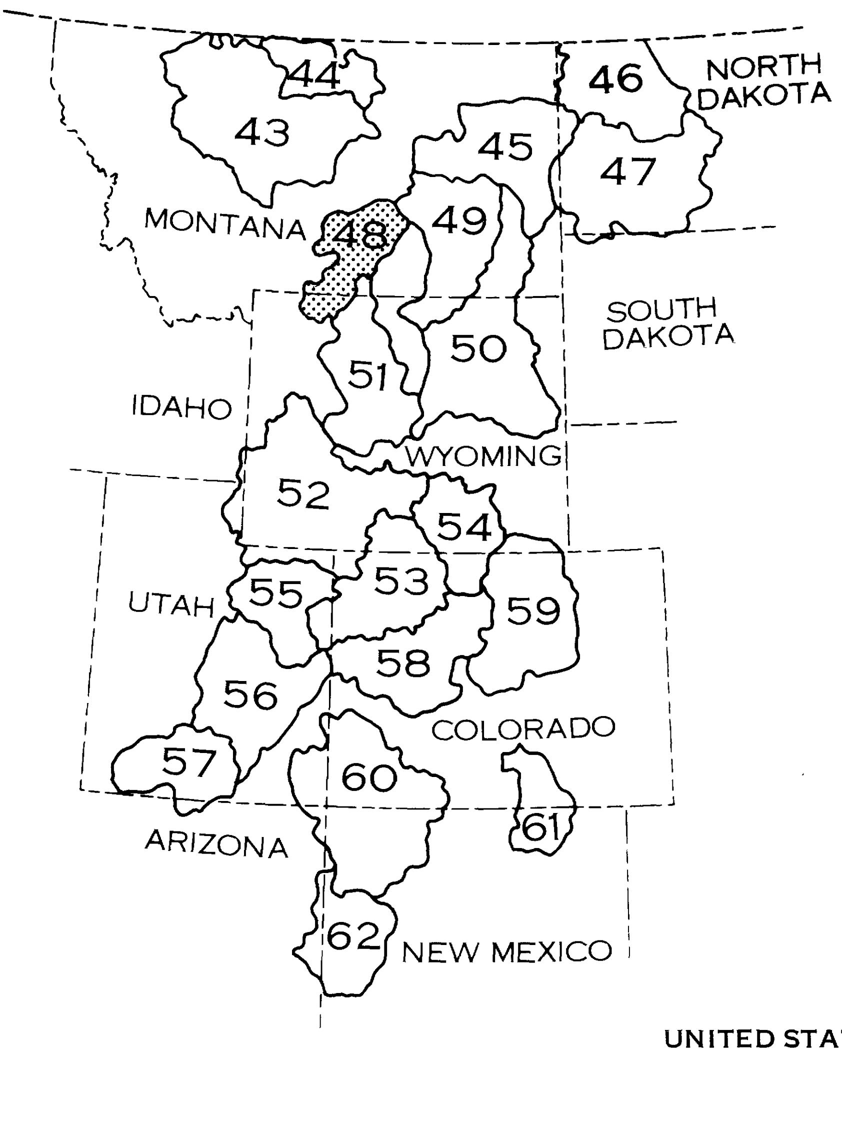
HYDROLOGY OF AREA 48, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND WYOMING



- YELLOWSTONE RIVER
- CLARKS FORK YELLOWSTONE RIVER
- MUSSELSHELL RIVER
- PRYOR CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 84-141

HYDROLOGY OF AREA 48, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, MONTANA AND WYOMING

BY
STEVEN E. SLAGLE AND OTHERS

U.S. GEOLOGICAL SURVEY

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HELENA, MONTANA
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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *SECRETARY*

GEOLOGICAL SURVEY

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CONTENTS

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

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

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

Multiply	By	To obtain
acre	4,047	square meter
acre-foot	1,233	cubic meter
British thermal unit per pound	2.326	kilojoule per kilogram
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
gallon per second	3.785	liter per second
inch	25.40	millimeter
micromho per centimeter at 25°Celsius	100	microsiemen per meter at 25° Celsius
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
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:

$$°F = 9/5\,(°C) + 32$$

$$°C = 5/9\,(°F - 32)$$

Abstract

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

Area 48 encompasses about 8,000 square miles in south-central Montana and northwestern Wyoming, in the northern part of the Northern Great Plains and Rocky Mountain Coal Provinces. The land surface in the area typically is characterized by high rugged mountains in the southern part, rolling prairie with abrupt ridges in the central part and relatively low rolling mountains in the northeast. The area is drained primarily by the Yellowstone River, Clarks Fork Yellowstone River, Musselshell River, and Pryor Creek and their tributaries.

Streamflow varies seasonally, with the largest flows commonly occurring in the spring as a result of rainfall and snowmelt. Peak flows in the larger prairie streams, such as the Musselshell River, generally occur in May as a result of snowmelt or during July through September as a result of thunderstorms. The composition of major ions and the dissolved-solids concentrations vary with changes in streamflow. Base-flow concentrations of dissolved solids ranged from 900 to 3,500 milligrams per liter. Magnesium, sodium, bicarbonate, and sulfate generally are the dominant ions. The water composition during base flow is indicative of the ground-water quality. During direct-runoff intervals, the relative proportions of calcium and bicarbonate increase and the water contains much smaller dissolved-solids concentrations. Dissolved-solids concentrations during periods of high flow ranged from 60 to 900 milligrams per liter.

Suspended-sediment yields vary widely as a result of differences in sediment availability among the basins and in stream discharges capable of transporting available sediment supplies. Average annual sediment yields at different stations ranged from 54.5 to 373 tons per square mile. Concentrations of suspended sediment measured in the area ranged from 2 to 109,000 milligrams per liter.

Bedrock in the area ranges in age from Precambrian through Tertiary and includes the Mississippian Madison Group; the Upper Cretaceous Eagle Sandstone, Judith River Formation, Bearpaw Shale, Fox Hills Sandstone, Hell Creek Formation; and the lower Tertiary Tullock, Lebo Shale, and Tongue River Members of the Fort Union Formation. Alluvium of Quaternary age is present along most streams. The principal coal deposits are located in the Eagle Sandstone, Judith River Formation, and Tongue River Member of the Fort Union Formation.

Alluvium and terrace deposits constitute major sources of ground water in Area 48. Alluvium along the major streams yields as much as 300 gal/min (gallons per minute) to wells, but yields from alluvium along smaller streams is generally less than 10 gal/min. Yields of 10 to 50 gal/min have been reported from terrace deposits. Yields from sandstone and fractured coal contained in Tertiary rocks are generally less than 20 gal/min. Sandstone within the Cretaceous section yields as much as 300 gal/min to wells but yields commonly are less than 10 gal/min. Paleozoic and Triassic rocks within the area have the potential for yielding extremely large quantities of water, but development is restricted by large depth. Yields of 1,000 to 3,000 gal/min are common and yields as large as 12,000 gal/min have been reported from the Madison Group.

Water from most aquifers generally is of the sodium sulfate type, with dissolved-solids concentrations of 126 to 16,500 milligrams per liter. Water from the Madison aquifer generally is of the calcium magnesium sulfate type.

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

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 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 48 in Montana and Wyoming, a part of the Northern Great Plains and Rocky Mountain Coal Provinces (fig. 1.1-1). This report is one of a series that describes the hydrology of coal provinces nationwide.

This report provides general hydrologic information, by means of a brief text with accompanying map, chart, graph, or other illustration, for each of a series of water-resources-related topics. Summation of the topical discussions provides a description of the hydrology of the area. The information contained herein will be useful to Federal agencies in the leasing and management of Federal coal lands and to surface-mine owners, operators, and others preparing permit applications and to regulatory authorities evaluating the adequacy of the applications.

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

NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES

Numbers represent project areas

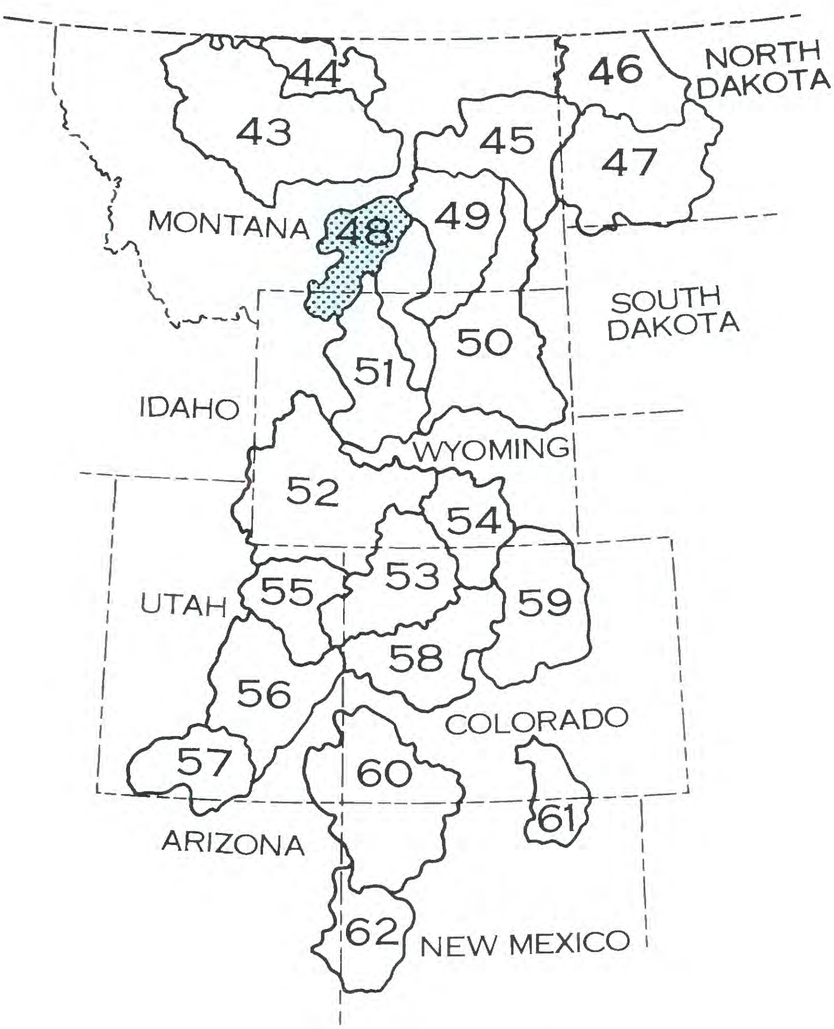


Figure 1.1-1 Location of Area 48.

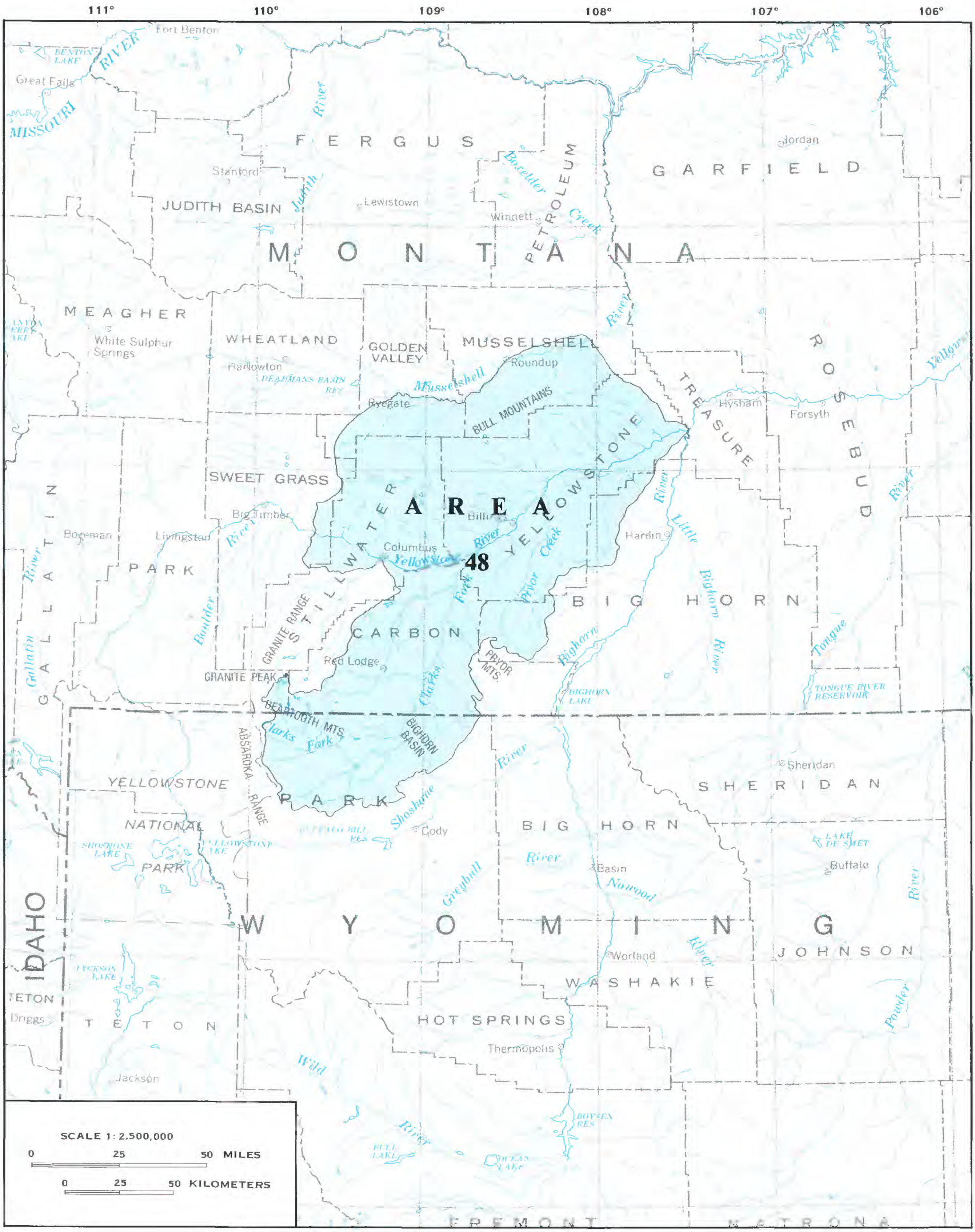
Area Includes Rocky Mountains and Northern Great Plains

Area 48 encompasses about 8,000 square miles in south-central Montana and northwestern Wyoming.

The project area includes parts of Golden Valley, Musselshell, Sweet Grass, Stillwater, Yellowstone, Park, Carbon, and Big Horn Counties in south-central Montana and Park County in northwestern Wyoming (fig. 1.2-1). The principal population center in the area is Billings, Montana, which, with an urbanized-area population of 84,328 in 1980 (U.S. Bureau of the Census, 1981), is the largest population center in the State. The rest of the area primarily is rural (U.S. Geological Survey, 1970), generally with a population density of less than five persons per square mile.

The land surface in the area is typified by high rugged mountains in the southern part, rolling prairie with abrupt ridges in the central part, and relatively low rolling mountains in the northeast. Land-surface elevation ranges from 12,799 feet at the top of Granite Peak, the highest point in Montana, to about 2,700 feet where the Yellowstone River exits the area.

Other than in the Billings area, which is a major industrial and service center in Montana, farming, ranching, and related services are the dominant industries. Oil and gas are also produced from the area.



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

Figure 1.2-1 Geographic features.

2.0 DEFINITION OF TERMS

Terms in Report Defined

Technical terms that occur in this hydrologic report are defined.

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

Bacteria are microscopic unicellular organisms, typically spherical, rod-like, or spiral and threadlike in shape, commonly living 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.

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

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

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

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

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 is the sum of all dissolved constituents in water. Most dissolved constituents in natural waters occur as ions, with the most abundant ones referred to as major ions.

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

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

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

Enteric bacteria are bacteria associated with the intestine of warm-blooded animals.

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 in any 1 year.

Flow-duration curve is a cumulative frequency curve that shows the percentage of time that a daily stream discharge was equaled or exceeded during the period of record at a station.

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

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

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

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

Multiple-regression equation is an equation developed using a statistical technique by which a relationship between a dependent variable and one or more independent variables is derived.

Peak flow is the largest discharge attained by a stream.

Perennial stream is a stream that flows continuously.

Periphyton are the community of microorganisms (algae in this report) 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 is a surface that represents the static hydraulic head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

Recurrence interval is the average time interval, in years, between occurrences of a flood of equal or greater magnitude.

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

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

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

Spoil material (spoils) is overburden material that is placed in the mine pit after completion of mining.

Station is a particular location on a stream or a well where data are collected at regular intervals.

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

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

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

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

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

Trace elements are substances that generally occur in small concentrations compared to the major ions.

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

Climate is Semiarid

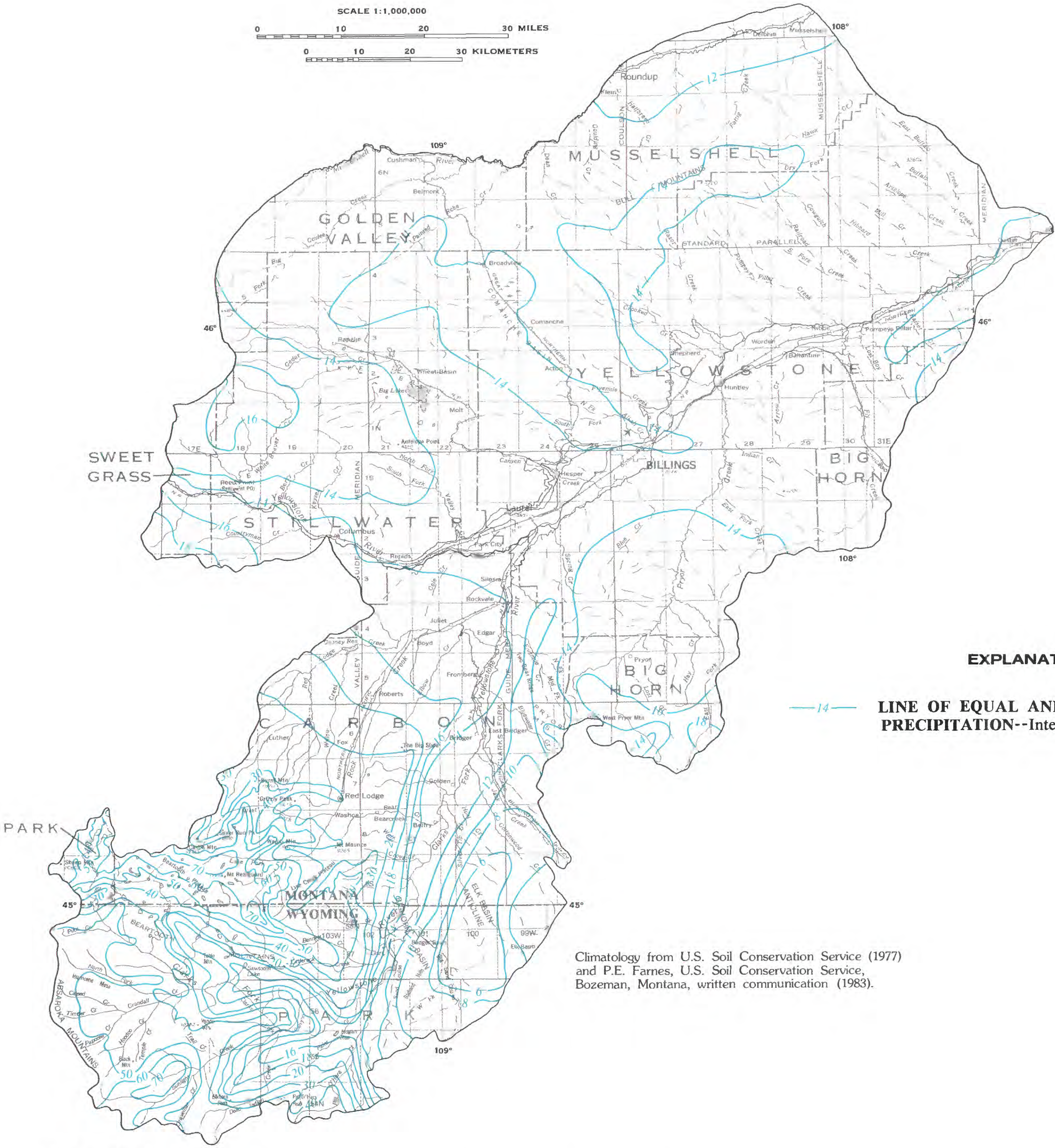
Area 48 has a predominantly semiarid climate, with most precipitation occurring during summer.

The climate of Area 48 is characterized by cold dry winters in the prairie areas and cold wet winters in the mountainous area, cool moist springs, hot moderately dry summers, and cool dry falls. Winter cold waves are often interrupted by extended intervals of warm weather. Summers are dominated by hot sunny days and cool nights. Average annual temperatures, based on the record for 1941-70, range from 42.1°F at Red Lodge, Montana, to 48.9°F at Joliet, Montana, according to National Weather Service records. January normally is the coldest month. Average January temperatures range from 19.6°F at Huntley, Montana, to 23.2°F at Billings, Montana. July normally is the warmest month. Average July temperatures range from 64.3°F at Red Lodge to 72.6°F at Ballantine, Montana. Several days annually with maximum temperatures in excess of 100°F are not uncommon in parts of Area 48.

Average annual precipitation varies from about 6 inches in the southern area near Belfry, Montana, to about 70 inches in small areas in the southwestern mountains. Annual precipitation generally is more variable, more intense, and less in total amount in the prairie areas than in the mountains. Most of the annual precipitation occurs from April through August, with June being the single wettest month. Winter months in the prairie areas are the driest; average monthly precipitation generally is less than 0.5 inch for November through February. Snow accumulation in the mountains and ground water provide a source of water to sustain streamflow throughout the summer.

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

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



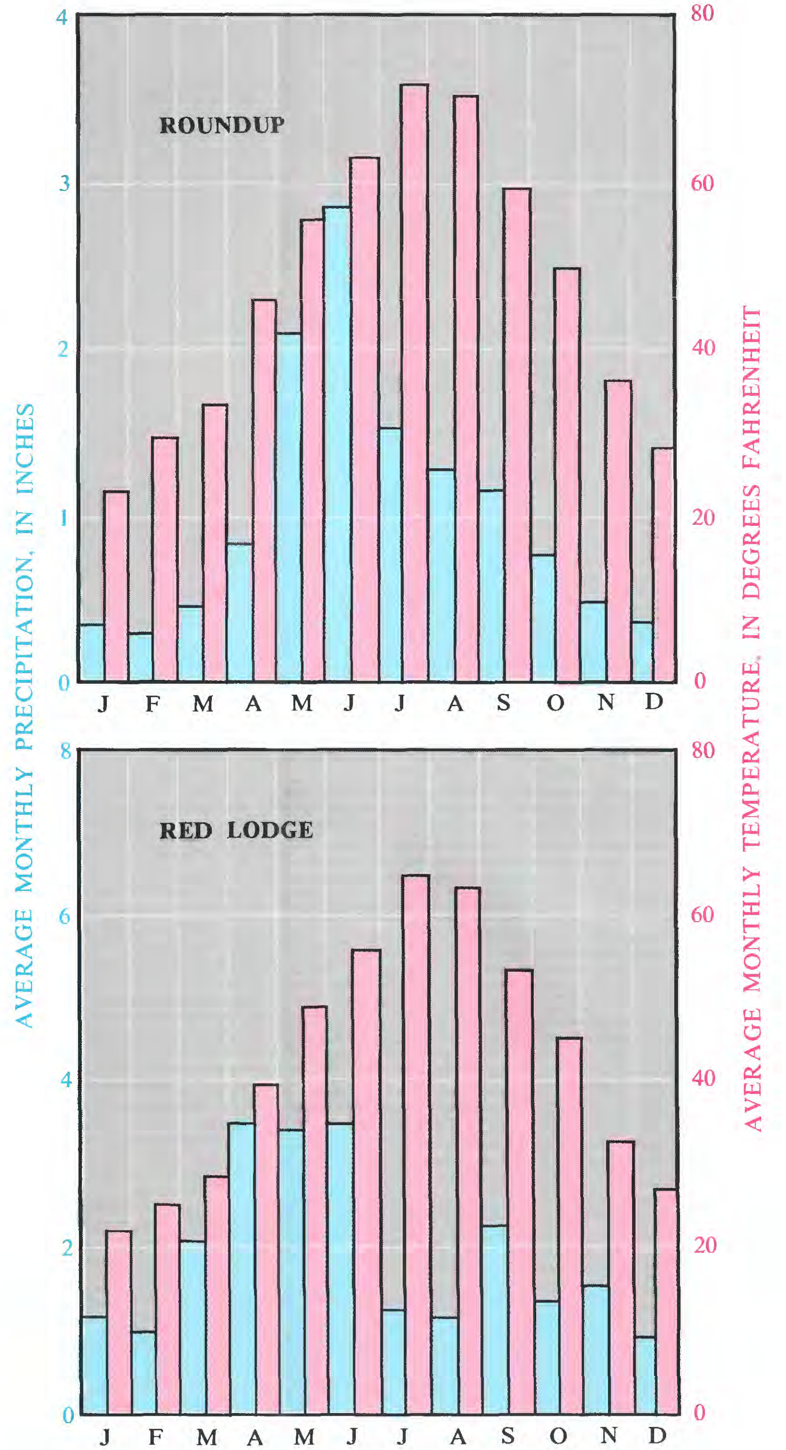
Climatology from U.S. Soil Conservation Service (1977) and P.E. Farnes, U.S. Soil Conservation Service, Bozeman, Montana, written communication (1983).

EXPLANATION

—14— **LINE OF EQUAL ANNUAL PRECIPITATION**--Intervals 2 and 10 inches

Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 3.1-1 Average annual precipitation.



EXPLANATION

PRECIPITATION

TEMPERATURE

Based on records of the National Weather Service (1941-70).

Figure 3.1-2 Average monthly precipitation and temperature at Roundup and Red Lodge, Montana.

Geologic Units Range in Age from Precambrian to Quaternary

Exposed bedrock units are composed principally of sandstone, siltstone, claystone, and shale of Cretaceous and Tertiary age.

The exposed bedrock in most of Area 48 consists of Cretaceous and Tertiary sedimentary rocks (fig. 3.2-1). Older sedimentary rocks of Cambrian to Jurassic age are exposed on the flanks of the mountains in the southern part of the area. Precambrian crystalline rocks are exposed in the Beartooth Mountains.

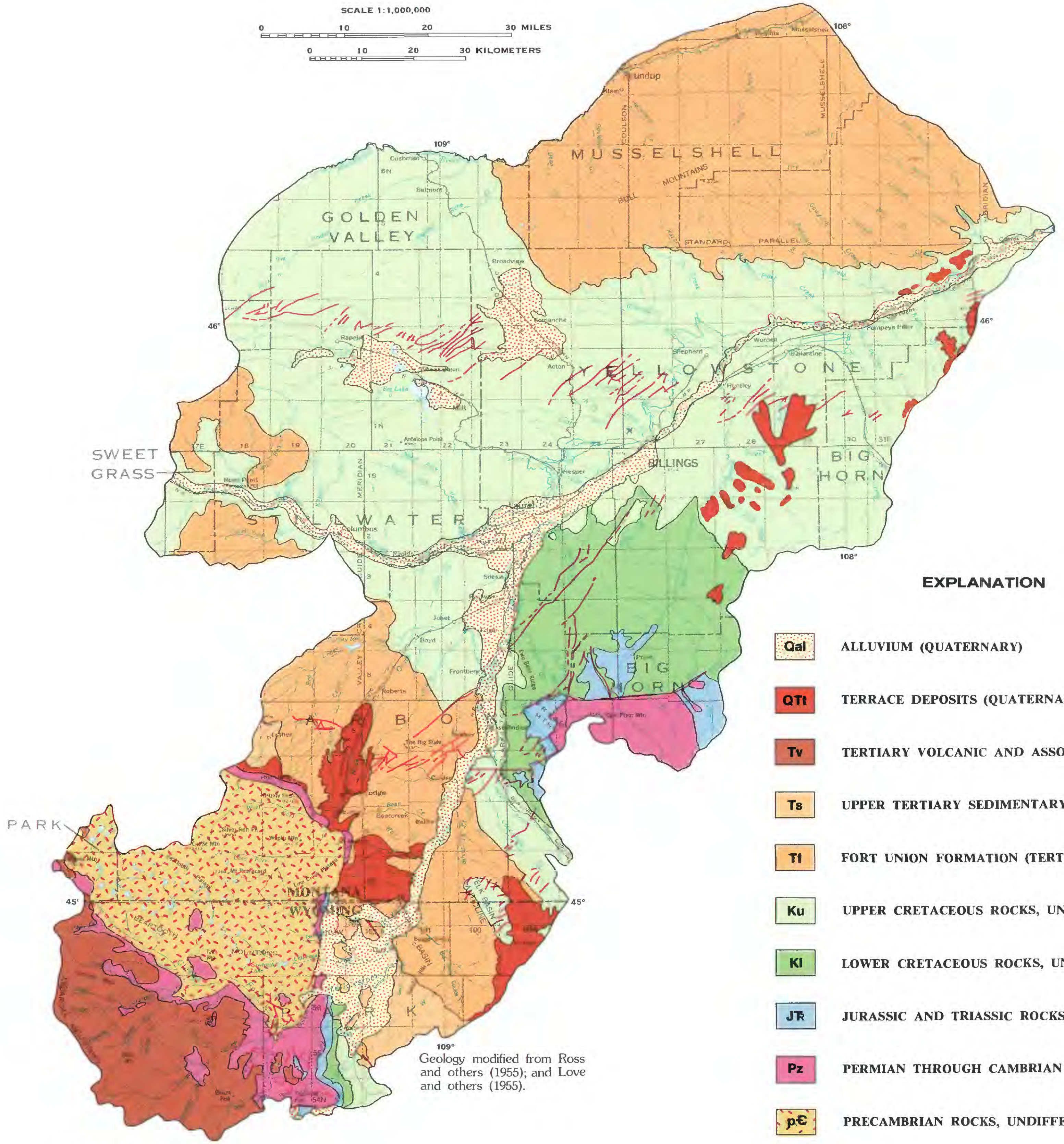
The sedimentary rocks in the southern part of the area occur in the intervening lowland that resulted from the uplift of the Beartooth and Pryor Mountains during middle Tertiary time. The valley forms a topographic expression of the north end of the Bighorn basin. Successfully younger sedimentary units are exposed westward from the Pryor uplift, dipping towards the axis of the Bighorn basin, which is very near a profound fault marking the Beartooth Mountain front. The Fort Union Formation, which is a principal coal-bearing unit in the area, consists of a sequence of sandstone, shale, clay, and coal (table 3.2-1) and has a maximum thickness of at least 8,500 feet (Montana Water Resources Board, 1969b). The large areas of terrace gravels represent the remnants of valley filling during Pleistocene time (Knappen and Moulton, 1931). Terrace gravels along the drainages are generally less than 115 feet thick but are as much as 200 feet thick along the mountain front in the vicinity of Red Lodge (Montana Water Resources Board, 1969b).

The exposed bedrock in the central part of Area 48 is an alternating sequence of about 5,000 feet of folded and faulted sandstone and shale of Cretaceous age. The present topography, which is typified by gently rolling flats separated by rough broken ridges, is largely a result of the differential erosion of the sandstones and shales.

Quaternary alluvium occupies the valleys of the Yellowstone and Clarks Fork Rivers. The valley of the Yellowstone River is as much as 12 miles wide and lies from 100 to 500 feet below the upland plain. Alluvium of the Yellowstone River valley is as much as 100 feet thick (Hall and Howard, 1929). Alluvium of the Clarks Fork valley averages about 30 feet (Montana Water Resources Board, 1969b). Terrace gravels are present at various levels above the present streams. The terraces are most conspicuous along the Yellowstone River and are locally known as "benches." Occurrence of the higher terraces has been attributed to regional rather than local causes, as many of the higher ridges in the area are capped by Tertiary gravels (Hall and Howard, 1929).

Northwest of Billings are two prominent undrained depressions containing Quaternary stream and lake deposits. These depressions are apparently due to warping and perhaps faulting that has occurred in recent geologic time (Ellis and Meinzer, 1924).

The exposed bedrock in the northeast part of Area 48 consists of nearly horizontal beds of sandstone, shale, and coal of the Fort Union Formation. The Fort Union Formation, which forms the Bull Mountains, occupies a broad synclinal basin that trends generally northwestward and is as much as 2,400 feet thick (Hall and Howard, 1929). The Fort Union Formation in this area is divided into three members. The lowermost member, the Tullock Member, consists primarily of shale with numerous beds of sandstone and coal. The Lebo Shale Member is composed of 200 to 300 feet of shale containing generally thin beds of arkosic or carbonaceous sandstone and coal. The uppermost member, the Tongue River Member, contains about 1,700 feet of alternating beds of massive resistant sandstone, claystone, shale, and coal.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Geology modified from Ross and others (1955); and Love and others (1955).

EXPLANATION

- Qal — ALLUVIUM (QUATERNARY)
- QTt — TERRACE DEPOSITS (QUATERNARY AND TERTIARY)
- Tv — TERTIARY VOLCANIC AND ASSOCIATED SEDIMENTARY ROCKS
- Ts — UPPER TERTIARY SEDIMENTARY ROCKS, UNDIFFERENTIATED
- Tf — FORT UNION FORMATION (TERTIARY)
- Ku — UPPER CRETACEOUS ROCKS, UNDIFFERENTIATED
- Kl — LOWER CRETACEOUS ROCKS, UNDIFFERENTIATED
- JTr — JURASSIC AND TRIASSIC ROCKS, UNDIFFERENTIATED
- Pz — PERMIAN THROUGH CAMBRIAN ROCKS, UNDIFFERENTIATED
- p€ — PRECAMBRIAN ROCKS, UNDIFFERENTIATED
- CONTACT
- FAULT -- Dashed where approximately located

Figure 3.2-1 Geology.

Table 3.2-1 Generalized stratigraphic section.

MAP SYMBOL	ERA-THEM	SYSTEM	SERIES	GEOLOGIC UNIT	PRINCIPAL LITHOLOGY
Qal	Cenozoic	Quaternary	Holocene	Alluvium	Sand, gravel, silt, clay
QTt			Pleistocene	Morainal material [1]	
			Pliocene or Miocene	Terrace gravel [1]	
Tv		Tertiary	Oligocene	Absaroka Volcanics	Volcanic rocks
Ts			Eocene	Crandall Fm. or Cathedral Cliffs Fm.	Tuff, breccia, carbonate clasts
				Wasatch Fm. or Willwood Fm.	Sandstone, claystone, shale
Tf			Paleocene	Fort Union Fm.: Tongue River Mbr.; Lebo Shale Mbr.; Tullock Mbr.	Sandstone, claystone, shale, coal
Ku	Mesozoic	Cretaceous	Upper	Hell Creek Fm. or Lance Fm.	Sandstone, claystone, shale, coal
				Montana Group: Fox Hills Ss. or Lennep Ss.	Sandstone
				Montana Group: Bearpaw Sh. / Meeteetse Fm.	Sandstone, shale, coal, bentonite
				Montana Group: Judith River Fm. (Mesaverde Fm.)	Sandstone, shale, coal
				Montana Group: Parkman Ss. (Mesaverde Fm.)	Sandstone
				Montana Group: Claggett Sh. (Mesaverde Fm.)	Shale
				Montana Group: Eagle Ss. (Mesaverde Fm.)	Sandstone, shale, coal
				Montana Group: Telegraph Creek Fm.	Sandstone, shale
				Colorado Group or equivalents: Cody Sh. — Niobrara Fm.	Shale
				Colorado Group or equivalents: Cody Sh. / Frontier Fm. — Carlile Sh.; Greenhorn Fm.; Belle Fourche Sh.	Sandstone, shale, coal
Kl			Lower	Colorado Group or equivalents: Mowry Sh.	Shale
				Colorado Group or equivalents: Muddy Ss	Sandstone
				Colorado Group or equivalents: Thermopolis Sh. or Skull Creek Sh.	Shale
				Fall River Ss. or "Dakota Ss." equivalents	Sandstone
				Cloverly Fm. (Fuson Sh.; Lakota Ss.) / Kootenai Fm.	Sandstone, claystone, conglomerate
JTr		Jurassic	Upper	Morrison Fm.	Sandstone, limestone, marl
				Ellis Group: Swift Fm.; Rierdon Fm. / Sundance Fm.	Sandstone, shale, limestone
			Middle	Ellis Group: Piper Fm. / Gypsum Spring Fm.	Shale, limestone, gypsum
		Triassic		Chugwater Fm.; Dinwoody Fm.	Sandstone, siltstone, shale, anhydrite, gypsum
Pz	Paleozoic	Permian		Phosphoria Fm. / Park City Fm.	Limestone, shale
		Pennsylvanian		Tensleep Ss.	Sandstone
				Amsden Fm. / Darwin Ss. Mbr.	Limestone, shale, sandstone
		Mississippian		Madison Group: Charles equivalent; Mission Canyon Ls.; Lodgepole Ls. / Madison Fm.	Limestone, dolomite
		Devonian		Undifferentiated	Shale, dolomite, limestone
		Silurian		Undifferentiated	Dolomite
		Ordovician		Undifferentiated	Dolomite, sandstone
		Cambrian		Undifferentiated	Sandstone, shale, limestone, dolomite
p€		Precambrian		Undifferentiated	Igneous and metamorphic rocks

[1] Order does not necessarily denote relative stratigraphic position

Modified from Montana Bureau of Mines and Geology (1971).

Land Used Primarily for Agriculture

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

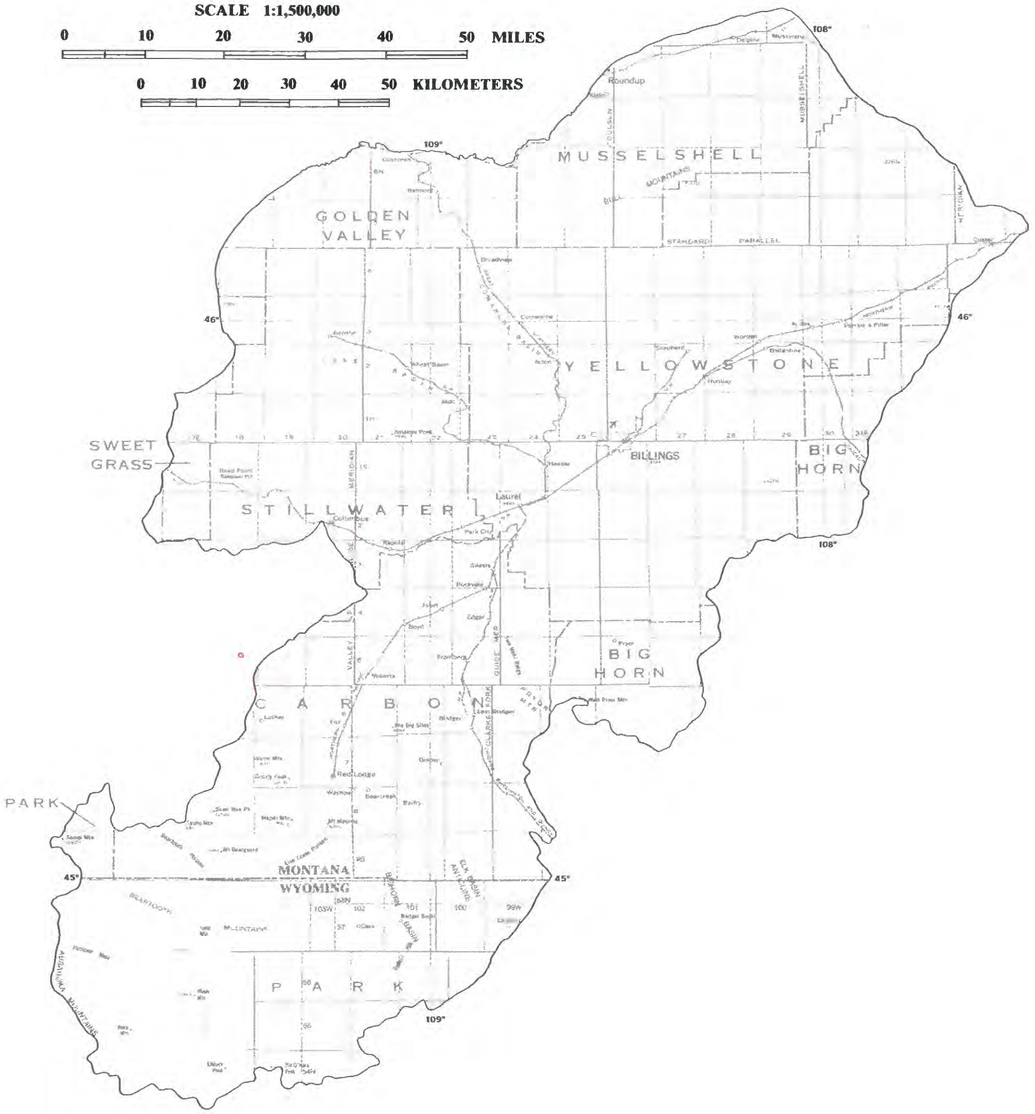
Land use is related primarily to the natural diversity of the land. The land use map (fig. 4.1-1) shows that about 74 percent of all counties in Area 48 is used for rangeland. The rangeland is used for raising stock; from 24 to 120 acres are needed to support each head of cattle on the rangeland in eastern Montana (F. F. Munshower, Montana State University, oral commun., 1982). Forest covers about 14 percent of the area. Cropland covers about 10 percent of the area. About 3 percent of the land is irrigated (table 4.1-1).

