PERSHING SOIL ASSOCIATIONS

PM: PUTNAM-MEXICO-GARA SOIL ASSOCIATION

FOREST NATURAL VEGETATION

MW: MENFRO-WINFIELD-WELDON SOIL ASSOCIATION

LK: LINDLEY-KESWICK-HATTON SOIL ASSOCIATION

ALLUVIAL VALLEY SOILS

S: SARPY-HAYNIE-ONAWA-WABASH SOIL ASSOCIATION

Figure 6.--Major soil and vegetation types in coal-mining regions of Missouri (modified from Scrivner and others, 1966).

These associations were derived from loess, shale and sandstone, or cherty limestone and dolomite. Soils derived primarily from shale and sandstone in this region generally have low to moderate permeabilities. In locales where the soils were mainly derived from cherty dolomite and sandstone, the permeability varies from moderate to high depending on the extent of solution development.

Topography of the western mining region varies from nearly level (0-2 percent slope) to gently rolling (2-5 percent slope). There are a few areas of limited extent which have slopes as steep as 14 percent. The more level areas are used as crop and forage land while the steeper slopes are used for pasture.

Land Use

Land use changes have been occurring in Missouri with increasing rapidity in the past few years. Most of the changes are either directly or indirectly related to the world's food crisis. More and more land is being converted to cropland and pasture to provide a greater source of food.

Missouri ranks as one of the principal food-producing states in the Nation. In 1978 there were approximately 139,000 farms with a total area of about 29,935,000 acres. Crop production from these farms resulted in national rankings of third in soybean production, eighth in corn production, and tenth in feedgrain exports.

In the north-central mining region corn and soybeans are the major crops while wheat and sorghum are produced to a lesser degree. Production in the various counties within this mining region is fairly well distributed with no one county being the chief producer. All counties rank fairly high within the State in crops produced. Of the two mining regions, the north-central region produces a larger amount of food crops.

Within the State, the four counties of the western mining region are among the top 10 in wheat and sorghum production (table 1). A significant part of the State's corn and soybean crop is also grown in this region (Missouri Dept. of Agriculture, 1979).

Forest land in the mining regions constitutes a very small part of the total land area.

In the north-central mining region, about 19 percent (approximately 502,000 acres) of the total area is woodland. The larger percentages of woodlands in the north-central region may be attributed to the hilly terrain, which leaves less land suitable for farming. In the western mining region only about 15 percent (approximately 282,200 acres) of the total area is woodland. Most of this timber is found along fencerows, streambanks, and generally in places not suitable for farming or grazing.

Table 1.--Total acreages for major crops in 1978, by county, in thousands of acres[1]

[From U.S. Department of Agriculture, 1979]

County	Corn	Wheat	Soybeans	Sorghum
Western Mining Region				
Barton	7.8	32.6	102.0	26.6
Bates	30.6	25.3	63.4	47.2
Henry	19.7	8.4	43.1	26.0
Vernon	22.0	28.3	70.9	0.5
Percentage of State total	3.6	11.3	5.1	11.8
North-Central Mining Region				
Adair	264.0	1.1	53.4	1.4
Boone	8.7	8.5	51.7	5.6
Chariton	56.1	7.6	142.0	11.1
Howard	25.4	8.8	37.0	4.2
Linn	24.1	1.5	72.0	9.8
Macon	35.4	1.7	93.0	4.0
Putnam	17.0	0.2	19.4	1.1
Randolph	16.1	2.3	63.4	7.2
Schuyler	11.7	0.4	20.3	0.8
Sullivan	17.3	1.4	34.7	4.8
Percentage of State total	23.5	5.9	14.1	9.5

[1]Only values for those parts of the counties shown in the study area are included.

Considerable land area is incorporated in state and federal parks in the mining regions. The north-central region has approximately 25,000 acres in recreation parks and wildlife refuges, while the western region has approximately 10,000 acres devoted to wildlife and recreation.

CLIMATE

The climate in both coal-mining regions is temperate. Mean annual precipitation ranges from 38 in. in the north-central region to 41 in. in the western region. Mean July temperatures range from 24.6°C in the north-central region to 25.8°C in the western region. Mean January temperatures range from -2.9°C in the north-central region to -0.3°C in the western region. Average snowfall ranges from 30 in. in the north-central region to 14 in. in the western region (National Oceanic and Atmospheric Administration, 1978).

The National Oceanic and Atmospheric Administration issues two monthly publications "Climatological Data" and "Hourly Precipitation Data" that contain data for stations throughout Missouri. These data include hourly precipitation and temperatures, plus wind velocity and snowfall data for a limited number of stations.

COAL-MINING PRACTICES

Surface (strip) mining is the oldest recorded method of extracting coal and other minerals from the earth (Pfleider, 1968). This method of mining completely alters the topography of the earth's surface, leaving an area of more or less parallel ridges or peaked mounds. Surface mining destroys all original vegetation and provides materials for new type soils.

The geologic and surface conditions of the coal field dictate the type of pit feasible for extraction of the coal. The rugged, hilly topography of extreme northern Missouri necessitates the use of contour or collar mining (fig. 7). This method of stripping is so named because cuts are made following the contours around hillsides. Successive cuts are made from the outcrop on the hillside until the amount of overburden to be removed becomes uneconomical or exceeds the limits of stripping equipment.

