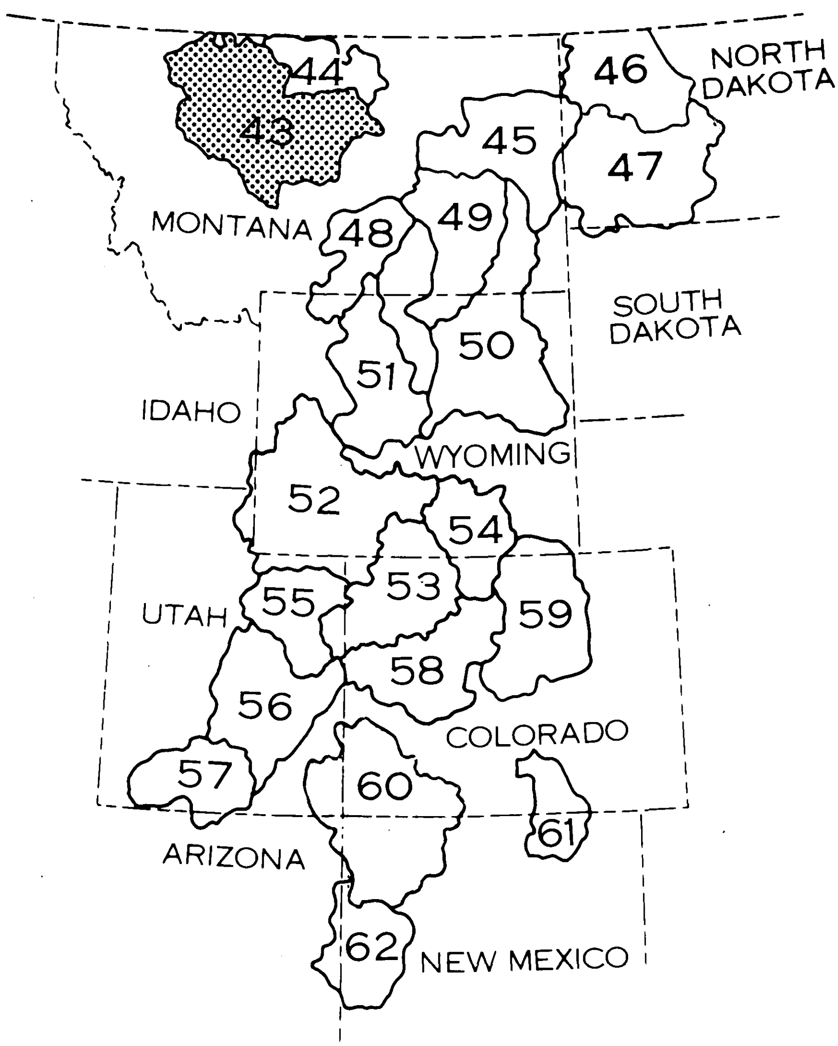
HYDROLOGY OF AREA 43, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA



- MISSOURI RIVER
- SMITH RIVER
- JUDITH RIVER
- MUSSELSHELL RIVER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 85-88

HYDROLOGY OF AREA 43, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA

BY
JOHN H. LAMBING AND OTHERS

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HELENA, MONTANA
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UNITED STATES DEPARTMENT OF THE INTERIOR
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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) OF UNITS

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

Multiply inch-pound units	By	To obtain SI units
acre-foot	0.001233	cubic hectometer
acre-foot per square mile	476.1	cubic meter per square kilometer
British thermal unit per pound	2.326	kilojoule per kilogram
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon per minute	0.06309	liter per second
gallon per second	3.785	liter per second
inch	25.40	millimeter
mile	1.609	kilometer
million gallons	3,785	cubic meter
million gallons per day	0.04381 3,785	cubic meter per second cubic meter per day
pound	453.6	gram
square mile	2.590	square kilometer
ton (short, 2,000 pounds)	0.9072	metric ton (megagram)
ton per day	0.9072	megagram per day
ton per square mile	0.3503	megagram per square kilometer
ton per year	0.9072	megagram per year

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

$$°F = 9/5\ (°C) + 32$$

$$°C = 5/9\ (°F - 32)$$

The units for reporting specific conductance (micromhos per centimeter at 25° Celsius) are equivalent to the SI units of microsiemens per centimeter at 25° Celsius.

HYDROLOGY OF AREA 43, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA

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Abstract

The U.S. Geological Survey has undertaken the preparation of a series of reports that describe the hydrology of coal provinces nationwide. These reports are designed to be useful to individuals or agencies that are involved in the mining, leasing, or management of coal lands. This report describes the general hydrology and related physical characteristics of Area 43 by presenting existing hydrologic information and identifying sources of hydrologic data.

Area 43 encompasses about 12,500 square miles in central Montana, in the northern part of the Northern Great Plains and Rocky Mountain Coal Provinces. The land surface is characterized by diverse topography, which ranges from broad expanses of rolling plains and wide valleys in the eastern and northern parts, to foothills and high mountain ranges in the western and southern parts. The area is drained primarily by the Missouri, Smith, Judith, and Musselshell Rivers and their tributaries.

Streamflow varies seasonally, with the largest flows commonly occurring in the spring or early summer as a result of rainfall and snowmelt. Water quality varies with streamflow and is largely dependent on whether the flow is derived primarily from ground-water sources or precipitation runoff. During low flow, dissolved-solids concentrations range from about 250 to 3,500 milligrams per liter. Calcium, magnesium, bicarbonate, and sulfate are the predominant ions during low flow in streams in the western part of the area. Sodium and sulfate are the predominant ions in streams in the eastern part. During high flow, dissolved solids typically are diluted, and concentrations range from about 150 to 1,300 milligrams per liter. The percentage of calcium and bicarbonate commonly increases during high flow. Generally, the dissolved-solids concentrations and composition vary less in the Missouri River than in other streams.

Suspended-sediment concentrations vary widely with streamflow and the availability of sediment sources within the basins. Concentrations of suspended sediment range from 2 to 19,500 milligrams per liter. Concentrations are at a minimum during low flows when overland runoff is absent. Maximum concentrations of suspended sediment occur during intervals of high flow when both overland runoff and channel erosion contribute sediment to the streams. In general, most of a stream's annual suspended-sediment load is transported during relatively short intervals of high flow.

Geologic formations in the area range in age from Precambrian to Quaternary. Predominant bedrock units include the Madison and Big Snowy Groups of Mississippian age and the Kootenai Formation, Colorado Group, and Montana Group of Cretaceous age. Unconsolidated deposits include terrace gravels, glacial deposits, and alluvium of Quaternary age. The principal coal deposits are located near the top of the Upper Jurassic Morrison Formation.

Most wells in Area 43 produce water from Quaternary deposits, the Eagle Sandstone, and the Kootenai Formation. Locally, Quaternary alluvium and terrace deposits produce water sufficient for most stock and domestic needs. In places, a massive sandstone at or near the base of the Upper Cretaceous Eagle Sandstone may yield as much as 70 gallons per minute. The basal part of the Lower Cretaceous Kootenai Formation, locally known as the Third Cat Creek sandstone, is a reliable aquifer and is used extensively for stock and domestic water supplies. Although not extensively used, Mississippian limestones and dolomites of the Madison Group have the potential for yielding large quantities of water under pressure to land surface, depending on the presence or absence of solution channels.

The quality of water in aquifers underlying Area 43 varies significantly, with median concentrations of dissolved solids ranging from 412 to 2,560 milligrams per liter. Median dissolved-solids concentrations are largest in water from the alluvium and glacial deposits, Judith River Formation, and Eagle Sandstone. The smallest concentrations occur in deep aquifers below the Eagle Sandstone. Water types in the principal aquifers vary from calcium-magnesium sulfate in the alluvium and glacial deposits, Colorado Group, Ellis Group, and deeper aquifers to sodium sulfate in the Judith River Formation, Eagle Sandstone, and Morrison Formation. The Kootenai Formation has water containing primarily sodium, sulfate, and bicarbonate.

Commercial coal mining in Area 43 has essentially ceased; however, the underground methods of production used have created the potential for hydrologic problems. Erosion of mine spoils can cause sediment deposition in streams that will reduce the transport efficiency of the channel and degrade the habitat of aquatic organisms. Land subsidence can occur from the collapse of underground mine tunnels. Ground-water levels can decline in and near mined areas where the excavation intersects water-yielding materials. Deterioration of water quality can result from acid mine drainage at abandoned, unreclaimed mines.

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. The need for information 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 43 in Montana, a part of the Northern Great Plains and Rocky Mountain Coal Provinces (fig. 1.1–1). This report is one of a series prepared by the U.S. Geological Survey that describes the hydrology of coal provinces nationwide.

This report describes the hydrology and related physical characteristics of the area. General hydrologic information is presented for each of a series of water-resources-related topics by means of a brief text with accompanying map, chart, graph, or other illustration. The information, supplemented by material available through sources identified in this report, can be used to describe the general hydrology in the vicinity of a proposed mine. This hydrologic information will be supplemented by the lease applicant's specific site data 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. This report is designed to be useful to individuals or agencies that are involved in the mining, leasing, or management of coal lands.

NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES

Numbers represent project areas

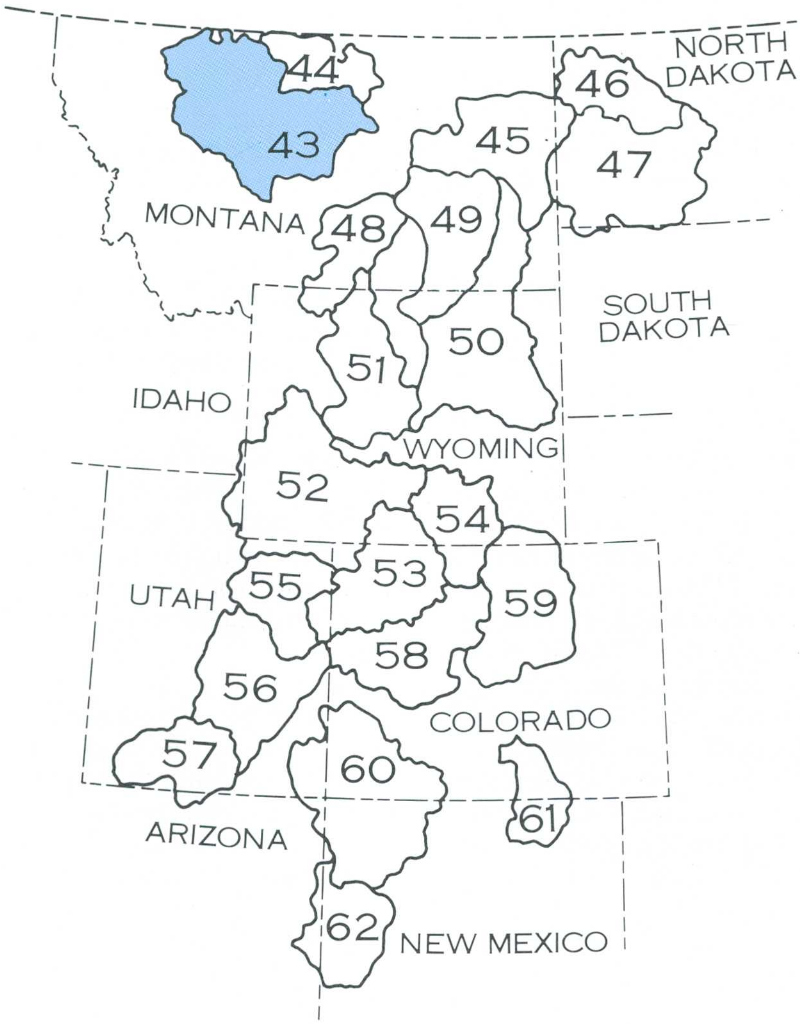


Figure 1.1-1 Location of Area 43.

Area 43 Located in Central Montana

The area, with boundaries revised to include only major coal fields, encompasses about 12,500 square miles in central Montana.

The original boundaries of Area 43, as shown in previous reports in this series (see fig. 1.1–1), extended from the Canadian border southeast to the Big Belt and Big Snowy Mountains in central Montana. However, a large part of the original area was omitted from study because commercial production of the thin, sporadic coal beds in the omitted area is unlikely. In addition, a small area east of the original Area 43 was added to include potentially mineable coal fields. A more thorough and relevant description of coal-related hydrology thus is possible by restricting the hydrologic descriptions to the area containing the major coal fields. The new project area generally is bounded on the north and west by the Missouri River, on the south by the drainage divide between the Musselshell River and the Smith and Judith Rivers, and on the east by the Musselshell River. The revised project area includes all or much of Cascade, Chouteau, Fergus, Judith Basin, Meagher, and Petroleum Counties and small parts of Lewis and Clark and Golden Valley Counties in central Montana (fig. 1.2–1).

The two principal population centers are Great Falls and Lewistown, with 1980 populations of 66,256 and 7,104, respectively (U.S. Bureau of the Census, 1981). The rest of the area primarily is rural, with a population density of less than 10 persons per square mile (U.S. Geological Survey, 1970).

Other than near Great Falls, which is a major industrial and service center in Montana, dominant industries in Area 43 include irrigated agriculture, forest products, livestock grazing, and dry cropland. Oil and gas production and mining of nonfuel minerals occur at several locations.

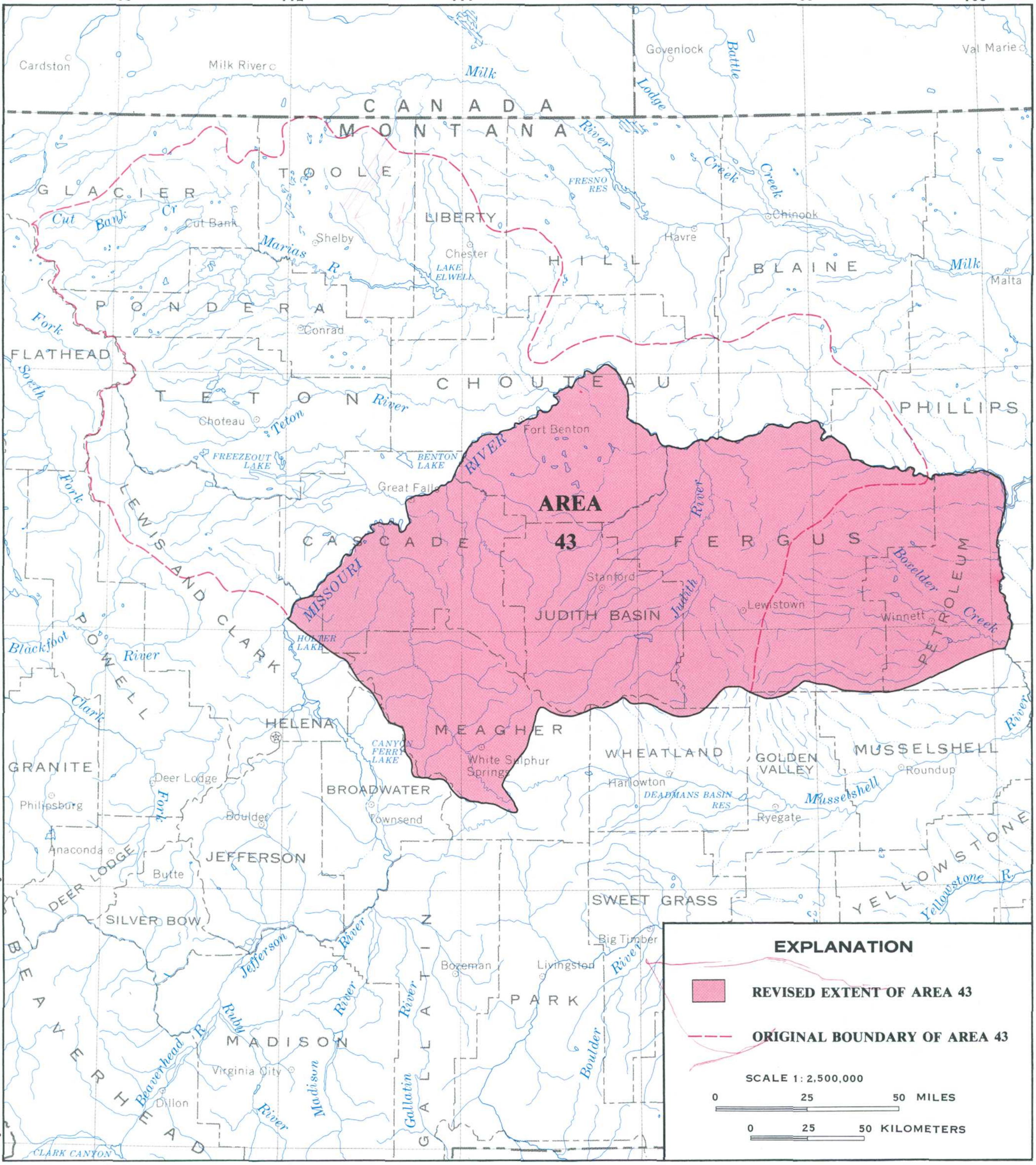


Figure 1.2-1 Geographic features.

2.0 DEFINITION OF TERMS

Terms in Report Discussed

Technical terms that occur in this hydrologic report are defined.

Acid mine drainage is acidic water discharging from a mine.

Active-channel width is the width of the lower part of the channel that is actively involved in transporting water and sediment.

Adit is a nearly horizontal passage from the land surface by which a mine is entered.

Algae are aquatic, single-celled, colonial, or multi-celled plants that contain chlorophyll and lack roots, stems, and leaves.

Alluvium is material such as soil, sand, or gravel that has been deposited by a stream.

Aquifer is a rock unit capable of yielding significant quantities of water to wells.

Arid soil is light-colored soil that generally contains little organic matter and lacks sufficient moisture for crop production without irrigation.

Artesian describes an aquifer overlain by a confining bed. The water level in artesian wells stands at some height above the top of the water body it taps.

Ash is mineral residue remaining after combustion of coal. Ash results from mud, silt, or sand being deposited with the coal.

Bacteria are microscopic unicellular organisms that lack chlorophyll; they are typically spherical, rod-like, or spiral and threadlike in shape and commonly live in colonies. Some bacteria cause disease; others perform an essential role in the recycling of materials—for example, by decomposing organic matter into a form available for reuse by plants.

Bankfull width is the horizontal distance between the tops of the banks of the main channel.

Base flow is sustained low flow. In most streams, base flow is composed largely of groundwater inflow.

Bench is an individual layer in a vertically discontinuous coal seam.

Benthic invertebrate is an animal without a backbone, living on or near the bottom of an aquatic environment. In this report, benthic invertebrates include those organisms that are retained on a 210-micrometer mesh sieve during sampling.

Biomass is the weight of matter incorporated into living organisms.

Bone is hard carbonaceous shale in coal seams.

British thermal unit (BTU) is the amount of heat required to raise the temperature of 1 pound of water from 63°to 64°F. This unit is used to represent the heat content of coal, which generally increases with rank of coal.

Buffering capacity is the ability of a solution to resist changes in pH.

"Chinook" wind is a warm southerly air flow that generally moves along the eastern front of the Continental Divide.

Continuous-record site is a particular location on a stream where a continuous record of stream stage and discharge is collected.

Crest-stage site is a particular location on a stream where only peak discharges are determined by recording the highest stages of streamflows.

Cubic foot per second is the unit commonly used to express stream discharge; 1 cubic foot per second is equivalent to about 7.48 gallons per second, 448.8 gallons per minute, or 0.02832 cubic meters per second.

Detection limit is the smallest concentration detectable by the laboratory technique used in a chemical analysis.

Diatoms are unicellular or colonial algae having siliceous shells.

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.

Dissolved refers to a 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.

Dissolved solids represent the sum of all dissolved constituents in water. Most dissolved solids in natural waters occur as ions, with those in most abundance referred to as major ions. Chemical analyses of dissolved solids consist of either calculated values representing the sum of major ion concentrations (after mathematically converting bicarbonate to carbonate) or actual values determined by residue weight after evaporation of water that has been filtered to remove suspended sediment.

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

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

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.

Exceedance probability is the percentage chance that a flood will exceed a given magnitude during any 1 year.

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

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

Grade represents the quality of coal based on the content of ash and sulfur.

Humic soil is a dark-colored soil that contains a substantial amount of organic matter and that is generally moist during most of the year.

Hydrograph is a plot of stream discharge versus time.

Identification number identifies a specific U.S. Geological Survey data-collection site. An 8-digit "downstream order" number is assigned to surface-water stations where data are collected on a routine basis. A 15-digit number (denoting latitude, longitude, and sequence number) is assigned to miscellaneous sites where data collection is limited.

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

Load is the amount, either by weight or volume, of a substance transported by a stream past a specific point during a specified length of time.

Loam is a class of soil texture intermediate between sandy and clayey.

Median is the middle value in a set of observations in which the values are ranked from smallest to largest. The median generally is a better measure of central tendency than the average when analyzing a small number of samples.

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

Milliequivalent per liter is a unit expressing the relative concentration of a chemical constituent in solution. It is calculated by multiplying concentration, in milligrams per liter, by the ionic charge and dividing by the formula weight of the ion in question. In milliequivalents per liter, unit concentrations of all ions are chemically equivalent.

Milligram per liter is a unit expressing the concentration of chemical constituents as mass (milligram) of constituent per unit volume (liter) of solution. In dilute solutions, 1 milligram per liter is equivalent to 1 part per million.

Miscellaneous site is a particular location on a stream where one-time or limited streamflow or water-quality data are collected as part of a special study or to supplement existing monitoring networks.

Parting is a thin layer of any impure or noncoal material dividing a coal seam into benches.

Perennial stream is a stream that flows continuously.

Periphyton are algae that are attached to or live upon submerged surfaces.

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

Phytoplankton are the plant part of the community of suspended or floating organisms, which drift passively with water currents.

Potentiometric surface, as related to an aquifer, is the level to which water will rise in a tightly cased well (static hydraulic head). The water table is a particular potentiometric surface.

Primary drinking-water standard is the maximum allowable concentration of a particular constituent established by the U.S. Environmental Protection Agency to protect human health.

Primary productivity is the rate, in mass per unit area per unit time, at which organic matter is produced by photosynthesis.

Proximate analysis is the determination of moisture, volatile matter, fixed carbon, and ash in coal.

Rank is a means of expressing successive stages in the formation of coal from lignite through anthracite based on the ratio of moisture, volatile matter, and fixed carbon.

Recurrence interval is the average time interval, in years, between occurrences of a flood of equal or greater magnitude. Recurrence interval is the reciprocal of exceedance probability, times 100.

Regression defines the relationship between two or more variables such that the value of the variable in question can be estimated from known values of the other variable(s).

Saline seep is an area of accumulated salts derived from the discharge of water containing large concentrations of salts leached from soils underlain by impervious materials. Evaporation of water at the point of discharge commonly leaves a crust of salt at the soil surface. Such areas are usually unproductive for crops.

Secondary drinking-water standard is the maximum suggested concentration of a particular constituent established by the U.S. Environmental Protection Agency to avoid undesirable aesthetic effects.

Sediment is solid material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; it also includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and causes of sediment in streams are affected by environmental factors such as topography, soil characteristics, land use, and quantity and intensity of precipitation. The suspended part of transported sediment is commonly measured in water-quality studies.

Sediment yield is the quantity of sediment per unit of drainage area transported from a watershed; it is commonly expressed as either a mass (tons) or volume (acre-feet) per square mile.

Specific conductance is a measure of the ability of water to conduct an electrical current. It commonly 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 to estimate the dissolved-solids concentration of the water.

Spoils are non-coal materials excavated from a mine cut. Spoils are commonly stored in large piles near the entrance to a mine. Unlike old abandoned mines, current mines are governed by reclamation laws requiring replacement of spoils into the mine cut after completion of mining.

Stage is the height of a water surface above an established reference elevation (also termed gage height).

Streamflow is the discharge that occurs in a natural channel. The term "runoff" is more general than "streamflow," because it refers to both channel and non-channel flow.

Substrate is the streambed material comprising the habitat of bottom-dwelling aquatic organisms.

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.

Taxa is a general term that refers to a group of organisms having similar features.

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-quality site is a particular location on a stream where water-quality data are collected either continuously, once-daily, or periodically as part of a routine sampling program.

Water year is the 12-month period from October 1 of one calendar year through September 30 of the next calendar year. The water year is designated by the calendar year in which it ends. Thus, the water year ending September 30, 1984, is the 1984 water year.

Physical Features are Diverse

Area 43 lies within two physiographic provinces: the Great Plains and the Northern Rocky Mountains.

The land surface of Area 43 is characterized by diverse topography, which ranges from broad expanses of rolling plains and wide valleys to extensive areas of uplifted foothills and mountain ranges. Such diversity represents the effects of geologically recent glaciation and a structural transition from the Great Plains to the Rocky Mountain front. The predominant mountain ranges include the Big Belt, Little Belt, Highwood, Big Snowy, and Judith Mountains. Land-surface altitudes range from about 2,300 feet above sea level where the Missouri River exits the study area to almost 9,000 feet at the top of several mountain peaks.

Areas of similar geology, topography, and climate are commonly classified as physiographic provinces. The physiographic divisions in Area 43 are shown in figure 3.1–1. The Great Plains physiographic province consists of relatively flat-lying sedimentary rocks modified by stream erosion or glaciation. In Area 43, the Great Plains province is divided into two subprovinces—the Glaciated Plains and Unglaciated Plains. The Glaciated Plains consist generally of gently rolling topography, whereas the Unglaciated Plains range from gently rolling prairies to sharply dissected topography such as river breaks and badlands. The mountain ranges in the Northern Rocky Mountains physiographic province in Area 43 rise out of the plains as isolated uplifts. Most streams originate in the mountains, with several forming wide intermountain valleys having productive soils derived from alluvial deposits. The topographic diversity in Area 43 is illustrated by figures 3.1–2 to 3.1–4.

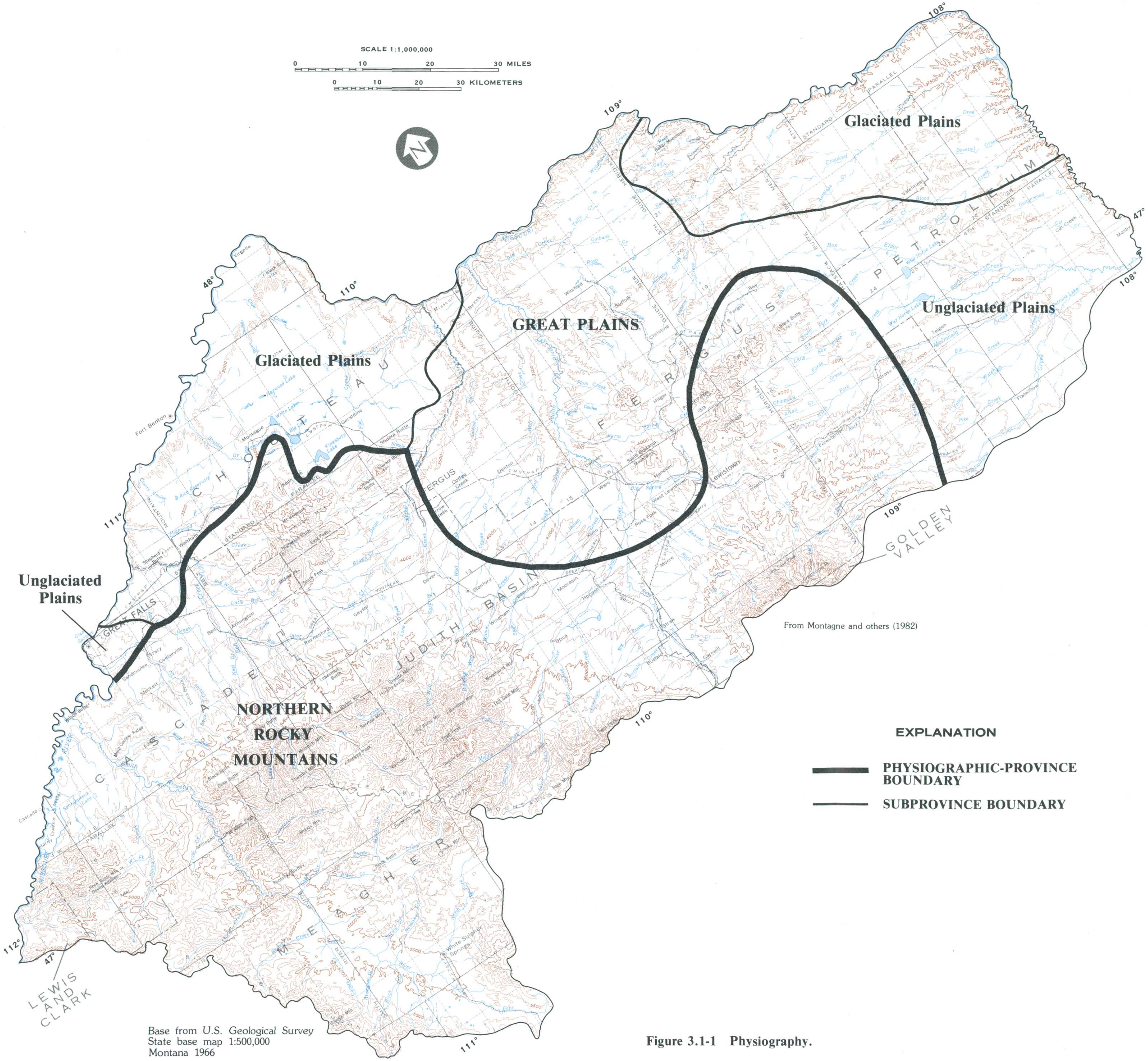


Figure 3.1-1 Physiography.

Figure 3.1-2 Big Belt Mountains and foothills in southwestern part of area.

Figure 3.1-3 Prairies in north-central part of area.

Figure 3.1-4 Badlands in eastern part of area.

Climate Varies from Semiarid to Temperate

Most precipitation occurs as rain during late spring and early summer in the lowlands; winter snowfalls generally account for most of the precipitation in the mountains.

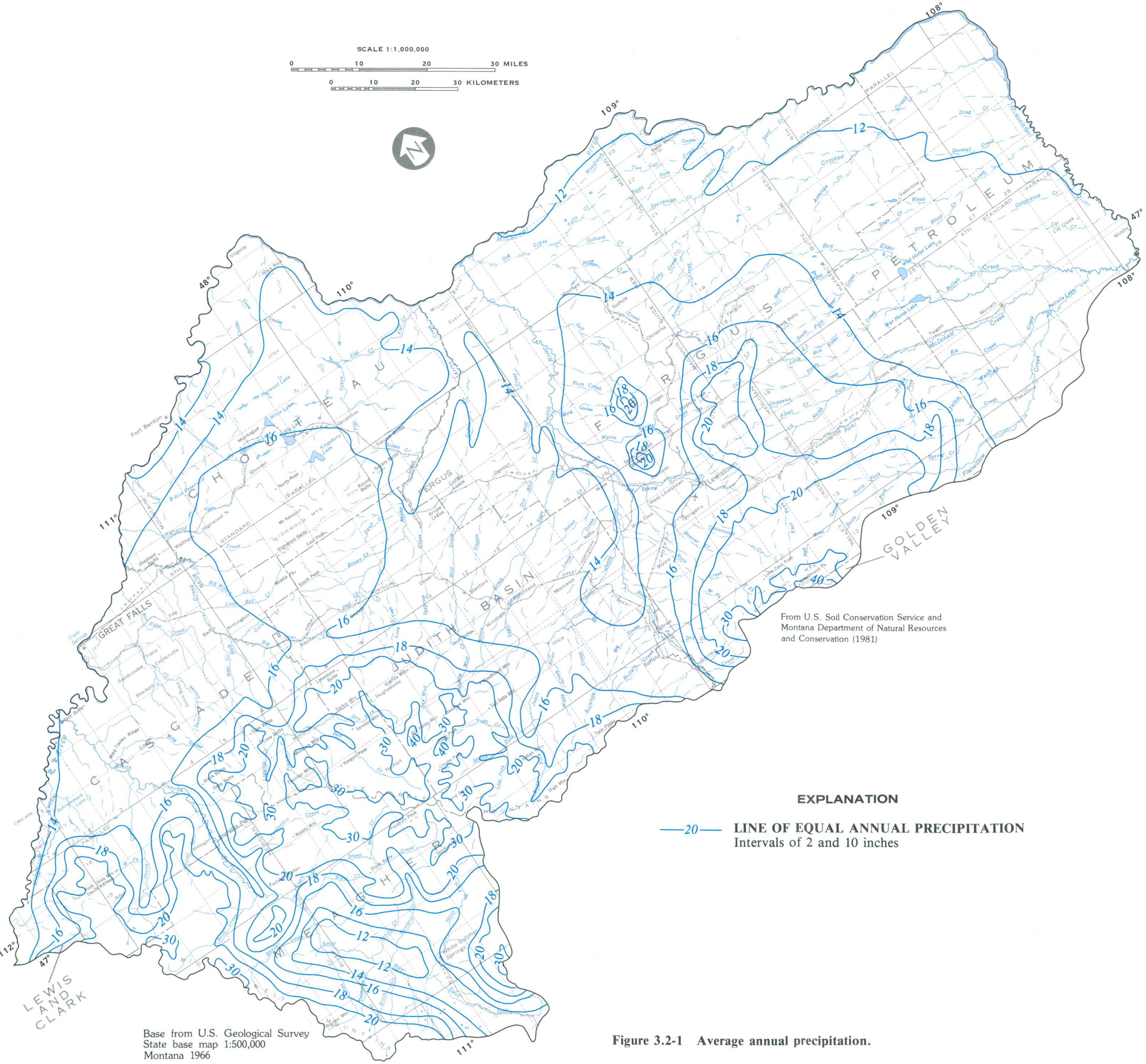
The climate of Area 43 is affected to a large degree by elevation and topographic position. The climate is characterized primarily by cold, dry winters in the valleys and prairies and cold, wet winters in the mountains; cool, moist springs, warm moderately dry summers, and cool, dry falls prevail throughout the area. Average annual temperatures, based on the record for 1941–70, range from 41.9°F at Lewistown, Montana, to 45.7°F at Cascade.

Summers are dominated by warm, sunny days and cool nights. July normally is the warmest month, with average temperatures ranging from 65.5°F at Lewistown to 69.7°F at Fort Benton. Temperatures in excess of 100°F occur infrequently at the lower elevations. Although winters can be very cold, especially at the higher elevations, prolonged cold spells are not common. "Chinook" winds generally occur several times during the winter and moderate the temperature. January is normally the coldest month, with average temperatures ranging from 17.1°F at Roy, Montana, to 23.1°F at Cascade.

Average annual precipitation varies from about 12 inches in the eastern lowlands of Area 43 and in isolated "rainshadow" areas on the leeward side of mountain slopes to about 40 inches on several high mountain peaks (fig. 3.2–1). Annual precipitation generally is more variable, more intense, and less abundant in the prairies and valleys than in the mountains.

Generally, more than 70 percent of the annual precipitation in the prairies and valleys occurs between April and September, with May and June being the wettest months (fig. 3.2–2). Winters in these areas are usually dry, with monthly precipitation commonly less than 1.0 inch for November through February. Most of the precipitation in the mountains occurs as snow from December through April, although rainfall can be substantial in May and June. The distribution of precipitation, by months, for Great Falls (prairie station) and Lewistown (foothills station) is shown in figure 3.2–2.

Daily temperature and precipitation data are published monthly as "Climatological Data for Montana" by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina. Statistical information is presented in U.S. Department of Commerce, National Weather Service, NOAA Atlas No. 2, titled, "Precipitation-frequency atlas of the Western United States" (Miller and others, 1973).



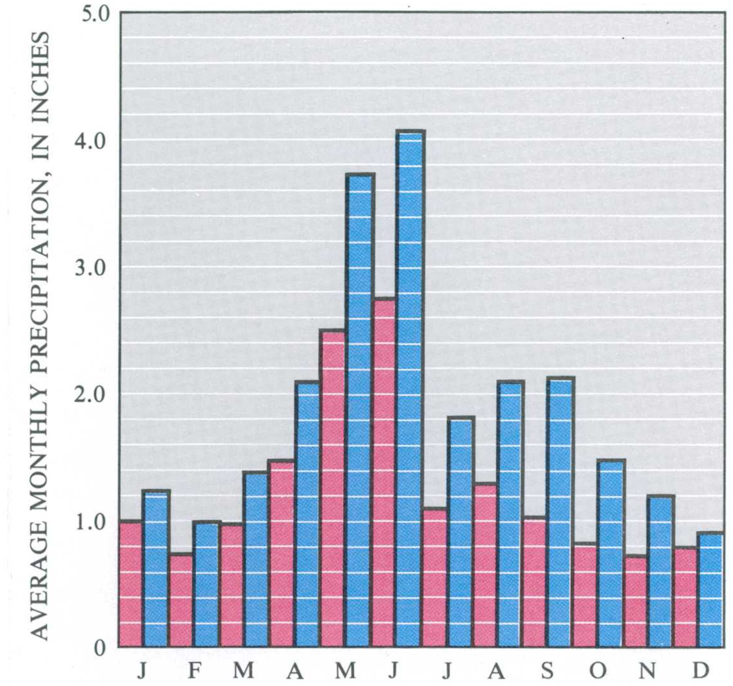
From U.S. Soil Conservation Service and Montana Department of Natural Resources and Conservation (1981)

Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

EXPLANATION

—20— **LINE OF EQUAL ANNUAL PRECIPITATION**
Intervals of 2 and 10 inches

Figure 3.2-1 Average annual precipitation.



Weather station	Altitude (feet)	Average annual precipitation (inches)
GREAT FALLS WSO	3662	15.24
LEWISTOWN 10 S	4900	23.47

Based on records of the National Weather Service (1951-80)

Figure 3.2-2 Average monthly precipitation at Great Falls and Lewistown, Montana.

Geologic Units Range in Age from Precambrian to Quaternary

Exposed bedrock units are principally sedimentary, but also include some intrusive and volcanic rocks.

Precambrian crystalline rocks and Cambrian sedimentary rocks are exposed in the Little Belt and Big Belt Mountains. Younger sedimentary rocks of Devonian through Jurassic age crop out along the northern flanks of the Little Belt and Big Snowy Mountains in the south-central part of the area. The exposed bedrock in most of Area 43 consists of Cretaceous sedimentary rocks. Cretaceous and Tertiary rocks of volcanic origin occur in some of the mountains and foothills. Quaternary formations consist of alluvium in the stream valleys, glacial deposits in the northern prairies, and terrace gravels in the benches in the central part of the area. A geologic map is presented as figure 3.3–1.

The sedimentary formations extensively exposed in the area are the Madison and Big Snowy Groups of Mississippian age and the Kootenai Formation, Colorado Group, and Montana Group of Cretaceous age. A generalized stratigraphic section is presented in table 3.3–1.

The Madison and Big Snowy Groups crop out along the northern flanks of the Little Belt and Big Snowy Mountains in the central part of the study area. The rocks dip steeply at the mountain front but generally flatten toward the north. The Madison Group is composed of massive gray dense limestone and dolomite. The Big Snowy Group overlies the eroded upper surface of the Madison and consists of shale, limestone, and sandstone.

