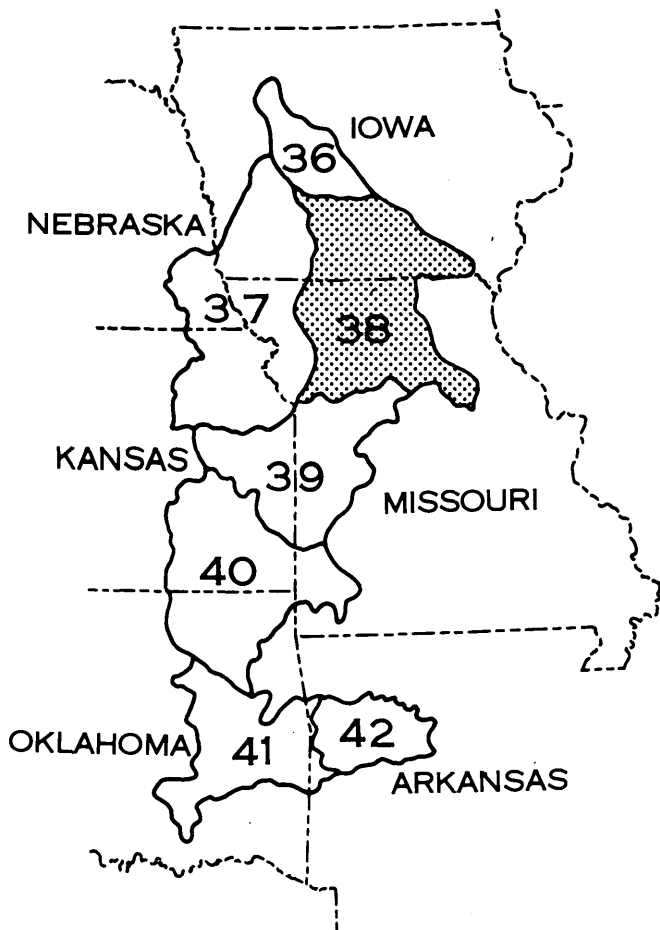


HYDROLOGY OF AREA 38, WESTERN REGION, INTERIOR COAL PROVINCE IOWA AND MISSOURI



- CHARITON RIVER
- DES MOINES RIVER
- THOMPSON RIVER
- GRAND RIVER
- ELK FORK SALT RIVER



UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 82-1014

HYDROLOGY OF AREA 38, WESTERN REGION, INTERIOR COAL PROVINCE IOWA AND MISSOURI

BY
MARK G. DETROY, JOHN SKELTON AND OTHERS

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 82-1014



ROLLA, MISSOURI
IOWA CITY, IOWA
MAY 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

For further information write to:

U. S. Geological Survey
P. O. Box 1230
400 South Clinton Street
Iowa City, Iowa 52244

or

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

CONTENTS

	Page
Abstract	1
1.01 Introduction	2
1.1 Objective	2
<i>F. A. Kilpatrick and J. R. Rollo</i>	
1.2 Project area	4
<i>John Skelton</i>	
1.3 Hydrologic problems related to surface coal mining	6
<i>James H. Barks</i>	
2.0 General features	8
2.1 Bedrock geology	8
<i>Pamela K. B. Hunt</i>	
2.2 Quaternary deposits	10
<i>Pamela K. B. Hunt</i>	
2.3 Soils	12
<i>Richard A. Karsten</i>	
2.4 Surface drainage	14
<i>John Skelton</i>	
2.5 Land use	16
<i>John Skelton</i>	
2.6 Water use	18
<i>Robert E. Hansen</i>	
2.7 Climate	20
<i>Richard A. Karsten</i>	
3.0 Coal mining	22
3.1 History and potential	22
<i>Robert C. Buchmiller</i>	
3.2 Methods of coal mining	24
<i>Robert C. Buchmiller</i>	
4.0 Surface water	26
4.1 Gaging stations	26
<i>John Skelton</i>	
4.2 Daily, seasonal, and average annual streamflow	28
<i>John Skelton</i>	
4.3 Low flow	30
<i>John Skelton</i>	
4.4 Flood flow	32
<i>John Skelton</i>	
4.5 Flow duration	34
<i>John Skelton</i>	

5.0	Quality of surface water	36
5.1	Water-quality stations <i>Mark G. Detroy</i>	36
5.2	Specific conductance and dissolved solids <i>James H. Barks</i>	38
5.3	pH and alkalinity <i>James H. Barks</i>	40
5.4	Sulfate <i>James H. Barks</i>	42
5.5	Iron <i>Mark G. Detroy</i>	44
5.6	Manganese <i>Mark G. Detroy</i>	46
5.7	Trace elements <i>Jerri V. Davis</i>	48
5.8	Acid-mine drainage <i>Jerri V. Davis</i>	50
6.0	Ground water	52
6.1	Hydrogeologic units and data sites <i>Pamela K. B. Hunt and Robert C. Buchmiller</i>	52
6.2	Cambrian-Ordovician aquifer <i>Michael R. Burkart</i>	54
6.3	Quaternary aquifers <i>Pamela K. B. Hunt</i>	56
6.4	Mississippian and Pennsylvanian aquifers <i>Robert E. Hansen</i>	58
6.5	Water levels <i>John Skelton</i>	60
7.0	Quality of ground water	62
7.1	Cambrian-Ordovician aquifer <i>Mark G. Detroy</i>	62
7.2	Quaternary aquifers <i>Mark G. Detroy</i>	64
7.3	Mississippian and Pennsylvanian aquifers <i>Mark G. Detroy</i>	66
8.0	Water-data sources	69
8.1	Introduction	69
8.2	National water-data exchange (NAWDEx)	70
8.3	WATSTORE	72
8.4	Index to water-data activities in coal provinces	74
9.0	Surface-water stations	76
10.0	List of references	84

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

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

Multiply	By	To obtain
inches (in)	25.40	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi ²)	2.590	square kilometers (km ²)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (mgal/d)	0.04381 3785.	cubic meters per second (m ³ /s) cubic meters per day (m ³ /d)
cubic feet per second (ft ³ /s)	0.02832	cubic meters per second (m ³ /s)
micromhos per centimeter at 25° Celsius (μmhos/cm)	100	microsiemens per meter at 25° Celsius (μS/m)
tons	0.9072	metric tons (t)
British thermal units	0.001055	joule (J)
pounds (lb)	0.4536	kilograms (kg)
acres	0.4047	hectares (ha)
acre-feet	0.00123	cubic hectometer (hm ³)
degrees Fahrenheit (°F)	0.56, after subtracting 32	degrees Celsius (°C)

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

HYDROLOGY OF AREA 38, WESTERN REGION, INTERIOR COAL PROVINCE IOWA AND MISSOURI

BY
MARK G. DETROY, JOHN SKELTON AND OTHERS

Abstract

A nationwide need for information characterizing hydrologic conditions in mined and potential mine areas has become paramount with the enactment of the Surface Mining Control and Reclamation Act of 1977. This report is designed to be useful to the mine owners, operators, and others by presenting information about the existing hydrologic conditions and by identifying sources of hydrologic information. General hydrologic information is presented using a brief text with an accompanying map, chart, graph, or other illustration for each of a series of water-resources-related topics. The summation of the topical discussions provides a description of the hydrology of the area.

Coal has been mined for 130 years in Area 38, but large reserves remain. Production peaked in 1917 when Iowa produced 9 million tons and Missouri produced 6 million tons. Underground mining has been replaced by surface mining in Area 38. Not all past surface-mined lands are subject to reclamation under recently enacted reclamation laws.

The surface-water monitoring network in Area 38 consists of 183 stations. Streamflow varies seasonally and from year to year. Water-quality data are available for 49 stations in the study area. Measurements of specific conductance, dissolved solids, pH, alkalinity, sulfate, iron, manganese, trace metals and other constituents are available for 36 stations operated between 1978 and 1981 expressly for the collection of water-quality data within basins containing coal mines.

A cumulative impact of coal mining on the mineralization of surface water is evident from specific-conductance data for stations downstream

from mining activities. Alkalinity in streams in Area 38 averaged greater than 118 milligrams per liter, providing the capability to neutralize acid-mine drainage to some extent. Sulfate concentrations in streamflow averaged 88 milligrams per liter at stations upstream from coal mines and 269 milligrams per liter at stations downstream from coal mines. Significant relationships exist between total-recoverable-iron concentrations and suspended-sediment concentrations. Manganese concentrations are larger in streams draining mined areas. Streamflow at 5 of the 36 coal-hydrology stations in Area 38, all located downstream from coal mines, exceeded acid-mine-drainage criteria at one time or another.

In Area 38 dissolved-solids concentrations in water from the Cambrian-Ordovician aquifer range from 300 to 15,000 milligrams per liter; in south-central Iowa and where the aquifer underlies the Missouri River alluvium, as in Boone County, Missouri, dissolved-solids concentrations are less than 1,000 milligrams per liter. In these areas the Cambrian-Ordovician aquifer is suitable for domestic and other uses. Chemical quality of water from Quaternary aquifers generally is suitable for domestic uses and other uses, dissolved-solids concentrations averaged less than 1,000 milligrams per liter. Iron, manganese and nitrate are excessive in some instances. Chemical quality of water from Mississippian and Pennsylvanian aquifers is unsuitable for domestic use and may be unsuitable for other uses. The Pennsylvanian and Mississippian aquifers have average sulfate concentrations in excess of 1,000 milligrams per liter.

1.0 INTRODUCTION

1.1 Objective

Report Summarizes Available Hydrology Data

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

Hydrologic information and analysis are needed to aid in decisions to lease Federally owned coal and for the preparation of the necessary Environmental Assessments and Impact Study Reports. This need has become even more critical with the enactment of Public Law 95-87, the "Surface Mining Control and Reclamation Act of 1977". This Act requires an appropriate regulatory agency to issue mining permits based on the review of permit-application data to assess hydrologic impacts. This need is partly fulfilled by this report, which broadly characterizes the hydrology of Area 38 in Iowa and Missouri, a part of the Western Region, Interior Coal Province (figure 1.1-1). This report is one of a series that describes coal provinces nationwide.

This report provides general hydrologic information by means of a brief text with accompanying map, chart, graph, or other illustration, for each of a series of water-resources-related topics. Summation

of the topical discussions provides a description of the hydrology of the area. The information contained herein will be useful to Federal agencies in the leasing and management of Federal coal lands and to surface-mine owners, operators, and others preparing permit applications and to regulatory authorities evaluating the adequacy of the applications.

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

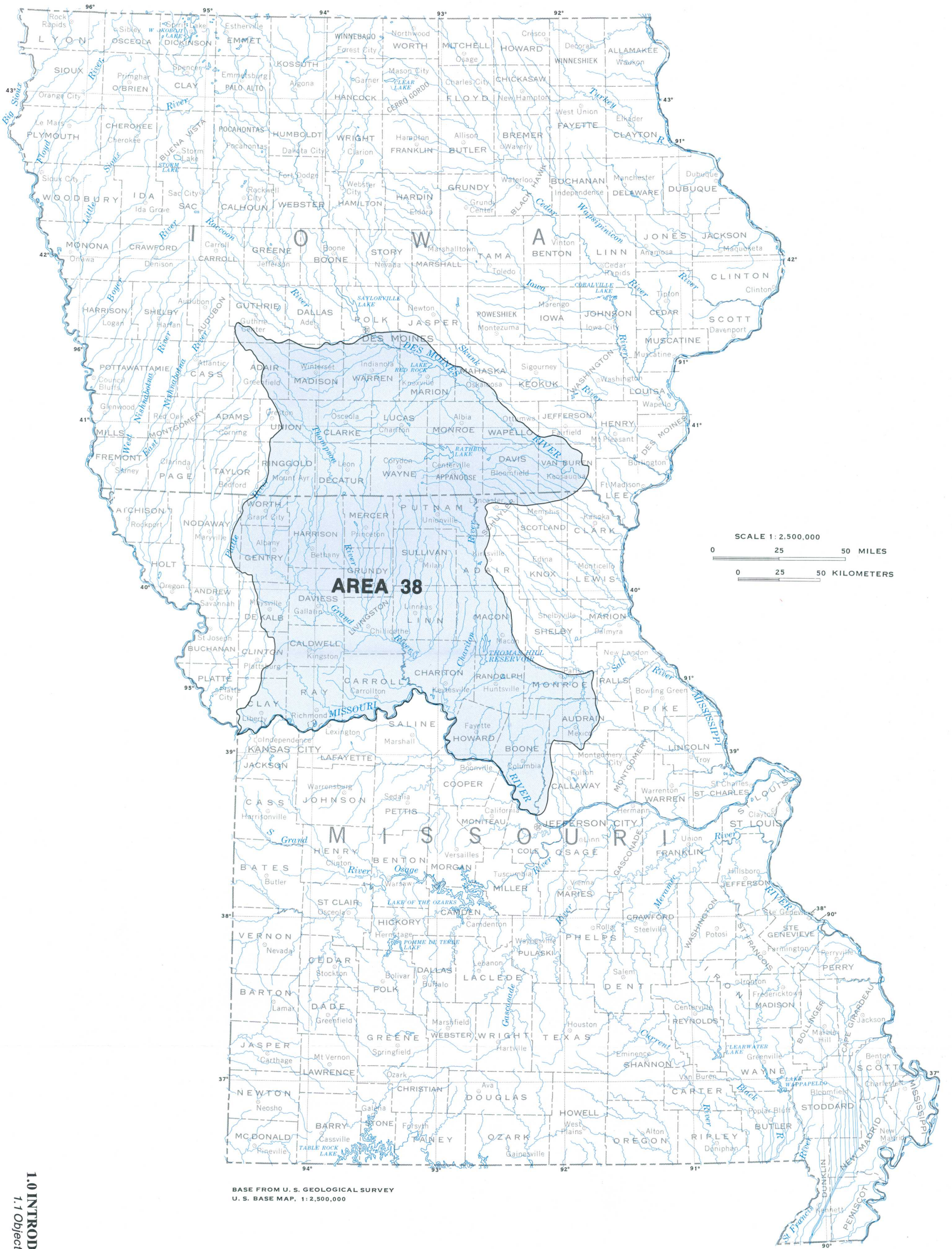


Figure 1.1-1 Location of Area 38 in Iowa and Missouri.

1.0 INTRODUCTION--Continued
1.2 Project Area

**Area 38 Located in Eastern Part of Western
Interior Coal Province**

This report summarizes the hydrology and water resources of Area 38 in the eastern part of the Western Interior Coal Province in Iowa and Missouri.

The Western Interior Coal Province is divided into seven reporting areas (report cover). Hydrologic factors, size, location, and mining activity were used to define the reporting areas. The location of Area 38 in south-central Iowa and north-central Missouri is shown in figure 1.2-1.

Area 38 includes all or parts of 22 counties in Iowa and 28 counties in Missouri with an area of approximately 17,000 square miles; about 60 percent

of the area is in Missouri. The area is in the eastern one-half of the Western Interior Coal Province, which includes parts of six States, and is in the Central lowland Province of the Interior Plains (figure 1.2-2). The land surface varies from rolling hills to smooth plains with land-surface altitudes ranging from about 600 feet in the southeast to 1200 feet in the north.

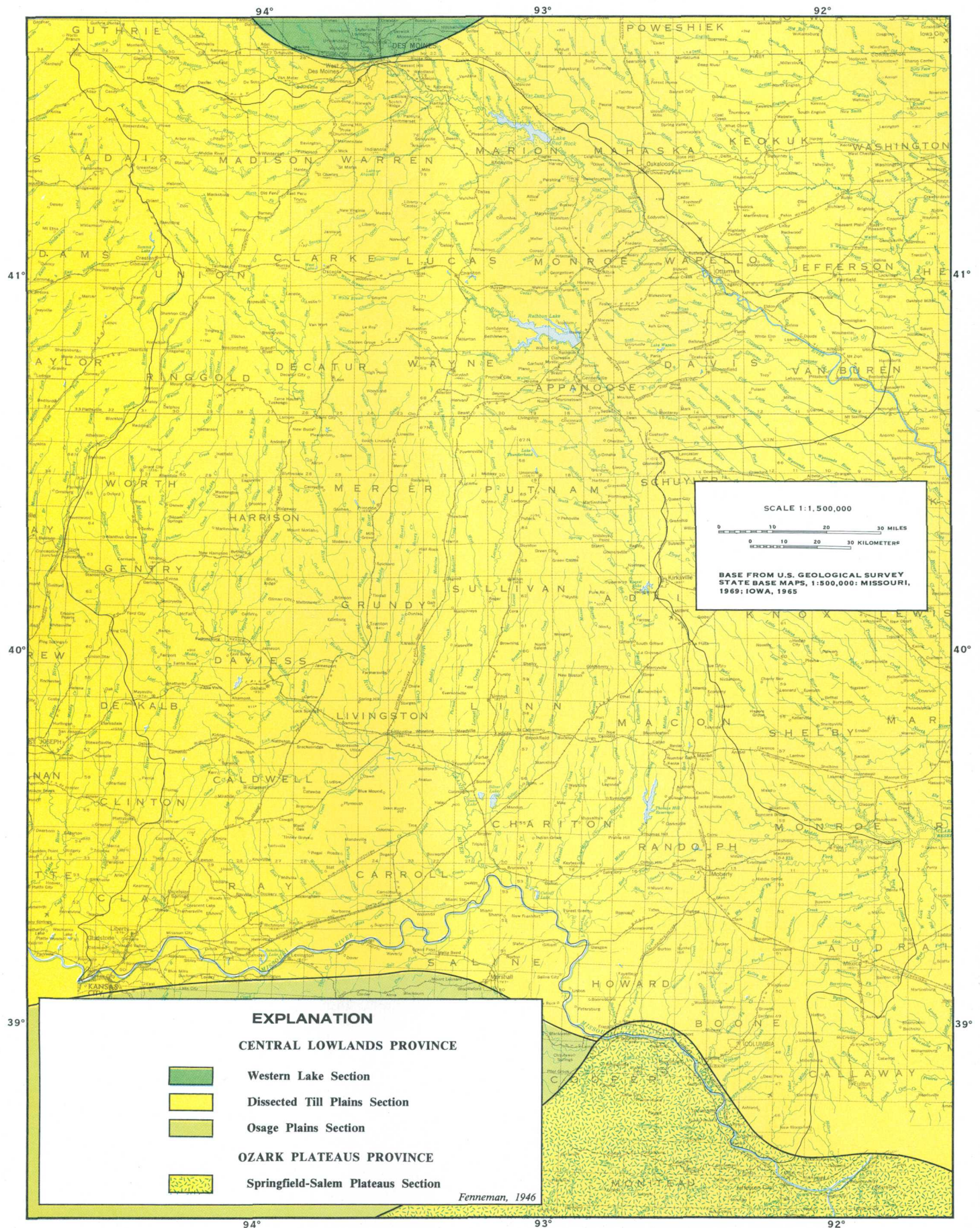


Figure 1.2-1 Location and physiographic map of Area 38.

1.0 INTRODUCTION--Continued

1.3 Hydrologic Problems Related to Surface Coal Mining

Hydrologic Environment can be Adversely Altered by Surface Coal Mining

Erosion, sedimentation, water-quality degradation, decline in ground-water levels, and diversion of drainage are typical problems associated with surface coal mining.

Hydrologic problems associated with surface coal mining are a result of environmental disturbance. Removal of vegetation, excavation, and deposition of large volumes of unconsolidated spoil materials cause significant changes to the environment. The magnitude of the effects of these changes depends on several physical and chemical factors. The more important factors include mining and reclamation methods, topography, geology, climate, rate of water movement and volumes, the distance to the mine site, and the time elapsed since mining began.

The process of erosion and sedimentation is accelerated greatly by surface mining (figure 1.3-1). Detrimental effects include decreased transport capacity of streams; a decreased storage capacity of lakes and ponds; decreased or destroyed aquatic habitat; increased turbidity that detracts from the recreational use of water and decreases photosynthetic activity; and transport of other pollutants such as nutrients, pesticides, and trace elements.

Coal-mining activities, by disturbing the natural geologic setting as shown in figure 1.3-2, expose sulfide minerals (most commonly, pyrite) to air and water, providing favorable conditions for acid production. Water draining such mined areas generally has pH values less than 5.0, large sulfate concentrations, and large concentrations of dissolved solids. The acidic water reacts with other minerals, increasing trace-element concentrations, such as aluminum, copper, lead, iron, manganese, and zinc. Adverse effects of acid-mine drainage may include decrease of

aquatic life, increased corrosiveness of water, limitations on use of water for domestic and industrial purposes, and decrease of esthetic value and recreational use. The effects of acid-mine effluents on the ecology of streams are documented by Parsons (1968) and Dieffenbach (1974).

A temporary decline in ground-water levels can occur in and near surface-mining areas when mining extends below the water table. After mining, the spoil material fills with water and an equilibrium water level is again attained. The spoil material has a greater permeability than the original undisturbed material because of cracks and larger openings in the spoil resulting from irregular lower compaction and because of the irregular placement of blocks of till and shale with smaller quantities of sandstone and limestone, and sand and gravel. Ground water in and near the spoils may be more mineralized than in original undisturbed material because of exposure of sulfide minerals to air and water.

Surface mining commonly causes alterations in stream drainage patterns (fig. 1.3-3). Such diversions change the streamflow characteristics. Adverse effects of surface mining are most apparent at and near the mine site. The receiving stream for surface and seepage drainage at the mine site usually is most affected. Effects of suspended sediment, mineral concentrations, and pH usually will decrease in severity downstream from the mine due to settling-out of the sediment, and increased buffering and dilution capacity of the stream.

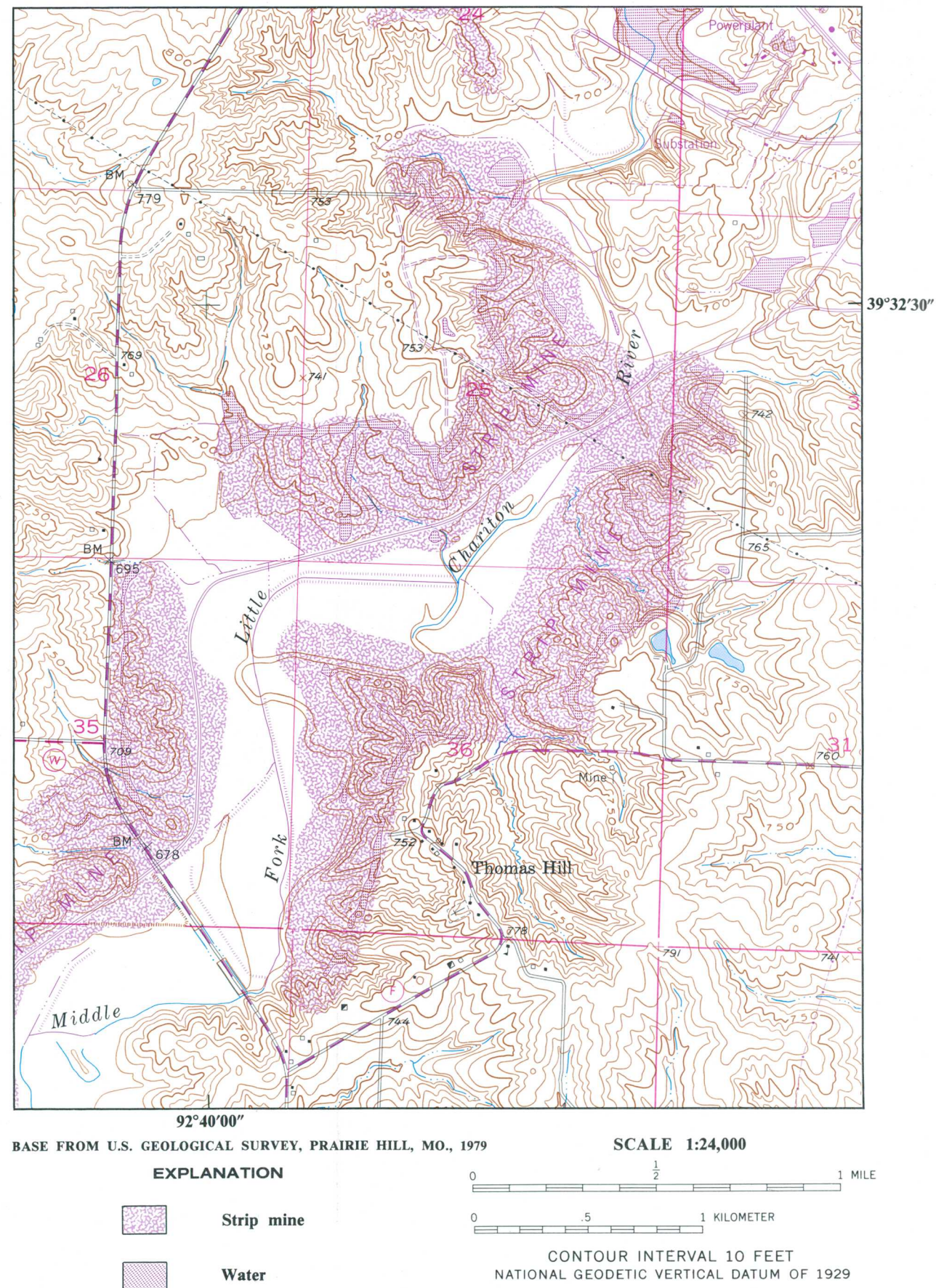


Figure 1.3-3 Section of 7.5 minute topographic map showing that surface mining alters drainage patterns.



Figure 1.3-1 Erosion is accelerated at a partly reclaimed mine.



Figure 1.3-2 Surface mining disturbs the natural geologic setting.

2.0 GENERAL FEATURES

2.1 Bedrock Geology

Pennsylvanian System is Predominant in Area 38

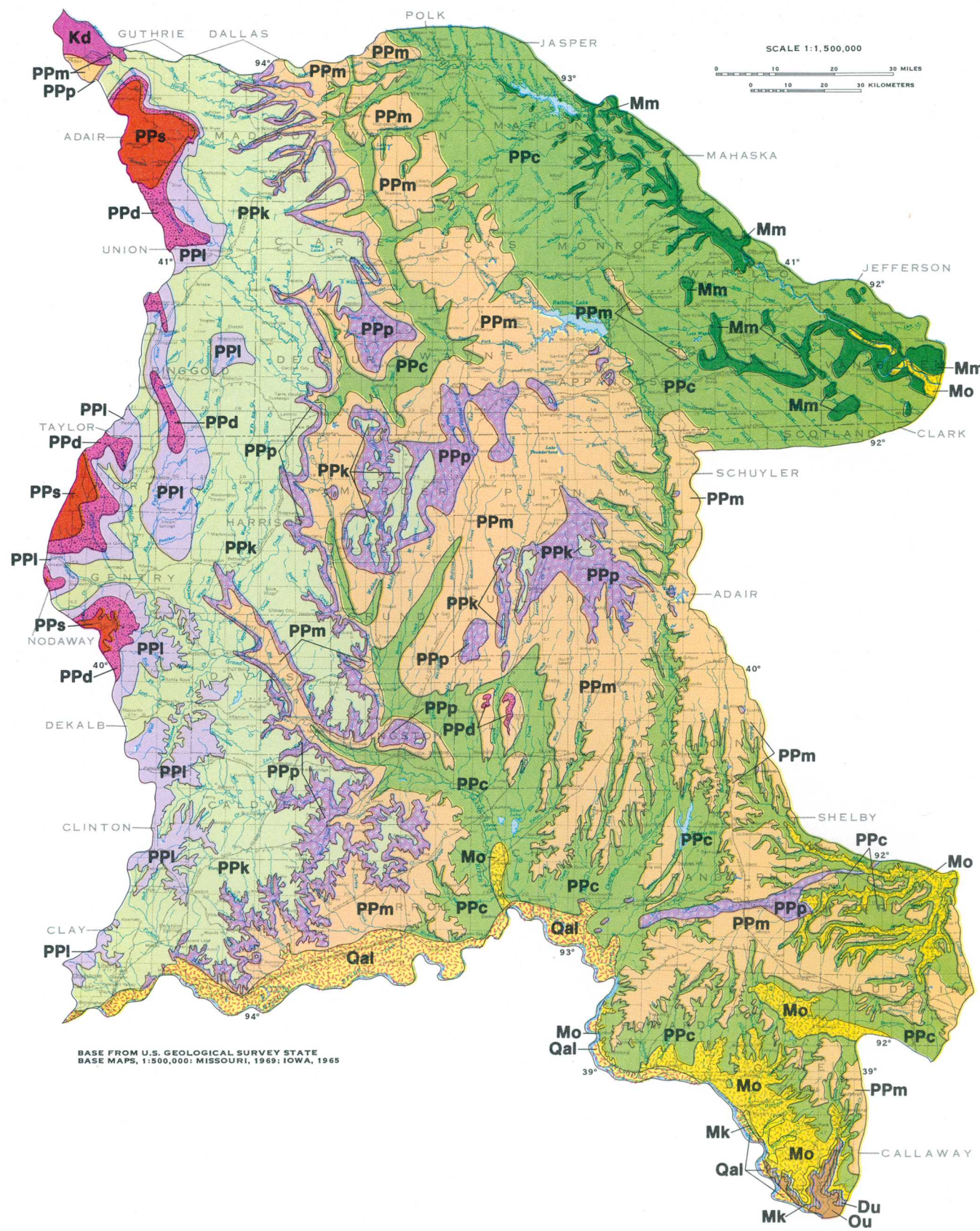
Coal-bearing formations are in the rocks of Pennsylvanian age.

The Pennsylvanian bedrock underlies most of Area 38 and is divided in descending order into the Virgilian, Missourian and Des Moinesian Series (figure 2.1-1). The Marmaton and Cherokee Groups of the Des Moinesian Series are the principal coalbearing units. The deposits which formed limestone, shale, sandstone, siltstone, claystone and coal are marine and non-marine and result from cyclic changes in ancient sea shorelines. Pennsylvanian rocks become progressively younger towards the northwest.

Other rocks in Area 38 are Mississippian, Devonian, Silurian or Ordovician age. The Meramecian, Osagean, and Kinderhookian Series are Missis-

sippian age. Principally the rocks are limestone, dolomite, sandstone and shale. Dolomite, limestone and chert typify the rocks of the Devonian and Silurian Systems in Area 38. Ordovician age rocks are principally sandstone, dolomite and limestone. The Missouri River alluvium of the Quaternary system is the youngest unit present in the southeastern section.

The bedrock geology has been modified by glaciation. All but an extremely small part of the area was glaciated and the glacial deposits are discussed in the next section.



CENOZOIC
MESOZOIC

PALEOZOIC

EXPLANATION	
QUATERNARY	Alluvium Sand, gravel, silt and clay
CRETACEOUS	Dakota Formation Sandstone and shale
PENNSYLVANIAN	Shawnee Group Limestone and shale
	Douglas Group Shale, siltstone and limestone
	Lansing Group Limestone and shale
	Kansas City Group Limestone and shale
	Pleasanton Formation Shale, limestone and sandstone
MISSISSIPPIAN	Marmaton Group Limestone and shale
	Cherokee Group Shale, clay, siltstone, sandstone, limestone and coal
	Meramecian Series Limestone, sandstone, dolomite and shale
	Osagean Series Limestone, sandstone, dolomite and shale
	Kinderhookian Series Limestone, dolomite, siltstone, sandstone, and shale
DEVONIAN	Devonian undifferentiated Dolomite, limestone and chert
ORDOVICIAN	Ordovician undifferentiated Sandstone, dolomite and limestone

Figure 2.1-1 Bedrock Geology.

Geology modified from Hershey (1969),
Cagle (1979), Cagle and Heintz (1978),
and Anderson (1979).

2.0 GENERAL FEATURES--Continued

2.2 Quaternary Deposits

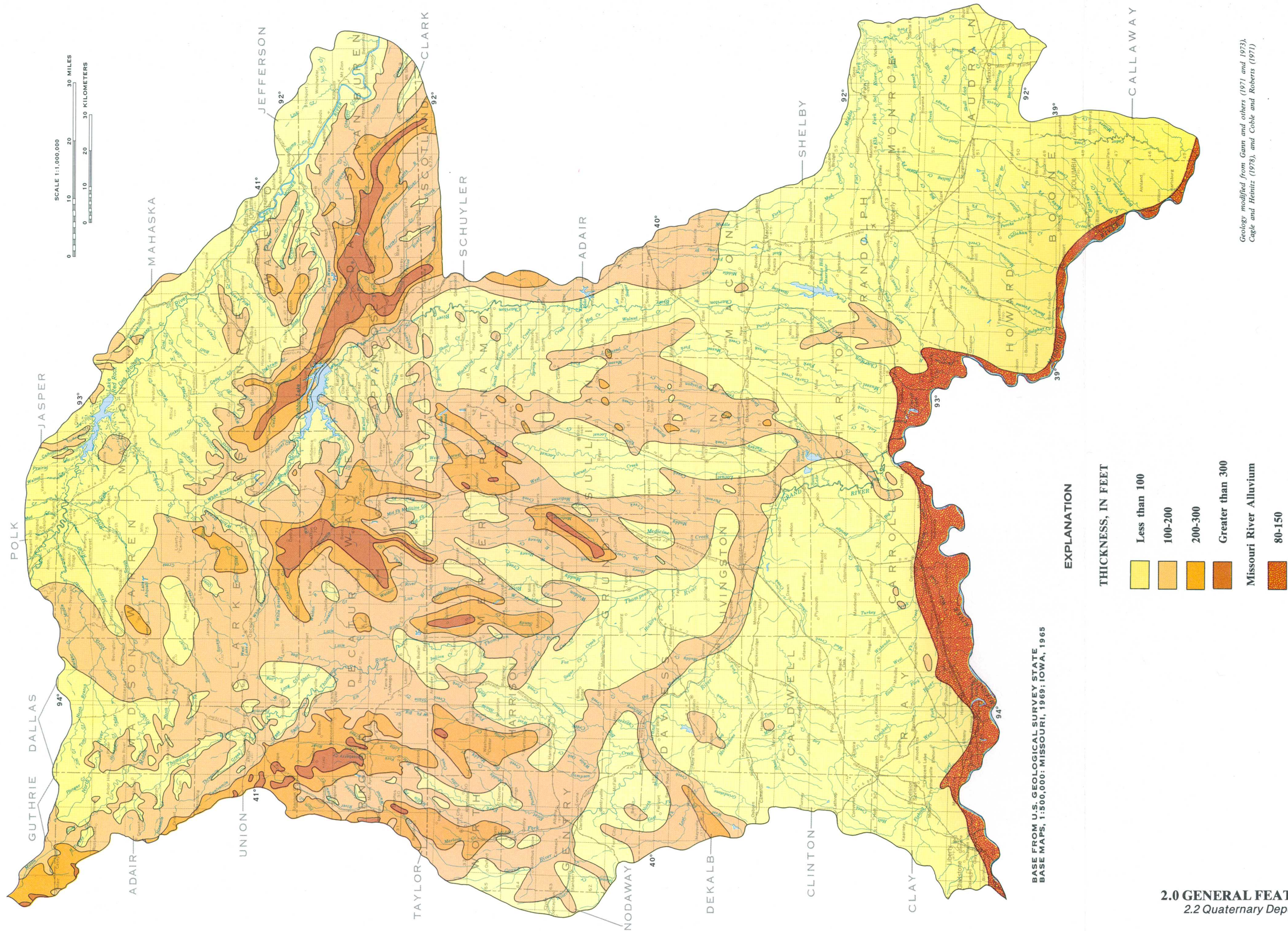
Glacial Drift, Alluvium, and Loess are Quaternary Deposits that Overlie the Bedrock Surface

Thickness of the Quaternary deposits varies from less than 100 feet to greater than 300 feet.

Quaternary deposits cover the surface of almost all of Area 38 except for small areas where the bedrock crops out. Quaternary deposits are unconsolidated and belong to the Pleistocene and Holocene Series. These materials are the youngest in geologic time; the alluvium is the most recent. Glacial drift, alluvium, and loess are materials resulting from distinctly different modes of transportation and deposition. Glacial drift is composed of material transported by the glaciers and deposited by ice or water from melting ice. The alluvial deposits consist of material transported and deposited by streams. Loess is widely interpreted as being deposited by wind action in arid zones around the ice caps (Smalley, 1975).

In much of the area, the thickness of Quaternary deposits is less than 100 feet (figure 2.2-1). Some streams have eroded their channels through the loess and into the drift and some have eroded to bedrock (Gann and others, 1973). In the northern part of Area 38, the unconsolidated Quaternary materials are more than 300 feet thick where preglacial valleys have been filled (Gann and others, 1973 Cagle and Heinitz, 1978). The Missouri River alluvial deposits are 80 to 150 feet thick (Gann and others, 1973).

The Quaternary deposits are hydrologically important because they form significant aquifers in the area. The effects on these deposits need to be considered during coal mining and land reclamation.



Geology modified from Gann and others (1971 and 1973), Cagle and Hénitz (1978), and Coble and Roberts (1971)

2.0 GENERAL FEATURES--Continued

2.3 Soils

Soils are Mainly of Glacial, Eolian, and Alluvial Origin

Most soils in Area 38 have been formed from pre-Wisconsin glacial drift, pre-Wisconsin till-derived paleosols, loess, and alluvium.

The assemblage of soil associations in figure 2.3-1 depicts the spatial distribution of major soils groups in Area 38. Major soil groups are subdivided into specific soil associations in table 2.3-1. A soil association is two or more soils that occur in a characteristic manner in a given area that can be distinguished among themselves but are grouped together because of their common areal relationship (Bates and Jackson, 1980).

The soils in Area 38 range from well drained to water-logged and from almost impermeable to very permeable (Runge and others, 1970 and Allgood, 1979). Slopes range from 0 to 50 percent (U.S. Department of Agriculture, 1978, and Allgood, 1979).

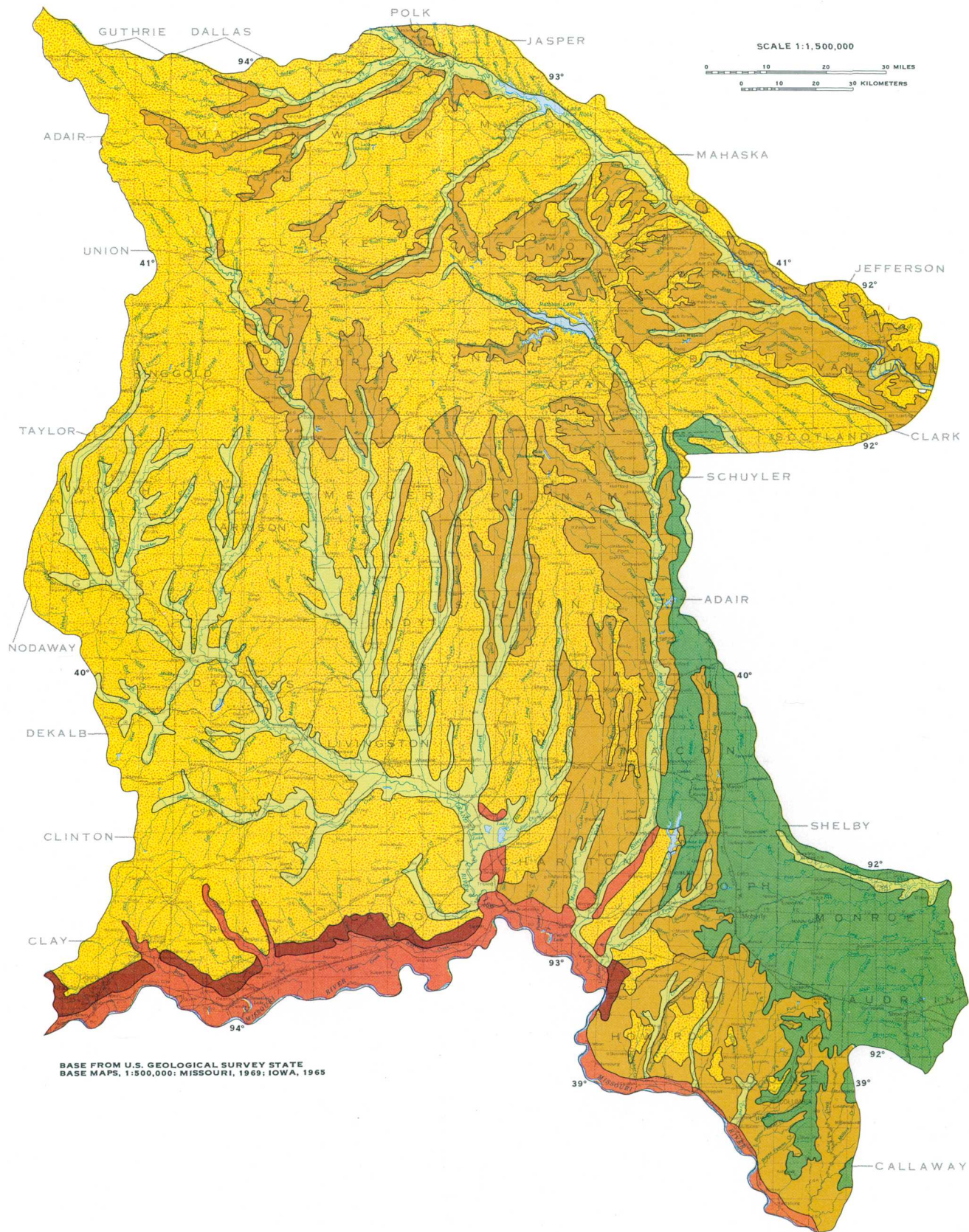
Natural conditions and matter that interact to form soil are parent material, climate, time, topography, and biota (Bates and Jackson, 1980). The major parent materials in Area 38 are pre-Wisconsin glacial drift, pre-Wisconsin till-derived paleosols, loess, and alluvium. Glacial drift is a general term for all material ranging in size from clay to boulders that was deposited by glacier ice or meltwater from the ice. Till-derived paleosols are buried soil horizons that were developed from till, which was deposited by glacier ice. Loess is an eolian (windblown) deposit

consisting mainly of silt that is porous and friable. Alluvium consists of material ranging in size from clay to boulders deposited by streams.

Soils are dynamic systems; they are in a continuing process of evolution, adjusting to changes in their environment (Strahler, 1966). Any disruptive activities will cause the soils to be altered to varying degrees. For example, the greater the percent of slope, the greater the velocity of the water flowing down the slope and the greater the erosion. Theoretically, if the velocity of water flow is doubled, the flow should move particles 64 times larger than before (Buckman and Brady, 1969). Wischmeir and Smith (1978) provide a useful study for conservation planning that uses the Universal Soil Loss Equation and includes such factors as rainfall and runoff, soil erodibility, topography, vegetation cover and management, and support practices.

The soil map (figure 2.3-1) is very general. For more detailed, precise information regarding the physical and chemical characteristics of a soil in a specific location, the reader is referred to the county soil surveys, compiled by the U. S. Department of Agriculture, Soil Conservation Service.

Table 2.3-1 Soil associations.



