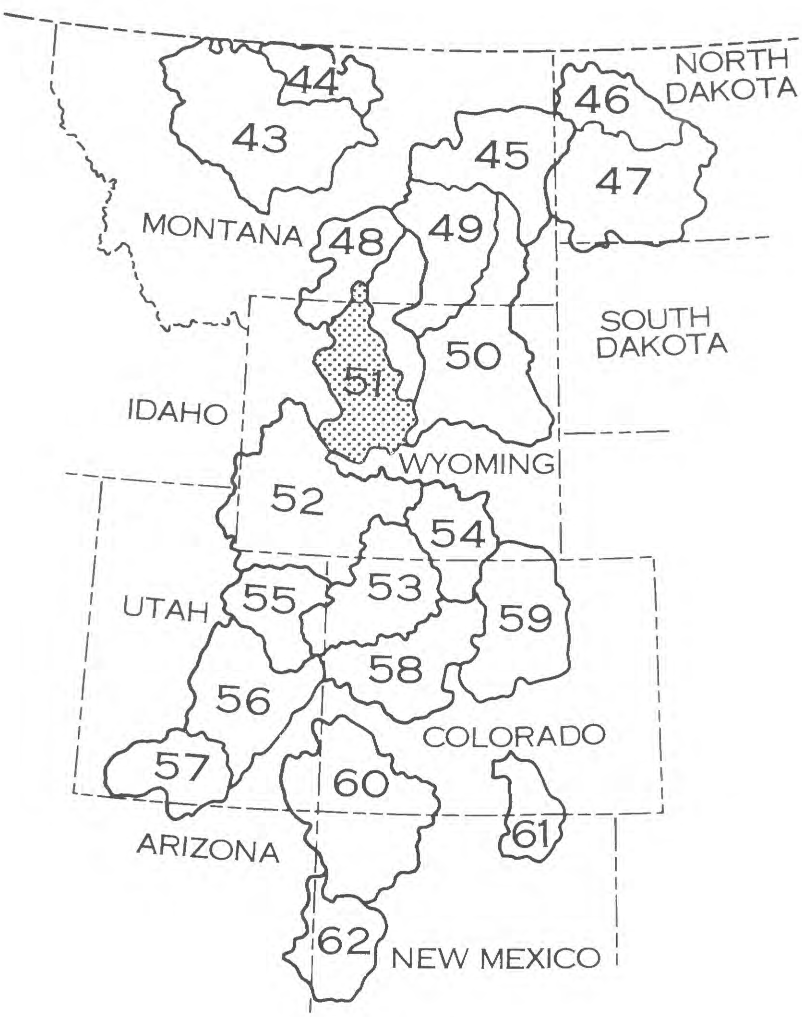
HYDROLOGY OF AREA 51, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, WYOMING AND MONTANA



- SHOSHONE RIVER
- BIGHORN RIVER
- GREYBULL RIVER
- WIND RIVER
- POPO AGIE RIVER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 84-734

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BY
DAVID A. PETERSON, K. L. MORA, MARLIN E. LOWRY, JAMES G. RANKL, JAMES F. WILSON, JR., H. W. LOWHAM, AND BRUCE H. RINGEN

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CHEYENNE, WYOMING
JUNE 1987

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, *SECRETARY*

GEOLOGICAL SURVEY

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CONVERSION FACTORS AND RELATED INFORMATION

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

Multiply inch-pound units	By	To obtain SI units
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre-ft/mi^2)	0.002100	cubic meter per square kilometer
barrel (petroleum, 42 gallons)	0.1590	cubic meter
British thermal unit (Btu)	0.2520	kilogram-calorie
British thermal unit per pound (Btu/lb)	0.5556	kilogram-calorie per kilogram
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
ton, short	0.9072	megagram

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

$$°F = 9/5(°C) + 32$$

$$°C = 5/9(°F - 32)$$

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Abstract

This report describes the physical and hydrological features of Area 51, a hydrologic division in the Rocky Mountain Coal Province. The land surface of Area 51 is approximately 11,800 square miles, most of which is in Wyoming but also projects slightly into Montana. The general topography consists of two large intermontane basins separated by interior mountains. Altitudes range from less than 3,900 feet to more than 13,000 feet above sea level. The major drainages of the area are the Wind and Bighorn Rivers.