The Kootenai Formation crops out primarily along the northern foothills of the Big Snowy and Little Belt Mountains and extends to Great Falls in the western part of the area. The Kootenai Formation consists of a basal sandstone unit (Third Cat Creek sandstone) overlain by a heterogeneous mixture of red, green, and gray shale and siltstone containing numerous limestone and sandstone lenses. The red siltstones are the source of the red soils in the area. Except for the basal sandstone, beds in the Kootenai Formation are commonly discontinuous.

The rolling hills and prairies in the northern and eastern parts of Area 43 are mostly underlain by rocks of the Colorado and Montana Groups. The Colorado Group consists primarily of fissile gray or black marine shale, which is easily weathered and only poorly exposed. At the base of the Colorado Group is a fine-grained sandstone unit of variable thickness, locally known as the First Cat Creek sandstone. The Montana Group, which in Area 43 includes the Telegraph Creek Formation, Eagle Sandstone, Claggett Shale, Judith River Formation, and Bearpaw Shale, crops out just south of the Missouri River. These poorly exposed formations primarily consist of sandstone and shale.

Igneous rocks of Cretaceous and Tertiary age occur primarily in the Highwood Mountains in the northwestern part of the area and along the edge of the Big Belt Mountains near the western boundary. Volcanic rocks, including flows and pyroclastic deposits, are largely composed of latite and andesite. Intrusive rocks, which occur as stocks, dikes, and sills, contain mostly syenite and leucite.

Tertiary sedimentary rocks occur in the Smith River valley between the Big Belt and Little Belt Mountains in the southwestern part of the area. These rocks have not been mapped in great detail and generally are of unknown thickness.

Unconsolidated Quaternary alluvium, glacial drift and lake deposits, and terrace deposits composed of interbedded gravel, sand, silt, and clay are the youngest geologic units in the area. Alluvium is thickest along major streams, including parts of the Missouri River, but also is present along many smaller streams. Glacial deposits overlie most of the bedrock units in the northern part of the area, with the exception of the north-central area near the downstream part of the Judith River. Terrace deposits occur mainly along the valley sides and uplands of the Arrow Creek and Judith River drainages.

The upper part of the Morrison Formation of Jurassic age is the principal coal-bearing unit in Area 43. Most of the coal occurs in a single stratigraphic horizon that ranges in thickness from a few inches to 12 feet (Silverman and Harris, 1967). The coal may occur in one or several benches separated by shale, sandstone, or siltstone partings; the average aggregate thickness is about 5 feet.

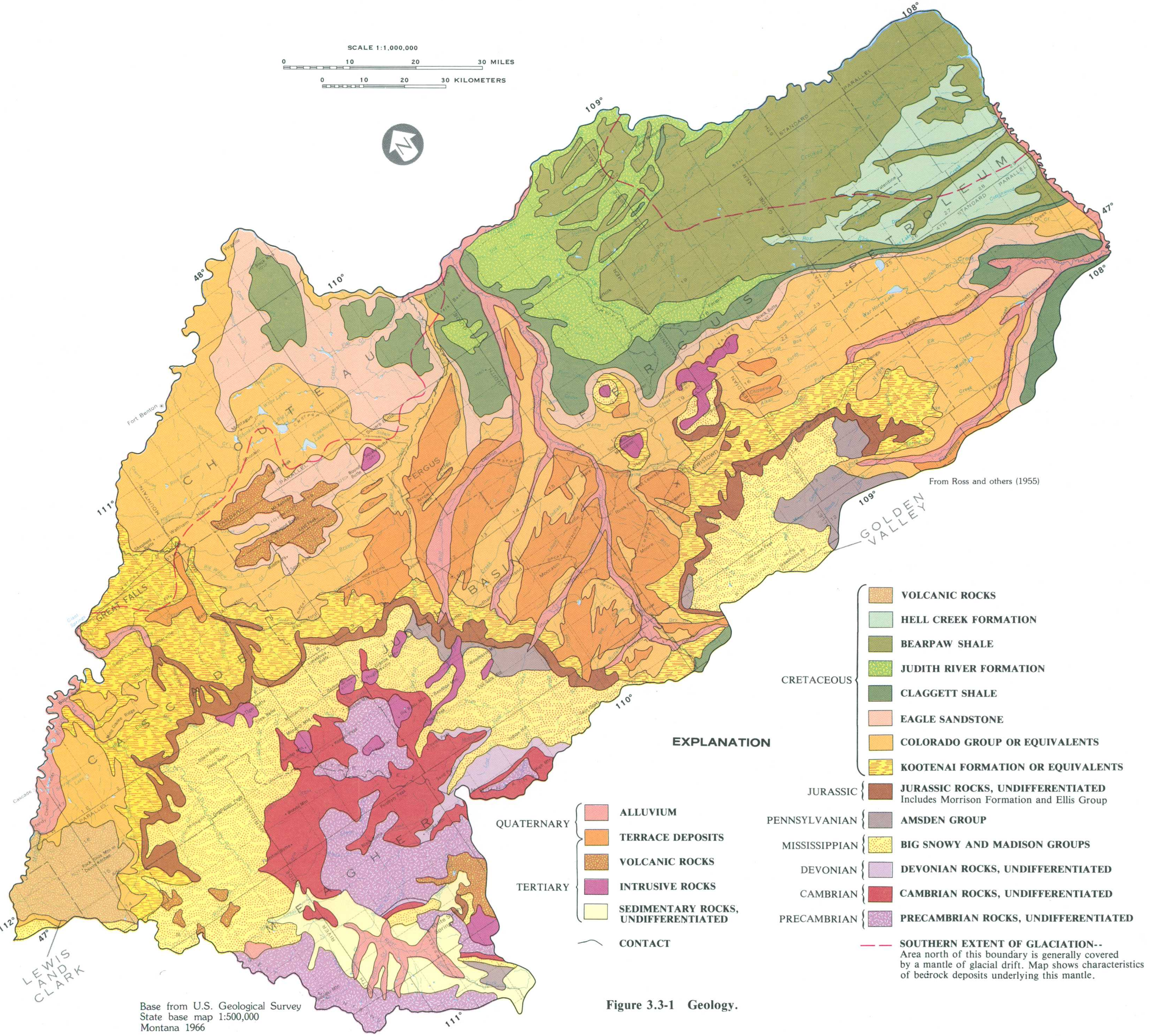


Figure 3.3-1 Geology.

Table 3.3-1 Generalized stratigraphic section.[1]

Erathem	System	Group	Stratigraphic unit	Approximate maximum thickness (feet)	Lithologic characteristics
Cenozoic	Quaternary		Alluvium	70	Unconsolidated gravel, sand, silt, and clay.
Cenozoic	Quaternary		Glacial drift and lake deposits	100	Unconsolidated boulders, cobbles, pebbles, and sand.
Cenozoic	Tertiary		Terrace deposits	100	Unconsolidated sand and gravel.
Cenozoic	Tertiary		Volcanic rocks	--	Mostly quartz latite and andesite, with some rhyolite and basalt.
Cenozoic	Tertiary		Intrusive rocks	--	Alkalic syenite, monzonite, quartz diorite, and leucite.
Cenozoic	Tertiary		Sedimentary rocks	--	Poorly consolidated gravel, sand, silt, and clay.
Mesozoic	Cretaceous		Volcanic rocks	--	Flows and pyroclastic rocks of variable composition, with local occurrences of interbedded sedimentary rocks.
Mesozoic	Cretaceous		Hell Creek Formation	200	Interbedded shale, siltstone, and sandstone.
Mesozoic	Cretaceous	Montana Group	Bearpaw Shale	1,100	Shale beds, silty sandstone, and siltstone.
Mesozoic	Cretaceous	Montana Group	Judith River Formation	600	Gray to brown sandstone, sandy shale, clay, and some coal.
Mesozoic	Cretaceous	Montana Group	Claggett Shale	400	Gray and brown shale; contains isolated sandstone lenses.
Mesozoic	Cretaceous	Montana Group	Eagle Sandstone	500	Massive tan and white sandstone; contains some sandy shale, evaporite beds, and minor amounts of coal.
Mesozoic	Cretaceous	Montana Group	Telegraph Creek Formation	300	Sandy shale; transitional between the Colorado Group and Eagle Sandstone. Mapped with the Colorado Group in figure 3.3-1.
Mesozoic	Cretaceous	Colorado Group or equivalents	Niobrara Formation / Marias River Shale	900	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Carlile Shale / Marias River Shale	900	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Greenhorn Formation / Marias River Shale	900	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Belle Fourche Shale / Blackleaf Formation	900	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Mowry Shale / Blackleaf Formation	800	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Newcastle or Muddy Sandstone / Blackleaf Formation	800	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	Skull Creek Shale / Blackleaf Formation	800	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Colorado Group or equivalents	First Cat Creek sandstone / Fall River Sandstone / Blackleaf Formation	100	Fissile light-gray to black shale; some local thin beds of bentonite and sandstone.
Mesozoic	Cretaceous	Kootenai Fm	Second Cat Creek Sandstone	600	Shale and siltstone containing limestone and sandstone lenses. The thick, fine- to coarse-grained Third Cat Creek sandstone at the base of the formation is locally referred to as the basal Kootenai sandstone.
Mesozoic	Cretaceous	Kootenai Fm	Third Cat Creek sandstone / Lakota Formation	600	Shale and siltstone containing limestone and sandstone lenses. The thick, fine- to coarse-grained Third Cat Creek sandstone at the base of the formation is locally referred to as the basal Kootenai sandstone.
Mesozoic	Jurassic		Morrison Formation	300	Siltstone, shale, sandstone, and limestone; contains a bed of coal and carbonaceous shale near the top.
Mesozoic	Jurassic	Ellis Group	Swift Formation	300	Sandstone, shale, and siltstone; some thin limestone beds occur locally.
Mesozoic	Jurassic	Ellis Group	Rierdon Formation	200	Sandstone, shale, and siltstone; some thin limestone beds occur locally.
Mesozoic	Jurassic	Ellis Group	Piper Formation	200	Sandstone, shale, and siltstone; some thin limestone beds occur locally.
Paleozoic	Pennsylvanian	Amsden Group	Alaska Bench Limestone	300	Upper unit of gray limestone. Lower unit of red shale, siltstone, and sandstone.
Paleozoic	Pennsylvanian	Amsden Group	Tyler Formation	600	Upper unit of gray limestone. Lower unit of red shale, siltstone, and sandstone.
Paleozoic	Mississippian	Big Snowy Group	Heath Formation	500	Carbonaceous shale, white to black limestone, sandstone, and gypsum.
Paleozoic	Mississippian	Big Snowy Group	Otter Formation	500	Carbonaceous shale, white to black limestone, sandstone, and gypsum.
Paleozoic	Mississippian	Big Snowy Group	Kibbey Sandstone	400	Carbonaceous shale, white to black limestone, sandstone, and gypsum.
Paleozoic	Mississippian	Madison Group	Charles Formation	700	Massive gray dense limestone with some dolomite and evaporite beds; greatly fractured and contains numerous solution openings.
Paleozoic	Mississippian	Madison Group	Mission Canyon Limestone	600	Massive gray dense limestone with some dolomite and evaporite beds; greatly fractured and contains numerous solution openings.
Paleozoic	Mississippian	Madison Group	Lodgepole Limestone	700	Massive gray dense limestone with some dolomite and evaporite beds; greatly fractured and contains numerous solution openings.
Paleozoic	Devonian		Undifferentiated	1,200	Limestone, dolomite, and shale.
Paleozoic	Cambrian		Undifferentiated	1,200	Limestone, dolomite, and shale.
Precambrian			Undifferentiated	--	Crystalline rocks.

[1]Modified from Feltis (1973, 1977), Zimmerman (1966), and Balster (1980).

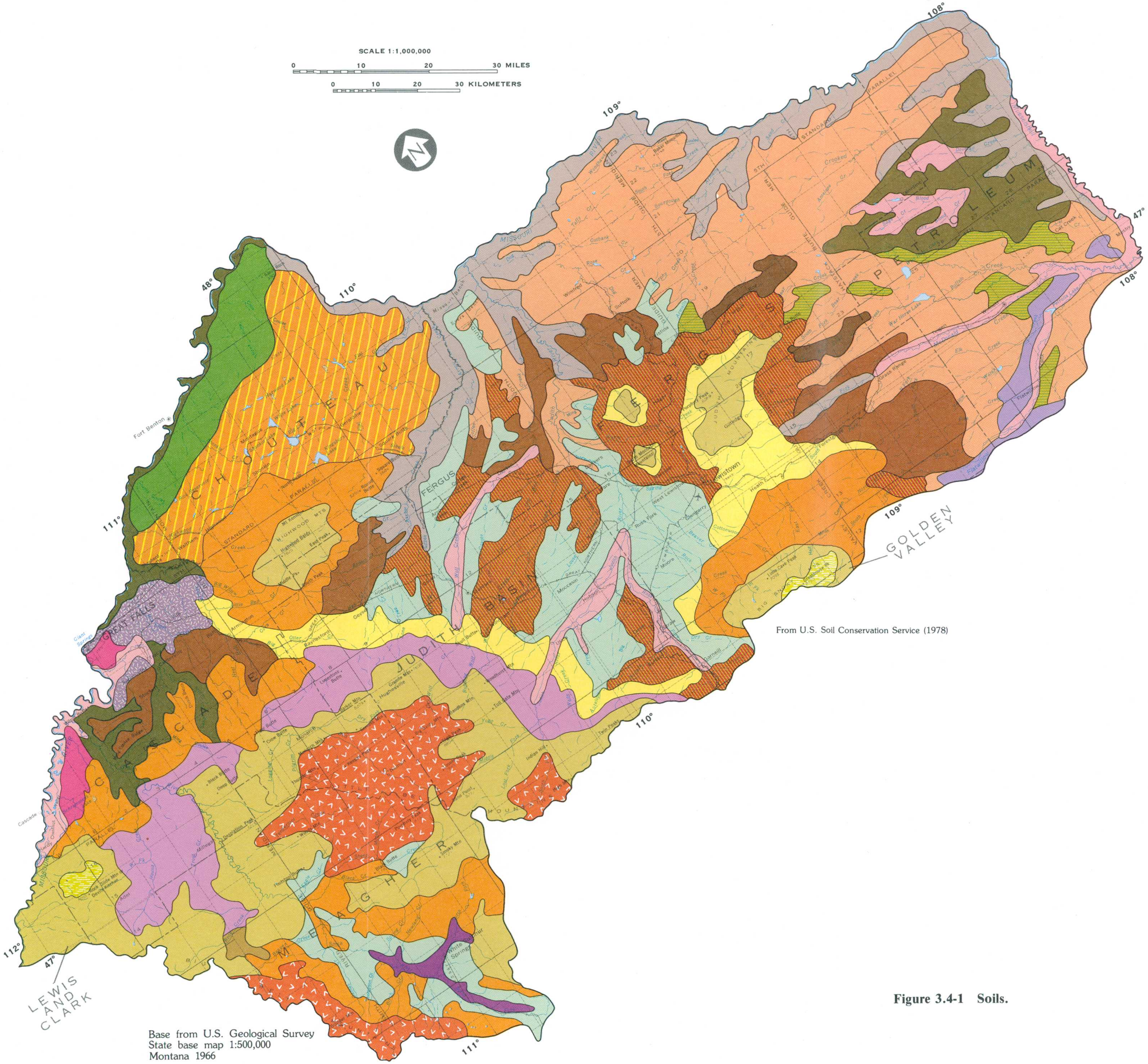
Soils Range from Deep Humic to Shallow Clayey

Soils reflect the diversity of geologic parent materials, topography, and climate.

Soils develop from the unconsolidated surface layer of geologic parent material that overlies bedrock. Predominant factors that affect soil formation include the type of parent material and the effects of topography and climate on processes of erosion, deposition, and biological activities. Because of the large diversity of parent materials in the area, soil types vary widely. Some of the predominant parent materials include alluvium, glacial till, shale, and sandstone.

The distribution of general soil types and associated landforms is shown in figure 3.4–1. Soil textures and depth are extremely variable, ranging from deep, humic soils in moist mountain areas to shallow, clayey soils in the more arid prairies in the eastern parts of the area. Undifferentiated alluvial soils occur primarily on flood plains in the downstream reaches of the stream valleys. These generally deep soils range from clayey loams to gravelly loams and are extensively irrigated. Soils formed from glacial till occur in the northern part of Area 43 near the Missouri River. These soils, as well as those of upland benches and sedimentary plains, are moderately deep to shallow and have a clayey to loamy texture. Soils of the plains and benches generally store sufficient soil moisture for dryland crop production of grains such as wheat and barley. In localized areas, drainage problems have created "saline seeps" where the accumulation of salts has resulted in conditions unsuitable for crop production. Arid soils occur in the eastern part of the study area; because of the limited soil moisture, clayey texture, and rough topography, vegetation is sparse and more suitable for livestock grazing than crops.

Average annual sediment yields vary widely, ranging from about 0.1 acre-foot per square mile in the forested mountain areas to about 3.0 acre-feet per square mile in deeply dissected drainage basins and badlands in the extreme eastern part of the area (Ed Juvan, U.S. Soil Conservation Service, written commun., 1983). Soil erosion is affected not only by soil type, but also by vegetative cover, topography, precipitation intensity, and land use.



From U.S. Soil Conservation Service (1978)

Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

Figure 3.4-1 Soils.

EXPLANATION

PREDOMINANT SOIL ORDER	LANDFORM	PARENT MATERIAL	SOIL DEPTH (inches)
Entisols--Aridisols--Inceptisols--Mollisols	Nearly level to strongly sloping soils on low terraces, fans, flood plains	Alluvium	40-60
Entisols--Inceptisols--Mollisols	Nearly level to strongly sloping soils on low terraces, fans, flood plains	Alluvium	20-60
Mollisols	Nearly level to steep soils on fans, benches, terraces	Alluvium, sandstone, quartzite, argillite	10-60
Mollisols	Moderately sloping to steep soils on foothills	Shale, sandstone	10-40
Mollisols--Entisols	Moderately sloping to steep soils on foothills	Alluvium, shale	20-40
Mollisols	Nearly level to steep soils on fans, benches, terraces	Alluvium, sandstone	20-40
Mollisols-Inceptisols	Moderately sloping to steep soils on foothills	Sandstone, granite, alluvium	20-40
Aridisols--Mollisols	Nearly level to moderately steep soils on fans, benches, terraces	Calcareous loamy alluvium	20-60
Inceptisols--Alfisols	Moderately sloping to very steep soils on mountains	Colluvium, igneous rock, sedimentary rock	10-60
Mollisols--Inceptisols--Alfisols	Gently sloping to very steep soils on mountains	Alluvium, colluvium, sedimentary rock, igneous rock	10-60
Mollisols	Nearly level to steep soils on fans, benches, terraces	Alluvium	20-60
Entisols--Inceptisols--Mollisols	Strongly sloping to steep soils on sedimentary bedrock plains and hills	Alluvium, shale, clayey sediment	20-60
Mollisols--Entisols	Nearly level to strongly sloping soils on sedimentary bedrock plains	Sandstone, shale, siltstone, alluvium	10-60
Mollisols--Entisols	Undulating to strongly sloping hills on glacial till plains	Glacial till,alluvium	40-60
Entisols--Mollisols	Strongly sloping to steep soils on dissected sedimentary bedrock plains and hills	Sedimentary rockbed, alluvium, lacustrine sediments	10-60
Mollisols--Aridisols	Nearly level to strongly sloping soils on sedimentary bedrock plains	Sandstone, shale, alluvium	10-60
No representative soil orders	Mountain peaks and gently sloping to very steep alpine grasslands	Rock outcrop, talus	10-60
Mollisols--Aridisols	Nearly level to moderately steep soils on glacial till plains	Glacial till	40-60
Aridisols--Mollisols	Nearly level to steep soils on fans, benches, terraces	Alluvium	40-60
Aridisols--Mollisols--Entisols	Nearly level to strongly sloping soils on fans, benches, terraces	Glacial till,lacustrine sediments, alluvium	40-60
Entisols--Aridisols	Strongly sloping to steep soils on dissected shale plains	Shale, alluvium	10-60
Badland--Entisols	Steep and very steep soils on deeply dissected river breaks	Claystone, shale, alluvium	10-40

Description from Montagne and others, 1982

Entire Area in the Missouri River Basin

Major streams include the Missouri, Smith, Judith, and Musselshell Rivers.

Area 43 lies entirely within the Missouri River basin. The main stem of the Missouri River flows northeastward along the western boundary (fig. 3.5–1) and then eastward along the northern boundary.

The Smith River flows in a northwesterly direction through the western part of the area. The headwaters of the Smith River flow from the Big Belt and Little Belt Mountains. Flow is perennial for most of the length of the Smith River. Most tributaries to the Smith River are small, but many are perennial streams that originate in the mountains.

The Judith River flows generally northward through the central part of the area and is the longest tributary of the Missouri River in Area 43. The Judith River originates in the Little Belt Mountains and is perennial for most of its length. Major tributaries to the Judith River are Ross Fork Creek, Big Spring Creek, Warm Spring Creek, and Wolf Creek.

The Musselshell River flows northward, forming the eastern boundary of the area. The major tributaries to the Musselshell River are Flatwillow Creek, Blood Creek, and Crooked Creek. Flow is intermittent in Flatwillow Creek and ephemeral in Crooked Creek and Blood Creek.

Other major Missouri River tributaries are Belt Creek, Highwood Creek, Shonkin Creek, Arrow Creek, Dog Creek, and Armells Creek. Of these tributary streams Belt and Highwood Creeks have perennial flow.

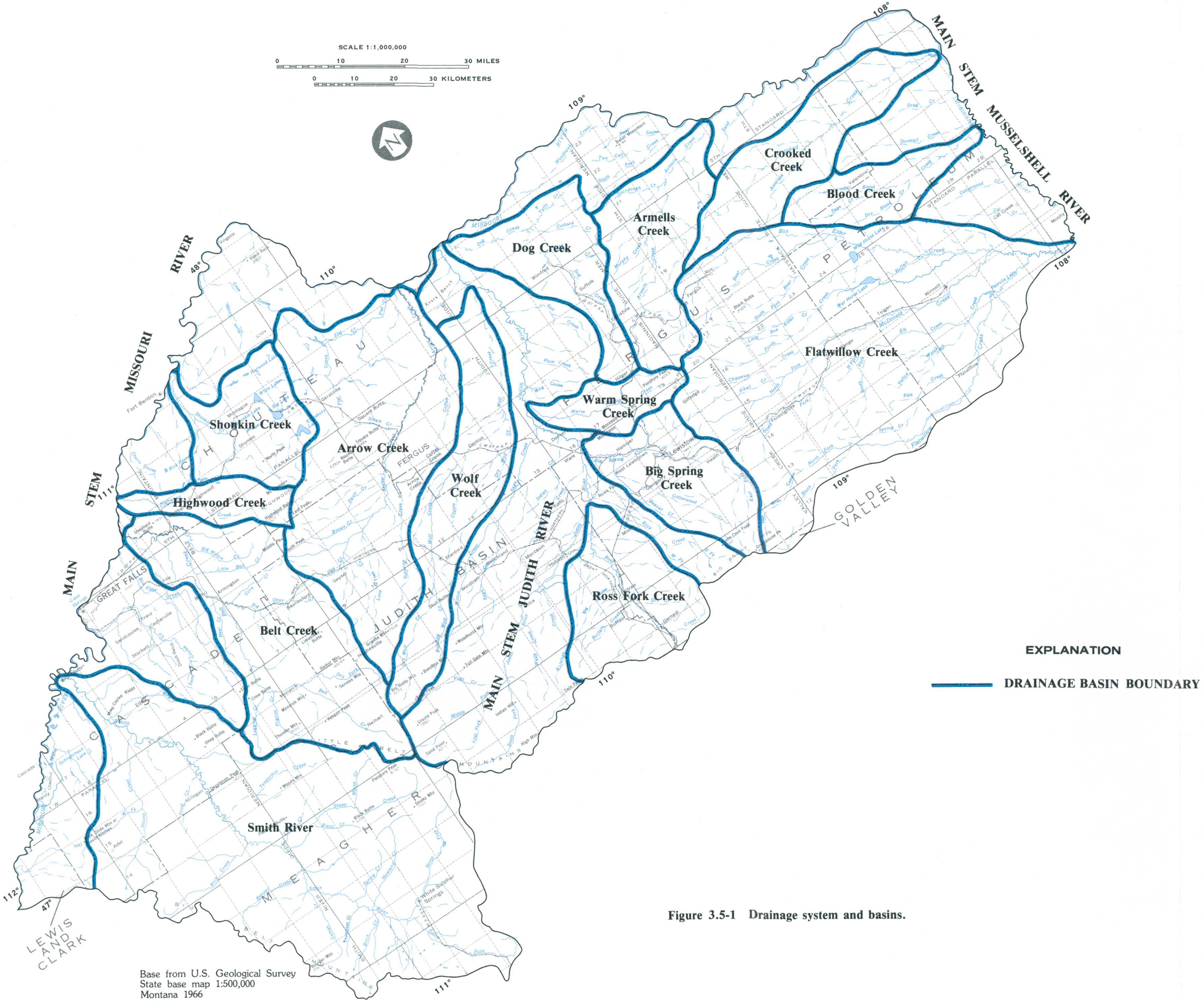


Figure 3.5-1 Drainage system and basins.

Land Used Primarily for Agriculture

Principal land uses include range, forest, and irrigated and dry cropland.

Land use is related primarily to the diversity of the area's natural resources. The land-use map (fig. 4.1–1) illustrates the geographic distribution of five land-use categories in Area 43. The percentage of land area used for each category is shown in figure 4.1–2.

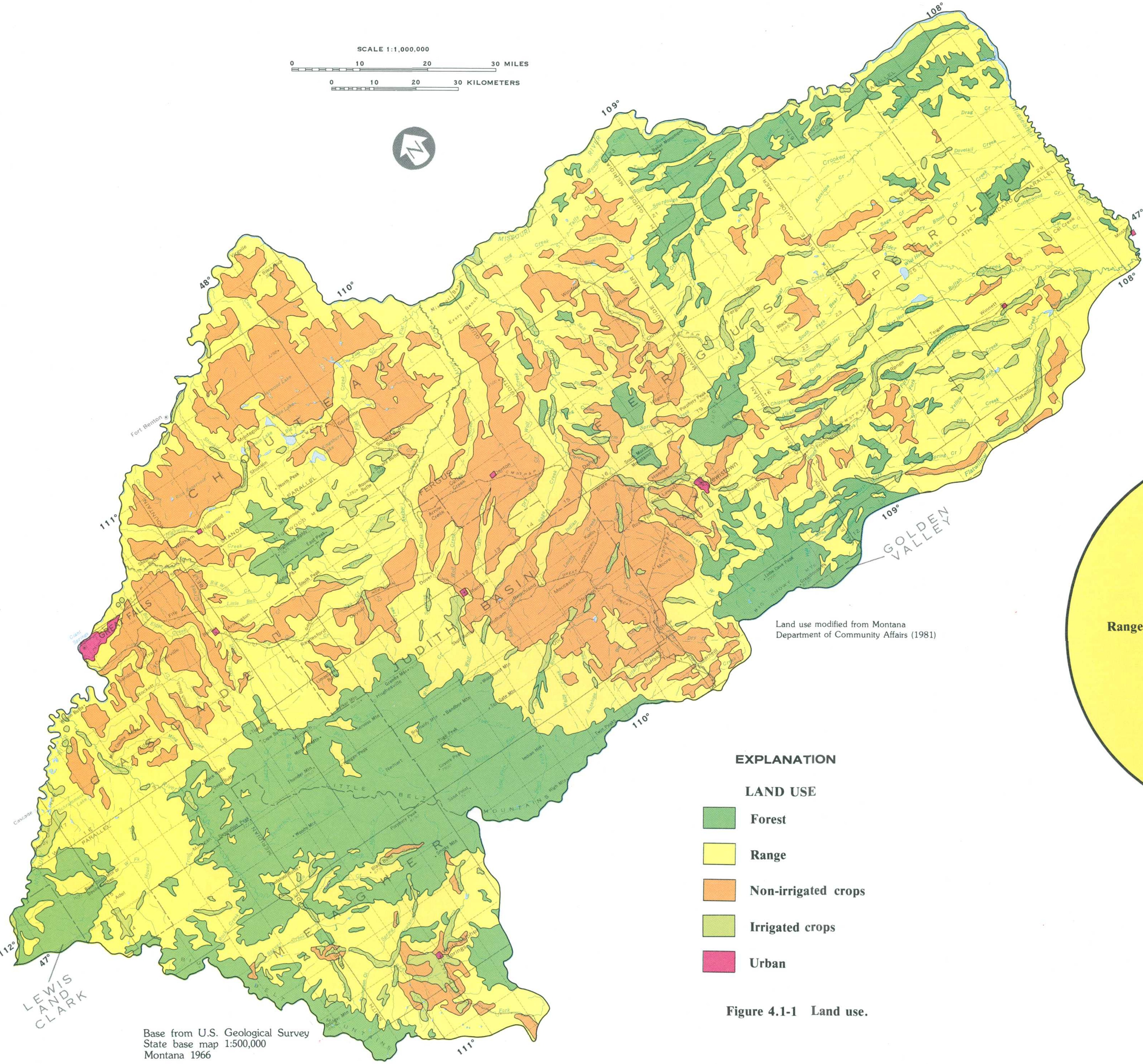
Rangeland comprises the largest single land use, accounting for about 57 percent of the land in the area. Rangeland is used for livestock production, primarily beef cattle. Forested lands, including both commercial and non-commercial woodlands, encompass about 20 percent of the area. Forests are generally limited to the mountains and adjacent foothills. About 23 percent of the area is utilized for crop production. Of the total cropland, about 14 percent is irrigated, with most irrigated lands occurring along the Missouri, Smith, and Judith Rivers and Flatwillow Creek. Irrigated crops consist primarily of wheat, alfalfa, hay, barley, and oats. About 86 percent of the cropland is non-irrigated, with wheat and barley accounting for the majority of dryland crops (Missouri River Basin Commission, 1981). Except for Great Falls, urban areas are small and constitute less than 1 percent of the land area.

Most coal deposits in Area 43 (section 5.1) are economically recoverable only by underground mining. Coal has not been commercially produced since about 1965. Areas associated with former underground coal mines (section 5.2) occupy a very small percentage of the land surface.

Because the Federal Government owns the rights to much of the Nation's coal, Federal land-use planning has an important role in determining which areas will be mined for coal and how the mines will be reclaimed. The principal objective in Federal land-use planning is to determine where coal can be mined without unduly damaging the environment. The major source of information for this determination is coal and economic data made available to the U.S. Bureau of Land Management by coal companies, Federal and State agencies, or the public. Coal areas found acceptable for lease consideration are delineated into tracts 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.



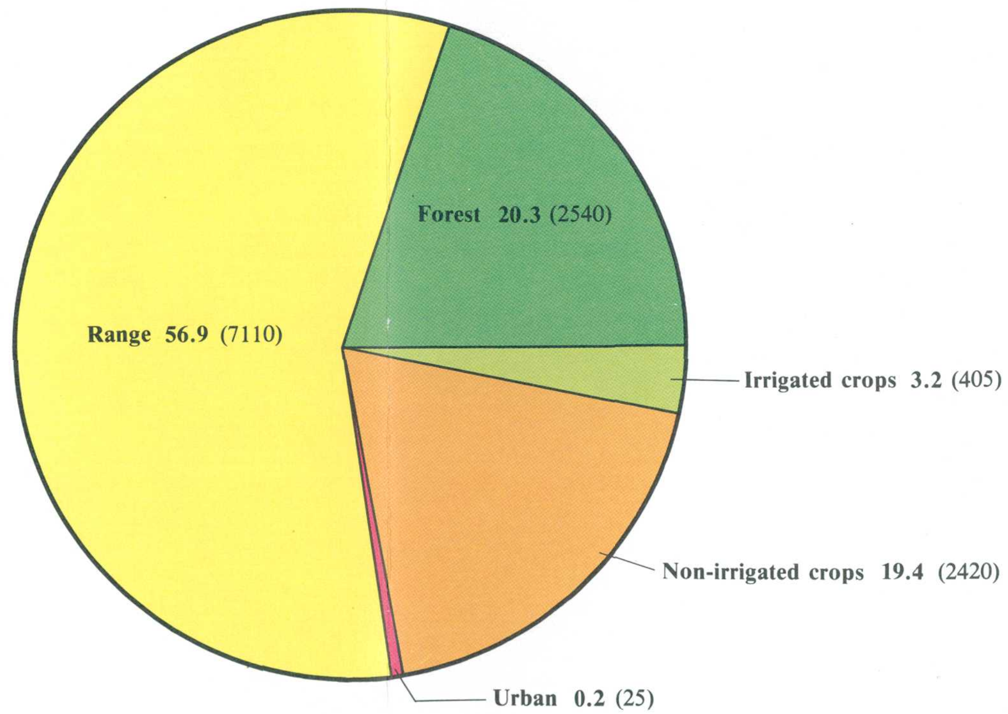
EXPLANATION

LAND USE

- Forest
- Range
- Non-irrigated crops
- Irrigated crops
- Urban

Figure 4.1-1 Land use.

LAND USE, IN PERCENT
(Square miles in parentheses)



Total land area: 12,500 square miles

Figure 4.1-2 Summary of land use.

Principal Water Use is Irrigated Agriculture

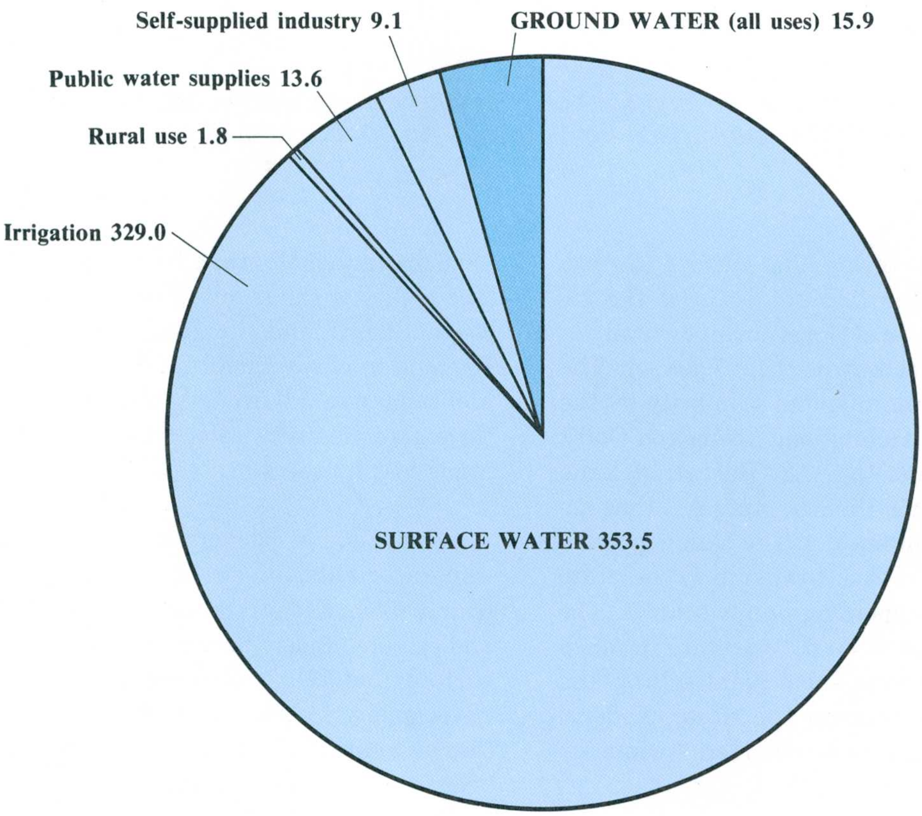
Average daily water use during 1980 was about 354 million gallons of surface water and about 16 million gallons of ground water; about 90 percent of the water was used for irrigated agriculture.

Irrigated agriculture was by far the largest use of water during 1980 (fig. 4.2–1), with about 329.0 Mgal/d (million gallons per day) being used from surface-water sources and 3.3 Mgal/d from ground-water sources. About 29 percent of the irrigation occurs along the Smith River, whereas the Judith River and Flatwillow Creek each account for 18 percent of the irrigation water use. The remaining irrigation water use occurs along the Musselshell and Missouri Rivers.

Water withdrawn for public supplies was the second largest water use during 1980. Great Falls, Montana, the largest community in the area, accounted for 14.5 Mgal/d combined surface water and ground water withdrawal. Water used for public supplies in 1980 totaled 18.4 Mgal/d, with about 26 percent (4.8 Mgal/d) of the total amount being from ground-water sources.

Self-supplied industrial water use was about 11.0 Mgal/d, of which about 1.9 Mgal/d was ground water. Most of the water for industry was used in Great Falls. Rural water use was about 7.7 Mgal/d, with about 5.9 Mgal/d of the total from ground-water sources.

WATER USE, IN MILLION GALLONS PER DAY



Total water use: 369.4 MGPD

Figure 4.2-1 Approximate water use during 1980.

Land and Coal Ownership is Complex

About three-fourths of the land surface is privately owned; however, the Federal Government owns subsurface rights to coal on about one-half of the land.

About 72 percent of the land surface in Area 43 is privately owned (table 4.3–1). Of the remaining land, the Federal Government owns about 21 percent, and the State owns about 7 percent. The Federal lands are administered primarily by the U.S. Forest Service (Helena and Lewis and Clark National Forests) and the U.S. Bureau of Land Management. 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. The checkerboard pattern of land ownership in much of the area resulted from subsequent selling and trading of sections between the State, Federal Government, and private landholders (primarily the railroads).

Ownership patterns of subsurface mineral rights to coal are complex. The Enabling Act of 1889 prevented Montana from owning the subsurface rights of the granted school sections if they were mineral lands. In 1927, the Minerals Lands Exemption of the Enabling Act was reversed and Montana was allowed to choose mineral lands through indemnity selection to replace mineral lands lost by the statutes of the original grant.

The Federal Government owns subsurface mineral rights on about one-half of the land, primarily on Federal lands, but also on some State and private lands. The general distribution of land surface and coal rights owned by the Federal government is shown in figure 4.3–1. Detailed surface and mineral ownership patterns are shown on "Surface-minerals management status" maps available from the U.S. Bureau of Land Management (see section 13.0 for reference to specific maps).

