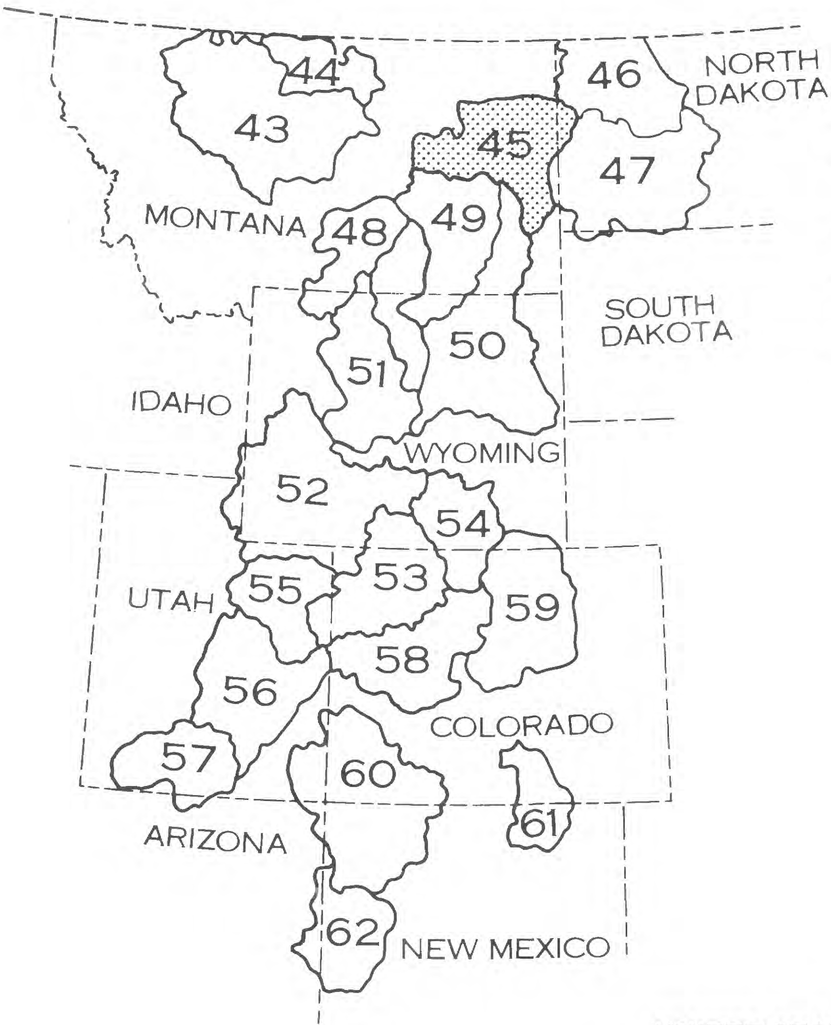
HYDROLOGY OF AREA 45, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND NORTH DAKOTA



- YELLOWSTONE RIVER
- MISSOURI RIVER
- REDWATER RIVER
- LITTLE DRY CREEK
- BIG DRY CREEK
- O'FALLON CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-527

HYDROLOGY OF AREA 45, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND NORTH DAKOTA

BY
STEVEN E. SLAGLE AND OTHERS

U.S. GEOLOGICAL SURVEY

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U.S. DEPARTMENT OF THE INTERIOR
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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *SECRETARY*

GEOLOGICAL SURVEY

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CONTENTS

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

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

Multiply	By	To obtain
acre	4,047	square meter
British thermal unit per pound	2.326	kilojoule per kilogram
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
gallon per minute	0.06309	liter per second
gallon per second	3.785	liter per second
inch	25.40	millimeter
micromho per centimeter at 25° Celsius	100	microsiemens per meter at 25° Celsius
mile	1.609	kilometer
million gallons per day	0.04381 3,785	cubic meter per second cubic meter per day
square mile	2.590	square kilometer
ton (short, 2,000 pounds)	0.9072	metric ton (megagram)
ton per day	0.0105	kilogram per second
ton per square mile	0.3503	megagram per square kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = 1.8°C + 32$$

$$°C = 0.556\,(°F - 32)$$

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 45, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND NORTH DAKOTA

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Abstract

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

Area 45 encompasses about 14,300 square miles in east-central Montana and west-central North Dakota, in the northern part of the Northern Great Plains Coal Province. The land surface typically is characterized by rolling uplands slightly eroded by intermittent streams and is drained primarily by the Missouri, Yellowstone, and Redwater Rivers and their tributaries.

Streamflow varies seasonally, with the largest flows occurring in response to rainfall and snowmelt. Peak flows in prairie streams generally occur in March as a result of snowmelt or during June through August as a result of rainfall. Composition of major ions and dissolved-solids concentration vary with streamflow. During base-flow intervals, water in the streams generally is of the sodium sulfate type and contains dissolved-solids concentrations of 1,000 to 3,000 milligrams per liter. The water composition during base flow is indicative of the ground-water quality. During direct-runoff intervals, the relative proportions of calcium and bicarbonate increase and the water contains much smaller dissolved-solids concentrations. Concentrations as small as 150 milligrams per liter have been measured from intermittent streams at times of snowmelt and frozen ground.

Suspended-sediment yields vary widely as a result of differences in sediment availability within the basins and in stream discharges capable of flushing sediment from the channel. Concentrations of suspended sediment measured in the area ranged from 2 to 23,000 milligrams per liter, which is indicative of the large variability that occurs throughout the annual flow cycle.

Bedrock geology in the area includes Upper Cretaceous to lower Tertiary rocks--the Bearpaw Shale; the Fox Hills Sandstone; the Hell Creek Formation; and the Tullock, Lebo Shale, and Tongue River Members of the Fort Union Formation. Alluvium of Quaternary age is present along most streams.

Reserves of strippable coal deposits within the area are about 7.3 billion tons. The principal coal deposits are in the Tongue River Member of the Fort Union Formation.

Aquifers in the area include the Fox Hills-lower Hell Creek, Tullock, Tongue River, and alluvium. Wells completed in the Fox Hills-lower Hell Creek aquifer may yield as much as 400 gallons per minute. Wells completed in other bedrock aquifers commonly yield 8 to 15 gallons per minute. Wells completed in alluvium may yield several hundred gallons per minute in local areas along major streams, but yields from alluvium commonly are 30 gallons per minute or less. Water in aquifers above the Bearpaw Shale generally can be divided into shallow and deep flow systems. Water in the shallow system generally is at depths of less than 200 feet and flows in the direction of the local topographic drainage. Water in the deep regional system, generally greater than 200 feet, flows generally northeast toward the Missouri River or northwest toward the Yellowstone River. Water from the shallow flow system generally is of the sodium sulfate type. Dissolved-solids concentration averages about 1,700 milligrams per liter. Water from deep flow systems above the Hell Creek Formation contains principally sodium and bicarbonate and has an average dissolved-solids concentration of about 1,900 milligrams per liter. Water from the Fox Hills-lower Hell Creek aquifer is of the sodium bicarbonate type and has an average dissolved-solids concentration of about 1,200 milligrams per liter.

Surface coal mining increases the potential for hydrologic problems. Increased erosion can cause channel filling by excessive sediment deposition, thereby decreasing the transport capacity of the stream and altering the habitat of aquatic organisms. Ground-water levels can decline in and near surface-mined areas where the excavation intersects water-yielding materials. These declines generally will be only temporary and water levels will recover to approximate premining conditions after mining is completed. Degradation of water quality can result from the reaction of water with fresh mineral surfaces in the unreclaimed tailings and in replaced overburden materials.

1.0 INTRODUCTION

1.1 Objective

Report Summarizes Available Hydrologic Data

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

Hydrologic information and analysis are needed to aid in decisions to lease Federally owned coal and for the preparation of the necessary Environmental 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 that an appropriate regulatory agency issue mining permits based on the review of the permit application data and the assessment of the hydrologic impacts. The need for hydrologic information is partly fulfilled by this report, which broadly characterizes the hydrology of Area 45 in Montana and North Dakota, a part of the Northern Great Plains Coal Province (fig. 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 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.

NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES

Numbers represent project areas

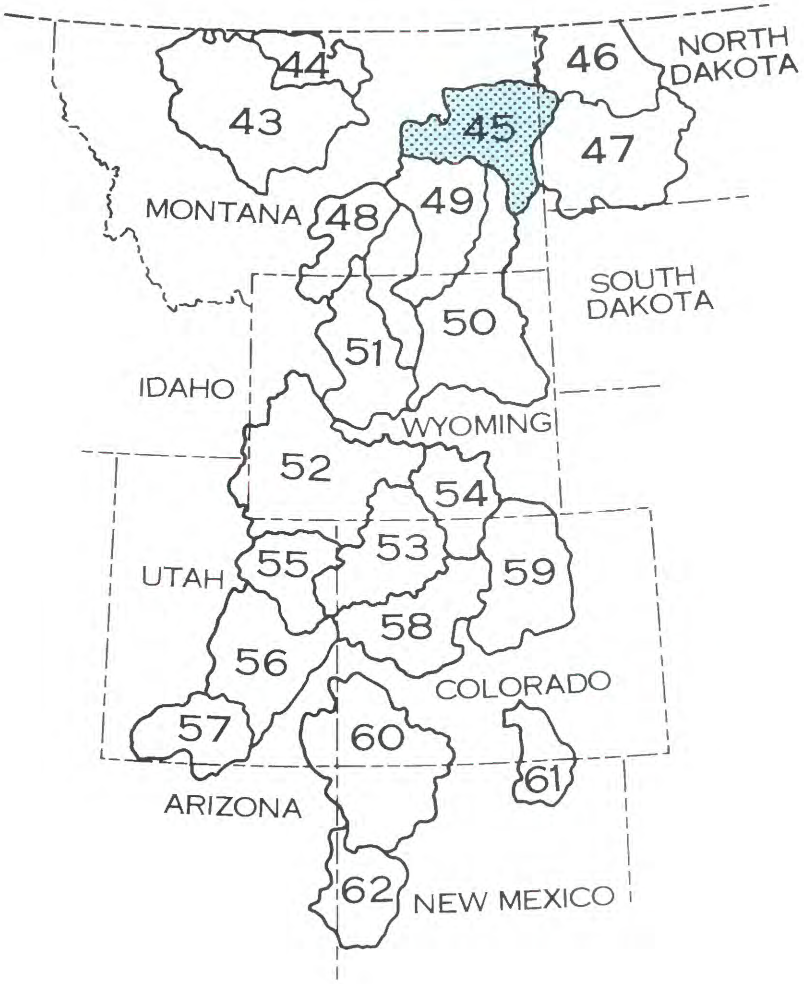


Figure 1.1-1 Location of Area 45 in Montana and North Dakota.

Area 45 Located in Northern Part of Northern Great Plains Coal Province

The area encompasses about 14,300 square miles in east-central Montana and west-central North Dakota.

The report area includes all or parts of Garfield, McCone, Richland, Dawson, Prairie, Custer, Fallon, Wibaux, and Carter Counties in Montana and Golden Valley and McKenzie Counties in North Dakota (fig. 1.2-1). The principal population centers in the area are Glendive and Sidney, Montana. The rest of the area primarily is rural, generally with a population density of less than five persons per square mile.

The land surface in the study area consists predominantly of gently rolling hills slightly eroded by intermittent and ephermal streams. Grass-covered rangeland is interspersed by nonirrigated farmland in the uplands and, where soil and water permit, by irrigated farmland in the valleys. Locally, badlands have developed in easily eroded shale and siltstone. Badlands are common in the northern part of the area south of the Missouri River where the upper part of the Hell Creek Formation is exposed. Badlands in this area commonly are referred to as the "Missouri River breaks." Major streams in the study area flow on alluvial flood plains that commonly are bordered by remnants of alluvial terraces.

Ranching, farming, and related services are the dominant industries. Oil and gas also are produced from the area.

Base map from U.S. Geological Survey
United States base map, 1980

Figure 1.2-1 Geographic features.

2.0 DEFINITION OF TERMS

Terms in Report Defined

Technical terms that occur in this hydrologic report are defined.

Base flow is sustained or fair-weather flow. In most streams, base flow is composed largely of ground-water inflow.

Crest-stage station is a particular location on a stream where peak discharges are determined by recording the highest stages resulting from flows.

Cubic foot per second is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second; it is equivalent to about 7.48 gallons per second, 448.8 gallons per minute, or 0.02832 cubic meter per second.

Cubic foot per second per square mile is the average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

Discharge is the volume of water (or more broadly, the volume of fluid plus suspended material) that passes a given point within a given interval of time.

Average discharge is the arithmetic average of individual discharges during a specific interval. Also reported as mean discharge.

Instantaneous discharge is the discharge at a particular instant of time.

Dissolved refers to the quantity of substance present in a true chemical solution. In practice, however, the term includes all forms of substance that will pass through a 0.45-micrometer membrane filter, and thus may include some very small (colloidal) suspended particles. Chemical analyses for dissolved constituents are performed using filtered samples.

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the river upstream from a specified point.

Drainage basin is a part of the surface of the Earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Ephemeral stream is a stream that flows only in direct response to precipitation or local surface runoff, and whose channel is at all times above the water table.

Flow-duration curve is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Gage height is the water-surface elevation referred to some arbitrary gage datum. Gage height commonly is used interchangeably with the more general term "stage," although gage height is more appropriate when used with a reading on a gage.

Gaging station is a particular location on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Intermittent stream is a stream that does not flow continuously in time, such as when water losses from evaporation or seepage exceed the available streamflow.

Microgram per liter is a unit expressing the concentration of chemical constituents in solution as mass (microgram) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter.

Milligram per liter is a unit expressing the concentration of chemical constituents in solution as mass (milligram) of solute per unit volume (liter) of water. Concentration of suspended sediment also is expressed in milligrams per liter (see suspended-sediment concentration).

Perennial stream is a stream that flows continuously.

pH is the negative base 10 logarithm of the hydrogen-ion activity in solution; it is a measure of the acidity or basicity of a solution.

Potentiometric contour is a representation of the static hydraulic head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells.

Sediment is solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and cause of sediment in streams are affected by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land use, and quantity and intensity of precipitation.

Site is a well or a position on a stream where data are collected one or more times but not at regular intervals.

Specific conductance is a measure of the ability of water to conduct an electrical current. It is expressed in micromhos per centimeter at 25° Celsius. Specific conductance is related to the type and concentration of ions in solution and can be used for approximating the dissolved-solids concentration of the water. Commonly, the concentration of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance (in micromhos per centimeter). This relationship is not constant, and may vary in the same source with changes in the composition of the water.

Spoil material (spoils) is non-coal overburden material that is removed during surface mining.

Station is a point on a stream where data are collected at regular intervals.

Streamflow is the discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff," as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Suspended sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Suspended-sediment concentration is the velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a point about 0.3 foot above the bed), expressed as milligrams of dry sediment per liter of water-sediment mixture.

Water year is the 12-month interval from October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year that ended September 30, 1981, is the 1981 water year.

Climate is Semiarid

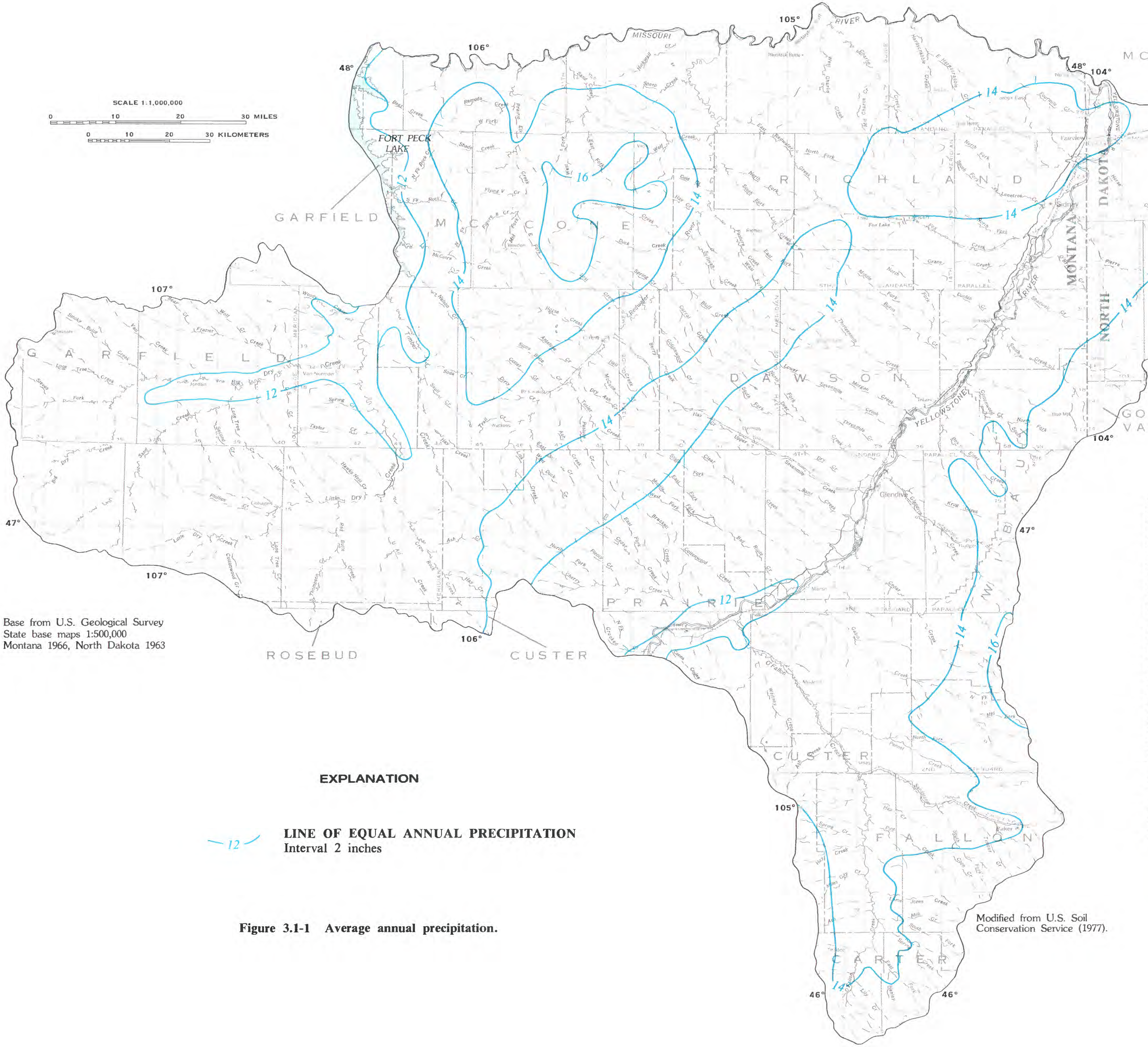
Area 45 has a semiarid climate, with most precipitation falling in summer and the least falling in winter.

The climate is characterized by cold dry winters, cool moist springs, hot moderately dry summers, and cool dry falls. Winter cold waves often are interrupted by extended intervals of warm weather. Summers are dominated by hot sunny days and cool nights. Average annual temperatures, based on the record for 1941-70, range from 41.5°F at Wibaux, Montana, to 46.0°F at Cohagen, Montana, according to National Weather Service records. January normally is the coldest month. Average January temperatures range from 10.1°F at Sidney, Montana, to 14.9°F at Glendive and Jordan, Montana. July normally is the warmest month. Average July temperatures range from 68.9°F at Wibaux to 74.0°F at Glendive. Several days annually with maximum temperatures in excess of 100°F are not uncommon.

Average annual precipitation varies from about 12 inches in the western and southern parts of the area to about 16 inches in small areas north of Circle and Baker, Montana. Most of the annual precipitation (about 65 percent) occurs from May through August, with June being the single wettest month. Winter months in the prairie areas are the driest; average monthly precipitation generally is less than 0.5 inch for November through February.

Average annual precipitation, in inches, for the study area is shown in figure 3.1-1. The base period for computation is 1941-70. The distribution of precipitation and temperature by months for Glendive is shown in figure 3.1-2.

Daily temperature and precipitation data are published monthly as "Climatological Data for Montana" and "Climatological Data for North Dakota" by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina. Statistical information is presented in U.S. Department of Commerce, National Weather Service, NOAA Atlas No. 2, titled, "Precipitation-frequency atlas of the Western United States."



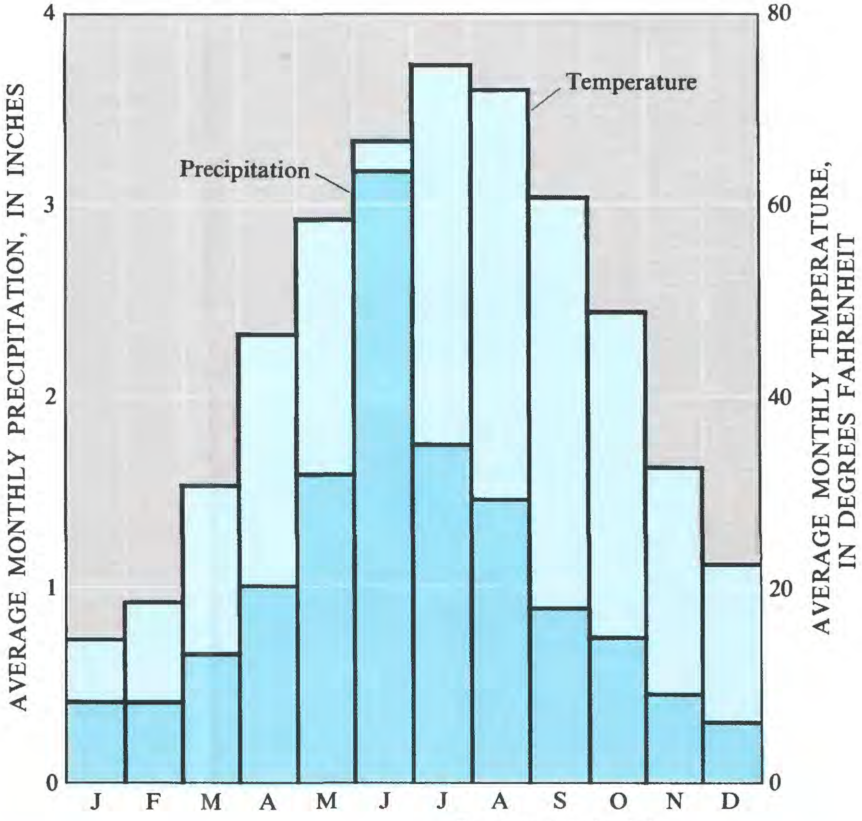
Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

— 12 — **LINE OF EQUAL ANNUAL PRECIPITATION**
Interval 2 inches

Modified from U.S. Soil
Conservation Service (1977).

Figure 3.1-1 Average annual precipitation.



Based on records of the
National Weather Service (1931-60).

Figure 3.1-2 Average precipitation and temperature at Glendive, Montana.

Bedrock Principally Composed of Cretaceous and Tertiary Sandstone, Siltstone, Claystone, Shale, and Coal

Principal geologic units include the Bearpaw Shale, Fox Hills Sandstone, Hell Creek Formation, and Fort Union Formation; most coal beds occur in the Tongue River Member of the Fort Union Formation.

Bedrock in Area 45 is composed of sedimentary geologic units ranging in age from Late Cretaceous to Paleocene which overlie older rocks ranging in age from Precambrian to Cretaceous. These sedimentary geologic units consist of marine deposits of the Bearpaw Shale and Fox Hills Sandstone, and continental deposits of the Hell Creek Formation and Fort Union Formation (fig. 3.2-1).

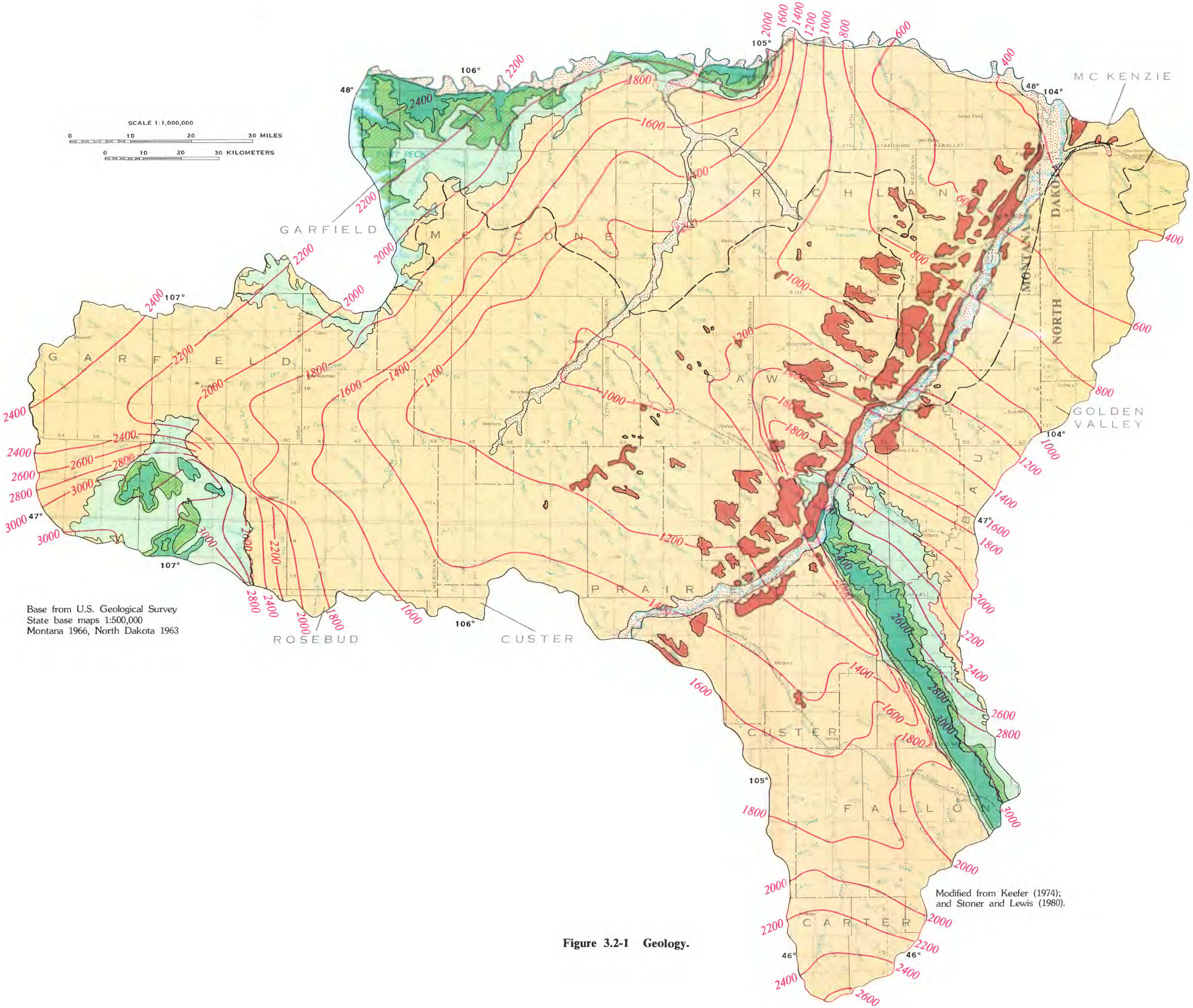
Upper Cretaceous units in the area include the Bearpaw Shale, the Fox Hills Sandstone, and the Hell Creek Formation. The Bearpaw Shale consists primarily of massive gray to black marine shale and shaly claystone containing local thin beds of siltstone, silty sandstone, and bentonite. The Fox Hills Sandstone consists of lower and upper predominantly fine- to medium-grained sandstone units separated by a thin shale bed. The Hell Creek Formation is composed of fairly well sorted medium-grained sandstone in the lower part of the unit and soft claystone, shale, siltstone, fine- to medium-grained sandstone, and thin coal beds in the upper part.

The Paleocene Fort Union Formation is composed of the Tullock, Lebo Shale, and Tongue River Members in ascending order. Interbedded shale, siltstone, sandstone, and thin coal beds of the lower Tullock Member grade upward into silty or sandy shale and local sandstone. The Lebo Shale Member is predominantly dark shale containing interbeds of siltstone and thin coal beds locally. The Tongue River Member is composed of alternating sandstone, siltstone, shale, and thick, extensive coal beds.

Outcrops of clinker (locally called "red shale" or "scoria") are common throughout the area. Clinker deposits, composed of the residue from burned coal beds and baked and fused overlying layers, occur throughout the coal-bearing formations discussed above.

Alluvium of Quaternary age and terrace deposits of Quaternary and Tertiary age are composed of interbedded clay, silt, sand, and gravel and comprise the youngest geologic units in the area. Terraces occur mainly near valley sides and uplands along the Yellowstone River. Alluvium is thickest along the Missouri and Yellowstone Rivers and their major tributaries but also is present along many smaller streams.

Glacial drift of Wisconsin age, principally consisting of ground moraine and outwash deposits, mantles the northern part of the area. The ground moraine consists of a compact mixture of clay, silt, sand, pebbles, cobbles, and boulders. Outwash deposits resulting from receding glacial ice are present in channels eroded into the moraine.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Modified from Keefer (1974);
and Stoner and Lewis (1980).

Figure 3.2-1 Geology.

EXPLANATION

TERTIARY QUATERNARY	Holocene	▨	**ALLUVIUM**
	Miocene (?) to Holocene	🟥	**TERRACE DEPOSITS**
	Paleocene	🟨	**FORT UNION FORMATION**
CRETACEOUS	Upper Cretaceous	🟩	**HELL CREEK FORMATION**
		▨	**FOX HILLS SANDSTONE**
		🟩	**BEARPAW SHALE** Includes equivalent Pierre Shale

CONTACT

STRUCTURE CONTOUR Shows altitude of top of Bearpaw Shale or equivalent. Contour interval 200 feet. Datum is sea level.

APPROXIMATE MAXIMUM EXTENT OF GLACIAL ADVANCE

Land Used Primarily for Grazing

Principal land uses are range, and nonirrigated and irrigated cropland.

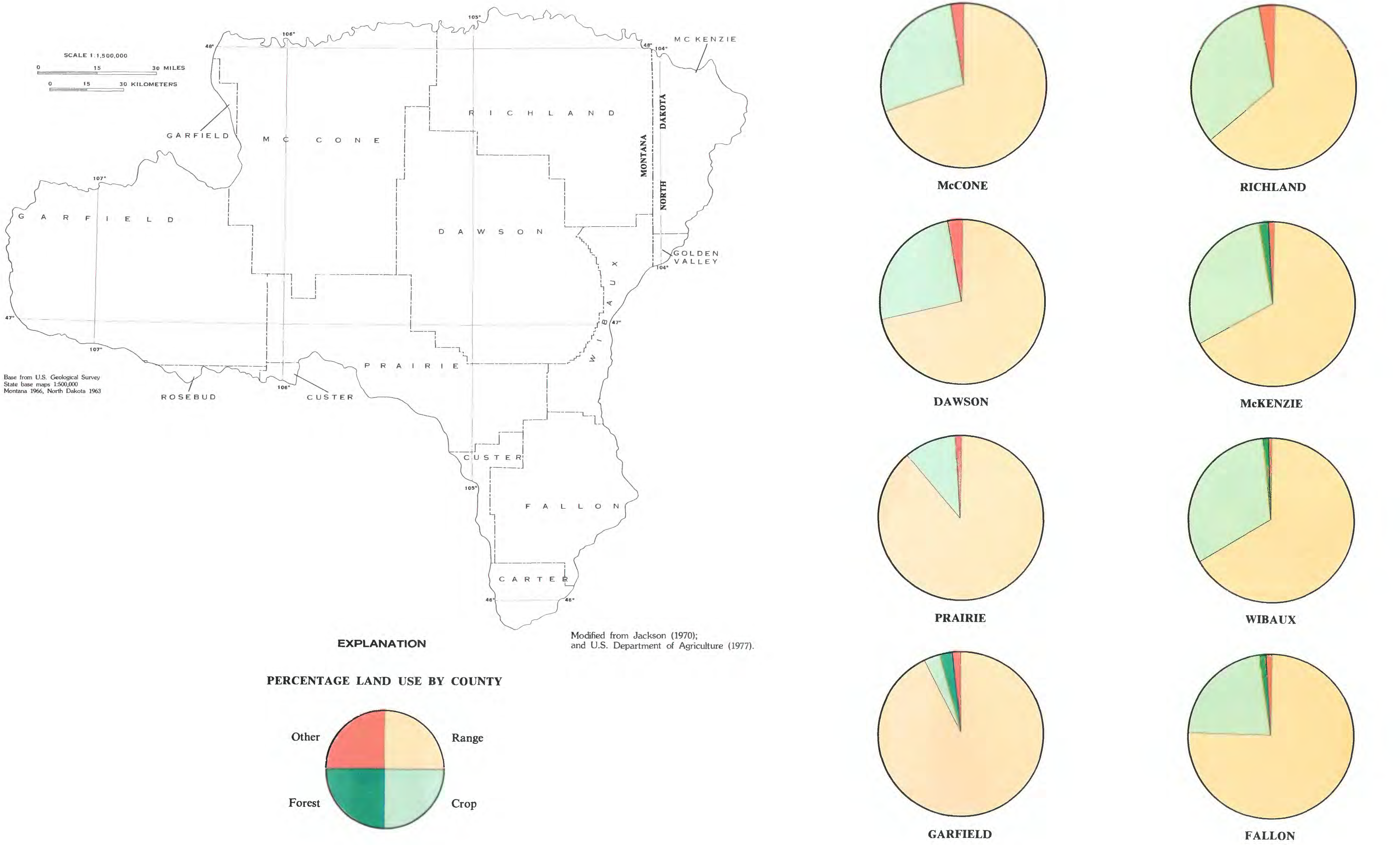
Land use is related primarily to the natural diversity of the land. The land-use map (fig. 4.1-1) shows that about 70 percent of the land is range. The rangeland is used for raising stock; from about 24 to 120 acres are needed to support each head of cattle on the rangeland in eastern Montana (F. F. Munshower, Montana State University, oral commun., 1982). Irrigated and nonirrigated cropland covers about 23 percent of the area. Forest covers about 1 percent of the land.