Precipitation is more closely related to altitude and location than latitude. The intermontane basins receive an average of 11 inches of precipitation per year; average precipitation in the mountains exceeds 25 inches per year. The terrain of the study area varies from desert badlands to alpine mountains. Sagebrush and grasses predominate within the semiarid basins; coniferous forests predominate in the mountains. Soils differences are mainly due to geologic and climatic conditions.

The Federal Government owns most of the land surface and mineral rights in Area 51. The U.S. Bureau of Land Management administers most of the federal holdings. Livestock grazing is the most common land use, although much of the land is used as wildlife habitat. Irrigation accounts for the largest amount of water consumed. Recreation, fish and wildlife habitat, and hydroelectric production are important water uses that are largely nonconsumptive.

The area contains a deposit of more than 18 million tons of strippable low-sulfur, bituminous coal, as well as other deposits of subbituminous coal. Other mineral and geothermal resources are abundant in the area: wells tap supplies of oil, gas, and geothermal water; uranium, bentonite, gypsum, and feldspar are mined in the area.

The quantity of surface-water runoff largely depends upon precipitation, most of which is in the form of snowfall on the mountains. The headwaters of the major streams are in the mountainous areas, where precipitation is the greatest. Chemical and sediment samples indicate excellent water quality in many streams draining the mountains. However, the water quality decreases in a downstream direction in many of the plains streams. Natural processes (such as erosion) and activities of man (such as irrigation, storage, and waste disposal) tend to increase the dissolved-solids, nitrogen, phosphorus, and suspended-sediment concentrations and also affect water temperature. Surface water in the area of active coal mining has not been significantly affected; acid mine drainage is not a problem.

Time-of-travel and dispersion information is available for a 113- river-mile reach of the Wind/Bighorn River. This information can be used to assess the capacity of the river to transport dissolved contaminants (solutes).

Ground water is available throughout Area 51. Ground water for stock and domestic use can be developed from wells less than 500 feet deep in most of the area. Deeper wells generally are needed to obtain larger yields. Ground-water data are available for about 1,300 ground-water sites in the area.

Good quality ground water is not available everywhere. Large dissolved-solids concentrations are a problem in many wells and springs. However, wells and springs nearer the mountain recharge areas produce less mineralized water.

The U.S. Geological Survey has collected hydrologic data and made interpretive studies in Area 51 since the late 1800's. A large extent of the present hydrologic knowledge of the area can be attributed to work done in cooperation with State and other Federal agencies—particularly the Wyoming State Engineer's Office, the Wyoming Department of Environmental Quality, the U.S. Bureau of Land Management, the U.S. Bureau of Reclamation, and the U.S. Environmental Protection Agency.

1.0 INTRODUCTION

Hydrologic Environment Can Be Drastically Changed by Surface Mining

Knowledge of the hydrologic conditions is essential for proper planning of mining and reclamation; a summary of the hydrology and sources of hydrologic information for Area 51 is presented in this report.

The use of coal has increased substantially in the United States during recent years. Development of coal resources is often by surface mining which significantly changes the natural landscape and may cause related changes to the hydrology (fig. 1.0–1). The magnitude of surface-mining impacts on the hydrologic environment depends on factors that are unique to each site. These factors include mining and reclamation methods, slope of land, type of soil and rock, amount of precipitation, quality of ground and surface waters, and rate of water movement.

Coal mining in the area dates back into the 1890's; however, large commercial operations did not begin until the early 1900's. Although commercial coal mining in Area 51 has a long history, production is meager when compared to that in the state of Wyoming as a whole. Several small surface mines have been operated in the area, but underground mining was the most predominant method of coal extraction (Glass and others, 1975, p. 224).

The removal of vegetation and overburden has the potential to affect hydrologic conditions in and near the mined area. For example, changes in vegetative cover and in soil infiltration rates can affect the amount and quality of surface runoff. If excavation extends below the water table, pumping may cause ground-water levels to decline, subsidence may occur, and nearby wells and springs may go dry. The potential for acid mine drainage in the area is small, compared to the Eastern United States, because of the alkalinity of the soils in the area.

Coal is currently (1984) being mined at only one surface mine in Area 51 (fig. 1.0–2). The actual land surface area of present mining is quite small. The arid climate of the coal-deposit area makes revegetation of reclaimed areas difficult (fig. 1.0–3); climate is the most important and least controllable factor affecting the success of reclamation. Although the study area includes humid mountainous regions with plentiful streamflow (fig. 1.0–4), water supplies within the basins are limited. The expansion of coal and other mineral production in the area will cause severe impacts unless the lands are adequately reclaimed. Reclamation of mined lands in the Western coal region are discussed in Narten and others (1983).