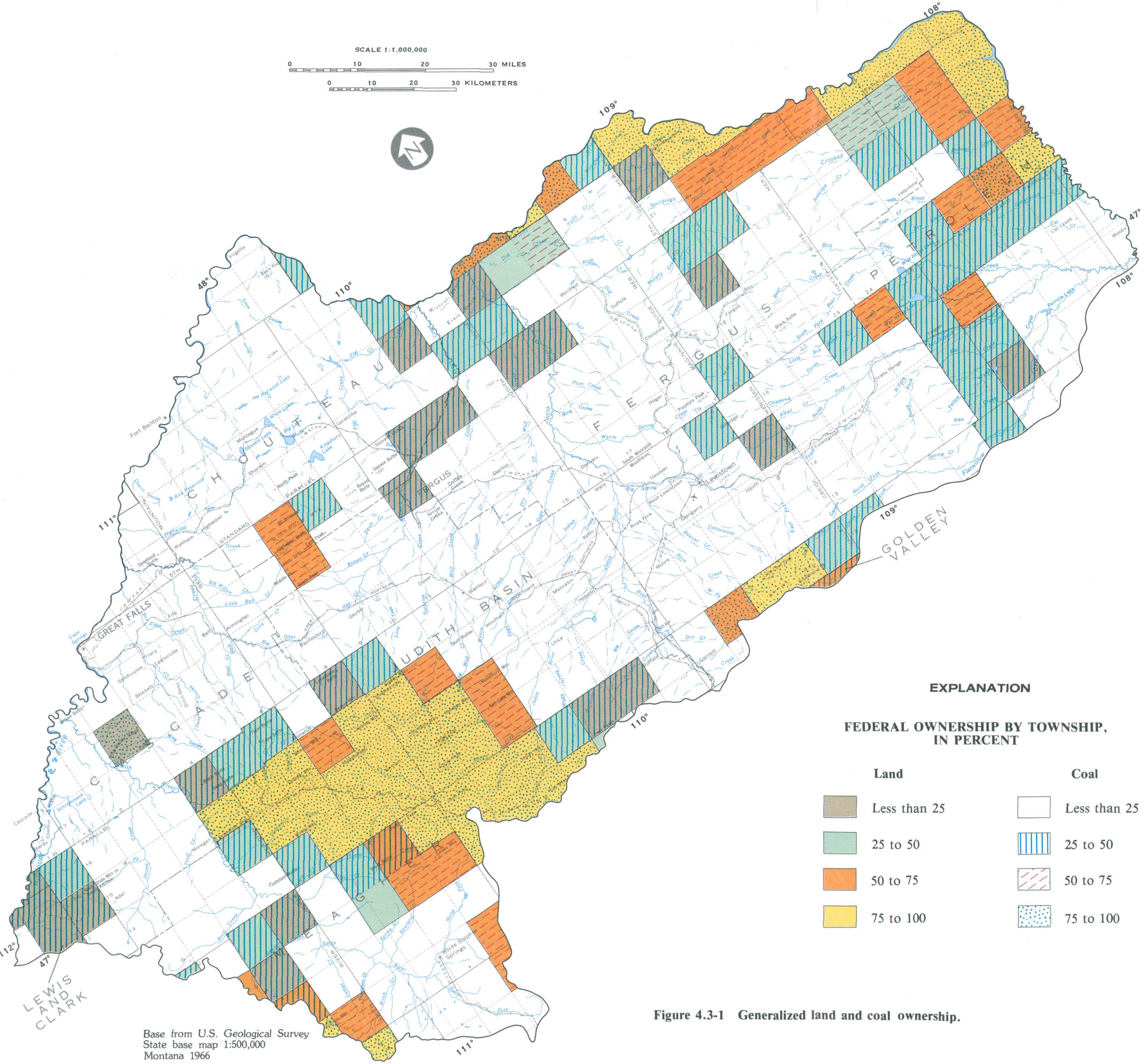


Figure 4.3-1 Generalized land and coal ownership.

Table 4.3-1 Land ownership, by county.

County	Percent ownership[1] Private	Federal	State	Indian Reservation
Cascade	83	12	5	0
Choteau	85	6	8	1
Fergus	76	18	6	0
Judith Basin	66	25	9	0
Meagher	64	30	6	0
Petroleum	57	37	6	0
Average of all counties	72	21	7	0

[1]Data from Missouri River Basin Commission (1979). Percentages represent the entire county.

5.0 COAL MINING
5.1 Coal Resources

Most Coal Contained in Rocks of Late Jurassic Age

Coal in the Great Falls and Lewistown coal fields is classified as medium-grade subbituminous to low-grade bituminous.

An appraisal of coal resources within the original boundaries of Area 43 (see fig. 1.2–1) indicated that the only commercially significant deposits occur south of the Missouri River in the Great Falls and Lewistown coal fields (fig. 5.1–1). However, a brief description of coal resources within the original area north of the Missouri River is given along with a more detailed account of coal in the Great Falls and Lewistown coal fields.

The coal underlying the area north of the Missouri River, within the original boundaries of Area 43, mainly occurs in the Blackfeet-Valier region, which extends south in a narrow belt from Canada through Glacier, Pondera, and Teton Counties. The coal in this belt occurs in three or four Upper Cretaceous stratigraphic horizons. The coal beds generally are thin (less than 14 inches thick), discontinuous, and of low-grade bituminous rank. North of the Great Falls and Lewistown coal fields, in the vicinity of the Bearpaw Mountains, the surface is underlain by subbituminous coal of indeterminate thickness and extent. Most of this coal occurs in thin discontinuous beds, primarily in the Judith River Formation and, to a minor extent, in the Eagle Sandstone. The coal-bearing rocks in this area are largely concealed by a cover of glacial drift.

The area south of the Missouri River contains mineable coal deposits in the Great Falls and Lewistown coal fields, which are located primarily in Cascade, Judith Basin, and Fergus Counties. The Great Falls field generally extends from the Missouri River near Great Falls southeastward to the vicinity of Utica. The Lewistown field extends eastward from the vicinity of Utica and terminates in the McDonald Creek basin near Forestgrove. The two fields are bounded on the south by the outcrop of the coal beds along the northern flanks of the Little Belt and Big Snowy Mountains. The northern boundaries, however, are not well-defined in the subsurface.

The Great Falls and Lewistown coal fields contain an estimated 822 x 10^6 short tons of bituminous coal reserves (table 5.1–1). This amount represents about 0.5 percent of Montana's coal (Bateman, 1966). Coal in the two fields occurs in a single stratigraphic horizon in the upper part of the Morrison Formation. The coal is of Late Jurassic age and is geologically the oldest coal in Montana (U.S. Geological Survey and Montana Bureau of Mines and Geology, 1968).

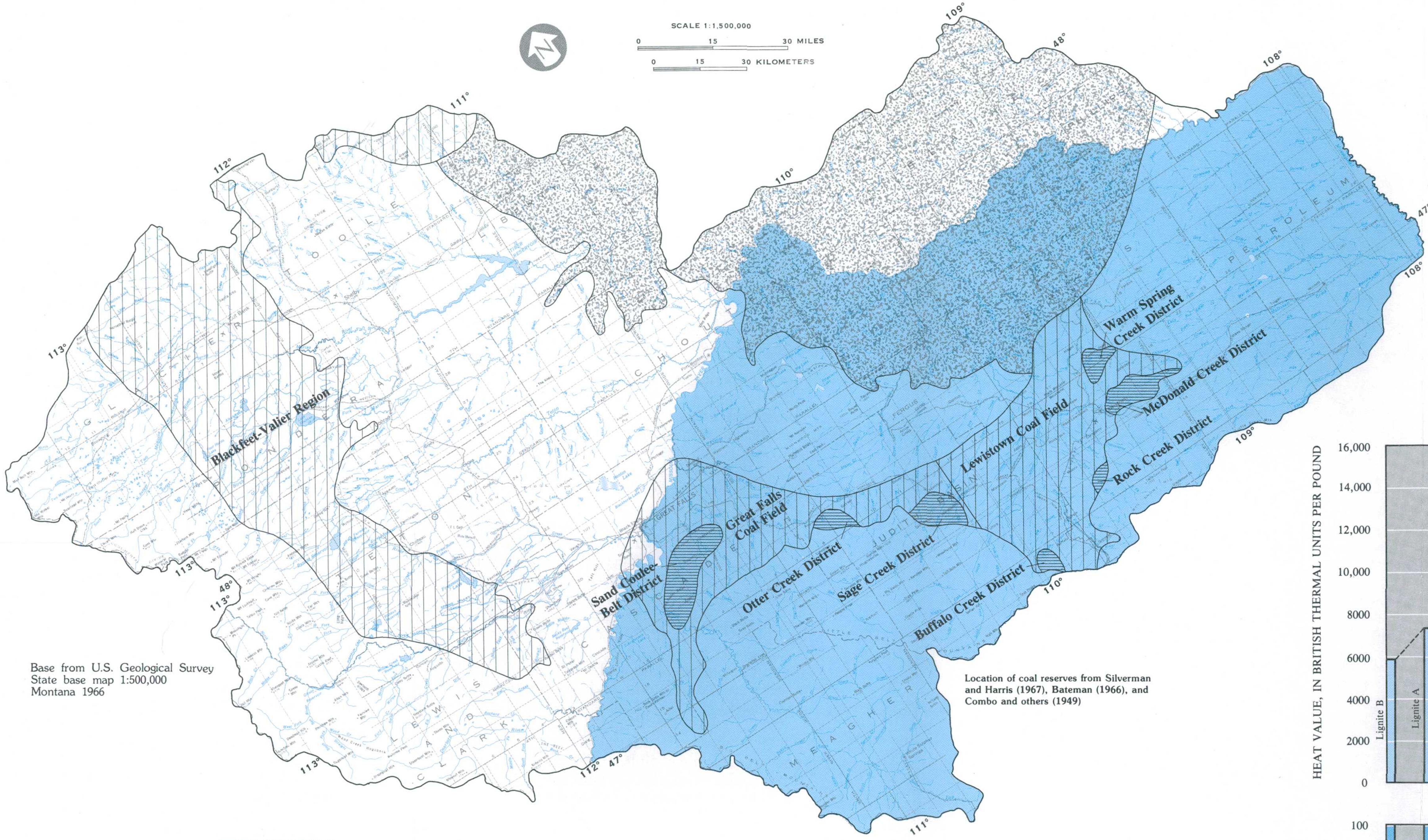
The coal-bearing rocks in the Great Falls field dip gently northward away from the Little Belt Mountains. Dips of strata at the mountain front are as much as 25°, but rapidly diminish basinward to about 5°. Minor faults having displacements of 5 to 20 feet are present throughout the coal field. Similar structure is present where the Lewistown field adjoins the Great Falls field. Farther east, however, the coal beds are arched and locally faulted, and are intruded by laccoliths associated with the Judith and Moccasin Mountains (Combo and others, 1949). The roof rock in this area is composed primarily of shale and siltstone of the Morrison Formation, which is overlain by the basal Kootenai sandstone (Third Cat Creek sandstone). Because of the prohibitive cost of removing the locally thick basal Kootenai sandstone, coal in the area can be recovered economically only by underground mining.

Because of downwarp and erosion during post-Jurassic time, the mineable coal horizon is discontinuous. It is preserved in workable thickness in seven distinct basins of deposition referred to as mining districts: Sand Coulee-Belt, Otter Creek, and Sage Creek districts in the Great Falls coal field; and the Buffalo Creek, Rock Creek, Warm Spring Creek, and McDonald Creek districts of the Lewistown coal field (fig. 5.1–1).

The Sand Coulee-Belt district is the largest coal basin in the Great Falls field, extending from the Smith River to Belt Creek. The coal generally occurs in two or three benches separated by thin partings of coaly shale. Average total thickness of coal beds is 4 feet at Hound Creek, 4.5 feet at the town of Belt, 7.5 feet at Smith River, and 8 feet at Sand Coulee. In the Otter Creek district the coal occurs in two benches separated by a thin bone and shale parting. Total thickness of the coal ranges from 3 to 6 feet and averages about 3.5 feet. The Sage Creek district contains three coal benches separated by shale partings. Total thickness of the coal benches ranges from 2.5 to 7 feet and averages 5.5 feet. The lower bench averages about 2.5 feet in thickness and contains the best-quality coal in terms of ash content and heating value.

In the Lewistown field, the Buffalo Creek district contains 2.5 to 4 feet of coal. The Rock Creek district contains 3 to 4 feet of coal in two benches of nearly equal thickness, separated by a thin parting of bone and shale. In the Warm Spring Creek district, the coal seam averages about 3.5 feet in total thickness and consists of two benches; the lower bench ranges from 2 to 2.5 feet in thickness. The McDonald Creek district is the largest coal basin in the Lewistown field, extending from Big Spring Creek on the west to Forestgrove on the east. The coal-bearing rocks are folded, locally faulted, and intruded by small laccoliths. The coal seam ranges in thickness from 2.5 to 8 feet and is divided into two or three benches by thin partings of shale and bone.

A comparison of heat value for coals of different rank is presented in figure 5.1–2. All coals in the area are classified as medium-grade subbituminous to low-grade bituminous. The sulfur in the coal averages 2.7 percent in the Great Falls field and 3.7 percent in the Lewistown field (Silverman and Harris, 1967). The amount of sulfur differs considerably within a given bench and between benches, ranging from 0.5 to 5.5 percent in individual samples. These sulfur percentages are generally larger than those measured in eastern Montana coal. The moisture content of the air-dried coal in the Great Falls field ranges from 1 to 4 percent, and in the Lewistown field from 7 to 23 percent (Silverman and Harris, 1967). Heating values range from 8,700 to 12,900 British thermal units per pound in the Great Falls field and from 10,100 to 12,900 British thermal units per pound in the Lewistown field. In general, coals from the Sand Coulee-Belt and McDonald Creek districts are thicker, contain less ash, and have greater heating values than those in the other coal districts.



EXPLANATION

KNOWN BITUMINOUS COAL LESS THAN 14 INCHES THICK

KNOWN BITUMINOUS COAL MORE THAN 14 INCHES THICK

AREA UNDERLAIN BY SUBBITUMINOUS COAL OF UNDETERMINED THICKNESS AND EXTENT

REVISED EXTENT OF AREA 43

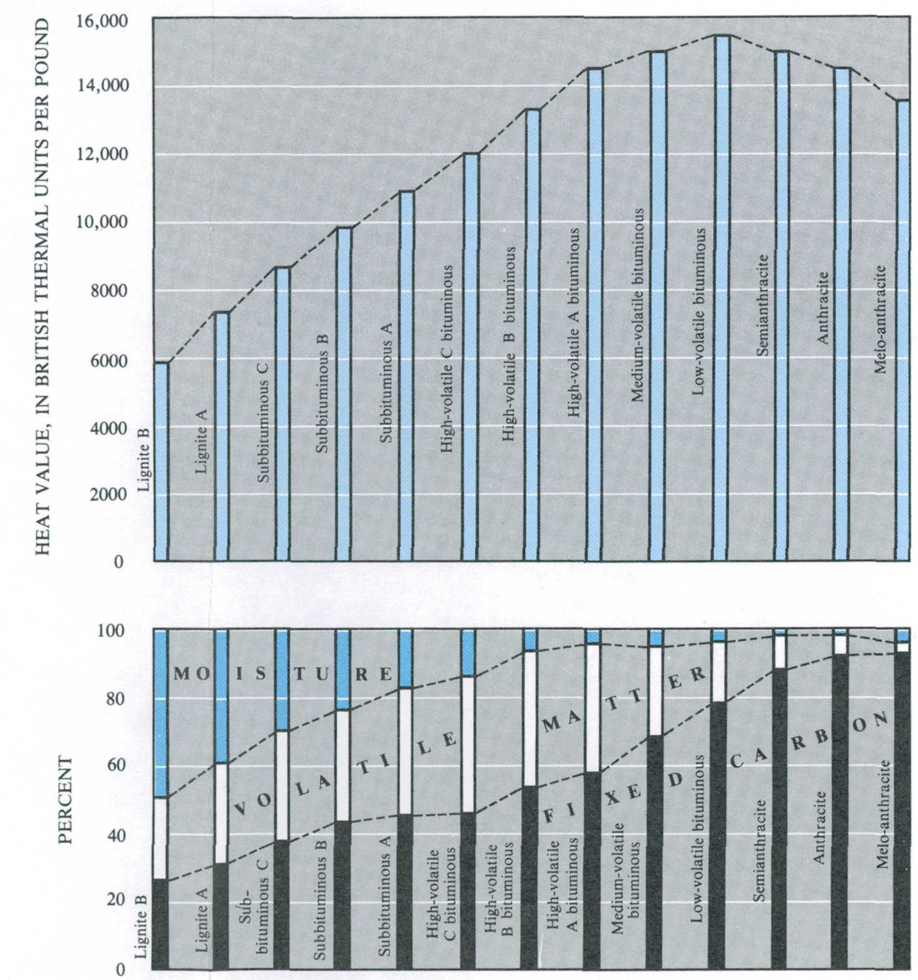
COAL-FIELD BOUNDARY

Figure 5.1-1 Coal resources.

Table 5.1-1 Summary of estimated total coal reserves for three classes of bed thickness in the Great Falls and Lewistown coal fields.

Bed thickness (inches)	Coal reserves (short tons x 10^6)
14-24	123
24-36	252
More than 36	447
Total	822

From Silverman and Harris (1967)



From Rocky Mountain Association of Geologists (1972)

Figure 5.1-2 Comparison of heat values and proximate analyses (moist, ash-free basis) of coal of different ranks.

Coal First Mined in the 1870's

Commercial coal production has essentially ceased, after almost 36 million tons of coal have been mined.

Historically, the major consumers of coal in the area were the railroads, metal mining companies, and local space-heating markets. In the 7 decades between 1885 and 1955, the Great Falls and Lewistown coal fields produced almost 36 million tons of coal, or about 23 percent of the State production during the period (Silverman and Harris, 1967). Nearly 12 million tons of coal were extracted in the first 2 decades of mining history. During this early period, the number of producing mines increased from 5 to 15 in Cascade County and from 4 to 10 in Fergus County. A few large mines yielded most of the production.

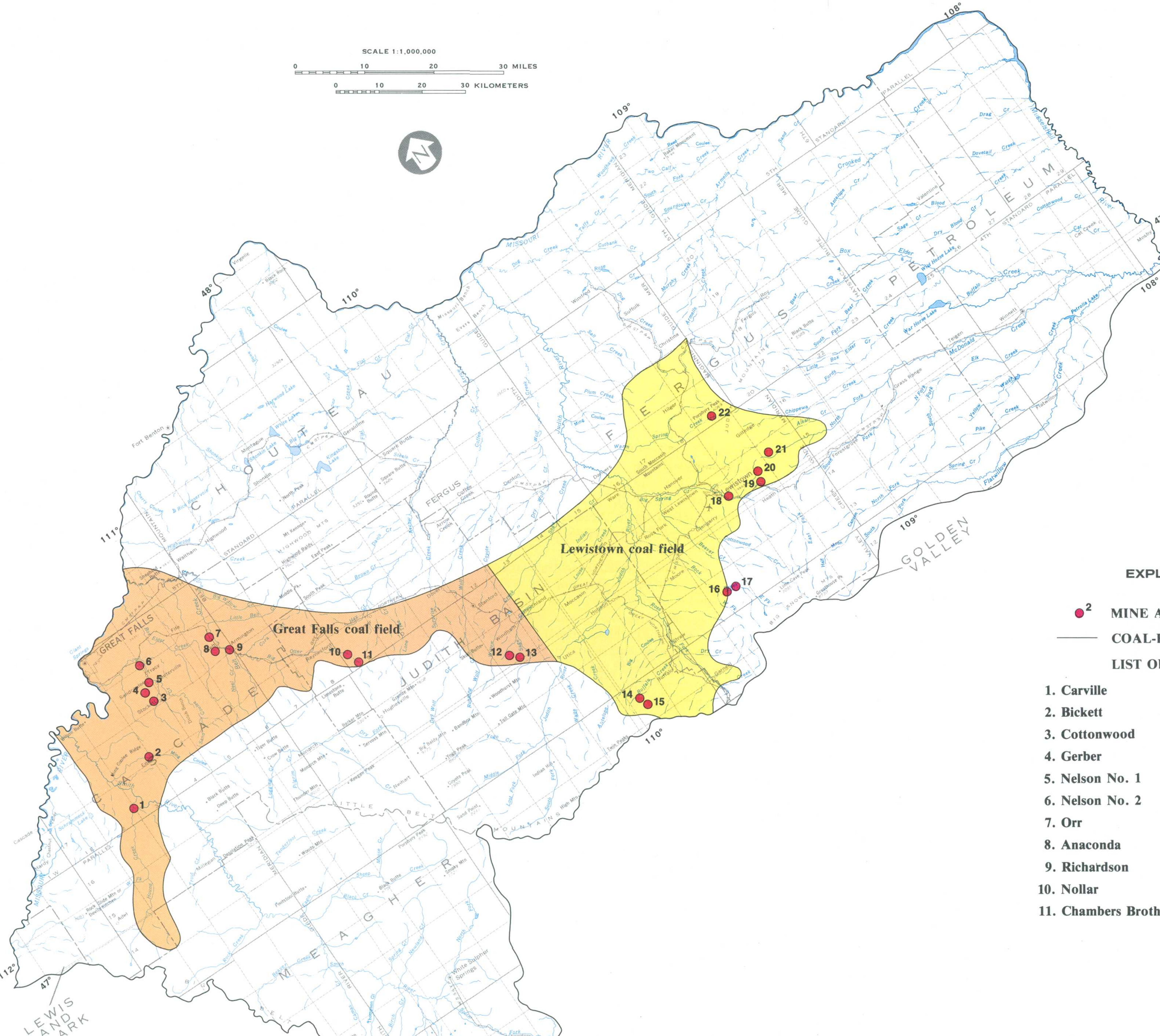
Development of the coal resources of the Great Falls and Lewistown fields began in the Sand Coulee-Belt district near the town of Belt in 1876. There, a small mine produced coal that was shipped overland to Fort Benton, a town situated near the head of navigation on the Missouri River. Coal output of this and later mines near the town of Sand Coulee was small during the first few years, but as railroad expansion and facilities for handling coal were completed, coal production steadily increased.

In 1885, the Castner Coal and Coke Company operated a mine at Belt, built 100 coke ovens, and employed 900 people (Morgan, 1966). The Anaconda Mining Company purchased this property in 1889 and operated it until 1913. During a 25-year period, production at this mine was estimated at 300,000 tons per year, or a total of 7.5 million tons (Silverman and Harris, 1967). The product from the coke ovens was used at the smelters in Great Falls and Anaconda. The Anaconda Mining Company also purchased a mine from the Lochray Coal Company at Belt in 1914 and operated it for 10 years. Estimated production from this mine was 230,000 tons per year, or a total of 2.3 million tons (Silverman and Harris, 1967).

The Cottonwood Coal Company, a subsidiary of the Great Northern Railroad, developed a mine at Stockett in the 1890's. It produced 465,000 tons of coal in 1905 and employed 509 men (Morgan, 1966). In the early 1930's this same company developed a mine at Giffen, a few miles south of Stockett. This mine employed 350 men and had a daily production of about 1,800 tons of coal. Operation of the mine continued until 1946 when the Great Northern Railroad installed diesel locomotives.

A number of smaller mines were developed throughout the Great Falls and Lewistown fields, primarily in the Sand Coulee-Belt district. Most of these mines were not extensively worked and accounted for only a minor percentage of total coal output for the area. Many of these mines were abandoned after a short period owing to poor quality coal, thin beds, or excessive water accumulation.

During the 3 decades between 1900 and 1930, operators in the Great Falls and Lewistown coal fields employed most of the 3,000 to 4,000 coal miners in Montana. In contrast, from 1955 to 1965, production was limited to several small underground mines, which employed only a few workers and produced less than 1 percent of the coal mined in the State (Silverman and Harris, 1967). Commercial production of coal ended about 1965, although seasonal operation of small mines still produces limited amounts of coal for local consumption. The primary factors resulting in the decline of coal production in the area included the railroads' conversion to diesel fuel, completion of pipelines delivering oil and gas, hydroelectric development, and increased production from more cost-competitive surface coal mines in southeastern Montana. The location of some of the larger formerly active coal mines is shown in figure 5.2–1.



Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

EXPLANATION

● 2 MINE AND NUMBER

——— COAL-FIELD BOUNDARY

LIST OF MINES

1. Carville	12. Seman
2. Bickett	13. Schultz
3. Cottonwood	14. Williams
4. Gerber	15. Saager Canyon
5. Nelson No. 1	16. Sharpe
6. Nelson No. 2	17. Cooper
7. Orr	18. Spring Creek
8. Anaconda	19. Black Diamond
9. Richardson	20. Hamilton
10. Nollar	21. Flaherty
11. Chambers Brothers	22. Mace

Figure 5.2-1 Formerly active coal mines.

Mining Can Create Hydrologic Problems

Potential problems include land subsidence, erosion, sediment deposition, acid mine drainage, and declining ground-water levels.

Degradation of local land and water resources can result from coal mines that are not adequately maintained during operation or reclaimed after mining is completed. Potential hydrologic problems that can result from mining include land subsidence, erosion, sediment deposition in stream channels, acid mine drainage, and declining ground-water levels. These problems are sometimes long term and can seriously affect domestic, industrial, recreational, and agricultural uses of land and water.

Underground mining, which has been and probably will be the only economic means of extracting coal in Area 43, alters the land surface to a lesser extent than surface strip mines. Underground mining involves the excavation and removal of large volumes of unconsolidated material. Removal of underground materials commonly weakens the structure of overlying formations and can result in a collapse of the land surface (fig. 5.3–1).

Excavated waste materials (spoils) are usually stored in large piles during mining (fig. 5.3–2). Spoil piles are subject to erosion, and unless sediment retention ponds are constructed the eroded spoils material will be transported by precipitation runoff to local streams. Once in the streams, the sediment increases the turbidity of the water and is deposited at various places in the channel. Such additions of sediment can decrease the water-transporting efficiency of the stream, blanket streambed habitat essential for aquatic organisms, reduce dissolved-oxygen concentrations, and increase treatment costs for industrial, municipal, and domestic supplies.

The quality of surface and ground water in the vicinity of underground coal mines can be affected by the removal and storage of excavated materials. The excavated materials, which originally existed in a nonoxidizing environment beneath the land surface, are exposed to oxygen in the atmosphere when brought to the surface. The unoxidized mineral surfaces of the fragmented spoils provide an opportunity for atmospheric oxidation and subsequent chemical reactions with water. Such reactions are responsible for converting mineral sulfides to sulfuric acid. The acidified water flowing out of a mine is commonly termed "acid mine drainage" (fig. 5.3–2). The low pH of acid drainage accelerates the dissolution of salts and trace elements, resulting in large concentrations of these constituents in receiving streams or alluvial aquifers. Subsequent oxidation of dissolved compounds can result in precipitation of metal compounds, which cover streambeds (fig. 5.3–3) and destroy habitat for benthic organisms. In some streams, the base flow is composed almost entirely of acid drainage. Acid mine drainage exists at several sites near abandoned coal mines in the Sand Coulee-Belt district. Descriptions of the hydrology and acid mine drainage conditions in the Sand Coulee-Belt district are provided in reports by Hydrometrics, Inc. (1982), McArthur (1970), and Osborne and others (1983).

Ground-water levels also can be affected by coal mining. Mine adits excavated above water-yielding zones have little, if any, effect on water levels. Where excavation intersects a water-yielding zone, the adit becomes a ground-water sink that intercepts the natural ground-water flow and induces flow toward the mine. Intercepting an aquifer results in dewatering of the area above the base of the adit and a lowering of water levels around the mine (fig. 5.3–4). Water-level declines can decrease production from nearby wells and springs. These effects generally are permanent in abandoned mine areas. Proper reclamation, in which the spoils are replaced and adits sealed after termination of mining, would tend to minimize the lowering of ground-water levels.

The areal extent of the effects of mining on water levels is largely dependent on the geologic and hydrologic setting of the mine. The upper part of the Morrison Formation, which contains the mineable coal horizon in Area 43, is not an important water-yielding formation. However, the overlying basal Kootenai sandstone (Third Cat Creek sandstone) is relatively thick and porous and is an important water-bearing formation in central Montana. Because this basal sandstone is generally continuous for large distances, the areal extent of water-level changes resulting from excavation of this aquifer can be significant.

Figure 5.3-1 Land subsidence from underground mining near Sand Coulee, Montana.

Figure 5.3-2 Acid mine drainage near Stockett, Montana.

Figure 5.3-3 Metal precipitate on streambed near Sand Coulee, Montana.

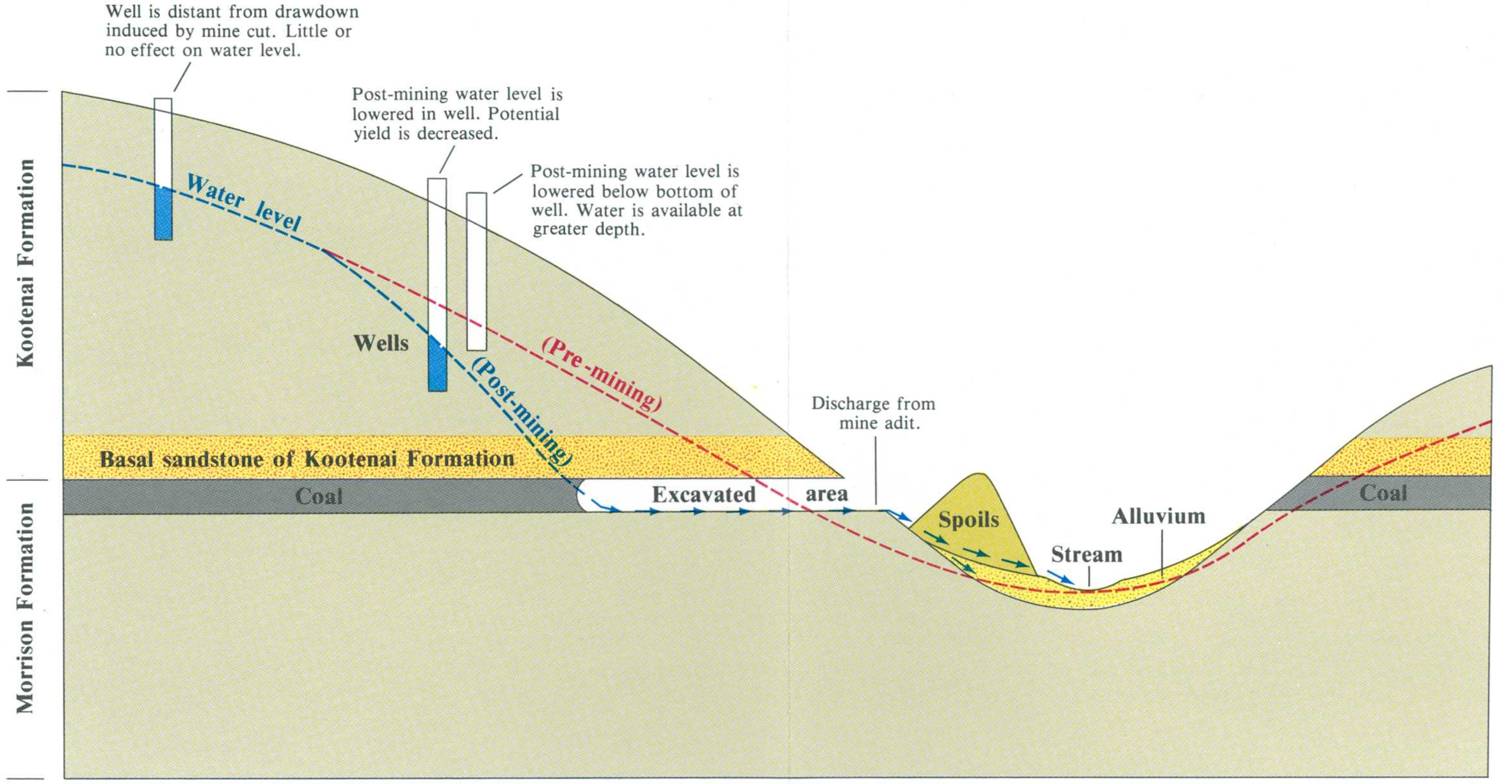


Figure 5.3-4 Potential impacts of mining on ground-water levels.

Hydrologic Studies Completed for Much of the Area

Previous and current studies contain information on ground water, surface water, and water quality.

Early hydrologic studies in Area 43 were conducted by Fisher (1909), Riffenburg (1926), and Perry (1931, 1932a,b,c, and d). Several nationwide studies in later years included general descriptions of the area hydrology. A number of regional studies also were made, primarily to assess the ground-water resources in the northern Great Plains and upper Missouri River basin. Several statewide investigations, supplemented by data-collection networks, were made to analyze streamflow characteristics. Generally, water-quality investigations of surface water in the area are limited. Because of currently active surface mining in southeastern Montana, few coal-related hydrologic studies have been initiated in Area 43 in recent years.

Published reports of completed hydrologic studies are listed in table 6.1–1. The project areas of regional and local studies are shown in figure 6.1–1.

Current (1984) hydrologic investigations include primarily the collection of surface-water, ground-water, and water-quality data from a small network of long-term monitoring sites. These data are used to document the occurrence, availability, and characteristics of surface and ground waters. Current investigations conducted by the U.S. Geological Survey are summarized in table 6.1–2.

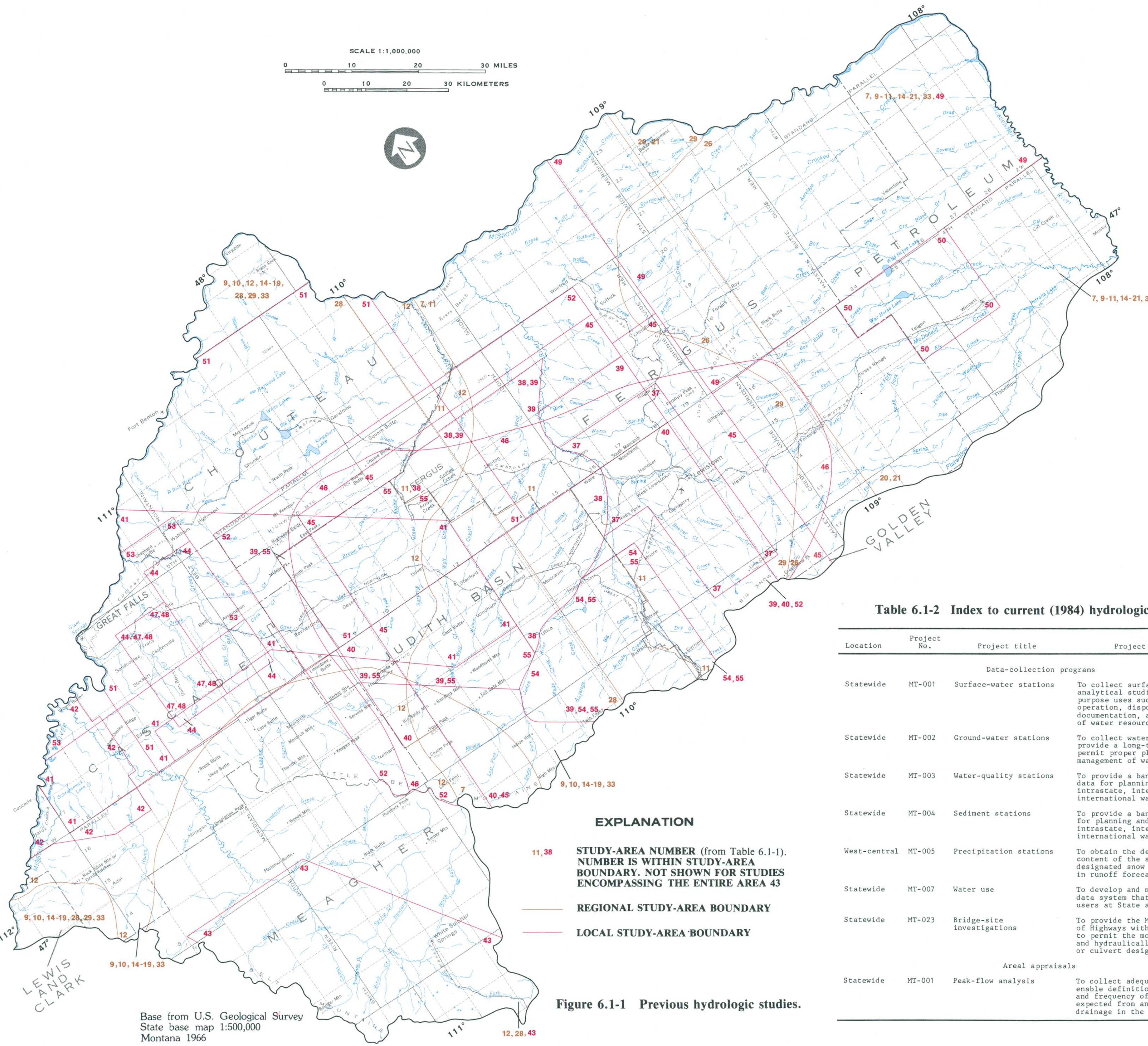


Figure 6.1-1 Previous hydrologic studies.

Table 6.1-2 Index to current (1984) hydrologic studies.

Location	Project No.	Project title	Project objective
		Data-collection programs	
Statewide	MT-001	Surface-water stations	To collect surface-water data for analytical studies and current-purpose uses such as evaluation, operation, disposal, legal documentation, and research of water resources.
Statewide	MT-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	MT-003	Water-quality stations	To provide a bank of water-quality data for planning and management of intrastate, interstate, and international waters.
Statewide	MT-004	Sediment stations	To provide a bank of sediment data for planning and management of intrastate, interstate, and international waters.
West-central	MT-005	Precipitation stations	To obtain the depth and water content of the snowpack at designated snow courses for use in runoff forecasting.
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.
		Areal appraisals	
Statewide	MT-001	Peak-flow analysis	To collect adequate data to enable definition of the magnitude and frequency of floods to be expected from any given small drainage in the State.

Table 6.1-1 Index to previous hydrologic studies.

Study area No. (fig. 6.1-1)	Reference (see section 13.0 for complete reference)	Principal subject of investigation				
		Surface water	Ground water	Water quality	Biology	Sediment
	Nationwide studies					
1	Blakey (1966)			X		
2	Busby (1966)	X				
3	Durfor and Becker (1964)			X		
4	McGuinness (1964)	X	X			
5	Meinzer (1927)	X				
	Regional studies					
6	Aagaard (1969)[1]			X		
7	Bahls and others (1981)			X	X	X
8	Boner and Omang (1967)[1]	X				
9	Feltis (1980b)		X	X		
10	Feltis (1980c)		X			
11	Hopkins (1976)		X			
12	Ingman and others (1979)			X	X	
13	LaRocque (1966)[1]		X			
14	Levings (1981a)		X			
15	Levings (1981b)		X	X		
16	Levings (1982a)		X			
17	Levings (1982b)		X			
18	Levings (1982c)		X			
19	Levings (1982d)		X			
20	Miller and Strausz (1980a)		X			
21	Miller and Strausz (1980b).		X			
22	Missouri River Basin Commission (1981)[1].	X	X	X	X	X
23	Montana Water Resources Board (1969)[1].		X			
24	Omang and others (1979)[1]	X				
25	Omang and others (1982)[1]	X				
26	Omang and others (1983)	X				
27	Parrett and Omang (1981)[1]	X				
28	Parrett and others (1982)	X				
29	Parrett and others (1983)	X				
30	Perry (1931)[1]		X	X		
31	Perry (1932b)[1]		X			
32	Reed and McMurtrey (1970)[1]		X			
33	Riffenburg (1926)		X	X		
34	Shields and White (1981)[1]	X				
35	Taylor (1978)[1]		X			
36	U.S. Geological Survey and Montana Bureau of Mines and Geology (1968)[1].	X	X	X	X	
	Local studies					
37	Feltis (1973)		X	X		
38	Feltis (1977)		X	X		
39	Feltis (1980a)		X	X		
40	Feltis and Shields (1982)	X				
41	Fisher (1909)		X			
42	Fox (1966)		X	X		
43	Groff (1965)		X	X		
44	Hydrometrics, Inc. (1982)	X	X	X		
45	Levings and Dodge (1981)		X	X		
46	Levings (1983)		X			
47	McArthur (1970)	X	X	X		
48	Osborne and others (1984)	X	X	X		
49	Osterkamp (1968)		X	X		
50	Perry (1932a)		X			
51	Perry (1932c)		X			
52	Perry (1932d)		X	X		
53	Wilke (1983)		X	X		
54	Zimmerman (1962)		X	X		
55	Zimmerman (1966)		X	X		

[1]Project area of study was either statewide or encompassed all of Area 43.