The most common type of mining used in the western region is known as furrow mining and is used mainly on flat terrain (fig. 8). A shovel or dragline excavates a furrow and casts the overburden over a ridge parallel to the cut. These furrows may not be parallel to the contour of the land, but they generally will be concentric with the overburden being cast whenever possible into the cut where the coal has been mined. This is a single-casting procedure. In a furrow pit a berm of coal is normally retained for haulage roads, access for horizontal drilling, and general workability of the pit. Where a dragline is in use, the extended bench method of stripping allows the dragline to dig deeper overburden than with single-casting procedure. At a

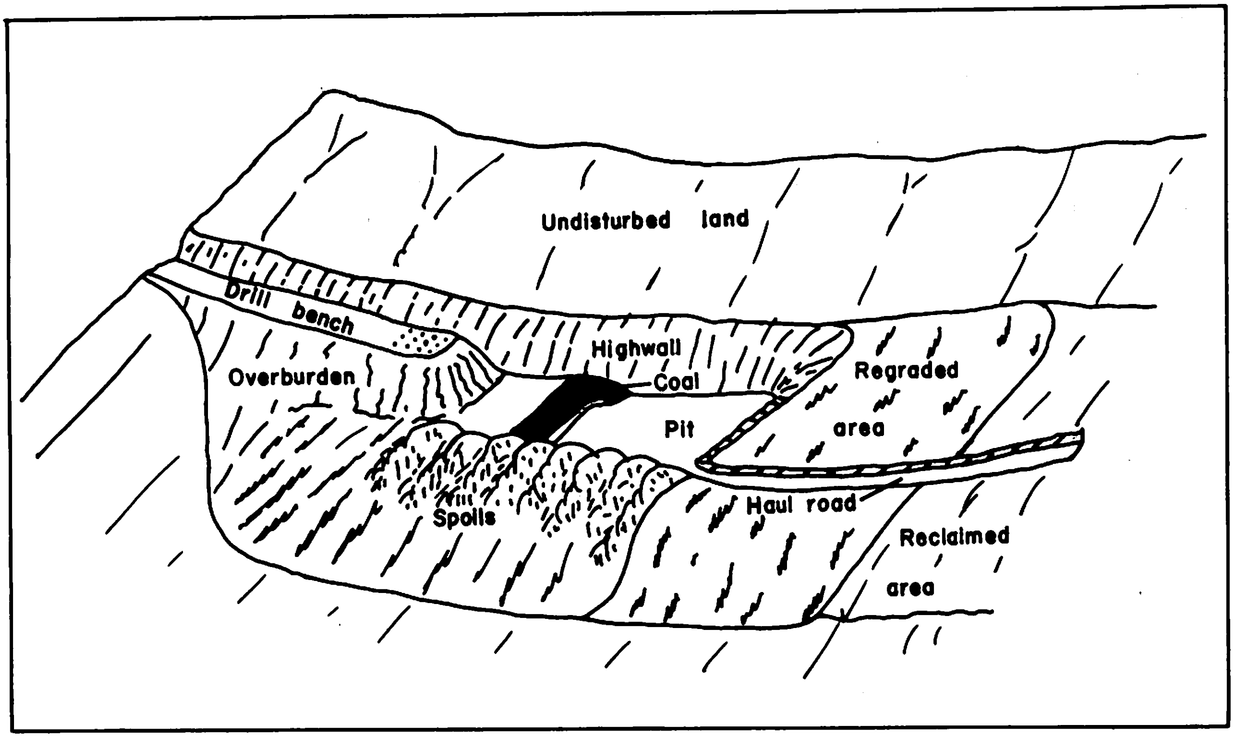


Figure 7.--Conventional contour-stripping method.

