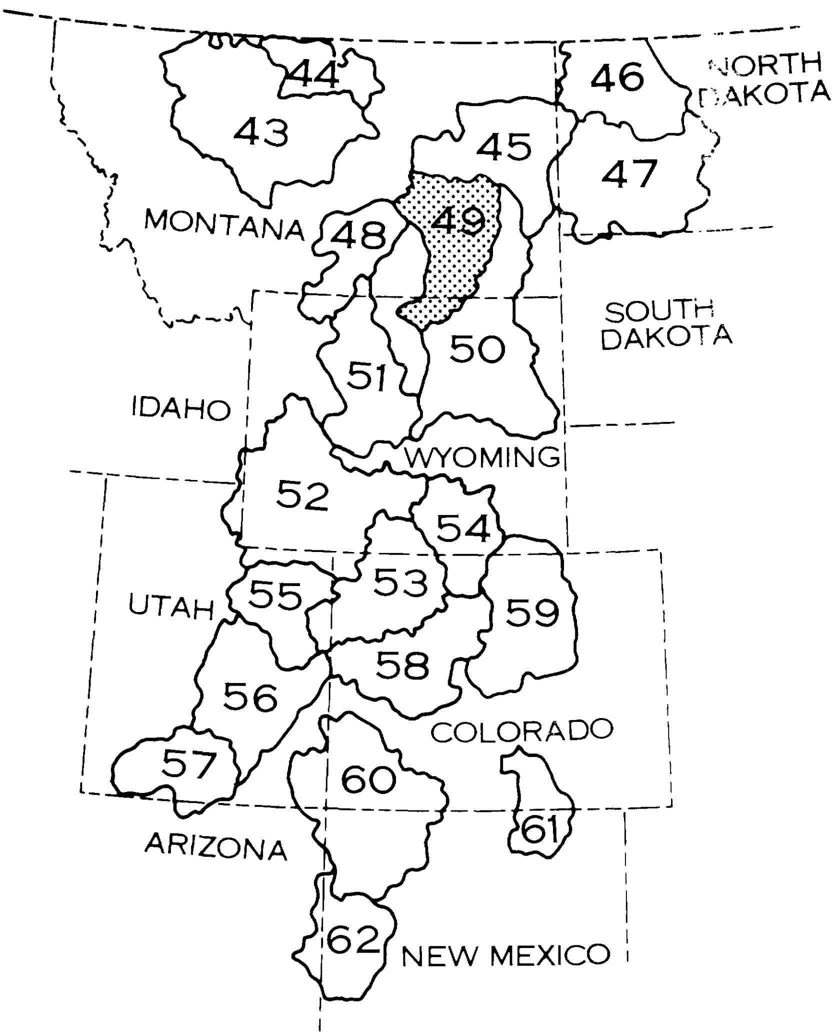
HYDROLOGY OF AREA 49, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND WYOMING



- YELLOWSTONE RIVER
- TONGUE RIVER
- ROSEBUD CREEK
- PUMPKIN CREEK
- LITTLE PORCUPINE CREEK
- GOOSE CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 82-682

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BY
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HELENA, MONTANA
JANUARY 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

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CONTENTS

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

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

Multiply	By	To obtain
acre	4047	square meter
British thermal unit	1055	joule
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
micromhos 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
pound	453.6	gram
square foot	0.09290	square meter
square mile	2.590	square meter
ton (short, 2,000 pounds)	0.9072	metric ton
ton per acre	0.0002241	megagram per square meter
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 49, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND WYOMING

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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 49 encompasses about 10,700 square miles in southeastern Montana and north-central Wyoming, near the center of the Northern Great Plains Coal Province. The land surface typically is characterized by rolling uplands dissected by steep-walled valleys and primarily is drained by the Yellowstone River, the Tongue River, and Rosebud Creek and their tributaries.

Streamflow varies seasonally, with the largest flows occuring in response to rainfall and snowmelt. Peak flows in mountain streams generally occur in June as a result of snowmelt mixed with rain. 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 varies with streamflow. During low-flow periods, water in the streams generally is of the sodium sulfate type and can contain dissolved-solids concentrations in excess of 4,000 milligrams per liter. The water composition during low flow is a reflection of the ground-water quality. During direct-runoff periods, the water generally is of the calcium magnesium bicarbonate type and has much smaller dissolved-solids concentrations. Concentrations of less than 100 milligrams per liter have been measured from intermittent streams at times of snowmelt and frozen ground.

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

Strippable coal deposits within the area are about 33.6 billion tons, primarily in the Tongue River Member of the Fort Union Formation. About 223 million tons of coal was produced from the area from 1970 through 1980. Peak production was 35.7 million tons during 1979.

Aquifers in the area include the Fox Hills-lower Hell Creek, Tullock, Tongue River-Wasatch, and alluvium. Wells completed in the Fox Hills-lower Hell Creek aquifer may yield as much as 200 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. Ground water above the Bearpaw Shale generally can be divided into a shallow and a deep flow system. Water in the shallow system generally is at depths of less than about 200 feet and flows in the direction of the local topographic drainage. Water in the deep system, which generally is present at depths greater than about 200 feet, flows more regionally and generally northward toward the Yellowstone River. Water from the shallow flow system generally is of the sodium sulfate type. Dissolved-solids concentration averages about 2,000 milligrams per liter. Water from the deep flow system contains principally sodium and bicarbonate and has an average dissolved-solids concentration of about 1,400 milligrams per liter.

Surface mining may increase the potential for hydrologic problems. Increased erosion can cause channel filling by excessive sediment deposition, thereby decreasing the carrying 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 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 in 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 an appropriate regulatory agency to issue mining permits based on the review of permit application data to assess hydrologic impacts. That need is partly fulfilled by this report, which broadly characterizes the hydrology of Area 49 in Montana and Wyoming, 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 hydrologic information will be supplemented by the lease applicant's specific site data as well as data from other sources. The purpose of the specific site data is to provide a detailed appraisal of the hydrology of the area in the vicinity of the mine and the anticipated hydrologic consequences of the mining operation.

NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES

Numbers represent project areas

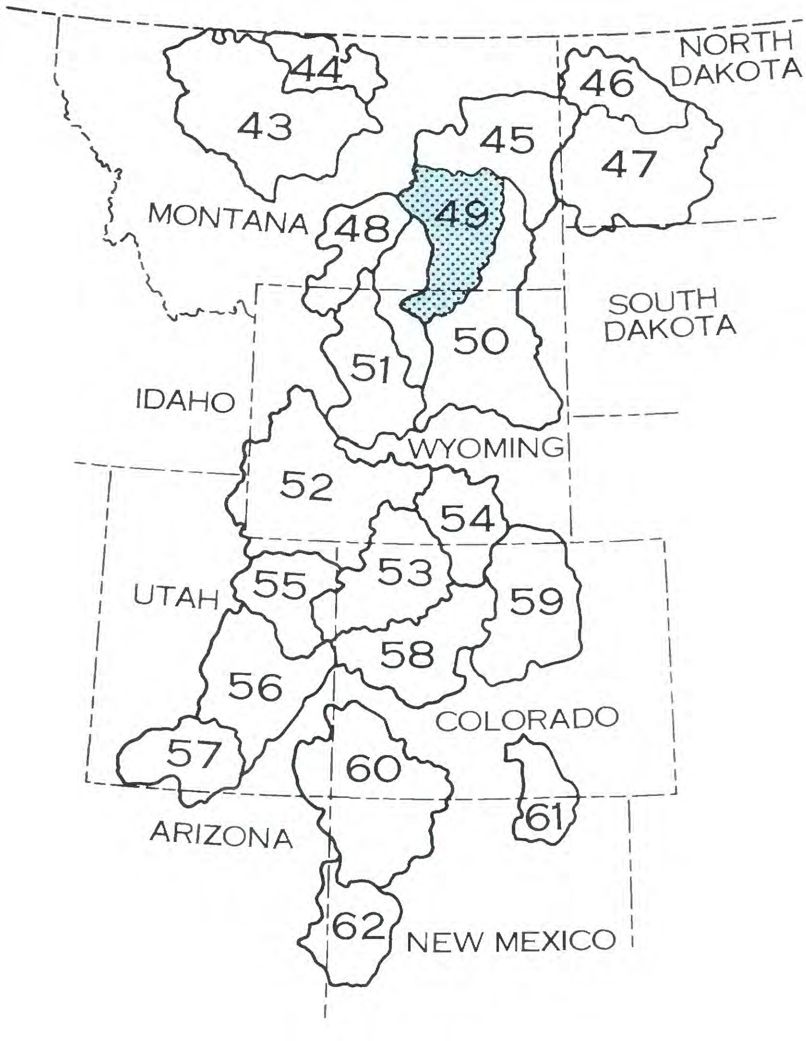


Figure 1.1-1 Location of Area 49.

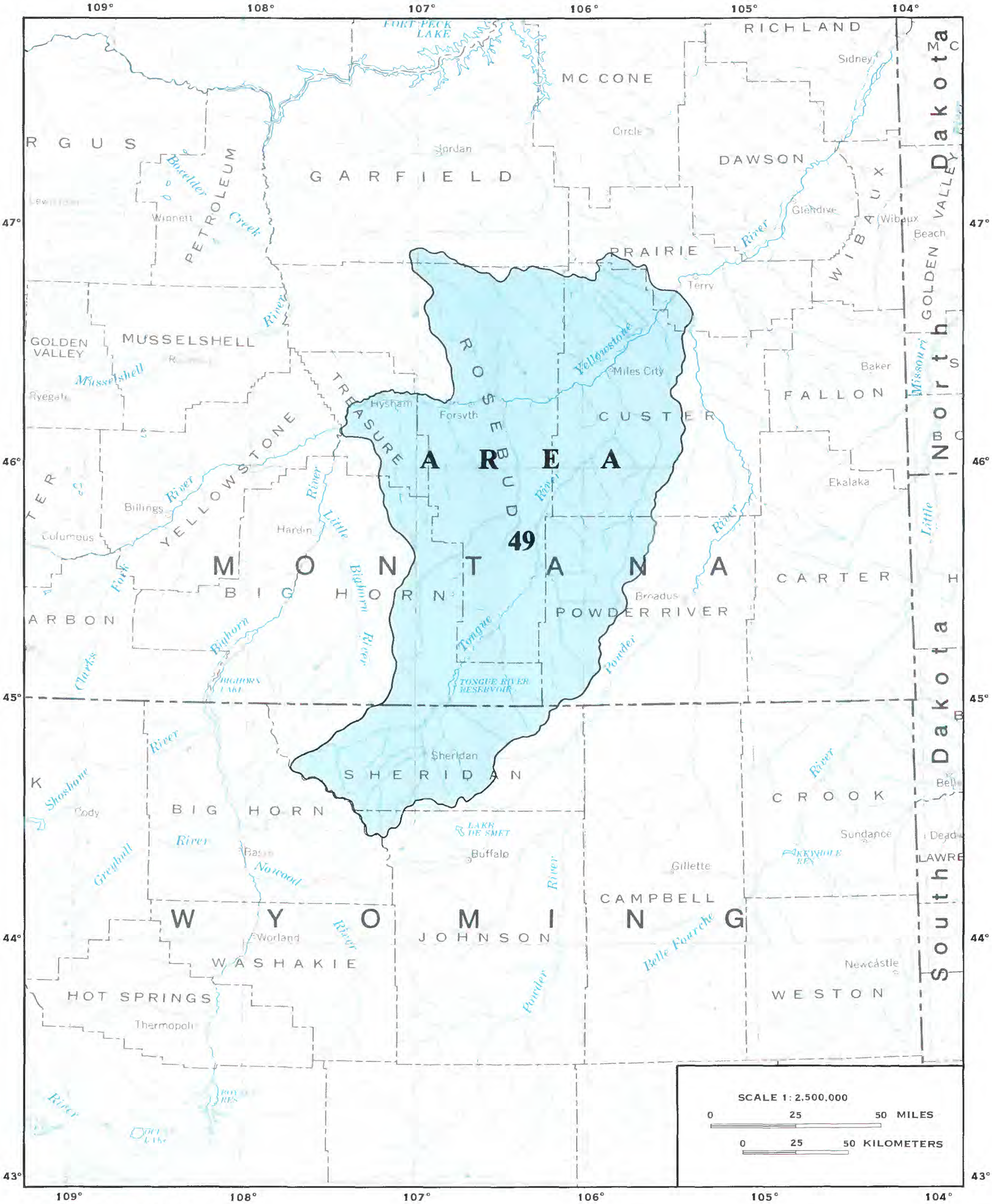
Area 49 Located in Central Part of Northern Great Plains Coal Province

Area 49 encompasses about 10,700 square miles in southeastern Montana and north-central Wyoming.

The project area includes parts of Prairie, Garfield, Treasure, Rosebud, Custer, Big Horn, and Powder River Counties in southeastern Montana and Sheridan and Johnson Counties in north-central Wyoming (fig. 1.2-1). The principal population centers in the area are Miles City, Montana, and Sheridan, Wyoming. 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 area typically is characterized by rolling uplands dissected by steep-walled valleys. Rugged ridges, mesas, or buttes are evident in many areas. Locally, badlands have developed in easily erodable shales. Local relief from hilltops to adjacent valley floors commonly is 100 to 500 feet.

Other than ranching, farming, and related services, coal mining and coal-fired, electric-power generation are the dominant major industries. Some oil and gas also are produced from the area.



BASE 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 effluent.

Benthic invertebrate, for this study, is an animal without a backbone, living on or near the bottom of an aquatic environment, which is retained on a 210-micrometer mesh sieve.

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 period of time.

Average discharge is the arithmetic average of individual discharges during a specific period. 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 are performed on filtered samples.

Diversity index is a numerical expression of distribution of aquatic organisms among the different species.

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 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.

Hydrologic unit is a geographic area representing all or part of a surface drainage basin or distinct hydrologic feature as delineated by the Office of Water Data Coordination on State Hydrologic Unit maps (U.S. Geological Survey, 1976a, 1976b); each hydrologic unit is identified by an 8-digit number.

Intermittent stream is a stream that does not flow continuously, 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).

Partial-record station is a particular site where limited streamflow or water-quality data, or both, are collected systematically during a period of years for use in hydrologic analyses.

Perennial streams 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 surface is a surface that represents the static hydraulic head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

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, characteristic, 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 position on a stream or a well 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 overburden material that is placed in the mine pit after completion of mining.

Stage-discharge relation is the relation between gage height (stage) and volume of water flowing in a channel per unit of time (discharge).

Station is a point on a stream or a well 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.

Taxonomy is the division of biology concerned with the classification and naming of organisms. The classification of organisms is based upon a hierarchical method beginning with Kingdom and ending with Species at the base. The less precise the classification, the fewer features the organisms have in common. For example, the taxonomy of a particular mayfly, *Hexagenia limbata*, is the following:

Kingdom	Animal
Phylum	Arthropoda
Class	Insecta
Order	Ephemeroptera
Family	Ephemeridae
Genus	*Hexagenia*
Species	*limbata*

Water year is the 12-month period 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 ended September 30, 1981, is the 1981 water year.

Climate is Semiarid

Area 49 has a semiarid climate, with most rainfall occurring in June and the driest months being in winter.

The climate is characterized by cold dry winters, cool moist springs, hot moderately dry summers, and cool dry falls. Winter cold waves are often interrupted by extended periods 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 44.7°F at Broadus, Montana, to 45.9°F at Colstrip, Montana, according to National Weather Service records. January normally is the coldest month. Average January temperatures range from 15.4°F at Miles City, Montana, to 21.0°F at Colstrip and at Sheridan, Wyoming. July is normally the warmest month. Average July temperatures range from 70.4°F at Sheridan to 74.4°F at Miles City. Several days with maximum temperatures in excess of 100°F are not uncommon.

Average annual precipitation ranges from about 12 inches along the northwest side of the area to about 20 inches in the mountains at the southern end. Annual precipitation generally is more variable, more intense, and less in the prairie areas than in the mountains. Most of the annual precipitation occurs from April through June, but seasonal variation is large. June has the most rainfall of the spring and summer months. The winter months in the prairie areas are the driest. Snow accumulation in the mountains provides a source of water to sustain streamflow throughout the summer months in streams that originate in the mountains.

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 rainfall by months for Miles City is shown in figure 3.1-2. The extremes are presented to show variations from normal for each month.

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

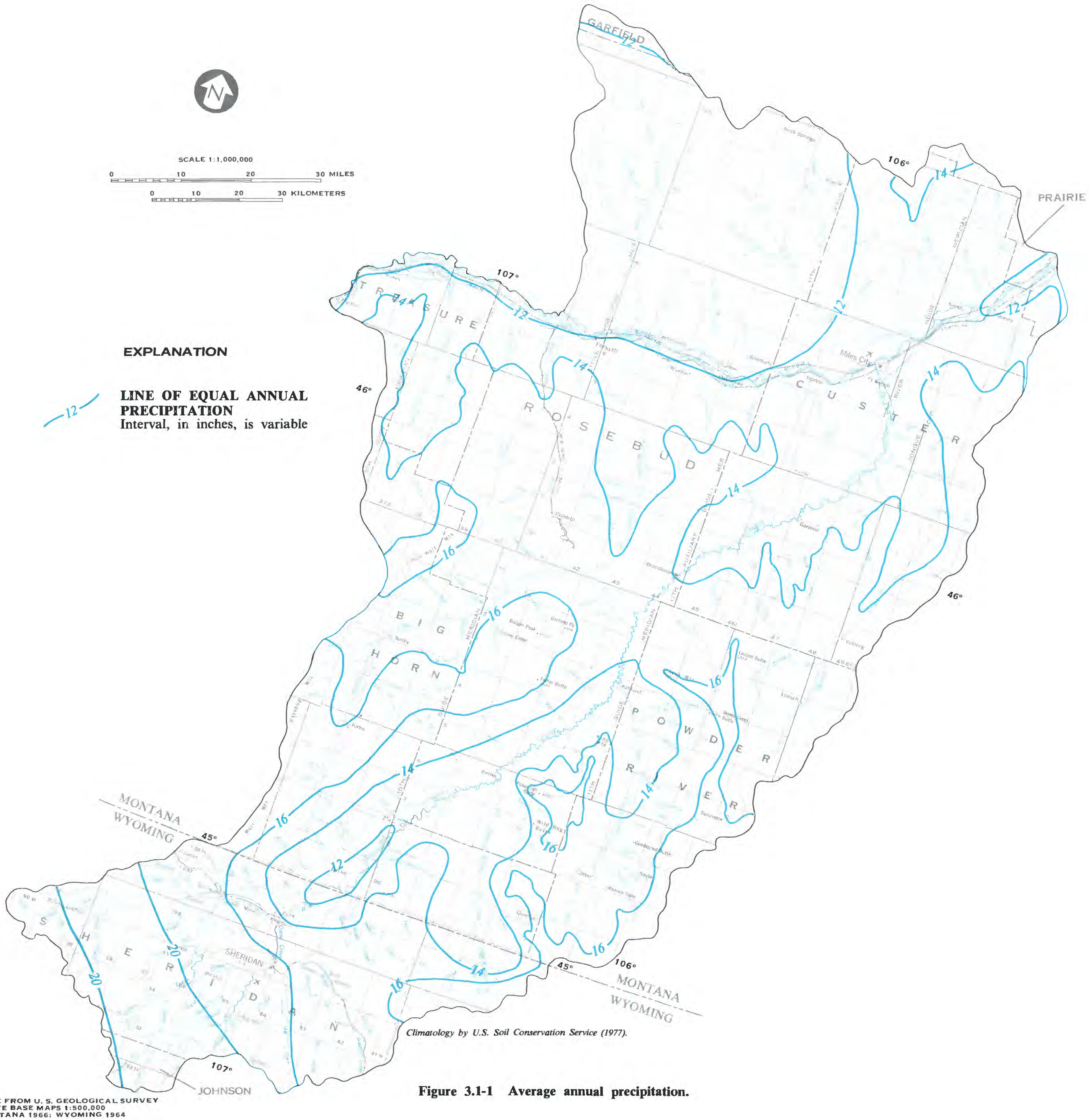
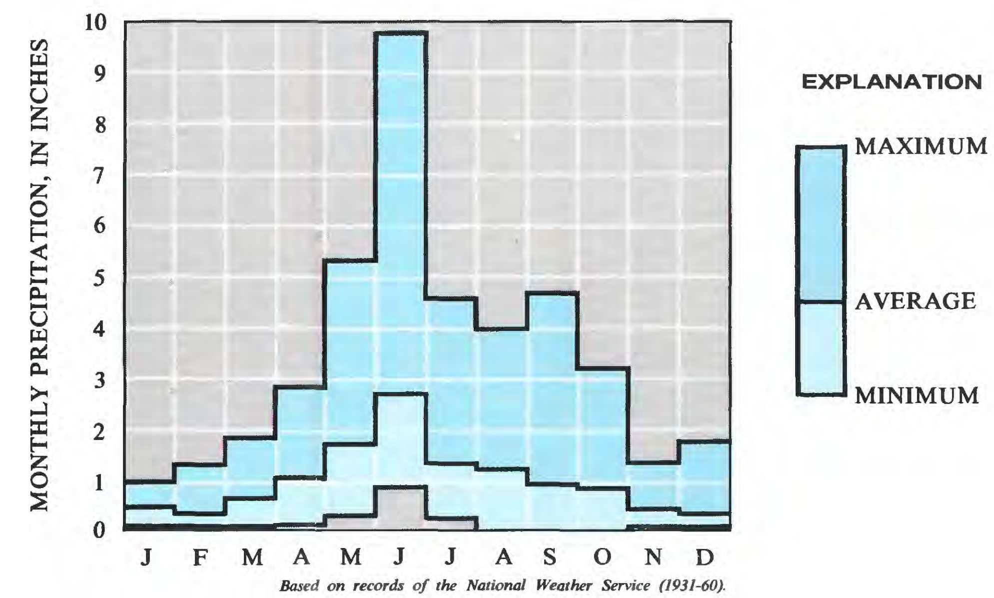


Figure 3.1-1 Average annual precipitation.



EXTREMES OF RECORD, IN INCHES

Maximum monthly precipitation	9.78	(June 1944)
Minimum monthly precipitation	0.00	(Many dates)
Maximum 24-hour precipitation	3.74	(May 1908)
Maximum monthly snowfall	35.3	(March 1894)
Maximum 24-hour snowfall	28.0	(March 1894)

Figure 3.1-2 Precipitation data for Miles City (Custer County), 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, Fort Union Formation, and Wasatch Formation; most coal beds occur in the Tongue River Member of the Fort Union Formation.

Area 49 is underlain by sedimentary geologic units ranging in age from Late Cretaceous to early Tertiary, 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, Fort Union Formation, and Wasatch Formation (fig. 3.2-1).

The Bearpaw Shale grades from massive dark shaly claystone and shale in the eastern part of the area to a sequence of silty sandstone, siltstone, and thin shale beds in the western part. The Fox Hills Sandstone does not crop out in the area. However, it is recognized in the subsurface by the use of geophysical logs as upper and lower predominantly sandstone units separated by a thin shale bed. The Hell Creek Formation is composed of interbedded shale, siltstone, and channel sandstone in the lower part of the unit and a locally massive shale with lenticular sandstone and interbedded claystone, silty sandstone, and thin coal beds in the upper part.

The 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 composed of dark shale containing interbeds of siltstone and thin coal beds locally. The Tongue River Member is composed of alternating sandstone, siltstone, shale, and thick and extensive coal beds.

The Wasatch Formation, which is restricted to the southern part of Area 49, contains lenticular sandstone interbedded with shale and coal. Coal beds are as thick and laterally persistent as in the underlying Tongue River Member of the Fort Union Formation.

Outcrops of clinker or "red shale" 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 section discussed in this report.

Quaternary alluvium and terrace deposits composed of interbedded clay, silt, sand, and gravel are the youngest geologic units in the area. Terraces occur mainly near valley sides and uplands along the Yellowstone River, with scattered deposits along the Tongue River. Alluvium is thickest along these same rivers and their major tributaries but also is present along many smaller streams. Because of the limited areal extent of the outcrops, alluvium and terrace deposits are not shown in fig. 3.2-1.

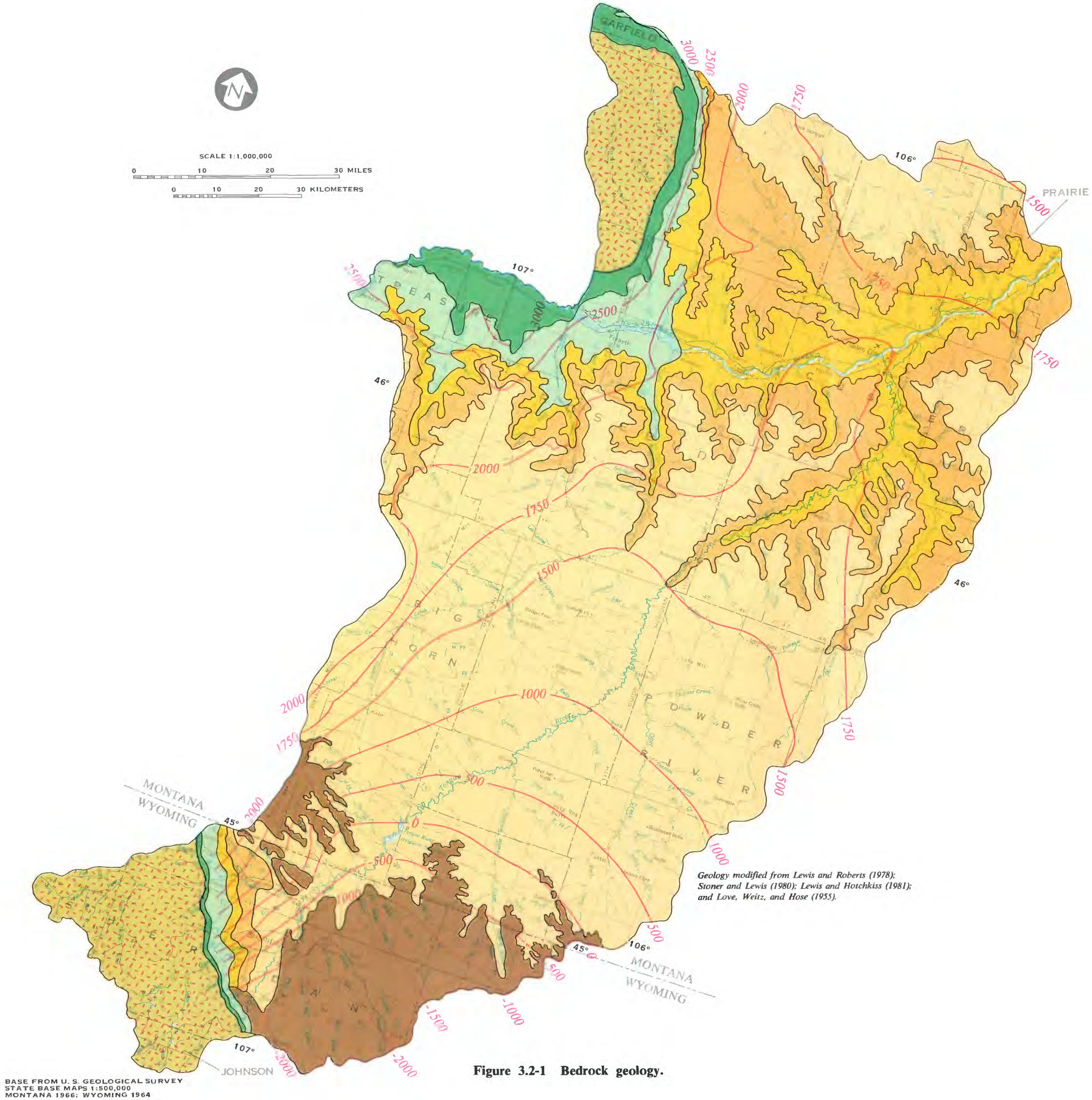


Figure 3.2-1 Bedrock geology.

Land Used Primarily for Grazing

Principal land use includes range, forest, nonirrigated cropland, and irrigated cropland.

Land use primarily is related to the natural diversity of the land. The land-use map (fig. 4.1-1) shows that about 83 percent of the land is range (fig. 4.1-2). 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 Area 49 (F. F. Munshower, Montana State University, oral commun., 1982). Forest covers about 11 percent of the area. Irrigated and nonirrigated cropland each covers about 3 percent of the area and is adjacent to or on the flood plain of the major streams draining the area.

Surface coal mines (section 5.2) occupy a very small percentage of the land area; however, the percentage is continually increasing. Lands reclaimed (spoils) after the coal has been extracted generally are returned to rangeland or nonirrigated cropland.

Because the Federal government owns the rights to much 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 of known recoverable reserves, coal will meet energy needs without unduly damaging the environment. The major source of information for this determination is through coal and economic data made available to the U.S. Minerals Management Service by coal companies, Federal and State agencies, or the public. Coal areas found acceptable for lease consideration are delineated into tracts by the Minerals Management Service 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.

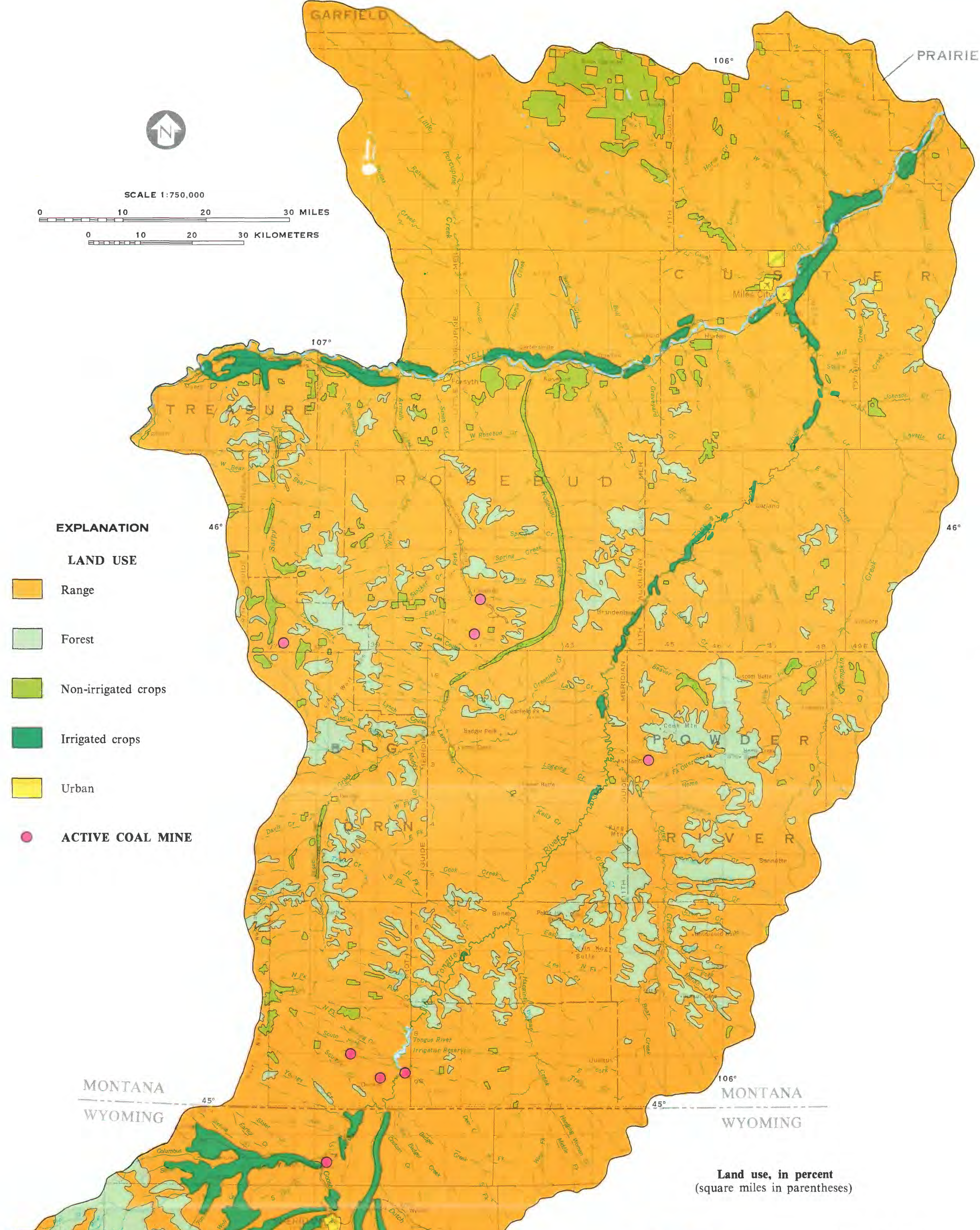


Figure 4.1-1 Land use.

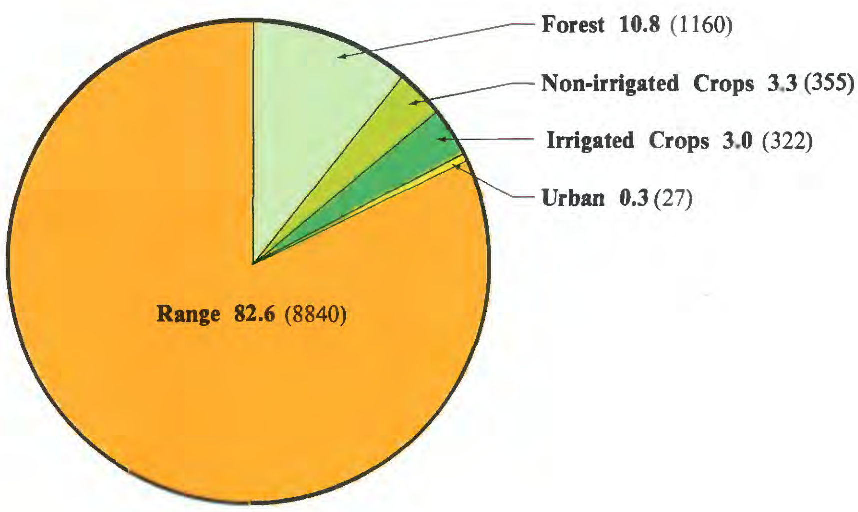


Figure 4.1-2 Summary of land use.

Principal Water Use is Irrigated Agriculture

During 1980 daily water use was about 494 million gallons of surface water and about 11 million gallons of ground water.

Irrigated agriculture was by far the largest use of water during 1980 (fig. 4.2-1), with 475 million gallons per day being used from surface-water sources and 3.9 million gallons per day from ground-water sources. Most of the irrigation occurs along the main stems of the Yellowstone and Tongue Rivers. Irrigated acreage and consumptive water use are about the same along both rivers. Limited irrigation occurs along the larger Tongue River tributaries, but the quantity of water used is relatively small and most is from spring runoff.

Water for public supplies was the second largest water use during 1980, as about 8.1 million gallons per day was obtained from surface-water sources and about 1.0 million gallons per day from ground-water sources. Most of the water for public supply was used in the communities of Sheridan, Wyoming, and Miles City, Montana.

Self-supplied industrial water use totaled about 6.7 million gallons per day during 1980, with about one-half being surface water and the rest ground water. Almost all industrial water use occurred in Wyoming.

Thermoelectric-power generation at Colstrip, Montana, accounted for 6.3 million gallons per day of water use. All water use for power generation was from surface-water sources.

The total estimated surface-water use during 1980 was 493.7 million gallons per day. The total estimated ground-water use was 10.7 million gallons per day.