IOWA

MISSOURI

- Prairie-derived, developed from alluvium**
Colo, Zook, and Hodaway; slope 0-5 percent
- Forest-derived, developed from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols**
Lindley and Weller; slope 2-25 percent
Lindley and Clinton; slope 2-30 percent
Clinton, Lindley, and Keswick; slope 5-30 percent
Fayette and Lindley; slope 2-25 percent
- Prairie to forest-derived, developed from loess, pre-Wisconsin till, or pre-Wisconsin till-derived paleosols**
Sharpsburg, Shelby, and Adair; slope 2-14 percent
Sharpsburg, Macksburg, Winterset, and Clarinda; slope 0-9 percent
Shelby, Adair, and Sharpsburg; slope 2-18 percent
Grundy and Haig; slope 0-9 percent
Grundy, Haig, Shelby, and Adair; slope 0-14 percent
Adair, Shelby, Lindley, and Grundy; slope 2-18 percent
Edina and Seymour; slope 0-9 percent
Seymour, Edina, Clarinda, Adair, and Shelby; slope 0-14 percent
Shelby, Adair, Lindley, and Seymour; slope 2-18 percent
Sharpsburg, Macksburg, and Winterset; slope 0-5 percent
Grundy, Pershing, Weller, Keswick, and Lindley; slope 2-14 percent
Otley, Mahaska, Ladoga, Clinton, and Adair; slope 0-14 percent
Otley, Clinton, and Lindley; slope 2-18 percent
Tana, Downs, and Fayette; slope 2-14 percent
- Prairie and mixed forest-derived, developed from alluvium**
Kennebec, Nodaway, Colo, and Zook; slope 0-5 percent
Arbela, Piopolis, and Blackoar; slope 0-2 percent
- Missouri and Mississippi Alluvium, grass and forest-derived**
Kennebec, Zook, and Blackoar; slope 0-5 percent
Buckney, Norborne, Leta, and Booker; slope 0-6 percent
Haynie, Leta, and Waldron; slope 0-5 percent
Chariton and Bremer; slope 0-2 percent
- Central Mississippi Valley Wooded Slopes, forest-derived, with some grass, developed from loess, glacial till, shale and limestone and cherty limestone residuum**
Menfro, Winfield, and Lindley; slope 2-30 percent
Lagonda, Keswick, and Lindley; slope 2-30 percent
Weller, Keswick, Lindley, and Mandeville; slope 2-30 percent
Hatton, Keswick, Lindley, and Goss; slope 2-45 percent
Hatton, Keswick, Goss, and Gasconade; slope 2-50 percent
Weller, Goss, and Gasconade; slope 2-50 percent
- Deep Loess and Drift, tall grass and forest-derived, with some alluvium and shale, also, as parent material**
Edina and Kilwinning; slope 0-9 percent
Kilwinning, Lanoni, and Armster; slope 2-20 percent
Seymour and Lagonda; slope 2-15 percent
Grundy and Lagonda; slope 1-15 percent
Sharpsburg, Higginsville, Lanoni, and Shelby; slope 0-25 percent
Sharpsburg, Gara, and Zook; slope 0-40 percent
Sharpsburg, Lagonda, and Shelby; slope 0-25 percent
Pershing, Armstrong, and Gara; slope 2-40 percent
Lagonda, Lamoni, Armster, and Snead; slope 2-20 percent
Lamoni, Shelby, and Zook; slope 0-25 percent
Adair, Shelby, and Zook; slope 0-25 percent
- Central Claypan Area, grass and forest-derived, developed from loess and glacial till**
Putnam and Mexico; slope 0-5 percent
Mexico, Leonard, Armstrong, and Lindley; slope 1-30 percent
- Deep Loess Hills, forest, mixed forest, and prairie-derived, developed from loess in the uplands and alluvium in the bottomlands**
Knox, Marshall, and Kennebec; slope 0-35 percent

Soils modified from U.S. Department of Agriculture (1978)--Iowa, and Allgood (1979), and Persinger (1979)--Missouri.

Figure 2.3-1 Soils of Area 38.

2.0 GENERAL FEATURES--Continued

2.4 Surface Drainage

Five Major Rivers Drain Most of Area 38

Surface-water drainage in Area 38 is into the Mississippi and Missouri Rivers.

Most of Area 38 is drained by five major rivers--Chariton, Des Moines, Elk Fort Salt, Grand, and Thompson. The Des Moines River drains about 60 percent of Area 38 in Iowa and flows into the Mississippi River about 45 miles east of the area. The remainder of the Iowa part of Area 38 is drained by the headwaters of the Chariton, Grand, and Thompson Rivers that flow southward into Missouri, and by the headwaters of several smaller tributaries of the Mississippi River, which flow southeastward into Missouri.

Of the four major rivers draining most of Area 38 in Missouri, only the Chariton and Grand Rivers flow directly into the Missouri River. The Thompson River is a tributary of the Grand River and the East

Fork Salt River flows into the Mississippi River about 40 miles east of the area. The remainder of Area 38 in Missouri is drained by smaller streams that flow directly into the Missouri River.

Most surface waters in Area 38 are classified to protect livestock and wildlife watering, aquatic life, noncontact recreation and crop irrigation. Most reaches of the major rivers are also classified to protect primary contact water use and (or) use of surface waters as sources of potable water. Detailed information on use classification of streams in Iowa and Missouri is available from the Iowa Department of Environmental Quality, 1980, and the Missouri Department of Natural Resources, 1981.

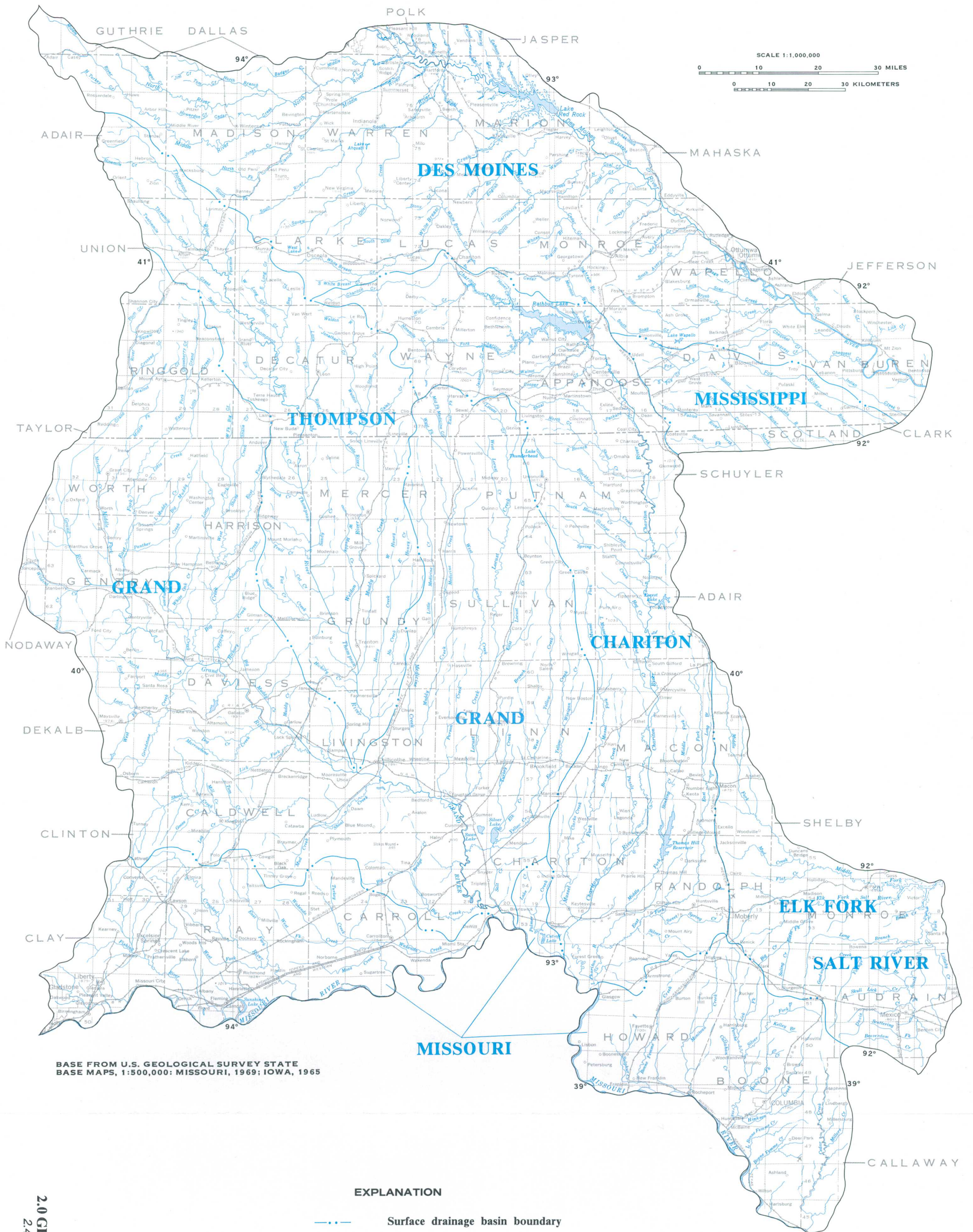


Figure 2.4-1 Surface drainage.

2.0 GENERAL FEATURES--Continued

2.5 Land Use

Most of Area 38 is Agricultural Land

Area 38 is primarily agricultural land and forest land with the remaining land use divided between urban land, barren land, and water.

Area 38 was divided into five general types of land use (Anderson and others, 1976) as shown on the land use map (figure 2.5-1). Of the five categories, by far the largest proportion of the land area is in agricultural land, with forest land next. Small areas are covered by reservoirs, lakes and ponds, urban areas, and by barren land (including strip mines).

Flow patterns in the area are affected by the use of the land surface. After mining, the topography of an area is completely altered. Level to rolling land that was in cultivation, rangeland, or forest is rearranged into a series of mounds and ridges. The rate

of infiltration is increased or decreased according to the materials that were brought to the surface. Urbanization and changes in agricultural practices also can affect infiltration rates and the volume of runoff.

Land-use and land-cover information and maps in greater detail can be found in U.S. Geological Survey open-file reports titled "Land Use Series." Information on the Land Use Series is available from the National Cartographic Information Center, U.S. Geological Survey, National Center, Reston, Virginia 22092.



Figure 2.5-1 Land use, 1976.

2.0 GENERAL FEATURES--Continued

2.6 Water Use

Eighty Percent of the Water Used in Area 38 is Obtained from Surface-Water Sources

Two-thirds of all of the water used is for electric-power generation.

The total water used in Area 38 during 1980 was 426.7 million gallons per day (Mgal/d), and was obtained from both surface- and ground-water sources. About 343 Mgal/d (80 percent) was from surface-water sources and 84 Mgal/d (20 percent) was from ground-water sources. Surface-water sources included streams, ponds, and reservoirs.

The largest volume of water used, 286.2 Mgal/d (67 percent), was for cooling in generating electric power. Almost all the water withdrawn for power generation was surface water. Location of the counties where power generation occurs is shown in figure 2.6-1, which also summarizes total water use by county.

Water for public, industrial, and rural uses required 140.5 Mgal/d or about 33 percent of the total volume withdrawn. Ground-water and surface-water sources provided 84.1 Mgal/d and 56.4 Mgal/d respectively for the above uses. Public-supply uses were 55.9 Mgal/d and rural use, including irrigation, required about 53.4 Mgal/d. Industrial demands for water were 31.2 Mgal/d.

Water use by source and category is given in figure 2.6-2. Water-use data were collected and compiled by state for 1980 and is available through the National Water Data Exchange (NAWDEX). For details about NAWDEX see section 8.2.

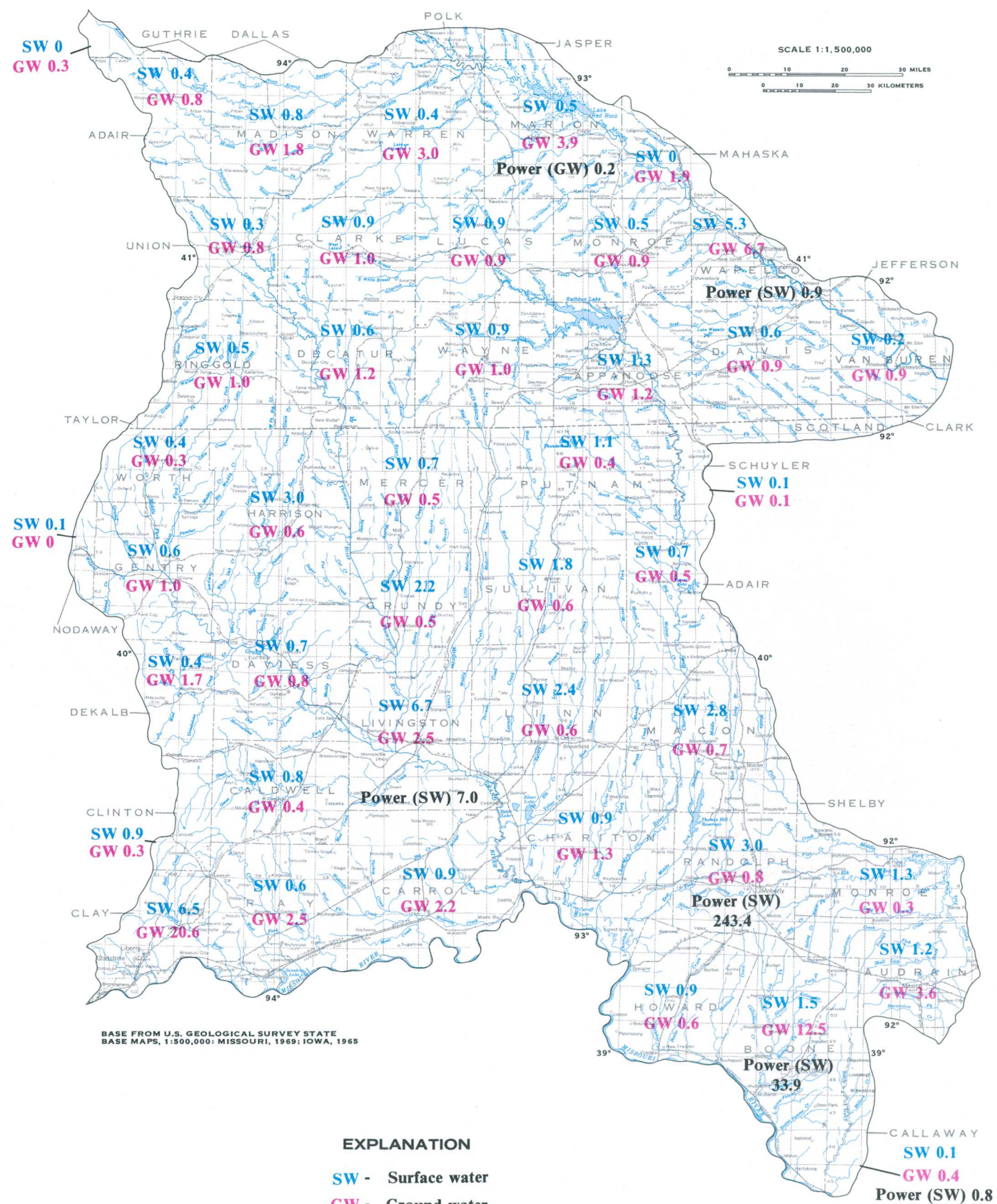


Figure 2.6-1 Water use by county, in million gallons per day-1980.

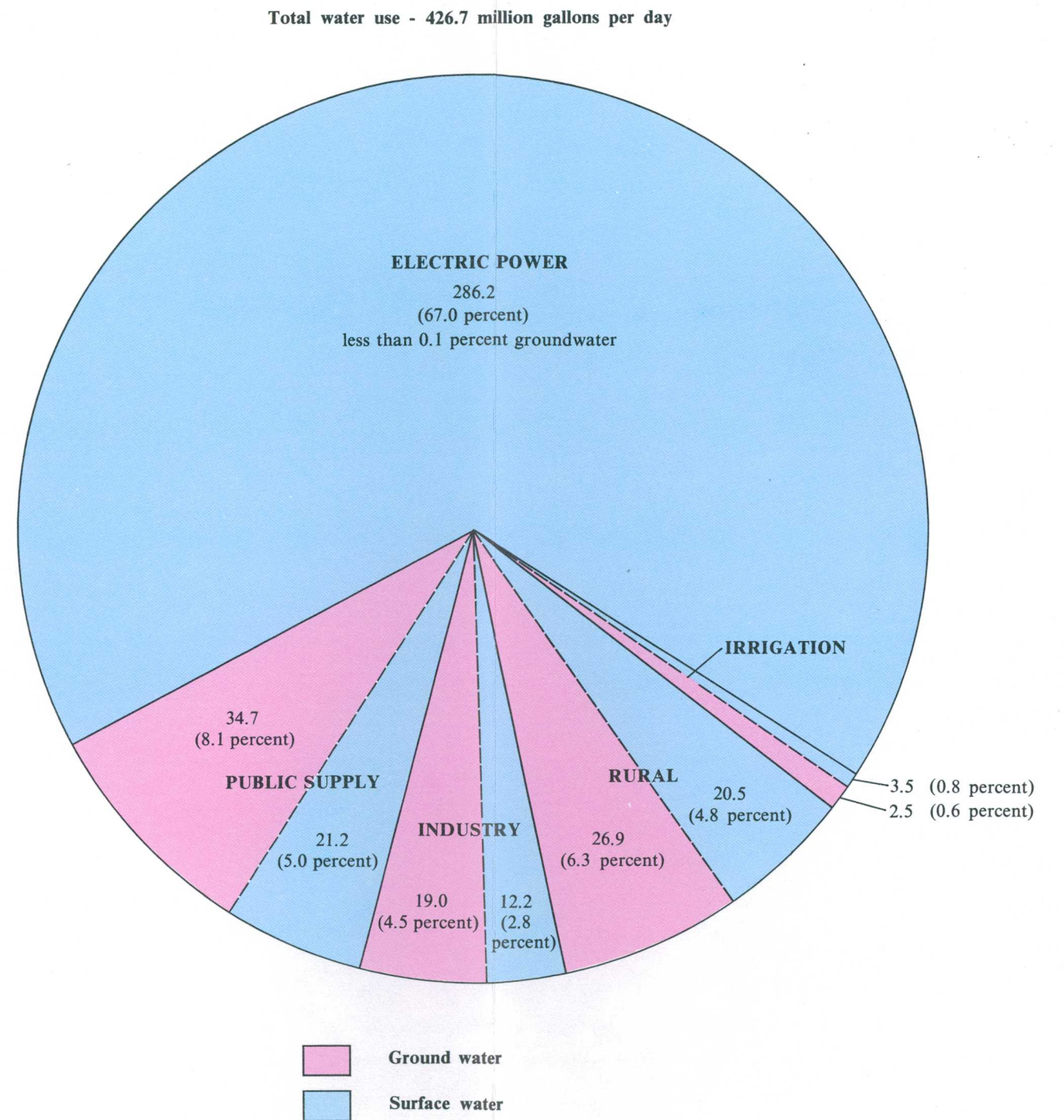


Figure 2.6-2 Total water use, in million gallons per day-1980.

2.0 GENERAL FEATURES--Continued

2.7 Climate

Climate is Temperate and Continental

The climate of Area 38 is characterized by long winters with a persistent snow cover, long summers with average July temperatures greater than 77° Fahrenheit and short spring and fall seasons.

The climate of the study area is classified as temperate and continental with a distinct contrast between the winter and summer (Trewartha, 1968). The average daily mean temperature during July is 77.12° Fahrenheit, and the average daily mean temperature during January is 23.96° Fahrenheit at Princeton, Missouri (Vernon K. Jones, Climatologist, Department of Atmospheric Science, University of Missouri-Columbia, written commun., 1982).

The mean annual precipitation ranges from about 31 inches in the extreme north-central part of the area to about 38 inches in the southeast part (figure 2.7-1). The maximum 24-hour rainfall that is expected to occur once every 2 years, on the average, ranges from 3.2 inches in the north to 3.4 inches in the south. Mean annual precipitation for selected stations and precipitation extremes for 1951-80 are presented in table 2.7-1. Data from the records of National Weather Service of the U.S. Department of Commerce have been used to develop the map and information presented in this section.

Precipitation in the area varies from year to year, with the departure from normal usually less than 10 inches. An 82-year record from the station at Chariton, Iowa, shows that a departure of more than 5 inches of precipitation from normal annual precipita-

tion (1941-70) occurred in 51 percent of the years and more than 10 inches in 11 percent of the years. Other stations in the area probably have similar trends (Cagle and Heinitz, 1978).

Precipitation is greatest during the spring and summer months. About 70 percent of the precipitation usually falls from April through September (Cagle and Heinitz, 1978). The cyclical pattern of precipitation generally ranges from about 1 inch during February to about 5 inches during the spring months due to moisture availability from the southeast and the proximity of eastward moving storms (Waite, 1970). Generally, rain constitutes almost 90 percent of the precipitation and snow almost 10 percent, with the other forms of precipitation constituting less than 1 percent (Waite, 1970).

Days with snow cover vary from 40 to 50 in the northern part of the area (Waite, 1970) to about 30 in the south (Trewartha, 1968). Normally, in the northern part of the region the snow season begins in November or early December and ends in March or early April. Average seasonal snowfall varies from more than 30 inches in the north to less than 25 inches farther south (Waite, 1970).

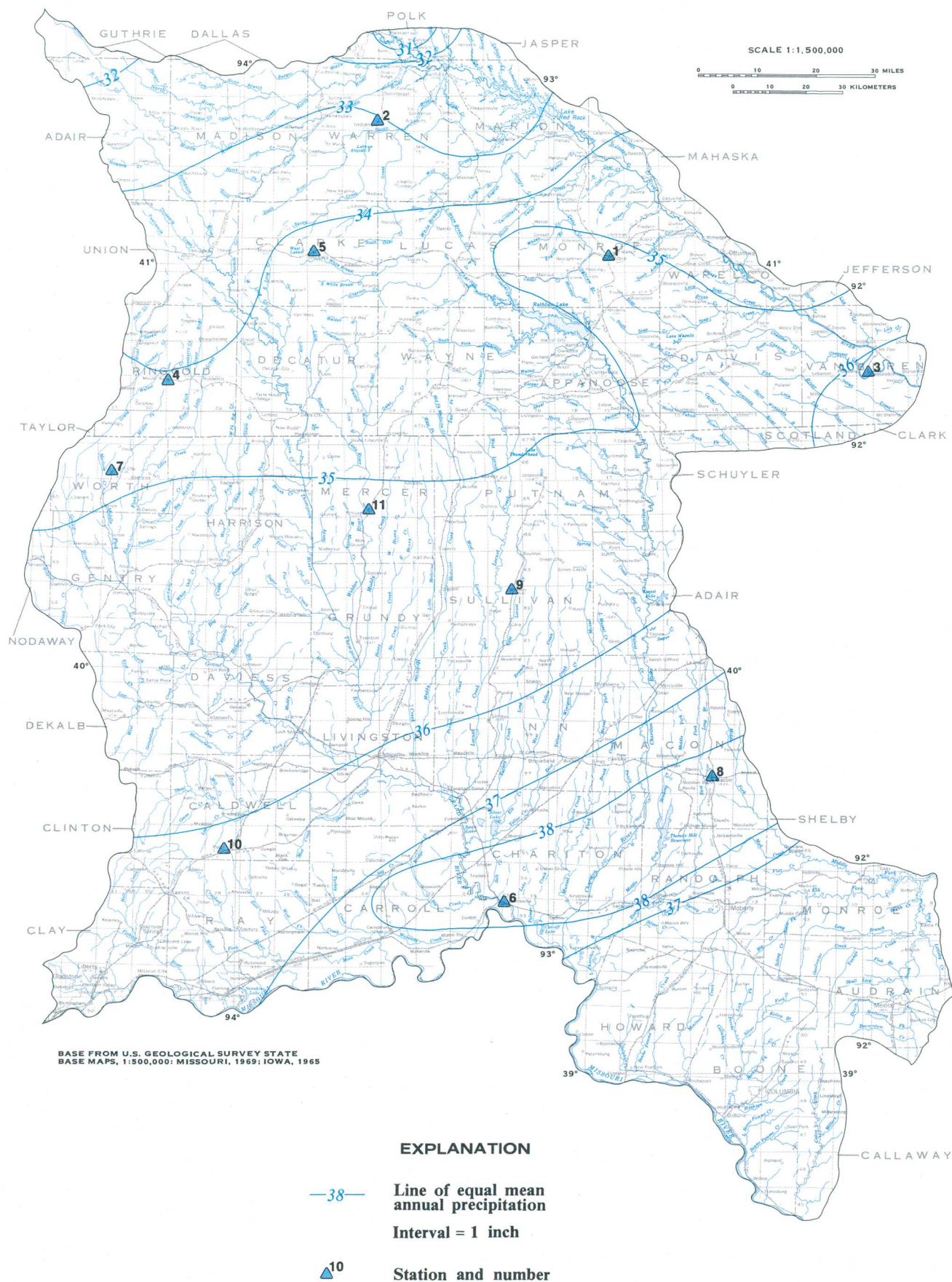


Table 2.7-1 Mean annual precipitation and precipitation extremes for selected stations, 1951-80.

Map No.	Station	Weather station number	30-year ^{1/} mean (inches)	Precipitation			
				Maximum ^{2/} (inches)	Year	Minimum ^{2/} (inches)	Year
1.	Albia, Monroe Co., Iowa	0112	35.62	56.18	1973	19.56	1953
2.	Indianola, Warren Co., Iowa	4063	33.17	54.23	1973	21.68	1956
3.	Keosauqua, Van Buren Co., Iowa	4389	36.42	62.94	1973	22.97	1956
4.	Mount Ayr, Ringgold Co., Iowa	5769	33.92	51.73	1973	*20.53	1953
5.	Osceola, Clarke Co., Iowa	6316	34.85	49.62	1959	22.27	1956
6.	Brunswick, Chariton Co., Mo.	1037	38.14	62.32	1961	19.42	1956
7.	Grant City, Worth Co., Mo.	3369	34.55	46.73	1973	24.01	1974
8.	Macon, Macon Co., Mo.	5175	38.66	56.99	1973	24.37	1953
9.	Milan, Sullivan Co., Mo.	5578	35.59	53.15	1973	25.65	1971
10.	Polo, Caldwell Co., Mo.	6775	36.85	54.09	1961	18.71	1956
11.	Princeton, Mercer Co., Mo.	6866	35.27	52.79	1961	23.39	1953

*-Estimate

^{1/} Iowa data from P. J. Waite, State Climatologist, Iowa Department of Agriculture, Des Moines, written commun., 1981. Preliminary Missouri data from V. K. Jones, Climatologist, University of Missouri, in Columbia, written commun., 1981.

^{2/} Iowa data from U.S. Department of Commerce 1951-81. Missouri data from V. K. Jones, Climatologist, University of Missouri, in Columbia, written commun., 1981.

Figure 2.7-1 Distribution of mean annual precipitation (in inches), 1951-80.

3.0 COAL MINING

3.1 History and Potential

Coal has been Mined for 130 Years, But Large Reserves Remain

Production has fluctuated with demand; currently (1982), demand is large and production is expected to increase.

Coal mining in Area 38 dates back to the 1840's. The use of coal at that time primarily was for the local population in the form of domestic heating and blacksmith shops. Production increased as other uses of coal began to compete for the available supply. Much of this increased demand came first from steamboats and later from the expanding railroad industry. Production peaked in 1917 when Iowa produced 9 million tons and Missouri produced 6 million tons. Decreases in production were caused by competition from inexpensive sources of alternative fuels such as natural gas and fuel oil. During the 1940's surface mining of coal began and production, which had decreased since 1917, began to increase. This increase was due largely to the increased demand for coal as a fuel to power steam-generation plants for the production of electric power. Existing powerplants in Missouri, typically require 0.75 to 2 million tons of coal yearly (Robertson, 1973). Recent expansions of some powerplants have increased their coal use to approximately 3.5 million tons per year.

An important factor in determining the past and future demand for coal in Area 38 is the quality of the coal. The coal is bituminous and has an average heat value of approximately 11,000 British Thermal Units per pound. A disadvantage of Area 38 coal is that it has a relatively large sulfur content, an average of 4.27 percent for Missouri (U.S. Geological Survey and others, 1967).

Coal occurs in numerous beds in Area 38. These beds vary in thickness, extent, and depth, sometimes within relatively short distances. The mining areas, shown in figure 3.1-1, reflect the access and suitability of coal beds to the mining methods in use during

the operation of the mine. Areas with quality coal deposits near the land surface received the most attention in past mining efforts. Future coal mining areas may be strongly influenced by the economics of the coal industry.

Several estimates of reserves have been made for both Iowa and Missouri. The extent of potentially mineable reserves in Area 38 is shown in figure 3.1-2. For the purpose of this report no attempt was made to distinguish between surface and underground mineable reserves. Estimates of total remaining reserves include identified, hypothetical, and speculative resources. Total recoverable reserves are estimated to be 50 percent of the total remaining reserves. Robertson and Smith (1981) estimate total recoverable reserves for the Missouri part of Area 38 to be approximately 3.3 billion tons. Iowa's total recoverable reserves in Area 38 are estimated to be more than 2.5 billion tons (Landis and Van Eck, 1965).

The potential for increased production from Iowa and Missouri coal fields is good. Currently (1982), a large part of the coal used within Iowa and Missouri is obtained from sources outside of these two States because of a lesser sulfur content. It appears that the costs of transporting coal from out-of-State may soon make the use of in-State coal more desirable. This, in addition to the policy of converting existing gas and oil-fired powerplants to coal in order to decrease this country's dependence on foreign oil, and creating synthetic petroleum products and gas from coal will undoubtedly increase demand for Iowa and Missouri coal.

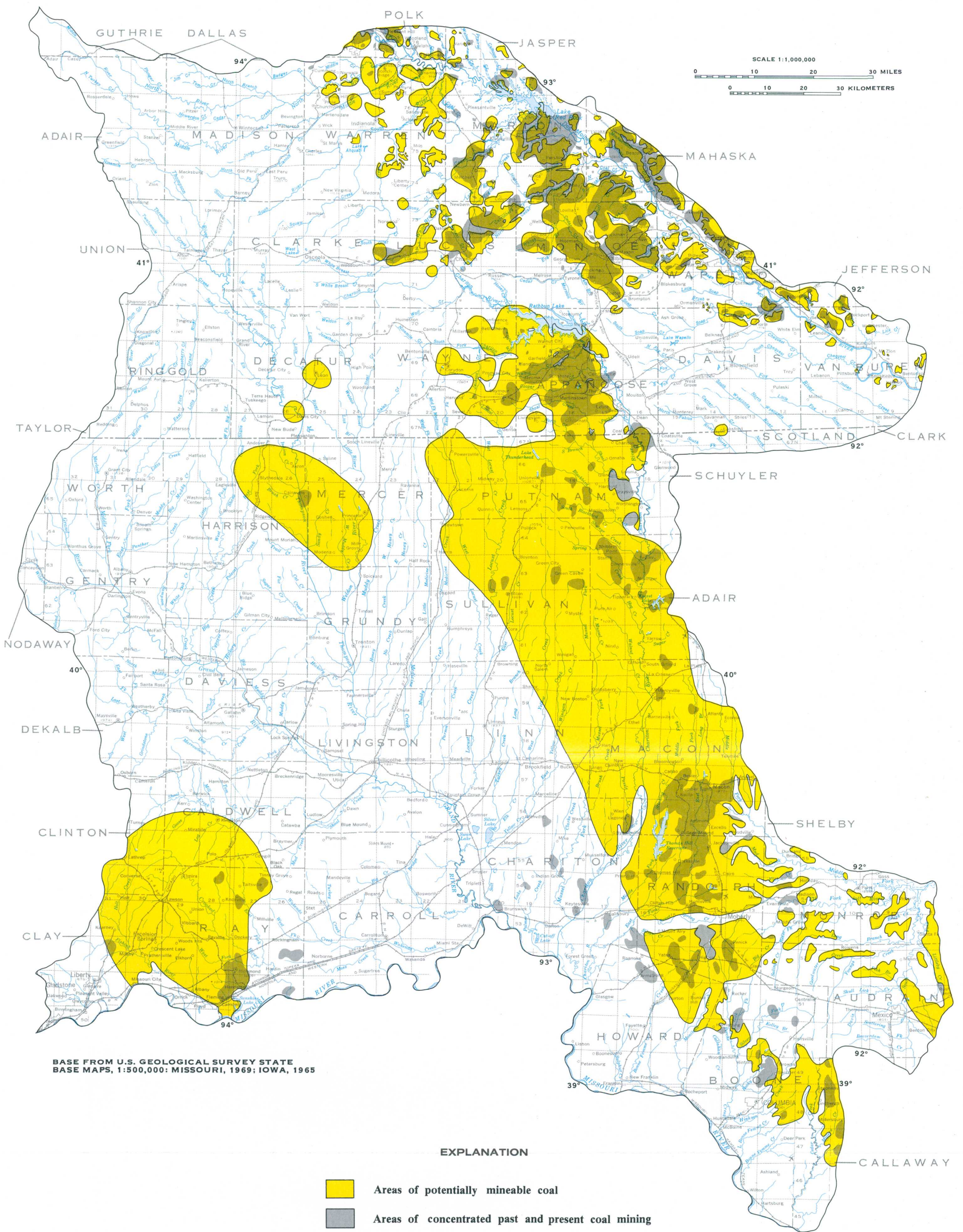


Figure 3.1-1 Coal-mining areas.

3.0 COAL MINING--Continued

3.2 Methods of Coal Mining

Underground Mining has been Replaced by Surface Mining

Not all past surface-mined lands are subject to reclamation under recently enacted reclamation laws.

During the 1840's local coal deposits were developed for local users. The most common method of obtaining the needed coal was by horizontally digging into outcrops (drift mines) along river valleys or by scraping small quantities of overburden off of deposits in river bottoms. Drift mines were limited in extent by the air naturally circulating in them.

As demand for coal increased, the quantity of coal that could be produced from drift mines was not sufficient. More and more mines were being extended as shaft or slope mines. The coal was mined mostly by men using hand tools, and animals were used to haul coal and spoil during the middle 1880's.

In underground mines two methods of mining were most commonly used. The room and pillar method, which was the most common, consisted of carving out rooms approximately 30 by 200 feet between at least two parallel horizontal tunnels. Walls of coal were left between the rooms to support the ceiling. This method by necessity left large quantities of coal in the form of walls or pillars.

The second underground method used was the long-wall method. In long-wall mining, a cut was made in the material beneath the coal seam and the weight of the coal broke the coal away from the wall. This method of mining permitted more complete removal of the coal although it was limited because it required strong rock ceilings and areas of removed

material could not become too large or the ceiling was subject to collapse.

With the advent of large earth-moving machines it has become economically possible to use surface-mining techniques to obtain suitable quantities of coal. Surface mines have now all but replaced underground mines in Iowa and Missouri.

The most common method of surface mining is area or advancing pit mining as shown in figures 3.2-1 and 3.2-2. In this method, overburden, sometimes as much as 100 feet thick, is removed from a long trench, exposing the coal at the bottom. After removal of the coal a second trench is dug adjacent to and parallel with the first trench. The overburden removed from the second trench is placed in the first trench. This continues across the area to be mined until the last trench is dug usually later filling with water forming a "final cut" lake. The advantages to this method are that the area is relatively easily leveled and reclaimed.

The U.S. Soil Conservation Service estimates that in Area 38, Iowa has 13,799 acres of land disturbed by surface mining that are not required by law to be reclaimed and 328 acres that are covered under reclamation laws. The Missouri part of Area 38 has 18,336 acres and 2,413 acres respectively (U.S. Soil Conservation Service, 1979).

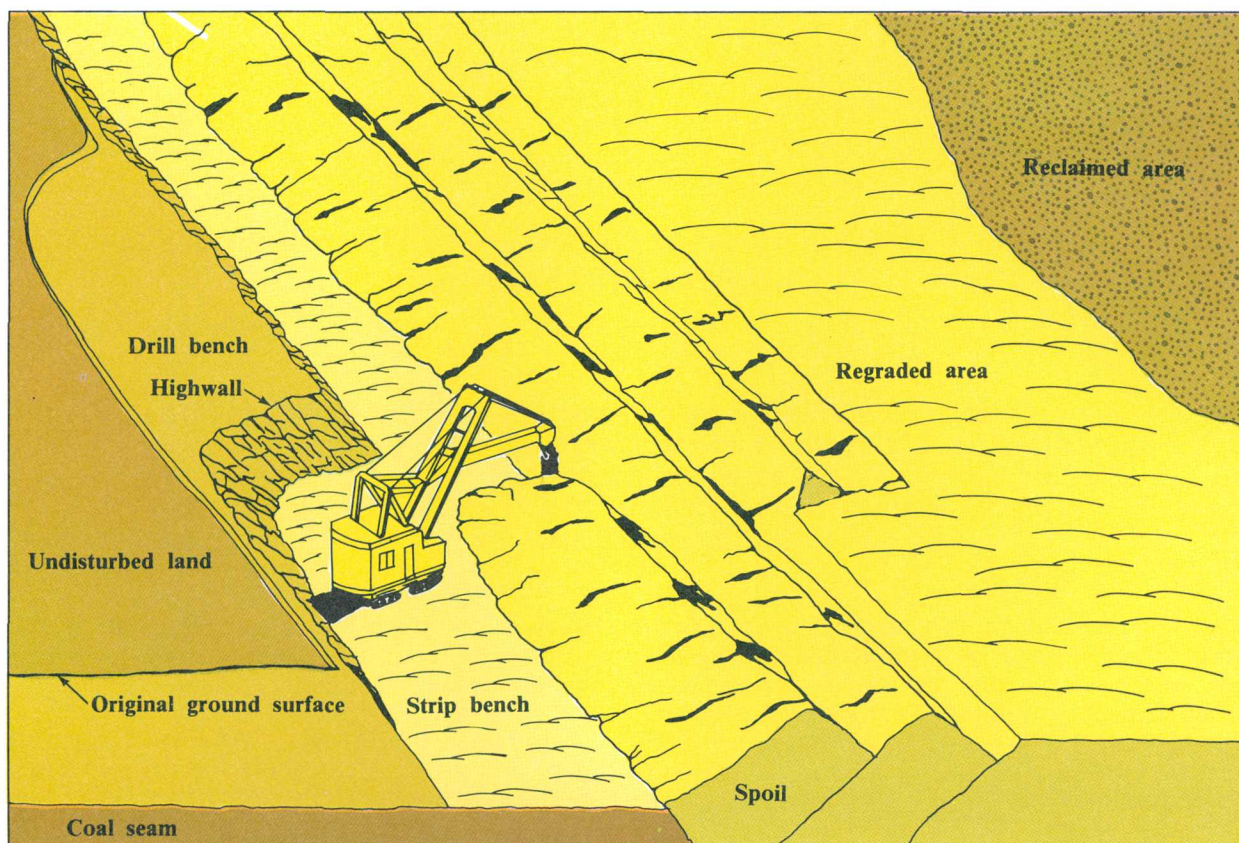


Figure 3.2-1 Sequence of mining using advancing-pit method.



Figure 3.2-2 Current (1982) mining operation in Missouri.

4.0 SURFACE WATER

4.1 Gaging Stations

Surface-Water Network for Collection of Hydrologic Data Consists of 183 Stations

The current (1982) surface-water network for collection of hydrologic data consists of 56 continuous-record, streamflow-gaging stations; 2 continuous-record, reservoir-stage stations; 13 partial-record, crest-stage stations; 89 partial-record, low-flow stations; 20 synoptic stations; and 3 other water-quality stations.

The primary objective of the surface-water network in Area 38 is to provide information on streamflow, water temperature, and specific conductance for all streams. At present (1982), data are available for 183 stations; these stations are shown in figure 4.1-1, and details about the period of record, types of data collected, and drainage areas are shown in table 10.1 at the back of the report. The network also includes 36 stations, where data was collected intensively during a short period of time to provide information required by Public Law 95-87 (Surface

Mining Control and Reclamation Act of 1977). At 20 of these stations, water-quality and discharge measurements were obtained on a synoptic basis.

Additional information about the stations and data is available from computer storage through National Water Data Exchange (NAWDEX) and is published annually in the U.S. Geological Survey reports "Water-Resources Data for Missouri" and "Water Resources Data for Iowa".

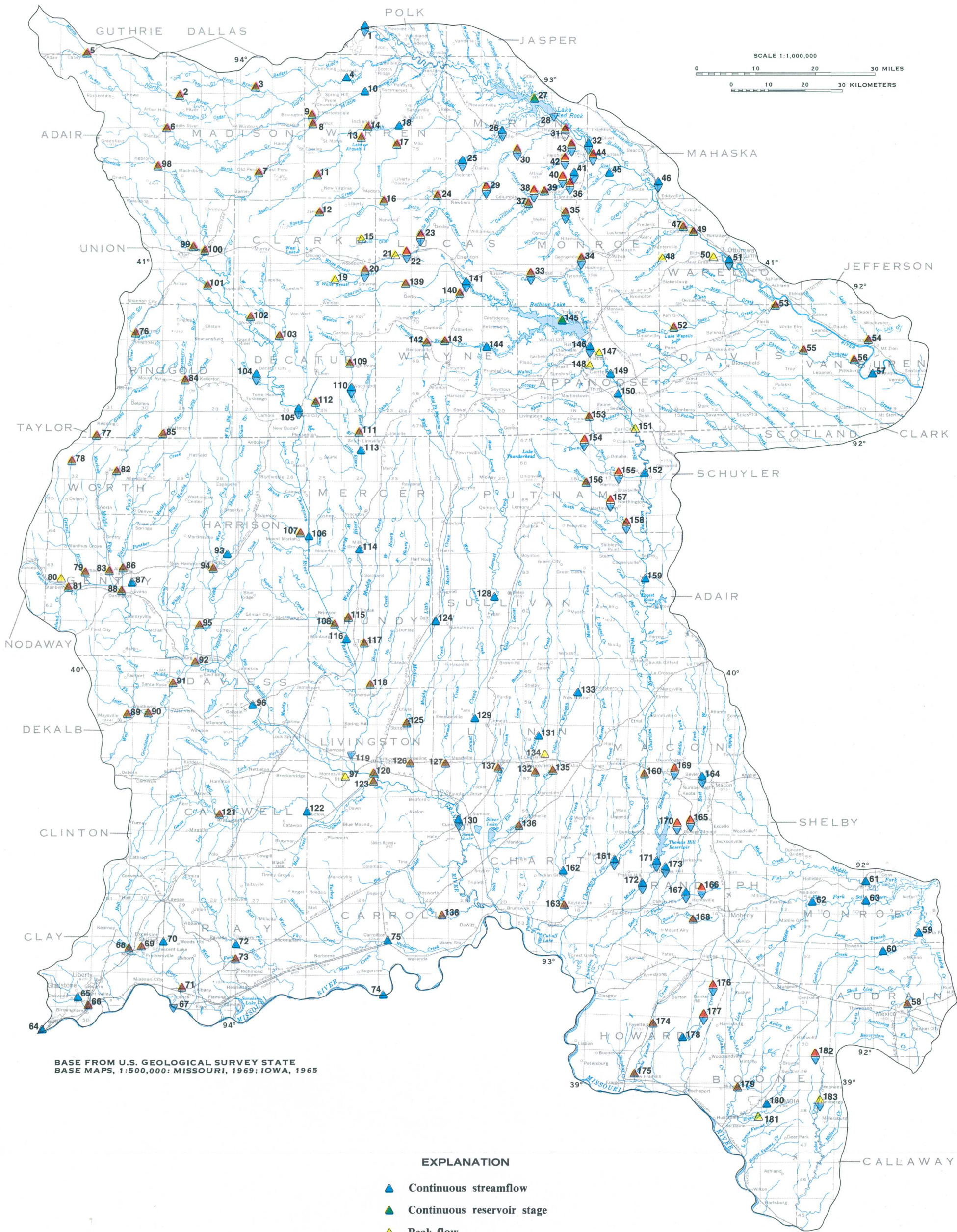


Figure 4.1-1 Location of streamflow-gaging stations and water-quality stations.