Discharge Information Available for 68 Surface-Water Sites

The U.S. Geological Survey collects surface-water flow information at 42 continuous-record sites and 26 crest-stage sites in Area 43.

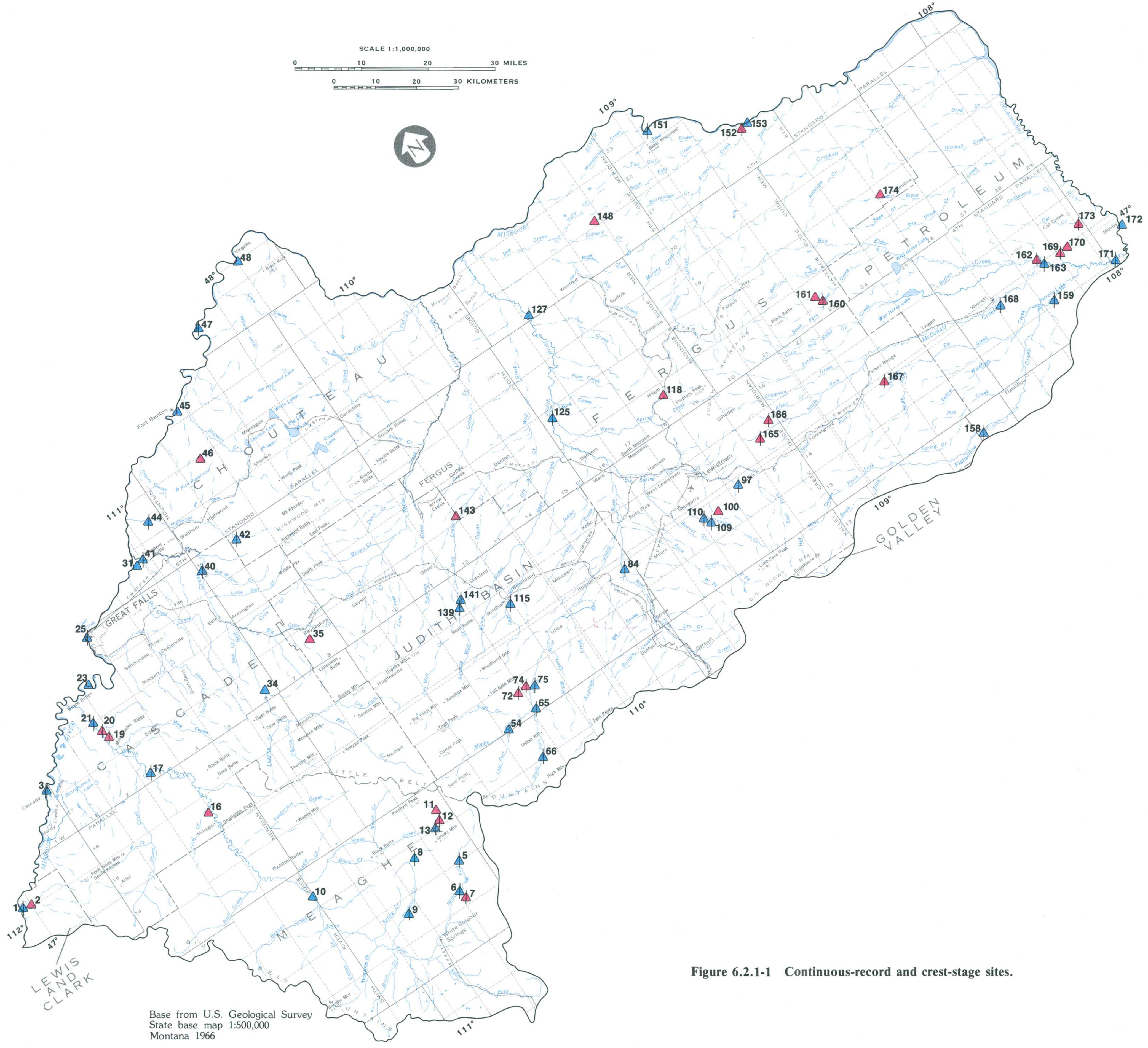
The U.S. Geological Survey obtains surface-water data at both continuous-record and crest-stage sites. A continuous-record site provides a continuous record of stream stage and discharge throughout the water year. Data collected for several years from continuous-record sites can be used for determining average-flow, low-flow, and high-flow characteristics of a stream. A crest-stage site provides a record of instantaneous peak stages that occur between visits, but usually only the largest peak stage and associated discharge for each year are published. Data from crest-stage sites can be used for determining annual peak-flow characteristics that are useful for flood studies.

The location of surface-water sites is shown in figure 6.2.1–1. Details for the period of record and type of data available are given in the supplemental list of streamflow and water-quality sites (section 12.0).

Most of the early continuous-record sites were established on the larger perennial streams to meet specific water-management needs. Later sites were established primarily to obtain data to document general hydrologic characteristics of the area. The number of continuous-record sites has fluctuated, but generally has increased with time to the present (1984) coverage. Several continuous-record sites have more than 10 years of data, which is usually considered the minimum period of record necessary for developing reliable statistics to describe average flow conditions or to make flow estimates.

The first crest-stage sites in Area 43 were established in the 1950's, primarily to collect information for highway culvert and bridge design. The crest-stage network in Montana was expanded in the 1960's and again in the 1970's. Twenty-seven crest-stage sites in the area have at least 10 years of record, which is the general requirement for developing peak-flow statistics.

Most of the data collected at continuous-record and crest-stage sites are available in computer-usable form. Data collected since 1965 also are available in the report series "Water Resources Data for Montana," published annually by the U.S. Geological Survey. Data collected before 1965 are published in U.S. Geological Survey Water-Supply Papers 1309, 1729, and 1916 (U.S. Geological Survey, 1959, 1964, and 1969). Data collected from 1961 through 1964 were also published annually in the series "Surface-Water Records of Montana."



EXPLANATION

- ACTIVE CONTINUOUS-RECORD SITE
- DISCONTINUED CONTINUOUS-RECORD SITE
- ACTIVE CREST-STAGE SITE
- DISCONTINUED CREST-STAGE SITE
- 46 SITE NUMBER

See section 12.0 for description of sites

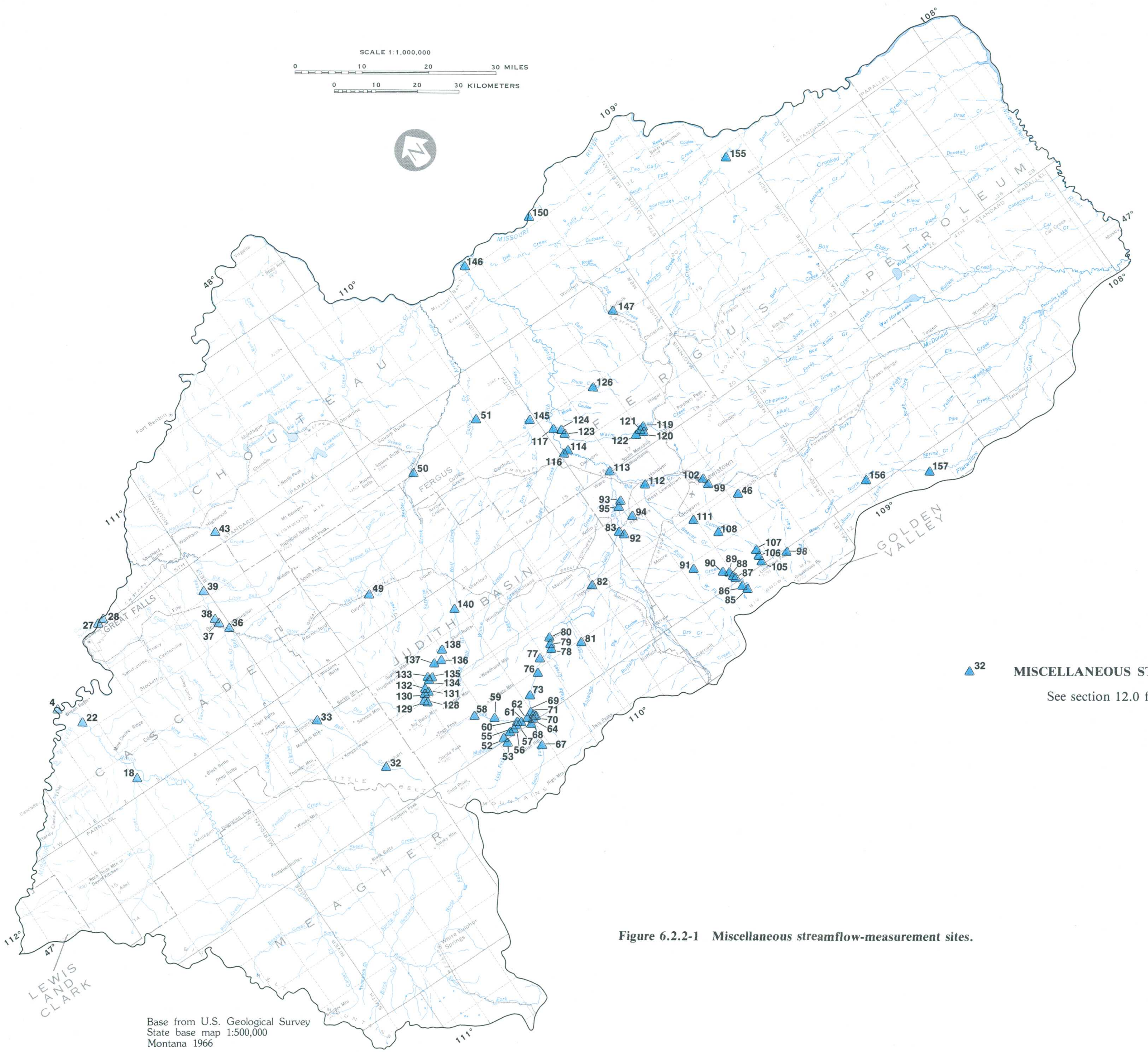
Figure 6.2.1-1 Continuous-record and crest-stage sites.

Stream Discharge Information Available for 91 Miscellaneous Streamflow 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 91 sites in Area 43 (fig. 6.2.2–1). Some measurements were made prior to 1920, but most have been made since 1960. Several miscellaneous streamflow measurements were made in conjunction with programs to study the quality of surface water. Numerous measurements were made during streamflow gain-or-loss studies to determine the interaction between ground water and surface water along specific stream reaches. Other measurements were made in conjunction with special studies.

Information on the period of record and type of data for each miscellaneous streamflow site is contained in the supplemental list of streamflow and water-quality sites (section 12.0). Additional data for the sites are available at the U.S. Geological Survey office in Helena, Montana.



EXPLANATION

▲32 **MISCELLANEOUS STREAMFLOW-MEASUREMENT SITE AND NUMBER**

See section 12.0 for description of sites

Figure 6.2.2-1 Miscellaneous streamflow-measurement sites.

6.0 HYDROLOGY PROGRAMS--Continued

6.2 Hydrologic Monitoring--Continued

6.2.2 Miscellaneous Streamflow Measurements

Water-Quality Data Available for 32 Sites

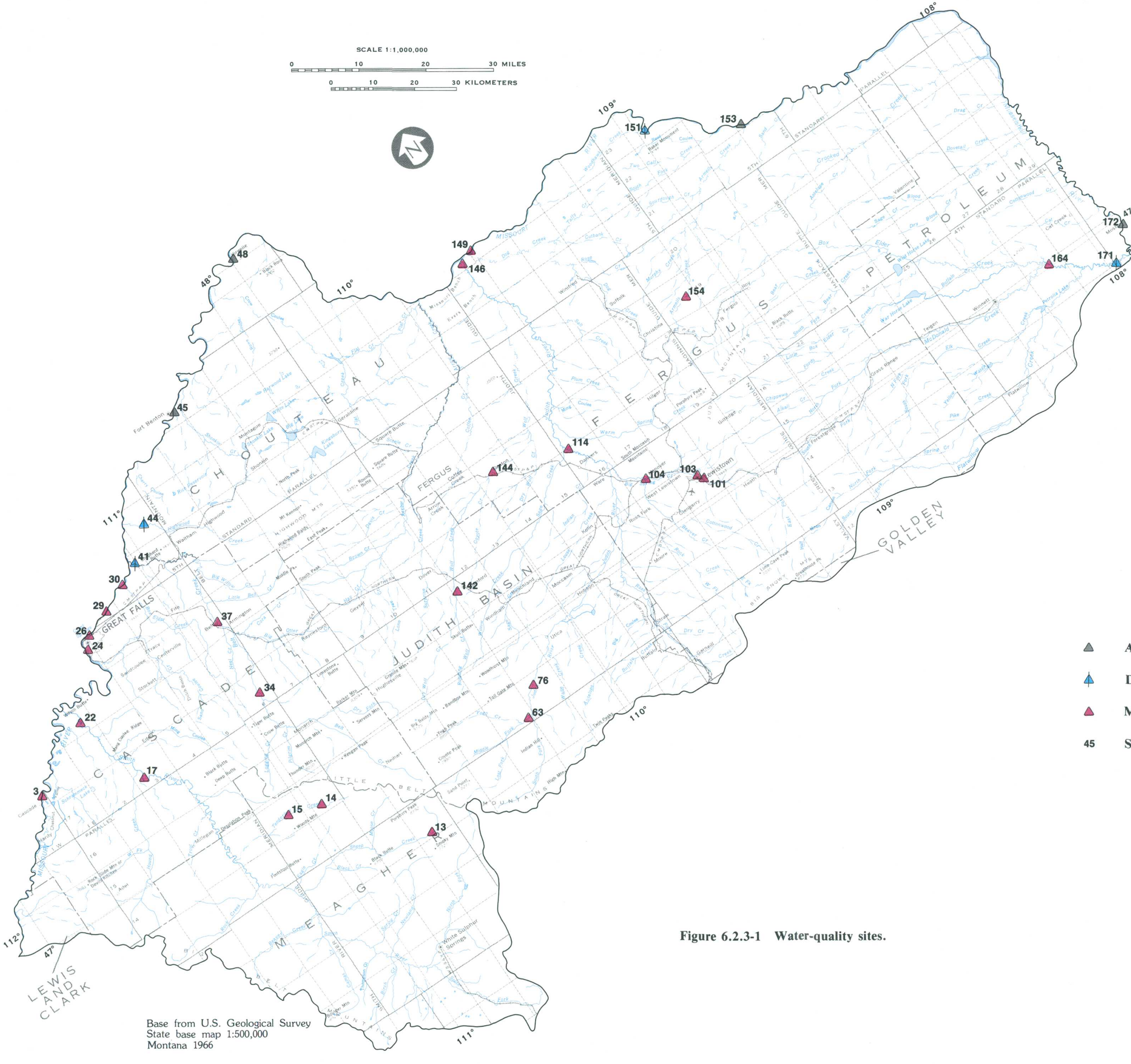
Water-quality data, which includes biological, chemical, sediment, and temperature measurements, are generally sparse for streams in Area 43.

Water-quality data have been collected during various years throughout the area since 1917, when temperature measurements were first recorded for the Missouri River at Ryan Dam, near Black Eagle (site 30). More recently, the U.S. Geological Survey established eight water-quality sites to characterize biological, chemical, and sediment conditions in the Missouri River and several major tributaries. Four of these sites subsequently have been discontinued. Twenty-four water-quality sites were established at stream locations where only temperature measurements were made or where samples were collected on a short-term basis for special studies. The available data from the 32 water-quality sites vary widely with respect to time and duration of collection.

Sites 45, 48, 153, and 172 have been operated as part of the National Stream Quality Accounting Network (NASQAN) since the 1975 water year. Thirteen sites were operated by the Montana Department of Health and Environmental Sciences from 1977 to 1979 as part of a statewide biological monitoring network. Continuous recordings or once-daily observations of water temperature were obtained at seven sites operated in cooperation with the Montana Department of Fish, Wildlife and Parks. Because only eight sites have been sampled routinely for 2 or more years, there is a limited data base from which to characterize areal and temporal variations of water-quality conditions in Area 43.

In the late 1940's, the U.S. Geological Survey began measuring water temperature when a streamflow measurement was made. In the last few years, specific conductance also has been recorded when streamflow is measured at continuous-record sites. These data have been published in the 1982 water year; specific-conductance and water-temperature measurements prior to 1982 are available in the files at the U.S. Geological Survey's District Office in Helena, Montana.

The locations of all water-quality sites (active and discontinued) within the study area are shown in figure 6.2.3–1. Additional information about water-quality sites is contained in the description of streamflow and water-quality sites at the end of this report (section 12.0).



EXPLANATION

- ACTIVE WATER-QUALITY SITE
- DISCONTINUED WATER-QUALITY SITE
- MISCELLANEOUS WATER-QUALITY SITE
- 45 SITE NUMBER

See section 12.0 for description of sites

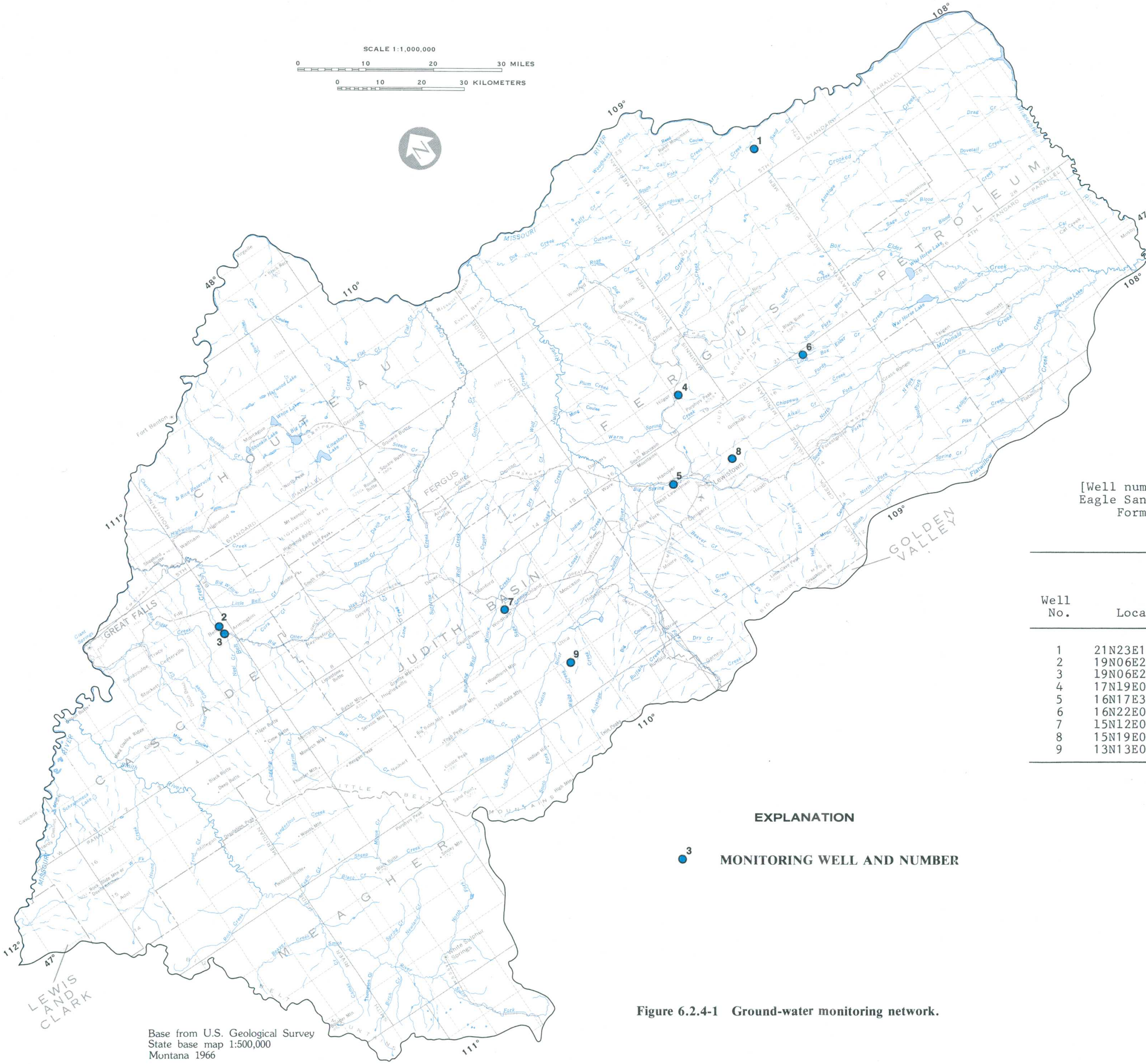
Figure 6.2.3-1 Water-quality sites.

Data Available for Many Wells

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

Inventories of hydrologic and geologic data are available for about 540 domestic, stock, irrigation, and public-supply wells in Area 43. 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 430 wells. Most analyses are for major ions but some trace-element and miscellaneous-constituent information is available for about 200 wells. Most well data are available in two reports by Levings (1981a, 1981b). Inventory and water-quality information also is stored and available for computer retrieval from the Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) and from the Montana Bureau of Mines and Geology, Butte, Montana.

Periodic water-level information is available for nine network wells in the area (table 6.2.4–1 and fig. 6.2.4–1). Network wells were established by the U.S. Geological Survey to monitor the response of the hydrologic system to natural climatic variations and induced stress. These wells became part of a statewide observation-well network during the past 10 years in response to the probability of increased ground-water development in the northern Great Plains. Water-level records for these wells are available from WATSTORE.



Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

EXPLANATION

3 MONITORING WELL AND NUMBER

Figure 6.2.4-1 Ground-water monitoring network.

Table 6.2.4-1 Ground-water monitoring network.

[Well number: Refers to locations in figure 6.2.4-1. Geologic unit: EGLE, Eagle Sandstone; KOTN, Kootenai Formation; MDSN, Madison Group; SWFT, Swift Formation. Frequency of measurement: A, annual; I, intermittent. Water level period of record: P, present (1984)]

Well No.	Local No.	Depth of well (feet below land surface)	Geologic unit	Frequency of measurement	Period of record: Water level	Period of record: Water quality
1	21N23E13CBBB01	1,630	EGLE	I	1980-P	1980
2	19N06E23BADA01	75	SWFT	A	1983-P	--
3	19N06E26ACAD01	435	MDSN	A	1983-P	--
4	17N19E07BBC01	510	EGLE	I	1966-P	--
5	16N17E36ABAA01	322	KOTN	I	1980-P	1980
6	16N22E05DDB01	1,431	KOTN	I	1979-P	1979
7	15N12E02BBBA01	1,165	SWFT	I	1980-P	1980
8	15N19E09BABC01	90	KOTN	I	1980-P	1980
9	13N13E04AADD01	380	KOTN	I	1980-P	1980

Seasonal Variations in Streamflow are Large

Mountain streams are generally perennial, whereas most prairie streams become dry at times.

Streamflow volumes differ greatly within the area. Flows in all unregulated streams have large seasonal variations, with the largest flows generally occurring during the spring or early summer as a result of snowmelt and rainstorms.

Daily flow hydrographs (fig. 7.1–1) indicate the seasonal variation in streamflows in 1962 for Belt Creek near Monarch (site 34) and for Ross Fork Creek near Hobson (site 84). The hydrographs show the effects of snowmelt and intense rainfall on the flow in an intermittent stream draining mostly prairie (Ross Fork Creek) and in a perennial stream draining mountains (Belt Creek). Winter snowmelt causes sharper peaks in the prairies than in the mountains. Streamflow in the prairies increases rapidly during May as a result of snowmelt, while streamflow in the mountains increases more gradually. Summer rainstorms can result in short intervals of increased streamflow in both the prairies and the mountains during June through August. Mountain streams have substantial base flow in the winter while most prairie streams become dry.

Another way of illustrating variability is with a flow-duration curve, which shows the percentage of time that a daily stream discharge was equaled or exceeded during the period of record at a station. Flow-duration curves for four streams are shown in figure 7.1–2.

Flow-duration curves for Ross Fork Creek and McDonald Creek are representative of flow in prairie streams. The curves are steep, indicating a large variation in streamflow throughout the period of record. The curves do not flatten at the lower end, which denotes a lack of sustained base flow. Average flows are less than 15 ft^3/s (cubic feet per second), and average daily discharges of less than 0.1 ft^3/s are likely about 15 percent of the time on Ross Fork Creek and about 35 percent of the time on McDonald Creek. Average daily discharges of more than 10 ft^3/s are likely to occur only about 20 percent of the time on both creeks.

Flow-duration curves for the South Fork Judith River and Belt Creek are representative of flow in mountain streams. The curves for these streams are much flatter than the curves for the prairie streams. Streamflows thus are substantial all the time in mountain streams, primarily because of abundant precipitation, the prolonged contribution to streamflow from mountain snowpack in the headwater areas, and the sustained base flow. Average flows are greater than 15 ft^3/s, and a discharge of less than 0.1 ft^3/s is not likely to occur. Discharges of more than 10 ft^3/s occur about 98 percent of the time on Belt Creek and 38 percent of the time on the South Fork Judith River.

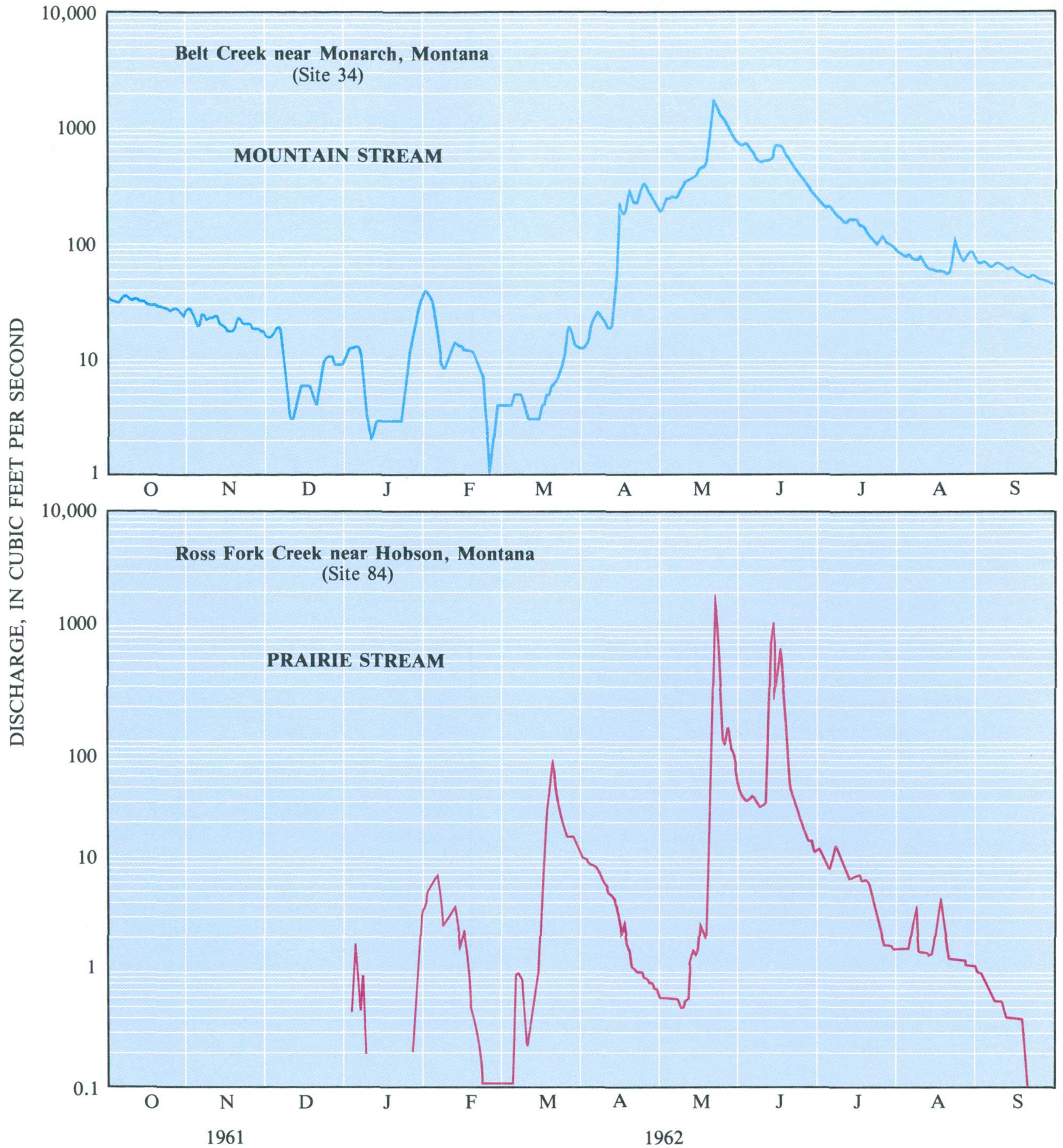


Figure 7.1-1 Daily flow hydrographs for Belt Creek near Monarch and Ross Fork Creek near Hobson, 1962 water year.

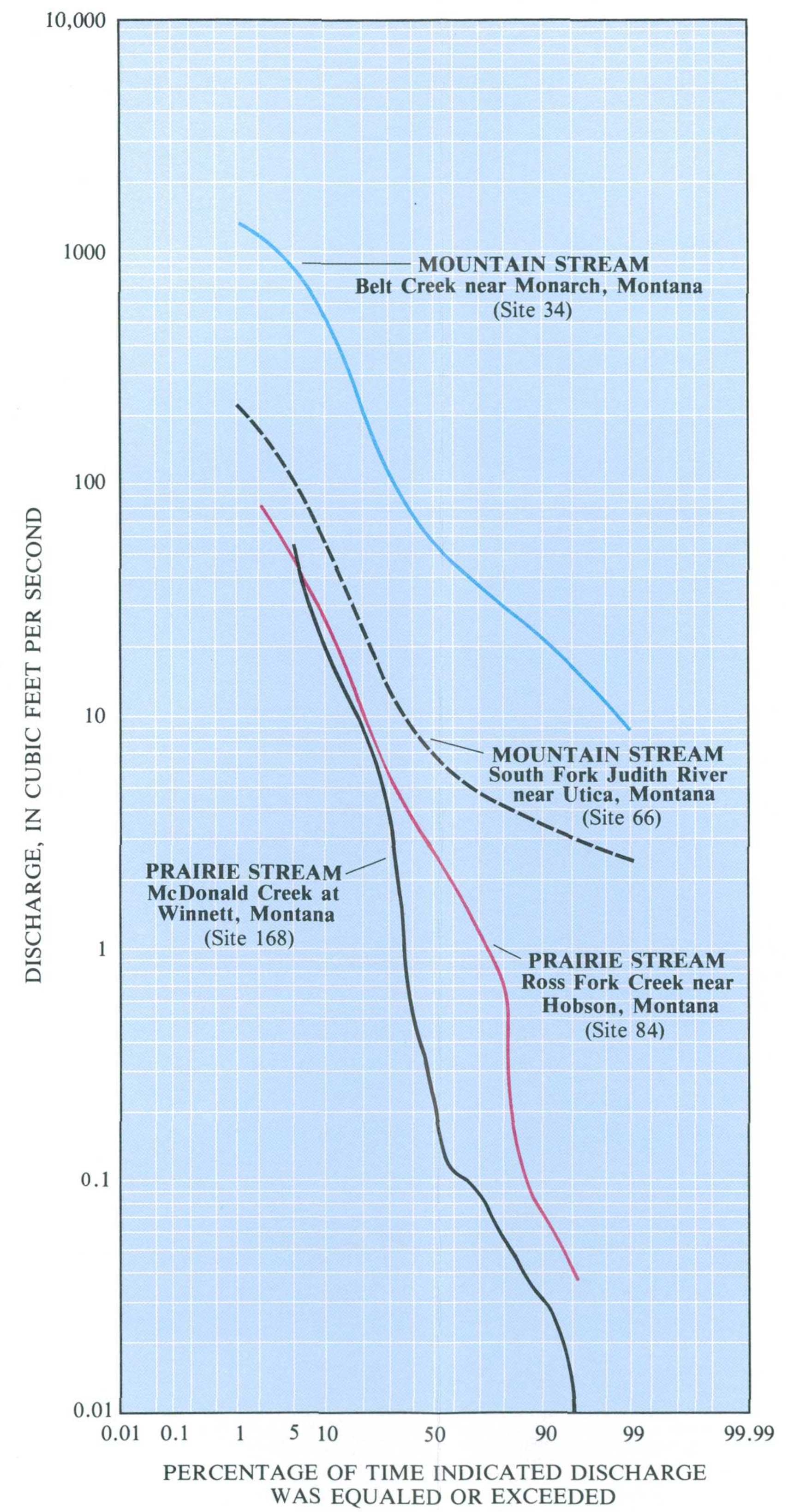


Figure 7.1-2 Flow-duration curves for selected streams.

Average-Flow Data Available for Most Streams

Average annual flow generally is small in prairie streams and larger in mountain streams.

Average-flow data are available for major streams draining Area 43. Average flow generally is small in streams that are ephemeral or intermittent. Such streams commonly occur in prairie areas. Zero or near-zero monthly flows have been recorded at most of the streamflow-gaging sites on prairie streams. The perennial-type mountain streams generally have much larger average flows. Belt Creek near Monarch (site 34), which is perennial and has a drainage area of 368 square miles, has an average annual flow of 192 cubic feet per second. Ross Fork Creek near Hobson (site 84), a prairie stream with a drainage area of 337 square miles, has an average annual flow of 14.0 cubic feet per second.

Average discharges at all selected streamflow-gaging sites having at least 5 years of record are given in table 7.2–1. In addition, average discharges are available in the annually published U.S. Geological Survey report "Water Resources Data for Montana."

Bar graphs for Belt Creek near Monarch and Ross Fork Creek near Hobson show average, maximum, and minimum monthly discharge, and average annual discharge (fig. 7.2–1). The two sites illustrate the difference between a stream with mountain headwaters (Belt Creek) and a stream draining mostly prairie (Ross Fork Creek). The mountain stream has most of its peak runoff in May and June as a result of melting of the mountain snowpack. The prairie stream has an earlier peak in March and April from snowmelt in lower areas and prolonged rainfall runoff through June with smaller volumes of discharge. During the winter, discharges are very small in prairie streams because of the lack of sustained groundwater inflow and ice formation caused by subfreezing air temperatures.

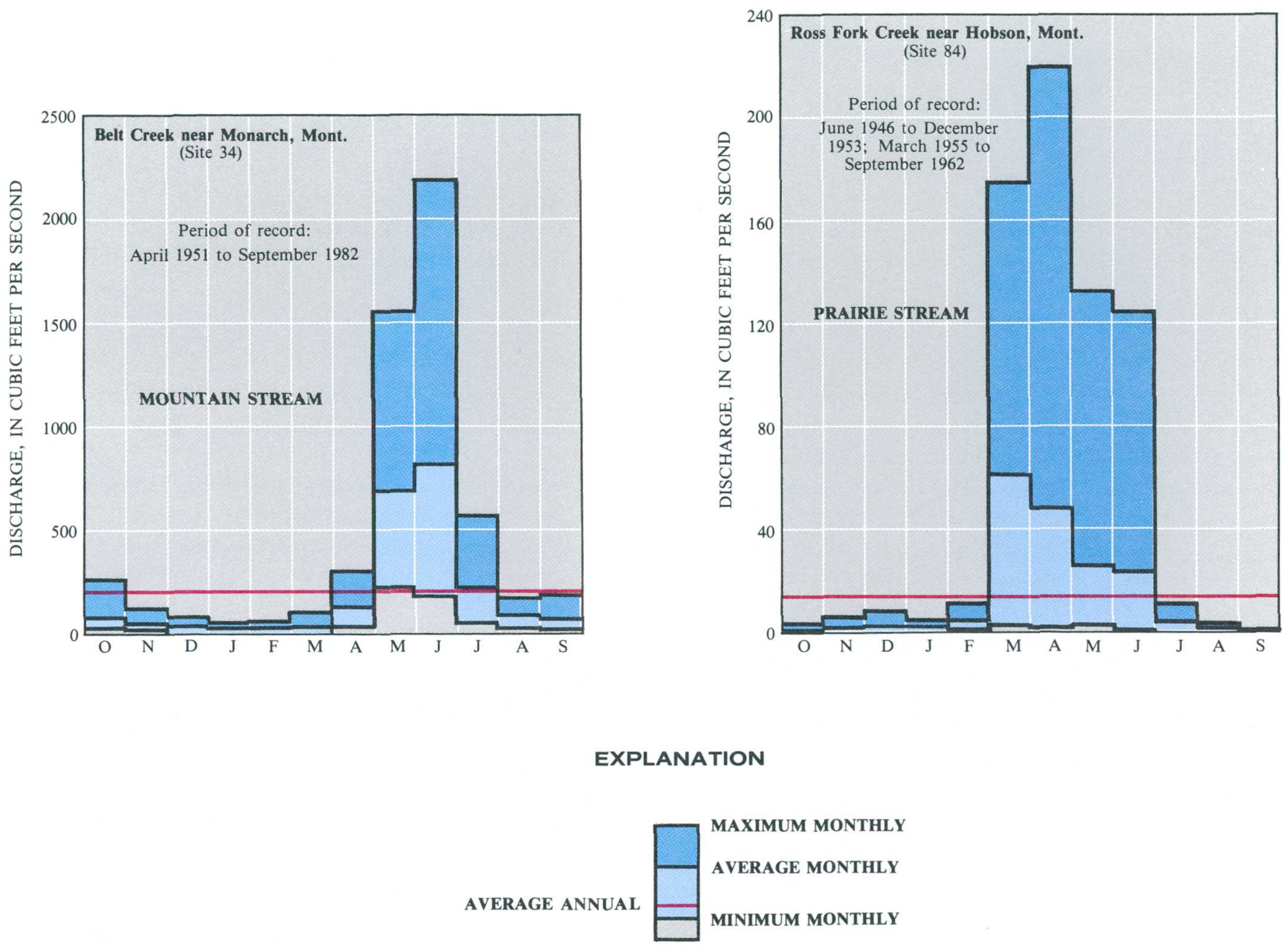


Figure 7.2-1 Average annual and monthly flows for Belt Creek near Monarch and Ross Fork Creek near Hobson.

Table 7.2-1 Average annual and monthly discharge at selected streamflow-gaging sites.