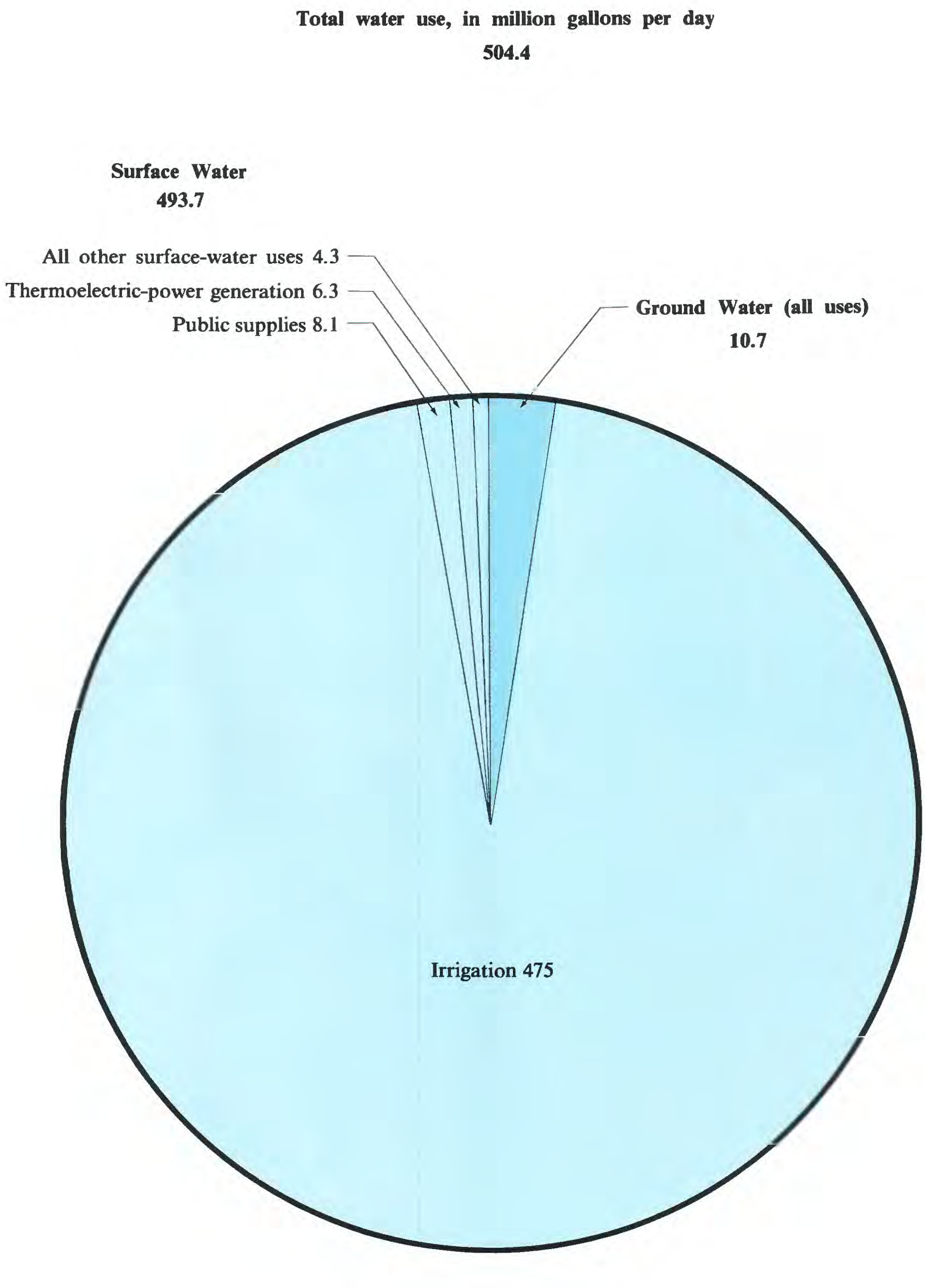


Figure 4.2-1 Approximate water use during 1980.

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 69 percent of the land surface is privately owned. About 12 percent is U.S. Forest Service land (Custer and Bighorn National Forests); 10 percent is Indian Reservation; 5 percent is owned by the State; and 4 percent is in Federal ownership, primarily administered by the U.S. Bureau of Land Management (figs. 4.3-1 and 4.3-2). The entire Northern Cheyenne Indian Reservation and the extreme eastern part of the Crow Indian Reservation lie within Area 49.

Major ownership of coal is divided about equally between the Burlington Northern Railroad and the Federal Government in the area north of the southern boundary of railroad grant lands (fig. 4.3-1). South of the boundary, about 88 percent of the coal is Federally owned; about 10 percent of the Federal coal is held in trust for Indian tribes. About 7 percent of the coal is privately owned and about 5 percent is owned by the State (fig. 4.3-3). The history of land surface and coal ownership gives insight into today's checker-board pattern of ownership, which is shown in detail on maps available from the U.S. Bureau of Land Management (1974, 1978, 1979).

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 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.

The westernmost edge of Area 49 was granted to the Crow Indians by government treaty in 1868. The area adjacent to the Crow Reservation on the east, an area of somewhat less than 10 percent of Area 49, was set apart as a reservation for the Northern Cheyenne Indian Tribe by executive order in 1884. Five years later 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). Because the Indian Reservation lands had not been surveyed, the State also was allowed to select lands of equal value and comparable acreage for the school sections lost to the State in the Northern Cheyenne Indian Reservation. Some school-section lands were subsequently sold; however, the mineral rights were retained by the State.

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.

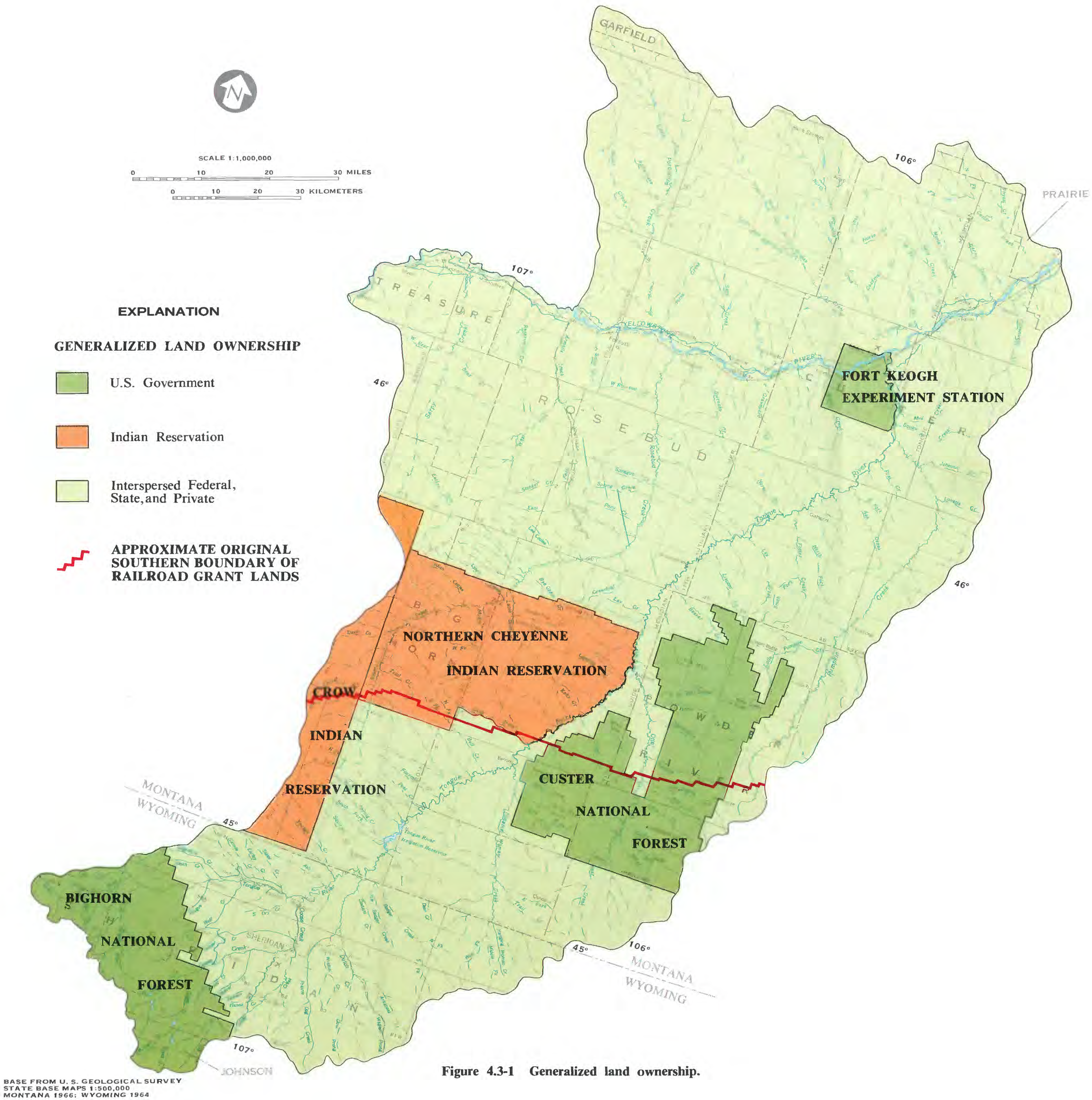


Figure 4.3-1 Generalized land ownership.

Representative ownership, in percent, calculated for the area south of the railroad land grant

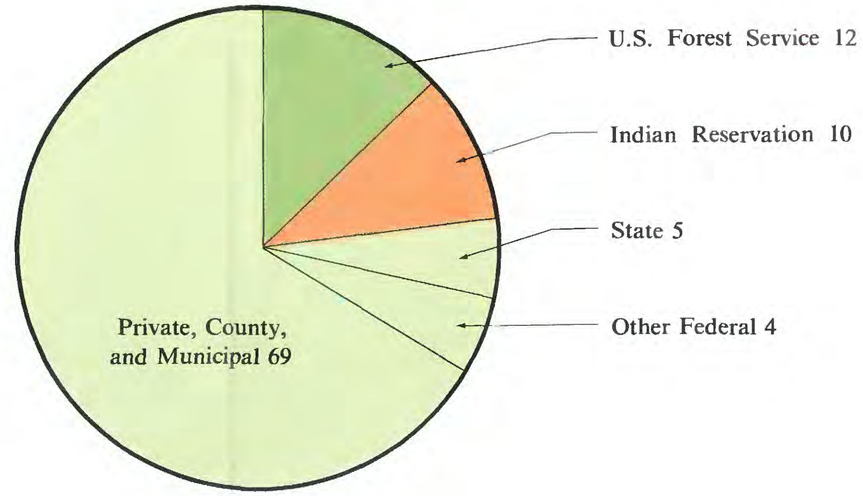


Figure 4.3-2 Surface ownership.

Representative ownership, in percent, calculated for the area south of the railroad land grant

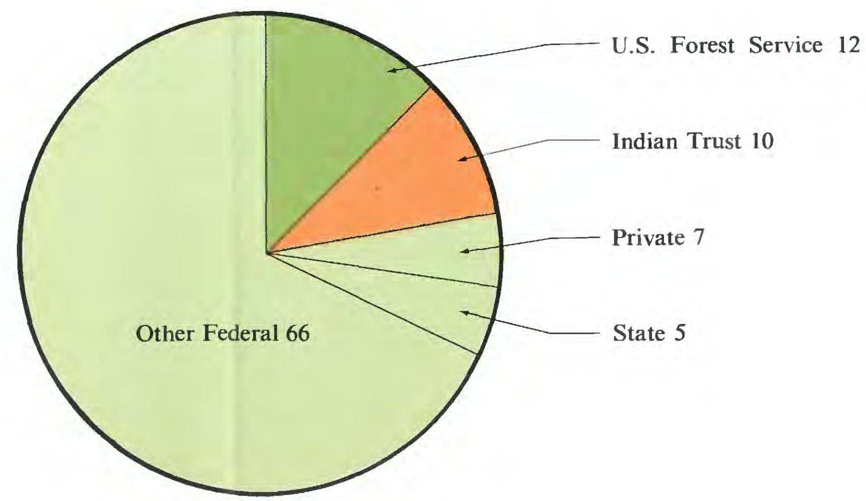


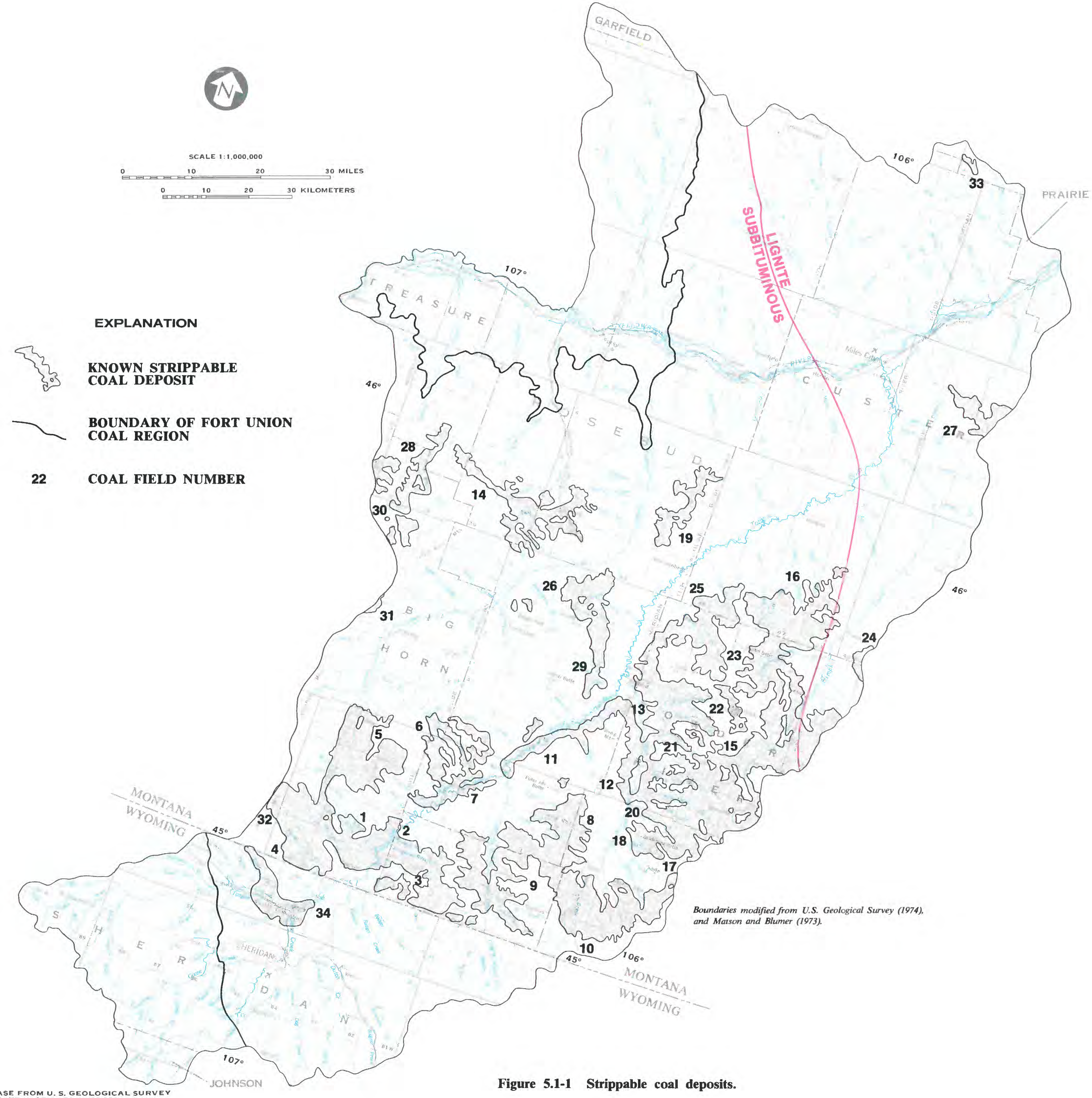
Figure 4.3-3 Coal ownership.

Lignite and Subbituminous Coal Beds Lie at or Near Land Surface in Much of the Area

Strippable reserves from 34 selected coal deposits are about 33.6 billion tons under about 773,000 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 operations 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 improve. 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. Thirty-four major strippable deposits in Area 49 are shown in figure 5.1-1. In addition, substantial resources of strippable and deeper coal resources exist outside of the delineated coal deposits, but data on these additonal resources are not readily available.

The value of coal at the various sites is dependent primarily upon heating value, percentage ash content, and percentage sulfur content. Generally, the coal increases in heating value from northeast (lignite) to southwest (subbituminous coal) across the area. The line separating lignite from subbitumiuous coal in Area 49 is shown in figure 5.1-1. The American Society for Testing and Materials classifies lignite as having a calorific value of 6,300 to 8,300 British thermal units per pound on a moist mineral-matter-free basis, and subbituminous coal as having a calorific value of 8,300 to ll,500 British thermal units per pound. Average heating content, ash, and sulfur values for each coal field are listed, if available, in table 5.1-1. To put coal value in general perspective, the average value for Montana coal during the 1980 calendar year was $7.67 per ton after the following taxes had been deducted: State severance, State resource indemnity trust, State net and gross proceeds, Federal work, Federal personal income, and Federal mining. Therefore, the $7.67 does not indicate the total production cost of the coal (J. D. Mockler, Montana Coal Council, written commun., 1981).



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
MONTANA 1966; WYOMING 1964

Figure 5.1-1 Strippable coal deposits.

Table 5.1-1 Strippable subbituminous and lignite coal deposits in Area 49.

[Coal content: Btu, British thermal units per pound]

Map No. (fig. 5.1-1)	Coal deposit	Coal bed	Estimated reserves: Millions of tons	Acreage	Average tons per acre	Coal content: Btu[1]	Ash[1] (percent)	Sulfur[1] (percent)
1	Decker	Anderson-Dietz 1,2	2,239.99	25,523	87,763	9,652	4.0	0.40
2	Deer Creek	Anderson-Dietz 1,2	495.65	14,214	35,397	9,282	4.0	.50
3	Roland	Roland	218.04	12,076	18,055	8,164	9.2	.74
4	Squirrel	Roland	133.41	6,208	21,490	7,723	5.5	.29
5	Kirby	Anderson	216.52	5,655	38,285	8,328	4.2	.32
		Wall	473.69	5,952	79,579			
		Dietz	834.35	17,516	47,630	8,509	5.8	.59
		Canyon	158.53	4,066	38,983	8,789	5.8	.24
6	Canyon	Wall	1,884.25	23,859	78,974	9,088	4.6	.30
		Brewster-Arnold	65.86	2,067	31,859	8,444	7.5	.40
7	Birney	Brewster-Arnold	180.55	6,969	25,905	9,055	5.1	.41
8	Poker Jim Lookout	Anderson-Dietz	872.65	19,609	44,501	7,925	5.2	.37
9	Hanging Woman Cr.	Anderson	1,583.29	30,547	51,830	8,496	4.9	.29
		Dietz	1,120.96	43,654	25,678	8,078	5.5	.33
10	West Moorhead	Anderson	883.74	19,660	44,949	8,296	5.3	.36
		Dietz	397.49	20,416	19,469	7,990	4.1	.41
		Canyon	690.19	22,547	30,611	8,055	5.6	.45
11	Poker Jim O'Dell	Knobloch	373.29	7,890	47,311	8,846	5.1	.22
		Knobloch	564.78	7,187	78,581			
12	Otter Creek	Knobloch	2,075.55	25,791	80,475	8,468	4.7	.36
13	Ashland	Knobloch	2,696.20	27,200	99,125	8,421	4.8	.15
		Sawyer, A, and C	357.49	20,262	17,643	7,883	4.9	.49
14	Colstrip	Rosebud	1,439.26	33,379	43,118	8,750	8.5	.75
15	Pumpkin Creek	Sawyer	2,426.50	45,695	53,102	7,438	7.5	.34
16	Foster Creek	Knobloch	708.13	27,801	25,470	7,573	7.8	.76
		Terrett	460.87	27,462	16,782	7,770	5.8	.21
		Flowers-Goodale	258.90	14,444	17,924	7,553	7.8	.51
17	Diamond Butte[2]	Canyon	209.01	10,681	19,566	7,330	4.8	.43
18	Goodspeed Butte	Cook	628.95	13,446	46,775	6,771	10.6	1.63
19	Sweeney-Snider	Terrett	326.33	10,921	29,880	8,175	9.1	.11
20	Yager Butte	Elk and Dunning	1,175.86	26,924	43,673	7,646	4.8	.33
		Cook	312.02	14,507	21,507	7,254	6.7	.63
21	Threemile Buttes	Canyon and Ferry	225.40	13,836	16,289	6,867	5.5	.94
22	Home Creek Butte	Canyon and Ferry	217.21	4,851	44,774	--	--	--
23	Little Pumpkin Cr.	E, X, C, D, Sawyer, and A	215.83	8,534	25,290	--	--	--
24	Sand Creek[2]	Knobloch	133.67	2,976	44,915	7,340	6.6	.30
25	Beaver-Liscom	Flowers-Goodale and Terrett	135.87	8,851	15,350	8,102	8.1	.96
		Knobloch	491.62	17,075	28,791	8,027	7.7	.50
26	Greenleaf-Miller Cr.	Rosebud, Knobloch, and Sawyer	453.71	14,918	30,413	8,422	7.5	.71
27	Pine Hills[2]	Dominy	96.94	3,011	32,191	7,293	7.2	.53
28	Sarpy Creek	Rosebud-McKay	1,500.00	42,373	35,400	8,450	9.0	.70
29	Cheyenne Meadows	Knobloch	1,200.00	13,560	88,500	8,400	4.1	.40
30	Little Wolf	Rosebud-McKay	314.00	7,411	42,370	--	--	--
31	Jeans Fork	--	90.00	3,800	23,685	--	--	--
32	Wolf Mountains	--	1,922.00	31,000	62,000	--	--	--
33	Little Sheep Mtn.[2]	A and C	100.00	5,136	19,470	--	--	--
34	Acme-Kleenburn[3]	Monarch and Dietz 3	39.30	2,029	19,369	9,655	4.4	.45
		Total	33,597.85	773,489				

1 "As received" basis (if more than one sample available, average figures are given).

2 Only one-half of coal field is in Area 49.

3 Only delineated Area 49 coal field in Wyoming, having strippable coal.

Total Coal Production from 1970 to 1980 Less Than 1 Percent of Reserves

In 1981, eight commercial surface coal mines were in production, four mines were proposed, and other potential mines were undergoing Federal land-use planning determinations.

Total coal production from 1970 through 1980 at eight mines (fig. 5.2-1) was about 223 million tons (W. R. Cox, Montana Department of Labor, written commun., 1981), which is less than 1 percent of the known strippable reserves (see section 5.1 - Strippable coal deposits). Annual coal production in Area 49 during this time is shown in figure 5.2-2.

Coal-production figures in Area 49 before 1970 are relatively unknown, but production before 1970 was small compared with production after 1970. Coal mined prior to 1970 was used primarily as fuel for steam-driven railroad locomotives and for home heating. Many of the ranchers in the area maintained their own "mines," which were actually natural coal outcrops where the ranchers dug coal for personal use. Commercial coal production began in the Sheridan, Wyoming, area in the early 1890's and ended about 1953. Most of this production was from underground mines. Commerical mining resumed in the area in 1962 with the opening of the Big Horn Mine north of Sheridan, Wyoming. The Northern Pacific Railroad opened the Rosebud Mine at Colstrip, Montana, in 1924 and used the coal until 1958 when the mine was closed. The Rosebud Mine at Colstrip was reopened in 1968 by Western Energy Company as a source of coal for thermoelectric-power generation.

Changes in coal production from year to year are the result of prevailing weather, economics, and energy-conservation conditions. Projections of production for 1985 and 1990 (fig. 5.2-2) were based on contracted tonnage data available from the U.S. Department of Energy (Montana Coal Council, 1981).

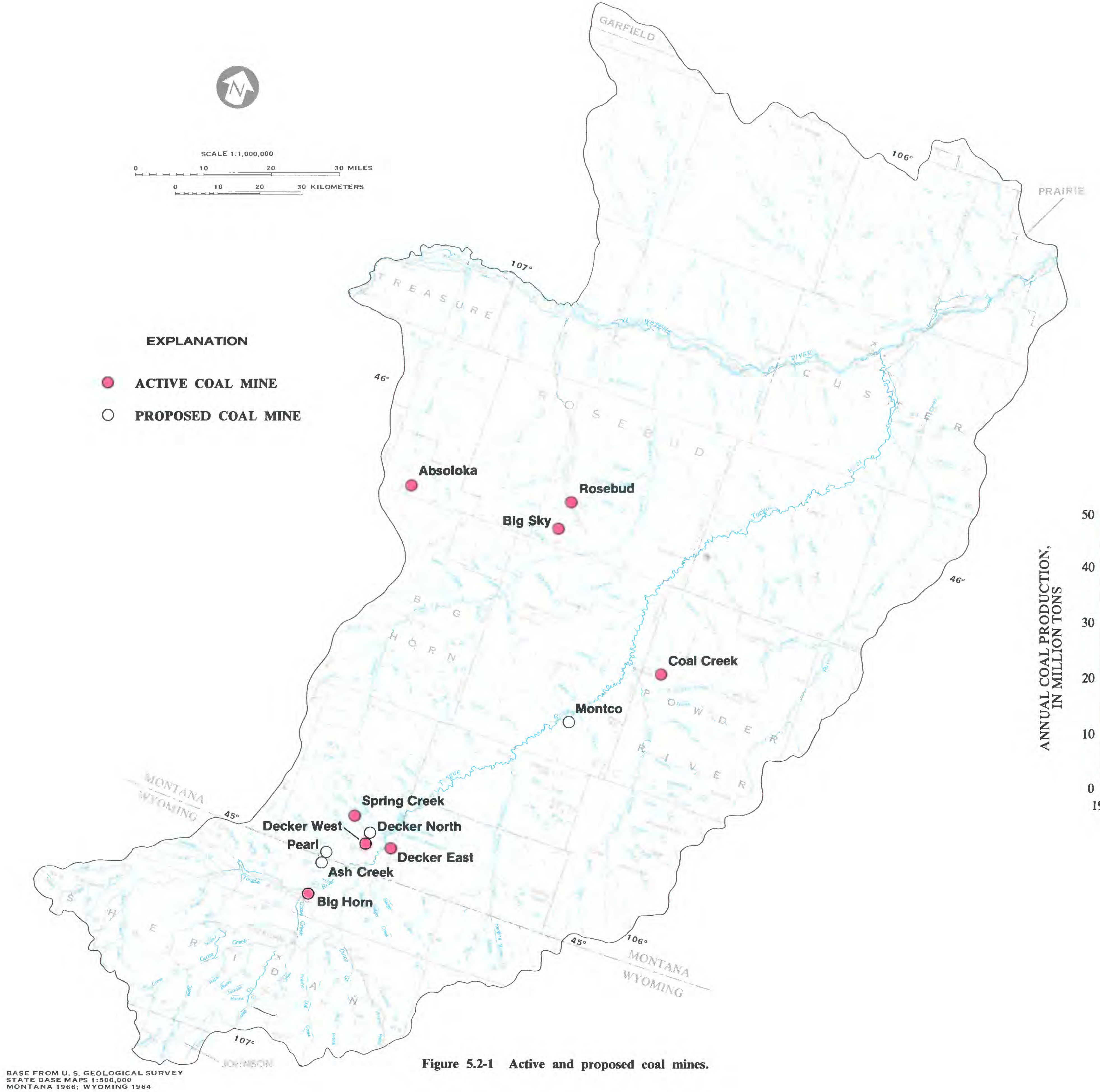


Figure 5.2-1 Active and proposed coal mines.

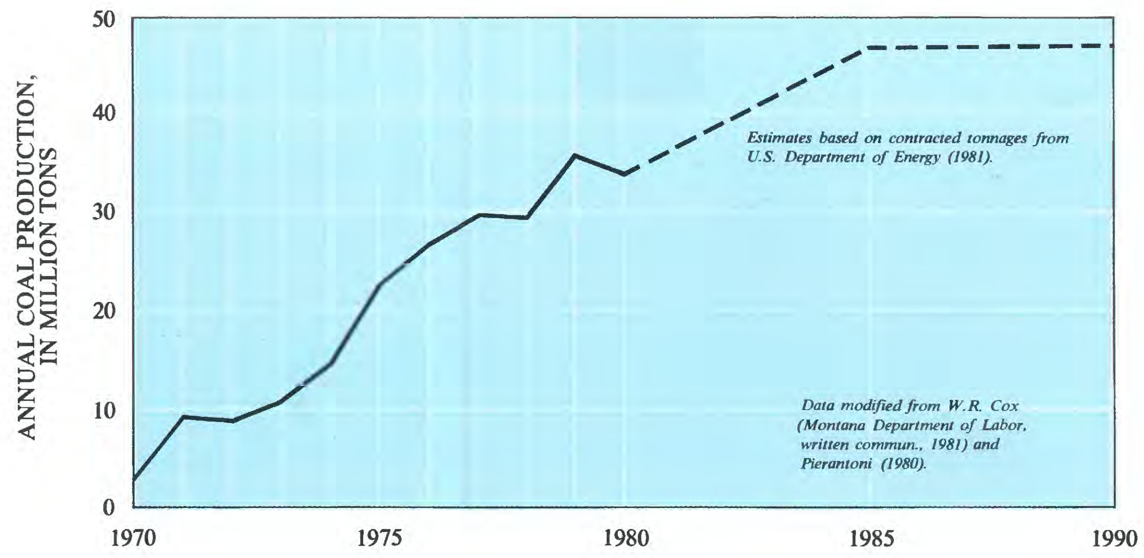


Figure 5.2-2 Coal production.

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-carrying capacity of the stream and may lead to increased flooding. The habitat of aquatic organisms may be altered through burial and decreased dissolved-oxygen concentration of the water, owing to decreased depth and increased temperature. Dissolution of minerals contained in sediment derived from recently excavated overburden material may result in increased dissolved-solids and 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 can decline in and near surface-mined areas where excavation intersects a water-yielding zone, and thus the aquifer is being mined. Water-level declines may cause a decrease or loss of production of wells and springs. These effects generally will be temporary and occur only during and for a limited time after the active mining period. The areal extent of mining effects on water levels is largely dependent on the geologic and hydrologic setting of the mine. 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 isolated aquifer. Recharge available to this individual aquifer is limited to leakage through the surrounding confining zones; 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 impacted 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. The actions of sulfate-reducing bacteria can decrease sulfate concentrations. Sulfate-reducing bacteria, which are present in the existing aquifers, have been reported to re-establish themselves in spoils aquifers (Dockins and others, 1980); however, waters having large sulfate concentrations have developed near some mines (Van Voast, 1974; Van Voast and Hedges, 1975). 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 is 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 dilution occurs downstream. Simulation of a hypothetical plan to simultaneously mine all Federally owned coal judged potentially available for mining in the Montana part of the Tongue River basin 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 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 toward 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).

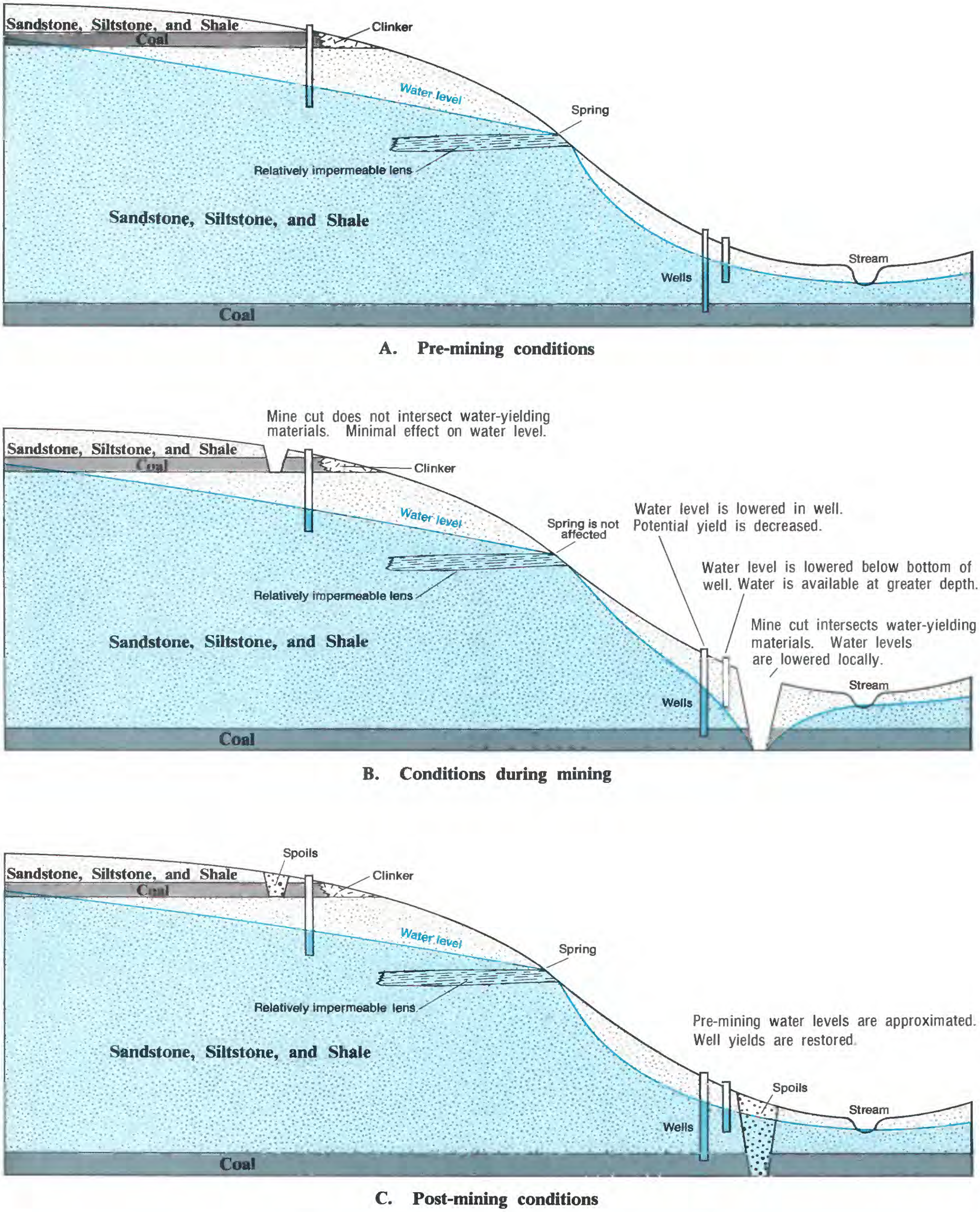


Figure 5.3-1 Possible impacts of mining aquifers.

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 49 were conducted by Renick (1924, 1929), Riffenburg (1926), and Perry (1931, 1932, 1935). Several additional studies were made between 1935 and the early 1970'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 dramatic increase in hydrologic studies to document premining conditions for future planning decisions and to determine the effects of the mining on the hydrologic system. Hydrologic studies conducted by the U.S. Geological Survey since 1966 are shown in figure 6.1-1 and listed in table 6.1-1. Additional hydrologic studies have been conducted by the Montana Bureau of Mines and Geology, the Water Quality Bureau of the Montana Department of Health and Environmental Sciences, and the Wyoming Geological Survey.

Figure 6.1-1 Previous studies.

Table 6.1-1 Index to previous studies.

Map No. (fig. 6.1-1)	Reference
1	Druse, Dodge, and Hotchkiss (1981)
2	Frickel and Shown (1974)
3	Frost (1974)
4	Ground-water Subgroup of Water Work Group, Northern Great Plains Resource Program (1974)
5	Lewis and Hotchkiss (1981)
6	Miller and Strausz (1980a, 1980b)
7	Parrett, Carlson, Craig, and Hull (1978)
8	Parrett, Carlson, Craig, and Chin (1982)
9	Swenson, Miller, Hodson, and Visher (1976)
10	Boner and Omang (1967)
11	Johnson and Omang (1976)
12	Feltis (1980a, 1980b, 1980c, 1980d)
13	Feltis, Lewis, Frasure, Rioux, Jauhola, and Hotchkiss (1981)
14	Knapton and Bochy (1976)
15	Levings (1981a, 1981b)
16	Miller (1976)
17	Moore and Shields (1980)
18	Omang, Hull, and Parrett (1979)
19	Omang, Parrett, and Hull (1982)
20	Parrett and Omang (1981)
21	Stoner and Lewis (1980)
22	Hodson, Pearl, and Druse (1973)
23	Dockins, Olson, McFeters, Turback, and Lee (1980)
24	Ferreira (1981)
25	Knapton and Ferreira (1980)
26	Knapton and Jacobson (1980)
27	Knapton and McKinley (1977)
28	Lee (1979, 1980)
29	Lee, Slagle, and Stimson (1981)
30	Lewis and Roberts (1978)
31	Slagle and Stimson (1979)
32	Boner, Lines, Lowry, and Powell (1976)
33	Feltis (1981a)
34	Feltis (1981b)
35	Feltis (1981c)
36	Hopkins (1972)
37	Lowry and Cummings (1966)
38	Ringen, Shown, Hadley, and Hinkley (1979)
39	Stoner (1981)
40	U.S. Department of the Interior (1975)
41	U.S. Department of the Interior (1977)
42	U.S. Department of the Interior (1978)
43	U.S. Department of the Interior (1982)
44	Wangsness (1977)
45	Woods (1981a, 1981b)
46	Whitcomb, Cummings, and McCullough (1966)

U.S. Geological Survey Currently Conducting 28 Investigations in the Area

Current studies focus on determining the impacts of surface mining.

Current water-resources studies by the U.S. Geological Survey in Area 49 (fig. 6.2-1) include collection of surface-water, ground-water, water-quality, and climatic data. The data can be used as a basis for determining the effects of present surface mining and potential surface mining. Additional studies include determination of present areal hydrologic conditions, analysis of stream channel and streamflow characteristics, research investigating probable changes of water quality in spoils, 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.