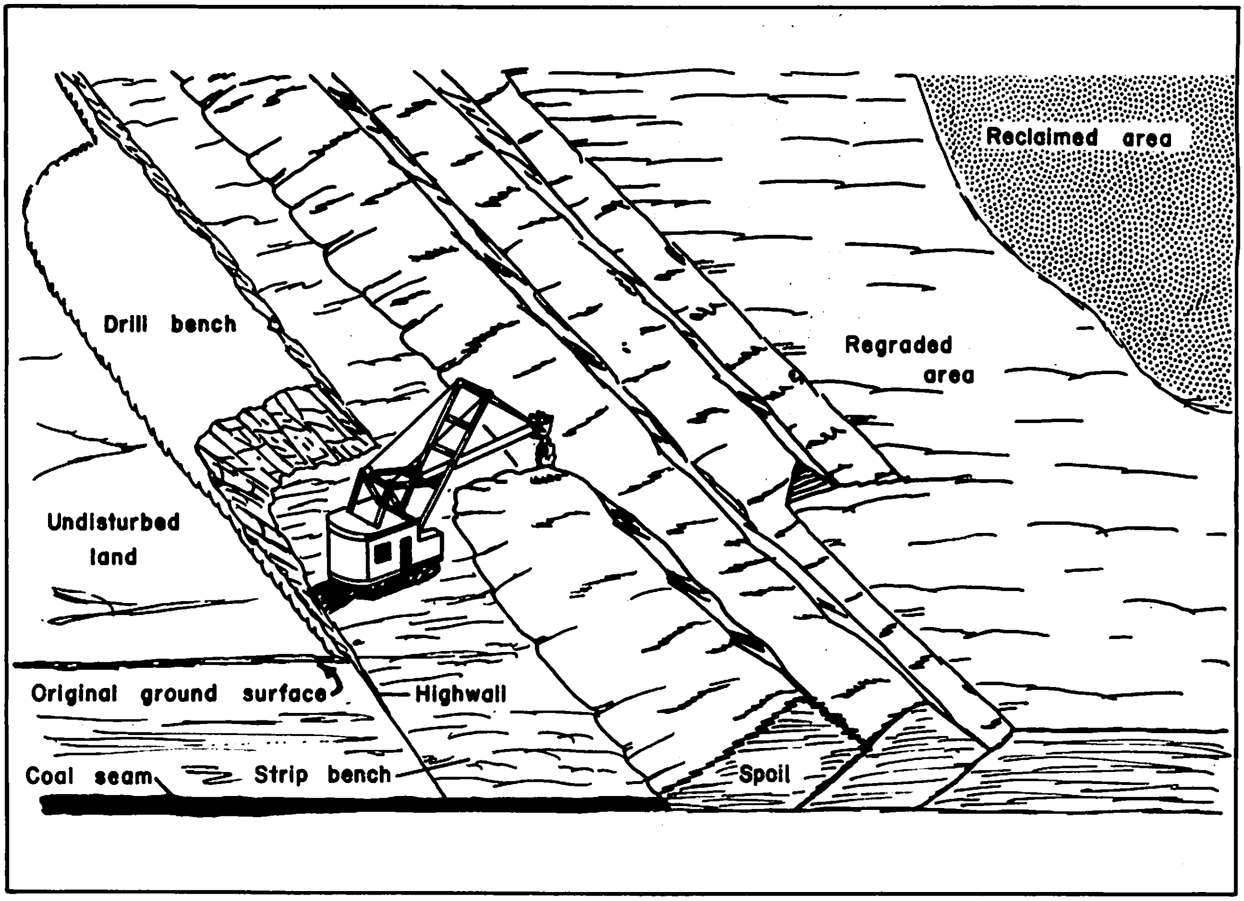


Figure 8.--Conventional furrow-stripping method.

favorable depth, a bench across the open pit is made with material being dug, thus the term extended bench. The dragline works on this bench from the most advantageous position in moving overburden to uncover the next coal pit.

A type of stripping common to the western mining region and the southern part of the north-central region is known as a "Y" pit (fig. 9). Designed for dragline operation the conventional pit has two working areas with the entrance or incline between. The purpose of the "Y" is to allow the coal of one leg to be mined while the dragline or excavator uncovers the coal in the other leg.

Most of the coal shallow enough to be recovered by surface mining is found under medium- to low-grade agricultural land or under areas still supporting a growth of timber (Pfleider, 1968). After mining, the topography of the area is completely altered. What may have been level to rolling land in cultivation, grass, or timber, is thrown up in a series of ridges or peaked mounds. The materials consist of varying percentages of rock, shale, slate, and soil material devoid of most plant and animal life. Prior to the Missouri Land Reclamation Law of 1972, much of the stripped-mined land was left unreclaimed. However, current laws and regulations require that land reclamation proceed with the mining. Some abandoned lands that have become problems are also being reclaimed. These problem lands are areas where acid-mine drainage is adversely affecting the quality of surface waters, where erosion is severe, or where the land has become unsightly or unattractive.

HYDROLOGY

Surface Water

Streamflow in the mining regions of the State is highly variable. The average flow of a given stream for a particular month may vary from year to year by a factor of 1,000. Thus storage reservoirs are required for maximum use of surface-water supplies. The north-central mining region contains approximately 150 impoundments of 50 acre-ft or more, while the western coal-mining region contains approximately 96 impoundments of 50 acre-ft or more (Missouri Division of Geology and Land Survey, 1974). These lakes, reservoirs, and watershed projects help stabilize streamflow, reduce flood damage and erosion, and provide water-based recreation.

Many streams in both mining regions (fig. 3) have little low-flow potential because of the generally low permeability of the shales and clays of the area. Low-flow frequency data are available (Skelton, 1976) to relate recurrence interval to lowest average discharge for periods of various lengths during each climatic year. Low-flow frequency curves representative of the different physiographic regions (see fig. 4) are shown in figure 10 to illustrate the contrast in low-flow characteristics across the State.