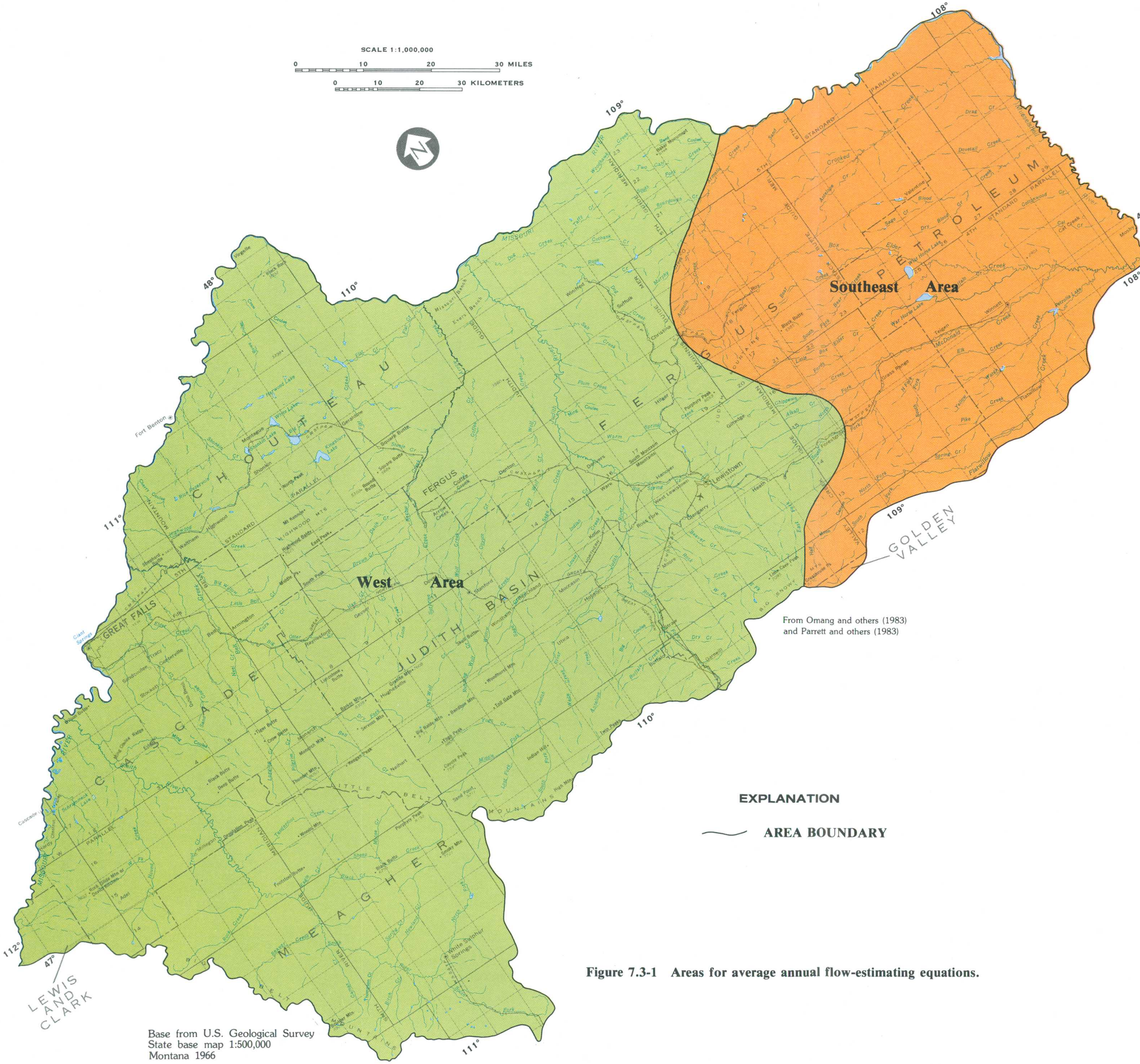
Site No. (fig. 6.2.1-1)	Site name	Record used for computation, by water year	Average discharge, in cubic feet per second, for period indicated												
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
3	Missouri River at Cascade.	1902-15	4,320	4,370	3,480	3,120	3,500	4,810	7,420	11,600	18,900	7,800	3,410	3,360	6,360
5	Smith River near White Sulphur Springs.	1923-31; 1934-36	10.0	9.27	7.53	5.52	5.84	9.51	34.0	58.7	57.5	21.6	11.3	8.83	20.7
8	Newland Creek near White Sulphur Springs.	1946-53	1.88	1.41	1.03	.84	.93	.88	2.78	7.74	7.77	4.23	2.73	2.20	2.87
9	Newland Creek near dam site, near White Sulphur Springs.	1950-57	6.12	3.57	2.83	2.06	2.13	3.36	11.6	20.9	28.7	14.7	11.0	7.70	9.54
10	Smith River near Fort Logan.	1978-83	130	116	116	95.6	128	199	223	389	502	282	109	111	200
13	Sheep Creek near White Sulphur Springs.	1941-72	15.6	12.9	10.4	9.22	9.10	9.34	20.6	94.8	115	43.2	23.2	18.0	31.9
17	Smith River near Eden.	1951-69	169	150	110	99.4	137	179	393	955	1,190	374	158	154	338
23	Missouri River near Ulm.	1957-83	5,220	5,690	5,960	5,960	5,960	6,200	7,020	10,100	12,300	8,320	5,090	4,700	6,880
31	Missouri River near Great Falls.	1957-83	6,010	6,440	6,460	6,530	6,760	7,100	7,860	12,200	15,700	9,570	6,160	5,620	8,030
34	Belt Creek near Monarch.	1951-82	68.0	49.6	35.3	28.6	31.2	36.5	127	697	819	226	91.2	73.6	192
45	Missouri River at Fort Benton.	1891-1983	5,260	5,430	5,090	4,870	5,190	6,240	8,360	14,400	19,800	9,490	4,970	4,720	7,830
48	Missouri River at Virgelle.	1935-83	6,160	6,350	6,230	6,090	6,470	7,420	9,040	14,500	19,800	10,200	6,070	5,680	8,710
65	Middle Fork Judith River near Utica.	1972-79	10.6	5.33	2.19	.70	.46	1.62	14.4	155	265	85.6	27.3	14.7	49.4
66	South Fork Judith River near Utica.	1958-79	6.77	5.30	4.42	3.94	3.97	5.09	20.7	104	73.0	23.5	11.5	8.38	22.7
75	Judith River near Utica.	1920-75	12.5	9.30	6.01	3.68	3.26	3.86	22.5	194	271	85.0	28.5	16.2	54.8
84	Ross Fork Creek near Hobson.	1946-53; 1955-62	.97	2.12	2.66	2.09	4.90	62.6	49.4	26.7	23.7	3.88	1.11	.44	14.0
97	Big Spring Creek near Lewistown.	1932-57	109	108	108	106	106	108	107	106	109	106	106	109	107
109	Cottonwood Creek near Lewistown.	1946-48; 1950-51	2.59	1.73	1.18	.63	1.06	4.56	8.68	33.5	71.4	20.4	7.16	3.96	13.1
110	Cottonwood Creek near Moore.	1957-63	0	0	0	0	.02	.75	.30	31.8	61.3	8.78	.29	0	8.59
141	Wolf Creek near Stanford.	1950-54; 1955-62	3.74	3.21	2.67	2.39	2.32	2.43	3.27	4.49	24.5	6.90	4.99	4.03	5.59
153	Missouri River near Landusky.	1934-83	6,580	6,830	6,620	6,390	6,900	8,750	10,100	15,500	21,500	11,200	6,530	6,060	9,470
158	Flatwillow Creek near Flatwillow.	1911-32; 1934-56	13.8	15.1	13.4	11.7	13.6	24.4	44.4	62.6	81.0	33.5	13.8	10.2	28.5
159	Flatwillow Creek near Winnett.	1921-32; 1948-51	15.6	16.0	16.0	15.2	15.5	54.8	43.2	67.4	132	61.7	12.0	7.49	44.4
168	McDonald Creek at Winnett.	1930-32; 1934-45; 1953-56	1.79	2.61	2.50	2.23	6.57	10.5	10.5	18.7	67.0	18.9	3.49	2.23	13.1
172	Musselshell River at Mosby.	1929-32; 1934-83	75.0	80.8	78.1	75.3	198	536	343	586	998	332	110	103	301

Average Annual Flow of Ungaged Streams Estimated from Site Geography

Multiple-regression equations using channel geometry and site location have been developed to estimate average annual flow at ungaged sites.

Multiple-regression equations using channel-geometry measurements recently have been developed for estimating average annual flow at ungaged sites in Montana (Omang and others, 1983; Parrett and others, 1983). The estimating equations were developed for different geographic areas. To use these equations, active-channel width and bankfull width must be measured at the ungaged site. The equations generally are applicable to streams virtually unaffected by urbanization or regulation. Detailed information on the channel-geometry method and the use, accuracy, and limitations of the estimating equations are presented in reports by Omang and others (1983) and Parrett and others (1983).

Area 43 contains two geographic areas for estimating average annual flow (fig. 7.3–1): a western mountainous area and a southeastern plains area. Because most streams are perennial in the west area, one set of equations applies. In the southeast area, streams contain either discontinuous (ephemeral or intermittent) or continuous (perennial) flow, and two different sets of equations apply. Equations corresponding to the two geographic areas are given in table 7.3–1.



Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

EXPLANATION

AREA BOUNDARY

Figure 7.3-1 Areas for average annual flow-estimating equations.

Table 7.3-1 Regression equations for estimating average annual flow at ungaged sites in Montana using channel-geometry characteristics.

[W_{AC}, active-channel width, in feet; W_{BF}, bankfull width, in feet]

Estimating equation for average annual flow (Q_A), in acre-feet	Standard error of estimate (percent)
West area	
All streams	
$Q_A = 128\ W_{AC}^{1.70}$	38
$Q_A = 47.9\ W_{BF}^{1.85}$	42
Southeast area	
Ephemeral and intermittent streams	
$Q_A = 18.5\ W_{AC}^{2.01}$	58
$Q_A = 4.83\ W_{BF}^{2.03}$	79
Perennial streams	
$Q_A = 277\ W_{AC}^{1.43}$	47
$Q_A = 325\ W_{BF}^{1.24}$	73

Peak-Flow Data Presented for 38 Streamflow-Gaging Sites

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

Peak flows in Area 43 may result from either snowmelt or rainfall. Mountain streams typically have their annual peak flows in June from snowmelt mixed with rain. Most of the annual peak flows on prairie streams result from snowmelt in March and April, but the larger peak flows on small drainages generally result from rainfall during May through September.

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. 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 for annual peak flows to occur more or less often than predicted.

Peak flows having a 1-percent exceedance probability (recurrence interval of 100 years) are commonly used as the basis for flood insurance regulations or for evaluation of the effects of Federal construction projects on floods. The areas inundated by the "100-year flood" are mapped in some parts of Area 43 (see section 7.6).

Computed peak flows for exceedance probabilities of 50, 10, 4, 2, and 1 percent for 38 streamflow-gaging sites are presented in table 7.4–1. These sites have 10 or more years of record and are not subject to significant regulation or diversion of peak flows. Peak flows were calculated by the methods described by the U.S. Water Resources Council (1981).

Table 7.4–1 is best interpreted by examples. For instance, in row 2 of the column "50-percent exceedance probability" the value 120 means that for site 5, there is a 50-percent chance that the annual peak flow in any year will be greater than 120 cubic feet per second. Similarly, for the same site under the column "4-percent exceedance probability" the value 516 means that for site 5, there is a 4-percent chance that the annual peak flow in any year will be greater than 516 cubic feet per second.

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

Site No. (fig. 6.2.1-1)	Site name	Drainage area (square miles)	Discharge, in cubic feet per second, for specified exceedance probability, in percent				
			50	10	4	2	1
2	Wegner Creek at Craig.	35.0	103	432	771	1,130	1,590
5	Smith River near White Sulphur Springs.	30.7	120	353	516	657	836
7	Fivemile Creek near White Sulphur Springs.	6.42	14	48	76	103	134
8	Newland Creek near White Sulphur Springs.	7.27	14	46	72	96	123
11	Sheep Creek near Niehart.	5.23	57	112	144	170	200
12	Nugget Creek near Niehart.	1.50	9	24	35	44	55
13	Sheep Creek near White Sulphur Springs.	42.8	208	380	485	570	660
16	Trout Creek near Eden.	13.2	46	239	493	815	1,310
17	Smith River near Eden.	1,594	2,070	5,160	7,230	9,020	10,900
19	Smith River tributary near Eden.	1.44	3	27	61	104	169
20	Goodman Coulee near Eden.	22.1	81	396	707	1,030	1,470
23	Missouri River near Ulm.	20,941	17,400	31,000	38,500	44,000	49,000
31	Missouri River near Great Falls.	23,292	21,500	52,000	67,000	70,000	76,000
34	Belt Creek near Monarch.	368	1,530	3,320	4,490	5,470	6,600
35	Little Otter Creek near Raynesford.	39.5	42	194	355	532	771
45	Missouri River at Fort Benton.	24,749	27,200	51,000	65,900	78,300	92,000
46	Ninemile Coulee near Fort Benton.	16.9	166	1,530	3,270	5,290	8,080
48	Missouri River at Virgelle.	34,379	27,000	55,200	74,900	92,400	113,000
66	South Fork Judith River near Utica.	58.7	241	659	932	1,160	1,410
72	Judith River tributary near Utica.	7.15	19	111	200	288	399
75	Judith River near Utica.	328	466	1,100	1,510	1,830	2,170
84	Ross Fork Creek near Hobson.	337	394	1,820	2,840	3,680	4,560
100	Mill Creek near Lewistown.	3.53	15	67	119	171	236
110	Cottonwood Creek near Moore.	47.9	255	686	1,040	1,420	1,910
118	Bull Creek tributary near Hilger.	.99	20	63	92	117	144
141	Wolf Creek near Stanford.	112	18	130	300	531	909
143	Wolf Creek tributary near Coffee Creek.	1.73	39	522	1,390	2,650	4,750
148	Taffy Creek tributary near Winifred.	2.95	58	191	285	365	453
152	Missouri River tributary near Landusky.	3.39	55	692	1,660	3,020	5,120
153	Missouri River near Landusky.	40,987	31,400	68,300	93,500	116,000	141,000
165	North Fork McDonald Creek tributary near Heath.	2.24	12	53	96	139	191
166	Alkali Creek near Heath.	3.76	25	158	296	457	677
167	South Fork McDonald Creek tributary near Grassrange.	.51	11	54	98	147	210
168	McDonald Creek at Winnett.	421	351	1,130	1,760	2,300	2,900
169	Gorman Coulee near Cat Creek.	2.32	64	365	697	1,090	1,610
170	Gorman Coulee tributary near Cat Creek.	.81	36	190	354	537	771
172	Musselshell River at Mosby.	7,846	4,080	12,600	18,400	23,300	28,700
173	Cat Creek near Cat Creek.	36.5	93	554	1,010	1,440	1,950

Peak Flows of Ungaged Streams Estimated from Basin Characteristics

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

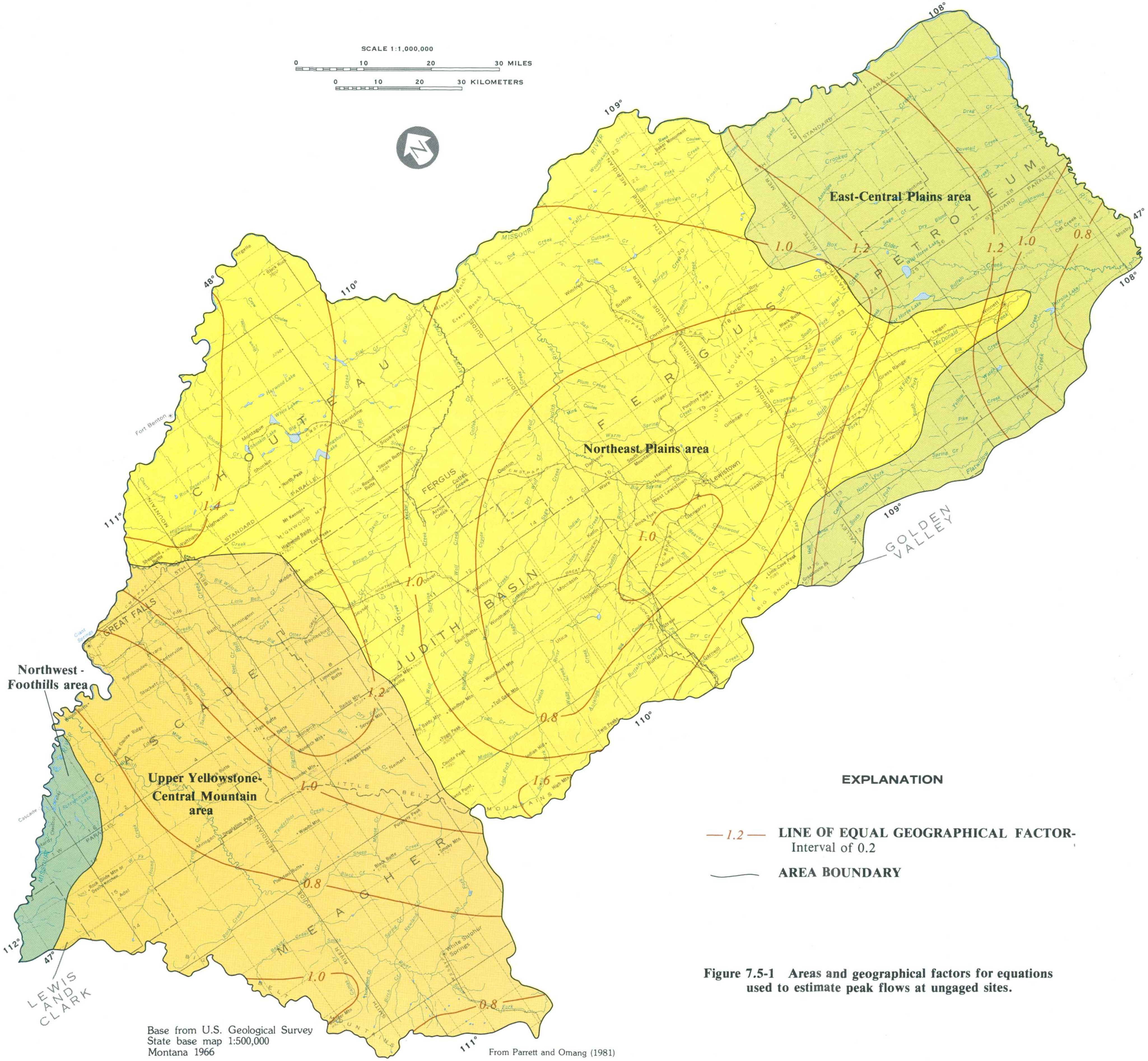
Multiple-regression equations have been developed for estimating flood peaks at ungaged-stream sites in Montana (Parrett and Omang, 1981). They are applicable in basins with drainage areas of less than 3,200 square miles. The equations apply only to unregulated streams where the drainage basins have not been altered significantly by man's activities. The equations thus may not be valid for areas with extensive surface mining.

The estimating equations were developed for different geographic areas. Within Area 43, there are four geographic areas for estimating peak flows (fig. 7.5–1), each with a corresponding set of equations (table 7.5–1). The four geographic areas have diverse topography and climate. The Upper Yellowstone-Central Mountain area is a mountainous, generally forested area where annual precipitation is large and runoff generally results from snowmelt. Annual flood peaks are smaller than in the other areas. The Northwest-Foothills area is mostly rolling plains and has the largest annual flood peaks of all the areas. The Northeast Plains area is predominantly flat prairie with variable runoff. In the East-Central Plains area flood peaks are larger and more variable than in the Northeast Plains area because this area is most affected by intense summer rainstorms.

All the equations contain a geographical factor (fig. 7.5–1). To estimate peak flows for streams that cross a geographic area boundary, the following weighting technique is used. First, compute the desired peak flow using the entire drainage area for each set of equations. Determine the proportion of drainage area that lies in each area, and multiply the peak-flow estimate from each area by the corresponding proportion. Add the two flow estimates to obtain a final, weighted peak-flow estimate.

More detailed information on the use, accuracy, and limitations of the estimating equations is presented in the report by Parrett and Omang (1981). Also described in that report are other techniques for estimating flood peaks on the Missouri and Musselshell Rivers, and on streams where some streamflow-gaging data are available.

Alternative equations using channel-geometry measurements for estimating peak flows at ungaged sites also have been developed for Area 43. These alternative equations are contained in reports of Omang and others (1983) and Parrett and others (1983).



EXPLANATION

— *1.2* — **LINE OF EQUAL GEOGRAPHICAL FACTOR-** Interval of 0.2

—— **AREA BOUNDARY**

Figure 7.5-1 Areas and geographical factors for equations used to estimate peak flows at ungaged sites.

Table 7.5-1 Regression equations for estimating peak discharges at ungaged sites in Montana.

[A, drainage area, in square miles; E, average basin elevation, in feet above sea level; HE, percentage of basin above 6,000 feet elevation; G_f, geographical factor determined from figure 7.5-1; and TI, average basin January minimum temperature, in degrees Fahrenheit]

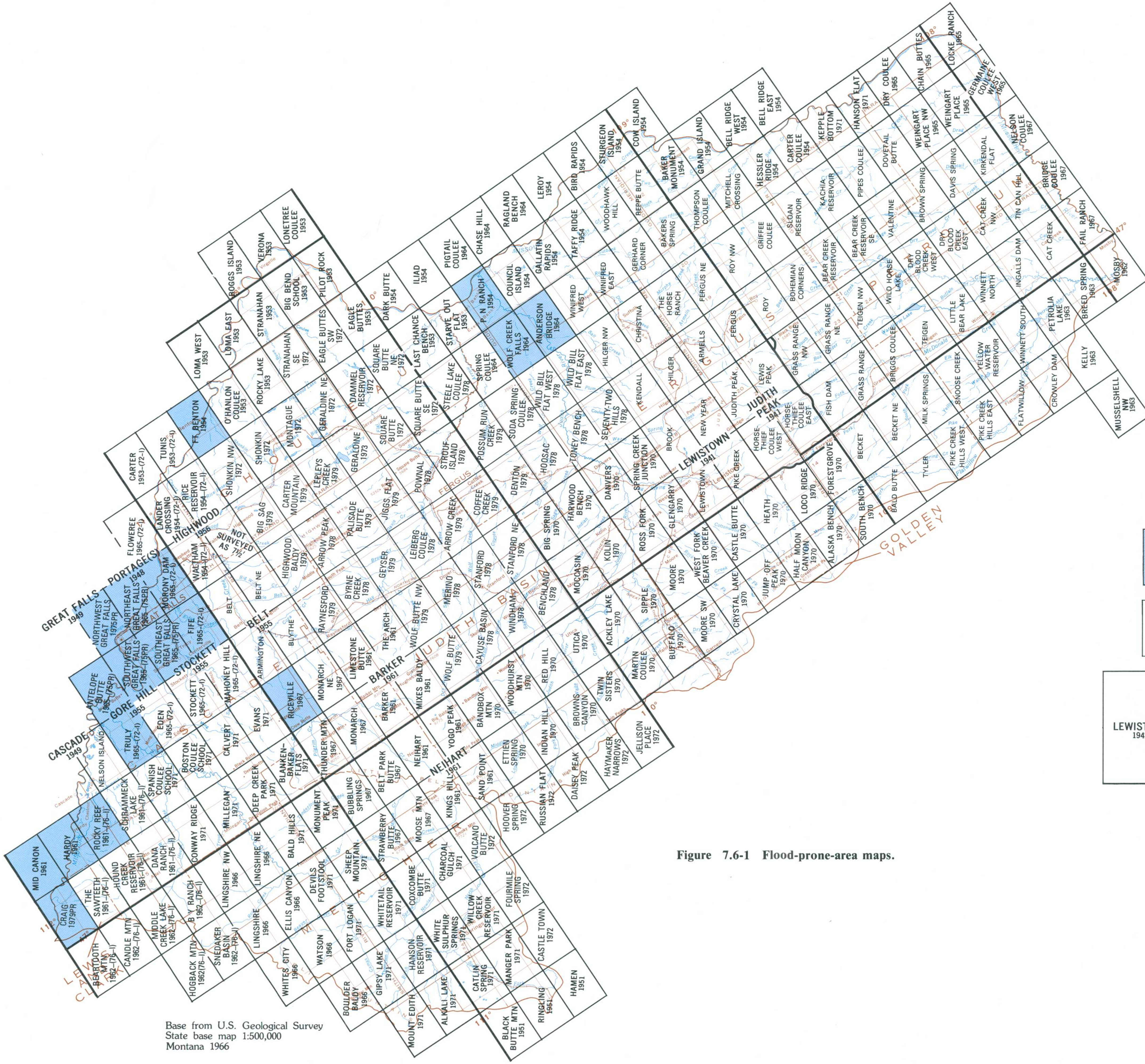
Exceedance probability (percent)	Estimating equation for peak discharge (Q), in cubic feet per second	Standard error of estimate (percent)
	Upper Yellowstone-Central Mountain area	
50	$Q = 0.146A^{0.87}(E/1000)^{3.88}(HE+10)^{-0.78}G_f$	57
10	$Q = 3.22A^{0.80}(E/1000)^{3.39}(HE+10)^{-1.02}G_f$	45
4	$Q = 10.6A^{0.77}(E/1000)^{3.20}(HE+10)^{-1.12}G_f$	42
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
10	$Q = 681A^{0.50}(E/1000)^{-1.31}G_f$	58
4	$Q = 1,100A^{0.48}(E/1000)^{-1.13}G_f$	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
	Northeast Plains area	
50	$Q = 26.3A^{0.65}(E/1000)^{0.53}(TI+10)^{-0.62}G_f$	61
10	$Q = 214A^{0.59}(E/1000)^{-0.11}(TI+10)^{-0.44}G_f$	39
4	$Q = 377A^{0.56}(E/1000)^{-0.28}(TI+10)^{-0.33}G_f$	40
2	$Q = 519A^{0.55}(E/1000)^{-0.38}(TI+10)^{-0.26}G_f$	43
1	$Q = 667A^{0.53}(E/1000)^{-0.46}(TI+10)^{-0.18}G_f$	47
	Northwest-Foothills area	
50	$Q = 0.342A^{0.52}(E/1000)^{2.96}G_f$	105
10	$Q = 3.87A^{0.45}(E/1000)^{2.63}G_f$	48
4	$Q = 9.68A^{0.43}(E/1000)^{2.48}G_f$	42
2	$Q = 17.7A^{0.42}(E/1000)^{2.37}G_f$	44
1	$Q = 30.7A^{0.40}(E/1000)^{2.27}G_f$	50

Flood-Prone-Area Maps Available

Flood-prone areas have been delineated on 17 topographic maps (scale 1:24,000) of the area.

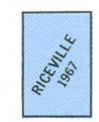
The National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 established programs for identifying areas subject to flooding. As of 1982, 17 flood-prone-area maps, at a scale of 1:24,000, have been prepared for selected 7 ½-minute topographic quadrangles within Area 43 (fig. 7.6–1). These maps show the area inundated by the "100-year flood" of certain streams; they were based upon existing stage data from streamflow-gaging records and miscellaneous measurements made during floods. The flood-prone-area maps were prepared by the U.S. Geological Survey, and are available from the Montana College of Mineral Science and Technology, Butte, Montana 59701.

Flood-insurance studies also have been completed for Cascade County and the towns of Great Falls and Belt, and for the towns of Lewistown, Denton, and Roy in Fergus County. Results of these studies, including maps, are available from the Montana Department of Natural Resources and Conservation, 1520 E. 6th Avenue, Helena, Montana 59620 and the Federal Emergency Management Agency, Denver Federal Center, Building 710, Denver, Colorado 80225.



Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

EXPLANATION



FLOOD-PRONE-AREA MAP
Includes name and date of topographic map

7½-MINUTE TOPOGRAPHIC MAP
Includes name and date

15-MINUTE TOPOGRAPHIC MAP
Includes name and date

Figure 7.6-1 Flood-prone-area maps.

Dissolved-Solids Concentrations Vary with Discharge

Dissolved-solids concentrations in the Missouri River are generally smaller and less variable than in other streams of Area 43.

Dissolved solids are derived primarily by the leaching of soluble minerals from soils and geologic formations underlying the drainage basin. The dissolved solids are composed largely of the cations calcium, magnesium, and sodium, and the anions bicarbonate, sulfate, and chloride. These ions, termed major ions, occur in varying concentrations depending on the type of subsurface minerals present. The predominant composition of dissolved solids (water type) indicates the individual ions occurring in the largest relative percentage.

Variations in the dissolved-solids concentration and composition in streams result primarily from changes in the amount and source of streamflow. During low flows, water in the streams is derived mostly from ground-water sources and will reflect the dissolved-solids concentration and water type of contributing aquifers. During high flows, most of the water entering the streams is from precipitation runoff. The relatively short period of time that the runoff is in contact with the soils of the basin provides little opportunity for the dissolution of minerals. Consequently, the increased volume of water during high flows reduces the dissolved-solids concentration by dilution.

In addition to streamflow variability and geology, other factors that affect the dissolved-solids concentration of a stream include irrigation return flows, saline seep, discharge from mines, and water losses from evapotranspiration. Variations in dissolved-solids concentrations and ion composition during typical low-flow and high-flow conditions are illustrated in figure 8.1–1.

Dissolved-solids concentrations during low flow in the western part of the area ranged from about 250 to 600 mg/L (milligrams per liter) at Belt Creek near Portage (site 41) and Highwood Creek near Portage (site 44). Concentrations during low flow in the eastern part of the area ranged from about 1,500 to 3,500 mg/L at Flatwillow Creek near Mosby (site 171) and Musselshell River at Mosby (site 172). The small concentrations of dissolved solids in Belt and Highwood Creeks during low flow probably can be attributed to extensive igneous and sandstone formations in their drainages and less irrigation than in Flatwillow Creek and the Musselshell River. The predominant ions in Belt and Highwood Creeks during low flow are calcium, magnesium, bicarbonate, and sulfate. Sodium is also present in significant quantities in Highwood Creek. The water type in Flatwillow Creek and the Musselshell River during low flow is sodium sulfate.

The dissolved-solids concentration generally decreases in these streams during high flows as a result of dilution. During high flows, concentrations ranged from about 150 to 250 mg/L in Belt and Highwood Creeks, and from about 500 to 1,300 mg/L in Flatwillow Creek and the Musselshell River. The percentage of calcium and bicarbonate commonly increased in relation to the other ions during high flow.

In contrast to sites 41, 44, 171, and 172, the concentration and composition of dissolved solids changed only slightly with discharge at the Missouri River sites. Dissolved-solids concentrations typically ranged from about 200 to 500 milligrams per liter at the Missouri River sites during all flows. Average concentration increased slightly in a downstream direction. Inflow from several major tributaries in basins intensively irrigated is a likely cause of the minor increase in dissolved solids. The water type at the Missouri River sites was primarily calcium bicarbonate. Sulfate was also present in significant amounts at the downstream site (site 153). The limited variability in dissolved-solids concentration and composition primarily results from the predominance of flow derived from mountain sources and partly from the storage and mixing of water in upstream reservoirs.

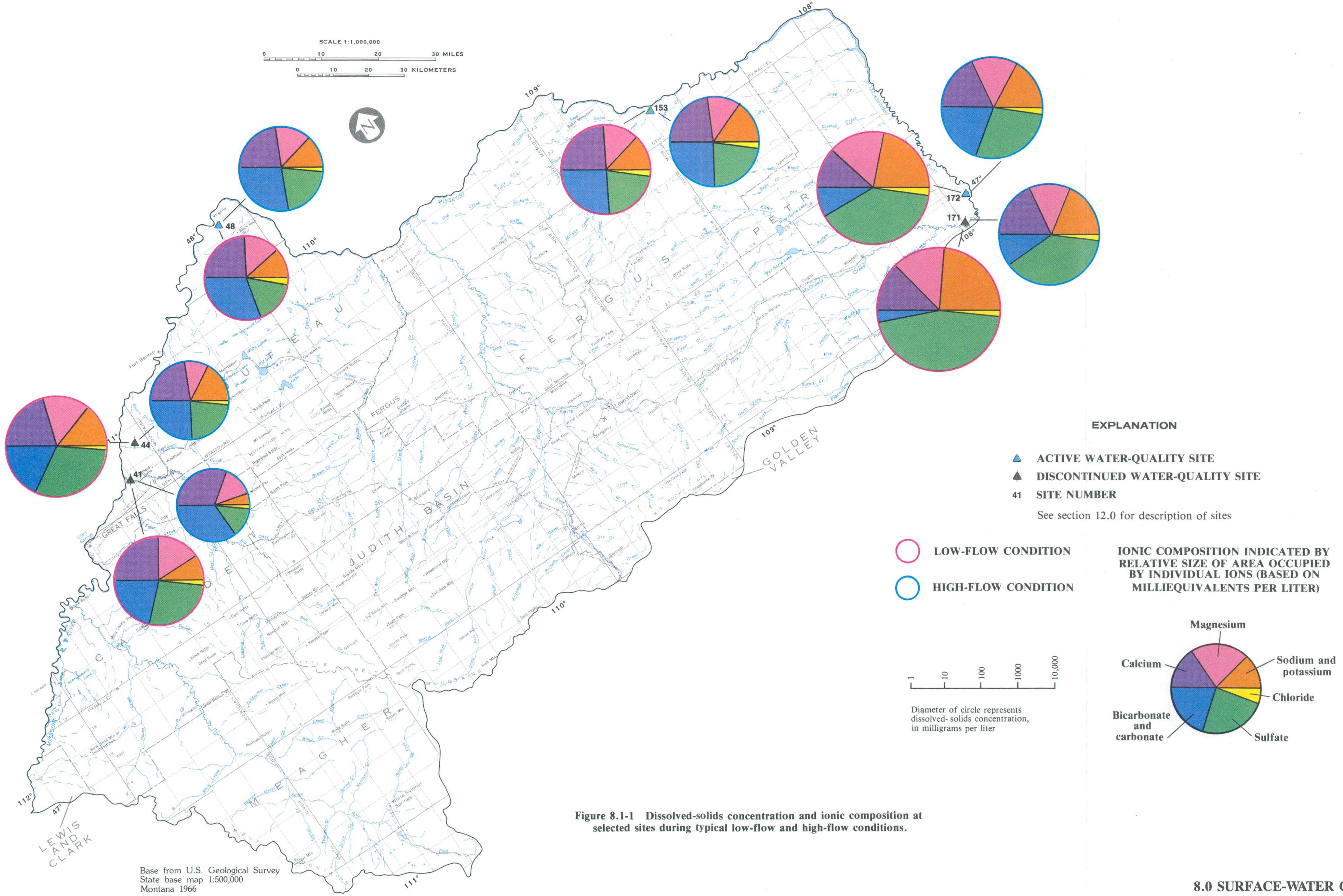


Figure 8.1-1 Dissolved-solids concentration and ionic composition at selected sites during typical low-flow and high-flow conditions.

Specific Conductance Can Be Used to Estimate Dissolved-Solids Concentration

Estimates of dissolved-solids concentrations can be used with streamflow records to calculate dissolved-solids loads.

The electrical conductivity of water, as measured by specific conductance, varies with the concentration of dissolved ions. Specific conductance is generally measured when water samples are collected for chemical analysis or when streamflow is measured. In addition, once-daily measurements of specific conductance are made at several sites. Specific-conductance measurements are inexpensive, in contrast to chemical analyses, and are thus a valuable tool for evaluating the major dissolved constituents in water.

If only the specific conductance is known, the concentration of dissolved solids or individual ions can be estimated by linear regression. In Area 43, paired values of specific conductance and dissolved-solids concentration were obtained from chemical analyses of water collected at seven sites on the Missouri and Musselshell Rivers, and Flatwillow, Belt, and Highwood Creeks (fig. 8.2–1). The relationship between specific conductance and the dissolved-solids concentration at these sites is shown in figure 8.2–2.

For sites where daily measurements of specific conductance are made, daily dissolved-solids concentrations can be estimated by use of the regression line developed for that site. Daily concentrations can be converted into average daily dissolved-solids loads using the equation:

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

where

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

Q = average daily stream discharge (obtained from streamflow records), in cubic feet per second;

C_{DS} = dissolved-solids concentration (obtained from figure 8.2–1), in milligrams per liter; and

K = 0.0027, a units conversion factor.

Monthly dissolved-solids loads during the 1981 water year, based on the summation of estimated daily loads, are shown for three sites in figure 8.2–3. The monthly loads at the three sites, although of different magnitude, follow a generally similar seasonal pattern. The largest loads are transported during late spring and early summer when streamflow is greatest.

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

EXPLANATION

▲ ACTIVE WATER-QUALITY SITE

▲ DISCONTINUED WATER-QUALITY SITE

45 SITE NUMBER

See section 12.0 for description of sites

Figure 8.2-1 Location of selected sites where regression equations relating specific conductance to dissolved-solids concentration were developed.

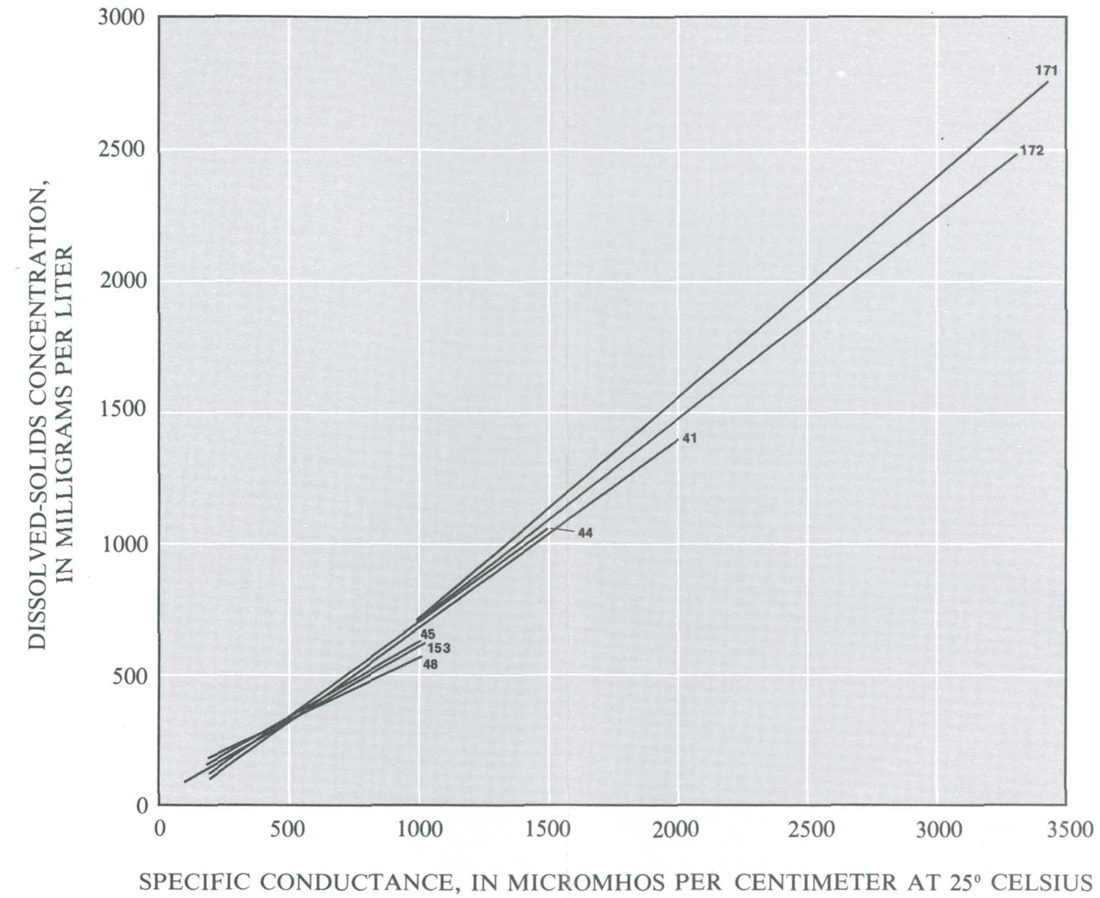


Figure 8.2-2 Relationship between specific conductance and dissolved-solids concentration at selected sites.