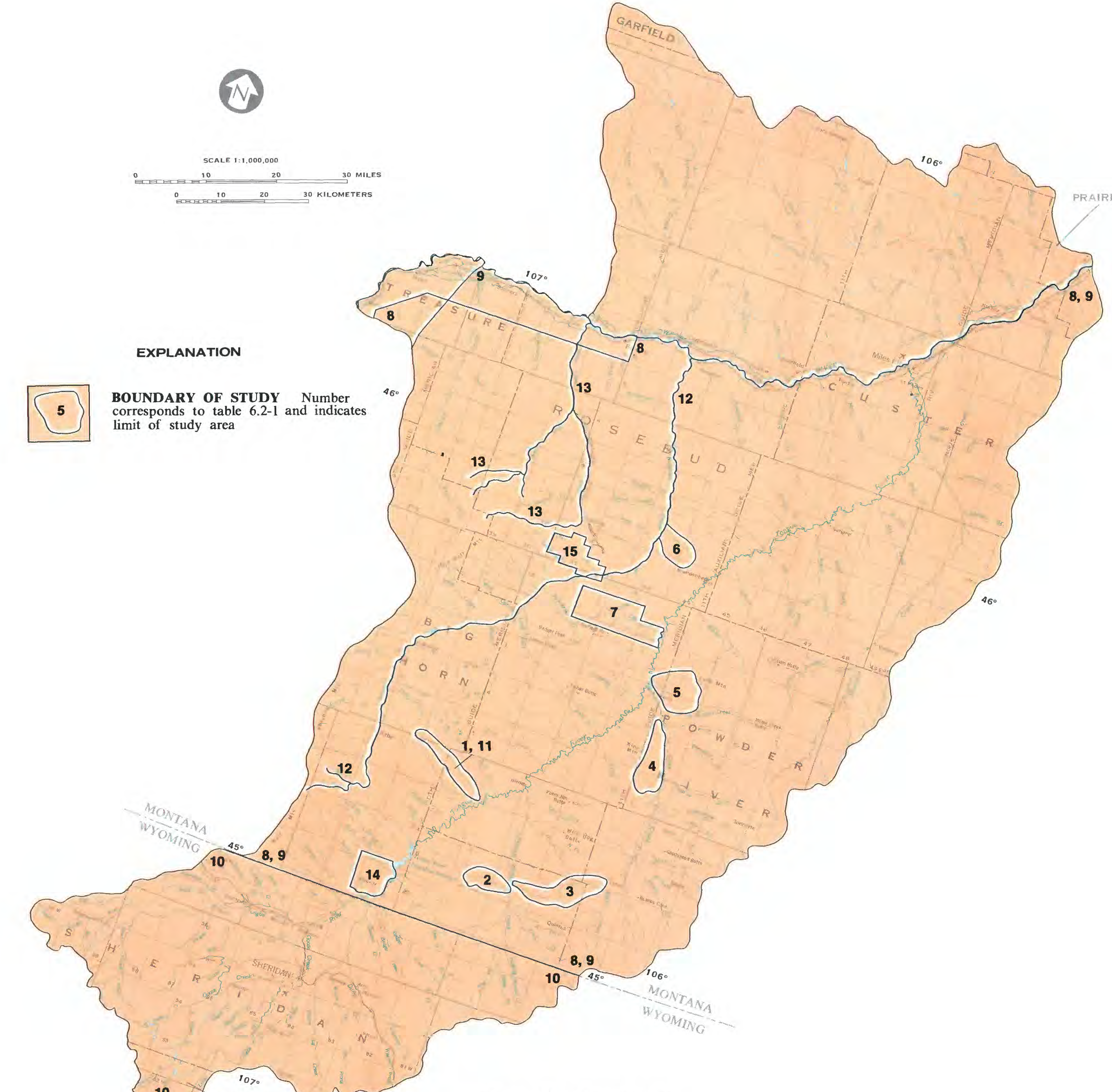


Figure 6.2-1 Current studies.

Table 6.2-1 Index to current studies.

Location within State: Montana	Location within State: Wyoming	Map No. (fig. 6.2-1)	Project No.	Project title	Project objectives
				Data-collection programs	
Statewide	Statewide	--	MT-001, WY-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, WY-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, WY-003	Water-quality stations	To provide a bank of water-quality data for planning management of intrastate, interstate, and international waters
Statewide	Statewide	--	MT-004, WY-004	Sediment stations	To provide a bank of sediment data for planning and management of intrastate, interstate, and international waters
Statewide	---	--	MT-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
Statewide	---	--	MT-030	Special investigations	To assist State and other Federal agencies in solving water-resources problems on short notice
				Areal appraisals	
Central and east	---	--	MT-056	Madison aquifer	To compile data from wells and test holes and 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; to evaluate the suitability of the reservoirs for various uses
				Coal-related studies	
Southeast	---	--	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	---	1-7	MT-066	EMRIA sites	To collect data and evaluate the potential hydrologic impacts of coal development at selected coal-lease application sites; to define premining conditions and document changes in the hydrologic systems associated with mining and reclamation
Southeast	---	8	MT-048	Effects of coal strip mining	To define the ground-water-flow systems above the Bearpaw Shale and to develop predictive models to assess the effects of mining on the hydrologic systems
East	---	--	MT-072	Water-quality monitoring	To present data in a semi-interpretive format, to review and modify the data monitoring network
Southeast	---	9	MT-078	Benthic study	To assist Montana Department of Health and Environmental Sciences in statistical evaluation of benthic-algae populations
				Regional studies	
Statewide	Statewide	--	MT-010, WY-010	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
---	Northeast	10	CO-119	Characteristics of stream channels	To develop consistent hydraulic and geomorphic relationships that are indicative of stream-channel stability
Central and east	Northeast	--	MT-067, WY-049	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
				Research projects	
Prairie Dog Creek	---	11	MT-065	Stream-response modeling	To develop a stream-response model capable of simulating effects of land-use changes on runoff
Rosebud and Armells Creeks	---	12,13	MT-084	Salinity modeling	To construct and calibrate models to evaluate impacts of mining, reclamation, agriculture, and other land-management practices on the salinity of Rosebud and Armells Creeks
Statewide	---	--	MT-070	Channel geometry	To collect data on chemical characteristics; to develop equations relating channel geometry to stream flow characteristics and determine the accuracy of the estimates
Decker and Big Sky Mines	---	14,15	MT-075	Geochemistry of mine spoils	To document water quality in mine spoils and adjacent aquifers; to predict effects of mine spoils on local hydrologic systems
---	Statewide	--	WY-054	Precipitation, infiltration, and runoff relations	To define infiltration rates for soils and determine the relationships between the infiltration rates computed from basin studies and those computed from infiltration tests

Discharge Information Available for 80 Streamflow Stations

The U.S. Geological Survey has surface-water flow information at 46 continuous-record stations and 34 crest-stage stations in the area.

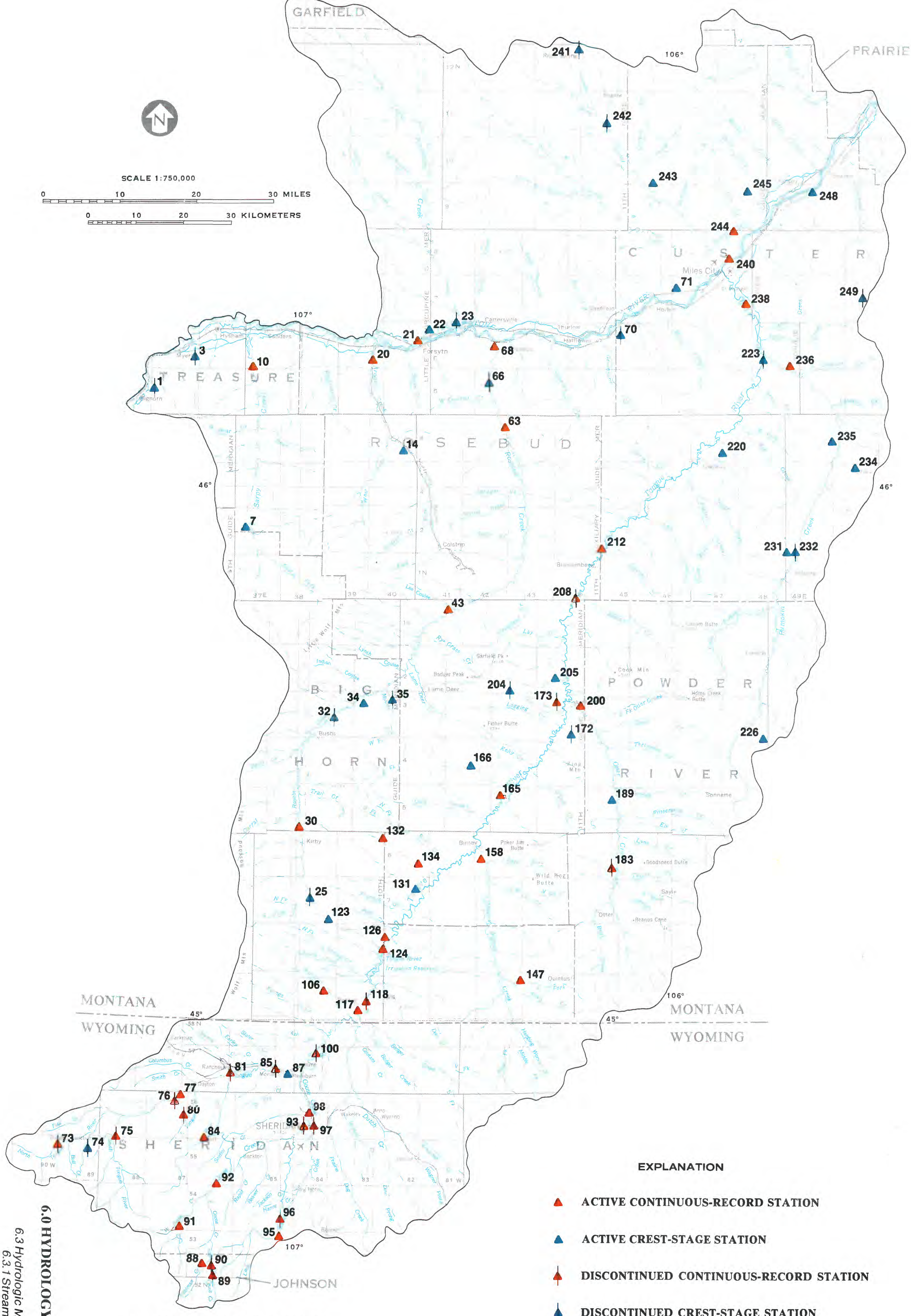
As the name indicates, a continuous-record station provides a continuous record of discharge throughout the water year. A crest-stage station provides only an annual peak discharge for each water year. Data from continuous-record stations can be used for determining average-flow characteristics, low-flow characteristics, and high-flow characteristics of streamflow. Data from crest-stage stations can be used only 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 at the end of this report.

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 assess the hydrology of the general area. Except for the main stem Tongue and Yellowstone Rivers, most of the continuous-record stations have less 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 in 1973. Twenty-two 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 also are available in published U.S. Geological Survey reports "Water Resources Data for Montana" and "Water Resources Data for Wyoming."



EXPLANATION

ACTIVE CONTINUOUS-RECORD STATION

ACTIVE CREST-STAGE STATION

DISCONTINUED CONTINUOUS-RECORD STATION

DISCONTINUED CREST-STAGE STATION

34 MAP NUMBER

See section 12.0 for description of stations

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
MONTANA 1966; WYOMING 1964

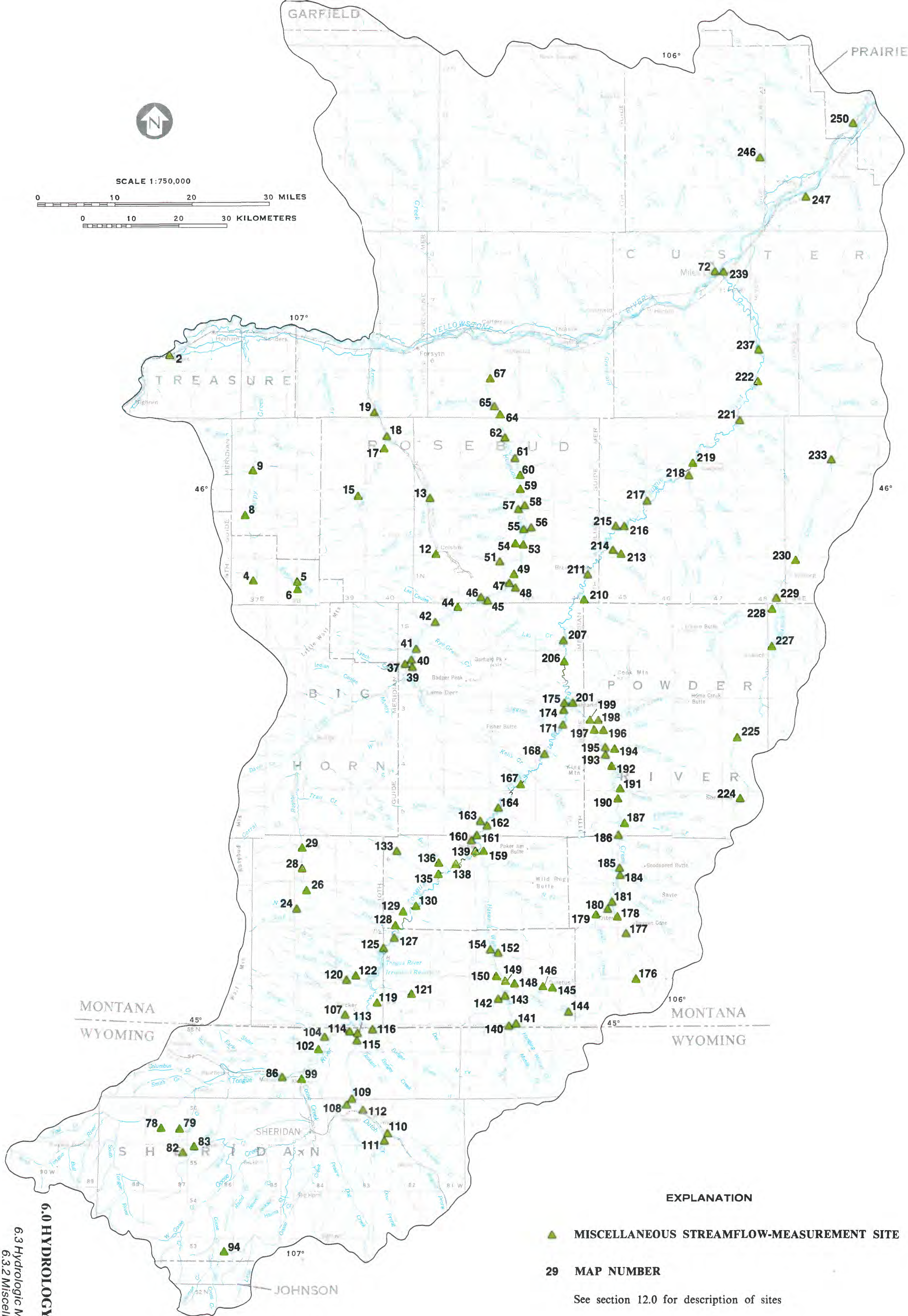
Figure 6.3.1-1 Continuous-record and crest-stage stations.

Surface-Water-Discharge Information Available for 144 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 144 locations in Area 49 (fig. 6.3.2-1). Some measurements were made as early as 1941, but most have been made since 1975. Many miscellaneous streamflow measurements were made in conjunction with surface-water-quality programs funded by the U.S. Geological Survey, the U.S. Bureau of Land Management, and the U.S. Environmental Protection Agency. 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 at the end of this report. Data from most of the measurements are contained in reports of Druse, Dodge, and Hotchkiss (1981); Ferreira (1981); and Lee, Slagle, and Stimson (1981). Additional data are available at the U.S. Geological Survey offices in Helena, Montana, and Cheyenne, Wyoming.



EXPLANATION

▲ MISCELLANEOUS STREAMFLOW-MEASUREMENT SITE

29 MAP NUMBER

See section 12.0 for description of sites

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
MONTANA 1966; WYOMING 1964

Figure 6.3.2-1 Miscellaneous streamflow-measurement sites.

Water-Quality Data Available from Streamflow Stations and Miscellaneous Sites

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

Prior to 1974, little information was available on the quality of surface water in the study area. Information that did exist was from a few sites on the Yellowstone and Tongue Rivers. Historically, the land-use practices that had the greatest impact on water quality were related to agriculture. Although the extraction of coal began in the late 1800's, the mines were few and, with a few exceptions, probably had little effect on surface-water quality. With the recent prospect of large-scale development of coal, concern has been expressed about the degradation of environmental quality; an important concern was the quality of surface water.

Beginning in 1974, a network of data-collection stations was established to monitor chemical and physical properties of surface water throughout the study area. Funding was provided by the U.S. Geological Survey, the U.S. Bureau of Land Management, and the U.S. Environmental Protection Agency. Stations in the network were designated as primary or secondary. Primary stations generally were located on major streams or at the mouths of larger tributaries. They were operated in conjunction with streamflow-gaging stations and programmed for long-term operation. The secondary stations were planned for shorter durations (about 3 years) and located in areas where future land-use changes were thought probable. Secondary stations are operated only long enough to collect baseline data and to establish correlations with primary stations. They can be reactivated if necessary.

The data base from the network will provide documentation of existing conditions and become a basis from which to assess possible future changes. Once the data base is adequate, predictive techniques (such as surface-water modeling) will be used to determine water-quality changes that are likely to result from various mining operations or other proposed land-use changes.

Additional water-quality sites have been established (or existed) for other purposes. A network of biological stations was operated by the Montana Department of Health and Environmental Sciences through funding provided by the U.S. Geological Survey. Intensive sampling for determination of chemical constituents and physical properties was done on selected streams or stream reaches during short periods to define ground-water inflow. National Stream Quality Accounting Network (NASQAN) stations, U.S. Environmental Protection Agency surveillance stations, and daily sediment sampling stations are other water-quality stations.

All water-quality stations (active and discontinued) and miscellaneous sites operated within the study area are shown in figure 6.3.3-1. Additional information about water-quality stations and miscellaneous sites is contained in the list of streamflow and water-quality stations and sites at the end of this report.

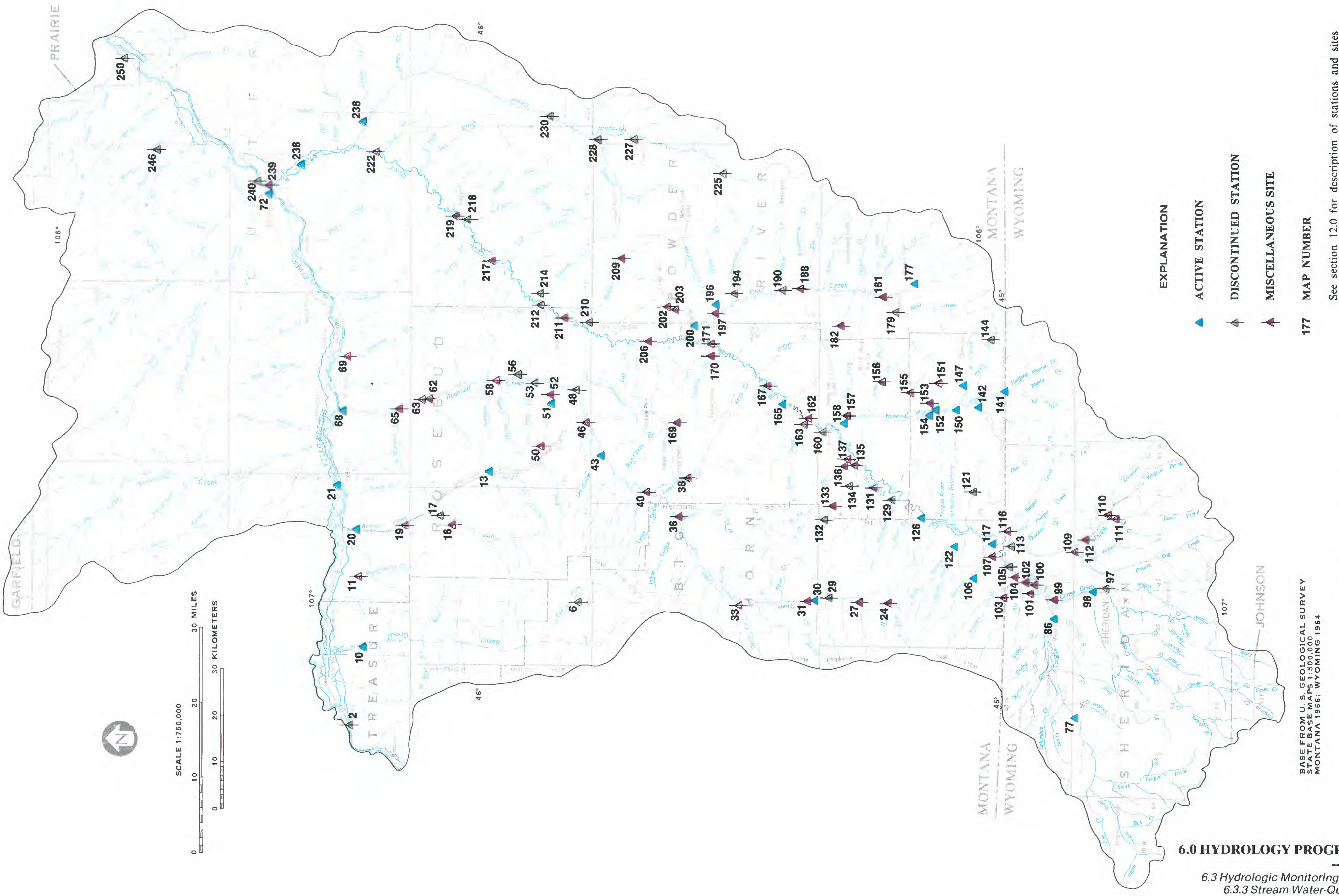


Figure 6.3.3-1 Water-quality stations and miscellaneous sites.

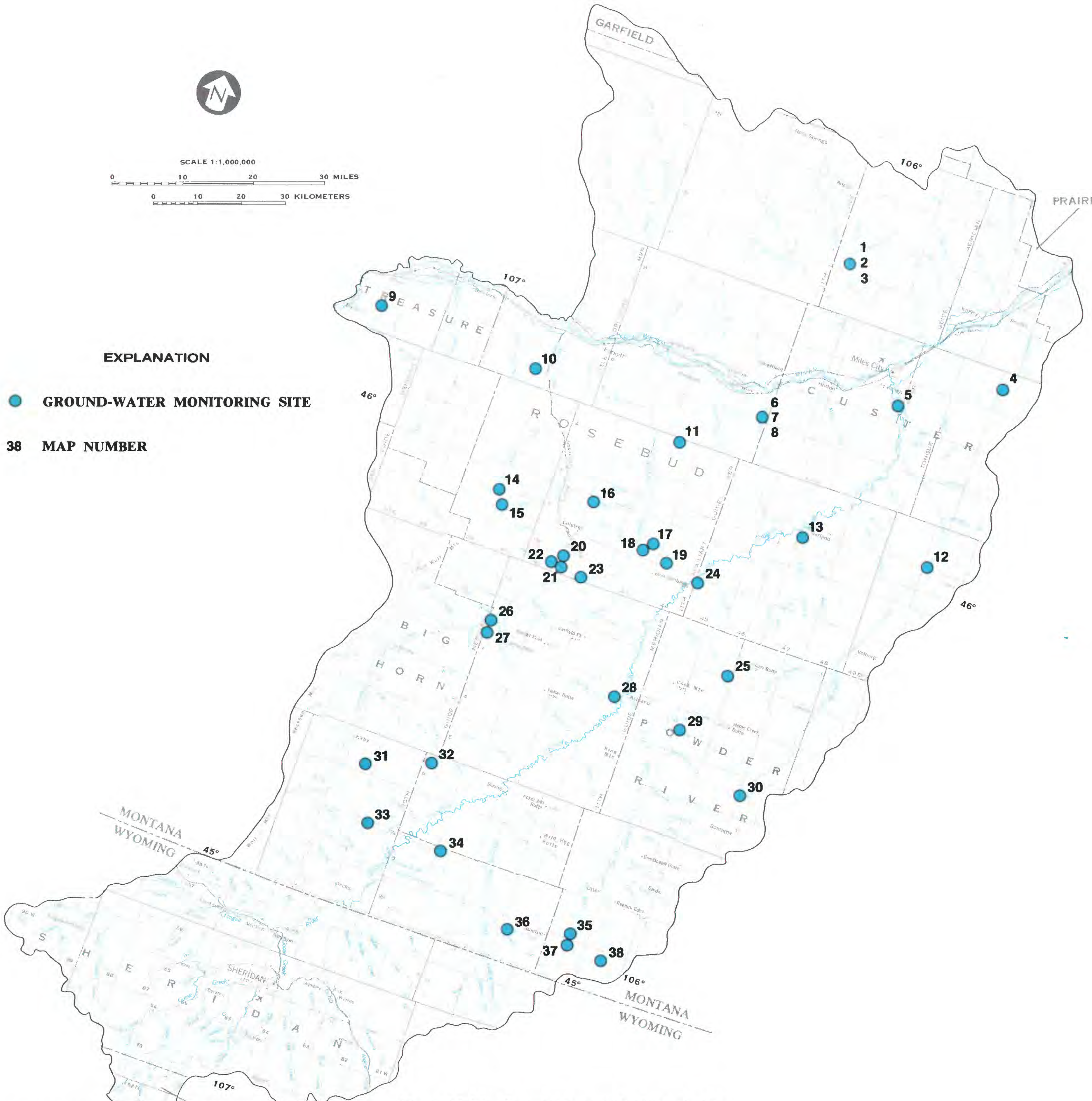
Ground-Water Data Available for Many Sites

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

Inventories of hydrologic and geologic data are available for about 2,000 domestic, stock, irrigation, and public-supply wells in Area 49. In addition, about 400 test holes have been cased and inventoried by the U.S. Geological Survey. 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 500 wells. Most analyses are for major ions but trace-element, radiochemical, and miscellaneous-constituent information is available for about 60 wells. Most data also are available in published reports, such as Slagle and Stimson (1979), Lee (1979), and Levings (1981a, 1981b). 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).

Long-term water-level information (table 6.3.4-1) is available for 38 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.

Computer-generated hydrographs of data collected at three wells (fig. 6.3.4-2) show relatively stable long-term trends in water level. The cyclic pattern for well 5 is a reflection of recharge from a nearby irrigation canal.



BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
MONTANA 1966; WYOMING 1964

Figure 6.3.4-1 Ground-water monitoring network.

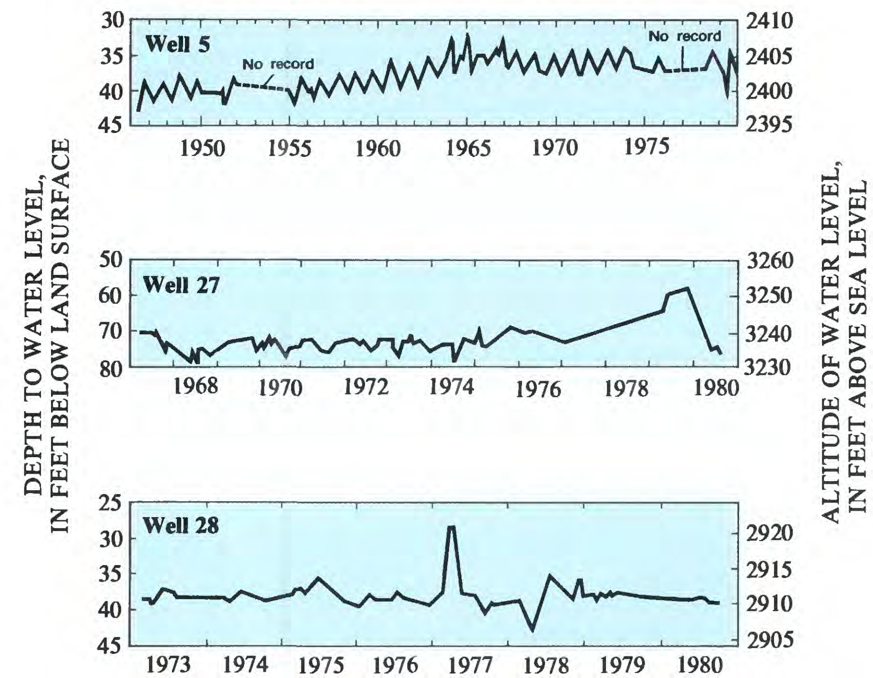


Figure 6.3.4-2 Water-level fluctuations in selected monitoring wells.

Table 6.3.4-1 Ground-water monitoring network.

[Map number: refers to locations in figure 6.3.4-1. Geologic unit: ALVM, alluvium; 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]

Map No.	Local No.	Depth of well (feet)	Geologic unit	Period of record (indicated year to present)	Map No.	Local No.	Depth of well (feet)	Geologic unit	Period of record (indicated year to present)
1	10N45E28BBBA01	951	FXHL	1979	20	01N41E24DDBB01	30	TGRV	1973
2	10N45E28BBBA02	362	TLCK	1980	21	01N41E25DDBB01	60	TGRV	1973
3	10N45E28BBBB01	762	HLCK	1979	22	01N41E26BCAB01	195	TGRV	1973
4	08N50E18BDBC01	280	TLCK	1976	23	01N42E33ADBC01	42	TGRV	1972
5	07N47E24AAD01	50	TLCK	1947	24	01N45E06BCBA01	27	ALVM	1975
6	06N44E36CACD01	902	FXHL	1980	25	01S46E36CDCD01	230	TGRV	1976
7	06N44E36CACD02	609	HLCK	1980	26	02S41E19DAB01	43	ALVM	1968
8	06N44E36CACD03	316	HLCK	1980	27	02S41E31ACB01	168	TGRV	1967
9	05N35E15AADA01	217	HLCK	1976	28	03S44E09ADD01	84	ALVM	1968
10	05N39E21CCDC01	110	HLCK	1976	29	03S46E17ADBC01	145	TGRV	1974
11	04N43E03AABB01	450	TLCK	1976	30	04S48E18BACD01	57	TGRV	1976
12	04N50E31CCAA01	110	TLCK	1976	31	06S39E26ABAA01	130	TGRV	1977
13	03N47E07BCAB01	60	TLCK	1976	32	06S41E08CCAC01	128	TGRV	1976
14	02N39E24CDDD01	46	TGRV	1973	33	07½S40E32ACDD01	120	TGRV	1976
15	02N40E31DCCD01	165	TGRV	1972	34	08S42E06ADBC01	398	TGRV	1980
16	02N42E06CBCD01	120	TGRV	1972	35	08S45E34CABC01	35	ALVM	1975
17	02N43E23CBAB01	68	LEBO	1972	36	09S44E07ADDC01	200	TGRV	1977
18	02N43E27CCBC01	213	TGRV	1972	37	09S45E03DABB01	144	TGRV	1976
19	02N44E32DAAC01	75	TGRV	1972	38	09S46E09BAAD01	120	TGRV	1974

Area Drained by Yellowstone River

The Tongue River is the largest Yellowstone River tributary in the area; smaller tributaries include Sarpy, Armells, Little Porcupine, Rosebud, and Sunday Creeks.

Area 49 lies entirely within the Yellowstone River basin. The main stem of the Yellowstone River flows northeastward through the northern part of the area (fig. 7.1-1).

The Tongue River flows generally north through the longest axis of the area and is by far the longest stream in the area. The Tongue River originates in the Bighorn Mountains in Wyoming and is perennial throughout its length. Major Tongue River tributaries include Goose Creek, Hanging Woman Creek, Otter Creek, and Pumpkin Creek.

Besides the Tongue River, the major Yellowstone River tributaries are Sarpy Creek, Armells Creek, Little Porcupine Creek, Rosebud Creek, and Sunday Creek. Of these tributary streams, only Rosebud Creek has perennial flow throughout its length.

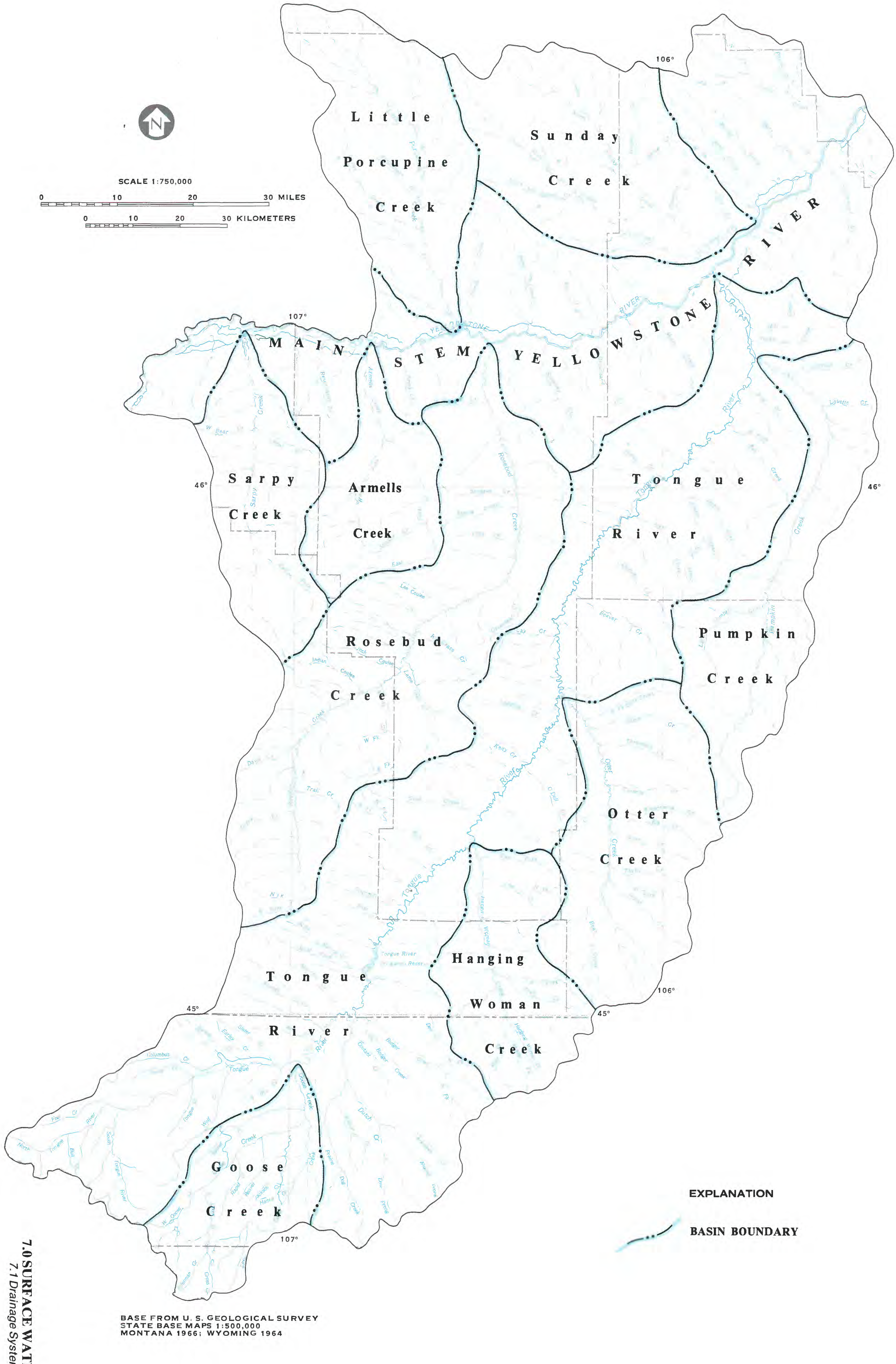


Figure 7.1-1 Drainage system and basins.

Average-Flow Data Available for Most of the Major Streams

Average annual flow tends to be small for the prairie streams and larger for the mountain streams.

Average flow data are available for major streams draining Area 49. Average flow tends to be small for the prairie streams, which generally are ephemeral or intermittent. Zero or near-zero average-monthly flows have been recorded in every month at most of the streamflow-gaging stations on prairie streams. The perennial-type mountain streams generally have much larger average flows.

Average discharges at selected streamflow-gaging stations are given in table 7.2-1. In addition, average discharges at two streamflow-gaging stations are displayed graphically in figure 7.2-1. A Geological Survey computer program was used to calculate average monthly and annual flows from daily discharges. The computed values were used to construct bar graphs for Armells Creek near Forsyth, Montana, and Goose Creek below Sheridan, Wyoming. These graphs show average monthly discharge, average maximum and minimum monthly discharge, and average annual discharge for the periods of available record (fig. 7.2-1). The two stations illustrate the difference between a mountain stream and a prairie stream in area 49. The bar graphs also show the difference during the period of snowmelt. The mountain stream generally has its peak snowmelt in June, whereas the prairie stream has an earlier snowmelt in March and then secondary high flows later in the summer from rainfall.