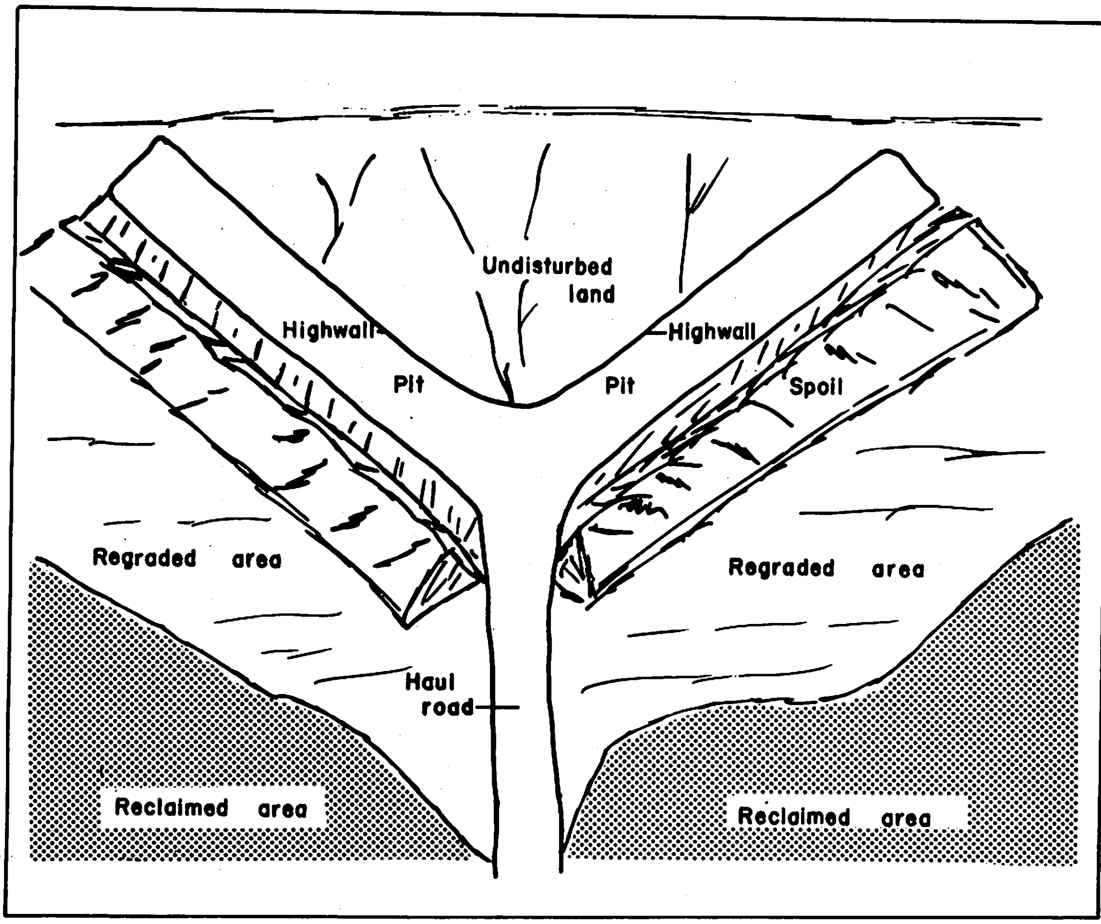


Figure 9.--Conventional "Y"-stripping method.