Currently producing (1983) and abandoned surface coal mines (section 5.2) occupy a very small percentage of the land area. Land reclaimed after the coal has been extracted commonly is returned to rangeland or nonirrigated cropland.

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

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

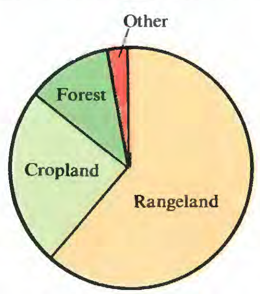
The Regional Coal Team recommends the lease sale schedule for final approval by the Secretary of the Interior.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

EXPLANATION

PERCENTAGE LAND USE BY COUNTY



Land use from Jackson (1970); and Wyoming Department of Administration and Fiscal Control (1981).

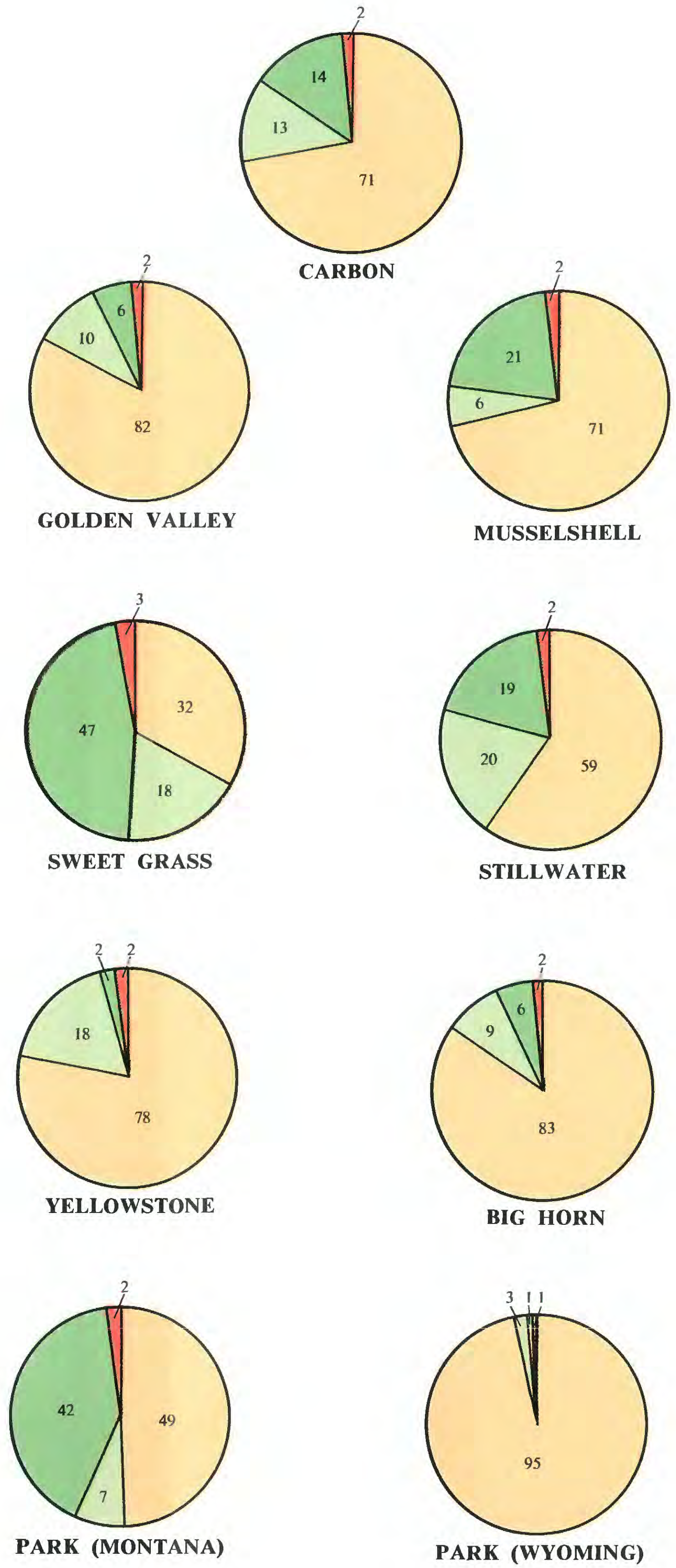


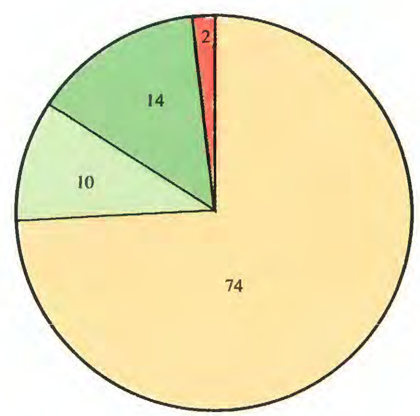
Figure 4.1-1 Land use.

Table 4.1-1 Irrigated acreage.

County	Total acres	Acres irrigated	Percent irrigated
Big Horn	3,235,200	49,275	1.5
Carbon	1,327,360	81,944	6.2
Golden Valley	755,200	8,643	1.1
Musselshell	1,207,680	11,736	1.0
Park (Mont.)	1,772,160	57,099	3.2
Stillwater	1,152,640	26,632	2.3
Sweet Grass	1,183,360	52,868	4.5
Yellowstone	1,706,240	87,945	5.2
Park (Wyo.)	3,349,120	147,246	4.4
ALL COUNTIES	15,688,960	523,388	Average: 3.3

Data from U.S. Bureau of the Census (1981a, 1981b)

PERCENTAGE LAND USE OF ALL COUNTIES IN AREA 48



Principal Water Use is Irrigated Agriculture

Average daily water use during 1980 was about 1,172 million gallons of surface water and about 30 million gallons of ground water; about 95 percent of water use was for irrigated agriculture.

Irrigated agriculture was by far the largest use of water during 1980 (fig. 4.2-1), with about 1,127 Mgal/d (million gallons per day) being used from surface water sources and 18.4 Mgal/d from ground-water sources. About 47 percent of the irrigation occurs along the Yellowstone River, and about 43 percent of the irrigation occurs along the Clarks Fork Yellowstone River and its tributaries. The remaining irrigation water use occurs along the Musselshell River and Pryor Creek.

Self-supplied industrial water use totaled 28.1 Mgal/d and was the second largest water use during 1980. Almost all industrial water use occurred in Billings, Montana, and 99 percent came from surface-water sources.

Water withdrawn for public supplies was about 18.5 Mgal/d, of which about 2.3 Mgal/d was ground water. Most of the water for public supplies was used in Billings. Rural water use was about 10.9 Mgal/d, with about 9.3 Mgal/d of the total coming from ground-water sources.

TOTAL WATER USE, IN MILLION GALLONS PER DAY
1202.9

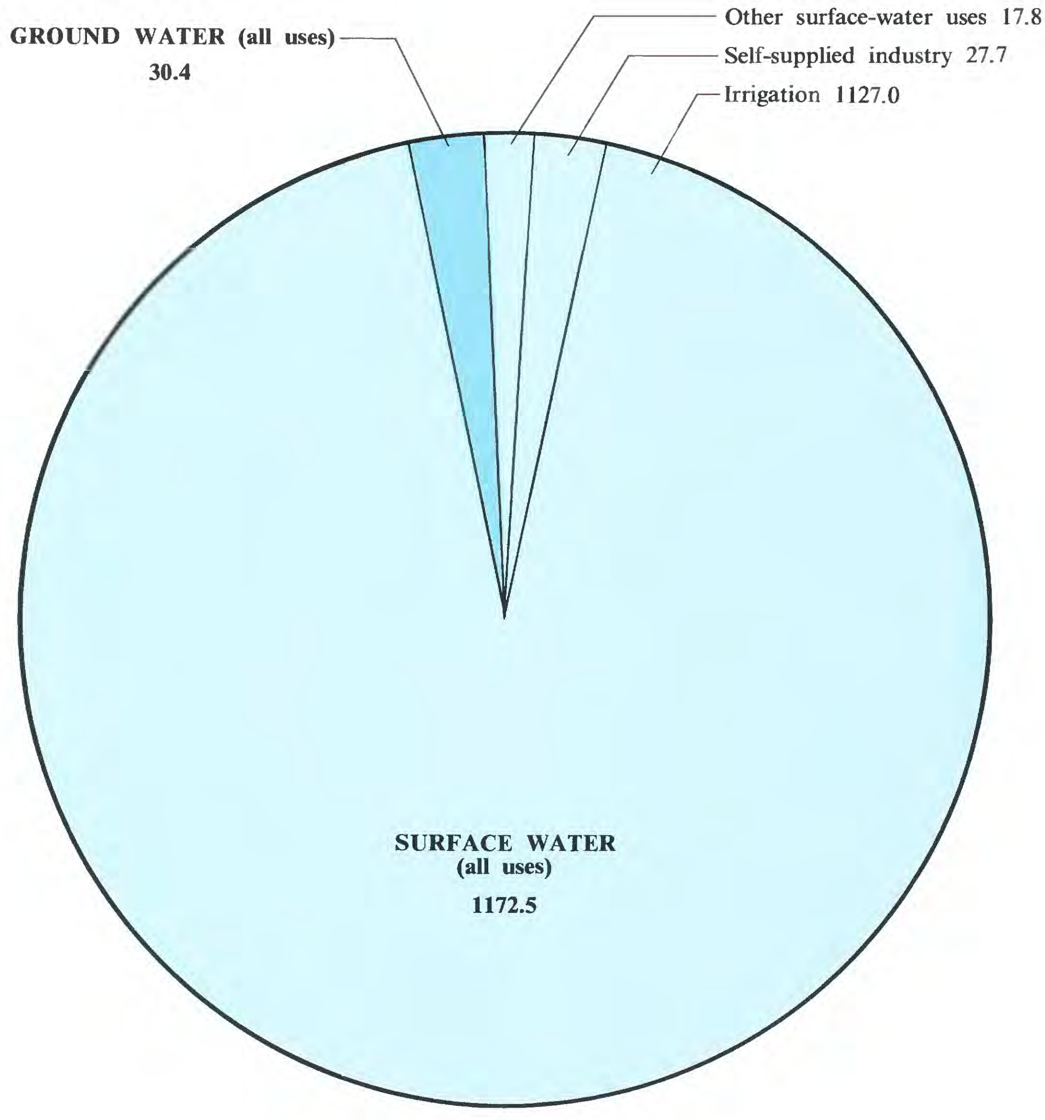


Figure 4.2-1 Approximate water use during 1980.

Land and Coal Ownership is Complex

About one-half of the land and coal is privately owned; the rest is administered by Federal and State agencies and Indian reservations.

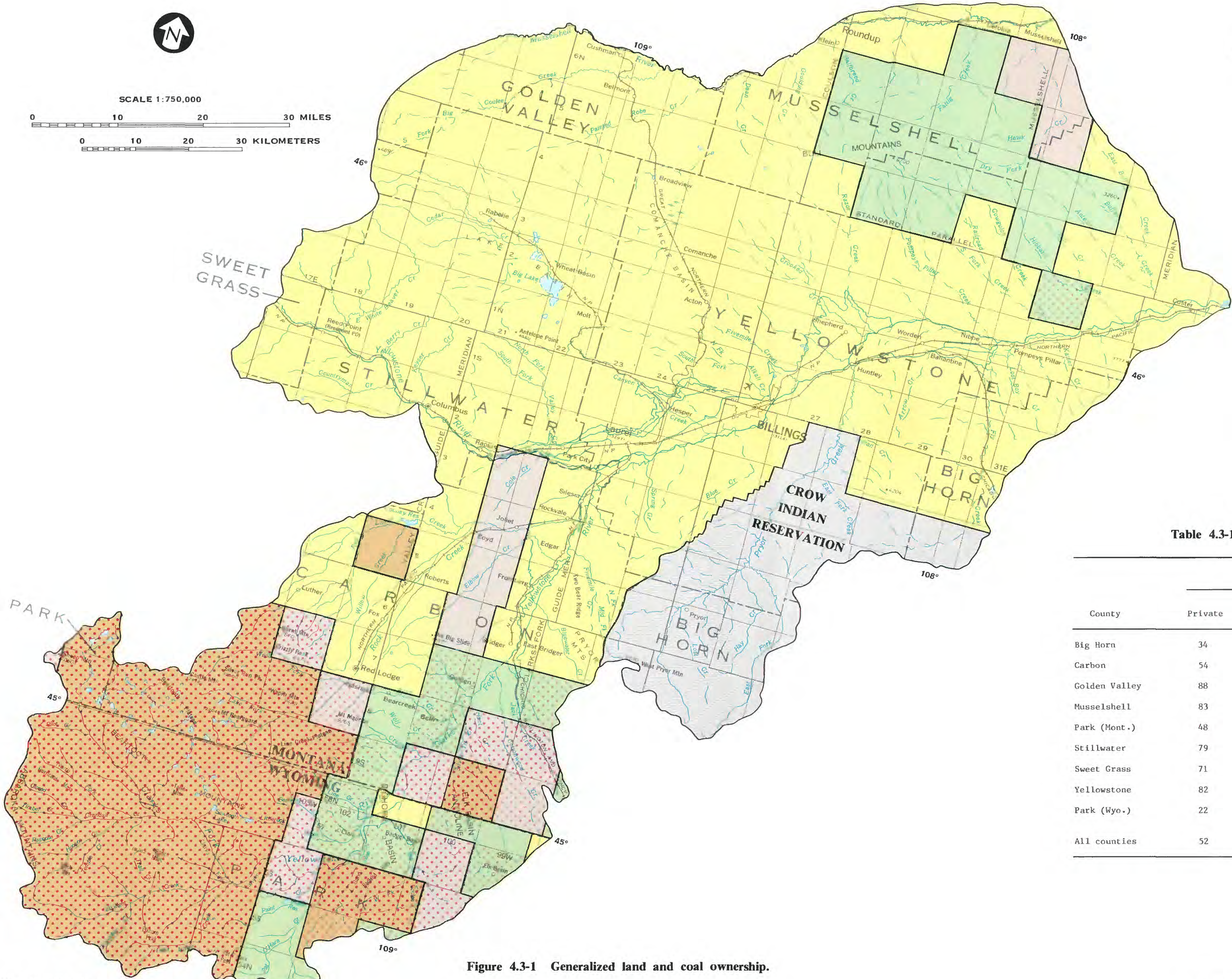
About 52 percent of the land surface of the counties included in Area 48 is privately owned. About 33 percent is Federally owned, primarily administered by the U.S. Forest Service (Custer and Shoshone National Forests) and the U.S. Bureau of Land Management. About 11 percent of the land lies within the Crow Indian Reservation and about 4 percent is owned by the State (table 4.3-1).

Ownership of about 85 percent of the coal is divided about equally between the Burlington Northern Railroad and the Federal Government in the Bull Mountains in the northeastern part of Area 48 (fig. 4.3-1). In the southern part of the area, most of the coal underlies Federal lands and is Federally owned. Most of the coal in and near the Crow Indian Reservation is held in trust for the Tribe. The coal in the rest of Area 48 is primarily privately owned, interspersed with small tracts of Federal coal. The history of land-surface and coal ownership gives insight into today's checkerboard pattern of ownership in the Bull Mountains area, which is shown in detail on maps available from the U.S. Bureau of Land Management (1974a, 1974b, 1978, 1979).

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

The easternmost edge of Area 48 was granted to the Crow Indians by government treaty in 1868. Twenty-one years later, in 1889, the Enabling Act that admitted the State of Montana to the Union granted sections 16 and 36 in each township to the State for the purpose of supporting public schools. By statute, Montana was not allowed to own the subsurface rights of these school sections if they were mineral lands, but the State could exchange mineral lands for other Federal Government lands of equal value (other than the mineral value).

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



EXPLANATION

FEDERAL OWNERSHIP BY TOWNSHIP, IN PERCENT

Land ownership

- Less than 25 percent
- 25 to 50 percent
- 50 to 75 percent
- Greater than 75 percent

Coal ownership

- Less than 25 percent
- 25 to 50 percent
- 50 to 75 percent
- Greater than 75 percent

Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 4.3-1 Generalized land and coal ownership.

Table 4.3-1 Land ownership, by county.

County	Private	Federal	State	Indian reservation
	Percent ownership			
Big Horn	34	14	3	49
Carbon	54	43	3	0
Golden Valley	88	5	7	0
Musselshell	83	11	6	0
Park (Mont.)	48	50	2	0
Stillwater	79	17	4	0
Sweet Grass	71	24	5	0
Yellowstone	82	5	4	9
Park (Wyo.)	22	73	5	0
All counties	52	33	4	11

Data from U.S. Bureau of Reclamation (1972); and Montana Department of State Lands (1976).

Coal Contained in Rocks of Cretaceous and Tertiary Age

All coals in the area are classified as high-grade subbituminous bituminous.

Coal in Area 48 is present in the Kootenai Formation (or Cloverly Formation), Eagle Sandstone, Claggett Shale, Judith River Formation, Meeteetse Formation, Lennep Sandstone, and Hell Creek Formation, all of Cretaceous age, and in the Fort Union Formation of Tertiary age. Coal seams in the Eagle, Judith River, and Fort Union have historically been the most important. Coal seams in other formations are commonly too thin to be of economic value. The principal coal resources are mapped in figure 5.1-1.

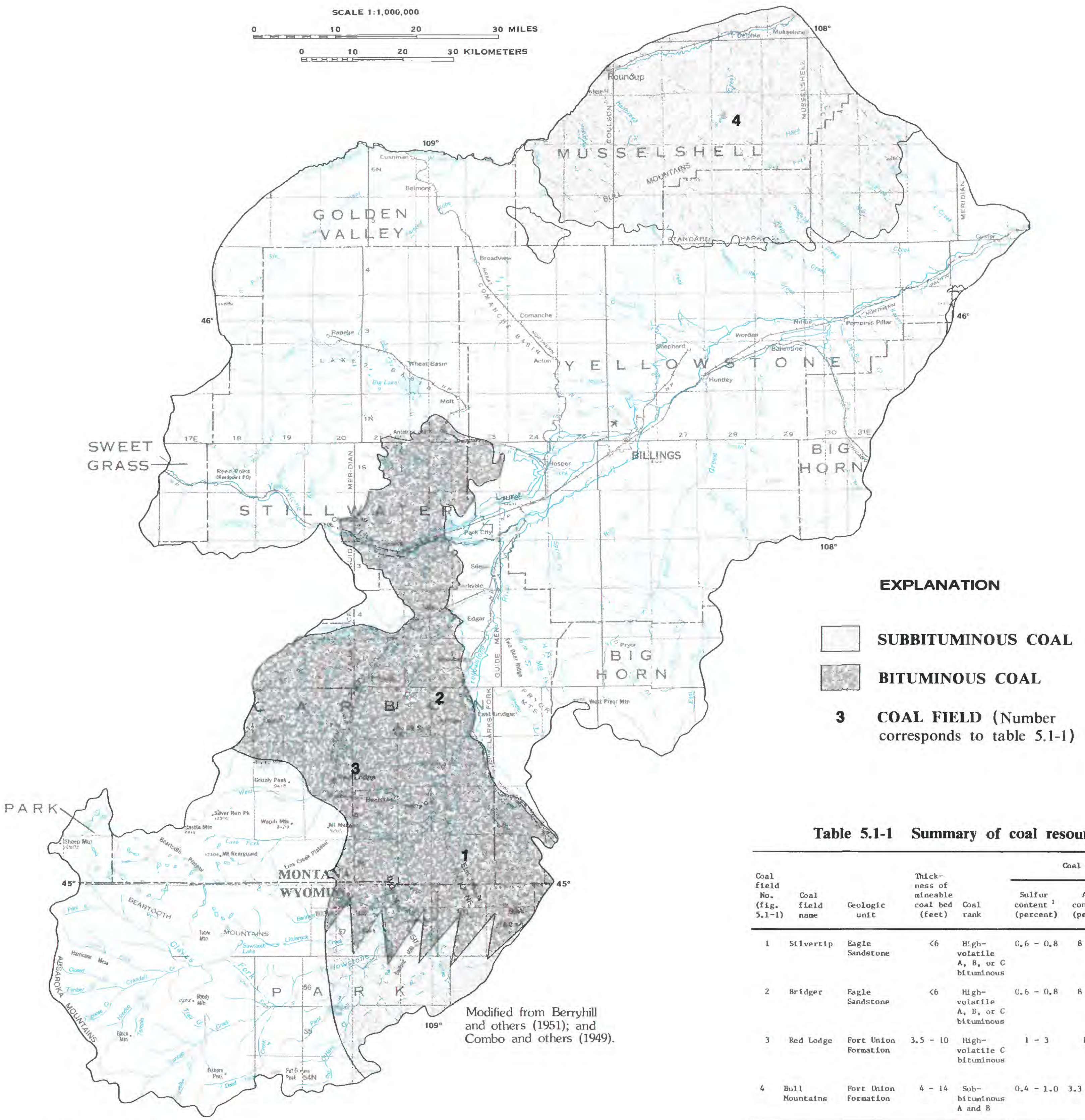
Coal in the Eagle Sandstone generally consists of three beds separated by carbonaceous shale and in some places the coal section is chiefly shale. The commercially productive zones, including partings, in the Bridger coal field commonly range in thickness from 45 to 65 inches, with total coal ranging from 23 to 46 inches and occurring 55 to 60 feet below the top of the formation (Knappen and Moulton, 1931). Six feet of coal in a 6.4-foot section has been reported in the Silvertip coal field near the Elk Basin anticline (Fisher, 1904). Coal thickness in the Eagle thins to less than 8 inches north of Joliet, Montana. Eagle coals crop out on the flanks of the Elk Basin anticline near Elk Basin, Wyoming, and between Boyd and Bridger, Montana. These coals plunge to a depth of 900 feet 2 miles west of Boyd. Coal in the Eagle Sandstone is known locally as Fromberg coal.

Coal is present in the Judith River Formation about 75 feet below the top of the formation. The total thickness of coal, excluding partings, commonly is between 11 and 23 inches and varies laterally in short distances (Knappen and Moulton, 1931). The coal is located between stream-deposited volcanic ash beds and contains much carbonaceous shale and has a large ash content. The coal of the Judith River Formation crops out northeast of Columbus, Montana, thins southward, and disappears in the vicinity of the Yellowstone River.

Coal in the Red Lodge - Bear Creek area is contained in the upper part of the Fort Union Formation in a stratigraphic section about 825 feet thick. Nine workable coal beds have been described, ranging in thickness from 3.5 to 12 feet (Darrow, 1954). Coal beds crop out at various places near the towns of Red Lodge and Bear Creek, Montana. Coal in the Red Lodge - Bear Creek area is roughly the stratigraphic equivalent of the coal in the Bull Mountains, where 26 coal beds have been described by Woolsey and others (1917). Most coals in the Bull Mountains area are lenticular in shape and, in general, thin westward.

All coals in the area are classified as subbituminous to bituminous (fig. 5.1-2), with heating values generally ranging from about 9,300 to 11,000 British thermal units per pound on an as-received basis (table 5.1-1). In general, the largest heating values are obtained from coals contained within the Eagle Sandstone and the smallest values from coals within the Judith River Formation.

Because of topography and steeply-dipping geologic structure, most coal in the area is deeply buried and can be recovered only by underground mining methods. Some of the coal in the Bull Mountains is recoverable by surface mining methods.



Modified from Berryhill and others (1951); and Combo and others (1949).

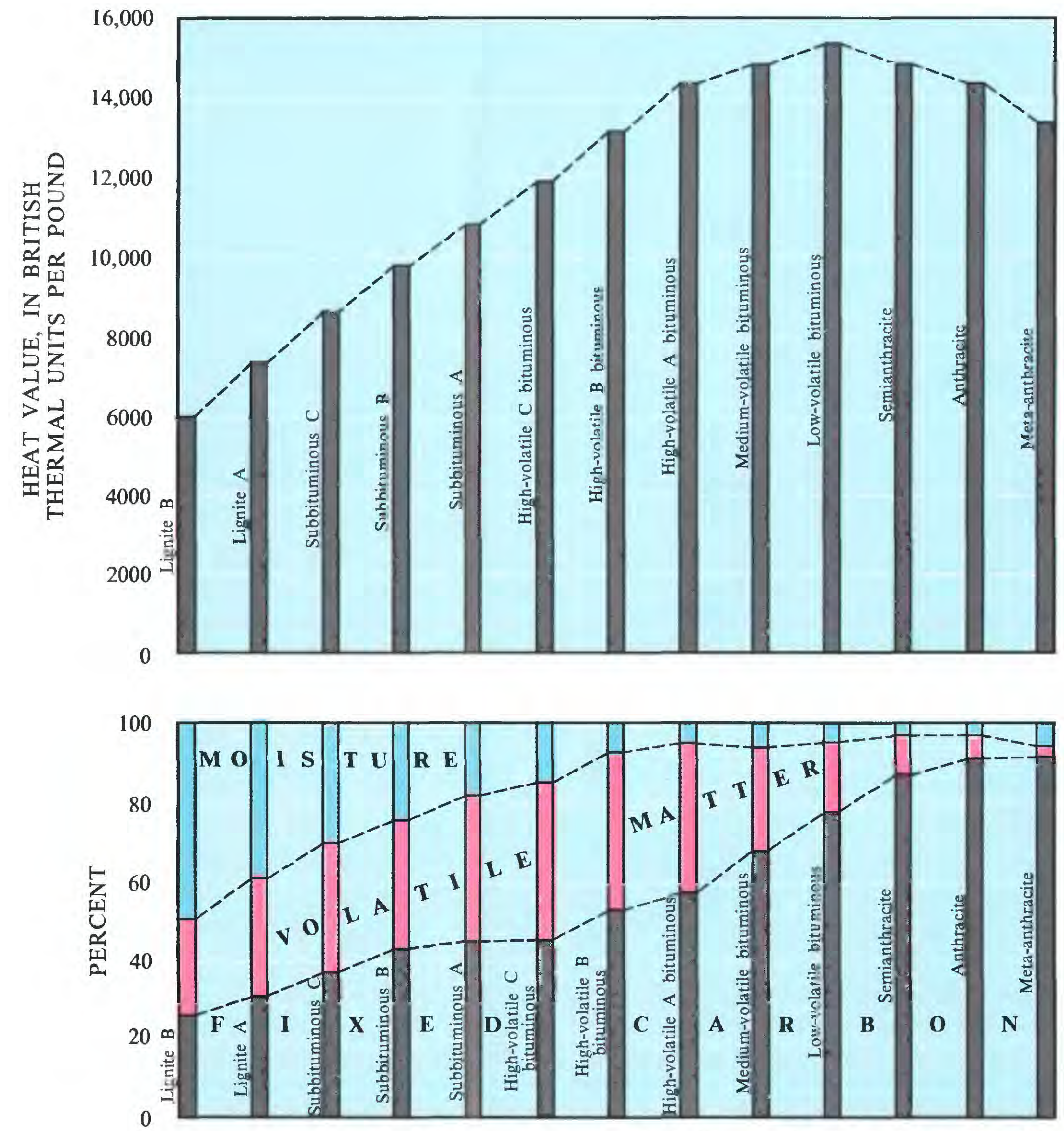
Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 5.1-1 Coal resources.

Table 5.1-1 Summary of coal resources.

Coal field No. (fig. 5.1-1)	Coal field name	Geologic unit	Thickness of mineable coal bed (feet)	Coal rank	Coal content: Sulfur content [1] (percent)	Coal content: Ash content [1] (percent)	Heating value [1] (Btu/lb)
1	Silvertip	Eagle Sandstone	<6	High-volatile A, B, or C bituminous	0.6 - 0.8	8 - 18	10,235
2	Bridger	Eagle Sandstone	<6	High-volatile A, B, or C bituminous	0.6 - 0.8	8 - 18	10,235
3	Red Lodge	Fort Union Formation	3.5 - 10	High-volatile C bituminous	1 - 3	13.4	10,000
4	Bull Mountains	Fort Union Formation	4 - 14	Sub-bituminous A and B	0.4 - 1.0	3.3 - 7.7	9,270 - 11,000

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



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 Early 1880's

Commercial coal production in Area 48 historically has been centered in three general localities.

Coal has been commercially mined from the Eagle Sandstone and the Judith River Formation along a northwest-southeast line from near Columbus, Montana, to Elk Basin, Wyoming, and from the Fort Union Formation near Red Lodge and Bearcreek, Montana, in the southern part of Area 48. All coal in these areas was extracted using underground methods. In the northeastern part of Area 48, coal has historically, and presently (1983) is, being mined from the Fort Union Formation in the Bull Mountains coal field near Roundup, Montana. Coal has been mined in the Bull Mountains by both underground and surface methods.

Coal was first mined in the Red Lodge area about 1882 and small mines were operated for several years to supply local needs. In 1896 the Northwestern Improvement Company began producing coal for use by the Northern Pacific Railroad. Total production for railroad use was 232,000 tons in 1896 and more than 1.0 million tons in 1917 (Powe, 1954). Production greatly declined after 1924 as the railroad began obtaining coal from surface mines at Colstrip in eastern Montana. The mines at Red Lodge were closed in 1932. Total production from the Red Lodge field was slightly more than 11 million tons, which included 8.5 million tons for railroad use and 2.5 million tons for electric and steam generation (Powe, 1954).

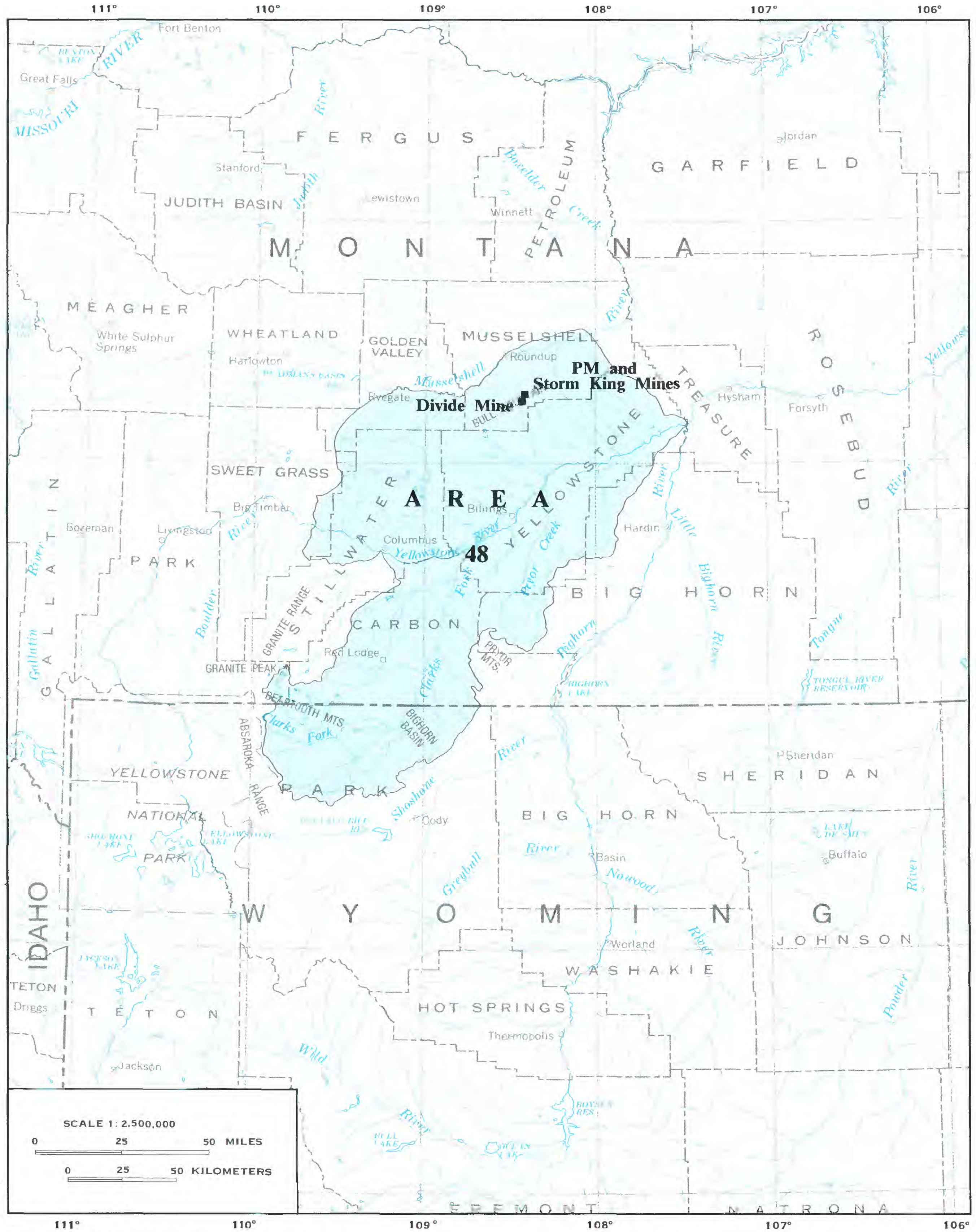
The Bear Creek coal field was discovered in 1884 and the first mine began production in 1900. A railroad was completed to Bearcreek in 1906. Peak production occurred between 1918 and 1925, with a production of 5,200 tons per day from seven mines in 1922. The market deteriorated rapidly after 1926 as the use of oil and gas began to replace coal. The field underwent a revival during World War II with a production of about 500,000 tons per year from 1942 to 1945 (Darrow, 1954). One mine in the field was reopened for a short time in 1979. Production during this period was small, amounting to 545 tons in 1979, 2,650 tons in 1980, and 16 tons in 1981 (Montana Department of Labor and Industry, unpublished reports).

Production from the Silvertip coal field on the flanks of the Elk Basin anticline at the Montana-Wyoming border has been small. Total reported production from two mines is less than 1,300 tons (Glass and others, 1975).

Most mines producing in the Joliet, Fromberg, Bridger areas of Montana were small and produced coal that was used primarily for local consumption. The productive zone is within the Eagle Sandstone and is locally called the Bridger coal or Fromberg coal. Production from these mines ranged from about 15 to 200 tons per day.

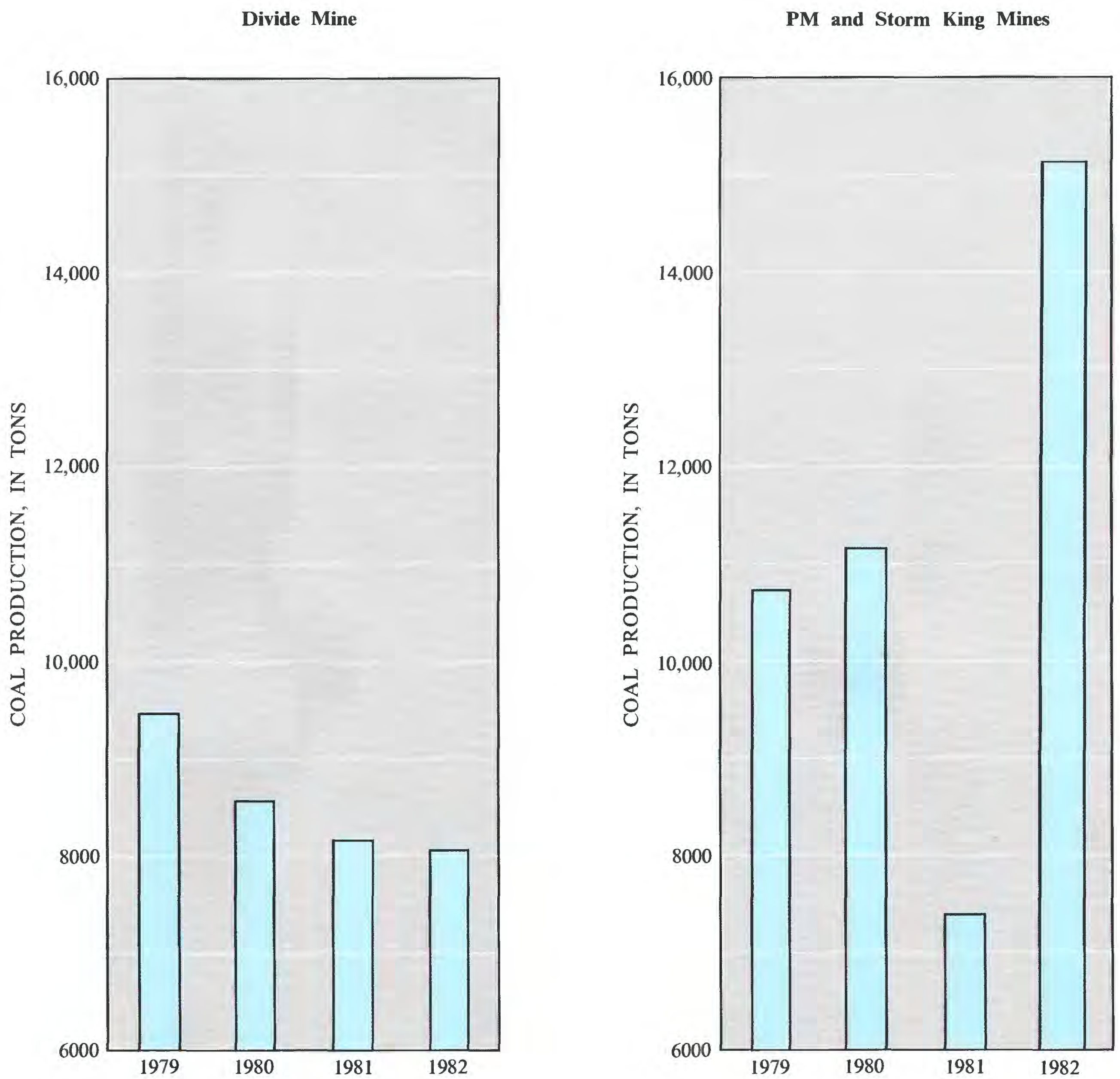
Several small mines produced coal for local use from the Judith River Formation northeast of Columbus, Montana, during the 1920's. The production of each of these mines was less than 10 tons per day (Knappen and Moulton, 1931). Small quantities of coal also have been extracted from the Kootenai Formation (or Cloverly Formation), and Lennep Sandstone.

The first commercial interest in coal from the Bull Mountains was during the early 1880's when a carload of coal was mined and shipped to Anaconda, Montana, about 200 miles west of the Bull Mountains, presumably for testing as a fuel source for the smelters. Commercial mining came into prominence in about 1906 when coal was mined as a source of fuel for the westward extension of the Chicago, Milwaukee, and St. Paul Railroad. As a consequence, mining in the field developed rapidly, especially in the vicinity of Roundup, Montana. By 1913, coal was not only being used as a source of fuel for the railroad and being shipped to smelters near Anaconda, Montana, but was being shipped as far west as the Columbia River and as far east as Sioux City, Iowa (Woolsey and others, 1917). Commercial mining in the Bull Mountains has continued to varying degrees. The most recent production in the Bull Mountains has been conducted by two mining operations operating three mines (fig. 5.2-1). Combined annual production from these mines ranged from about 15,500 to about 23,200 tons between 1979 and 1982 (fig. 5.2-2). Production of coal from two mines was terminated in November 1982 and production from the third mine ceased in May 1983. One mine reopened with a reported production of 23 tons in August 1983 and 753 tons in September 1983. A second mine was reopened in September 1983 with a reported production of 1,323 tons.