Mean annual and monthly flow statistics for other stations listed in the description of streamflow and water-quality stations and sites at the end of report are available from:

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

for stations in Montana

or

U.S. Geological Survey
Water Resources Division
J.C. O'Mahoney Federal Center
Room 4007, P.O. Box 1125
2120 Capitol Avenue
Cheyenne, WY 82003

for stations in Wyoming

Equations for estimating average-annual flows at ungaged sites are available only for the Wyoming part of Area 49. Estimating equations are contained in reports of Lowham (1976) and Craig and Rankl (1978). Reliable estimating equations are presently not available for the Montana part of Area 49, but a study to develop such equations is underway. Information about the progress of the study can be obtained from the U.S. Geological Survey at the above address.

Table 7.2-1 Average discharge at selected gaging stations.

[Map No.: refers to location in figure 6.3.1-1]

Map No.	Station No.	Station name	Average discharge, in cubic feet per second, for period indicated												
			Annual	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
10	06294940	Sarpy Creek near Hysham, Mont.	8.62	0.58	0.86	1.19	8.46	6.80	43.6	12.9	17.9	5.99	1.08	0.33	2.15
20	06294995	Armells Creek near Forsyth, Mont.	8.40	.68	.97	.82	8.60	9.40	39.0	10.0	19.0	5.70	.91	.39	4.40
68	06296003	Rosebud Creek at mouth, near Rosebud, Mont.	67.0	25.0	28.0	29.0	33.0	51.0	130	101	191	120	46.0	23.0	23.0
98	06305500	Goose Creek below Sheridan, Wyo.	184	105	96.1	80.6	71.6	85.1	98.4	149	462	753	166	55.2	88.5
158	06307600	Hanging Woman Creek near Birney, Mont.	5.91	1.36	1.65	1.81	7.00	7.18	17.3	5.61	17.0	6.68	2.94	1.19	1.00
200	06307740	Otter Creek at Ashland, Mont.	8.26	2.34	3.87	4.14	10.0	11.6	27.9	11.6	14.0	7.15	3.44	1.66	1.40
236	06308400	Pumpkin Creek near Miles City, Mont.	18.3	.37	.55	.27	3.00	21.5	76.9	26.3	54.5	21.4	4.20	.85	9.40
238	06308500	Tongue River at Miles City, Mont.	449	255	261	201	201	284	611	517	792	1,410	482	179	200
240	06309000	Yellow-stone R. at Miles City, Mont.	11,570	7,695	7,014	5,536	5,049	6,033	8,580	8,266	17,530	36,780	20,980	8,133	7,174
244	06309075	Sunday Creek near Miles City, Mont.	46.6	5.99	2.51	1.16	1.17	43.9	206	50.1	126	65.1	14.7	13.8	26.8

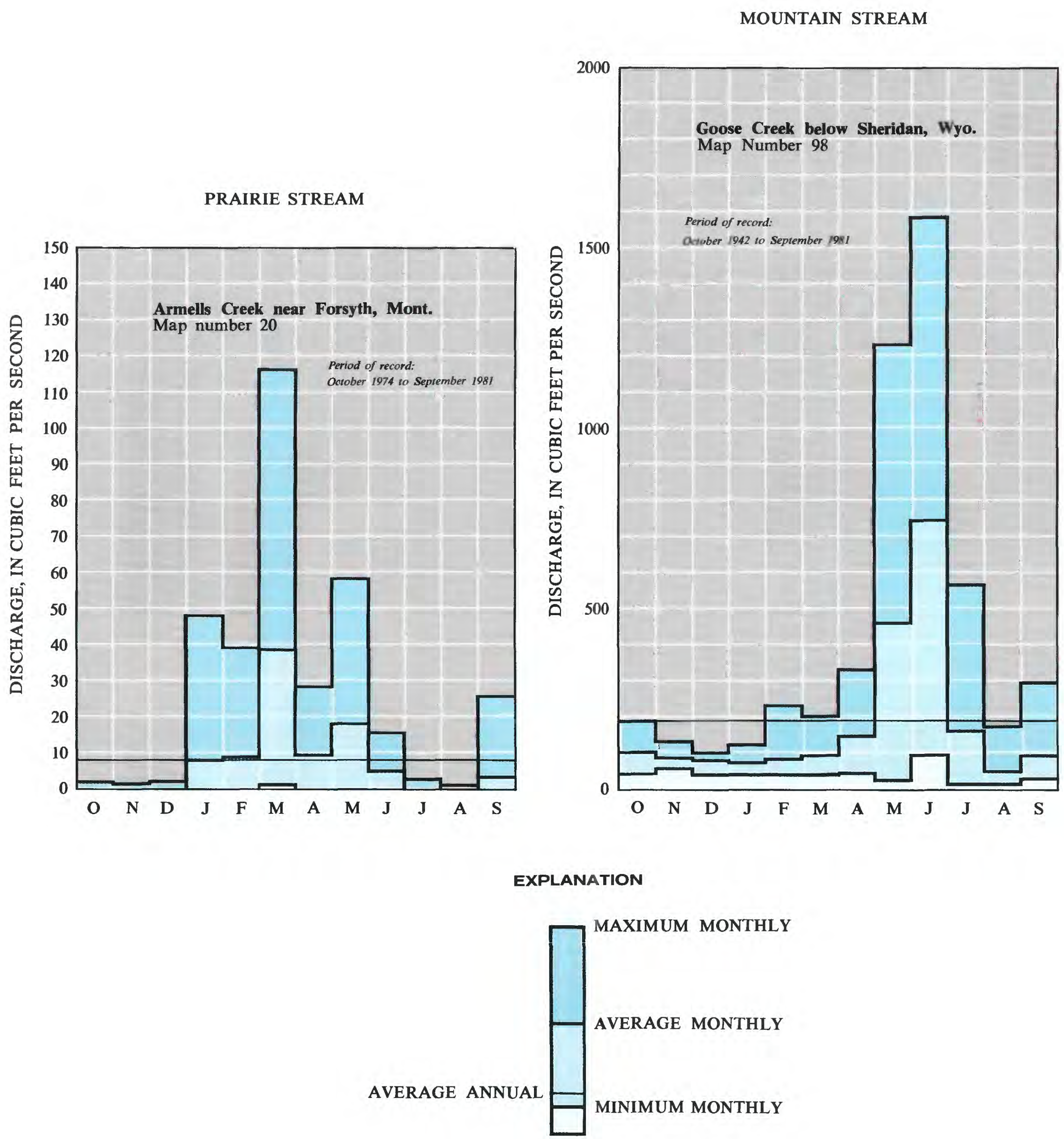


Figure 7.2-1 Average flows for Armells Creek near Forsyth, Montana, and Goose Creek below Sheridan, Wyoming.

Streamflow Variable in Area

Year-to-year and seasonal variations are large, particularly on tributaries draining the prairies.

Streamflow fluctuates widely in the area. Flows in all streams have large seasonal variations, with the largest flows occurring in the spring as a result of snowmelt and rainfall.

Daily flow hydrographs indicating the seasonal variation in streamflows in 1979 have been prepared for Goose Creek below Sheridan, Wyoming, and for Armells Creek near Forsyth, Montana. These daily-flow hydrographs (fig. 7.3-1) show the day-to-day variations in streamflow for a typical mountain stream and for a typical prairie stream.

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

Flow-duration curves for the Tongue River show that unit daily streamflow, in cubic feet per second per square mile of drainage area, is greater for the Tongue River at State line than for the Tongue River at Miles City, Montana. A greater percentage of the streamflow at the State line site results from mountainous tributaries where unit streamflows are larger.

Flow-duration curves for East Fork Big Goose Creek and for West Fork Big Goose Creek near Big Horn, Wyoming, are indicative of streamflow from mountainous areas where the unit discharges tend to be substantially greater than from prairie streams. The gradual flattening of the lower end of the curves for the the two mountain streams also indicates that base flow is sustained.

Flow-duration curves for Armells Creek near Forsyth, Montana; Hanging Woman Creek near Birney, Montana; and Pumpkin Creek near Miles City, Montana, show a much smaller unit discharge for all exceedance percentages than do the duration curves for mountain streams. Flow-duration curves for these prairie streams are also steeper than the curves for the mountain streams, indicating a greater variation in streamflow in the prairie areas. Of the three prairie streams, only Hanging Woman Creek has an appreciable base flow.

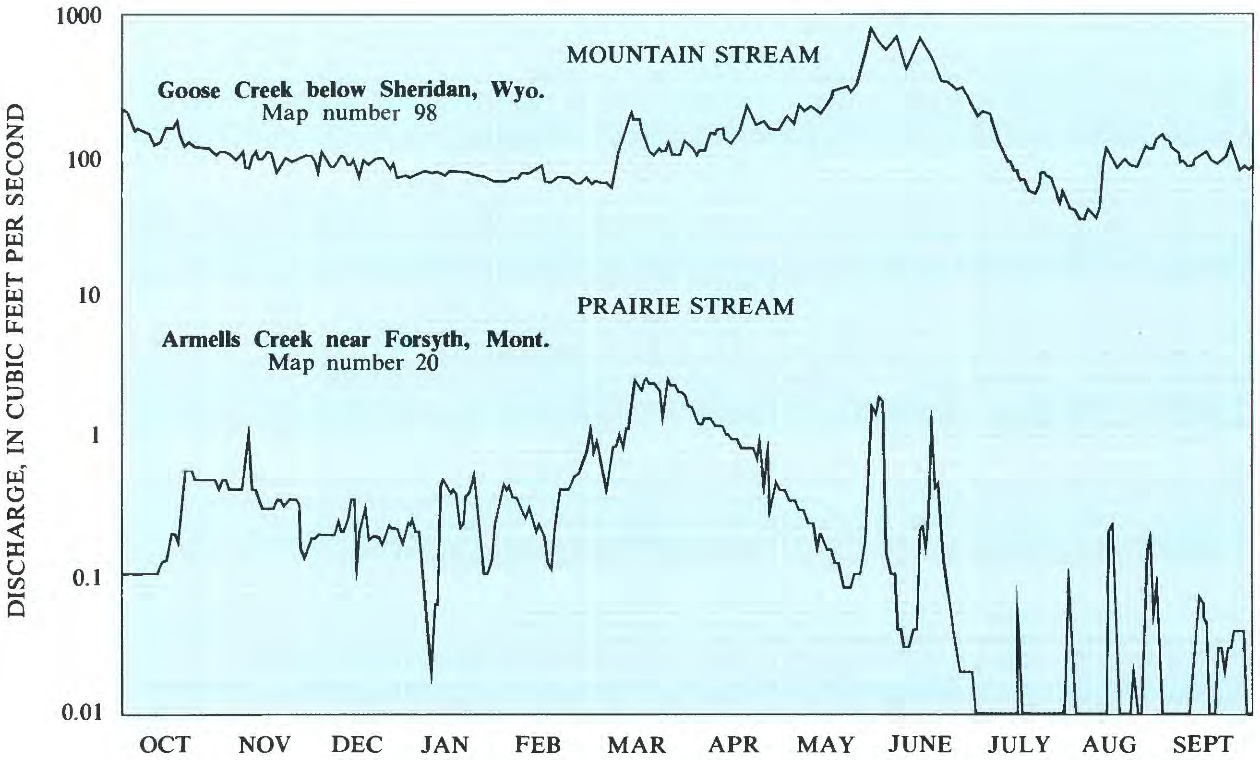


Figure 7.3-1 Daily hydrographs for Armells Creek near Forsyth, Montana, 1980 water year, and Goose Creek below Sheridan, Wyoming, 1979 water year.

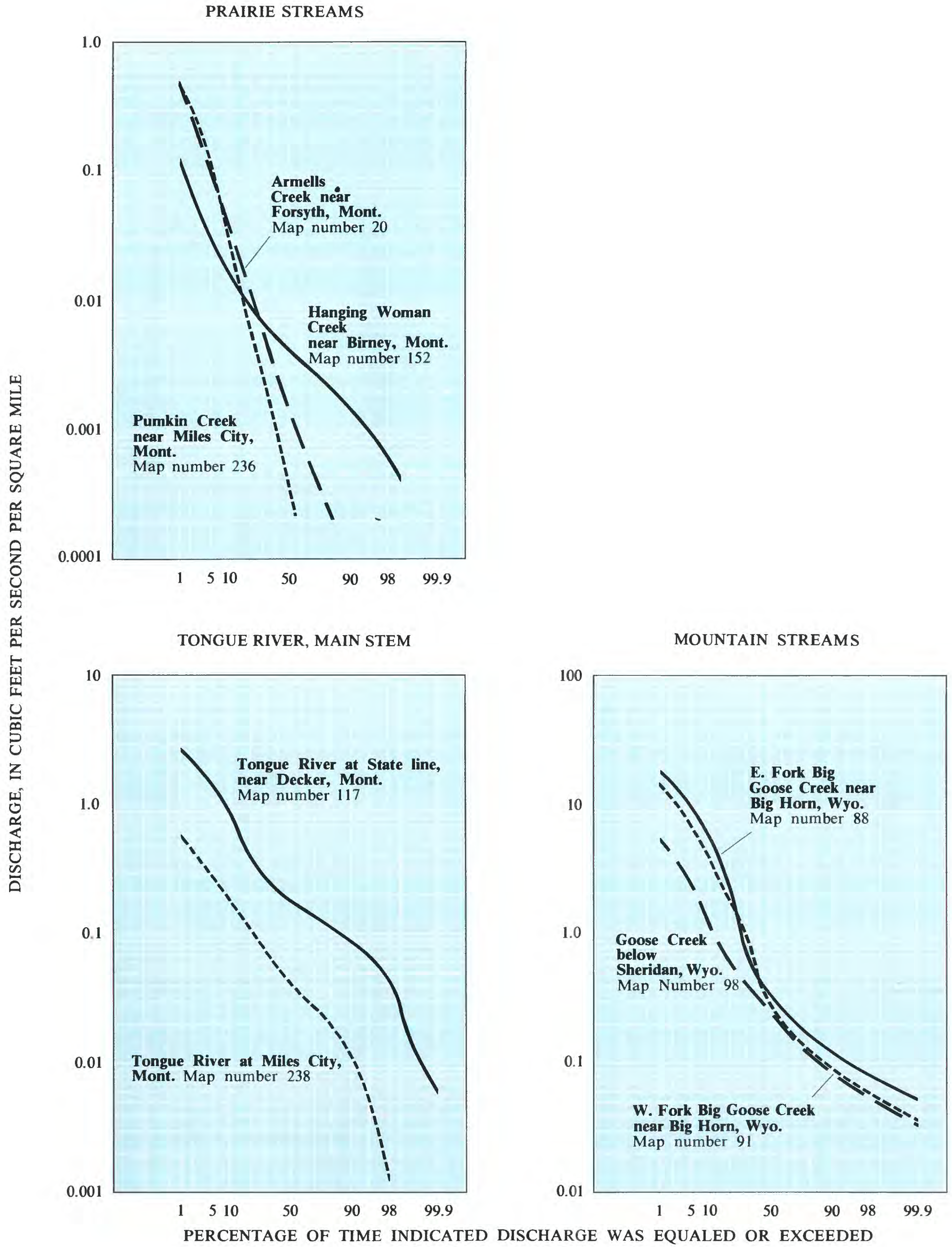


Figure 7.3-2 Flow-duration curves for selected streams.

Peak-Flow Data Presented for 25 Gaging Stations

Streamflow records were used to compute peak discharges and exceedance probabilities at 25 gaging stations in the area.

Peak flows in the study area may result from snowmelt or rainfall. Mountain streams typically have their annual peak flows in June from snowmelt mixed with rain. Annual peak flows on prairie streams may result from snowmelt in March or from summer thunderstorms in June through August. Most of the annual peak flows on prairie streams result from snowmelt, but the larger peak flows usually 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 25 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, the value 1,480 in row 2 of the column "50-percent exceedance probability" means that for station 23, there is a 50-percent chance that the annual peak flow in any year will be greater than 1,480 cubic feet per second. Similarly, the value 6,370 for the same site under the column "4-percent exceedance probability" means that for station 23, there is a 4-percent chance that the annual peak flow in any year will be greater than 6,370 cubic feet per second.

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

[Map number: refers to locations in figure 6.3.1-1]

Map No.	Station No.	Station name	Discharge, in cubic feet per second, for specified exceedance probability, in percent — Percent 50	10	4	2	1
22	06295020	Short Creek near Forsyth, Mont.	104	774	1,590	2,640	4,050
23	06295050	Little Porcupine Creek near Forsyth, Mont.	1,480	4,200	6,370	8,410	10,600
25	06295100	Rosebud Creek near Kirby, Mont.	98	356	590	815	1,080
35	06295200	Whitedirt Creek near Lame Deer, Mont.	8	35	58	82	112
66	06296000	Rosebud Creek near Forsyth, Mont.	325	1,130	1,890	2,640	3,600
70	06296100	Snell Creek near Hathaway, Mont.	98	341	530	709	921
77	06298000	Tongue River near Dayton, Wyo.	1,670	2,650	3,140	3,500	3,860
80	06298500	Little Tongue River near Dayton, Wyo.	128	333	470	586	712
84	06299500	Wolf Creek at Wolf, Wyo.	312	621	805	952	1,120
88	06300500	East Fork Big Goose Creek near Big Horn, Wyo.	514	779	917	1,020	1,130
117	06306300	Tongue River at State line, near Decker, Mont.	3,840	6,670	8,270	9,710	11,400
122	06306900	Spring Creek near Decker, Mont.	136	812	1,550	2,310	3,310
123	06306950	Leaf Rock Creek near Kirby, Mont.	43	203	359	519	720
172	06307640	Spring Creek near Ashland, Mont.	120	342	489	627	793
173	06307660	Walking Horse Creek near Ashland, Mont.	7	61	130	206	309
204	06307760	Stebbins Creek near Ashland, Mont.	4	23	47	73	106
205	06307780	Stebbins Creek at mouth, near Ashland, Mont.	80	508	955	1,450	2,120
231	06308200	Basin Creek tributary near Volborg, Mont.	14	83	157	233	330
232	06308300	Basin Creek near Volborg, Mont.	163	924	1,660	2,400	3,350
240	06309000	Yellowstone River at Miles City, Mont.	45,000	68,000	86,000	101,000	117,000
241	06309020	Rock Springs Creek tributary at Rock Springs, Mont.	11	70	137	199	280
242	06309040	Dry House Creek near Angela, Mont.	152	1,030	1,540	2,850	3,980
243	06309060	North Fork Sunday Creek trib. No. 2 near Angela, Mont.	41	152	260	370	503
248	06309080	Deep Creek near Kinsey, Mont.	579	1,740	2,510	3,170	3,940
250	06309090	Ash Creek near Locate, Mont.	22	170	335	511	741

Peak-Flow Characteristics May Be Estimated for Ungaged Streams

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

Multiple-regression equations have recently been developed for estimating flood peaks at ungaged stream sites within Area 49 (Parrett and Omang, 1981). The equations generally are applicable to unregulated streams where the drainage basins have not been significantly altered 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 49 three geographic areas were delineated, and three 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 other two areas. All equations utilize a geographical factor that must be obtained from a map. The area map (fig. 7.5-1) shows the boundaries of the three geographic areas and the geographical factors for each area. The estimating equations are presented in table 7.5-1.

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 main stem Yellowstone River and on streams where some streamflow-gaging data are available also are given by Parrett and Omang.

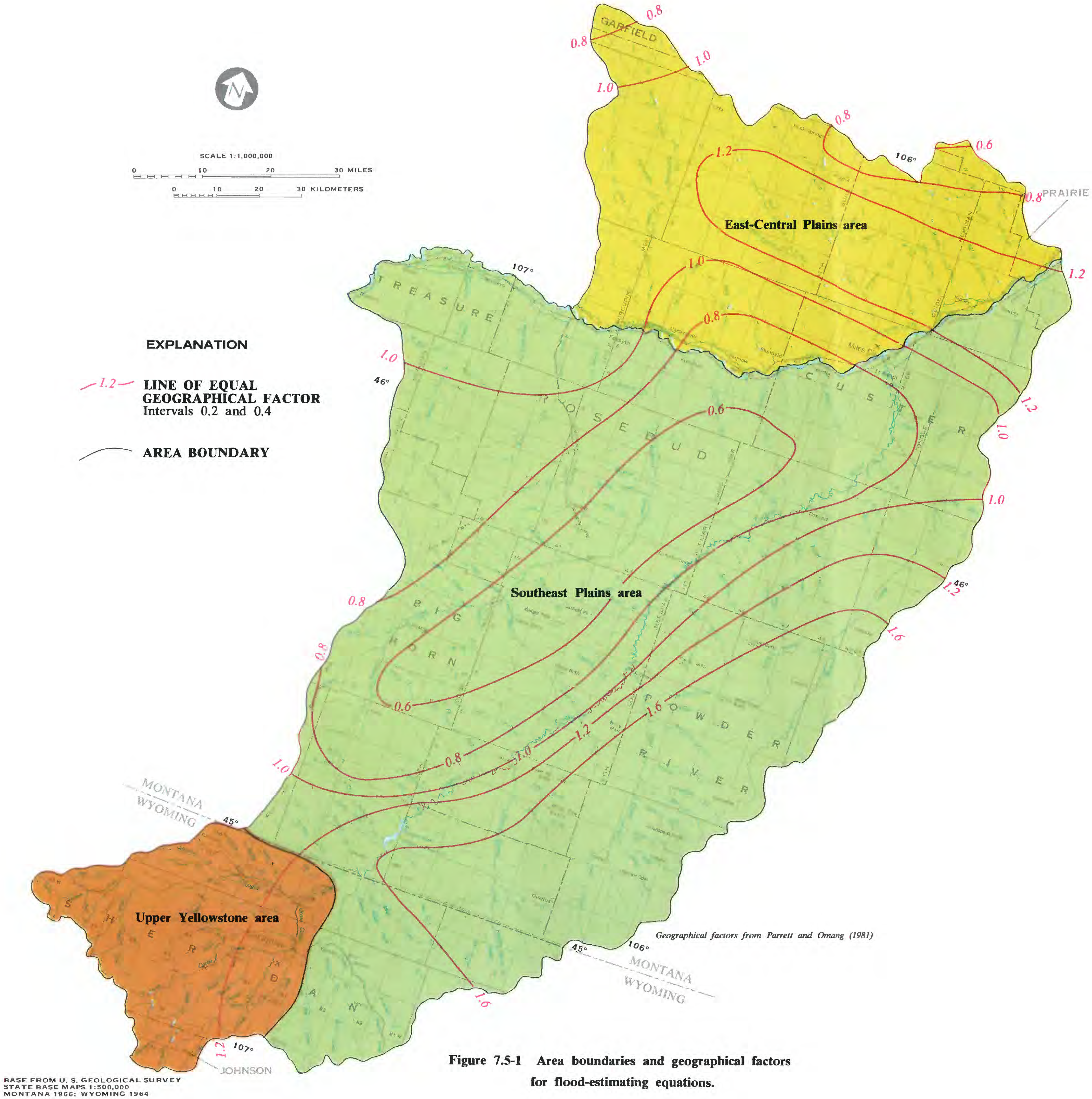


Figure 7.5-1 Area boundaries and geographical factors for flood-estimating equations.

Table 7.5-1 Regression equations for estimating peak discharge.

Exceedance probability (percent)	Estimating equation[1] for peak discharge (Q), in cubic feet per second	Standard error of estimate (percent)
	Upper Yellowstone area	
50	$Q = 0.146A^{0.87}(E/1000)^{3.88}(HE+10)^{-0.78}G_f$	57
20	$Q = 1.08A^{0.82}(E/1000)^{3.56}(HE+10)^{-0.93}G_f$	47
10	$Q = 3.22A^{0.80}(E/1000)^{3.39}(HE+10)^{-1.02}G_f$	45
2	$Q = 23.6A^{0.75}(E/1000)^{3.06}(HE+10)^{-1.18}G_f$	43
1	$Q = 48.8A^{0.73}(E/1000)^{2.95}(HE+10)^{-1.24}G_f$	44
	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

[1] A = drainage area, in square miles;
E = average basin elevation, in feet above sea level;
HE = percentage of basin above 6,000 feet elevation;
F = percentage of basin covered by forest; and
G_f = geographical factor determined from figure 7.5-1.

Flood-Prone-Area Maps Available

Flood-prone areas have been delineated on 66 7½-minute topographic maps in 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 outlining flood-prone areas on topographic maps. From 1968 to 1970 the Geological Survey delineated 28 flood-prone areas of the maximum known flood on 7½-minute topographic quadrangle maps using existing information. In 1970, the 100-year flood (1-percent exceedance probability peak flow) was selected as the index flood for mapping.

As of 1981, the area inundated by the 1-percent exceedance probability flood has been delineated for selected streams on 38 additional 7½-minute topographic quadrangle maps within Area 49. 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). Copies of these maps, prepared by the U.S. Geological Survey, are available from the Montana College of Mineral Science and Technology, Butte, Montana 59701, for the Montana part of Area 49 and from the U.S. Geological Survey, J.C. O'Mahoney Federal Center, Room 4007, P.O. Box 1125, 2120 Capitol Avenue, Cheyenne, Wyoming 82003, for the Wyoming part of Area 49.

Aerial photography of flooding also is available for certain streams. Channel reaches that have aerial-photography coverage are shown in figure 7.6-1.

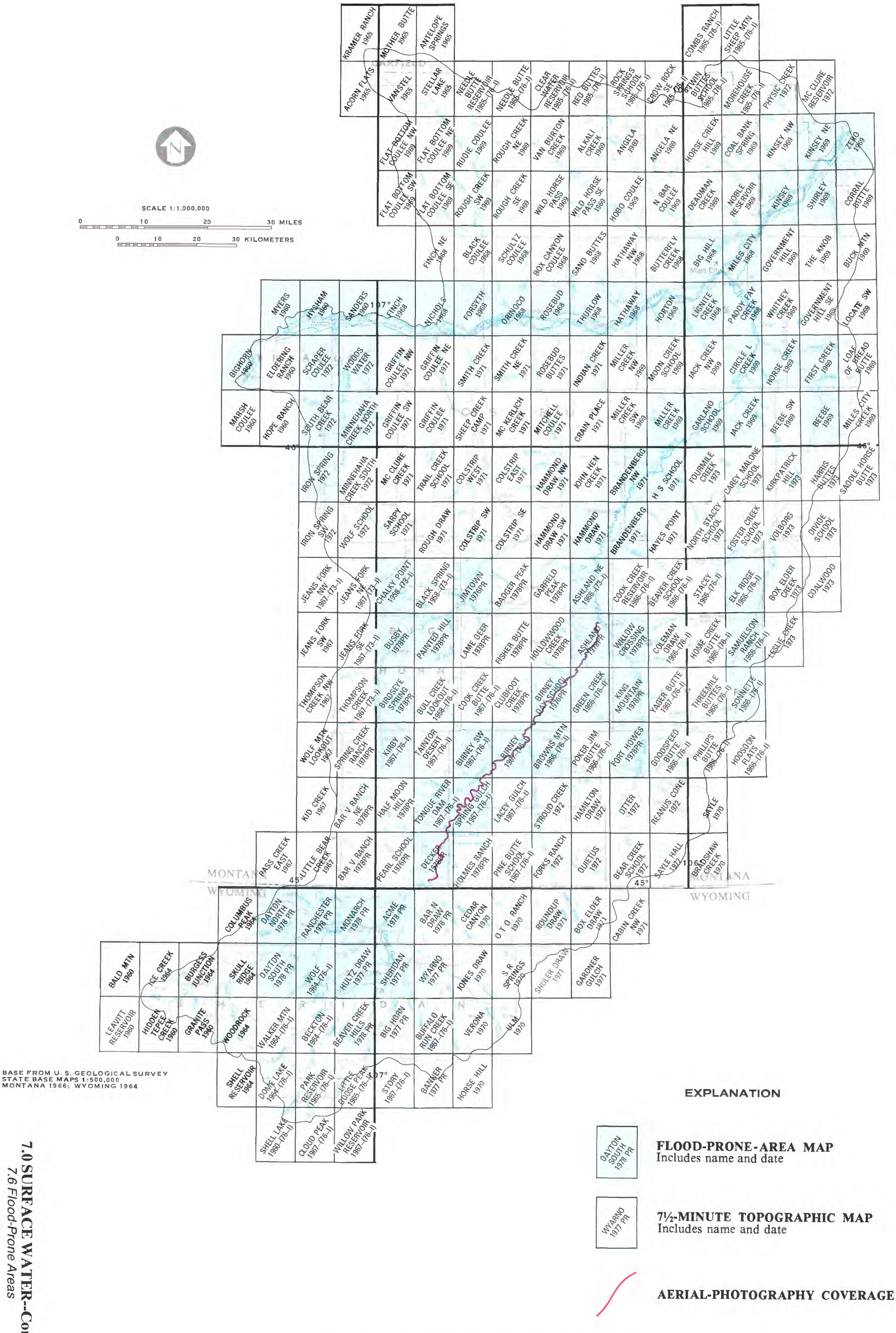


Figure 7.6-1 Flood-prone-area maps and aerial-photography coverage.

Dissolved Solids Variable

Dissolved-solids concentrations vary during the annual flow cycle at individual stream stations, as well as from stream to stream.

Dissolved solids is the sum of all dissolved constituents in water. Because trace elements account for such a small percentage, dissolved solids can be considered to be the sum of the major ions in solution. The major-ion content of water in streams generally is derived from soluble minerals in soil and geologic strata underlying the drainage. For this area, the ions most commonly comprising the larger percentages of dissolved solids are cations of calcium, magnesium, and sodium, and anions of bicarbonate, sulfate, and chloride.

The greatest variations in concentration and composition of major ions occur as a result of changes in seasonal flow. Areal differences both within and between drainages also are apparent (fig. 8.1-1), but are more subtle than changes with time at individual stations.

Much of the variation in dissolved solids during the annual flow cycle can be related to the dominance of either the base-flow or the direct-runoff component of flow at various times of the year. Areal differences are affected mostly by lithology, soil types, and land-use practices. Other natural and artificial conditions tend to affect both time and areal variability of dissolved solids. Evaporation and transpiration, reactions of water with sediment, and aquatic biota all cause changes. In addition, the many impoundments and diversions for agriculture purposes affect the dissolved solids.

The base-flow component of streamflow is derived primarily from ground water that has had long contact with minerals in the aquifer. Consequently, base flows generally are associated with large concentrations of dissolved solids. Near the mouth of the Tongue River during periods of low flow, concentrations were sometimes measured in excess of 1,000 milligrams per liter. Some of the smaller streams had dissolved-solids concentrations greater than 4,000 milligrams per liter. Sodium and sulfate generally are the dominant cation and anion during periods of base flow.

In contrast to base flow, the direct-runoff component generally has much smaller concentrations of dissolved solids. The smallest concentrations were measured on intermittent streams at times of snowmelt and frozen ground when the base-flow component was absent. Concentrations were sometimes less than 100 milligrams per liter. Because the base-flow component always is present in some of the larger streams, concentrations during periods of direct runoff are not nearly this small. Direct-runoff water is characterized by the calcium or magnesium cation and the bicarbonate anion.

Areal comparisons indicate that ranges in dissolved-solids concentrations are larger in smaller streams than in the Tongue River and Rosebud Creek. The larger streams and some of the smaller ones generally have a downstream increase in dissolved-solids concentration during all flow conditions. As the concentrations increase, sodium and sulfate become more dominant.

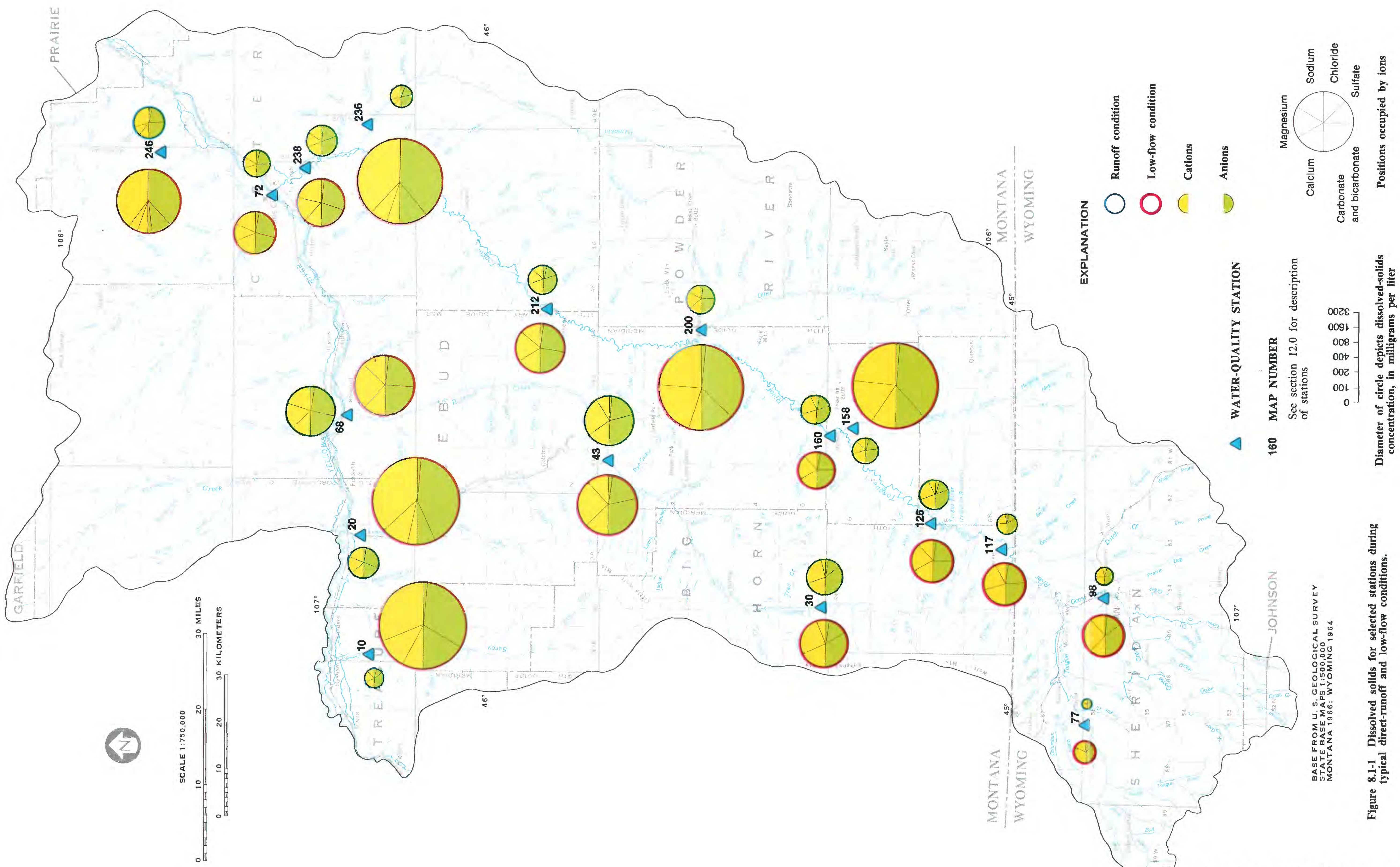


Figure 8.1-1 Dissolved solids for selected stations during typical direct-runoff and low-flow conditions.

Specific Conductance Can Be Used to Estimate Dissolved-Solids Concentration

Paired values of specific conductance and dissolved-solids concentration were used to calculate monthly and annual loads of dissolved solids.

Specific conductance of water depends upon the ability of ionized material in solution to conduct an electrical current and, therefore, gives an indication of the concentration of ions in solution. In this study, specific conductance is reported as micromhos per centimeter at 25° Celsius. Because it can be readily determined at streamside and inexpensively in the laboratory, specific conductance has been measured extensively. Specific conductance was measured each time a water sample was collected for laboratory analysis. In addition, daily measurements for specific conductance were made at selected stations.

Specific-conductance values generally showed a significant correlation to dissolved-solids concentrations as well as to concentrations of many of the individual constituents that compose dissolved solids. Paired values of specific conductance, in micromhos, and dissolved-solids concentration, in milligrams per liter, from routine samples collected at stations shown in figure 8.2-1 were used to develop linear regression equations that are shown graphically in figures 8.2-2 and 8.2-3. The graphs can be used to estimate dissolved-solids concentrations from a simple measurement of specific conductance.