Currently producing and abandoned surface coal mines (section 5.2) occupy a very small percentage of the land area. Land reclaimed after the coal has been extracted commonly is returned to rangeland or nonirrigated cropland.

Because the Federal government owns the rights to most of the coal in the area, Federal land-use planning has an important role in determining which areas will be mined for coal and how the spoils will be reclaimed. The principal objective in Federal land-use planning is to determine where, from among the millions of acres known to contain recoverable reserves, coal can be mined without unduly damaging the environment. The major source of information for this determination is from coal and economic data made available to the U.S. Bureau of Land Management by coal companies, Federal and State agencies, or the public. Coal areas found acceptable for lease consideration are delineated into tracts and ranked by the U.S. Bureau of Land Management under the guidance of a Regional Coal Team composed of Federal and State representatives. The criteria for delineation and ranking include:

1. Expressions of industry and public interest,
2. Availability of technical data about coal reserves,
3. Calculations of maximum economic recovery,
4. Surface ownership, and
5. Target leasing schedules established by the U.S. Department of Energy.

The Regional Coal Team recommends the lease sale schedule for final approval by the Secretary of the Interior.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Modified from Jackson (1970);
and U.S. Department of Agriculture (1977).

Figure 4.1-1 Land use.

Principal Water Use is Irrigated Agriculture

Average daily water use during 1980 was about 679 million gallons of surface water and about 13 million gallons of ground water; about 94 percent of water use was for irrigated agriculture.

Irrigated agriculture was by far the largest use of water during 1980 (fig. 4.2-1), with about 641 Mgal/d (million gallons per day) being used from surface-water sources and 5.9 Mgal/d from ground-water sources. About 74 percent of the irrigation occurs along the Yellowstone River, and about 16 percent occurs along the Missouri River. Limited irrigation occurs along the larger tributaries, such as Dry Creek, the Redwater River, and O'Fallon Creek, but the quantity of water used is relatively small and most is from spring runoff.

Water for thermoelectric power generation at Glendive and Sidney, Montana, was the second largest water use during 1980. Thirty-one million gallons per day was withdrawn, all from surface-water sources.

Rural water use was about 3.4 Mgal/d for domestic purposes and 2.7 Mgal/d for livestock watering. About 4.8 Mgal/d of the total was from ground-water sources.

Water withdrawn for public supplies was about 3.5 Mgal/d, of which about 2.3 Mgal/d was ground water. Most of the water for public supplies was used in Glendive and Sidney, Montana.

Self-supplied industrial water use totaled about 4.0 Mgal/d during 1980, almost all of which came from surface-water sources. Almost all industrial water use occurred in Montana.

The total estimated surface-water use during 1980 was 678.8 Mgal/d. The total estimated ground-water use was 13.2 Mgal/d.

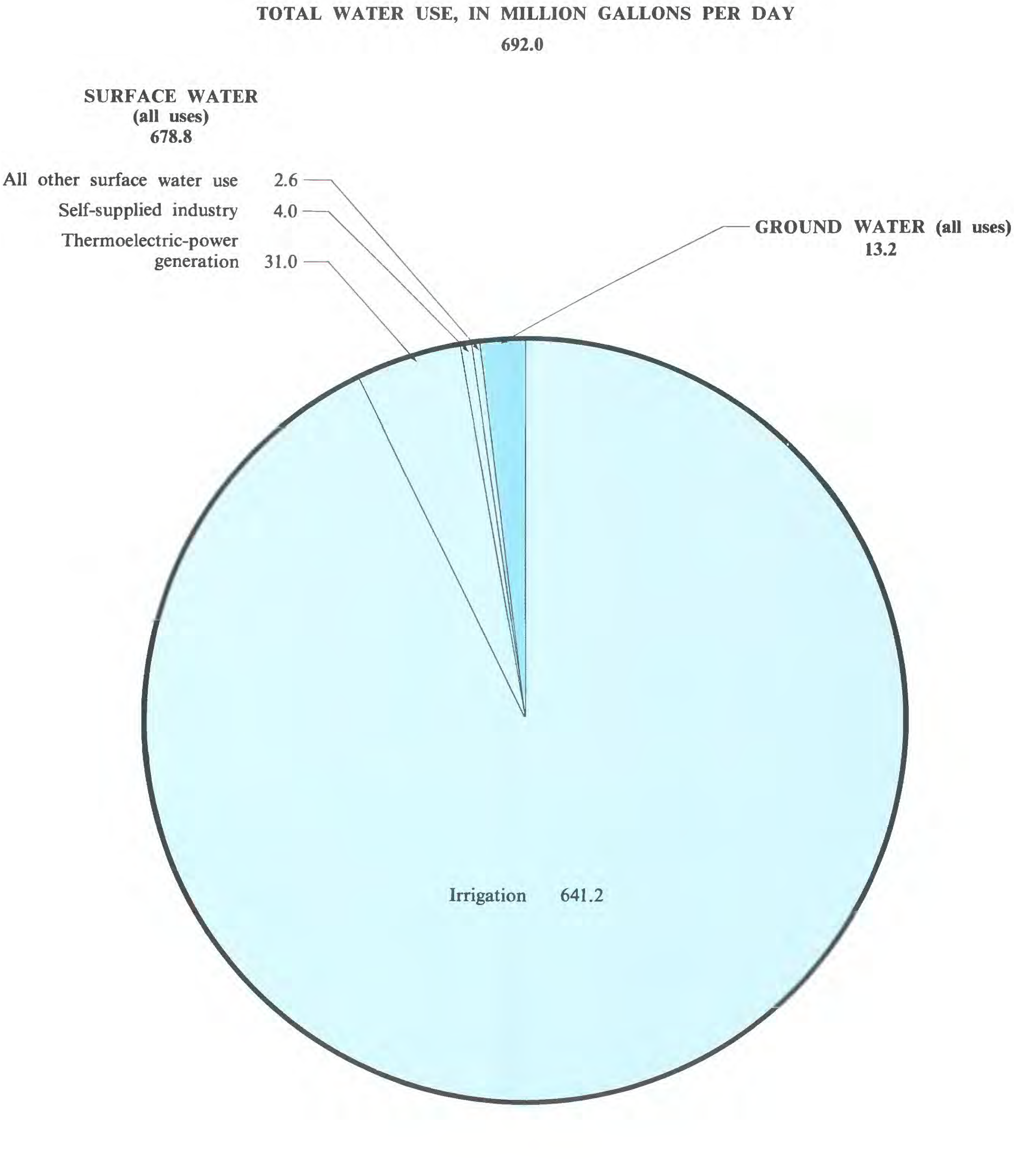


Figure 4.2-1 Approximate water use during 1980.

Land and Coal Ownership is Complex

Although most of the land surface is privately owned, most of the coal is owned by the Federal Government.

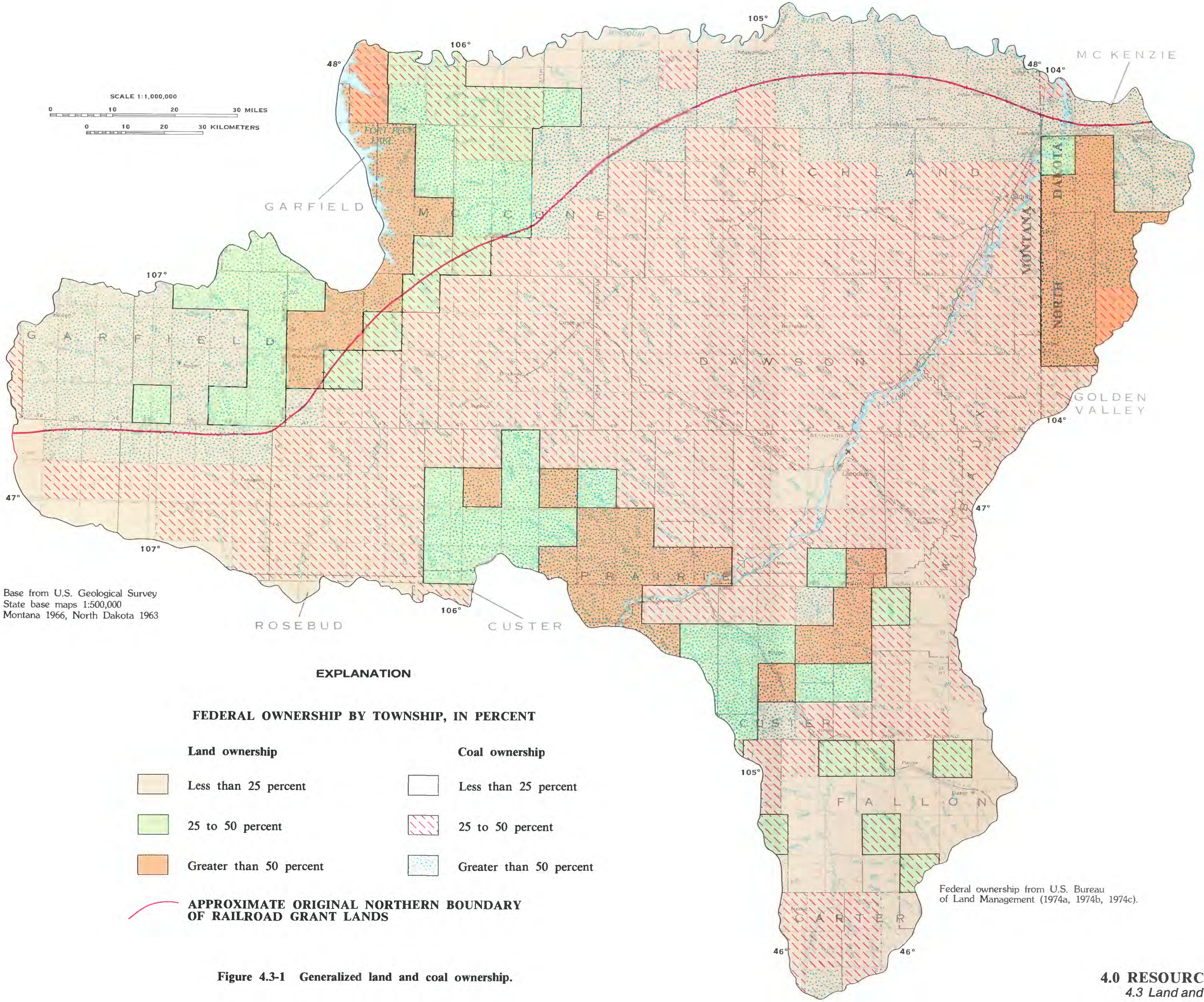
Approximately 80 percent of the land surface is privately owned. About 15 percent is Federally owned, primarily administered by the U.S. Bureau of Land Management. About 5 percent is owned by the State (fig. 4.3-1).

Ownership of about 90 percent of the coal is divided about equally between the Burlington Northern Railroad and the Federal Government in most of the area south of the northern boundary of railroad grant lands (fig. 4.3-1). In most of the area north of the boundary, about 90 percent of the coal is Federally owned; about 5 percent is privately owned, and about 5 percent is owned by the State. The history of land surface and coal ownership gives insight into today's checkerboard pattern of ownership, which is shown in detail on maps available from the U.S. Bureau of Land Management (1974a, 1974b, 1974c).

The United States Congress passed the Land Grant Act of 1864 for the construction of railroad and telegraph lines to the Pacific coast by the northern route. As part of this Act, right-of-way from Lake Superior to Puget Sound and title to odd-numbered sections for 60 miles to each side of each mile of the right-of-way were granted to the Northern Pacific Railroad. The Northern Pacific was to complete the rail line by 1879 and was to sell or otherwise use the land to provide income to finance the construction costs of building the railroad and telegraph lines. The Federal Government retained subsurface ownership of all mineral lands (deposits of coal and iron were not considered to be minerals under the Act). The subsequent trading of railroad sections for equivalent-valued government land was undertaken from time to time for the convenience of both the railroad and the Federal Government. In addition, the railroad sold much of its land, but retained its mineral rights. The Northern Pacific finished the contracted Lake Superior to Puget Sound line 4 years late in 1883. In 1970, the Northern Pacific, the Great Northern, and the Chicago, Burlington, and Quincy Railroads merged to form the present Burlington Northern Railroad.

In 1889, the Enabling Act that admitted the State of Montana to the Union granted sections 16 and 36 in each township to the State for the purpose of supporting public schools. By statute, Montana was not allowed to own the subsurface rights of these school sections if they were mineral lands, but the State could exchange mineral lands for other Federal Government lands of equal value (other than the mineral value).

In 1927 the Mineral Lands Exemption Section of the Enabling Act was reversed and Montana was allowed to choose mineral lands through indemnity selection in lieu of the mineral lands lost by the statutes of the original grant. Montana thereby obtained ownership of mineral rights to those mineral lands in sections 16 and 36 that had originally been withheld. Some school-section lands were subsequently sold; however, the mineral rights were retained by the State.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Federal ownership from U.S. Bureau of Land Management (1974a, 1974b, 1974c).

EXPLANATION

FEDERAL OWNERSHIP BY TOWNSHIP, IN PERCENT

Land ownership

- Less than 25 percent
- 25 to 50 percent
- Greater than 50 percent

Coal ownership

- Less than 25 percent
- 25 to 50 percent
- Greater than 50 percent

APPROXIMATE ORIGINAL NORTHERN BOUNDARY OF RAILROAD GRANT LANDS

Figure 4.3-1 Generalized land and coal ownership.

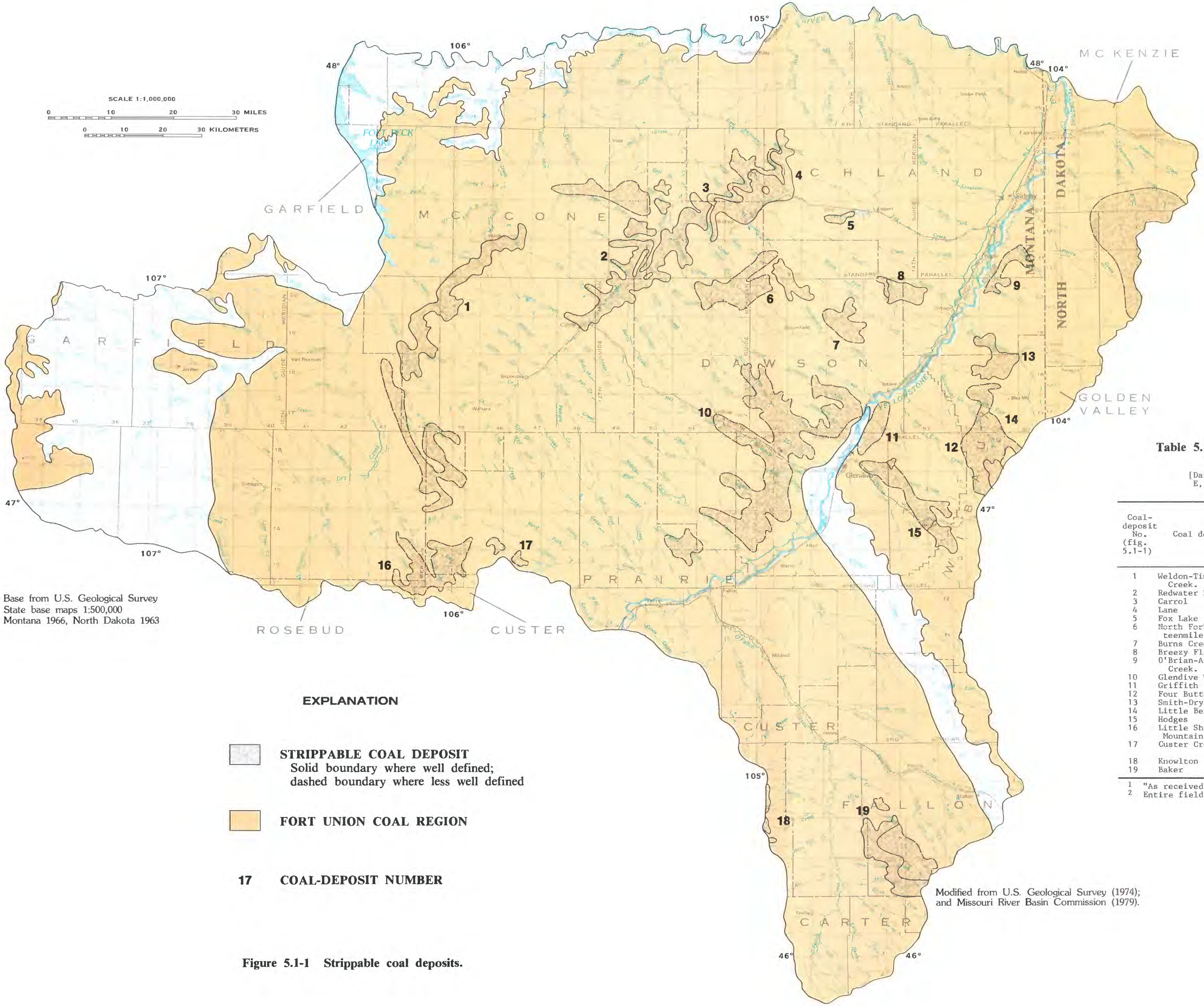
Lignite is At or Near Land Surface in Much of the Area

Strippable reserves from 19 selected coal deposits are about 7.3 billion tons under about 380,000 acres of land.

Strippable coal is that coal that can be economically mined using surface-mining techniques to expose the coal seam. As early as 1972 some active mining operations in Montana projected removal of as much as 150 feet of overburden to mine a 25-foot coal seam. As coal becomes more important in meeting the energy needs of the Nation and as near-surface seams are depleted, the feasibility for strip mining deeper coal deposits will increase. For this reason, the Montana Bureau of Mines and Geology tabulates strippable coal reserves by thickness of coal seam and overburden. Coal seams less than 10 feet thick are tabulated for overburden less than 100 feet thick; coal seams 10 to 25 feet thick are tabulated for overburden less than 150 feet thick; coal seams 25 to 40 feet thick are tabulated for overburden less than 200 feet thick; and coal seams greater than 40 feet are tabulated for overburden less than 250 feet thick.

Nineteen major strippable deposits (table 5.1-1) in Area 45 are shown in figure 5.1-1. Substantial deposits of strippable and deeper coal resources exist outside of the delineated coal deposits, but data on these additional resources are not presently (1983) available.

The value of coal at the various sites is dependent primarily upon heat value, percentage ash content, and percentage sulfur content. The American Society for Testing and Materials classifies lignite as having a heat value of 6,300 to 8,300 British thermal units per pound on a moist mineral-matter-free basis. Average heating content, ash, and sulfur values for coal in each coal field are listed, if available, in table 5.1-1.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

▨ **STRIPPABLE COAL DEPOSIT**
Solid boundary where well defined;
dashed boundary where less well defined

🟧 **FORT UNION COAL REGION**

17 **COAL-DEPOSIT NUMBER**

Modified from U.S. Geological Survey (1974); and Missouri River Basin Commission (1979).

Figure 5.1-1 Strippable coal deposits.

Table 5.1-1 Summary of strippable lignite deposits in Area 45.

[Data from Missouri River Basin Commission (1979). Abbreviations: E, estimated; Btu, British thermal units per pound; <, less than]

Coal-deposit No. (fig. 5.1-1)	Coal deposit	Coal beds	Coal-bed thickness (feet)	Estimated reserves		Coal content		
				Millions of tons	Acreage	Btu[1]	Ash[1] (percent)	Sulfur[1] (percent)
1	Weldon-Timber Creek.	S	6-20	724	25,500	7,527	5.9	0.4
2	Redwater River	S	8-21	642	24,200	7,075	8.4	.3
3	Carrol	Carrol	4-9	345	29,800	7,400	5.5	.3
4	Lane	Lane	5-11	561	44,600	7,150	6.6	.9
5	Fox Lake	Pust	7-17	46	2,400	6,880	6.0	.5
6	North Fork Thirteenmile Creek.	do--	10-43	225	5,100	6,530	7.3	.3
7	Burns Creek	do--	20-36	200	7,050	6,810	7.1	.4
8	Breezy Flat	do--	9-25	220-245E	8,950	7,090	6.8	.5
9	O'Brian-Alkali Creek.	G,H	5-15	150E	8,500	6,880	6.3	.6
10	Glendive West	U	<12	750E	100,000E	7,178	7.4	1.0
11	Griffith	Unnamed	<24	10E	1,300	6,876	8.7	1.2
12	Four Buttes	C	5-20	91	5,200	6,140	9.6	1.0
13	Smith-Dry Creek	G	5-11	145E	8,500E	7,130	7.4	1.0
14	Little Beaver	G	5-20E	134	8,450	6,140	9.6	1.0
15	Hodges	Unnamed	<14	10E	800	6,140	9.6	1.0
16	Little Sheep Mountain.	A,C,HH	5-14	375E	50,000E	--	--	--
17	Custer Creek	G,H,J	5-13	200E	25,000-50,000E	--	--	--
18	Knowlton	Dominy	9-31	868	24,000	6,700	6.9	.4
19	Baker	do--	<12	1,600E	unknown[2]	6,020	9.2	.3

[1] "As received" basis (if more than one sample available, average figures are given).
[2] Entire field underlies most of southwestern Fallon County.

Coal Produced in Area for Many Years

One commercial coal mine is currently (1983) in operation.

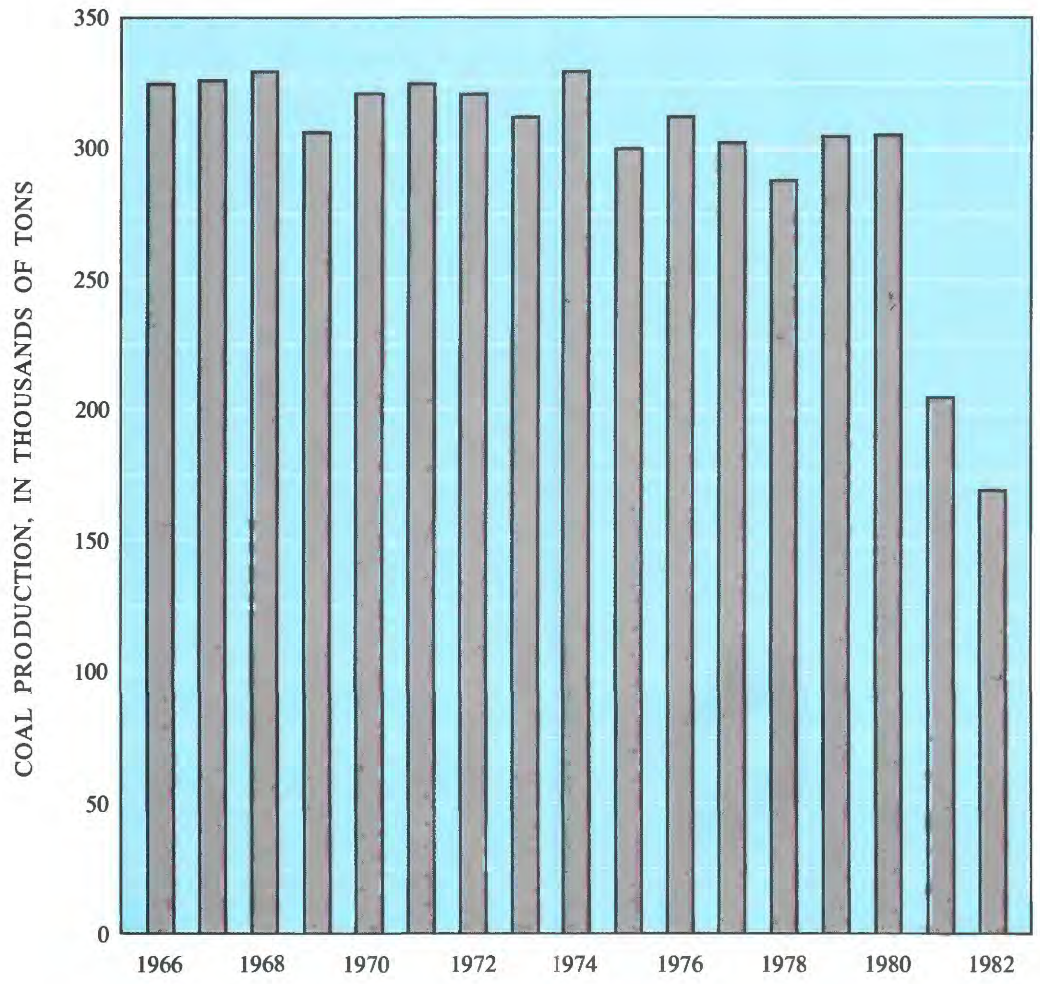
Coal has been mined on a small scale for domestic use since the settlement of the area. For many years coal was the only source of fuel and many ranchers maintained their own "mines," which were actually natural outcrops where coal was obtained for personal use.

Several small commercial mines in the area produced from about 500 to 2,000 tons annually during the 1930's through the 1960's (Prichard and Landis, 1975; Sahinen, 1956). Total annual production during these years is not known, but annual production during the early and mid-1950's is reported to have been about 11,000 to 15,000 tons (Prichard and Landis, 1975; Sahinen, 1956). Most of the commercial production during this time was from underground mines.

Commercial coal production currently (1983) is from a single surface mine, the Savage Mine, about 4.5 miles west of Savage, Montana (fig. 5.2-1). The mine was opened in 1955 to supply fuel for the Lewis and Clark electric generating station near Sidney, Montana. Because the coal is used only for the generation of electricity at one plant, the annual production from the mine prior to 1981 has been relatively uniform at about 300,000 tons (fig. 5.2-2). The decrease in production during 1981 and 1982 resulted from a decrease in electric generation at the Lewis and Clark station, with the shortfall in electric demand being supplied by generating plants outside the area (Doris Asplund, Knife River Coal Mining Company, Bismarck, N. Dak., oral commun., January 1983).

Base map from U.S. Geological Survey
United States base map, 1980

Figure 5.2-1 Location of current (1983) commercial coal mining.



Modified from Cole and others (1980);
Data for 1980-82 from Montana
Department of Labor and Industry (1980-82).

Figure 5.2-2 Coal production from Savage Mine, Savage, Montana.

Surface Mining Increases Potential for Hydrologic Problems

Erosion, sediment deposition, decline in water levels, and degradation of surface-water and ground-water quality are potential problems associated with surface mining.

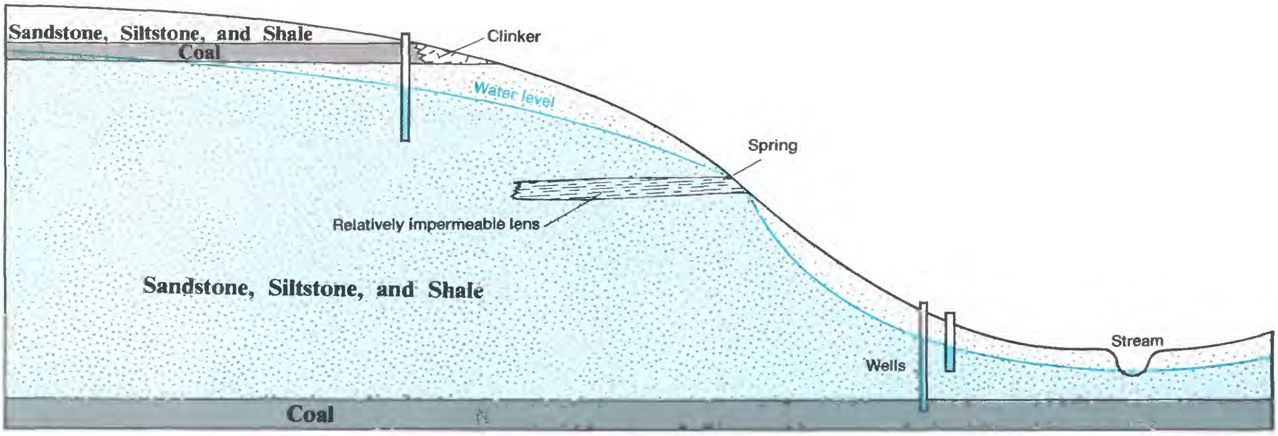
Surface coal mining alters the configuration of the land surface and subsurface strata, and long-term detrimental effects may result if the area is not properly reclaimed. Mining operations that include vegetation removal, excavation, and production of large volumes of unconsolidated spoil material increase the potential for erosion and sedimentation. Adverse effects generally associated with increased erosion include excessive sediment deposition in streams and reservoirs. Channel filling by sediment deposition decreases the water-transporting capacity of the stream and may lead to increased flooding. The habitat of aquatic organisms may be altered through burial and by decreased dissolved-oxygen concentration of the water, caused by decreased depth and increased temperature. Dissolution of minerals contained in sediment derived from recently excavated overburden material may result in increased dissolved-solids concentrations, including trace-constituent concentrations, and decreased pH values.

Ground-water levels may be affected by surface coal mining (fig. 5.3-1). Mines located above water-yielding zones have little, if any, effect on water levels. Ground-water levels may decline in and near surface-mined areas where excavation intersects a water-yielding zone. Water-level declines may cause a decrease or loss of production or flow in wells and springs. These effects generally will be temporary and occur only during and for a limited time after active mining. The areal extent of mining effects on water levels is largely dependent on the geologic and hydrologic setting of the mine and the duration of mine dewatering. The intertonguing and interfingering of sandstone, siltstone, and shale characterized by abrupt lateral and vertical changes in lithology compose a system of numerous lenticular aquifers and confining zones of limited areal extent. Coal beds are characterized by fracture systems that provide limited paths for the movement of water. Consequently, each sand lens or fracture system not contiguous with another can be considered to be an individual and relatively isolated aquifer. Recharge available to this individual aquifer is limited to leakage through the surrounding confining layers; thus, the areal extent of water-level changes resulting from mining can be relatively local. In most instances, upon completion of mining, water levels will rise until premining equilibrium conditions are approximated.

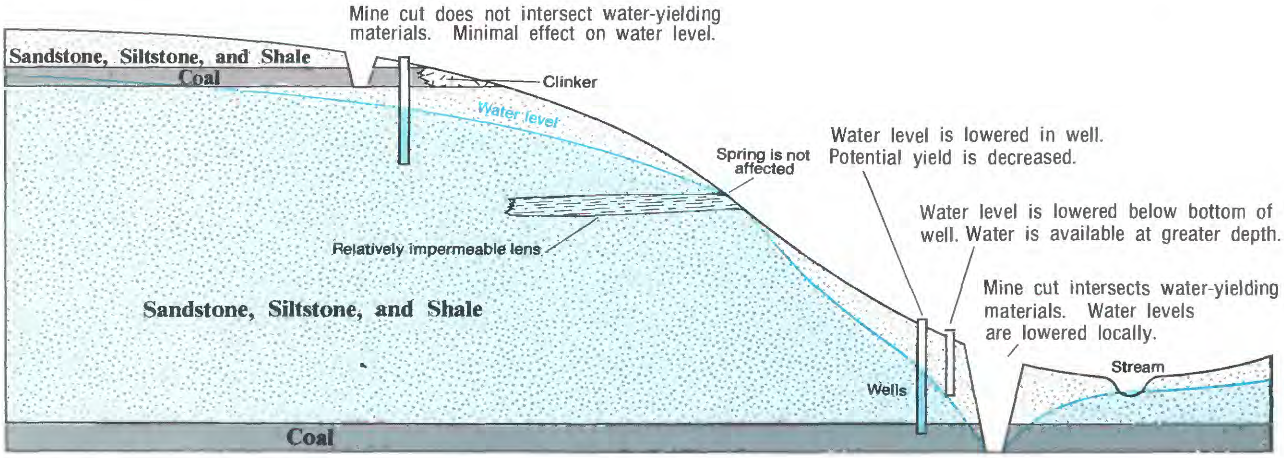
The quality of ground water in the vicinity of surface mines may be affected by the replacement of overburden material after the coal is removed. Replacement of overburden results in the exposure of fresh mineral surfaces and provides the opportunity for renewed chemical reactions. Large sulfate concentrations, which have developed near some mines (Van Voast, 1974; Van Voast and Hedges, 1975) are common products of these chemical reactions. However, the actions of sulfate-reducing bacteria can decrease sulfate concentrations. Sulfate-reducing bacteria, which are present in the existing aquifers, have been reported to reestablish themselves in spoils aquifers (Dockins and others, 1980). Chemical analyses of spoil-derived water from the Powder River Basin of Montana and Wyoming (Rahn, 1975; Van Voast and others, 1978) have indicated that the median dissolved-solids concentration of water in spoils can be 160 to 173 percent of that in stock and domestic wells.