4.0 SURFACE WATER--Continued

4.2 Daily, Seasonal, and Average Annual Streamflow

Streamflow Varies Seasonally and from Year to Year

Daily and seasonal variations in flow rates combine to produce considerable variations in flow patterns and volumes.

Daily variations in streamflow are illustrated by the sample hydrograph in figure 4.2-1. Lowest flows usually occur during late summer and fall, followed by a gradual increase to the highest flows of the year during spring and early summer. Daily variation of flow and variability of flow from month to month are illustrated in figures 4.2-1 and 4.2-2; flows during water years 1979 and 1980 generally were lower than long-time monthly average flows, and the peak flow for the year was considerably lower than the all-time maximum.

Annual average flows at streamflow-gaging stations where continuous record was sufficient to establish an average annual flow rate are shown in

table 4.2-1. Average annual flows of ungaged streams in Area 38 (except the Missouri and Des Moines Rivers) can be estimated by using the equation,

$$Q = 0.73 A^{0.97},$$

where average annual streamflow (Q) is in cubic feet per second, and drainage area (A) is in square miles. The equation is based on records for 45 streamflow-gaging stations with drainage areas ranging from 2.51 to 6,880 square miles. A presentation of the relationship between drainage area and average annual flow is shown in figure 4.2-3.

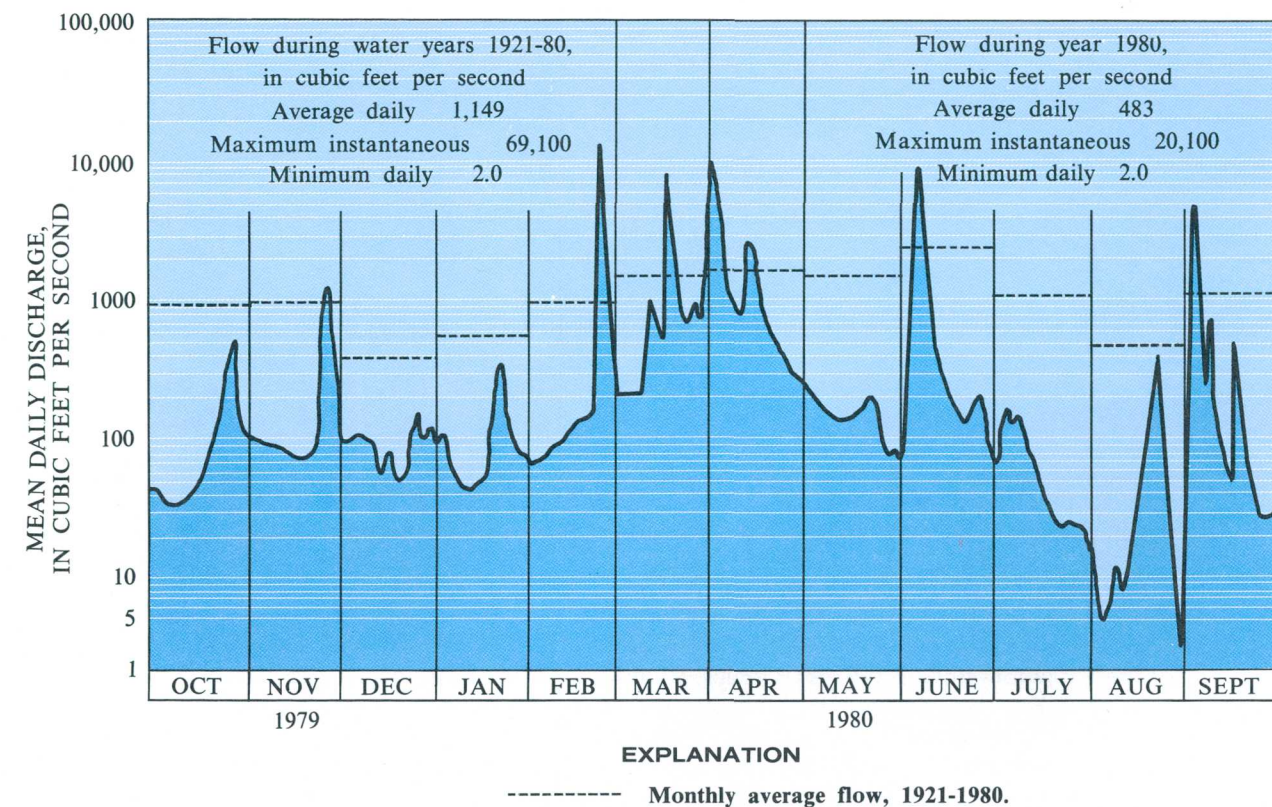


Figure 4.2-1 Average daily discharge and average monthly discharge for water years 1921-1980 at Grand River near Gallatin, MO., Station 96 (06897500).

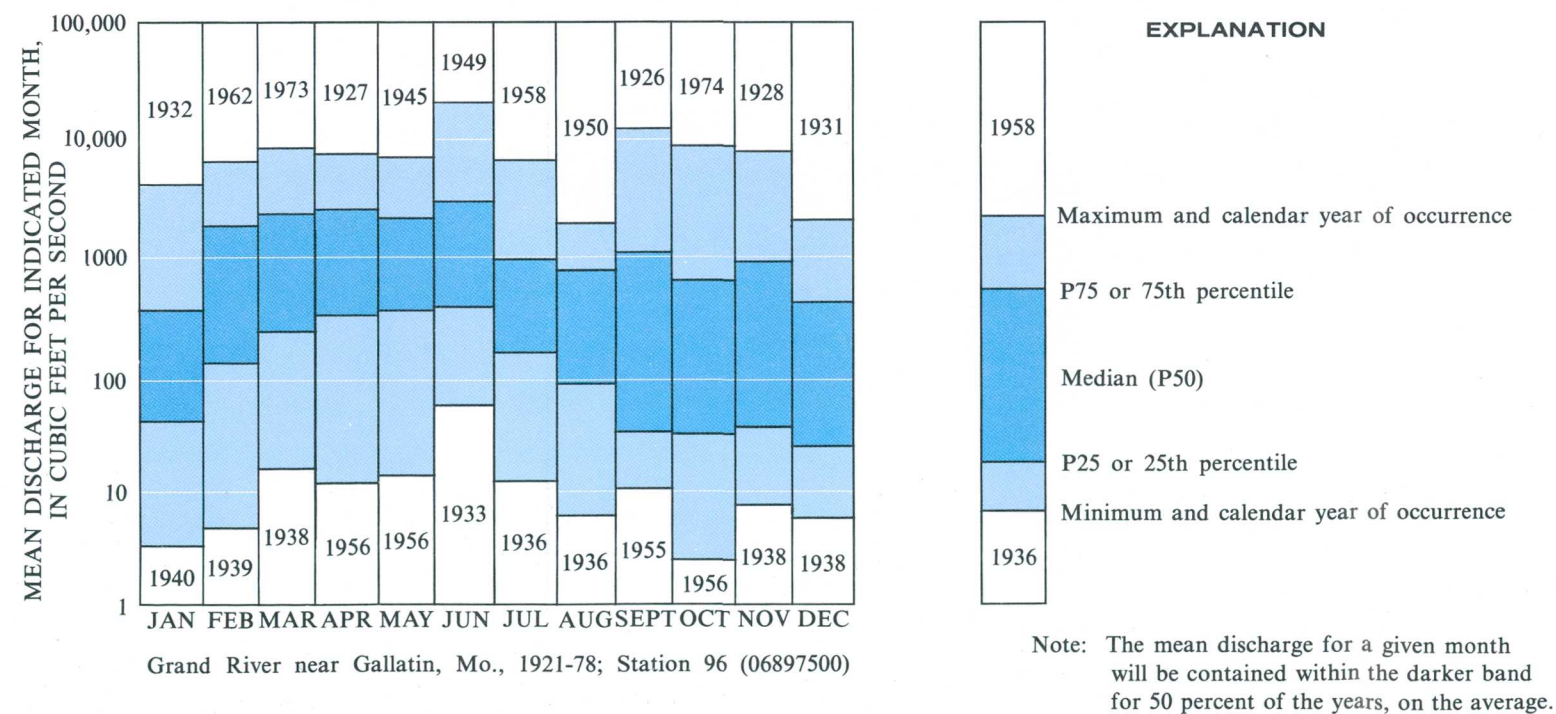


Figure 4.2-2 Monthly flow data for Grand River near Gallatin, MO., Station 96 (06897500).

Table 4.2-1 Average annual flow at streamflow gaging stations.

Map no. (fig. 4.1-1)	Station No.	Station name	Drainage area (square miles)	Average annual flow, in cubic feet per second
▲4	05486000	North River near Norwalk, Ia.	349	176
▲10	05486490	Middle River near Indianola, Ia.	503	251
▲18	05487470	South River near Ackworth, Ia.	460	257
▲25	05487980	White Breast Creek near Dallas, Ia.	342	182
▲26	05488000	White Breast Creek near Knoxville, Ia.	380	198
▲32	05488500	Des Moines River near Tracy, Ia.	12,479	4,667
▲41	05489000	Cedar Creek near Bussey, Ia.	374	198
▲51	05489500	Des Moines River at Ottumwa, Ia.	13,374	5,103
▲57	05490500	Des Moines River at Keosauqua, Ia.	14,038	5,531
▲59	05505000	South Fork Salt River at Santa Fe, Mo.	298	190
▲60	05506000	Youngs Creek near Mexico, Mo.	67.4	43.8
▲61	05506500	Middle Fork Salt River at Paris, Mo.	356	240
▲63	05507000	Elk Fork Salt River near Paris, Mo.	262	181
▲64	06893000	Missouri River at Kansas City, Mo.	485,200	54,830
▲70	06894500	E. F. Fishing River at Excelsior Springs	20.0	12.9
▲72	06895000	Crooked River near Richmond, Mo.	159	98.7
▲74	06895500	Missouri River at Waverly, Mo.	487,200	48,940
▲75	06896000	Wakenda Creek at Carrollton, Mo.	248	141
▲87	06896500	Thompson Branch near Albany, Mo.	5.58	2.83
▲93	06897000	East Fork Big Creek near Bethany, Mo.	95	48.3
▲96	06897500	Grand River near Gallatin, Mo.	2,250	1,160
▲104	06897950	Elk Creek near Decatur City, Ia.	52.5	30.0
▲105	06898000	Thompson River at Davis City, Ia.	701	366
▲106	06898100	Thompson River at Mt. Moriah, Mo.	891	516
▲110	06898400	Weldon River near Leon, Ia.	104	72.8
▲113	06898500	Weldon River near Mercer, Mo.	246	138
▲114	06899000	Weldon River at Mill Grove, Mo.	494	246
▲116	06899500	Thompson River at Trenton, Mo.	1,670	434
▲122	06899700	Shoal Creek near Braymer, Mo.	391	244
▲124	06900000	Medicine Creek near Galt, Mo.	225	141
▲128	06901000	Locust Creek near Milan, Mo.	225	153
▲129	06901500	Locust Creek near Linneus, Mo.	550	325
▲130	06902000	Grand River near Sumner, Mo.	6,880	3,826
▲131	06902200	West Yellow Creek near Brookfield, Mo.	135	101
▲133	06902500	Hamilton Branch near New Boston, Mo.	2.51	2.19
▲141	06903400	Chariton River near Chariton, Ia.	182	103
▲144	06903700	S. F. Chariton R. near Promise City, Ia.	168	106
▲146	06903900	Chariton River near Rathbun, Ia.	549	314
▲149	06904000	Chariton River near Centerville, Ia.	708	336
▲159	06904500	Chariton River at Novinger, Mo.	1,370	776
▲161	06905500	Chariton River near Prairie Hill, Mo.	1,870	1,147
▲162	06906000	Mussel Fork near Musselfork, Mo.	267	202
▲164	06906200	E. F. Little Chariton R. near Macon, Mo.	112	110
▲167	06906300	E. F. Little Chariton R. at Huntsville, Mo.	220	174
▲178	06909500	Moniteau Creek near Fayette, Mo.	81	36.7
▲180	06910230	Hinkson Creek at Columbia, Mo.	70.2	50.8
▲183	06910410	Cedar Creek near Columbia, Mo.	52.2	40.7

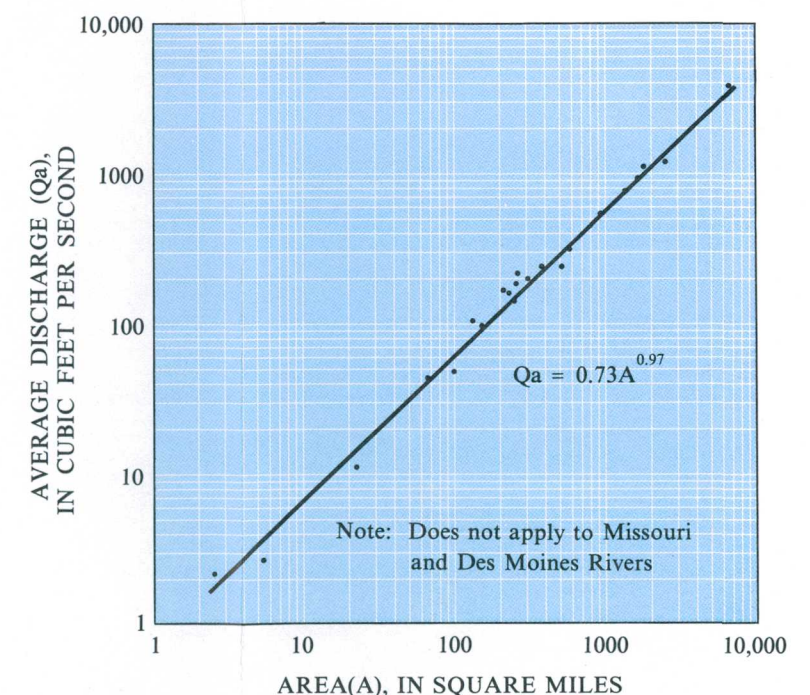


Figure 4.2-3 Area 38 average annual flow.

4.0 SURFACE WATER--Continued

4.3 Low Flow

Most Streams are not Sustained by Ground-Water Inflow During Droughts

Most streams with drainage areas less than 50 square miles will cease to flow for 7 consecutive days or more at some time during 50 percent of the years.

Low flows of most streams in Area 38 are not sustained by ground-water inflow during droughts because of the low hydraulic conductivity of the clays and shales of the area. Exceptions are the downstream reaches of the Grand, Thompson, Des Moines, and Chariton Rivers. The frequency curves for the 7-day low flow in the Des Moines, Chariton and Grand Rivers (figure 4.3-1) show that the low flows are well sustained (flatter curves) in comparison to the low flows of Medicine Creek and North River (steeper curves). Low-flow frequency data for streamflow-gaging stations are summarized in table 4.3-1. Low-flow frequency data are available for other time periods and on a seasonal basis from the district offices of the U.S. Geological Survey in Iowa City, Iowa; and Rolla, Missouri; and in reports by Lara (1979) and Skelton (1976).

For perennial streams in Area 38, low-flow characteristics at ungaged sites are best estimated by making discharge measurements at the site and relating them graphically to concurrent discharges at nearby continuous-record stations. The equipment and information needed to follow these procedures in the State are located at the district offices of the U.S. Geological Survey.

The following conclusions can be drawn from figures 4.3-2 and 4.3-3.

a. Seven-day, 2-year low flow (7-day Q_2) - For drainage basins of about 50 square miles or less, the 7-day Q_2 is almost always zero. About 50 percent of the streams with drainage areas of 50 to 200 square miles will have 7-day Q_2 of zero and the rest will have 7-day Q_2 of less than 0.7 cubic foot per second. For drainage basins larger than 200 square miles, drainage area is an unreliable characteristic to use in estimating 7-day Q_2 , and measurements of flow are needed.

b. Seven-day, 10-year low flow (7-day Q_{10}) - For drainage basins of about 150 square miles or less, the 7-day Q_{10} is almost always zero. About 50 percent of the streams with drainage areas of 150 to 500 square miles will have 7-day Q_{10} of less than 2 cubic feet per second. For drainage basins larger than 500 square miles, drainage area is an unreliable characteristic to use in estimating 7-day Q_{10} and measurements of flow are needed.

Interpolation between gaged points on streams in Area 38 needs to be considered when low-flow frequency estimates are required. By referring to the data in table 4.3-1, and the station locations in figure 4.1-1, the user of this report can decide if gaged points on the stream are close enough to an area of interest to allow interpolation.

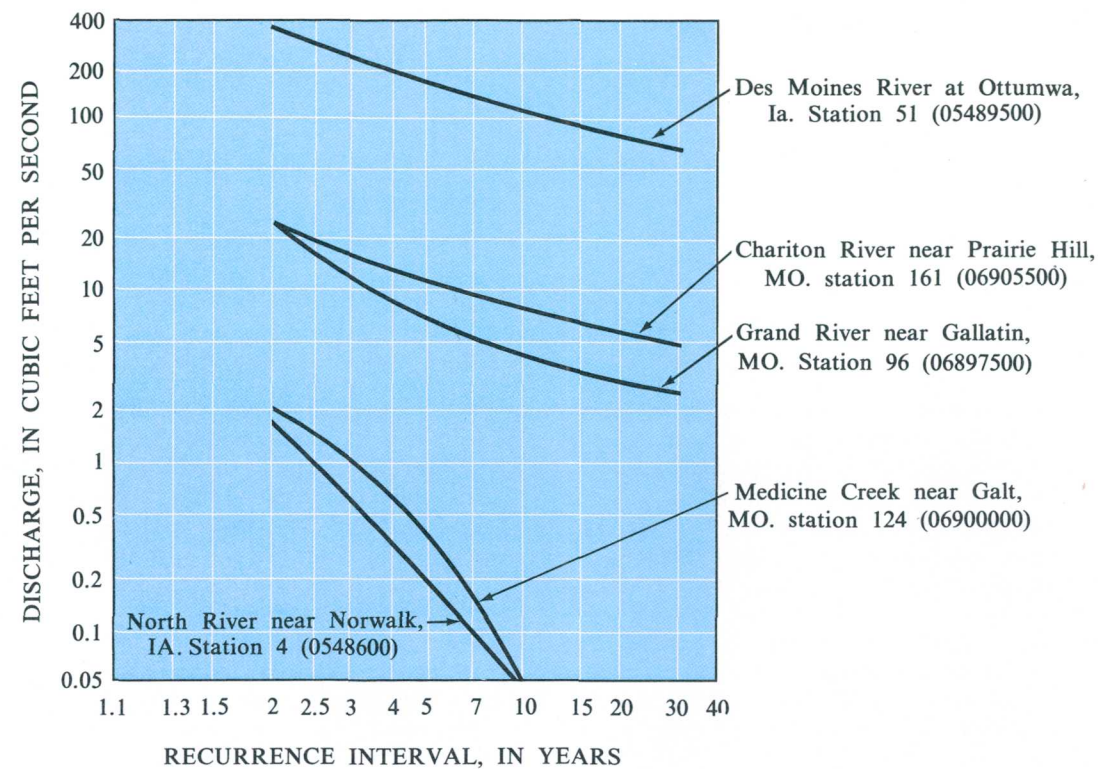


Figure 4.3-1 Seven-day low-flow frequency curves.

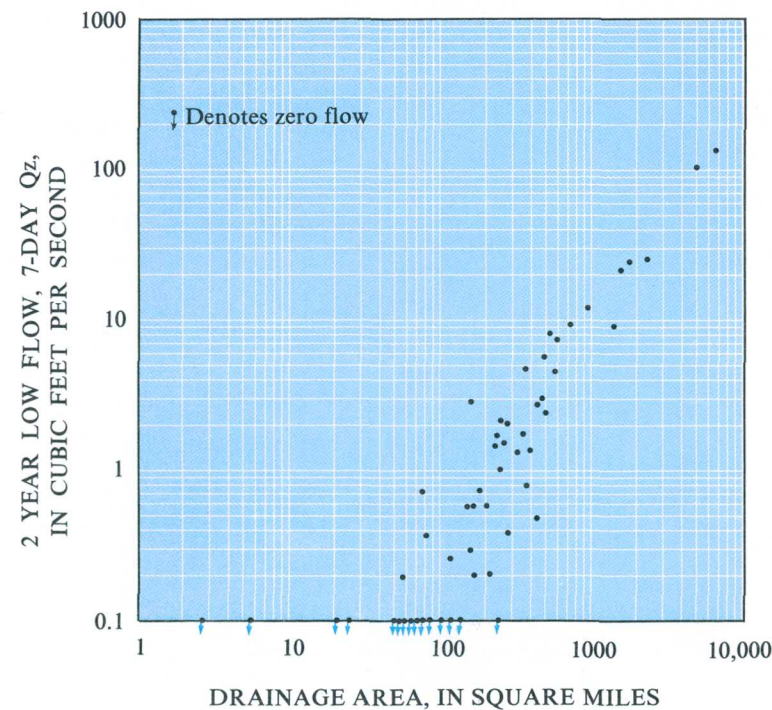


Figure 4.3-2 Relationship between drainage area and 7-day 2-year low flow.

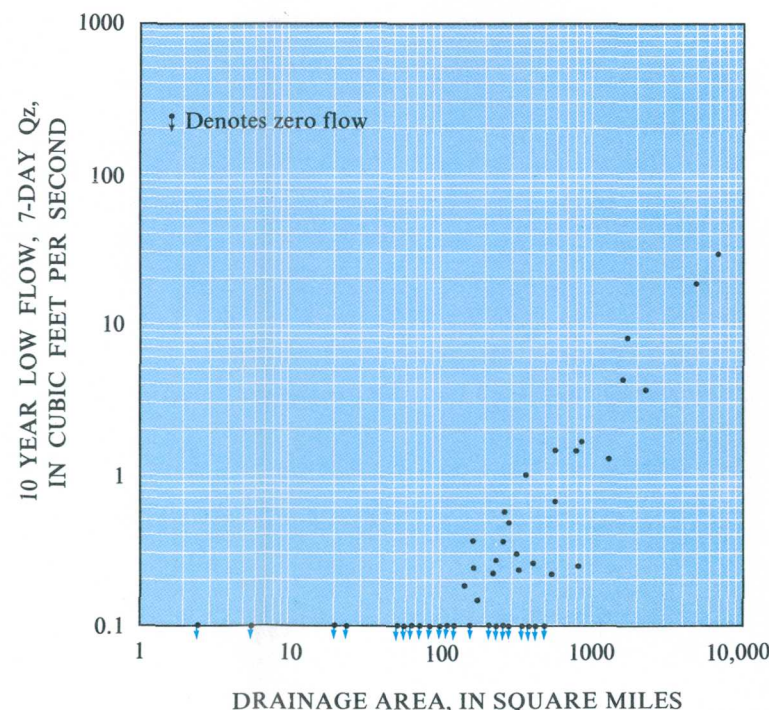


Figure 4.3-3 Relationship between drainage area and 7-day 10-year low flow.

Table 4.3-1 Seven-day low-flow discharges, in cubic feet per second.

Map No. (Fig. 4.1-1)	Station No.	Station name	Drainage area (square miles)	2	Recurrence interval, (years)	5	10	20
2	05485700	North River near Earlham, IA	68.9	0.1	---	0	0	0
3	05485900	North River near Winterset, IA	203	0.4	---	0	0	0
4	05486000	North River near Norwalk, IA	345	1.7	0.2	---	0	0
5	05486100	Middle River near Casey, IA	159	0.7	---	0.1	---	---
6	05481500	Middle River at Middle River, IA	164	2.9	---	0.4	---	---
7	05486300	Clanton Creek at East Peru, IA	84.5	0	0	---	0	0
8	05486350	Clanton Creek near Martinsdale, IA	159	0.6	---	0.1	---	---
9	05486400	Middle River at Martinsdale, IA	451	5.4	---	1.0	---	1.0
10	05486490	Middle River near Indianola, IA	503	7.8	2.8	1.6	1.0	---
11	05486700	South River near New Virginia, IA	65.4	0	0	0	0	0
12	05486900	Squaw Creek near Jamison, IA	60.8	0	0	0	0	0
13	05487100	Squaw Creek near Indianola, IA	134	0.6	---	0.2	---	---
14	05487200	South River near Indianola, IA	278	1.6	---	0.5	---	---
16	05487400	Otter Creek near Norwood, IA	102	0	0	0	0	0
17	05487450	Otter Creek near Milo, IA	155	0.3	---	0.1	---	---
18	05487470	South River near Ackworth, IA	460	3.2	1.4	0.9	0.6	---
20	05487700	White Breast Creek near Woodburn, IA	82.9	0.1	0	0	0	0
21	05487800	White Breast Creek near Lucas, IA	128	0.1	---	0	0	0
24	05487900	White Breast Creek near Newbern, IA	243	0.4	---	0.1	---	---
25	05487980	White Breast Creek near Dallas, IA	342	1.4	0.4	0.2	0.1	---
26	05488000	White Breast Creek near Knoxville, IA	380	1.7	0.8	0.6	0.4	---
30	05488200	English Creek near Knoxville, IA	75.0	0	0	0	0	0
31	05488300	English Creek near Harvey, IA	108	0.1	---	0	0	0
32	05488500	Des Moines River near Tracy, IA ¹	12,479	346	181	125	91	---
33	05488550	Cedar Creek near Melrose, IA	23.9	0	0	0	0	0
34	05488600	Cedar Creek near Albia, IA	102	0.4	---	0.1	---	---
35	05488700	Cedar Creek near Lovilia, IA	211	0.6	---	0.1	---	---
37	05488800	North Cedar Creek near Lovilia, IA	61.3	0.1	---	0	0	0
39	05488900	North Cedar Creek near Marysville, IA	111	0.1	---	0	0	0
41	05489000	Cedar Creek near Bussey, IA	374	1.9	0.6	0.2	0.1	---
47	05489100	South Avery Creek at Chillicothe, IA	60.1	0.1	---	0	0	0
49	05489400	South Avery Creek at Chillicothe, IA	51.6	0	0	0	0	0
51	05489900	Des Moines River at Ottumwa, IA ¹	13,374	356	176	118	83	---
52	05489900	Soap Creek near Ash Grove, IA	97.3	2.1	---	0.2	---	---
53	05490100	Soap Creek near Floris, IA	243	0.1	---	0	0	0
54	05490200	Lick Creek at Kilbourn, IA	82.7	0	0	0	0	0
55	05490300	Chequest Creek near Troy, IA	85.0	0	0	0	0	0
56	05490400	Chequest Creek near Pittsburg, IA ¹	123	0	0	0	0	0
57	05490500	Des Moines River at Keosauqua, IA ¹	14,038	403	207	143	105	---
58	05504400	South Fork Salt River at Santa Fe, MO ²	298	0.3	0	0	0	0
59	05505000	Youngs Creek near Mexico, MO	67.4	0	0	0	0	0
60	05506000	Middle Fork Salt River at Paris, MO	336	0.8	0	0	0	0
61	05506500	Elk Fork Salt River near Madison, MO	200	0.2	---	0	0	0
62	05506800	Elk Fork Salt River near Paris, MO	262	0.3	---	0	0	0
63	05507000	Shoal Creek near Liberty, MO	---	0.5	---	0.1	---	---
66	06893700	Fishing River at Mosby, MO	---	0	0	0	0	0
68	06894300	Williams Creek at Mosby, MO	20.0	0	0	0	0	0
69	06894400	E. F. Fishing River at Scalesior Springs, MO	---	2.0	---	0.2	---	---
70	06894500	Fishing River near Orrick, MO	159	0.2	0	0	0	0
72	06895000	West Fork Crooked River at Richmond, MO	248	1.6	0.7	0.4	0.3	---
73	06895000	Wakenda Creek at Carrollton, MO	67.5	0.1	---	0.1	---	---
75	06896000	Grand River at Knowlton, IA	207	0.2	---	1.0	---	---
76	06896100	Grand River near Blackton, IA	---	3.0	---	1.4	---	---
77	06896150	Grand River near Grant City, MO	---	3.8	---	1.4	---	---
78	06896160	Wildcat Creek at Stanberry, MO	---	0.1	---	0	0	0
81	06896182	Middle Fork Grand River at Grant City, MO	---	0.1	---	0	0	0
82	06896185	Middle Fork Grand River near Albany, MO	---	1.3	---	0.1	---	---
83	06896190	East Fork Grand River near Mt. Ayr, IA	64.7	0.1	---	0.1	---	---
84	06896200	East Fork Grand River south of Mt. Ayr, IA	95.9	0.1	---	0.1	---	---
85	06896250	East Fork Grand River at Albany, MO	---	1.7	---	0.1	---	---
86	06896400	Thompson Branch near Albany, MO	5.58	9.0	---	2.5	---	---
87	06896500	Grand River near Darlington, MO	---	0	0	0	0	0
88	06896550	West Fork Lost Creek at Maysville, MO	---	0	0	0	0	0
89	06896750	Lost Creek near Weatherly, MO	---	1.1	---	0	0	0
90	06896800	Grindstone Creek near Pattonburg, MO	---	1.1	---	0	0	0
91	06896850	Grand River near Pattonburg, MO	1,680	17.0	---	3.0	---	---
92	06896900	East Fork Big Creek near Bathany, MO	95	0.4	---	0	0	0
93	06897000	Big Creek at Bathany, MO	---	1.2	---	0	0	0
94	06897100	Grand River near Gallatin, MO	2,250	26	7.0	4.0	3.0	---
95	06897300	Thompson River near Hebron, IA	80.0	0.4	---	0.1	---	---
96	06897500	Thompson River near Afton, IA	54.8	0.1	---	0.1	---	---
98	06897770	Thompson River near Afton, IA	231	1.3	---	0.1	---	---
99	06897800	Thompson River near Arispe, IA	117	0.1	---	0.1	---	---
100	06897820	Thompson River near Grand River, IA	401	2.9	---	0.3	---	---
101	06897880	Long Creek near Van Wert, IA	117	0.1	---	0.1	---	---
102	06897900	Elk Creek near Decatur City, IA	52.5	0.2	---	0	0	0
103	06897940	Thompson River at Davis City, IA	701	0.9	---	1.8	1.1	---
104	06897950	Thompson River at Mt. Moriah, MO	891	12	3.4	0	0	0
105	06898100	Panther Creek at Mt. Moriah, MO	---	13	2.6	0	0	0
106	06898110	Thompson River near Trenton, MO	---	0.1	---	0.1	---	---
107	06898180	Weldon River east of Leon, IA	72.4	0.3	0.03	0	0	0
108	06898200	Weldon River near Pleasanton, IA	228	1.0	---	1.0	---	---
109	06898300	Weldon River near Leon, IA	69.2	0.1	---	0	0	0
110	06898400	Weldon River near Mercer, MO	246	0.3	---	0	0	0
111	06898450	Weldon River at Mill Grove, MO	494	2.7	---	1.8	---	---
112	06898470	Weldon River near Trenton, MO	---	6.5	---	4.6	2.8	---
113	06898500	Thompson River at Trenton, MO	1,670	21	8.0	0	0	0
114	06899000	Muddy Creek at Trenton, MO	---	0.5	---	0	0	0
115	06899100	Honey Creek near Trenton, MO	---	0	0	0	0	0
116	06899500	Grand River at Chillicothe, MO	4,850	100	---	19	---	---
117	06899550	Shoal Creek at Kingston, MO	---	0.6	---	0	0	0
118	06899600	Shoal Creek near Brayner, MO	391	1.3	0.1	0	0	0
119	06899650	Shoal Creek near Chillicothe, MO	---	2.0	---	0.2	---	---
120	06899700	Medicine Creek near Galt, MO	225	1.8	---	1.8	---	---
121	06899800	Medicine Creek near Sturges, MO	368	4.8	---	1.0	---	---
122	06899850	Medicine Creek near Wheeling, MO	---	7.0	---	1.0	---	---
123	06899900	Parson Creek at Meadville, MO	---	0	0	0	0	0
124	06900000	Locust Creek near Milan, MO	225	0.3	---	0	0	0
125	06900500	Locust Creek near Linneus, MO	550	4.5	1.5	0.7	0.3	---
126	06900600	Grand River near Sumner, MO	6,880	135	52	32	20	---
127	06900700	West Yellow Creek near Brookfield, MO	---	0	0	0	0	0
128	06901000	West Yellow Creek below Brookfield, MO	---	0	0	0	0	0
129	06901500	Hamilton Branch near New Boston, MO	2.51	0	0	0	0	0
130	06902000	East Yellow Creek near Brookfield, MO	---	0	0	0	0	0
131	06902200	Yellow Creek near Rothville, MO	405	0.5	---	0	0	0
132	06902300	Turkey Creek near Laclede, MO	---	0	0	0	0	0
133	06902500	Big Creek near Bosworth, MO	---	0.1	---	0	0	0
134	06903000	Wolf Creek near Chariton, IA	71.0	0	0	0	0	0
135	06903100	Chariton River near Chariton, IA	65.0	0	0	0	0	0
136	06903200	Chariton River near Cambria, IA	182	0.6	---	0.2	---	---
137	06903300	South Fork Chariton River near Corydon, IA	58.8	0.1	---	0	0	0
138	06903400	S. F. Chariton River near Promise City, IA	168	0.3	---	0.1	0	0
139	06903500	Chariton River near Rathbun, IA ³	549	1.7	0.5	0.2	0.1	---
140	06903600	Chariton River near Gentryville, IA	708	6.0	---	1.0	---	---
141	06903700	Chariton River at Livonia, MO ³	864	0	0	0	0	0
142	06903800	Shoal Creek near Glendale, MO	168.1	0	0	0	0	0
143	06903900	Shoal Creek at Glendale, MO	154	0	0	0	0	0
144	06904000	North Blackbird Creek near Unionville, MO	---	9.5	3.0	1.3	0.6	---
145	06904100	Chariton River at Novinger, MO ³	1,370	22	---	6.0	---	---
146	06904200	Chariton River near Galt, MO	---	0	0	0	0	0
147	06904300	Chariton River near Prairie Hill, MO ³	1,870	24	12	8.6	6.2	---
148	06904400	Muskel Creek near Masselfork, MO	267	0.4	---	0	0	0
149	06904500	E. F. Little Chariton River near Macon, MO	---	0.1	---	0	0	0
150	06904600	Bonne Femme Creek at Fayette, MO	220	0	0	0	0	0
151	06904700	Bonne Femme Creek at Fayette, MO	---	0.2	---	0	0	0
152	06904800	Bonne Femme Creek at Fayette, MO	---	0	0	0	0	0
153	06904900	Moniteau Creek near Fayette, MO	81.0	0	0	0	0	0
154	06905000	Petche Creek near Columbia, MO	---	0.1	---	0	0	0
155	06905100	Hinkson Creek at Columbia, MO	70.2	0.1	---	0	0	0
156	06905200	Cedar Creek near Columbia, MO	52.2	0	0	0	0	0

1Flow partly regulated by Red Rock Reservoir since 1969.
2Low flows augmented by sewage effluent.
3Flow partly regulated by Rathbun Reservoir since 1969. Minimum release from Rathbun is about 10 cubic feet per second during low-flow season. Low-flow frequency data represent natural conditions prior to regulation.

4.0 SURFACE WATER--Continued

4.4 Flood Flow

Magnitude of Flooding Increases from North to South

For a given drainage-area size and channel slope, flood peaks and volumes are greater in the southern part of Area 38.

Increases in rainfall quantities and intensity and variations in topography from north to south across Area 38 require that equations for estimating flood frequency at ungaged sites be adjusted to avoid excessive standard errors. Accordingly, separate flood-frequency equations are provided in table 4.4-1 for Iowa and Missouri streams (Lara, 1973; Hauth, 1974). The equations, which are applicable to unregulated natural streams only, may be applied to those drainage areas greater than 2 square miles in Iowa and to drainage areas of 0.1 to 7,000 square miles in Missouri, except for streams draining from Iowa into Missouri.

For Area 38 streams that flow from Iowa into Missouri and have drainage basins greater than 200 square miles, results from flood-frequency equations (table 4.4-1) for a given drainage area and slope are significantly different. A comparison of Area 38 streamflow-gaging station frequency data (table 4.4-2) and estimates from statewide equations indicates that the estimates generally will be improved if results from Iowa and Missouri equations are averaged for streams with drainage areas between 200 and 3,000 square miles. Therefore, the best estimates

generally can be obtained if results from Iowa and Missouri equations for the 2- to 100-year floods are averaged for ungaged sites on streams that have drainage areas of 200 to 3,000 square miles and flow from Iowa into Missouri. For all other ungaged sites, use equations for the appropriate State. Gaging-station frequency data (table 4.4-2) need to be used whenever possible.

Selected flood-peak and flood-volume data for streamflow-gaging stations in Area 38 are presented in table 4.4-2. Much additional data are available in reports by Lara (1974) and Skelton (1973).

During 1968, the U.S. Geological Survey began delineating "flood-prone" areas by approximate methods on 7½- and 15-minute topographic maps. These maps have proven to be useful because many flood-prone areas are occupied by industrial, commercial, and residential developments. Information on flood-prone areas indicated in figure 4.4-1 can be obtained from U.S. Geological Survey offices in Rolla, Missouri, and Iowa City, Iowa.

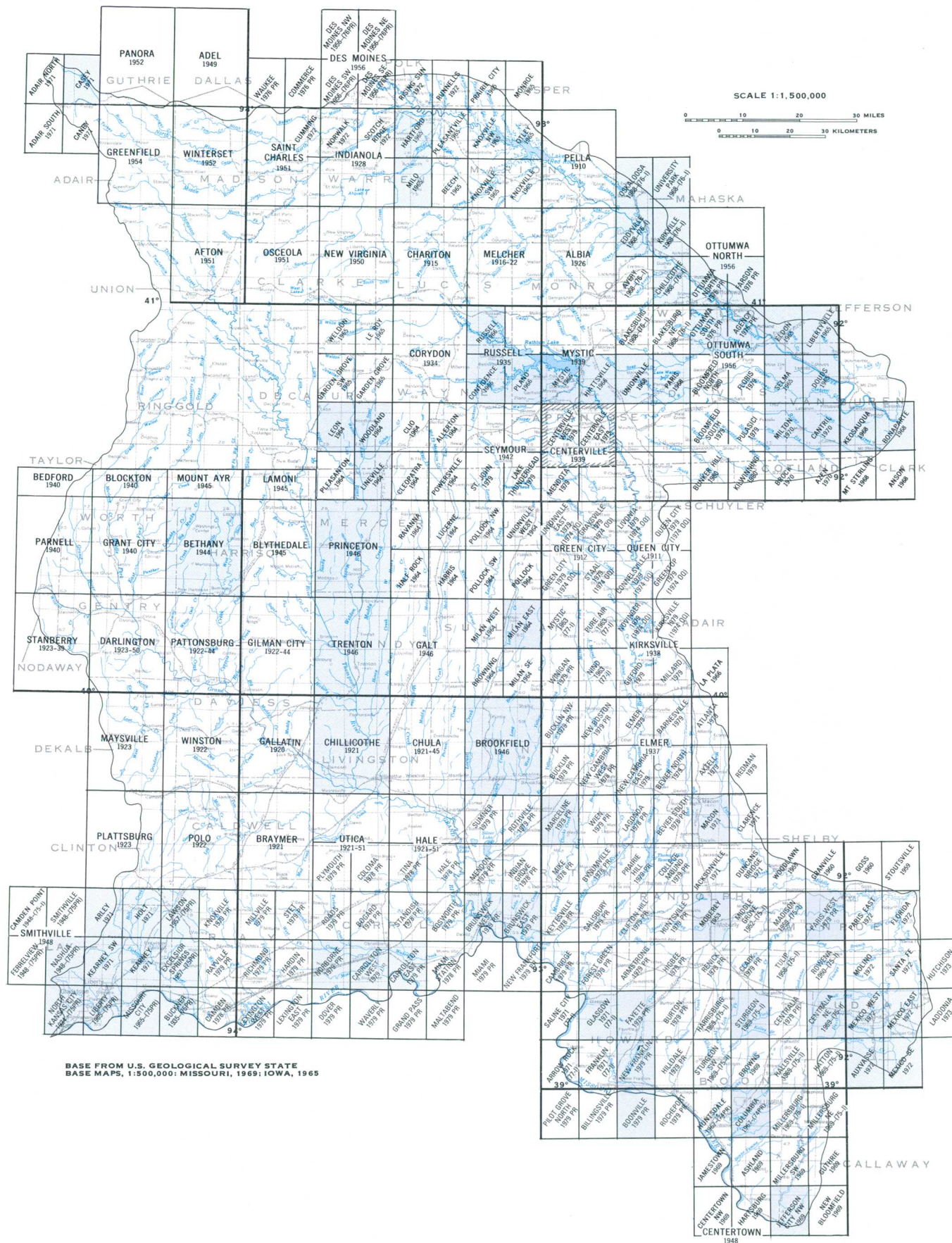


Figure 4.4-1 Maps of flood-prone areas available in 1982 (shaded).

Table 4.4-1 Summary of flood-frequency equations.

[Q = Floodpeak in cubic feet per second for t -year recurrence interval; A = drainage area in square miles; S = slope in feet per mile, between points 10 and 85 percent of the distance along the mainstream channel from the site to the basin divide]

Recurrence interval, in years	C	X	Y	Standard error, in percent
Iowa streams : $Q_t = C_t A^{X_t} S^{Y_t}$ (from Lara, 1973)				
2	31.2	0.701	0.490	40
5	82.5	.651	.445	29
10	143	.618	.410	26
25	262	.579	.367	31
50	394	.551	.335	37
100	571	.524	.305	44
Missouri streams : $Q_t = C_t A^{X_t} A^{-0.02 S^{Y_t}}$ (from Hauth, 1974)				
2	53.5	0.851	0.356	38.6
5	64	.886	.450	34.7
10	67.6	.905	.500	34.5
25	73.7	.924	.542	35
50	79.8	.926	.560	33.3
100	85.1	.934	.576	33.3

Table 4.4-2 Peak flows and 7-day high flows for recurrence intervals of 2, 10, 50, and 100 years.