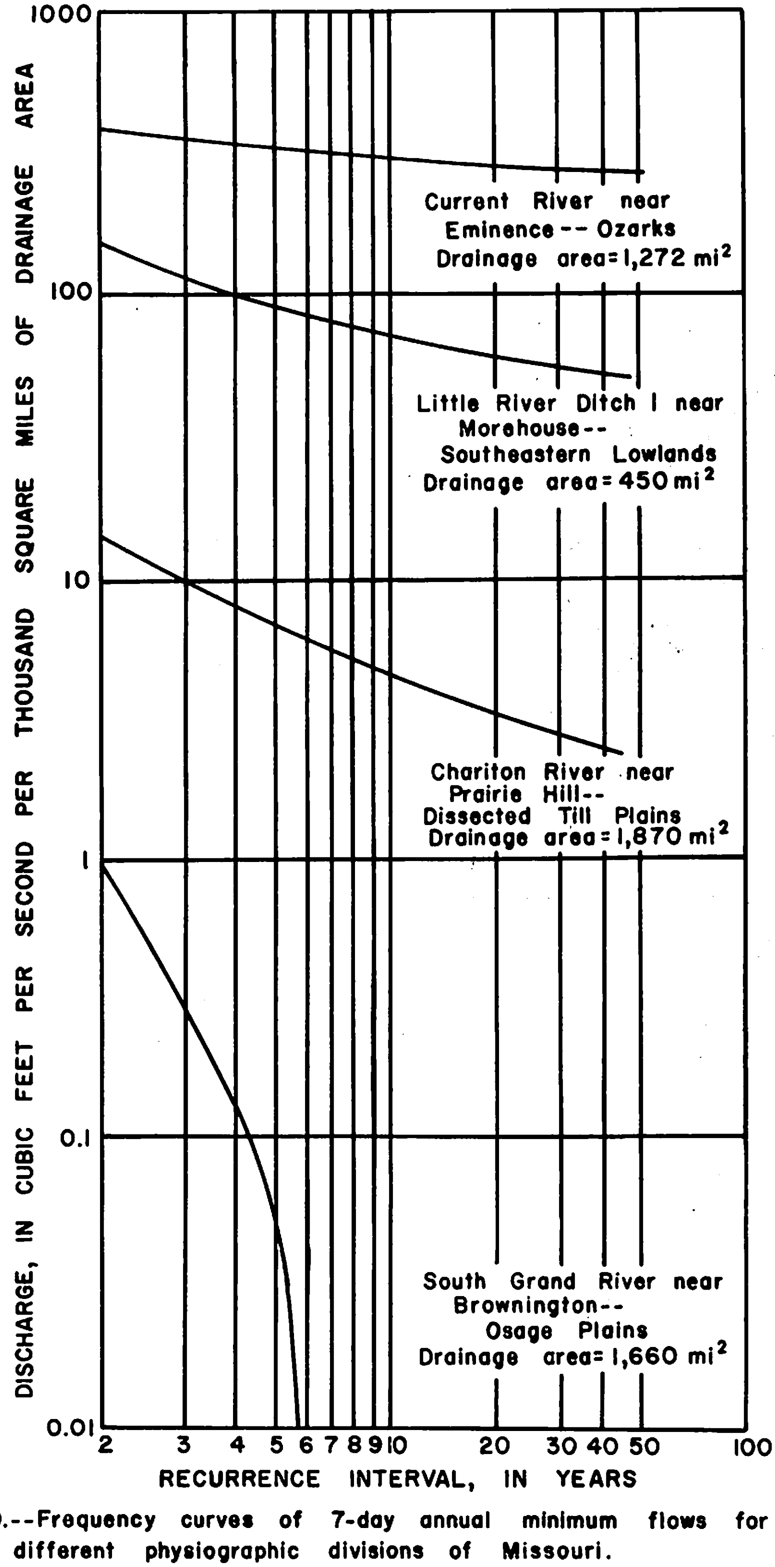


Figure 10.--Frequency curves of 7-day annual minimum flows for streams in the different physiographic divisions of Missouri.

As shown by the frequency curves, large streams in the north-central mining region (Chariton River) are better sustained than those of the western region (South Grand River) but less than those in southern Missouri (Current River and Little River ditch 1). The better sustained streams have low-flow frequency curves that are flat, indicating significant ground-water contribution. The greater ground-water contribution in the north-central mining region compared to the western mining region comes from the glacial drift and coarser grained alluvium derived from the drift.

The term 7-day Q_2 is defined as the average minimum flow for 7 consecutive days that has a recurrence interval of 2 years and commonly is used in low-flow studies because it is a median low-flow value. Generally, "***for drainage basins of 100 mi^2 (259 km^2) or less, the 7-day Q_2 is almost always zero. About 60 percent of Plains streams with drainage areas of 100 to 200 mi^2 (259 to 518 km^2) will have a 7-day Q_2 of zero, and the rest will have 7-day Q_2 of 0.1 to 1.0 ft^3/s (0.003 to 0.028 m^3/s). For drainage basins larger than 200 mi^2 (518 km^2), drainage area size is an unreliable parameter to use in estimating 7-day Q_2 and field observations of flow are required." (Skelton, 1976, p. 57.)

The magnitude and frequency of flooding for streams of the mining regions may be estimated from equations developed by regional analysis. Hauth (1974) developed equations from which flood magnitudes having recurrence intervals of 2, 5, 10, 50, and 100 years can be computed for ungaged natural sites if the contributing drainage basin size and slope are known. Regional flood height-frequency relations for both Plains areas were defined by Gann (1968) to compute flood heights corresponding to selected frequencies at ungaged sites where natural floodflows exist.

Water from streams in the north-central mining region generally contains less than 400 mg/L of dissolved-solids (Gann and others, 1973). The water is a calcium bicarbonate type, but magnesium and sulfate also are significant parts of the total ionic composition. Acid-mine drainage has affected the quality of some streams in the north-central mining areas as shown by the water-quality data in table 2.

The East Fork Little Chariton River is located in the central part of the mining region (fig. 11). The East Fork Little Chariton River upstream from Macon receives little, if any, runoff from mining activities. Between Macon and Huntsville, drainage into the river is from subbasins in which there is or has been large-scale mining activity. A comparison of data collected near Huntsville (trend station) with data collected near Macon (reference station) shows the effects of the coal-mining activity on the quality of water in the East Fork Little Chariton River.

The median dissolved-solids concentrations was 498 mg/L for Huntsville compared to 171 mg/L for Macon. Most of the increase in dissolved solids

Table 2.--Water-quality characteristics of selected streams in the north-central Missouri coal-mining region (Monthly samples from October 1971 to September 1974)

[Results in milligrams per liter, except as indicated]

Parameter	East Fork Little Chariton River near Macon (drainage area 112 mi^2)			East Fork Little Chariton River near Huntsville[1] (drainage area 220 mi^2)			Cedar Creek near Columbia[1] (drainage area 44.8 mi^2)		
	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum
Discharge (ft^3/s)	16	1,250	0.00	58	3,250	4.0	4.7	510	0.05
pH (units)	7.6	8.1	7.1	7.3	8.3	5.6	5.5	6.8	3.4
Specific conductance (μmho/cm at 25°C)	286	670	120	750	1,730	177	750	2,000	305
Dissolved solids (residue at 180°C)	171	401	76	498	1,410	129	540	2,260	192
Dissolved calcium (Ca)	34	75	13	80	190	24	86	270	32
Dissolved magnesium (Mg)	7.0	23	3.0	30	96	4.5	32	120	9.0
Bicarbonate (HCO_3)	106	218	32	100	190	6	6	28	0
Dissolved sulfate (SO_4)	41	120	19	280	830	39	360	1,500	97
Dissolved iron (Fe) [μg/L]	140	950	10	100	2,500	0	860	17,000	0
Dissolved manganese (Mn) [μg/L]	200	800	30	980	3,500	0	4,800	18,000	1,000

[1]Affected by acid-mine drainage from coal mines.