Computer modeling designed to assess potential increases in dissolved solids in streams as a result of leaching of spoil materials (Woods, 1981b) indicates that large increases in dissolved-solids concentration are local and that dilution occurs downstream. Simulation of a hypothetical plan to simultaneously mine all Federally owned coal considered potentially available for mining in the Montana part of the Tongue River basin in southeastern Montana resulted in a maximum increase of 4.7 percent of the average annual dissolved-solids concentration of the Tongue River at Miles City.

Cooperative and individual studies of effects of existing mines in southeastern Montana by the U.S. Geological Survey and the Montana Bureau of Mines and Geology have shown that: (1) Ground-water inflow to mine pits generally has been small, (2) mine effluents have not created serious water-quality problems, (3) water-level declines can be significant locally during mining, (4) water levels generally will recover to approximately premining positions after mining ceases, (5) mine spoils generally transmit water as well as or better than the natural aquifers, (6) the problem of mineralization of water is small regionally, and (7) deeper aquifers are available to replace water supplies that are permanently lost (Montana Bureau of Mines and Geology and U.S. Geological Survey, 1978).



A. Premining conditions



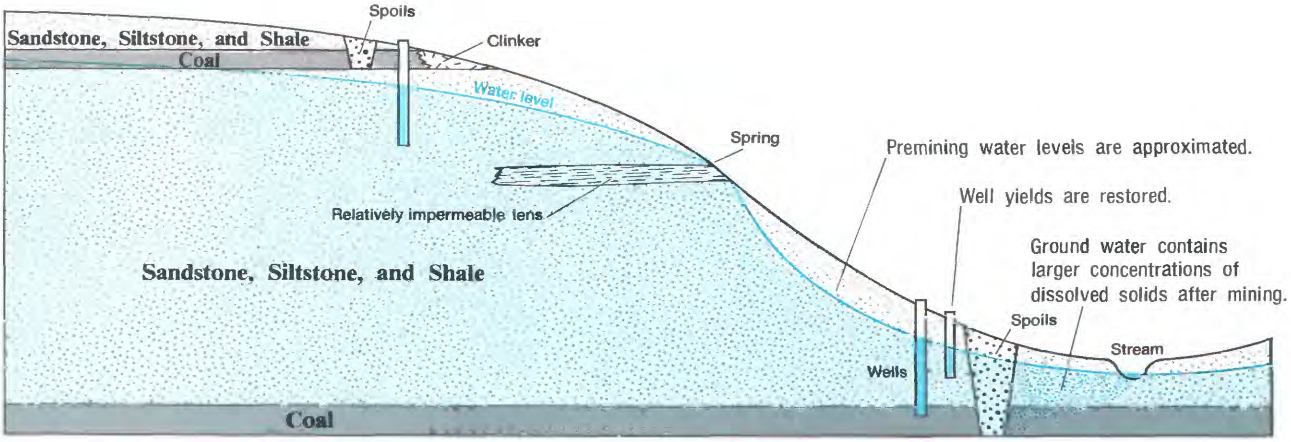
Mine cut does not intersect water-yielding materials. Minimal effect on water level.

Water level is lowered in well. Potential yield is decreased.

Water level is lowered below bottom of well. Water is available at greater depth.

Mine cut intersects water-yielding materials. Water levels are lowered locally.

B. Conditions during mining



Premining water levels are approximated.

Well yields are restored.

Ground water contains larger concentrations of dissolved solids after mining.

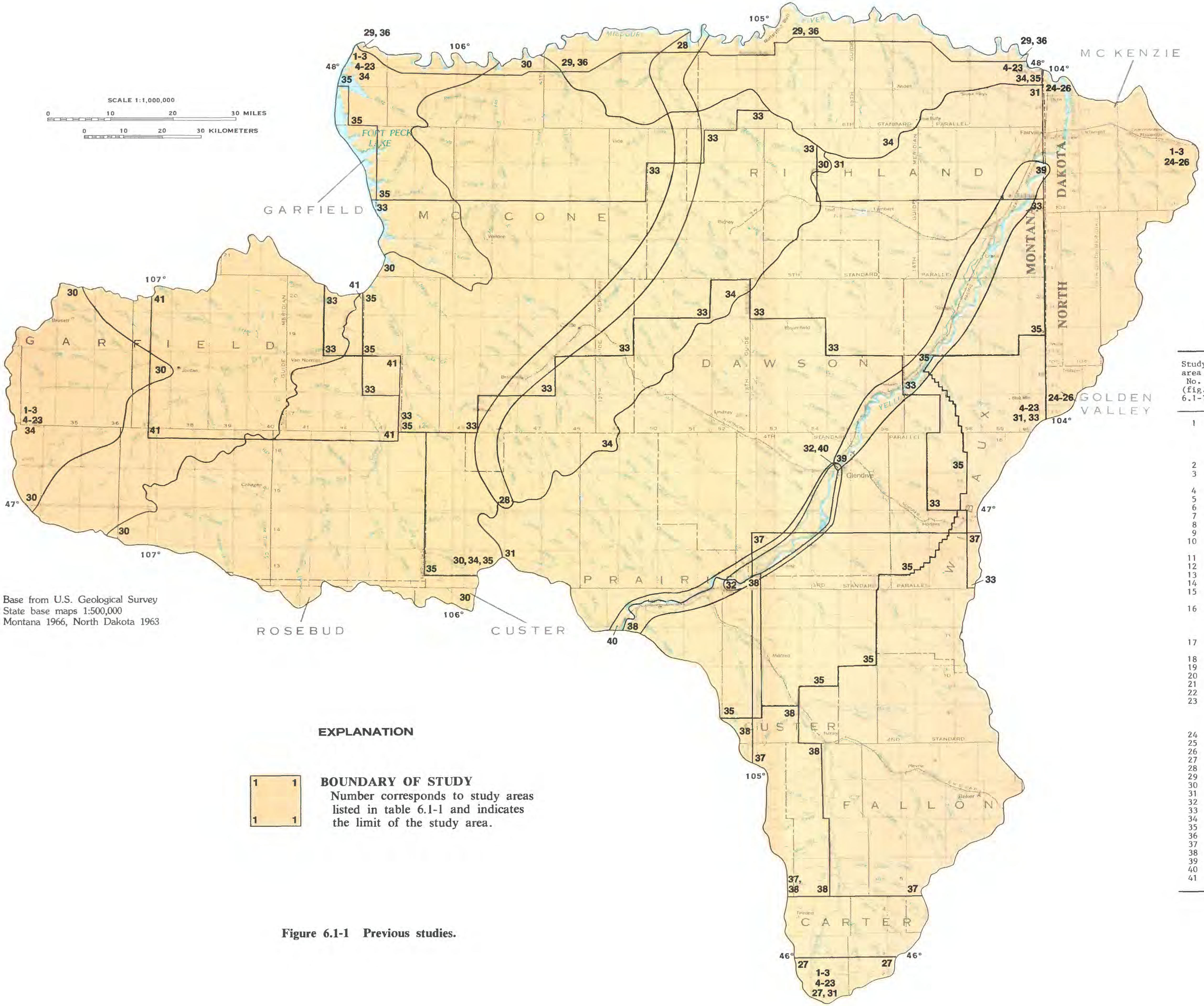
C. Postmining conditions

Figure 5.3-1 Possible impacts of mining aquifers.

Hydrologic Studies Completed for Much of the Area

Completed studies contain information on surface water, ground water, and water quality.

Early hydrologic studies in Area 45 were conducted by Renick (1924), Riffenburg (1926), and Perry (1931). Several additional studies were made in the 1950's and 1960's. The energy shortages of the early 1970's and consequent increased interest in coal as a source of energy resulted in increased attention to coal-bearing regions. Concern about the effects of surface coal mining on the water resources spurred a significant increase in hydrologic studies to document premining conditions for future planning decisions and to determine the effects of the mining on the hydrologic system. Since 1951, hydrologic studies have been conducted by the U.S. Geological Survey, the Montana Bureau of Mines and Geology, the Water Quality Bureau of the Montana Department of Health and Environmental Sciences, the North Dakota State Water Commission, and the North Dakota Geological Survey. The location of these studies is shown in figure 6.1-1 and listed in table 6.1-1.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

BOUNDARY OF STUDY
Number corresponds to study areas listed in table 6.1-1 and indicates the limit of the study area.

Figure 6.1-1 Previous studies.

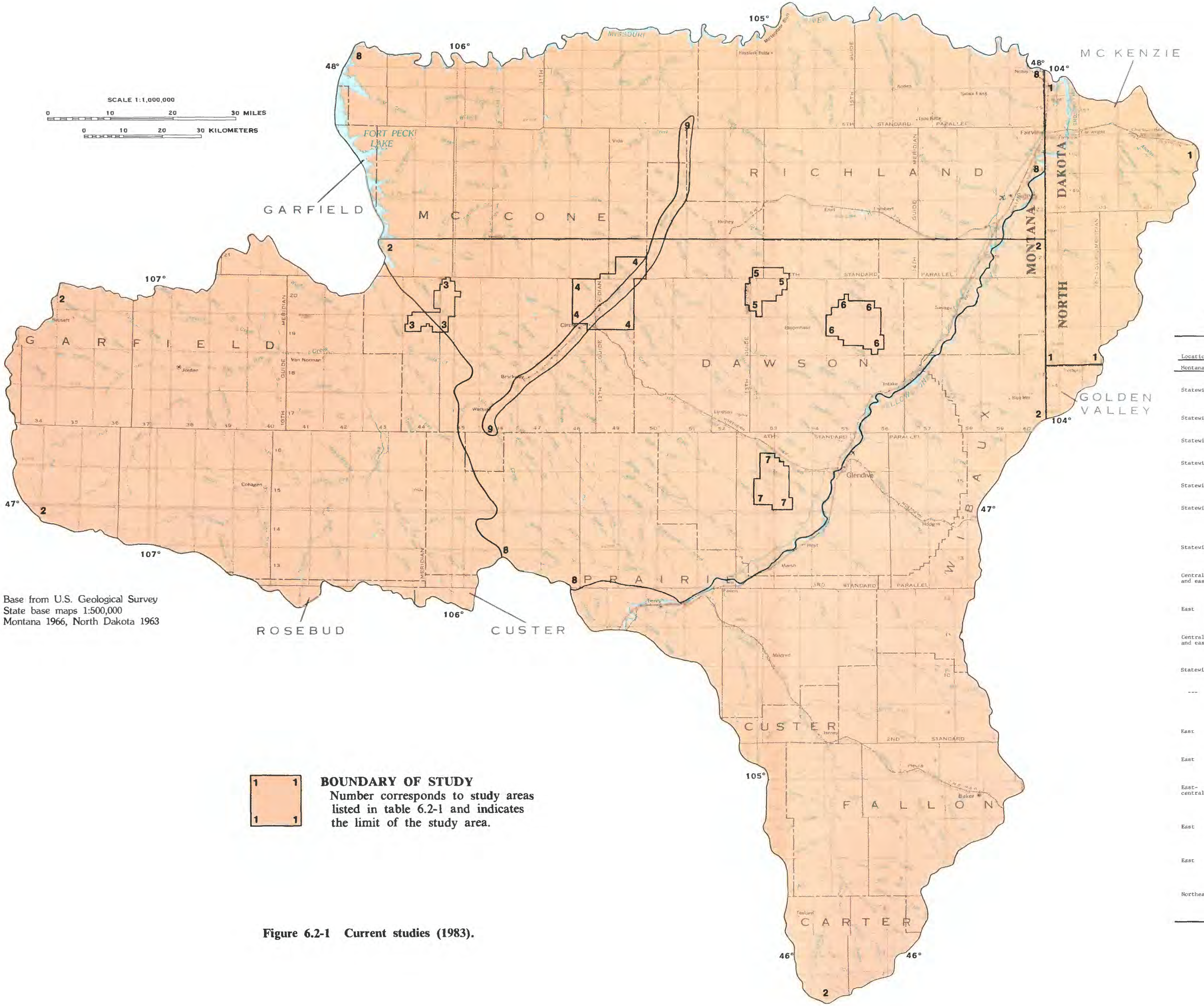
Table 6.1-1 Index to previous hydrologic studies.

Study area No. (fig. 6.1-1)	Reference (see section 12.0 for complete reference)	Principal subject of investigation				
		Surface water	Ground water	Water quality	Sedi-ment	Biol-ogy
1	Ground-water Subgroup of Water Work Group, Northern Great Plains Resource Program (1974).	X	X	X	X	X
2	Konikow (1976)		X			
3	Miller and Strausz (1980a, 1980b).		X			
4	Bahls and others (1981)					X
5	Berwick (1958)	X				
6	Bond (1975)		X	X		
7	Boner and Omang (1967)	X				
8	Druse and others (1981)	X		X		
9	Feltis (1980a)		X			
10	Feltis (1980b, 1980c, 1980d).			X		
11	Feltis and others (1981)		X			
12	Hopkins (1976)		X	X		
13	Johnson and Omang (1976)	X				
14	Knapton and Bochy (1976)			X		
15	Levings (1981a, 1981b, 1982).		X			
16	Montana Bureau of Mines and Geology and U.S. Geological Survey (1978).		X	X		
17	Montana Water Resources Board (1969).	X	X	X	X	X
18	Omang and others (1979)	X				
19	Omang and others (1982)	X				
20	Parrett and Omang (1981)	X				
21	Reed and McMurtrey (1970)		X			
22	Stoner and Lewis (1980)		X			
23	U.S. Geological Survey and Montana Bureau of Mines and Geology (1968).	X	X	X		X
24	Crosby (1974, 1975)	X				
25	Moran and others (1978)		X	X		
26	Smith and Harkness (1981)	X	X			
27	Bergantino (1981)		X	X		
28	Dodge and Levings (1980)	X		X		
29	Hopkins and Tilstra (1966)		X	X		
30	McKinley (1979)	X		X	X	
31	Moore and Shields (1980)	X				
32	Moulder and Kohout (1958)		X	X		
33	Roberts (1980)		X	X		
34	Shields and White (1981)	X				
35	Slagle (1981)		X			
36	Swenson (1955)		X	X		
37	Taylor (1965)		X	X		
38	Taylor (1968)		X	X		
39	Torrey and Kohout (1956)		X	X		
40	Torrey and Swenson (1956)		X	X		
41	Van Lewen and King (1971)		X	X		

U.S. Geological Survey Currently Conducting Investigations in the Area

Current (1983) studies focus primarily on determining the hydrologic impacts surface coal mining.

Current (1983) water-resources studies by the U.S. Geological Survey in Area 45 (fig. 6.2-1) include collection of surface-water, ground-water, and water-quality data. The data can be used as a basis for determining the hydrologic effects of present and future surface coal mining. Additional studies include determination of present area hydrologic conditions, analysis of stream channel and streamflow characteristics, and digital modeling of the effects of mining on the salinity of ground water and surface water. Many studies include intensive data collection and analysis in small areas--usually to determine the hydrologic impacts of mining; these studies receive financial assistance from the U.S. Bureau of Land Management under the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program of coal-tract evaluation. The current investigations are summarized in table 6.2-1.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Figure 6.2-1 Current studies (1983).

Table 6.2-1 Index to current (1983) hydrologic studies.

Location within State		Study area No. (fig. 6.2-1)	Project No.	Project title	Project objectives
Montana	North Dakota				
				Data-collection programs	
Statewide	Statewide	--	MT-001, ND-001	Surface-water stations	To collect surface-water data for analytical studies and current-purpose uses such as evaluation, operation, disposal, legal, and research of water resources.
Statewide	Statewide	--	MT-002, ND-002	Ground-water stations	To collect water-level data to provide a long-term data base to permit proper planning and management of water resources.
Statewide	Statewide	--	MT-003, ND-003	Water-quality stations	To provide water-quality data for planning management of intrastate, interstate, and international waters.
Statewide	Statewide	--	MT-004, ND-004	Sediment stations	To provide sediment data for planning and management of intrastate, interstate, and international waters.
Statewide	Statewide	--	MT-007, ND-007	Water use	To develop and maintain a water-use data system that is responsive to users at State and national levels.
Statewide	---	--	MT-023	Bridge-site investigations.	To provide the Montana Department of Highways with sufficient data to permit the most economical and hydraulically safe bridge or culvert design possible.
				Areal appraisals	
Statewide	---	--	MT-001	Peak-flow analysis	To collect adequate data to enable definition of the magnitude and frequency of floods to be expected from any given small drainage in the State.
Central and east.	---	--	MT-056	Madison aquifer	To compile data from wells and test holes and to prepare maps describing the altitude and configuration of the top of the aquifer, potentiometric surface, and quality of water.
East	---	--	MT-064	Reservoir study	To characterize the present physical, chemical, and biological conditions in selected reservoirs and to evaluate the suitability of the reservoirs for various uses.
Central and east.	Statewide	--	MT-067, ND-083	Northern Great Plains regional aquifer system analysis.	To evaluate the principal hydrologic systems, the quantity and quality of water, the availability of water, and the effects of withdrawing the water.
Statewide	---	--	MT-091	Evaluation of ground-water quality.	To statistically evaluate the ground-water-quality data files for Montana and determine areas of deficiency.
---	West-central	1	ND-086	Ground-water resources of McKenzie County.	To determine the quantity and quality of ground water available for municipal, domestic, livestock, industrial, and irrigation uses.
				Coal-related studies	
East	---	2	MT-059	Coal-lease monitoring	To determine characteristics of the regional water-resources system and to detect and document any changes in the system as a result of coal mining.
East	---	3-7	MT-066	EMRIA sites	To collect data at selected coal-lease application sites, to define premining conditions, and to evaluate the potential hydrologic impacts of coal development.
East-central	---	8	MT-076	Water resources of Fort Union coal region.	To determine the occurrence, availability, and quality of water in aquifers above the Bearpaw Shale; to define premining hydrologic conditions.
				Research projects	
East	---	--	MT-072	Surface-water-quality monitoring.	To analyze the data collected, to review and modify the data-monitoring network as needed, and to present the information obtained from the network in a logical format for land-use managers.
East	---	--	MT-073	Surface-water-flow analysis.	To develop methods to estimate runoff characteristics from ungaged watersheds and to estimate mean annual flow, peak discharges, and flood boundaries at selected ungaged sites.
Northeast	---	9	MT-090	Salinity modeling of Redwater River.	To construct and calibrate models to evaluate impacts of mining, reclamation, agriculture, and other land-management practices on stream salinity.

Discharge Information Available for 74 Streamflow Stations

The U.S. Geological Survey has surface-water flow information at 26 continuous-record stations and 48 crest-stage stations in the area.

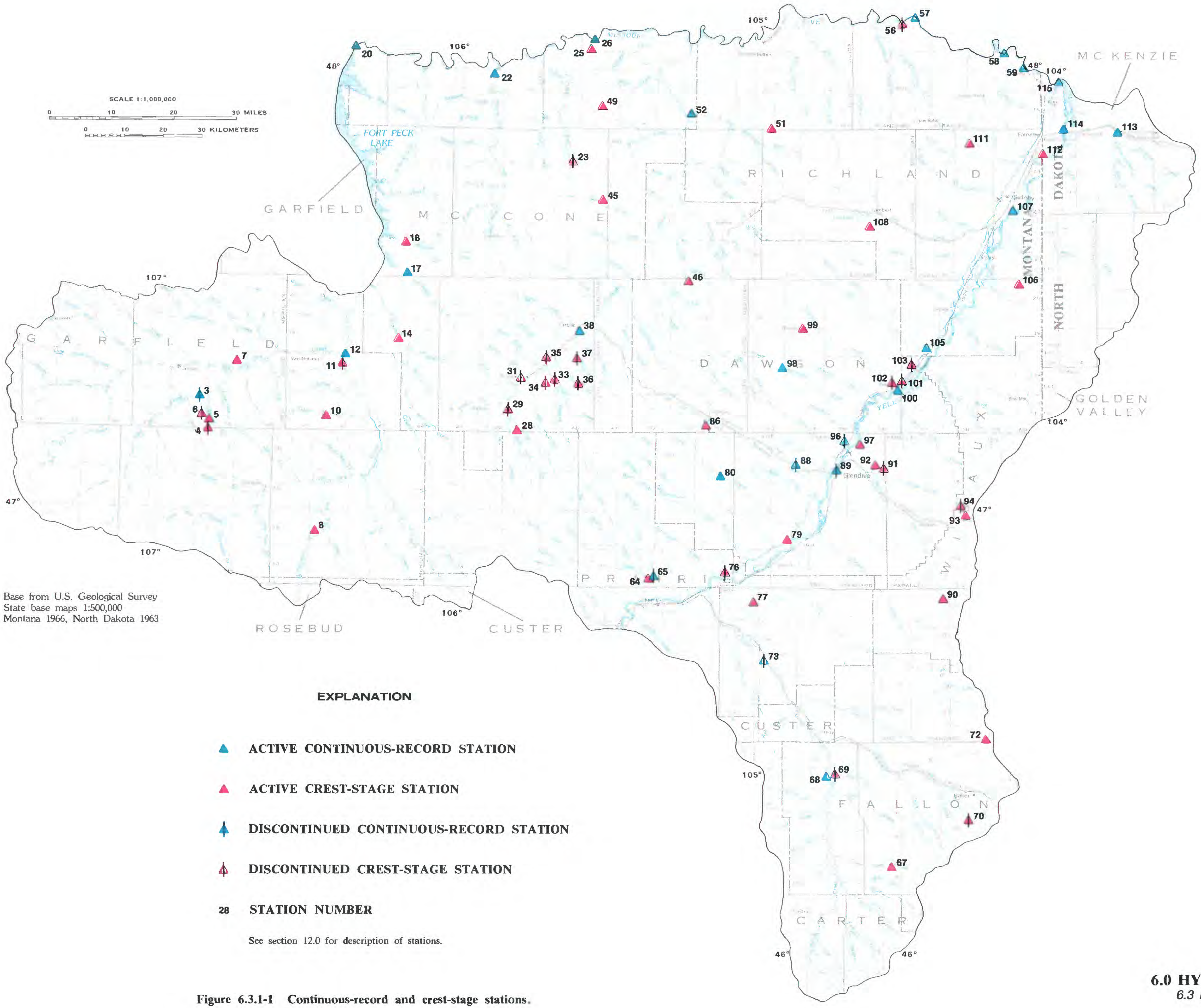
As the name indicates, a continuous-record station provides a continuous record of discharge throughout the year. A crest-stage station provides a record of peak discharges that occur between station visits, but usually only the largest discharge value for each year is published. Data from continuous-record stations can be used for determining average-flow characteristics, low-flow characteristics, and high-flow characteristics of streamflow. Data from crest-stage stations can be used for determining annual peak-flow characteristics useful for flood studies.

The surface-water stations are shown in figure 6.3.1-1. Details for the period of record and type of data available are given in the supplemental list of streamflow and water-quality stations and sites (Section 12).

Before 1970, most of the continuous-record stations were established on the larger perennial streams to meet some specific water-management need. During the 1970's the continuous-record station network was expanded to obtain data to evaluate the hydrology of the general area. Except for the stations added during the 1970's, most of the continuous-record stations have more than 10 years of data. Developing reliable statistics for making long-term average, low-flow, or high-flow estimates usually requires at least 10 years of record.

The first crest-stage stations were established in 1955 and were intended primarily for highway culvert and bridge design. The crest-stage network was expanded in 1963 and again in 1973. Thirty crest-stage stations presently have at least 10 years of record, which is the general requirement for developing reliable peak-flow statistics.

Most of the data collected at continuous-record and crest-stage stations is available in computer-usable form. The data collected since 1965 also are available in annually published U.S. Geological Survey reports "Water Resources Data for Montana" and "Water Resources Data for North Dakota." Data collected before 1965 are in published U.S. Geological Survey Water-Supply Papers 1309, 1729, and 1916.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

▲ ACTIVE CONTINUOUS-RECORD STATION

▲ ACTIVE CREST-STAGE STATION

▲ DISCONTINUED CONTINUOUS-RECORD STATION

▲ DISCONTINUED CREST-STAGE STATION

28 STATION NUMBER

See section 12.0 for description of stations.

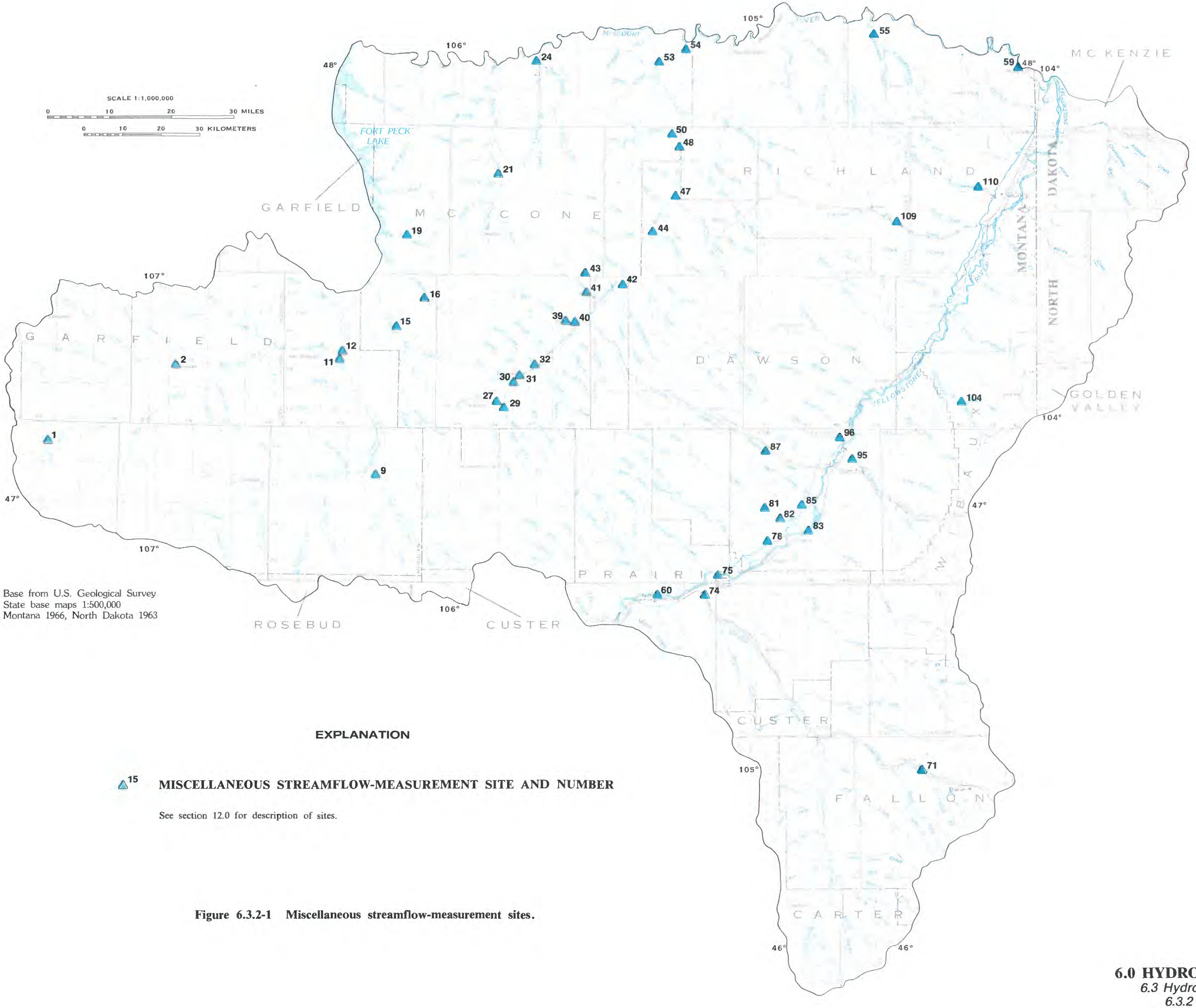
Figure 6.3.1-1 Continuous-record and crest-stage stations.

Surface-Water-Discharge Information Available for 44 Miscellaneous Sites

Miscellaneous-discharge measurements generally were made at sites where water-quality samples were collected or as part of streamflow gain-or-loss studies.

Miscellaneous streamflow measurements have been made at 44 locations in Area 45 (fig. 6.3.2-1). Some measurements were made as early as 1921, but most have been made since 1975. Many miscellaneous streamflow measurements were made in conjunction with surface-water-quality programs. Numerous measurements were made during streamflow gain-or-loss studies to determine the interaction of surface water and ground water; these studies were part of the U.S. Geological Survey Coal Hydrology Program to describe the water resources in the coal-bearing areas of the northern Great Plains.

Additional hydrologic information about the sites is contained in the supplemental list of streamflow and water-quality stations and sites (Section 12). Data from most of the measurements are contained in a report by Dodge and Levings (1980). Additional data are available at the U.S. Geological Survey office in Helena, Montana.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

△15 **MISCELLANEOUS STREAMFLOW-MEASUREMENT SITE AND NUMBER**

See section 12.0 for description of sites.

Figure 6.3.2-1 Miscellaneous streamflow-measurement sites.

Water-Quality Data Available for Streamflow Stations and Miscellaneous Sites

Water-quality data include measurements of physical, chemical, and biological variables.

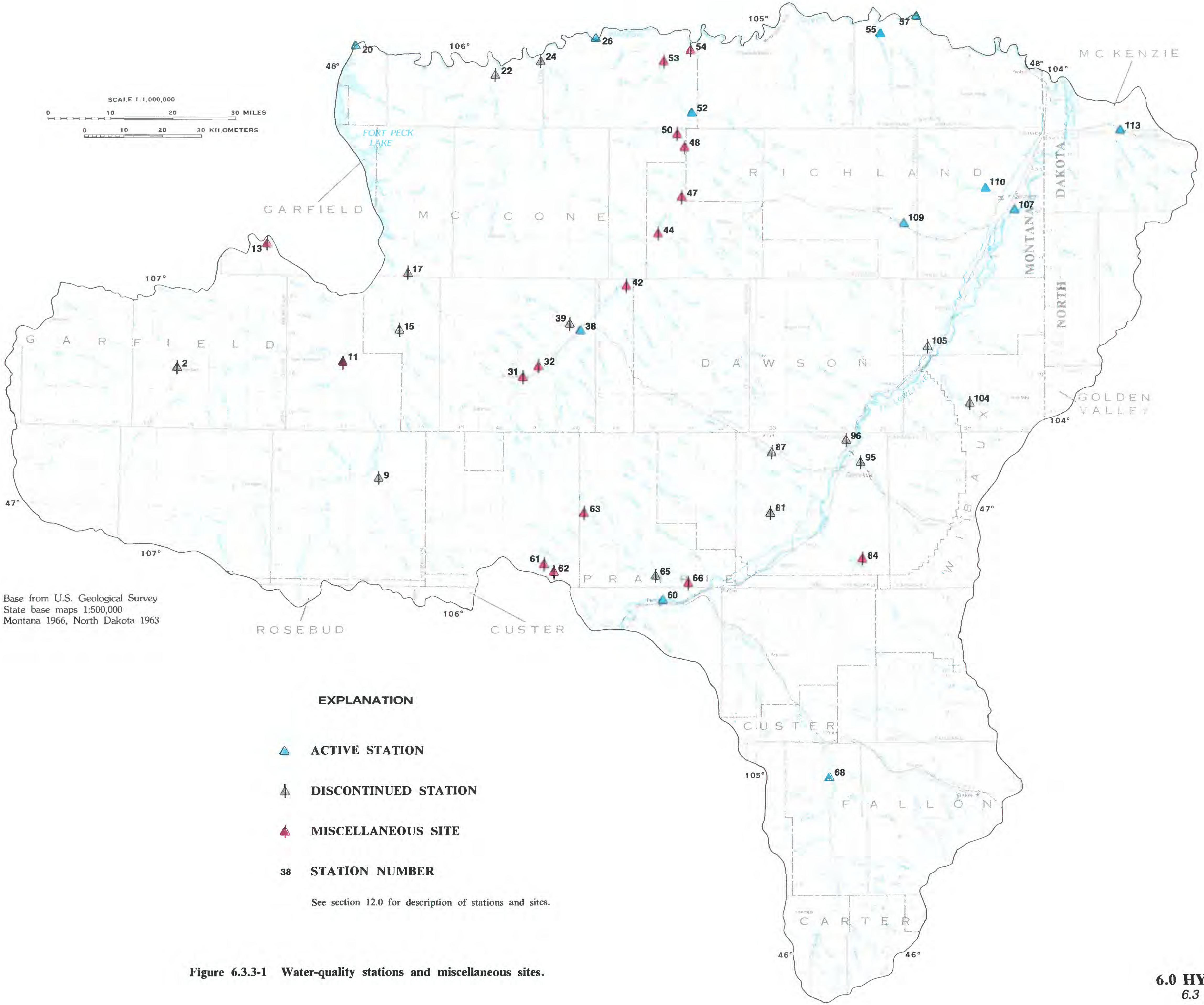
Prior to 1975, only limited water-quality information was available for streams in the study area. Some data had been collected on the Missouri and Yellowstone Rivers, but information was lacking for the smaller streams. The prospect of extensive surface coal mining has created public concern about impacts to the water quality of streams. Although the data acquired within the study area approximate premining conditions, the data do not necessarily represent undisturbed natural conditions. Other activities of man, primarily agriculture, have affected the land and water-quality characteristics for some time.