Map No. (fig. 4.1-1)	Station No.	Station name	Drainage area (square miles)	Peak discharge, in cubic feet per second				7-day high flow, in acre feet			
				2	10	50	100	2	10	50	100
4	05486000	North River near Norwalk, Ia.	349	3,560	9,180	15,400	18,300	19,900	42,500	57,700	62,800
10	05486490	Middle River near Indianola, Ia.	503	7,130	13,600	19,000	21,200	28,900	55,200	71,100	76,200
18	05487470	South River near Ackworth, Ia.	460	10,500	20,500	28,200	31,100	32,300	65,900	91,200	101,000
19	05487600	South White Breast Creek near Osceola, Ia.	28.0	1,920	3,310	4,400	4,820	---	---	---	---
21	05487800	White Breast Creek near Lucas, Ia.	128	3,380	9,750	16,900	20,200	---	---	---	---
25	05487980	White Breast Creek near Dallas, Ia.	342	6,730	9,120	10,700	11,200	---	---	---	---
26	05488000	White Breast Creek near Knoxville, Ia.	380	6,340	12,000	16,700	18,600	---	---	---	---
32	05488500	Des Moines River near Tracy, Ia. ¹	12,479	33,200	68,700	97,600	109,000	---	---	---	---
41	05489000	Cedar Creek near Bussey, Ia.	374	8,000	17,700	27,200	31,300	27,700	58,800	86,800	---
48	05489350	South Avery Creek near Blakesburg, Ia.	33.1	4,910	11,200	17,200	19,700	---	---	---	---
51	05489500	Des Moines River at Ottumwa, Ia. ¹	13,374	36,000	66,900	88,900	96,900	---	---	---	---
57	05490500	Des Moines River at Keosauqua, Ia. ¹	14,038	37,500	71,800	106,000	122,000	---	---	---	---
59	05505000	South Fork Salt River at Santa Fe, Mo.	298	6,370	13,000	18,500	20,600	26,000	58,400	96,600	---
60	05506000	Youngs Creek near Mexico, Mo.	67.4	2,500	5,710	8,600	9,970	6,600	14,000	22,400	25,200
61	05506500	Middle Fork Salt River at Paris, Mo.	356	5,460	11,100	15,700	17,600	30,200	59,100	74,700	86,400
63	05507000	Elk Fork Salt River near Paris, Mo.	262	7,380	14,800	21,000	23,400	26,500	53,800	92,400	---
70	06894500	E. F. Fishing R. nr Excelsior Springs, Mo.	20.0	2,370	7,330	13,200	---	1,400	5,530	13,700	---
72	06895000	Crooked River near Richmond, Mo.	159	4,250	11,700	19,600	---	12,900	43,400	94,600	---
75	06896000	Wakenda Creek at Carrollton, Mo.	248	4,820	7,690	9,740	---	20,400	42,800	61,600	---
80	06896180	De Moss Branch near Stanberry, Mo.	0.38	145	248	345	383	---	---	---	---
87	06896500	Thompson Branch near Albany, Mo.	5.58	740	2,020	2,880	3,220	448	1,460	2,450	---
93	06897000	East Fork Big Creek near Bethany, Mo.	95	2,520	5,720	8,800	10,100	9,400	16,500	26,600	30,800
96	06897500	Grand River near Gallatin, Mo.	2,250	23,700	45,800	64,400	72,000	154,000	377,000	563,000	634,000
97	06897700	Grand River tributary near Utica, Mo.	1.44	392	560	761	854	---	---	---	---
105	06898000	Thompson River at Davis City, Ia.	701	7,640	14,400	20,400	22,800	44,000	87,900	130,000	149,000
110	06898400	Weldon River near Leon, Ia.	104	5,870	11,400	16,000	17,900	11,000	22,800	---	---
113	06898500	Weldon River near Mercer, Mo.	246	11,900	25,500	37,800	43,000	21,800	53,200	88,200	---
114	06899000	Weldon River at Mill Grove, Mo.	494	10,900	24,600	37,500	43,000	36,700	84,600	127,000	144,000
116	06899500	Thompson River at Trenton, Mo.	1,670	21,900	48,600	73,500	84,100	114,000	252,000	392,000	462,000
122	06899700	Shoal Creek near Braymer, Mo.	391	7,180	13,200	---	---	---	---	---	---
124	06900000	Medicine Creek near Galt, Mo.	225	5,700	14,100	22,400	25,900	21,700	43,800	64,400	72,800
129	06901500	Locust Creek near Linneus, Mo.	550	9,200	23,200	37,300	43,600	46,200	99,700	147,000	168,000
130	06902000	Grand River near Sumner, Mo.	6,880	51,200	106,000	154,000	174,000	461,000	967,000	1,400,000	1,540,000
131	06902200	West Yellow Creek near Brookfield, Mo.	135	2,800	5,740	---	---	---	---	---	---
133	06902500	Hamilton Branch near New Boston, Mo.	2.51	576	1,210	1,780	1,980	420	840	1,360	---
134	06902800	Onion Branch near St. Catherine, Mo.	1.04	231	494	718	809	---	---	---	---
141	06903400	Chariton River near Chariton, Ia.	182	3,060	6,000	8,500	9,510	---	---	---	---
159	06904500	Chariton River at Novinger, Mo. ²	1,370	9,700	18,800	26,400	29,400	78,500	176,000	260,000	294,000
161	06905500	Chariton River near Prairie Hill, Mo. ²	1,870	13,400	22,000	28,400	30,800	110,000	207,000	308,000	350,000
167	06906300	E. F. Little Chariton R. nr Huntsville, Mo.	220	4,730	15,300	---	---	18,900	47,100	---	---
178	06909500	Moniteau Creek near Fayette, Mo.	81	2,930	5,700	7,920	---	5,000	8,800	12,200	---
180	06910230	Hinkson Creek at Columbia, Mo.	70.2	4,300	7,940	11,700	13,500	---	---	---	---
181	06910250	Traxler Branch near Columbia, Mo.	0.55	277	564	755	825	---	---	---	---
183	06910410	Cedar Creek near Columbia, Mo.	52.2	2,620	5,480	8,380	9,700	---	---	---	---

¹Flow partially regulated by Red Rock Reservoir since 1969.
²Flow partially regulated by Rathbun Reservoir since 1969.

4.0 SURFACE WATER--Continued

4.5 Flow Duration

Flow-Duration Curves Similar for Streams of Comparable Size

Similar shape of flow-duration curves for comparable size drainage basins indicates a similarity in hydrologic and geologic characteristics of the drainage basins.

Typical flow-duration curves indicate similar streamflow characteristics of Area 38 streams (figure 4.5-1). The curves are based on discharges for the period of record at a station and show the percentage of time that a selected discharge has been equaled or exceeded (Skelton, 1976).

The flattening of the lower end of the curves for Des Moines River and Grand River is typical of streams in the area with drainage areas greater than 1,000 square miles. The downstream reaches of these streams generally contain substantial alluvial depos-

its that gradually release water to the streams during dry weather.

The steep slope of the Medicine Creek and North River curves is indicative of variable streamflow, such as that from direct surface runoff. The flow of these streams is not well sustained during dry weather, but runoff during storms may be greater on a unit basis than that from the larger streams.

Flow-duration data for continuous-record, streamflow-gaging stations in the area are shown in table 4.5-1.

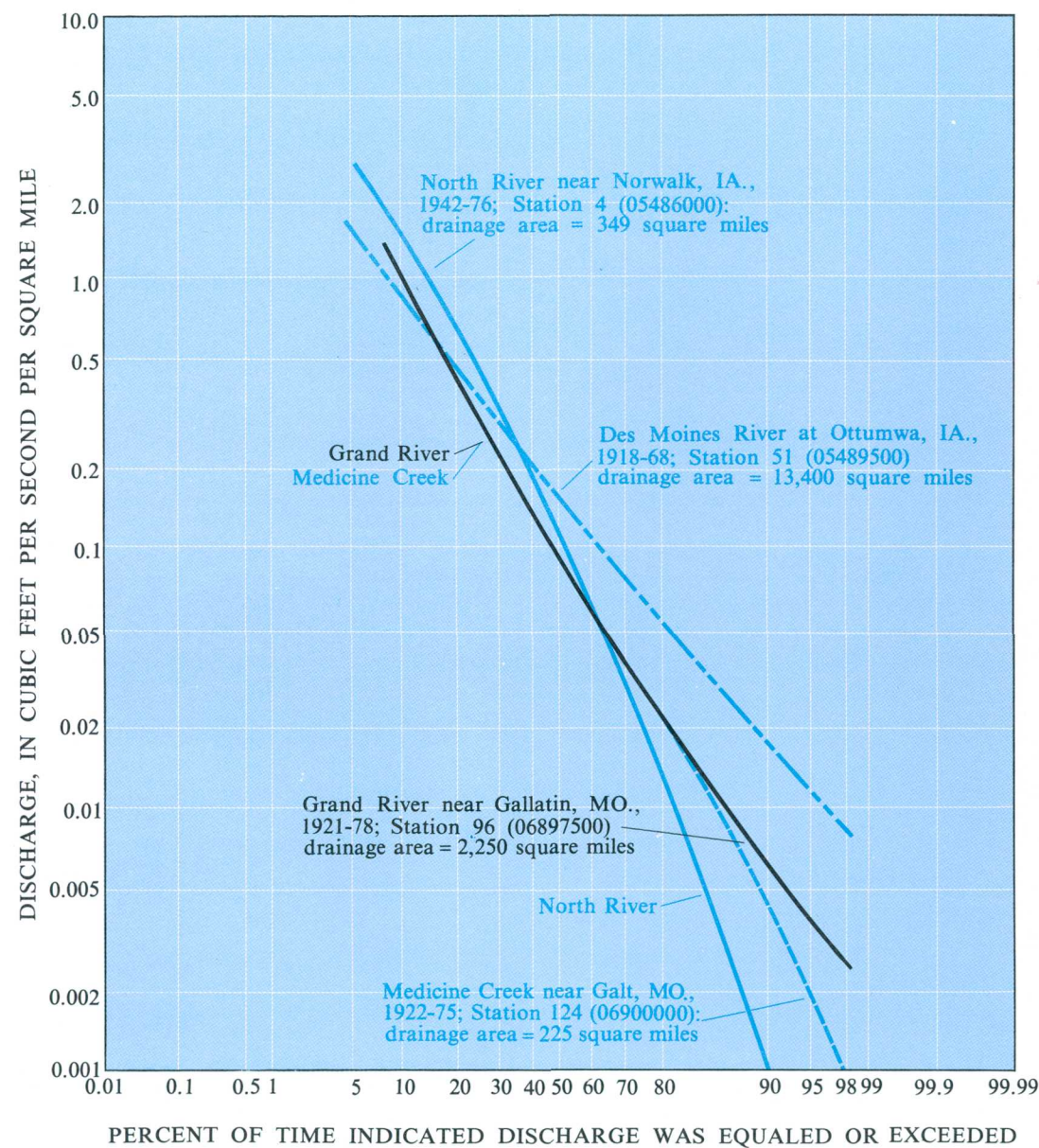


Figure 4.5-1 Flow-duration curves for selected continuous-record streamflow-gaging stations.

Table 4.5-1 Flow-duration discharge, in cubic feet per second.

Map No.	Station No.	Station name	Drainage area (square miles)	Flow that was exceeded for indicated percent of time				
				95	90	70	50	10
4	05486000	North River near Norwalk, Ia.	349	0.5	1.4	12	37	416
10	05486490	Middle River near Indianola, Ia.	503	4.3	7.0	25	64	564
18	05487470	South River near Ackworth, Ia.	460	1.7	2.6	9.0	33	449
25	05487980	White Breast Creek near Dallas, Ia.	342	1.2	1.9	9.5	30	375
26	05488000	White Breast Creek near Knoxville, Ia.	380	1.1	1.6	4.7	21	394
32	05488500	Des Moines River near Tracy, Ia.	12,479	246	372	960	1,870	10,300
41	05489000	Cedar Creek near Bussey, Ia.	374	0.8	1.9	8.4	30	381
51	05489500	Des Moines River at Ottumwa, Ia.	13,374	248	391	1,100	2,110	11,600
57	05490500	Des Moines River at Keosauqua, Ia.	14,038	292	440	1,150	2,330	12,900
59	05505000	South Fork Salt River at Santa Fe, Mo.	298	0.3	1.0	3.7	12	280
60	05506000	Youngs Creek near Mexico, Mo.	67.4	0	0	0.4	2.0	64
61	05506500	Middle Fork Salt River at Paris, Mo.	356	19	25	60	110	1,400
63	05507000	Elk Fork Salt River near Paris, Mo.	262	0.3	0.8	4.6	17	320
64	06893000	Missouri River at Kansas City, Mo.	485,200	13,000	16,000	30,000	40,000	88,000
70	06894500	E. F. Fishing River at Excelsior Springs, Mo.	20.0	0	0.01	0.3	1.6	20
72	06895000	Crooked River near Richmond, Mo.	159	0.1	0.4	3.4	14	160
74	06895500	Missouri River at Waverly, Mo.	487,200	13,000	16,000	30,000	40,000	90,000
75	06896000	Wakenda Creek at Carrollton, Mo.	248	0.8	1.4	4.2	12	210
87	06896500	Thompson Branch near Albany, Mo.	5.58	0.01	0.02	0.07	0.2	3
93	06897000	East Fork Big Creek near Bethany, Mo.	95	0	0	0.8	3.7	80
96	06897500	Grand River near Gallatin, Mo.	2,250	13	24	82	200	2,300
105	06898000	Thompson River at Davis City, Ia.	701	4.7	8.9	31	74	789
106	06898100	Thompson River at Mt. Moriah, Mo.	891	19	26	61	130	1,200
110	06898400	Weldon River near Leon, Ia.	104	0.2	0.5	2.2	7.2	102
113	06898500	Weldon River near Mercer, Mo.	246	0.09	0.3	2.2	9.5	200
114	06899000	Weldon River at Mill Grove, Mo.	494	1.1	2.6	11	31	410
116	06899500	Thompson River at Trenton, Mo.	1,670	16	25	79	190	2,100
122	06899700	Shoal Creek near Braymer, Mo.	391	0.6	1.6	12	39	460
124	06900000	Medicine Creek near Galt, Mo.	225	1.3	2.1	7.7	21	230
128	06901000	Locust Creek near Milan, Mo.	225	1.8	2.5	10	25	320
129	06901500	Locust Creek near Linneus, Mo.	550	2.6	4.1	15	44	590
130	06902000	Grand River near Sumner, Mo.	6,880	71	110	370	870	9,200
131	06902200	West Yellow Creek near Brookfield, Mo.	135	0.04	0.08	1.4	8.3	170
133	06902500	Hamilton Branch near New Boston, Mo.	2.51	0.01	0.02	0.06	0.1	2.2
141	06903400	Chariton River near Chariton, Ia.	182	0.5	0.8	3.6	11	246
146	06903900	Chariton River near Rathbun, Ia.	549	2.4	4.3	14	48	1,060
149	06904000	Chariton River near Centerville, Ia.	708	1.1	1.8	9.5	39	865
159	06904500	Chariton River at Novinger, Mo.	1,370	5.4	10	38	110	2,000
161	06905500	Chariton River near Prairie Hill, Mo.	1,870	17	24	80	200	2,800
167	06906300	E. F. Little Chariton R. nr Huntsville, Mo.	220	0.3	1.2	10	28	510
178	06909500	Moniteau Creek near Fayette, Mo.	81	0	0	0.4	2.2	59
180	06910230	Hinkson Creek at Columbia, Mo.	70.2	0.1	0.3	2.5	7.9	95
183	06910410	Cedar Creek near Columbia, Mo.	52.2	0.04	0.1	0.9	3.3	51

5.0 QUALITY OF SURFACE WATER

5.1 Water-Quality Stations

Water-Quality Data are Available for 49 Stations in the Study Area

Measurements of specific conductance, dissolved solids, pH, alkalinity, sulfate, iron, manganese, trace metals, and other constituents are available for 36 stations operated upstream and downstream from mining operations.

Specific conductance, dissolved solids, pH, alkalinity, sulfate, total and dissolved iron and total and dissolved manganese are important when assessing water quality of areas affected by surface mining. The data included in this report have been collected in Area 38 by the U. S. Geological Survey, the Iowa Department of Environmental Quality, and the Missouri Division of Geology and Land Survey. The type of data and frequency of collection vary at each station and generally vary between stations.

The location of stations where water-quality information has been collected is shown on figure 5.1-1. Of the 49 stations, 19 stations were operated in Iowa, and 17 stations were operated in Missouri

expressly for the collection of water-quality data downstream or upstream from coal-mining operations. Except for station 46, these stations were operated between water years 1978 and 1981. Nineteen of the water-quality stations were located immediately downstream from past or present mining operations, and 17 stations were located upstream or not immediately downstream from mining operations. The list of stations (table 5.1-1) also contains other water-quality stations within the project area, which are current or historical stations operated for reasons other than monitoring the effects of coal mining. For more complete information on station location refer to section 9.0.

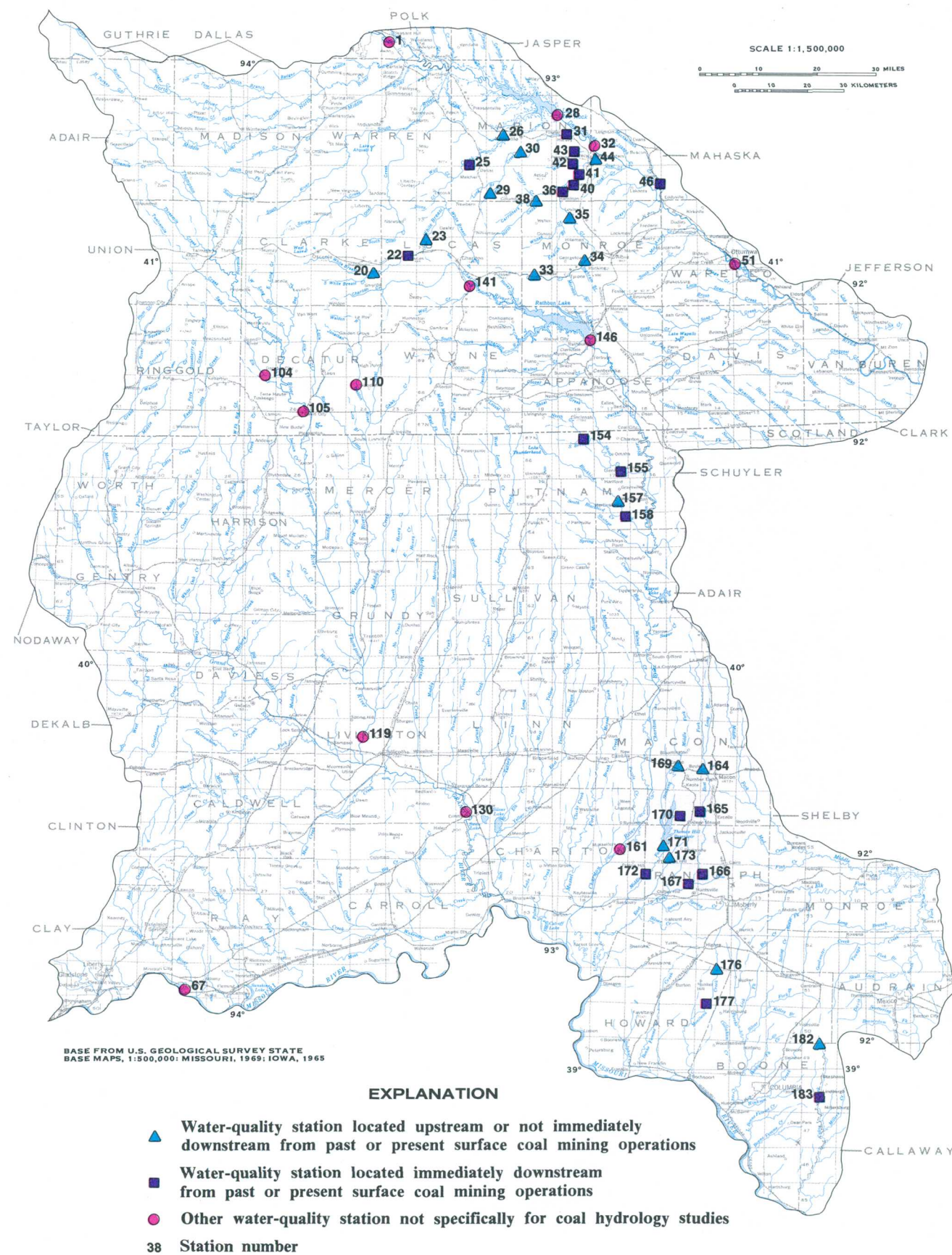


Figure 5.1-1 Location of water-quality stations in Area 38.

Table 5.1-1 Water-quality stations in Area 38.

Map Symbol	Map No.	Station No.	Station name and location	Drainage area (square miles)	Water year of record
●	1	05485520	Des Moines River below Des Moines, Ia., Polk County	9,091	1975-81
▲	20	05487700	White Breast Creek near Woodburn, Ia., Clarke County	82.9	1978-81
■	22	05487810	White Breast Creek near Lucas, Ia., Lucas County	150	1978-81
▲	23	05487880	White Breast Creek near Lacona, Ia., Lucas County	243	1978-81
■	25	05487980	White Breast Creek near Dallas, Ia., Marion County	342	1978-81
▲	26	05488000	White Breast Creek near Knoxville, Ia., Marion County	380	1978-81
●	28		Des Moines River below Lake Red Rock, Ia., Marion County	12,323	1971-
▲	29	05488180	English Creek near Columbia, Ia., Marion County	24.8	1978-81
▲	30	05488200	English Creek near Knoxville, Ia., Marion County	73.0	1978-81
■	31	05488300	English Creek near Harvey, Ia., Marion County	108	1978-81
●	32	05488500	Des Moines River near Tracy, Ia., Mahaska County	12,479	1920-67
▲	33	05488550	Cedar Creek near Melrose, Ia., Monroe County	23.9	1978-81
▲	34	05488600	Cedar Creek near Albia, Ia., Monroe County	102	1978-81
▲	35	05488700	Cedar Creek near Lovilia, Ia., Monroe County	211	1978-81
■	36	05488750	Cedar Creek near Hamilton, Ia., Marion County	241	1980-81
▲	38	05488895	North Cedar Creek near Attica, Ia., Monroe County	104	1978-81
■	40	05488990	North Cedar Creek near Bussey, Ia., Marion County	125	1978-81
■	41	05489000	Cedar Creek near Bussey, Ia., Marion County	374	1978-81
■	42	05489010	Honey Creek near Tracy, Ia., Marion County	9.0	1980-81
■	43	05489020	Walnut Creek near Tracy, Ia., Marion County	23.6	1980-81
▲	44	05489030	Cedar Creek near Tracy, Ia., Mahaska County	423	1978-81
■	46	05489190	Muchakinock Creek near Eddyville, Ia., Mahaska County	70.2	1976
●	51	05489500	Des Moines River at Ottumwa, Ia., Wapello County	13,374	1965-79
●	67	06894100	Missouri River at Sibley, Mo., Jackson County		1971-75
●	104	06897950	Elk Creek near Decatur City, Ia., Decatur County	52.5	1967-
●	105	06898000	Thompson River at Davis City, Ia., Decatur County	701	1968-73
●	110	06898400	Weldon River near Leon, Ia., Decatur County	104	1968-73
●	119	06899620	Thompson River near Chillicothe, Mo., Livingston County		1968-75
●	130	06902000	Grand River near Sumner, Mo., Chariton County	6,880	1967-81
●	141	06903400	Chariton River near Chariton, Ia., Lucas County	182	1971-
●	146	06903900	Chariton River near Rathbun, Ia., Appanoose County	549	1971-
■	154	06904200	Little Shoal Creek at Mendota, Mo., Putnam County	41.6	1979-81
■	155	06904250	Shoal Creek at Glendale, Mo., Putnam County	154	1979-81
■	157	06904280	North Blackbird Creek near Martinstown, Mo., Putnam County	81.5	1980-81
■	158	06904290	Blackbird Creek near Sidney, Mo., Putnam County	137	1980-81
■	161	06905500	Chariton River near Prairie Hill, Mo., Chariton County	1,870	1962-
■	164	06906200	East Fork Little Chariton River near Macon, Mo., Chariton County	112	1979-81
■	165	06906250	Unnamed Creek at Ardmore, Mo., Macon County	1.0	1979-81
■	166	06906290	Sinking Creek near Huntsville, Mo., Randolph County	5.4	1981
■	167	06906300	East Fork Little Chariton River near Huntsville, Mo., Randolph County	220	1979-81
■	169	06906330	Middle Fork Little Chariton River near Callao, Mo., Macon County	53.4	1980-81
■	170	06906340	South Fork Claybank Creek near College Mound, Mo., Macon County	4.0	1979-81
■	171	06906360	Middle Fork Little Chariton River near Thomas Hill, Mo., Randolph County	147	1980-81
■	172	06906430	Middle Fork Little Chariton River near Prairie Hill, Mo., Randolph County	159	1980-81
■	173	06906460	Muncas Creek near Thomas Hill, Mo., Randolph County	4.8	1981
■	176	06909460	Moniteau Creek near Higbee, Mo., Howard County	18.7	1979-81
■	177	06909480	Moniteau Creek near Harrisburg, Mo., Howard County	28.0	1979-81
■	182	06910405	Cedar Creek near Hallsville, Mo., Boone County	5.1	1979-81
■	183	06910410	Cedar Creek near Columbia, Mo., Boone County	52.2	1979-81

5.0 QUALITY OF SURFACE WATER--Continued

5.2 Specific Conductance and Dissolved Solids

Specific Conductance a Measure of Increased Dissolved-Solids in Surface Water

Specific conductance averaged 460 micromhos per centimeter for stations upstream from mining and 730 micromhos per centimeter for stations downstream from mining; dissolved-solids concentrations averaged 300 milligrams per liter for stations upstream from mining and 592 milligrams per liter for stations downstream from mining.

Specific conductance, a measure of the ability of water to transmit electric current, can be used to estimate dissolved-solids concentrations by using the following equation (Hem, 1970):

$$KA = S,$$

where

K is specific conductance, in micromhos per centimeter at 25° Celsius (μmho);

A is a regression coefficient; and

S is dissolved-solids concentration, in milligrams per liter (mg/L).

In Coal Area 38, stations upstream from mining had a regression coefficient of 0.65 and a standard error of 38 mg/L for 189 measurements. Stations downstream from mining had a regression coefficient of 0.81 and a standard error of 116 mg/L for 156 measurements. The larger coefficient for downstream stations is an indication of large sulfate concentrations.

Accelerated weathering of pyritic minerals present in spoil in coal-mine areas results in the produc-

tion of sulfuric acid and large quantities of soluble mineral salts that are contributed to streamflow draining mined areas. The acidic water reacts with other minerals and produces water containing large dissolved-solids concentrations.

Specific conductance values are summarized in table 5.2-1 and dissolved-solids concentrations are summarized in table 5.2-2 for water-quality stations in Coal Area 38. For stations upstream from coal mining, specific conductance ranged from 106 to 1,480 and averaged 460 (μmho). For stations downstream from coal mining, specific conductance ranged from 160 to 2,850 and averaged 730 μmho . Average specific conductance exceeded 1,000 μmho for six of the downstream stations (figure 5.2-1).

The cumulative impact of coal mining on the mineralization of surface water can be seen by comparing the summary values in table 5.2-1 for the upstream (map no. 164) and downstream (map no. 167) stations on East Fork Little Chariton River. The drainage area between the stations is 108 square miles, of which 15.7 square miles or 14 percent have been disturbed by surface mining. The average specific conductance was 250 μmho for the upstream station and 750 μmho for the downstream station.

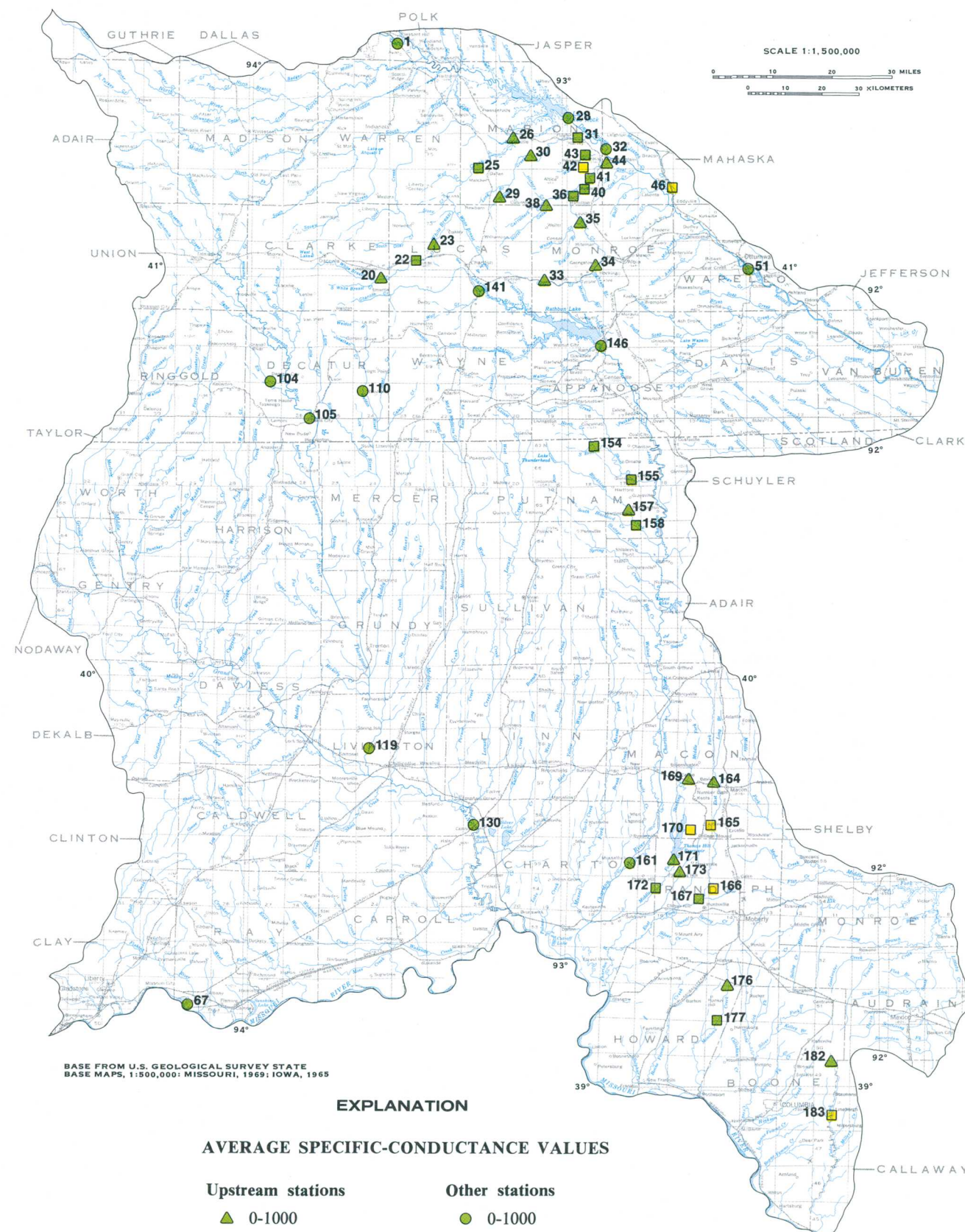


Figure 5.2-1 Average specific-conductance values for water quality stations.

Table 5.2-1 Summary of specific-conductance values (micromhos per centimeter at 25 degrees C.).

Map symbol No.	Map No.	Number of samples	Average	Range	Number of samples greater than 1,000
● 1		52	690	420 - 1,200	2
▲ 20		10	530	400 - 720	0
■ 22		15	525	380 - 640	0
▲ 23		10	485	240 - 565	0
■ 25		15	450	290 - 510	0
▲ 26		10	595	285 - 950	0
● 28		297	660	250 - 1,044	1
▲ 29		10	475	385 - 540	0
▲ 30		13	600	410 - 780	0
■ 31		10	850	345 - 1,310	0
● 32		35	580	320 - 980	0
▲ 33		11	485	110 - 800	0
▲ 34		13	470	200 - 625	0
■ 35		15	500	200 - 660	0
■ 36		8	545	380 - 710	0
▲ 38		16	600	140 - 1,480	3
■ 40		16	715	160 - 1,500	2
■ 41		16	640	170 - 1,210	2
■ 42		3	1,070	425 - 1,620	2
■ 43		4	785	495 - 1,170	1
▲ 44		16	625	180 - 1,040	1
■ 46		2	1,225	850 - 1,600	1
● 51		35	605	290 - 900	0
● 67		49	695	412 - 850	0
● 104		166	505	140 - 900	0
● 105		36	405	130 - 590	0
● 110		55	490	180 - 900	0
● 119		80	415	167 - 690	0
● 130		166	415	140 - 680	0
● 141		52	465	120 - 1,300	1
■ 146		49	380	230 - 2,200	1
■ 154		5	630	332 - 797	0
■ 155		5	540	165 - 800	0
■ 157		3	390	344 - 466	0
■ 158		3	430	379 - 503	0
● 161		133	380	125 - 745	0
▲ 164		30	250	131 - 321	0
■ 165		3	2,555	2,470 - 2,700	3
■ 166		2	1,355	416 - 2,290	1
■ 167		31	750	234 - 1,820	8
▲ 169		3	360	234 - 472	0
■ 170		4	1,650	1,270 - 2,080	4
▲ 171		14	385	200 - 550	0
■ 172		14	510	217 - 752	0
▲ 173		11	370	108 - 698	0
▲ 176		3	350	204 - 465	0
■ 177		3	465	190 - 780	0
▲ 182		2	160	106 - 216	0
■ 183		4	1,325	688 - 2,850	1

Table 5.2-2 Summary of dissolved solids concentrations (milligrams per liter).

Map symbol	Map No.	Number of samples	Average	Range	Number of samples greater than 750
● 1		52	445	288 - 704	0
▲ 20		10	320	239 - 411	0
■ 22		15	315	169 - 367	0
▲ 23		10	290	179 - 345	0
■ 25		15	275	182 - 323	0
▲ 26		10	375	178 - 558	0
● 28		49	375	91 - 620	0
▲ 29		10	300	270 - 327	0
▲ 30		13	400	263 - 684	0
■ 31		10	645	219 - 1,100	3
● 32		0	-	-	-
● 33		11	295	90 - 537	0
▲ 34		13	295	141 - 347	0
▲ 35		15	320	122 - 404	0
■ 36		7	365	245 - 463	0
▲ 38		15	390	107 - 1,120	2
■ 40		16	535	99 - 1,310	2
■ 41		16	445	100 - 947	1
■ 42		1	970	972 - 972	1
■ 43		0	-	-	-
▲ 44		16	435	105 - 800	1
■ 46		2	965	534 - 1,400	1
● 51		39	380	106 - 598	0
● 67		49	440	254 - 534	0
● 104		108	325	76 - 542	0
● 105		12	260	142 - 340	0
● 110		11	285	200 - 379	0
● 119		78	250	114 - 421	0
● 130		164	250	99 - 456	0
● 141		63	315	131 - 648	0
■ 146		78	265	156 - 1,600	1
■ 154		5	455	299 - 564	0
■ 155		5	395	208 - 572	0
▲ 157		3	260	230 - 284	0
■ 158		3	285	266 - 309	0
● 161		133	240	84 - 470	0
▲ 164		30	160	96 - 248	0
■ 165		3	2,525	2,430 - 2,570	3
■ 166		2	1,220	305 - 2,130	1
■ 167		31	570	153 - 1,600	8
▲ 169		3	230	154 - 287	0
■ 170		4	1,460	985 - 1,980	4
▲ 171		14	250	131 - 326	0
■ 172		14	345	146 - 531	0
▲ 173		11	265	114 - 461	0
■ 176		3	235	178 - 293	0
■ 177		3	325	156 - 541	0
▲ 182		2	125	71 - 178	0
■ 183		4	1,005	503 - 2,210	1

5.0 QUALITY OF SURFACE WATER--Continued

5.3 pH and Alkalinity

Values of pH Indicate Streams Slightly Alkaline

The median pH was 7.7 for stations upstream from mining and 7.4 for stations downstream from mining; alkalinity averaged 138 milligrams per liter for stations upstream from mining and 118 milligrams per liter for stations downstream from mining.

Values of pH are a measure of the hydrogen-ion activity of solutions and are used to express their relative acidity or alkalinity. A pH value of 7.0 represents neutral water. Progressively smaller values indicate increasing acidity of water, and progressively larger values indicate increasingly alkaline water.

The pH has a significant effect on the suitability of water for industrial, municipal, and recreational purposes. Prolonged pH levels of less than 5.5 can significantly affect aquatic corrosivity, productivity, and the toxicity, mobility, and solubility of many chemical compounds.

The pH of water draining areas affected by surface coal mining may be altered by chemical reactions with minerals in spoils. The oxidation of pyrite, marcasite, and other minerals containing sulfur results in the production of sulfuric acid. If the acid production is significant and the carbonate buffering capacity is minimal, mine drainage may have pH values of 2.0 to 5.0. The Surface Mining Control and Reclamation Act has established a permissible range of pH of 6.0 to 9.0 for effluents from mining operations.

Values of pH less than 6.0 in coal-mining areas may indicate acid-mine drainage. The range of values for stations in Coal Area 38 is shown in figure 5.3-1 and table 5.3-1. Five stations downstream from coal mining had at least one pH measurement of less than 6.0. The pH ranged from 6.4 to 8.8 with a median of 7.7 for stations upstream from coal mining; pH ranged from 3.4 to 8.6 with a median of 7.4 for stations downstream from coal mining. Some of the smaller pH values may have been affected by gob-and-slurry disposal areas that contain material with significant sulfide mineral content and minimal buffering capacity. In most places in Coal Area 38, water in the spoils is buffered by the thin beds of limestone that were present in the overburden.

Alkalinity of water is its capacity to neutralize acid, and in natural water is due primarily to the presence of carbonates and bicarbonates. Alkalinity as calcium carbonate ranged from 20 to 260 mg/L and averaged 138 mg/L for stations upstream from coal mining (table 5.3-2). Alkalinity ranged from 0 to 260 mg/L and averaged 118 mg/L for stations downstream from mining.

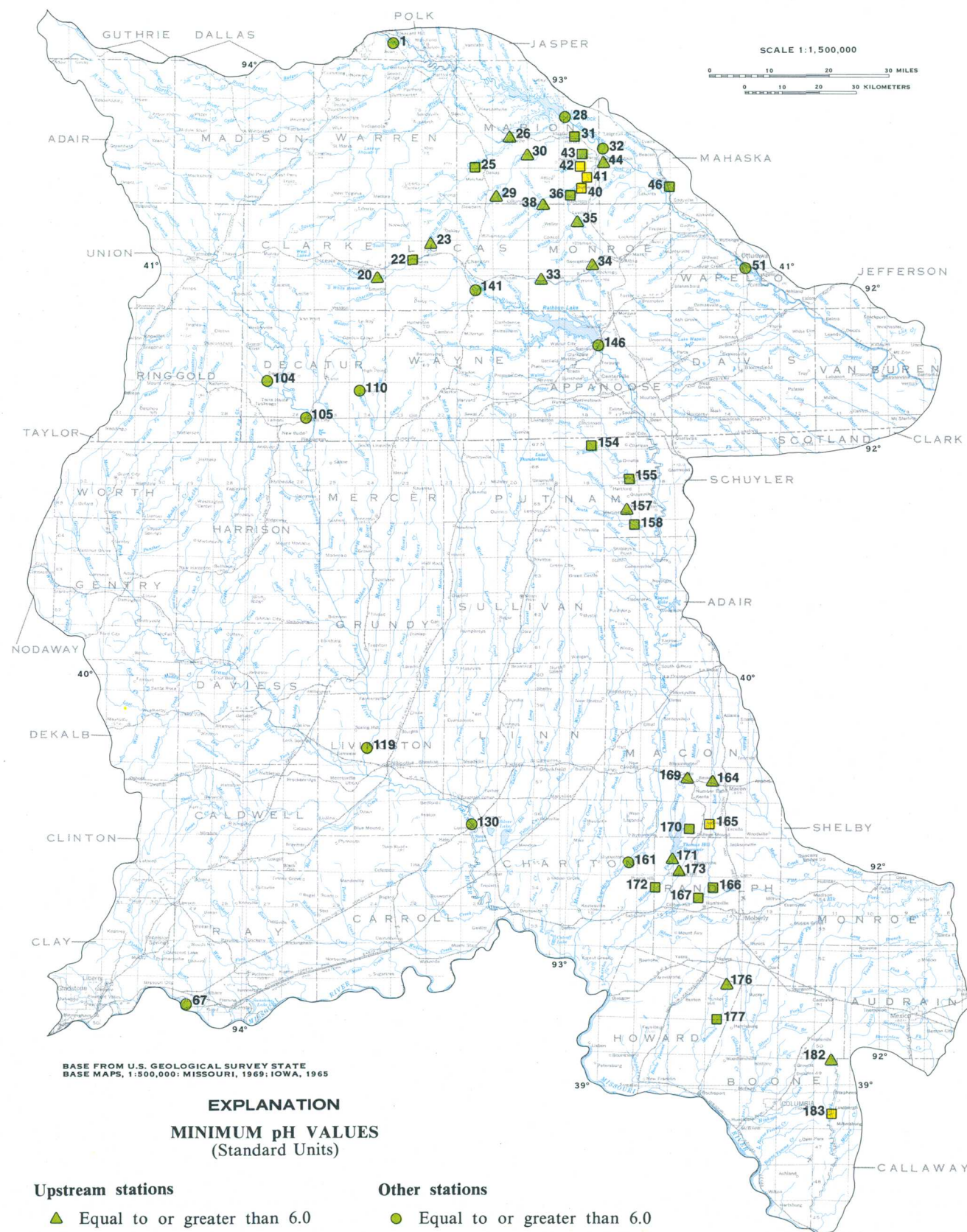


Figure 5.3-1 Minimum pH values for water-quality stations.

Figure 5.3-1 Summary of pH values (standard units).

Map symbol	Map No.	Number of samples	Median	Range	Number of samples less than 6.0
▲	1	52	8.2	7.0 - 8.7	0
▲	20	10	7.8	7.2 - 8.1	0
▲	22	15	8.0	7.3 - 8.6	0
▲	23	10	7.9	7.1 - 8.4	0
▲	25	15	8.1	7.4 - 8.6	0
▲	26	10	7.7	7.2 - 8.8	0
▲	28	410	8.0	6.7 - 9.1	0
▲	29	10	7.6	7.1 - 8.2	0
▲	30	13	7.8	7.2 - 8.2	0
▲	31	10	7.8	7.2 - 8.3	0
▲	32	16	8.2	7.6 - 8.8	0
▲	33	11	7.9	6.9 - 8.4	0
▲	34	13	7.9	7.3 - 8.4	0
▲	35	15	7.7	7.0 - 8.4	0
▲	36	8	7.6	7.3 - 8.1	0
▲	38	16	7.7	7.0 - 8.1	0
▲	40	16	7.4	4.9 - 7.7	2
▲	41	16	7.5	4.4 - 8.1	1
▲	42	3	6.5	5.6 - 7.5	1
▲	43	4	7.1	7.0 - 7.5	0
▲	44	16	7.2	6.5 - 8.4	0
▲	46	2	7.1	6.6 - 7.6	0
▲	51	42	7.9	7.2 - 8.5	0
▲	67	49	8.0	7.5 - 8.4	0
▲	104	166	7.9	6.6 - 8.9	0
▲	105	34	7.9	6.8 - 8.7	0
▲	110	43	7.9	6.9 - 8.5	0
▲	119	80	7.9	7.0 - 8.7	0
▲	130	166	7.8	6.7 - 8.6	0
▲	141	81	7.4	6.7 - 8.1	0
▲	146	92	7.6	6.7 - 8.1	0
▲	154	5	7.5	7.2 - 8.0	0
▲	155	5	7.9	7.2 - 8.3	0
▲	157	3	7.7	7.1 - 8.3	0
▲	158	3	7.8	7.3 - 8.2	0
▲	161	133	7.8	6.6 - 8.9	0
▲	164	30	7.8	7.0 - 8.3	0
▲	165	3	3.8	3.4 - 4.3	3
▲	166	2	7.6	7.2 - 8.0	0
▲	167	31	7.6	6.9 - 8.3	0
▲	169	3	7.9	6.9 - 8.2	0
▲	170	4	7.1	6.4 - 7.2	0
▲	171	14	7.9	6.7 - 8.3	0
▲	172	14	7.6	6.8 - 8.3	0
▲	173	11	7.3	6.6 - 8.0	0
▲	176	3	7.7	7.7 - 7.8	0
▲	177	3	7.6	7.6 - 7.7	0
▲	182	2	6.9	6.4 - 7.3	0
▲	183	4	3.8	3.6 - 7.2	3

Table 5.3-2 Summary of alkalinity concentrations (milligrams per liter as CaCO_3).