EXPLANATION
For Fig. 8.2-3

SITE 48

SITE 153

SITE 172

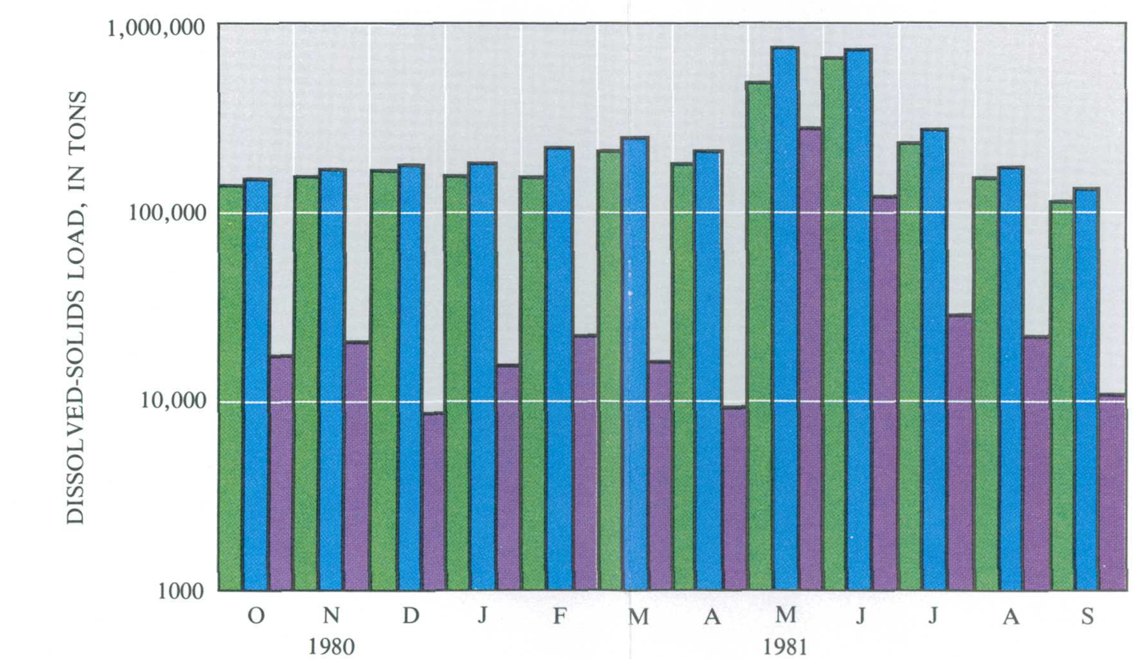


Figure 8.2-3 Monthly dissolved-solids loads, in tons, at selected sites during the 1981 water year.

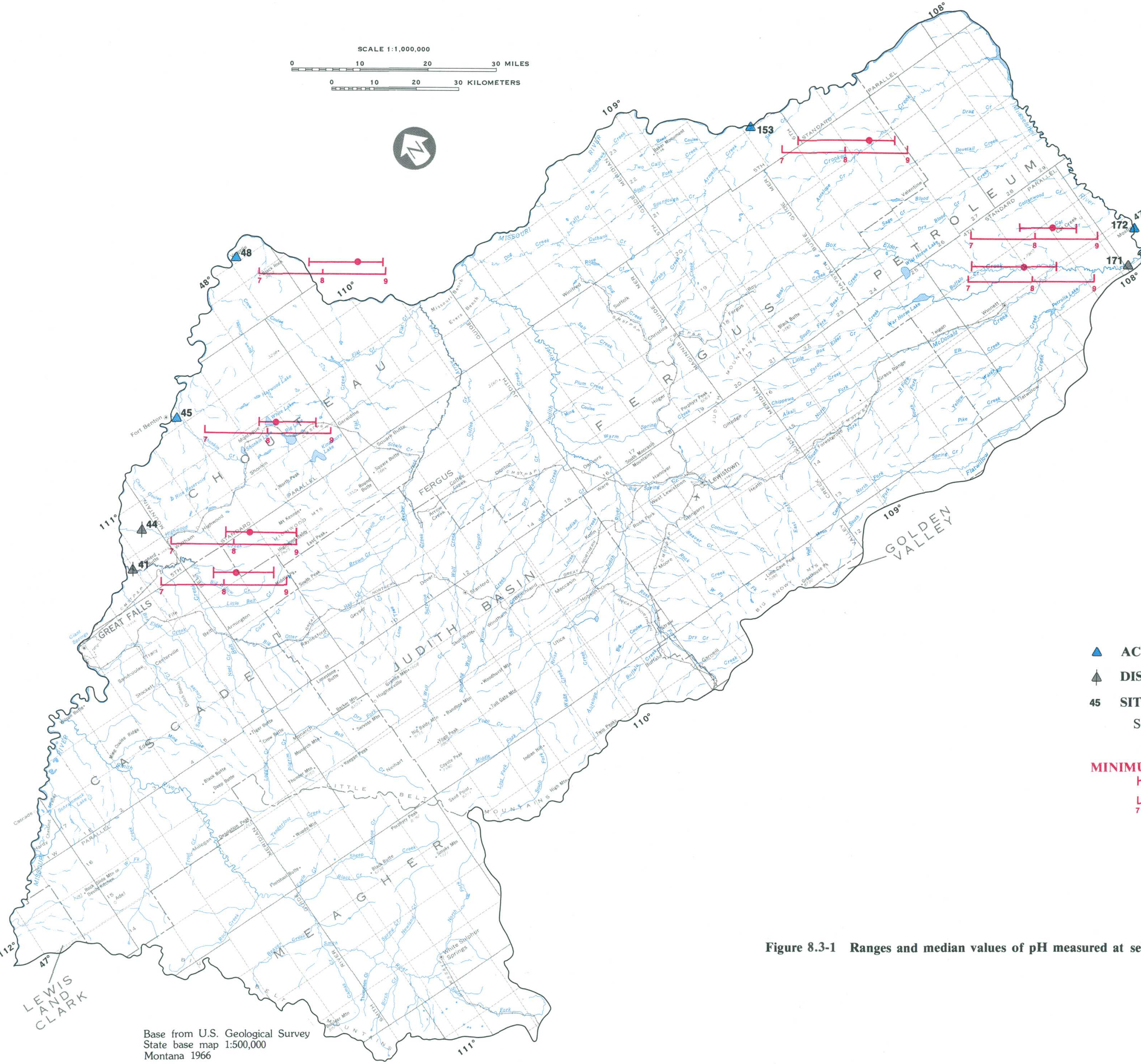
Stream pH Variable But Generally in Near-Neutral Range

The variation in pH measured in most streams is typical of well-buffered natural waters; however, acidic water exists at some abandoned mines.

Values of pH can range from 0 to 14. The pH of a neutral solution is 7, with smaller values indicating acidic conditions and larger values indicating alkaline conditions. Streams in areas not affected by pollution generally have a pH between 6.5 and 8.5 (Hem, 1970).

The pH of surface water can be modified substantially by numerous processes, both natural and man-induced. Precipitation is normally slightly acidic because of dissolved atmospheric carbon dioxide. Man-induced processes that can lower the pH of surface water to values less than 6.5 include oxidation of subsurface rocks exposed by mining (see section 5.3), industrial discharges, and atmospheric emissions. Photosynthesis by aquatic plants can increase the pH of surface water to values greater than 8.5 by removing carbon dioxide from solution. Inflowing ground water can either increase or decrease the pH of surface water, depending upon the mineralogy of the soil and geologic source. Most streams that have been sampled in Area 43 have generally large alkalinities, which provide a buffering capacity that prevents large changes in pH from persisting far downstream.

Measured pH values at U.S. Geological Survey water-quality sites in Area 43 ranged from 7.1 to 9.0, which is typical of most natural waters in Montana. The lower pH values generally are associated with rain and snowmelt. The pH of water discharging from abandoned mines in the Sand Coulee Creek drainage ranges from about 2.2 to 5.4 (Osborne and others, 1984). This acid mine drainage is a serious local phenomenon, but generally diminishes with distance from the mine. The largest pH values commonly were measured during low flows when the water in streams consisted primarily of ground-water seepage, and photosynthesis was occurring. Ranges in pH measured at selected U.S. Geological Survey water-quality sites in the study area are shown in figure 8.3–1.



EXPLANATION

▲ ACTIVE WATER-QUALITY SITE

▲ DISCONTINUED WATER-QUALITY SITE

45 SITE NUMBER

See section 12.0 for description of sites

MINIMUM MEDIAN MAXIMUM

7 8 9

pH, IN UNITS

Figure 8.3-1 Ranges and median values of pH measured at selected sites.

Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

Concentrations of Dissolved Trace Elements Rarely Exceed Water-Quality Standards

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

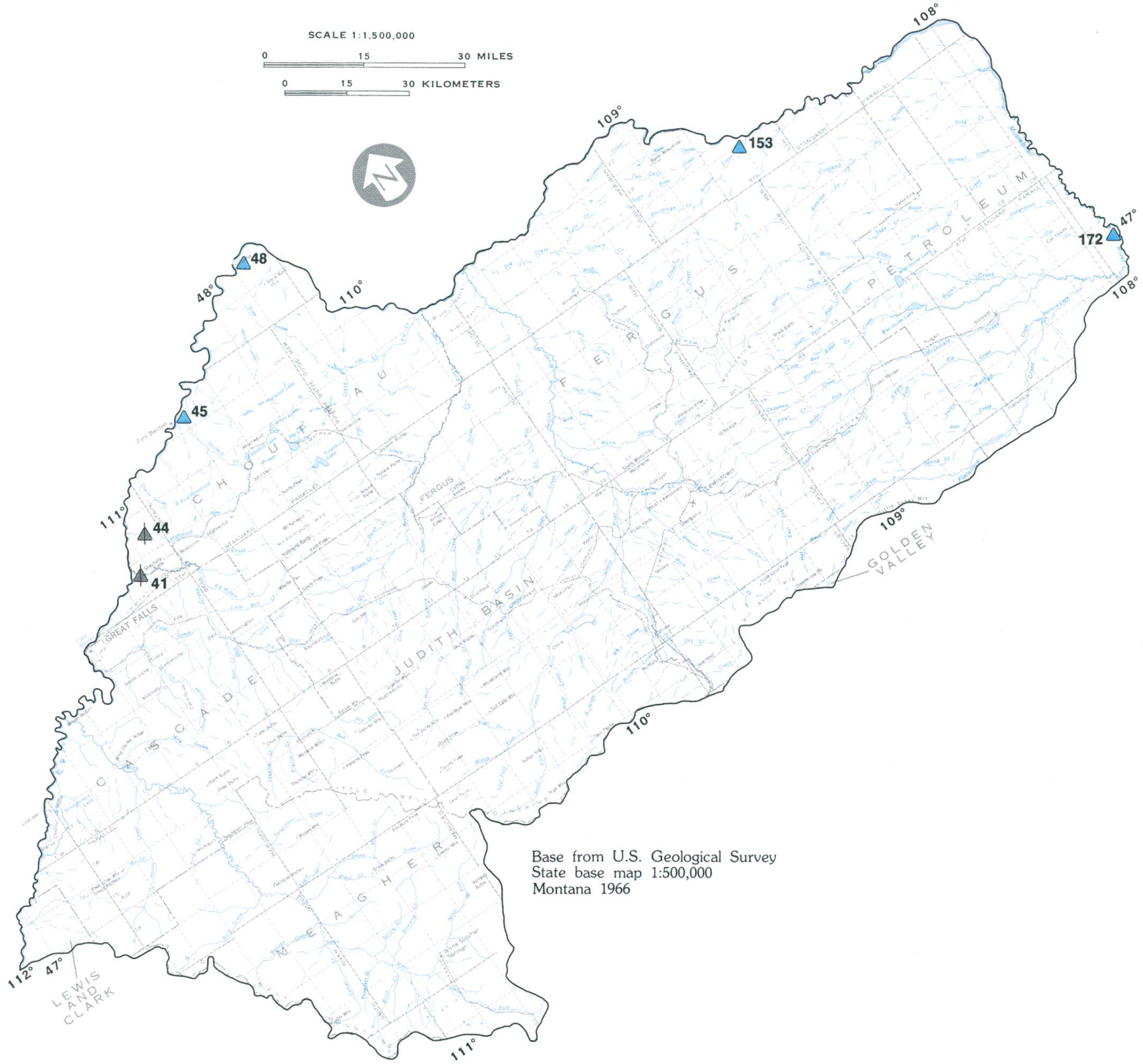
Trace elements are substances that generally occur in small concentrations compared to the major ions. Although some trace elements can be toxic, many are essential to plants and animals in small concentrations. Natural sources of trace elements are soils, geologic formations, and atmospheric fallout. Large concentrations can occur naturally in streams, but more commonly are associated with either manufacturing wastes or drainage from mined areas where the excavated materials contain large amounts of sulfide minerals. The acidic water that may develop would have the potential to dissolve certain minerals, thereby producing large concentrations of trace elements.

Trace elements either can exist in a dissolved phase or can be attached to sediment particles. Some trace elements bind to sediment particles and are transported primarily during high-flow conditions when large amounts of suspended-sediment and streambed material are being moved. Concentrations of trace elements analyzed from raw samples that have not been filtered to remove sediment include both the dissolved and suspended phases, and are referred to as total recoverable concentrations. Total recoverable concentrations are representative of concentrations that would be ingested when drinking untreated water. Concentrations of trace elements in the dissolved phase are determined from filtered samples and would be representative of concentrations in most sediment-free domestic water supplies.

Analyses of dissolved and total recoverable trace elements in water are available for six sites in Area 43 (fig. 8.4-1). In table 8.4-1, the median and range of concentration for each analyzed constituent are compared with maximum limits established by the U.S. Environmental Protection Agency (1977a,b; 1979) and the National Academy of Sciences and National Academy of Engineering (1973) for specific water uses. These limits are intended to provide a reasonable margin of safety for human health, aquatic life, crops, and livestock. Limits given for primary drinking-water standards are legally enforceable, whereas limits for secondary drinking-water standards, aquatic life, irrigation, and livestock represent suggested guidelines for long-term water use. The suitability of water for certain uses cannot be verified if the detection limit (indicated by a "<" in table 8.4-1) is larger than the water-quality standard.

The data in table 8.4-1 indicate that concentrations of dissolved trace elements at the six sampled sites rarely exceed maximum limits. Maximum concentrations of dissolved iron and manganese in the Musselshell River at Mosby (site 172) were the only occurrences of dissolved trace elements exceeding domestic water-supply standards. Because iron and manganese limits pertain to aesthetic considerations in domestic water use, the infrequent exceedance of these standards does not necessarily indicate a health hazard. Concentrations of dissolved trace elements at all six sites were less than the maximum limits established for aquatic life, irrigation, or livestock consumption. Maximum concentrations of dissolved trace elements most often occur during low-flow conditions. An important factor in maintaining generally small dissolved concentrations is the near-neutral pH in the streams, which prevents extensive dissolution of many trace elements.

Total recoverable concentrations of cadmium, chromium, iron, lead, and manganese occasionally exceed maximum limits for domestic water-supply standards at several sites. Total recoverable concentrations of iron and lead at several stations also occasionally exceed maximum limits for livestock consumption. In general, median total recoverable concentrations for all trace elements, except iron and manganese, are less than the recommended maximum limits for various water uses. Large concentrations of iron and manganese occur primarily during high flows when large amounts of sediment containing adsorbed trace elements are being transported; large concentrations of these elements are common in central and eastern Montana. Although total recoverable concentrations of iron and manganese frequently exceed limits for domestic water supplies, settling and other treatments would remove most of the sediment on which these constituents are adsorbed.



EXPLANATION

- ▲ ACTIVE WATER-QUALITY SITE
- ▲ DISCONTINUED WATER-QUALITY SITE
- 45 SITE NUMBER

See section 12.0 for description of sites

Figure 8.4-1 Location of selected trace-element sampling sites.

Table 8.4-1 Summary of trace-element concentrations measured at selected water-quality sites.

[Concentrations are in micrograms per liter. N, number of samples; <, less than; ND, not detected. Site numbers are from figure 8.4-1]

	Site 41			Site 44			Site 45			Site 48			Site 153			Site 172			
Constituent	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	Maximum limit [1]
Arsenic:																			50^a, 100^d
Dissolved	6	1-3	1	7	1-3	1	8	5-20	18	38	3-20	14.5	28	2-18	11.5	39	1-8	1	
Total recoverable	7	1-50	2	7	1-20	1	4	18-40	20	33	9-20	15	23	7-28	14	33	1-52	2	
Boron:																			750^d
Dissolved	29	10-210	40	29	20-190	60	21	40-190	70	--	--	--	26	70-130	90	--	--	--	
Total recoverable	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Cadmium:																			10^a, 50^e
Dissolved	7	ND-2	<2	7	<2-3	<2	8	<2-3	<2	38	ND-2	<2	27	ND-5	<2	39	ND-7	<2	
Total recoverable	7	ND-15	<2	7	ND-<2	<2	4	ND-2	<2	32	ND-<20	<2	23	ND-<20	<2	33	ND-<20	<2	
Chromium:																			50^a, 100^c
Dissolved	7	ND-<20	ND	7	ND-<20	<20	8	ND-<20	<2	37	ND-20	ND	28	ND-20	<2	39	ND-40	<2	
Total recoverable	7	<20-110	<20	7	ND-90	<20	4	ND-30	<20	33	ND-20	<20	24	ND-70	<20	33	ND-90	<20	
Copper:																			$1,000^b$
Dissolved	7	2-5	4	7	<2-6	2	8	<2-8	3.5	37	ND-20	4	28	2-9	4	39	ND-15	2	
Total recoverable	7	4-490	13	7	2-120	6	4	8-130	41	33	<2-90	20	24	3-170	20	33	4-180	20	
Iron:																			300^b, $1,000^c$
Dissolved	29	3-100	20	29	3-100	10	25	3-30	11	38	3-80	10	45	6-280	20	39	5-540	30	
Total recoverable	7	70-130,000	2,400	7	140-72,000	600	4	230-39,000	13,500	33	120-38,000	530	24	140-110,000	1,950	33	150-110,000	820	
Lead:																			50^a, 100^e
Dissolved	7	ND-8	1	7	1-4	2	8	1-4	1.5	38	ND-5	1	27	ND-34	1	39	ND-15	2	
Total recoverable	7	1-1,500	8	7	ND-70	5	4	2-99	8.5	32	ND-200	23	22	1-200	11	33	ND-200	48	
Manganese:																			50^b
Dissolved	7	3-20	6	7	2-10	5	8	2-10	3	38	1-30	9.5	28	1-20	6.5	39	<10-60	20	
Total recoverable	7	10-8,800	100	7	<10-1,800	20	4	20-1,400	60	34	<10-820	30	24	<10-2,000	60	32	20-2,400	80	
Mercury:																			2^a, 10^e
Dissolved	7	<.1-.1	<.1	7	<.1-.1	<.1	8	<.1-.1	<.1	38	<.1-.5	<.1	26	<.1-.5	<.1	--	--	--	
Total recoverable	7	<.1-.5	<.1	7	<.1-.2	<.1	4	<.1-.2	<.1	34	<.1-.5	<.1	23	<.1-.8	<.1	--	--	--	
Selenium:																			10^a, 50^e
Dissolved	7	<1-1	<1	7	1-2	1	8	<1-1	<1	38	<1-1	<1	28	<1-2	1	39	1-5	2	
Total recoverable	7	<1-3	<1	7	<1-3	2	4	<1-3	<1	34	<1-2	1	24	<1-6	1	33	1-5	2	
Zinc:																			$5,000^b$, $25,000^e$
Dissolved	7	3-50	9	7	3-12	4	8	3-10	5.5	38	ND-150	6	28	ND-40	6.5	40	ND-100	20	
Total recoverable	7	10-3,100	60	7	10-350	20	4	20-490	80	33	20-270	40	24	ND-540	45	30	10-430	40	

[1] a, Primary drinking-water standard (U.S. Environmental Protection Agency, 1977a)
b, Secondary drinking-water standard (U.S. Environmental Protection Agency, 1979)
c, Limit recommended for aquatic life (U.S. Environmental Protection Agency, 1977b)
d, Limit recommended for irrigation (U.S. Environmental Protection Agency, 1977b)
e, Limit recommended for livestock consumption (National Academy of Sciences and National Academy of Engineering, 1973)

Missouri River Transports More Than 11 Million Tons of Suspended Sediment per Year

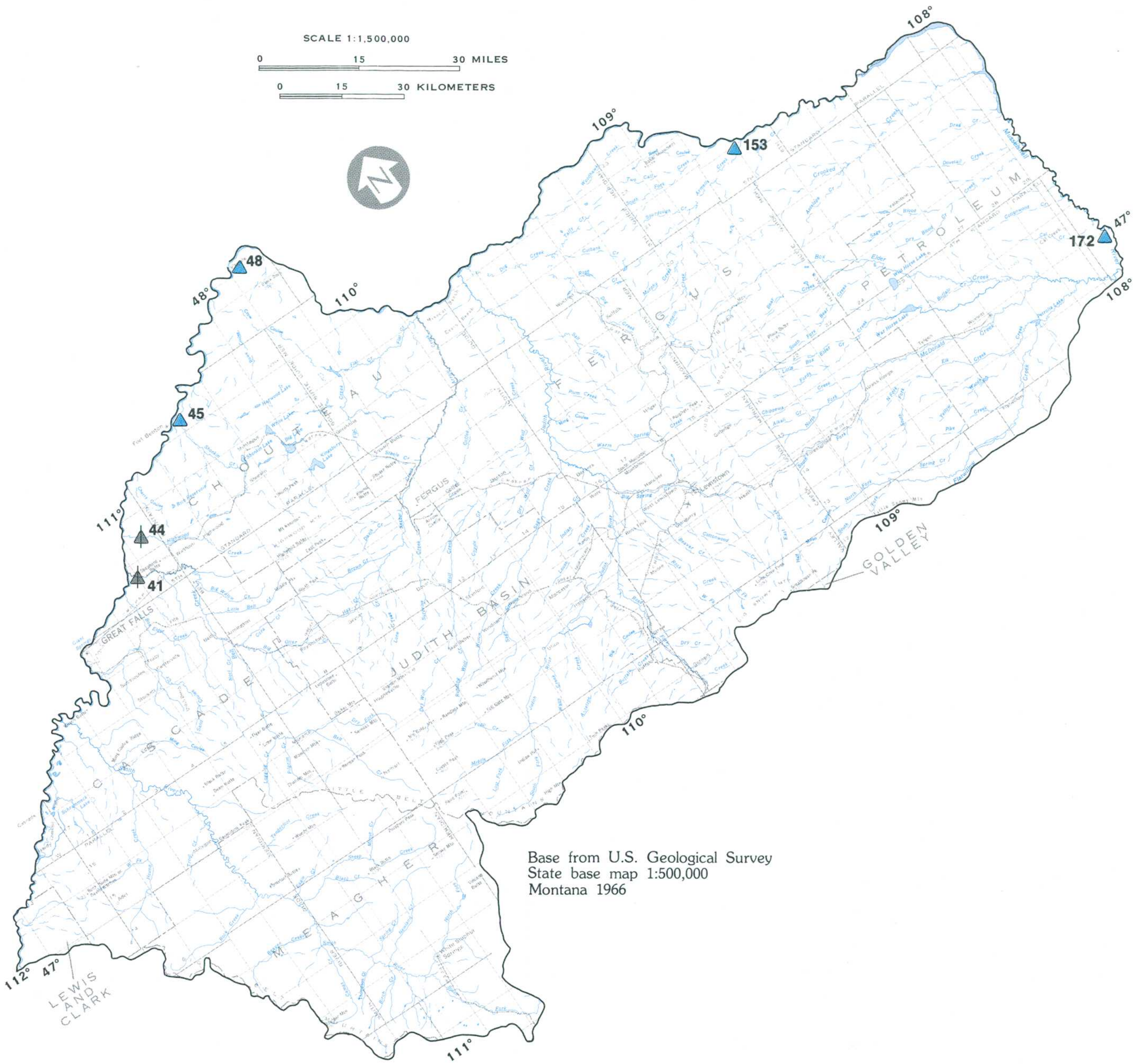
Most of the annual suspended-sediment load is transported during high flow.

Sediment transported by streams is derived from soil erosion caused by overland runoff during storms and by erosion of channel banks and beds during high flow. Erodability of soils depends largely on particle size, topographic relief, vegetative cover, rainfall duration and intensity, and land-use practices. Channel erosion is affected primarily by the magnitude and velocity of streamflow and the texture of bank and bed materials. Stream hydraulics and the available sediment supply determine the composition of sediment particle sizes transported by a stream. Generally, more than 70 percent of the sediment suspended in the streams of Area 43 is fine grained (less than 0.062 millimeter in diameter).

Concentrations of suspended sediment measured in the study area range from 2 to 19,500 milligrams per liter. Maximum concentrations of suspended sediment occur during storm and snowmelt runoff, when both overland flow and channel erosion contribute sediment to the streams. Minimum concentrations generally occur during low flows when overland runoff is absent and the hydraulic capacity to move sediment is decreased. The location of the six suspended-sediment sampling sites in Area 43 is shown in figure 8.5–1.

Daily suspended-sediment samples have been collected at the Missouri River near Landusky (site 153) for 11 years. Based on daily concentrations, the average annual suspended-sediment load at this site is 11.5 million tons. In general, most of the annual suspended-sediment load is transported during high flows (fig. 8.5–2). Although daily sediment data are unavailable for other sites in Area 43, tributaries of the Missouri River are thought to transport most of the year's sediment load during high flows. In small streams, such flows are infrequent.

The variation in suspended-sediment load with stream discharge is commonly shown by a sediment-transport curve. Sediment-transport curves for the sampling sites are shown in figure 8.5–3. As evidenced by their position on the right side of the graph, the three Missouri River sites (45, 48, and 153) transport less suspended sediment per given streamflow than the smaller streams (sites 41, 44, and 172). The steep and generally similar slopes for all the sites indicate that little sediment is transported by the streams at low flow; however, suspended-sediment loads increase rapidly in response to larger streamflows. The rate of increase is controlled by the texture of the available sediment supply, which, in Area 43, is predominantly fine grained. This fine-grained material is easily dislodged during storms that are commonly responsible for the higher flows.



EXPLANATION

▲ ACTIVE SUSPENDED-SEDIMENT SAMPLING SITE

▲ DISCONTINUED SUSPENDED-SEDIMENT SAMPLING SITE

45 SITE NUMBER

See section 12.0 for description of sites

Figure 8.5-1 Location of selected suspended-sediment sampling sites.

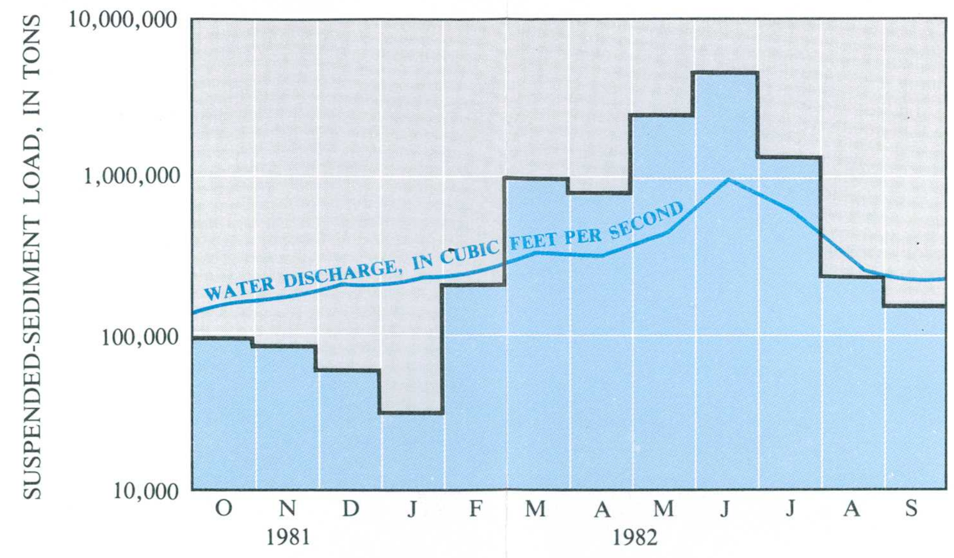


Figure 8.5-2 Monthly suspended-sediment loads at the Missouri River near Landusky, 1982 water year.

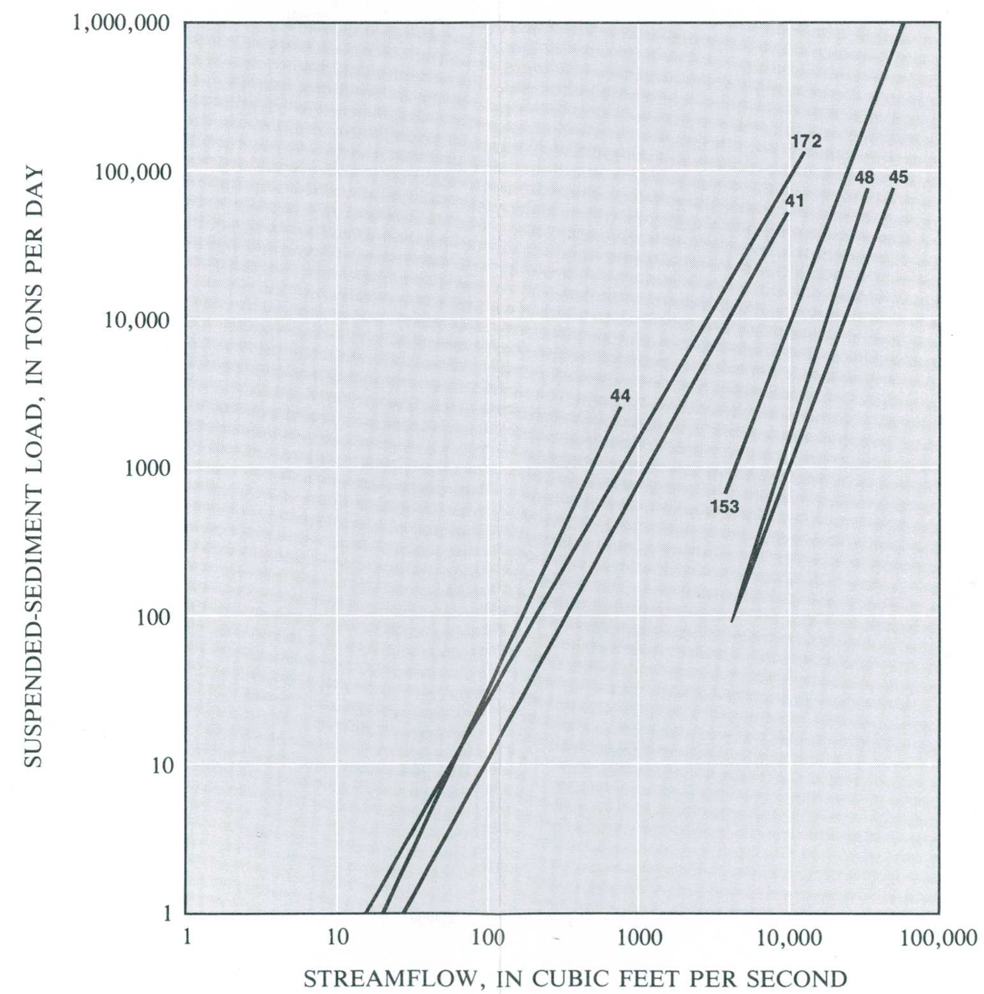


Figure 8.5-3 Relationship between streamflow and suspended-sediment load at selected sites.

Benthic Invertebrate and Periphyton Communities are Diverse

Dominant taxa of benthic invertebrate and periphyton populations are representative of water quality that is generally non-stressful to aquatic organisms.

Biological samples from streams in Area 43 have included benthic invertebrates (bottom-dwelling organisms of the class Insecta), periphyton (attached algae), phytoplankton (free-floating algae), and enteric bacteria (bacteria native to the intestines of warm-blooded animals). The numbers, composition, and diversity of these aquatic organisms commonly are used as indicators of water quality. Generally, populations that are composed of a nearly equal distribution of organisms among a large number of taxa are considered to be diverse and indicative of non-stressful water quality.

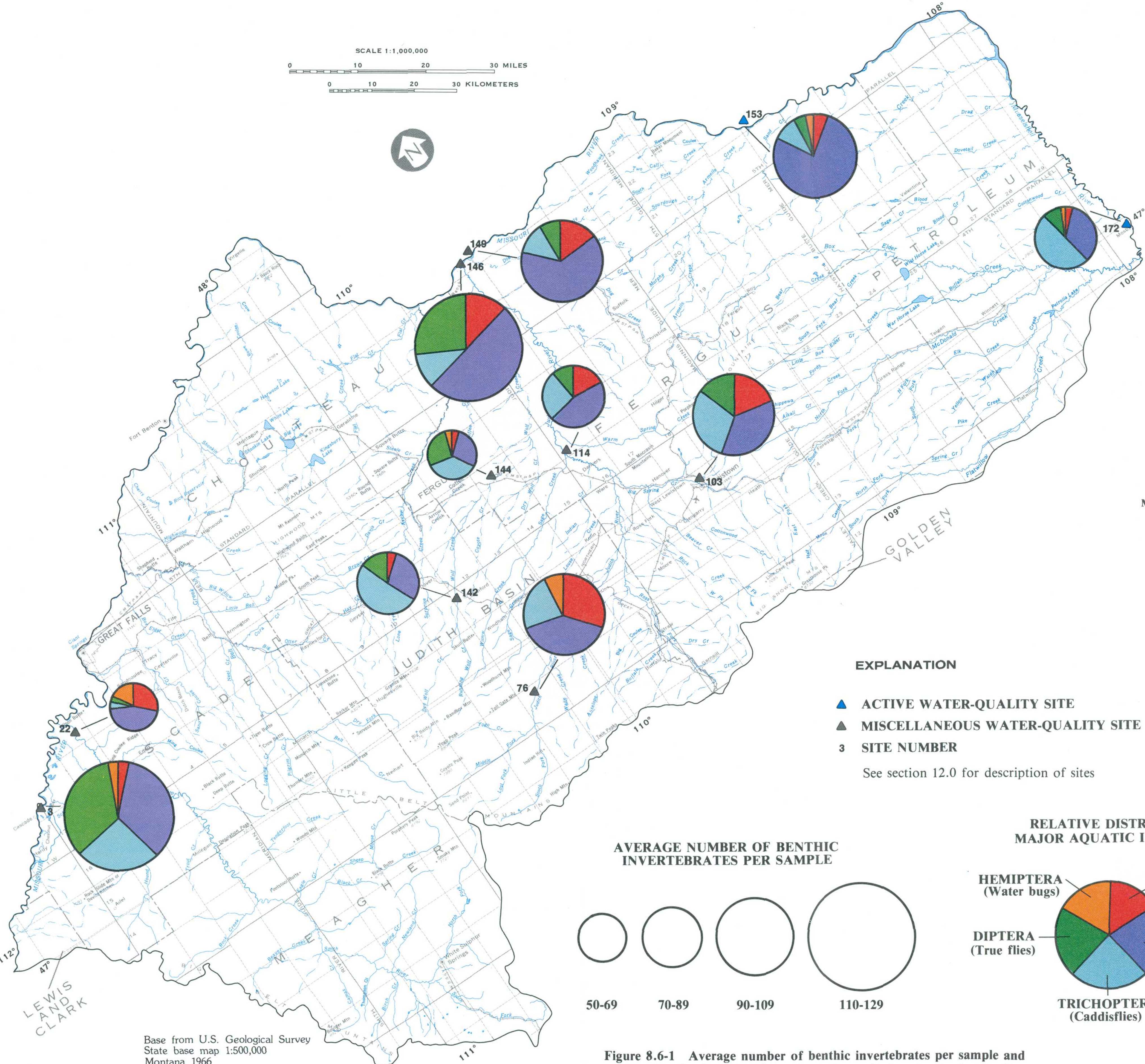
The average number and composition of aquatic insects collected at selected sites are shown in figure 8.6–1. At each site, except No. 3, the orders Plecoptera, (stoneflies), Ephemeroptera, (mayflies), and Trichoptera (caddisflies) were the predominant aquatic insects, together composing more than 70 percent of the total number of benthic invertebrates collected. Most species in these three groups, in contrast to most species in Diptera (true flies) and Hemiptera (water bugs), are considered to be intolerant of oxygen-consuming wastes, and their presence indicates adequate concentrations of dissolved oxygen. Generally, if adequate concentrations of dissolved oxygen are present, the concentrations of other water-quality constituents will remain within the tolerance range of most aquatic organisms.

The suitability of water-quality conditions for aquatic organisms is also indicated by the number of taxa and the diversity index. As a general reference, if the number of taxa in a stream is larger than 15 (Bahls and others, 1981), and the diversity index is equal to or greater than 2.6 (Wilhm, 1970), the water quality can be characterized as non-stressful to aquatic organisms. At sampled sites in Area 43, the number of taxa ranged from 7 to 14, thereby indicating some stress to invertebrates. In addition, average diversity index values at sites 3, 22, 142, 144, 153, and 172 were less than 2.6. Although these results indicate marginal conditions (possibly resulting from sediment, substrate limitations, or irrigation dewatering), statistically reliable samples of at least 100 organisms were not always obtained. Therefore, because most of the sampled taxa were classified as "pollution intolerant," water-quality conditions at sampling locations probably are adequate to support a healthy benthic invertebrate community.

Except in large, deep rivers, the periphyton community in most Montana streams is more important in terms of aquatic plant production and diversity than the phytoplankon community (Bahls and others, 1981). Periphyton characteristics measured at 11 sites in Area 43 are presented in table 8.6–1. Chlorophyll *a* production rates less than or equal to 0.50 milligram per square meter per day and biomass production rates less than or equal to 115 milligrams per square meter per day indicate streams unenriched with nutrients (Bahls and others, 1981). Of the sites having two or more measurements of primary productivity, only site 146 (Judith River at mouth, near Winifred) had chlorophyll *a* and biomass values indicative of unenriched waters. The larger values at the other sites indicate that nutrient concentrations potentially could stimulate plant production. However, the dominance of diatoms collected in samples (more than 25 species) and diversity indexes of about 3 or greater at each of the sites indicate that water-quality conditions generally would not be stressful to aquatic organisms.

Total coliform, fecal coliform, and fecal streptococcal bacteria commonly are used to assess the safety of water for drinking and swimming. The absence of these bacteria indicates bacteriologically safe water. Because most surface waters that are used for drinking supplies would be treated to remove these bacteria, the primary consideration given to bacteria concentrations relates to recreational uses of streams. A general criterion for the protection of people who directly contact water by swimming is a maximum concentration of 200 fecal coliform bacteria per 100 milliliters of water (U.S. Environmental Protection Agency, 1977b). Bacteria samples have been collected on a routine basis at four sites on the Missouri and Musselshell Rivers (sites 45, 48, 153, and 172). Minimum, maximum, and median concentrations of fecal coliform bacteria at these sites are illustrated in figure 8.6–2. Maximum concentrations generally occur at times of storm runoff when bacteria are flushed with sediment from overland sources into the streams. Median concentrations at the four sites indicate that the streams are generally satisfactory for direct body contact when overland runoff is absent.