Daily values of specific conductance at selected stations were converted into daily dissolved-solids concentrations using computer techniques. The daily concentrations were further transformed into mean daily dissolved-solids loads, in tons, using the following relationship:

$$L_{DS} = Q\, C_{DS} K$$

where

L_{DS} = dissolved-solids load, in tons per day;

Q = mean daily stream discharge, in cubic feet per second;

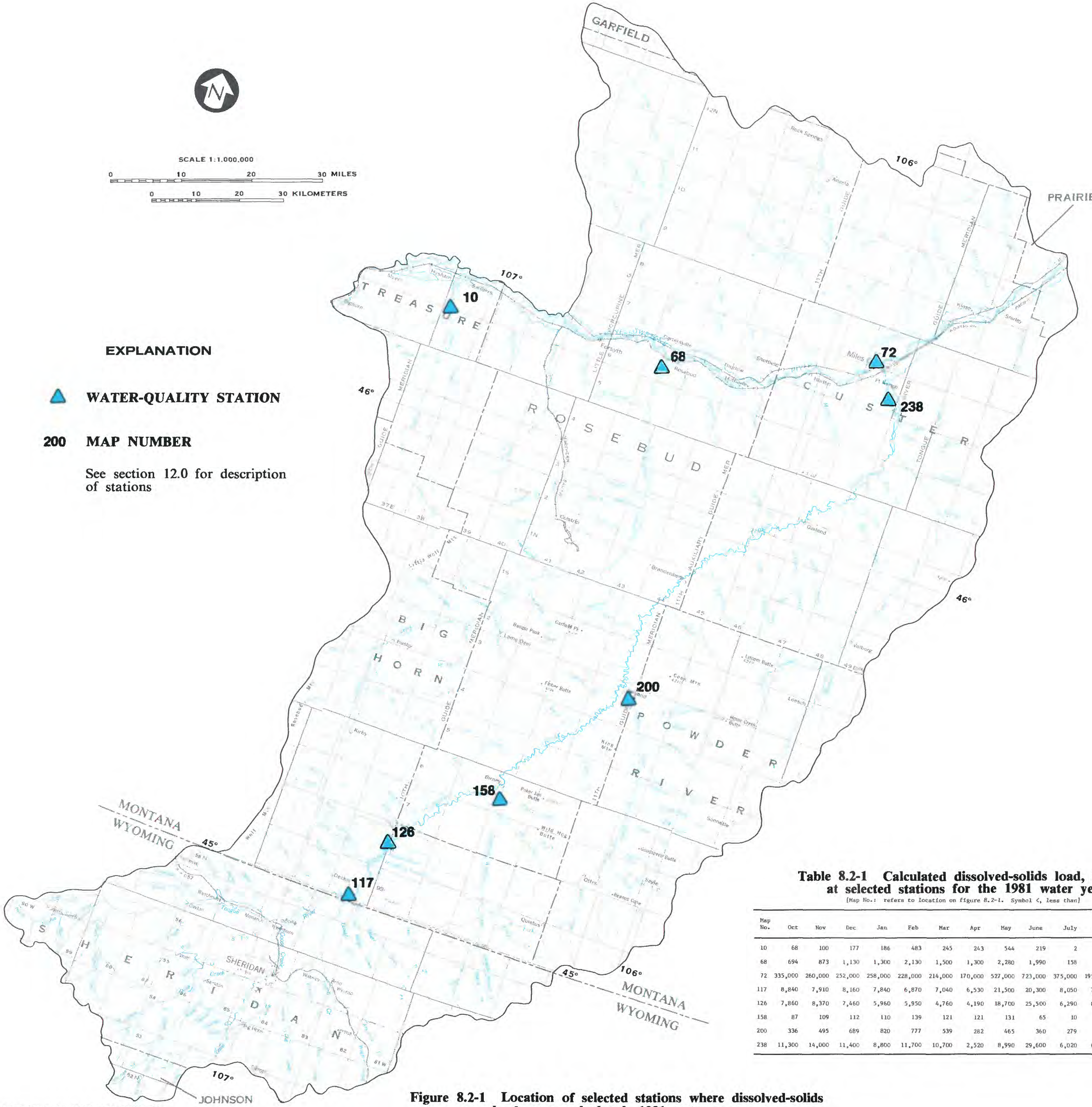
C_{DS} = dissolved-solids concentration, in milligrams per liter; and

K = 0.0027.

The summation of daily loads at individual stations provides a means of determining monthly and annual loads for dissolved solids (table 8.2-1).

The methods described above to determine loads for dissolved solids (and individual constituents as well) are of importance in measuring future stream impacts that may result from changing land-use practices such as coal mining, agriculture, and industry. The sensitivity afforded from continuous or daily specific conductance after transformation to loads will readily show changes when compared to preimpact data. In addition, the above techniques and load information are essential in developing accurate stream models for use in predicting impacts for various management plans of land use.

Information on chemical loads of streams has other uses. Often a need exists for yields of dissolved solids or individual constituents from drainages or parts of drainages. The yields are obtained by dividing annual loads by the area within the drainage. Thus, comparasions can be made between drainages and within drainages. For example, during the 1981 water year, Sarpy Creek (station 10) had a yield of 5.0 tons per square mile compared with Rosebud Creek (station 68), which had 10.4 tons per square mile of drainage. The Tongue River drainage upstream from the Montana-Wyoming State line (station 117) had a yield of 78.1 tons per square mile compared with the entire Tongue River drainage (station 238), which had a yield of 24.0 tons per square mile.



EXPLANATION

▲ WATER-QUALITY STATION

200 MAP NUMBER

See section 12.0 for description of stations

BASE FROM U. S. GEOLOGICAL SURVEY
STATE BASE MAPS 1:500,000
MONTANA 1966; WYOMING 1964

Figure 8.2-1 Location of selected stations where dissolved-solids loads were calculated, 1981 water year.

Table 8.2-1 Calculated dissolved-solids load, in tons, at selected stations for the 1981 water year.

[Map No.: refers to location on figure 8.2-1. Symbol <, less than]

Map No.	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
10	68	100	177	186	483	245	243	544	219	2	1	<1	<2,269
68	694	873	1,130	1,300	2,130	1,500	1,300	2,280	1,990	158	128	6	13,489
72	335,000	260,000	252,000	258,000	228,000	214,000	170,000	527,000	723,000	375,000	195,000	169,000	3,706,000
117	8,840	7,910	8,160	7,840	6,870	7,040	6,530	21,500	20,300	8,050	7,010	5,270	115,320
126	7,860	8,370	7,460	5,960	5,950	4,760	4,190	18,700	25,500	6,290	8,840	9,380	113,260
158	87	109	112	110	139	121	121	131	65	10	2	<1	<1,008
200	336	495	689	820	777	539	282	465	360	279	108	69	5,219
238	11,300	14,000	11,400	8,800	11,700	10,700	2,520	8,990	29,600	6,020	6,860	7,080	128,970

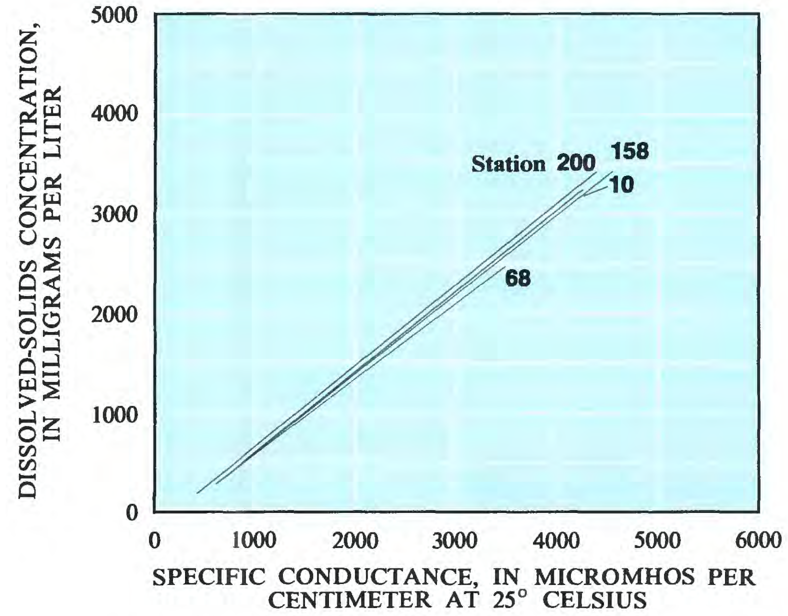


Figure 8.2-2 Relationship between specific conductance and dissolved solids for selected stations on small streams.

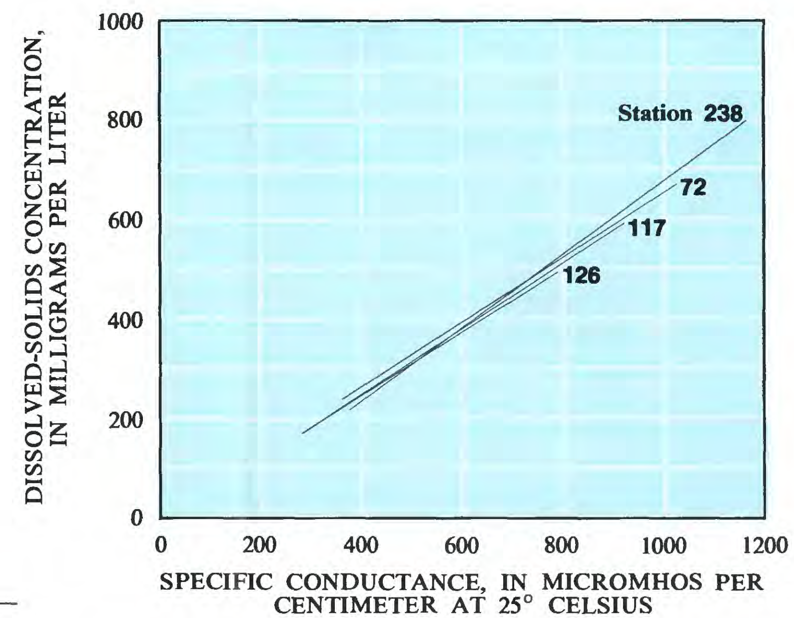


Figure 8.2-3 Relationship between specific conductance and dissolved solids for selected stations on the Tongue and Yellowstone Rivers.

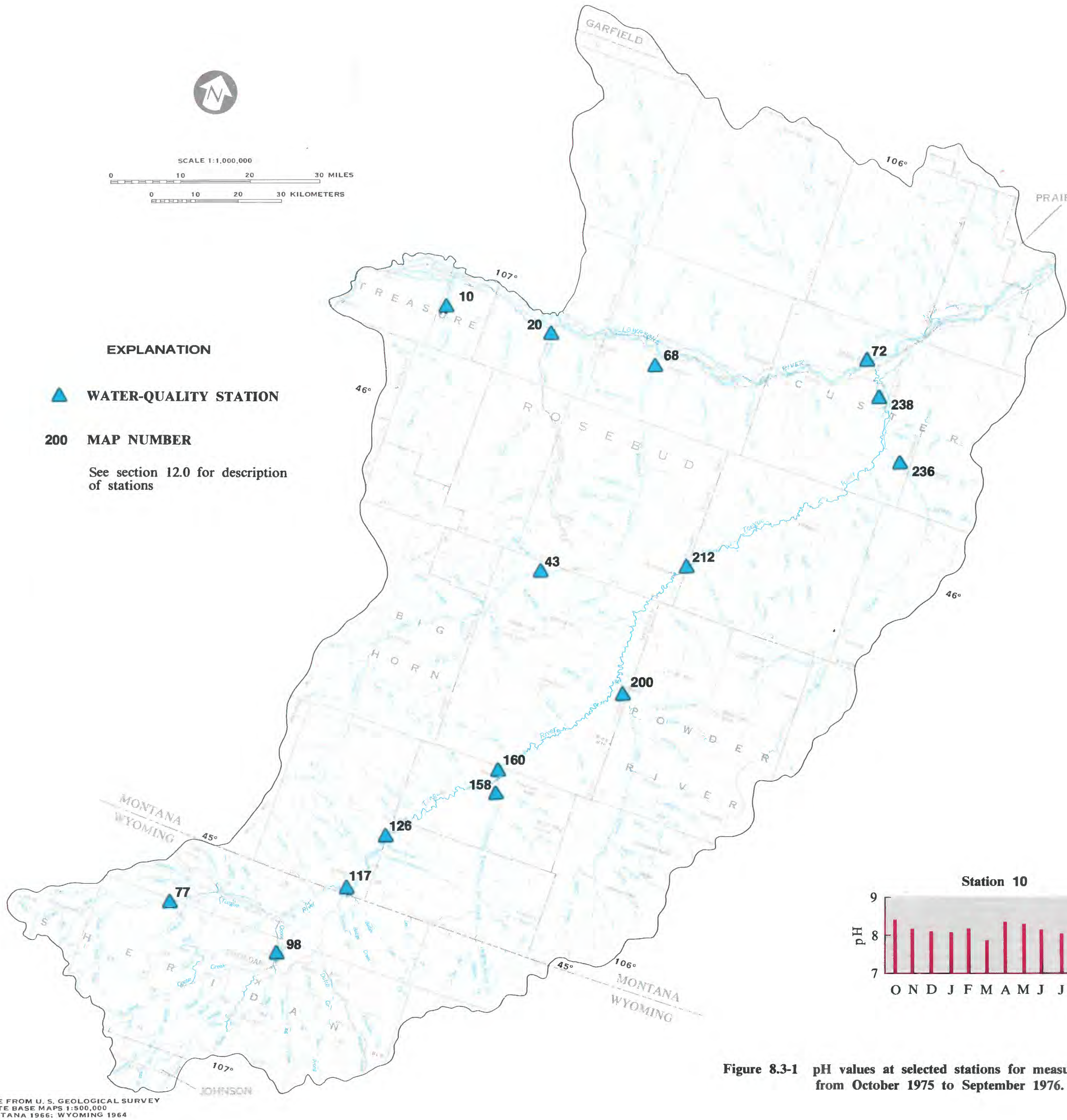
Streamflow pH Variable But Generally in Near-Neutral Range

Stream pH ranges from 6.9 to 8.9 and is caused mostly by natural conditions.

Acidity, or the concentration of hydrogen ions in solution, generally is expressed as pH. The pH of a neutral solution is 7, with smaller values being acidic and larger values being basic. Carbon dioxide in the atmosphere generally causes rain and snow to be slightly acidic. Water that has had extensive contact with carbonate rocks of an aquifer tends to be basic. Stream water in areas not affected by pollution generally has a pH between 6.5 and 8.5 (Hem, 1970). Values of pH can be greater that 8.5 when abundant aquatic photosynthesis uses much of the dissolved carbon dioxide. Values less than 6.5 may be caused by industrial activities, including coal mining, in which the weathering of iron sulfides and subsequent reactions create acid conditions.

In the study area, pH values ranged from 6.9 to 8.9. Variations occurred at individual stations throughout the annual flow cycle (fig. 8.3-1). The smallest pH values generally were associated with direct runoff in which the water had characteristics of rain and snow. Larger pH values generally were measured during periods of base flow and probably were affected by the lithology of aquifers. Also evident, especially during periods of late summer base flow, was the condition caused by aquatic photosynthesis in which some pH values were increased even more.

No evidence was found in which mining or mining activities decreased pH values in streams. The reason may be due to the fact that little or no effluent from mining enters directly into 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 dispensed into streams. Accelerated mining, different mining practices, and effluent reaching streams via the ground-water system are conditions that could alter pH values of streams in the study area.



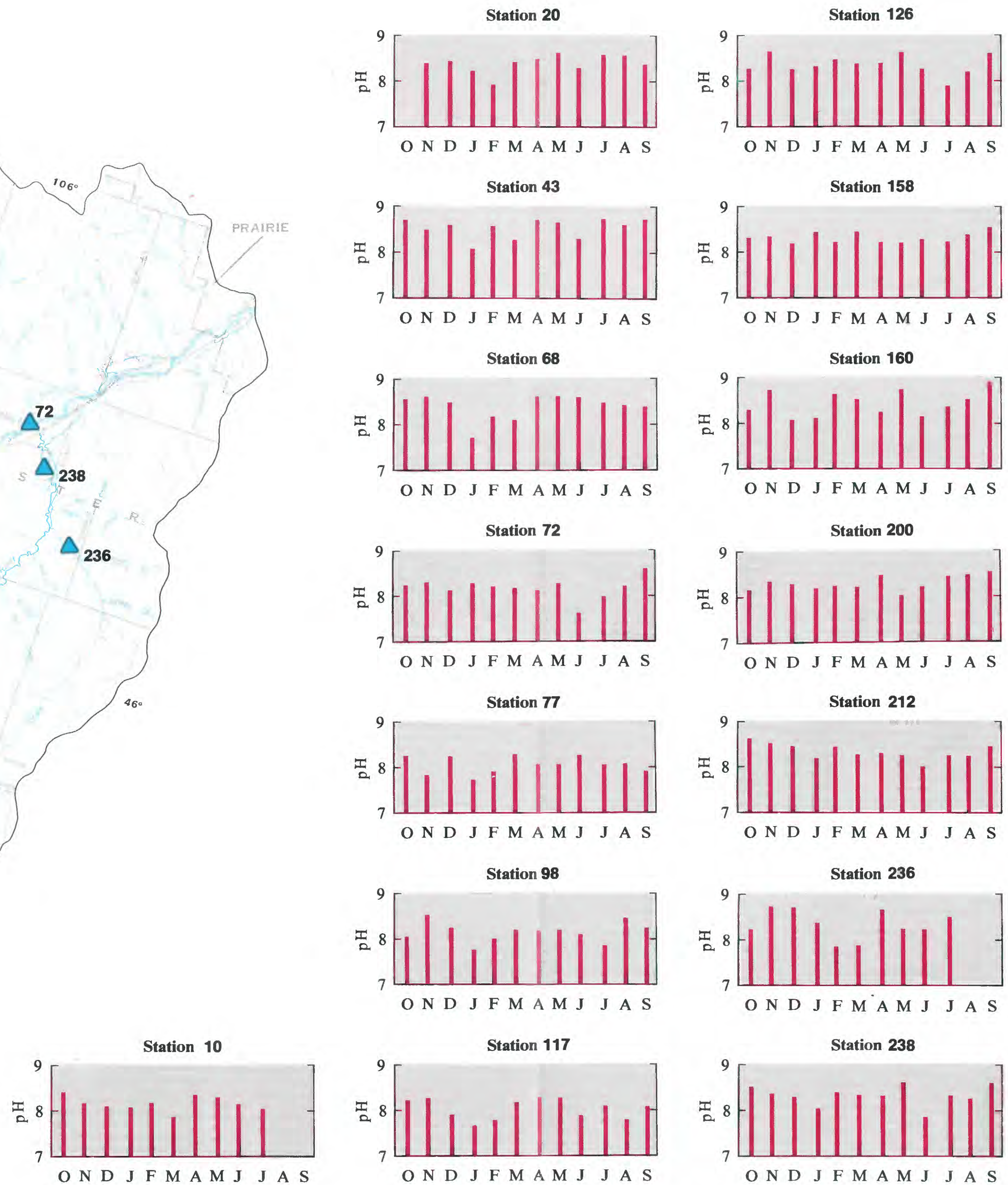


Figure 8.3-1 pH values at selected stations for measurements made from October 1975 to September 1976.

Excessive Concentrations of Trace Elements Rarely Found

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

Some constituents in water are grouped as trace elements, because they generally occur in small concentrations compared to the major ions. Although many of these elements can be toxic to the biologic environment, some are essential to plants and animals in small concentrations. Natural sources of trace elements are generally soils, geologic strata, and normal atmospheric fallout. Large concentrations can occur naturally in streams, but generally they are associated with municipal and industrial-waste discharges, including water from coal mining. The weathering of pyritic minerals present in coal mines and mine spoils can produce acid water, which may react with minerals to produce large concentrations of trace elements.

Trace elements, in addition to being transported in the dissolved state, are attached loosely and carried downstream by sediment--primarily clay materials and organic debris. Concentrations of trace elements analyzed from the mixture of water and sediment are referred to as total recoverable concentrations. Analysis of water after filtration to remove sediment provides concentrations of trace elements that are solely dissolved (table 8.4-1). Analyses were made for both total recoverable and dissolved concentrations of selected trace elements. Some of the stations having samples analyzed for trace elements are shown in figure 8.4-1.

Several standards have been adopted listing maximum concentrations of trace elements that can be tolerated for various water uses. Common standards used to judge many waters are Primary Drinking Water Standards (U.S. Environmental Protection Agency, 1977a) and Secondary Drinking Water Standards (U.S. Environmental Protection Agency, 1977b). Trace elements such as boron are of concern in the use of water for irrigation of some crops.

Excessive concentrations of dissolved trace elements rarely were found during the study and, of those that were found, none could be related directly to mining or mining activities. Dissolved iron sometimes surpassed the limit established in the Secondary Drinking Water Standards; however, this is a natural occurrence for many streams in eastern Montana. Water pH, being a primary control for dissolution and transport of many trace elements, always was found to be near neutral. This condition is an important factor in maintaining small concentrations of dissolved trace elements. The largest concentrations of most trace elements were from samples of the water-sediment mixture in which sediment was the major means of transport. Correlation generally was good between concentrations of suspended sediment and total recoverable trace elements in streams.

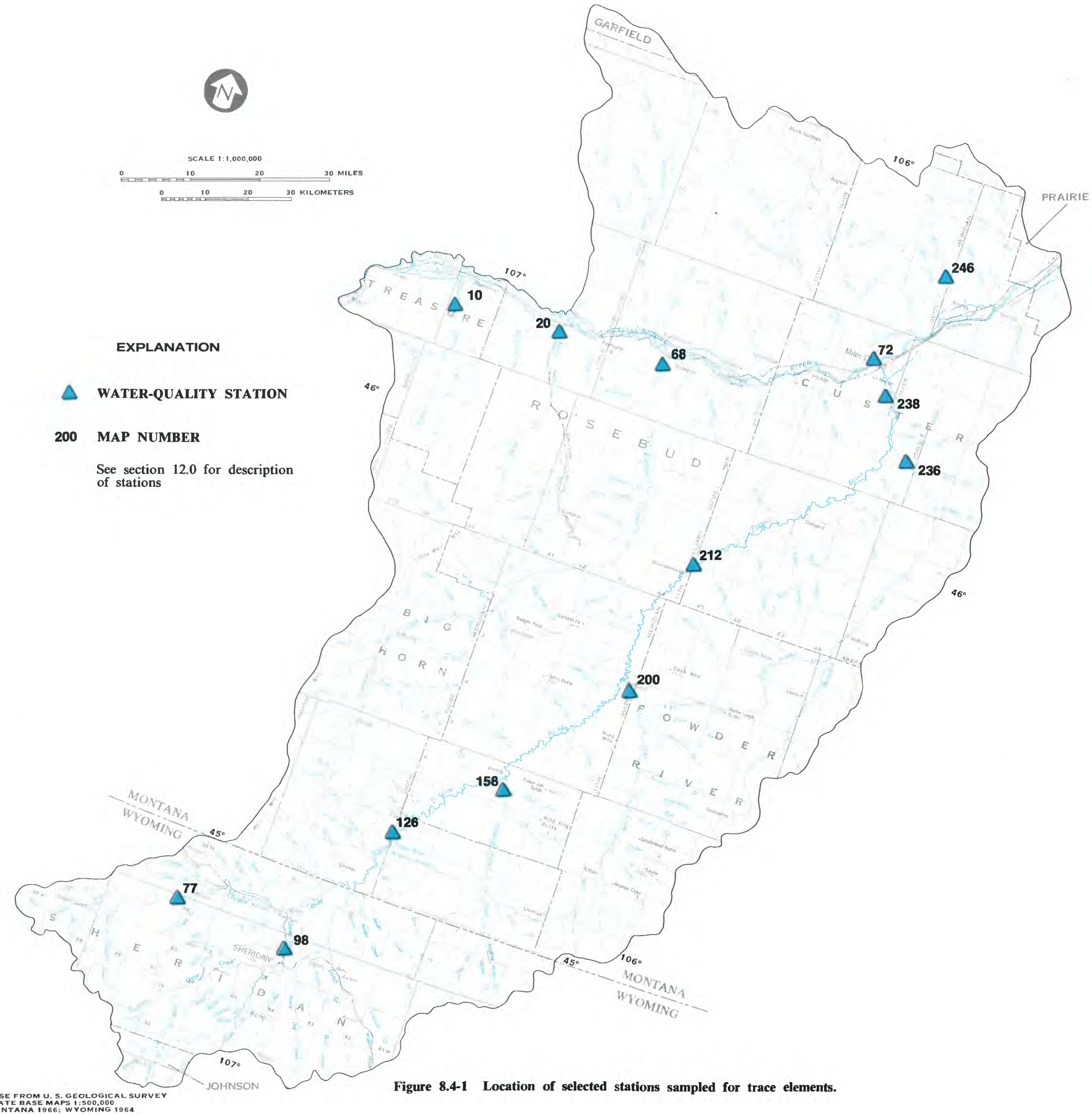


Figure 8.4-1 Location of selected stations sampled for trace elements.

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

[Constituents are dissolved and constituent values are reported in micrograms per liter. Map number: refers to locations in figure 8.4-1. Number in parentheses beneath trace element is the criterion specified by the footnote reference for drinking water or irrigation water. Symbol <, less than]

Map No.[1]	Number of samples	Concentration Average	Concentration Minimum	Concentration Maximum	Number of samples	Concentration Average	Concentration Minimum	Concentration Maximum	Number of samples	Concentration Average	Concentration Minimum	Concentration Maximum
			Arsenic [1](50)				Boron [2](1000)				Cadmium [1](10)	
10	12	2	1	3	57	370	110	780	12	1	0	3
20	16	2	1	6	70	450	120	730	15	1	0	2
68	17	2	1	4	75	210	80	500	16	1	0	3
72	22	6	1	9	78	150	20	220	22	1	0	2
77	10	1	0	1	6	61	8	210	10	1	0	2
98	16	1	0	1	7	96	20	160	16	1	0	2
126	17	2	1	5	62	90	4	250	16	2	0	2
158	16	1	1	3	73	280	110	820	16	<3	0	<35
200	15	2	1	3	72	440	50	660	15	<5	0	<50
212	17	1	0	3	70	110	20	300	17	2	0	6
236	9	2	1	4	40	350	80	840	9	2	0	3
238	30	1	1	3	3	150	110	180	30	2	0	6
246	6	2	1	3	8	99	30	150	6	2	0	8
			Chromium [1](50)				Iron [3](300)				Lead [1](50)	
10	12	6	0	20	57	70	10	410	11	3	0	6
20	16	8	0	20	70	64	10	510	15	3	0	13
68	16	10	0	30	75	45	10	420	16	4	0	17
72	22	3	0	20	113	57	10	1,800	22	2	0	6
77	10	2	0	20	11	55	10	410	14	3	0	12
98	16	3	0	20	18	46	10	110	20	3	0	12
126	17	8	0	20	62	56	10	980	16	4	0	10
158	16	9	0	20	72	80	10	1,500	16	4	0	10
200	15	9	0	20	72	55	10	490	15	6	0	18
212	17	4	0	20	70	31	10	190	17	6	0	21
236	9	6	0	20	40	97	10	1,000	9	6	0	17
238	30	3	0	20	43	30	10	150	30	7	0	41
246	6	12	0	20	8	207	50	720	6	11	0	36
			Mercury [1](2)				Selenium [1](10)				Zinc [3](5000)	
10	12	0.2	0.0	0.5	11	1	0	1	12	23	0	50
20	16	.3	.0	.5	14	1	0	1	16	19	0	70
68	16	.2	.0	.9	14	1	0	2	16	16	0	40
72	22	.2	.0	.5	22	1	1	2	22	42	0	720
77	14	.5	.0	.6	14	1	0	2	14	11	0	20
98	20	.3	.0	.5	19	1	0	2	20	11	0	20
126	17	.2	.0	.5	17	1	0	1	17	15	0	20
158	16	.3	.0	.5	15	1	0	1	16	17	0	30
200	15	.2	.0	.5	14	1	0	2	15	23	0	110
212	17	.3	.0	.5	16	1	0	2	17	19	0	90
236	9	.2	.0	.5	9	2	1	4	9	24	5	60
238	30	.2	.0	.5	30	1	0	1	30	15	0	70
246	5	.1	.0	.1	6	3	1	7	6	30	3	98

1 U.S. Environmental Protection Agency (1977a) primary drinking water standards
2 U.S. Salinity Laboratory Staff (1954) irrigation water standards
3 U.S. Environmental Protection Agency (1977b) secondary drinking water standards

Suspended-Sediment Yield Varies Substantially

Annual suspended-sediment yield ranges from about 10 to 100 tons per square mile of drainage area.

Suspended sediment in streams within the study area (fig. 8.5-1) is derived from a combination of soil erosion from overland flow and channel erosion. Soils are predominantly shallow (less than 25 inches deep) shaley to silty loams developed over shales or siltstones on moderate to steep slopes. Erodability depends mostly on grain size and slope. Loosely textured alluvial deposits are easily eroded, especially by channel cutting and bank erosion. The magnitude of sediment yield in Area 49 is a result of natural conditions that commonly have been altered by many small and large dams, cattle grazing, irrigation practices, and local mining.

Sampled suspended-sediment concentrations in the study area ranged from 2 to 23,400 milligrams per liter and were indicative of large variability throughout annual flow cycles. Maximum concentrations occurred at times of direct runoff over thawed surfaces, when both channel scour and overland flow contributed sediment to the streams. Generally, more than 80 percent of the suspended material is smaller than sand.

Sediment movement in the smaller drainages such as Sarpy, Armells, Otter, and Hanging Woman Creeks is affected greatly by the pool-and-riffle nature of their channels. The pools act as sediment traps during low and declining stream stages and are flushed at times of rising stages. Rosebud Creek, like these smaller streams, can exhibit these same characteristics at small flows, but more often carries flows that prevent sediment entrapment in the pools. The Tongue River is characterized primarily by a small supply of sediment downstream from the Tongue River Dam, with the supply becoming more abundant in passage downstream. The Yellowstone River transports much of its sediment through the area during late May and June from upstream tributary sources. The major contributing source to the Yellowstone River from the study area is the Tongue River.

Suspended-sediment concentrations correlated with stream discharge, and it was possible to develop relationships as shown in figures 8.5-2, 8.5-3, and 8.5-4. The slope and position of the line on each graph are indicative of the availability of sediment to the stream. The increase in availability is most obvious for the Tongue River, where progressive downstream stations from the Tongue River Dam indicate larger suspended-sediment discharges for equal water discharge.

Sediment yields are presented in figure 8.5-1 for the drainages where adequate data are available. The yields are somewhat less than those predicted by the general relationship between sediment yield and mean annual precipitation (Langbein and Schumm, 1958). This condition indicates that some of the eroded material is not entering the stream but is being stored in the basin.

Federal mining laws specify that mine discharges contain less than 45 milligrams per liter of suspended sediment. Average concentrations for many of the study area streams exceed this value naturally. However, some stream reaches such as the one downstream from the Tongue River Dam consistently have suspended-sediment concentrations less than 45 milligrams per liter. The severity of sediment problems from surface coal mining and mining-related activities will be determined by prevailing flow conditions of the receiving streams and the quantity and quality of effluent received.

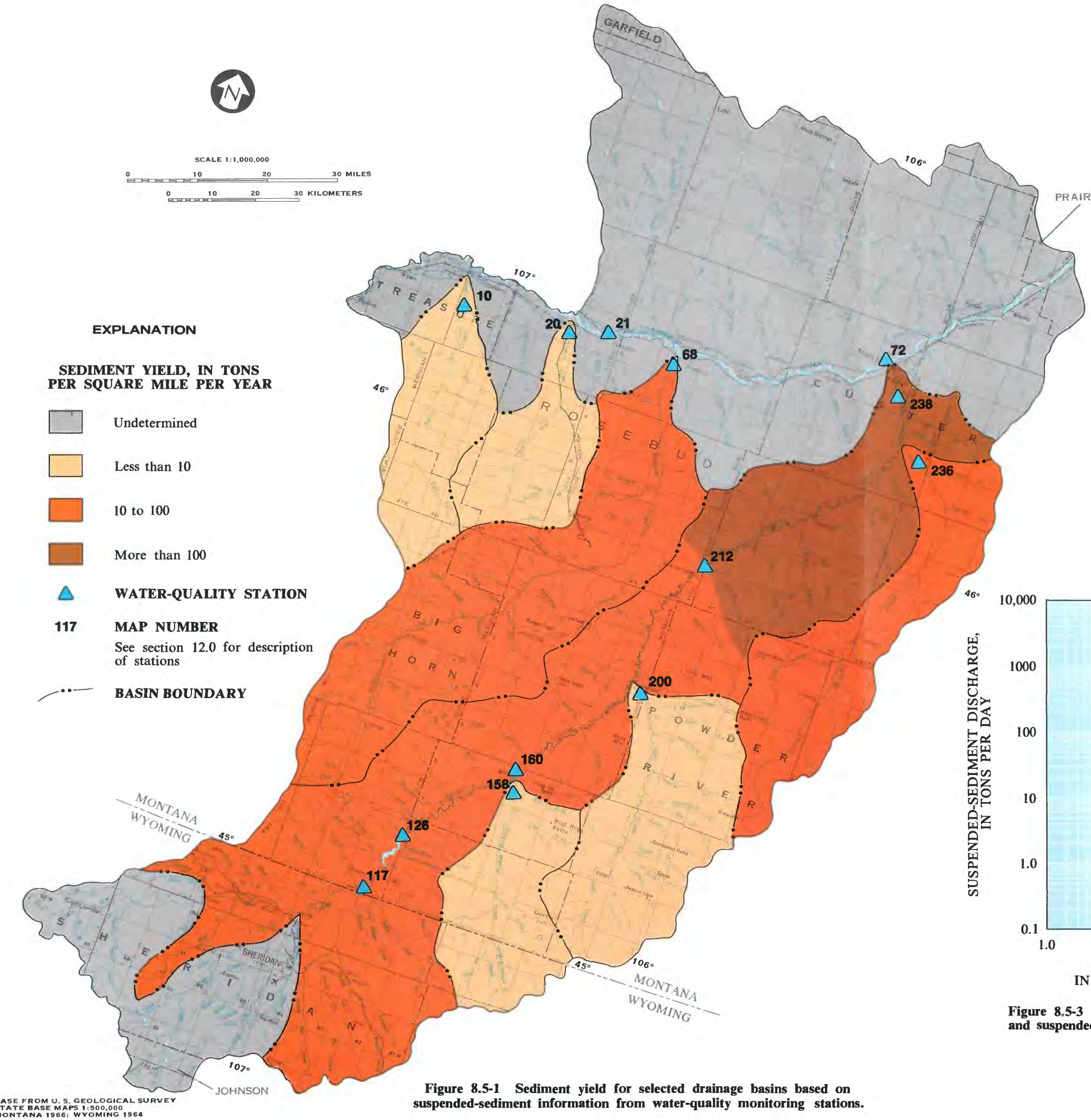


Figure 8.5-1 Sediment yield for selected drainage basins based on suspended-sediment information from water-quality monitoring stations.

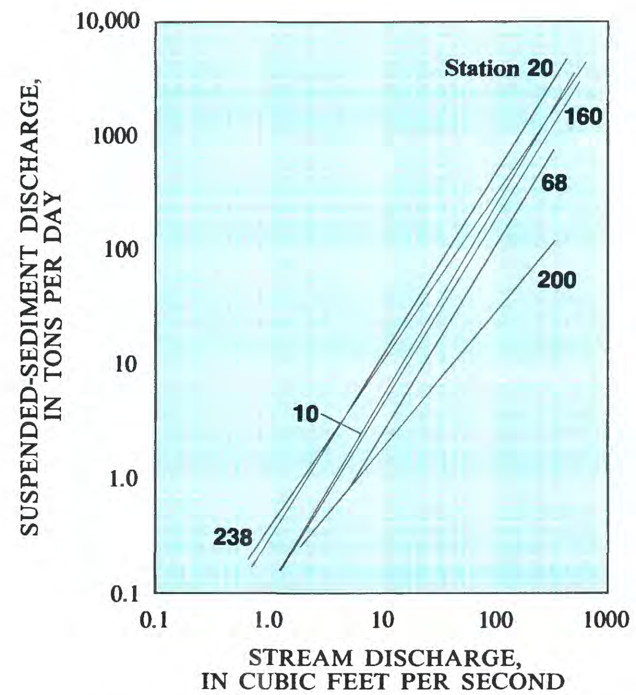


Figure 8.5-2 Relationship between stream discharge and suspended-sediment discharge at selected stations on small streams.