Map symbol	Map No.	Number of samples	Average	Range
▲	1	40	215	93 - 333
▲	20	20	200	130 - 250
▲	22	15	208	98 - 260
▲	23	10	187	72 - 240
▲	25	15	169	85 - 210
▲	26	10	176	81 - 210
▲	28	400	214	70 - 413
▲	29	10	176	98 - 230
▲	30	13	184	96 - 250
▲	31	10	123	66 - 160
▲	32	0	-	-
▲	33	11	176	34 - 250
▲	34	13	163	60 - 210
▲	35	15	161	53 - 210
▲	36	8	137	84 - 190
▲	38	16	160	43 - 260
▲	40	16	108	0 - 180
▲	41	16	110	0 - 190
▲	42	2	6	5 - 7
▲	43	2	90	69 - 110
▲	44	15	106	44 - 170
▲	46	2	113	102 - 123
▲	51	53	181	39 - 296
▲	67	49	171	123 - 218
▲	104	102	211	52 - 365
▲	105	10	154	60 - 248
▲	110	9	193	121 - 400
▲	119	80	161	62 - 277
▲	130	163	164	56 - 289
▲	141	62	157	25 - 316
▲	146	74	131	54 - 340
▲	154	5	208	69 - 246
▲	155	5	167	54 - 230
▲	157	3	175	131 - 197
▲	158	3	186	148 - 213
▲	161	131	122	33 - 259
▲	164	30	87	49 - 121
▲	165	3	0	0 - 1
▲	166	2	105	46 - 164
▲	167	31	93	38 - 156
▲	169	3	108	59 - 180
▲	170	4	75	56 - 98
▲	171	14	66	43 - 82
▲	172	14	42	20 - 62
▲	173	11	90	20 - 164
▲	176	3	110	54 - 164
▲	177	3	101	52 - 131
▲	182	2	35	28 - 41
▲	183	4	9	0 - 33

5.0 QUALITY OF SURFACE WATER--Continued

5.4 Sulfate

Sulfate Concentrations are Greater in Streams Draining Mined Areas

Sulfate concentrations averaged 88 milligrams per liter for stations upstream from mining and 269 milligrams per liter for stations downstream from mining.

Sulfur occurs in coal and associated strata as metallic sulfides, mainly pyrite and marcasite. When oxidized, the sulfides yield sulfate ion and ferric oxide. The neutralization of acid-mine drainage by alkaline or buffered waters in streams leaves significant quantities of sulfates in solution. Therefore, dissolved sulfate is one of the constituents commonly used to identify mine drainage.

Sulfate concentrations ranged from 3 to 620 mg/L (milligrams per liter) and averaged 88 mg/L for upstream stations, and ranged from 17 to 1,800 mg/L and averaged 269 mg/L for downstream stations (table 5.4-1). Twelve of the downstream stations had average sulfate concentrations greater than 200 mg/L (figure 5.4-1).

The major inorganic constituents in water at Cedar Creek near Lovilia, Iowa (map no. 35, upstream from mining) and Cedar Creek near Bussey, Iowa (map no. 41, downstream from mining) are represented and compared in figures 5.4-2 and 5.4-3. These ion-distribution diagrams are designed to represent simultaneously the total solute concentration and the proportions assigned to each ionic species for a group of analyses. The Lovilia station has a total solute concentration of 10.9 milliequivalents per liter whereas the Bussey station has a total solute concentration of 13.7 milliequivalents per liter. A major difference between the two stations is

the larger sulfate to bicarbonate ratio and the larger total solute concentration for the downstream station.

The concentration of sulfate correlates significantly with specific conductance. The correlation coefficient for upstream stations, 190 measurements, is 0.81 and for downstream stations, 160 measurements, the correlation coefficient is 0.97. The regression equations for upstream and downstream stations are:

$$S = 0.33(K) - 66 \text{ upstream}$$

and

$$S = 0.65(K) - 205 \text{ downstream}$$

where

S is sulfate concentration, in milligrams per liter; and

K is specific conductance, in micromhos per centimeter at 25° Celsius.

The standard error for the equations is 48 mg/L for upstream stations and 82 mg/L for downstream stations.

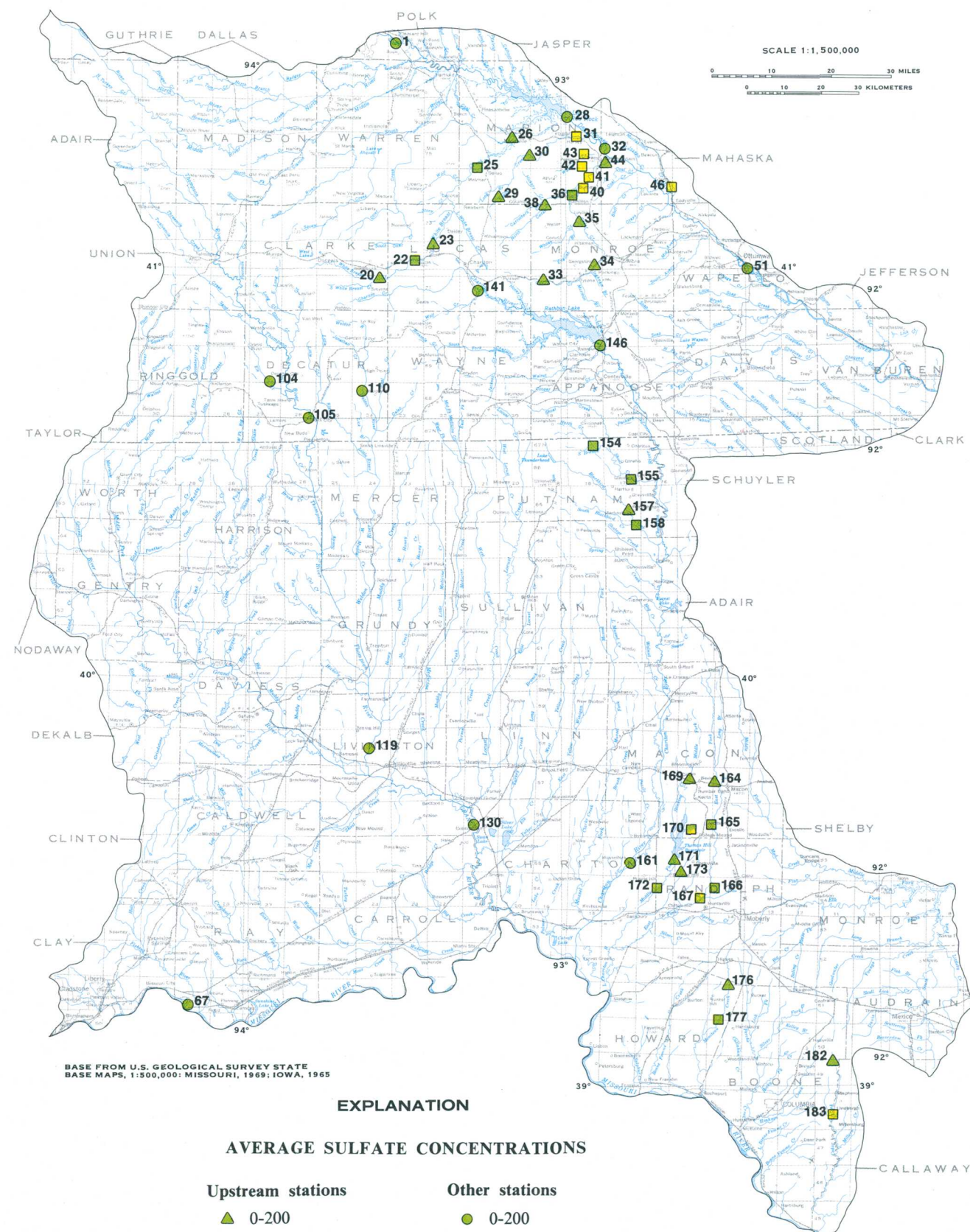


Figure 5.4-1 Average sulfate concentrations for water-quality stations.

Table 5.4-1 Summary of sulfate concentrations (milligrams per liter).

Map symbol	Map No.	Number of samples	Average	Range	Number of samples greater than 200
▲	1	29	88	48 - 150	0
▲	20	10	38	15 - 52	0
▲	22	15	43	23 - 69	0
▲	23	10	46	22 - 70	0
▲	25	15	51	37 - 78	0
▲	26	10	102	35 - 170	0
▲	28	24	50	0 - 119	0
▲	29	10	62	36 - 77	0
▲	30	13	110	66 - 180	0
▲	31	10	329	74 - 650	7
▲	32	4	94	30 - 140	0
▲	33	11	74	10 - 180	0
▲	34	13	79	26 - 130	0
▲	35	15	93	40 - 130	0
▲	36	8	130	66 - 180	0
▲	38	16	151	14 - 620	3
▲	40	16	270	17 - 870	9
▲	41	16	207	20 - 630	4
▲	42	2	730	590 - 870	2
▲	43	2	250	140 - 360	1
▲	44	15	196	27 - 440	4
▲	46	2	535	260 - 810	2
▲	51	31	88	31 - 130	0
▲	67	49	147	70 - 220	3
▲	104	109	54	8 - 100	0
▲	105	10	42	22 - 62	0
▲	110	8	53	35 - 71	0
▲	119	80	41	12 - 73	0
▲	130	166	40	6 - 74	0
▲	141	28	67	12 - 340	5
▲	146	26	90	25 - 820	1
▲	154	5	144	21 - 220	1
▲	155	5	126	40 - 220	1
▲	157	3	34	9 - 62	0
▲	158	3	48	27 - 79	0
▲	161	133	63	18 - 146	0
▲	164	30	32	3 - 62	0
▲	165	3	1,567	1,200 - 1,800	3
▲	166	2	780	160 - 1,400	1
▲	167	31	301	31 - 880	17
▲	169	3	54	23 - 100	0
▲	170	4	903	590 - 1,300	4
▲	171	14	117	46 - 170	0
▲	172	14	202	55 - 340	9
▲	173	11	74	3 - 160	0
▲	176	3	64	45 - 73	0
▲	177	3	134	44 - 260	1
▲	182	2	10	4 - 15	0
▲	183	4	678	320 - 1,500	4

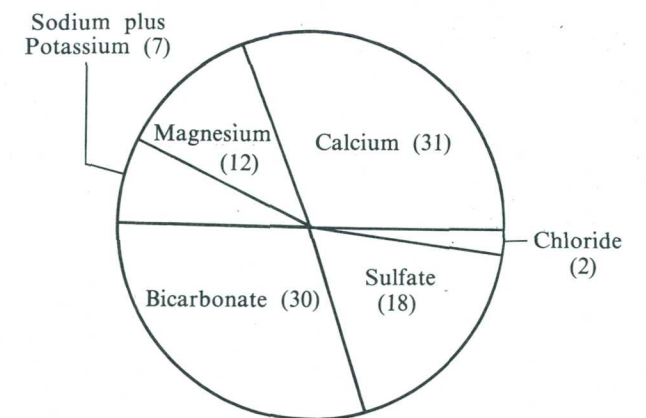


Figure 5.4-2 average chemical composition for a selected station upstream from surface mining (station 05488700 Map No. 35).

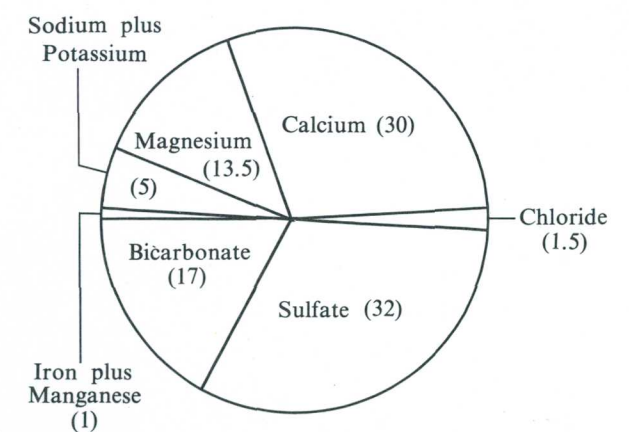


Figure 5.4-3 Average chemical composition for a selected station downstream from surface mining (station 05489000 Map No. 41).

5.0 QUALITY OF SURFACE WATER--Continued

5.5 Iron

Total Recoverable-Iron Concentrations are Larger in Streams Draining Mined Areas, Whereas Dissolved-Iron Concentrations are Smaller

Median, total recoverable-iron concentrations were 1,550 micrograms per liter for upstream stations and 2,300 micrograms per liter for downstream stations; median dissolved-iron concentrations were 70 micrograms per liter for stations upstream from mining and 60 micrograms per liter for stations downstream from mining.

Iron is an important constituent of surface and ground waters because it is one of the most abundant metals in the Earth's crust. Under natural conditions, iron is found primarily in the ferrous form (Fe^{+2}). Several factors control the solubility of iron, the most important of which are pH, dissolved oxygen, dissolved carbon dioxide, redox potential, and sulfur species. Insoluble iron precipitates are formed through the oxygenation of mine drainage containing large concentrations of dissolved iron. Precipitates also form when mine drainage mixes with streams with greater pH (Hem, 1970). Surface-mining processes expose iron-bearing rocks and soil to weathering, accelerating the oxidation and dissolution of iron compounds resulting in increased dissolved-iron concentrations.

Dissolved-iron concentrations in excess of 300 $\mu\text{g/L}$ (micrograms per liter) cause staining, impart an undesirable taste to water, and require treatment for most uses (U.S. Environmental Protection Agency, 1976). In streams, where dissolved iron precipitates through oxygenation, "yellow boy" (ferrous hydroxide, an ochre-yellow precipitate), is produced which flocculates and settles on river beds adversely affecting bottom aquatic life.

Dissolved-iron concentrations ranged from less than 10 to 2,100 $\mu\text{g/L}$ with a median of 70 $\mu\text{g/L}$ for upstream stations and ranged from less than 10 to 32,000 $\mu\text{g/L}$ with a median of 60 $\mu\text{g/L}$ for downstream stations (table 5.5-1). Seven of the downstream stations and one of the upstream stations had median dissolved-iron concentrations greater than 300 $\mu\text{g/L}$ (figure 5.5-1). Two of these downstream stations had median concentrations greater than 1,000 $\mu\text{g/L}$ dissolved iron.

Total recoverable-iron concentrations ranged

from 90 to 82,000 $\mu\text{g/L}$ with a median of 1,550 $\mu\text{g/L}$ for upstream stations and ranged from 20 to 69,000 $\mu\text{g/L}$ with a median of 2,300 $\mu\text{g/L}$ for downstream stations (table 5.5-2). The Surface Mining Control and Reclamation Act has established a maximum permissible concentration of 7,000 $\mu\text{g/L}$ of total recoverable iron for effluents from mining operations.

Large quantities of iron-bearing minerals in particulate form are transported to streams resulting in increased total recoverable iron concentrations. A significant relationship exists for Area 38 data between concentrations of total recoverable iron and suspended sediment. The correlation coefficient for this relationship is 0.90. The regression equation describing the relationship for water-quality stations (Map nos. 20, 23, 26, 29, 30, 33, 34, 35, and 38) in Iowa upstream from mining is:

$$(1) \quad Y = 37.2 (X^{0.93}) \quad 38 \text{ measurements}$$

where

Y equals total iron concentration, in micrograms per liter; and

X equals suspended sediment concentration, in milligrams per liter

A regression equation for two Iowa downstream stations (Map nos. 40 and 41) is:

$$(2) \quad Y = 92.1 (X^{0.79}) \quad 17 \text{ measurements}$$

Unmined conditions are described by equation (1). Equation (2) describes the relationship for conditions where mining activities are affecting chemical quality, a larger total-iron concentration per milligram of suspended sediment.

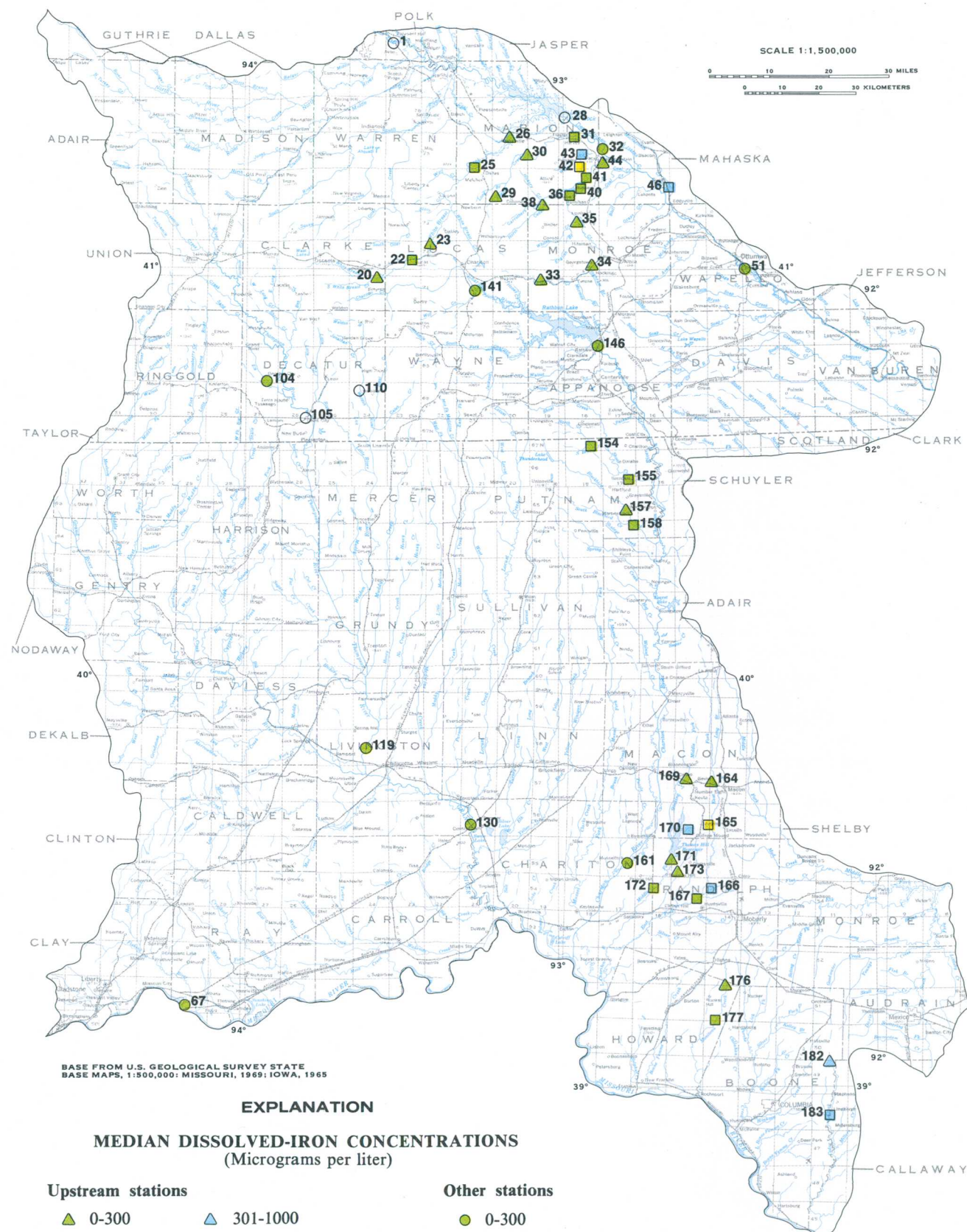


Figure 5.5-1 Median dissolved-iron concentrations for water-quality stations.

Table 5.5-1 Summary of dissolved-iron concentrations (micrograms per liter).

Map symbol	Map No.	Number of samples	Median	Range	Number of samples greater than 300
○1	0	-	-	-	0
▲20	6	70	<10	220	0
▲22	12	20	<10	1,400	2
▲23	4	20	<10	140	0
▲25	12	20	<10	480	1
▲26	3	20	<10	230	0
○28	0	-	-	-	0
▲29	6	50	13	110	0
▲30	9	20	<10	140	0
▲31	6	30	<10	210	0
▲32	4	110	40	200	0
▲33	5	10	<10	290	0
▲34	9	140	20	2,100	2
▲35	12	50	<10	1,600	1
▲36	8	50	<10	220	0
▲38	9	30	<10	520	1
▲40	12	20	<10	2,000	2
▲41	12	20	<10	2,400	1
▲42	2	2,600	1,100	4,100	2
▲43	2	420	90	740	1
▲44	11	20	<10	1,800	1
▲46	2	410	70	650	1
▲51	27	60	10	300	1
▲67	49	50	<10	750	1
○104	23	80	<10	900	1
○105	0	-	-	-	0
○110	0	-	-	-	0
▲119	70	60	<10	970	4
▲130	94	50	<10	5,600	5
▲141	28	120	10	1,500	4
▲146	25	120	19	760	3
▲154	5	70	30	1,300	1
▲155	5	110	<10	9,200	1
▲157	3	50	20	60	0
▲158	3	<10	<10	150	0
▲161	85	60	<10	600	3
▲164	28	70	10	400	1
▲165	3	4,000	770	32,000	3
▲166	2	480	10	940	1
▲167	28	80	<10	5,200	2
▲169	2	60	20	90	0
▲170	4	370	60	900	2
▲171	13	60	30	120	0
▲172	13	50	<10	1,100	1
▲173	11	120	70	250	0
▲176	3	70	30	200	0
▲177	3	30	30	260	0
▲182	2	350	240	450	1
▲183	3	970	70	2,400	2

Table 5.5-2 Summary of total-recoverable iron concentrations (micrograms per liter).

Map symbol	Map No.	Number of samples	Median	Range
○1	0	-	-	-
▲20	10	1,750	510	12,000
▲22	15	1,700	760	28,000
▲23	7	2,100	1,800	46,000
▲25	15	2,250	1,200	55,000
▲26	7	3,800	8,400	64,000
○28	0	-	-	-
▲29	10	1,350	290	9,900
▲30	13	2,000	590	24,000
▲31	10	1,650	620	57,000
▲32	0	-	-	-
▲33	8	1,580	690	32,000
▲34	13	1,400	340	82,000
▲35	15	1,900	970	36,000
▲36	8	3,400	1,700	69,000
▲38	13	2,800	640	28,000
▲40	16	2,000	1,000	32,000
▲41	16	2,600	20	45,000
▲42	2	4,950	4,100	4,800
▲43	2	10,500	2,000	19,000
▲44	15	2,550	380	48,000
▲46	2	2,650	2,000	3,300
▲51	0	-	-	-
▲67	0	-	-	-
○104	13	500	220	33,000
○105	0	-	-	-
○110	0	-	-	-
▲119	0	-	-	-
▲130	29	3,000	440	24,000
▲141	0	-	-	-
▲146	0	-	-	-
▲154	5	590	350	64,000
▲155	5	2,000	830	35,000
▲157	3	1,000	670	2,500
▲158	3	1,500	590	2,200
▲161	14	1,550	270	12,000
▲164	30	700	140	5,800
▲165	3	1,200	1,100	5,600
▲166	2	9,100	200	18,000
▲167	31	3,100	100	43,000
▲169	3	1,500	860	4,700
▲170	4	1,610	730	3,100
▲171	14	630	90	2,800
▲172	14	1,650	160	31,000
▲173	11	2,700	1,300	38,000
▲176	3	970	450	5,900
▲177	3	1,800	1,500	17,000
▲182	2	3,200	3,100	3,300
▲183	4	2,700	1,500	6,900

5.0 QUALITY OF SURFACE WATER--Continued

5.6 Manganese

Manganese Concentrations are Larger in Streams Draining Mined Areas

Median dissolved-manganese concentrations were 240 micrograms per liter for stations upstream from mining and 600 micrograms per liter for stations downstream from mining; median total recoverable-manganese concentrations were 700 micrograms per liter for upstream stations and 1,100 micrograms per liter for downstream stations.

Manganese is one of the most common elements in soils and rocks. Soils rich in organic matter are one of the primary sources of manganese to natural waters. The reactions, transport, and dissolution of manganese in natural waters are similar to those of iron, with significant quantities of manganese suspended in particulate forms. The factors controlling the solubility of manganese are complex. However it is important to note that manganese oxide does have a tendency to form coatings on other mineral surfaces (Hem, 1970); thus manganese generally is sorbed on suspended-sediment particles.

Dissolved manganese in excess of 50 $\mu\text{g/L}$ (micrograms per liter) imparts objectionable taste, may cause staining, and generally renders water unfit for many industrial and domestic supplies. Most water-supply criteria (U.S. Environmental Protection Agency, 1977) contain maximum limits for dissolved manganese (50 $\mu\text{g/L}$).

Manganese concentrations in streams do not change consistently or greatly with change in stream-flow. Correlation coefficients for the relationships between dissolved or total recoverable manganese with streamflow are less than 0.10 for data from stations both upstream and downstream from mining activities.

Dissolved manganese concentrations ranged from less than 10 to 6,400 $\mu\text{g/L}$ and had a median of 240 $\mu\text{g/L}$ for upstream stations and ranged from 20 to 24,000 $\mu\text{g/L}$ and had a median of 600 $\mu\text{g/L}$ for stations downstream of mining (table 5.6-1). Nine of the downstream stations and one of the upstream stations had average dissolved-manganese concentrations of greater than 1,000 $\mu\text{g/L}$ (figure 5.6-1).

The relationship between suspended-sediment concentration and total recoverable-manganese concentration for data in Area 38 is not significant. The correlation coefficient for this relationship for data upstream and downstream from mining is less than 0.10.

Total recoverable manganese concentrations ranged from 50 to 8,500 $\mu\text{g/L}$ and had a median of 700 $\mu\text{g/L}$ for upstream stations and ranged from 70 to 25,000 $\mu\text{g/L}$ and had a median of 1,100 $\mu\text{g/L}$ for downstream stations (table 5.6-2). The Surface Mining Control and Reclamation Act specifies 4,000 $\mu\text{g/L}$ as the maximum permissible concentration of total manganese in effluents from mining activities. The larger concentrations of manganese at stations downstream from mining results from the weathering of disturbed overburden associated with coal mining.

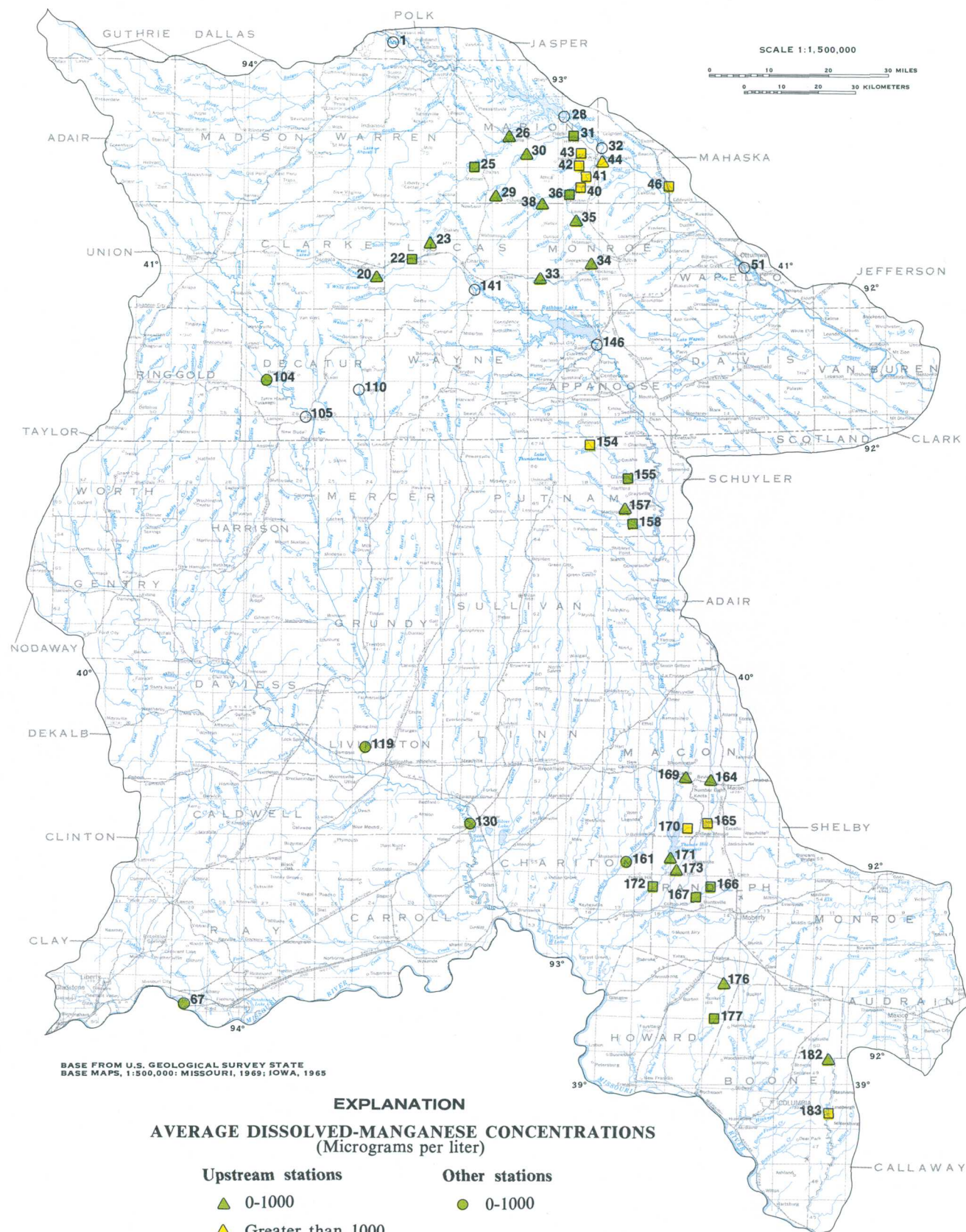


Figure 5.6-1 Median dissolved-manganese concentrations for water-quality stations.

Table 5.6-1 Summary of dissolved-manganese concentrations (micrograms per liter).

Map symbol	Map No.	Number of samples	Median	Range	Number of samples greater than 1000
○1		0	-	-	-
▲20		6	220	<10 - 1,100	1
▲22		11	150	30 - 1,100	1
▲23		3	120	110 - 450	0
▲25		11	60	20 - 450	0
▲26		3	230	100 - 620	0
○28		0	-	-	-
▲29		6	190	83 - 460	0
▲30		9	550	260 - 2,100	2
▲31		6	950	340 - 2,600	3
○32		0	-	-	-
▲33		4	420	<10 - 590	0
▲34		9	300	69 - 1,700	2
▲35		11	700	80 - 1,600	3
▲36		8	1,000	180 - 3,000	4
▲38		9	420	190 - 3,800	2
▲40		12	1,850	20 - 5,600	8
▲41		12	1,900	330 - 11,000	9
▲42		2	17,500	11,000 - 24,000	2
▲43		2	2,500	1,900 - 4,200	2
▲44		12	1,300	320 - 6,400	8
▲46		2	4,100	2,300 - 5,900	2
○51		0	-	-	-
●67		49	20	<10 - 90	0
●104		22	230	<10 - 4,800	1
○105		0	-	-	-
○110		0	-	-	-
●119		80	60	<10 - 2,100	3
●130		119	80	<10 - 2,000	7
○141		0	-	-	-
○146		0	-	-	-
▲154		5	1,800	120 - 4,600	4
▲155		5	430	20 - 880	0
▲157		3	240	210 - 290	0
▲158		3	210	150 - 710	0
●161		111	50	<10 - 5,100	3
▲164		28	170	20 - 1,000	0
▲165		3	8,400	8,200 - 9,200	3
▲166		2	450	240 - 660	0
▲167		28	570	90 - 2,700	8
▲169		2	210	180 - 240	0
▲170		4	2,250	800 - 2,600	3
▲171		13	30	10 - 130	0
▲172		13	250	50 - 590	0
▲173		11	500	110 - 2,300	2
▲176		3	170	150 - 280	0
▲177		3	260	250 - 930	0
▲182		2	100	30 - 170	0
▲183		3	3,200	440 - 3,400	2

Table 5.6-2 Summary of total-recoverable manganese concentrations (micrograms per liter).

Map symbol	Map No.	Number of samples	Median	Range
○1	0	-	-	-
▲20	10	680	280 - 2,400	
▲22	15	580	160 - 2,800	
▲23	7	740	220 - 1,700	
▲25	15	470	160 - 2,100	
▲26	7	1,700	260 - 2,700	
○28	0	-	-	-
▲29	10	265	150 - 2,700	
▲30	13	990	320 - 2,600	
▲31	10	1,250	560 - 2,800	
○32	0	-	-	-
▲33	8	930	330 - 1,600	
▲34	13	760	150 - 3,300	
▲35	15	1,300	200 - 2,300	
▲36	8	1,750	460 - 3,200	
▲38	13	1,200	290 - 8,500	
▲40	16	3,300	1,100 - 22,000	
▲41	16	2,100	930 - 15,000	
▲42	2	18,000	11,000 - 25,000	
▲43	2	3,050	1,900 - 4,200	
▲44	16	1,750	1,000 - 6,800	
▲46	0	0	-	-
○51	33	100	<10 - 690	
●67	0	-	-	-
●104	26	580	<10 - 50,000	
○105	10	110	<10 - 1,200	
○110	7	70	<10 - 360	
●119	0	-	-	-
●130	29	560	180 - 2,600	
○141	28	460	70 - 940	
○146	24	200	<10 - 940	
▲154	5	1,900	1,300 - 5,700	
▲155	5	570	320 - 10,000	
▲157	3	280	240 - 330	
▲158	3	250	180 - 910	
▲161	14	300	50 - 730	
▲164	30	350	70 - 1,100	
▲165	3	7,600	230 - 8,800	
▲166	2	520	260 - 780	
▲167	31	880	340 - 2,600	
▲169	3	600	210 - 860	
▲170	4	2,250	880 - 2,800	
▲171	14	90	50 - 560	
▲172	14	270	70 - 980	
▲173	11	690	550 - 2,500	
▲176	3	280	260 - 390	
▲177	3	700	360 - 890	
▲182	2	160	70 - 240	
▲183	4	3,400	460 - 16,000	

5.0 QUALITY OF SURFACE WATER--Continued

5.7 Trace Elements

Trace-Element Concentrations Vary

Concentrations of some trace elements differed between stations upstream and downstream from coal mining.

Trace elements generally are found in most streams in small concentrations and are considered essential to plant and animal life. Some trace elements, in sufficiently large concentrations, are toxic to aquatic life and make the water unusable for irrigation, industrial, rural or domestic water supplies (Missouri Department of Natural Resources, 1978). Primary natural sources of trace elements include soil, rock strata underlying the stream basin, and atmospheric fallout. Large concentrations of trace elements in streams may occur naturally, but usually are associated with waste discharge (Harkins and others, 1980). In coal-mine areas, minerals that contain trace elements are exposed to the environment allowing the weathering process to oxidize and transport them to streams. This process is accelerated when the sulfide minerals associated with the coal are oxidized and acid is produced. Acidic water reacts with the trace elements, making them soluble and available to other reactions, such as the formation of precipitates in water with a pH of 7.0 or sorption on sediments. Therefore, concentrations of trace elements generally are greatest in streams at or near surface coal mines, but decrease downstream.

Some trace elements associated with coal mining and analyzed for in Area 38 are aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, and zinc. A summary of the analyses of samples collected at stations upstream and downstream from past or present surface coal-mining operations is shown in table 5.7-1. Other water-quality stations not specifically for coal hydrology data collection have been included for comparison. Differences in average concentrations of trace elements at upstream or downstream stations were observed. Barium, cadmium, copper, lead, mercury, nickel, and zinc had larger average total concentrations downstream than upstream from mining; lead and zinc showed the most significant difference. Large concentrations of trace elements at upstream or noncoal-hydrology stations could be attributed to waste discharge. Recommended total concentration limits established by the U.S. Environmental Protection Agency (1977a and 1977b) were exceeded by cadmium, chromium, lead, mercury, and zinc (table 5.7-1).

Table 5.7-1 Summary of trace-element concentrations.

Map No.	Trace element	Upstream Downstream Other	△ □ ○	Dissolved, in micrograms per liter				Total, in micrograms per liter					Bottom material, in micrograms per gram			
				Samples	Minimum	Maximum	Average	Samples	Minimum	Maximum	Average ^{1]}	Limits ^{2]}	Samples	Minimum	Maximum	Average ^{1]}
16 13	Aluminum	△ □		23 11	20 20	1,000 1,300	150 260	33 18	40 30	24,000 17,000	4,200 4,000	--	10 13	100 60	9,000 12,000	3,500 4,000
18 14 2	Arsenic	△ □ ○		55 36 49	0 0 0	3 3 3	1 1 1	106 57 43	1 1 0	20 10 32	3 3 5	50	24 17 --	4 4 --	25 14 --	11 8 --
15 7 4	Barium	△ □ ○		24 12 38	<100 <100 0	300 300 200	100 200 60	75 34 33	<100 <100 <100	400 600 400	100 200 200	1,000	-- -- --	-- -- --	-- -- --	-- -- --
18 14 4	Cadmium	△ □ ○		55 36 55	0 0 0	3 3 14	1 0 1	105 58 47	12 0 16	1 25 1	0 2 0	10	24 17 --	0 0 --	6 19 --	1 2 --
18 14 4	Chromium	△ □ ○		55 36 55	0 0 0	20 20 10	3 5 1	106 57 47	0 0 0	90 90 60	10 10 10	50	24 17 --	2 0 --	11 14 --	6 6 --
7 9 4	Cobalt	△ □ ○		-- -- 55	-- -- 0	-- -- 8	-- -- 1	-- -- 47	-- -- 0	-- -- 26	-- -- 4	--	10 13 --	10 0 --	40 20 --	15 12 --
18 14 4	Copper	△ □ ○		55 36 55	1 0 ND	42 25 160	6 5 17	105 58 47	0 2 120	100 91 23	12 16 4	1,000	24 17 --	2 1 --	70 22 --	16 9 --
18 14 4	Lead	△ □ ○		55 36 55	0 0 0	23 23 82	4 3 8	105 58 47	0 0 3	120 2,000 190	13 82 22	50	24 17 --	0 0 --	180 48 --	35 16 --
18 14 2	Mercury	△ □ ○		32 24 49	0.0 0.0 0.0	0.1 0.2 1.6	0.0 0.0 1.6	83 45 45	0.0 0.0 0.1	0.4 0.4 1.8	0.1 0.2 0.3	2.0	24 17 --	0.00 0.00 --	0.20 0.50 --	0.02 0.05 --
15 13 4	Nickel	△ □ ○		23 12 24	ND 2 0	36 31 30	8 12 8	29 16 18	2 5 5	47 48 84	13 20 24	--	10 13 --	7 2 --	30 55 --	16 19 --
18 14 2	Selenium	△ □ ○		25 13 49	<1 0 0	1 3 3	1 1 0	74 34 47	0 0 0	2 2 3	1 1 1	10	24 17 --	0 0 --	1 2 --	0 0 --
15 7 4	Silver	△ □ ○		-- -- 40	-- -- 0	-- -- 6	-- -- 0	50 22 41	0 0 0	<1 1 5	0 0 0	50	-- -- --	-- -- --	-- -- --	-- -- --
18 14 4	Zinc	△ □ ○		55 36 55	0 <3 <3	70 100 310	14 15 36	106 58 47	0 0 <20	340 7,600 280	40 200 70	5,000	24 17 --	7 7 --	51 200 --	23 65 --

^{1]} For averaging purposes, "not detected" (ND) and "less than" values (<) were considered 0. ^{2]} U.S. Environmental Protection Agency, 1977a and 1977b

5.0 QUALITY OF SURFACE WATER--Continued

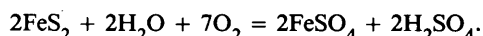
5.8 Acid-Mine Drainage

Present and Past Water-Quality Studies Indicate Acid-Mine Drainage in Area 38

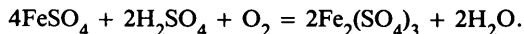
Five streams met or exceeded the established criteria for identification of acid-mine drainage during the study.

Acid-mine drainage from active and abandoned surface coal mines is a major source of water-quality degradation. Runoff from coal-mine areas is characterized by small pH values and large sulfate and trace-element concentrations, which adversely affect stream aquatic life and limit the use of the water for industrial, domestic, or recreational purposes.

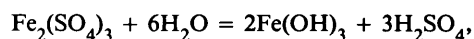
Sulfuric acid is produced when iron sulfide minerals, pyrite and marcasite, associated with the coal are oxidized (Missouri Department of Natural Resources, 1978). Acid formation occurs naturally, but mining accelerates the process by exposing large quantities of pyrite to the environment. Initially, water (H₂O) and oxygen (O₂) react with the pyrite (FeS₂) forming ferrous sulfate (FeSO₄) and sulfuric acid (H₂SO₄), as shown in the equation,



In the presence of a sufficient quantity of sulfuric acid and oxygen, ferrous sulfate is oxidized to water-soluble ferric sulfate [Fe₂(SO₄)₃],



This reaction is accelerated by iron-oxidizing bacteria of the Thiobacillus-Ferrobacillus group. Once in solution, the ferric ion hydrolyzes,



to form the insoluble ferric hydroxide [Fe(OH)₃] which forms an orange coating ("yellow boy") on streambeds, gives the water a reddish appearance when in suspension, or sorbs on stream sediments (figure 5.8-1). Additional sulfuric acid is released to the water in this step. The acidic water can then solubilize other constituents which are found in the coal-bearing strata including many trace elements such as aluminum, manganese, arsenic, cadmium, mercury, and zinc. As in the case of iron, these trace elements are subject to other reactions such as formation of precipitates or sorption on sediments.

Acid-mine water may collect in pits or flow directly to streams. Water in the pits generally is unsuitable for most aquatic life, but the pits serve to contain the acid water. During intense rainfall, however, acid water discharges from the pits causing fish kills and other damage to aquatic life in the receiving stream (figure 5.8-2). Streams receiving continual discharge of acid water may have permanent damage, including a partial or total destruction of the biological community. Few species of plants and animals can tolerate acid conditions and, therefore, species diversity is minimal.

The following criteria have been established as indicators of acid-mine drainage (U.S. Department of the Interior, 1968):

1. pH less than 6.0,
2. acidity greater than alkalinity,
3. total-iron concentration greater than 500 micrograms per liter,
4. total-manganese concentration greater than 500 micrograms per liter and
5. sulfate concentration greater than 75 milligrams per liter.

Streamflow at 5 of the 36 water-quality stations established for monitoring effects of coal mining in Area 38 (all located downstream from coal mining) exceeded all five criteria at one time or another. All five criteria may not have been exceeded in a single sample, but were exceeded once or many times at that station during the sampling period (1978-81). Acidity was not determined at the stations in Iowa, but because of the small pH values at those stations, it is assumed that the acidity was greater than the alkalinity. Locations of the stations that meet the acid-mine drainage criteria are shown in figure 5.8-3.