Biological samples document the existing population characteristics of aquatic organisms in Area 43. The data base can be used to evaluate environmental quality and to detect future water-quality changes. Samples of benthic invertebrates and periphyton were collected during 1977–79 by the Water Quality Bureau, Montana Department of Health and Environmental Sciences; results are published in reports by Ingman and others (1979) and Bahls and others (1981). Samples of phytoplankton and bacteria were collected by the U.S. Geological Survey; results are published annually in the report series "Water Resources Data for Montana."



EXPLANATION

▲ ACTIVE WATER-QUALITY SITE

▲ MISCELLANEOUS WATER-QUALITY SITE

3 SITE NUMBER

See section 12.0 for description of sites

AVERAGE NUMBER OF BENTHIC INVERTEBRATES PER SAMPLE

50-69
70-89
90-109
110-129

RELATIVE DISTRIBUTION OF MAJOR AQUATIC INSECT ORDERS

HEMIPTERA (Water bugs)
PLECOPTERA (Stoneflies)
DIPTERA (True flies)
EPHEMEROPTERA (Mayflies)
TRICHOPTERA (Caddisflies)

Figure 8.6-1 Average number of benthic invertebrates per sample and relative distribution of major orders of aquatic insects at selected sites.

Table 8.6-1 Characteristics of periphyton collected from selected streams.[1]

Site No. (fig. 8.6-1)	Average primary productivity, in milligrams per square meter per day [2]		Number of diatom species	Average diatom species diversity index [3]
	Chlorophyll *a*	Biomass		
3	--	--	34	3.42
22	--	--	46	4.02
76	--	--	43	4.18
103	1.72	157	26	3.14
114	2.04	336	30	2.97
142	1.37	196	37	3.64
144	.96	157	30	3.06
146	.08	20	30	3.05
149	--	--	44	3.10
153	--	--	56	4.41
172	--	--	36	3.15

[1]Modified from Ingman and others (1979) and Bahls and others (1981).
[2]Missing values indicate fewer than two measurements available.
[3]Shannon-Weaver species diversity index (Weber, 1973).

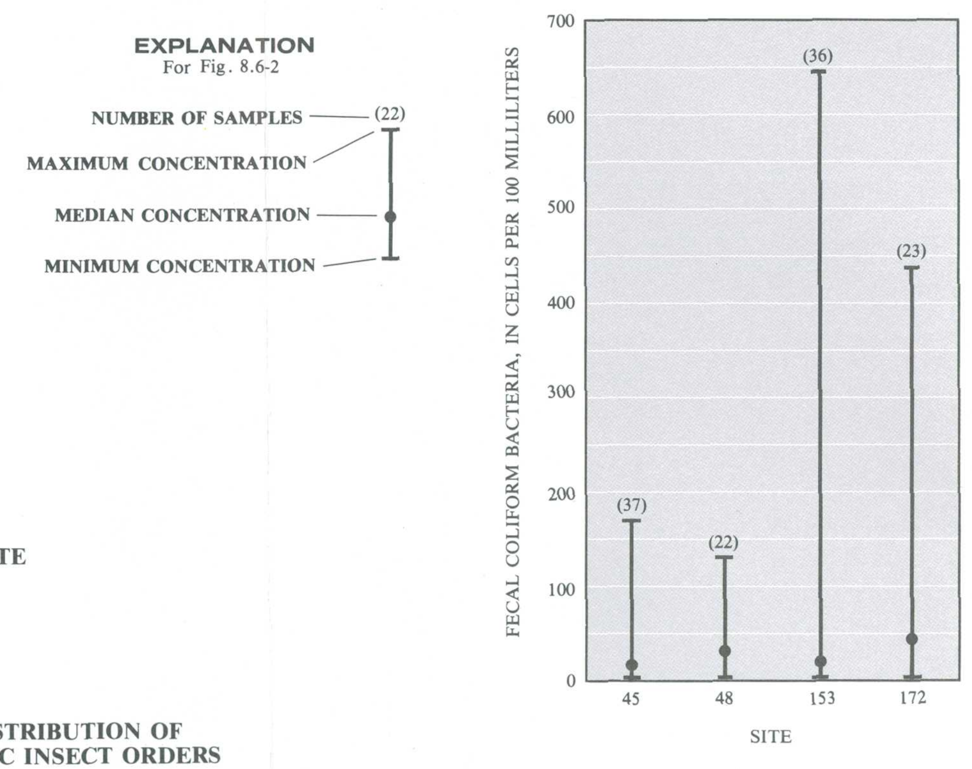


Figure 8.6-2 Minimum, maximum, and median concentrations of fecal coliform bacteria at selected sites.

Water Available from Sand, Gravel, Sandstone, and Limestone

Principally used aquifers are Quaternary deposits, Eagle Sandstone, and Kootenai Formation.

Locally, mixtures of sand and gravel contained in Quaternary alluvium, glacial deposits, and terrace deposits produce water in sufficient quantity for most stock and domestic needs (table 9.1–1). In some places, alluvium along major streams is capable of producing a sufficient quantity of water for small-scale irrigation use. Except for isolated sand and gravel lenses, glacial-drift deposits are generally poorly sorted and are not considered to be an aquifer. In the vicinity of Great Falls, glacial-lake deposits may yield as much as 40 gal/min (gallons per minute) from well-sorted and stratified beds of fine sand. Terrace gravels are generally thin, not fully saturated, and drain readily where they have been dissected by erosion; therefore they commonly yield only small to moderate quantities of water.

Tertiary sedimentary rocks crop out in the Smith River valley. Generally, only small yields are obtainable from these sediments. However, yields exceeding 1,000 gal/min have been obtained in at least two wells that intersected an ancient buried stream channel within this unit containing very permeable sand and gravel.

Cretaceous and Jurassic sedimentary rocks composed of a sequence of alternating sandstone and shale beds crop out or underlie Quaternary deposits in approximately two-thirds of Area 43 (fig. 9.1–1). The uppermost part of the Judith River Formation and the Eagle Sandstone generally consist of friable sandstone interbedded with shale and thin coal seams that produce enough water for domestic and stock needs. In some places, a massive sandstone at or near the base of the Eagle Sandstone may produce water at a rate of as much as 70 gal/min. The intervening Bearpaw Shale, Claggett Shale, and Telegraph Creek Formation are not considered to be aquifers.

The upper part of the Colorado Group, which is composed mostly of shale, is not an aquifer. The lower part of this unit yields an adequate supply of water for stock and domestic needs from a fine-grained sandstone at the base (First Cat Creek sandstone) and from thin, discontinuous sandstone beds in the section above it.

The basal part of the Kootenai Formation (Third Cat Creek sandstone) consists of a thick, crossbedded, fine- to coarse-grained, moderately permeable sandstone. A sequence of fine- to coarse-grained, water-bearing sandstone lenses is generally present in the middle part of the Kootenai Formation (Second Cat Creek sandstone). Because of their productivity, these units within the Kootenai Formation are used extensively for stock and domestic water supplies. Some small communities also obtain municipal supplies from them.

The Morrison Formation is generally not considered to be an aquifer. However, the coal bed commonly present at or near the erosional surface at the top of the formation may be hydraulically connected to the basal sandstone of the Kootenai Formation in places.

The uppermost part of the Swift Formation of the Ellis Group yields moderate to large amounts of water for domestic and stock supplies. It is used for supplies mainly in the foothills where the Kootenai Formation is not present or is unsaturated. Beneath the Swift Formation are several lithologically diverse units that generally are not considered to be aquifers. These units include the lower part of the Ellis Group, the Amsden Group, and the upper part of the Big Snowy Group. The fine-grained Kibbey Sandstone at the base of the Big Snowy Group has potential as a small-yield aquifer in the foothills. It may be hydraulically connected to rocks of the underlying Madison Group.

Limestones and dolomites of the Madison Group have the potential for yielding large quantities of water under pressure to the land surface. Well yields are affected substantially by the presence or absence of solution channels in the rock. Most wells currently producing water from the Madison were drilled as deep oil test holes.

The water-yielding potential of rocks older than the Madison Group is largely unknown. Precambrian crystalline basement rocks as well as Tertiary igneous and volcanic rocks have negligible primary permeability. Water yields are dependent locally on the degree of fracturing and the hydraulic connection of fractures to a source of recharge.

The depth of drilling required to intercept any aquifers other than the Quaternary deposits is largely dependent on the geologic structure of the region. In Area 43, the oldest rocks are exposed in the core of the mountains to the south. Formations as young as the Kootenai dip steeply away from the mountain front in an essentially north-northeast direction, descending within short distances to uneconomical drilling depths for a domestic or stock water supply. In the northern one-half of Area 43, the beds dip less steeply.

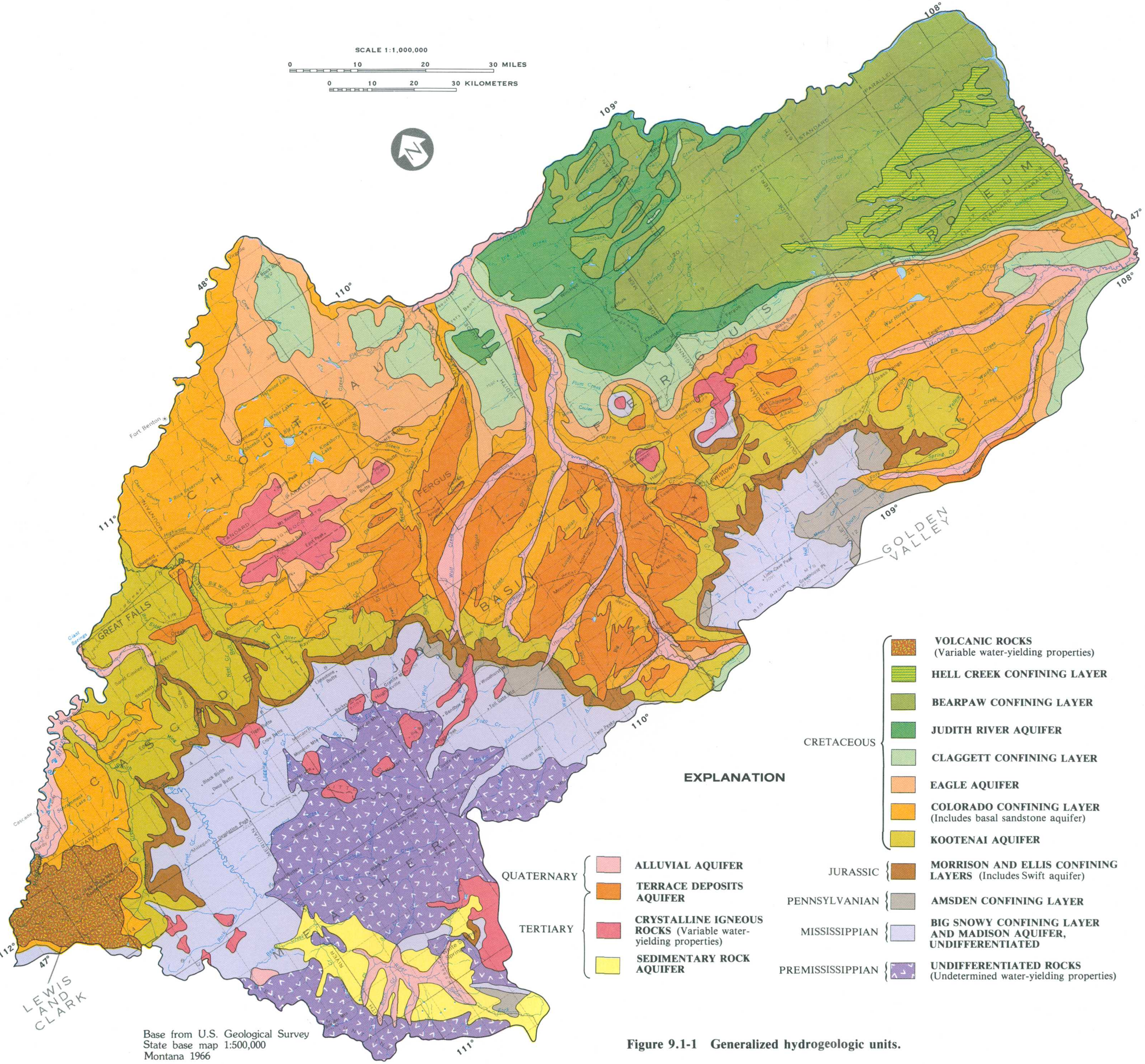


Figure 9.1-1 Generalized hydrogeologic units.

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

[gal/min, gallons per minute]

Erathem	System	Stratigraphic unit	Hydrogeologic unit	Water-yielding characteristics
Cenozoic	Quaternary	Alluvium	Alluvial aquifer	Yields as much as 30 gal/min to wells where materials are coarse, well-sorted, and adequately recharged.
		Glacial drift and lake deposits	--	Generally are not aquifers or yield only minimal quantities of water to wells. In isolated areas, glacial-lake deposits may yield as much as 40 gal/min.
		Terrace deposits	Terrace deposits aquifer	Well yields are adequate for domestic and stock use where deposits are widespread and undrained. Yields as much as 30 gal/min to wells.
	Tertiary	Volcanic rocks; Intrusive rocks	Crystalline igneous rocks	Generally relatively impermeable except where jointed and fractured. Yields water to small seeps and springs.
		Sedimentary rocks	Sedimentary rock aquifer	Very small yields except from sand and gravel of ancient buried stream channels where yield may be moderate to large.
Mesozoic	Cretaceous	Volcanic rocks	Volcanic rocks	Not likely to yield water except where fractured.
		Hell Creek Formation	Hell Creek confining layer	Sandstone may yield 5 to 15 gal/min to wells; shale commonly does not yield water or yields only small amounts of very mineralized water.
		Montana Group: Bearpaw Shale	Bearpaw confining layer	Generally not considered an aquifer. Meager supplies produced from sandy zones are very mineralized, almost always unfit for domestic supplies, and commonly unfit for livestock.
		Montana Group: Judith River Formation	Judith River aquifer	Sandstone commonly yields water suitable for domestic use. Yields to wells and springs generally are adequate for stock and domestic uses.
		Montana Group: Claggett Shale	Claggett confining layer	Generally not considered an aquifer. Subordinate sandstone yields small quantities of very mineralized water. Water commonly is unsuitable for domestic use.
		Montana Group: Eagle Sandstone	Eagle aquifer	Well yields are variable but generally adequate for stock or domestic use. Generally, yields 1 to 50 gal/min to wells but may locally yield as much as 70 gal/min. Some wells produce very mineralized water as a result of dissolution of evaporite beds in the middle shale unit.
		Montana Group: Telegraph Creek Formation	--	Not an aquifer.
		Colorado Group or equivalents: Niobrara Formation; Carlile Shale; Greenhorn Formation (Marias River Shale); Belle Fourche Shale; Mowry Shale (Blackleaf Formation)	Colorado confining layer	Shale is nearly impermeable. Numerous wells are completed in sandstone beds in the formation. Some wells yield water too mineralized for domestic use. Yields generally range from 0.5 to 25 gal/min but may be as much as 100 gal/min.
		Colorado Group or equivalents: Newcastle or Muddy Sandstone; Skull Creek Shale; First Cat Creek sandstone; Fall River Sandstone (Blackleaf Formation)		Sandstone near the base of the Blackleaf Formation provides water for stock and domestic uses in the Great Falls area.
		Kootenai Fm: Second Cat Creek sandstone; Third Cat Creek sandstone; Lakota Formation	Kootenai aquifer	Sandstone beds are moderately permeable and are used extensively for domestic and stock water supply. Yields to wells commonly are 1 to 65 gal/min and can be as large as 300 gal/min.
	Jurassic	Morrison Formation	Morrison confining layer	Not considered a reliable aquifer although some wells obtain water from fine-grained sandstone and limestone beds. In places may yield as much as 30 gal/min to wells.
		Ellis Group: Swift Formation	Ellis confining layer	Yields moderate to large quantities of water. Yields to wells commonly are 25 to 100 gal/min and can be as much as 220 gal/min.
		Ellis Group: Rierdon Formation		Not an aquifer.
		Ellis Group: Piper Formation		Not an aquifer.
Paleozoic	Pennsylvanian	Amsden Group: Alaska Bench Limestone	Amsden confining layer	A potential aquifer in the southern part of the Judith basin and along the northern flank of the Little Belt and Big Snowy Mountains where pre-Ellis Group erosion did not remove the limestone and sandstone beds.
		Amsden Group: Tyler Formation		Sandstone beds may yield water to wells; however, the formation is not generally regarded as an aquifer.
	Mississippian	Big Snowy Grp: Heath Formation	Big Snowy confining layer	Not an aquifer.
		Big Snowy Grp: Otter Formation		Not an aquifer.
		Big Snowy Grp: Kibbey Sandstone		Potential aquifer although fine-grained material may cause production problems such as caving and pumping of sand and silt. Locally, the quality of water may be adversely affected by solution of gypsum beds.
		Madison Group: Charles Formation	Madison aquifer	Potential aquifer if evaporite beds have been leached and if solution channels are extensive.
		Madison Group: Mission Canyon Limestone		Potential aquifer if solution channels are extensive.
		Madison Group: Lodgepole Limestone		Probably not an aquifer because the formation lacks collapse breccia zones and evaporite zones where solution channels could develop.
	Devonian	Undifferentiated	Undifferentiated rocks	Potential is unknown. Most of sequence is limestone, dolomite, shale, and crystalline rock and is not likely to yield water except where fractured.
	Cambrian	Undifferentiated		
Precambrian		Undifferentiated		

[1]Modified from Feltis (1973, 1977), Zimmerman (1966), and Balster (1980).

Ground-Water Flow Generally Northward and Eastward

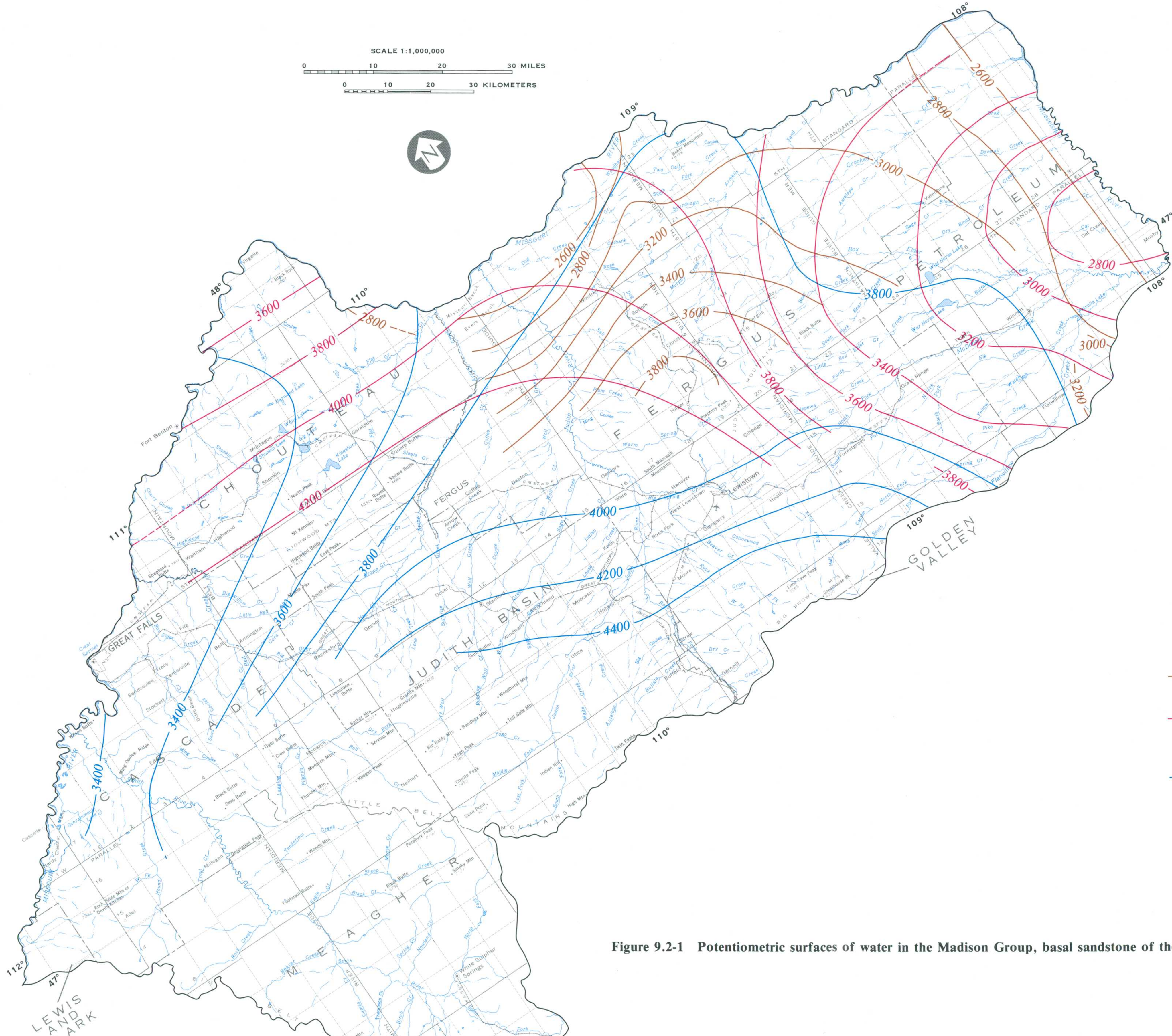
Most aquifers are artesian and have regional flow systems.

Water in most aquifers flows across Area 43 in a northerly or easterly direction. Recharge areas for the Madison Group and the basal sandstones of the Kootenai Formation are the Little Belt and Big Snowy Mountains. The Eagle Sandstone is primarily recharged from outcrop areas in the semiarid plains.

Potentiometric-surface contours for three major bedrock aquifers are shown in figure 9.2–1. The contours depict the altitude at which water would stand in tightly cased wells completed in the aquifer. Ground-water flow is approximately perpendicular to the contours in a downgradient direction.

Water in aquifers occurs under either water-table or artesian conditions. In general, water-table conditions exist near the outcrops where overlying confining beds are absent. Artesian conditions prevail where the aquifers occur at depth and are confined by an overlying unit that restricts vertical movement of water. Bedrock aquifers in Area 43 are, for the most part, under artesian conditions.

Recharge to the aquifers is primarily from infiltration of precipitation on the outcrops but may also occur from infiltration of streamflow across the outcrops, from interaquifer leakage, and, in the deeper aquifers, from subsurface inflow from outside the area. Flow patterns for most aquifers are regional, and discharge within the area is not evident except for Giant Springs near Great Falls, which is probably a discharge point for the Madison Group (Wilke, 1983).



EXPLANATION

POTENTIOMETRIC CONTOUR-- Shows approximate altitude of water surface in wells completed in the indicated unit. Dashed where approximately located. Contour interval 200 feet. Datum is sea level.

—*2800*--- **Eagle Sandstone and equivalent units** (from Levings, 1982d)

—*3200*--- **Basal sandstone of Kootenai Formation** (equivalent to Lakota Formation) (from Levings, 1982b)

—*3600*--- **Madison Group** (from Feltis, 1980b)

Figure 9.2-1 Potentiometric surfaces of water in the Madison Group, basal sandstone of the Kootenai Formation, and Eagle Sandstone.

Base from U.S. Geological Survey
State base map 1:500,000
Montana 1966

10.0 GROUND-WATER QUALITY

10.1 Major Constituents and Properties

Chemical Quality Among Aquifers Diverse

Ground water has a large range in dissolved-solids concentration.

Dissolved-solids concentrations in aquifers in Area 43 differ greatly, with values ranging from 141 to 53,200 milligrams per liter (fig. 10.1–1). Median dissolved-solids concentrations for the individual aquifers range from 412 to 2,560 milligrams per liter. Median dissolved-solids concentrations are largest for the near-surface alluvium and glacial deposits, the Judith River Formation, and the Eagle Sandstone and are smallest for aquifers stratigraphically below the Eagle Sandstone. The ranges in dissolved-solids concentrations are largest for the alluvium and glacial deposits, the Colorado Group, and aquifers stratigraphically below the Ellis Group; ranges are smallest for the Morrison Formation and the Ellis Group.

Calcium, magnesium, and sulfate are the predominant ions in water from the alluvium and glacial deposits, Colorado Group, Ellis Group, and deep aquifers below the Ellis. Sodium and sulfate are the predominant ions in water from the Judith River Formation, Eagle Sandstone, and Morrison Formation. Water from the Kootenai Formation contains primarily sodium, sulfate, and bicarbonate.

Water from the Judith River Formation and the Eagle Sandstone generally is "soft" to "moderately hard" according to the classification given by Hem (1970, p. 225). Water from other aquifers generally is "hard" to "very hard."

The pH of ground water in the area generally is in the near-neutral range. Median pH of water in the aquifers ranges from 7.4 to 8.0. The minimum pH of 3.4 occurred in water from glacial deposits in the northwestern part of the area and the maximum pH of 9.4 occurred in water from the Colorado Group and Eagle Sandstone in several areas.

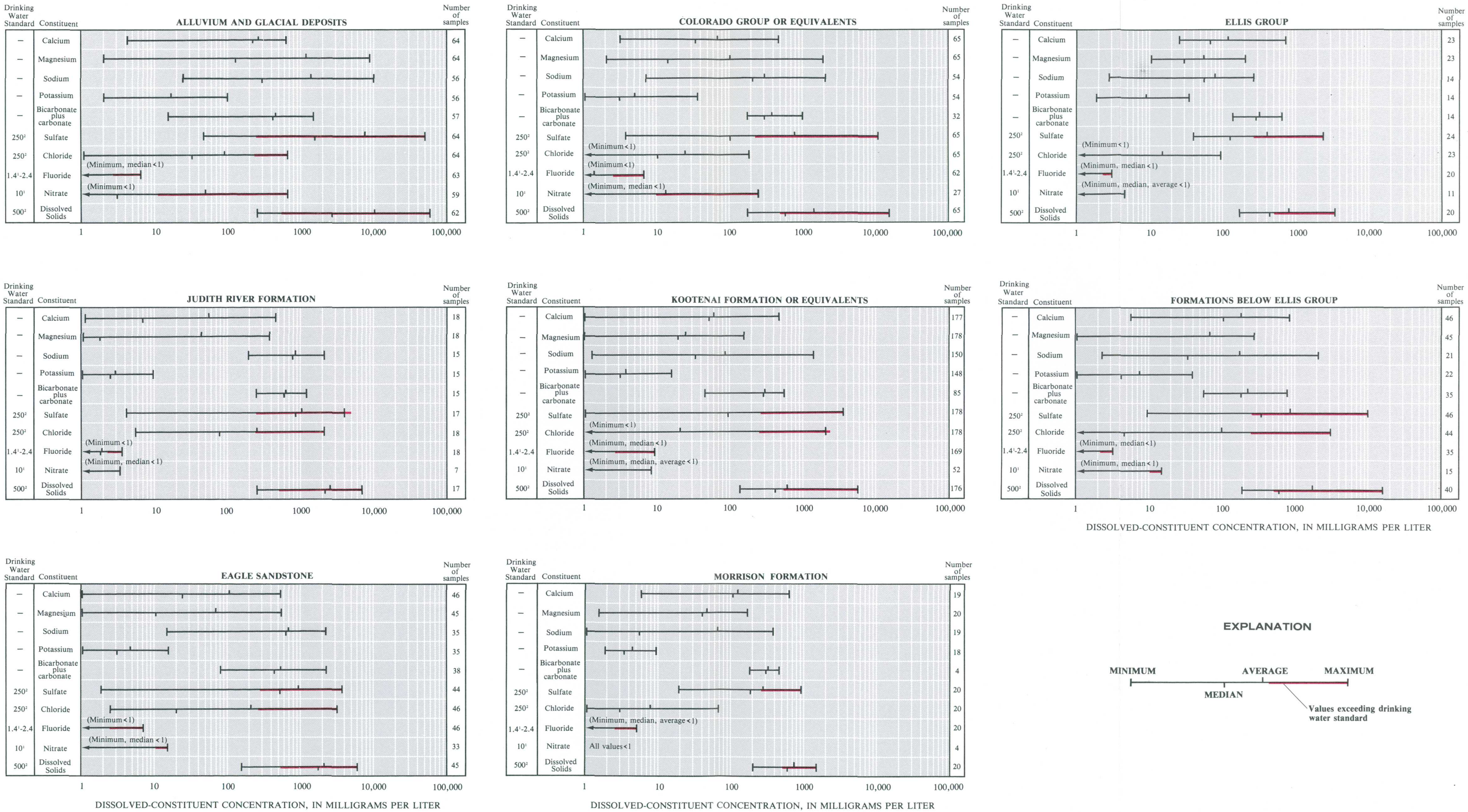
Some ground water in the area contains concentrations of nitrate and fluoride in excess of the primary drinking-water standards established by the U.S. Environmental Protection Agency (1977a). Concentrations of nitrate in water from the alluvium and glacial deposits exceeded the primary standard in about one-third of the samples (table 10.1–1). Nitrate concentrations only rarely exceed the primary standard in the Eagle Sandstone, Colorado Group, and formations below the Ellis Group. Concentrations of fluoride in water from all aquifers rarely exceed the primary standard, except in the Judith River Formation, where more than one-third of the samples had concentrations in excess of the standard. However, median concentrations of nitrate and fluoride in water from all aquifers are less than the primary standards.

Some ground water in the area contains concentrations of sulfate, chloride, and dissolved solids in excess of the secondary drinking-water standards of the U.S. Environmental Protection Agency (1979). The secondary standards relate primarily to the aesthetic quality of the water, such as taste, odor, color, and appearance, and do not necessarily indicate health hazards.

Table 10.1–1—Ratio of number of samples exceeding drinking-water standards for common constituents to total number of samples from each aquifer

	Constituent				
Aquifer	Fluoride	Nitrate (as N)	Sulfate	Chloride	Dissolved solids
Alluvium and glacial deposits	5/63	20/59	53/64	10/64	55/62
Judith River Formation	7/18	0/7	13/17	2/18	16/17
Eagle Sandstone	7/46	3/33	29/44	5/46	39/45
Colorado Group	6/62	4/27	24/65	0/65	37/65
Kootenai Formation	6/169	0/52	34/178	1/178	60/176
Morrison Formation	1/20	0/4	8/20	0/20	12/20
Ellis Formation	1/20	0/11	8/24	0/23	9/20
Formations below Ellis Group	3/35	1/15	24/46	2/44	24/40
	Primary standards[1]		Secondary standards[2]		
Drinking-water standards, in milligrams per liter	1.4–2.4[3]	10	250	250	500

[1] U. S. Environmental Protection Agency, 1977a.
[2] U. S. Environmental Protection Agency, 1979.
[3] Actual standard for fluoride varies with the annual average of maximum daily air temperature.



¹Primary drinking-water standard (U.S. Environmental Protection Agency, 1977a)

²Secondary drinking-water standard (U.S. Environmental Protection Agency, 1979)

Figure 10.1-1 Concentrations of major dissolved constituents in water from selected aquifers.

Trace-Element Concentrations Generally Similar Among Aquifers

Median concentrations of most trace elements are less than established standards for drinking water; however, maximum concentrations exceeded standards in some aquifers.

Variation in the median concentration of most dissolved trace elements is small from aquifer to aquifer, except for boron, strontium, iron, and manganese (table 10.2–1). Median concentrations of boron range from 60 μg/L (micrograms per liter) in water from the Morrison Formation to 1,200 μg/L in water from alluvium and glacial deposits. Median concentrations of strontium range from 440 μg/L in water from the Judith River Formation to 2,500 μg/L in water from aquifers below the Ellis Group. Median concentrations of iron range from 50 μg/L in water from the Colorado Group to 270 μg/L in water from the Kootenai Formation. Median concentrations of manganese range from less than 10 μg/L in water from the Judith River Formation to 110 μg/L in water from the alluvium and glacial deposits.

Most ground water in the area contains median concentrations of trace elements that are less than the primary drinking-water standards of the U.S. Environmental Protection Agency (1977a) (table 10.2–2). However, the maximum observed concentrations of lead for most aquifers exceed the primary standard. Maximum concentrations of selenium in water from alluvium and glacial deposits, Judith River Formation, Eagle Sandstone, and Colorado Group exceed the primary standard; maximum concentrations of mercury in water from alluvium and glacial deposits and the Kootenai Formation also exceed the primary standard. The maximum concentrations of cadmium in water from alluvium and glacial deposits and the Colorado Group exceed the primary standard. Concentrations of cadmium in water from other aquifers may also exceed the primary standard, although exceedance cannot be verified because the analytical detection limit was greater than the standard.

Median concentrations of most ground water in the area meet the secondary drinking-water standards of the U.S. Environmental Protection Agency (1979) for iron and manganese. However, maximum concentrations of iron and manganese in water from all aquifers exceed the secondary standards. The proportion of samples, by aquifer, exceeding primary and secondary drinking-water standards is indicated in table 10.2–2.

Table 10.2-1 Summary of dissolved trace-element concentrations in water from selected aquifers.

[Concentrations are in micrograms per liter. N, number of samples; <, less than; ND, not detected]

	Alluvium and glacial deposits			Judith River Formation			Eagle Sandstone			Colorado Group			Kootenai Formation			Morrison Formation			Ellis Group			Formations below Ellis Group			
Constituent	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	N	Range	Median	Maximum limit
Arsenic	17	0.6-5	2	4	2	2	9	2	2	7	2-4	2	19	<1-18	1	3	<1-2	<1	3	<1-3	2	15	<1-14	1	50[a], 100[c]
Boron	17	300-4,400	1,200	9	120-4,000	840	20	70-5,600	880	39	20-2,800	310	86	20-3,000	65	13	20-180	60	8	30-640	75	9	30-600	90	750[c]
Cadmium	14	<20-90	<20	--	--	--	1	5	--	29	<2-20	3	89	<2-<20	<2	16	<2-<20	3	8	<2-<20	4	17	ND-<20	<2	10[a], 50[d]
Chromium	17	<20-120	<20	4	<20	<20	10	<2-20	<20	33	<2-30	<2	88	ND-20	<2	16	<2-<20	4	9	<2-<20	3	17	ND-<20	10	50[a]
Copper	19	<20-120	20	4	<20-20	<20	10	<2-350	<20	33	<2-50	5	89	ND-52	<2	16	<2-34	<20	9	<2-<20	7	18	ND-<20	8	1,000[b]
Iron	42	<10-39,000	120	18	<10-1,300	65	45	<10-15,000	80	63	<10-4,000	50	167	<10-11,000	270	20	<10-5,400	140	19	<10-3,700	200	34	<10-13,000	110	300[b]
Lead	17	<50-770	80	4	50-80	50	10	<40-170	50	34	<40-380	40	90	ND-70	<40	16	<2-120	<40	9	<40-50	40	18	ND-70	<40	50[a], 100[d]
Manganese	34	<10-130,000	110	15	1-130	<10	34	<10-1,300	10	51	<1-510	11	147	<1-6,900	20	18	<1-240	10	13	<1-710	40	19	2-180	20	50[b]
Mercury	2	<.1-3	1.5	--	--	--	--	--	--	--	--	--	18	<.1-3	<.1	3	<.1-.5	<.1	2	<.1-.5	.2	14	<.1-5	<.5	2[a], 10[d]
Selenium	25	2-900	8	9	<1-29	<1	16	<1-190	2	11	<1-810	2	28	<1-2	<1	--	--	--	1	2	--	6	<1-1	<1	10[a], 50[d]
Strontium	26	90-13,000	2,400	9	70-2,400	440	20	40-12,000	660	39	10-8,700	480	103	1-3,300	550	13	140-6,000	740	8	70-7,900	1,750	9	280-10,000	2,500	--
Zinc	21	<20-320	30	4	<20-220	35	10	3-1,600	60	33	3-120	20	90	ND-2,000	30	16	3-2,500	25	9	20-630	80	17	ND-14,000	40	5,000[b], 25,000[d]

a, Primary drinking-water standard (U.S. Environmental Protection Agency, 1977a)
b, Secondary drinking-water standard (U.S. Environmental Protection Agency, 1979)
c, Limit recommended for irrigation (U.S. Environmental Protection Agency, 1977b)
d, Limit recommended for livestock consumption (National Academy of Sciences and National Academy of Engineering, 1973)

Table 10.2-2 Ratio of number of samples exceeding drinking-water standards for trace elements to total number of samples from each aquifer.

	Trace element									
Aquifer	Arsenic	Cadmium	Chromium	Lead	Mercury	Selenium	Copper	Iron	Manganese	Zinc
Alluvium and glacial deposits	0/17	5/14	2/17	11/17	1/2	12/25	0/19	9/42	19/34	0/21
Judith River Formation	0/4	--	0/4	1/4	--	2/9	0/4	1/18	1/15	0/4
Eagle Sandstone	0/9	0/1	0/10	3/10	--	3/16	0/10	12/45	10/34	0/10
Colorado Group	0/7	2/29	0/33	3/34	--	3/11	0/33	12/63	16/51	0/33
Kootenai Formation	0/19	0/89	0/88	4/90	2/18	0/28	0/89	80/167	40/147	0/90
Morrison Formation	0/3	0/16	0/16	1/16	0/3	--	0/16	7/20	6/18	0/16
Ellis Group	0/3	0/8	0/9	0/9	0/2	0/1	0/9	6/19	4/13	0/9
Formations below Ellis Group	0/15	0/17	0/17	1/18	0/14	0/6	0/18	10/34	4/19	3/17
	Primary standards[1]						Secondary standards[2]			
Drinking-water standards, in micrograms per liter	50	10	50	50	2	10	1,000	300	50	5,000

[1]U.S. Environmental Protection Agency, 1977a
[2]U.S. Environmental Protection Agency, 1979

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

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

Four activities, primarily within the U.S. Geological Survey, 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 amounts 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.

(4) STORET, which catalogs data relating to the quality of the waterways within the contiguous United States, and is maintained by the U.S. Environmental Protection Agency.