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

Figure 5.2-1 Active coal mines.



Data from Mining Informational Services (1980-82); and Montana Department of Labor and Industry, unpublished reports.

Figure 5.2-2 Coal production.

Mining Increases Potential for Hydrologic Problems

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

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

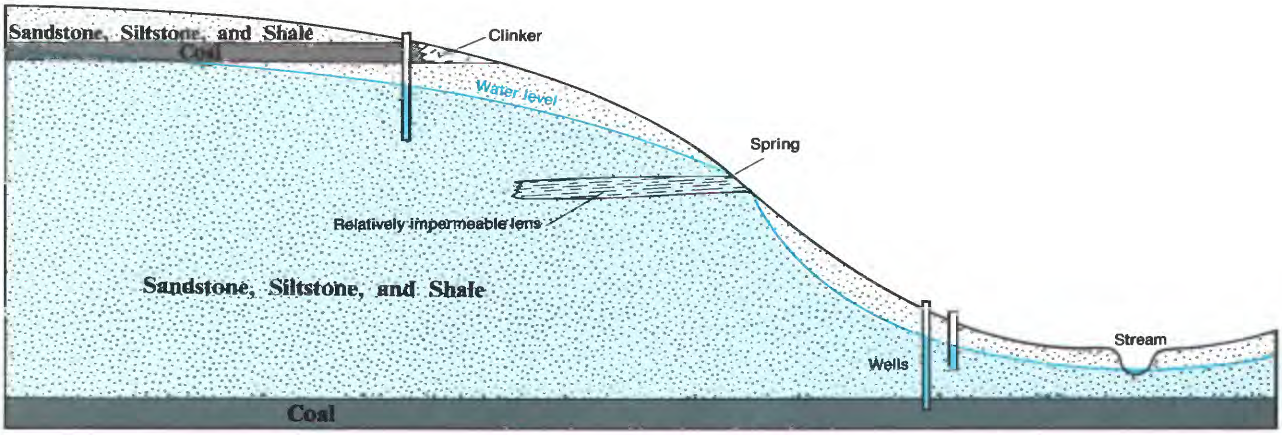
Ground-water levels can be affected by coal mining (fig. 5.3-1). The effects of surface and underground mines are similar. Mines located above water-yielding zones have little, if any, effect on water levels. Where excavation intersects a water-yielding zone, a mine, whether surface or underground, becomes a ground-water sink that intercepts the natural ground-water flow and induces flow toward the mine. The result is dewatering of the area above the base of the workings and a depression of water levels around the mine. Water-level declines can cause a decrease or loss of production of nearby wells and springs. These effects generally will be temporary and occur only during and for a limited time after the active mining period.

The areal extent of mining effects on water levels is largely dependent on the geologic and hydrologic setting of the mine. The interbedding of sandstone, siltstone, and shale of the Fort Union Formation is characterized by abrupt lateral and vertical changes in lithology and composes a system of numerous aquifers and confining zones of limited areal extent. Coal beds are characterized by fracture systems that provide limited paths for the movement of water. Consequently, each sand lens or fracture system not contiguous with another can be considered to be an individual and isolated aquifer. Recharge available to this individual aquifer is limited to leakage through the surrounding confining zones; thus, the areal extent of water-level changes resulting from mining can be relatively local. In most instances, upon completion of mining, water levels will rise until premining equilibrium conditions are approximated.

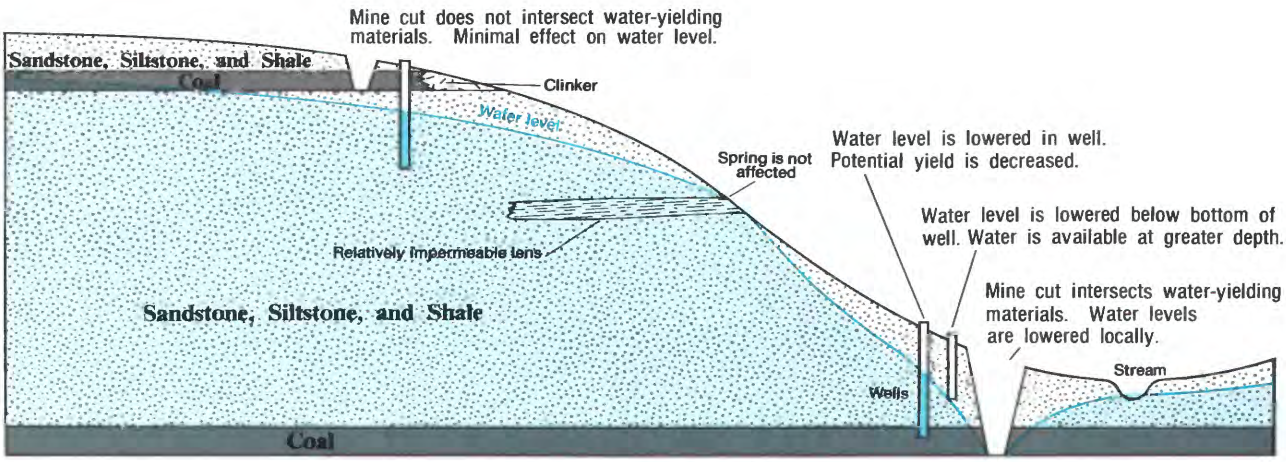
The quality of ground water in the vicinity of surface mines can be affected by the replacement of overburden material after the coal is removed. Replacement of overburden results in the exposure of fresh mineral surfaces, the placement of minerals in the reduced state into the oxidizing zone, and provides the opportunity for renewed chemical reactions. The actions of sulfate-reducing bacteria can decrease sulfate concentrations. Sulfate-reducing bacteria, which are present in the Fort Union Formation of southeastern Montana, have been reported to re-establish themselves in spoils aquifers (Dockins and others, 1980); however, waters having large sulfate concentrations have been reported near some mines (Van Voast, 1974; Van Voast and Hedges, 1975). Chemical analyses of spoil-derived water from the Powder River Basin of southeastern Montana and northeastern Wyoming (Rahn, 1975; Van Voast and others, 1978) have indicated that the median dissolved-solids concentration of water in spoils is 160 to 173 percent of that in stock and domestic wells completed in the Fort Union Formation.

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

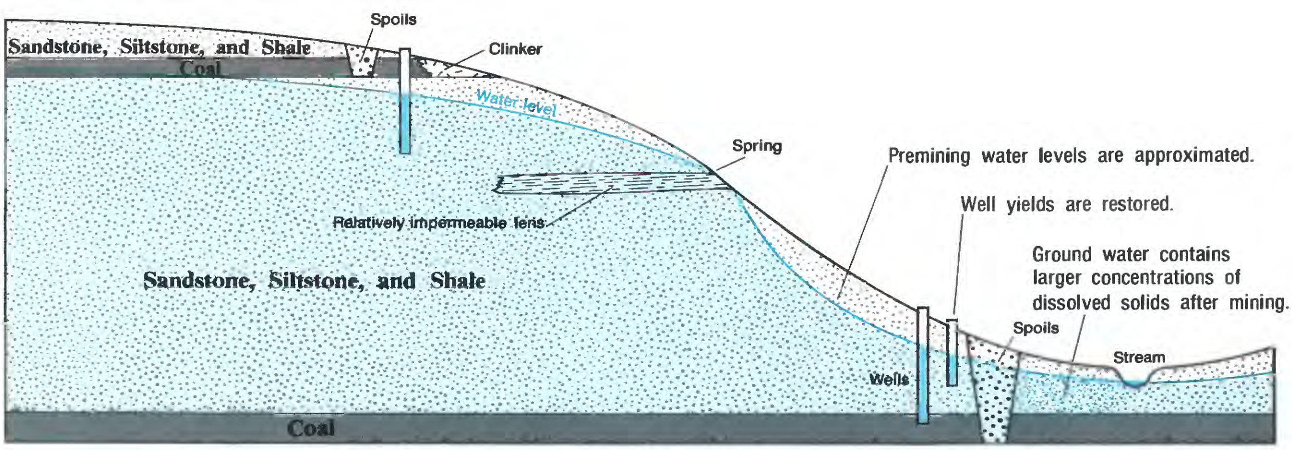
Cooperative and individual studies of effects of existing mines in southeastern Montana by the U.S. Geological Survey and the Montana Bureau of Mines and Geology have shown that: (1) Ground-water inflow to mine pits generally has been small, (2) mine effluents have not created serious water-quality problems,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



A. Premining conditions



B. Conditions during mining



C. Postmining conditions

Figure 5.3-1 Possible impacts of mining aquifers.

Hydrologic Studies Completed for Much of the Area

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

Early hydrologic studies in Area 48 were conducted by Ellis and Meinzer (1924), Riffenburg (1926), Hall and Howard (1929), and Perry (1931). Several regional and national studies made between 1964 and the early 1970's included the area. The energy shortages of the early 1970's and consequent increased interest in coal as a source of energy resulted in increased attention to coal-bearing regions. Concern about the effects of coal mining on the water resources spurred a significant increase in hydrologic studies to document premining conditions for future planning decisions and to determine the effects of the mining on the hydrologic system. Hydrologic studies conducted by the U.S. Geological Survey, the Montana Bureau of Mines and Geology, the Water Quality Bureau of the Montana Department of Health and Environmental Sciences, and the Montana Water Resources Board are shown in figure 6.1-1 and listed in table 6.1-1.

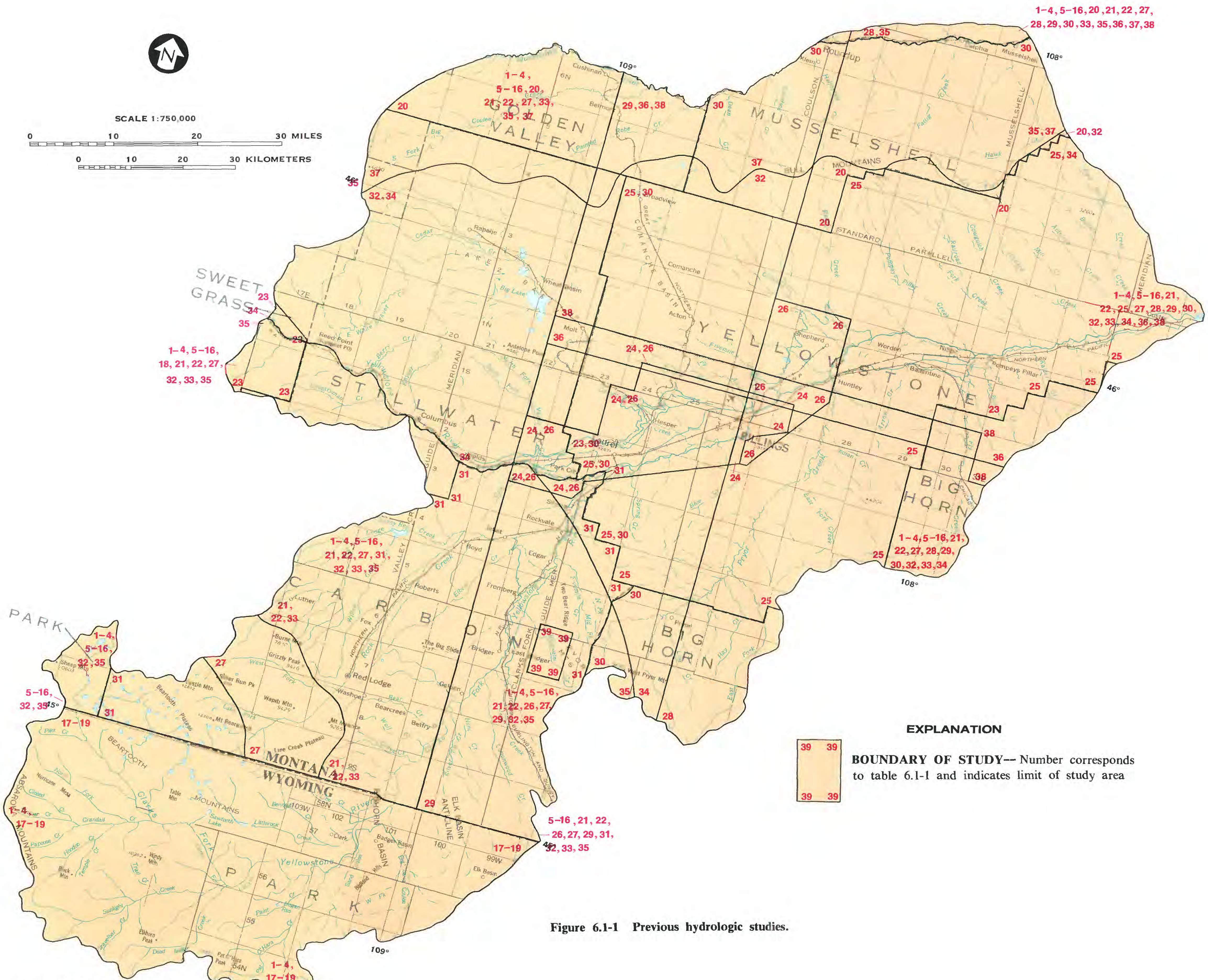


Figure 6.1-1 Previous hydrologic studies.

Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Table 6.1-1 Index to previous hydrologic studies.

Study-area No. (fig. 6.1-1)	Reference (see section 12.0 for complete reference)	Principal subject of investigation: Surface water	Ground water	Water quality	Biology	Sediment
1	Blakey (1966)			X		
2	Busby (1966)	X				
3	Durfor and Becker (1964)			X		
4	McGuinness (1964)	X	X			
5	Aagaard (1969)			X		
6	Bahls and others (1981)			X	X	X
7	Boner and Omang (1967)	X				
8	Hopkins (1976)		X	X		
9	Knapton and Jacobson (1980)			X		
10	Montana Water Resources Board (1969a)		X			
11	Omang and others (1979)	X				
12	Omang and others (1982)	X				
13	Perry (1931)		X	X		
14	Reed and McMurtrey (1970)		X			
15	Riffenburg (1926)			X		
16	U.S. Geological Survey and Montana Bureau of Mines and Geology (1968)	X	X	X	X	
17	Craig and Rankl (1978)	X				
18	Lowham (1976)	X				
19	Lowry and others (1976)	X	X	X		X
20	Ellis and Meinzer (1924)		X	X		
21	Feltis (1980a)		X			
22	Feltis (1980a, 1980b, 1980c, 1980d)			X		
23	Feltis and Wood (1982)		X	X		
24	Gosling and Pashley (1973)	X	X	X		
25	Hall and Howard (1929)		X	X		
26	Hutchinson (1983)		X	X		
27	Levings (1981a, 1981b, 1982a, 1982b, 1982c, 1982d)		X			
28	Miller (1976)		X	X		
29	Miller and Strausz (1980a, 1980b)		X			
30	Montana Bureau of Mines and Geology and U.S. Geological Survey (1978)		X	X		
31	Montana Water Resources Board (1969b)		X			
32	Moore and Shields (1980)	X				
33	Noble and others (1982)		X	X		
34	Omang and others (1983)	X				
35	Parrett and others (1983)	X				
36	Rioux and Dodge (1980)	X	X	X		
37	Shields and White (1981)	X				
38	Stoner and Lewis (1980)		X			
39	Zimmerman (1964)		X	X		

U.S. Geological Survey Currently Conducting Investigations in Area

Current studies focus on definition and evaluation of water resources.

Current (1983) water-resources studies by the U.S. Geological Survey in Area 48 (fig. 6.2-1) include collection of surface-water, ground-water, and water-quality data. The data can be used as a basis for determining the hydrologic effects of present and future mining. Current studies include determination of present areal hydrologic conditions, analysis of stream-channel and streamflow characteristics, and evaluation of the suitability of water resources for various uses. The current investigations are summarized in table 6.2-1.

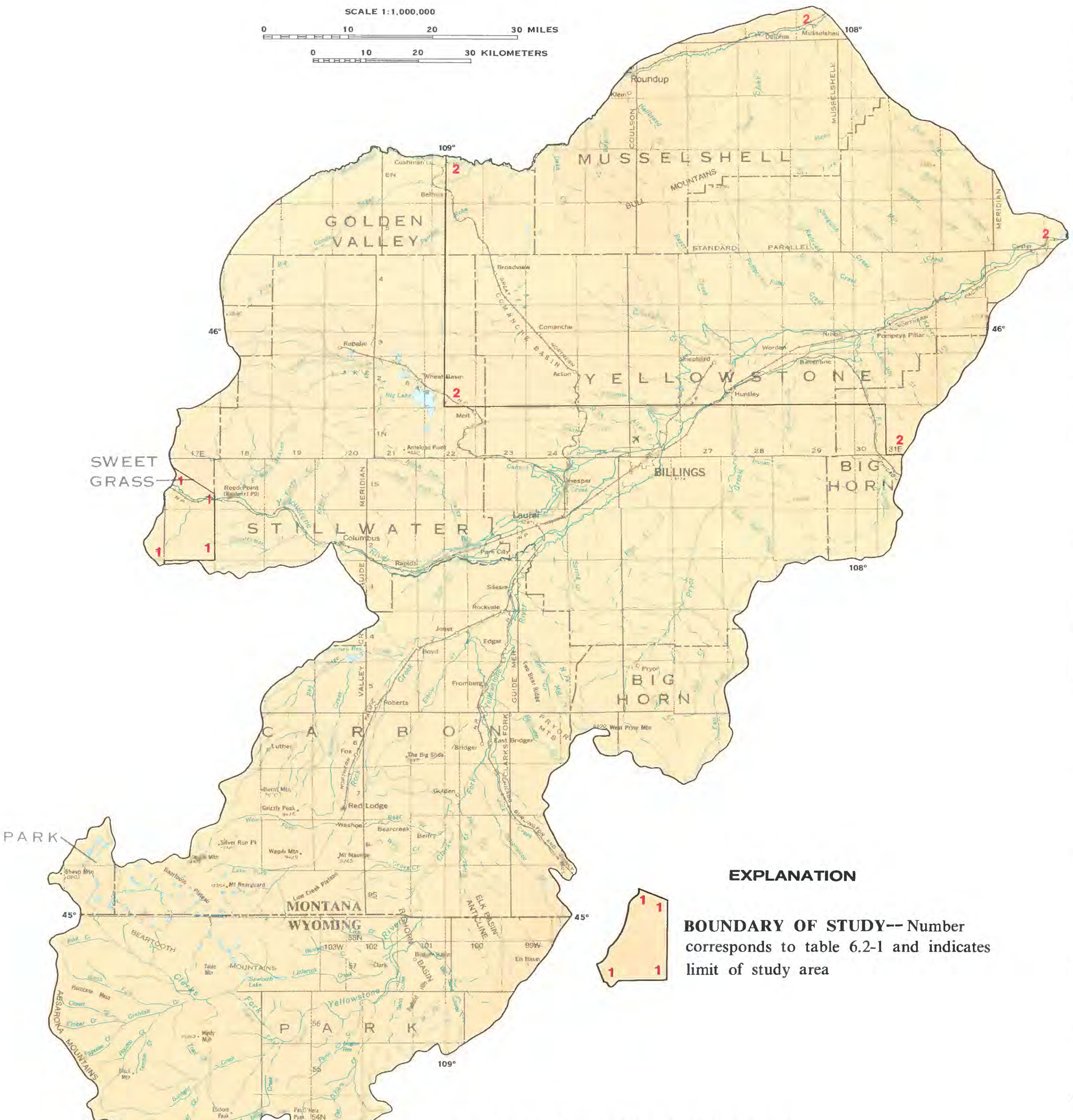


Figure 6.2-1 Current (1983) hydrologic studies.

Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

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

Location within State: Montana	Location within State: Wyoming	Map No. (fig. 6.2-1)	Project No.	Project title	Project objective
				Data-collection programs	
Statewide	Statewide	--	MT-001, WY-001	Surface-water stations	To collect surface-water data for analytical studies and current-purpose uses such as evaluation, operation, disposal, legal, and research of water resources.
Statewide	Statewide	--	MT-002, WY-002	Ground-water stations	To collect water-level data to provide a long-term data base to permit proper planning and management of water resources.
Statewide	Statewide	--	MT-003, WY-003	Water-quality stations	To provide a bank of water-quality data for planning management of intrastate, interstate, and international waters.
Statewide	Statewide	--	MT-004, WY-004	Sediment stations	To provide a bank of sediment data for planning and management of intrastate, interstate, and international waters.
Statewide	Statewide	--	MT-007 WY-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	Statewide	--	MT-001 WY-010	Peak-flow analysis	To collect adequate data to enable definition of the magnitude and frequency of floods to be expected from any given small drainage in the State.
Central and east.	---	--	MT-056	Madison aquifer	To compile data from wells and test holes and to prepare maps describing the altitude and configuration of the top of the aquifer, potentiometric surface, and quality of water.
South-central.	---	1	MT-079	Stillwater Complex	To develop a streamflow and water-quality monitoring network, determine the availability and quantity of ground water, and develop a plan of study for quantitative hydrologic and geochemical investigations to assess the impacts of mining on the water resources of parts of Stillwater and Sweet Grass Counties, Montana.
Statewide	---	--	MT-091	Evaluation of ground-water quality.	To statistically evaluate the ground-water-quality data for Montana and determine areas of deficiency.
				Coal-related studies	
East	---	2	MT-059	Water monitoring-coal	To determine characteristics of the regional water-resources system and to detect and document any changes in the system as a result of coal mining.
				Research projects	
East	Statewide	--	MT-073 WY-056	Surface-water-flow analysis.	To develop methods to estimate runoff characteristics from ungaged watersheds and to estimate mean annual flow, peak discharges, and flood boundaries at selected ungaged sites.
---	Statewide	--	WY-054	Runoff relations for small basins.	To define infiltration-rate curves for soils and other surficial materials and determine the relations between infiltration rates computed from basin studies and those computed from infiltration tests.

Discharge Information Available for 52 Streamflow Stations

The U.S. Geological Survey has surface-water flow information at 39 continuous-record stations and 13 crest-stage stations in Area 48.

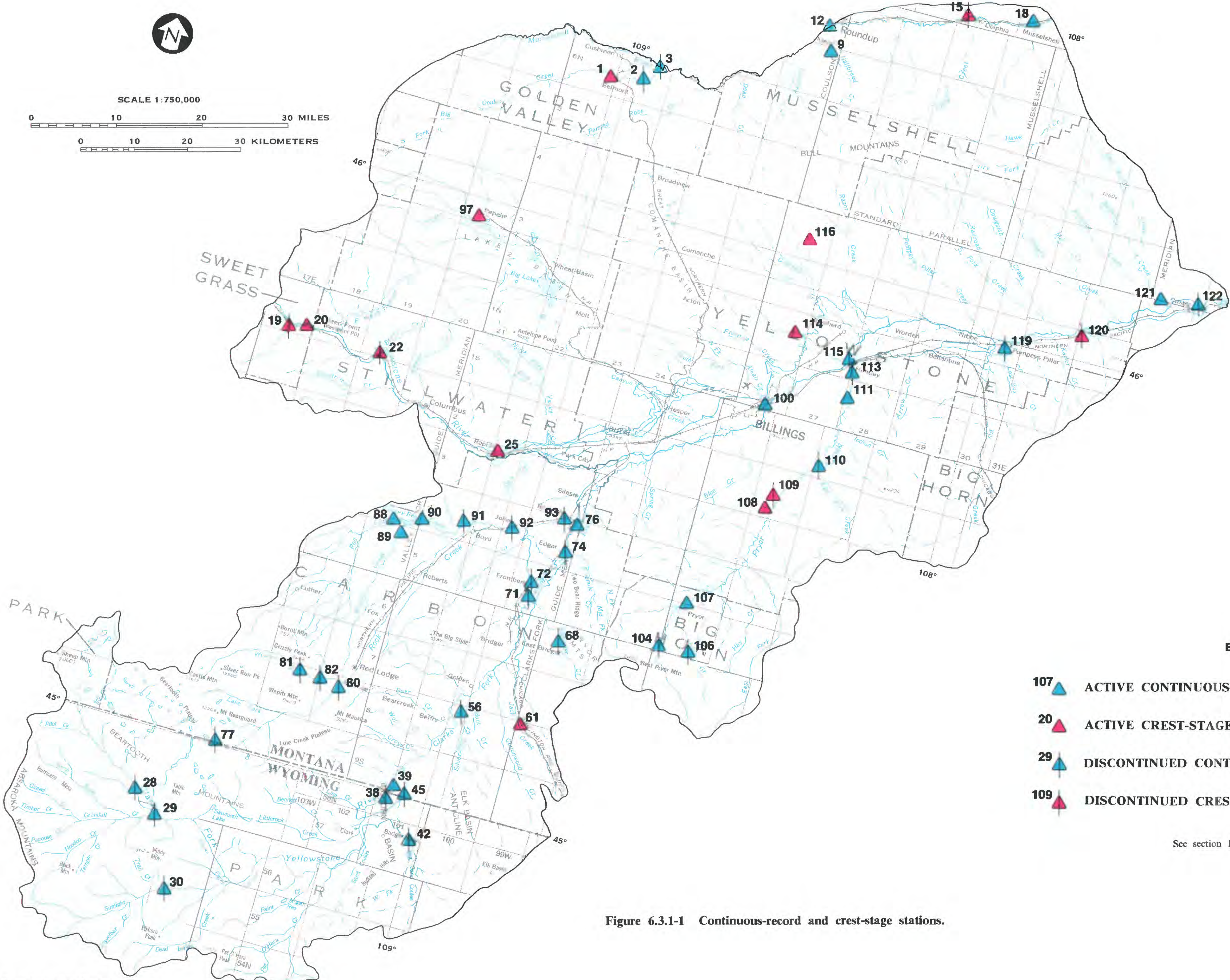
As the name indicates, a continuous-record station provides a continuous record of discharge throughout the water year. A crest-stage station provides a record of peak discharges that occur between station visits, but usually only the largest discharge value for each year is published. Data from continuous-record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

The surface-water stations are shown in figure 6.3.1-1. Details for the period of record and type of data available are given in the supplemental list of streamflow and water-quality stations and sites (section 12.0).

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

The first crest-stage stations were established in 1955 primarily to collect information for highway culvert and bridge design. The crest-stage network in Montana was expanded in 1963 and again in 1973. Eight crest-stage stations in Area 48 presently have at least 10 years of record, which is the general requirement for developing reliable peak-flow statistics.

Most of the data collected at continuous-record and crest-stage stations are available in computer-usable form. The data collected since 1965 also are available in annually published U.S. Geological Survey reports "Water Resources Data for Montana" and "Water Resources Data for Wyoming." Data collected before 1965 are in published 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 are also published in an annual series titled "Surface-Water Records of Montana" and "Surface-Water Records of Wyoming."



EXPLANATION

107 ACTIVE CONTINUOUS-RECORD STATION AND NUMBER

20 ACTIVE CREST-STAGE STATION AND NUMBER

29 DISCONTINUED CONTINUOUS-RECORD STATION AND NUMBER

109 DISCONTINUED CREST-STAGE STATION AND NUMBER

See section 12.0 for description of stations.

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

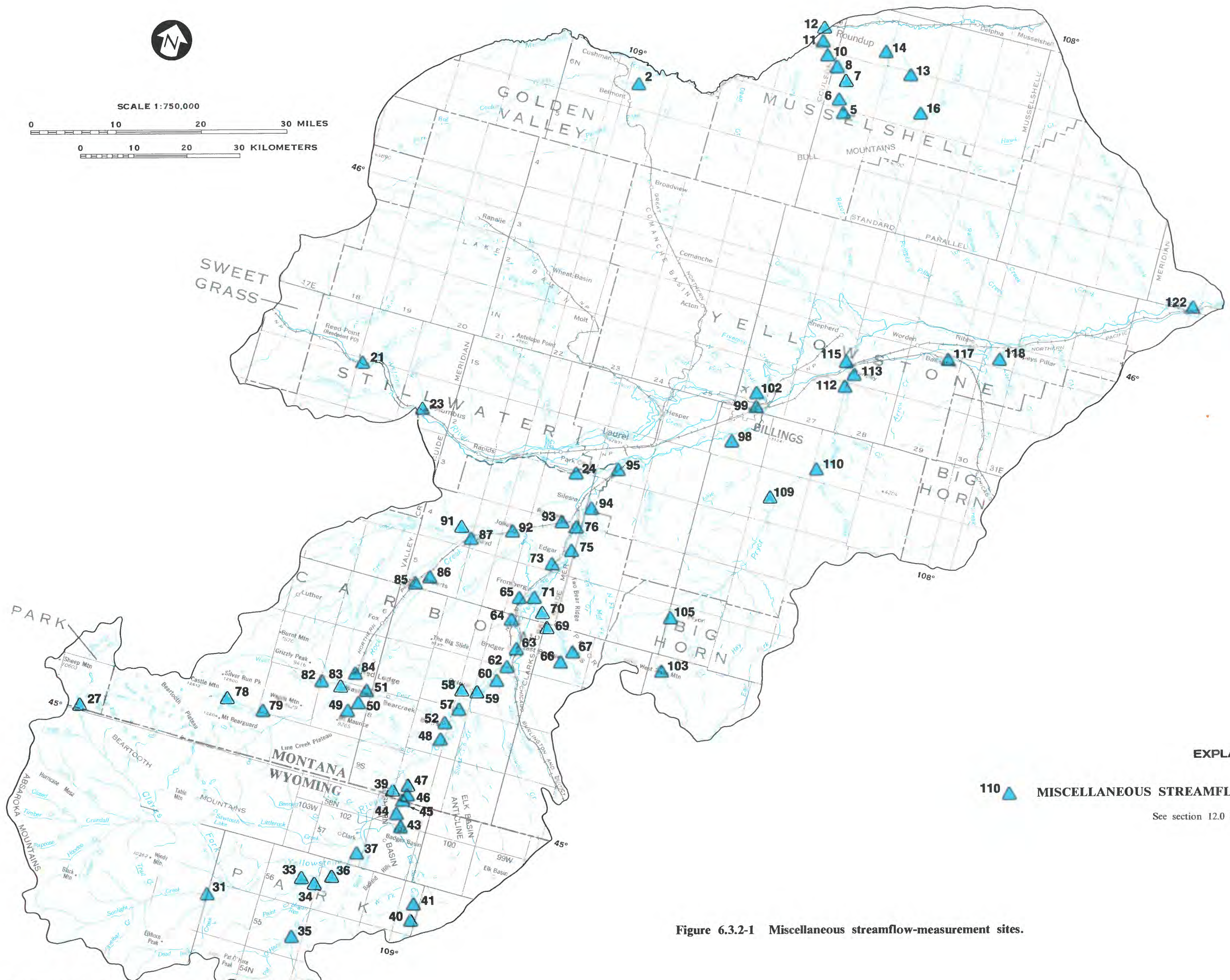
Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Surface-Water-Discharge Information Available for 76 Miscellaneous Sites

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

Miscellaneous streamflow measurements have been made at 76 locations in Area 48 (fig. 6.3.2-1). Some measurements were made as early as 1905, but most have been made since 1960. Many miscellaneous streamflow measurements were made in conjunction with programs to study the quality of surface water. Several measurements were made during streamflow gain-or-loss studies to determine the interaction of surface water and ground water; these studies were part of the U.S. Geological Survey Coal Hydrology Program to describe the water resources in the coal-bearing areas of the northern Great Plains. Other measurements were made in conjunction with special studies.

Additional hydrologic information about the sites is contained in the supplemental list of streamflow and water-quality stations and sites (section 12.0). Additional data for sites in the respective states are available at the U.S. Geological Survey offices in Helena, Montana or Cheyenne, Wyoming.



EXPLANATION

110 ▲ MISCELLANEOUS STREAMFLOW-MEASUREMENT SITE AND NUMBER

See section 12.0 for description of sites.

Figure 6.3.2-1 Miscellaneous streamflow-measurement sites.

Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Water-Quality Data Available for 28 Stations and 17 Sites

Water-quality data include measurements of chemical constituents and suspended sediment; biological data are generally limited.

The prospect of expanding coal development within the study area has created public concern about impacts to the water quality of streams. Although water-quality data have been collected at 45 sites, Area 48 generally lacks sufficient data from which to make a thorough assessment of premining conditions. A water-quality study of streams in the Bull Mountains in the northeastern part of the area provides the only data that were collected specifically for the purpose of documenting existing conditions in a potential coal mining area. Data collection for the water-quality study began in October 1977 and continued until September 1981.

Erosion and stream sedimentation problems are persistent in the middle drainage of the Clarks Fork Yellowstone River and more specifically in tributaries such as Big Sand Coulee, Silver Tip Creek, and Bluewater Creek. Suspended-sediment data have been collected on these tributary streams as well as on the main stem of the Clarks Fork to assess the extent of sedimentation in the basins.

Water-quality surveillance stations were operated, in cooperation with the U.S. Environmental Protection Agency, near the mouth of the Clarks Fork Yellowstone River and at four locations on the Yellowstone River. Station 100, Yellowstone River at Billings, has been in the National Stream Quality Accounting Network (NASQAN) since October 1974; prior to then it was an irrigation network station. Several biological stations were operated by the Montana Department of Health and Environmental Sciences in cooperation with the U.S. Geological Survey. The remaining water-quality stations and sites generally were operated for the purpose of monitoring irrigation waters or to provide additional hydrologic information.

All water-quality stations (active and discontinued) and water-quality sites within the study area are shown in figure 6.3.3-1. Additional information about water-quality stations and sites is contained in the description of streamflow and water-quality stations and sites at the end of this report (section 12.0).

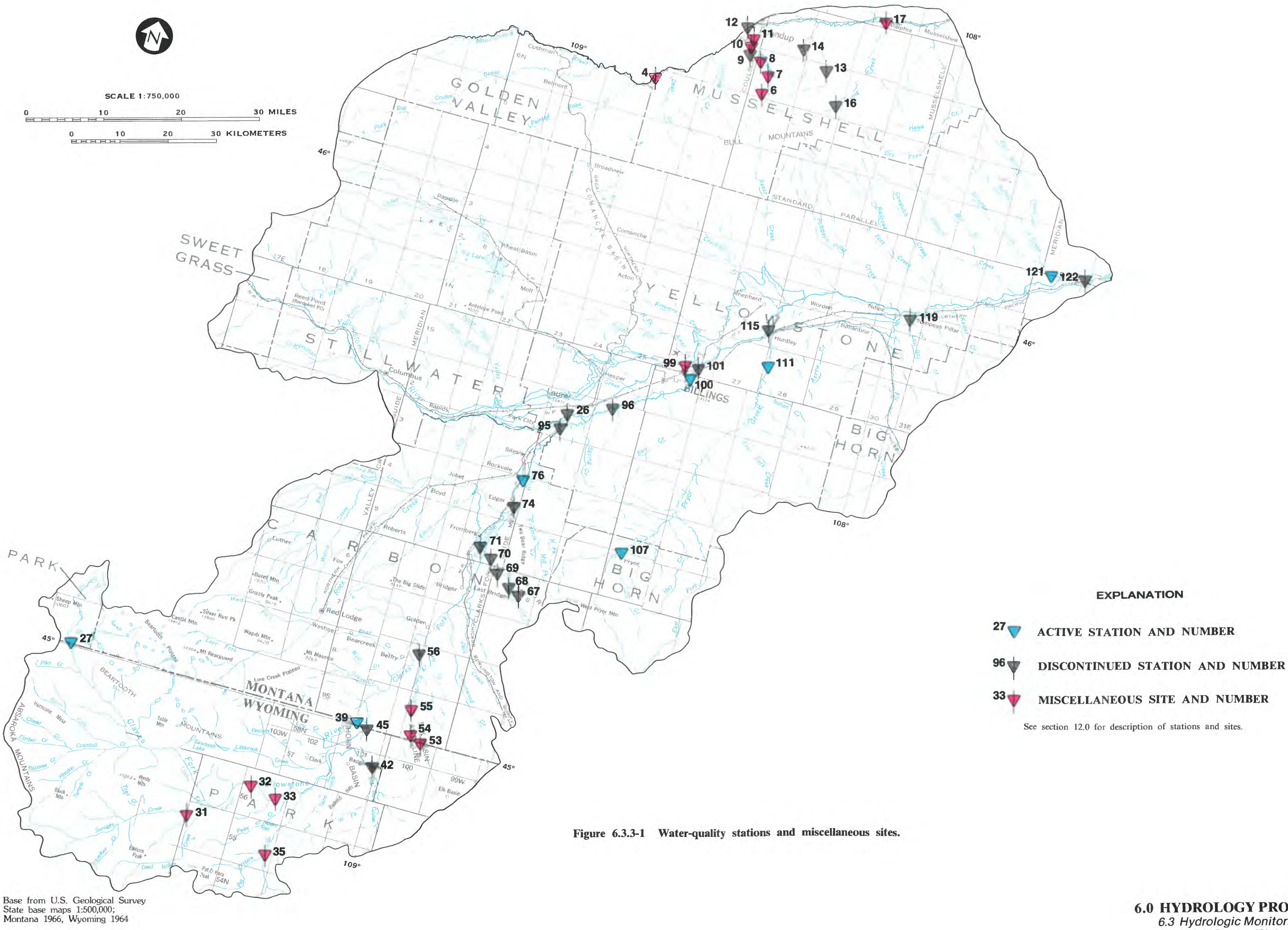


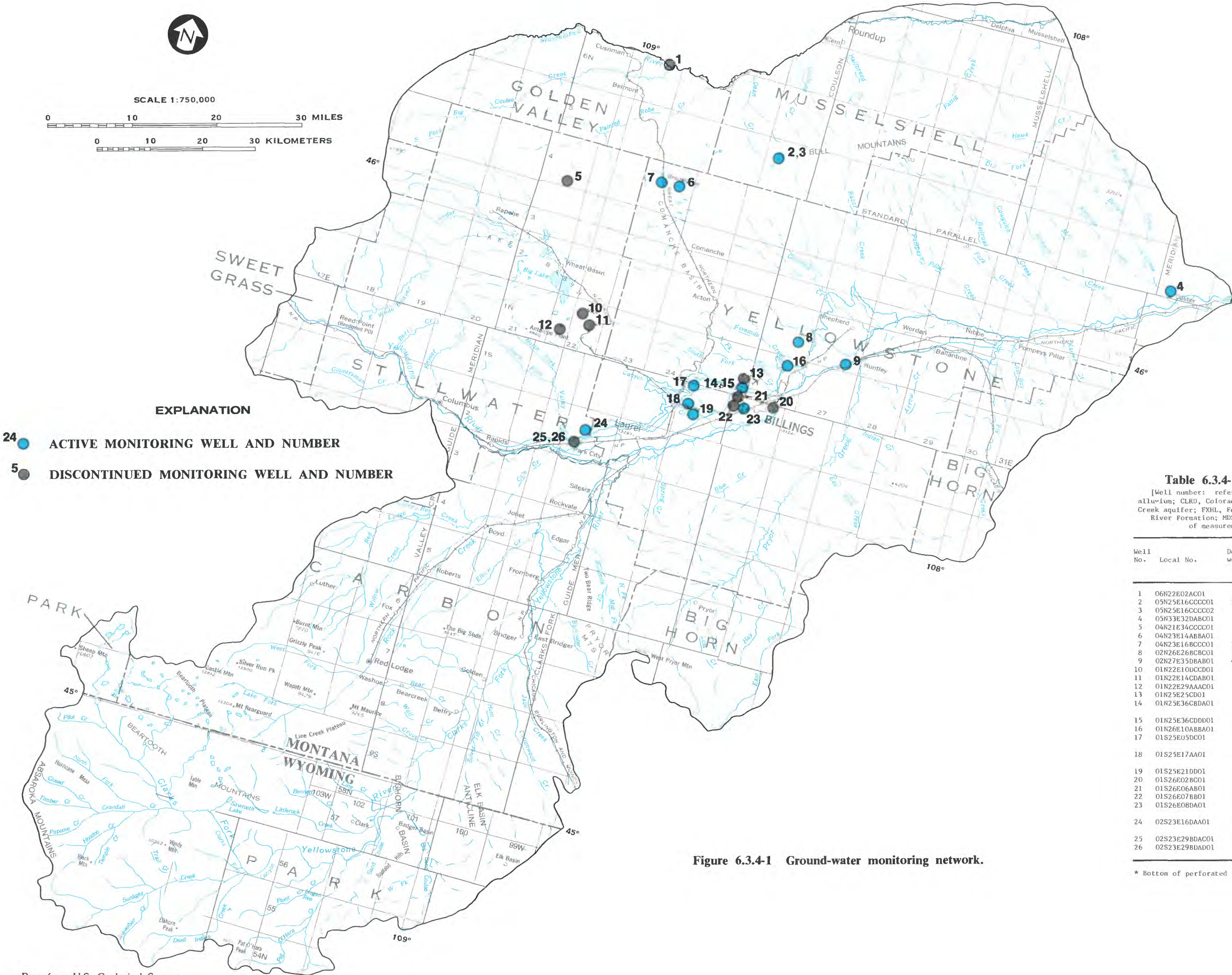
Figure 6.3.3-1 Water-quality stations and miscellaneous sites.