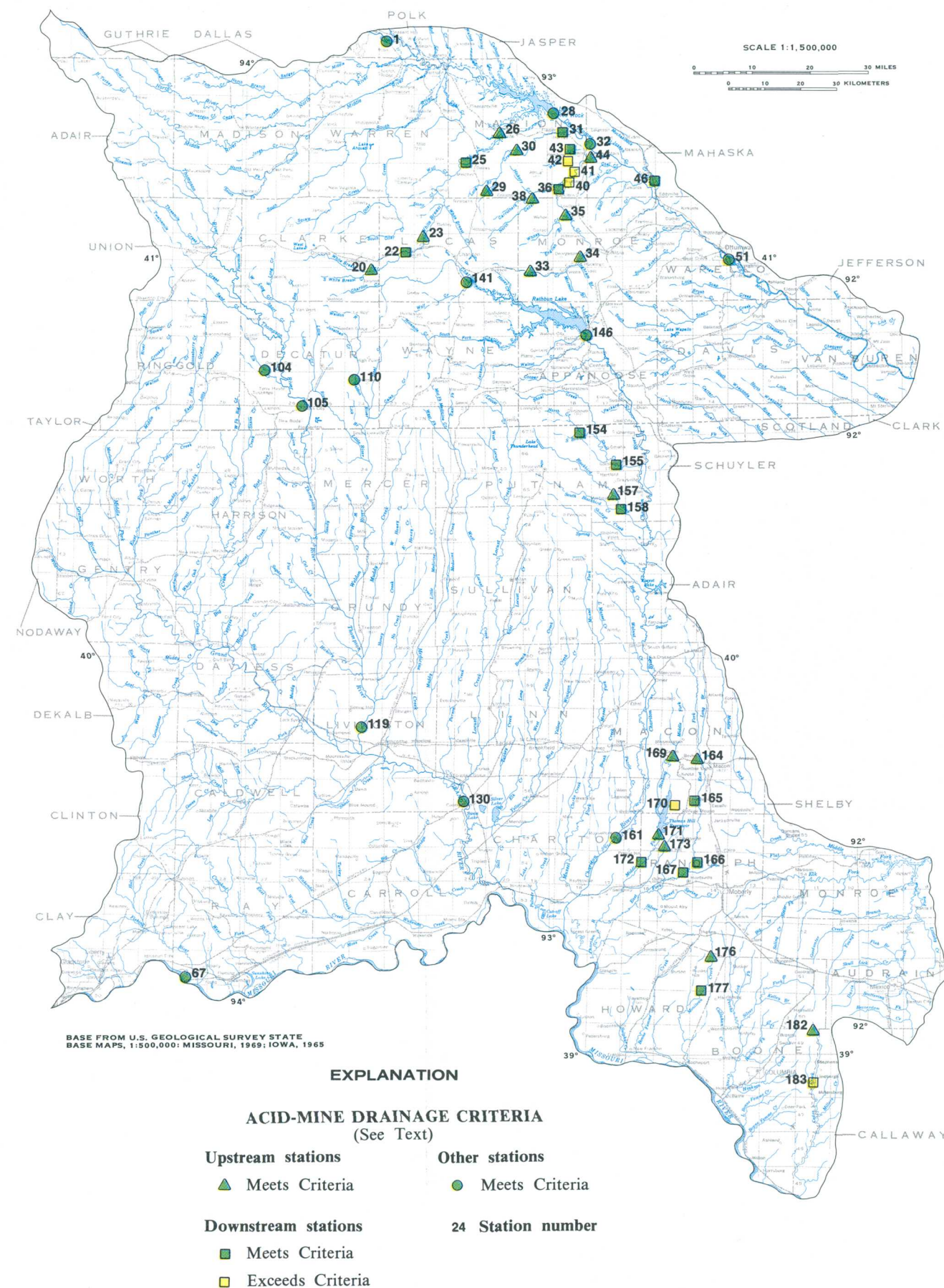


Figure 5.8-3 Location of water-quality stations as compared to acid-mine drainage criteria.

Although the five criteria will identify waters receiving acid-mine drainage, they will not identify all waters affected by acid-mine drainage. For example, a stream may have large concentrations of sulfate, iron, manganese, and trace elements, but have a pH greater than 6.0. The water, which would not qualify as being affected by acid-mine drainage, would be unsuitable for many purposes. Acidic-mine drainage commonly is neutralized by near-neutral or alkaline water in the receiving stream and usually is a problem only adjacent to the mined area. Trace elements, including iron and manganese, may not remain in solution in nonacidic waters, but neutralization does not change the concentration of sulfate (Toler, 1980) making it the best indicator of acid-mine drainage.

Previous studies by the Missouri Department of Natural Resources (1978) have determined at least 15

streams and one small lake to be adversely affected by acid-mine drainage in the Missouri part of Area 38. A total of 58.5 miles of streams are affected intermittently and 29 miles are affected continuously. These designations were based on fish-kill reports, limited water-quality data, and general observations. Cedar Creek in Missouri is a well-documented example of a stream affected by continuous and intermittent discharges of acid-mine drainages. Cedar Creek in Iowa, not the same stream as above, has been affected by discharges of acid-mine drainage, but only to a limited and intermittent extent. Effects of runoff from coal-mine areas to Muchakinock Creek in Iowa included decreases in pH and significant increases in dissolved solids (University Hygienic Laboratory, 1977).



Figure 5.8-1 Iron (yellow boy) precipitates from acid-mine drainage.



Figure 5.8-2 Fish kill in Cedar Creek near Columbia, Missouri.

6.0 GROUND WATER

6.1 Hydrogeologic Units and Data Sites

Three Groups of Aquifers are Significant in Area 38

The Cambrian-Ordovician aquifer system and Quaternary aquifers are regionally important sources of water; Mississippian and Pennsylvanian aquifers are locally important sources of water.

Aquifers are composed of permeable materials that transmit and yield water readily. Examples of these materials are sand, gravel, limestone, dolomite and sandstone. Materials such as shale and clay are relatively impermeable and retard the infiltration and movement of water. These materials form confining units.

The Cambrian-Ordovician aquifer system yields large quantities of water although the quality of this water is questionable and the aquifer is deeply buried. The Quaternary aquifers are at or near the surface and in Area 38 yield large quantities of desirable quality water to wells. In the northern part of Area 38, the Mississippian and Pennsylvanian rocks are potential sources of limited quantities of water. The limestone, dolomite and sandstone of the Mississippian aquifer have a large areal extent but yield limited quantities of water. In much of the area the Pennsylvanian rocks are a confining unit composed of layers of shale interbedded with limestone and sandstone. The water-bearing limestones and sandstones in the Pennsylvanian are aquifers of limited potential and extent.

The Devonian aquifer in Area 38 is not known to yield large quantities of water and the quality of

water is generally brackish. The Silurian, Upper Ordovician, and the Lower Cambrian rocks are not acceptable aquifers because the rocks do not yield water readily or contain unusable quality water. The Precambrian igneous and metamorphic rocks are not potential water sources. The information shown in table 6.1-1 includes summaries and general evaluations of sources of ground-water in Area 38.

The locations of wells that are the source of the ground-water data used in the preparation of this report are shown in figure 6.1-1. The data include water-level measurements, water-quality analyses, geologic descriptions, well yields, and water-withdrawal information. These data were compiled from previously published reports in Iowa and Missouri (Cagle and Heinritz, 1978 and Heim and Howe, 1962) and from records on file at the offices of the U.S. Geological Survey in Iowa City, Iowa, and Rolla, Missouri. Additional information about Area 38 is also available in the files of the U.S. Geological Surveys in Iowa City, Iowa, and Rolla, Missouri, the Iowa Geological Survey in Iowa City, Iowa, and the Missouri Division of Geology and Land Survey in Rolla, Missouri.

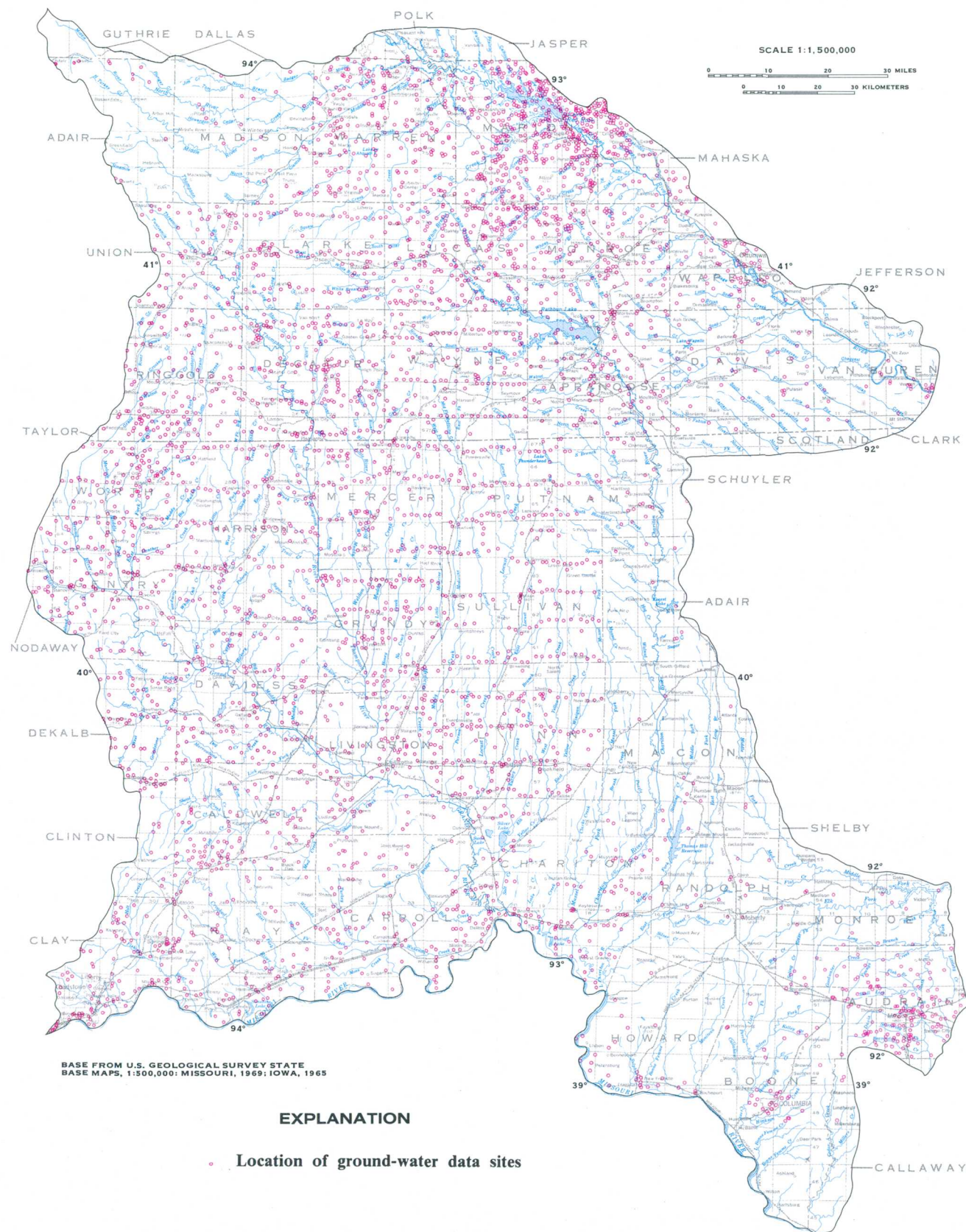


Figure 6.1-1 Location of groundwater data sites.

Table 6.1-1 Hydrogeologic units in Area 38.

System	General thickness (feet)	Age	Major lithology	Well yields
Quaternary	0-430	0-1 million years old	Sand, gravel, silt, clay	Yields as much as 2,000 gallons per minute particularly in the alluvial aquifer.
Pennsylvanian	0-510	280-320 million years old	Shale, sandstone, limestone, coal	Yields generally less than 20 gallons per minute, source of domestic water supplies in some localities. Considered a primary confining bed.
Mississippian	0-600	310-345 million years old	Limestone, shale, dolomite, sandstone	Yields generally less than 20 gallons per minute, adequate for domestic uses.
Devonian	0-615	345-400 million years old	Limestone, dolomite, shale	Yields generally much less than 20 gallons per minute, adequate for domestic uses.
Silurian	0-105	400-425 million years old	Limestone, dolomite	Generally not considered an aquifer because yields generally much less than 20 gallons per minute.
Upper Ordovician	0-600	425-500 million years old	Limestone, dolomite, shale, sandstone	Potential source of large yields-- (as much as 1,000 gallons per minute).
Lower Ordovician	275-1100		Dolomite, sandstone	
Upper Cambrian			Dolomite, sandstone, shale	
Lower Cambrian	75-1200	500-600 million years old	Sandstone, shale, dolomite, siltstone	
Precambrian	not known	600 million to more than 2 billion years old	Igneous and metamorphic rocks	No data available to determine relative yield because depths are extreme.

Modified from Cagle and Heinritz, 1978, and Gann and others, 1973.

6.0 GROUND WATER--Continued
6.2 Cambrian-Ordovician Aquifer

**Cambrian-Ordovician Aquifer System is Deeply
Buried in Much of Area 38**

Depths to the Cambrian-Ordovician aquifer system are as much as 3,000 feet; sandstone and dolomite that comprise the aquifer may yield more than 1,000 gallons per minute to wells.

The Cambrian-Ordovician aquifer system is a sequence of sandstone and dolomite of Late Cambrian and Early Ordovician age. The Jordan Sandstone of Late Cambrian age in Iowa and the Gunter Sandstone of Lower Ordovician age in Missouri are similar rocks although given different names and ages in the two States. The altitude of the top of these units is shown in figure 6.2-1 as representative of the structural form of the rocks comprising the aquifer system. The aquifer system is confined beneath relatively impermeable rocks throughout Area 38 except where it underlies the alluvium along the Missouri River in southern Boone County, Missouri. The aquifer system generally is between 400 and 800 feet thick.

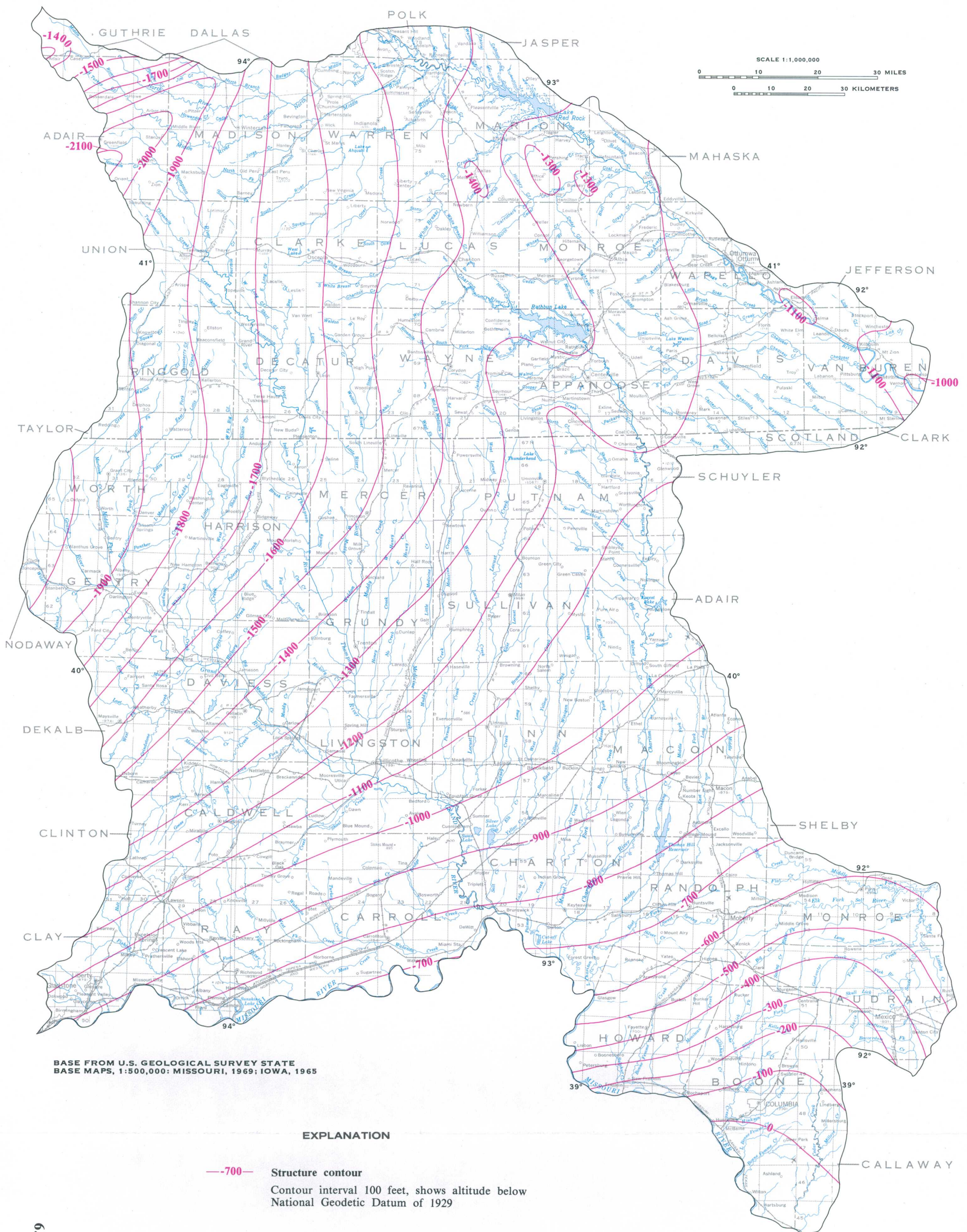
The Cambrian-Ordovician aquifer system is buried very deeply in much of Area 38. Depths to the aquifer are as much as 3,000 feet in southern Iowa and northern Missouri although parts of the aquifer system directly underlie the alluvium along the Missouri River in southern Boone County, Missouri.

Yields to wells from the Cambrian-Ordovician aquifer system generally are in excess of 1,000 gallons

per minute. The system is an important source of large volumes of water, particularly in southern Iowa. Although the system is deeply buried and the water generally is of marginal quality, in some areas it provides the only source of water for large users. The dolomite in the Prairie du Chien Group in Iowa and the Potosi Dolomite in Missouri are believed to yield the majority of water from this aquifer system in Area 38.

Recharge to the Cambrian-Ordovician aquifer system in Area 38 is almost exclusively from percolation of water through overlying rocks. Direct recharge from surface sources may occur along the Missouri River in Boone County, Missouri where Lower Ordovician rocks occur near the land surface. Most of the surficial recharge to this aquifer system occurs outside Area 38 in Iowa, Minnesota and Missouri.

Additional information about the Cambrian-Ordovician aquifer system may be obtained from Horick and Steinhilber, 1978; Cagle and Heinitz, 1978; and Gann and others, 1971.



Modified from Horick and Steinhilber, 1978.

Figure 6.2-1 Altitude of the top of the Jordan Sandstone in Iowa and the Gunter Sandstone member of the Gasconade Dolomite in Missouri.

6.0 GROUND WATER--Continued

6.3 Quaternary Aquifers

Glacial Drift, Buried-Channel Deposits, and Alluvium Comprise the Quaternary Aquifers

Sand and gravel deposits comprise most of the Quaternary aquifers.

Some types of glacial drift, buried-channel deposits and alluvium are Quaternary aquifers. Their location is outlined in figure 6.3-1 and they will be discussed as three separate aquifers. The Quaternary aquifers are not continuous. In some places they are very thick and widespread and in other areas they are missing. These unconsolidated aquifers are important because they produce water of suitable quality for most uses including drinking-water supplies and are close to the land surface.

The glacial-drift aquifers are the most widespread of the Quaternary aquifers. Boulders, gravel, sand, silt, and clay comprise the glacial drift. The sand and gravel beds are the water-yielding units and they generally are not extensive, thus ability to store and transmit the water is limited. Reported yields of wells completed in glacial drift generally range 5 to 25 gallons per minute in Area 38, sufficient for domestic use. Locally, yields may be somewhat greater (Gann and others, 1973, Cagle and Heinritz, 1978).

Stream deposits that filled ancient valleys or channels commonly occur near or below alluvial aquifers and are called buried-channel aquifers. The location of the axes of these valleys is shown on figure 6.3-1. Sand and gravel are the major deposits in this type of aquifer and are as much as 50 feet thick. Wells completed in the buried-channel aquifer yield as much as 1,000 gallons per minute to individual wells in several places (Gann and others, 1973, Coble and Roberts, 1971, Cagle and Heinritz, 1978).

These aquifers can yield sufficient water to supply small municipalities in some areas and domestic needs in most areas.

The alluvial aquifers are sources of large quantities of water. They are recharged by precipitation and by infiltration from the streams. These aquifers are composed principally of sand and gravel usually overlain by clay and silt. The thickness of the sand and gravel is as much as 150 feet in the Missouri River valley. Generally the aquifers are thinnest near the edges of the valley and thicker near the center of the valley. Reported yields for wells completed in the alluvial aquifer in tributaries of the Missouri River range of 10 to 500 gallons per minute, and wells capable of yielding 1,000 to 2,000 gallons per minute have been completed in the Missouri River alluvium, (Gann and others, 1971, Emmett and Jeffery, 1969a and 1969b, Cagle and Heinritz, 1978). The well yields are sufficient to supply municipalities and irrigation water in some locations and domestic users in most areas.

The Missouri Division of Geology and Land Survey, in Rolla Missouri; the Iowa Geological Survey in Iowa City, Iowa; and the U.S. Geological Survey offices in these cities have additional data regarding areal extent of the buried-channel aquifers and also will provide information on specific yields or other hydrologic aspects for the three Quaternary aquifers at particular localities.

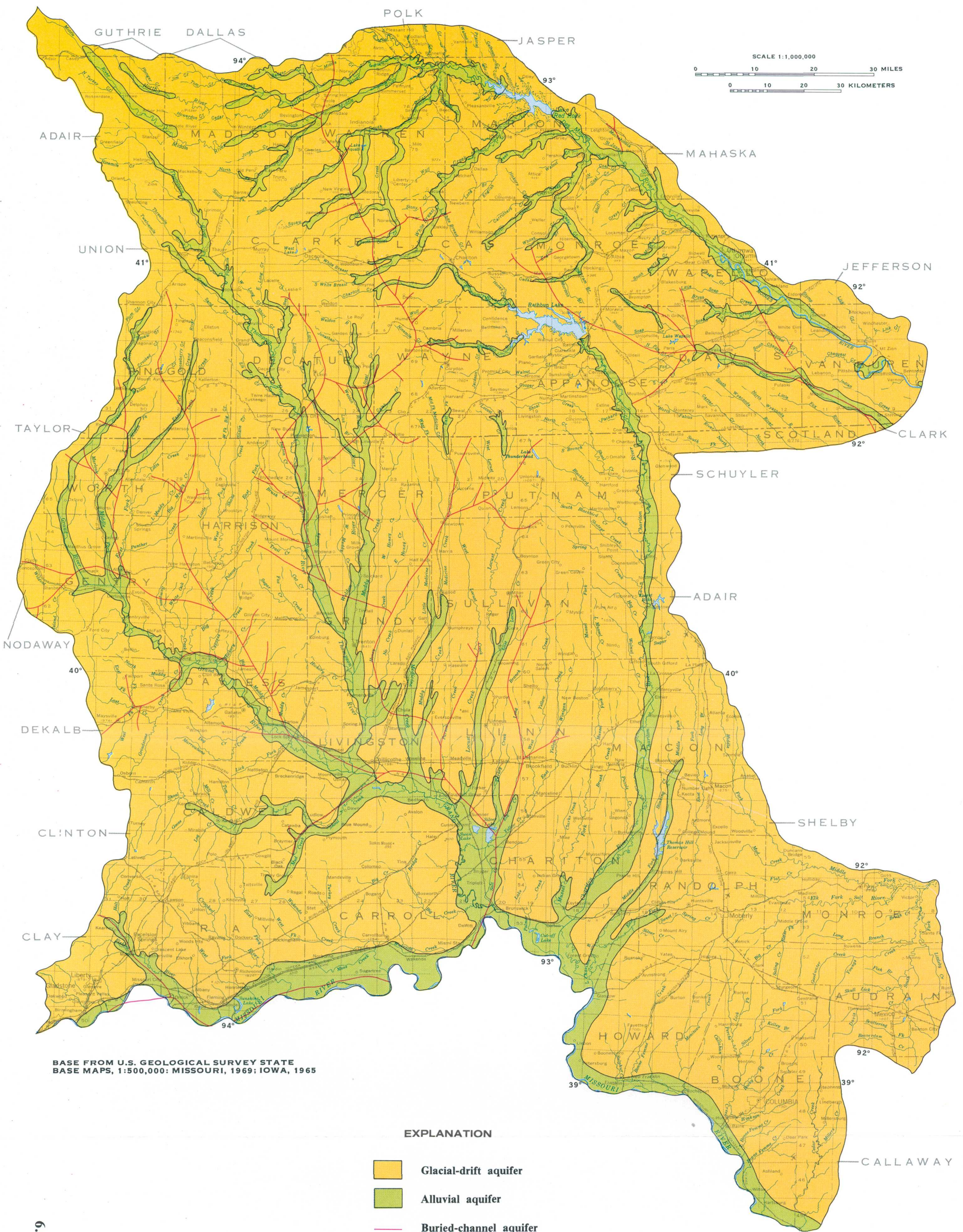


Figure 6.3-1 Areal extent of Quaternary aquifers.

6.0 GROUND WATER--Continued

6.4 Mississippian and Pennsylvanian Aquifers

Well Yields from the Mississippian Aquifer and from the Pennsylvanian Aquifer Generally are Less Than 20 Gallons per Minute

The rocks of Mississippian and Pennsylvanian aquifers in places can yield sufficient water for domestic use but they are not important as a source of large quantities of water in much of the area.

The Mississippian aquifer is mainly a sequence of limestone with beds of shale, dolomite, and sandstone. The aquifer generally is confined above and below by other bedrock units but crops out at the bedrock surface in both the northeastern and southeastern parts of the project area and crops out in areas where the glacial drift is thin or absent. The altitude of the top of the aquifer is shown in figure 6.4-1; the thickness of the aquifer generally is between 150 and 600 feet. Some gypsum and anhydrite beds occur locally in upper parts of the aquifer above the shale zone and dissolution of these minerals will affect the quality of the water.

The Mississippian aquifer has the best potential for development where it forms the bedrock surface (figure 6.4-1) or where the overlying Pennsylvanian rocks are relatively thin. Wells completed in or near these areas of recharge usually have greater yields and less mineralized water. Generally, yields are greater in carbonate rocks where the fissure system is well developed whether near the surface or at depth.

Yields from the Mississippian are variable, but are not well known throughout much of the project area. Where the aquifer is overlain by a thick sequence of Pennsylvanian rocks, wells drilled for small, domestic supplies usually obtain sufficient water from the glacial drift or Pennsylvanian sandstone and do not penetrate the Mississippian aquifer. Wells completed in the Mississippian aquifer generally yield 5 to 20 gallons per minute, which is sufficient for domestic use. A few wells have produced as much as 43 gallons per minute. In the northeastern part of the area where the aquifer is the bedrock surface and is overlain by more permeable surficial material, the existing well data indicate well yields ranging from 5 to 60 gallons per minute.

The bedrock closest to or at the land surface

throughout more than 95 percent of the area consists of Pennsylvanian strata (figure 6.4-1). These rocks principally are shale confining beds interlayered with thin sandstone and limestone that may be aquifers of local and subregional extent.

Based on information available for Pennsylvanian rocks, sandstone in the Cherokee Group and limestone in the Kansas City Group are water-yielding units. These units are not known to exist everywhere within Area 38 or to yield water at every location where they do exist. In the southern part of Area 38, the Warrensburg Sandstone Member of the Pleasanton Formation is a local sandstone that is a water-yielding unit. Similar units may exist in other groups but are not yet defined by reliable well data.

Well yields from the Pennsylvanian aquifer units generally are sufficient only for domestic use. Yields typically are less than 20 gallons per minute and generally range between 3 and 10 gallons per minute. Locally, in the thicker parts of the aquifer units, or where the aquifers occur near the bedrock surface it is possible to obtain yields greater than 20 gallons per minute. Some yields as much as 100 gallons per minute have been reported.

Recharge to the aquifer is from precipitation that falls on the areas of outcrop. Also, some recharge occurs by percolation of water through overlying unconsolidated units.

Additional information about the Mississippian aquifer may be obtained in Cagle and Heinritz, 1978; Gann and others, 1971 and 1973; and Horick and Steinhilber, 1973. Additional information about the Pennsylvanian aquifer may be obtained in Coble and Roberts, 1971; Cagle and Heinritz, 1978; Gann and others 1971 and 1973; and Heim and Howe, 1962.

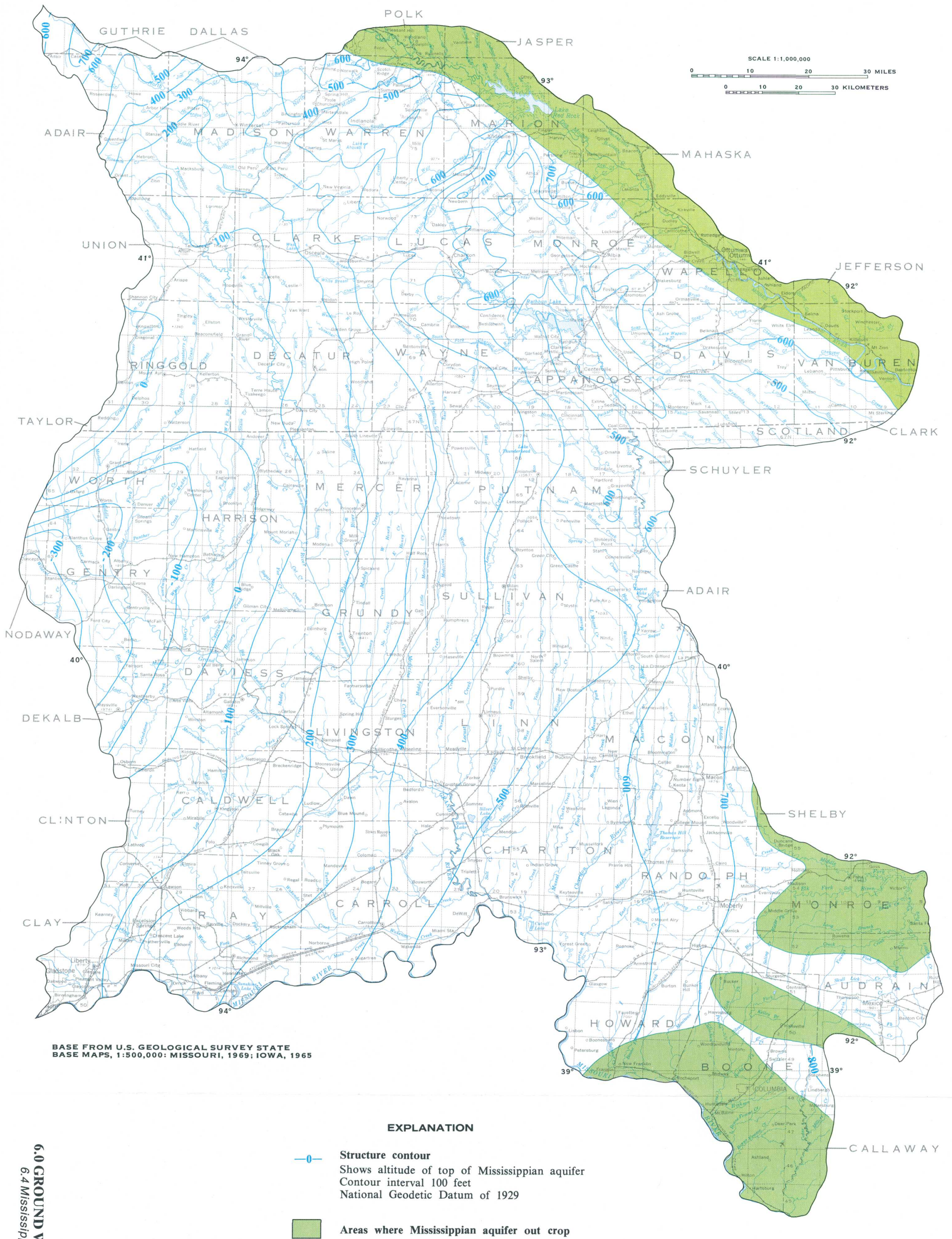


Figure 6.4-1 Altitude of top of Mississippian aquifer.

Modified from Cagle and Heintz (1978) and Horick and Steinhilber (1973)-Iowa, Division of Geology and Land Survey unpublished data-Missouri.

6.0 GROUND WATER--Continued

6.5 Water Levels

Water Levels in Quaternary Aquifers Fluctuate Seasonally

Water levels in the Quaternary aquifers respond to seasonal variations in the rate of recharge to and discharge from the ground-water reservoir.

Water levels in unconfined (water table) Quaternary aquifers respond more quickly to recharge from precipitation than water levels in confined (artesian) Quaternary aquifers. For example, two well hydrographs are shown in figure 6.5-1. The well at Melcher, Iowa, (figure 6.5-2) is an unused well completed in unconfined glacial till of Pleistocene age. This well is part of the statewide observation well network monitored by the U.S. Geological Survey. The well is 12 feet deep, 18 inches in diameter, and lined with tile. The pattern of water-level fluctuations is typical of water-table aquifers in the central United States. The highest water levels generally occur in the spring, in response to precipitation and snow-melt. The lowest water levels occur in the fall, after a general summer decline during the growing season. Water levels show a rapid response to rainfall. Extended dry periods are well documented for 1953 to 1956. No

overall lowering of water levels is indicated for 1950 to 1980.

The well in northwestern Grundy County near Spickard, Missouri (figure 6.5-2) is an observation well maintained by the Missouri Division of Geology and Land Survey as part of their statewide network. This well is completed in glacial drift of Pleistocene age. The well is 140 feet deep, has 137 feet of 6-inch diameter casing and is screened from 137 to 140 feet. The lithologic log of this well shows that the aquifer is confined by overlying glacial till. This is further demonstrated by the hydrograph in figure 6.5-1. The water-level in the observation well shows an almost immediate decline when an irrigation well 600 feet away is turned on; this response is typical of a confined aquifer. The otherwise subdued fluctuation of the hydrograph is due to the thick overlying confining bed.

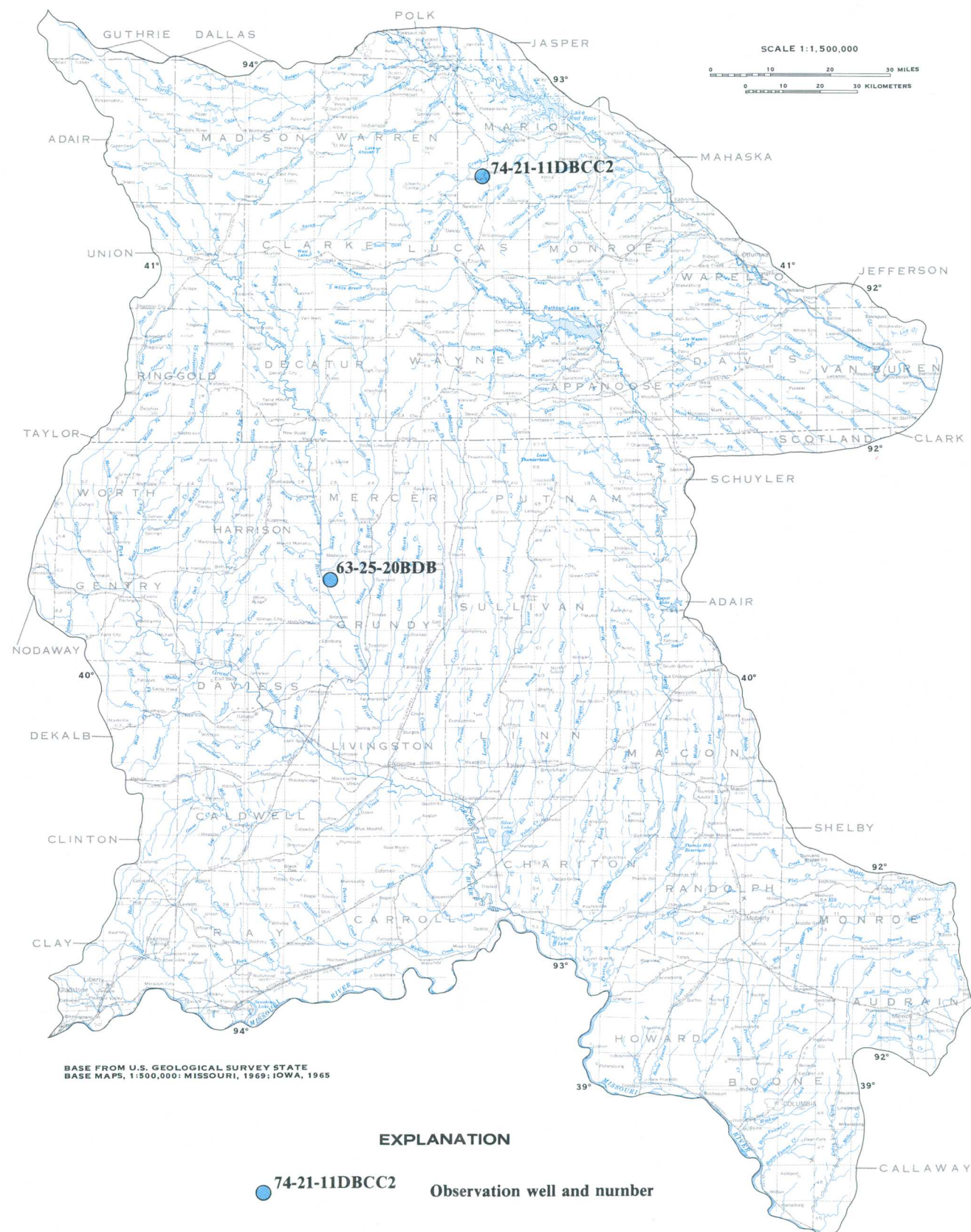


Figure 6.5-2 Location of observation wells.

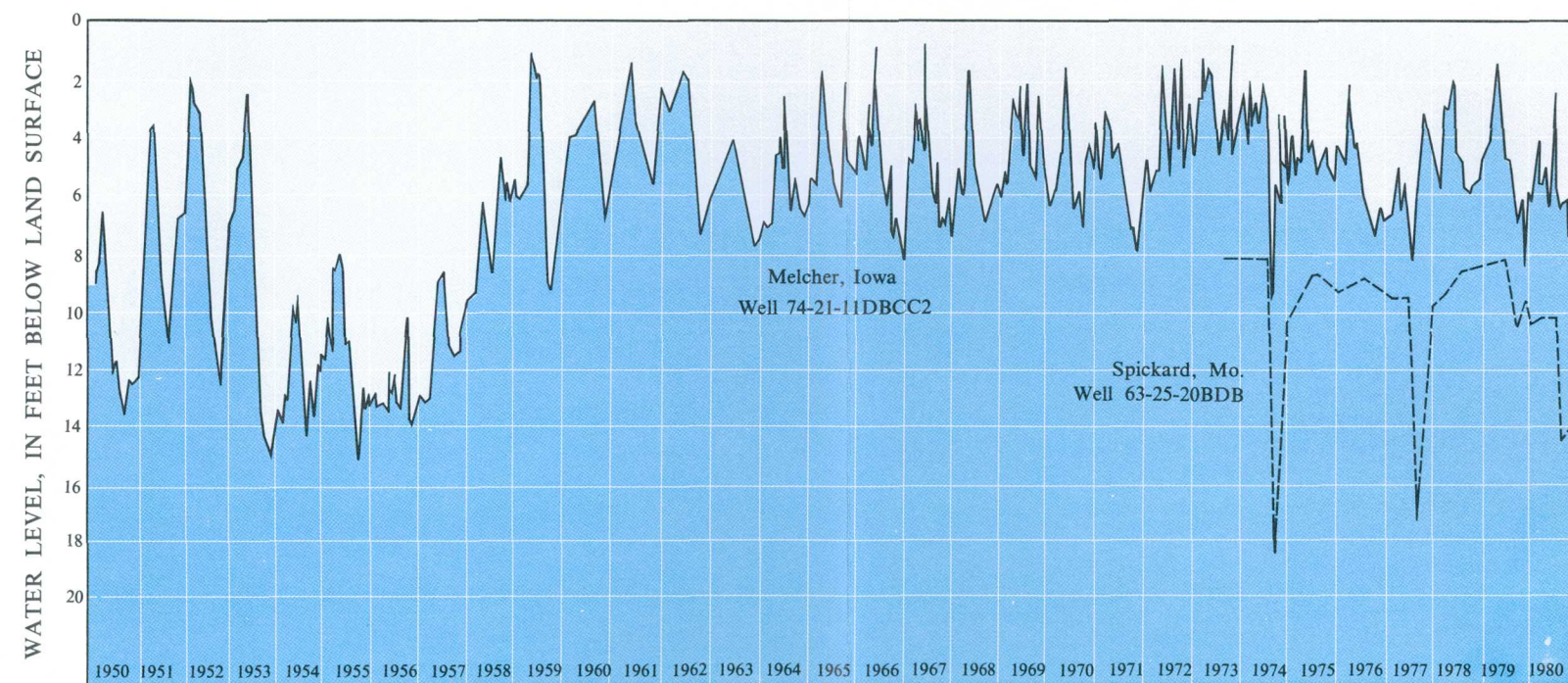


Figure 6.5-1 Two well hydrographs.

7.0 QUALITY OF GROUND WATER

7.1 Cambrian-Ordovician Aquifer

Chemical Quality of Water from the Cambrian-Ordovician Aquifer is Variable in Most of Area 38

Dissolved-solids concentrations in water from the aquifer ranged from 300 to 15,000 milligrams per liter; dissolved-solids concentrations are less than 1,000 milligrams per liter in south-central Iowa and where the aquifer underlies Missouri River alluvium.

The quality of water in the Cambrian-Ordovician aquifer is brackish most everywhere in Area 38; however in south-central Iowa the quality of water is classed as fresh to brackish and in parts of Missouri, where the aquifer underlies Missouri River alluvium, the quality of water is fresh. Chemical quality of water in the aquifer is a function of the mineral composition of the rocks through which the water percolates in the recharge area and where in the flow system the water occurs (Horick and Steinhilber, 1978). The aquifer is a sequence of sandstone and dolomite; most recharge occurs outside Area 38 in Iowa, Minnesota and Missouri. Direct recharge may occur along the Missouri River in Boone County, Missouri.

Because of the variability of water quality in the Cambrian-Ordovician aquifer and limited availability of wells to define the characteristics of the aquifer only a general data analysis has been provided. Figure 7.1-1 shows the dissolved-solids concentrations for water from wells completed in the Cambrian-Ordovician aquifer in Area 38. Few wells for the aquifer are located south of the Iowa border, because of the poor quality water. Dissolved-solids concentrations are very large in this area partly because the aquifer is deeply buried and the residence time of the water within the aquifer is great. The figure also illustrates a general areal trend of poorer quality water in the aquifer in a south and southwest direction. However where the aquifer underlies alluvium and receives local recharge from the overlying alluvium as in southern Boone County, Missouri, the quality of water is good, dissolved-solids concentrations are less than 650 milligrams per liter.

Minimum, maximum and average values for

major chemical constituents in water from the Cambrian-Ordovician aquifer are shown in tables 7.1-1 and 7.1-2. Ion-distribution diagrams are shown in figures 7.1-2 and 7.1-3. These diagrams are designed to represent simultaneously the total solute concentration and the proportions assigned to each ionic species for a group of analyses.

Water from wells completed in the Cambrian-Ordovician aquifer in the northern part of Area 38 had a median pH of 7.5, an average alkalinity of 248 mg/L (milligrams per liter), an average sulfate concentration of 477 mg/L and an average dissolved-solids concentration of 1,260 mg/L. The water is generally a sodium-sulfate type. Results of 27 chemical analyses, 26 in Iowa and 1 in Missouri, were used to compile figure 7.1-2, which represents a total solute concentration of 39 milliequivalents per liter. Iron concentrations ranged from 0.05 to 4.1 mg/L and manganese concentrations ranged from less than 0.01 to 0.05 mg/L.