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

NAWDEX Simplifies Access to Water Data

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

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

NAWDEX can assist any organization or individual in identifying and locating needed water data by providing the name of 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 of 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 costs 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, VA 22092
Telephone: (703) 648-5663
FTS 959-5663
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, MT 59626
Telephone: (406) 449-5263
FTS 585-5263
Hours: 8:00–4:45 Mountain Time

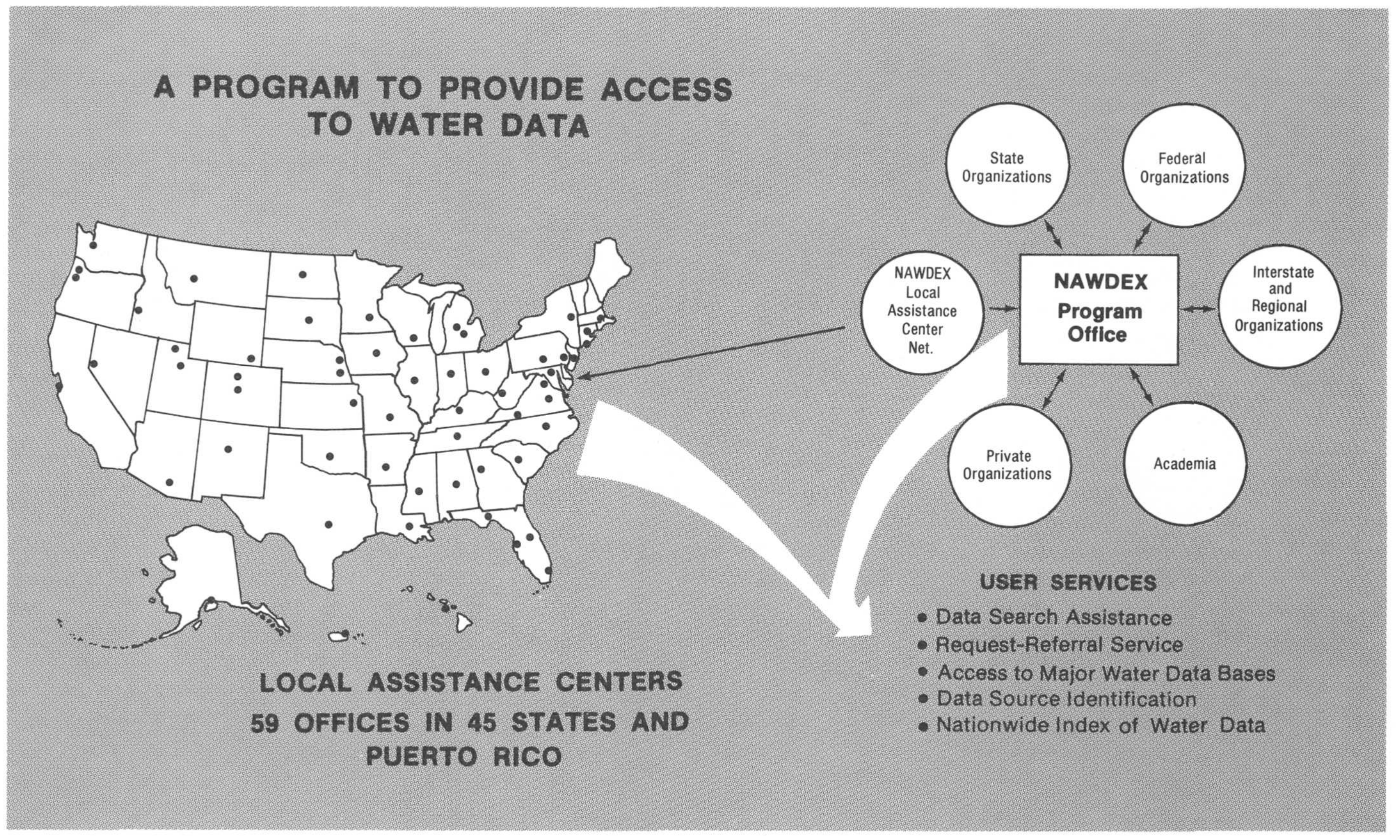


Figure 11.2-1 Access to water data.

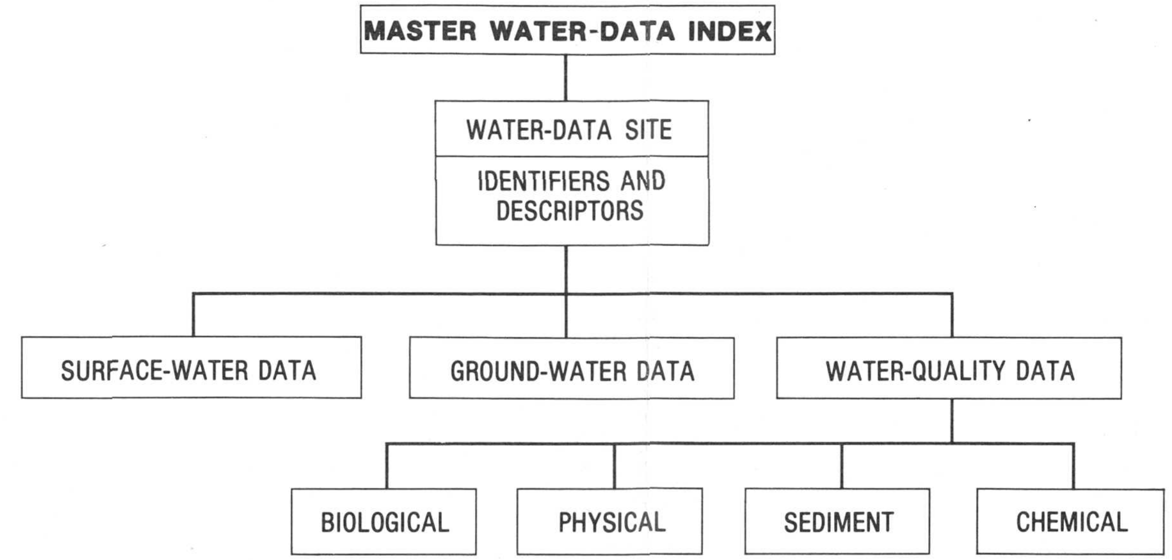


Figure 11.2-2 Master Water-Data Index.

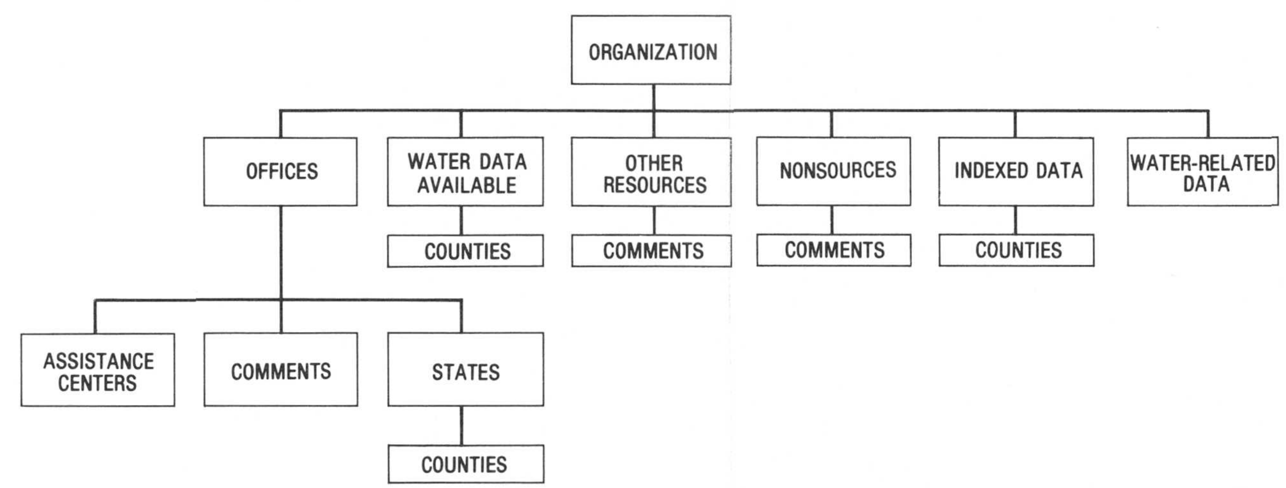


Figure 11.2-3 Water-Data Sources Directory.

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.

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

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

or

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

The Geological Survey currently (1984) collects data nationwide at about 17,000 crest-stage or streamflow-gaging sites, 5,200 surface-water-quality sites, 27,000 water-level observation wells, and 7,400 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 activites.

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 allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) Surface-water, quality-of-water, and ground-water parameters measured on a daily or continuous basis; (2) water parameters measured more frequently than daily; (3) annual peak values for streamflow stations; (4) chemical analyses for surface- and ground-water sites; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system also is maintained (fig. 11.3–1). A brief description of each file is as follows.

Station-Header File: Information pertinent to the identification, location, and physical description of nearly 220,000 sites are contained in this 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.

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, river stages, reservoir contents, water temperatures, specific conductance, sediment concentrations, sediment discharges, and ground-water levels.

Peak-Flow File: Annual maximum (peak) streamflow (discharge) and gage height (stage) values at surface-water sites comprise this file, which currently contains more than 400,000 peak observations.

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

Unit-Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and water temperature 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 for wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time onsite measurements such as water temperature. The file is designed to accommodate 225 data elements and currently contains data for nearly 700,000 sites.

Water-Use File: This file also is 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 and 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 enter data into or retrieve data from the system within an interval of 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 16-channel paper tape; the tape is removed periodically from the recorder, and the data are transmitted over telephone lines to the receiver at Reston, Virginia. The data are re-recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for transmitting real-time hydrologic data on a national scale. Battery-operated transmitters are used as the communication link to the satellite. About 500 data-relay stations are being operated currently (1984) by the Water Resources Division.

Central-Laboratory System: The Water Resources Division's water-quality laboratory, located in Denver, Colorado, analyzes more than 150,000 water samples per year. This laboratory is equipped to automatically perform chemical analyses ranging from determinations of simple inorganic substances, 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 tables of data 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. Many formats are available to display the many types of data.

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

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package called SAS (Statistical Analysis System) 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 in other computers or for use as input to user-written computer programs. These data are available in the standard format of the WATSTORE system or in the form of punched cards or card images on magnetic tape.

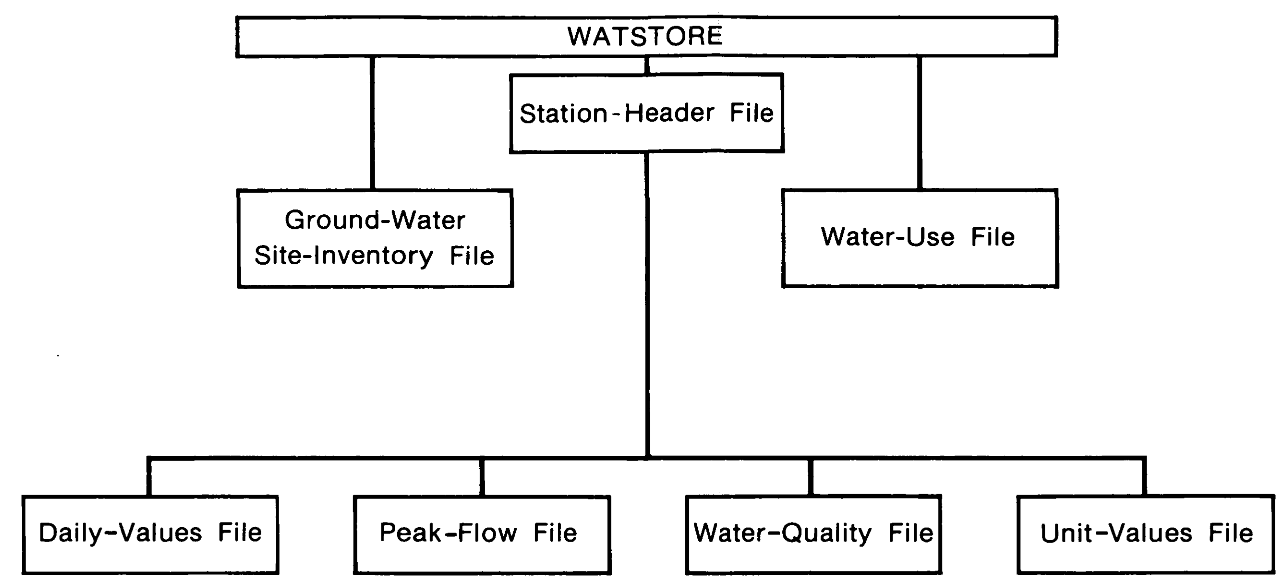


Figure 11.3-1 Index to file-stored data.

Water Data Indexed for Coal Provinces

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

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information about the availability of water-resources data for 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 of water-data acquisition activities in the United States, and its territories and possessions, with some international activities included.

This special index consists of five volumes (fig. 11.4–1). Volume I, Eastern Coal Province; Volume II, Interior Coal Province; Volume III, Northern Great Plains and Rocky Mountain Coal Provinces; Volume IV, Gulf Coast Coal Province; and Volume V, Pacific Coast and Alaska Coal Provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

Each volume of this special index consists of four parts: Part A, Streamflow and Stage Stations; Part B, Quality of Surface-Water Stations; Part C, Quality of Ground-Water Stations; and Part D, Areal Investigations and Miscellaneous Activities. Information given for each activity in Parts A–C includes: (1) The identification and location of the station, (2) the major types of data collected, (3) the frequency of data collection, (4) the form in which the data are stored, and (5) the agency or organization reporting the activity. Part D summarizes areal hydrologic investigations and water-data activities not included in the other parts of the index. The agencies that submitted the information, the agency codes, and the number of activities reported by type are listed in a table.

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

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

U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, MT 59626
Telephone (406) 449-5263
FTS 585-5263

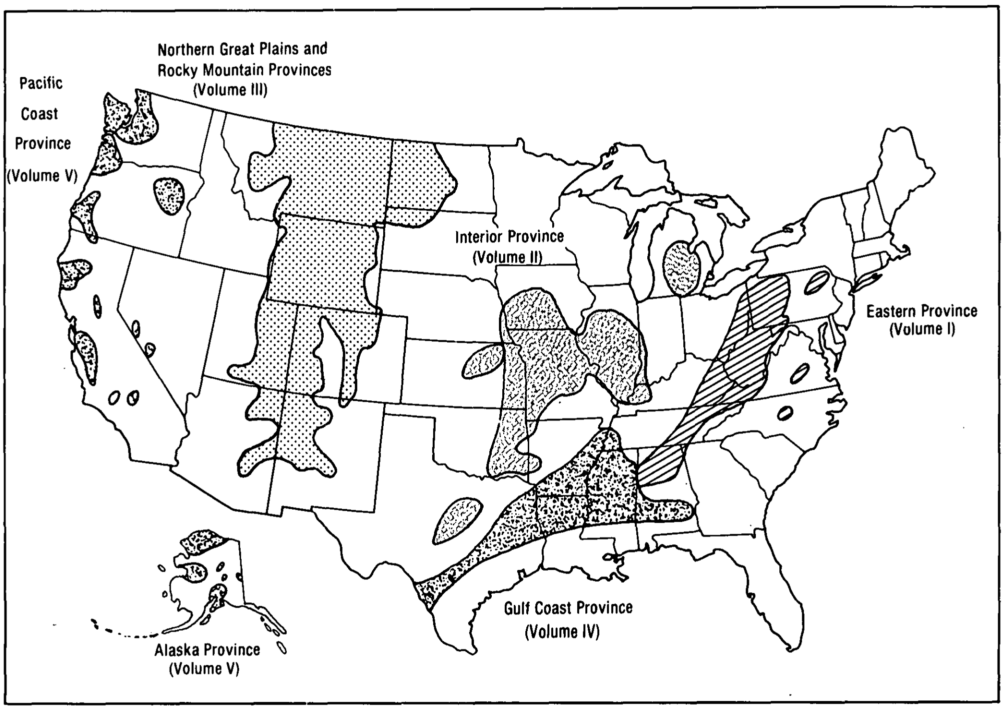


Figure 11.4-1 Index volumes and related coal provinces.

STORET Water-Quality Data Base System

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

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

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

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

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

Environmental Services Division
Data Analysis Branch, 8 ES-DA
U.S. Environmental Protection Agency
Region VIII, One Denver Place
999 18th Street, Suite 500
Denver, CO 80202-2405
Telephone: (303) 293-1442
FTS 564-1442

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

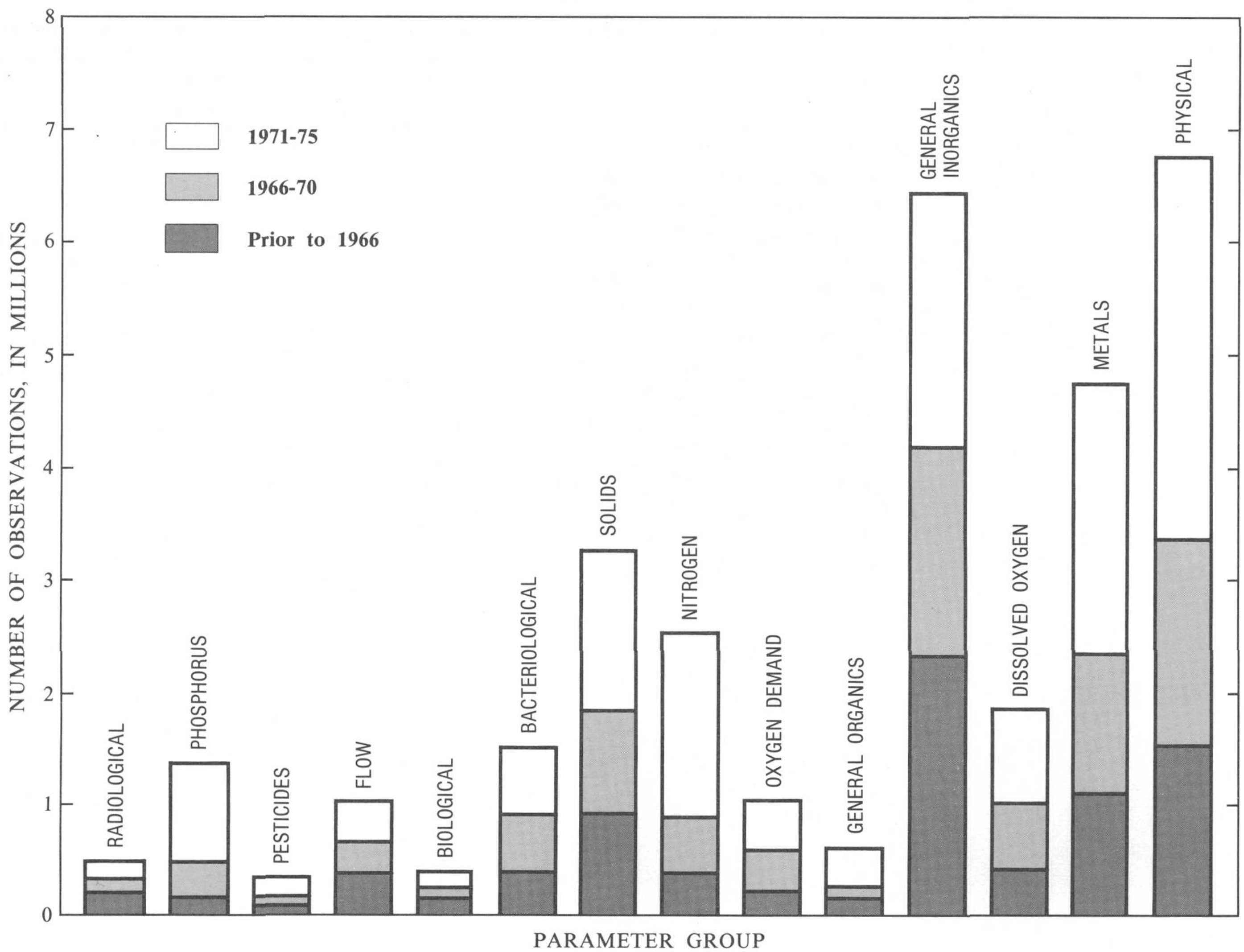


Figure 11.5-1 Parameter groups and number of observations in the STORET Water-Quality File.

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY SITES

[Site number used in report: Refers to locations shown in figures of this report. Name: mi, miles. Water quality: Letters following period of record indicate data category--B, biological; C, chemical; S, suspended sediment; T, continuous recording or daily observation of water temperature. Period of water-quality record for sites having two or more data categories represents the combined periods of record for each category.]

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
1	06071500	---	Missouri River at Craig, Mont.	17,739	1890-92	--	--	--
2	06071600	---	Wegner Creek at Craig, Mont.	35.0	--	--	1959-	--
3	06074000	---	Missouri River at Cascade, Mont.	18,493	1902-15; 1953	1967; 1976; 1978	--	[a]1977-78 BC
4	--	4725501113006	Missouri River at Ulm, Mont.	--	--	1978	--	--
5	06074500	---	Smith River near White Sulphur Springs, Mont.	30.7	1923-31; 1934-36	--	--	--
6	06075500	---	Smith River above Fivemile Creek, near White Sulphur Springs, Mont.	73.2	1934-43	--	--	--
7	06075600	---	Fivemile Creek near White Sulphur Springs, Mont.	6.42	--	--	1959-74	--
8	06076000	---	Newland Creek near White Sulphur Springs, Mont.	7.27	1946-53	--	1960-73	--
9	06076500	---	Newland Creek near dam site, near White Sulphur Springs, Mont.	44.8	1950-57	--	--	--
10	06076690	---	Smith River near Fort Logan, Mont.	846	1978-	--	--	--
11	06076700	---	Sheep Creek near Niehart, Mont.	5.23	--	--	1959-	--
12	06076800	---	Nugget Creek near Niehart, Mont.	1.50	--	--	1959-73	--
13	06077000	---	Sheep Creek near White Sulphur Springs, Mont.	42.8	1941-72	1934; 1936; 1972-73; 1975; 1980	--	1980 CS
14	--	4655351105405	Tenderfoot Creek near Niehart, Mont.	--	--	--	--	1963 T
15	--	4657021110847	Tenderfoot Creek near Monarch, Mont.	--	--	--	--	1962-63 T
16	06077300	---	Trout Creek near Eden, Mont.	13.2	--	--	1975-	--
17	06077500	---	Smith River near Eden, Mont.	1,594	1951-69	1975	--	1962-64 T
18	--	4712391112437	Hound Creek near Eden, Mont.	--	--	1953	--	--
19	06077700	---	Smith River tributary near Eden, Mont.	1.44	--	--	1959-75	--
20	06077800	---	Goodman Coulee near Eden, Mont.	22.1	--	--	1959-82	--
21	06078000	---	Smith River at Truly, Mont.	2,006	1905-07; 1929-32	1967-68; 1953	--	--
22	--	4723321112655	Smith River near Ulm, Mont.	--	--	1976; 1978-79; 1981	--	[a]1977-78 BC
23	06078200	---	Missouri River near Ulm, Mont.	20,941	1957-	--	--	--
24	06078300	---	Missouri River above Sun River, at Great Falls, Mont.	--	--	1953; 1964	--	1937-65 T
25	0609000	---	Missouri River at Great Falls, Mont.	22,294	1890; 1894-95; 1910-11	--	--	--
26	06090100	---	Missouri River at Black Eagle Dam, at Black Eagle, Mont.	--	--	--	--	1951 C
27	--	4731501111415	Missouri River above Giant Springs, at Great Falls, Mont.	--	--	1973	--	--

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year			
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
28	--	4732101111335	Missouri River below Giant Springs, at Great Falls, Mont.	--	--	1973	--	--
29	--	4732101111145	Missouri River below Rainbow Dam, near Great Falls, Mont.	--	--	--	--	1971 C
30	--	4734151110720	Missouri River at Ryan Dam, near Black Eagle, Mont.	--	--	--	--	1917-28; 1930-64 T
31	06090300	---	Missouri River near Great Falls, Mont.	23,292	1953; 1957-	--	--	--
32	--	4656001104410	Belt Creek at Niehart, Mont.	--	--	1920	--	--
33	--	4706001105020	Belt Creek at Monarch, Mont.	--	--	1920	--	--
34	06090500	---	Belt Creek near Monarch, Mont.	368	1951-82	--	--	1977-81 T
35	06090550	---	Little Otter Creek near Raynesford, Mont.	39.5	--	--	1974-	--
36	--	4720561105420	Belt Creek at Armington, Mont.	--	--	1981	--	--
37	--	4723001105550	Belt Creek at Belt, Mont.	--	--	1920	--	1962 T
38	--	4725051105525	Belt Creek 2 mi north of Belt, Mont.	--	--	1971	--	--
39	--	4728001105420	Belt Creek 5.5 mi north of Belt, Mont.	--	--	1953	--	--
40	06090600	---	Belt Creek near Belt, Mont.	700	1905-06	1953	--	--
41	06090610	---	Belt Creek near Portage, Mont.	799	1980-83	--	--	1980-83 CST
42	06090700	---	Highwood Creek near Highwood, Mont.	57.8	1905-06	--	--	--
43	--	4733501104645	Highwood Creek 2 mi southeast of Highwood, Mont.	--	--	1953; 1964	--	--
44	06090720	---	Highwood Creek near Portage, Mont.	122	1980-83	--	--	1980-83 CST
45	06090800	---	Missouri River at Fort Benton, Mont.	24,749	1873-76; 1891-	--	--	1965 S; 1969-73 BC; [a]1977-78 BC; 1978- BCS
46	06090810	---	Ninemile Coulee near Fort Benton, Mont.	16.9	--	1972	1974-	--
47	06109000	---	Missouri River at Loma, Mont.	34,221	1935-53	--	--	--
48	06109500	---	Missouri River at Virgelle, Mont.	34,379	1935-	--	--	[b]1962-69 S; 1975- BCST
49	--	4715161102920	McCarthy Creek at Geyser, Mont.	--	--	1978	--	--
50	--	4725061100942	Arrow Creek near Coffee Creek, Mont.	--	--	1968-71	--	--
51	--	4726281095415	Coffee Creek near Denton, Mont.	--	--	1968-71	--	--
52	--	4650131102242	Middle Fork Judith River above Lost Fork, near Utica, Mont.	--	--	1964	--	--
53	--	4650111102242	Lost Fork Judith River near Utica, Mont.	--	--	1964	--	--
54	06109750	---	Middle Fork Judith River below Lost Fork, near Utica, Mont.	--	1972-76	1972; 1975	--	--
55	--	4650301102148	Middle Fork Judith River above Arch Coulee, near Utica, Mont.	--	--	1973; 1975	--	--

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY SITES

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year			
					Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
56	--	4650501101955	Middle Fork Judith River below Ettien Gulch, near Utica, Mont.	--	--	1972	--	--
57	--	4650481101935	Middle Fork Judith River above Ettien Coulee, near Utica, Mont.	--	--	1972-73; 1975	--	--
58	--	4654451102445	Yogo Creek 1 mi above sapphire washing plant, near Utica, Mont.	--	--	1964	--	--
59	--	4652481102145	Yogo Creek 3.9 mi above mouth, near Utica, Mont.	--	--	1975	--	--
60	--	4650521101838	Yogo Creek at crossing 0.2 mi above mouth, near Utica, Mont.	--	--	1972	--	--
61	--	4650471101837	Yogo Creek at mouth, near Utica, Mont.	--	--	1972; 1975	--	--
62	--	4650501101758	Middle Fork Judith River above diversion, near Utica, Mont.	--	--	1973; 1975	--	--
63	06109775	---	Middle Fork Judith River at ranger station, near Utica, Mont.	--	--	1964; 1975	--	1964 C
64	--	4650501101629	Middle Fork Judith River below Peck ditch diversion, near Utica, Mont.	--	--	1973; 1975	--	--
65	06109780	---	Middle Fork Judith River near Utica, Mont.	160	1972-79	1972; 1975	--	--
66	06109800	---	South Fork Judith River near Utica, Mont.	58.7	1958-79	1975	--	--
67	--	4646441101800	South Fork Judith River below Dry Pole Canyon, near Utica, Mont.	--	--	1972	--	--
68	--	4648451101724	South Fork Judith River 0.3 mi above Indian Hill Campground, near Utica, Mont.	--	--	1975	--	--
69	--	4649421101707	South Fork Judith River 0.3 mi below Rocky Gulch, near Utica, Mont.	--	--	1975	--	--
70	--	4650501101614	South Fork Judith River near mouth, near Utica, Mont.	--	--	1964; 1971-73; 1975	--	--
71	--	4651341101544	Judith River below Pagil Gulch, near Utica, Mont.	--	--	1975	--	--
72	06109900	---	Judith River tributary near Utica, Mont.	7.15	--	--	1959-74	--
73	--	4653051101435	Judith River above Missouri Coulee, near Utica, Mont.	--	--	1975	--	--
74	06109950	---	Judith River tributary No. 2 near Utica, Mont.	6.97	--	--	1959-67	--
75	06110000	---	Judith River near Utica, Mont.	328	1920-75	--	--	--
76	--	4655101101100	Judith River 6 mi southwest of Utica, Mont.	--	--	1966	--	[a]1979 BC
77	--	4656201100800	Judith River tributary above Waite Creek, near Utica, Mont.	--	--	1921	--	--
78	--	4656581100632	Waite Creek near Utica, Mont.	--	--	1920	--	--
79	--	4657011100620	Judith River below Waite Creek, near Utica, Mont.	--	--	1921	--	--
80	--	4657101100532	Judith River 1 mi south of Utica, Mont.	--	--	1921	--	--

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
81	--	4655301100110	Antelope Creek near Utica, Mont.	--	--	1920; 1926	--	--
82	--	4700401095255	Judith River at Hobson, Mont.	--	--	1967-68	--	--
83	--	4704201094310	Judith River above Ross Fork Creek, near Ross Fork, Mont.	--	--	1967	--	--
84	06111000	---	Ross Fork Creek near Hobson, Mont.	337	1946-53; 1955-62	1968-71; 1975	--	--
85	--	4648501093020	Rock Creek above East Fork Rock Creek, near Garneill, Mont.	--	--	1967-68	--	--
86	--	4649041092957	Rock Creek below East Fork Rock Creek, near Garneill, Mont.	--	--	1967-68; 1975	--	--
87	--	4650401093020	Rock Creek above National Forest boundary, near Garneill, Mont.	--	--	1967-68	--	--
88	--	4651101093035	Rock Creek at National Forest boundary, near Moore, Mont.	--	--	1967	--	--
89	--	4651311093034	Rock Creek below National Forest boundary, near Moore, Mont.	--	--	1968; 1975	--	--
90	--	4652071093108	Rock Creek above Dry Pole Creek, near Moore, Mont.	--	--	1967	--	--
91	--	4653471093530	Rock Creek near Moore, Mont.	--	--	1967-69	--	--
92	--	4703541094315	Ross Fork Creek near Ross Fork, Mont.	--	--	1966-67	--	--
93	--	4707291094044	Judith River above Little Rock Creek, near Ross Fork, Mont.	--	--	1967-69	--	--
94	--	4704591094025	Little Rock Creek east of Ross Fork, Mont.	--	--	1967	--	--
95	--	4707351094022	Little Rock Creek north of Ross Fork, Mont.	--	--	1966-69	--	--
96	--	4700101092040	Big Spring Creek below Big Springs, near Lewistown, Mont.	--	--	1957	--	--
97	06111500	---	Big Spring Creek near Lewistown, Mont.	20.9	1932-57	1931; 1966-71	--	--
98	--	4732051092005	East Fork Big Spring Creek near Heath, Mont.	--	--	1968	--	--
99	--	4702301092400	Big Spring Creek above Casino Creek, near Lewistown, Mont.	--	--	1953	--	--
100	06111700	---	Mill Creek near Lewistown, Mont.	3.53	--	--	1959-	--
101	06111750	---	Big Spring Creek below Casino Creek, at Lewistown, Mont.	140	--	--	--	1967-68 T
102	--	4704121092540	Big Spring Creek at Boulevard Bridge, at Lewistown, Mont.	170	--	1911; 1953; 1970; 1975	--	--
103	--	4706301093205	Big Spring Creek below Lewistown, Mont.	--	--	--	--	[a]1979 BC
104	06111850	---	Big Spring Creek at Hanover, Mont.	260	--	1931; 1967-71	--	1967-68 T
105	--	4650201092500	Cottonwood Creek above National Forest boundary, near Heath, Mont.	--	--	1967	--	--
106	--	4651071092448	Cottonwood Creek at National Forest boundary, near Heath, Mont.	--	--	1967-68	--	--
107	--	4652251092415	Cottonwood Creek below National Forest boundary, near Heath, Mont.	--	--	1968	--	--

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY SITES

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
108	--	4657281092850	Cottonwood Creek at Heller Ranch, near Lewistown, Mont.	--	--	1962-63	--	--
109	06112000	---	Cottonwood Creek near Lewistown, Mont.	45.6	1946-48; 1950-51	1948-49; 1959-63	--	--
110	06112100	---	Cottonwood Creek near Moore, Mont.	47.9	1957-63	--	1964-73; 1975	--
111	--	4700171093102	Cottonwood Creek near Glengarry, Mont.	--	--	1960-63	--	--
112	--	4707361093410	Cottonwood Creek at Hanover, Mont.	--	--	1967-71	--	--
113	--	4711401093745	Big Spring Creek near Danvers, Mont.	--	--	1966	--	--
114	--	4716251094310	Judith River near Danvers, Mont.	--	--	1967	--	[a]1979 BC
115	06112500	---	Sage Creek at Windham, Mont.	58.6	1920-22	1968-71	--	--
116	--	4716271094335	Sage Creek near Danvers, Mont.	--	--	1968-71	--	--
117	--	4719551094230	Judith River above Warm Spring Creek, near Danvers, Mont.	--	--	1931	--	--
118	06112800	---	Bull Creek tributary near Hilger, Mont.	.99	--	--	1974-	--
119	--	4713021092815	Warm Spring Creek above Warm Spring, near Hilger, Mont.	--	--	1975	--	--
120	--	4713051092930	Kendall Power Canal below Warm Spring, near Hilger, Mont.	--	--	1919; 1931	--	--
121	--	4713141092808	Warm Spring Creek below Warm Spring, near Hilger, Mont.	146	--	1919; 1931; 1966-71; 1975	--	--
122	--	4713231093055	Lincoln Ditch below diversion intake on Warm Spring Creek, near Hilger, Mont.	--	--	1919	--	--
123		4718201074130	Warm Spring Creek near Danvers, Mont.	--	--	1967-71	--	--
124	--	4719551094215	Warm Spring Creek near mouth, near Danvers, Mont.	--	--	1910; 1931; 1966	--	--
125	06113000	---	Judith River near Lewistown, Mont.	1,939	1910-11	1966	--	--
126	--	4720571093150	Plum Creek near Hilger, Mont.	--	--	1967	--	--
127	06113500	---	Judith River near Winifred, Mont.	2,160	1929-32	--	--	--
128	--	4659591103055	Dry Wolf Creek above Placer Creek, near Stanford, Mont.	--	--	1964	--	--
129	--	4700041103055	Placer Creek near Stanford, Mont.	--	--	1964	--	--
130	--	4700491103030	Butcherknife Gulch near Stanford, Mont.	--	--	1964	--	--
131	--	4700501103015	Dry Wolf Creek below Butcherknife Creek, near Stanford, Mont.	--	--	1975	--	--
132	--	4701051102950	Dry Wolf Creek at ranger station, near Stanford, Mont.	--	--	1964	--	--
133	--	4702131102734	Dry Wolf Creek above Taylor Ranch diversion, near Stanford, Mont.	--	--	1975	--	--
134	--	4702151102735	Taylor Ranch diversion canal, near Stanford, Mont.	--	--	1964	--	--
135	--	4702151102730	Dry Wolf Creek below Taylor Ranch diversion, near Stanford, Mont.	--	--	1964; 1975	--	--
136	--	4703351102540	Dry Wolf Creek above sinks, near Stanford, Mont.	--	--	1964	--	--

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
137	--	4703361102539	Dry Wolf Creek below sinks, near Stanford, Mont.	--	--	1964	--	--
138	--	4704161102346	Dry Wolf Creek below Mud Spring Creek, near Stanford, Mont.	--	--	1975	--	--
139	06114000	---	Wolf Creek at Neubert Ranch, near Stanford, Mont.	79.2	1920-26	1927-28; 1971	--	--
140	--	4706451101725	Neubert Ranch ditch, near Stanford, Mont.	--	--	1920	--	--
141	06114500	---	Wolf Creek near Stanford, Mont.	112	1950-54; 1955-62	1968-71; 1975	--	--
142	--	4709301101505	Wolf Creek at Stanford, Mont.	--	--	--	--	[a]1979 BC
143	06114550	---	Wolf Creek tributary near Coffee Creek, Mont.	1.73	--	--	1974-	--
144	--	4719151095450	Wolf Creek at Denton, Mont.	--	--	--	--	[a]1979 BC
145	--	4723361094440	Wolf Creek near Denton, Mont.	--	--	1967-71	--	--
146	--	4744051093840	Judith River at mouth, near Winifred, Mont.	--	--	1941	--	[a]1979 BC
147	--	4727431092113	Dog Creek at Suffolk, Mont.	--	--	1978	--	--
148	06114900	---	Taffy Creek tributary near Winifred, Mont.	2.95	--	--	1974-	--
149	--	4744201093720	Missouri River below Judith River, near Winifred, Mont.	--	--	--	--	[a]1979 BC
150	--	4744151092320	Missouri River at Stafford Ferry, near Winifred, Mont.	--	--	1980-81	--	--
151	06115000	---	Missouri River at power plant ferry, near Zortman, Mont.	40,763	1934-69	--	--	[b]1948-51; 1957-68 S
152	06115100	---	Missouri River tributary near Landusky, Mont.	3.39	--	--	1962-77	--
153	06115200	---	Missouri River near Landusky, Mont.	40,987	1934-	--	--	[b]1969-71 S; 1972-75 S; 1976- BCST; [a]1979 BC
154	06115250	---	Armells Creek near Christina, Mont.	--	--	--	--	1964 C
155	--	4735001084730	Armells Creek near Roy, Mont.	370	--	1962	--	--
156	--	4650301085430	Flatwillow Creek near Tyler, Mont.	--	--	1925; 1932	--	--
157	--	4647001085000	Durfee Creek near Darrel, Mont.	--	--	1921-22; 1925	--	--
158	06127900	---	Flatwillow Creek near Flatwillow, Mont.	188	1911-32; 1934-56	--	--	--
159	06128200	---	Flatwillow Creek near Winnett, Mont.	642	1921-32; 1948-51	--	--	--
160	06128400	---	South Fork Bear Creek near Roy, Mont.	39.6	--	--	1962-76	--
161	06128500	---	South Fork Bear Creek tributary near Roy, Mont.	5.40	--	--	1962-	--
162	06128900	---	Box Elder Creek tributary near Winnett, Mont.	16.2	--	--	1955-73	--
163	06129000	---	Box Elder Creek near Winnett, Mont.	684	1930-32; 1934-38; 1958-72	--	--	--
164	--	4700001081000	Box Elder Creek below McDonald Creek, near Winnett, Mont.	--	--	--	--	[a]1979 BC

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY SITES

Site number used in report	U.S. Geological Survey identification number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
165	06129100	---	North Fork McDonald Creek tributary near Heath, Mont.	2.24	--	--	1959-75	--
166	06129200	---	Alkali Creek near Heath, Mont.	3.76	--	--	1959-74	--
167	06129400	---	South Fork McDonald Creek tributary near Grassrange, Mont.	.51	--	--	1963-77	--
168	06129500	---	McDonald Creek at Winnett, Mont.	421	1930-32; 1934-45; 1953-56	--	1957-75	--
169	06129700	---	Gorman Coulee near Cat Creek, Mont.	2.32	--	--	1955-73	--
170	06129800	---	Gorman Coulee tributary near Cat Creek, Mont.	.81	--	--	1955-	--
171	06130000	---	Flatwillow Creek near Mosby, Mont.	1,855	1964-66	--	--	1964-66 CST
172	06130500	---	Musselshell River at Mosby, Mont.	7,846	1929-32; 1934-	--	--	1975- BCST; [a]1979 BC
173	06130600	---	Cat Creek near Cat Creek, Mont.	36.5	--	--	1958-73	--
174	06130620	---	Blood Creek tributary near Valentine, Mont.	1.97	--	--	1974-	--

[a]Water-quality data collected by Montana Water Quality Bureau as part of statewide biological monitoring network. Data are published in Ingman and others (1979) and Bahls and others (1981).

[b]Sediment data collected by U.S. Army Corps of Engineers. Data are published in U.S. Army Corps of Engineers (1970, 1972, 1976).

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