In recognition of the potentially adverse hydrologic impacts of coal mining, the Surface Mining Control and Reclamation Act of 1977 was enacted August 3, 1977 (Public Law 95–87). The Act requires an appropriate Federal or State agency to issue mining permits partially on the basis of the assessment of the hydrologic impacts in the mining-permit area. As a result, hydrologic information on a National scale is required by the Act to enable the surface-mine industry and consultants to prepare the required permit applications and to enable regulatory authorities to appraise the adequacy of the permit applications.

This report presents a broad summary of the physical and hydrologic features of Area 51, one of the hydrologic reporting areas in the Northern Great Plains and Rocky Mountain Coal Provinces (see report cover). Area 51 includes parts of Wyoming and Montana. This report provides the background for the more detailed site-specific studies that will be needed by a mining-permit applicant to satisfy requirements of the Surface Mining and Reclamation Act.

Wyoming and Montana have established State programs and have been granted authority from the U.S. Office of Surface Mining to enforce the Surface Mining Control and Reclamation Act within their States. No coal mining is currently (1984) being done within the Montana portion of Area 51.

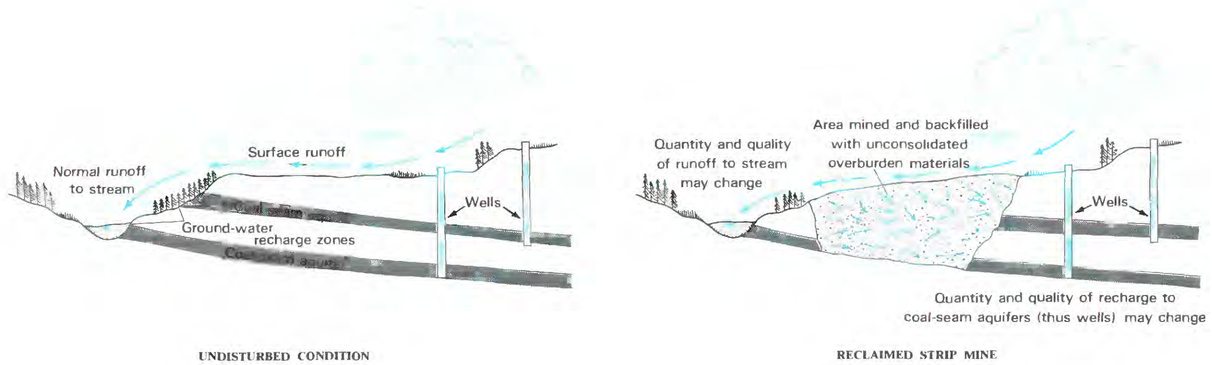


Figure 1.0-1 Potential impacts of mining on landscape and hydrology.