Beginning in 1975, a network of data-collection stations was established by the U.S. Geological Survey to monitor chemical and physical properties of surface water throughout the study area. Water-quality stations were located in areas where future land-use changes were thought probable. Long-term stations were established at major potential-impact sites and operated in conjunction with continuous streamflow monitors. In addition, shorter term water-quality stations were established at miscellaneous streamflow sites to provide additional hydrologic information. These stations generally have a data base of at least 2 years.

Biological data have been collected intermittently on several small streams within the network and at National Stream Quality Accounting Network (NASQAN) stations on the Missouri and Yellowstone Rivers. Additional miscellaneous water-quality sites were established for short-term project studies that addressed specific problems. Intensive sampling for determination of chemical constituents and physical properties was done on selected stream reaches to define ground water-surface water relationships.

The data base established from the network sampling program documents existing conditions and can be used as a reference for assessing future changes in water quality. Where the data base is adequate, water-quality characteristics between stations can be compared and potential changes with time can be detected. In addition, the data can be used in computer models to predict water-quality changes that might result from various mining operations or other proposed land-use changes.

All water-quality stations (active and discontinued) and miscellaneous water-quality sites within the study area are shown in figure 6.3.3-1. Additional information about water-quality stations and miscellaneous sites is contained in Section 12.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

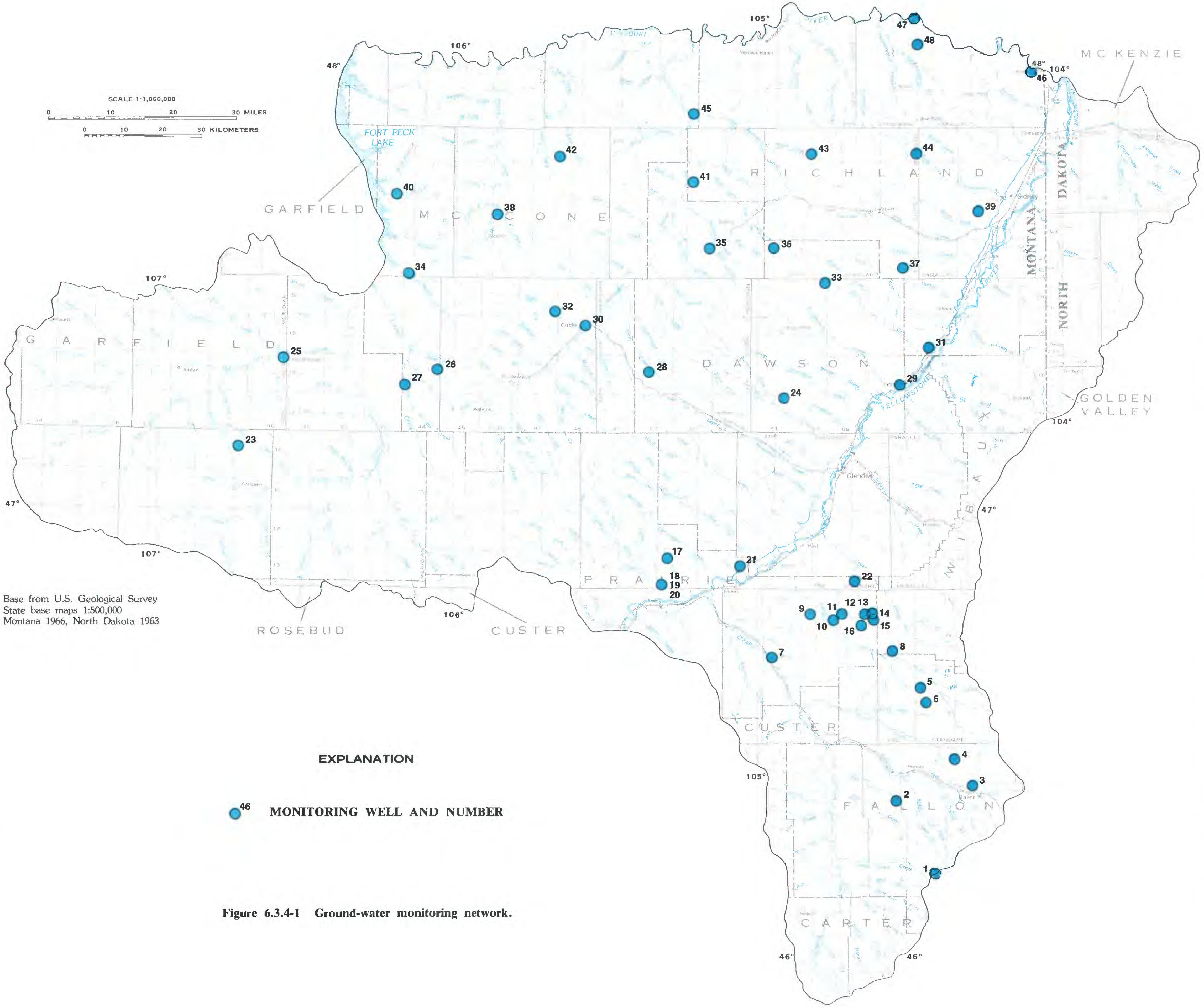
Figure 6.3.3-1 Water-quality stations and miscellaneous sites.

Ground-Water Data Available for Many Sites

Ground-water data have been collected from supply and observation wells.

Inventories of hydrologic and geologic data are available for about 3,000 domestic, stock, irrigation, public-supply and test wells in Area 45. Data inventories include well location, depth of well, principal aquifer, water level, specific conductance of water, water temperature, and lithologic descriptions of geologic units. Water-quality data are available for about 350 wells. Most analyses are for major ions but trace-element and miscellaneous-constituent information is available for about 100 wells. Inventory and water-quality information is stored and available for computer retrieval from the Geological Survey's National Water Data Storage and Retrieval System (WATSTORE). Most data also are available in published reports, such as Slagle (1981) and Levings (1981a, 1981b).

Long-term water-level information (table 6.3.4-1) is available for 48 network wells in the area (fig. 6.3.4-1). Most of these wells became part of a statewide observation-well network during the past 10 years. The network was established in response to the need for premining ground-water data created by the probability of increased coal development in the northern Great Plains. Water-level records for these wells are available from WATSTORE.



Base from U.S. Geological Survey
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EXPLANATION

● 46 **MONITORING WELL AND NUMBER**

Figure 6.3.4-1 Ground-water monitoring network.

Table 6.3.4-1 Ground-water monitoring network.

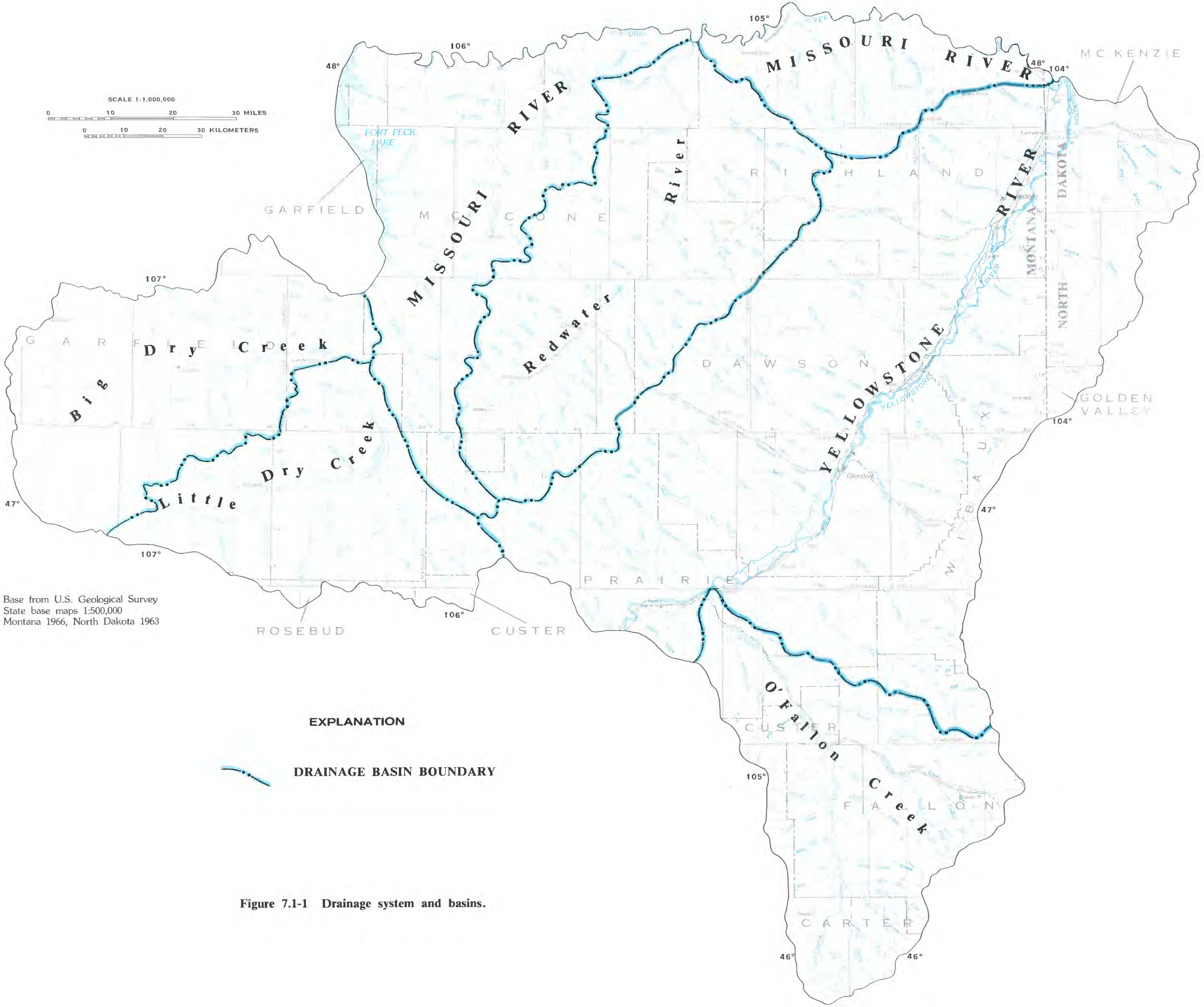
[Geologic unit: ALVM, alluvium; FHHC, Fox Hills Sandstone and lower part of Hell Creek Formation; FRUN, Fort Union Formation; FXHL, Fox Hills Sandstone; HLCK, Hell Creek Formation; LEBO, Lebo Shale Member of Fort Union Formation; TGRV, Tongue River Member of Fort Union Formation; TLCK, Tullock Member of Fort Union Formation; TRRC, terrace deposits. Status: A, active; I, inactive. Frequency of measurement: A, annual; I, intermittent; M, monthly]

Well No. (fig. 6.3.4-1)	Local No.	Depth of well (feet)	Geologic unit	Status	Frequency of measurement	Period of record
1	05N58E14BBBB01	360	TGRV	A	I	1977-
2	07N57E24BBCB01	362	TGRV	A	I	1977-
3	07N59E02CD01	27	FHHC	I	I	1962-77
4	08N59E16BC01	250	FHHC	A	I	1962-
5	10N58E19ABBA01	166	FHHC	A	I	1962-
6	10N58E32DBB01	463	FHHC	I	I	1962-73
7	11N54E29CACD01	800	FHHC	A	I	1976-
8	11N57E21CB01	1,230	FHHC	A	I	1963, 1970-
9	12N55E20DCCA01	1,185	FHHC	A	I	1962, 1966-
10	12N55E25CDC01	1,275	FHHC	A	I	1964
11	12N56E19CD01	1,140	FHHC	I	I	1962-71
12	12N56E23CC01	1,449	FHHC	A	I	1981-
13	12N56E23DCCB01	1,185	FHHC	A	I	1962-
14	12N56E24CABD01	145	FXHL	A	I	1962-
15	12N56E25CB01	1,480	FHHC	A	I	1981-
16	12N56E34DA01	1,467	FHHC	A	I	1962-
17	13N51E08BAAD01	198	TGRV	A	I	1979-
18	13N51E31BCDD01	565	HLCK	A	I	1979-
19	13N51E31BCDD02	340	TLCK	A	I	1979-
20	13N51E31BDCB01	973	FHHC	A	I	1979-
21	13N53E18ABAA01	62	TGRV	A	I	1981-
22	13N56E30CCBB01	100	FHHC	A	I	1962-
23	16N40E18AAD01	15	ALVM	I	I	1965-72
24	17N53E01CBAD01	133	FRUN	A	I	1977-
25	18N40E01DBB01	158	FRUN	A	I	1965-
26	18N44E13AAAB01	278	TGRV	A	I	1976-
27	18N44E30CDD01	60	TGRV	A	I	1976-
28	18N50E16CBBB01	160	LEBO	A	I	1981-
29	18N56E25CB01	28	TRRC	I	I	1947-70
30	19N48E11BC01	53	ALVM	I	I	1954-72
31	19N57E27DDAC01	17	ALVM	I	I	1975-79
32	20N47E36ADDD01	220	TGRV	A	A	1976-
33	20N54E01DCDD01	220	TGRV	A	I	1976
34	21N43E36BCCD01	18	ALVM	I	I	1975-79
35	21N51E10ABCD01	131	TGRV	A	I	1975-
36	21N53E08ADCC01	70	TGRV	A	I	1976-
37	21N56E28ADDC01	220	TGRV	A	I	1976-
38	22N46E18ADAA01	168	FRUN	A	I	1981-
39	22N58E10CCCC01	135	FRUN	A	I	1976-
40	23N43E34BABC01	175	FRUN	A	I	1978-
41	23N51E20BBBD01	175	FRUN	A	I	1975-
42	24N47E35BBBA01	101	LEBO	A	I	1980-
43	24N54E29CACB01	190	TGRV	A	I	1975-
44	24N56E25DDAC01	60	TGRV	A	I	1980-
45	25N50E24CABC01	33	ALVM	A	I	1975-
46	26N59E22DBDD01	212	TGRV	A	I	1980-
47	27N56E03CCA01	75	ALVM	I	M	1963-77
48	27N56E34AABC01	118	TGRV	A	I	1980-

Area Drained by Missouri River

The Yellowstone River is the largest Missouri River tributary in the area; smaller tributaries include Big Dry Creek and the Redwater River.

Area 45 lies entirely within the Missouri River basin. The Missouri River flows eastward and forms the northern boundary of the area (fig. 7.1-1). The Yellowstone River, a major tributary of the Missouri River, flows northeastward through the eastern part of the area. Lesser tributaries of the Missouri River are the Redwater River and Big Dry Creek. The only major Yellowstone River tributary in the area is O'Fallon Creek. The Missouri and Yellowstone Rivers and the downstream reaches of the Redwater River and Prairie Elk Creek are the only perennial streams in Area 45.



Base from U.S. Geological Survey
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Figure 7.1-1 Drainage system and basins.

Average-Flow Data Available for Most Streams

Average annual flow tends to be small, except for the Missouri and Yellowstone Rivers.

Average-flow data are available for major streams draining Area 45. Average flow tends to be small for the streams that generally are ephemeral or intermittent. Zero or near-zero flows have been recorded in every month at most of the streamflow-gaging stations on nearly all streams. The only exceptions are the Missouri and Yellowstone Rivers.

Average discharges at all selected streamflow-gaging stations having at least 5 years of record are given in table 7.2-1. In addition, average discharges are available in published U.S. Geological Survey reports "Water Resources Data for Montana" and "Water Resources Data for North Dakota." Bar graphs for Yellowstone River near Sidney, Montana, and Redwater River at Circle, Montana, show average monthly discharge, maximum and minimum monthly discharge, and average annual discharge for the period of record (fig. 7.2-1). The two stations illustrate the difference between a large stream with mountainous headwaters (Yellowstone River) and a smaller stream draining only the prairie in Area 45 (Redwater River). The bar graph shows the increased flow during times of rainfall and snowmelt.

Equations for estimating average annual flows at ungaged sites are presently not available, but a study to develop such equations is underway in Montana. Information about the progress of the study can be obtained from:

U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, MT 59626

Table 7.2-1 Average discharge at selected gaging stations.

Station No. (fig. 6.3.1-1)	Station name	Period of record	Average discharge, in cubic feet per second, for month indicated												Average annual discharge (cubic feet per second)
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
3	Sand Creek near Jordan, Mont.	1957-67	0.11	0.18	0.11	0.14	6.10	36.0	6.80	2.60	5.70	8.00	0.17	0.06	5.54
12	Big Dry Creek near Van Norman, Mont.	1940-47; 1949-69; 1970-	5.40	3.10	3.00	2.90	56.0	317	128	36.0	74.0	28.0	21.0	15.0	57.4
17	Nelson Creek near Van Norman, Mont.	1976-	.14	.03	.04	.10	.69	8.37	7.17	2.97	2.33	3.32	1.79	2.71	2.48
20	Missouri River below Fort Peck Dam, Mont.	1943-	13,180	9,575	8,909	9,385	9,314	7,645	7,466	8,341	8,450	10,570	13,410	13,480	9,986
22	Prairie Elk Creek near Oswego, Mont.	1976-	5.04	2.10	1.08	1.90	12.0	108	34.0	10.1	30.1	14.5	4.34	12.8	19.7
26	Missouri River near Wolf Point, Mont.	1943-	13,350	9,792	8,792	9,318	9,557	9,020	10,650	9,654	9,395	11,030	13,600	13,700	10,660
38	Redwater River at Circle, Mont.	1929-72; 1975-	.23	.26	.40	.25	16.0	83.0	25.0	4.40	15.0	15.0	2.80	.44	13.6
52	Redwater River near Vida, Mont.	1976-	5.25	5.86	4.16	2.06	29.0	146	198	39.4	58.2	67.4	12.8	7.57	47.9
57	Missouri River near Culbertson, Mont.	1943-51; 1958-	12,350	10,120	9,147	9,746	10,590	10,920	11,870	10,260	9,957	11,090	12,660	12,760	10,960
89	Yellowstone River at Glendive, Mont.	1897-1910; 1931-34	6,666	5,570	4,479	4,612	4,633	8,844	8,488	19,550	46,310	30,280	12,260	7,982	13,440
105	Burns Creek near Savage, Mont.	1958-67	.96	.99	.77	.52	4.90	42.0	14.0	4.00	5.50	4.20	.49	.64	6.60
107	Yellowstone River near Sidney, Mont.	1910-31; 1933-	8,386	7,329	5,831	5,222	6,709	11,470	10,830	18,770	41,310	24,310	9,046	7,244	13,070
113	Charbonneau Creek near Charbonneau, No. Dak.	1966-	1.10	.68	.98	2.90	24.0	83.0	40.0	7.90	9.10	3.30	2.70	.89	14.7

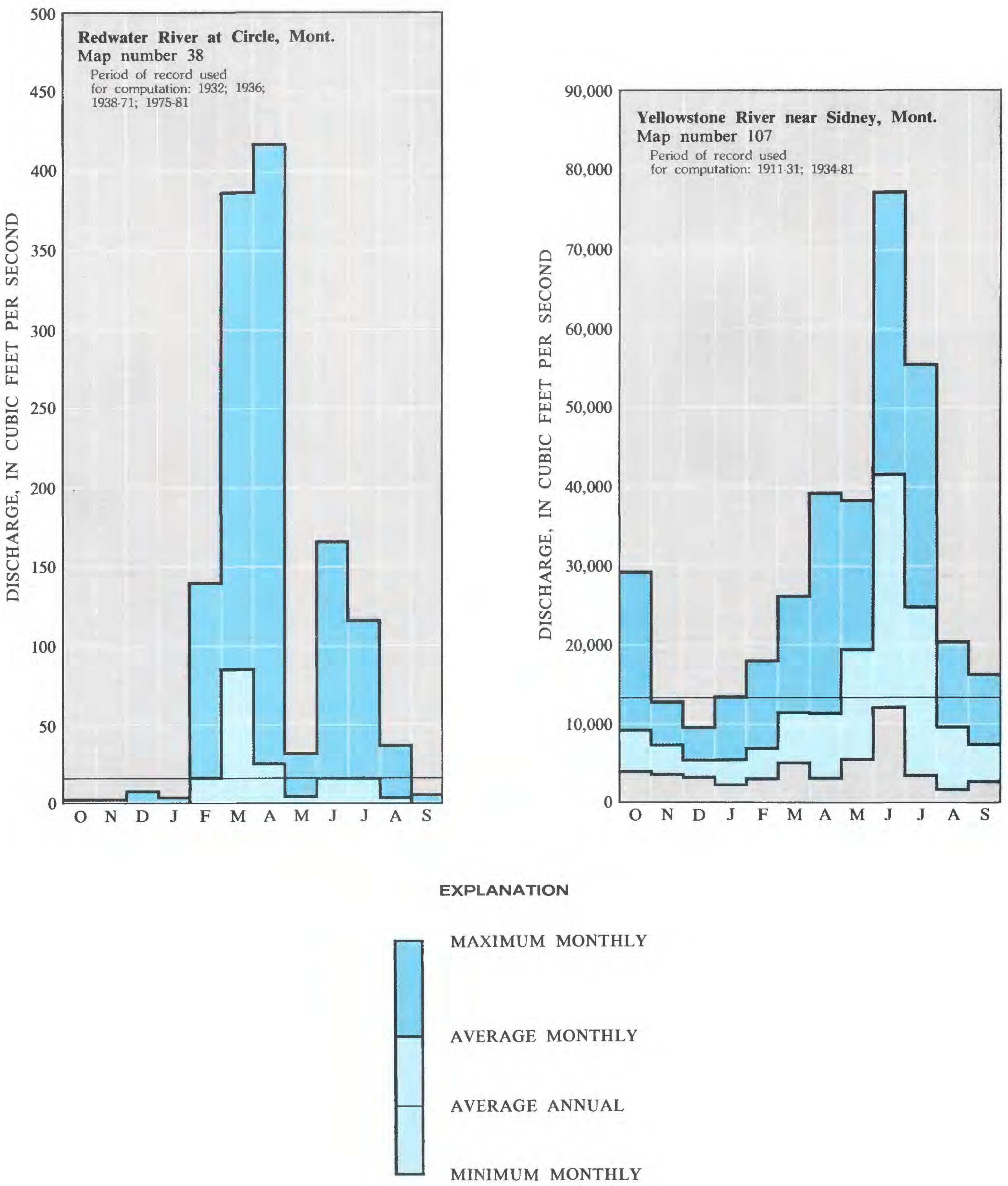


Figure 7.2-1 Average flows for station 38 (Redwater River at Circle, Montana), and station 107 (Yellowstone River near Sidney, Montana).

Streamflow Greatly Variable

Variations are large, particularly on tributaries draining the prairies.

Streamflow volumes vary greatly within the area. Flows in all unregulated streams have large seasonal variations, with the largest flows occurring in the spring as a result of snowmelt and rainfall. Streamflow in the Missouri River is not as variable because of the effects of upstream storage reservoirs.

Daily flow hydrographs (fig. 7.3-1) indicate the seasonal variation in streamflows in 1980 for Redwater River at Circle, Montana, and for Yellowstone River near Sidney, Montana. The hydrographs show the effects of snowmelt and rainfall on the streamflow in a typical prairie stream and a large perennial stream. Increased streamflow in the Redwater River during March and April and in the Yellowstone River during May and June are the result of snowmelt. Summer thunderstorms result in short intervals of increased streamflow in the Redwater River during June through September but show little effect on the streamflow in the Yellowstone River.

Another way of illustrating flow variation is with a flow-duration curve, which shows the percentage of time that a daily streamflow was equaled or exceeded during the period of record at a station. Flow-duration curves for four streams are shown in figure 7.3-2.

Flow-duration curves for Sand Creek and Big Dry Creek are representative of flow in prairie streams. The curves are steep, indicating a large variation in streamflow. The curves do not flatten at the lower end, which denotes a lack of sustained base flow.

The curves for the Missouri River and the Yellowstone River are much flatter than the curves for the smaller prairie streams. Streamflows are substantial all the time on these large streams because of the large drainage areas and the contribution to streamflow from mountain snowpack in the headwater areas.

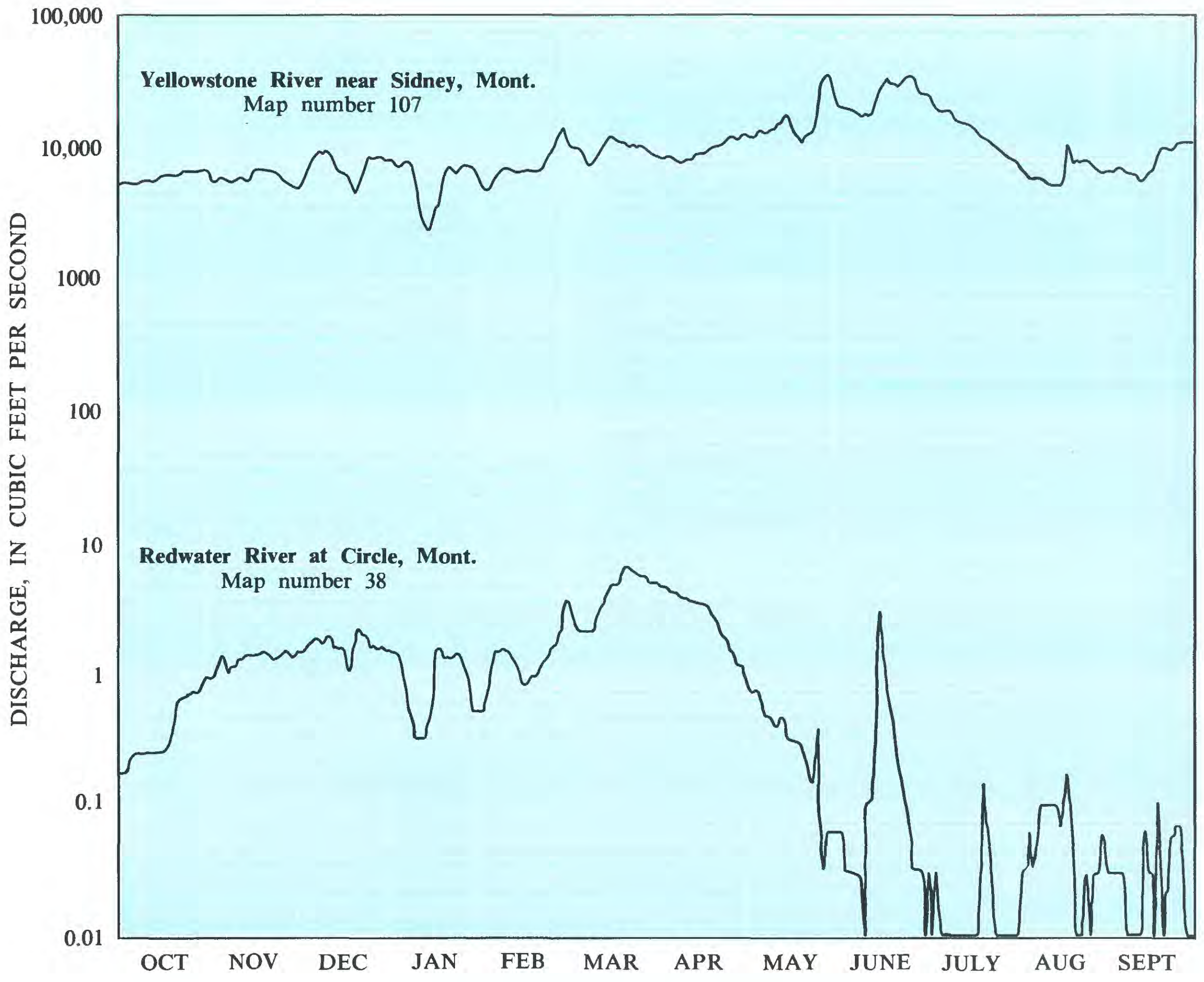


Figure 7.3-1 Daily hydrographs for station 38 (Redwater River at Circle, Montana), and station 107 (Yellowstone River near Sidney, Montana) 1980 water year.

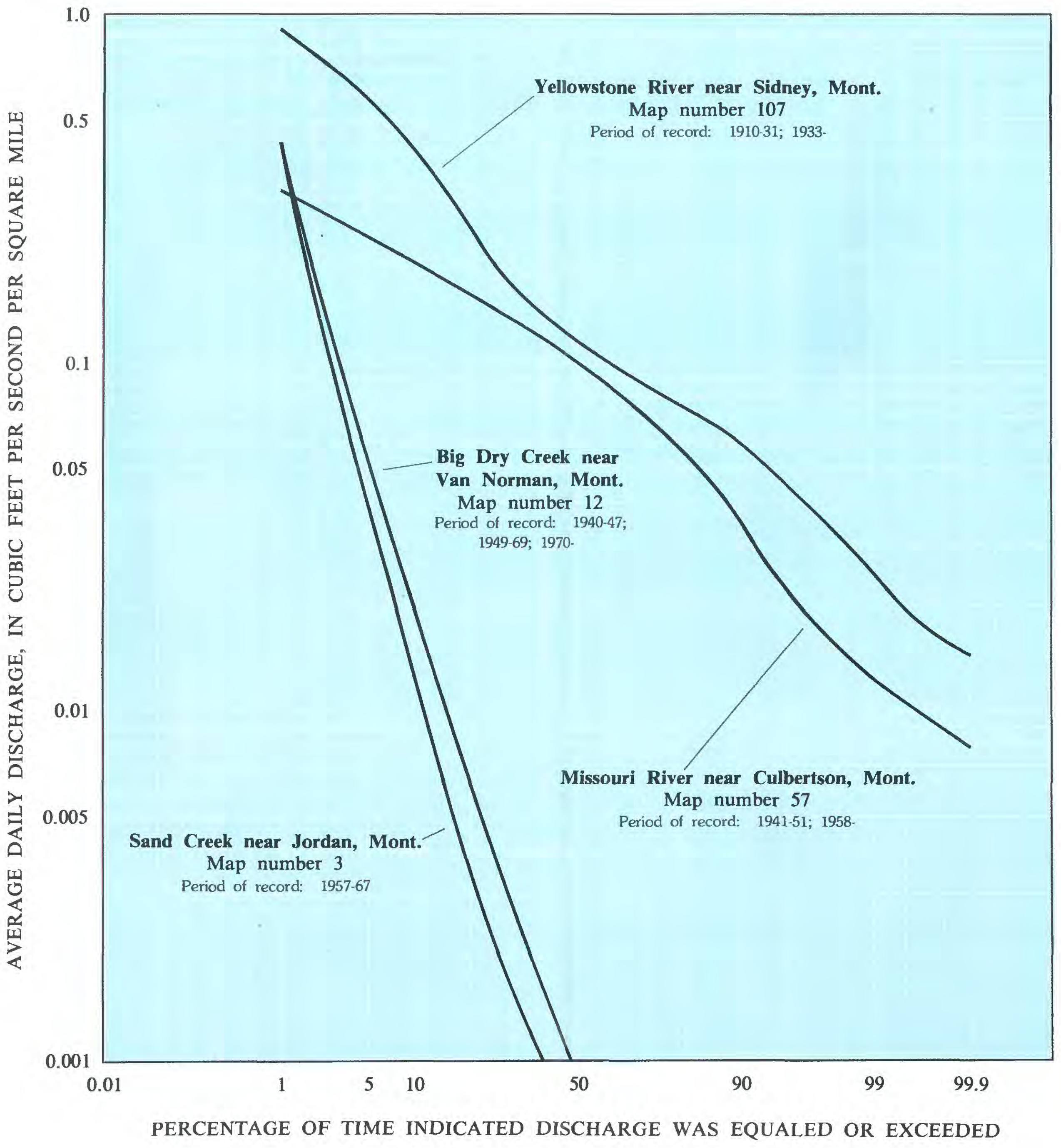


Figure 7.3-2 Flow-duration curves for selected streams.

Peak-Flow Data Presented for 26 Gaging Stations

Streamflow records were used to compute peak discharges and exceedance probabilities in the area.

Peak flows in the study area may result from snowmelt or rainfall. The Missouri and Yellowstone Rivers typically have their annual peak flows in June from mountain snowmelt outside the study area or from snowmelt mixed with rain. Annual peak flows on prairie streams may result from spring snowmelt in March and April or from summer thunderstorms in June through September. Most of the annual peak flows on prairie streams result from snowmelt, but the larger peak flows generally result from rainfall.

Peak-flow data normally are expressed using exceedance probabilities. An annual peak flow with an exceedance probability of 10 percent has a 10-percent chance of being exceeded in any given year. Exceedance-probability percentages are the reciprocals of the previously used "recurrence intervals." An exceedance probability of 10 percent is analogous to a recurrence interval of 10 years. An annual peak flow with a recurrence interval of 10 years can be expected to be exceeded, on the average, once in 10 years. Because recurrence intervals represent long-term averages, it is entirely possible to have annual peak flows with recurrence intervals of 10 and 25 years (exceedance probabilities of 10 and 4 percent) occurring in successive years, or even in the same year.

Computed peak flows for exceedance probabilities of 50, 10, 4, 2, and 1 percent for 26 gaging stations are presented in table 7.4-1. These stations have 10 or more years of record and are not subject to significant regulation or diversion of peak flows.