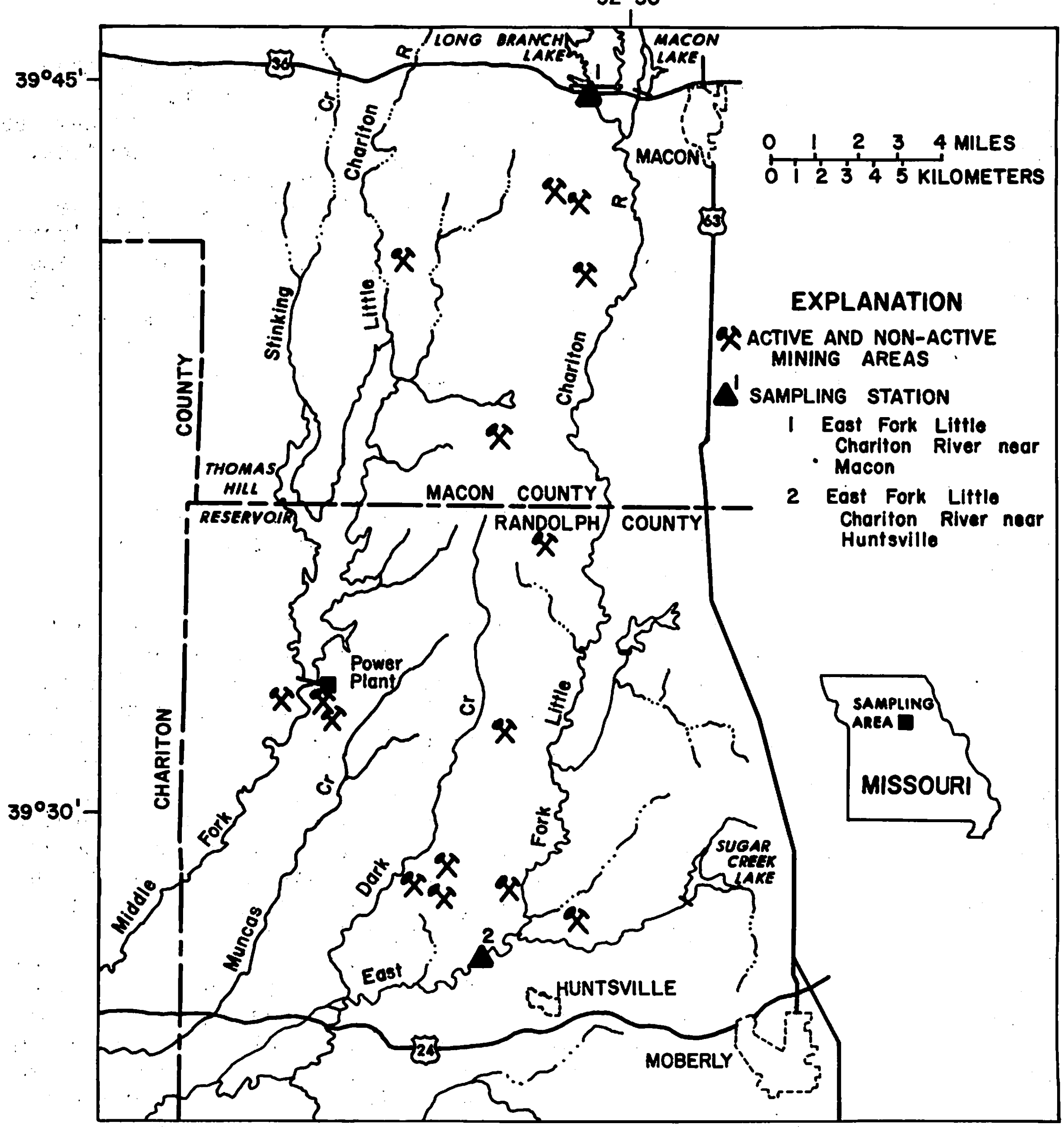


Figure 11.--Locations of water-quality sampling stations on East Fork Little Chariton River in relation to coal-mining activity.

resulted from increases in calcium and sulfate. Iron and manganese concentrations were higher near Huntsville than near Macon when the pH was low near Huntsville. However, this occurred only occasionally because the stream is large enough to maintain its buffering capacity except during an occasional low-flow period.

Cedar Creek near Columbia (fig. 12) has a smaller drainage area than East Fork Little Chariton River near Huntsville and water quality is seriously affected by runoff from about 2,000 acres of abandoned strip-mined land upstream from the sampling station. During periods of very low flow, water with pH values less than 5 becomes pooled in upper Cedar Creek. Dissolved-solids concentrations sometimes exceed 2,000 mg/L during these periods and are caused mainly by high concentrations of calcium and sulfate. Because pH values are less than 5 during these periods, dissolved iron and manganese concentrations exceed 10,000 μg/L (micrograms per liter). About every 2 years a summer storm will flush acid water down Cedar Creek and result in a substantial fish kill for several miles downstream from the sampling station (Missouri Department of Natural Resources, 1978).

Ground Water

Aquifers of the mining regions in Missouri may be classified in two general groups: (1) Unconsolidated aquifers (glacial drift and alluvium), and (2) consolidated or bedrock aquifers.