Data Available for Many Wells

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

Inventories of hydrologic and geologic data are available for about 1,200 domestic, stock, irrigation, and public-supply wells in Area 48. 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 400 wells. Most analyses are for major ions but some trace-element and miscellaneous-constituent information is available for about 300 wells. Most well data are available in a report of 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.

Long-term water-level information (table 6.3.4-1) is available for 26 network wells in the area (fig. 6.3.4-1). Network wells were established to monitor the response of the hydrologic system to natural climatic variations and induced stress. Many wells became part of a statewide observation-well network during the past 10 years in response to the need for premining ground-water data created by the probability of increased coal development in the northern Great Plains. Water-level records for these wells are available from WATSTORE.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Figure 6.3.4-1 Ground-water monitoring network.

Table 6.3.4-1 Ground-water monitoring network.

[Well number: refers to locations in figure 6.3.4-1. Geologic unit: ALVM, alluvium; CLRD, Colorado Group; EGLE, Eagle Sandstone; FHHC, Fox Hills-lower Hell Creek aquifer; FXHL, Fox Hills Sandstone; HLCK, Hell Creek Formation; JDRV, Judith River Formation; MDSN, Madison Group; TRRC, terrace deposits. Frequency of measurement: A, annual; I, intermittent; M, monthly.]

Well No.	Local No.	Depth of well (feet)	Geologic unit	Frequency of measurement	Period of record	
					Water level	Water quality
1	06N22E02AC01	35	ALVM	I	1967-74	
2	05N25E16CCCC01	1,350	FXHL	A	1980-	
3	05N25E16CCCC02	427	HLCK	A	1980-	
4	05N33E32DABC01	102	FHHC	A	1980-	
5	04N21E34CCCC01	--	CLRD	I	1976-80	
6	04N23E14ABBA01	80	FHHC	A	1980-	1980-
7	04N23E16BCCC01	1,100	EGLE	A	1980-	1980-
8	02N26E26BCBC01	260	JDRV	A	1978-	
9	02N27E35DBAB01	4,378 *	MDSN	A	1982-	
10	01N22E10DCCD01	74	JDRV	I	1975-82	1978-82
11	01N22E14CDAB01	24	JDRV	I	1975-82	
12	01N22E29AAAC01	83	JDRV	I	1976-82	
13	01N25E25CD01	119	ALVM	M	1968-69	
14	01N25E36CBDA01	12	ALVM	M	1966-69 1980-	
15	01N25E36CDDD01	17	ALVM	A	1978-	
16	01N26E10ABBA01	193	EGLE	A	1978-	1978
17	01S25E05DC01	62	ALVM	A	1968-69 1981-	
18	01S25E17AA01	13	ALVM	I	1968-69 1981-	
19	01S25E21DD01	55	ALVM	I	1968-	
20	01S26E02BC01	15	ALVM	M	1967-69	
21	01S26E06AB01	14	ALVM	M	1966-69	
22	01S26E07BB01	14	ALVM	M	1967-69	
23	01S26E08DA01	24	ALVM	M	1968-69 1981-	
24	02S23E16DAA01	63	ALVM	A	1968-69 1981-	
25	02S23E29BDAC01	24	ALVM	I	1947-68	
26	02S23E29BDAD01	16	TRRC	I	1977-81	

* Bottom of perforated interval

Area Drained by Yellowstone and Musselshell Rivers

Most of the area is drained by the Yellowstone River, whose largest tributary in the area is the Clarks Fork Yellowstone River.

Area 48 lies within the Yellowstone and Musselshell River basins. The main stem of the Yellowstone River flows northeastward through the central part of the area (fig. 7.1-1). The Musselshell River flows eastward and generally coincides with the northern boundary of the area.

The Clarks Fork Yellowstone River flows generally northward through the southern part of the area and is by far the longest tributary. The Clarks Fork Yellowstone River originates in the Beartooth Mountains and is perennial throughout its length. Tibutaries to the Clarks Fork Yellowstone River are Rock Creek, Elbow Creek, Silver Tip Creek, and Cottonwood Creek. Besides the Clarks Fork Yellowstone River, the major Yellowstone River tributaries in Area 48 are Pryor Creek, Fly Creek, Razor Creek, and Buffalo Creek. Of these tributary streams Pryor Creek and Fly Creek have perennial flow.

The major tributaries to the Musselshell River in Area 48 are Big Coulee, Halfbreed Creek, and Painted Robe Creek. Flow is intermittent in Big Coulee Creek and Painted Robe Creek and perennial in Halfbreed Creek.

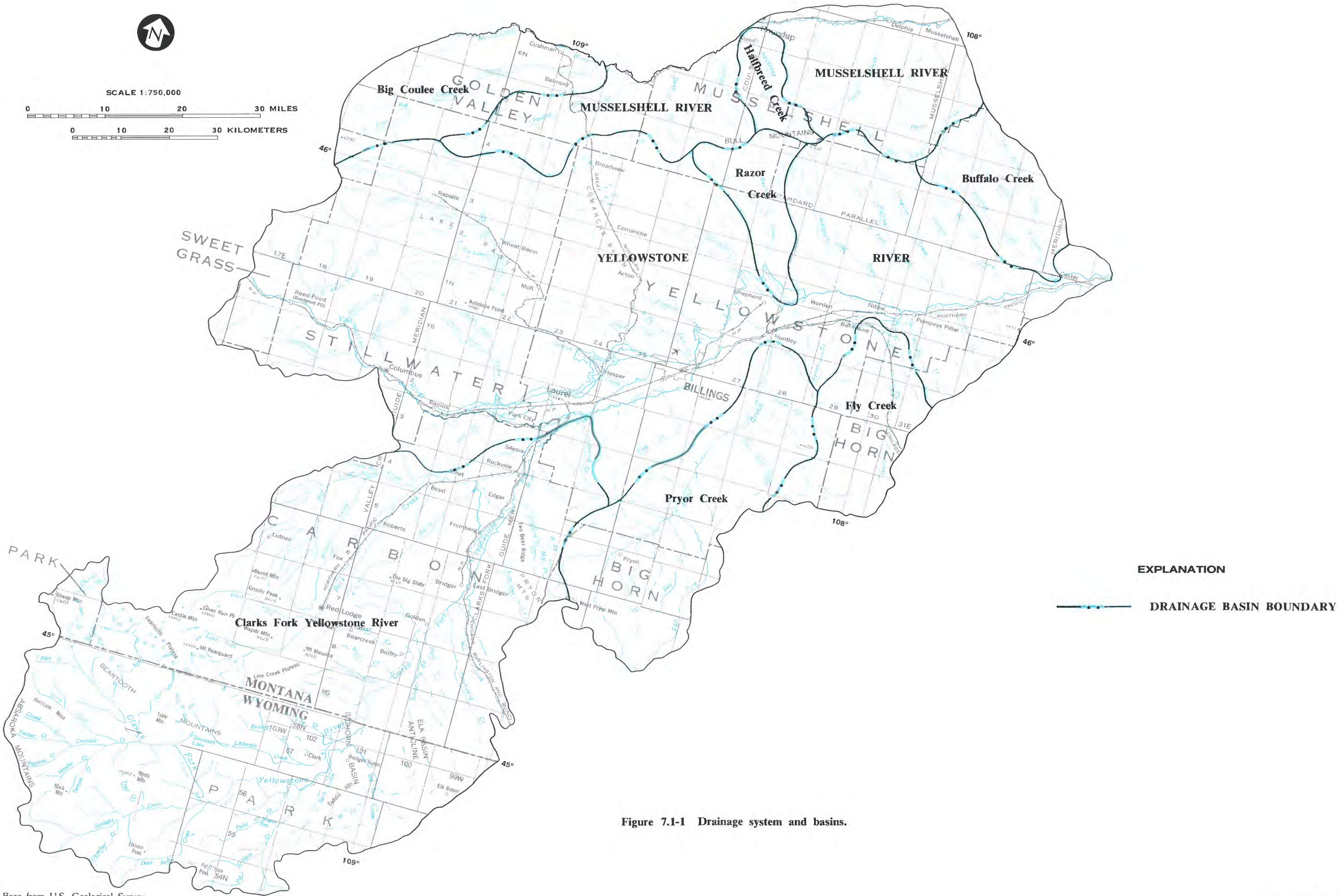


Figure 7.1-1 Drainage system and basins.

Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Average-Flow Data Available for Most Streams

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

Average flow data are available for major streams draining Area 48. Average flow tends to be small for the streams that are ephemeral or intermittent. Zero or near-zero flows have been recorded in every month at most of the streamflow-gaging stations on prairie streams. The perennial-type mountain streams generally have much larger average flows.

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

Table 7.2-1 Average annual and average monthly discharge at selected stations.

Station No. (fig. 6.3.1-1)	Station name	Record used for computation	Average discharge, in cubic feet per second for month indicated												Average annual discharge (cubic feet per second)
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	
2	Big Coulee Creek near Lavina, Mont.	1957-71	3.10	3.00	2.40	1.90	3.30	11.0	6.10	9.80	33.0	7.90	3.70	3.00	7.37
9	Halfbreed Creek near Klein, Mont.	1978-82	1.27	1.26	1.27	1.07	1.50	1.79	1.54	2.44	1.72	1.23	1.04	1.15	1.44
12	Musselshell River near Roundup, Mont.	1946-82	77.8	81.0	78.3	68.4	106	252	233	507	804	321	203	134	239
18	Musselshell River at Musselshell, Mont.	1928-29; 1931-32; 1945-79	76.0	79.0	77.0	68.0	105	285	246	436	696	265	147	115	216
28	Clarks Fork Yellowstone River above Squaw Creek, near Painter, Wyo.	1945-51	111	78.1	58.6	46.0	39.2	45.8	164	980	1,680	1,260	401	152	420
30	Sunlight Creek near Painter, Wyo.	1929-32; 1945-50; 1952-71	51.9	35.0	25.8	21.3	19.9	20.8	41.5	224	554	332	121	66.2	126
38	Clarks Fork Yellowstone River near Clark, Wyo.	1918-24	348	216	183	173	168	187	305	2,090	4,220	2,150	668	360	917
39	Clarks Fork Yellowstone River near Belfry, Mont.	1921-82	293	298	262	229	223	217	411	2,020	4,170	2,320	649	349	954
56	Silver Tip Creek near Belfry, Mont.	1967-75	1.36	.85	.16	.38	4.19	3.03	2.95	2.10	6.02	1.04	2.59	1.16	2.14
68	Bluewater Creek near Bridger, Mont.	1961-70	28.0	28.6	28.6	28.8	28.8	28.9	29.4	28.5	27.8	26.2	26.1	28.0	28.2
72	Clarks Fork Yellowstone River at Fromberg, Mont.	1906-12	451	369	335	295	309	389	550	2,060	6,080	3,760	1,320	688	1,380
74	Clarks Fork Yellowstone River at Edgar, Mont.	1921-69	539	501	405	358	354	364	540	2,060	4,130	2,120	657	513	1,040
76	Clarks Fork Yellowstone River near Silesia, Mont.	1969-82	629	568	494	407	427	437	527	2,030	4,680	2,650	804	697	1,200
80	Rock Creek near Red Lodge, Mont.	1932; 1934-82	83.7	56.1	42.2	34.9	31.5	30.0	40.6	220	615	517	266	144	174
82	West Fork Rock Creek near Red Lodge, Mont.	1935-44	26.7	23.3	19.1	14.9	13.3	12.8	23.1	109	268	167	59.1	38.8	66.5
90	Red Lodge Creek below Cooney Reservoir, near Boyd, Mont.	1937-82	84.7	72.7	39.3	29.7	31.6	46.6	84.2	181	231	173	133	111	102
92	Rock Creek at Joliet, Mont.	1945-53	202	236	144	111	100	141	221	360	622	439	262	193	253
93	Rock Creek at Rockvale, Mont.	1920-22; 1934-40	104	142	99.2	85.7	104	135	125	140	487	110	23.9	43.0	133
100	Yellowstone River at Billings, Mont.	1928-82	4,010	3,570	2,800	2,470	2,690	3,100	4,120	12,400	25,900	14,200	5,340	4,190	7,070
104	Pryor Creek above Pryor, Mont.	1966-74	2.23	2.08	1.66	1.53	2.04	1.88	4.57	35.5	31.9	8.10	3.70	2.69	8.18
107	Pryor Creek at Pryor, Mont.	1967-82	38.9	38.2	37.8	35.4	37.2	39.6	39.7	75.9	61.5	32.1	25.6	33.8	41.3
110	Pryor Creek near Billings, Mont.	1938-53	45.8	42.6	35.5	31.6	50.9	98.4	95.0	99.9	91.3	38.1	21.6	35.4	52.1
119	Fly Creek at Pompeys Pillar, Mont.	1968-81	18.7	8.81	6.57	9.34	38.5	75.4	18.5	76.1	60.1	39.4	44.5	61.0	38.1

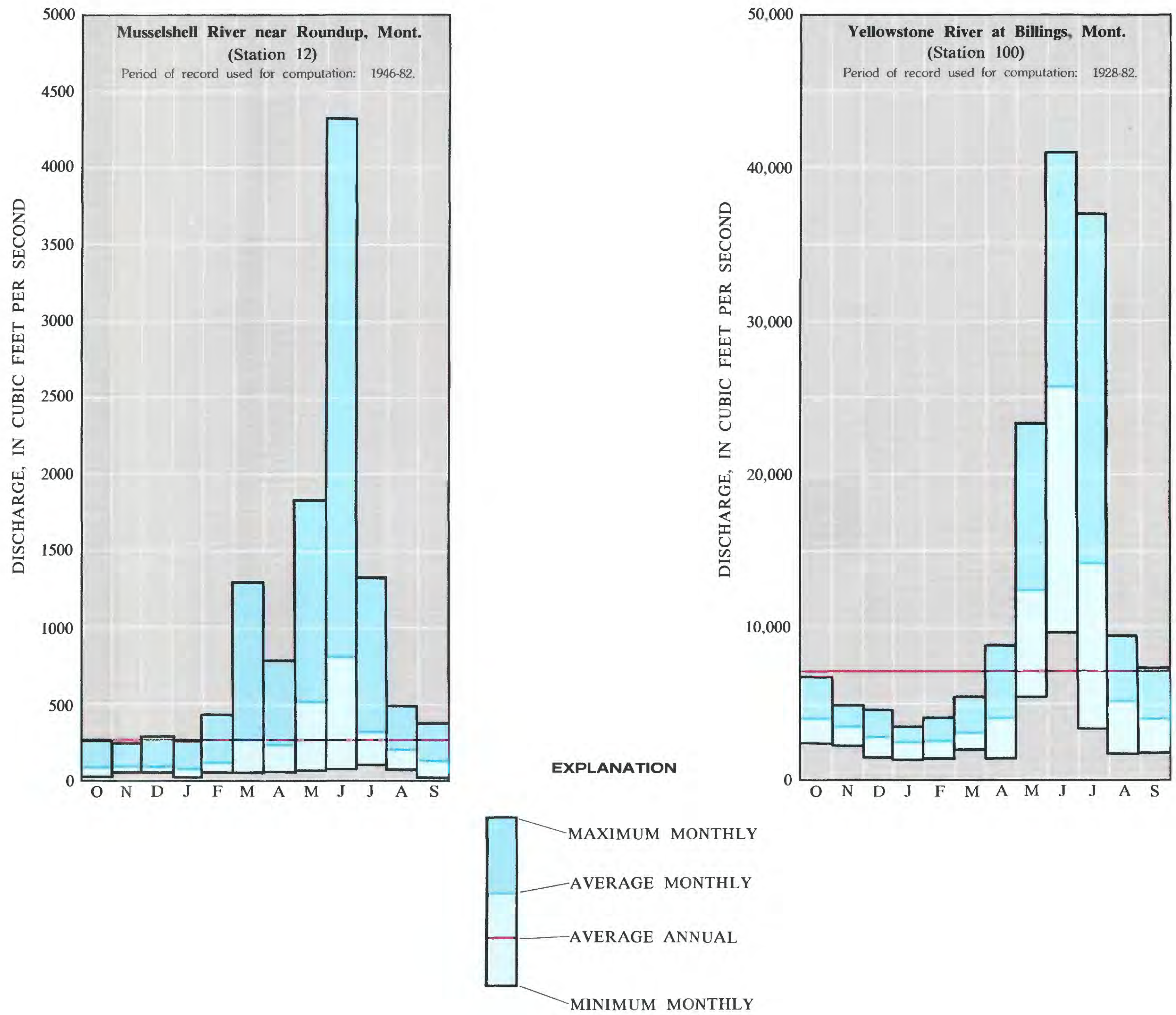


Figure 7.2-1 Average annual and average monthly discharge for Musselshell River near Roundup, Montana, and Yellowstone River at Billings, Montana.

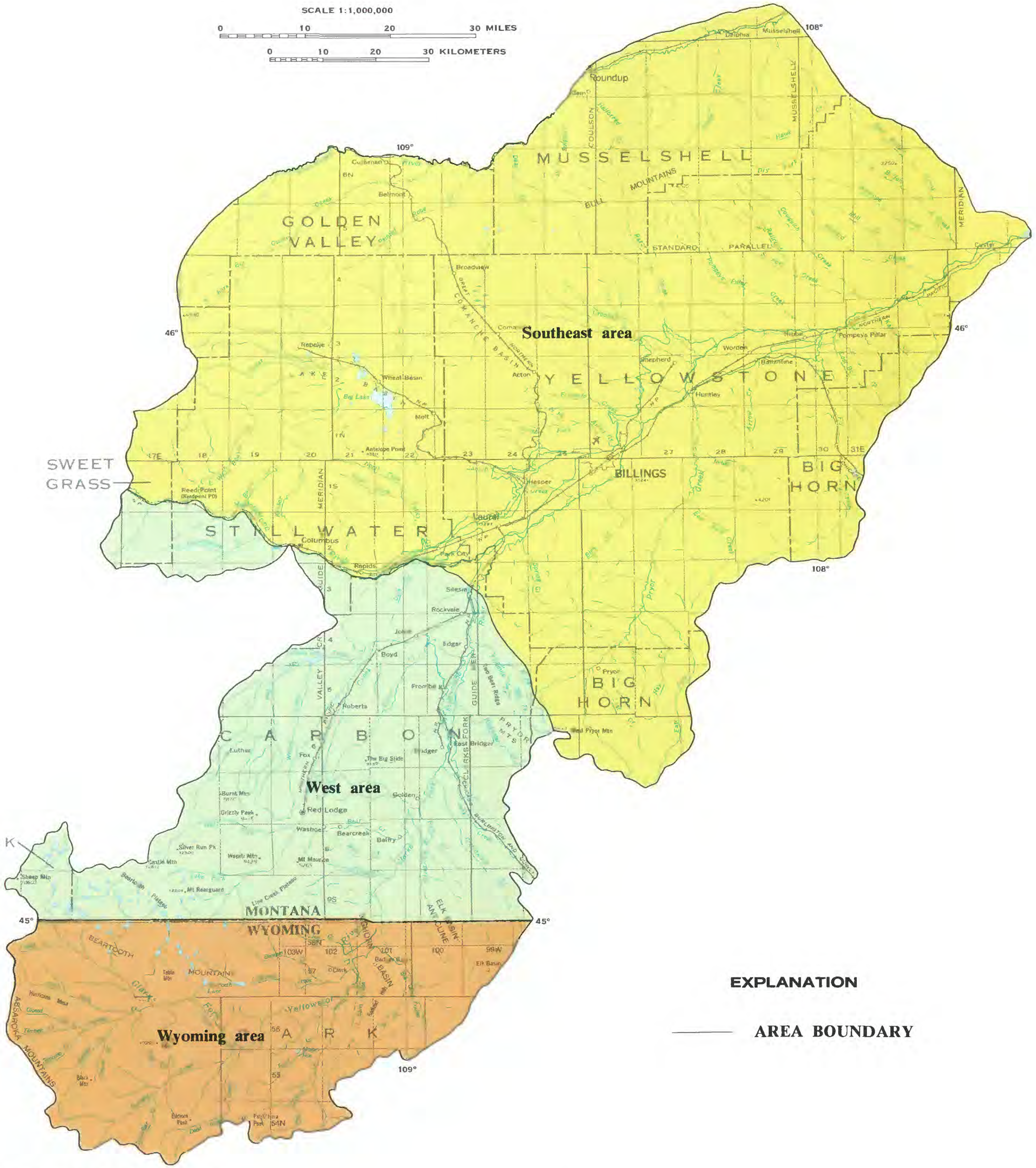
Average Annual Flow can be Estimated for Ungaged Streams

Multiple-regression equations using channel geometry have been developed for estimating average annual flow at ungaged sites.

Multiple-regression equations using channel-geometry measurements recently have been developed for estimating average-annual flow within Area 48 in Montana (Omang and others, 1983; Parrett and others, 1983). The equations generally are applicable to streams virtually unaffected by urbanization or regulation.

The estimating equations were developed for different geographic areas. Within Area 48 two geographic areas in Montana (fig. 7.3-1) are included, and two corresponding sets of equations are presented in table 7.3-1. To use these equations, active-channel width and bankfull width must be measured at the ungaged site. 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).

Equations using channel-geometry measurements for estimating average annual flow are also available for the Wyoming part of Area 48. To use these equations, main channel width is meausred and the status of streamflow (whether perennial, intermittant, or ephemeral) is determined. The estimating equations to be used are presented in table 7.3-2. Detailed information on use of the method for the Wyoming area is presented in a report by Lowham (1976).



Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 7.3-1 Area boundaries 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.

Estimating equation for average annual flow (Q_A), in acre-feet	Standard error of estimate (percent)
West area	
$Q_A = 128\ W_{AC}^{1.70}$	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

W_{AC}, active-channel width, in feet, and
W_{BF}, bankfull width, in feet.

Table 7.3-2 Regression equations for estimating average annual flow at ungaged sites in Wyoming using channel-geometry characteristics.

Estimating equation[1] for average annual flow (Q_A), in cubic feet per second[2]	Standard error of estimate (percent)
Ephemeral and intermittent streams	
$Q_A = 0.003\ W^{2.2}$	([3])
Perennial streams	
$Q_A = 0.06\ W^{1.9}$	50

[1] W, main channel width, in feet.
[2] 724 x Q_A in cubic feet per second is equivalent to Q_A in acre-feet (table 7.3-1).
[3] Graphical regression was performed owing to small number of stations.

Streamflow Variable in Area

Variations are large, particularly on tributaries draining the prairies.

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

Daily flow hydrographs (fig. 7.4-1) indicate the seasonal variation in stream-flows in 1981 for Yellowstone River at Billings, Montana, and for Musselshell River near Roundup, Montana. The hydrographs show the effects of snowmelt and rainfall on the flow in a stream draining mostly prairie area (Musselshell River), and in a large perennial stream in the proximity of its mountain headwaters (Yellowstone River). Winter snowmelt causes larger peaks in the prairie areas than in the mountains, because melting of the snowpack occurs more rapidly in the prairie areas. Streamflow in the Musselshell River increases rapidly during May as a result of snowmelt, while streamflow in the Yellowstone River increases more gradually. Summer thunderstorms result in short intervals of increased streamflow in the Musselshell River during July through September but show little effect on the streamflow in the Yellowstone River.

Another way of illustrating variability is with a flow-duration curve. Flow-duration curves for four streams are shown in figure 7.4-2.

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

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

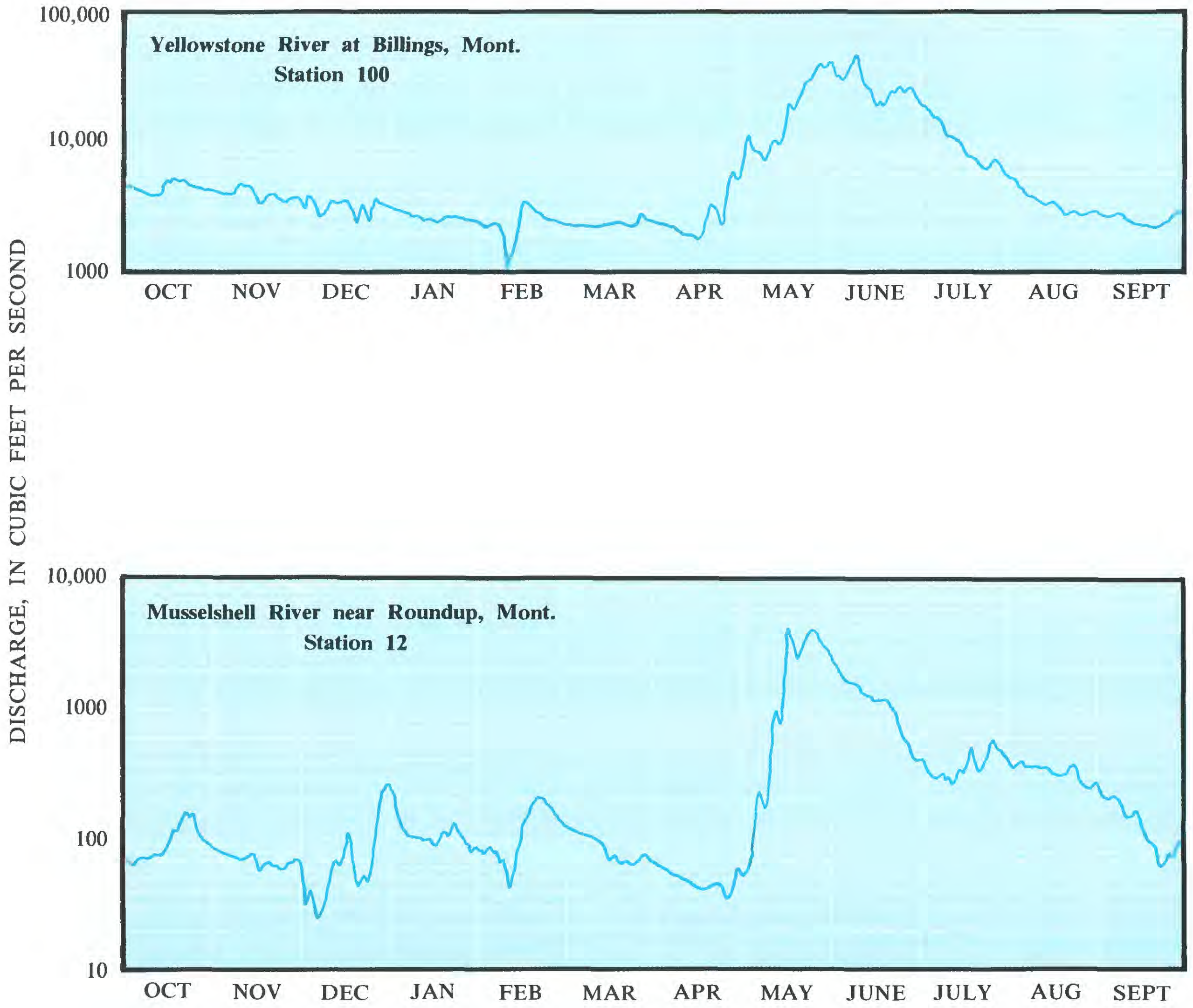


Figure 7.4-1 Daily hydrographs for Yellowstone River at Billings, Montana, and Musselshell River near Roundup, Montana, 1981 water year.

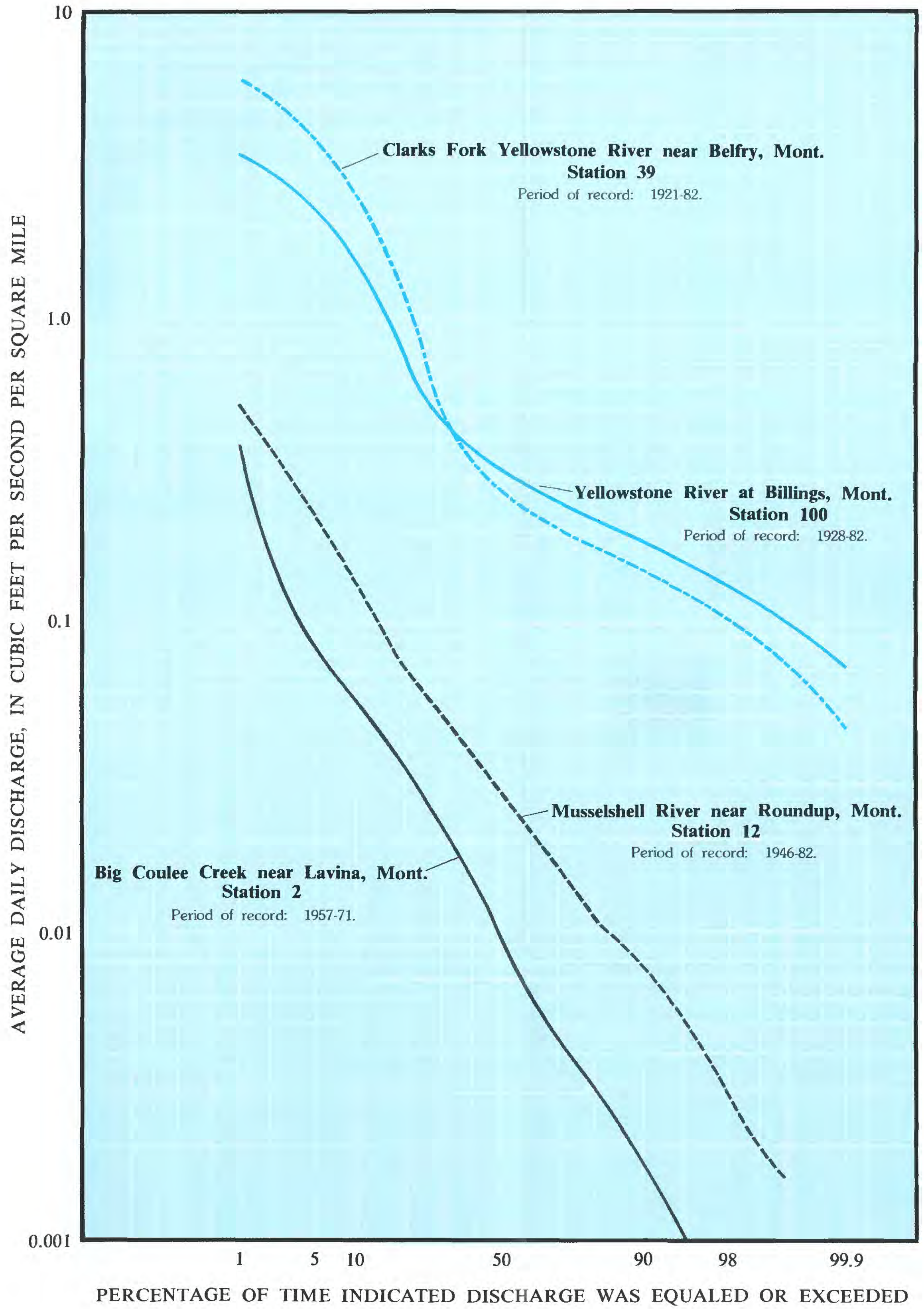


Figure 7.4-2 Flow-duration curves for selected streams.

Peak Flows Result from Snowmelt or Rainfall

Peak-flow data are presented for 25 gaging stations having 10 or more years of record.

Peak flows in Area 48 may result from snowmelt or rainfall. Mountain streams typically have their annual peak flows in June from mountain snowmelt mixed with rain. Annual peak flows on prairie streams may result from spring snowmelt in March and April or from spring and summer thunderstorms in May through September. Most of the annual peak flows on prairie streams result from snowmelt, but the larger peak flows on small drainages generally result from rainfall.

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

Computed peak flows for exceedance probabilities of 50, 10, 4, 2, and 1 percent for 25 gaging stations are presented in table 7.5-1. These stations have 10 or more years of record and are not subject to significant regulation or diversion of peak flows.

Interpretation and use of this table are best explained by examples. For instance, in row 2 of column "50-percent exceedance probability" the value 1,800 means that for station 12, there is a 50-percent chance that the annual peak flow in any year will be greater than 1,800 cubic feet per second. Similarly, for the same stations under the column "4-percent exceedance probability" the value 7,330 means that for station 12, there is a 4-percent chance that the annual peak flow in any year will be greater than 7,330 cubic feet per second.

Table 7.5-1 Peak discharge for specified exceedance probabilities at selected gaging stations.

Station No. (fig. 6.3.1-1)	Station name	Drainage area (square miles)	Discharge, in cubic feet per second, for specified exceedance probability, in percent				
			50	10	4	2	1
2	Big Coulee Creek near Lavina, Mont.	232	136	893	1,690	2,520	3,580
12	Musselshell River near Roundup, Mont.	4,023	1,800	4,990	7,330	9,430	11,900
15	Musselshell River tributary near Musselshell, Mont.	10.8	48	232	424	612	847
18	Musselshell River at Musselshell, Mont.	4,568	1,630	4,990	7,660	10,100	13,100
19	Work Creek near Reed Point, Mont.	32.5	113	829	1,680	2,650	4,010
20	Hump Creek near Reed Point, Mont.	7.61	41	230	446	687	1,020
25	Allen Creek near Park City, Mont.	7.17	81	372	663	969	1,410
30	Sunlight Creek near Painter, Wyo.	135	1,100	1,830	2,440	3,020	3,730
39	Clarks Fork Yellowstone River near Belfry, Mont.	1,154	7,560	9,880	10,900	11,700	12,400
68	Bluewater Creek near Bridger, Mont.	28.1	121	653	1,220	1,830	2,630
74	Clarks Fork Yellowstone River at Edgar, Mont.	2,032	7,680	10,400	11,700	12,700	13,700
76	Clarks Fork Yellowstone River near Silesia, Mont.	2,093	7,680	10,400	11,700	12,700	13,700
80	Rock Creek near Red Lodge, Mont.	124	1,210	2,060	2,500	2,830	3,170
81	West Fork Rock Creek below Basin Creek, near Red Lodge, Mont.	63.1	532	995	1,250	1,450	1,650
82	West Fork Rock Creek near Red Lodge, Mont.	66.9	532	995	1,250	1,450	1,650
88	Red Lodge Creek above Cooney Reservoir, near Boyd, Mont.	143	583	1,830	2,790	3,670	4,690
89	Willow Creek near Boyd, Mont.	53.3	250	891	1,470	2,040	2,770
100	Yellowstone River at Billings, Mont.	11,795	40,600	58,500	66,200	72,000	80,000
104	Pryor Creek above Pryor, Mont.	39.6	143	403	580	731	902
107	Pryor Creek at Pryor, Mont.	117	186	524	781	1,010	1,270
108	West Wets Creek near Billings, Mont.	8.80	115	283	413	540	705
109	West Buckeye Creek near Billings, Mont.	2.64	74	253	406	553	760
110	Pryor Creek near Billings, Mont.	440	659	2,010	3,180	4,340	5,740
116	Crooked Creek tributary near Shepherd, Mont.	7.21	140	1,060	2,290	3,960	6,410
119	Fly Creek at Pompeys Pillar, Mont.	285	430	2,400	4,450	6,760	9,760

Peak-Flow Characteristics can be Estimated for Ungaged Sites

Annual flood peaks generally are larger and more variable in the East-Central Plains area than in the Upper Yellowstone or Southeast Plains area.

Multiple-regression equations recently have been developed for estimating flood peaks at ungaged stream sties within Area 48 in Montana (Parrett and Omang, 1981). The equations generally are applicable to unregulated streams where the drainage basins have not been altered significantly by man's activities. The equations thus may not be valid for areas where extensive surface mining occurs or for estimating effects of mining.

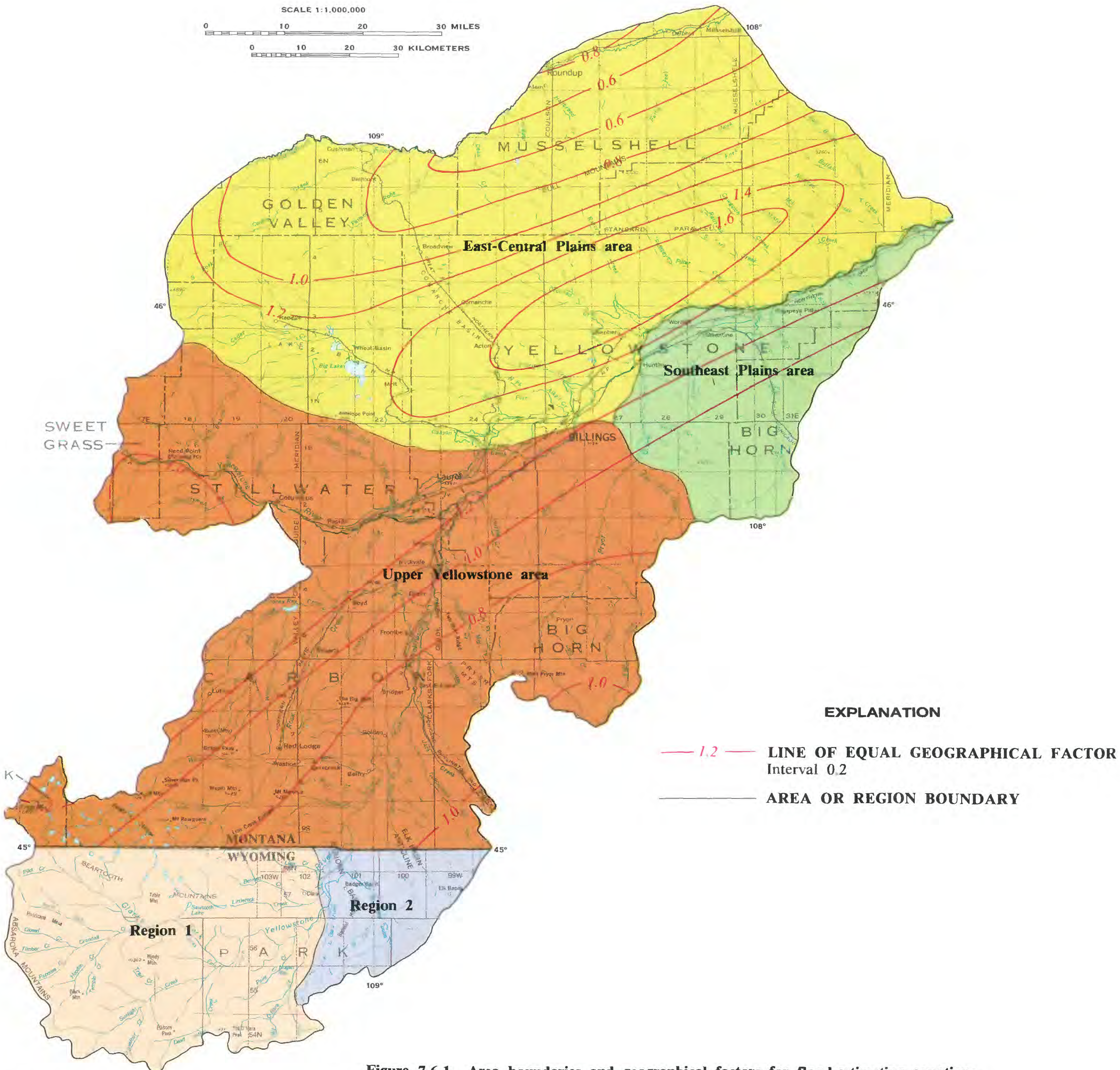
The estimating equations were developed for different geographic areas. Within the part of Area 48 in Montana, three geographic areas are delineated, and three corresponding sets of equations are presented in table 7.6-1. Annual flood peaks generally are larger and more variable in the East-Central Plains area than in the Upper Yellowstone or Southeast Plains area. All equations use a geographical factor that must be obtained from a map. The geographical factor is a multiplier which represents the difference between the predicted peak flow and the actual peak flow. The area map (fig. 7.6-1) shows the boundaries of the three geographic areas and the geographical factors for each area. The estimating equations are applicable to drainage areas of 0.5 to about 2,600 square miles.