Interpretation and use of this table are best explained by examples. For instance, in row 4 of the column "50-percent exceedance probability" the value 2,700 means that for station 12, there is a 50-percent chance that the annual peak flow in any year will be greater than 2,700 cubic feet per second. Similarly, for the same station under the column "4-percent exceedance probability" the value 21,200 means that for station 12, there is a 4-percent chance that the annual peak flow in any year will be greater than 21,200 cubic feet per second.

Table 7.4-1 Peak discharge for specified exceedance probabilities at selected gaging stations.

			Discharge, in cubic feet per second for specified exceedance probability, in percent				
Station No. (fig. 6.3.1-1)	Station name	Drainage area (square miles)	50	10	4	2	1
4	Second Creek tributary near Jordan, Mont.	0.52	17	117	230	356	517
5	Second Creek tributary No. 2 near Jordan, Mont.	2.08	40	216	393	575	797
6	Second Creek tributary No. 3 near Jordan, Mont.	.72	14	113	224	345	502
12	Big Dry Creek near Van Norman, Mont.	2,554	2,700	12,800	21,200	29,600	39,000
28	East Fork Duck Creek near Brockway, Mont.	12.4	90	414	710	994	1,320
29	Duck Creek near Brockway, Mont.	54.0	206	1,030	1,800	2,550	3,400
31	Redwater River at Brockway, Mont.	216	480	2,240	3,770	5,220	6,820
33	Tusler Creek near Brockway, Mont.	90.2	152	834	1,460	2,030	2,690
34	Tusler Creek tributary near Brockway, Mont.	3.17	14	246	634	1,190	2,060
35	Redwater River tributary near Brockway, Mont.	.29	9	85	177	279	412
36	South Fork Dry Ash Creek near Circle, Mont.	5.74	33	159	286	398	535
37	McCune Creek near Circle, Mont.	29.9	107	809	1,530	2,280	3,170
38	Redwater River at Circle, Mont.	547	1,130	4,770	7,700	10,300	13,200
45	Cow Creek tributary near Vida, Mont.	1.71	71	464	860	1,270	1,760
49	Wolf Creek tributary near Vida, Mont.	.91	46	503	1,090	1,800	2,730
56	Missouri River tributary No. 3 near Culbertson, Mont.	1.23	19	356	922	1,740	2,980
68	O'Fallon Creek near Ismay, Mont.	669	1,230	4,410	6,820	8,960	11,400
69	O'Fallon Creek tributary near Ismay, Mont.	.17	29	63	86	106	131
70	Deep Creek near Baker, Mont.	1.55	102	179	234	286	348
72	Pennel Creek near Baker, Mont.	1.00	58	135	194	246	306
76	Yellowstone River tributary No. 4 near Fallon, Mont.	.67	64	196	310	421	546
79	Yellowstone River tributary No. 5 near Marsh, Mont.	.87	22	156	296	438	611
102	Indian Creek at Intake, Mont.	.46	13	100	186	271	374
103	War Dance Creek near Intake, Mont.	3.69	15	106	212	312	426
107	Yellowstone River near Sidney, Mont.	69,103	69,000	113,000	130,000	144,000	156,000
111	First Hay Creek near Sidney, Mont.	29.1	70	463	881	1,270	1,710

Peak-Flow Characteristics May Be Estimated for Ungaged Streams

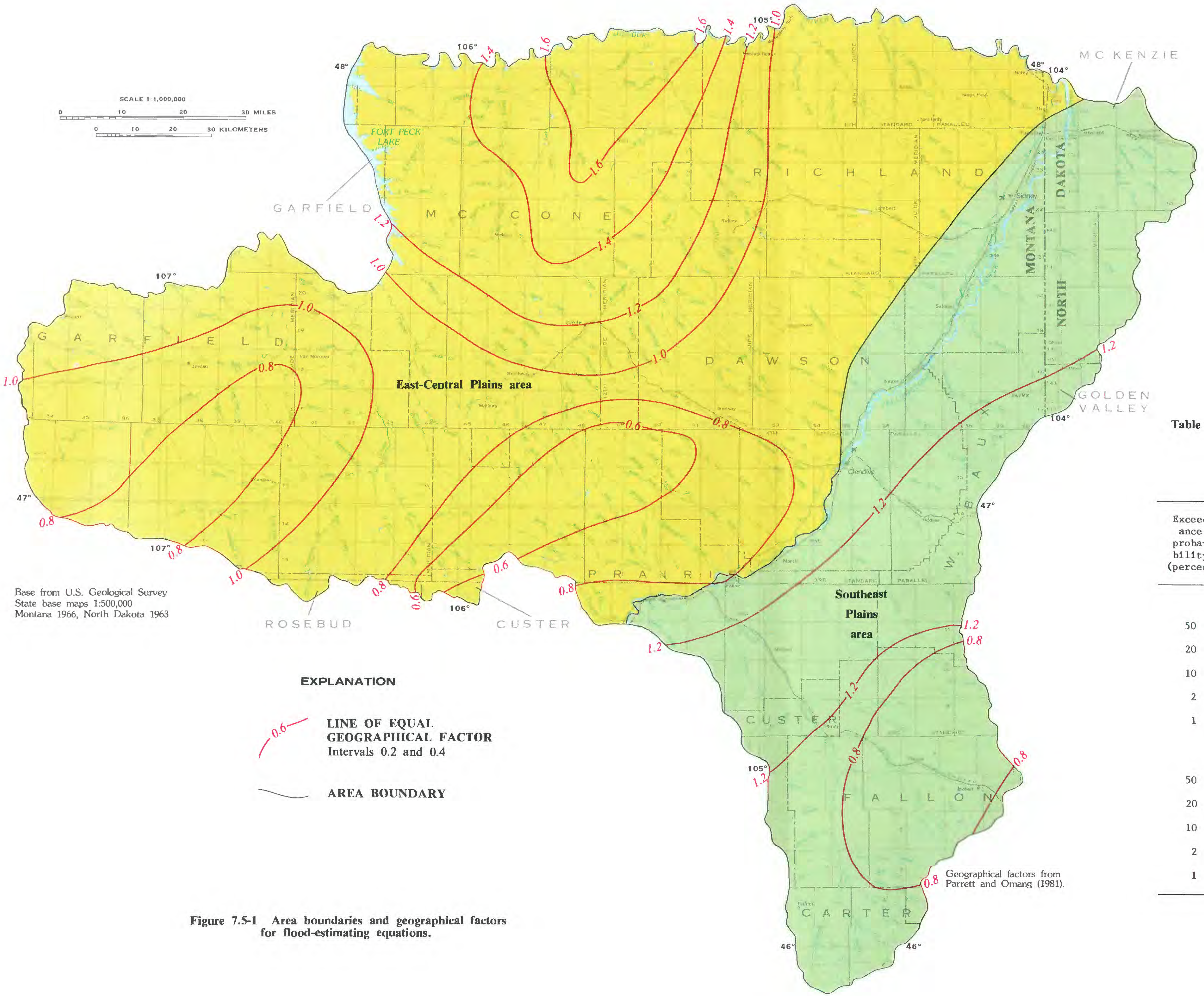
Multiple-regression equations for estimating peak flows for various exceedance probabilities have been developed for two geographic areas.

Multiple-regression equations recently have been developed for estimating flood peaks at ungaged stream sites within Area 45 (Parrett and Omang, 1981). The equations generally are applicable to unregulated streams where the drainage basins have not been altered significantly by man's activities. The equations thus may not be valid for areas where extensive surface mining occurs or to estimate impacts of mining.

The estimating equations were developed for different geographic areas. Within Area 45 two geographic areas are delineated, and two corresponding sets of equations are presented in table 7.5-1. In general, annual flood peaks are larger and more variable in the East-Central Plains area than in the Southeast Plains area. All equations use a geographical factor that must be obtained from the map. The area map (fig. 7.5-1) shows the boundaries of the two geographic areas and the geographical factors for each. The estimating equations are applicable to drainage areas of 0.04 to about 3,000 square miles.

To estimate peak flows for streams that cross the area boundary, the following weighting technique is used. First, compute the desired peak flow using the entire drainage area for each set of equations. Determine the proportion of drainage area that lies in each area and multiply the peak-flow estimate from each area by the corresponding proportion. Add the two flow estimates to obtain a final, weighted peak-flow estimate.

More detailed information on the use, accuracy, and limitations of the estimating equations is presented in the report by Parrett and Omang (1981). Other techniques for estimating flood peaks on the Yellowstone River and on streams where some streamflow-gaging data are available also are given by Parrett and Omang.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Geographical factors from Parrett and Omang (1981).

Figure 7.5-1 Area boundaries and geographical factors for flood-estimating equations.

Table 7.5-1 Regression equations for estimating peak discharge.

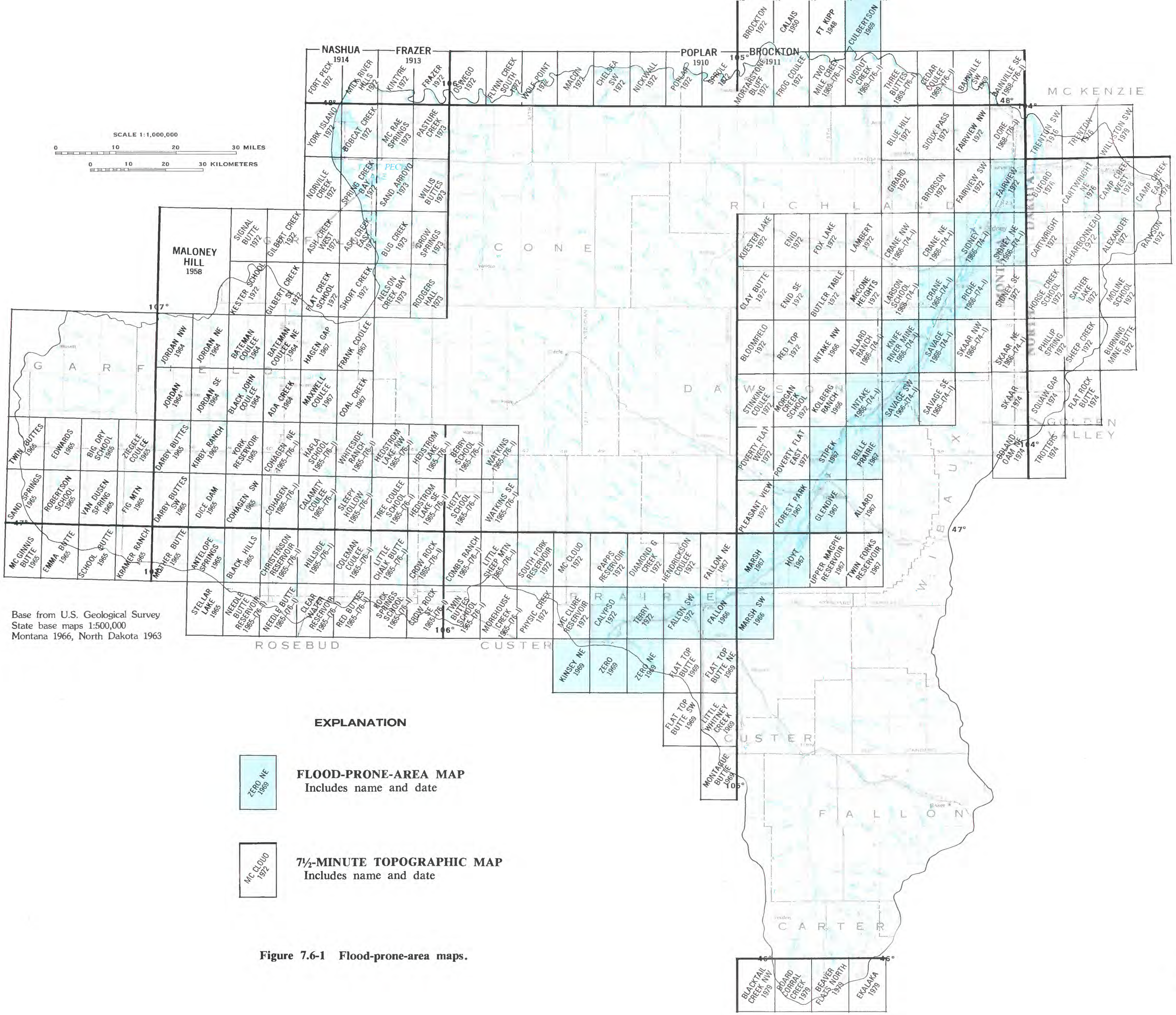
[Symbols: A, drainage area, in square miles; E, average basin elevation, in feet above sea level;- F, percentage of basin covered by forest; and G_f, geographical factor determined from figure 7.5-1]

Exceedance probability (percent)	Estimating equation for peak discharge (Q), in cubic feet per second	Standard error of estimate (percent)
	East-Central Plains area	
50	$Q = 117A^{0.56}(E/1000)^{-1.50}G_f$	77
20	$Q = 402A^{0.52}(E/1000)^{-1.42}G_f$	58
10	$Q = 681A^{0.50}(E/1000)^{-1.31}G_f$	66
2	$Q = 1{,}460A^{0.47}(E/1000)^{-0.99}G_f$	74
1	$Q = 1{,}750A^{0.45}(E/1000)^{-0.82}G_f$	83
	Southeast Plains area	
50	$Q = 360A^{0.59}(F+10)^{-0.98}G_f$	105
20	$Q = 1{,}010A^{0.58}(F+10)^{-0.99}G_f$	77
10	$Q = 1{,}320A^{0.56}(F+10)^{-0.91}G_f$	72
2	$Q = 2{,}340A^{0.54}(F+10)^{-0.81}G_f$	69
1	$Q = 2{,}770A^{0.53}(F+10)^{-0.76}G_f$	71

Flood-Prone-Area Maps Available

Flood-prone areas have been delineated on 24 7½-minute topographic maps within the area.

The National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 established programs for identifying towns and streams subject to flooding and for delineating flood-prone areas on topographic maps. As of 1981, the area inundated by the 1-percent exceedance probability flood (100-year flood) has been delineated for selected streams on 24 7½-minute topographic quadrangle maps within Area 45. The delineations were based upon existing flood-depth data from streamflow-gaging station records and miscellaneous flood measurements. Flood-prone maps available in the area are indicated on the index map of topographic quadrangles (fig. 7.6-1). These maps, prepared by the U.S. Geological Survey, are available from the Montana Bureau of Mines and Geology, Montana College of Mineral Science and Technology, Butte, Montana 59701.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Figure 7.6-1 Flood-prone-area maps.

Dissolved-Solids Concentration Greatest During Base Flow

Dissolved-solids concentrations vary with streamflow conditions at individual stations, as well as from stream to stream.

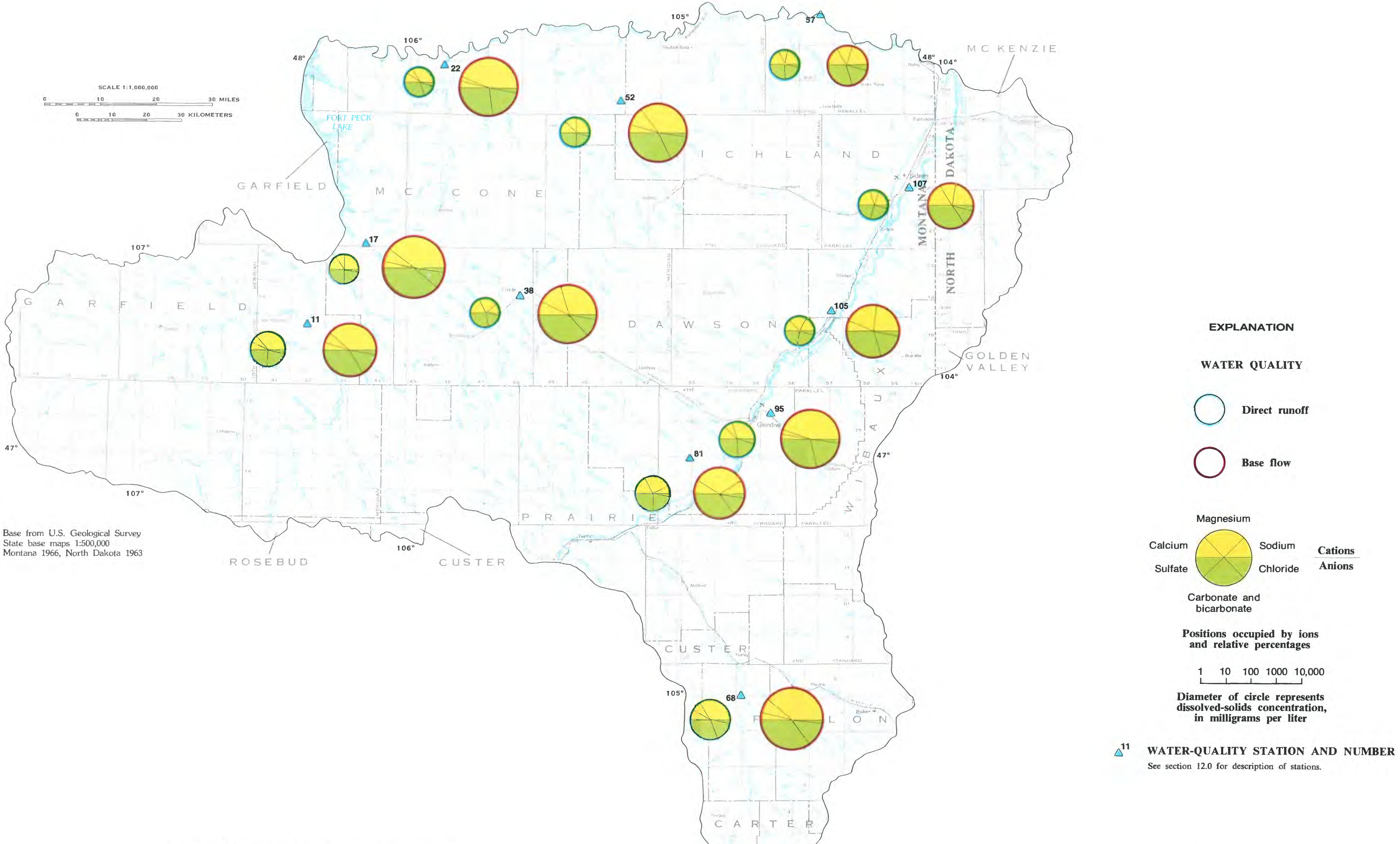
Dissolved solids is the sum of all constituents dissolved in water. Most dissolved solids occur as ions in natural water, with those composing the largest percentage of the dissolved-solids content referred to as major ions. The major ions in solution in streams are derived primarily from the leaching of soluble minerals from soils and geologic strata underlying the drainage basin. The most prevalent ions in the surface waters of the study area are the cations calcium, magnesium, and sodium, and the anions bicarbonate, sulfate, and chloride.

The concentration and composition of dissolved solids vary during the year as a result of fluctuating streamflow conditions, which range from base flow to direct runoff. The base-flow component of streamflow is composed primarily of ground water that has entered the stream channel. Ground water typically has long contact with minerals in the aquifer. Consequently, large concentrations of dissolved solids generally are associated with base flows. During periods of base flow, concentrations commonly ranged from 1,000 to 3,000 milligrams per liter, and at times exceeded 5,000 milligrams per liter. Sodium and sulfate generally are the dominant ions in base flow.

In contrast to base flow, direct runoff from rainfall or snowmelt typically has much smaller concentrations of dissolved solids. During direct runoff, water is routed quickly into stream channels with little opportunity for leaching of minerals from the soil. The larger quantities of water present during runoff have a diluting effect on dissolved-solids concentrations. During direct runoff, concentrations generally ranged from 150 to 600 milligrams per liter at most stations. At times of medium and large streamflows, the relative percentages of calcium and bicarbonate increased, occasionally approaching and sometimes exceeding the ionic percentages of sodium and sulfate. Magnesium commonly was present in significant quantities, and varied less with streamflow than the other cations. Chloride composed only a small fraction of the anions at all magnitudes of streamflow.

Areal comparisons indicate somewhat similar ranges in dissolved-solids concentrations for most stations (fig. 8.1-1). However, differences in the ionic composition of dissolved solids among stations are more evident. Areal differences in concentration and ion composition of dissolved solids are attributed mostly to differences in lithology, soil type, or land-use practices. Stations located on streams in the western one-half of the study area that drain into the Missouri River generally have larger percentages of sodium than other cations. Those streams draining into the Yellowstone River have large percentages of magnesium which, for station 81, is the dominant cation during base flows.

In addition to the factors previously mentioned, other natural and artificial conditions tend to affect the temporal and areal variability of dissolved solids. Evaporation and transpiration, chemical reactions with sediment, and aquatic biota all cause changes. In addition, the many impoundments and diversions for agricultural purposes can affect the dissolved solids to varying degrees.



Base from U.S. Geological Survey
State base maps 1:500,000
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Figure 8.1-1 Dissolved solids for selected stations during typical direct-runoff and base-flow conditions.

Specific Conductance Can Be Used to Estimate Dissolved-Solids Concentration

Paired values of specific conductance and dissolved-solids concentration were used to develop regression equations for calculating dissolved-solids loads.

Specific conductance is a measure of the ability of water to conduct an electrical current as a result of the ionized material in solution. Therefore, specific conductance gives an indication of the concentration of ions (dissolved solids) in the water. Because measurements can be made easily and inexpensively onsite or in the laboratory, specific-conductance determinations have been used extensively. Specific conductance was measured each time a water sample was collected for chemical analysis. In addition, daily measurements of specific conductance were made at several stations on the Missouri and Yellowstone Rivers.

Specific-conductance measurements are valuable to many water-quality studies, because of the generally significant correlation of specific-conductance values with concentrations of dissolved solids and many of the individual ions that compose dissolved solids. Paired values of specific conductance and dissolved-solids concentration from routine samples were used to develop linear regression equations for most stations. The form of the regression equation is as follows:

$$Y = a + bX \qquad (1)$$

where: Y = dissolved-solids concentration, in milligrams per liter (dependent variable), a = regression constant (y-axis intercept), b = regression coefficient (slope), and X = specific conductance, in micromhos per centimeter at 25° Celsius (independent variable).

Graphical displays of the regression equations are presented for selected small streams (fig. 8.2-1) and for the Missouri and Yellowstone Rivers (fig. 8.2-2). The graphs can be used to estimate dissolved-solids concentrations from a simple measurement of specific conductance.

For stations where daily measurements of specific conductance were made, the values can be converted to daily dissolved-solids concentrations by use of the regression equation developed for that station. Daily concentrations can be transformed further into mean daily dissolved-solids loads, in tons, using the following equation:

$$L_{DS} = Q\,C_{DS}K \qquad (2)$$

where: L_{DS} = dissolved-solids load, in tons per day; Q = average daily stream discharge, in cubic feet per second; C_{DS} = dissolved-solids concentration, in milligrams per liter; and $K = 0.0027$, a units conversion factor.

The summation of daily loads provides a means for determining monthly and annual loads of dissolved solids. Calculated monthly loads for stations where specific conductance was measured daily are compared in figure 8.2-3.

The methods described above for calculating dissolved-solids loads also can be used to determine loads of individual constituents of interest. The knowledge of how constituent loads vary in response to changing land-use practices or streamflow conditions is of importance in assessing water-quality impacts. Comparisons of loads through time can enable detection of trends associated with such developments as coal mining, agriculture, and industry. In addition, load information is essential in developing accurate stream models for predicting impacts from various land-use management plans.

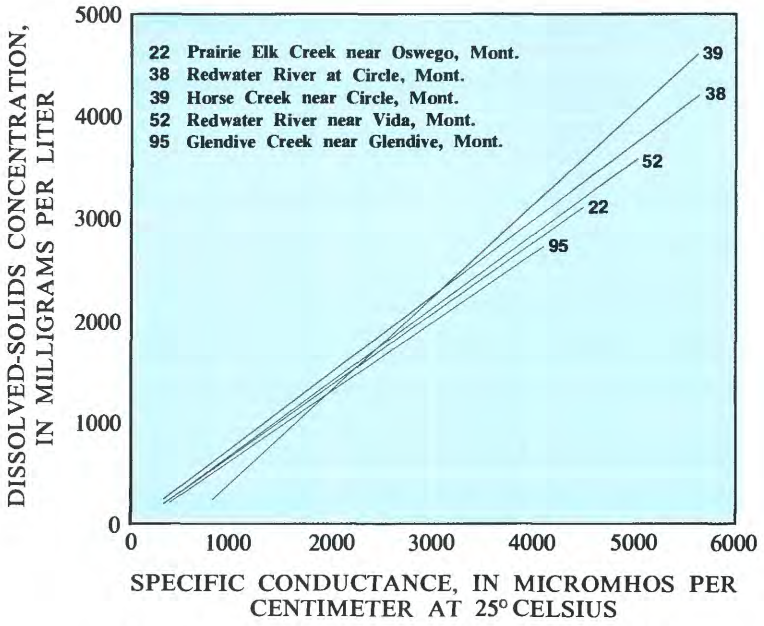


Figure 8.2-1 Relationship between specific conductance and dissolved-solids concentration for selected stations on small streams.

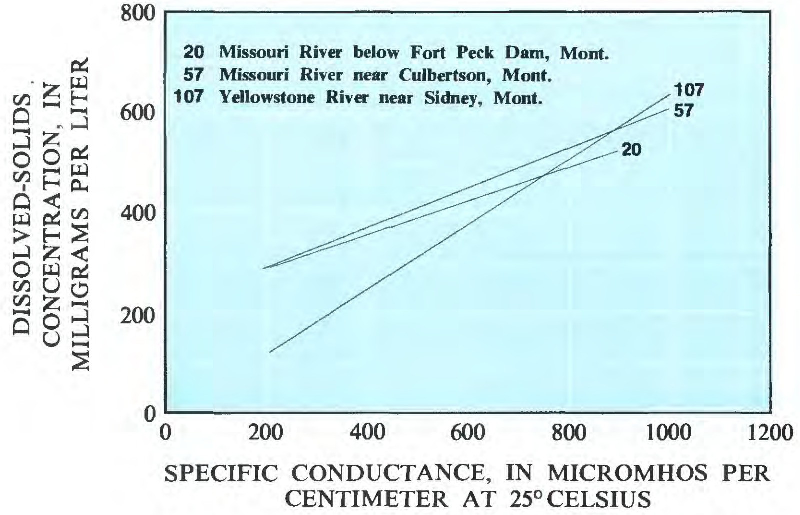
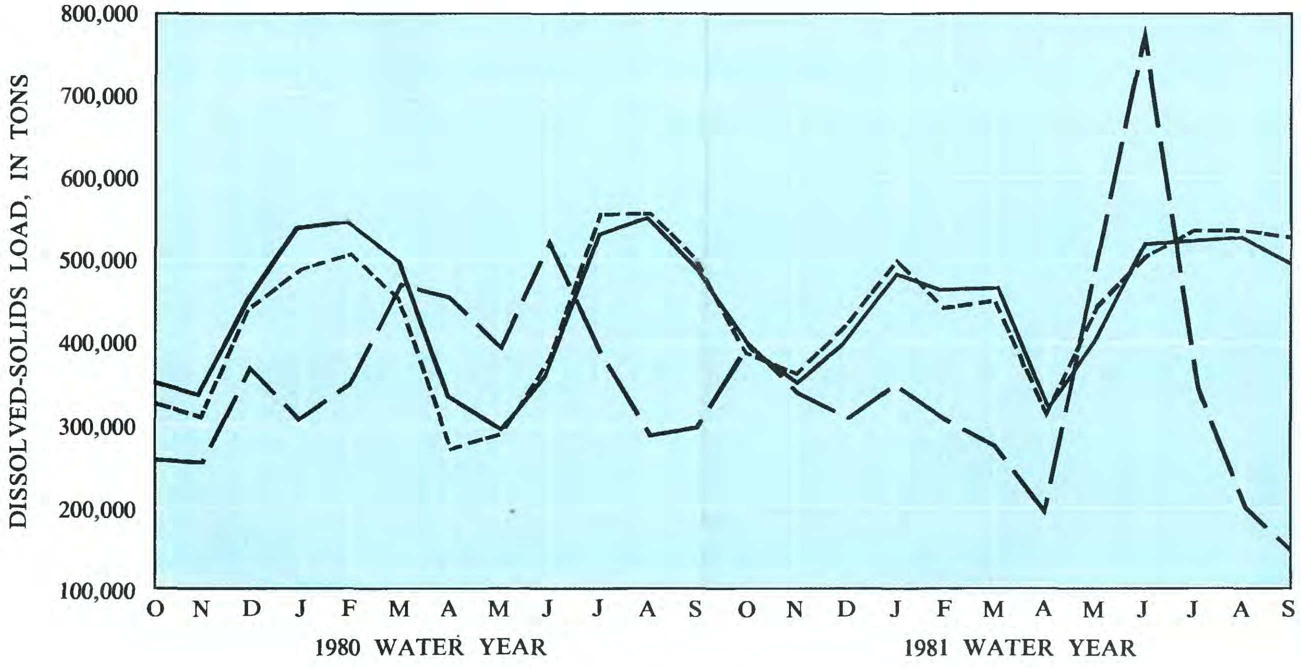


Figure 8.2-2 Relationship between specific conductance and dissolved-solids concentration for selected stations on the Missouri and Yellowstone Rivers.



EXPLANATION

STATION NUMBER AND NAME

- - - - 20 Missouri River below Fort Peck Dam, Mont.

—— 57 Missouri River near Culbertson, Mont.

— — 107 Yellowstone River near Sidney, Mont.

Figure 8.2-3 Monthly dissolved-solids loads, in tons, at selected stations for the 1980 and 1981 water years.

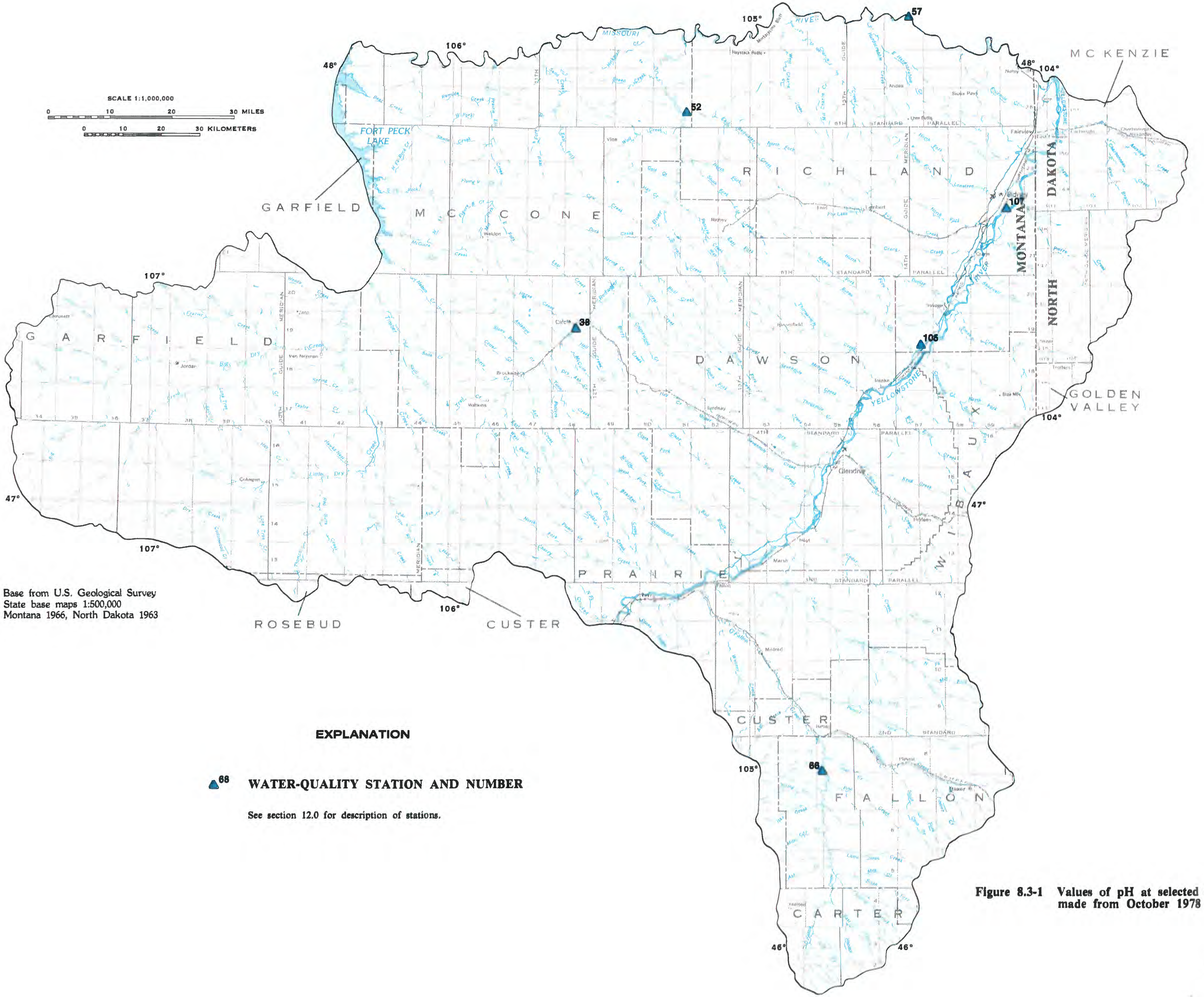
Streamflow pH Variable But Generally in Near-Neutral Range

Stream pH ranges from 7.2 to 9.5 and is caused mostly by natural conditions.