In the north-central mining region unconsolidated aquifers are the most important source of water. The principal sources of freshwater are the alluvium of the Missouri River valley, the alluvium of tributary valleys, and the outwash deposits of buried bedrock valleys. Favorable areas for developing wells in glacial drift are indicated by the presence of sand or gravel deposits that contain little or no silt and clay. Due to the mode of deposition, these deposits are usually separated both laterally and vertically by deposits of silt or clay, and sustained well yields generally are less than might be expected for equal thicknesses of sand occurring in a single continuous unit. The cleaner and coarser sands usually occur near the base of the glacial drift. In general, areas having 10 to 100 ft of clean drift sands are capable of yields sufficient for rural domestic supplies (2-30 gal/min) and areas having greater than 100 ft of clean sands are capable of yields sufficient for municipal, industrial, and irrigation supplies (30-500 gal/min, and occasionally as much as 1,000 gal/min). Most municipal water supplies are obtained from wells in alluvium and only a few are derived from glacial drift. An estimated 2 Mgal/d is taken from aquifers for domestic and livestock use in rural areas. Irrigation and industry are concentrated along the Missouri River where the supply of water from the alluvium is much larger than the demand. Industrial use of saline water (more than 1,000 mg/L of dissolved solids) is small. Probably the largest user is the coal industry, which uses saline water as wash water in processing and grading plants (U.S. Geological Survey and Missouri Geological

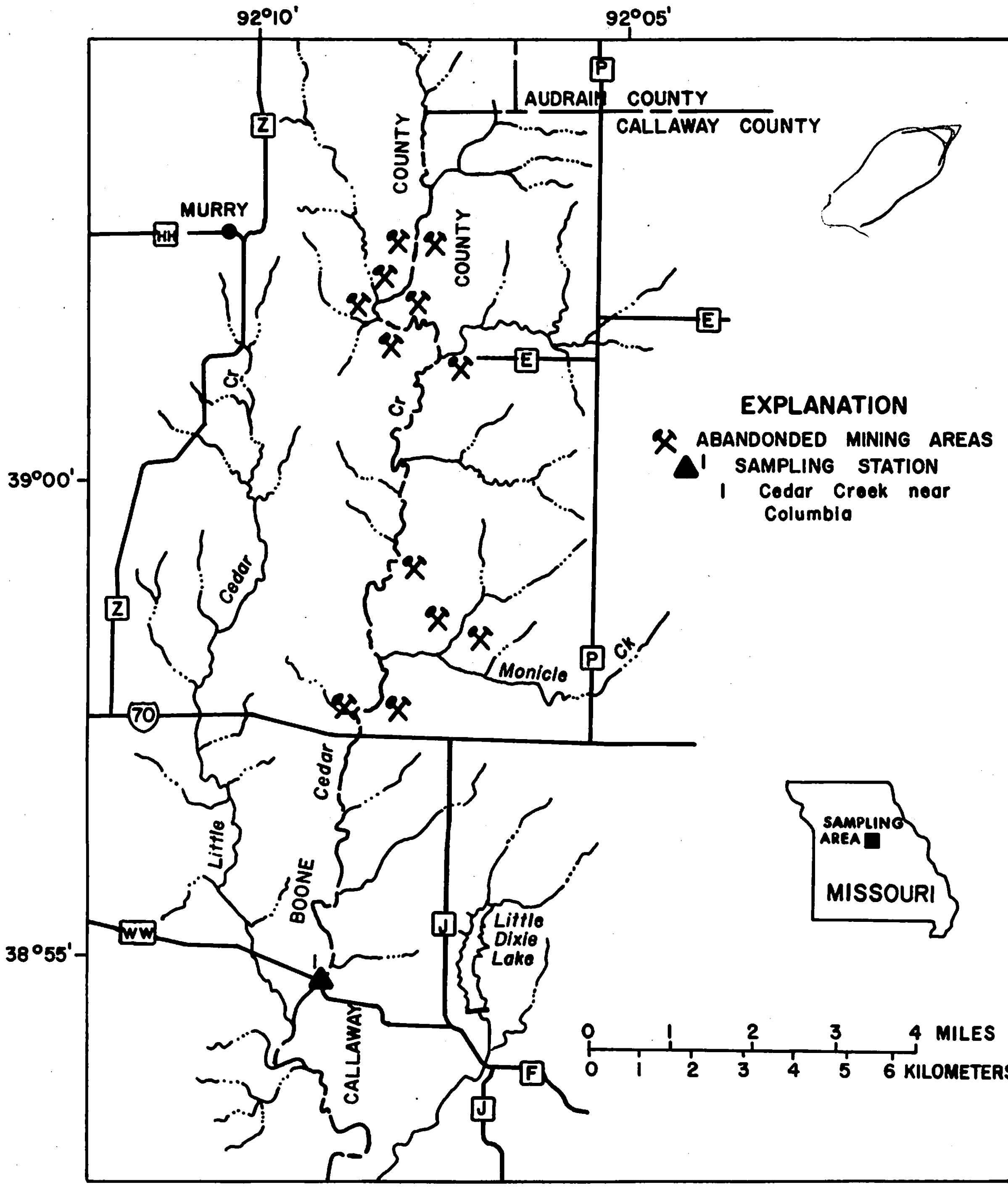


Figure 12.--Location of water-quality sampling station on Cedar Creek in relation to coal-mining activity.

Survey and Water Resources, 1967, p. 303). Of some value as aquifers, but limited in yields, are the outwash sands and gravels that were deposited on the uplands. Small quantities (2-3 gal/min) of water are obtained locally from shallow drift wells; however, such supplies generally are undependable and may be insufficient for domestic needs.

Shallow consolidated aquifers in the north-central mining region yield small supplies of moderately mineralized water in local areas. Water from the deeper consolidated aquifers is more highly mineralized, and often unsuitable for use.