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). Other techniques for estimating flood peaks on the Yellowstone River, Musselshell River, and on streams where some streamflow-gaging data are available also are given by Parrett and Omang (1981).

Equations using basin characteristics for estimating peak flows are also available for the Wyoming part of Area 48. The estimating equations were developed for two different regions within Area 48 (fig. 7.6-1) and corresponding sets of equations are presented in table 7.6-2. Detailed information on use of the method for the Wyoming area is presented in the report by Lowham (1976).

Alternative equations using channel-geometry measurements for estimating peak flows at ungaged sites also have been developed for the area. These alternative equations are contained in reports of Omang and others (1983) and Parrett and others (1983) for the Montana part of Area 48 and in a report of Lowham (1976) for the Wyoming part.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Figure 7.6-1 Area boundaries and geographical factors for flood-estimating equations.

Table 7.6-1 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; F, percentage of basin covered by forest; and G_f, geographical factor determined from figure 7.6-1]

Exceedance probability (percent)	Estimating equation for peak discharge (Q), in cubic feet per second	Standard error of estimate (percent)
	Upper Yellowstone area	
50	$Q = 0.146A^{0.87}(E/1000)^{3.88}(HE+10)^{-0.78}G_f$	57
20	$Q = 1.08A^{0.82}(E/1000)^{3.56}(HE+10)^{-0.93}G_f$	47
10	$Q = 3.22A^{0.80}(E/1000)^{3.39}(HE+10)^{-1.02}G_f$	45
2	$Q = 23.6A^{0.75}(E/1000)^{3.06}(HE+10)^{-1.18}G_f$	43
1	$Q = 48.8A^{0.73}(E/1000)^{2.95}(HE+10)^{-1.24}G_f$	44
	East-Central Plains area	
50	$Q = 117A^{0.56}(E/1000)^{-1.50}G_f$	77
20	$Q = 402A^{0.52}(E/1000)^{-1.42}G_f$	58
10	$Q = 681A^{0.50}(E/1000)^{-1.31}G_f$	66
2	$Q = 1,460A^{0.47}(E/1000)^{-0.99}G_f$	74
1	$Q = 1,750A^{0.45}(E/1000)^{-0.82}G_f$	83
	Southeast Plains area	
50	$Q = 360A^{0.59}(F+10)^{-0.98}G_f$	105
20	$Q = 1,010A^{0.58}(F+10)^{-0.99}G_f$	77
10	$Q = 1,320A^{0.56}(F+10)^{-0.91}G_f$	72
2	$Q = 2,340A^{0.54}(F+10)^{-0.81}G_f$	69
1	$Q = 2,770A^{0.53}(F+10)^{-0.76}G_f$	71

Table 7.6-2 Regression equations for estimating peak discharges at ungaged sites in Wyoming.

[A, drainage area, in square miles; E, average basin elevation, in feet above sea level]

Exceedance probability (percent)	Estimating equation for peak discharge (Q), in cubic feet per second	Standard error of estimate (percent)
	Region 1	
50	$Q = 0.009A^{0.85}E^{3.44}$	54
20	$Q = 0.070\ A^{0.81}E^{2.75}$	51
10	$Q = 0.203\ A^{0.79}E^{2.39}$	51
2	$Q = 1.32\ A^{0.76}E^{1.76}$	55
1	$Q = 2.57\ A^{0.75}E^{1.53}$	58
	Region 2	
50	$Q = 56.8A^{0.38}$	84
20	$Q = 146\ A^{0.35}$	74
10	$Q = 239\ A^{0.34}$	73
2	$Q = 572\ A^{0.32}$	84
1	$Q = 779\ A^{0.31}$	91

Flood-Prone-Area Maps Available

Flood-prone areas have been delineated on 39 7½-minute topographic maps 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 and for delineating flood-prone areas on topographic maps. As of 1982, the area inundated by the 1-percent exceedance probability flood (100-year flood) for selected streams has been delineated on 39 7½-minute topographic quadrangle maps within Area 48. The delineations were based upon existing flood-depth data from streamflow-gaging-station records and miscellaneous measurements made during floods. Flood-prone-area maps available in the area are indicated on the index map of topographic quadrangles (fig. 7.7-1). These maps, prepared by the U.S. Geological Survey, are available from the Montana Bureau of Mines and Geology, Montana College of Mineral Science and Technology, Butte, Montana 59701.

Flood-insurance studies also have been completed for Yellowstone County and the towns of Billings and Laurel and for Carbon County and the towns of Red Lodge, Joliet, and Fromberg. Results of these studies, including maps, are available from the Montana Department of Natural Resources and Conservation, 32 S. Ewing, Helena, Montana 59620 and the Federal Emergency Management Agency, Denver Federal Center, Building 710, Denver, Colorado 80225.

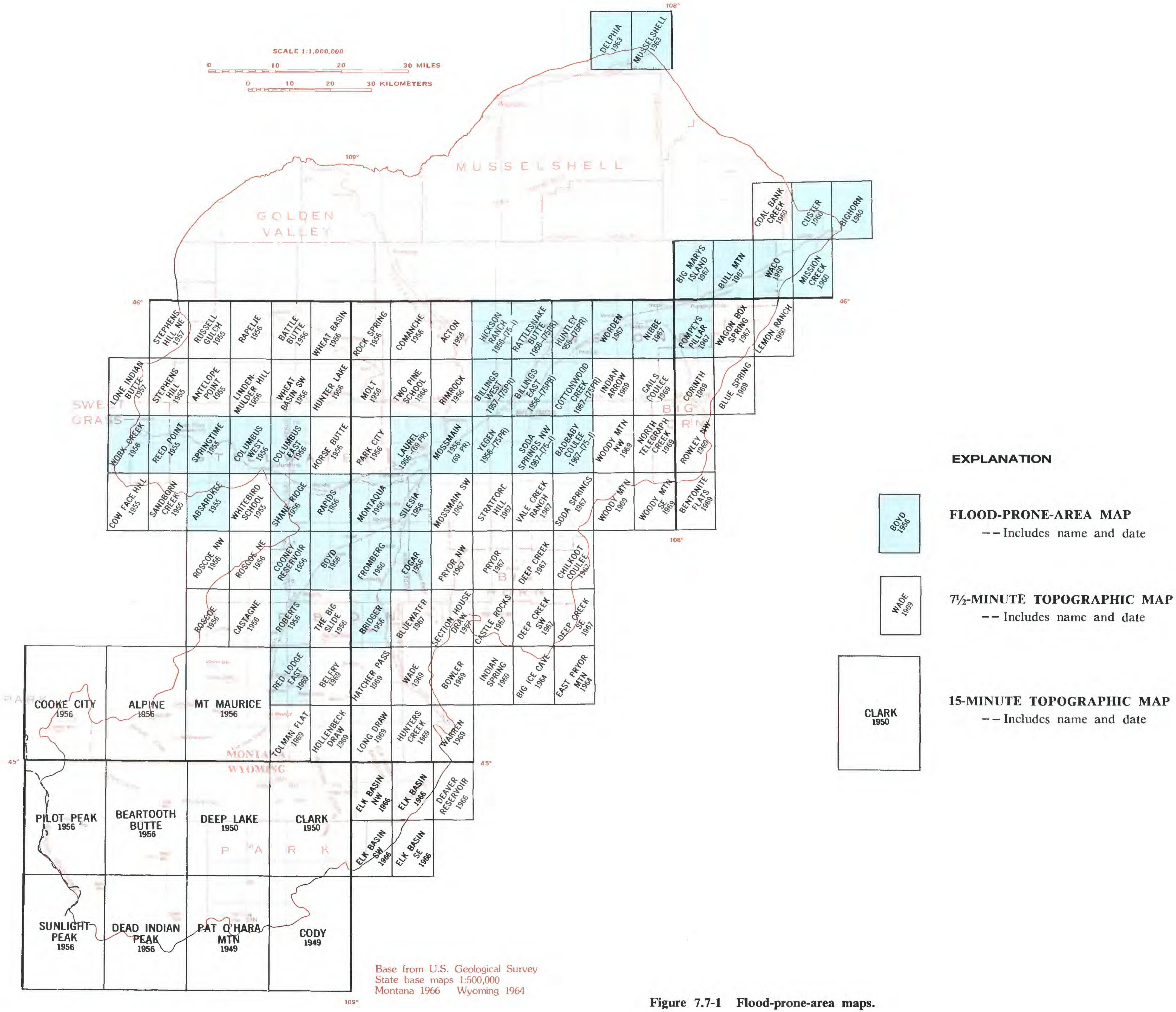


Figure 7.7-1 Flood-prone-area maps.

Dissolved-Solids Concentration Greatest During Base Flow

Natural dissolved-solids concentrations in Area 48 are less in mountain streams than in prairie streams.

Dissolved-solids in streams are derived primarily from the leaching of soluble minerals from soils and geologic formations in the drainage basin. The most prevalent ions in solution in the surface waters of Area 48 are the cations calcium, magnesium, and sodium, and the anions bicarbonate, sulfate, and chloride.

Dissolved-solids concentrations and the ion composition of the water can vary significantly during the year as a result of fluctuating streamflow, which ranges from base flow to direct runoff. In addition to natural variability in dissolved solids, land-use practices and irrigation also can affect dissolved-solids concentrations. Differences in dissolved solids in relation to stream discharge are much more evident in prairie streams than in streams with head-waters in mountainous areas. The main stems of the Musselshell, Clarks Fork Yellowstone, and Yellowstone Rivers originate in high mountains, whereas the smaller tributary streams generally drain only prairie regions. Areal differences in dissolved-solids concentrations and water type for selected stations are illustrated in figure 8.1-1.

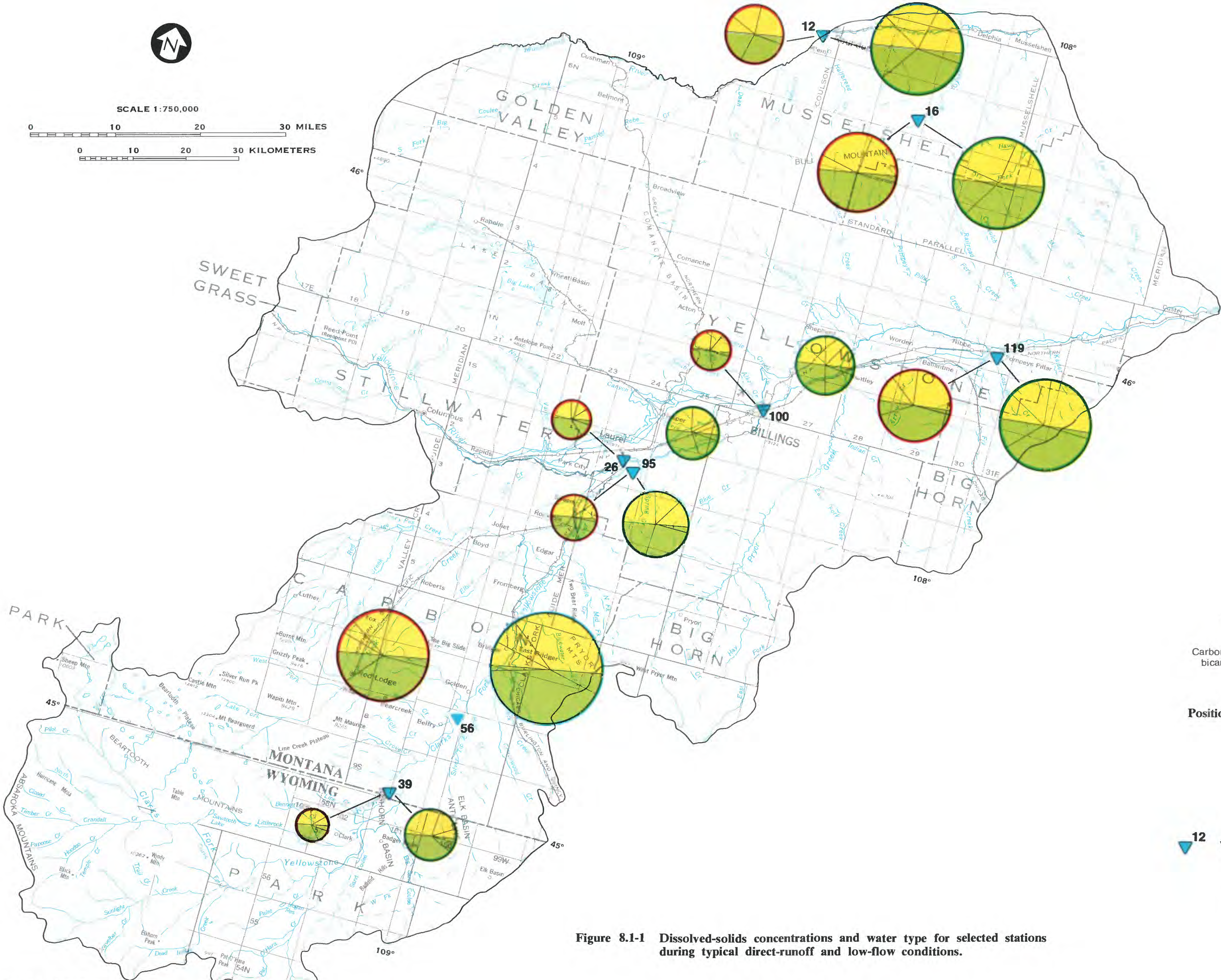
During base-flow conditions, overland runoff is absent in the prairies and streamflow is composed primarily of water that has discharged from an aquifer into the stream channel. Because water in aquifers in the prairie has large dissolved-solids concentrations, the concentrations of dissolved solids generally associated with base flows in these areas are large. In addition, water losses from evaporation and transpiration tend to concentrate dissolved solids.

During intervals of base flow, dissolved-solids concentrations commonly ranged from 900 to 1,700 milligrams per liter in the prairie streams. One exception was Silver Tip Creek, where stations 53-57 consistently had dissolved-solids concentrations in excess of 3,500 milligrams per liter. This condition may have been the result of saline discharges from nearby oil fields. Sodium, magnesium, and sulfate generally are the dominations during base flow in prairie streams of Area 48.

Base flow is a small part of the total flow on the larger main stems because mountain snowmelt contributes to flow during most of the year. This factor, in addition to geologic characteristics, is a major reason that dissolved-solids concentrations in the mountain headwater streams were smaller and fluctuated less than in the prairie streams. However, because of generally less snowpack and less extensive crystalline igneous formations in the headwaters of the Musselshell River basin, dissolved-solids concentrations during low flows on the Musselshell are typically more characteristic of prairie streams. Dissolved-solids concentrations during low flows at sites on the Clarks Fork Yellowstone and Yellowstone Rivers commonly ranged from 200 to 500 milligrams per liter, whereas in the Musselshell River at Roundup (station 12) concentrations ranged from about 900 to 1,300 milligrams per liter. Water type during the low flows in the Clarks Fork Yellowstone and Yellowstone Rivers was calcium bicarbonate and in the Musselshell River was sodium sulfate.

In contrast to base flow, direct runoff from rainfall or snowmelt typically has much smaller concentrations of dissolved solids. During direct runoff, water is routed quickly into stream channels with little opportunity for leaching of minerals from the soil. The larger volume of water present during runoff has a diluting effect on dissolved-solids concentrations.

Dissolved-solids data for runoff conditions are scarce for the prairie streams; however, concentrations for Fly Creek at Pompeys Pillar (station 119) were about 200 to 400 milligrams per liter during several high flows. Main-stem dissolved-solids concentrations during high flows ranged from 60 to 200 milligrams per liter in the Clarks Fork and Yellowstone rivers and from 450 to 900 milligrams per liter in the Musselshell River. Water type during runoff conditions did not differ appreciably from that during base flow.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

EXPLANATION

WATER QUALITY

Runoff conditions

Low-flow conditions

Magnesium

Calcium — Sodium — **Cations**

Carbonate and bicarbonate — Chloride — **Anions**

Sulfate

Positions occupied by ions and relative percentages (based on milliequivalents per liter)

10 100 1000 10,000

Diameter of circle depicts dissolved-solids concentration, in milligrams per liter

12 WATER-QUALITY STATION AND NUMBER

See section 12.0 for description of stations.

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

Specific Conductance can be Used to Estimate Dissolved-Solids Concentrations

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

Most dissolved substances occur as ions in solution. Therefore, specific conductance gives an indication of the concentration of dissolved solids in the water. Because measurements can be made easily and inexpensively on-site or in the laboratory, specific-conductance determinations have been used extensively. Specific conductance was measured each time a water sample was collected for chemical analysis. In addition, daily measurements of specific conductance were made at several stations.

Specific-conductance measurements are valuable to many water-quality studies because of the generally significant correlation of specific-conductance values with concentrations of dissolved solids and with many of the individual ions that compose dissolved solids. Paired values of specific conductance and dissolved-solids concentration from routine samples were used to develop linear regression equations to estimate dissolved-solids concentrations at selected stations (fig. 8.2-1). Graphical displays of the regression equations are presented for selected small prairie streams (fig. 8.2-2) and for the Musselshell, Clarks Fork Yellowstone, and Yellowstone Rivers (fig. 8.2-3). The regression lines can be used to estimate dissolved-solids concentrations from a measurement of specific conductance.

For stations where daily measurements of specific conductance were made, daily dissolved-solids concentrations can be estimated by use of the regression line developed for that station. Daily concentrations can be transformed further into average daily dissolved-solids loads using the following equation:

$$L_{DS} = Q \times C_{DS} \times K \qquad (1)$$

where

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

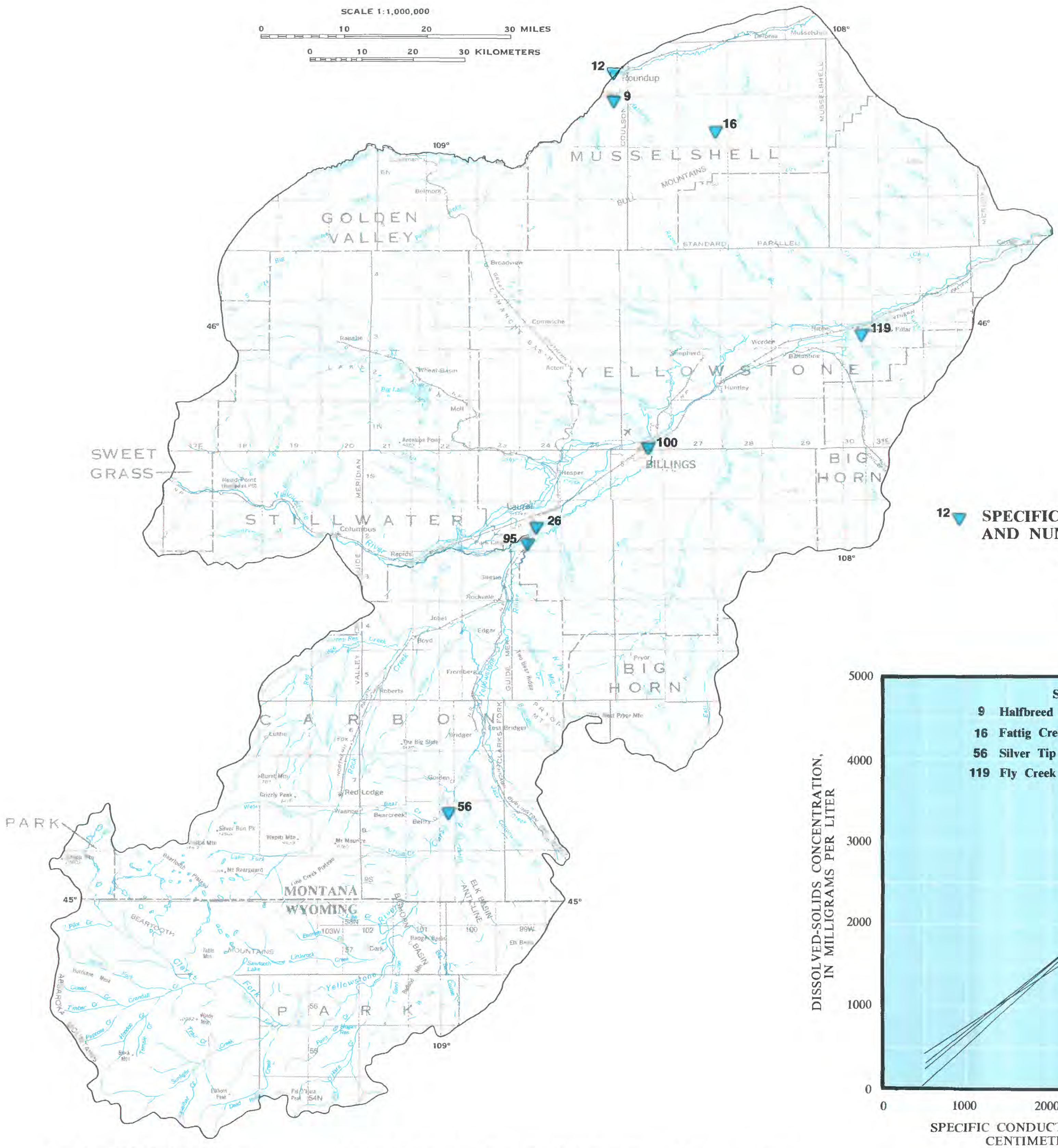
Q = average daily stream discharge (obtained from streamflow records), in cubic feet per second;

C_{DS} = dissolved-solids concentration (obtained from regression line), in milligrams per liter, and

K = 0.0027, a units conversion factor.

The summation of daily loads provides a means for determining monthly and annual loads of dissolved solids. Caculated monthly loads for two stations where specific conductance was measured daily are shown in figure 8.2-4 for the 1980 and 1981 water years. The dissolved-solids loads at the two stations, although of different magnitude, follow a generally similar seasonal pattern. The largest loads are transported during late spring and early summer when stream-flow is the greatest.

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



Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 8.2-1 Location of selected stations where regression equations between specific conductance and dissolved-solids concentration were developed.

EXPLANATION

12 ▼ **SPECIFIC-CONDUCTANCE MEASUREMENT STATION AND NUMBER**

See section 12.0 for description of stations.

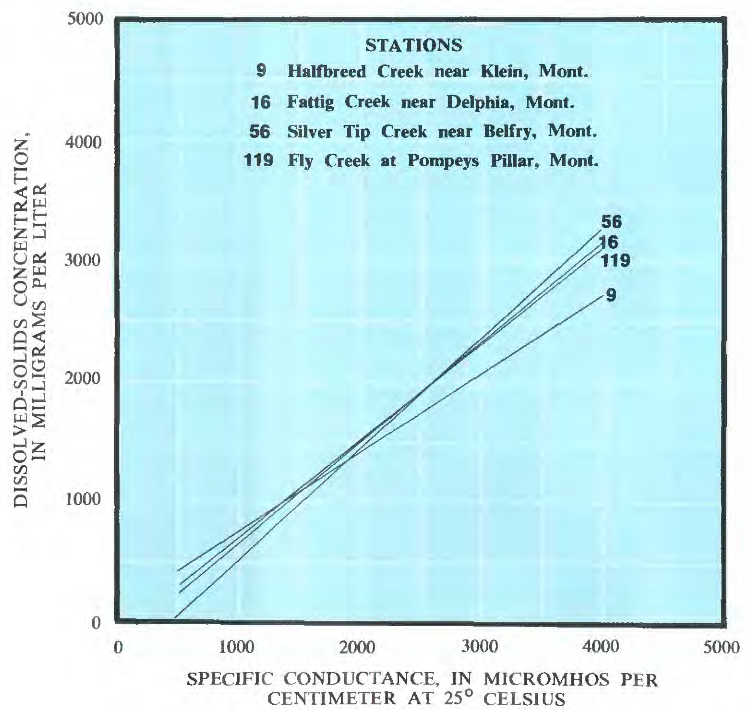


Figure 8.2-2 Relationship between specific conductance and dissolved-solids concentration for selected stations on small prairie streams.

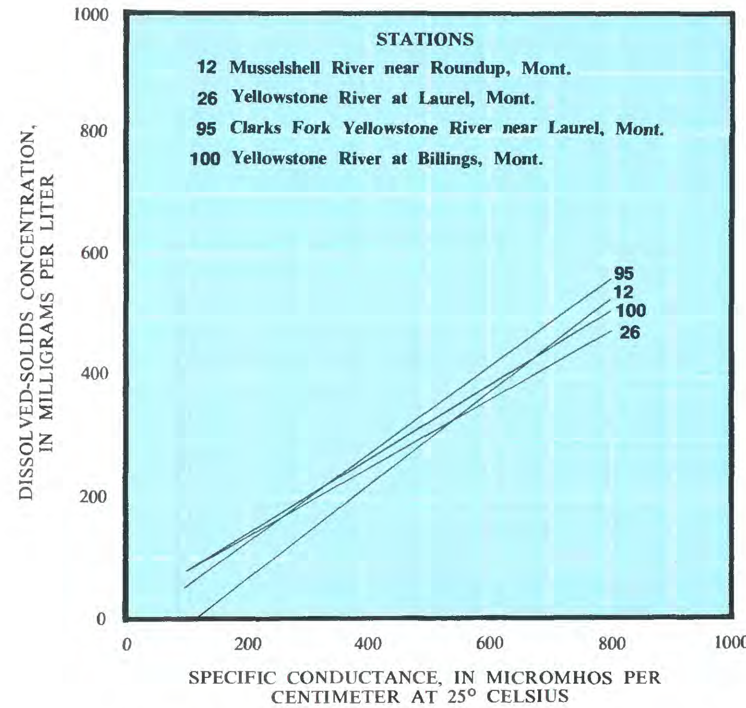


Figure 8.2-3 Relationship between specific conductance and dissolved-solids concentration for selected stations on the Musselshell, Clarks Fork Yellowstone, and Yellowstone Rivers.

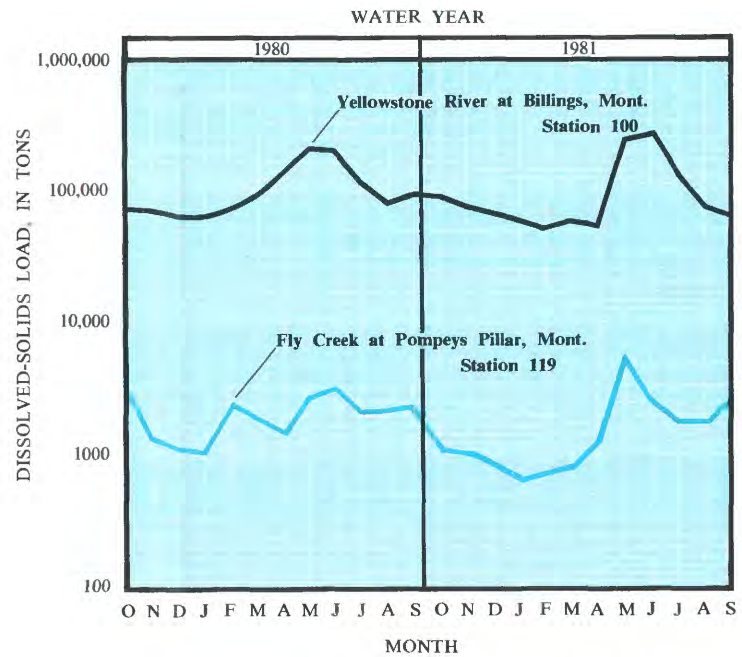


Figure 8.2-4 Monthly dissolved-solids loads, in tons, at selected stations for the 1980 and 1981 water years.

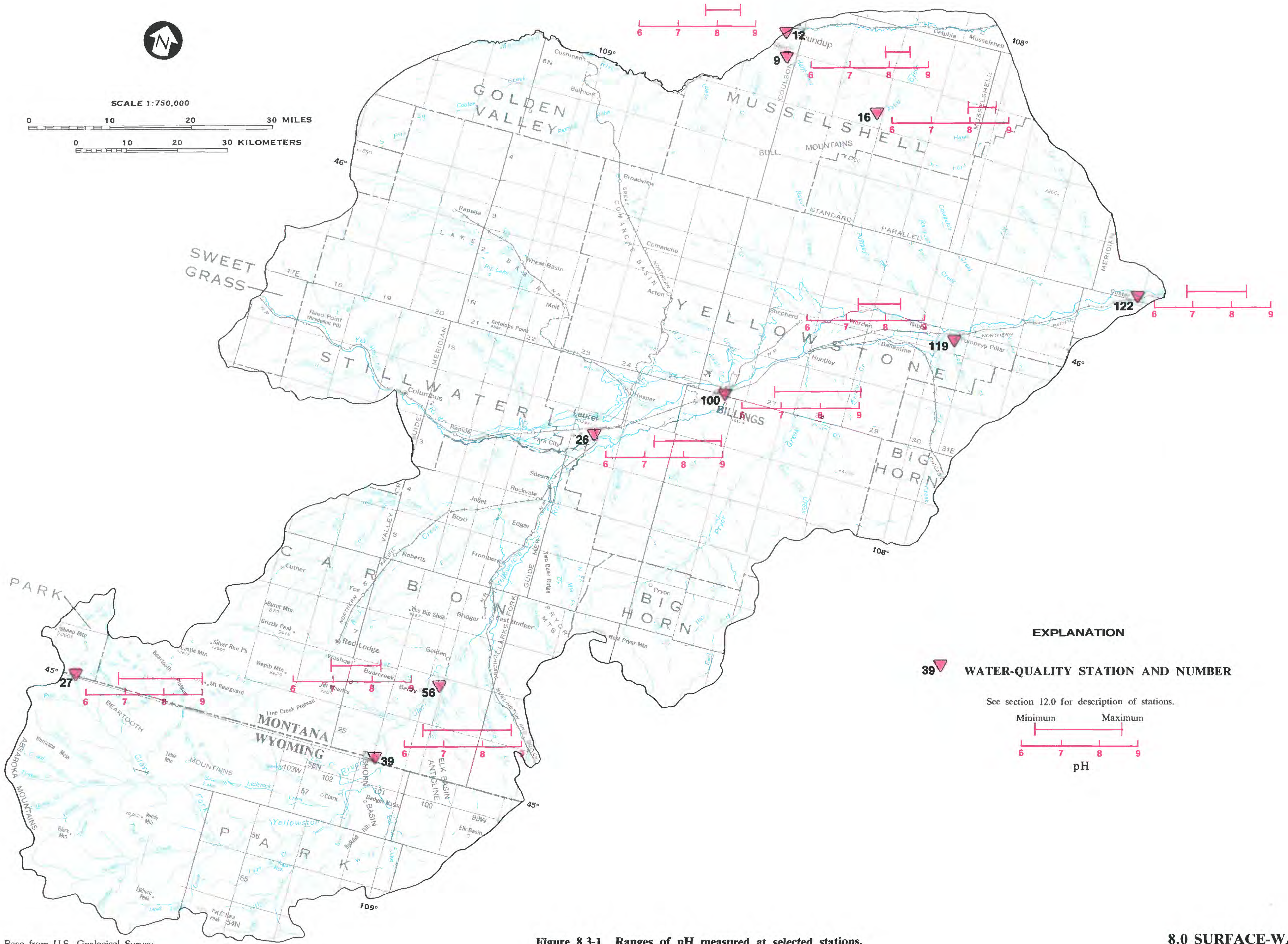
Stream pH Variable but Generally in Near-Neutral Range

Stream pH ranged from 6.5 to 9.2 in Area 48 and is affected mostly by natural conditions.

The effective concentration (activity) of hydrogen ions in dilute solution generally is expressed as pH. 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 basic conditions. Carbon dioxide in the atmosphere generally causes rain and snow to be slightly acidic. Water percolating through subsurface materials can undergo extensive pH changes depending on the type of minerals present. Streams in areas not affected by pollution generally have a pH between 6.5 and 8.5 (Hem, 1970). However, pH values can be somewhat larger than 8.5 during times of photosynthesis by aquatic plants because carbon dioxide is removed from solution. Values less than 6.5 may result from industrial activities, including coal mining. The oxidation of iron sulfides and subsequent reactions occurring in materials exposed by overburden removal may create the potential for acidic conditions.

The pH values measured in the study area ranged from 6.5 to 9.2. The smaller pH values generally were associated with direct-runoff water, which reflected the acidic nature of rain and snow. Larger pH values commonly were measured during base flows when the water consisted primarily of ground-water seepage and photosynthesis was occurring. Ranges in pH measured at selected stations in the study area are shown in figure 8.3-1.

From the available data, there is no indication that either past or present mining operations have had any significant effects on pH in streams. Alkalinities of streams in Area 48 generally are large, thereby providing a considerable buffering capacity to neutralize small volumes of acidic effluent that might be discharged into streams. Expanded mining operations, however, could produce effluent in volumes sufficient to alter natural pH values of streams in the area.



Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

Figure 8.3-1 Ranges of pH measured at selected stations.

8.0 SURFACE-WATER QUALITY--Continued

8.3 pH

Concentrations of Trace Elements Occasionally Exceeded Water-Quality Standards

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

Although many trace elements can be toxic, some are essential to plants and animals in small concentrations. Natural sources of trace elements are soils, geologic strata, and normal atmospheric fallout. Large concentrations can occur naturally in streams, but more commonly they are associated with industrial-waste discharges, including water from coal mining. The oxidation of pyritic minerals exposed by overburden removal can produce acidic water, which may dissolve certain minerals to produce large concentrations of trace elements.

In addition to being transported in the dissolved state, trace elements can be attached to sediment particles and transported with suspended-sediment or bed material. Concentrations of trace elements analyzed from raw, unfiltered samples include both the dissolved and the suspended phases and are referred to as total recoverable concentrations. Analysis of stream water that has been filtered to remove sediment particles provides concentrations of trace elements in the dissolved phase.

Results of dissolved and total recoverable trace-element analyses of water from selected stations are presented in table 8.4-1. The location of these stations is shown in figure 8.4-1. The number of samples and the range of concentration are given, along with a maximum limit for each element established by the U.S. Environmental Protection Agency (1978). Maximum values for several trace elements occurred at concentrations smaller than the detection limit of the applied analysis. In these instances, a less than (<) value is reported rather than an actual concentration. Although the true maximum concentration is unknown in these instances, comparison of the detection limit with the water-quality standard, in some instances, can indicate whether or not a standard was exceeded. If the detection limit is smaller than the standard, then the standard was not exceeded. If the detection limit is greater than the standard, the data are inconclusive.

The limits given in table 8.4-1 are intended to provide a reasonable margin of safety for human health, aquatic life, crops, and livestock. Limits given for domestic water supplies represent legal standards whereas limits for aquatic life, irrigation, and livestock represent suggested guidelines for long-term production. Limits generally refer to dissolved concentrations. However, where limits refer to ingestion of water by animals, including man, total recoverable concentrations are applicable.

The data in table 8.4-1 indicate that concentrations of dissolved trace elements occasionally exceeded recommended maximum limits for boron, iron, manganese, and selenium. The limit for boron was established to prevent injury to sensitive crops receiving long-term irrigation. Iron and manganese limits pertain mostly to esthetic considerations in domestic water use. Large concentrations of dissolved iron and manganese are a common occurrence in many areas of eastern Montana. The limit for selenium is more critical, as some health risk is involved with large concentrations. The maximum limits indicated in table 8.4-1 were generally exceeded in only a small number of samples. Maximum concentrations of dissolved trace elements commonly were measured during base-flow conditions. An important factor in maintaining generally small concentrations is the near-neutral pH in the study streams, which prevents extensive dissolution of many trace elements.

Except for iron and manganese, total recoverable concentrations of most trace elements seldom exceeded the given limits. The largest total recoverable concentrations corresponded to runoff conditions when large amounts of sediment containing adsorbed trace elements were being transported. Although total recoverable concentrations of iron and manganese frequently exceeded limits for domestic water supplies, settling and other required treatments would eliminate most of the sediment to which these constituents are sorbed.

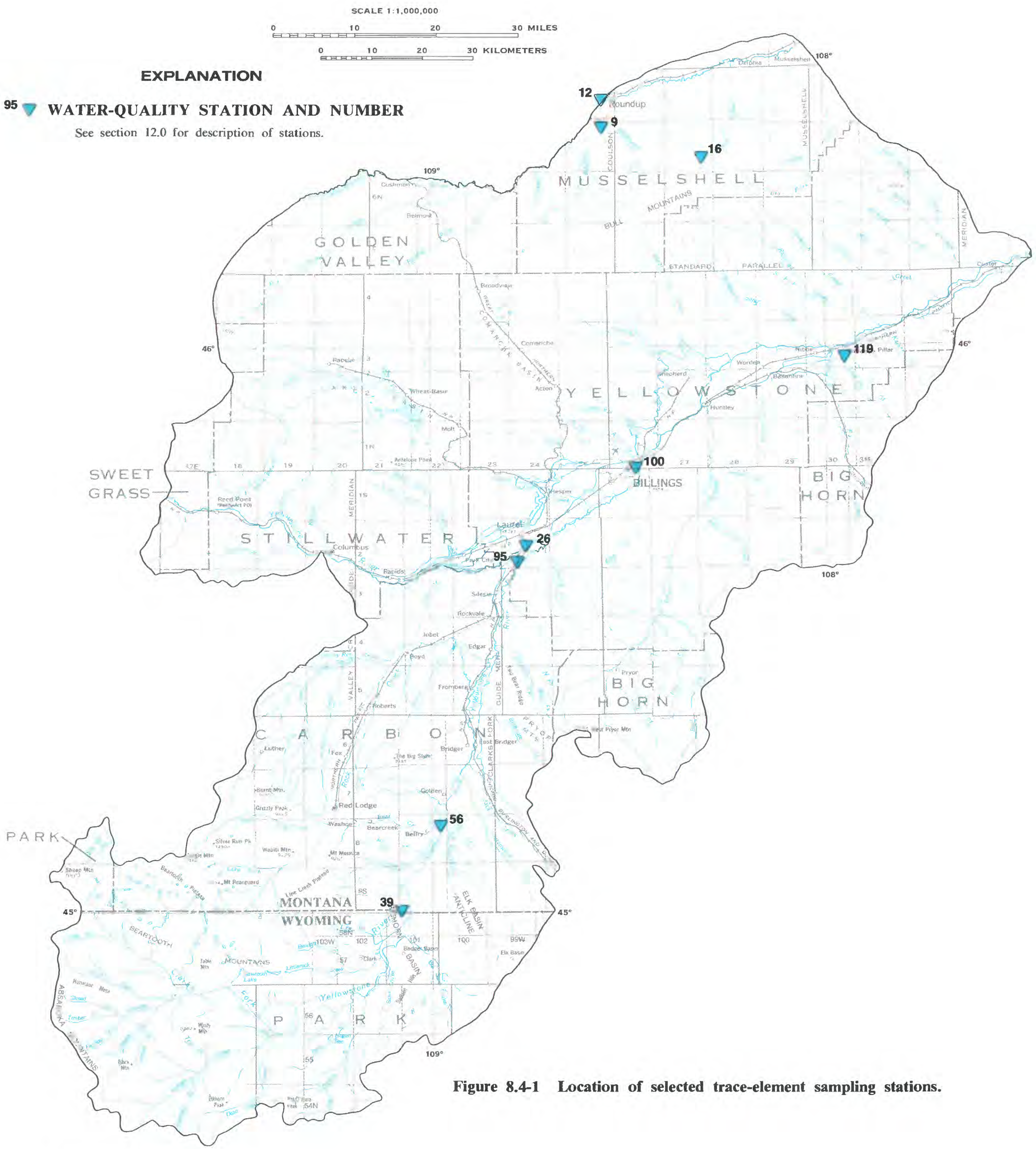


Figure 8.4-1 Location of selected trace-element sampling stations.

Base from U.S. Geological Survey
State base maps 1:500,000;
Montana 1966, Wyoming 1964

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

[Concentrations are in micrograms per liter. N, number of samples; <, less than. Station numbers from figure 8.4-1.]