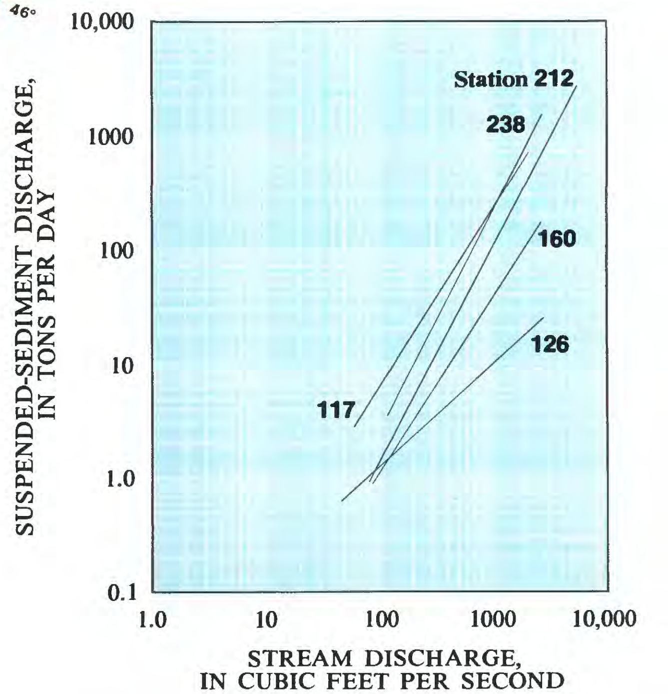


Figure 8.5-3 Relationship between stream discharge and suspended-sediment discharge at selected stations on the Tongue River.

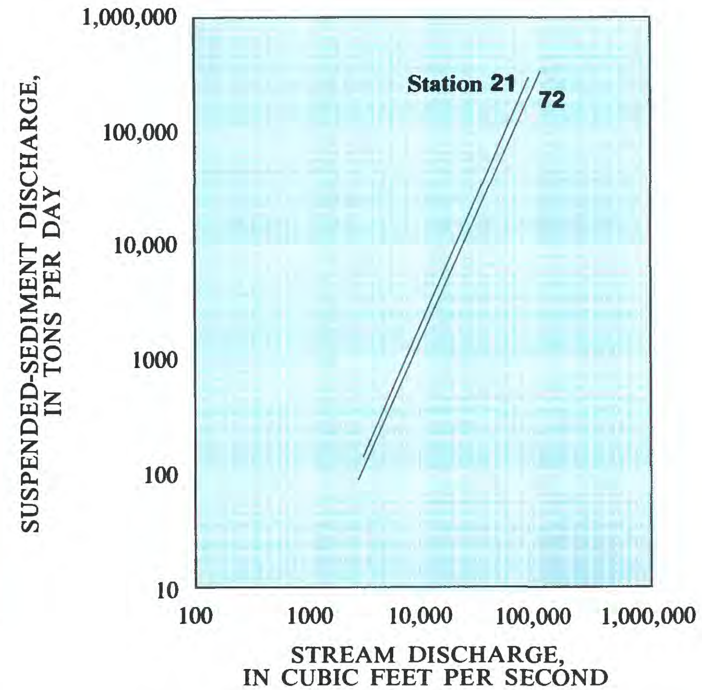


Figure 8.5-4 Relationship between stream discharge and suspended-sediment discharge at selected stations on the Yellowstone River.

Periphyton Community Diverse in Most Streams

Most streams contain periphyton communities that are dominated by diverse diatom populations, indicating that periphyton are relatively free from excessive water-quality stress.

The composition of communities of algae can be used to indicate the quality of water in which they live. Perphyton (attached algae) and phytoplankton (free-floating algae) have been collected at several stations and sites in Area 49. The data from these collections characterize the existing algal community from which future water-quality impacts can be studied. In terms of primary production, periphyton are more important than phytoplankton in most Montana streams, excluding the downstream reaches of large rivers. To study the effects of salinity on algae, the U.S. Geological Survey contracted with the Montana Department of Health and Environmental Sciences to collect periphyton samples from 32 streams and 2 spring-fed ponds (Klarich and others, 1980; Bahls, 1980).

In streams having water quality unstressful to algae, diatoms generally are the dominant algae. Diatom populations composed of an equal distribution of organisms among a large number of taxa are considered to be diverse (healthy) and indicative of non-stressful water quality. Diatom populations composed of an unequal distribution of organisms among a small number of taxa are considered to be non-diverse (unhealthy) and indicative of stressful water quality. Bahls and others (1979) proposed the following scale for evaluating water quality, using a numerical diversity index for diatom communities:

Diatom diversity	Water quality
More than 4.50	Excellent
3.50-4.50	Good
2.50-3.50	Fair
Less than 2.50	Poor

Based on diatom diversity, most of the sampled stations had water quality within the good range (table 8.6-1).

The number of diatom species and the diatom diversity found in 1978 and 1979 correlated significantly with specific conductance. Bahls (1980) postulates that within the range of specific conductance measured in the study area (239 to 640 micromhos per centimeter), diatom productivity might be stimulated by increased specific conductance.

Streams in the study area differ considerably in the composition of diatom populations they support. The large variation in number of diatom taxa among the sampled sites is exemplified by figure 8.6-1. The differences in percent relative abundance of the diatom genera *Achnanthes* sp. and *Nitzschia* sp. are shown in the figure. *Achnanthes* sp. is an attached form of algae, which commonly is found in large numbers in streams having a large dissolved-oxygen concentration. *Nitzschia* sp. is a motile form of periphyton, which is entrapped among other attached algae and generally is found in large numbers in waters having large nitrogen concentrations (Bahls and others, 1981).

The composition of diatom populations between stations can be compared numerically using a formula for percentage similarity, which ranges from 0 to 100. The percentage similarity in diatom composition between pairs of intensively sampled stations generally was small, indicating that the composition of diatoms varied considerably among stations (table 8.6-2). The totals for percentage similarity showed that Hanging Woman Creek near Birney (station 158) had the most species of diatoms in common with those found at the other stations.

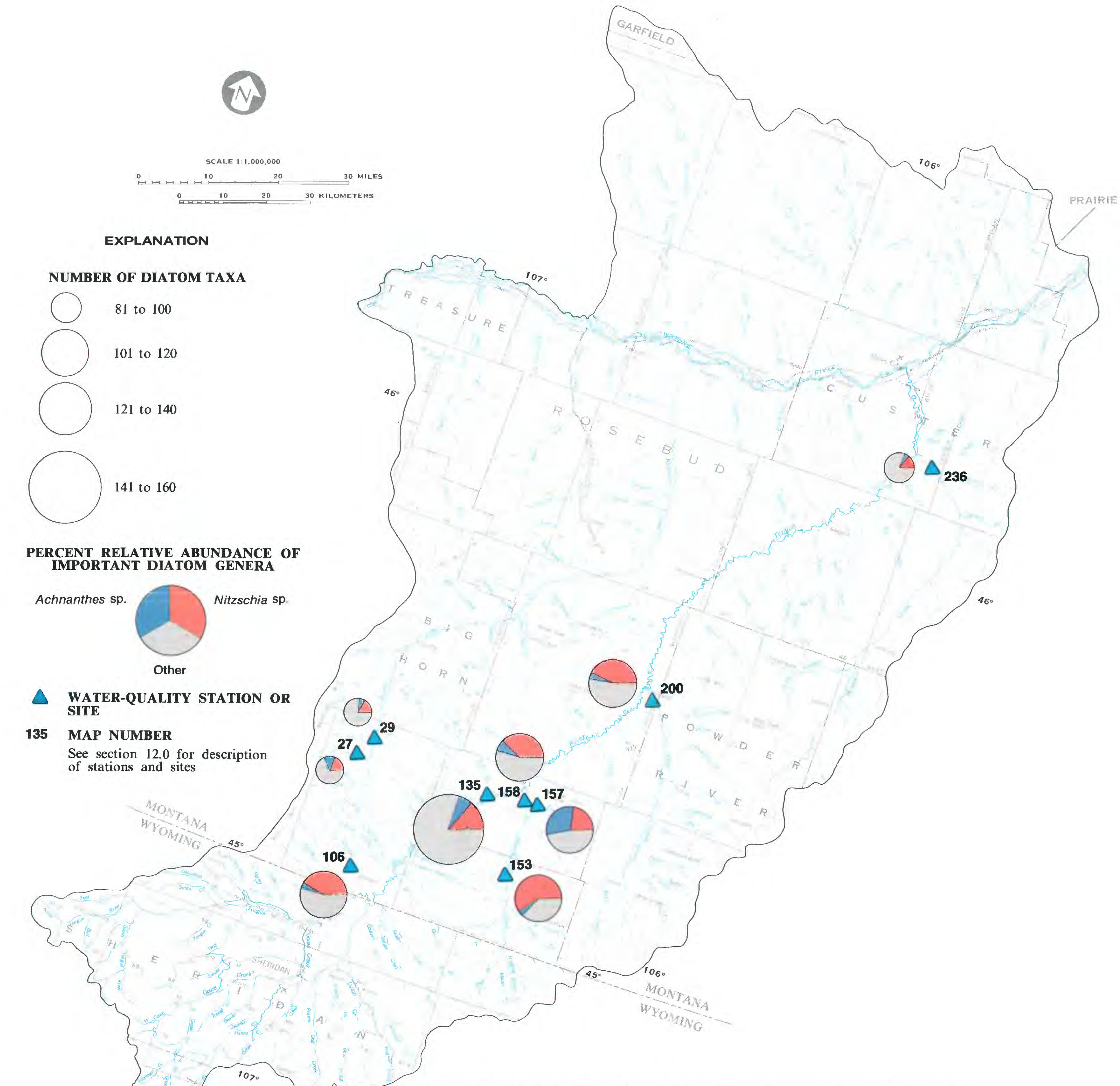


Figure 8.6-1 Variation in number of diatom taxa and percent relative abundance of important diatom genera at sampled stations and sites, August 5-11, 1979.

Table 8.6-1 Number of samples and minimum, maximum, and average values for diatom species diversity at sampled stations and sites.

[Map No.: refers to locations in figure 8.6-1]

Map No.	Station or site name	Number of samples	Diatom diversity Minimum	Maximum	Average
29	Rosebud Creek at Kirby, Mont.	9	2.61	4.25	3.57
106	Squirrel Creek near Decker, Mont.	9	2.41	4.56	3.70
135	Tongue River at Prairie Dog Creek, Mont.	12	2.85	4.88	3.87
153	Hanging Woman Creek at OW Ranch, Mont.	10	3.51	4.68	4.12
157	East Fork Hanging Woman Creek near Birney, Mont.	12	2.15	4.84	3.98
158	Hanging Woman Creek near Birney, Mont.	12	2.57	5.37	4.27
200	Otter Creek at Ashland, Mont.	10	2.89	4.52	3.62
236	Pumpkin Creek near Miles City, Mont.	5	1.72	4.20	2.97

Table 8.6-2 Percentage similarity in diatom composition between sampled stations and sites, August 5-11, 1979.

[Map No.: refers to locations in figure 8.6-1]

Map No.	Station or site name	Percentage similarity between indicated stations or sites: 27	29	106	135	153	157	158	200	236
27	Indian Creek near Kirby, Mont.	--	60	8	19	18	24	27	9	15
29	Rosebud Creek at Kirby, Mont.	60	--	30	27	15	18	24	11	6
106	Squirrel Creek near Decker, Mont.	8	30	--	31	24	26	33	25	15
135	Tongue River at Prairie Dog Creek, Montana	19	27	31	--	21	28	22	9	18
153	Hanging Woman Creek at OW Ranch, Mont.	18	15	24	21	--	28	43	36	41
157	East Fork Hanging Woman Creek near Birney, Mont.	24	18	26	28	28	--	28	16	21
158	Hanging Woman Creek near Birney, Mont.	27	24	33	22	43	28	--	57	25
200	Otter Creek at Ashland, Mont.	9	11	25	9	36	16	57	--	18
236	Pumpkin Creek near Miles City, Mont.	15	6	15	18	41	21	25	18	--
	Totals	180	191	192	175	226	189	259	181	159

Increased Salinity Can Stress Benthic-Invertebrate Communities

Benthic-invertebrate diversity decreases with increased salinity, although the total number of organisms is relatively unaffected.

Several stations in Area 49 were sampled in 1978 and 1979 to characterize the benthic-invertebrate community in coal-area streams. With this data base, future impacts that various resource and agricultural developments might have on water quality can be studied.

Changes in the composition of benthic-invertebrate communities can be indicative of water-quality changes. Because benthic invertebrates are relatively immobile and long lived, their community composition expresses water-quality conditions that might have existed several months prior to sampling. Understanding the effects that various water-quality constituents and properties have on benthic invertebrates will allow more precise interpretation of their community composition.

The average densities of benthic invertebrates collected from stations in Area 49 ranged from 1,184 to 38,111 organisms per square meter (10.76 square feet). The average density of 9,538 and median density of 7,080 organisms per square meter for all stations indicate that secondary production is large (Klarich and Regele, 1980). A commmon physical factor that could affect benthic-invertebrate density is volume of streamflow. However, benthic-invertebrate density within size classes of streams was variable, signifying that volume of streamflow is not a major controlling factor (fig. 8.7-1). The data show that intermittent streams have a smaller total benthic-invertebrate density than do perennial streams.

An average similarity index of 46.5 percent in the study area indicates that the streams generally were different in community composition (Klarich and Regele, 1980). Organisms of the class Insecta were the most prevalent benthic invertebrates in the study area. The largest contribution of Insecta to total density was from the orders Diptera (flies) and Trichoptera (caddis flies), with Coleoptera (beetles) and Ephemeroptera (mayflies) being the only other numerous orders (fig. 8.7-1).

As a measure of community stability (health) and therefore an indicator of the level of water-quality stress, two diversity indexes (Margalef, 1952; Shannon and Weaver, 1949) were calculated for benthic invertebrate samples collected in Area 49 (table 8.7-1). The classification used in the study for both diversity indexes is shown below.

Benthic-invertebrate diversity index		Community stability	Water-quality stress
Margalef	Shannon-Weaver		
More than 2.00	More than 3.00	Excellent	Unstressed
1.35-2.00	2.00-3.00	Good	Slight
0.67-1.35	1.00-2.00	Fair	Moderate
Less than 0.67	Less than 1.00	Poor	Severe

Most streams had good community stability and only slightly stressful water quality. Generally, larger perennial streams had diversity indexes larger than small perennial streams, and both of these stream types had diversity indexes larger than intermittent streams.

Determining the exact causes for changes in the community composition of benthic invertebrates is difficult, because of the large number of possible controlling factors. Salinity, as estimated by specific conductance, is a water-quality variable commonly impacted by resource and agricultural development. The average Margalef diversity generally decreased as average specific conductance increased for samples collected in Area 49. Twenty-one percent of the variability in benthic invertebrate diversity is explained by this relationship. Based on the classification for the Margalef diversity index, the relationship indicates that unstressful water quality would have a specific conductance less than 1,325 micromhos per centimeter and severely stressful water quality would have a specific conductance greater than 8,325 micromhos per centimeter. The question still remains whether or not increased salinity affects benthic invertebrates directly or whether some other controlling water-quality variable is associated with salinity.

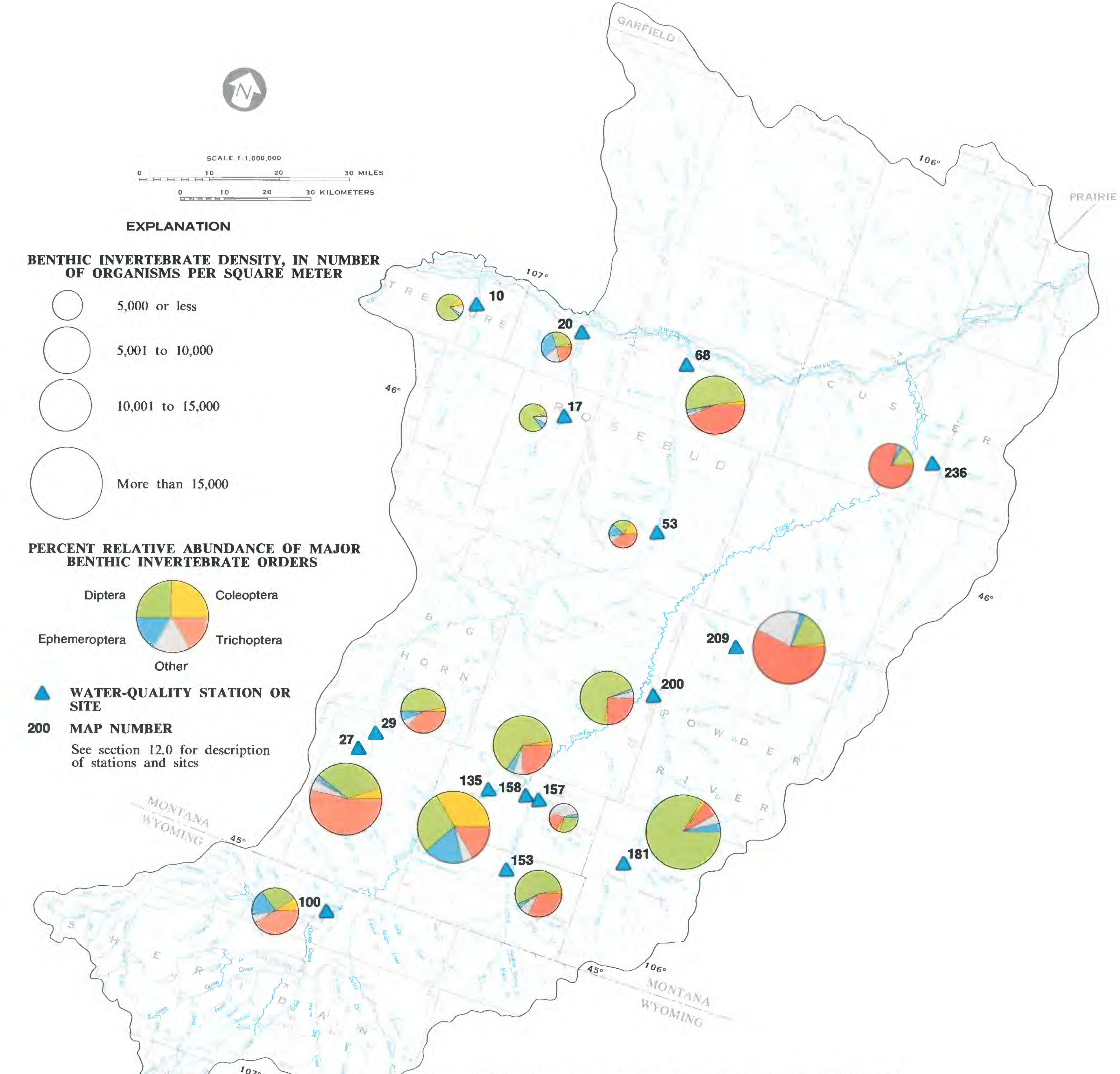


Figure 8.7-1 Total number of benthic invertebrates per square meter and percent relative abundance of major orders of Insecta collected at selected stations and sites during 1978 and 1979.

Table 8.7-1 Average Margalef and Shannon-Weaver diversity indexes for benthic invertebrates collected from stations and sites in 1978 and 1979.

[Map No.: refers to locations in figure 8.7-1]

Map No.	Station or site name	Diversity index: Margalef	Diversity index: Shannon-Weaver
10	Sarpy Creek near Hysham, Mont.	1.39	1.79
17	West Fork Armells Creek near Forsyth, Mont.	1.17	1.60
20	Armells Creek near Forsyth, Mont.	1.02	2.58
27	Indian Creek near Kirby, Mont.	2.21	2.57
29	Upper Rosebud Creek at Kirby, Mont.	1.51	2.40
53	Rosebud Creek above Pony Cr, near Colstrip, Mont.	3.01	3.51
68	Rosebud Creek at mouth, near Rosebud, Mont.	1.71	2.27
100	Tongue River near Acme, Wyo.	2.38	3.29
135	Tongue River at Prairie Dog Creek, Mont.	2.24	3.56
153	Hanging Woman Creek at OW Ranch, Mont.	1.51	2.11
157	East Fork of Hanging Woman Creek near Birney, Mont.	2.15	3.06
158	Hanging Woman Creek near Birney, Mont.	1.22	1.99
181	Otter Creek bl Bear Creek, Mont.	1.51	1.79
200	Otter Creek at Ashland, Mont.	1.40	2.24
209	Beaver Creek near Brandenberg, Mont.	1.65	1.98
236	Pumpkin Creek near Miles City, Mont.	1.04	1.43

Water in Alluvium, Sandstone, Clinker, and Coal Beds

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

Alluvium and the Tongue River-Wasatch aquifer are the sources of most water withdrawn from wells in Area 49. Not only are these aquifers reliable sources of water but, because they occur near land surface in most of the area, they generally are the most easily accessible. Most water supplies in these aquifers are withdrawn from sand and gravel contained in the alluvium and from sandstone, fractured coal, and clinker in the Tongue River-Wasatch aquifer. 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 saturated rocks or unconsolidated deposits that are sufficiently permeable and contain sufficient saturated material to yield significant quantities of water to wells and springs. Confining layers are materials with minimal permeability that 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 function as confining layers and units mapped as confining layers locally may function as 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 direct hydraulic connection. Therefore, the Fox Hills-lower Hell Creek aquifer contains the Fox Hills Sandstone and from 0 to 600 feet of the overlying Hell Creek Formation. The Tongue River Member of the Fort Union Formation and the Wasatch Formation are considered to be a single aquifer.

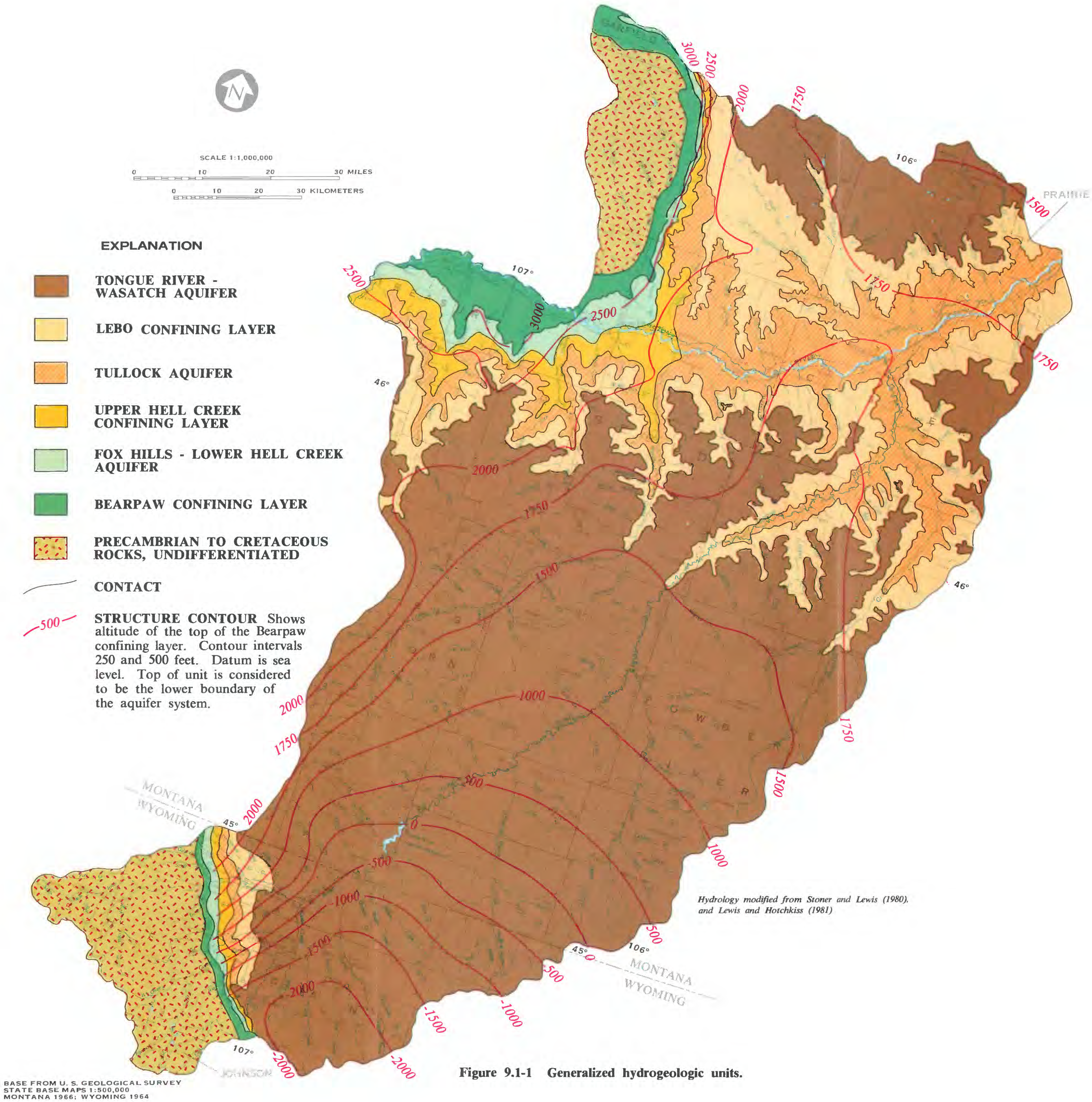


Figure 9.1-1 Generalized hydrogeologic units.

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

[gal/min, gallons per minute]

Hydrogeologic unit	Thickness (feet)	Water-yielding characteristics
Alluvial aquifer (not shown in fig. 9.1-1 because of limited areal extent)	0-100	Alluvium composed of coarse gravel may yield several hundred gallons of water per minute to wells in local areas along larger perennial streams. Yields from alluvium commonly are 30 gal/min or less to stock and domestic wells. Most terraces are topographically high and deposits are not saturated.
Tongue River-Wasatch aquifer	0-3,800	Yields from wells completed in sandstone and coal beds average about 8 gal/min but yields as large as 160 gal/min have been measured from wells penetrating large saturated thicknesses. Fractured clinker may yield as much as 50 gal/min.
Lebo confining layer	0-1,800	A limited source of water; in selected areas where saturated coarse-grained channel sandstone deposits are penetrated, yields are as large as 35 gal/min.
Tullock aquifer	0-800	Yields from fine-grained sandstones and fractured coal beds may be as much as 40 gal/min but generally average about 15 gal/min.
Upper Hell Creek confining layer	0-500	A major retarding unit; locally, flowing wells completed in sandy deposits yield as much as 4 gal/min.
Fox Hills-lower Hell Creek aquifer	0-800	Yields as much as 200 gal/min to properly constructed wells. Yields to domestic and stock wells generally are less than 70 gal/min. A reliable source of water for artesian wells; wells flow as much as 20 gal/min along major river valleys.
Bearpaw confining layer	0-800	A major confining unit. Top of unit is considered to be the lower boundary of the aquifer system.

Two Flow Systems Present

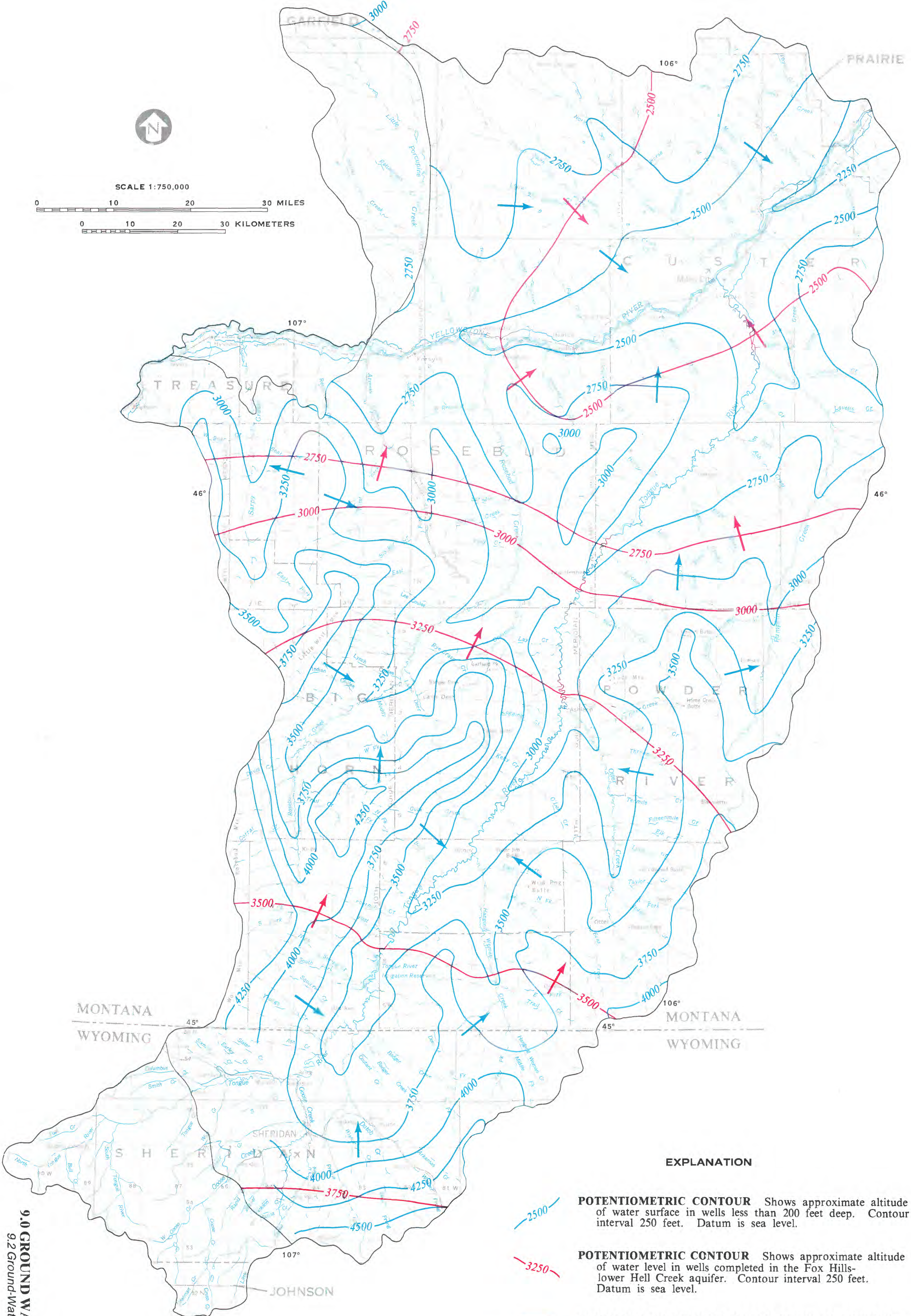
Water in shallow aquifers flows from topographically high areas to stream valleys, and water in deeper aquifers flows generally northward.

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 a more regional flow pattern, with water flowing generally toward the Yellowstone River.

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 contours, and discharges to streams. The downslope movement is commonly retarded or diverted by material of poor permeability, 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 into the regional aquifers near the margins of the Powder River Basin 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 discharges to the major drainages or flows out of the area, primarily northward toward the valley of the Yellowstone River.

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



EXPLANATION

POTENTIOMETRIC CONTOUR Shows approximate altitude of water surface in wells less than 200 feet deep. Contour interval 250 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 250 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

LIMIT OF AREAL EXTENT OF FOX HILLS - LOWER HELL CREEK AQUIFER

Figure 9.2-1 Ground-water flow patterns.

Chemical Quality Diverse

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

Water from most springs and from wells less than 200 feet deep and at local topographically high areas generally is dominant in magnesium, calcium, sodium, and bicarbonate. Moderate concentrations of sulfate also are present. Dissolved-solids concentration generally ranges from about 150 to 5,000 mg/L (milligrams per liter) and averages about 1,500 mg/L. These are probably recharge waters.

Water from wells less than 200 feet deep and at topographically lower areas, principally the valleys, generally is dominant in sodium and sulfate with smaller concentrations of magnesium, calcium, and bicarbonate. Dissolved-solids concentration generally ranges from about 400 to 6,000 mg/L and averages about 2,000 mg/L. Sodium and bicarbonate sometimes dominate water from coal-bed aquifers. These are probably discharge waters.

Water from wells deeper than 200 feet generally is dominated by sodium and bicarbonate. Dissolved-solids concentration of water in these deeper aquifers ranges from about 400 to 5,700 mg/L and averages about 1,400 mg/L. A summary of dissolved constituents in water from wells and springs is given in table 10.1-1.

Dissolved sulfide concentrations in ground water of Area 49 may be as much as 3 to 4 mg/L but are generally less than 1 mg/L (Dockins and others, 1980). Hydrogen sulfide gas commonly is present.

Because of the large concentrations of dissolved solids and some individual constituents, most ground water in the area exceeds the maximum contaminant levels for human consumption established by the U.S. Environmental Protection Agency (1977a, 1977b). 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 chemical constituents in water from wells and springs.

Source of water	Number of samples	Statistical category	Dissolved-constituent concentration, in milligrams per liter								
			Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids
Springs	149	Minimum	9.5	3.0	6.6	2	5	0	15	1.3	160
		Average	110	140	240	10	580	2	830	8.0	1,630
		Maximum	400	510	1,800	31	1,500	37	5,500	36	7,770
Well depths	375	Minimum	1.7	.3	3.2	1	20	0	0	.4	110
less than		Average	120	120	410	8	650	2	1,100	13	2,100
200 feet		Maximum	460	680	1,900	48	2,000	53	4,400	120	6,300
Well depths	141	Minimum	1.0	.1	13	1	230	0	.1	3.0	390
greater than		Average	32	27	450	4	850	14	390	36	1,400
200 feet		Maximum	350	330	1,700	14	2,000	440	3,300	770	5,720

Trace-Element Concentrations Generally Less Than Recommended Maximums for Drinking

Trace-elements concentrations are small because of large pH and the presence of sulfide.

Trace-element concentrations in ground water (table 10.2-1) vary throughout Area 49, and most are less than the maximum contaminant levels established for drinking water by the U.S. Environmental Protection Agency (1977a, 1977b). Only iron and manganese concentrations commonly exceed the recommended maximums. Boron and strontium concentrations in excess of 1,000 micrograms per liter also were reported.

Concentrations of nitrate (as nitrogen) were 6.2 milligrams per liter or less, except one anomalously large value of 14 milligrams per liter. That concentration was in excess of maximum contaminant levels for drinking water.

Radionuclide concentrations in water sampled from wells generally were in excess of the maximum contaminant levels specified for public water supplies by the U.S. Environmental Protection Agency (1976). The average dissolved gross alpha and maximum suspended gross alpha levels were both larger than the specified maximum of 15 picocuries per liter (10.2 micrograms per liter). The maximum dissolved gross beta level detected was three times the specified maximum of 50 picocuries per liter; however, average dissolved gross beta and suspended gross beta levels were within the acceptable levels.