The effective concentration of hydrogen ions in dilute solution generally is expressed as pH. The pH of a neutral solution is 7, with smaller values indicating acidic conditions and larger values indicating basic conditions. Carbon dioxide in the atmosphere generally causes rain and snow to be slightly acidic. Water percolating through subsurface materials can undergo extensive pH changes depending on the type of minerals present. River water in areas not affected by pollution generally has a pH between 6.5 and 8.5 (Hem, 1970). However, pH values can be somewhat larger than 8.5 during times of photosynthesis by aquatic plants when carbon dioxide is removed from solution. Values less than 6.5 may sometimes result from industrial activities, including coal mining, in which the oxidation of iron sulfides and subsequent reactions create acid conditions.

Measured pH values in the study area ranged from 7.2 to 9.5. Variations that occurred at individual stations throughout the annual flow cycle are shown in figure 8.3-1. The smaller pH values generally were associated with direct-runoff water that was affected by the acidic nature of rain and snow. Larger pH values commonly were measured during base flow when the water consisted primarily of ground-water seepage. Photosynthesis by aquatic plants throughout the summer also accounted for increases in pH.

Mining is presently (1983) conducted on a small scale in the study area, and no evidence was found that mining activities had any significant effects on pH in streams. Alkalinities of streams in the study area generally are large, thereby providing a considerable buffering capacity to neutralize small volumes of acid effluent that might be discharged into streams. Expanded mining operations, however, could produce effluent, both overland flow or ground water, in volumes sufficient to alter pH values of streams in the study area.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

EXPLANATION

▲68 **WATER-QUALITY STATION AND NUMBER**

See section 12.0 for description of stations.

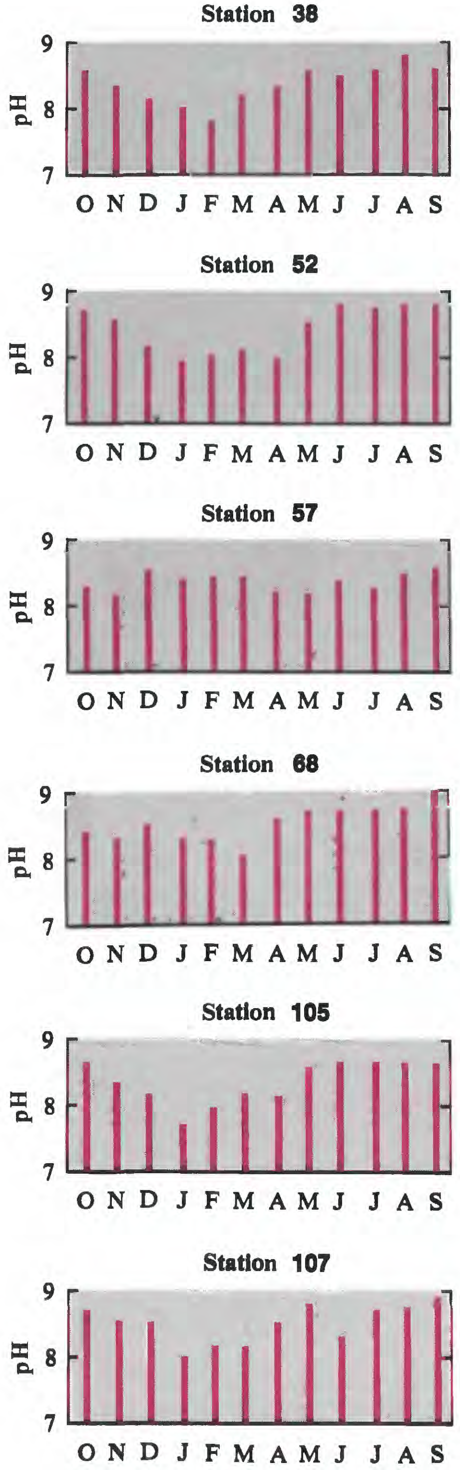


Figure 8.3-1 Values of pH at selected stations for monthly measurements made from October 1978 to September 1979.

Concentrations of Trace Elements Occasionally Exceeded Water-Quality Standards

The near-neutral pH of the streams is an important factor in maintaining generally small concentrations of dissolved trace elements.

Trace elements are substances that generally occur in small concentrations compared to the major ions. Although many trace elements can be toxic, some are essential to plants and animals in small concentrations. Natural sources of trace elements are soils, geologic strata, and normal atmospheric fallout. Large concentrations can occur naturally in streams, but more commonly they are associated with industrial-waste discharges, including water from coal mining. The oxidation of pyritic minerals present in coal mines and mine spoils can produce acid water, which may dissolve certain minerals to produce large concentrations of trace elements.

In addition to being transported in the dissolved state, trace elements can be attached to sediment particles and transported downstream in the suspended phase. Concentrations of trace elements analyzed from an unfiltered water-sediment mixture include both the dissolved and suspended phases and are referred to as total-recoverable concentrations. Analysis of stream water that has been filtered to remove sediment particles provides concentrations of trace elements that are, by convention, defined as being in the dissolved state (table 8.4-1). Analyses typically were made for both total-recoverable and dissolved concentrations of selected trace elements. The location of selected stations with trace-element analyses is shown in figure 8.4-1.

Several standards have been established listing maximum concentrations of trace elements that can be tolerated for various water uses. Common standards used to judge domestic water supplies are Primary Drinking Water Standards (U.S. Environmental Protection Agency, 1977) and Secondary Drinking Water Standards (U.S. Environmental Protection Agency, 1979). Standards also exist for some trace elements that are of concern in water used for irrigation of crops, for livestock watering, and for maintenance of a healthy habitat for aquatic life.

Concentrations of dissolved trace elements in some samples in Area 45 exceeded standards. The Secondary Drinking Water Standard for iron was surpassed at several stations at times of maximum concentrations, which typically occurred during base flow. However, large concentrations of dissolved iron are a common occurrence for many streams in eastern Montana. Boron is of concern in water used for continual irrigation of crops. Injury to plants is dependent on the boron concentration of the applied water, crop tolerance to boron, and soil texture. Although standards for several other trace elements were exceeded for short intervals at some locations, the effect on most water uses is seldom serious. Water pH, being a primary control for dissolution of many trace elements, was always larger than 7. This condition is an important factor in maintaining generally small concentrations of dissolved trace elements. The largest concentrations of most trace elements were from unfiltered samples in which the elements sorbed onto sediment particles. Correlation generally was good between concentrations of suspended sediment and total-recoverable trace elements in streams.

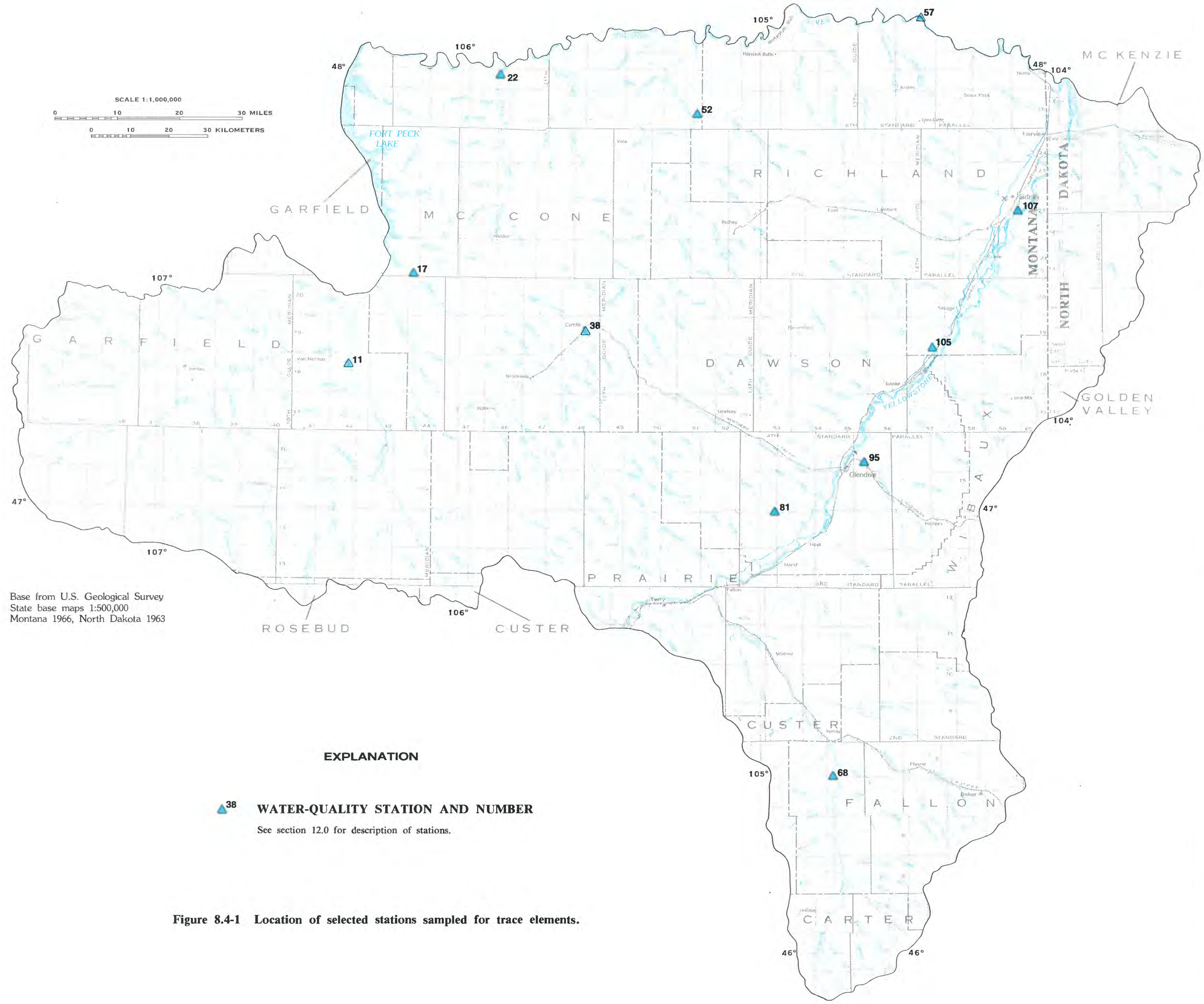


Figure 8.4-1 Location of selected stations sampled for trace elements.

Table 8.4-1 Summary of trace-element concentrations measured at selected stations.

[Constituents are dissolved and concentrations are in micrograms per liter. Number in parentheses beneath trace element is the limit specified by the footnote reference. Symbol <, less than.]

Station No. (fig. 8.4-1)	Number of samples	Concentration Minimum	Concentration Maximum	Number of samples	Concentration Minimum	Concentration Maximum
		Arsenic [1](50)			Boron [2](1,000)	
11	9	1	1	9	120	360
17	9	1	2	26	70	1,400
22	11	1	4	46	60	1,000
38	15	0	4	78	110	970
52	18	1	5	69	80	600
57	30	1	4	2	90	140
68	13	1	2	37	20	1,000
81	7	1	2	17	90	360
95	10	1	5	32	50	2,000
105	14	1	3	46	20	510
107	28	1	6	31	40	340
		Cadmium [1](10)			Chromium [3](50)	
11	9	0	<2	9	0	<20
17	9	0	9	9	0	<20
22	10	0	4	11	0	<20
38	14	0	6	15	0	<20
52	17	0	8	18	0	<20
57	30	0	8	30	0	<20
68	12	0	10	13	0	10
81	7	0	4	7	0	5
95	10	0	9	10	0	30
105	14	0	8	14	0	<20
107	28	0	11	28	0	20
		Iron [3](300)			Lead [1](50)	
11	9	10	510	9	0	5
17	25	20	460	9	0	9
22	43	10	840	10	0	6
38	78	10	270	14	0	14
52	69	10	320	17	0	29
57	55	9	980	30	0	12
68	37	10	210	10	0	100
81	17	10	70	7	0	36
95	31	40	2,000	10	0	16
105	46	10	290	14	0	8
107	71	10	2,700	28	0	15
		Mercury [1](2)			Selenium [1](10)	
11	9	<.5	<.5	9	1	1
17	9	<.1	<.5	9	<1	2
22	9	<.1	<.5	11	<1	5
38	15	<.1	<.5	14	0	2
52	18	<.1	<.5	18	0	1
57	29	0	.7	30	0	2
68	13	0	.3	13	0	2
81	7	0	.1	7	0	3
95	10	0	.6	10	<1	2
105	14	<.1	<.5	14	<1	3
107	27	0	.7	28	0	4
		Zinc [2](5,000)				
11	9	0	20			
17	9	<20	30			
22	11	<20	130			
38	15	0	430			
52	18	0	20			
57	30	0	30			
68	13	3	33			
81	7	0	20			
95	10	0	40			
105	14	0	30			
107	28	0	70			

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[1] U.S. Environmental Protection Agency (1977) primary drinking water standards.

[2] U.S. Salinity Laboratory Staff (1954) irrigation water standards.

[3] U.S. Environmental Protection Agency (1979) secondary drinking water standards.

Suspended-Sediment Concentrations Vary Substantially Throughout the Study Area

Suspended-sediment concentrations fluctuate in response to stream discharge and sediment availability within the drainages.

Sediment transported by streams is derived from a combination of channel scour and soil erosion from overland runoff. Soils in the study area are shallow and range from sandy to silty loams. Erodability of soils depends largely on grain size and topographic relief. In addition, vegetation cover, season, rainfall intensity, and agricultural and industrial practices affect the availability of sediment for transport. Fine sediment particles are easily suspended by the fluid forces in natural streams and tend to be removed from the basin (Guy, 1970). In contrast, coarse sediment particles resist suspension and may be transported only short distances during high flows or in reaches of sufficient velocity. Generally, more than 90 percent of the suspended material in the study area is smaller than sand (less than 0.062 millimeter in diameter).

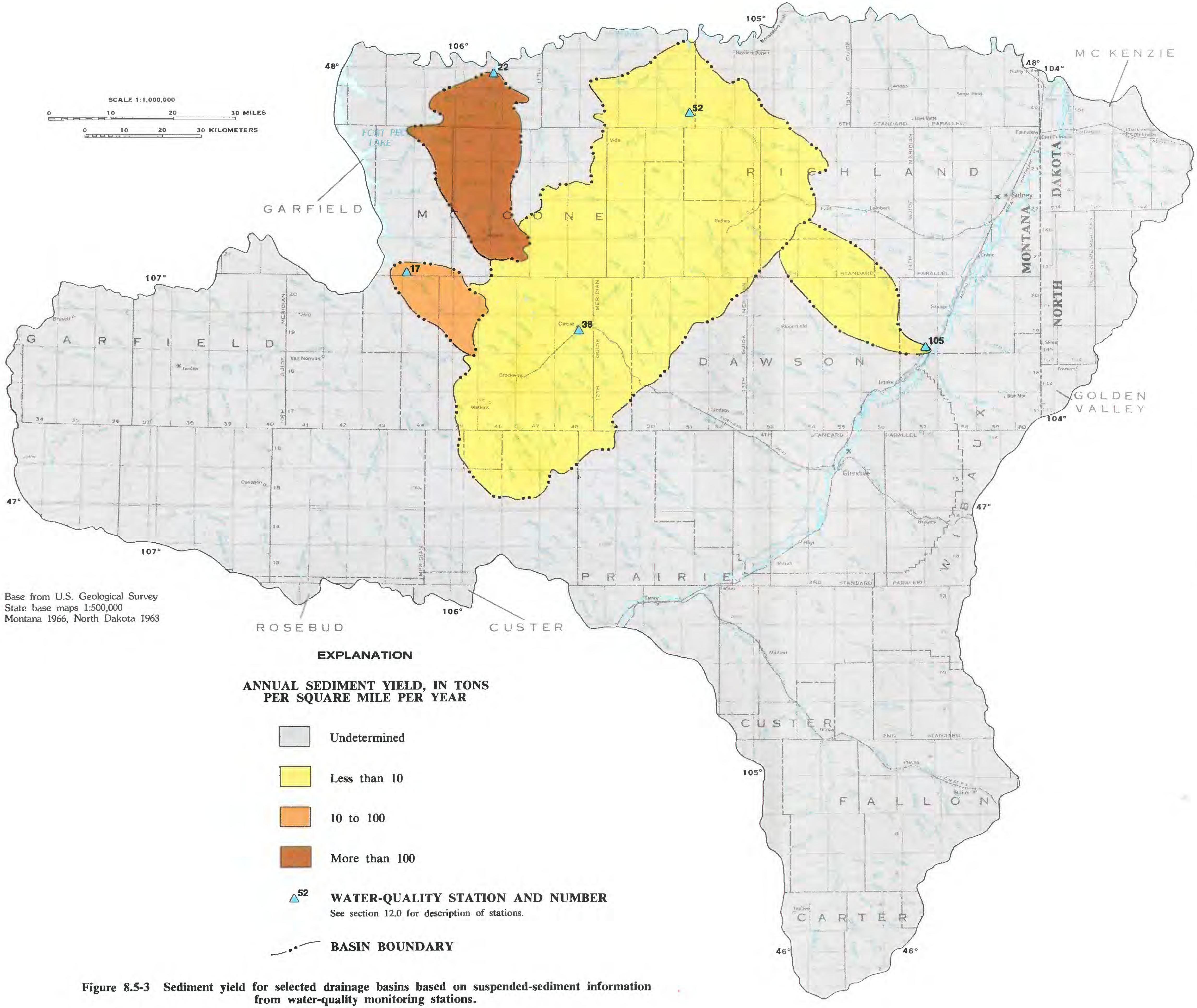
Concentrations of suspended sediment measured in the study area ranged from 2 to 23,000 milligrams per liter and were indicative of the large variation in sediment availability and discharge throughout the annual flow cycle. Maximum concentrations of suspended sediment were measured at times of direct runoff, when both channel scour and soil erosion contributed sediment to the streams. Minimum concentrations generally were measured during base flow or during snowmelt runoff over partly frozen surfaces.

Sediment transport in the smaller streams is affected greatly by the pool and riffle nature of the channels. Pools function as sediment traps during low flows but can be flushed during high flows. The small frequency of flows large enough to transport available sediment supplies, however, indicates that net deposition probably is occurring in most of the small streams. Large rivers reflect the accumulation of transported sediment (called sediment load or discharge) from numerous tributaries and generally have flows capable of maintaining much of the incoming sediment in suspension.

The variation in sediment load with stream discharge commonly is shown by sediment-transport curves. The slope of each line indicates the degree of sediment availability, and the position on the graph indicates the relative load transported at a given discharge. The sediment-transport curves for small streams (fig. 8.5-1) show relatively similar slopes for all stations, with the two distinct groupings possibly resulting from flow characteristics and regional variation in geology and soil type. In figure 8.5-2, the downstream increase in sediment loads for a given discharge is most obvious for the Missouri River near Culbertson (station 57), where sediment from tributaries and channel scour adds significantly to the relatively small sediment loads of the Missouri River downstream from Fort Peck Dam (station 20). The small quantity of available sediment downstream from the reservoir, as a result of deposition in the reservoir, is illustrated in figure 8.5-2 by the less-steep slopes of the curves of the Missouri River (stations 20 and 57) compared to those of the Yellowstone River (stations 60 and 107).

Dividing the sediment load by drainage area gives sediment yield, in tons per square mile. In many instances, sediment yields can indicate the effects of land disturbance. Average annual sediment yields for small drainages where adequate data were available are presented geographically in figure 8.5-3. Yields vary widely as a result of differences in sediment availability within the basins and in stream discharges capable of flushing sediment from the channel.

Federal mining laws specify that mine discharges contain less than 45 milligrams per liter of suspended sediment. Naturally occurring average concentrations for many of the area streams presently exceed this value. Consequently, significant increases in the sediment yields of the basins would not be expected to occur from properly designed surface coal mines or mine-related activities. Prevailing flow conditions of receiving steams and the quantity and quality of effluent discharged will be major factors controlling the severity of potential sediment problems.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Figure 8.5-3 Sediment yield for selected drainage basins based on suspended-sediment information from water-quality monitoring stations.

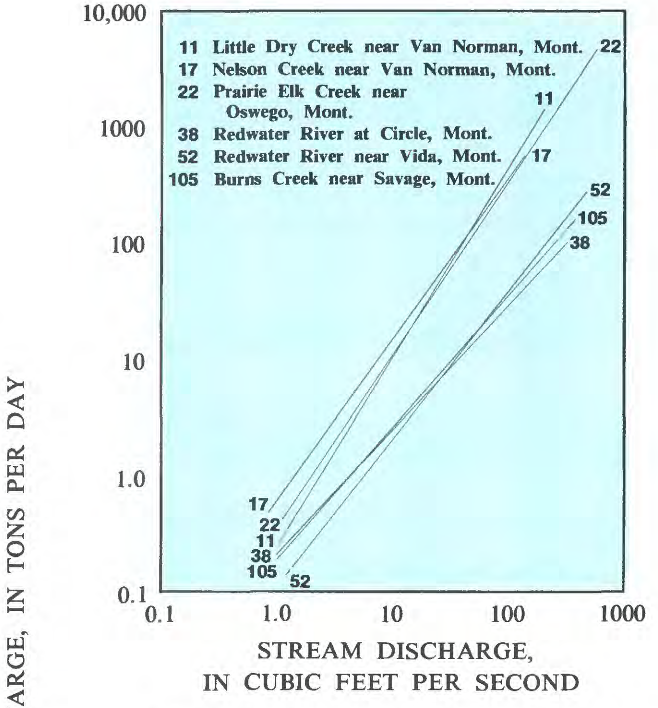


Figure 8.5-1 Relationship between stream discharge and suspended-sediment discharge at selected stations on small streams.

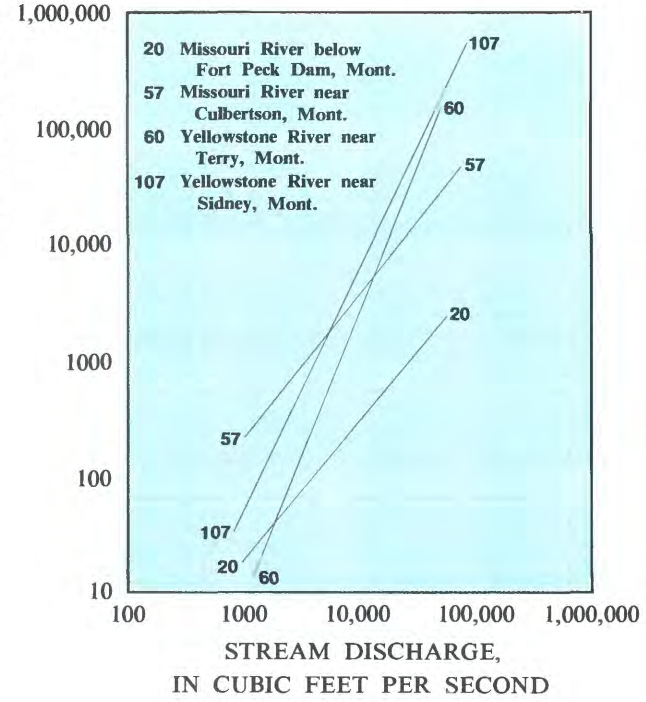


Figure 8.5-2 Relationship between stream discharge and suspended-sediment discharge at selected stations on the Missouri and Yellowstone Rivers.

Phytoplankton Community is Variable Areally and Temporally

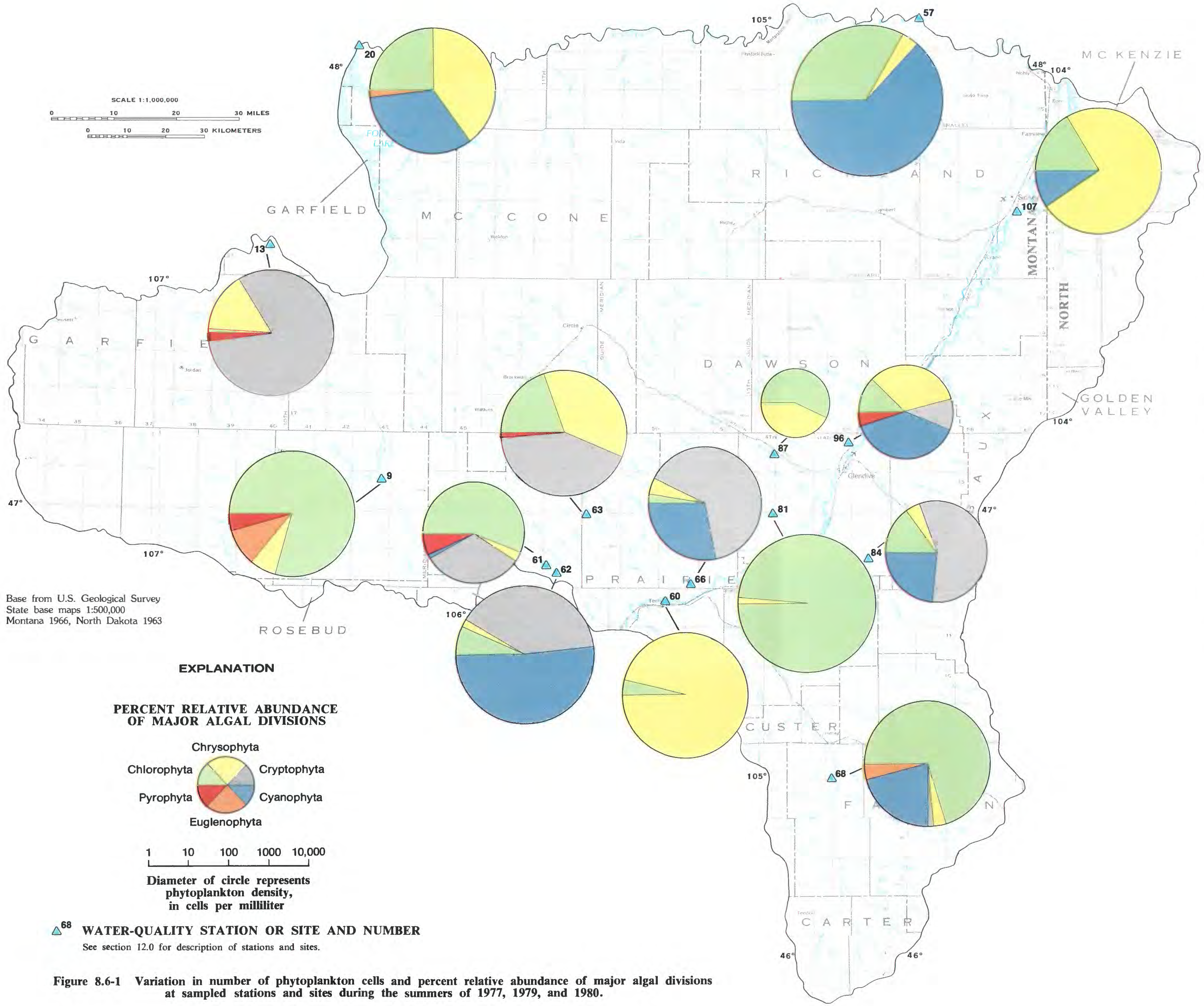
Phytoplankton concentrations range from 0 to 140,000 cells per milliliter.

Community structures, associations, and diversities of aquatic organisms are used as indicators of water quality (Greeson, 1982). With emphasis on preservation of environmental quality, a need exists for a long-term data base of aquatic organisms from which water-quality changes can be detected. State and Federal programs support several sampling networks for the collection of benthic invertebrates (aquatic insects), periphyton (attached algae), and phytoplankton (free-floating algae). In Area 45 the most extensively sampled aquatic organisms are phytoplankton.

As an example of summer phytoplankton distributions in Area 45, concentrations and percent relative abundance of major algae divisions are shown in figure 8.6-1. The reservoir samples were collected in August 1980 and the stream samples were collected in June 1979, except for one station (station 60), which was sampled in June 1977. In terms of algal plant diversity and production, periphyton are most important in small streams, whereas phytoplankton are most important in lakes and the downstream reaches of large rivers (Bahls and others, 1981). The importance of phytoplankton in lakes and large streams in Area 45 is evidenced by the large phytoplankton concentrations collected from the Missouri River near Culbertson (station 57) and Grant Reservoir near Terry (site 62). The smallest phytoplankton concentrations were from the small streams, Upper Sevenmile Creek near Lindsay (station 87) and Deer Creek near Glendive (station 96).

The relative abundance of major algal divisions is variable. In the streams, Chlorophyta (green algae), Chrysophyta (includes diatoms), and Cyanophyta (blue-green algae) compose the largest percentage of phytoplankton. In the reservoirs, the largest percentage of phytoplankton is composed of Cryptophyta (cryptomonads) and either Chlorophyta, Cyanophyta, or Chrysophyta. The cryptomonads in the reservoirs might exist in such large concentrations compared to the other divisions because of their ability to thrive during cold periods of the year under conditions of relatively little light (Wetzel, 1975). Paucity of cryptomonads in the streams generally is characteristic of streams in the United States (Greeson, 1982).

The phytoplankton community is variable temporally as well as areally. The changes in phytoplankton concentrations in the Missouri River (station 20) and the Yellowstone River (station 60) exemplify the fluctuations that occur with time (fig. 8.6-2). Phytoplankton concentrations are affected by several environmental factors, including temperature changes, nutrient availability, phytoplankton input from tributary streams, and light availability. These factors differ with time at various locations, which accounts for the large variation in phytoplankton distributions and erratic fluctuations in concentration shown in figure 8.6-2.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Figure 8.6-1 Variation in number of phytoplankton cells and percent relative abundance of major algal divisions at sampled stations and sites during the summers of 1977, 1979, and 1980.

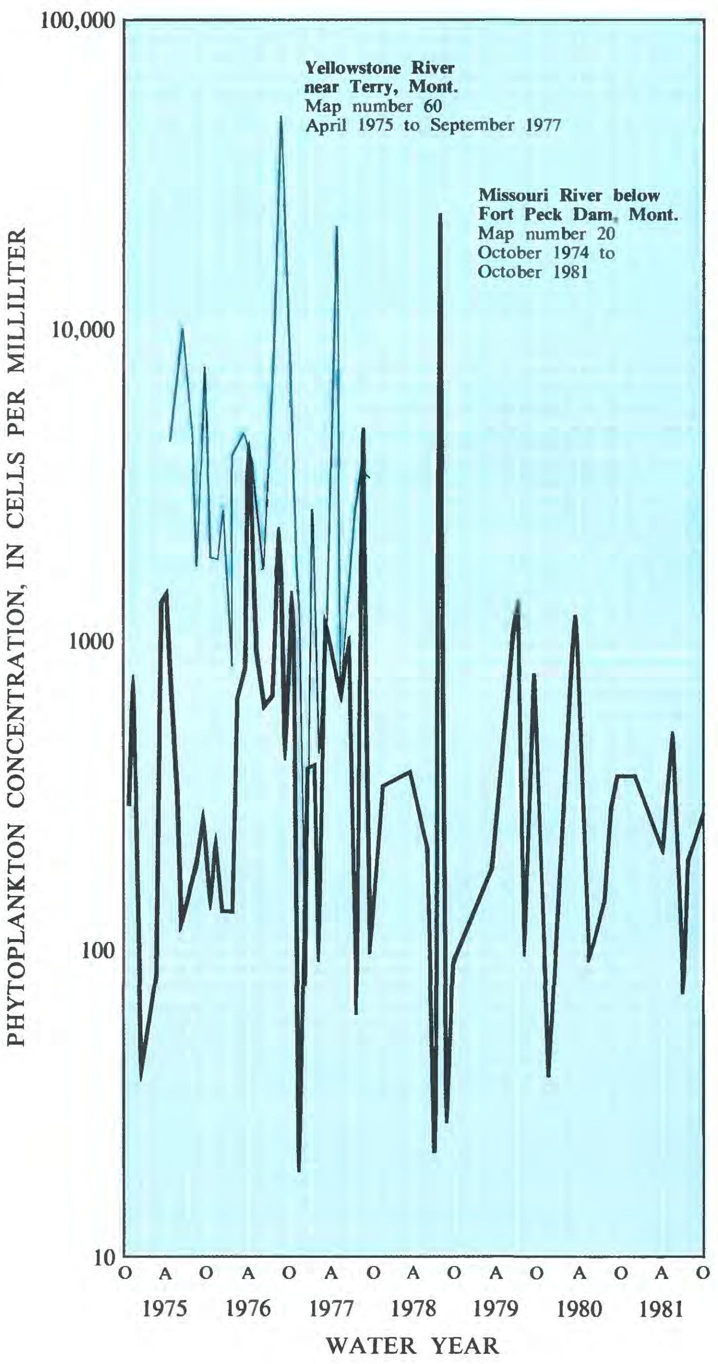


Figure 8.6-2 Variation in phytoplankton concentration in the Missouri and Yellowstone Rivers.

Sand, Gravel, Sandstone, Clinker, and Coal Beds Provide Water

Most of the wells produce water from alluvium or the Tongue River aquifer.