Constituent		Station 9 (N)	Station 9 Range in concentration	Station 12 (N)	Station 12 Range in concentration	Station 16 (N)	Station 16 Range in concentration	Station 26 (N)	Station 26 Range in concentration	Station 39 (N)	Station 39 Range in concentration	Station 56 (N)	Station 56 Range in concentration	Station 95 (N)	Station 95 Range in concentration	Station 100 (N)	Station 100 Range in concentration	Station 119 (N)	Station 119 Range in concentration	Maximum limit[1,2]
Arsenic	Dissolved	11	1-5	12	1-12	9	<1-6	10	4-14	--	--	--	--	8	<1-15	36	2-14	--	--	50a, 100c
	Total recoverable.	7	2-6	9	2-20	8	1-3	36	6-40	--	--	--	--	--	--	30	4-18	--	--	
Boron	Dissolved	49	60-220	50	20-270	33	100-850	30	50-280	148	<20-180	87	20-3,390	8	20-80	121	9-490	82	10-530	750c
	Total recoverable.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Cadmium	Dissolved	11	<2-3	12	<2-3	9	<2-2	10	<2-3	--	--	--	--	8	<1-1	38	<2-5	--	--	10a, 50d
	Total recoverable.	7	<2-2	9	<2-2	8	<2-2	31	<2-<20	--	--	--	--	--	--	32	<2-<20	--	--	
Chromium	Dissolved	11	<20-20	12	<20-20	9	<20-20	10	<20-20	--	--	--	--	7	<20-<20	34	<20-28	--	--	50a, 100b
	Total recoverable.	7	<20-30	9	<20-80	8	<20-30	33	<20-30	--	--	--	--	1	<2	36	<20-100	--	--	
Copper	Dissolved	11	<2-3	12	<2-13	9	<2-6	10	<20-40	--	--	--	--	8	<2-6	37	<20-42	--	--	1,000a
	Total recoverable.	7	<2-18	9	1-120	8	2-9	37	<20-120	--	--	--	--	--	--	32	<20-200	--	--	
Iron	Dissolved	49	10-190	50	10-240	26	<10-80	32	10-360	24	<10-490	92	<10-1,800	1	140	127	<10-370	163	<10-700	300a, 1,000b
	Total recoverable.	7	230-1,200	9	240-81,000	8	30-490	37	40-9,800	25	<10-210	1	90	--	--	34	<10-14,000	--	--	
Lead	Dissolved	11	<2-23	12	<2-11	9	<2-11	10	2-12	--	--	--	--	8	<2-7	38	<2-17	--	--	50a,100d
	Total recoverable.	7	<2-31	9	1-65	7	2-13	35	<2-<200	--	--	--	--	--	--	32	2-<200	--	--	
Manganese	Dissolved	11	39-120	12	6-80	9	<10-50	14	4-30	--	--	83	<10-560	8	<10-67	78	<10-170	152	<10-190	50a
	Total recoverable.	7	50-150	9	20-2,100	8	<10-40	36	10-320	--	--	--	--	--	--	34	<10-1,200	1	<10	
Mercury	Dissolved	11	<.1-.1	12	<.1-.7	9	<.1-.1	9	<.5	--	--	--	--	7	<.1-.3	33	<.1-<.5	--	--	2a,10d
	Total recoverable.	7	<.1-.3	9	<.1-.2	8	<.1-.1	33	.1-<.5	--	--	--	--	1	<.1	33	<.1-1.3	--	--	
Selenium	Dissolved	11	1-4	12	1-3	9	<1-3	10	1-1	--	--	--	--	8	1-34	36	<1-9	--	--	10a,50d
	Total recoverable.	7	<1-2	9	<1-3	8	<1-2	37	1-2	--	--	--	--	--	--	32	<1-2	--	--	
Zinc	Dissolved	11	2-20	12	3-70	9	10-40	10	<2-40	--	--	--	--	8	<2-20	38	<2-50	--	--	5,000a, 25,000d
	Total recoverable.	7	<2-60	9	20-300	8	10-60	37	<2-440	--	--	--	--	--	--	32	<2-140	--	--	

[1]Limit established by U.S. Environmental Protection Agency (1978) for: a, domestic water supply; b, aquatic life; c, irrigation.

[2]Limit established by National Academy of Sciences and National Academy of Engineering (1973) for: d, livestock consumption.

Suspended-Sediment Concentrations Vary Substantially Throughout the Area

Suspended-sediment concentrations fluctuate in response to stream discharge and sediment availability within the drainages; naturally occurring suspended-sediment concentrations exceed mining standards in many Area 48 streams.

Sediment transported by streams is derived from a combination of soil erosion from overland runoff and channel erosion (bank cutting and bed scour). Soils in the area range from stable humic soils in the mountains to erosive sandy to silty loams in the foothills and prairies. Erodability of soils depends to a large extent on grain size, topographic relief, vegetative cover, rainfall duration and intensitiy, and land-use practices. Channel erosion is affected primarily by the magnitude and velocity of streamflow and the erodability of bed and bank materials. Stream hydraulics dictate the maximum size of sediment particles that the stream can transport. Generally, the smaller prairie streams transport primarily fine-grained sediments (less than 0.062 millimeter in diameter), whereas the larger streams can transport a significant amount of larger sediments (greater than 0.062 millimeter in diameter), especially during high flows.

Concentrations of suspended sediment measured in the study area ranged from 2 to 109,000 milligrams per liter. This range is large because of the great variation in sediment availability within the basins and in the capacity of the streams to transport sediment. Maximum concentrations of suspended sediment were measured during times of direct runoff, when both channel and overland erosion contributed sediment to the streams. Minimum concentrations generally were measured during base flow or during snowmelt runoff over partly frozen surfaces. The location of selected suspended-sediment sampling sites is shown in figure 8.5-1.

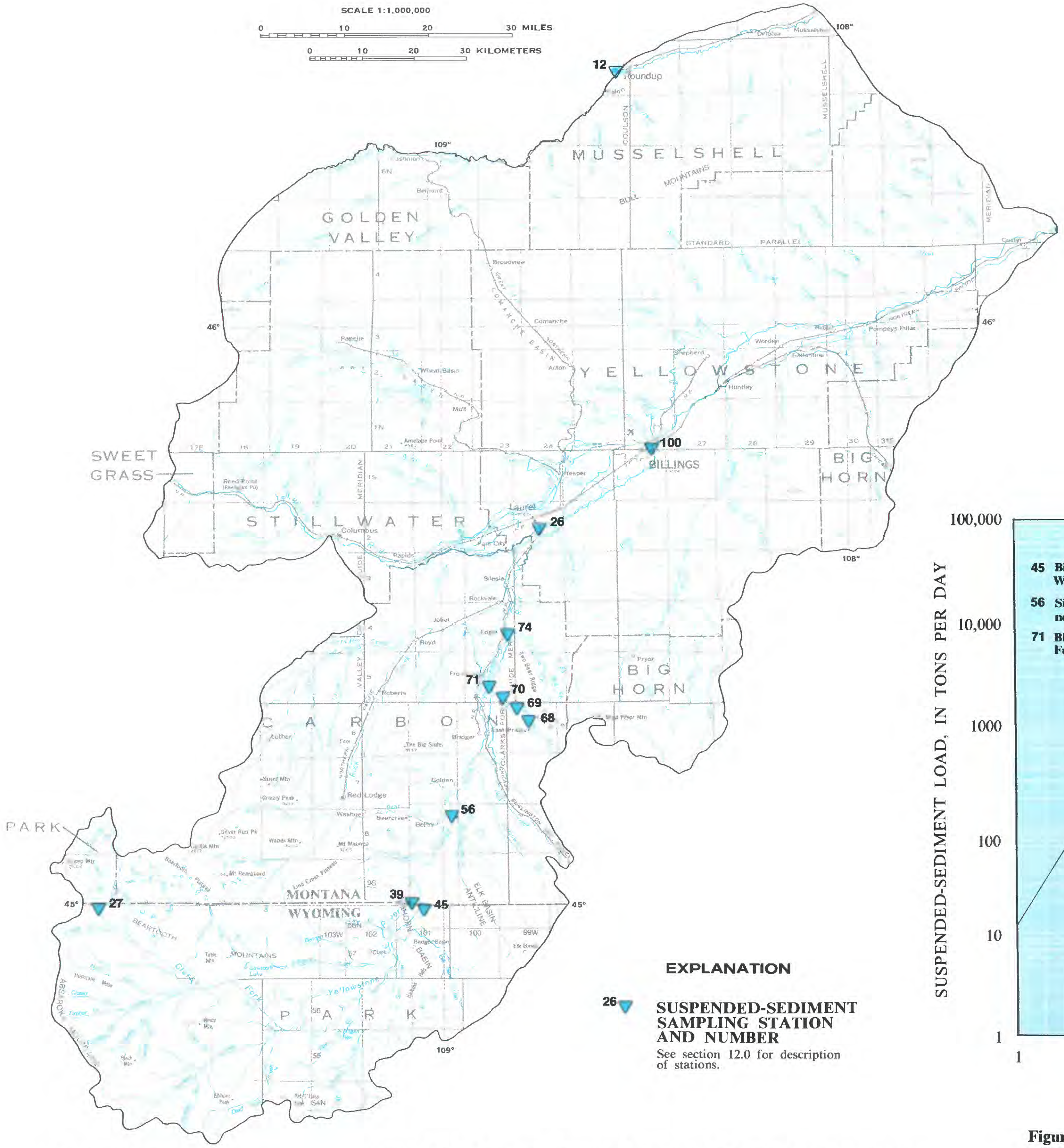
The magnitudes of base flows in the small streams of Area 48 are generally insufficient to transport available sediment supplies, and consequently, deposition of sediment within the channel is common. During runoff conditions, high flows will flush large amounts of sediment from tributary channels into the main-stem rivers. This situation is especially evident in the middle and downstream parts of the Clarks Fork Yellowstone River basin. Very erosive soils throughout much of the basin coupled with poor irrigation practices have resulted in locally severe sedimentation problems.

The amount of suspended sediment transported by a stream (suspended-sediment load) at various stream discharges is commonly shown by a sediment-transport curve. Sediment-transport curves for small streams in the Clarks Fork Yellowstone River basin are shown in figure 8.5-2. Comparison of the three curves shows similar slopes; however, the position of the curve for Silver Tip Creek near Belfry (station 56) indicates a larger load transported at all magnitudes of stream discharge. Sediment-transport curves for the large streams in Area 48 (fig. 8.5-3) illustrate more variation in slope and position than those for the small streams. The most obvious difference exists between the curves for Clarks Fork Yellowstone River near Belfry (station 39) and Clarks Fork Yellowstone River at Edgar (station 74). Station 39 is located upstream from the three streams graphed in figure 8.5-2. The effect of the sediment loads transported into the Clarks Fork by these streams is evidenced by the slope and position of the curve for station 74, which is downstream from these tributaries. Station 74 transports a much larger suspended-sediment load for a given discharge, especially at low flows, than that of the uptstream station 39.

The overall impact of sediment in the Clarks Fork Yellowstone River on the Yellowstone River is a moderate increase in suspended-sediment load per given discharge. This increase is illustrated by the two curves representing the Yellowstone River upstream (station 26) and downstream (station 100) from the Clarks Fork. The slope of the sediment-transport curve for the Musselshell River near Roundup (station 12) is similar to those for the Yellowstone River; however, its position indicates a greater load transported at a given streamflow.

Sufficient data were available at several stations to calculate an average annual suspended-sediment load for the period of record. These average loads, in tons, were further divided by drainage area to arrive at an average annual sediment yield, in tons per square mile. Results of the calculations are presented in table 8.5-1. Average annual suspended-sediment yields ranged from 54.5 tons per square mile at Musselshell River near Roundup (station 12) to 373 tons per square mile at Silver Tip Creek near Belfry (station 56). The determination of sediment yield provides useful information that can be used to assess the effects of land disturbance or the effectiveness of soil conservation practices.

Coal-mining point source standards established by the U.S. Environmental Protection Agency (1982) set a maximum effluent limitation for suspended-sediment (total suspended solids) at 70.0 milligrams per liter for any 1 day or an average of 35.0 milligrams per liter for 30 consecutive days. Naturally occurring average concentrations for many area streams presently exceed these values. Consequently, significant impacts to the natural sediment yields of the basins would not be expected to occur from properly designed surface coal mines or mine-related activities.



Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

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

Table 8.5-1 Average annual suspended-sediment loads and basin yields for selected stations.

Station No. (fig. 8.5-1)	Site	Drainage area (square miles)	Average annual suspended-sediment load (tons)	Average annual suspended-sediment yield (tons per square mile)	Length of record (years)
12	Musselshell River near Roundup, Mont.	4,023	[1]219,100	54.5	3
56	Silver Tip Creek near Belfry, Mont.	88.0	[2]32,810	373	4.3
68	Bluewater Creek near Bridger, Mont.	28.1	[2]2,962	105	8
69	Bluewater Creek at Sanford Ranch near Bridger, Mont.	43.9	[2]11,790	269	7
70	Bluewater Creek near Fromberg, Mont.	46.6	[2]12,430	267	7
100	Yellowstone River at Billings, Mont.	11,795	[2]1,705,000	145	5

[1]Computed by sediment-transport, flow-duration method (Knapton, 1982)
[2]Computed from daily suspended-sediment records

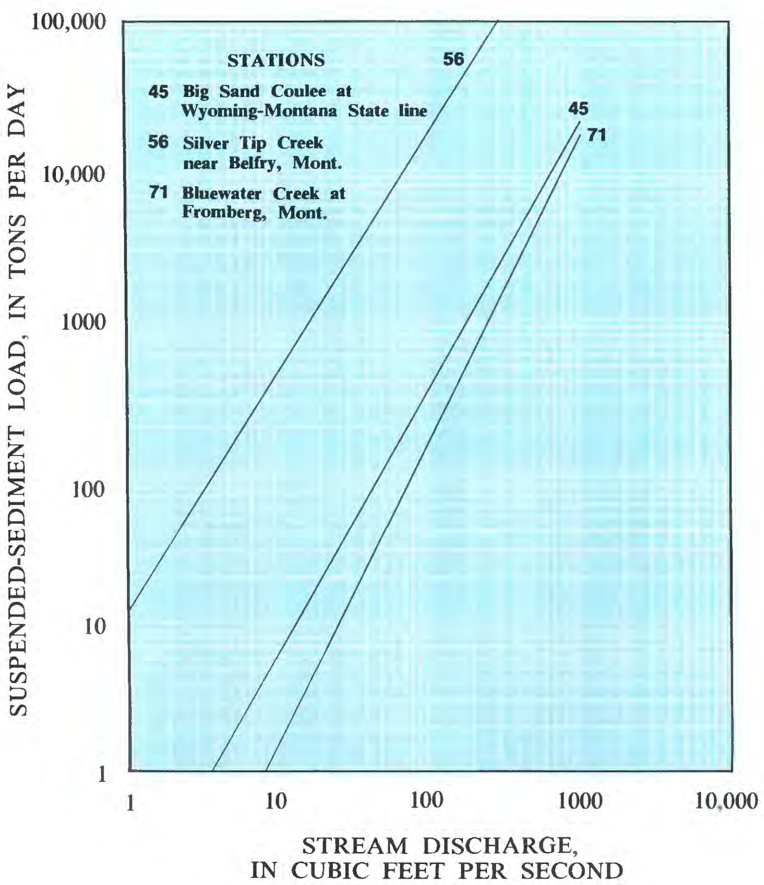


Figure 8.5-2 Relationship between stream discharge and suspended-sediment load at selected stations on small streams.

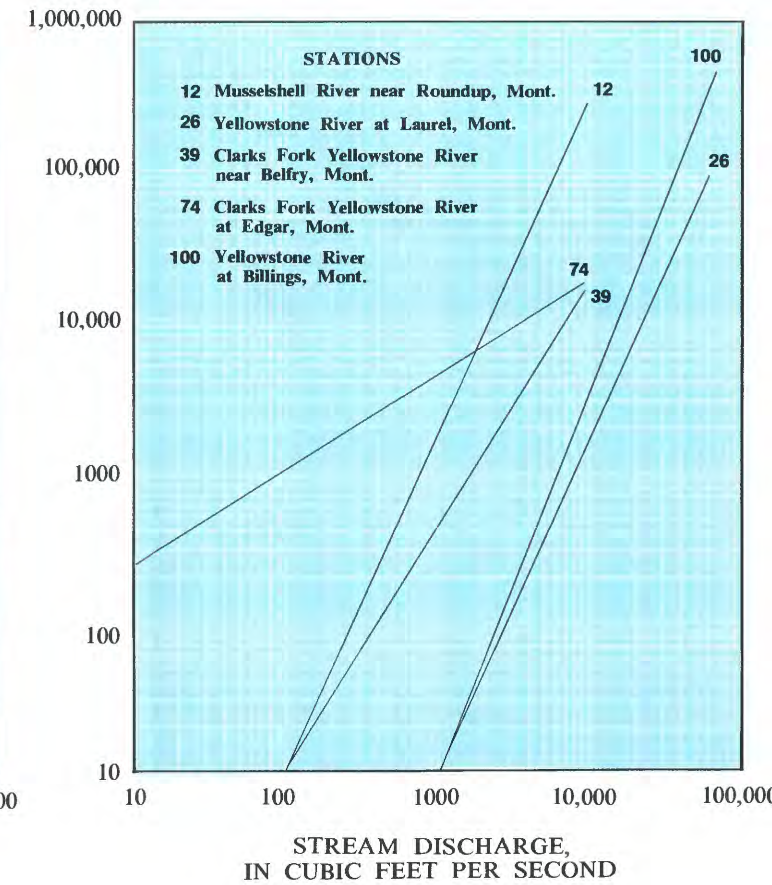


Figure 8.5-3 Relationship between stream discharge and suspended-sediment load at selected stations on large streams.

Benthic Invertibrate and Periphyton Communities are Diverse

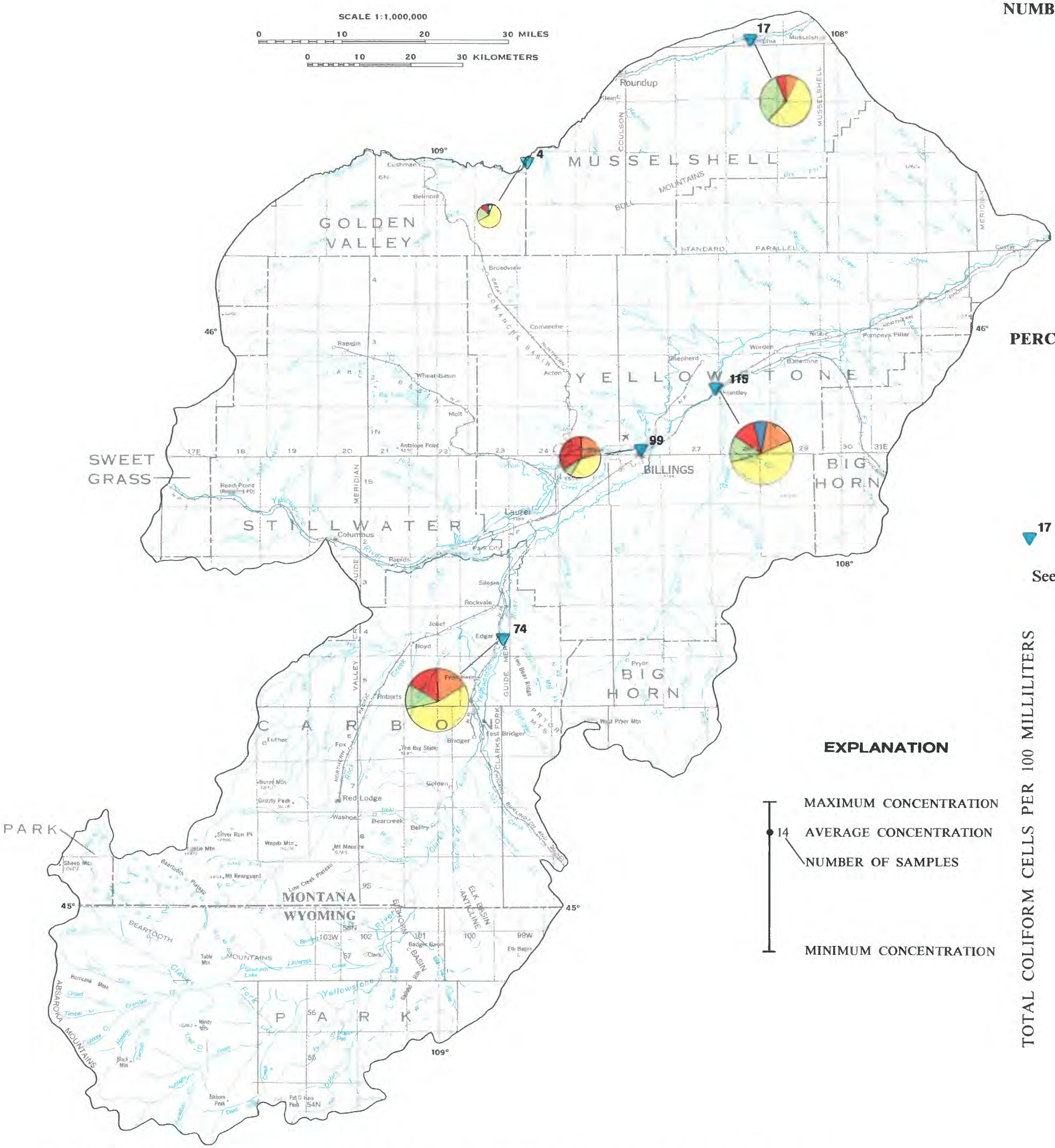
Domination by fast-flowing-water forms of Insecta and diatom populations in sampled streams indicates that biota are relatively free from water-quality stress.

Biological samples from Area 48 form a data base that describes the community composition of aquatic organisms from which future water-quality changes can be detected. Biological samples from streams have included benthic invertibrates (aquatic insecta), periphyton (attached algae), and enteric bacteria (bacteria associated with the intestine of warm-blooded animals). Community structures, associations, and diversities of these types of aquatic organisms are commonly used as indicators of water quality.

The average percentage composition of major groups (orders) and the total number of Insecta collected in 1979 by Bahls and others (1981) are shown in figure 8.6-1. At each station or site, except number 99, the orders Plecoptera, Ephemeroptera, and Trichoptera together composed more than 70 percent of the total number of benthic invertebrates collected. Most species in these three groups, as opposed to most species in Diptera and Hemiptera, are considered to be intolerant of oxygen-demanding waste and their presence indicates adequate concentrations of dissolved oxygen. Generally, if concentrations of dissolved oxygen are adequate, the concentrations of other water-quality constituents are within the tolerance ranges and therefore are unstressful to most aquatic biota. Unstressful water quality is also indicated by benthic invertebrates if the number of taxa in a stream is larger than 15 (Bahls and others, 1981), and the Shannon-Weaver diversity index is equal to or greater than 2.6 (Wilhm, 1970). At the sampled stations and sites in Area 48, the number of collected taxa ranged from 17 to 22 and the diversity indexes were all greater than 2.6.

Periphyton collections in 1979 also indicate unstressful water quality. Chlorophyll *a* accrual rates less than or equal to 0.5 milligram per square meter per day and biomass accrual rates less than or equal to 115 milligrams per square meter per day indicate streams unenriched with nutrients (Bahls and others, 1981). Chlorophyll *a* and biomass accrual rates for periphyton at stations 11, 17, and 99 are generally small, indicating small concentrations of nutrients from organic inputs (table 8.6-1). In addition, the dominance of diatoms (more than 25 species) and diversity indexes greater than 3.00 at each of the stations (table 8.6-1) also indicate unstressful water quality at the sampled stations (Bahls and others, 1981).

Samples for analysis of bacteria have been collected at stations 26, 95, 96, 99, 115, and 122. Total coliform, fecal coliform, and fecal streptococcal bacteria are commonly used to indicate the safety of water for drinking and swimming. Total coliform bacteria, whose absence is evidence of bacteriologically safe water, were the most commonly analyzed bacteria at these stations and were detected in most of the samples. Stations 26 and 115, which have the longest period of record for total coliform samples (8 to 14 years), exemplify the annual variability and wide range to total coliform concentrations present in Area 48 (fig. 8.6-2).



Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

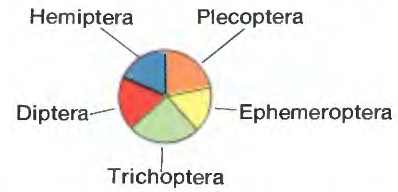
Figure 8.6-1 Total number of benthic invertebrates per sample and percentage composition of major orders of aquatic Insecta at stations and sites sampled in 1979 (Bahls and others, 1981).

EXPLANATION

NUMBER OF BENTHIC INVERTEBRATES PER SAMPLE

- 70 to 79
- 80 to 89
- 90 to 99
- 100 to 109

PERCENTAGE COMPOSITION OF MAJOR ORDERS



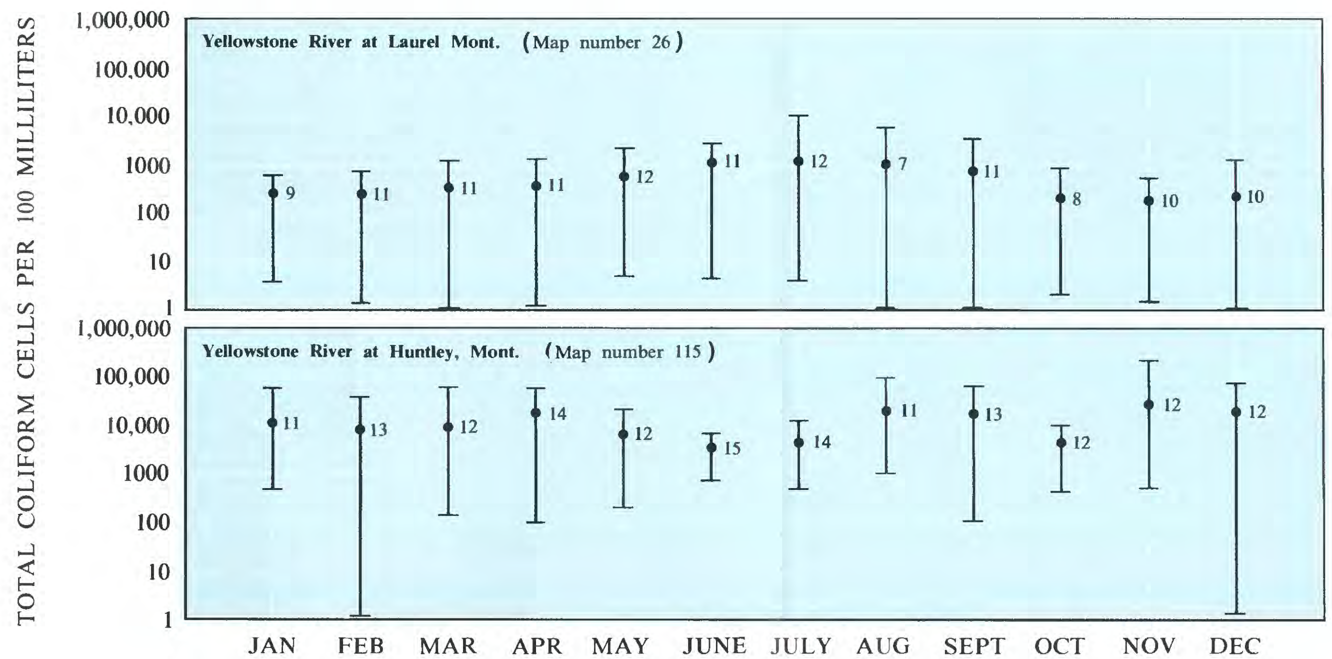
17 WATER-QUALITY STATION AND NUMBER

See section 12.0 for description of stations and sites

Table 8.6-1 Characteristics of periphyton collected from streams in Area 48 (Bahls and others, 1981).

Station	Average accrual rate, in milligrams per square meter per day: Chlorophyll *a*	Average accrual rate, in milligrams per square meter per day: Biomass	Number of diatom species	Average diatom species diversity index[1]
11	0.08	42	56	4.66
17	.04	20	34	4.09
74	1.16	132	33	3.56
99	.45	96	38	3.06
115	1.44	197	32	3.34

[1] Shannon-Weaver species diversity (Weber, 1973)



EXPLANATION

MAXIMUM CONCENTRATION

14 AVERAGE CONCENTRATION

NUMBER OF SAMPLES

MINIMUM CONCENTRATION

Figure 8.6-2 Monthly average, minimum, and maximum total coliform concentration (in cells per 100 milliliters) for period of record at Yellowstone River at Laurel, Montana, and Yellowstone River at Huntley, Montana.

Water Available from Sand, Gravel, Limestone, Sandstone, and Coal

Most wells produce water from Cretaceous sandstone.

Sand and gravel contained in alluvium and terrace deposits constitute a major source of water in Area 48. Alluvium along the major streams (fig. 9.1-1) is capable of producing a sufficient quantity of water to wells for irrigation use (table 9.1-1). Alluvium along the smaller streams generally yields insufficient quantities of water for commercial irrigation. Terrace gravel, because of its relatively high topographic position on valley walls or ridgetops, readily drains; therefore, it commonly yields only small to moderate quantities of water. Gravels in the vicinity of Red Lodge, Montana, which are in large part glaciofluvial outwash from the Beartooth Mountains, occur in an area of relatively low relief and are of sufficient thickness to maintain a saturation capable of yielding large quantities of water.

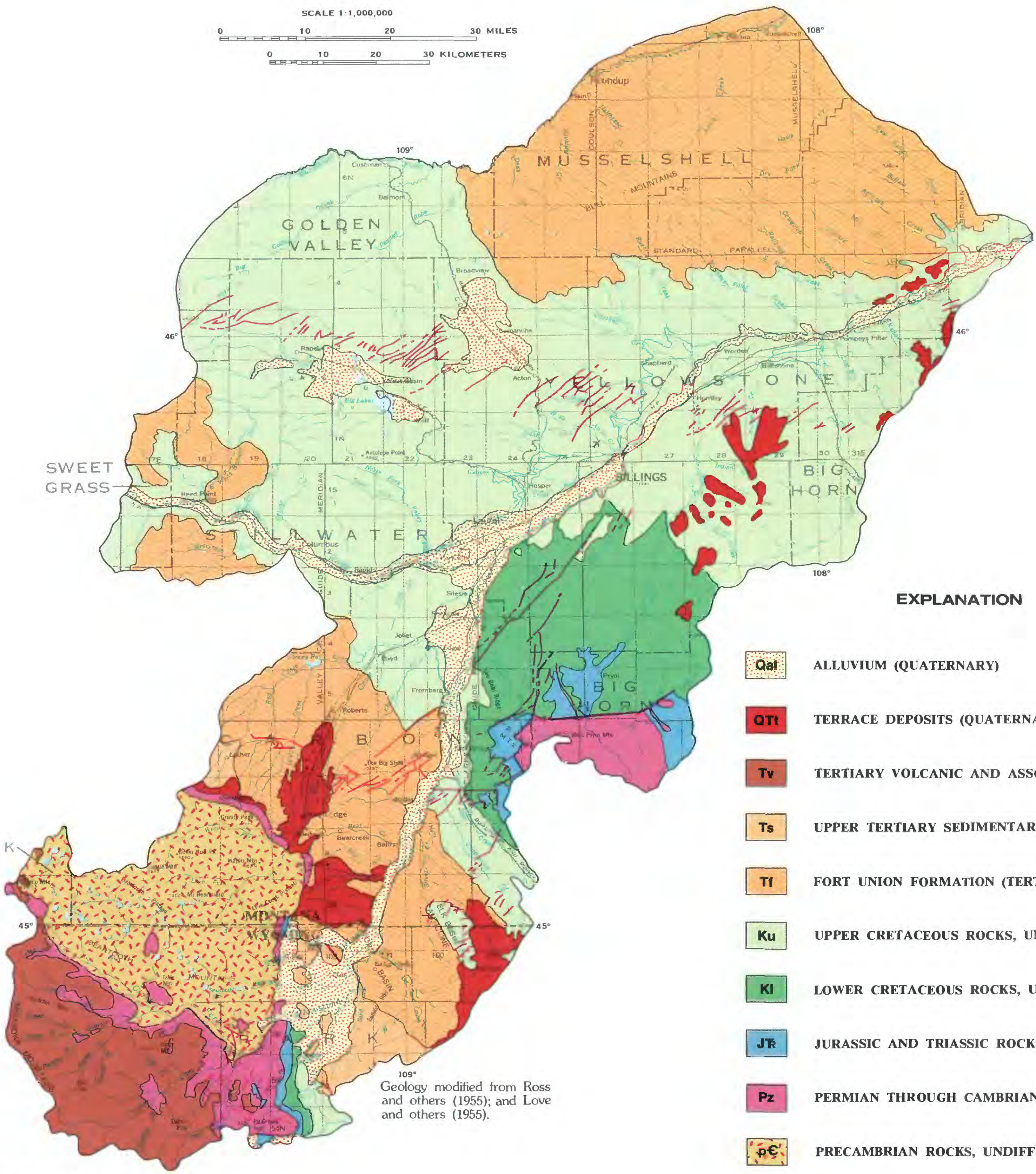
Tertiary sediments, which include the Fort Union, Wasatch, and Willwood Formations, constitute important aquifers where they are present. These formations, in general, consist of many beds of lenticular sandstone and shale of great vertical and horizontal variability and contain both continuous and discontinuous coal beds. Water is obtained from sandstone and fractured coal. Beds of unconsolidated sand not only hamper drilling because of sand caving into the hole, but also because of well-completion problems, yield little or no water. The Tongue River Member of the Fort Union Formation contains the largest percentage of sandstone and coal and, therefore, is the most promising Tertiary aquifer.

Rocks exposed in most of Area 48 consist of an alternating sequence of sandstone and shale of Cretaceous age. Because of their proximity to the surface, these rocks are the most frequently explored sources for water supplies. The shales in this sequence either do not yield water or yield only meager quantities of mineralized water. The sandstones generally yield adequate quantities of water for domestic and stock use.

Depth of drilling required to intercept a water-yielding sandstone is complicated by the geologic structure of the area. The rocks are not flat-lying but are tilted to varying degrees and in various directions. The regional dip trends toward the northeast but this trend, at places, is interrupted by faulting and minor folding. Because of the inclination of the rocks, the depth to a water-yielding sandstone is primarily dependent on the dip of the beds rather than the topographic expression of the land surface (fig. 9.1-2).

Paleozoic and Triassic rocks, although having a potential for yielding extremely large quantities of water, are readily available for use only in limited areas. Because they are generally steeply dipping and faulted, surface exposures are small and the formations plunge to great depths in short distances. Many water wells that produce from these aquifers were originally drilled as oil and gas tests.

Rocks in the Beartooth and Absaroka Mountains in the extreme southwestern part of Area 48 consist primarily of Precambrian crystalline and Tertiary volcanic rocks that have practically no primary permeability. Some water may be available where the rocks are fractured or in areas of stream alluvium, volcanic-derived sediments, or glacial debris. Because most of this area is undeveloped, the potential for water supplies is untested.



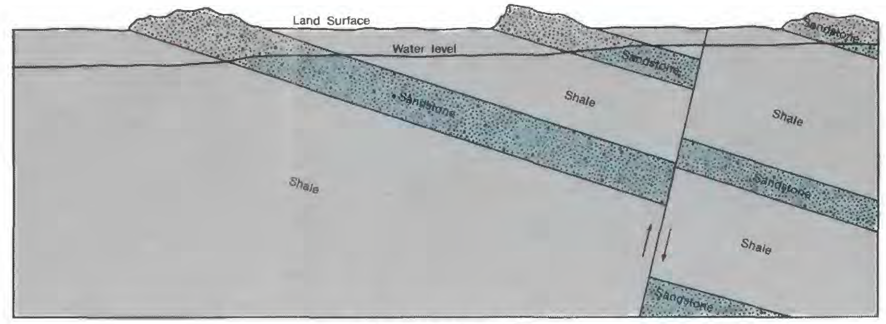
Geology modified from Ross and others (1955); and Love and others (1955).

Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

Figure 9.1-1 Generalized hydrogeologic units.

EXPLANATION

- Qal — ALLUVIUM (QUATERNARY)
- QTt — TERRACE DEPOSITS (QUATERNARY AND TERTIARY)
- Tv — TERTIARY VOLCANIC AND ASSOCIATED SEDIMENTARY ROCKS
- Ts — UPPER TERTIARY SEDIMENTARY ROCKS, UNDIFFERENTIATED
- Tf — FORT UNION FORMATION (TERTIARY)
- Ku — UPPER CRETACEOUS ROCKS, UNDIFFERENTIATED
- Kl — LOWER CRETACEOUS ROCKS, UNDIFFERENTIATED
- J$\bar{R}$ — JURASSIC AND TRIASSIC ROCKS, UNDIFFERENTIATED
- Pz — PERMIAN THROUGH CAMBRIAN ROCKS, UNDIFFERENTIATED
- p€ — PRECAMBRIAN ROCKS, UNDIFFERENTIATED
- CONTACT
- FAULT -- Dashed where approximately located



EXPLANATION

WATER-YIELDING MATERIALS

Figure 9.1-2 Hypothetical cross-section illustrating relation of structure to ground-water availability.

Table 9.1-1 Generalized stratigraphic section.

MAP SYMBOL	ERATHEM	SYSTEM	SERIES	GEOLOGIC UNIT	PRINCIPAL LITHOLOGY
Qal	Cenozoic	Quaternary	Holocene	Alluvium	Sand, gravel, silt, clay
QTt			Pleistocene	Morainal material [1]	
		Tertiary	Pliocene or Miocene	Terrace gravel [1]	
Tv			Oligocene	Absaroka Volcanics	Volcanic rocks
Ts			Eocene	Crandall Fm. or Cathedral Cliffs Fm.	Tuff, breccia, carbonate clasts
				Wasatch Fm or Willwood Fm	Sandstone, claystone, shale
Tf			Paleocene	Fort Union Fm: Tongue River Mbr; Lebo Shale Mbr; Tullock Mbr	Sandstone, claystone, shale, coal
Ku	Mesozoic	Cretaceous	Upper	Hell Creek Fm or Lance Fm	Sandstone claystone, shale, coal
				Montana Group: Fox Hills Ss or Lennep Ss	Sandstone
				Montana Group: Bearpaw Sh / Meeteetse Fm	Sandstone, shale, coal bentonite
				Montana Group: Judith River Fm (Mesaverde Fm)	Sandstone, shale, coal
				Montana Group: Parkman Ss (Mesaverde Fm)	Sandstone
				Montana Group: Claggett Sh (Mesaverde Fm)	Shale
				Montana Group: Eagle Ss (Mesaverde Fm)	Sandstone, shale, coal
				Montana Group: Telegraph Creek Fm	Sandstone shale
				Colorado Group or equivalents: Cody Sh — Niobrara Fm	Shale
				Colorado Group or equivalents: Carlile Sh; Frontier Fm — Greenhorn Fm, Belle Fourche Sh	Sandstone, shale, coal
Kl			Lower	Colorado Group or equivalents: Mowry Sh	Shale
				Colorado Group or equivalents: Muddy Ss	Sandstone
				Colorado Group or equivalents: Thermopolis Sh or Skull Creek Sh	Shale
				Fall River Ss or "Dakota Ss" equivalents	Sandstone
				Cloverly Fm; Fuson Sh, Lakota Ss; Kootenai Fm	Sandstone, claystone, conglomerate
J$\bar{R}$		Jurassic	Upper	Morrison Fm	Sandstone, limestone, marl
				Ellis Group: Swift Fm, Rierdon Fm; Sundance Fm	Sandstone, shale, limestone
			Middle	Ellis Group: Piper Fm; Gypsum Spring Fm	Shale limestone, gypsum
		Triassic		Chugwater Fm; Dinwoody Fm	Sandstone, siltstone, shale, anhydrite, gypsum
Pz	Paleozoic	Permian		Phosphoria Fm / Park City Fm	Limestone, shale
		Pennsylvanian		Tensleep Ss	Sandstone
				Amsden Fm; Darwin Ss Mbr	Limestone, shale, sandstone
		Mississippian		Madison Group (Madison Fm): Charles equivalent; Mission Canyon Ls; Lodgepole Ls	Limestone, dolomite
		Devonian		Undifferentiated	Shale dolomite limestone
		Silurian		Undifferentiated	Dolomite
		Ordovician		Undifferentiated	Dolomite, sandstone
		Cambrian		Undifferentiated	Sandstone, shale, limestone, dolomite
p€	Precambrian			Undifferentiated	Igneous and metamorphic rocks

[1] Order does not necessarily denote relative stratigraphic position

Modified from Montana Bureau of Mines and Geology (1971).