Table 10.2-1 Summary of trace, radionuclide, and miscellaneous constituents in water from selected wells.[1]

[Constituents are dissolved except as indicated. Constituent values are reported in micrograms per liter except where indicated as milligrams per liter (mg/L) or picocuries per liter (pCi/L)]

	Aluminum (Al)	Arsenic (As)	Barium (Ba)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Molybdenum (Mo)	Selenium (Se)	Strontium (Sr)	Vanadium (V)	Zinc (Zn)
Number of samples	51	56	52	52	52	57	46	57	57	52	29	37	21	47	52	56	51
Minimum	0	0	0	5	0	0	0	0	0	10	0	.0	0	0	100	0	0
Average	84	1	124	217	.1	29	4	1,786	28	106	235	.3	21	.5	2,027	22	94
Maximum	470	25	600	1,100	1	100	30	53,000	100	360	2,100	1.7	100	8	9,000	100	550
Recommended maximum	--	[2]50	[2]1,000	--	[2]10	[2]50	[3]1,000	[3]300	[2]50	--	[3]50	[2]2	--	[2]10	--	--	

[1]Modified from Lee (1979)

[2]U.S. Environmental Protection Agency (1977a)

[3]U.S. Environmental Protection Agency (1977b)

	Total sulfide (S) (mg/L)	Fluoride (F) (mg/L)	Bromide (Br) (mg/L)	Iodide (I) (mg/L)	Silica (SiO_2) (mg/L)	Total nitrogen, as N (mg/L)	Total phosphorus (P) (mg/L)	Gross alpha as U-nat.	Suspended gross alpha as U-nat.	Gross beta as Sr90/Y90 (pCi/L)	Suspended gross beta as Sr90/Y90 (pCi/L)	Total organic carbon (C) (mg/L)	Organic carbon (C) (mg/L)
Number of samples	45	65	50	49	65	63	64	59	59	59	59	41	11
Minimum	.0	.1	.0	.00	5.8	.14	.00	7.1	.4	1.9	.4	.1	.7
Average	.6	1.2	.2	.01	24.6	2.61	.10	32.5	4.5	12.1	2.5	11.1	2.6
Maximum	3.0	5.0	1.3	.18	840	14	.71	140	47	150	19	83	5.0
Recommended maximum	--	--	--	--	--	[2]10	--	[4]10.2	[4]10.2	[5]50	[5]50	--	--

[4]U.S. Environmental Protection Agency (1976); maximum contaminant level specified as 15 pCi/L

[5]U.S. Environmental Protection Agency (1976)

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

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

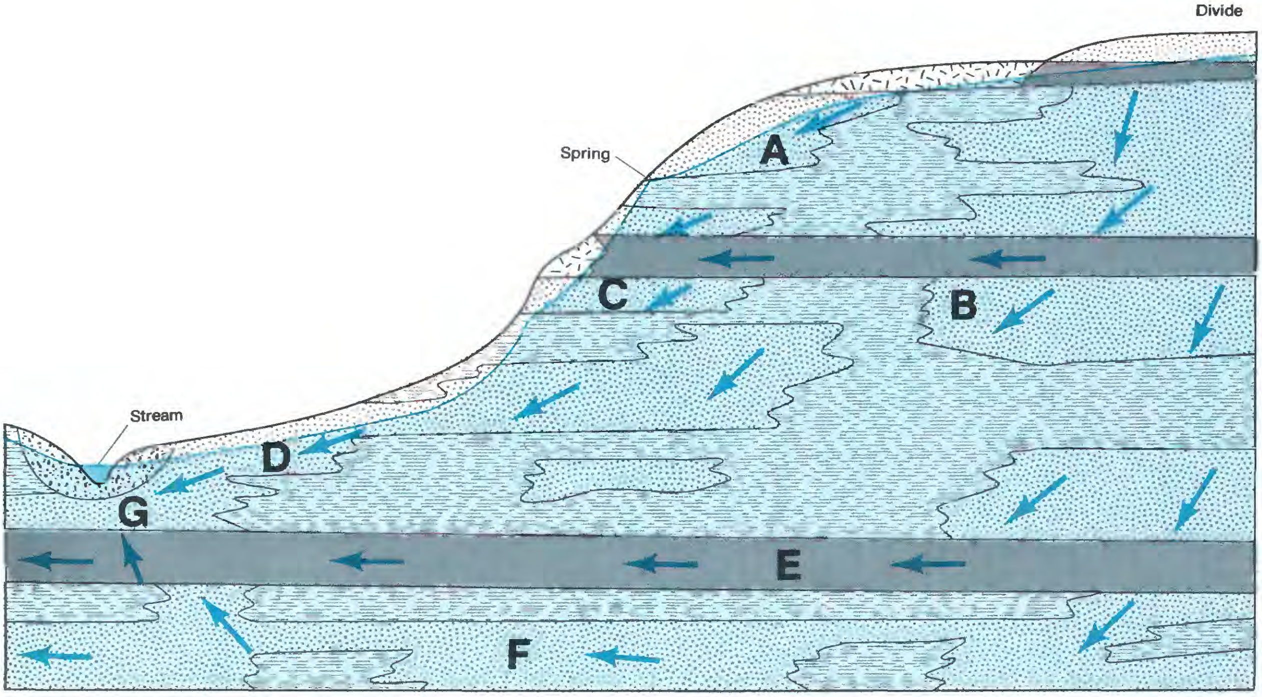
Geochemical changes occur within the shallow ground-water system as water flows from areas of recharge to deeper parts of the aquifers. Aquifer mineralogy and solution chemistry largely are responsible for the concentrations of solutes, although time, distance of travel, and biological factors also are 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 containing larger percentages of calcium and magnesium percolates through the soils and dilutes ground water containing larger percentages of sodium.

Sulfate and bicarbonate plus carbonate provide the major competition among the anions for dominance in solution. Sulfate enrichment is the dominant chemical process in the shallow ground-water system. Direct sulfate enrichment may occur 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 occur 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 Area 49. Dockins and others (1980) imply that small sulfate concentrations in some ground water in the area likely results from sulfate depletion by bacterial sulfate reduction.

A generalized geochemical conceptual model (fig. 10.3-1) was developed from probable mineral-water interactions, aqueous chemistry, geology, and hydrology in southeastern Montana (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, water quality 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, water quality 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 water quality approaching that for recharge water; that is, lesser percentage of sodium and sulfate. At D, water quality 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, static 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.



EXPLANATION

SANDSTONE

SHALE

COAL

ALLUVIUM

CLINKER

WATER TABLE

DIRECTION OF WATER MOVEMENT

WATER-QUALITY ZONE

A Recharge area

B Shallow aquifer downgradient from recharge area

C Shallow aquifer underlying recharge area

D Shallow aquifer near discharge area

E Deep coal-bed aquifer

F Deep regional or subregional aquifer

G Zone of mixing of waters from deep and shallow aquifers

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

11.0 WATER-DATA SOURCES
11.1 Introduction

NAWDEX, WATSTORE, and OWDC 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.

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

NAWDEX Simplifies Access to Water Data

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

or

NAWDEX ASSISTANCE CENTER
MONTANA
U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, Montana 59626
Telephone: (406) 449-5263
FTS 585-5263
Hours: 8:00-4:45 Mountain Time

or

NAWDEX ASSISTANCE CENTER
WYOMING
U.S. Geological Survey
Water Resources Division
J.C. O'Mahoney Federal Center
Room 4007, P.O. Box 1125
2120 Capitol Avenue
Cheyenne, Wyoming 82003
Telephone (307) 778-2220, Ext. 2153
FTS 328-2153
Hours: 8:00 - 4:30 Mountain Time

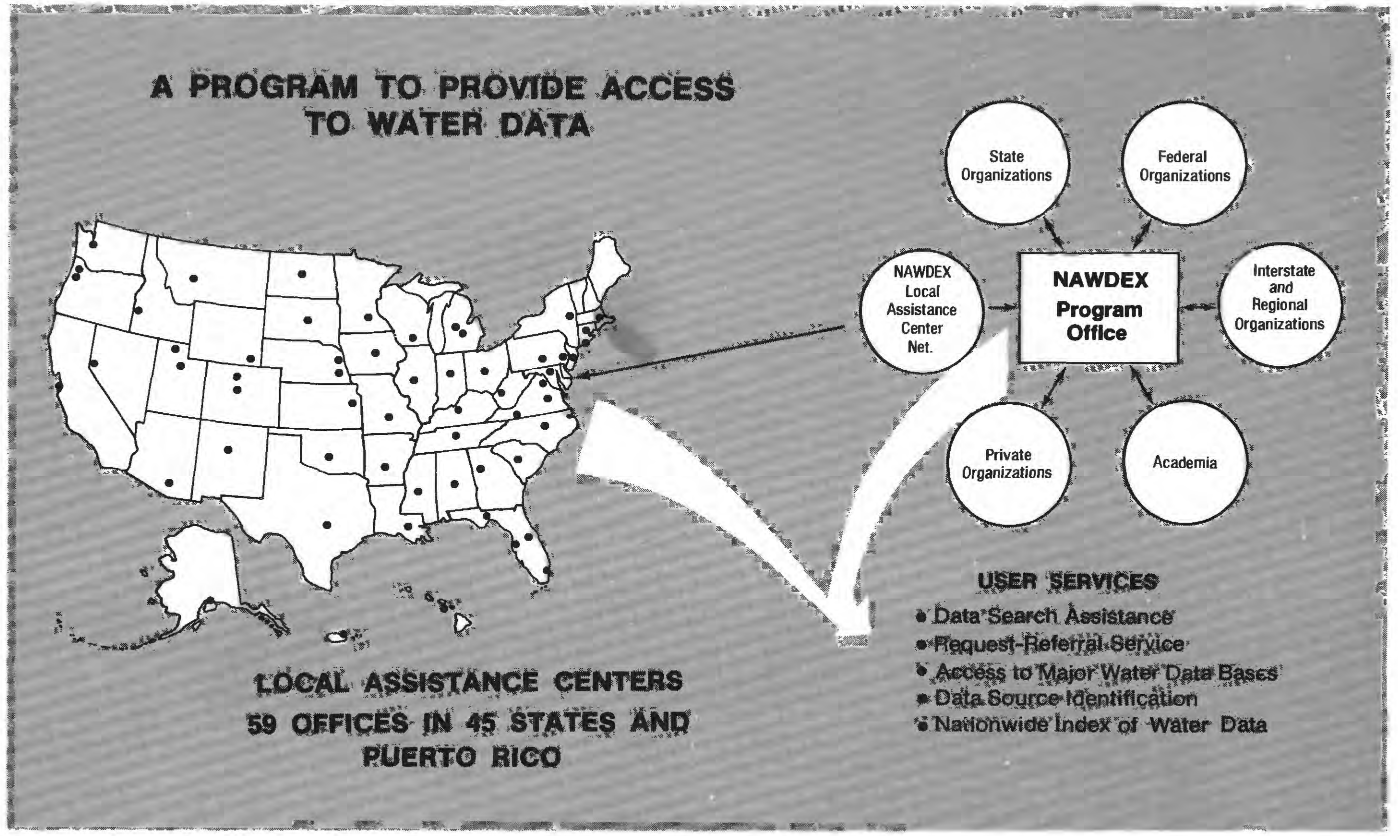


Figure 11.2-1 Access to water data.

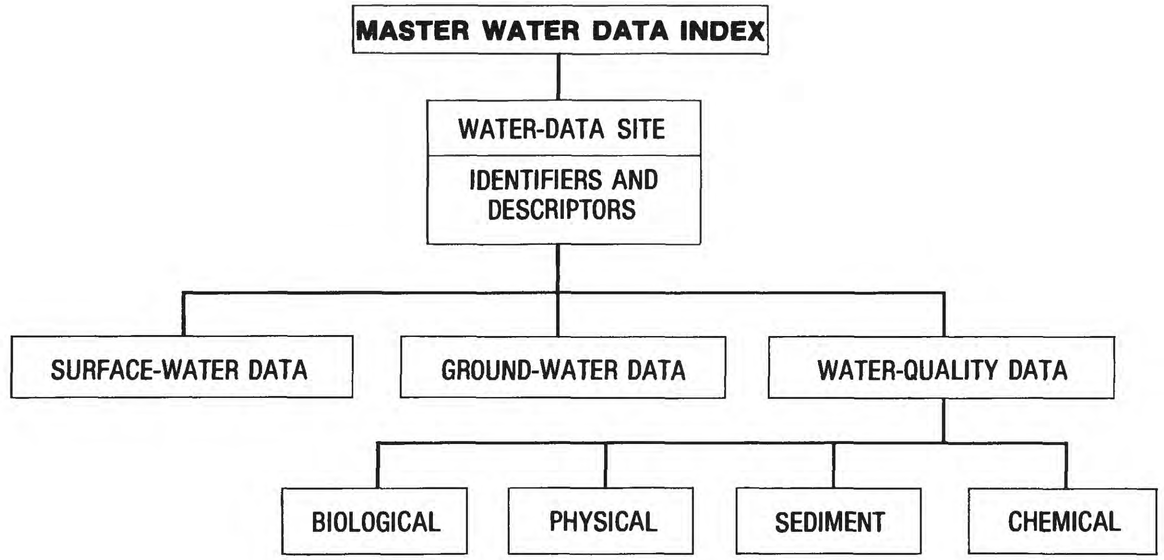


Figure 11.2-2 Master water-data index.

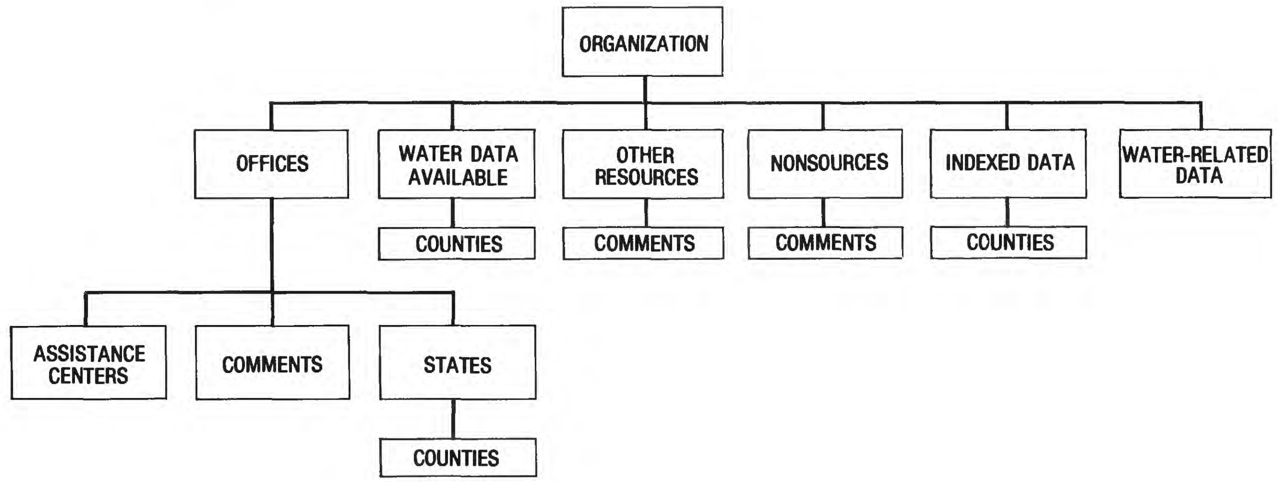


Figure 11.2-3 Water-data sources directory.

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 46 district offices. General inquiries about WATSTORE may be directed to:

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

or

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

or

Wyoming
U.S. Geological Survey
Water Resouces Division
J.C. O'Mahoney Federal Center
Room 4007, P.O. Box 1125
2120 Capitol Avenue
Cheyenne, Wyoming 82003

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 observation wells, and 12,500 ground-water-quality wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data collection activities.

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system 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 peak observations.

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 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 include site location and identification, geohydrologic characteristics, well-construction history, and one-time onsite measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 700,000 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 site to put data into or retrieve data from the system within several minutes to overnight, depending upon the priority placed on the request. The number of remote job-entry sites is increased as the need arises.

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river 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 are being operated currently (1980).

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

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

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

Computer-Printed Graphs: Computer-printed graphs for the rapid 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.

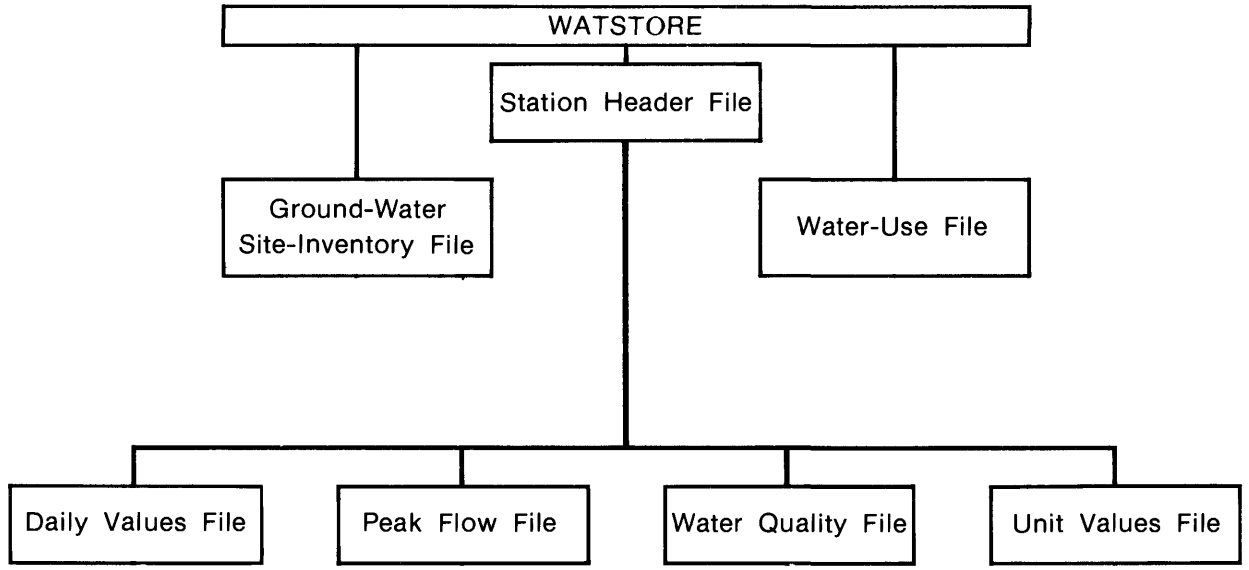


Figure 11.3-1 Index to file-stored data.

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-resouces 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 aquisition 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 l0076
Helena, Montana 59626

Telephone (406) 449-5263
FTS 585-5263

or

U.S. Geological Survey
Water Resources Division
J.C. O'Mahoney Federal Center
Room 4007, P.O. Box 1125
2120 Capitol Avenue
Cheyenne, Wyoming 82003

Telephone (307) 778-2220, Ext. 2153
FTS 328-2153

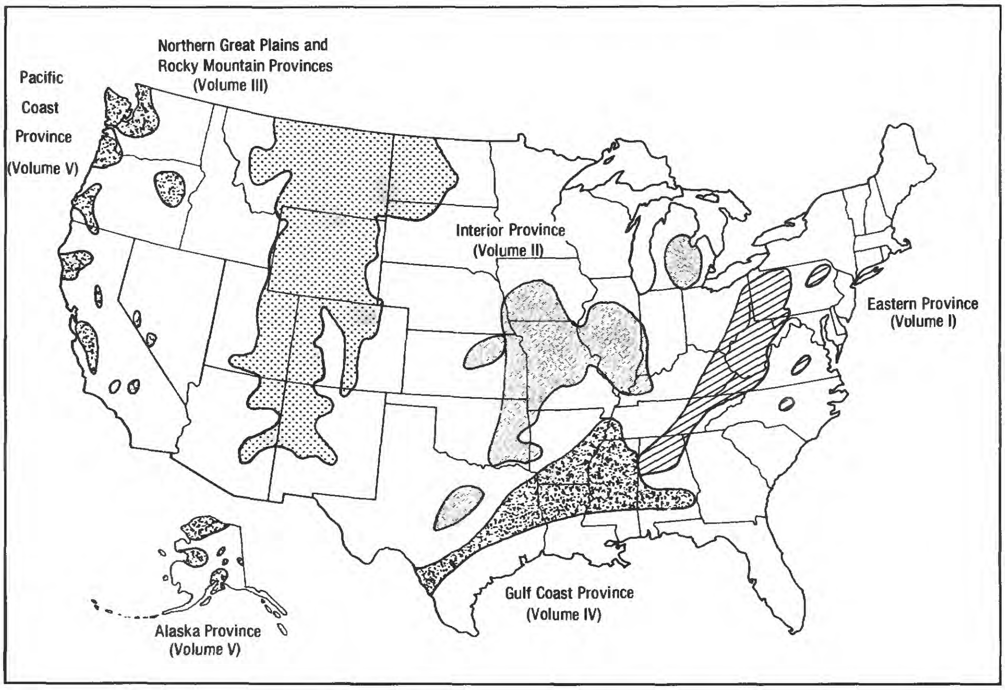


Figure 11.4-1 Index volumes and related provinces.

Description of streamflow and water-quality stations and sites.

[Map number: refers to locations shown on figures 6.3.1-1, 6.3.2-1, and 6.3.3-1. 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]

Map No.	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	06294800	---	Unknown Creek nr Bighorn, Mont.	14.6	---	---	1962-76	---
2	06294840	---	Yellowstone River at Myers, Mont.	37,680	---	1971-72; 1974-77	---	1974-77 CBS
3	06294850	---	Buckingham Coulee nr Myers, Mont.	2.63	---	---	1962-76	---
4	---	454947107064401	Sarpy Creek ab Spring Creek, Mont.	---	---	1978-79	---	---
5	---	454900106594401	East Fork Sarpy Creek nr Sarpy Creek, Mont.	---	---	1978-79	---	---
6	06294920	---	East Fork Sarpy Creek nr Colstrip, Mont.	---	---	1981	---	1981 CS
7	06294930	---	Sarpy Creek tributary nr Colstrip, Mont.	4.44	---	---	1972	---
8	---	455704107083001	Sarpy Creek bl Iron Spring Coulee, Mont.	---	---	1978-79	---	---
9	---	460234107070401	Sarpy Creek ab Beaver Creek, Mont.	---	---	1978-79	---	---
10	06294940	---	Sarpy Creek nr Hysham, Mont.	453	1973-	1978-79	---	1975- CBS
11	---	461451106562901	Reservation Creek nr Forsyth, Mont.	---	---	---	---	1978-79 CBS
12	---	455233106373501	East Fork Armells Creek at State Highway 39 bridge, Mont.	---	---	1978-79	---	---
13	06294980	---	East Fork Armells Creek nr Colstrip, Mont.	97.3	---	1975-81	---	1975- CS
14	06294985	---	East Fork Armells Creek tributary nr Colstrip, Mont.	1.87	---	---	1973-	---
15	---	455922106502901	West Fork Armells Creek bl Trail Creek, Mont.	---	---	1978-79	---	---
16	---	460337106465901	West Fork Armells Creek ab West Sheep Creek, Mont.	---	---	---	---	1978-79 CB
17	06294991	---	West Fork Armells Creek nr Forsyth, Mont.	148	---	1975-77	---	1975-77 CBS
18	---	460607106454201	Armells Creek bl confluence, Mont.	---	---	1978-	---	---

Map No.	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
19	---	460902106474301	Armells Creek ab Cottonwood Creek, Mont.	---	---	1979	---	1979 C
20	06294995	---	Armells Creek nr Forsyth, Mont.	370	1974-	1978-79	---	1975- CBS
21	06295000	---	Yellowstone River at Forsyth, Mont.	40,339	1921-23; 1977-	1974-77	---	1974- CBS
22	06295020	---	Short Creek nr Forsyth, Mont.	3.23	---	---	1962-	---
23	06295050	---	Little Porcupine Creek nr Forsyth, Mont.	614	---	---	1958-73	---
24	---	451302106583201	Rosebud Creek nr Kobold Ranch, Mont.	---	---	1978-79	---	1978 C
25	06295100	---	Rosebud Creek nr Kirby, Mont.	34.2	---	---	1960-74	---
26	---	451445106580201	Rosebud Creek nr Helvy Ranch, Mont.	---	---	1978	---	---
27	---	451622106594101	Indian Creek nr Kirby, Mont.	---	---	---	---	1978-79 CB
28	---	451746106591101	Rosebud Creek 2 miles south of Kirby, Mont.	---	---	1977	---	---
29	06295110	---	Rosebud Creek at Kirby, Mont.	116	---	1978-79	---	1978-79 CBS
30	06295113	---	Rosebud Creek at reservation boundary, nr Kirby, Mont.	102	1980-	---	---	1980- CS
31	---	452147106591401	Unnamed pond (slough) nr Kirby, Mont.	---	---	---	---	1978-79 CB
32	06295130	---	Rosebud Creek tributary nr Busby, Mont.	1.14	---	---	1963-77	---
33	---	453018107001501	Davis Creek nr Busby, Mont.	---	---	---	---	1978-79 CB
34	06295150	---	Ridgewalker Creek nr Busby, Mont.	2.24	---	---	1959-62	---
35	06295200	---	Whitedirt Creek nr Lame Deer, Mont.	1.58	---	---	1959-73	---
36		453713106454701	Muddy Creek nr Lame Deer, Mont.	---	---	---	---	1978-79 CB
37		453905106424701	Rosebud Creek nr Lame Deer, Mont.	---	---	1968-69	---	---
38		453548106390401	Lame Deer Creek ab Spotted Elk Creek, nr Lame Deer, Mont.	---	---	---	---	1978-79 CB
39		454004106415701	Lame Deer Creek nr Lame Deer, Mont.	---	---	1968	---	---
40		454044106415601	Rosebud Creek west of Jimtown, Mont.	---	---	1978-79	---	1978-79 C
41		454150106405001	Rosebud Creek bl Lame Deer Creek, Mont.	---	---	1977	---	---
42		454437106383801	Rosebud Creek bl Richard Coulee, Mont.	---	---	1978	---	---
43	06295250	---	Rosebud Creek nr Colstrip, Mont.	799	1974-	1978-79	---	1975- CS
44		454713106320601	Miller Coulee nr mouth, Mont.	---	---	1978	---	---
45		454808106300301	Hay Coulee nr mouth, Mont.	---	---	1978	---	---
46		454806106292901	Rosebud Creek bl Hay Coulee, Mont.	---	---	1978	---	1978 C
47		454945106252301	Rosebud Creek ab Greenleaf Creek, Mont.	---	---	1977	---	---
48	06295350	---	Greenleaf Creek nr Colstrip, Mont.	30.5	---	1975-77	---	1975-76 CS
49		454945106252201	Rosebud Creek bl Greenleaf Creek, Mont.	---	---	1978-79	---	---
50		455200106343001	Cow Creek tributary nr Rosebud Mine, Mont.	---	---	---	---	1976 C
51	06295380	---	Cow Creek nr Colstrip, Mont.	27.2	---	1980-81	---	1980- CS
52		455202106252201	Cow Creek bl 06295380, near Colstrip, Mont.	---	---	---	---	1979 CB
53	06295400	---	Rosebud Creek ab Pony Creek, nr Colstrip, Mont.	1,153	---	1975-78	---	1975-79 CBS
54		455342106241501	Pony Creek at mouth, Mont.	---	---	1978	---	---
55		455527106231501	Rosebud Creek ab West Snider Creek, Mont.	---	---	1978	---	---
56	06295420	---	Snider Creek nr Brandenberg, Mont.	11.8	---	1978-81	---	1978-81 CS
57		455747106235401	Spring Creek at mouth, Mont.	---	---	1978	---	---
58		455810106233301	Rosebud Creek bl Spring Creek, Mont.	---	---	1978	---	1978 C
59	---	460001106240001	Rosebud Creek bl Sprague Creek, Mont.	---	---	1977	---	---
60	---	460122106241901	Rosebud Creek ab Goodman Creek, Mont.	---	---	1978-79	---	---
61	---	460409106255301	Rosebud Creek bl Mitchell Coulee, Mont.	---	---	1978	---	---
62	---	460557106264601	Rosebud Creek ab Cottonwood Creek, Mont.	---	---	1978-79	---	1978-79 C
63	06295500	---	Rosebud Creek nr Rosebud, Mont.	1,193	1938-43	1944; 1974-77	---	1975-77 CS
64	---	460837106275201	Vance Creek at mouth, Mont.		---	1978	---	---
65	---	460914106282201	Rosebud Creek bl Vance Creek, Mont.		---	1978	---	1978 C

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

Map No.	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
66	06296000	---	Rosebud Creek nr Forsyth, Mont.	1,279	1947-53	---	1955-57; 1959; 1961-67; 1969	---
67	---	461237106293601	Rosebud Creek bl 06296000, Mont.	---	---	1978	---	---
68	06296003	---	Rosebud Creek at mouth, nr Rosebud, Mont.	1,302	1974-	1978-79	---	1975- CBS
69	---	461555106193201	Sweeney Creek nr Rosebud, Mont.	---	---	---	---	1978-79 CB
70	06296100	---	Snell Creek nr Hathaway, Mont.	10.5	---	---	1963-77	---
71	06296115	---	Reservation Creek nr Miles City, Mont.	6.29	---	---	1973-	---
72	06296120	---	Yellowstone River nr Miles City, Mont.	42,847	---	1977-79	---	1969- CBS
73	06296500	---	North Fork Tongue River nr Dayton, Wyo.	32.4	1945-57	---	---	---
74	06296700	---	Big Willow Creek nr Dayton, Wyo.	7.08	---	---	1961-73	---
75	06297000	---	South Tongue River nr Dayton, Wyo.	85.0	1945-71	---	---	---
76	06297480	---	Tongue River at Tongue Canyon Campground, nr Dayton, Wyo.	202	1975-79	---	---	---
77	06298000	---	Tongue River nr Dayton, Wyo.	204	1919-29; 1941-	---	---	1967-81 CB
78	06298480	---	Little Tongue River at Steamboat Point, nr Dayton, Wyo.	11.4	---	1973-74	---	---
79	06298490	---	Little Tongue River ab South Fork Little Tongue River, nr Dayton, Wyo.	14.1	---	1973-74	---	---
80	06298500	---	Little Tongue River nr Dayton, Wyo.	25.1	1951-53; 1955-74	---	---	---
81	06299000	---	Tongue River at Dayton, Wyo.	259	1903	---	---	---
82	06299480	---	Wolf Creek bl Alden Creek, near Wolf, Wyo.	32.8	---	1973-74	---	---
83	06299490	---	Wolf Creek ab Red Canyon Creek, at Wolf, Wyo.	33.8	---	1973-74	---	---

Map No.	Station and 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
84	06299500	---	Wolf Creek at Wolf, Wyo.	37.8	1945-	---	---	---
85	06299900	---	Slater Creek nr Monarch, Wyo.	18.0	---	---	1967-	---
86	06299980	---	Tongue River at Monarch, Wyo.	---	---	1978-79	---	1974-81 CB
87	06300000	---	Tongue River at Carneyville, Wyo.	495	1911-17	---	---	---
88	06300500	---	East Fork Big Goose Creek, nr Big Horn, Wyo.	20.1	1954-	---	---	---
89	06300900	---	Cross Creek ab Big Horn Reservoir, nr Big Horn, Wyo.	9.29	1961-71	---	---	---
90	06301000	---	Cross Creek nr Big Horn, Wyo.	9.63	1954-60	---	---	---
91	06301500	---	West Fork Big Goose Creek nr Big Horn, Wyo.	24.4	1954-	---	---	---
92	06302000	---	Big Goose Creek nr Sheridan, Wyo.	120	1929-	---	---	---
93	06302500	---	Goose Creek at Sheridan, Wyo.	182	1909-16	---	---	---
94	06303000	---	Willow Creek nr Big Horn, Wyo.	2.99	---	1952-55	---	---
95	06303500	---	Little Goose Creek in canyon, nr Big Horn, Wyo.	51.6	1941-	---	---	---
96	06304000	---	Little Goose Creek nr Big Horn, Wyo.	71.0	1919-21	---	---	---
97	06304500	---	Little Goose Creek at Sheridan, Wyo.	---	1896-97; 1911-13	---	---	1979- C
98	06305500	---	Goose Creek bl Sheridan, Wyo.	392	1942-	---	---	1959-65; 1968- CS
99	---	445258106591301	Goose Creek nr mouth, nr Kleenburn, Wyo.	---	---	1978-79	---	1978-79 C
100	06306000	---	Tongue River nr Acme, Wyo.	894	1938-57	1958-60	---	1978-79 B
101	---	445642106563401	Interstate Ditch nr Acme, Wyo.	---	---	---	---	1979 CB
102	---	445700106563101	Ash Creek at mouth, nr Acme, Wyo.	---	---	1978-79	---	1978-79 CB
103	---	445948106570401	Youngs Creek at State line	---	---	---	---	1978 C
104	---	445832106551401	Youngs Creek nr mouth, nr Decker, Mont.	---	---	1978-79	---	1978-79 CB
105	06306020	---	Tongue River bl Youngs Creek, nr Acme, Wyo.	---	---	---	---	1969-70 C
106	06306100	---	Squirrel Creek nr Decker, Mont.	33.6	1975-	---	---	1976- CBS
107	---	450047106514201	Squirrel Creek nr mouth, at Decker, Mont.	---	---	1979	---	1979 C
108	---	445126106520801	Prairie Dog Ditch No. 13 ab Bates Draw, nr Wakeley, Wyo.	---	---	1978-79	---	---
109	---	445130106511601	Prairie Dog Creek ab Bates Draw, nr Wakeley, Wyo.	---	---	1978-79	---	1978-79 C
110	---	444732106452801	Dutch Creek ab Dow Prong, nr Wyarno, Wyo.	---	---	1978-79	---	1978-79 C
111	---	444708106452201	Dow Prong at mouth, nr Wyarno, Wyo.	---	---	1978-79	---	1978-79 C
112	---	44494710648220	Dutch Creek ab Plum Creek, nr Wyarno, Wyo.	---	---	1979	---	1979 C
113	06306250	---	Prairie Dog Creek nr Acme, Wyo.	358	---	1979	---	1976-78 CBS
114	---	445904106495501	Unnamed ditch nr Praire Dog Creek, nr Decker, Mont.	---	---	1978-79	---	---
115	---	445907106502401	Wilson and Symons ditch nr Decker, Mont.	---	---	1978-79	---	---
116	---	445943106473801	Badger Creek nr mouth, nr Decker, Mont.	---	---	1979	---	1979 C
117	06306300	---	Tongue River at State line, nr Decker, Mont.	1,477	1960-	1979	---	1965- CBS
118	06306500	---	Tongue River nr Decker, Mont.	1,585	1928-38	1942; 1953	---	---
119	---	450236106464101	Coal Creek nr Decker, Mont.	---	---	1976-78	---	---
120	---	450429106502601	Pearson Creek nr Decker, Mont.	---	---	1975-78	---	---
121	06306800	---	Deer Creek nr Decker, Mont.	38.3	---	1975-77	---	1975-77 CS
122	06306900	---	Spring Creek nr Decker, Mont.	34.7	---	1978-81	1958-	1978- CS
123	06306950	---	Leaf Rock Creek nr Kirby, Mont.	6.14	---	---	1958; 1960-	---
124	06307000	---	Tongue River Reservoir nr Decker, Mont.	1,770	1938-	---	---	---
125	---	450802106460501	Tongue River on Tongue River Dam apron, Mont.	---	---	1975; 1978	---	---
126	06307500	---	Tongue River at Tongue River Dam, near Decker, Mont.	1,770	1939-	1978-81	---	1976- CS
127	---	450918106445201	Tongue River ab Anderson Creek, Mont.	---	---	1976	---	---
128	---	451052106434601	Tongue River ab Fourmile Creek, Mont.	---	---	1978	---	---

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

Map No.	Station and 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
129	06307510	---	Fourmile Creek nr Birney, Mont.	22.3	---	1975-77	---	1975-76 CS
130	---	451259106413601	Tongue River bl Fourmile Creek, Mont.	---	---	1975; 1978-79	---	---
131	06307520	---	Canyon Creek nr Birney, Mont.	50.2	---	1978	1973-	1978-79 CB
132	06307525	---	Prairie Dog Creek ab Jack Creek, nr Birney, Mont.	6.57	1979-	1978-81	---	1978-81 CS
133	---	451856106433303	Prairie Dog Creek bl 06307525, Mont.	---	---	---	---	1980 C
134	06307528	---	Prairie Dog Creek nr Birney, Mont.	19.6	1979-	1978-81	---	1978-81 CS
135	---	451607106372801	Tongue River at Prairie Dog Creek, Mont.	---	---	1975; 1978-79	---	1978-79 CB
136	06307530	---	Bull Creek nr Birney, Mont.	45.8	---	1975-76	---	1975-76 CS
137	---	451820106373801	Bull Creek ab Salesbury Draw, nr Birney, Mont.	---	---	---	---	1979 CB
138	---	451727106334401	Tongue River bl Battle Butte Creek, Mont.	---	---	1978	---	---
139	---	451902106312601	Tongue River ab Hanging Woman Creek, Mont.	---	---	1975	---	---
140	---	450004106253001	West Prong Hanging Woman Creek at confluence, Mont.	---	---	1978-79	---	---
141	06307540	---	Hanging Woman Creek at State line, nr Otter, Mont.	90.2	---	1978-81	---	1980- CS
142	06307545	---	Waddle Creek nr Otter, Mont.	51.0	---	1980-81	---	1980- CS
143	---	450301106265701	Hanging Woman Creek bl Waddle Creek, Mont.	---	---	1978-79	---	---
144	06307550	---	Trail Creek nr Otter, Mont.	17.8	---	1980-81	---	1980- CS
145	---	450408106215401	East Trail Creek Flume No. 1, Mont.	---	---	1976-78; 1980	---	---
146	---	450415106231201	East Trail Creek Flume No. 2, Mont.	---	---	1977-78; 1980	---	---
147	06307560	---	East Trail Creek nr Otter, Mont.	31.3	1976-81	---	---	1977- CS
148	---	450409106243501	East Trail Creek Flume No. 4, Mont.	---	---	1976-78; 1980	---	---
149	---	450447106265801	Trail Creek at mouth, Mont.	---	---	1978		