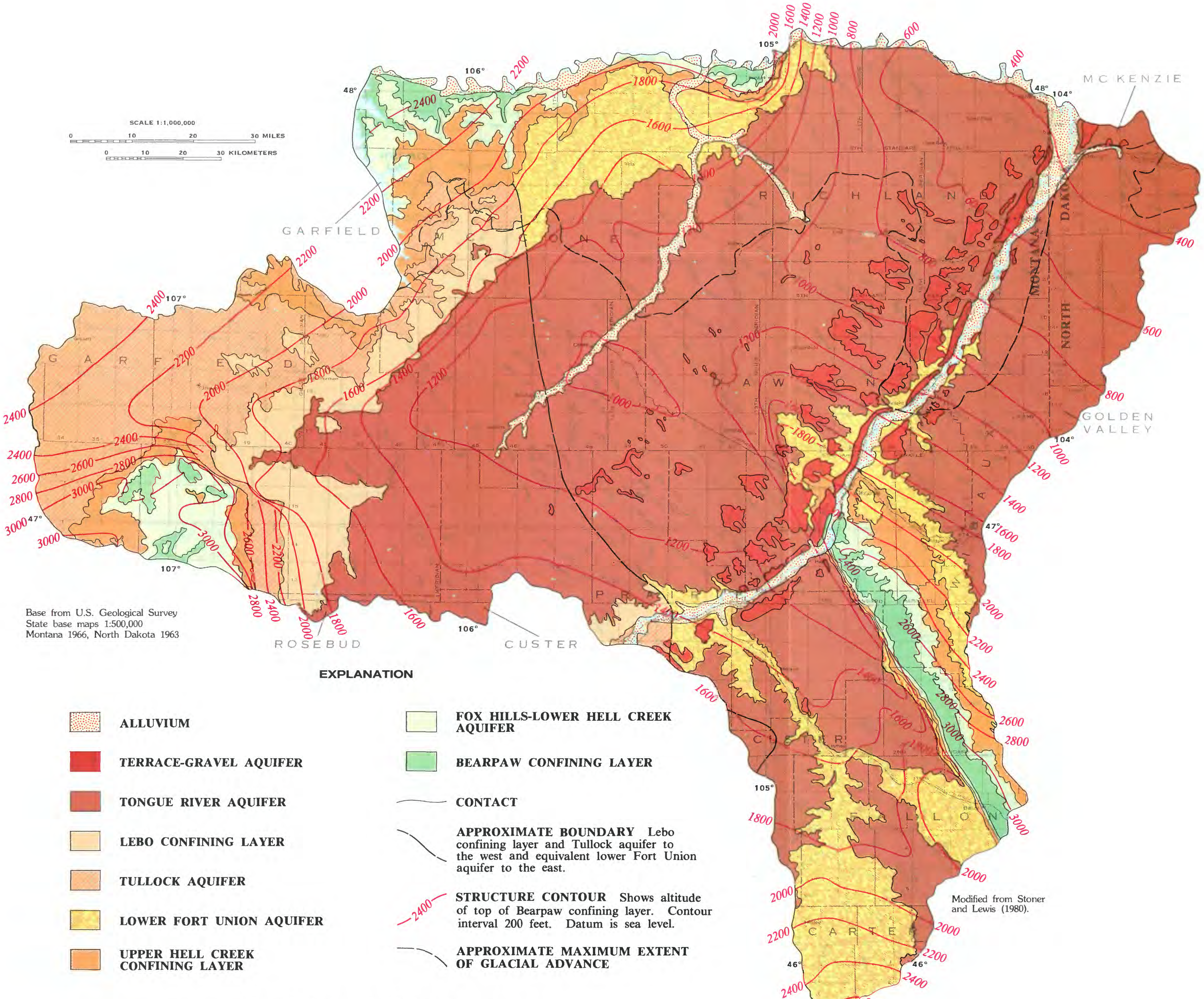
Most wells in Area 45 produce water from sand and gravel contained in the alluvium and from sandstone, fractured coal, and clinker in the Tongue River aquifer. Not only are these aquifers reliable sources of water but, because they are near land surface in most of the area, they generally are the most easily accessible. Clinker, which results from baking and fusing of surrounding rocks by burning coal beds, generally contains many fractures and provides an excellent medium for production of large quantities of water. However, it occurs mostly in topographically high areas and drains readily, so it commonly is not saturated.

The hydrogeologic units shown in figure 9.1.1 were delineated primarily on the basis of geophysical logs and generally depict the relative ability of the rocks to transmit water (table 9.1-1). The hydrogeologic units are separated into two categories: aquifers and confining layers. Aquifers are rocks or unconsolidated deposits that contain sufficient saturated permeable material to yield significant quantities of water to wells and springs. Confining layers are materials that are relatively impermeable, restrict the vertical movement of water between aquifers, and yield little or no water to wells and springs. Hydrologic anomalies exist for both categories of hydrologic units, because of the abrupt vertical and horizontal local differences in lithology of geologic units in the area. Units mapped as aquifers locally may be confining layers and units mapped as confining layers locally may be aquifers.

Aquifer boundaries generally coincide with geologic-unit contacts (see fig. 3.2-1). Depending on local lithology, specific aquifer boundaries may be above or below stratigraphic contacts. The Fox Hills Sandstone and the lower part of the Hell Creek Formation are considered to be a single aquifer because of similar lithology and hydraulic connection. Therefore, the Fox Hills-lower Hell Creek aquifer contains the Fox Hills Sandstone and from 0 to 200 feet of the overlying Hell Creek Formation. Because of regional trends in lithology, the Tullock aquifer and Lebo confining layer are combined to form the lower Fort Union aquifer in the eastern part of the area. Regionally, this unit is inferior in water-yielding properties to the overlying Tongue River aquifer.

Wells completed in the Fox Hills-lower Hell Creek aquifer may yield as much as 400 gallons per minute. Wells in other bedrock aquifers commonly yield 8 to 15 gallons per minute.

9.0 GROUND WATER
9.1 Hydrogeologic Units



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Modified from Stoner and Lewis (1980).

Figure 9.1-1 Generalized hydrogeologic units.

Table 9.1-1 Water-yielding characteristics of hydrogeologic units.

[gal/min, gallons per minute]

Hydrogeologic unit	Thickness (feet)	Water-yielding characteristics
Alluvial aquifer	0-130	Coarse gravels along major streams are reported to yield as much as 1,000 gal/min to large-diameter wells. Along smaller streams with less saturated thickness, yields of 50 gal/min have been reported. Yields commonly are 30 gal/min or less to stock and domestic wells.
Terrace-gravel aquifer	0-100	Terrace deposits are generally isolated and have limited saturation. Yields to domestic and stock wells may be as much as 20 gal/min from larger deposits at lower altitudes along major streams.
Glacial-drift aquifer	0-70	Glacial drift is a source of water in the northern part of the study area, generally within the area affected by continental glaciation. Yields to wells generally are less than 20 gal/min. Larger yields may be available from extensive gravel lenses.
Tongue River aquifer	0-1,200	Sandstone and coal beds compose the major water-yielding units. Siltstone and shale do not yield appreciable quantities of water. Yields to wells of as much as 50 gal/min have been reported, but yields to most stock and domestic wells are less than 20 gal/min. Where saturated, fractured clinker may yield as much as 50 gal/min to wells.
Lebo confining layer	0-300	A limited source of water in the study area. Relatively impermeable shale in this unit retards vertical movement of water. Yields to wells of as much as 40 gal/min have been reported; however, yields of this magnitude are rare. Local lenticular sandstones within the unit are the probable source of these yields.
Tullock aquifer	0-200	Fine-grained sandstone and coal beds supply small quantities of water for stock and domestic use. Yields to wells of as much as 42 gal/min have been reported, but generally are less than 15 gal/min.
Upper Hell Creek confining layer	0-600	Consists of the upper part of Hell Creek Formation. Limited as a water supply in the study area. Well yields of as much as 38 gal/min have been measured, but generally average about 5 gal/min.
Fox Hills-lower Hell Creek aquifer	0-600	Consists of the lower part of the Hell Creek Formation and the Fox Hills Sandstone; considered to be one aquifer in the study area. A significant source of water for artesian wells in the study area. Natural flows of as much as 70 gal/min have been measured, and maximum yields of 400 gal/min have been reported from large-capacity wells.
Bearpaw confining layer	600-1,200	Relatively impermeable. Generally does not yield water to wells in the study area.

Two Flow Patterns Present

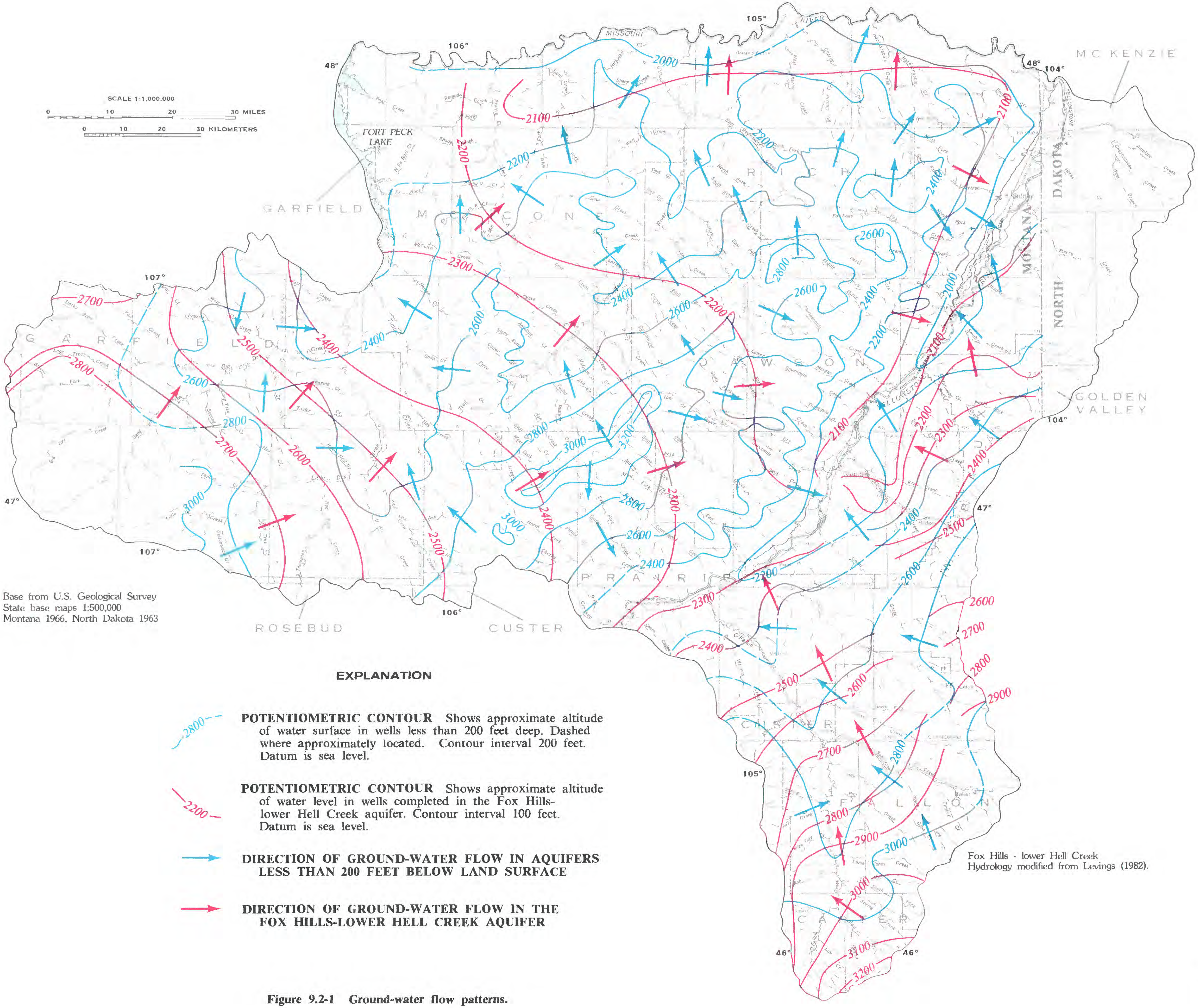
Water in shallow aquifers flows from topographically high areas to stream valleys, and water in deeper aquifers flows generally northeast toward the Missouri River or northwest toward the Yellowstone River.

Water in aquifers at depths of less than about 200 feet is characterized primarily by many localized flow patterns and a ground-water surface that reflects the land-surface topography (fig. 9.2-1). Water in aquifers at depths greater than about 200 feet is characterized by more regional flow patterns, with water flowing generally toward the Missouri and Yellowstone Rivers.

Recharge areas generally coincide with the topographically high areas. In these areas the potentiometric head decreases with depth, signifying a downward component of movement in the flow system. Water from rainfall or snowmelt enters the shallow flow system by infiltration through the land surface, generally flows downslope perpendicular to the water-level contours, and discharges to streams. The downslope movement commonly is retarded or diverted by relatively impermeable material, causing the water to discharge as springs or seeps upslope from the streams. Part of the water from this shallow system continues downward to recharge the underlying aquifers. Water is added to the deep system by direct infiltration of precipitation on the outcrops of the regional aquifers and by downward leakage from overlying aquifers.

Discharge areas generally coincide with the valleys. These areas are characterized by an upward component of flow and increasing potentiometric head with depth. Water moves upward through the aquifers and confining layers to the land surface, where it discharges as base flow to streams, evaporates, or is used by plants. Water in aquifers at depths greater than about 200 feet generally flows northeast and discharges to the major drainages or flows out of the area.

Differential head can be determined by comparing potentiometric contours of aquifers less than 200 feet deep and deeper aquifers (represented by the Fox Hills-lower Hell Creek aquifer). The potentiometric contours are shown in figure 9.2-1.



Base from U.S. Geological Survey
State base maps 1:500,000
Montana 1966, North Dakota 1963

Fox Hills - lower Hell Creek
Hydrology modified from Levings (1982).

EXPLANATION

POTENTIOMETRIC CONTOUR Shows approximate altitude of water surface in wells less than 200 feet deep. Dashed where approximately located. Contour interval 200 feet. Datum is sea level.

POTENTIOMETRIC CONTOUR Shows approximate altitude of water level in wells completed in the Fox Hills-lower Hell Creek aquifer. Contour interval 100 feet. Datum is sea level.

DIRECTION OF GROUND-WATER FLOW IN AQUIFERS LESS THAN 200 FEET BELOW LAND SURFACE

DIRECTION OF GROUND-WATER FLOW IN THE FOX HILLS-LOWER HELL CREEK AQUIFER

Figure 9.2-1 Ground-water flow patterns.

Chemical Quality Diverse

Waters from wells and springs have a large range in dissolved-solids concentration.

Ground-water quality in the area varies considerably as a function of both depth and aquifer. Water from the aquifers above the Hell Creek Formation and at depths of less than 200 feet contains an average dissolved-solids concentration of 1,740 mg/L (milligrams per liter) (table 10.1-1). Sodium, sulfate, and bicarbonate are the primary constituents. Average concentrations are 380 mg/L for sodium, 690 mg/L for bicarbonate, and 780 mg/L for sulfate. Water from shallow wells (less than 200 feet) in recharge areas commonly contains a smaller percentage of sodium and sulfate, a larger percentage of calcium and bicarbonate, and a smaller dissolved-solids concentration, as small as 159 mg/L. In many instances, calcium is the dominant cation. As water moves from recharge areas to discharge areas, dissolution of minerals and cation exchange result in increased percentages of sodium and sulfate. In discharge areas, water from shallow wells generally is dominated by sodium and sulfate and may contain dissolved-solids concentrations as large as about 6,500 mg/L.

Water quality in aquifers at depths greater than about 200 feet and above the Hell Creek Formation is more uniform than water in shallower aquifers and contains slightly larger dissolved-solids concentrations. Sodium concentrations are noticeably larger and calcium concentrations commonly are smaller. Average sodium concentration of water sampled was 600 mg/L and average calcium concentration was 39 mg/L. Bicarbonate concentrations mostly are larger than sulfate concentrations, whereas the reverse is generally true in the shallower aquifers. Average bicarbonate concentration is 980 mg/L and average sulfate concentration is 680 mg/L. Dockins and others (1980) reported that the decrease in sulfate concentration in ground water in southeastern Montana resulted from the action of sulfate-reducing bacteria. Although not documented, the same process probably takes place in Area 45.

Water from wells completed in the Fox Hills-lower Hell Creek aquifer is notably different in chemical character from water contained in overlying aquifers. The water is dominated by sodium and bicarbonate and contains smaller concentrations of calcium and sulfate. Average concentrations for constituents in water samples obtained from the Fox Hills-lower Hell Creek aquifer less than 200 feet deep are: calcium, 5.8 mg/L; sodium, 460 mg/L; bicarbonate, 920 mg/L; and sulfate, 220 mg/L. Average concentrations for water sampled from depths greater than 200 feet in the Fox Hills-lower Hell Creek aquifer are: calcium, 2.5 mg/L; sodium, 470 mg/L; bicarbonate, 860 mg/L; and sulfate, 140 mg/L. Average dissolved-solids concentration is similar to water in shallower aquifers but the range is smaller. Water in the aquifer generally is "soft" with an average hardness, as calcium carbonate, of 13 mg/L, whereas water in overlying aquifers generally is very "hard" with an average hardness of 510 mg/L. The proportions of chemical constituents in the Fox Hills-lower Hell Creek aquifer do not vary significantly with depth.

Analyses of water samples collected from wells in the study area show that most water contains constituent concentrations in excess of standards for drinking water established by the U.S. Environmental Protection Agency (1977, 1979). Maximum values for sulfate, fluoride, and dissolved solids from all aquifers sampled exceeded the standards. The maximum value for nitrate in aquifers above the Hell Creek Formation exceeded the standard. Average and median values of sulfate from aquifers above the Hell Creek and the average and median values of dissolved solids from all aquifers exceeded the standards. Dissolved-solids and sodium concentrations of most ground water are in excess of maximums recommended for irrigation waters by the U.S. Salinity Laboratory Staff (1954).

Table 10.1-1 Summary of selected physical properties and chemical constituents in water from wells.

[Constituents are dissolved and constituent values are reported in milligrams per liter. Micromhos, micromhos per centimeter at 25° Celsius]

		Aquifers above Hell Creek Formation							Fox Hills-lower Hell Creek aquifer						
Property or constituent	Standard[1]	Number of samples	Number of samples exceeding standard	Maximum	Minimum	Median	Average	Number of samples for average	Number of samples	Number of samples exceeding standard	Maximum	Minimum	Median	Average	Number of samples for average
Specific conductance (micromhos)	--	344	--	9,700	450	2,290	2,420	344	52	--	5,500	760	1,740	1,850	52
pH (*onsite*)	--	213	--	10.5	6.3	7.8	--	--	31	--	9.2	7.6	8.6	--	--
Hardness as $CaCO_3$	--	340	--	3,000	3	380	510	340	57	--	99	0	6	13	57
Noncarbonate hardness	--	340	--	2,600	0	0	200	340	57	--	0	0	0	0	57
Calcium (Ca)	--														
Wells less than 200 feet deep		266	--	440	1.2	82	100	266	12	--	17	1.5	3.0	5.8	12
Wells more than 200 feet deep		74	--	330	1.4	7.6	39	74	45	--	18	.0	1.8	2.5	45
Magnesium (Mg)	--	340	--	490	.1	46	70	340	57	--	15	.0	.3	1.2	56
Sodium (Na)	--														
Wells less than 200 feet deep		266	--	1,400	3.1	290	380	266	12	--	740	140	460	460	12
Wells more than 200 feet deep		74	--	1,500	34	620	600	74	37	--	1,300	300	420	470	37
Sodium-adsorption ratio	--	340	--	171	.1	9	21	340	52	--	98	6	70	68	52
Potassium (K)	--	339	--	19	.6	5	5	339	49	--	5	.7	1	1	49
Bicarbonate (HCO_3)	--														
Wells less than 200 feet deep		266	--	2,090	60	620	690	266	12	--	1,550	370	920	920	12
Wells more than 200 feet deep		72	--	1,740	230	940	980	72	39	--	1,960	360	770	860	39
Carbonate (CO_3)	--	125	--	230	0	0	15	125	33	--	160	0	40	42	33
Alkalinity ($CaCO_3$)	--	338	--	1,710	116	570	620	338	55	--	1,610	303	670	770	55
Sulfide (S)	--	4	--	1.6	.0	.6	.7	4	--	--	--	--	--	--	--
Sulfate (SO_4)	250														
Wells less than 200 feet deep		265	200	[3]4,200	.3	[3]640	[3]780	265	12	4	[3]660	5.3	160	220	12
Wells more than 200 feet deep		72	53	[3]2,400	.2	[3]740	[3]680	72	45	6	[3]1,300	1.8	61	140	45
Chloride (Cl)	250	337	--	130	.6	9.4	14	337	57	--	210	3.1	26	40	57
Fluoride (F)	[2]2.2	335	44	[3]5.7	< .1	.4	.9	324	57	30	[3]5.3	.1	2.2	2.2	57
Silica (SiO_2)	--	340	--	50	.9	9.6	11	340	48	--	21	8.3	11	12	48
Dissolved solids (sum of constituents)	500														
Wells less than 200 feet deep	--	265	242	[3]6,450	159	[3]1,540	[3]1,740	265	12	7	[3]2,040	461	[3]1,170	[3]1,180	12
Wells more than 200 feet deep		69	69	[3]4,220	[3]681	[3]1,810	[3]1,910	69	36	36	[3]3,620	[3]746	[3]1,070	[3]1,190	36
Nitrate (as N)	10	157	10	[3]33	.02	1.2	2.8	157	11	--	1.0	.00	.00	.18	11
Phosphorus (P)	--	--	--	--	--	--	--	--	3	--	.70	.26	.69	.55	3

---

[1] U.S. Environmental Protection Agency (1977, 1979).
[2] Based on annual average maximum daily air temperature of 53.8° to 58.3° Fahrenheit.
[3] Exceeds standards established by U.S. Environmental Protection Agency (1977, 1979).

Trace-Element Concentrations Generally Uniform from Aquifer to Aquifer

Median values for all trace elements are less than standards for drinking water.

Variation in concentration of most trace elements commonly is not large from aquifer to aquifer (table 10.2-1). Where significant variation exists, concentrations generally are larger in aquifers above the Hell Creek Formation. Median values for boron, iron, manganese, nickel, and zinc show a 1- to 3-fold variation. The variation in copper and strontium is most pronounced; median values show a 6-fold variation in copper and a 10-fold variation in strontium.

Concentrations of trace elements commonly are less than the standards for drinking water established by the U.S. Environmental Protection Agency (1977, 1979). Some samples, however, contain concentrations in excess of the standards. Maximum values for barium, cadmium, iron, lead, manganese, selenium, and zinc in water sampled from aquifers above the Hell Creek Formation exceeded the standards. Maximum values for iron and manganese in water from the Fox Hills-lower Hell Creek aquifer also are in excess of the standards. Median values for all trace elements are less than the standards. The extremely large maximum values for iron, manganese, and zinc may be the result of contamination by the well casing and lack of sufficient pumping before the sample was collected; however, large concentrations of iron and zinc have been detected in water collected from streams in the area.

Table 10.2-1 Summary of trace elements in water from wells.

[Constituents are dissolved. Constituent values are reported in micrograms per liter. <, less than]

		Aquifers above Hell Creek Formation					Fox Hills-lower Hell Creek aquifer				
Trace element	Standard[1]	Number of samples	Number of samples exceeding standard	Maximum	Minimum	Median	Number of samples	Number of samples exceeding standard	Maximum	Minimum	Median
Aluminum (Al)	--	76	--	370	<30	30	9	--	100	<30	<30
Arsenic (As)	50	72	--	24	0	0	9	--	3	0	0
Barium (Ba)	1,000	83	1	[2]1,100	<10	50	11	--	200	<50	50
Boron (B)	--	97	--	2,700	<20	310	15	--	1,600	90	1,000
Cadmium (Cd)	10	73	3	[2]16	<2	2	8	--	6	<2	<2
Chromium (Cr)	50	76	--	30	<2	3	8	--	3	<2	<2
Copper (Cu)	1,000	78	--	58	<2	12	9	--	10	<2	<2
Iron (Fe)	300	248	80	[2]26,000	<2	100	56	4	[2]2,100	0	55
Lead (Pb)	50	81	11	[2]150	0	40	9	--	50	0	40
Lithium (Li)	--	137	--	240	<2	50	21	--	200	30	60
Manganese (Mn)	50	335	114	[2]4,200	<1	30	47	1	[2]210	<3	10
Mercury (Hg)	2	7	--	.5	< .5	.5	1	--	< .5	< .5	< .5
Molybdenum (Mo)	--	81	--	90	<5	20	9	--	60	<5	20
Nickel (Ni)	--	76	--	120	<10	20	9	--	40	<4	10
Selenium (Se)	10	79	7	[2]80	0	0	12	--	5	0	0
Silver (Ag)	50	76	--	43	<2	2	8	--	6	<2	<2
Strontium (Sr)	--	90	--	12,000	70	1,200	12	--	590	30	110
Vanadium (V)	--	76	--	57	<1.0	6.5	9	--	11	<1.0	<1.0
Zinc (Zn)	5,000	76	2	[2]28,000	<4	60	9	--	250	0	20

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[1] U.S. Environmental Protection Agency (1977, 1979).

[2] Exceeds standard established by U.S. Environmental Protection Agency (1977, 1979).

Ground-Water Quality Controlled by Hydrologic, Geologic, and Microbiological Factors

Aquifer mineralogy and solution chemistry largely are responsible for concentrations of solutes.

Geochemical changes occur within the shallow ground-water system as water flows from areas of recharge to deeper parts of the aquifers. Aquifer mineralogy and solution chemistry largely are responsible for the concentrations of solutes, although time, distance of travel, and microbiological factors also are important.

Sodium enrichment constitutes the primary cation modification. Direct sodium enrichment results from leaching of sodium from the sediments and cation exchange of sodium for calcium and magnesium. Indirect sodium enrichment results from precipitation of calcium and magnesium carbonates, which effectively increases the ratio of sodium to other cations. Sodium dilution can occur where water containing a small concentration of sodium mixes with water containing a large concentration of sodium. Sodium dilution generally occurs where recharge water percolates through the soils and dilutes ground water containing larger percentages of sodium.

Sulfate and bicarbonate plus carbonate are the principal anions in solution. Sulfate enrichment is the dominant chemical process in the shallow ground-water system. Direct sulfate enrichment may result from weathering of pyrite or dissolution of gypsum and is accompanied by increases in dissolved-solids concentration. Increases in the ratio of sulfate to other ions may be caused by precipitation of calcium and magnesium carbonates, which effectively removes bicarbonate from solution. The apparent loss of sulfate may be caused in many instances by mixing of water containing large concentrations of sulfate with recharge water or water from deeper aquifers containing small concentrations of sulfate. Anaerobic bacteria, which reduce sulfate to sulfide, have been identified in relatively large numbers in some ground water in southeastern Montana. Dockins and others (1980) imply that small sulfate concentrations in some ground water in the area likely result from sulfate depletion by bacterial sulfate reduction.

A conceptual geochemical model (fig. 10.3-1) for a geologically and hydrologically similar area in southeastern Montana was developed from probable mineral-water interactions, aqueous chemistry, and geologic and hydrologic principles (Lee, 1980). The model is restricted to localized flow systems where the distance from recharge to discharge is less than about 20 miles.

At point A, chemical composition would represent recharge water dominated by magnesium, calcium, and bicarbonate, with significant concentrations of sodium and sulfate, but having a small dissolved-solids concentration. As the water percolates through the system, sodium and sulfate enrichment results in larger percentages of sodium, sulfate, and dissolved solids at B. At C, chemical composition would represent a mixture of an intermediate sodium and sulfate water and recharge water that has percolated through a very permeable clinker facies. The mixing results in a solution containing a smaller dissolved-solids concentration than at B, with a chemical composition approaching that for recharge water; that is, lesser percentage of sodium and sulfate. At D, chemical composition is predominantly sodium and sulfate (developed by sodium and sulfate enrichment), which may discharge as base flow to the stream. In the deep coal bed at E, sulfate reduction may dominate the geochemistry of the water, producing a sodium bicarbonate quality that is almost indistinguishable from water qualities of deeper aquifers. At F, water quality of the deeper regional systems (whose chemical character probably developed similar to water at E) would be dominated by sodium and bicarbonate. Finally at G, upward leakage would result in water that is a composite of waters from D, E, and F. Chemical character of water at G would be determined by the dominant water supply from D, E, or F.

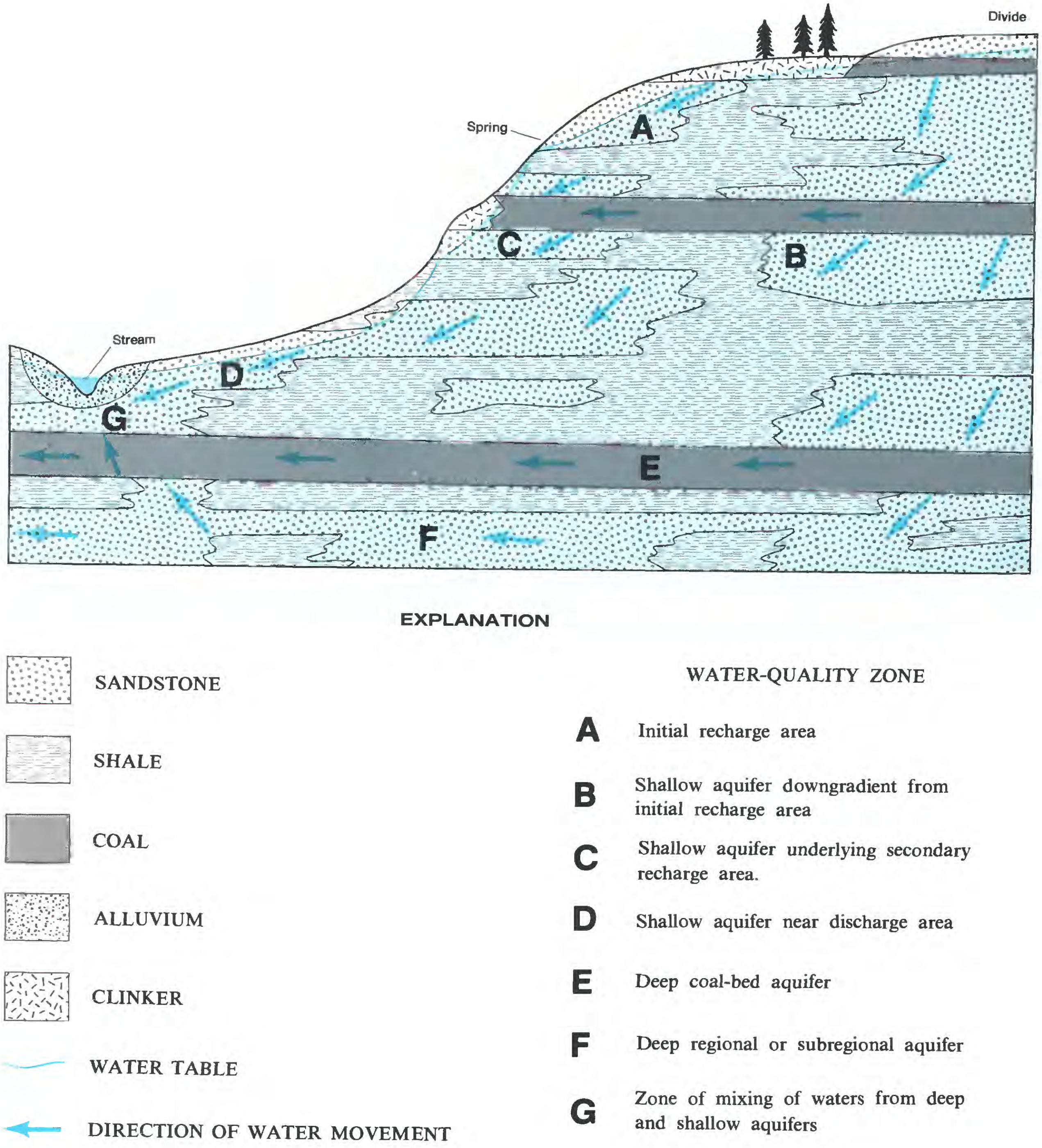

Figure 10.3-1 Conceptual geochemical model of the shallow ground-water system.

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

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

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

(1) The National Water Data Exchange (NAWDEX), which indexes the water data available from more than 400 organizations and serves as a central assistance center to help those needing water data to determine what information already 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.

In addition to U.S. Geological Survey water-data activities, the U.S. Environmental Protection Agency operates a data base called the Water Quality Control Information System (STORET). This data base is used for the storage and retrieval of data relating to the quality of waterways within and contiguous to the United States.

A more detailed explanation of these activities is given in sections 11.2, 11.3, 11.4, and 11.5.

NAWDEX Simplifies Access to Water Data

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

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

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities (see fig. 11.2-1). A directory (Edwards, 1980) is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations.