Ground-Water Flow Generally Eastward

Most aquifers are artesian and contain regional flow systems.

Water in most aquifers flows across Area 48 in an easterly direction, following the general trend of the Yellowstone River. Water in the southern part of the area probably flows from the flanks of the Beartooth and Pryor Mountains and has a northerly component in the lowlands occupied by the Clarks Fork of the Yellowstone River and Rock Creek, although sufficient data to verify the flow patterns are not available.

Flow patterns in Area 48 are shown on potentiometric-surface maps for seven aquifers (figs. 9.2-1, 9.2-2, 9.2-3). The contours depict the altitude at which water would stand in tightly cased wells completed in the subject aquifer. Ground-water flow is approximately perpendicular to the contours.

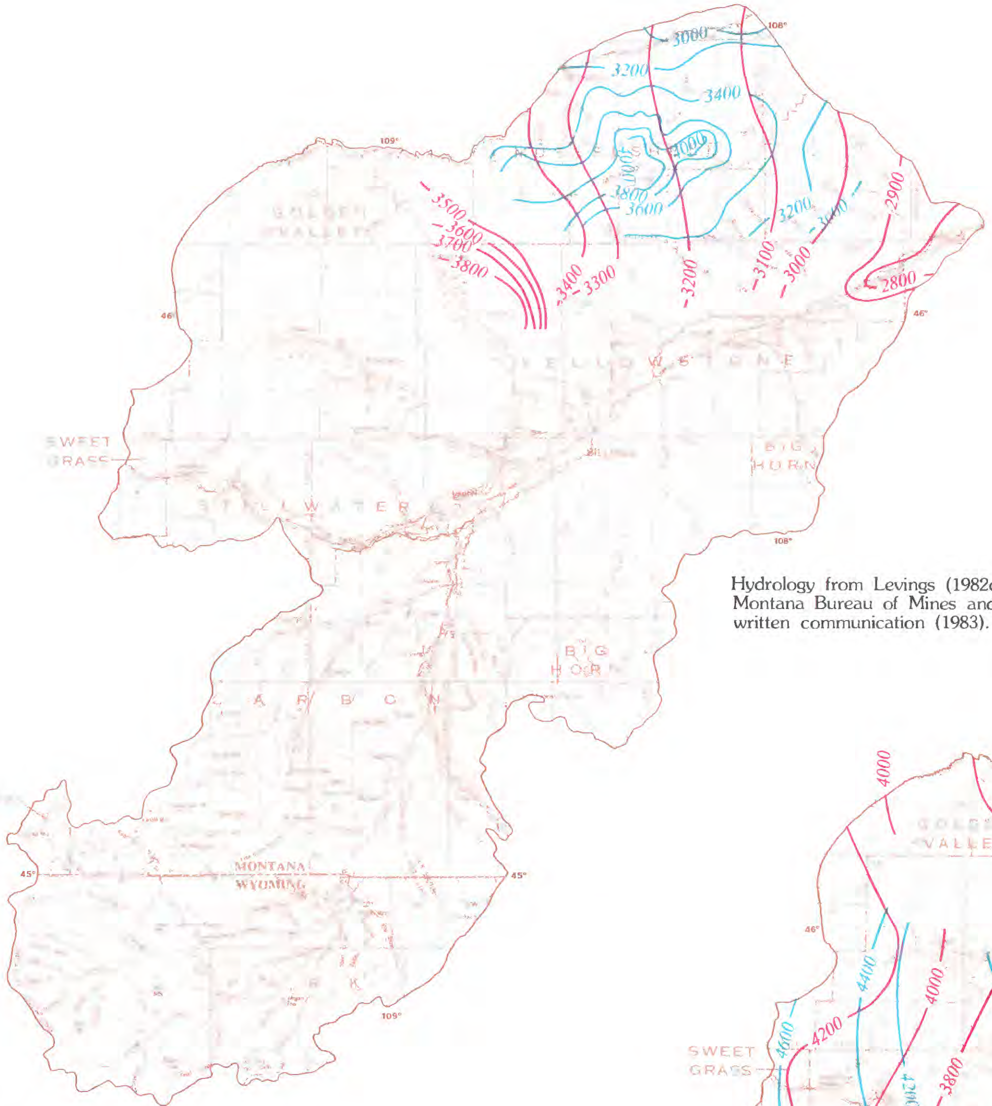
Water in bedrock aquifers occurs under water-table and artesian conditions. In general, water-table conditions exist near the outcrops, and artesian conditions prevail where the aquifers occur at depth. Bedrock aquifers in Area 48 are, for the most part, under confined conditions.

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 flow from outside the area. Discharge from aquifers commonly is to streams and rivers. Flow patterns for most aquifers in Area 48 are regional, and discharge within the area is not evident except from the Fox Hills-lower Hell Creek aquifer and Fort Union Formation in the vicinity of the Bull Mountains (fig. 9.2-1).

SCALE 1:1,500,000

0 10 20 30 40 50 MILES

0 10 20 30 40 50 KILOMETERS



Hydrology from Levings (1982c) and W.A. Van Voast; Montana Bureau of Mines and Geology, written communication (1983).

Base from U.S. Geological Survey State base maps 1:500,000; Montana 1966, Wyoming 1964

EXPLANATION

—— 3400 —— Fort Union Formation

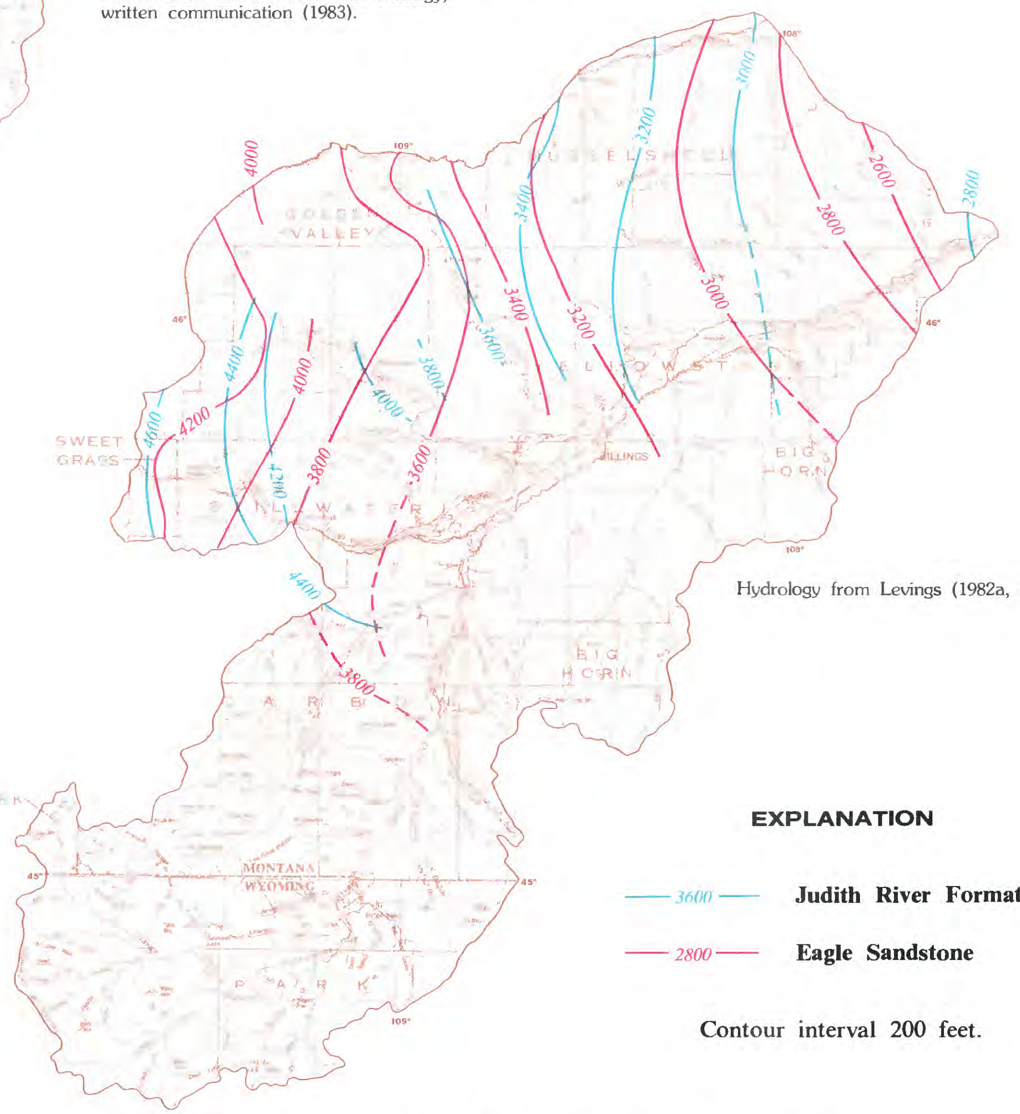
—— 3300 —— Fox Hills - lower Hell Creek aquifer

Contour intervals 100 and 200 feet.

Figure 9.2-1 Potentiometric surfaces of the Fort Union Formation and Fox Hills-lower Hell Creek aquifer.

EXPLANATION
For All Figures

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



Hydrology from Levings (1982a, 1982d).

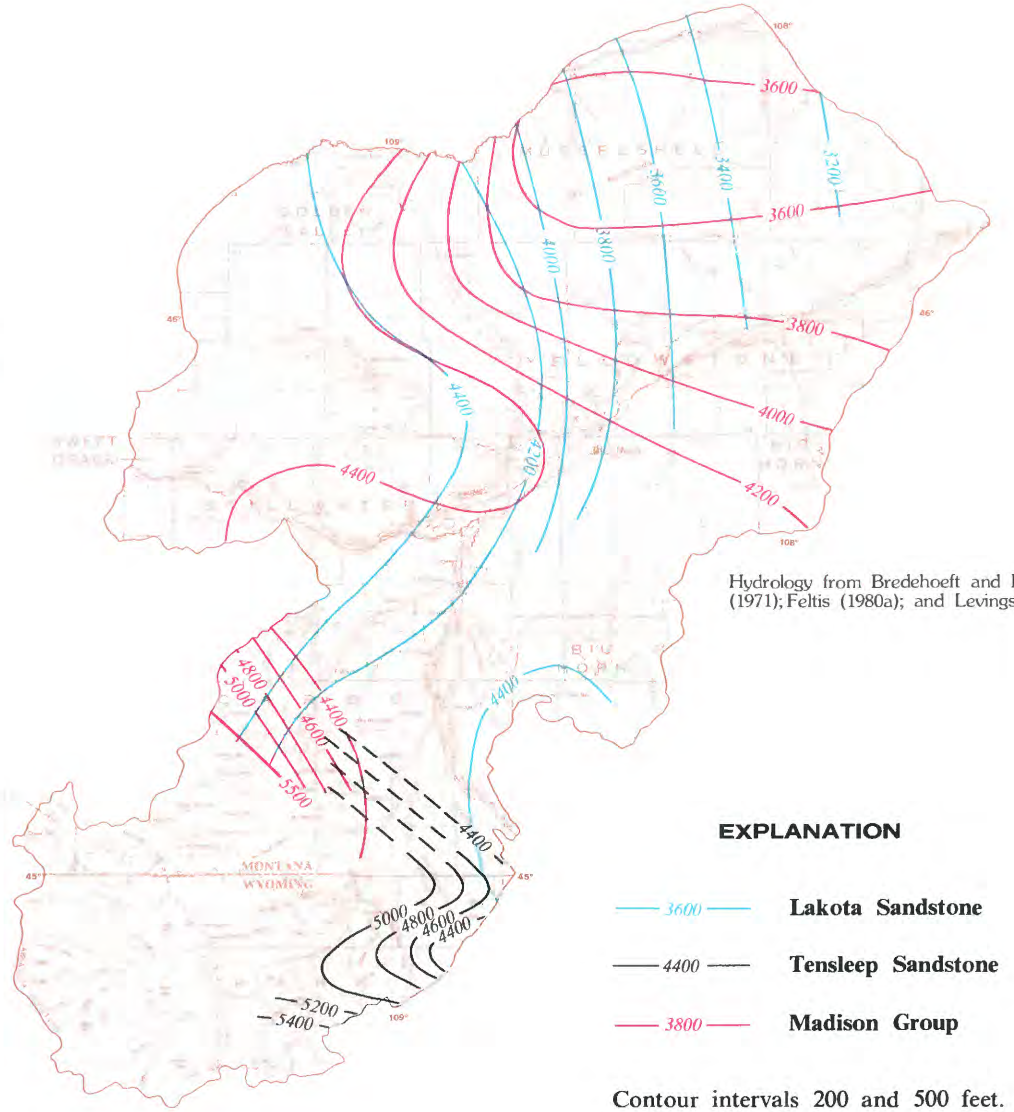
EXPLANATION

—— 3600 —— Judith River Formation

—— 2800 —— Eagle Sandstone

Contour interval 200 feet.

Figure 9.2-2 Potentiometric surfaces of the Judith River Formation and Eagle Sandstone.



Hydrology from Bredehoeft and Bennett (1971); Feltis (1980a); and Levings (1982b).

EXPLANATION

—— 3600 —— Lakota Sandstone

—— 4400 —— Tensleep Sandstone

—— 3800 —— Madison Group

Contour intervals 200 and 500 feet.

Figure 9.2-3 Potentiometric surfaces of the Lakota Sandstone, Tensleep Sandstone, and Madison Group.

Chemical Quality Diverse

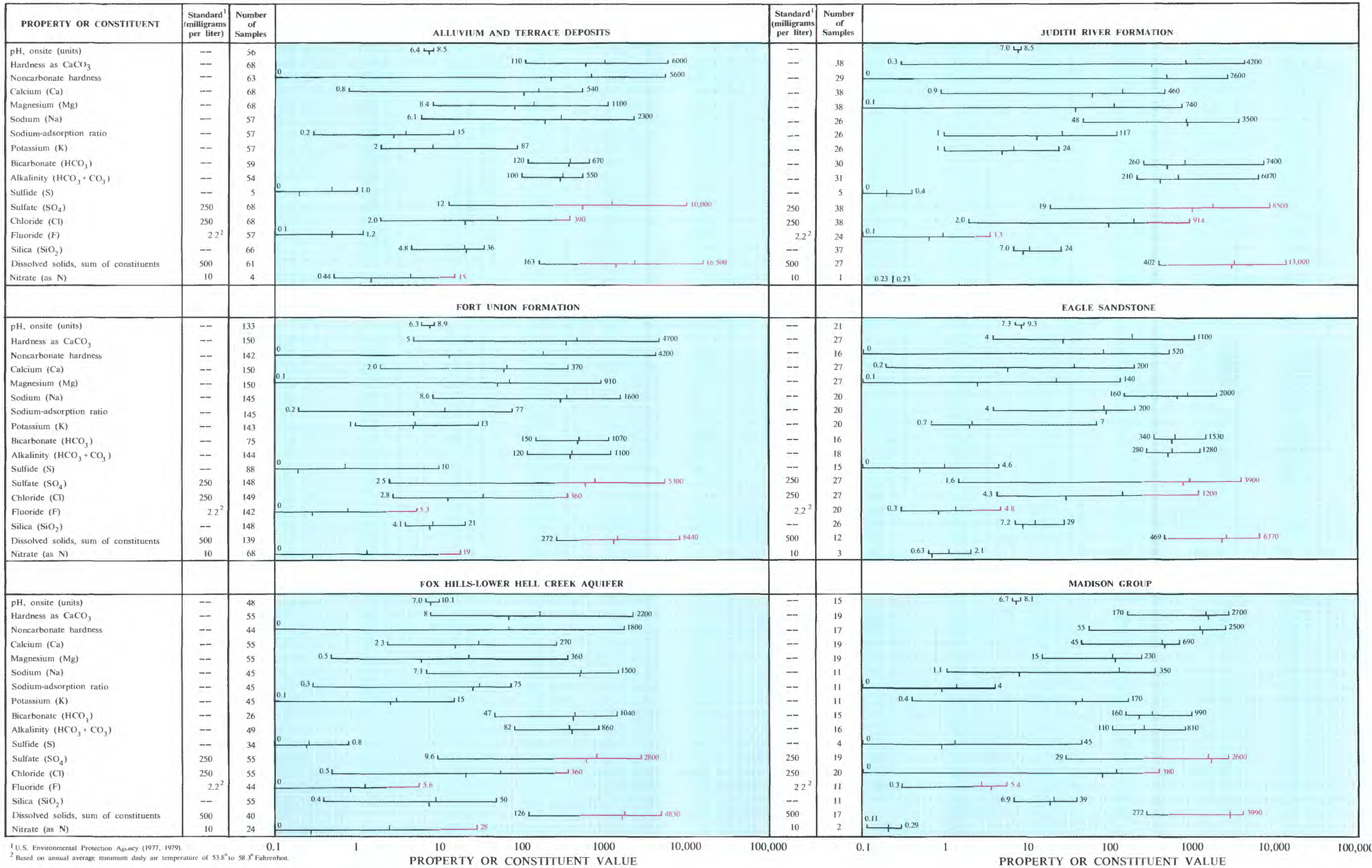
Ground water has a large range in dissolved-solids concentration; some concentrations are in excess of drinking water standards

Dissolved-solids concentration in all aquifers in Area 48 differs greatly with values ranging from 126 to 16,500 milligrams per liter (fig. 10.1-1). Average dissolved-solids concentration for various aquifers ranges from 1,570 to 3,300 milligrams per liter. Range in dissolved-solids concentration generally decreases as the age of the aquifer increases.

Sodium and sulfate are the primary constituents in water from most aquifers in the area. In the Madison Group, however, calcium and magnesium are the dominant ions. Average hardness as calcium carbonate in all aquifers ranges from 170 to 1,500 milligrams per liter, with most waters being in the "hard" to "very hard" range (Hem, 1970, p. 225). A few aquifers in local areas contain water that is classified as "soft". The maximum range in hardness, 110 to 6,000 milligrams per liter, is in water from the alluvium and minimum range in hardness, 4 to 1,100 milligrams per liter, occurs in water from the Eagle Sandstone.

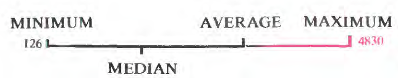
The pH in ground water of the area is generally in the near-neutral range. Median pH of water in all aquifers ranges from 7.3 to 8.5. Minimum pH of 6.3 occurs in water from the Fort Union Formation and maximum pH of 10.1 occurs in water from the Fox Hills-lower Hell Creek aquifer.

Most ground water in the area contains some constituent concentrations in excess of primary or secondary standards for drinking water established by the U.S. Environmental Protection Agency (1977, 1979). Maximum values for chloride in some water from all aquifers exceed the standard. Maximum values for fluoride exceed the standard in all aquifers except alluvium, and maximum values for nitrate are exceeded in the alluvium, Fort Union Formation, and Fox Hills-lower Hell Creek aquifer. Maximum, average, and median values for sulfate and dissolved solids in water from all aquifers exceed the standards. Dissolved-solids and sodium concentrations of most ground water are in excess of maximums recommended for irrigation waters by the U.S. Salinity Laboratory Staff (1954).



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

EXPLANATION



PROPERTY OR CONSTITUENT VALUE--Red denotes values exceeding drinking-water standard established by U.S. Environmental Protection Agency (1977, 1979). Values are reported in milligrams per liter, except as indicated.

Figure 10.1-1 Summary of selected water-quality properties and constituents in ground water.

Trace-Element Concentrations Generally Uniform from Aquifer to Aquifer

Concentrations of most trace elements are less than established standards for drinking water.

Variation in concentration of most trace elements commonly is not large from aquifer to aquifer (fig. 10.2-1). Variation of median concentration for most trace elements is less than three-fold. The variation in selenium and strontium is most pronounced. Median concentrations for selenium range from 0 to 140 micrograms per liter, whereas median concentration for strontium range from 340 to 8,900 micrograms per liter. The larger concentrations are not limited to any particular aquifer. Where significant variation exists, concentrations generally are larger in the sandstone aquifers.

Concentrations of trace elements commonly are less than the maximums for primary and secondary drinking water standards established by the U.S. Environmental Protection Agency (1977, 1979). Some samples, however, contain concentrations in excess of the standards. Maximum concentrations of iron and manganese in water sampled from all aquifers exceeded the standards. Maximum values for selenium exceed the standards in water collected from the Fox Hills-lower Hell Creek aquifer, Judith River Formation, and Eagle Sandstone. All samples collected from the alluvium exceeded the standard for selenium. Maximum and median concentrations for lead in water collected from the Fort Union Formation and all lead concentrations in water from the alluvium were in excess of the standard. Samples collected from the alluvium and Fort Union Formation may have exceeded the standard for cadmium, although exceedance cannot be verified because the detection limit was greater than the standard.

ALLUVIUM AND TERRACE DEPOSITS

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Aluminum (Al)	---	6	50	300
Arsenic (As)	50	4	< 20	< 20
Boron (B)	---	16	10	800
Cadmium (Cd)	10	4	< 20	< 20
Chromium (Cr)	50	4	< 20	30
Copper (Cu)	1,000	4	20	40
Iron (Fe)	300	53	< 10	1600
Lead (Pb)	50	4	130	5000
Lithium (Li)	---	41	40	840
Manganese (Mn)	50	45	0	980
Molybdenum (Mo)	---	2	< 20	< 20 (med=<20)
Nickel (Ni)	---	4	70	140
Selenium (Se)	10	7	11	1800
Strontium (Sr)	---	7	1300	15,000
Zinc (Zn)	5,000	6	30	70

FORT UNION FORMATION

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Aluminum (Al)	---	8	< 50	< 50
Arsenic (As)	50	10	< 2	< 2 (med=<2)
Barium (Ba)	1,000	3	70	210
Boron (B)	---	14	< 20	170
Cadmium (Cd)	10	10	< 20	< 20
Chromium (Cr)	50	10	< 20	< 20
Copper (Cu)	1,000	10	< 20	< 20
Iron (Fe)	300	143	< 10	7400
Lead (Pb)	50	10	< 50	80
Lithium (Li)	---	32	< 10	150
Manganese (Mn)	50	138	0	200
Molybdenum (Mo)	---	10	< 20	< 20 (med=<20)
Nickel (Ni)	---	10	10	70
Selenium (Se)	10	12	< 2	4
Silver (Ag)	50	10	< 20	< 20
Strontium (Sr)	---	15	300	7800
Zinc (Zn)	5,000	10	20	1100

FOX HILLS–LOWER HELL CREEK AQUIFER

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Barium (Ba)	1,000	9	7	170
Boron (B)	---	13	< 20	810
Iron (Fe)	300	51	< 10	1700
Lithium (Li)	---	20	< 10	110
Manganese (Mn)	50	45	0	130
Selenium (Se)	10	9	0	11
Strontium (Sr)	---	14	40	4200

JUDITH RIVER FORMATION

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Aluminum (Al)	---	2	50	50
Barium (Ba)	1,000	5	70	200
Boron (B)	---	6	200	2300
Iron (Fe)	300	35	< 10	5200
Lithium (Li)	---	22	< 10	770
Manganese (Mn)	50	26	0	80
Molybdenum (Mo)	---	2	20	20
Selenium (Se)	10	8	0	190
Strontium (Sr)	---	8	300	6000

EAGLE SANDSTONE

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Barium (Ba)	1,000	8	< 50	330
Boron (B)	---	12	220	1600
Iron (Fe)	300	24	< 10	2200
Lithium (Li)	---	17	40	170
Manganese (Mn)	50	20	< 10	140
Selenium (Se)	10	9	0	11
Strontium (Sr)	---	12	110	4000

MADISON GROUP

CONSTITUENT	Standard[1] (micrograms per liter)	Number of samples	Minimum	Maximum
Aluminum (Al)	---	6	10	100 (med=<100)
Arsenic (As)	50	4	1	1
Barium (Ba)	1,000	4	< 100	200
Boron (B)	---	10	10	2800
Cadmium (Cd)	10	2	< 2	< 2
Chromium (Cr)	50	4	< 2	20
Copper (Cu)	1,000	4	< 20	< 20
Iron (Fe)	300	8	< 10	9000
Lead (Pb)	50	4	< 2	4
Lithium (Li)	---	7	< 10	960
Manganese (Mn)	50	8	< 1	490
Molybdenum (Mo)	---	5	< 1	6
Selenium (Se)	10	5	0	2
Strontium (Sr)	---	7	240	9500
Zinc (Zn)	5,000	5	< 10	30 (med=<10)

CONSTITUENT VALUE (0.1 – 1 – 10 – 100 – 1000 – 10,000 – 100,000)

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

EXPLANATION

MINIMUM < 1 — MEDIAN — MAXIMUM 490

CONSTITUENT CONCENTRATION–Red denotes values exceeding drinking-water standard established by U.S. Environmental Protection Agency (1977, 1979). Constituents are dissolved and constituent values are reported in micrograms per liter. <, less than; med, median

Figure 10.2-1 Summary of selected trace elements in ground water.

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

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

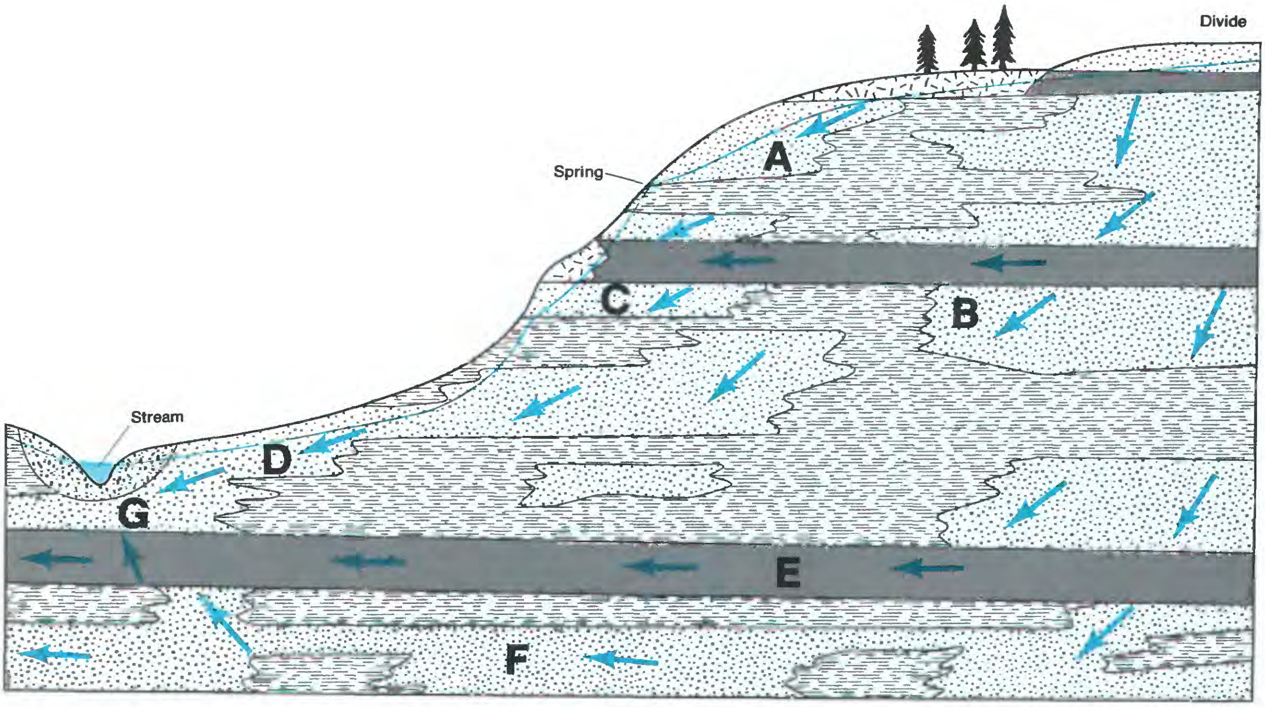
Geochemical changes occur within the ground- water system as water flows within the aquifer from areas of recharge to areas of discharge. Aquifer mineralogy and solution chemistry are largely responsible for the concentrations of solutes, although, time, distance of travel, and in some instances, microbiological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

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

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

A conceptual geochemical model of the precesses occurring in the Fort Union Formation (fig. 10.3-1) was developed by Lee (1980) from probable mineral- water interaction, aqueous chemistry, and geologic and hydrologic principles. The model was developed for an area in southeastern Montana that is geologically and hydrologically similar to the Bull Mountains basin. Geochemical data from the Fort Union Formation in the vicinity of Red Lodge, Montana, indicate that the model may also be applicable to the Tertiary aquifers in the northern part of the Bighorn basin. The geochemical processes described by the model generally are restricted to localized flow systems where the distance from recharge to discharge is less than about 20 miles.

At point A (fig. 10.3-1), chemical composition would represent recharge water dominated by magnesium, calcium, and bicarbonate, with significant concentrations of sodium and sulfate, but having a small dissolved-solids concentration. As the water percolates through the system, sodium and sulfate enrichment results in larger percentages of sodium, sulfate, and dissolved solids at B. At C, chemical composition would represent a mixture of an intermediate sodium and sulfate water and recharge water that has percolated through a very permeable clinker facies. The mixing results in a solution containing a smaller dissolved-solids concentration than at B, with a chemical composition approaching that for recharge water; that is, lesser percentage of sodium and sulfate. At D, chemical composition is predominately sodium and sulfate (developed by sodium and sulfate enrichment); the water may discharge as base flow to the stream. In the deep coal bed at E, sulfate reduction may dominate the geochemistry of the water, producing a sodium bicarbonate quality that is almost indistinguishable from water qualities of deeper aquifers. At F, water quality of the deeper regional systems (whose chemical character probably developed similar to water at E) would be dominated by sodium and bicarbonate. Finally at G, upward leakage would result in water that is a composite of waters from D, E, and F. Chemical character of water G would be determined by the dominant water supply from D, E, or F.



Modified from Lee (1980).

EXPLANATION

SANDSTONE

SHALE

COAL

ALLUVIUM

CLINKER

WATER TABLE

DIRECTION OF WATER MOVEMENT

WATER-QUALITY ZONE

A Initial recharge area

B Shallow aquifer downgradient from initial recharge area

C Shallow aquifer underlying secondary recharge area.

D Shallow aquifer near discharge area

E Deep coal-bed aquifer

F Deep regional or subregional aquifer

G Zone of mixing of waters from deep and shallow aquifers

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

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

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

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

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

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

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

NAWDEX Simplifies Access to Water Data

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

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

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water-Data Index (fig. 11.2-2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A Water-Data Sources Directory (fig. 11.2-3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs incurred by NAWDEX in the course of providing services. In all instances, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and when costs are anticipated to be substantial.

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

Program Office
National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, Virginia 22092
Telephone: (703) 860-6031
FTS 928-6031
Hours: 7:45-4:15 Eastern Time

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

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

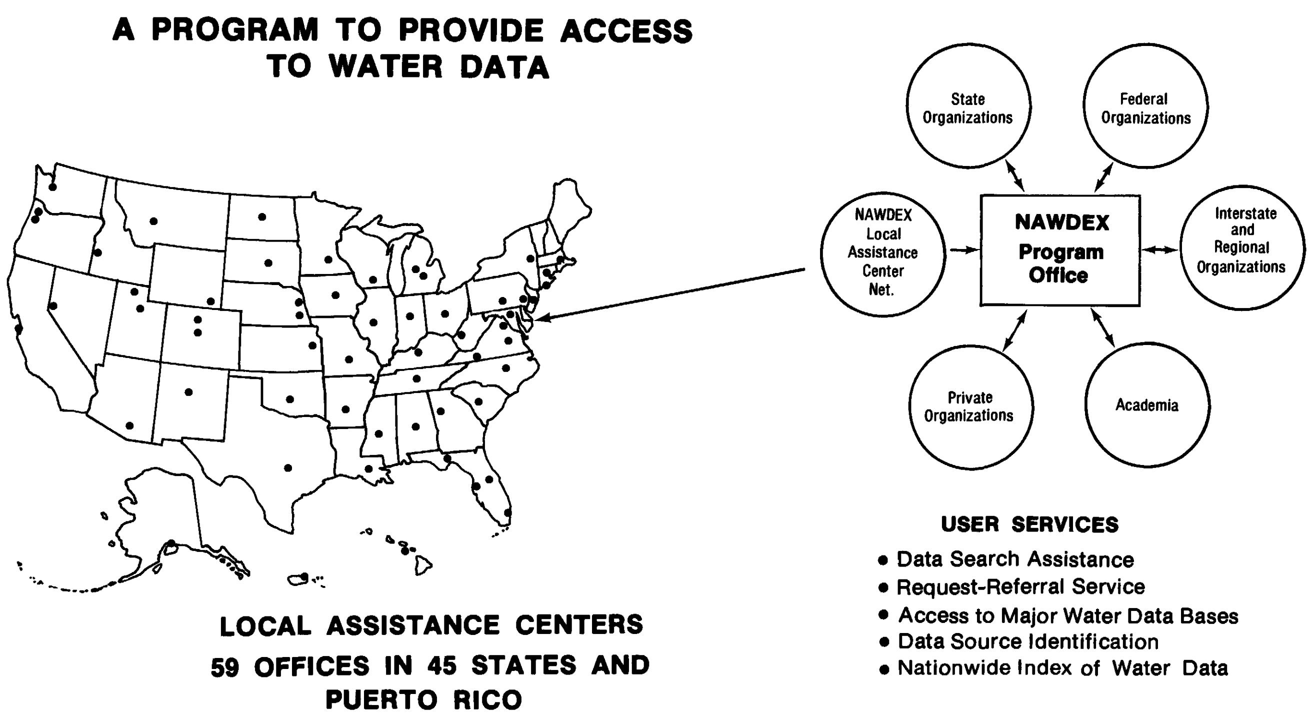


Figure 11.2-1 Access to water data.

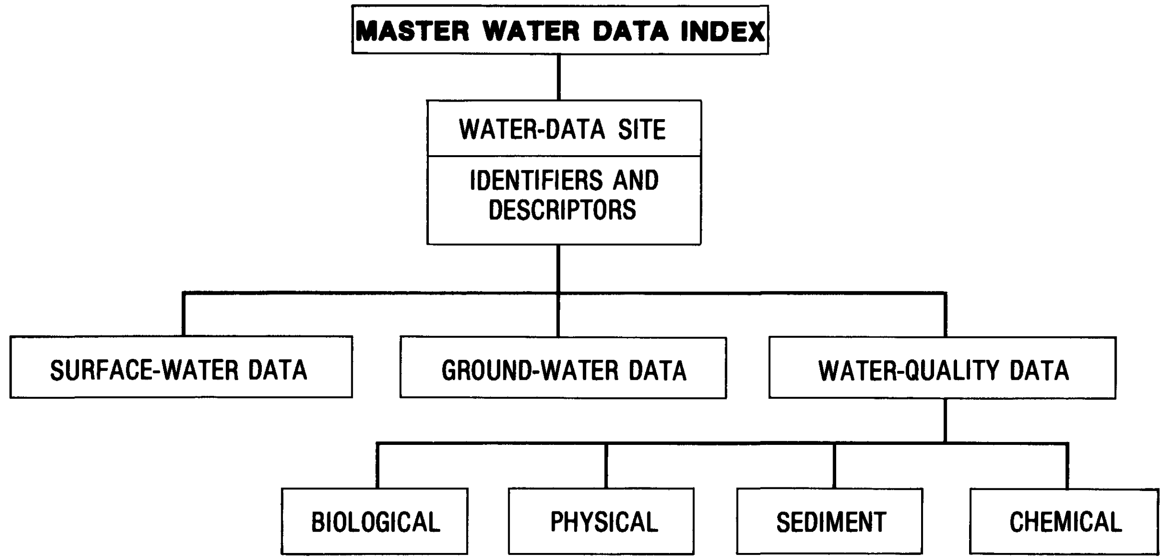


Figure 11.2-2 Master Water-Data Index.

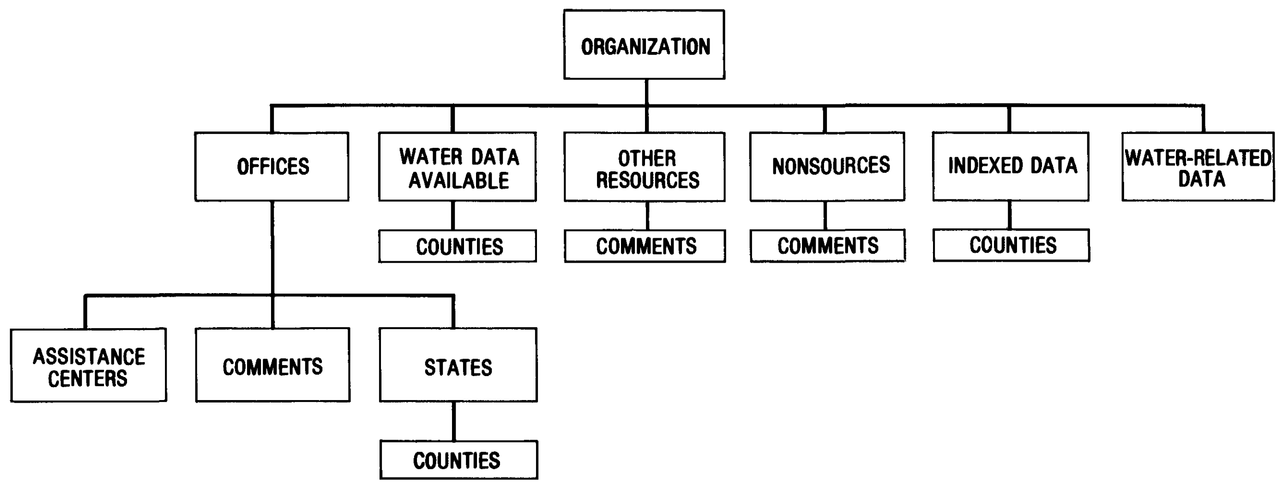


Figure 11.2-3 Water-Data Sources Directory.

WATSTORE Automated Data System

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

The National Water Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide 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
or
U.S. Geological Survey
Water Resources Division
P.O. Box 1125
Cheyenne, WY 82003

The Geological Survey currently (1983) collects data at about 17,000 stage or streamflow-gaging stations, 5,200 surface-water-quality stations, 27,000 water-level observation wells, and 7,400 ground-water-quality monitoring wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of diversified data, both current and historical, are amassed by the Survey's data-collection activities.

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

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

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

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

Water-Quality File: Results of more than 1.4 million analyses of water samples are contained in this file. These analyses contain data for as many as 185 different constituents 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 temperature data are examples of the types of data stored in the Unit-Values File.

Ground-Water Site-Inventory File: This file is maintained within WATSTORE independent of the files discussed above, but it is cross-referenced to the Water-Quality File and the Daily-Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time onsite measurements such as water temperature. The file is designed to accommodate 225 data elements and currently contains data for nearly 700,000 sites.

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

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

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

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stage, conductivity, water temperature, turbidity, wind direction, and chloride concentration. Data are recorded on a 16-channel paper tape, which is removed from the recorder and transmitted via telephone lines to the receiver at Reston, Virginia. The data are 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 radios are used as the communication link to the satellite. About 500 data-relay stations currently (1983) are being operated by the Water Resources Division.

Central-Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colorado, and Atlanta, Georgia, analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform chemical analyses ranging from determinations of simple inorganic 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 data tables to complex statistical analyses. A minimal fee, plus the actual computer cost incurred in producing a desired product, is charged to the requester.

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

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

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package 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 off-line plotters available at the central computer site. Plots that can be obtained include hydrographs, frequency distribution curves, X-Y point plots, contour plots, and three-dimensional plots.