Ground water from the principal sources in the north-central coal-mining region has different chemical characteristics. The least mineralized water is in the alluvium. Water from alluvial aquifers is a calcium bicarbonate type and has dissolved-solids concentrations less than 1,000 mg/L and commonly less than 500 mg/L. Water from the glacial drift is a mixed calcium bicarbonate sodium sulfate type, is hard and has high iron concentrations. High concentrations of sodium, sulfate, and chloride make some of the glacial drift water saline. The quality of water in bedrock aquifers varies with location and depth. Available data indicate that mineralization probably increases with depth, although available data are insufficient to relate mineralization to rock formations. Dissolved-solids concentrations usually exceed 1,000 mg/L at some locations in the Pennsylvanian rocks. These high concentrations of dissolved solids can usually be attributed to increased concentrations of sodium, sulfate, and chloride. Water from the bedrock aquifers is very hard and usually has high iron concentrations.

In the western mining region, unconsolidated aquifers are limited in extent. Bedrock aquifers are the most important source of water in the region. Ground-water quality in the mining region is divided northeast to southwest by a saline-freshwater boundary (see fig. 3). Generally, this boundary coincides with the limit of the Pennsylvanian rocks in northern and western Missouri. North of the boundary, the mining region is considered to be part of the saline ground-water province while south of the boundary, it is considered part of the freshwater Ozarks (U.S. Geological Survey and Missouri Geological Survey and Water Resources, 1967, p. 283). The saline ground-water province is defined as that area in which the dissolved-solids concentrations exceed 1,000 mg/L in consolidated aquifers capable of yielding adequate water volumes to municipalities or industries. The low permeability of the Pennsylvanian strata impedes water movement both laterally and vertically. Because of this, there is little opportunity for ground-water recharge or discharge. Production would probably be largely from storage and, as a consequence, water levels would decline. The recharge that does occur is probably due to lateral water movement within the deeper aquifers. Supplies of 5 to 10 gal/min can usually be obtained in this area from Pennsylvanian sandstone and Mississippian limestone at depths ranging from 250 to 400 ft. The limestone of Mississippian age, which underlies and forms the surface of the southern section of the mining area, is a large reservoir of freshwater. As much as 450 ft of limestone may be present before the more intensively used Ordovician and Cambrian aquifers are reached at depth. Nearly all cities in this area obtain their water supplies from Ordovician and Cambrian aquifers. Rural and stock water supplies are derived from wells, springs, spring-fed streams, and ponds.

Water from Ordovician and Cambrian aquifers in the southeastern part of the western mining area is a calcium magnesium bicarbonate type and water from Mississippian aquifers is a calcium bicarbonate type. Water from consolidated aquifers in the northwestern part of the region is a sodium chloride type and is highly mineralized. The dissolved-solids concentrations in ground water increases rapidly toward the northwest from approximately 500 mg/L to more than 40,000 mg/L. Chloride concentrations also increase toward the northwest from less than 5 mg/L to more than 18,000 mg/L.

PLANS FOR FUTURE DATA COLLECTION AND ANALYSIS

The Surface Mining Control and Reclamation Act of 1977 requires a thorough understanding of surface-flow regimens, ground-water movement and recharge, ground-water to surface-water relationships, and water quality for mine permit and adjacent areas. Review of existing information shows that the hydrologic data base for the coal-mining regions is limited.

Additional information will be collected during the second phase of this project that will increase the data base and make possible a better general description of the hydrology of the coal-mining regions. This will be accomplished through a network of continuous surface-water and monthly water-quality stations formed by upgrading existing stations and adding a limited number of new stations, and through extensive collection of synoptic data for wells and streams. The network of continuous stations will include some reference stations (upstream from coal mining) and trend stations (downstream from coal mining).

Digitized precipitation, slope, soil type, and land use data will be used to model surface-water flow and will provide a means of classifying subbasins according to physical and hydrologic characteristics.

Thickness maps of the glacial drift in the north-central mining region and the Pennsylvanian System in both mining regions will be prepared. Ground-water levels and quality will be determined for both areas by obtaining information from driller's logs and core sample logs and by inventorying wells in both regions, collecting water samples from selected wells, and periodically measuring water levels in selected wells.

SUMMARY

There are approximately 50 billion tons of bituminous coal resources in Missouri. The coal occurs in rocks of Pennsylvanian age. The generally low hydraulic conductivity of these rocks impedes vertical and lateral water movement and results in limited sustained streamflow, especially in the western coal region where the topography is level to gently rolling.

Dissolved-solids concentrations in water from streams in both mining regions are generally less than 400 mg/L, except where streams are affected by acid-mine drainage. These streams may have dissolved-solids concentrations greater than 1,000 mg/L and dissolved iron and manganese concentrations greater than 100,000 μg/L. Calcium and sulfate account for most of the increase in dissolved-solids concentrations. Fish kills as a result of acid-mine drainage have been documented for several streams in both coal-mining regions.

The quality of water in the Pennsylvanian rocks and the glacial drift that covers them in northern Missouri is generally unsuitable for many uses. Dissolved-solids concentrations (mainly calcium, magnesium, sodium, bicarbonate, sulfate, and chloride) commonly exceed 1,000 mg/L. Iron concentrations also are high in much of the ground water.

Hydrologic information for the coal-mining regions is limited. During the second phase of this study, data will be collected to increase the data base, define hydrologic relationships, and provide a general hydrologic description of the coal-mining regions.

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