Map No.	Station and 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
151	---	450743106273901	Horse Creek ab 06307567, Mont.	---	---	---	---	1980 C
152	06307567	---	Horse Creek nr Birney, Mont.	16.0	---	1980-81	---	1980- CS
153	---	450808106284401	Hanging Woman Creek at OW Ranch, Mont.	---	---	---	---	1978-79 CB
154	06307570	---	Hanging Woman Creek bl Horse Creek, nr Birney, Mont.	321	---	1977-81	---	1978- CS
155	---	451031106253401	Stroud Creek nr Quietus, Mont.	---	---	---	---	1979 CB
156	---	451249106214201	Lee Creek nr Birney, Mont.	---	---	---	---	1979 CB
157	---	451752106290401	East Fork Hanging Woman Creek nr Birney, Mont.	---	---	---	---	1978-79 CB
158	06307600	---	Hanging Woman Creek nr Birney, Mont.	470	1973-	1980	---	1975- CBS
159	---	451912106310501	Hanging Woman Creek at mouth, Mont.	---	---	1978-79	---	---
160	06307610	---	Tongue River bl hanging Woman Creek, nr Birney, Mont.	2,533	---	1974; 1977-78	---	1974-79 CBS
161	---	452007106304701	Tongue River ab Brown Cattle Company ditch, Mont.	---	---	1976	---	---
162	---	452240106294001	Tongue River ab Cook Creek, Mont.	---	---	1978-79	---	1978 C
163	06307615	---	Cook Creek nr Birney, Mont.	62.6	---	1975-77	---	1975-77 CS
164	---	452430106273701	Tongue River nr Birney, Mont.	---	---	1941	---	---
165	06307616	---	Tongue River at Birney Day School bridge, nr Birney, Mont.	2,621	1980-	1976; 1978	---	1980- CS
166	06307620	---	Tie Creek nr Birney, Mont.	18.7	---	---	1973-	---
167	---	452708106242801	Tongue River ab Pawnee Creek, Mont.	---	---	1978-79	---	1978-79 C
168	---	453019106195101	Tongue River ab King Creek, Mont.	---	---	1976-78	---	---
169	---	453658106312001	Crazy Head Springs pond nr Lame Deer, Mont.	---	---	---	---	1979 CB
170	---	453332106192401	Logging Creek nr Ashland, Mont.	---	---	---	---	1978-79 CB
171	---	453301106181301	Tongue River bl Logging Creek, Mont.	---	---	1978	---	1978 C
172	06307640	---	Spring Creek nr Ashland, Mont.	1.56	---	---	1962-76	---
173	06307660	---	Walking Horse Creek nr Ashland, Mont.	3.33	---	---	1963-77	---
174	---	453535106171101	Tongue River at U.S. Highway 212, Mont.	---	---	1978-79	---	---
175	---	453555106164101	Tongue River at Ashland, Mont.	---	---	1976	---	---
176	---	450437106055201	Otter Creek bl Long Creek, Mont.	---	---	1978	---	---
177	06307665	---	Otter Creek nr Otter, Mont.	40.9	---	1978-81	---	1978- CS
178	---	451134106085901	Otter Creek ab Bear Creek, Mont.	---	---	1978	---	---
179	06307670	---	Bear Creek at Otter, Mont.	90.4	---	1975-77	---	1975-77; 1979 CS
180	---	451313106101001	Bear Creek ab confluence, Mont.	---	---	1978	---	---
181	---	451330106100201	Otter Creek bl Bear Creek, Mont.	---	---	1978-79	---	1978-79 B
182	---	451837106144201	Cow Creek nr Fort Howes Ranger Station, nr Otter, Mont.	---	---	---	---	1978-79 CB
183	06307700	---	Cow Creek at Fort Howes Ranger Station, nr Otter, Mont.	8.37	---	---	1972-	---
184	---	451659106084701	Taylor Creek ab Cow Creek, Mont.	---	---	1978	---	---
185	---	451732106085001	Otter Creek bl Cow Creek, Mont.	---	---	1977-79	---	---
186	---	452106106085301	Otter Creek bl Gate Creek, Mont.	---	---	1978	---	---
187	---	452311106081701	Fifteenmile Creek at mouth, Mont.	---	---	1978	---	---
188	---	452329106085201	Otter Creek nr Fifteenmile road	---	---	---	---	1981 C
189	06307720	---	Brian Creek nr Ashland, Mont.	8.03	---	---	1973-	---
190	06307725	---	Otter Creek ab Tenmile Creek, nr Ashland, Mont.	---	---	1978-81	---	1978-81 C
191	---	452611106082801	Tenmile Creek ab confluence, Mont.	---	---	1978	---	---
192	---	452854106101601	Otter Creek bl Newell Creek, Mont.	---	---	1978	---	---
193	---	453017106102801	Otter Creek ab Threemile Creek, Mont.	---	---	1978	---	---
194	06307730	---	Threemile Creek nr Ashland, Mont.	51.5	---	1975-76	---	1975 CS
195	---	453117106110501	Otter Creek bl Threemile Creek, Mont.	---	---	1978-79	---	---
196	06307735	---	Home Creek nr Ashland, Mont.	58.7	---	1976-81	---	1977- CS
197	---	453246106124101	Otter Creek bl Home Creek, Mont.	---	---	1978-79	---	1978-79 C
198	---	453338106123701	East Fork Otter Creek ab confluence, Mont.	---	---	1978	---	---

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

Map No.	Station and 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
199	---	453323106125801	Otter Creek bl East Fork, Mont.	---	---	1978-79	---	---
200	06307740	---	Otter Creek at Ashland, Mont.	707	1972-	1978-79	---	1975- CBS
201	---	453601106161001	Otter Creek ab confluence, Mont.	---	---	1978	---	---
202	---	453840106101201	Cook Creek nr headwaters, Mont.	---	---	---	---	1980 C
203	---	453842106110501	Cook Creek ab Cook Creek Reservoir, Mont.	---	---	---	---	1980 C
204	06307760	---	Stebbins Creek nr Ashland, Mont.	5.41	---	---	1963-77	---
205	06307780	---	Stebbins Creek at mouth, nr Ashland, Mont.	19.9	---	---	1963-	---
206	---	454103106171401	Tongue River nr reservation boundary, Mont.	---	---	1978	---	1978 C
207	---	454307106173501	Tongue River ab Lay Creek, nr Ashland, Mont.	---	---	1976; 1978-79	---	---
208	06307800	---	Tongue River nr Ashland, Mont.	3,830	1966-73	1976	---	---
209	---	45443310605001	Beaver Creek nr Brandenberg, Mont.	---	---	---	---	1978-79 CB
210	06307810	---	Beaver Creek nr Ashland, Mont.	92.3	---	1975-76; 1978	---	1975-76 CS
211	---	455023106131201	Tongue River at Brandenberg Bridge, Mont.	---	---	1941; 1978-79	---	1978-79 C
212	06307830	---	Tongue River bl Brandenberg Bridge, nr Ashland, Mont.	4,062	1973-	1978-79	---	1974-81 CS
213	---	455303106083601	Liscom Creek 1.6 miles ab 06307840, Mont.	---	---	1978	---	---
214	06307840	---	Liscom Creek nr Ashland, Mont.	47.6	---	1975-77	---	1975-77 CS
215	---	455531106083901	S-H diversion ditch bl diversion gate, Mont.	---	---	1978	---	---
216	---	455528106083501	Tongue River bl S-H dam, nr Brandenberg, Mont.	---	---	1976; 1978	---	---
217	---	45584410603190	Tongue River at Moon Creek bridge, Mont.	---	---	1976; 1978-79	---	1978-79 C
218	06307890	---	Foster Creek nr Volborg, Mont.	116	---	1975-78	---	1975-77 CS
219	---	460244105560201	Tongue River bl Foster Creek, Mont.	---	---	1976; 1978	---	1978 C

Map No.	Station and 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
221	---	460802105483301	Tongue River bl Ash Creek, Mont.	---	---	1976-79	---	---
222	---	461237105454701	Tongue River bl Dry Creek, Mont.	---	---	1978	---	1978 C
223	06308000	---	Tongue River nr Miles City, Mont.	4,539	1929-33	---	---	---
224	---	452423105503001	Pumpkin Creek bl Dry Creek, Mont.	---	---	1978-79	---	---
225	06308080	---	Pumpkin Creek nr Sonnette, Mont.	70.7	---	1976-79	---	1976-77 CS
226	06308100	---	Sixmile Creek tributary nr Epsie, Mont.	.24	---	---	1973-	---
227	06308160	---	Pumpkin Creek nr Loesch, Mont.	170	---	1976-79	---	1976-79 CS
228	06308170	---	Little Pumpkin Creek nr Volborg, Mont.	101	---	1976-79	---	1976-77 CS
229	---	454739105430801	Pumpkin Creek bl Little Pumpkin Creek, Mont.	---	---	1978-79	---	---
230	06308190	---	Pumpkin Creek nr Volborg, Mont.	386	---	1976-77	---	1976-77 CS
231	06308200	---	Basin Creek tributary nr Volborg, Mont.	.14	---	---	1955-	---
232	06308300	---	Basin Creek nr Volborg, Mont.	10.9	---	---	1955-73	---
233	---	460317105334201	Pumpkin Creek ab Deer Creek, Mont.	---	---	1978-79	---	---
234	06308330	---	Deer Creek tributary nr Volborg, Mont.	1.65	---	---	1973-	---
235	06308340	---	LaGrange Creek nr Volborg, Mont.	3.66	---	---	1973-	---
236	06308400	---	Pumpkin Creek nr Miles City, Mont.	697	1972-	1949; 1952; 1978-79	---	1976- CBS
237	---	461538105455201	Tongue River bl Pumpkin Creek, Mont.	---	---	1976; 1978-79	---	---
238	06308500	---	Tongue River at Miles City, Mont.	5,379	1938-42; 1946-	---	---	1946- CBS
239	---	462413105512801	Tongue River in Miles City, Mont.	---	---	1978-79	---	1965; 1978-79 CS
240	06309000	---	Yellowstone River at Miles City, Mont.	48,253	1922-23; 1928-	---	---	1948-52; 1965 CS
241	06309020	---	Rock Springs Creek tributary at Rock Springs, Mont.	0.96	---	---	1963-77	---
242	06309040	---	Dry House Creek nr Angela, Mont.	38.6	---	---	1963-77	---
243	06309060	---	North Fork Sunday Creek tributary No. 2 nr Angela, Mont.	0.34	---	---	1962-	---
244	06309075	---	Sunday Creek nr Miles City, Mont.	714	1974-	---	---	---
245	06309078	---	Tree Creek nr Kinsey, Mont.	4.13	---	---	1972; 1974-	---
246	06309079	---	Muster Creek nr Kinsey, Mont.	28.5	---	1977-80	---	1978-80 CBS
247	---	463323105380201	Dixon Creek nr Miles City, Mont.	---	---	1958; 1972	1972	---
248	06309080	---	Deep Creek nr Kinsey, Mont.	11.5	---	---	1962-	---
249	06309090	---	Ash (Meadow) Creek nr Locate, Mont.	6.23	---	---	1962-76	---
250	06309145	---	Custer Creek nr Kinsey, Mont.	151	---	1977-80	---	1978-80 CBS

13.0 LIST OF SELECTED REFERENCES

Aagaard, F. C., 1969, Temperature of surface waters in Montana: Montana Fish and Game Department special publication, 613 p.

Bahls, L. L., 1980, Salinity and the structure of benthic algae (periphyton) communities in streams of the Southern Fort Union Region, Montana: Montana Department of Health and Environmental Sciences, 35 p.

Bahls, L. L., Fillinger, Michael, Greene, Robert, Horpestad, Abraham, Ingman, Gary, and Weber, Erich, 1979, Biological water quality monitoring, northwest Montana, 1978-1979: Montana Department of Health and Environmental Sciences, Water Quality Bureau, 59 p.

________1981, Biological water-quality monitoring, eastern Montana, 1979: Montana Department of Health and Environmental Sciences, Water Quality Bureau Report 81-3, 93 p.

Bergantino, R. N., 1977 [1980], Preliminary geologic map of the Miles City 1-degree by 2-degree quadrangle, Montana: Montana Bureau of Mines and Geology Open-File Report 49, 1 sheet.

________1980a, Geologic map of the Ekalaka 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 1-A, 1 sheet.

________1980b, Geologic map of the Hardin 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 2-A, 1 sheet.

________1980c, Ground-water resources map of the Hardin 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 2-C, 1 sheet.

________1981, Ground-water resources of the Ekalaka 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 1-B, 1 sheet.

Bergantino, R. N., and Cole, G. A., 1981, Mineral resources map of the Ekalaka 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 1-C, 1 sheet.

Bergantino, R. N., Pederson, R. J., and Berg, R. B., 1980, Mineral resources map of the Hardin 1° × 2° quadrangle, southeastern Montana: Montana Bureau of Mines and Geology Montana Atlas 2-B, 1 sheet.

Berryhill, H. L., Jr., Brown, D. M., Brown, Andrew, and Taylor, D. A., 1950, Coal resources of Wyoming: U.S. Geological Survey Circular 81, 78 p.

Berwick, V. K., 1958, Floods in eastern Montana, magnitude and frequency: U.S. Geological Survey open-file report, 23 p.

Blakey, J. F., 1966, Temperature of surface waters in the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-235, 3 sheets.

Boettcher, A. J., and Haralick, R. M., 1977, Use of thermal-infrared imagery in ground-water investigations *in* Montana, in Eleventh International Symposium on Remote Sensing of Environment Proceedings: Ann Arbor, Mich., Environmental Research Institute of Michigan, p. 1161-1170.

Bond, E. W., 1975, A study of the influence of seismic shotholes on ground water and aquifers in eastern Montana: Montana Bureau of Mines and Geology Special Publication 67, 87 p.

Boner, F. C., Lines, G. C., Lowry, M. E., and Powell, J. E., 1976, Geohydrologic reconnaissance and measurement of perennial streams crossing outcrops of the Madison Limestone, northeastern Wyoming, 1974: U.S. Geological Survey Open-File Report 75-614, 63 p.

Boner, F. C., and Omang, R. J., 1967, Magnitude and frequency of floods from drainage areas less than 100 square miles in Montana: U.S. Geological Survey open-file report, 23 p.

Botz, M. K., and Bond, E. W., 1966, Index and bibliography of ground-water studies in Montana: Montana Bureau of Mines and Geology Special Publication 37, 1 sheet.

Busby, M. R., 1966, Annual runoff in the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-212, 1 sheet.

Cary, L. E., and Johnson, J. D., 1981, Selected hydrologic and climatologic data from the Prairie Dog Creek basin, southeastern Montana, water year 1979: U.S. Geological Survey Open-File Report 81-412, 73 p.

________1982, Selected hydrologic and climatologic data from the Prairie Dog Creek basin, southeastern Montana, water year 1980: U.S. Geological Survey Open-File Report 82-273, 74 p.

Cole, G. A., 1980, Wall coal--Structure, isopach, overburden and reserves, southeastern part of Tongue River Dam quadrangle and southwestern part of Spring Gulch quadrangle: Montana Bureau of Mines and Geology Open-File Report 31, 1 sheet.

________1981, Sedimentology of the Anderson-Dietz coal zone, southeastern Montana, *with a section on* Coal resources, by D. E. Fine: Montana Bureau of Mines and Geology Geologic Map 23, 3 sheets.

Cole, G. A., and Fine, D. E., 1980a, Dietz No. 2 and

Wyoming and southeastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-847-B, 1 sheet.

Frost, L. R., Jr., 1974, Evaluation and simulation of chemical-quality data for five Montana sampling stations: U.S. Geological Survey open-file report, 50 p.

Gaylord, D. R., and Marrs, R. W., 1978, Land-use map, *in* Sheridan County, Wyoming: Geological Survey of Wyoming County Resource Series No. 5, 1 sheet.

Gilmour, E. H., and Williams, L. A., 1969, Geology and coal resources of the Foster Creek coal deposit, eastern Montana: Montana Bureau of Mines and Geology Bulletin 73, 9 p.

Glass, G. B., 1976, Update on the Powder River coal basin: Wyoming Geological Association Twenty-eighth Annual Field Guidebook, p. 209-220.

Green, S. L., 1981, Water-resources investigations of the U.S. Geological Survey in Wyoming, fiscal year 1980: U.S. Geological Survey Open-File Report 81-201, 118 p.

Ground-water Subgroup of Water Work Group, Northern Great Plains Resource Program, 1974, Shallow ground water in selected areas in the Fort Union coal region: U.S. Geological Survey Open-File Report 74-371, 132 p.

Hall, G. M., and Howard, C. S., 1929, Ground water in Yellowstone and Treasure Counties, Montana: U.S. Geological Survey Water-Supply Paper 599, 118 p.

Hedges, R. B., Van Voast, W. A., McDermott, J. J., 1980, Hydrogeology of an area of proposed surface coal mining near lower Youngs Creek, southeastern Montana: Montana Bureau of Mines and Geology Open-File Report 43, 46 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2d ed): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hodson, W. G., Pearl, R. H., and Druse, S. A., 1973, Water resources of the Powder River Basin and adjacent areas, northeastern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas 465, 4 sheets.

Hopkins, W. B., 1972, Water resources of the Northern Cheyenne Indian Reservation and adjacent area, southeastern Montana: U.S. Geological Survey Hydrologic Investigations Atlas 468, 2 sheets.

________1976, Water-resources data for deep aquifers of eastern Montana: U.S. Geological Survey Water-Resources Investigations 76-40, 37 p.

Johnson, M. V., and Omang, R. J., 1976, A method for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 75-650, 35 p.

Keefer, W. R., and Schmidt, P. W., 1973, Energy resources map of the Powder River Basin, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-847-A, 1 sheet.

Klarich, D. A., and Regele, S. M., 1980, Structure, general characteristics, and salinity relationships of benthic macroinvertebrate associations in streams draining the southern Fort Union coalfield region of southeastern Montana: Montana Department of Health and Environmental Sciences, Water Quality Bureau, 148 p.

Klarich, D. A., Regele, S. M., and Bahls, L. L., 1980, Data report for the benthic macroinvertebrate and periphyton community inventory of streams draining the southern Fort Union coalfield region of southeastern Montana: Montana Department of Health and Environmental Sciences, Water Quality Bureau Report, 268 p.

Knapton, J. R., and Bochy, B. M., 1976, Results of phytoplankton sampling at National Stream Quality Accounting Network stations in Montana--1975 water year: U.S. Geological Survey Open-File Report 76-219, 27 p.

Knapton, J. R., and Ferreira, R. F., 1980, Statistical anaylses of surface-water-quality variables in the coal area of southeastern Montana: U.S. Geological Survey Water-Resources Investigations 80-40, 128 p.

Knapton, J. R., and Jacobson, M. A., 1980, Simulation of water-quality data at selected stream sites in the Missouri River basin, Montana: U.S. Geological Survey Water-Resources Investigations 80-76, 30 p.

Knapton, J. R., and McKinley, P. W., 1977, Water quality of selected streams in the coal area of southeastern Montana: U.S. Geological Survey Water-Resources Investigations 77-80, 145 p.

Konikow, L. F., 1976, Preliminary digital model of ground-water flow in the Madison Group, Powder River Basin and adjacent areas, Wyoming, Montana, South Dakota, North Dakota, and Nebraska: U.S. Geological Survey Water-Resources Investigations 63-75, 44 p.

Langbein, W. B., and Schumm, S. A., 1958, Yield of sediment in relation to mean annual precipitation: American Geophysical Union Transactions, v. 39, no. 6, p. 1076-1084.

Lee, R. W., 1979, Ground-water-quality data from the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 79-133i, 55 p.

________1980, Geochemistry of water in the Fort Union Formation of the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Water-Supply Paper 2076, 17 p.

Lee, R. W., Slagle, S. E., and Stimson, J. R., 1981, Magnitude and chemical quality of base flow of Otter Creek, Tongue River, and Rosebud Creek, Canyon coals--Structure, isopach, overburden, reserves, fence diagram and projected outcrop (prior to Tongue River reservoir), Decker and southern part of Tongue River Dam quadrangle: Montana Bureau of Mines and Geology Open-File Report 32, 2 sheets.

________1980b, Structure and isopach of the Canyon coal, southeastern Montana, showing regional extent, outcrop, clinker, structure and thickness isopach: Montana Bureau of Mines and Geology Open-File Report 39, 2 sheets.

________1980c, Coal correlation diagram--Bar V Ranch NE and Half Moon Hill quadrangles, Montana, showing coal correlation in fence diagram format for the coals in the area directly north of the Pearl School and Decker areas: Montana Bureau of Mines and Geology Open-File Report 40, 1 sheet.

Cole, G. A., Matson, R. E., and Pederson, R. J., 1980, Montana coal: A guide to coal geology, resources and production: Montana Bureau of Mines and Geology Special Publication 83, 20 p.

Cole, G. A., and Sholes, M. A., 1980, Geology of the Anderson and Dietz coal beds, Big Horn County, Montana, *with a section on* Coal resources, by D. E. Fine, R. E. Matson and J. A. Daniel: Montana Bureau of Mines and Geology Geologic Map 14, 6 sheets.

Combo, J. X., Brown, D. M., Pulver, H. F., and Taylor, D. A., 1949, Coal resources of Montana: U.S. Geological Survey Circular 53, 28 p.

Craig, G. S., and Rankl, J. G., 1978, Analysis of runoff from small drainage basins in Wyoming: U.S. Geological Survey Water-Supply Paper 2056, 70 p.

Dockins, W. S., Olson, G. J., McFeters, G. A., Turback, S. C., and Lee, R. W., 1980, Sulfate reduction in ground water of southeastern Montana: U.S. Geological Survey Water-Resources Investigations 80-9, 13 p.

Druse, S. A., Dodge, K. A., and Hotchkiss, W. R., 1981, Base flow and chemical quality of streams in the northern Great Plains area, Montana and Wyoming, 1977-78: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-692, 60 p.

Dunrud, C. R., and Osterwald, F. W., 1980, Effects of coal mine subsidence in the Sheridan, Wyoming, area: U.S. Geological Survey Professional Paper 1164, 49 p.

Durfor, C. N., and Becker, Edith, 1964, Chemical quality of public water supplies of the United States and Puerto Rico, 1962: U.S. Geological Survey Hydrologic Investigations Atlas HA-200, 1 sheet.

Edwards, M. D., 1980, Directory of assistance centers of the national water data exchange (NAWDEX): U.S. Geological Survey Open-File Report 80-1193, 10 p.

Feltis, R. D., 1980a, Map showing potentiometric surface of water in the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 2, 1 sheet.

________1980b, Map showing dissolved-solids concentration of water in the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 1.

________1980c, Map showing ratio of sodium, potassium, and chloride to dissolved-solids concentration in water of the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 2.

________1980d, Map showing ratio of sulfate to total anions in water of the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 3.

________1981a, Map showing configuration of the top of the Madison Group, Miles City 1-degree by 2-degree quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 20, 1 sheet.

________1981b, Map showing configuration of the top of the Madison Group, Ekalaka 1-degree by 2-degree quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 21, 1 sheet.

________1981c, Map showing configuration of the top of the Madison Group, Forsyth 1-degree by 2-degree quadrangle, Montana: Montana Bureau of Mines and Geology Geologic Map 22, 1 sheet.

Feltis, R. D., Lewis, B. D., Frasure, R. L., Rioux, R. P., Jauhola, C. A., and Hotchkiss, W. R., 1981, Selected geologic data from the northern Great Plains area of Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-415, 63 p.

Ferreira, R. F., 1981, Mean annual streamflow of selected drainage basins in the coal area of southeastern Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-61, 21 p.

Feth, J. H., and others, 1965, Preliminary map of the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Investigations Atlas HA-199, 2 sheets.

Fine, D. E., Cole, G. A., and Matson, R. E., 1980, Structure, isopach and potentially minable areas of the Canyon coal, Tongue River Dam area; the study area is located in parts of the Tongue River Dam, Half Moon Hill, Pearl School, Decker, Holmes Ranch and Spring Gulch quadrangles: Montana Bureau of Mines and Geology Open-File Report 44, 2 sheets.

Frickel, D. G., and Shown, L. M., 1974, Map showing streamflow volumes in northeastern southeastern Montana, October 26-November 5, 1977: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-1298, 25 p.

Levings, G. W., 1981a, Selected hydrogeologic data from the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 81-534, 241 p.

________1981b, Selected drill-stem-test data from the northern Great Plains area of Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-326, 20 p.

Levings, J. F., Levings, G. W., Feltis, R. D., Hotchkiss, W. R., and Lee, R. W., 1981, Selective annotated bibliography of geology and ground-water resources for the Montana part of the northern Great Plains regional aquifer-system analysis: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-401, 91 p.

Lewis, B. D., and Hotchkiss, W. R., 1981, Thickness, percent sand, and configuration of shallow hydrogeologic units in the Powder River Basin, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-1317, 6 sheets.

Lewis, B. D., and Roberts, R. S., 1978, Geology and water-yielding characteristics of rocks of the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-847-D, 2 sheets.

Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming, U.S. Geological Survey, 1 sheet.

Lowham, H. W., 1976, Techniques for estimating flow characteristics of Wyoming streams: U.S. Geological Survey Water-Resources Investigations 76-112, 83 p.

Lowry, M. E., and Cummings, T. R., 1966, Ground-water resources of Sheridan County, Wyoming: U.S. Geological Survey Water-Supply Paper 1807, 77 p.

McClymonds, N. E., 1982, Hydrology of the Prairie Dog Creek drainage basin, Rosebud and Big Horn Counties, Montana: U.S. Geological Survey Water-Resources Investigations 81-37, 63 p.

McGuinness, C. L., 1964, Generalized map showing annual runoff and productive aquifers in the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-194.

Margalef, Ramon, 1952, Diversidad de Especies en las Communidades Naturales: Proceedings of the Institute of Biology, v. 9, p. 5-27.

Matson, R. E., and Blumer, J. W., 1973, Quality and reserves of strippable coal, selected deposits, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 91, 135 p.

Matson, R. E., Dahl, G. G., Jr., and Blumer, J. W., 1968, Strippable coal deposits on state land, Powder River County, Montana: Montana Bureau of Mines and Geology Bulletin 69, 81 p.

Miller, M. R., Bermel, W. M., Bergantino, R. N., Sonderegger, J. L., Norbeck, P. M., and Schmidt, F. A., 1977, Compilation of hydrogeological data for southeastern Montana (*in map form*): Montana Bureau of Mines and Geology Open-File Report 26, 7 p.

Miller, W. R., 1976, Water in carbonate rocks of the Madison Group in southeastern Montana--A preliminary evaluation: U.S. Geological Survey Water-Supply Paper 2043, 51 p.

________1981, Water resources of the southern Powder River area, southeastern Montana: Montana Bureau of Mines and Geology Memoir 47, 53 p.

Miller, W. R., and Strausz, S. A., 1980a, Preliminary map showing freshwater heads for the Mission Canyon and Lodgepole Limestones and equivalent rocks of Mississippian age in the Northern Great Plains of Montana, North and South Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Open-File Map 80-729, 1 sheet.

________1980b, Preliminary map showing freshwater heads for the Red River Formation, Bighorn Dolomite, and equivalent rocks of Ordovician age in the Northern Great Plains of Montana, North and South Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Open-File Map 80-730, 1 sheet.

Montana Bureau of Mines and Geology and U.S. Geological Survey, 1978, Ground water of the Fort Union Coal Region, eastern Montana: Montana Bureau of Mines and Geology Special Publication 80, 47 p.

Montana Coal Council, [1981], Montana coal: Helena, Mont., brochure.

Montana Coal Task Force, 1973, Coal development in eastern Montana: Montana Department of Natural Resources and Conservation, 80 p.

Montana Department of Community Affairs, coordinator, 1981, Existing land use, Rosebud, Big Horn, Powder River, Treasure, Custer, and Garfield Counties, Montana, as part of Montana Statewide Cooperation Land Use Mapping Program: Individual maps.

Moore, L. G., and Shields, R. R., 1980, Streamflow characteristics of the Yellowstone River basin, Montana, through 1976: U.S. Geological Survey Water-Resources Investigations 80-41, 67 p.

Nielsen, G. F., ed., 1981, Keystone coal industrial manual: New York, McGraw-Hill, 1419 p.

Omang, R. J., Hull, J. A., and Parrett, Charles, 1979, Annual peak discharges from small drainage areas in Montana for stations discontinued before 1978: U.S. Geological Survey Open-File Report 79-510, 124 p.

Omang, R. J., Parrett, Charles, and Hull, J. A., 1982, Annual peak discharges from small drainage areas in Montana through September 1981: U.S. Geological Survey Open-File Report 82-270, 114 p.

Parrett, Charles, Carlson, D. D., Craig, G. S., Jr., and Chin, E. H., 1982, Floods of May 1978 in southeastern Montana and northeastern Wyoming: U.S. Geological Survey Professional Paper 1244 (in press).

Parrett, Charles, Carlson, D. D., Craig, G. S., Jr., and Hull, J. A., 1978, Data for floods of May 1978 in northeastern Wyoming and southeastern Montana: U.S. Geological Survey Open-File Report 78-985, 16 p.

Parrett, Charles, and Omang, R. J., 1981, Revised techniques for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 81-917, 66 p.

Perry, E. S., 1931, Ground water in eastern and central Montana: Montana Bureau of Mines and Geology Memoir 2, 59 p.

________1932, Shallow wells near Terry, Montana, as a source of irrigation water: Montana Bureau of Mines and Geology Miscellaneous Contribution 3, 7 p.

________1935, Geology and ground-water resources of southeastern Montana: Montana Bureau of Mines and Geology Memoir 14, 67 p.

Pierantoni, Marino, 1980, Annual report of the state inspector of mines of Wyoming: Cheyenne, Wyoming, 84 p.

Pinchock, J. M., 1975, Index map and bibliography of coal studies in Montana: Montana Bureau of Mines and Geology Special Publication 71, 1 sheet.

Rahn, P. H., 1975, Ground water in coal strip-mine spoils, Powder River basin: Montana Academy of Sciences, Proceedings of Fort Union Coal Field Symposium, v. 3, Reclamation Section, p. 348-361.

________1976, Potential of coal strip-mine spoils as aquifers in the Powder River basin: Old West Regional Commission Project Completion Report, Project No. 10470025, 108 p.

Rainwater, F. H., 1962, Stream composition of the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-61, 3 sheets.

Reed, T. E., and McMurtrey, R. G., 1970, Water levels and artesian pressures in observeration wells in Montana, 1966-69: Montana Bureau of Mines and Geology Bulletin 76, 36 p.

Renick, B. C., 1924, Base exchange in ground water by silicates as illustrated in Montana: U.S. Geological Survey Water-Supply Paper 520-D, p. 53-72.

________1929, Geology and ground-water resources of central and southern Rosebud County, Montana, with chemical analyses of the water, by H. G. Riffenburg: U.S. Geological Survey Water-Supply Paper 600, 140 p.

Riffenburg, H. B., 1926, Chemical character of ground waters of the northern Great Plains: U.S. Geological Survey Water-Supply Paper 560-B, p. 31-52.

Ringen, B. H., Shown, L. M., Hadley, R. F., and Hinkley, T. K., 1979, Effect on sediment yield and water quality of a nonrehabilitated surface mine in northcentral Wyoming: U.S. Geological Survey Water-Resources Investigations 79-47, 23 p.

Roger, G. S., and Lee, Wallace, 1923, Geology of the Tullock Creek coal field, Rosebud and Big Horn Counties, Montana: U.S. Geological Survey Bulletin 749, 181 p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geological Survey, 1 sheet.

Shannon, C. E., and Weaver, Warren, 1949, The mathematical theory of communication: Urbana, Ill, University of Illinois Press, 177 p.

Slagle, S. E., and Stimson, J. R., 1979, Hydrogeologic data from the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 79-1332, 111 p.

Stoner, J. D., 1981, Horizontal anisotropy determined by pumping in two Powder River Basin coal aquifers, Montana: Ground Water, v. 19, p. 34-40.

Stoner, J. D., and Lewis, B. D., 1980, Hydrogeology of the Fort Union coal region, eastern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1236, 2 sheets.

Swenson, F. A., Miller, W. R., Hodson, W. G., and Visher, F. N., 1976, Maps showing configuration and thickness, and potentiometric surface and water quality in the Madison Group, Powder River Basin, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-847-C, 2 sheets.

Thom, W. T., Jr., Hall, G. M., Wegemann, C. H., and Moulton, G. F., 1935, Geology of Big Horn County and the Crow Indian Reservation with special reference to the water, coal, oil, and gas resources: U.S. Geological Survey Bulletin 856, 200 p.

Torrey, A. E., and Swenson, F. A., 1951, Ground-water resources of the lower Yellowstone River valley between Miles City and Glendive, Montana, *with a section on* The chemical quality of the water by H. A. Swenson: U.S. Geological Survey Circular 93, 72 p.

U.S. Bureau of Land Management, 1974, Surface ownership, northern Great Plains resources program region: Denver Service Center, Colo., map.

________1978, State of Wyoming land status: Denver Service Center, Colo., map.

________1979, State of Wyoming mineral status: Denver Service Center, Colo., map.

U.S. Department of Energy, 1981, Western coal survey: Office of Coal Supply Development, 57 p.

U.S. Department of the Interior, 1975, Resource and potential reclamation evaluation, Otter Creek study site, Otter Creek coalfield, Montana: EMRIA Report 1, 234 p.

________1977, Resource and potential reclamation evaluation, Bear Creek study area, West Moorhead coalfield, Montana: EMRIA Report 8, 259 p.

________1978, Resource and potential reclamation evaluation, Hanging Woman Creek study area [Montana] EMRIA Report 12, 309 p.

________1982, Resource and potential reclamation evaluation, Pumpkin Creek study area, East Pumpkin Creek coalfield, Montana: EMRIA Report 11, 64 p.

U.S. Environmental Protection Agency, 1976, Interim primary drinking water regulations. Promulgation of regulations on radionuclides: Federal Register, v. 41, no. 133, July 9, p. 28401-28409.

________1977a, National interim primary drinking water regulations: Environmental Protection Agency, Office of Water Supply, EPA-570/9-76-003, 159 p.

________1977b, National secondary drinking water regulations (proposed): Federal Register, v. 42, no. 62, Mar. 31, Part I, p. 17143-17147.

U.S. Geological Survey, 1974, Stripping coal deposits of the northern Great Plains, Montana, Wyoming, North Dakota, and South Dakota: U.S. Geological Survey Miscellaneous Field Studies Map MF-590, 1 sheet.

________1975, Plan of study of the hydrology of the Madison Limestone and associated rocks in parts of Montana, Nebraska, North Dakota, South Dakota, and Wyoming: U.S. Geological Survey Open-File Report 75-631, 37 p.

________1976a, Hydrologic unit map--1974, State of Montana.

________1976b, Hydrologic unit map--1974, State of Wyoming.

________1981a, Water resources data for Montana--Water year 1980, v. 1, Hudson Bay Basin and Missouri River basin: U.S. Geological Survey Water-Data Report MT-80-1, 651 p.

________1981b, Water resources data for Montana--Water year 1980, v. 2, Upper Columbia River Basin: U.S. Geological Survey Water-Data Report MT-80-2, 184 p.

________1981c, Water-resources investigations of the U.S. Geological Survey in Montana, October 1980 through September 1981: U.S. Geological Survey Open-File Report 81-817, 46 p.

U.S. Geological Survey and Montana Bureau of Mines and Geology for U.S. Committee on Interior and Insular Affairs, 1968, Mineral and water resources of Montana: Washington, D.C., U.S. Government Printing Office, Senate Document 98, 90th Congress, 2d Session, 166 p.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture Handbook 60, 160 p.

U.S. Soil Conservation Service, 1977, Average annual precipitation in Montana based on 1941-1970 base period: Bozeman, Montana, U.S. Department of Agriculture, 13 p.

Van Voast, W. A., 1974, Hydrologic effects of coal strip mining in southeastern Montana--Emphasis: One year of mining near Decker: Montana Bureau of Mines and Geology Bulletin 93, 24 p.

Van Voast, W. A., and Hedges, R. B., 1974 [1980], Hydrology of the area of West-moreland Resources, tract 3 coal reserves near Sarpy Creek, southeastern Montana: Montana Bureau of Mines and Geology Open-File Report 54, 50 p.

________1975, Hydrogeologic aspects of existing and proposed strip coal mines near Decker, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 97, 31 p.

Van Voast, W. A., Hedges, R. B., and McDermott, J. J., 1977, Hydrogeologic conditions and projections related to mining near Colstrip, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 102, 43 p.

________1978, Hydrologic characteristics of coal-mine spoils, southeastern Montana: Bozeman, Montana University Joint Water Resources Research Center Report 94, 34 p.

Wangsness, D. J., 1977, Physical, chemical, and biological relations of four ponds in the Hidden Water Creek strip-mine area, Powder River Basin, Wyoming: U.S. Geological Survey Water-Resources Investigations 77-72, 48 p.

Wendell, W. G., Glass, G. B., Breckenridge, R. M., Root, F. K., Lageson, David, and the Remote Sensing Lab, University of Wyoming, 1976, Johnson County, Wyoming geologic map atlas and summary of land, water and mineral resources: Geological Survey of Wyoming County Resource Series No. 4, 9 sheets.

Whitcomb, H. A., Cummings, T. R., and McCullough, R. A., 1966, Ground-water resources and geology of northern and central Johnson County, Wyoming: U.S. Geological Survey Water-Supply Paper 1806, 99 p.

Wilner, F. N., 1981, Railroad land grants: Paid in full: Washington, D. C., Association of American Railroads, 25 p.

Woods, P. F., 1981a, Documentation of a dissolved-solids model of the Tongue River, south-

eastern Montana: U.S. Geological Survey Open-File Report 81-479, 41 p.
________1981b, Modeled impacts of surface coal mining on dissolved solids in the Tongue River, southeastern Montana: U.S. Geological Survey Water-Resources Investigations 81-64, 73 p.
Yellowstone River Compact Commission, 1951-80, Annual report: Issued annually.

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