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

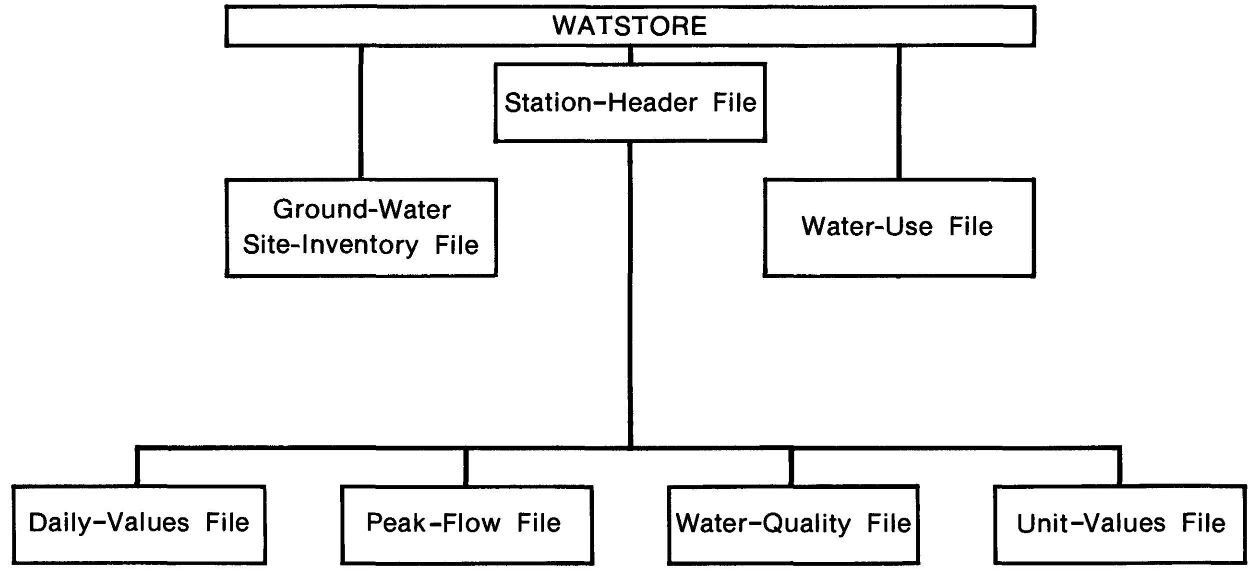


Figure 11.3-1 Index to file-stored data.

Water Data Indexed for Coal Provinces

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

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

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

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

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

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

U.S. Geological Survey
Water Resources Division
428 Federal Building
Drawer 10076
Helena, MT 59626
Telephone (406) 449-5496
FTS 585-5496
or
U.S. Geological Survey
Water Resources Division
J. C. O'Mahoney Federal Center
Room 4007, P.O. Box 1125
2120 Capitol Avenue
Cheyenne, WY 82003
Telephone (307) 778-2220, Ext. 2153
FTS 328-2153

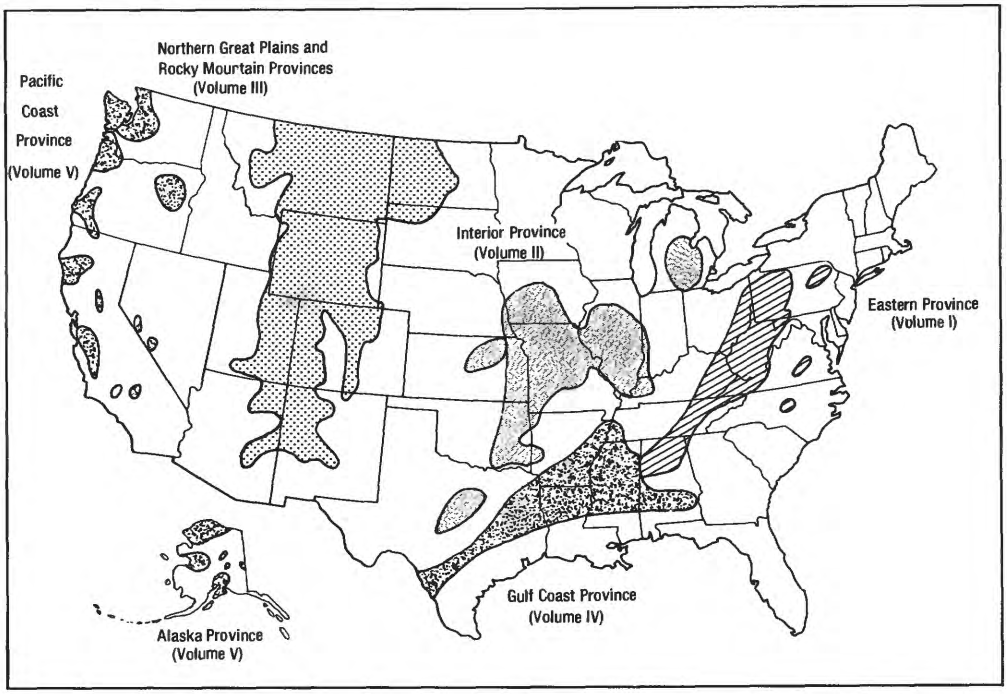


Figure 11.4-1 Index volumes and related provinces.

STORET Water-Quality Data Base System

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

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

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

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

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

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

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

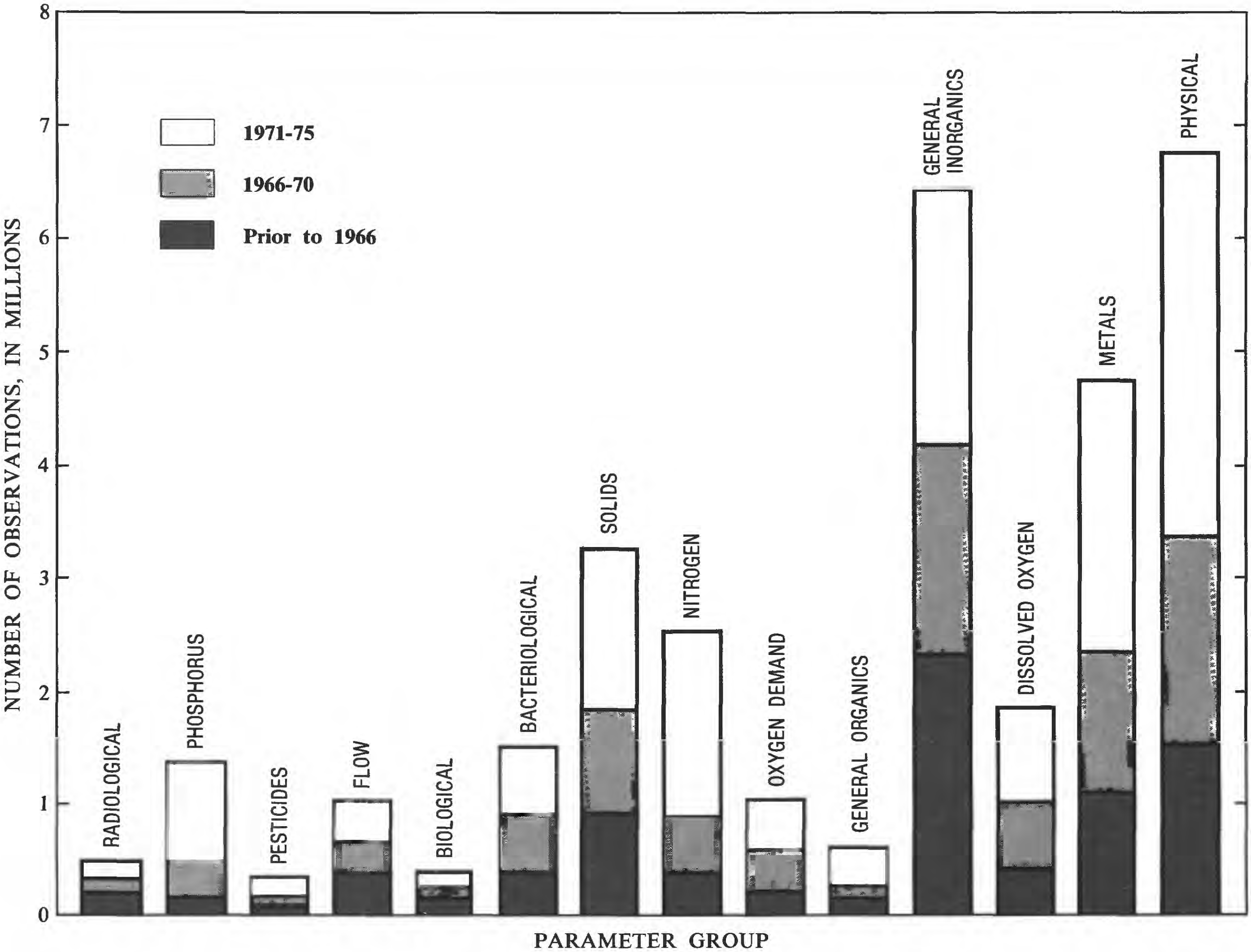


Figure 11.5-1 Parameter groups and number of observations in the STORET Water-Quality File.

12.0 DESCRIPTION OF STREAMFLOW AND WATER-QUALITY STATIONS AND SITES

12.0 *Description of streamflow and water-quality stations and sites*

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

Number used in report	U.S. Geological Survey station or site 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	06125680	---	Big Coulee Creek tributary nr Cushman, Mont.	1.23	---	---	1974-	---
2	06125700	---	Big Coulee Creek nr Lavina, Mont.	232	1957-72	1906	---	---
3	06126000	---	Musselshell River at Lavina, Mont.	2,928	1906	---	---	---
4	---	4617571084659	Musselshell River at Bundy, ab Roundup, Mont.	---	---	---	---	1979B
5	06126450	---	Rehder Creek nr Klein, Mont.	23.1	---	1978-81[1]	---	---
6	---	4619131082908	Halfbreed Creek low flow site No. 1 at Klein, Mont.	---	---	1978	---	1978C
7	---	4621091082910	Halfbreed Creek low flow site No. 2 at Klein, Mont.	---	---	1978	---	1978C
8	---	4622271083102	Halfbreed Creek low flow site No. 3 at Klein, Mont.	---	---	1978	---	1978C
9	06126470	---	Halfbreed Creek nr Klein, Mont.	53.2	1978-	---	---	1978-81CS
10	---	4624451083313	Halfbreed Creek low flow site No. 5 at Klein, Mont.	---	---	1978	---	1978C
11	---	4625361083419	Halfbreed Creek low flow site No. 6 at Roundup, Mont.	---	---	1978	---	1978C
12	06126500	---	Musselshell River nr Roundup, Mont.	4,023	1946-	1924-25	---	1978-81CS
13	06127150	---	East Parrot Creek nr Roundup, Mont.	20.2	---	1978-81	---	1978-81CS
14	06127160	---	West Parrot Creek nr Roundup, Mont.	20.5	---	1978-81	---	1978-81CS
15	06127200	---	Musselshell River tributary nr Musselshell, Mont.	10.8	---	---	1963-77	---
16	06127300	---	Fattig Creek nr Delphia, Mont.	22.9	---	1978-81	---	1978-81CS
17	---	4630291081257	Musselshell River at Delphia, below Roundup, Mont.	---	---	---	---	1979B
18	06127500	---	Musselshell River at Musselshell, Mont.	4,568	1928-32; 1945-79; 1983-	---	---	---
19	06201650	---	Work Creek nr Reed Point, Mont.	32.5	---	---	1959-73	---
20	06201700	---	Hump Creek nr Reed Point, Mont.	7.61	---	---	1959-	---
21	---	4541121092615	Yellowstone River nr Reed Point, Mont.	---		1969-70	---	---
22	06201750	---	Berry Creek nr Columbus, Mont.	23.5	---	---	1959-73	---
23	---	4537421091516	Yellowstone River nr Columbus, Mont.	---	---	1980	---	---
24	---	4535081090517	Yellowstone River at Westover Island, Mont.	---	---	1975	---	---
25	06205100	---	Allen Creek nr Park City, Mont.	7.17	---	---	1961-	---
26	06205200	---	Yellowstone River at Laurel, Mont.	8,189	---	---	---	1974-79CBS
27	06205450	---	Clarks Fork Yellowstone River at Montana-Wyoming State line, nr Cooke City, Mont.	---	---	1972	---	1975- CS
28	06205500	---	Clarks Fork Yellowstone River above Squaw Creek, nr Painter, Wyo.	---	1945-51	---	---	---

12.0 *Description of streamflow and water-quality stations and sites*--Continued

Number used in report	U.S. Geological Survey station or site number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
29	06206000	---	Clarks Fork Yellowstone River bl Crandall Creek nr Painter, Wyo.	---	1929-32; 1949-57	---	---	---
30	06206500	---	Sunlight Creek near Painter, Wyo.	135	1929-32; 1945-71; 1974	---	---	---
31	06206550	---	Sunlight Creek nr Clark, Wyo.	---	---	1972	---	1972S
32	06206570	---	Clarks Fork Yellowstone River bl Falls Creek nr Clark, Wyo.	---	---	---	---	1971T
33	06206600	---	Clarks Fork Yellowstone River ab Paint Creek, nr Clark, Wyo.	---	---	1974; 1975	---	1975CS
34	---	4450061091220	Paint Creek at mouth, nr Clark, Wyo.	---	---	1974; 1975	---	---
35	06206650	---	Pat O'Hara Creek nr Clark, Wyo.	---	---	1972	---	1972S
36	---	4451001091020	Pat O'Hara Creek at mouth, nr Clark, Wyo.	---	---	1974; 1975	---	---
37	---	4453201090703	Clarks Fork Yellowstone River at State Highway 120, nr Clark, Wyo.	---	---	1974; 1975	---	---
38	06207000	---	Clarks Fork Yellowstone River nr Clark, Wyo.	---	1918-24	---	---	---
39	06207500	---	Clarks Fork Yellowstone River nr Belfry, Mont.	1,154	1921-	1912	---	1965- CS
40	---	4448441085837	Big Sand Coulee at county bridge 8 miles northwest of Ralston, Wyo.	---	---	1963	---	---
41	---	4449381085836	Big Sand Coulee at county bridge 9.5 miles northwest of Ralston, Wyo.	---	---	1962	---	---
42	06207507	---	Big Sand Coulee ab State ditch, nr Badger Basin, Wyo.	---	1973-75	---	---	1973-75S
43	---	4457581090338	Big Sand Coulee at State Highway 120, nr Badger Basin, Wyo.	---	---	1963; 1967	---	---
44	---	4459221090334	Big Sand Coulee bl Clark Ditch wasteway, nr Badger Basin, Wyo.	---	---	1967	---	---
45	06207510	---	Big Sand Coulee at Wyoming-Montana State line, nr Chance, Mont.	134	1973-81	1934-41; 1943-48; 1962-63; 1971	---	1973-81CS
46	---	4500381090337	Big Sand Coulee at mouth nr Chance, Mont.	---	---	1967	---	---
47	---	4501431090337	Clarks Fork Yellowstone River bl Big Coulee, nr Chance, Mont.	---	---	1962	---	---
48	---	4506471090044	Clarks Fork Yellowstone River ab Bear Creek, nr Belfry, Mont.	---	---	1971	---	---
49	---	4506561091441	South Fork Bear Creek ab sink (No. 1), nr Bearcreek, Mont.	---	---	1965	---	---
50	---	4507041091431	South Fork Bear Creek 1 mile bl No. 1 (No. 2), at Bearcreek, Mont.	---	---	1965	---	---
51	---	4507411091347	South Fork Bear Creek ab intake (No. 3), at Bearcreek, Mont.	---	---	1965	---	---
52	---	4508421090019	Bear Creek at mouth nr Belfry, Mont.	---	---	1971	---	---

12.0--*Description of streamflow and water-quality stations and sites*--Continued

Number used in report	U.S. Geological Survey station or site number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
53	06207520	---	Silver Tip Creek bl Amoco dam, nr Chance, Mont.	---	---	---	---	1972C
54	06207523	---	Silver Tip Creek bl Sinclair oil field, nr Chance, Mont.	---	---	---	---	1972C
55	06207530	---	Silver Tip Creek ab Gobblers Draw, nr Chance, Mont.	---	---	---	---	1971C
56	06207540	---	Silver Tip Creek nr Belfry, Mont.	87.6	1967-75	---	---	1969-75CS
57	---	4510481085930	Silver Tip Creek at mouth, nr Belfry, Mont.	---	---	1971	---	---
58	---	4511331085907	Dry Creek at mouth, nr Belfry, Mont.	---	---	1971	---	---
59	---	4513051085718	Clarks Fork Yellowstone River ab Cottonwood Creek, at Bridger, Mont.	---	---	1971	---	---
60	---	4514091085527	Cottonwood Creek at mouth, nr Bridger, Mont.	---	---	1971	---	---
61	06207600	---	Jack Creek tributary nr Belfry, Mont.	.85	---	---	1975-	---
62	---	4515421085431	Bridger Creek at mouth, nr Bridger, Mont.	---	---	1971	---	---
63	---	4517471085356	Clarks Fork Yellowstone River at Bridger, Mont.	---	---	1905	---	---
64	---	4520191085458	Sand Creek at mouth, nr Bridger, Mont.	---	---	1971	---	---
65	---	4523111085409	Clarks Fork Yellowstone River ab Bluewater Creek, nr Fromberg, Mont.	---	---	1971	---	---
66	---	4520001084952	South Fork Bluewater Creek nr Bridger, Mont.	---	---	1960	---	---
67	06207700	---	North Fork Bluewater Creek nr Bridger, Mont.	---	---	1960-65; 1968-70	---	1960-70CS
68	06207800	---	Bluewater Creek nr Bridger, Mont.	28.1	1960-70	---	---	1960-70CS
69	06207850	---	Bluewater Creek at Sanford Ranch, nr Bridger, Mont.	43.9	---	1960-70	---	1960-70CS
70	06207870	---	Bluewater Creek nr Fromberg, Mont.	46.6	---	1960-70	---	1960-70CS
71	06207900	---	Bluewater Creek at Fromberg, Mont.	53.2	1961-64	1960-61; 1965; 1969-70	---	1960-70; 1980CS
72	06208000	---	Clarks Fork Yellowstone River at Fromberg, Mont.	1,940	1905-13	---	---	---
73	---	4526501085148	Elbow Creek at mouth, nr Edgar, Mont.	---	---	1971	---	---
74	06208500	---	Clarks Fork Yellowstone River at Edgar, Mont.	2,032	1921-69	---	---	1964-65; 1972-73CS
75	---	4528191084956	Fivemile Creek nr Edgar, Mont.	---	---	1971	---	---
76	06208800	---	Clarks Fork Yellowstone River nr Silesia, Mont.	2,093	1969-	1955;	---	1977- C
77	06209010	---	Rock Creek bl Glacier Lake, near Red Lodge, Mont.	3.89	1960-64	---	---	---
78	---	4505161093142	Lake Creek (Fork) at Keyser Lake outlet, nr Red Lodge, Mont.	---	---	1920	---	---
79	---	4505031093045	Lake Creek bl Black Canyon, nr Red Lodge, Mont.	---	---	1920	---	---

12.0--*Description of streamflow and water-quality stations and sites*--Continued

Number used in report	U.S. Geological Survey station or site number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
80	06209500	---	Rock Creek nr Red Iodge, Mont.	124	1932; 1934-82	---	---	---
81	06210000	---	West Fork Rock Creek bl Basin Creek, nr Red Lodge, Mont.	63.1	1937-56	---	---	---
82	06210500	---	West Fork Rock Creek nr Red Lodge, Mont.	66.9	1932; 1934-44	1912; 1914-16; 1921; 1944-47	---	---
83	---	4509291091605	West Fork Rock Creek at mouth, nr Red Lodge, Mont.	---	---	1972	---	---
84	---	4510451091444	Rock Creek at Red Lodge, Mont.	---	---	1934; 1937; 1940-42	---	---
85	---	4521401090926	Rock Creek at Roberts, Mont.	---	---	1937; 1940-42	---	---
86	---	4522281090844	Clear Creek nr Roberts, Mont.	---	---	1972	---	---
87	---	4527281090446	Rock Creek at Boyd, Mont.	---	---	1937; 1940-41	---	---
88	06211000	---	Red Lodge Creek ab Cooney Reservoir, nr Boyd, Mont.	143	1937-	---	---	---
89	06211500	---	Willow Creek nr Boyd, Mont.	53.3	1937-	---	---	---
90	06212500	---	Red Lodge Creek bl Cooney Reservoir, nr Boyd, Mont.	210	1937-	---	---	---
91	06213000	---	Red Lodge Creek nr Boyd, Mont.	234	1932; 1934-36	1937	---	---
92	06213500	---	Rock Creek at Joliet, Mont.	539	1945-53	1920; 1937; 1940-41	---	---
93	06214000	---	Rock Creek at Rockvale, Mont.	569	1920-22; 1934-40	1940-42; 1971	---	---
94	---	4533191084901	Cottonwood Creek nr Silesia, Mont.	---	---	1971	---	---
95	06214050	---	Clarks Fork Yellowstone River nr Laurel, Mont.	2,783	---	1973	---	1969-73CB
96	06214100	---	Yellowstone River nr Laurel, Mont.	11,060	---	---	---	1969-72CB
97	06214150	---	Mills Creek at Rapalje, Mont.	3.32	---	---	1974-	---
98	---	4543391083155	Blue Creek nr Billings, Mont.	---	---	1969; 1978	---	---
99	---	4547511082809	Yellowstone River at East Bridge, nr Billings, Mont.	---	---	1979	---	1979B
100	06214500	---	Yellowstone River at Billings, Mont.	11,795	1904-05; 1928-	---	---	1950-58;CBS 1963-
101	06214502	---	Yellowstone River at Billings, Mont.	11,795	---	---	---	1969-72C
102	---	4547581082819	Alkali Creek at Billings, Mont.	---	---	1968	---	---
103	---	4519371083310	Pryor Creek at old Wilson Ranch, nr Pyror, Mont.	---	---	1970	---	---
104	06215000	---	Pryor Creek ab Pryor, Mont.	39.6	1921-24; 1966-74	---	---	---
105	---	4524111083339	Pryor Creek nr Pryor, Mont.	---	---	1911	---	---
106	06215500	---	Lost Creek nr Pryor, Mont.	9.72	1921-24	---	---	---
107	06216000	---	Pryor Creek at Pryor, Mont.	117	1921-24; 1967-	---	---	1980-C
108	06216200	---	West Wets Creek nr Billings, Mont.	8.80	---	---	1955-	---

12.0- *Description of streamflow and water-quality stations and sites*--Continued

Number used in report	U.S. Geological Survey station or site number		Name	Drainage area (square miles)	Period and type of record, by water year: Daily discharge	Miscellaneous-measurement discharge	Crest-stage discharge	Water quality
109	06216300	---	West Buckeye Creek nr Billings, Mont.	2.64	---	1978	1955-73; 1978	---
110	06216500	---	Pryor Creek nr Billings, Mont.	440	1911-24; 1938-53	1978	1955-73; 1978	---
111	06216900	---	Pryor Creek nr Huntley, Mont.	582	1979-	---	---	1980-C
112	---	4553141081809	Pryor Creek at I-94 crossing, nr Huntley, Mont.	---	---	1978	---	---
113	06217000	---	Pryor Creek at Huntley, Mont.	606	1904-16	1964; 1978	---	---
114	06217300	---	Twelvemile Creek nr Shepherd, Mont.	9.05	---	---	1973-	---
115	06217500	---	Yellowstone River at Huntley, Mont.	12,840	1907-16	1945; 1977-78	---	1951-52;CBS 1971-81
116	06217700	---	Crooked Creek tributary nr Shepherd, Mont.	7.21	---	---	1962-	---
117	---	4556131080459	Gravel Pit Coulee nr Worden, Mont.	---	---	1979	---	---
118	---	4559201075718	Lost Boy Creek at Pompeys Pillar, Mont.	---	---	1974-78	---	---
119	06217750	---	Fly Creek at Pompeys Pillar, Mont.	285	1968-81	---	---	1969-81C
120	06217800	---	Yellowstone River tributary No. 2 nr Pompeys Pillar, Mont.	.70	---	---	1962-73	---
121	06217950	---	Buffalo Creek nr Custer, Mont.	221	1980-	---	---	1980-C
122	06218000	---	Yellowstone River at Custer, Mont.	14,427	1906-07	1969	---	1969-70CB

[1] No flow for period of record.

13.0 LIST OF SELECTED REFERENCES

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

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geological Survey Professional Paper 174, 133 p.

Andrews, D. A., Pierce, W. G., and Eargle, D. H. 1947, Geologic map of the Big Horn Basin, Wyoming and Montana, showing terrace deposits and physiographic features: U.S. Geological Survey Oil and Gas Investigations Map 71, 1 sheet.

Averitt, Paul, 1975, Coal resources of the United States—January 1, 1974: U.S. Geological Survey Bulletin 1412, 131 p.

Bahls, Loren, Fillinger, Michael, Greene, Robert, Horpestad, Abraham, Ingman, Gary, and Weber, Erich, 1981, Biological water quality monitoring, Eastern Montana, 1979: Montana Department of Health and Environmental Sciences, 93 p.

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

Berryhill, H. L., Jr., Brown, D. M., Burns, R. N., and Combo, J. X., 1951, Coal resources map of Wyoming: U.S. Geological Survey Coal Investigations Map C6, 1 sheet.

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

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

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

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

Bredehoeft, J. D., and Bennett, R. R., 1971, Potentiometric surface of the Tensleep Sandstone in the Big Horn basin, west-central Wyoming: U.S. Geolgical Survey map, 1 sheet.

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

Calvert, W. R., 1916, Geology of the upper Stillwater basin, Stillwater and Carbon Counties, Montana with special reference to coal and oil: U.S. Geological Survey Bulletin 641-G, p. 199-214.

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

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

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

Darrow, George, 1954, The Bear Creek coal field, *in* Billings Geological Society Guidebook, Fifth annual field conference, Billings, p. 130-132.

Darton, N. H., 1907, Coals of Carbon County, Mont., *in* Contributions to economic geology 1906: U.S. Geological Survey Bulletin 316-C, p.174-193.

Dobbin, C. E., and Erdmann, C. E., 1955, Structure contour map of the Montana Plains: U.S. Geological Survey Oil and Gas Investigations Map OM-178B.

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

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

Edwards, M. D., 1980, Directory of assistance centers of the National Water Data Exchange (NAWDEX): U.S. Geological Survey Open-File Report 80-1193, 10 p.

Eldridge, G. H., 1894, A geologic reconnaissance in northwest Wyoming, with special reference to its economic resources: U.S. Geological Survey Bulletin 119, 72 p.

Ellis, A. J., and Meinzer, O. E., 1924, Ground water in Musselshell and Golden Valley Counties, Montana: U.S. Geological Survey Water-Supply Paper 518, 92 p.

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

_______1980b, Map showing dissolved-solids concentration of water in the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 1.

_______1980c, Map showing ratio of sodium, potassium, and chloride to dissolved-solids concentration in water of the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 2.

_______1980d, Map showing ratio of sulfate to total anions in water of the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrogeologic Map 3, sheet 3.

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

Feltis, R. D., and Wood, W. A., 1982, Selected hydrogeologic data from southern Sweet Grass County, south-central Montana: U.S. Geological Survey Open-File Report 82-265, 12 p.

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

Fisher, C. a., 1904, Coal of the Bighorn Basin in northwest Wyoming: *in* Contributions to economic geology, 1903: U.S. Geological Survey Bulletin 225-G, p. 345-362.

_______1906, Mineral resources of the Bighorn Basin [Wyoming], *in* Contributions to economic geology, 1905: U.S. Geological Survey Bulletin 285-F, p. 311-315.

Glass, G. B., 1981, Wyoming's energy minerals: The Interstate Oil Compact Commission Committee Bulletin, Vol. 23, No. 1, p. 47-52.

Glass, G. B., Westervelt, Katherine, and Oviatt, C. G., 1975, Coal mining in the Bighorn coal basin of Wyoming: Wyoming Geological Association Twenty-Seventh Annual Field Guidebook, p. 221-224.

Gosling, A. W., and Pashley, E. F., Jr. 1973, Water resources of the Yellowstone River Valley, Billings to Park City, Montana: U.S. Geological Survey Hydrologic Investigations Atlas HA-454, 2 sheets.

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

Guy, H. P., 1970, Fluvial sediment concepts: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chapter C1, 55 p.

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

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

Hopkins, W. B., 1976, Water-resources data for deep aquifers of eastern Montana: U.S. Geological Survey Water-Resources Investiga tions 76-40, 37 p.

Hutchinson, R. D., 1983, Change in the shallow ground-water resources of the Yellowstone River valley near Billings, Montana, August 1968-78: Montana Bureau of Mines and Geology Hydrogeologic map 6, 6 sheets.

Jackson, P. V., 1970, Summary of Montana rangeland resource program: Montana State Soil Conservation Committee, 106 p.

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

Keefer, W. R., 1974, Regional topography, physiography, and geology of the Northern Great Plains: U.S. Geological Survey Open-File Report 74-50, 17 p.

Knappen, R. S., and Moulton, G. F., 1931, Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater counties, Montana, *in* Contributions to economic geology 1930: U.S. Geological Survey Bulletin 822-A,p. 1-70.

Knapton, J. R., 1982, Quality of streams in the Bull Mountains region, south-central Montana: U.S. Geological Survey Water-Resources Investigations Report 82-2, 50 p.

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

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

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

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

Lee, R. W., 1980, Geochemistry of water in the Fort Union Formation of the northern Powder River Basin, southeastern Montana: U.S. Geological Survey Water-Supply Paper 2076, 17 p.

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

_______1981b, Selected drill-stem-test data from the northern Great Plains area of Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-326, 20 p.

_______1982a, Potentiometric-surface map of water in the Judith River Formation in the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 82-562, 1 sheet.

_______1982b, Potentiometric-surface map of water in the Lakota Formation and equivalent units in the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 82-563, 1 sheet.

_______1982c, Potentiometric-surface map of water in the Fox Hills-lower Hell Creek aquifer in the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 82-564, 1 sheet.

_______1982d, Potentiometric-surface map of water in the Eagle Sandstone and equivalent units in the northern Great Plains area of Montana: U.S. Geological Survey Open-File Report 82-565, 1 sheet.

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

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

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

Lowry, M. E., Lowham, H. W., and Lines, G. C., 1976, Water Resources of the Bighorn Basin, northwestern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-512, 2 sheets.

Lupton, C. T., 1911, The eastern part of the Bull Mountain coal field, Montana, *in* Contributions to economic geology 1909, Part II - Mineral fuels: U.S. Geological Survey Bulletin 431-B, p. 163-189.

Mackenzie, R. C., 1963, Retention of exchangeable ions by montmorillonite, *in* Rosenquist, I., and Graff-Petersen, Paul, eds., International Clay Conference, at Stockholm, Sweden, August 12-16: Oxford, New York, Pergamon Press [distributed by Macmillian Company], p. 183-193.

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

Mercer, M. W., and Morgan, C. O., 1982, Storage and retrieval of ground-water data at the U.S. Geological Survey: U.S. Geological Survey Circular 856, 9 p.

Miller, J. F., Frederick, R. H., and Tracey, R. J., 1973, Precipitation-frequency atlas of the western United States--Volume I, Montana: National Oceanic and Atmospheric Administration NOAA Atlas 2, 41 p.

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

Miller, W. R., and Strausz, S. A., 1980a, Preliminary map showing freshwater heads for the Mission Canyon and Lodgepole

Limestones and equivalent rocks of Mississippian age in the Northern Great Plains of Montana, North and South Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Open-File Map 80-729, 1 sheet.

——— 1980b, Preliminary map showing freshwater heads for the Red River Formation, Bighorn Dolomite, and equivalent rocks of Ordovician age in the Northern Great Plains of Montana, North and South Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Open-File Map 80-730, 1 sheet.

Mining Informational Services, 1975-82, issued annually, Keystone coal industry manual: New York, McGraw-Hill Mining Publications. Montana Bureau of Mines and Geology, 1971, Stratigraphic correlations for Montana and adjacent areas: Montana Bureau of Mines and Geology Special Publication 55, 1 sheet.

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

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

Montana Department of State Lands, 1976, State of Montana major government and Indian owned nontaxable acreage as of June 30, 1976: Helena, unpublished report, 1 p.

Montana Water Resources Board, 1969a, Ground water in Montana: Montana Water Resources Board Inventory Service Report 16, 145 p.

——— 1969b, Ground water inventory, Carbon County, Montana: Helena, 40 p.

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

Mueller, P. A., and Wooden, J. L., compilers, 1982, Precambrian geology of the Beartooth Mountains, Montana and Wyoming: Montana Bureau of Mines and Geology Special Publication 84, 167 p.

National Academy of Sciences and National Academy of Engineering, 1973, Water quality criteria, 1972: U.S. Government Printing Office, 594 p. [1974].

National Oceanic and Atomospheric Administration, 1897-1982 (issued monthly), Climatological data for Montana: Ashville, N.C., National Climatic Center.

——— 1897-1982 (issued monthly), Climatological data for Wyoming: Ashville, N.C., National Climatic Center.

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

Noble, R. A., Bergantino, R., N., Patton, T. W., Sholes, Brenda, Daniel, Faith, and Schofield, Judeyday, 1982, Occurrence and characteristics of ground water in Montana, volume 1, the Great Plains region: Montana Bureau of Mines and Geology Open-File Report MBMG 99, 82 p.

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

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

——— 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in southeastern Montana: U.S. Geological Survey Water-Resources Investigations 82-4092, 33 p.

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

Parrett, Charles, Omang, R. J., and Hull, J. A., 1983, Mean annual runoff and peak flow estimates based on channel geometry of streams in northeastern and western Montana: U.S. Geological Survey Water-Resources Investigations Report 83-4046, 53 p.

Patterson, E. D., 1966, Geologic map of the Montaqua quadrangle, Carbon and Still-water Counties, Montana: U.S. Geological Survey Geologic Quadrangle map GQ-580, 1 sheet.

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

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

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

Powe, G. R., 1954, The Red Lodge coal fields, *in* Billings Geological Society Guidebook, Fifth annual field conference, Billings, p. 133.

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

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

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

Rice, D. D., 1976, Stratigraphic sections from well logs and outcrops of Cretaceous and Paleocene rocks, northern Great Plains, Montana: U.S. Geological Survey Oil and Gas Investigations Chart OC-71, 3 sheets.

Richards, R. W., 1910, The central part of the Bull Mountain coal field, Montana, *in* Contributions to economic geology, 1909: U.S. Geological Survey Bulletin 381-A, p. 60-81.

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

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

Rioux, R. P., and Dodge, K. A., 1980, Hydrologic data from the Bull Mountains area, south-central Montana: U.S. Bureau of Land Management Report, 146 p.

Rocky Mountain Association of Geologists, 1972, Geologic Atlas of the Rocky Mountain Region of the United States of America: Denver, 331 p.

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

Shields, R. R., and White, M. K., 1981, Streamflow characteristics of the Hudson Bay and upper Missouri River basins, Montana through 1979: U.S. Geological Survey Water-Resources Investigations 81-32, 144 p.

Smith, H. L., 1963, Geologic map of the Castagne quadrangle, Carbon County, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-264, 1 sheet.

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

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

U.S. Bureau of the Census, 1981a, 1978 Census of agriculture, Montana: Washington, D.C., Department of Commerce, State and county data, v. 1, pt. 26, 452 p.

_______ 1981b, 1978 Census of agriculture, Wyoming: Washington, D.C., Department of Commerce, State and county data, v. 1, pt. 50, 267 p.

_______ 1981c, 1980 Census of population—Characteristics of the population, number of inhabitants, Montana: Department of Commerce, Twentieth Decennial Census of the United States, v. 1, chap. A, pt. 28, 35 p.

U.S. Bureau of Land Management, 1974a, Minerals management map, Northern Great Plains resources program, State of Montana: Denver Service Center, 1 sheet.

_______ 1974b, Surface ownership map, Northern Great Plains resources program: Denver Service Center, 1 sheet.

_______ 1978, State of Wyoming land status: Denver Service Center, Colo., map.

_______ 1979, State of Wyoming mineral status: Denver Service Center, Colo., map.

U.S. Bureau of Reclamation, 1972, Report on resources of eastern Montana basins: Pick-Sloan Missouri Basin Program, 91 p.

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

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

_______ 1977, National interim primary drinking water regulations: Environmental Protection Agency, Office of Water Supply, EPA-570/9-76-003, 159 p.

_______ 1978, Quality criteria for water, July 1976: Washington, D.C., U.S. Government Printing Office, 0-278-727, 256 p.

_______ 1979, National secondary drinking water regulations: Federal Register, v. 44, no. 140, July 19, p. 42195-42202.

_______ 1982, Coal mining point source category; effluent limitations guidelines for existing sources and standards of performance for new sources—final rule: Federal Register, Part 2, v. 47, no. 198, October 13, p.45382-45399.

U.S. Geological Survey, 1959, Compilation of records of surface waters of the United States through September 1950, Part 6-A. Missouri River Basin above Sioux City, Iowa: U.S. Geological Survey Water-Supply Paper 1309, 672 p.

_______ 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, Part 6-A. Missouri River basin above Sioux City, Iowa: U.S. Geological Survey Water-Supply Paper 1729, 507 p.

_______ 1969, Surface water supply of the United States, 1961-65, Part 6. Missouri River basin, Volume 1. Missouri River basin above Williston, North Dakota: U.S. Geological Survey Water-Supply Paper 1916, 800 p.

_______ 1970, The National atlas of the United States of America: Washington, D.C., 417 p.

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

_______ 1975, Plan of study of the hydrology of the Madison Limestone and associated rocks in parts of Montana, Nebraska, North Dakota, South Dakota, and Wyoming: U.S. Geological Survey Open-File Report 75-631, 37 p.

_______ 1976a, Hydrologic unit map—1974, State of Montana.

_______ 1976b, Hydrologic unit map—1974, State of Wyoming.

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

_______ 1982a, Water resources data for Montana—Water year 1980, v. 1, Hudson Bay basin and Missouri River basin: U.S. Geological Survey Water-Data Report MT-81-1, 647 p.

_______ 1982b, Water resources data for Montana—Water year 1980, v. 2, Upper Columbia River basin: U.S. Geological Survey Water-Data Report MT-81-2, 174 p.

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

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

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

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

Van Voast, W. A., and Hedges, R. B., 1975, hydrogeologic aspects of existing and proposed strip coal mines near Decker, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 97, 31 p.

Van Voast, W. A., Hedges, R. B., and McDermott, J. J., 1978, Hydrologic characteristics of coal-mine spoils, southeastern Montana: Bozeman, Montana University Joint Water Resources Research Center Report 94, 34 p.

Wanek, A. A., 1963a, Geologic map of the Cooney Reservoir quadrangle, Carbon and Stillwater Counties, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-265, 1 sheet.

_______ 1963b, Geologic map of the Rapids quadrangle, Carbon and Stillwater Counties, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-270, 1 sheet.

Washburne, C. W., 1909, Coal fields of the northeast side of the Bighorn Basin, Wyoming, and of Bridger, Montana, *in* Contributions of economic geology 1907: U.S. Geological Survey Bulletin 341-B, p. 165-199.

Weber, C. I., ed., 1973, Biological field and laboratory methods for measuring the quality of surface waters and effluents: U.S. Environmental Protection Agency, Office of Research and Development, 176 p.

Wetzel, R. G., 1975, Limnology: Philadelphia, W. B., Saunders Co., 743 p.

Wilhm, J. L., 1970, Ranges of deversity index in benthic macroinvertebrate populations: Journal of the Water Pollution Control Federation, v. 42, no. 2, part 2, p. R221-R224.

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

Woods, P. F., 1981a, Documentation of a dissolved-solids model of the Tongue River, southeastern Montana: U.S. Geological Survey Open-File Report 81-479, 41 p.

———1981b, Modeled impacts of surface coal mining on dissolved solids in the Tongue River, southeastern Montana: U.S. Geological Survey Water-Resources Investigations 81-64, 73 p.

Woolsey, L. H., 1909, The Bull Mountain coal field, Montana, *in* Contributions to economic geology, 1907, Part II—Coal and lignite: U.S. Geological Survey Bulletin 341, p. 62-77.

Woolsey, L. H., Richards, R. W., and Lupton, C. T., 1917, The Bull Mountain coal field, Musselshell and Yellowstone counties, Montana: U.S. Geological Survey Bulletin 647, 218 p.

Wyoming Department of Administration and Fiscal Control, 1981, Wyoming data handbook 1981, 5th ed.: Cheyenne Division of Research and Statistics, 201 p.

Yellowstone River Compact Commission, 1951-80, Annual report: Issued annually.

Zeller, H. D., 1963, Geologic map of the Roberts quadrangle, Carbon County, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-266, 1 sheet.

Zimmerman, E. A., 1956, Preliminary report on the geology and ground-water resources of parts of Musselshell and Golden Valley Counties, Montana: Montana Bureau of Mines and Geology Information Circular 15, 13 p.

———1964, Geology and water resources of the Bluewater Springs area, Carbon County, Montana: U.S. Geological Survey Water-Supply Paper 1779-J, 24 p.