Water from wells completed in the Cambrian-Ordovician aquifer in Boone County, Missouri had a median pH of 7.5, and average alkalinity of 306 mg/L, an average sulfate concentration of 348 mg/L and an average dissolved-solids concentration of 536 mg/L. The water is generally a calcium-magnesium bicarbonate type. Results of 27 selected chemical analyses in southern Boone County, were used to compile figure 7.1-3, which represents a total solute concentration of 15 milliequivalents per liter. Iron concentrations ranged from 0.02 to 5.0 mg/L and manganese concentrations ranged from less than 0.01 to 0.02 mg/L.

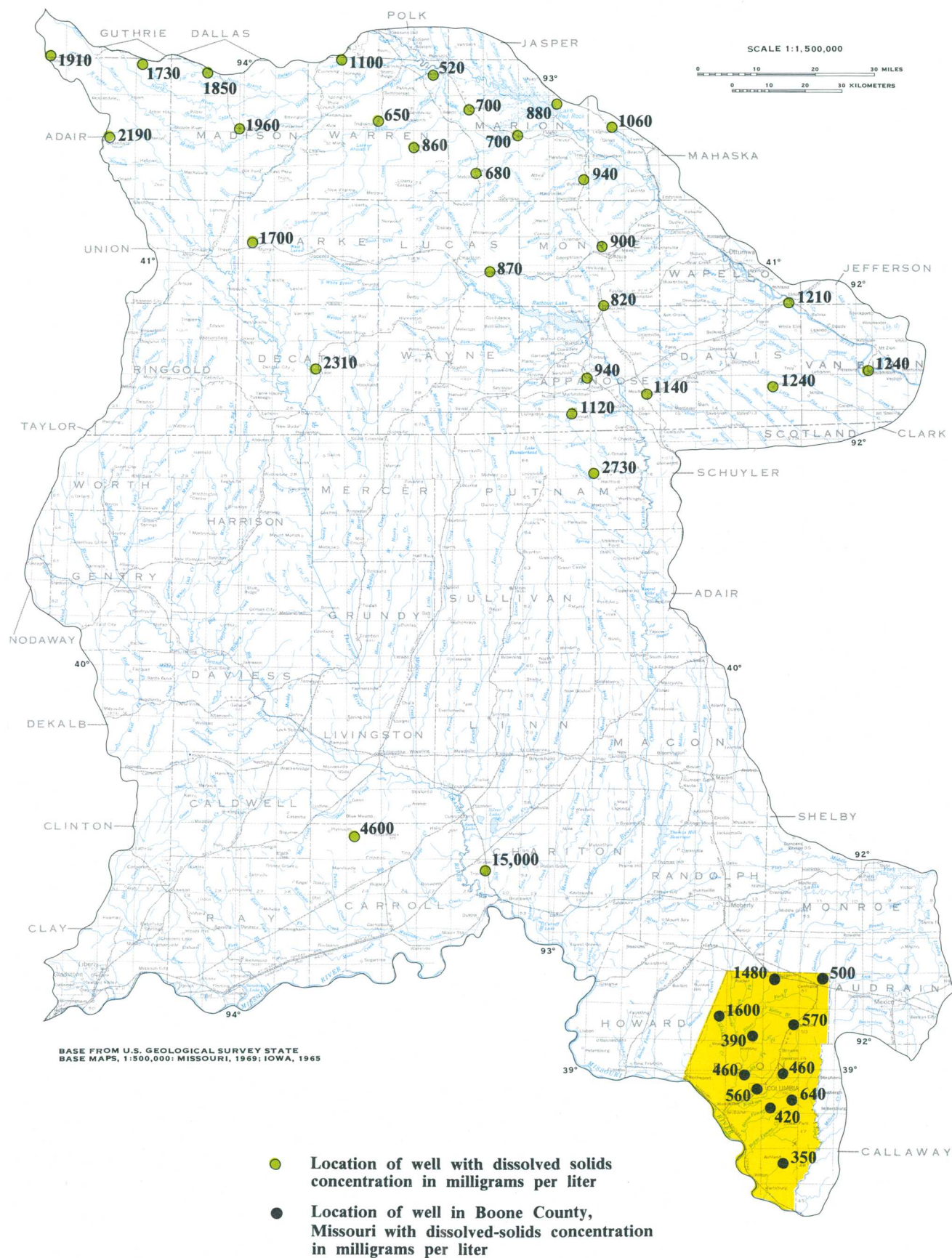
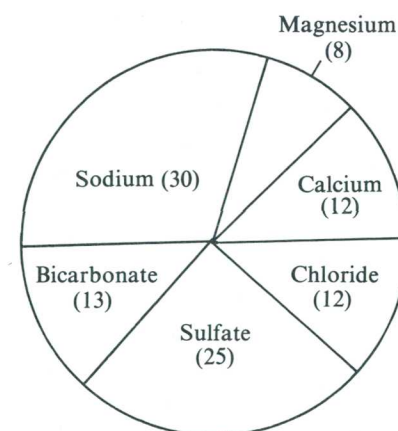


Figure 7.1-1 Dissolved-solids concentration for water from wells in the Cambrian-Ordovician aquifer in Area 38.



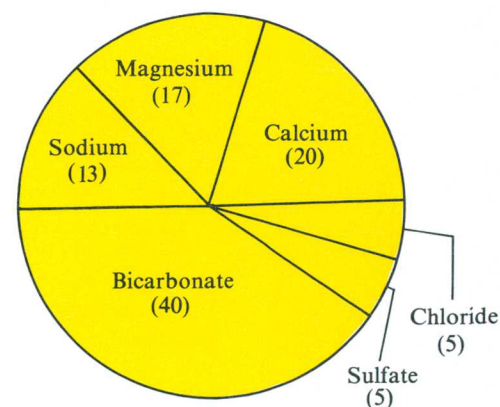
VALUES, IN PERCENTAGE OF TOTAL MILLEQUIVALENTS PER LITER

Figure 7.1-2 Average chemical composition for water from wells in the Cambrian-Ordovician aquifer in the northern part of Area 38.

Table 7.1-1 Summary of water-quality data available for the Cambrian-Ordovician aquifer in the northern part of Area 38.

[Concentrations in milligrams per liter unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.05 - 4.1	1.5	27
Manganese (Mn)	<0.01 - 0.05	0.02	27
Calcium (Ca)	55 - 176	94	27
Magnesium (Mg)	22 - 69	36	27
Sodium (Na)	83 - 710	268	27
Potassium (K)	13 - 39	22	27
Bicarbonate (HCO ₃)	210 - 405	308	19
Sulfate (SO ₄)	150 - 1,200	477	27
Chloride (Cl)	3.4 - 450	166	27
Nitrate (NO ₃)	<0.1 - 2.3	0.5	27
pH	7.1 - 7.8	(median)7.5	27
Hardness (CaCO ₃)	230 - 710	387	26
Alkalinity (CaCO ₃)	172 - 332	248	26
Dissolved solids	520 - 2,730	1,260	27
Specific conductance (micromhos per centimeter at 25° Celsius)	825 - 3,410	1,805	26



VALUES, IN PERCENTAGE OF TOTAL MILLEQUIVALENTS PER LITER

Figure 7.1-3 Average chemical composition for water from selected wells in the Cambrian-Ordovician aquifer in Boone County, Missouri.

Table 7.1-2 Summary of water-quality data available for the Cambrian-Ordovician aquifer in Boone County, Missouri.

[Concentrations in milligrams per liter unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.02 - 5	0.7	29
Manganese (Mn)	<0.01 - 0.2	0.01	19
Calcium (Ca)	41 - 166	66	29
Magnesium (Mg)	22 - 74	34	29
Sodium (Na)	12 - 328	58	24
Potassium (K)	0.5 - 20	7.3	27
Bicarbonate (HCO ₃)	278 - 500	380	29
Sulfate (SO ₄)	12 - 648	61	29
Chloride (Cl)	3.2 - 548	45	29
Nitrate (NO ₃)	<0.1 - 1.2	0.2	29
pH	7.0 - 7.9	(median)7.5	29
Hardness (CaCO ₃)	198 - 378	281	29
Alkalinity (CaCO ₃)	228 - 411	307	29
Dissolved solids	300 - 1,600	526	29

7.0 QUALITY OF GROUND WATER--Continued

7.2 Quaternary Aquifers

Chemical Quality of Water from Quaternary Aquifers is Variable, but Generally Suitable for Most Domestic Uses

Dissolved-solids concentrations are less than 1,000 milligrams per liter in water from wells completed in Quaternary aquifers; however undesirable concentrations of nitrate, iron and manganese may be found in water from some wells, especially those completed in glacial drift.

The Quaternary aquifers, namely glacial drift, alluvium and buried valleys are important sources of potable water in Area 38. The areal distribution of Quaternary aquifers is shown in figure 7.2-1. Because of the heterogeneity of shallow ground waters, there does not exist an adequate data base to define the characteristics of these waters; however, a general data analysis has been provided. Minimum, maximum and average values for major chemical constituents in water from glacial-drift (includes buried valleys) and alluvial aquifers are shown in tables 7.2-1 and 7.2-2. Ion-distribution diagrams are shown in figures 7.2-2 and 7.2-3. These diagrams are designed to represent simultaneously the total solute concentration and the proportions assigned to each ionic species for a group of analyses.

Water from wells completed in glacial drift had a median pH of 7.2, an average alkalinity of 266 mg/L (milligrams per liter), and an average dissolved-solids concentration of 840 mg/L. The water is a mixed type with calcium, bicarbonate, sodium, and sulfate all being important ionic species. This is characteristic of water from wells that are completed in sand and gravel consisting of mostly insoluble siliceous materials. Results of 271 chemical analyses, 136 in Iowa and 135 in Missouri, were used to compile figure 7.2-2, which represents a total solute concentration of 26 milliequivalents per liter. Nitrate concentrations ranged from less than 0.1 to 430 mg/L and averaged 24.6 mg/L, iron concentrations ranged from 0.01 to 16 mg/L and manganese concentrations ranged from less than 0.01 to 2.1 mg/L.

Iron, manganese, and nitrate are undesirable for potable water supplies. A primary drinking water standard of 45 mg/L of nitrate expressed as NO_3 has been set to protect the health of infants (U.S. Environmental Protection Agency, 1977a). Secondary regulations for iron and manganese have been set at 0.3 mg/L and 0.05 mg/L to avoid taste problems and fixture and laundry staining (U.S. Environmental Protection Agency, 1977b). Unlike nitrate that may indicate contamination from man's activities on land surface, concentrations of iron and manganese can be linked to natural materials.

Water from wells completed in alluvium had a median pH of 7.1, an average alkalinity of 223 mg/L and an average dissolved-solids concentration of 530 mg/L. The water generally can be characterized as a calcium/bicarbonate type, similar to water from glacial-drift aquifers, but significantly affected by the chemical quality of streams that recharge the alluvial aquifers. Results of 55 chemical analyses from Missouri were used to compile figure 7.2-3, which represents a total solute concentration of 15 milliequivalents per liter. Nitrate concentrations, which ranged from 1.0 to 88 mg/L and averaged 3.2 mg/L, are not as great as in water from glacial-drift aquifers. Iron concentrations ranged from 0.01 to 16 mg/L and averaged 9.6 mg/L, and manganese concentrations ranged from 0.05 to 17 mg/L and averaged 1.4 mg/L.

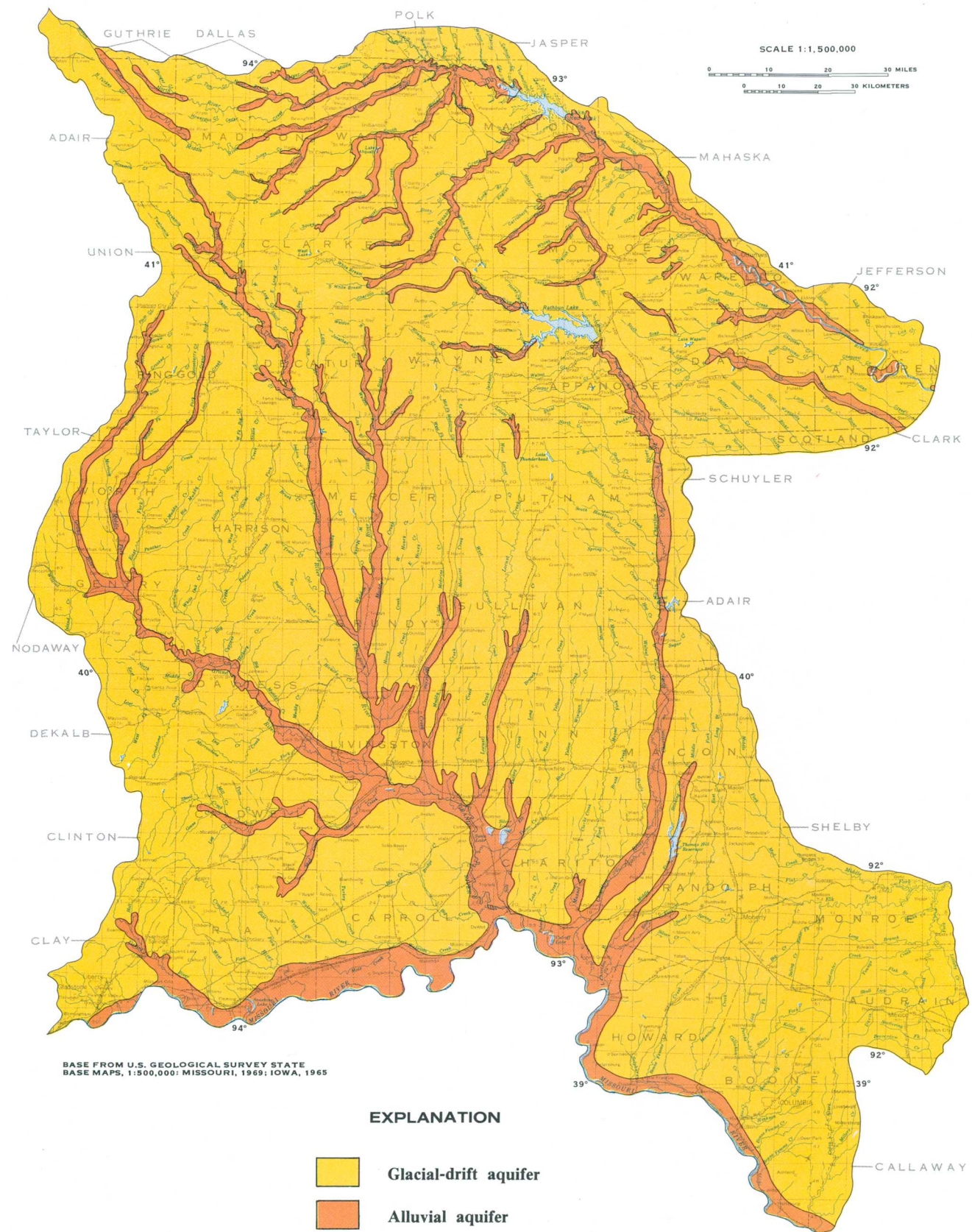


Figure 7.2-1 Areal distribution of glacial-drift and alluvial aquifers.

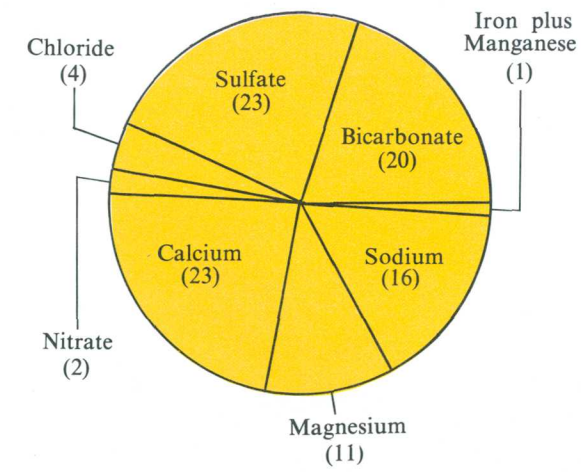


Figure 7.2-2 Average chemical composition for water from glacial-drift wells.

Table 7.2-1 Summary of water-quality data available for the glacial-drift aquifers.
[Concentrations in milligrams per liter unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.01 - 16	2.9	234
Manganese (Mn)	0.01 - 2.1	0.30	249
Calcium (Ca)	12 - 529	118	271
Magnesium (Mg)	3.5 - 243	36	272
Sodium (Na)	2 - 874	96	271
Potassium (K)	0.1 - 21	3.2	197
Bicarbonate (HCO ₃)	28 - 908	333	230
Sulfate (SO ₄)	2 - 2,180	283	271
Chloride (Cl)	0.5 - 1,160	39	271
Nitrate (NO ₃)	<0.1 - 430	24.6	264
pH	6.1 - 8.7 (median)	7.2	271
Hardness (CaCO ₃)	44 - 1,950	441	271
Alkalinity (CaCO ₃)	22 - 830	266	270
Dissolved solids	88 - 3,900	840	271
Specific conductance (micromhos per centimeter at 25° Celsius)	150 - 3,600	915	153

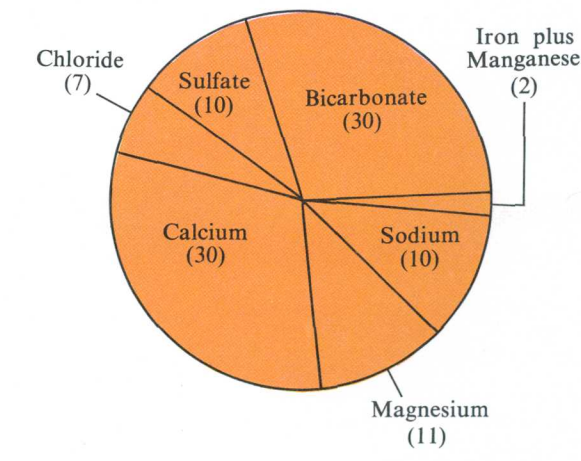


Figure 7.2-3 Average chemical composition for water from alluvial wells.

Table 7.2-2 Summary of water-quality data available for alluvial aquifers.
[Concentrations in milligrams per liter unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.04 - 130	7.3	89
Manganese (Mn)	0.03 - 17	1.1	69
Calcium (Ca)	30.4 - 220	100	79
Magnesium (Mg)	5.9 - 70.5	25	79
Sodium (Na)	5.5 - 247	31	78
Potassium (K)	0.8 - 44	3.4	64
Bicarbonate (HCO ₃)	21 - 740	326	92
Sulfate (SO ₄)	<0.1 - 490	115	92
Chloride (Cl)	0.2 - 385	29	92
Nitrate (NO ₃)	<0.1 - 66	3.2	90
pH	6.1 - 8.1 (median)	7.1	91
Hardness (CaCO ₃)	112 - 978	365	92
Alkalinity (CaCO ₃)	34 - 598	223	64
Dissolved solids	180 - 1,330	532	79
Specific conductance (micromhos per centimeter at 25° Celsius)	310 - 1,700	785	71

7.0 QUALITY OF GROUND WATER--Continued

7.3 Mississippian and Pennsylvanian Aquifers

Chemical Quality of Water from Mississippian and Pennsylvanian Aquifers is Variable and Generally Not Potable

Dissolved-solids concentrations in water from the Mississippian aquifer ranged from 370 to 8,220 milligrams per liter and in water from the Pennsylvanian aquifer dissolved-solids concentrations ranged from 250 to 6,790 milligrams per liter; sulfate and sodium are the dominant ionic species in water from both aquifers.

The quality of water in the Mississippian and Pennsylvanian aquifers is variable from place to place, but the water generally is not potable. The areal extent of Mississippian and Pennsylvanian bedrock throughout Area 38 is significant (figure 7.3-1). Neither the Pennsylvanian nor the Mississippian aquifer is a significant source of potable water in Area 38. Limited data for bedrock wells make it difficult to adequately define the characteristics of bedrock water throughout Area 38; however a general data analysis has been provided.

Minimum, maximum and average values for major chemical constituents in water from the Mississippian and Pennsylvanian aquifers are shown in tables 7.3-1 and 7.3-2. Ion-distribution diagrams are shown in figures 7.3-2 and 7.3-3 for both bedrock aquifers. These diagrams are designed to represent simultaneously the total solute concentration and the proportions assigned to each ionic species for a group of analyses.

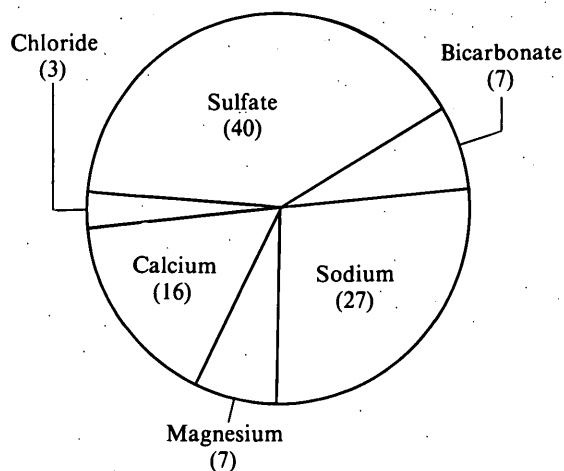
Concentrations of dissolved solids averaged 3,140 mg/L (milligrams per liter) in water from wells completed in the Mississippian aquifer. The median pH was 7.2, and the average alkalinity was 345 mg/L. Sulfate concentrations ranged from 22 to 4,500 mg/L and sodium concentrations ranged from 6.8 to 2,660 mg/L. Sulfate and sodium are the dominant ionic species as they comprise 40 and 27 percent of the total solute concentration (93 milliequivalents per liter) in water from a typical well. Results of 70 chemical analyses of water from wells completed in the Mississippian aquifer in Iowa were used to compile figure 7.3-2.

The Mississippian aquifer is composed principal-

ly of carbonate rocks (limestone and dolomite). In Iowa, the aquifer can be divided into upper and lower units. The upper unit contains some gypsum and anhydrite beds that significantly affect the chemical quality of water (Cagle and Heinritz, 1978).

Concentrations of dissolved solids averaged 2,340 mg/L in water from wells completed in the Pennsylvanian aquifer. The median pH was 7.5 and the average alkalinity was 360 mg/L. Sulfate concentrations ranged from 1 to 4,000 mg/L and sodium concentrations ranged from 5.5 to 2,400 mg/L. Sodium and sulfate are the dominant ionic species as they comprise 35 and 31 percent of the total solute concentration (72 milliequivalents per liter) in water from a typical well. Results of 98 chemical analyses of water from wells completed in the Pennsylvanian aquifer, 76 in Iowa and 22 in Missouri, were used to compile figure 7.3-3.

The Pennsylvanian bedrock in Area 38 is composed predominately of impermeable shale beds, which are a regional confining bed that separates the surficial aquifer from underlying aquifers. However, limestone and sandstone beds are aquifers of local and subregional extent in parts of south-central Iowa (Cagle and Heinritz, 1978). Sources of the sodium and sulfate ions are ion exchange for sodium and pyrite for sulfate. Wells that penetrate clay and shale generally obtain water with excessive dissolved solids directly from the shale layers, which have large cation-exchange capabilities (Hem, 1970). Pyrite is commonly associated with biogenic deposits such as coal, which were deposited under extreme reducing conditions.



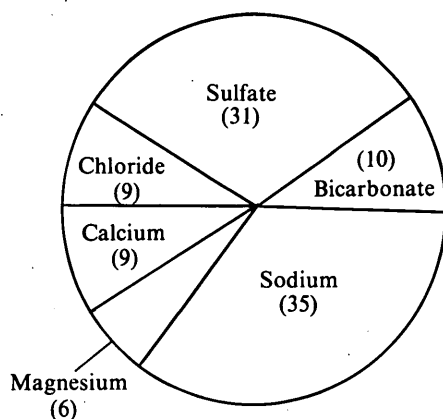
VALUES, IN PERCENTAGE OF TOTAL
MILLEQUIVALENTS PER LITER

Figure 7.3-2 Average chemical
composition for water from wells in the Mississippian
aquifer.

Table 7.3-1. Summary of water-quality data
available for the Mississippian aquifer.

[Concentrations in milligrams per liter
unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.02 - 50	6.3	70
Manganese (Mn)	0.01 - 1.4	0.17	70
Calcium (Ca)	10 - 642	279	70
Magnesium (Mg)	3.1 - 340	77	70
Sodium (Na)	6.8 - 2,660	584	70
Potassium (K)	0.2 - 45	14	68
Bicarbonate (HCO_3)	168 - 1,350	420	70
Sulfate (SO_4)	22 - 4,500	1,697	70
Chloride (Cl)	0.5 - 3,570	137	70
Nitrate (NO_3)	<0.1 - 150	4.5	70
pH	6.3 - 8.0	(median) 7.2	66
Hardness (CaCO_3)	38 - 2,950	1,029	69
Alkalinity (CaCO_3)	138 - 1,100	345	70
Dissolved solids	370 - 8,220	3,138	66
Specific conductance (micromhos per centimeter at 25° Celsius)	370 - 9,000	3,850	63



VALUES, IN PERCENTAGE OF TOTAL
MILLEQUIVALENTS PER LITER

Figure 7.3-3 Average chemical
composition for water from wells in the
Pennsylvanian aquifer.

Table 7.3-2. Summary of water-quality data
available for the Pennsylvanian aquifer.

[Concentrations in milligrams per liter
unless otherwise specified; < = less than]

Constituent	Range	Average	Number of samples
Iron (Fe)	0.01 - 22	2.5	96
Manganese (Mn)	0.01 - 2.3	0.16	95
Calcium (Ca)	2.4 - 460	133	97
Magnesium (Mg)	1.5 - 394	48	97
Sodium (Na)	5.5 - 2,400	574	96
Potassium (K)	0.9 - 38	8.5	84
Bicarbonate (HCO_3)	120 - 1,240	437	94
Sulfate (SO_4)	1 - 4,000	1,046	97
Chloride (Cl)	0.5 - 3,060	222	98
Nitrate (NO_3)	<0.1 - 200	4.3	97
pH	6.5 - 8.3	(median) 7.5	95
Hardness (CaCO_3)	29 - 2,000	528	96
Alkalinity (CaCO_3)	98 - 1,080	360	98
Dissolved solids	250 - 6,790	2,339	98
Specific conductance (micromhos per centimeter at 25° Celsius)	350 - 7,700	3,075	75

8.0 WATER-DATA SOURCES

8.1 Introduction

NAWDEX, WATSTORE, and OWDC Information

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

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

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

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

of data on the quantity and quality of both surface and ground waters.

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

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

8.0 WATER-DATA SOURCES--Continued
8.2 National Water-Data Exchange (NAWDEX)

NAWDEX Simplifies Access to Water Data

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

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

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 states and Puerto Rico, which provide local and convenient access to NAWDEX facilities (fig. 8.2-1). A directory is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations [Directory of Assistance Centers of the National Water Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 79-423 (revised)].

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water Data Index (fig. 8.2-2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A water Data Sources Directory (fig. 8.2-3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In

all cases, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and in all cases where costs are anticipated to be substantial.

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

Program Office
National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

Telephone: (703) 860-6031
FTS 928-6031

or

NAWDEX ASSISTANCE CENTER
IOWA
U.S. Geological Survey
Water Resources Division
Room 269 - Federal Building
400 South Clinton Street
P.O. Box 1230
Iowa City, IA 52244

Telephone: (319) 337-4191
FTS 863-6521

or

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

Telephone: (314) 341-0824
FTS 277-0824

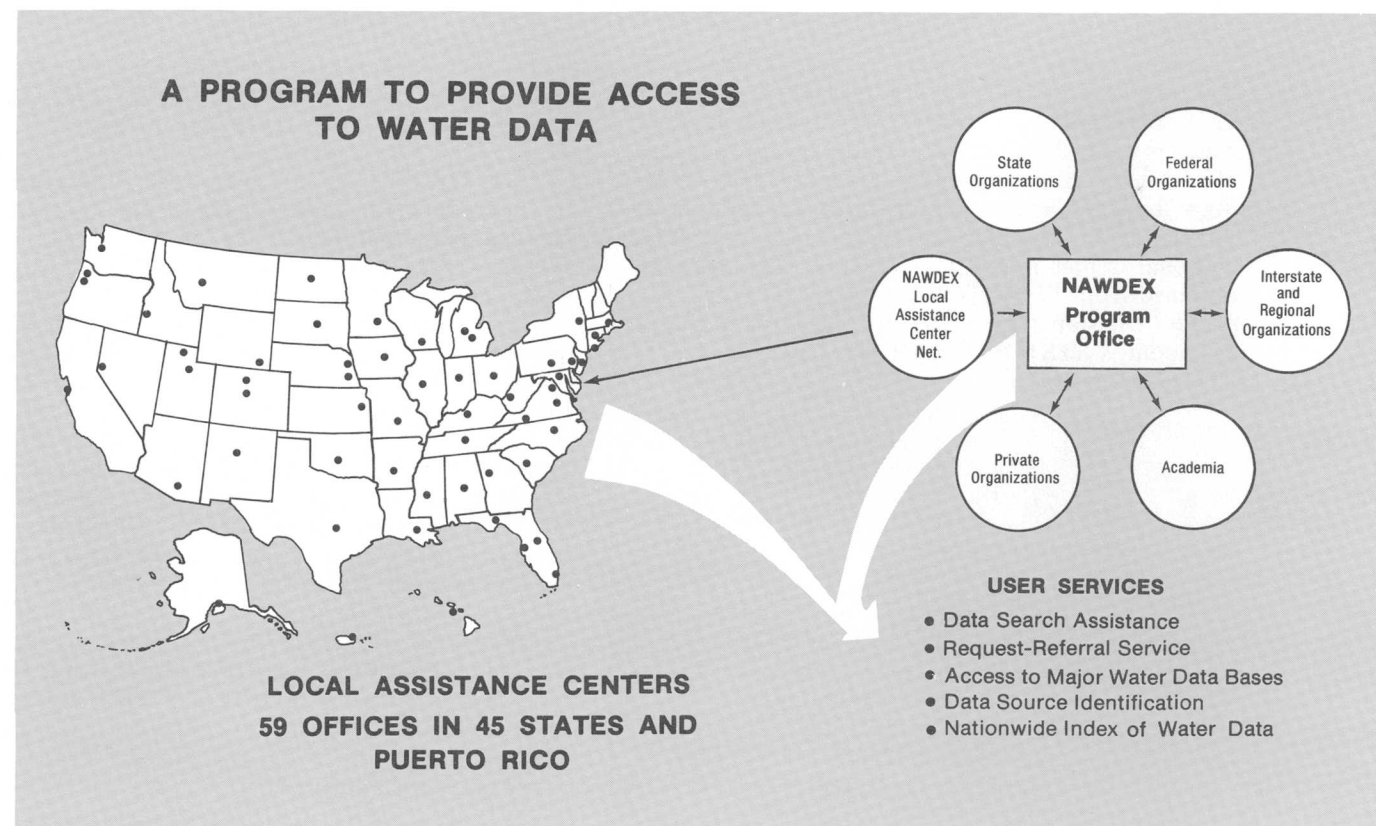


Figure 8.2-1 Access to water data.

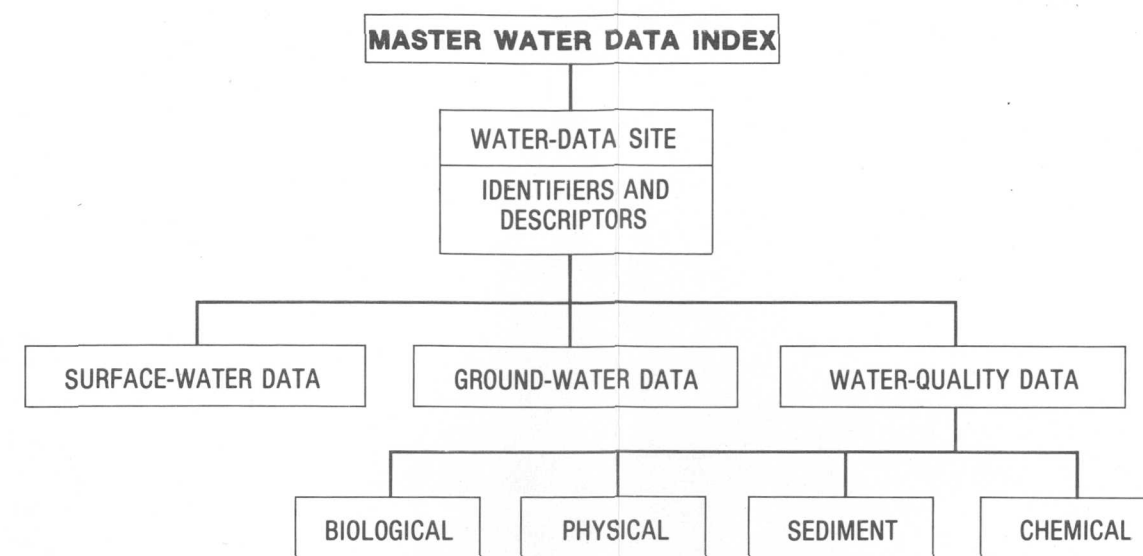


Figure 8.2-2 Master water-data index.

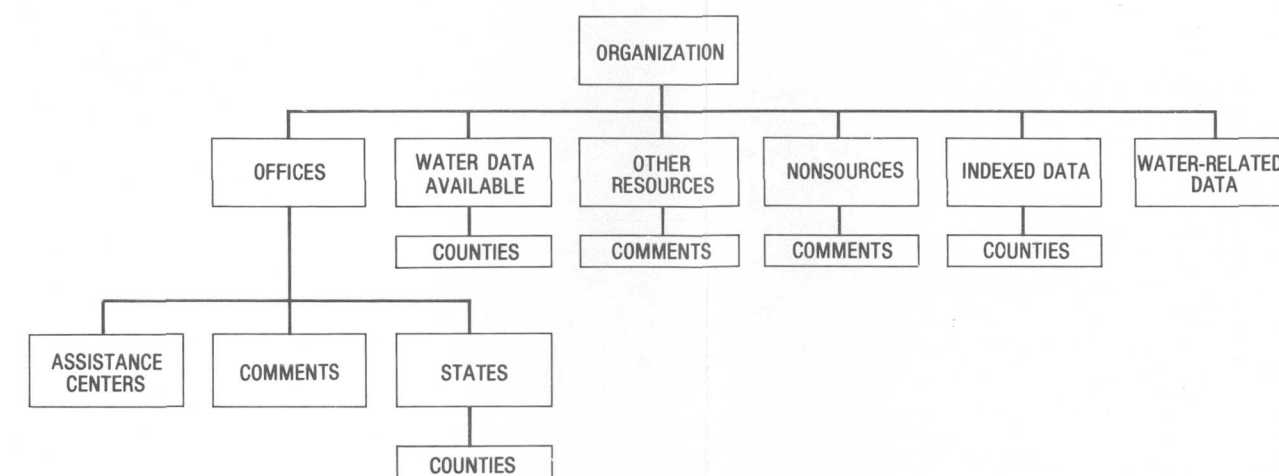


Figure 8.2-3 Water-data sources directory.

8.0 WATER-DATA SOURCES--Continued

8.3 WATSTORE

WATSTORE Automated Data System

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

The National Water Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide for more effective and efficient management of its data-releasing activities. The system is operated and maintained on the central computer facilities of the Survey at its National Center in Reston, Virginia. Data may be obtained from WATSTORE through the Water Resources Division's 46 district offices. General inquiries about WATSTORE may be directed to:

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

or

Iowa
U.S. Geological Survey
Water Resources Division
Room 269 - Federal Building
400 South Clinton Street
P.O. Box 1230
Iowa City, IA 52244

or

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

The Geological Survey currently (1980) collects data at approximately 16,000 streamgaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,020 sediment stations, 30,000 water-level observation wells, and 12,500 ground-water quality wells. Each year many water-data collection sites are added and others are discontinued; thus,

large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system is also designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 8.3-1). A brief description of each file is as follows:

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

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

Peak Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values

at surface-water sites comprise this file, which currently contains over 400,000 peak observations.

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

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

Ground-Water Site-Inventory File: This file is discussed above, but it is cross-referenced to the Water-Quality File and the Daily Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 70,000 sites.

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

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

Digital Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chlorides. Data are recorded on 16-channel paper tape, which is removed from the recorder and transmitted over telephone lines to the receiver at Reston, Virginia. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data collection platforms indicates their feasibility for collecting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200

data relay stations are being operated currently (1980).

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

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

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

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

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

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

Data in Machine-Readable Form: Data stored in WATSTORE can be obtained in machine-readable

form for use on other computers or for use as input to user-written computer programs. These data are available in the standard storage format of the WAT-

STORE system or in the form of punched cards or card images on magnetic tape.

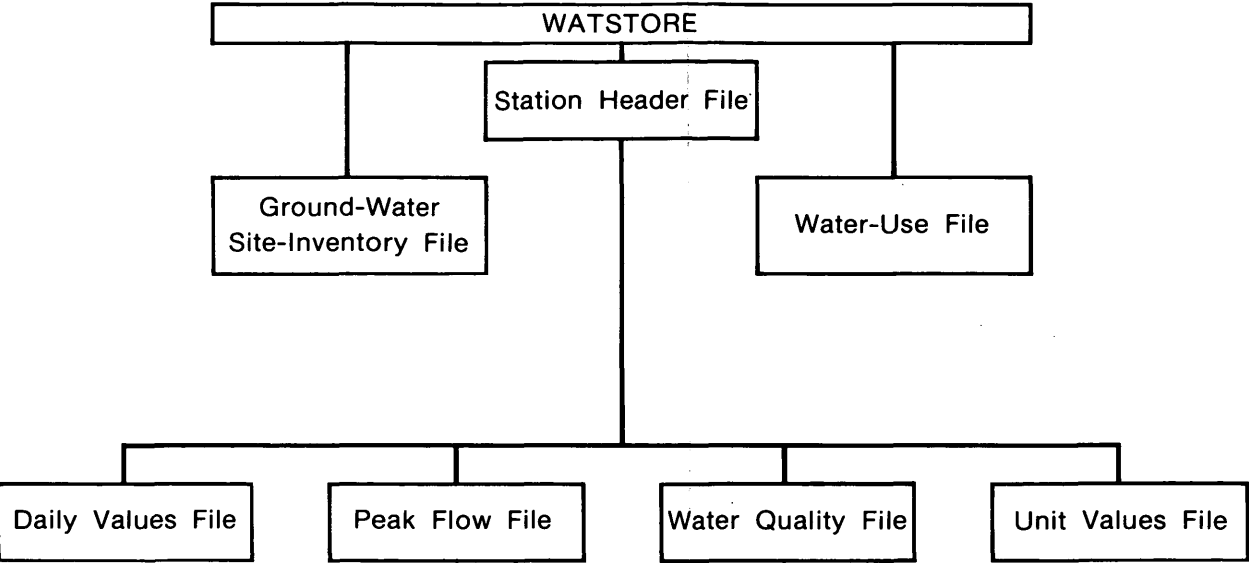


Figure 8.3-1 Files of stored data.

8.0 WATER-DATA SOURCES--Continued

8.4 Index to Water-Data Activities in Coal Provinces

Water Data Indexed for Coal Provinces

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

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

This special index consists of five volumes (fig. 8.4-1): volume I, Eastern Coal province; volume II, Interior Coal province; volume III, Northern Great Plains and Rocky Mountain Coal provinces; volume IV, Gulf Coast Coal province; and volume V, Pacific Coast and Alaska Coal provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal

Investigations and Miscellaneous Activities. Information given for each activity in Parts A-C includes: (1) the identification and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are shown in a table.

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

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

Office of Surface Mining
U.S. Department of the Interior
818 Grande Avenue, Scarritt Building
Kansas City, MO 64106

Telephone: (816) 374-3920
FTS 758-5162

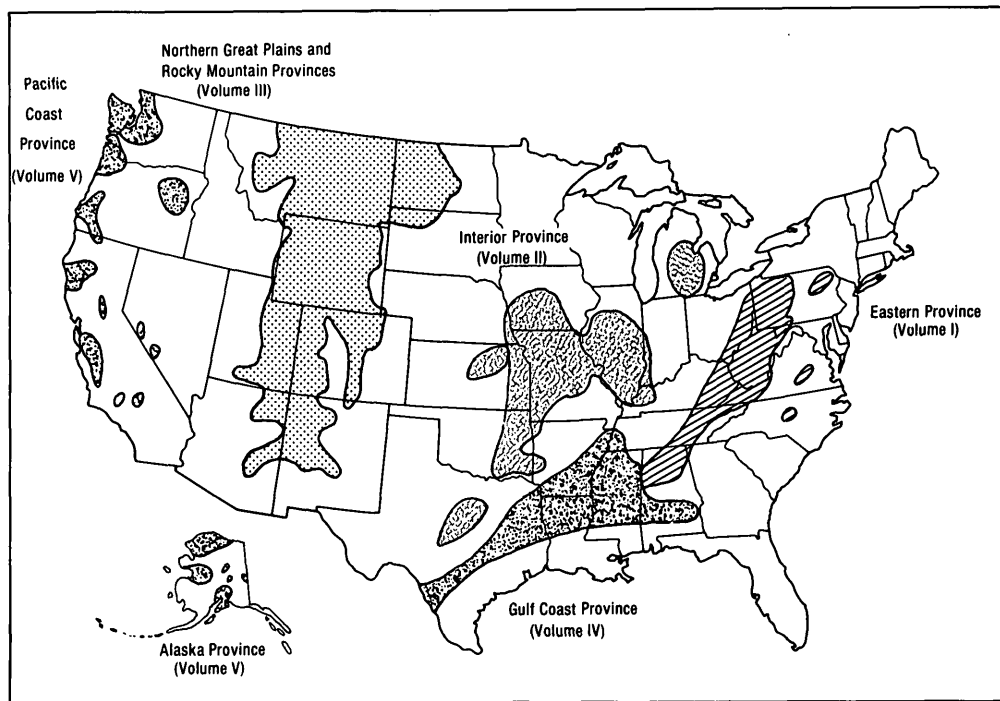


Figure 8.4-1 Index volumes and related provinces.