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water-Data Index (fig. 11.2-2), 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. 11.2-3) 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 incurred by NAWDEX in the course of providing services. In all instances, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and when 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, Virginia 22092
Telephone: (703) 860-6031
FTS 928-6031
Hours: 7:45-4:15 Eastern Time

NAWDEX ASSISTANCE CENTER
MONTANA
U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, Montana 59626
Telephone: (406) 449-5496
FTS 585-5496
Hours: 8:00-4:45 Mountain Time

NAWDEX ASSISTANCE CENTER
NORTH DAKOTA
U.S. Geological Survey
Water Resources Division
821 E. Interstate Avenue
Bismarck, North Dakota 58501
Telephone: (701) 255-4011, Ext. 601
FTS 783-4601
Hours: 8:00-5:00 Central Time

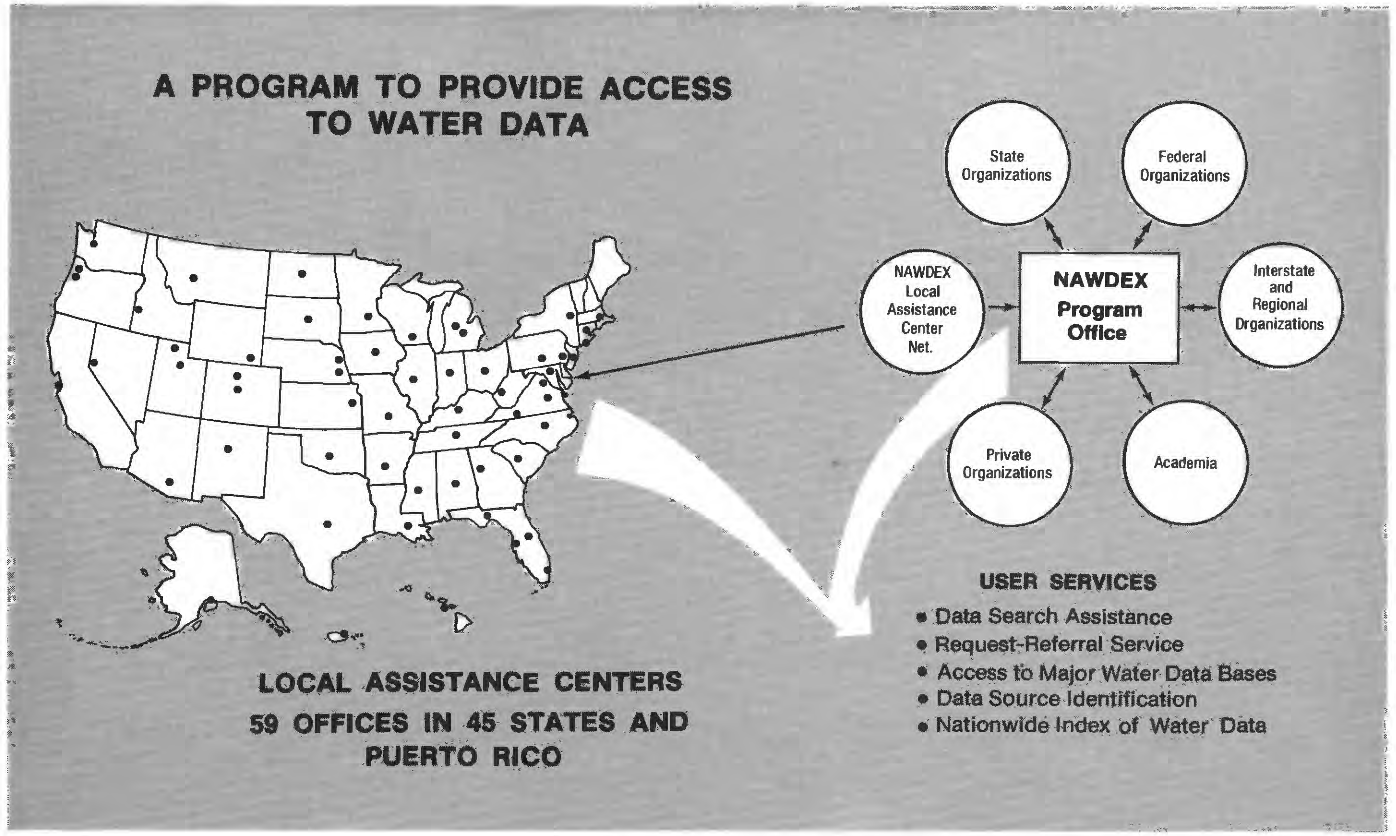

Figure 11.2-1 Access to water data.

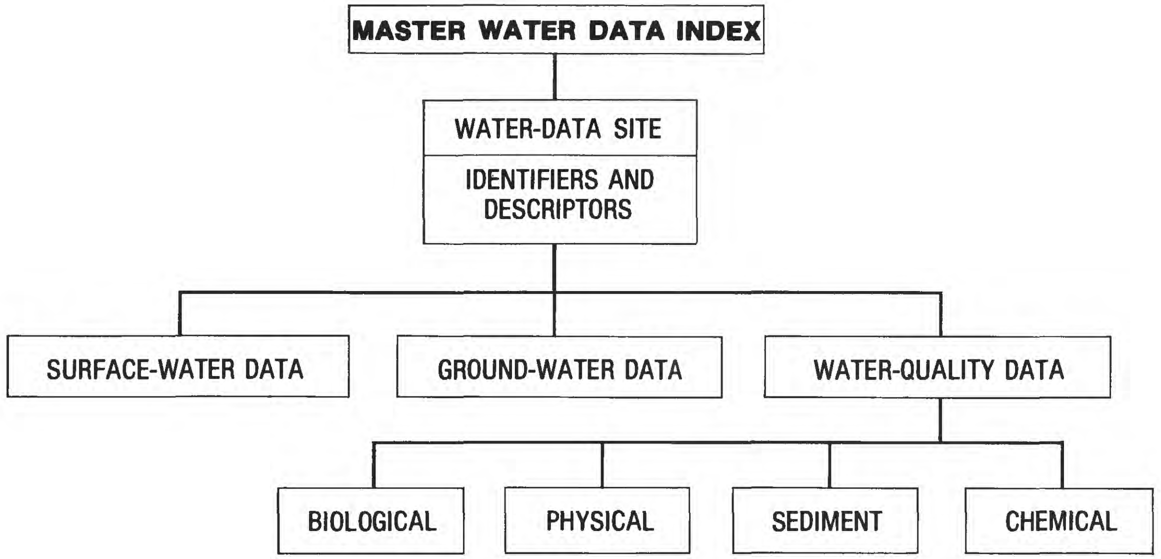

Figure 11.2-2 Master water-data index.

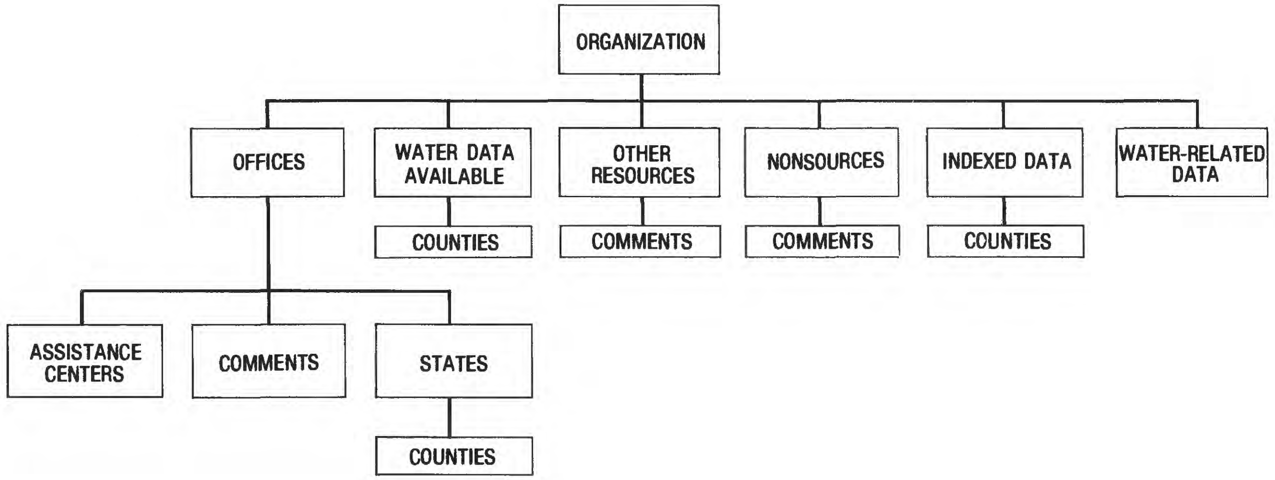

Figure 11.2-3 Water-data sources directory.

WATSTORE Automated Data System

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

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

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

Montana
U.S. Geological Survey
Water Resources Division
428 Federal Building
Helena, Montana 59626

North Dakota
U.S. Geological Survey
Water Resources Division
821 E. Interstate Avenue
Bismarck, North Dakota 58501

The Geological Survey currently (1980) collects data at about 16,000 streamflow-gaging stations, 1,000 lakes and reservoirs, 5,200 surface-water-quality stations, 1,020 sediment stations, 30,000 water-level monitoring wells, and 12,500 ground-water-quality monitoring wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to permit 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; (5) geologic and inventory data for ground-water sites; and (6) water-use data. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 11.3-1). A brief description of each file 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 more than 200 million daily values, including data on streamflow, 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 compose this file, which currently contains more than 400,000 observations of peak flow.

Water-Quality File: Results of more than 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

1,850 different constituents. Each analysis contains a maximum of 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 maintained within WATSTORE independent of the files discussed above, but it is cross-referenced to the Water-Quality File and the Daily-Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time onsite measurements such as water temperature. The file is designed to accommodate 270 data elements and currently contains data for nearly 780,000 sites.

Water-Use File: This file is also an independent file maintained within WATSTORE that contains aggregated estimates of water usage by county and hydrologic unit. The Water-Use File has the capability to store and disseminate aggregated data on water withdrawals and returns.

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 Water Resources Division district offices are equipped with high-speed computer terminals for remote access to the WATSTORE system. These terminals allow each office 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 stage, conductivity, water temperature, turbidity, wind direction, and chloride concentration. Data are recorded on a 16-channel paper tape, which is removed from the recorder and transmitted via 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 currently (1980) are being operated.

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 analyses 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, analysis of variance, transformations, and correlations.

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

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

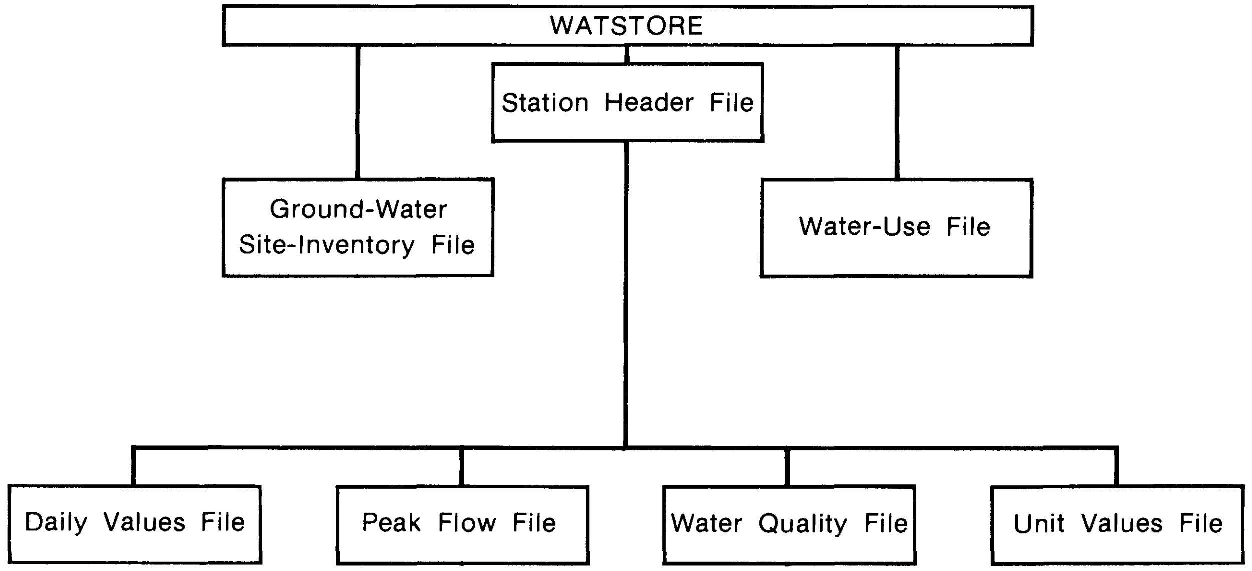

Figure 11.3-1 Index to file-stored data.

Water Data Indexed for Coal Provinces

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

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information about 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. 11.4-1): 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, the agency codes, and the number of activities reported by type are listed in a table.

Assistance in obtaining additional information from the Catalog file or in obtaining water data is available from the National Water Data Exchange (NAWDEX) (see section 11.2).

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

U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, Montana 59626
Telephone: (406) 449-5496
FTS 585-5496

U.S. Geological Survey
Water Resources Division
821 E. Interstate Avenue
Bismarck, North Dakota 58501
Telephone: (701) 255-4011, Ext. 601
FTS 783-4601

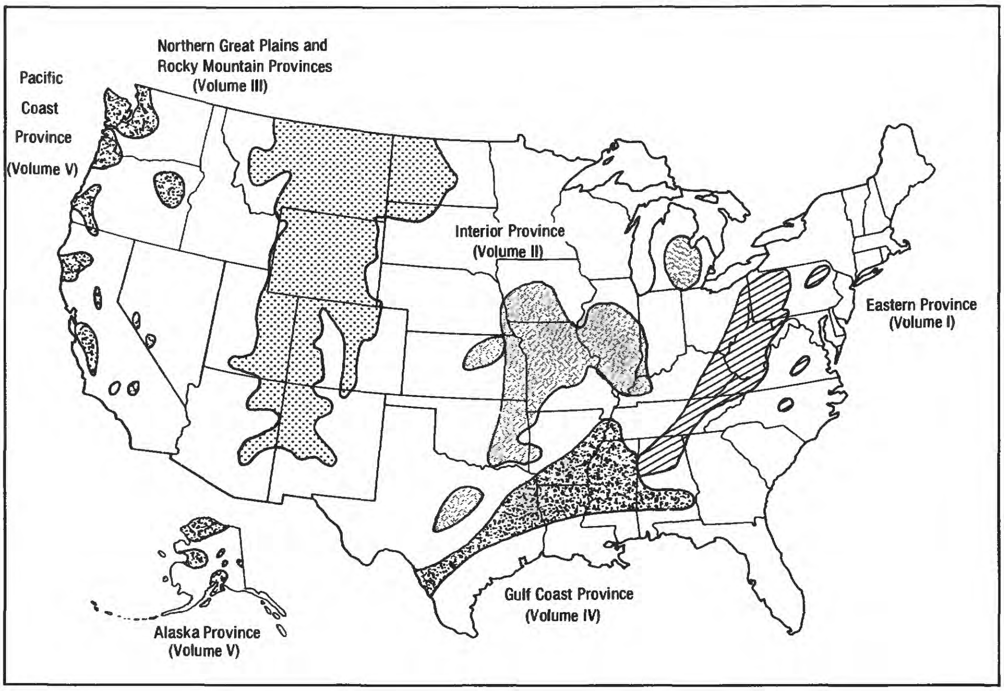

Figure 11.4-1 Index volumes and related provinces.

STORET Water-Quality Data Base System

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

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

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

About 1,800 water-quality parameters are defined with STORET's Water Quality File. In 1976 the data in the system represented more than 200,000 unique collection points. The groups of parameters and number of observations that are in the Water Quality File are illustrated in figure 11.5-1.

State, Federal, interstate, and local government agencies can become STORET users. Information on becoming a user of the system can be obtained by contacting the Environmental Protection Agency. The point of contact for the Northern Great Plains and Rocky Mountain Coal Provinces is:

Director
Surveillance and Analysis Division
Environmental Protection Agency
8ES-DA
1860 Lincoln Street
Denver, CO 80295
Telephone: (303) 837-2226
FTS 327-2226

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

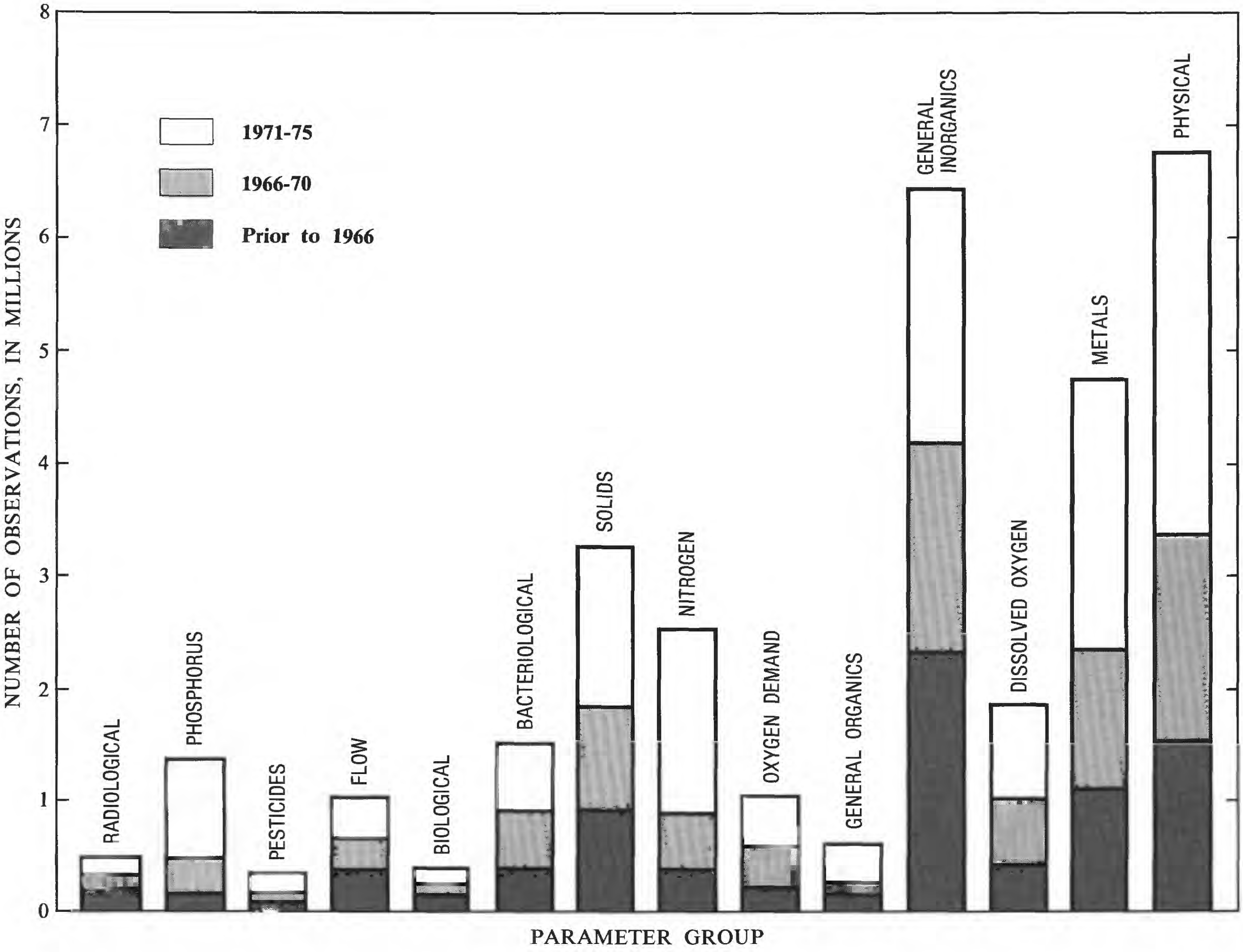

Figure 11.5-1 Parameter groups and number of observations in the Water Quality File.

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY STATIONS AND SITES

Description of streamflow and water-quality stations and sites.

[Map number: Refers to locations shown in figures in this report. Water quality: Letters following period of record indicate data category--B, biological; C, chemical; S, suspended sediment. Period of water-quality record refers to single or combined data category]

Number used in report	U.S. Geological Survey station or site No.		Name	Drainage area (square miles)	Period and type of record, by water year			
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
1	---	470811107242501	Dugout Coulee nr Sand Springs, Mont.	--	--	1970	--	--
2	06130680	---	Big Dry Creek at Jordan, Mont.	--	--	1976-77	--	1975-77 CS
3	06130700	---	Sand Creek nr Jordan, Mont.	317	1957-67	--	--	--
4	06130800	---	Second Creek tributary nr Jordan, Mont.	.52	--	--	1958-73	--
5	06130850	---	Second Creek tributary No. 2 nr Jordan, Mont.	2.08	--	--	1958-	--
6	06130900	---	Second Creek tributary No. 3 nr Jordan, Mont.	.72	--	--	1958-72	--
7	06130915	---	Russian Coulee nr Jordan, Mont.	3.45	--	--	1974-	--
8	06130925	---	Thompson Creek tributary nr Cohagen, Mont.	1.23	--	--	1974-	--
9	06130935	---	Crow Rock Creek nr Cohagen, Mont.	213	--	1977-80	--	1978-80 CBS
10	06130940	---	Spring Creek tributary nr Van Norman, Mont.	1.39	--	--	1974-	--
11	06130950	---	Little Dry Creek nr Van Norman, Mont.	1,224	1980	1976-77	1958-75	1976-77 CS
12	06131000	---	Big Dry Creek nr Van Norman, Mont.	2,554	1940-47; 1949-69; 1970-	1948-49	--	--
13	---	473623106363801	Pass Creek Reservoir nr Haxby, Mont.	--	--	--	--	1980 CB
14	06131100	---	Timber Creek tributary nr Van Norman, Mont.	.74	--	--	1974-	--
15	06131120	---	Timber Creek nr Van Norman, Mont.	287	--	1976-79	--	1976-79 CS
16	---	472830106044001	Nelson Creek nr Weldon, Mont.	--	--	1977	--	--
17	06131200	---	Nelson Creek nr Van Norman, Mont.	100	1976-	--	--	1976-79 CS
18	06131300	---	McGuire Creek tributary nr Van Norman, Mont.	.74	--	--	1974-	--
19	---	473708106090801	McGuire Creek nr Weldon, Mont.	--	--	1977	--	--
20	06132000	---	Missouri River bl Fort Peck Dam, Mont.	57,556	1934-	--	--	1964; 1974- CBS
21	---	474625105510701	Prairie Elk Creek nr Weldon, Mont.	--	--	1977	--	--
22	06175540	---	Prairie Elk Creek nr Oswego, Mont.	352	1976-	--	--	1976-79 CS
23	06175550	---	East Fork Sand Creek nr Vida, Mont.	8.51	--	--	1963-77	--
24	06175580	---	Sand Creek nr Wolf Point, Mont.	--	--	1976-77	--	1976-77 CS
25	06176950	---	Missouri River tributary No. 6 nr Wolf Point, Mont.	.08	--	--	1974-	--
26	06177000	---	Missouri River nr Wolf Point, Mont.	82,290	1928-	--	--	1949-51; 1961-62; 1965-68; 1970; 1980- CBS

Description of streamflow and water-quality stations and sites--continued.

Number used in report	U.S. Geological Survey station or site No.		Name	Drainage area (square miles)	Period and type of record, by water year			
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
27	---	471419105541701	Redwater River 8 mi southwest of Brockway, Mont.	--	--	1921-22	--	--
28	06177050	---	East Fork Duck Creek nr Brockway, Mont.	12.4	--	--	1955-	--
29	06177100	---	Duck Creek nr Brockway, Mont.	54.0	--	1921-22	1957-73	--
30	---	471757105464601	Redwater River 0.5 mi west of Brockway, Mont.	--	--	1921-22	--	--
31	06177150	---	Redwater River at Brockway, Mont.	216	--	1980	1958-73	1970 C
32	---	471920105424001	Stoney Butte Creek nr Brockway, Mont.	--	--	1977	--	1977 C
33	06177200	---	Tusler Creek nr Brockway, Mont.	90.2	--	--	1957-72	--
34	06177250	---	Tusler Creek tributary nr Brockway, Mont.	3.17	--	--	1957-73	--
35	06177300	---	Redwater River tributary nr Brockway, Mont.	.29	--	--	1954; 1958-73	--
36	06177350	---	South Fork Dry Ash Creek nr Circle, Mont.	5.74	--	--	1955-72	--
37	06177400	---	McCune Creek nr Circle, Mont.	29.9	--	--	1955-73	--
38	06177500	---	Redwater River at Circle, Mont.	547	1929-72; 1975-	--	--	1975- CS
39	06177520	---	Horse Creek nr Circle, Mont.	101	--	1976-79	--	1977-79 CS
40	---	472530105343301	Horse Creek at Circle, Mont.	--	--	1976	--	--
41	---	472919105320001	Lost Creek nr Circle, Mont.	--	--	1976	--	--
42	---	473036105253101	Redwater River (sec. 2) nr Circle, Mont.	--	--	1980	--	1980 C
43	---	473154105320001	South Fork Buffalo Creek nr Circle, Mont.	11.6	--	1976	--	--
44	---	473748105192901	Redwater River ab Cow Creek, nr Richey, Mont.	--	--	1980	--	1980 C
45	06177700	---	Cow Creek tributary nr Vida, Mont.	1.71	--	--	1963-	--
46	06177720	---	West Fork Sullivan Creek nr Richey, Mont.	13.8	--	--	1974-	--
47	---	474242105150001	Redwater River (sec. 36) nr Richey, Mont.	--	--	1980	--	1980 C
48	---	474947105150401	Redwater River (sec. 24) nr Vida, Mont.	--	--	1980	--	1980 C
49	06177800	---	Wolf Creek tributary nr Vida, Mont.	.91	--	--	1963-	--
50	---	475101105153101	Wolf Creek (sec. 11) nr Vida, Mont.	--	--	1980	--	1980 C
51	06177820	---	North Creek tributary nr Richey, Mont.	.74	--	--	1974-	--
52	06177825	---	Redwater River nr Vida, Mont.	1,974	1976-	--	--	1980- CS
53	---	480111105182001	Redwater River nr Nickwall, Mont.	--	--	1980	--	1980 C
54	---	480315105125001	Redwater River at mouth, nr Poplar, Mont.	--	--	1980	--	1980 C
55	06185150	---	Hardscrable Creek nr Culbertson, Mont.	121	--	1981-	--	1981- CS
56	06185200	---	Missouri River tributary No. 3 nr Culbertson, Mont.	1.23	--	--	1963-77	--

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY STATIONS AND SITES

Description of streamflow and water-quality stations and sites--continued.

Number used in report	U.S. Geological Survey station or site No.		Name	Drainage area (square miles)	Period and type of record, by water year				
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality	
57	06185500	---	Missouri River nr Culbertson, Mont.	91,557	1941-51; 1958-	--	--	1945; 1965-	CBS
58	06185600	---	Missouri River stage gage No.4 nr Nohly, Mont.	93,000 Approx.	[1]1959-	--	--	--	
59	06185650	---	Missouri River stage gage No.5 at Nohly, Mont.	93,000 Approx.	[1]1959-	1947-49	--	--	
60	06326530	---	Yellowstone River nr Terry, Mont.	63,447	--	1974-77; 1980-	--	-- 1974-	CBS
61	---	465319105422001	Clark Reservoir nr Terry, Mont.	--	--	--	--	1980	CB
62	---	465223105384001	Grant Reservoir nr Terry, Mont.	--	--	--	--	1980	CB
63	---	470030105333001	Homestead Reservoir nr Terry, Mont.	--	--	--	--	1980	CB
64	06326550	---	Cherry Creek tributary nr Terry, Mont.	2.52	--	--	1973-	--	
65	06326555	---	Cherry Creek nr Terry, Mont.	358	1978-81	--	--	1978-81	CS
66	---	465050105145501	Coal Creek Reservoir nr Fallon, Mont.	--	--	--	--	1980	CB
67	06326580	---	Lame Jones Creek tributary nr Willard, Mont.	.49	--	--	1974-	--	
68	06326600	---	O'Fallon Creek nr Ismay, Mont.	669	1978-	--	1963-77	1978-	CBS
69	06326650	---	O'Fallon Creek tributary nr Ismay, Mont.	.17	--	--	1963-76	--	
70	06326700	---	Deep Creek nr Baker, Mont.	1.55	--	--	1963-76	--	
71	---	462413104231101	Sandstone Creek nr Plevna, Mont.	106 Approx.	--	1955	--	--	
72	06326800	---	Pennel Creek nr Baker, Mont.	1.00	--	--	1963-	--	
73	06326850	---	O'Fallon Creek at Mildred, Mont.	1,396	1975-78	--	--	--	
74	---	464950105084401	O'Fallon Creek at Fallon, Mont.	--	--	1949-50 1952; 1972	--	--	
75	---	465120105065701	Yellowstone River nr Fallon, Mont.	--	--	1969	--	--	
76	06326900	---	Yellowstone River tributary No.4 nr Fallon, Mont.	.67	--	--	1963-76	--	
77	06326940	---	Spring Creek tributary nr Fallon, Mont.	3.10	--	--	1973-	--	
78	---	4656061045626	Cracker Box Creek nr Marsh, Mont.	--	--	1980	--	--	
79	06326950	---	Yellowstone River tributary No.5 nr Marsh, Mont.	.87	--	--	1963-	--	
80	06326952	---	Clear Creek nr Lindsay, Mont.	101	1982-	--	--	--	
81	06326953	---	Clear Creek nr Hoyt, Mont.	138	--	1978-80	--	1978-80	CBS
82	---	465836104512601	Clear Creek nr Glendive, Mont.	--	--	1921-22	--	--	
83	---	465923104461201	Yellowstone River bl Clear Creek, nr Glendive, Mont.	--	--	1956	--	--	
84	---	465339104383601	Big Drop Reservoir nr Hoyt, Mont.	--	--	--	--	1980	CB
85	---	470035104495901	Whoopup Creek nr Glendive, Mont.	--	--	1980	--	--	
86	06326960	---	Timber Creek tributary nr Lindsay, Mont.	1.23	--	--	1974-	--	
87	06326995	---	Upper Sevenmile Creek nr Lindsay, Mont.	137	--	1978-80	--	1978-80	CBS

Description of streamflow and water-quality stations and sites--continued.

Number used in report	U.S. Geological Survey station or site No.		Name	Drainage area (square miles)	Period and type of record, by water year			
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
88	06327000	---	Upper Sevenmile Creek nr Glendive, Mont.	--	1921-22	--	--	--
89	06327500	---	Yellowstone River at Glendive, Mont.	66,788	1897-1910; 1931-34	--	--	--
90	06327550	---	South Fork Horse Creek tributary nr Wibaux, Mont.	1.73	--	--	1974-	--
91	06327700	---	Griffith Creek nr Glendive, Mont.	15.5	--	--	1955-67	--
92	06327720	---	Griffith Creek tributary nr Glendive, Mont.	3.48	--	--	1965; 1974-	--
93	06327790	---	Krug Creek tributary No. 2 nr Wibaux, Mont.	.49	--	--	1974-	--
94	06327800	---	Krug Creek tributary nr Wibaux, Mont.	1.74	--	--	1955-61	--
95	06327850	---	Glendive Creek nr Glendive, Mont.	300	--	1978-81	--	1978-81 CS
96	06328000	---	Deer Creek nr Glendive, Mont.	198	1921-22	1978-80	--	1978-80 CBS
97	06328100	---	Yellowstone River tributary No. 6 nr Glendive, Mont.	2.93	--	--	1974-	--
98	06328200	---	Lower Sevenmile Creek nr Bloomfield, Mont.	--	1982-	--	--	--
99	06328400	---	Thirteenmile Creek tributary nr Bloomfield, Mont.	.67	--	--	1972; 1974-	--
100	06328500	---	Lower Yellowstone Canal at Lower Yellowstone Dam, at Intake, Mont.	--	1908-	--		--
101	06328700	---	Linden Creek at Intake, Mont.	4.20	--	--	1958-73	--
102	06328800	---	Indian Creek at Intake, Mont.	.46	--	--	1958-73	--
103	06328900	---	War Dance Creek nr Intake, Mont.	3.69	--	--	1958-73	--
104	06329000	---	Cottonwood Creek nr Intake, Mont.	85.3	--	1978-81	--	1978-81 CS
105	06329200	---	Burns Creek nr Savage, Mont.	233	1958-67; 1976-	--	--	1976-79 CS
106	06329350	---	Alkali Creek tributary nr Sidney, Mont.	.49	--	--	1974-	--
107	06329500	---	Yellowstone River nr Sidney, Mont.	69,103	1910-31; 1933-	--	--	1948- CBS
108	06329510	---	Fox Creek tributary nr Lambert, Mont.	5.07	--	--	1972; 1974-	--
109	06329520	---	Fox Creek nr Lambert, Mont.	183	--	1981-	--	1981- CS
110	06329540	---	Lone Tree Creek nr Sidney, Mont.	39.4	--	1981-	--	1981- CS
111	06329570	---	First Hay Creek nr Sidney, Mont.	29.1	--	--	1963-	--
112	06329590	---	Yellowstone River stage gage No.1 nr Fairview, Mont.	--	--	--	1959-	--
113	06329597	---	Charbonneau Creek nr Charbonneau, N. Dak.	149	1966-	--	--	1972- C
114	06329610	---	Yellowstone River stage gage No.2 nr Cartwright, N. Dak.	70,000 Approx.	[1]1959-	--	--	--
115	06329620	---	Yellowstone River stage gage No.3 nr Buford, N. Dak.	70,000 Approx.	[1]1959-	--	--	--

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[1] Seasonal stage record only.

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