9.0 SURFACE-WATER STATIONS

Table 10.1 Surface-water stations

(ID = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water years of record
1	05485520	Des Moines River below Des Moines, Ia. Polk County Lat 41°33'03", long 93°31'24", in NE1/4NE1/4 sec. 20, T.78N., R.23W.	9,901	Q	1975-81
2	05485700	North River near Earlham, Ia. Madison County Lat 41°24'XX", long 94°11'XX", in NE1/4 sec. 9, T.76 N., R.29W.	68.9	L	
3	05485900	North River near Winterset, Ia. Madison County Lat 41°26'XX", long 93°55'XX", in NW1/4 sec.36, T.77N., R.27W.	203	L	
4	05486000	North River near Norwalk, Ia. Warren County Lat 41°27'25", long 93°39'10", in NW1/4SW1/4 sec. 20, T.77N., R.24W.	349	D	1940-
5	05486100	Middle River near Casey, Ia. Guthrie County Lat 41°30'XX", long 94°29'XX", in SW1/4 sec. 36, T.78N., R.32W.	72.8	L	
6	0548150	Middle River at Middle River, Ia. Madison County Lat 41°20'XX", long 94°14'XX", near center of sec. 6, T.75N., R.29W.	164	L	
7	05486300	Clanton Creek at East Peru, Ia. Madison County Lat 41°14'XX", long 93°55'XX", in NE1/4 sec. 11, T.74N., R.27W.	84.5	L	
8	05486350	Clanton Creek near Martensdale, Ia. Warren County Lat 41°21'XX", long 93°45'XX", in NE1/4 sec. 32, T.76N., R.25W.	159	L	
9	05486400	Middle River at Martensdale, Ia. Warren County Lat 41°22'XX", long 93°44'XX", in SE1/4 sec. 21, T.76N., R.25W.	451	L	
10	05486490	Middle River near Indianola, Ia. Warren County Lat 41°25'27", long 93°35'09", in SE1/4SE1/4 sec. 35, T.77N. R.24W.	503	D	1940-
11	05486700	South River near New Virginia, Ia. Warren County Lat 41°13'XX", long 93°44'XX", in NE1/4 sec. 16, T.74N., R.25W.	65.4	L	
12	05486900	Squaw Creek near Jamison, Ia. Clarke County Lat 41°08'XX", long 93°44'XX", in NE1/4 sec. 16, T.73N., R.25W.	60.8	L	
13	05487100	Squaw Creek near Indianola, Ia. Warren County Lat 41°18'XX", long 93°36'XX", in NE1/4 sec. 15, T.75N., R.24W.	134	L	
14	05487200	South River near Indianola, Ia. Warren County Lat 41°20'XX", long 93°35'XX", in NE1/4 sec. 2, T.75N., R.24W.	278	L	
15	05487350	South Otter Creek TR. near Woodburn, Ia. Clarke County Lat 41°03'XX", long 93°36'XX", near SW corner sec. 11	.71	C	

Table 10.1 Surface-water stations--continued.
(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
16	05487400	Otter Creek near Norwood, Ia. Lucas County Lat 41°09'XX", long 93°32'XX", in SW1/4 sec. 5, T.73N.,R.23W.	102	L	
17	05487450	Otter Creek near Milo, Ia. Warren County Lat 41°17'02", long 93°29'09", in NE1/4 sec. 22, T.75N.,R.23W.	155	L	
18	05487470	South River near Ackworth, Ia. Warren County Lat 41°20'14", long 93°29'10", in SE1/4SE1/4 sec. 34, T.76N.,R.23W.	460	D	1940-
19	05487600	South White Breast Creek near Osceola, Ia. Clarke County Lat 40°57'36", long 93°41'28", near SW corner sec. 12, T.71N.,R.25W.	28.0	C	1953-
20	05487700	White Breast Creek near Woodburn, Ia. Clarke County Lat 40°58'36", long 93°35'14", in SE1/4NW1/4 sec.2, T.71N.,R.24W.	82.9	L Q	1978-81
21	05487800	White Breast Creek near Lucas, Ia. Lucas County Lat 41°01'XX", long 93°28'XX", in NE1/2 sec. 23, T.72N.,R.23W.	128	C	1953-
22	05487810	White Breast Creek near Lucas, Ia. Lucas County Lat 41°03'26", long 93°24'41", in SE1/4SW1/4 sec. 5, T.72N.,R.22	150	Q	1978-81
23	05487880	White Breast Creek near Lacona, Ia. Lucas County Lat 41°09'38", long 93°21'05", in NE1/4NW1/4 sec. 2, T.73N.,R.22W.	243	Q	1978-81
24	05487900	White Breast Creek near Newbern, Ia. Warren County Lat 41°10'XX", long 93°21'XX", in SE1/4 sec. 35, T.72N.,R.22W.	243	L	
25	05487980	White Breast Creek near Dallas, Ia. Marion County Lat 41°14'04", long 93°16'08", in NW1/4NW1/4 sec. 3, T.74N., R.21W.	342	D Q	1962- 1978-81
26	05488000	White Breast Creek near Knoxville, Ia. Marion County Lat 41°19'25", long 93°08'55", in NE1/4SW1/4 sec. 3, T.75N., R.20W.	380	D Q	1947-62 1978-81
27	05488100	Lake Red Rock near Pella, Ia. Marion County Lat 41°22'11", long 92°58'48", in NE1/4NW1/4 sec. 19, T.76N.,R.18W.	12,323	D	1969-
28	05488110	Des Moines River below Lake Red Rock, Ia. Marion County Lat 41°21'40", long 92°58'15", in NE1/4NE1/4 sec. 30, T.76N.,R.18W.	12,323	Q	1971-
29	05488180	English Creek near Columbia, Ia. Marion County Lat 41°10'54", long 93°11'56", in SE1/4NE1/4 sec. 30, T.74N.,R.20W.	24.8	Q	1978-81
30	05488200	English Creek near Knoxville, Ia. Marion County Lat 41°16'16", long 93°05'27", in NW1/4SE1/4 sec. 30, T.75N.,R.19W.	73.0	L Q	1978-81
31	05488300	English Creek near Harvey, Ia. Marion County Lat 41°19'35", long 93°56'51", in SW1/4NW1/4 sec. 4, T.75N.,R.18W.	108	L Q	1978-81
32	05488500	Des Moines River near Tracy, Ia. Mahaska County Lat 41°16'52", long 92°51'34", in NW1/4SE1/4 sec. 19, T.75N.,R.17W.	12,479	D Q	1920-67 1967
33	05488550	Cedar Creek near Melrose, Ia. Monroe County Lat 40°58'00", long 93°03'00", in SE1/4SW1/4 sec. 4, T.71N.,R.19W.	23.9	L Q	1978-81
34	05488600	Cedar Creek near Albia, Ia. Monroe County Lat 41°01'00", long 92°53'00", in NE1/4SW1/4 sec. 26, T.72N.,R.18W.	102	L Q	1978-81
35	05488700	Cedar Creek near Lovilia, Ia. Monroe County Lat 41°07'00", long 92°56'00", in SW1/4SE1/4 sec. 16, T.73N.,R.18W.	211	L Q	1978-81
36	05488750	Cedar Creek near Hamilton, Ia. Marion County Lat 41°11'10", long 92°55'55", in NW1/4NW1/4 sec. 27, T.74N.,R.18W.	241	Q	1980-81
37	05488800	North Cedar Creek near Lovilia, Ia. Monroe County Lat 41°09'XX", long 93°03'XX", in NE1/4 sec. 4, T.73N.,R.19W.	61.3	L	
38	05488895	North Cedar Creek near Attica, Ia. Monroe County Lat 41°09'14", long 93°00'56", in NE1/4SW1/4 sec. 4, T.73N.,R.19W.	104	Q	1978-81
39	05488900	North Cedar Creek near Marysville, Ia. Marion County Lat 41°11'XX", long 93°01'XX", in SW1/4 sec. 26, T.74N.,R.19W.	111	L	
40	05488990	North Cedar Creek near Bussey, Ia. Marion County Lat 41°12'44", long 92°55'50", in NE1/4SE1/4 sec. 16, T.74N.,R.18W.	125	Q	1978-81
41	05489000	Cedar Creek near Bussey, Ia. Marion County Lat 41°13'09", long 92°54'38", at SW corner sec. 11, T.74N.,R18W.	374	D Q	1947- 1978-81
42	05489010	Honey Creek near Tracy, Ia. Marion County Lat 41°14'35", long 92°55'40", in NE1/4SE1/4 sec. 4, T.74N.,R.18W.	9.0	Q	1980-81
43	05489020	Walnut Creek near Tracy, Ia. Marion County Lat 41°17'07", long 92°56'20", in NW1/4SE1/4 sec. 22, T.75N.,R.18W.	23.6	Q	1980-81
44	05489030	Cedar Creek near Tracy, Ia. Mahaska County Lat 41°15'18", long 92°51'26", in NE1/4SW1/4 sec. 31, T.75N.,R.17W.	423	Q	1978-81
45	05489090	South Coal Creek near Bussey, Ia. Makaska County Lat 41°13'18", long 92°47'36", in SE1/4SE1/4 sec. 10, T.74N.,R.17WW.	12.9	D	1976-81
46	05489190	Muchakinock Creek near Eddyville, Ia. Mahaska County Lat 41°12'04", long 92°38'24", in SW1/4NW1/4 sec. 19, T.74N.R.15W.	70.2	D Q	1975-79 1976
47	05489300	North Avery Creek at Chillicothe, Ia. Wapello County Lat 41°06'XX", long 92°33'XX", in SE1/4 sec. 26, T.73N.,R.15W.	60.1	L	

9.0 SURFACE-WATER STATIONS--Continued

Table 10.1 Surface-water stations--continued.

(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
48	05489350	South Avery Creek near Blakesburg, Ia. Wapello County Lat 41°01'XX", long 92°37'XX", in SE1/4 sec. 19, T.72N., R.15W.	33.1	C	1955-
49	05489400	South Avery Creek at Chillicothe, Ia. Wapello County Lat 41°05'XX", long 92°32'XX", at E1/4 corner sec. 36, T.73N., R.15W.	51.6	L	
50	05489490	Bear Creek at Ottumwa, Ia. Wapello County Lat 41°00'43", long 92°27'54", in NW1/4 sec. 27, T.72N., R.14W.	22.9	C	1965-
51	05489500	Des Moines River at Ottumwa, Ia. Wapello County Lat 41°00'39", long 92°24'40", in SE1/4NE1/4 sec. 25, T.72N., R.14W.	13,374	D Q	1917- 1965-79
52	05489900	Soap Creek near Ash Grove, Ia. Davis County Lat 40°51'XX", long 92°36'XX", in SW1/4 sec. 21, T.70N., R.15W.	97.3	L	
53	05490100	Soap Creek near Floris, Ia. Davis County Lat 40°53'57", long 92°15'53", near center of sec. 5, T.70N., R.12W.	243	L	
54	05490200	Fick Creek at Kilbourn, Ia. Van Buren County Lat 40°48'XX", long 91°58'XX", in SW1/4 sec. 1, T.69N., R.10W.	82.7	L	
55	05490300	Chequest Creek near Troy, Ia. Davis County Lat 40°47'17", long 92°11'01", in SE1/4 sec. 12, T.69N., R.12W.	85.0	L	
56	05490400	Chequest Creek near Pittsburg, Ia. Davis County Lat 40°45'41", long 92°00'57", near center of sec. 21, T.69N., R.10W.	123	L	
57	05490500	Des Moines River at Keosauqua, Ia. Van Buren County Lat 40°43'40", long 91°57'34", in SE1/4SW1/4 sec. 36, T.69N., R.10W.	14,038	D	1911-
58	05504400	South Fork Salt River at Mexico, Mo. Audrain County Lat 39°11'23", long 91°52'27", in NW1/4 sec. 24, T.51N., R.9W.		L	
59	05505000	South Fork Salt River at Santa Fe, Mo. Monroe County Lat 39°21'45", long 91°49'09", in NW1/4NE1/4 sec. 20, T.53N., R.8W.	298	D	1939-
60	05506000	Youngs Creek near Mexico, Mo. Audrain County Lat 39°18'40", long 91°56'40", in SW1/4 sec. 5, T.52N., R.9W.	67.4	D	1931-69
61	05506500	Middle Fork Salt River at Paris, Mo. Monroe County Lat 39°29'05", long 91°59'50", in NW1/4NW1/4 sec. 11, T.54N., R.10W.	356	D	1939-

Table 10.1 Surface-water stations--continued.
(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
62	05506800	Elk Fork Salt River near Madison, Mo. Monroe County Lat 39°26'05", long 92°10'04", in NE1/4SW1/4 sec. 29, T.54N.,R.11W.	200	D	1969-
63	05507000	Elk Fork Salt River near Paris, Mo. Monroe County Lat 39°26'25", long 92°00'05", in SW1/4SW1/4 sec. 23, T.54N.,R.10W.	262	D	1935-54
64	06893000	Missouri River at Kansas City, Mo. Jackson County Lat 39°06'43", long 94°35'16", in sec. 32, T.50N.,R.33W.	485,200	D	1897-
65	06893670	Shoal Creek at Claycomo, Mo. Clay County Lat 39°12'27", long 94°28'45", in NE1/4NW1/4 sec. 27, T.51N.,R.32W.	29.8	D	1975-
66	06893700	Shoal Creek near Liberty, Mo. Clay County Lat 39°10'32", long 94°26'52", in N1/2 sec. 1, T.50N.,R.32W.		L	
67	06894100	Missouri River at Sibley, Mo. Jackson County Lat 39°10'46", long 94°11'03", in NE1/4 sec. 2, T.51N.,R.30W.		Q	1971-75
68	06894300	Fishing River at Mosby, Mo. Clay County Lat 39°10'10", long 94°18'47", in N1/2 sec. 18, T.52N.,R.30W.		L	
69	06894400	Williams Creek at Mosby, Mo. Clay County Lat 39°19'32", long 94°16'58", in SW1/4 sec. 9, T.52N.,R.30W.		L	
70	06894500	East Fork Fishing River at Excelsior Springs, Mo. Clay County Lat 39°20'20", long 94°12'45", in SE1/4 sec. 1, T.52N.,R.30W.	20.0	D	1952-72
71	06894600	Fishing River near Orrick, Mo. Ray County Lat 39°13'19", long 94°09'29", btwn secs. 16 and 21, T.51N.,R.29W.		L	
72	06895000	Crooked River near Richmond, Mo. Ray County Lat 39°19'58", long 93°58'46", in NW1/4 sec. 7, T.52N.,R.27W.	159	D	1948-70
73	06895050	West Fork Crooked River at Richmond, Mo. Ray County Lat 39°17'48", long 93°58'24", in S1/2 sec. 19, T.52N.,R.27W.		L	
74	06895500	Missouri River at Waverly, Mo. Lafayette County Lat 39°12'50", long 93°30'50", in sec. 14, T.51N.,R.24W.	487,200	D	1928-
75	06896000	Wakenda Creek at Carrollton, Mo. Carroll County Lat 39°20'50", long 93°29'45", in NE1/4SE1/4 sec. 5, T.52N.,R.23W.	248	D	1948-70
76	06896100	Grand River at Knowlton, Ia. Ringgold County Lat 40°50'XX", long 94°20'XX", in SE1/4 sec. 29, T.70N.,R.30W.	67.5	L	
77	06896150	Grand River near Blockton, Ia. Ringgold County Lat 40°34'XX", long 94°27'XX", in SW1/4 sec. 29, T.67N.,R.31W.	207	L	
78	06896160	Grand River near Grant City, Mo. Worth County Lat 40°30'25", long 94°31'50", in W1/2 sec. 21, T.66N.,R.32W.		L	
79	06896170	Grand River near Stanberry, Mo. Gentry County Lat 40°14'28", long 94°29'13", in SE1/4 sec. 22, T.63N.,R.32W.		L	
80	06896180	De Moss Branch near Stanberry, Mo. Gentry County Lat 40°13'35", long 94°33'35", in NE1/4SE1/4 sec. 36, T.63N.,R.33W.	0.38	C	1955-79
81	06896182	Wildcat Creek at Stanberry, Mo. Gentry County Lat 40°12'08", long 94°31'46", in S1/2 sec. 5, T.62N.,R.32W.		L	
82	06896185	Middle Fork Grand River at Grant City, Mo. Worth County Lat 40°29'10", long 94°23'10", in NE1/4 sec. 34, T.66N.,R.31W.		L	
83	06896190	Middle Fork Grand River near Albany, Mo. Gentry County Lat 40°14'27", long 94°24'12", in SW1/4 sec. 21, T.63N.,R.31W.		L	
84	06896200	East Fork Grand River near Mt. Ayr, Ia. Ringgold County Lat 40°43'XX", long 94°10'XX", in SE1/4 sec. 3, T.68N.,R.29W.	64.7	L	
85	06896250	East Fork Grand River south of Mt. Ayr, Ia. Ringgold County Lat 40°35'XX", long 94°14'XX", in SW1/4 sec. 19, T.67N.,R.29W.	95.9	L	
86	06896400	East Fork Grand River at Albany, Mo. Gentry County Lat 40°14'53", long 94°21'35", in NW1/4 sec. 23, T.63N.,R.31W.		L	
87	06896500	Thompson Branch near Albany, Mo. Gentry County Lat 40°12'50", long 94°19'57", in SE1/4 sec. 36, T.63N.,R.31W.	5.58	D	1957-72
88	06896550	Grand River near Darlington, Mo. Gentry County Lat 40°11'41", long 94°21'31", in N1/2 sec. 11, T.62N.,R.31W.		L	
89	06896750	West Fork Lost Creek at Maysville, Mo. Dekalb County Lat 39°53'34", long 94°20'29", in SE1/4 sec. 26, T.59N.,R.31W.		L	
90	06896800	Lost Creek near Weatherby, Mo. Dekalb County Lat 39°53'55", long 94°16'18", center sec. 28, T.59N.,R.30W.		L	
91	06896850	Grindstone Creek near Pattonsburg, Mo. Daviess County Lat 39°58'41", long 94°11'49", btwn secs. 30 & 31, T.60N.,R.29W.		L	
92	06896900	Grand River near Pattonsburg, Mo. Daviess County Lat 40°01'30", long 94°07'32", in SW1/4 sec. 11, T.60N.,R.29W.	1,680	L	
93	06897000	East Fork Big Creek near Bethany, Mo. Harrison County Lat 40°17'50", long 94°01'36", in SE1/4 sec. 34, T.64N.,R.28W.	95	D	1935-72

9.0 SURFACE-WATER STATIONS-Continued

Table 10.1 Surface-water stations--continued.

(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
94	06897100	Big Creek at Bethany, Mo. Harrison County Lat 40°14'52", long 94°04'09", in NE1/4 sec. 20, T.63N., R.28W.		L	
95	06897300	Big Creek near Pattonsburg, Mo. Daviess County Lat 40°07'05", long 94°06'07", in NE1/4 sec. 1, T.61N., R.29W.		L	
96	06897500	Grand River near Gallatin, Mo. Daviess County Lat 39°55'37", long 93°56'33", in SW1/4NW1/4 sec. 16, T.59N., R.27W.	2,250	D	1921-
97	06897700	Grand River tributary near Utica, Mo. Livingston County Lat 39°44'22", long 93°38'18", in SW1/4NE1/4 sec. 19, T.57N., R.24W.	1.44	C	1960-
98	06897770	Thompson River near Hebron, Ia. Adair County Lat 41°14'XX", long 94°16'XX", in SW1/4 sec. 1, T.74N., R.30W.	80.0	L	
99	06897800	Threemile Creek near Afton, Ia. Union County Lat 41°02'XX", long 94°08'XX", near center of sec. 13, T.72N., R.29W.	54.8	L	
100	06897820	Thompson River near Afton, Ia. Union County Lat 41°02'XX", long 94°06'XX", in SW1/4 sec.17, T.72N., R.28W.	231	L	
101	06897880	Twelveville Creek near Arispe, Ia. Decatur County Lat 40°56'XX", long 94°06'XX", in SE1/4 sec. 17, T.71N., R.28W.	117	L	
102	06897900	Thompson River near Grand River, Ia. Decatur County Lat 40°52'XX", long 93°58'XX", in NE1/4 sec. 16, T.70N., R.27W.	401	L	
103	06897940	Long Creek near Van Wert, Ia. Decatur County Lat 40°49'XX", long 93°52'XX", in NE1/4 sec. 32, T.70N., R.26W.	117	L	
104	06897950	Elk Creek near Decatur City, Ia. Decatur County Lat 40°43'18", long 93°56'12", in SE corner sec. 34, T.69N., R.27W.	52.5	D Q	1967- 1968-
105	06898000	Thompson River at Davis City, Ia. Decatur County Lat 40°38'25", long 93°48'29", in SW1/4SE1/4 sec. 35, T.68N., R.26W.	701	D Q	1941- 1968-73
106	06898100	Thompson River at Mt. Moriah, Mo. Harrison County Lat 40°20'11", long 93°46'02", btwn secs. 13 & 24, T.64N., R.26W.	891	D	1960-77
107	06898110	Panther Creek at Mt. Moriah, Mo. Harrison County Lat 40°21'25", long 93°45'15", NW1/4 sec. 27, T.64N., R.26W.		L	

Table 10.1 Surface-water stations--continued.
(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
108	06898200	Thompson River near Trenton, Mo. Grundy County Lat 40°08'50", long 93°42'06", btwn secs. 22 & 27, T.62N.,R.25W.		L	
109	06898300	Weldon River east of Leon, Ia. Decatur County Lat 40°45'18", long 93°38'05", in SE1/4 sec. 20, T.59N.,R.29W.	72.4	L	
110	06898400	Weldon River near Leon, Ia. Decatur County Lat 40°41'45", long 93°38'07", in NE1/4NE1/4 sec. 17, T.68N.,R.24W.	104	D Q	1958- 1968-73
111	06898450	Weldon River near Pleasanton, Ia. Decatur County Lat 40°35'40", long 93°36'20", in NW1/4 sec. 22, T.67N.,R.24W.	228	L	
112	06898470	Little River near Leon, Ia. Decatur County Lat 40°39'36", long 93°44'59", in SE1/4 sec. 29, T.68N.,R.25W.	69.2	L	
113	06898500	Weldon River near Mercer, Mo. Mercer County Lat 40°32'56", long 93°36'10", in SW1/4 sec. 3, T.66N.,R.24W.	246	D	1940-58
114	06899000	Weldon River at Mill Grove, Mo. Mercer County Lat 40°18'35", long 93°35'38", in SE1/4 sec. 28, T.64N.,R.24W.	494	D	1930-72
115	06899100	Weldon River near Trenton, Mo. Grundy County Lat 40°08'03", long 93°38'13", in SE1/4 sec. 30, T.62N.,R.24W.		L	
116	06899500	Thompson River at Trenton, Mo. Grundy County Lat 40°04'46", long 93°38'39", in NE1/4SW1/4 sec. 18, T.61N.,R.24W.	1,670	D	1921-23, 1928-
117	06899550	Muddy Creek at Trenton, Mo. Grundy County Lat 40°04'32", long 93°35'21", btwn. secs. 15 & 22, T.61N.,R.24W.		L	
118	06899570	Honey Creek near Trenton, Mo. Grundy County Lat 39°59'37", long 93°33'20", between secs. 24 & 25, T.60N.,R.24W.		L	
119	06899620	Thompson River near Chillicothe, Mo. Livingston County Lat 39°49'50", long 93°36'25", in NW1/4 sec. 21, T.58N.,R.24W.		Q	1968-75
120	06899680	Grand River at Chillicothe, Mo. Livingston County Lat 39°45'21", long 93°33'31", in NE1/4 sec. 14, T.57N.,R.24W.	4,850	L	
121	06899690	Shoal Creek at Kingston, Mo. Caldwell County Lat 39°39'03", long 94°02'22", btwn secs. 21 & 22, T.56N.,R.28W.		L	
122	06899700	Shoal Creek near Braymer, Mo. Caldwell County Lat 39°40'50", long 93°46'05", in NE1/4 sec. 13, T.56N.,R.26W.	391	D	1958-77
123	06899800	Shoal Creek near Chillicothe, Mo. Livingston County Lat 39°43'59", long 93°33'19", in SW1/4 sec. 24, T.37N.,R.24W.		L	
124	06900000	Medicine Creek near Galt, Mo. Sullivan County Lat 40°07'45", long 93°21'45", in SW1/4NW1/4 sec. 34, T.62N.,R.22W.	225	D	1921-
125	06900500	Medicine Creek near Sturges, Mo. Livingston County Lat 39°52'44", long 93°26'47", btwn sec. 35,T.59N.,R.23W. & sec. 2,T.58N.,R.23W.	368	L	
126	06900600	Medicine Creek near Wheeling, Mo. Livingston County Lat 39°46'36", long 93°24'56", in S1/2 sec. 6, T.57N.,R.22W.		L	
127	06900700	Parson Creek at Meadville, Mo. Linn County Lat 39°46'39", long 93°19'20", in SW1/4 sec. 1, T.57N.,R.22W.		L	
128	06901000	Locust Creek near Milan, Mo. Sullivan County Lat 40°11'00", long 93°10'13", in SW1/4 sec. 8, T.62N.,R.20W.	225	D	1922-32
129	06901500	Locust Creek near Linneus, Mo. Linn County Lat 39°53'45", long 93°14'10", in NW1/4NE1/4 sec. 34, T.59N.,R.21W.	550	D	1929-72
130	06902000	Grand River near Sumner, Mo. Chariton County Lat 39°38'25", long 93°16'25", in NE1/4 sec. 29, T.56N.,R.21W.	6,880	D Q	1923- 1962-63, 1967-
131	06902200	West Yellow Creek near Brookfield, Mo. Linn County Lat 39°50'40", long 93°01'36", in NE1/4 sec. 16, T.58N.,R.19W.	135	D	1959-77
132	06902300	West Yellow Creek below Brookfield, Mo. Linn County Lat 39°45'48", long 93°02'10", btwn secs. 9 & 16, T.57N.,R.19W.		L	
133	06902500	Hamilton Branch near New Boston, Mo. Linn County Lat 39°57'08", long 92°54'08", in SE1/4SW1/4 sec. 3, T.59N.,R.18W.	2.51	D	1955-72
134	06902800	Onion Branch at St. Catherine, Mo. Linn County Lat 39°47'46", long 92°59'17", in SE1/4 sec. 35, T.58N.,R.19W.	1.04	C	1955-
135	06902900	East Yellow Creek near Brookfield, Mo. Linn County Lat 39°45'44", long 92°58'59", in SW1/4 sec. 12, T.57N.,R.19W.		L	
136	06903000	Yellow Creek near Rothville, Mo. Chariton County Lat 39°37'43", long 93°05'06", btwn sec. 31, T.56N.,R19W., & sec. 36, T.56N.,R.20W.	405	L	
137	06903100	Turkey Creek near Laclede, Mo. Linn County Lat 39°46'44", long 93°08'52", in SW1/4 sec. 9, T.57N.,R.20W.		L	
138	06903200	Big Creek near Bosworth, Mo. Carroll County Lat 39°24'42", long 93°19'42", in NW1/4 sec. 13, T.53N.,R.22W.		L	
139	06903300	Chariton River near Derby, Ia. Lucas County Lat 40°57'XX", long 93°28'XX", in NW1/4 sec. 13, T.71N.,R.23W.	71.0	L	

9.0 SURFACE-WATER STATIONS--Continued

Table 10.1 Surface-water stations--continued.

(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
140	06903350	Wolf Creek near Chariton, Ia. Lucas County Lat 40°56'XX", long 93°16'XX", in SE1/4 sec. 16, T.71N., R.21W.	65.0	L	
141	06903400	Chariton River near Chariton, Ia. Lucas County Lat 40°87'12", long 93°15'37", in SW1/4NE1/4 sec. 15, T.71N., R.21W.	182	D Q	1965- 1971-
142	06903600	South Fork Chariton River near Cambria, Ia. Wayne County Lat 40°49'XX", long 93°23'XX", in NW1/4 sec. 3, T.69N., R.22W.	58.8	L	
143	06903650	South Fork Chariton River near Corydon, Ia. Wayne County Lat 40°49'XX", long 93°19'XX", in NW1/4 sec. 6, T.69N., R.21W.	68.1	L	
144	06903700	South Fork Chariton River near Promise City, Ia. Wayne County Lat 40°48'02", long 93°11'31", in SW1/4SW1/4 sec. 5, T.69N., R.20W.	168	D	1967-
145	06903880	Rathbun Lake near Rathbun, Ia. Appanoose County Lat 40°49'30", long 92°53'33", in NW1/4NE1/4 sec. 35, T.70N., R.18W.	549	D	1969-
146	06903900	Chariton River near Rathbun, Ia. Appanoose County Lat 40°49'22", long 92°53'22", in SE1/4NE1/4 sec. 35, T.70N., R.18W.	549	D Q	1956- 1971-
147	06903980	Chariton River near Udel, Ia. Appanoose County Lat 40°46'53", long 92°50'12", in NE1/4 sec. 17, T.69N., R.17W.	631	C	1972-
148	06903990	Cooper Creek at Centerville, Ia. Appanoose County Lat 40°45'02", long 92°51'36", in NW1/4 sec. 30, T.69N., R.17W.	47.8	C	1966-
149	06904000	Chariton River near Centerville, Ia. Appanoose County Lat 40°44'20", long 92°48'05", in NE1/4NW1/4 sec. 34, T.69N., R.17W.	708	D	1938-59
150	06904010	Chariton River near Moulton, Ia. Appanoose County Lat 40°41'30", long 92°46'15", in SE1/4NE1/4 sec. 14, T.68N., R.17W.	740	D	1979-
151	06904040	Chariton River at Coal City, Ia. Appanoose County Lat 40°35'35", long 92°42'40", in NE1/4 sec. 20, T.67N., R.16W.	816	C	1972-
152	06904050	Chariton River at Livonia, Mo. Schuyler County Lat 40°29'00", long 92°41'10", in SE1/4NW1/4 sec. 34, T.66N., R.16W.	864	D	1974-
153	06904150	Shoal Creek near Cincinnati, Ia. Wayne County Lat 40°37'XX", long 92°52'XX", in SW1/4 sec. 6, T.67N., R.17W.	68.1	L	

Table 10.1 Surface-water stations--continued.
(D = Continuous-record streamflow gaging station; L = Low-flow station; C = Crest-gage station; Q = Quality of water station)

Map No. Fig. 4.1-1	Station No.	Station name and location	Drainage area, in square miles	Type	Water Years of record
154	06904200	Little Shoal Creek at Mendota, Mo. Putnam County Lat 40°33'53", long 92°53'47", in SW1/4 sec. 35, T.67N.,R.18W.	41.6	Q	1979-80
155	06904250	Shoal Creek at Glendale, Mo. Putnam County Lat 40°28'58", long 92°46'16", in NE1/4 sec. 35, T.66N.,R.17W.	154	Q	1979-80
156	06904270	North Blackbird Creek near Unionville, Mo. Putnam County Lat 40°27'58", long 92°52'42", in E1/2 sec. 2, T.65N.,R.18W.		L	
157	06904280	North Blackbird Creek near Martinstown, Mo. Putnam County Lat 40°24'24", long 92°47'12", in SE1/4 sec. 27, T.65N.,R.17W.	81.5	Q	1980-
158	06904290	Blackbird Creek near Sidney, Mo. Putnam County Lat 40°22'21", long 92°46'00", in SE1/4 sec. 2, T.64N.,R.17W.	137	Q	1980-
159	06904500	Chariton River at Novinger, Mo. Adair County Lat 40°14'05", long 92°41'14", in SE1/4NE1/4 sec. 28, T.63N.,R.16W.	1,370	D	1930-52, 1954-
160	06905200	Chariton River near Callao, Mo. Macon County Lat 39°45'36", long 92°41'09", in SE1/4 sec. 9, T.57N.,R.16W.		L	
161	06905500	Chariton River near Prairie Hill, Mo. Chariton County Lat 39°32'25", long 92°47'23", in NW1/4SW1/4 sec. 26, T.55N.,R.17W.	1,870	D Q	1928- 1962-
162	06906000	Mussel Fork near Mussel Fork, Mo. Chariton County Lat 39°31'26", long 92°56'59", in SW1/4SE1/4 sec. 32, T.55N.,R.18W.	267	D	1948-51, 1962-
163	06906100	Mussel Fork at Keytesville, Mo. Chariton County Lat 39°25'58", long 93°56'42", btwn secs. 4 & 5, T.53N.,R.18W.		L	
164	06906200	East Fork Little Chariton River near Macon, Mo. Macon County Lat 39°44'47", long 92°31'05", in NW1/4 sec. 18, T.57N.,R.14W.	112	D Q	1971- 1979-81
165	06906250	Unnamed Creek at Ardmore, Mo. Macon County Lat 39°38'16", long 92°31'49", in SE1/4 sec. 24, T.56N.,R.15W.	0.99	Q	1979-80
166	06906290	Sinking Creek near Huntsville, Mo. Randolph County Lat 39°28'49", long 92°31'14", in NE1/4 sec. 18, T.54N.,R.14W.	5.43	Q	1981-
167	06906300	East Fork Little Chariton River near Huntsville, Mo. Randolph County Lat 39°27'16", long 92°34'16", in NE1/4 sec. 26, T.54N.,R.15W.	220	D Q	1962- 1963-68, 1973-75 1978-81
168	06906315	Sweet Spring Creek near Moberly, Mo. Randolph County Lat 39°23'33", long 92°36'49", in NE1/4 sec. 17, T.53N.,R.15W.		L	
169	06906330	Middle Fork Little Chariton River near Callao, Mo. Macon County Lat 39°45'33", long 92°35'49", in SE1/4 sec. 8, T.57N.,R.15W.	53.4	Q	1980-
170	06906340	South Fork Claybank Creek near College Mound, Mo. Macon County Lat 39°38'32", long 92°34'10", in SE1/4 sec. 22, T.56N.,R.15W.	3.99	Q	1979-81
171	06906360	Middle Fork Little Chariton River near Thomas Hill, Mo. Randolph County Lat 39°33'00", long 92°38'41", in SE1/4 sec. 24, T.55N.,R.16W.	147	D Q	1980- 1980-81
172	06906430	Middle Fork Little Chariton River near Prairie Hill, Mo. Randolph County Lat 39°29'09", long 92°41'44", in NW1/4 sec. 15, T.54N.,R.16W.	159	D Q	1980- 1980-81
173	06906460	Muncas Creek near Thomas Hill, Mo. Randolph County Lat 39°31'23", long 92°37'48", in NE1/4 sec. 31, T.55N.,R.15W.	4.84	D Q	1980- 1981-
174	06909250	Bonne Femme Creek at Fayette, Mo. Howard County Lat 39°08'18", long 92°40'10", between secs. 12 and 13, T.50N.,R.16W..		L	
175	06909350	Bonne Femme Creek at New Franklin, Mo. Howard County Lat 39°01'01", long 92°43'46", at center sec. 28, T.49N.,R.16W.		L	
176	06909460	Moniteau Creek near Higbee, Mo. Howard County Lat 30°14'48", long 92°28'35", in NE1/4 sec. 3, T.51N.,R.14W.	18.7	Q	1980-
177	0699480	Moniteau Creek near Harrisburg, Mo. Howard County Lat 39°11'02", long 92°29'44", in SE1/4 sec. 28, T.51N.,R.14W.	28.0	Q	1980-
178	06909500	Moniteau Creek near Fayette, Mo. Howard County /4 sec. 14, T.50N.,R.15W.	81.0	D	1948-69
		County Lat 38°58'16", long 92°24'36", in NW1/4 sec. 8, T.48N.,R.13W.		L	
180	06910230	Hinkson Creek at Columbia, Mo. Boone County Lat 38°55'42", long 92°20'26", in NW1/4SW1/4 sec. 24, T.48N.,R.13W.	70.2	D	1967-
181	06910250	Traxler Branch near Columbia, Mo. Boone County Lat 38°51'15", long 92°19'45", in NE1/4SE1/4 sec. 13, T.47N.,R.13W.	0.55	C	1958-79
182	06910405	Cedar Creek near Hallsville, Mo. Boone County Lat 39°03'52", long 92°07'53", in SE1/4 sec. 34, T.50N.,R.11W.	5.14	Q	1980-
183	06910410	Cedar Creek near Columbia, Mo. Boone County Lat 38°54'40", long 92°09'30", in NE1/4 sec. 28, T.48N.,R.11W.	52.2	C Q	1964-75 1964-75

10.0 LIST OF REFERENCES

- Allgood, F. P., 1979, Missouri general soil map and soil association descriptions: U.S. Department of Agriculture, Soil Conservation Service, 74 p.
- Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.
- Anderson, K. H., 1979, Geological map of Missouri: Missouri Geological Survey and Water Resources, scale 1:500,000.
- Bates, R. L., and Jackson, J. A., 1980, Glossary of geology (2d ed.): Falls Church, Virginia, American Geological Institute, 749 p.
- Buckman, H. O., and Brady, N. C., 1969, The nature and properties of soils (7th ed.): New York, The Macmillan Co., 653 p.
- Cagle, J. W., 1979, Definition and hydrology of the sandstone aquifers in the coal-bearing Pennsylvanian strata of south-central Iowa: unpublished data on file in Iowa City office of U.S. Geological Survey.
- Cagle, J. W., and Heinritz, A. J., 1978, Water resources of south-central Iowa: Iowa Geological Survey Water Atlas 5, 97 p.
- Coble, R. W., and Roberts, J. V., 1971, The water resources of southeast Iowa: Iowa Geological Survey Water Atlas 4, 101 p.
- Dieffenbach, W. H., 1974, Effects of acid coal mine drainage on benthic macroinvertebrates in Cedar Creek, Boone-Callaway Counties: Transactions of the Missouri Academy of Science, v. 7-8, p. 111-121.
- Emmett, L. F., and Jeffery, H. G., 1969a, Reconnaissance of the ground-water resources of the Missouri River alluvium between Kansas City, Missouri and the Iowa border: U.S. Geological Survey Hydrologic Investigations Atlas HA-336, 1 sheet.
- _____, 1969b, Reconnaissance of the ground-water resources of the Missouri River alluvium between Jefferson City, Missouri and Miami, Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-340, 1 sheet.
- Fenneman, N. M., 1946, Physical divisions of the United States: U.S. Geological Survey Physiographic Committee, map, scale 1:7,000,000.
- Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall Inc., 604 p.
- Gann, E. E., Harvey, E. J., Jeffery, H. G., and Fuller, D. L., 1971, Water resources of north-eastern Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-372, 4 sheets.
- Gann, E. E., Harvey, E. J., Barks, J. H., and Fuller, D. L., 1973, Water resources of northwestern Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-444, 4 sheets.
- Harkins, J. R., and others, 1980, Hydrologic assessment eastern coal province, Area 23, Alabama: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-683, 76 p.
- Harl, N. E., Achterhof, J. B., Anderson, P. F., and Wiese, Karen, 1977, Coal mine maps for eight Iowa counties: Iowa State University, Agriculture and Home Economics Experiment Station, Miscellaneous Bulletin 12, 191 p.
- Hauth, L. D., 1974, Technique for estimating the magnitude and frequency of Missouri floods: U. S. Geological Survey open-file report, 20 p.
- Heim, G. E. Jr., and Howe, W. B., 1962, Map of the bedrock topography of northwestern Missouri: Division of Geological Survey and Water Resources.
- Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.
- Hershey, H. G., 1969, Geological map of Iowa: Iowa Geological Survey, scale 1:500,000.
- Horick, P. J., and Steinhilber, W. L., 1973, Mississippian aquifer of Iowa: Iowa Geological Survey Miscellaneous Map Series 3, 3 sheets.
- _____, 1978, Jordan aquifer of Iowa: Iowa Geological Survey Miscellaneous Map Series 6, 3 sheets.
- Hoyer, B. E. (ed.), 1973, Resource development, land-and water-use management, south-central Iowa--eleven county regions: Miscellaneous Map Series 4, Iowa Geological Survey, 35 p.
- Iowa Department of Environmental Quality, 1980, Iowa water quality report: Des Moines, Iowa, p. 57-89.
- Landis, E. R., and Van Eck, O. J., 1965, Coal resources of Iowa: Iowa Geological Survey Technical Paper 4, 141 p.
- Lara, O. G., 1973, Floods in Iowa--Technical manual for estimating their magnitude and frequency: Iowa Natural Resources Council Bulletin 11, 56 p.
- _____, 1974, Flood-volume data for Iowa streams: Iowa Natural Resources Council Bulletin 14, 48 p.
- _____, 1979, Annual and seasonal low-flow characteristics of Iowa streams: Iowa Natural Resources Council Bulletin 13, 507 p.
- Missouri Department of Natural Resources, 1978,

- Missouri water quality report, 1978, appendix III: Rolla, Missouri, 91 p.
- Missouri Department of Natural Resources, 1981, Water quality standards, code of State regulations: Rolla, Missouri, Clean Water Commission, p. 6-55.
- Murray, C. R., and Reeves, E. B., 1977, Estimated use of water in the United States in 1975: U.S. Geological Survey Circular 765, 39 p.
- Pan, Carl, and Anderson Ray, 1980, Southwest Iowa seismicity study--Thickness of unconsolidated materials: Iowa Geological Survey, map, scale 1:500,000.
- Parsons, J. D., 1968, The effects of acid strip mine effluents on the ecology of a stream: *Archiv Fur Hydrobiologie*, v. 65, p. 25-50.
- Persinger, I. D., 1979, General soil map of Missouri: U.S. Department of Agriculture Soil Conservation Service, scale 1:500,000.
- Robertson, C. E., 1973, Mineable coal reserves of Missouri: Missouri Geological Survey and Water Resources Report of Investigations 54, 71 p.
- Robertson, C. E., and Smith, D. C., 1981, Coal resources and reserves of Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey Report of Investigations 66, 49 p.
- Runge, E. C. A., Dideriksen, R. I., and Riecken, F. F., 1970, Distribution of soils by natural drainage class and by slope class for Iowa counties: *Proceedings of the Iowa Academy of Science*, v. 77, p. 61-85.
- Skelton, John, 1973, Flood-volume design data for Missouri streams: Missouri Division of Geology and Land Survey Water-Resources Report 28, 28 p.
- _____, 1976, Missouri stream and springflow characteristics, low-flow frequency and flow duration: Missouri Division of Geology and Land Survey Water-Resources Report 32, 71 p.
- Skougstad, M. W., Fishman, M. J., Friedman, C. C., Endmann, D. E., and Duncan, S. S. (eds.), 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.
- Slack, L. J., 1979, Baseline water quality of Iowa's coal region: U.S. Geological Survey Open-File Report 79-980, 74 p.
- Smalley, I. J., 1975, Loess--Lithology and genesis: New York, John Wiley, 429 p.
- Stolp, R. N., and Deluca, F. P., 1976, Perspectives on Iowa coal: Iowa State University, Energy and Mineral Resources Research Institute, 66 p.
- Strahler, A. N., 1966, Introduction to physical geography: New York, John Wiley, 455 p.
- Toler, L. G., 1980, Some chemical characteristics of mine drainage in Illinois: U.S. Geological Survey Open-File Report 80-416, 47 p.
- Trewartha, G. T., 1968, An introduction to climate (4th ed.): New York, McGraw-Hill, 408 p.
- U.S. Department of Agriculture, 1978, Iowa soil association map: Iowa Agriculture and Home Economics Experiment Station, scale 1:506,800.
- U.S. Department of Commerce, 1951-81, Climatological data--Iowa, Annual Summary: Washington, D.C.
- U.S. Department of the Interior, 1968, Stream pollution by coal mine drainage upper Ohio River basin: Federal Water Pollution Control Administration, 110 p.
- U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979, Surface coal mining and reclamation operations: Federal Register, v. 44, no. 50, Tuesday, March 13, 1979, Part II, p. 15311-15463.
- U.S. Environmental Protection Agency, 1976a, Quality criteria for water: Washington, D.C., U.S. Government Printing Office, 256 p.
- _____, 1977b, National secondary drinking water regulations: Federal Register, v. 42, no. 62, Thursday, March 31, 1977, Part 1, p. 17143-17147.
- U.S. Geological Survey, (published annually since 1976), Water resources data for Iowa: U.S. Geological Survey Water-Data Reports IA.
- U.S. Geological Survey and others, 1967, Mineral and water resources of Missouri: Document no. 19, 90th Congress, Washington, U.S. Government Printing Office, 399 p.
- U.S. Soil Conservation Service, [1979], The status of land disturbed by surface mining in the United States -- Basic statistics by State and county as of July 1, 1977: U.S. Department of Agriculture, 124 p.
- University Hygienic Laboratory, 1977, Water quality survey of a coal mining watershed, Muchakinock Creek: Des Moines, Iowa, Iowa Department of Environmental Quality, 19 p.
- Vaill, J. E., and Barks, J. H., 1980, Physical environmental and hydrologic characteristics of coal-mining areas in Missouri: U.S. Geological Survey Water-Resources Investigations 80-67, 33 p.
- Waite, P. J., 1970, Iowa precipitation in Water Resources of Iowa, Horick, P. J., ed., Iowa City, University Printing Service, p. 3-15.
- Wischmeir, W. H., and Smith, D. D., 1978, Predicting rainfall erosion losses--A guide to conservation planning: U.S. Department of Agriculture Handbook 537, 58 p.