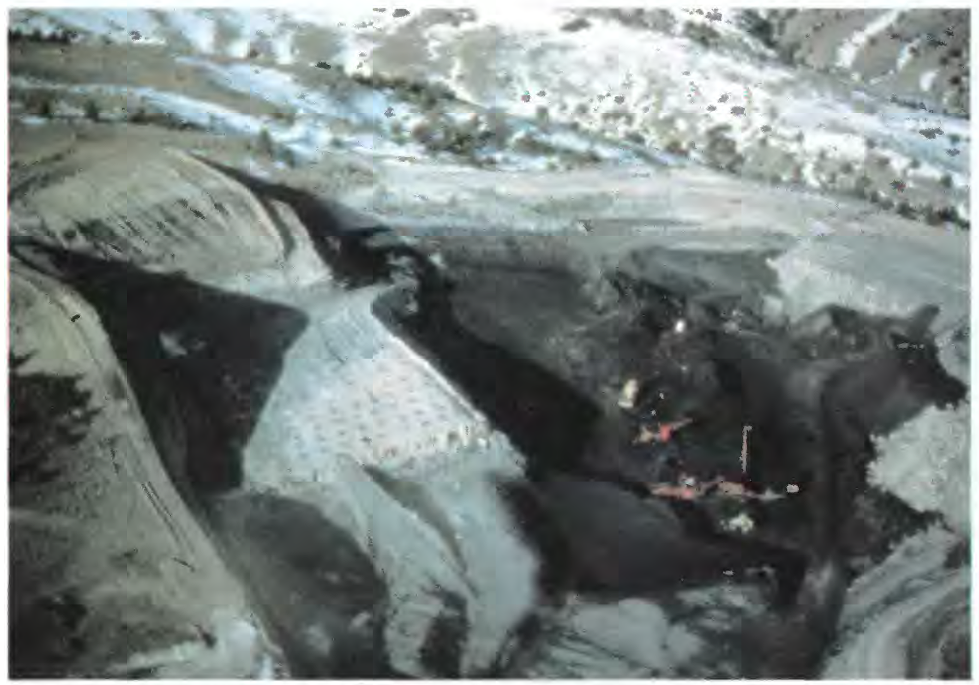


Figure 1.0-2 The only producing coal mine in Area 51 (1984) is a small operation compared to other surface mines in Wyoming. (Photo courtesy of U.S. Bureau of Land Management.)

Figure 1.0-3 Most of Area 51 has an arid or semiarid climate.

Figure 1.0-4 Mountains surround the basins of the study area. (Photo courtesy of Wyoming Travel Commission.)

Terrain of Area 51 Varies from High, Rugged Mountains to Desert Badlands

Generally, streams originating in the mountains are perennial; streams originating in the basins are ephemeral.

The boundary of Area 51 was defined by surface drainage for the most part and covers approximately 11,800 square miles (fig. 2.1–1). General topography consists of two large intermontane basins separated by interior mountains. The northern basin is the Bighorn Basin; the southern basin is the Wind River Basin. Both basins extend outside the study area.

Area 51 is surrounded by the Pryor Mountains on the north, the Bighorn Mountains on the east, the Absaroka Range on the west, and the Wind River Range on the southwest. Several other mountain ranges, which are outside the study area to the northwest and to the south, further encompass the study area. The Owl Creek Mountains and the Bridger Mountains are the interior mountains that separate the Bighorn and the Wind River Basins.

The floor of the Bighorn Basin consists of a series of benches and terraces ranging in altitude from less than 3,900 to about 5,000 feet (ft) above sea level and is dissected by numerous water courses with narrow valleys. In addition to plains, rolling hills, and steep canyons, much of the intermontane basin has a "badland" appearance. Yet, some fairly level areas are suitable for irrigation development. The mountains and foothills along the margins of the basin generally are rugged with many high peaks and deep canyons.

The Wind River Basin, although somewhat smaller than the Bighorn Basin, is of similar topographic expression: rolling hills, narrow river valleys, and badlands comprising a lowland rimmed by hills and high mountains. The altitude of the basin floor is about 4,000 to 5,000 ft above sea level. The general slope of the surface of the Bighorn and the Wind River Basins is from south to north. The interior mountains are from 7,000 to 9,000 ft above sea level.

The study area contains numerous canyons, draws and gulches. The Wind River incised the principal canyon in the area between the Owl Creek and Bridger Mountains. The Wind River Canyon is about 10 miles long and has a maximum depth of 2,250 ft.

Mountain and basin boundaries within the area are defined in figure 2.1–1. The 7,000-foot contour line was used for delineation. The drainages that originate in the mountains cross the 7,000-foot contour line.

The Wind/Bighorn River, the principal river in the area, drains both basins; the Wind and Bighorn Rivers are actually the same stream—the name changes a few miles south of Thermopolis at the mouth of the Wind River Canyon at a point called the "Wedding of the Waters." The Wind River flows southeasterly toward Riverton, Wyo., then northerly to the mouth of the Wind River Canyon. The Bighorn River flows from the Wedding of the Waters northward to the Yellowstone River, which is outside the study area.

The Wind River has numerous tributaries that head at high elevations in the Wind River, Absaroka, and Owl Creek Mountains. Major tributaries to the Bighorn River are the Greybull and Shoshone Rivers, both of which head in the Absaroka Range and flow eastward (fig. 2.1–2). The mountain streams flow into gorges or narrow canyons at the foot of the mountains, then flow across the plains to join the main stem of the Wind/Bighorn River.

In general, streams in Area 51 originating in the mountains are perennial; streams originating in the plains are ephemeral or intermittent. Perennial streams flow continuously. Ephemeral streams flow only in direct response to precipitation and do not receive ground-water discharge. Intermittent streams flow seasonally and only while receiving ground-water discharge or water from surface runoff (U.S. Geological Survey, 1960, p. 18).

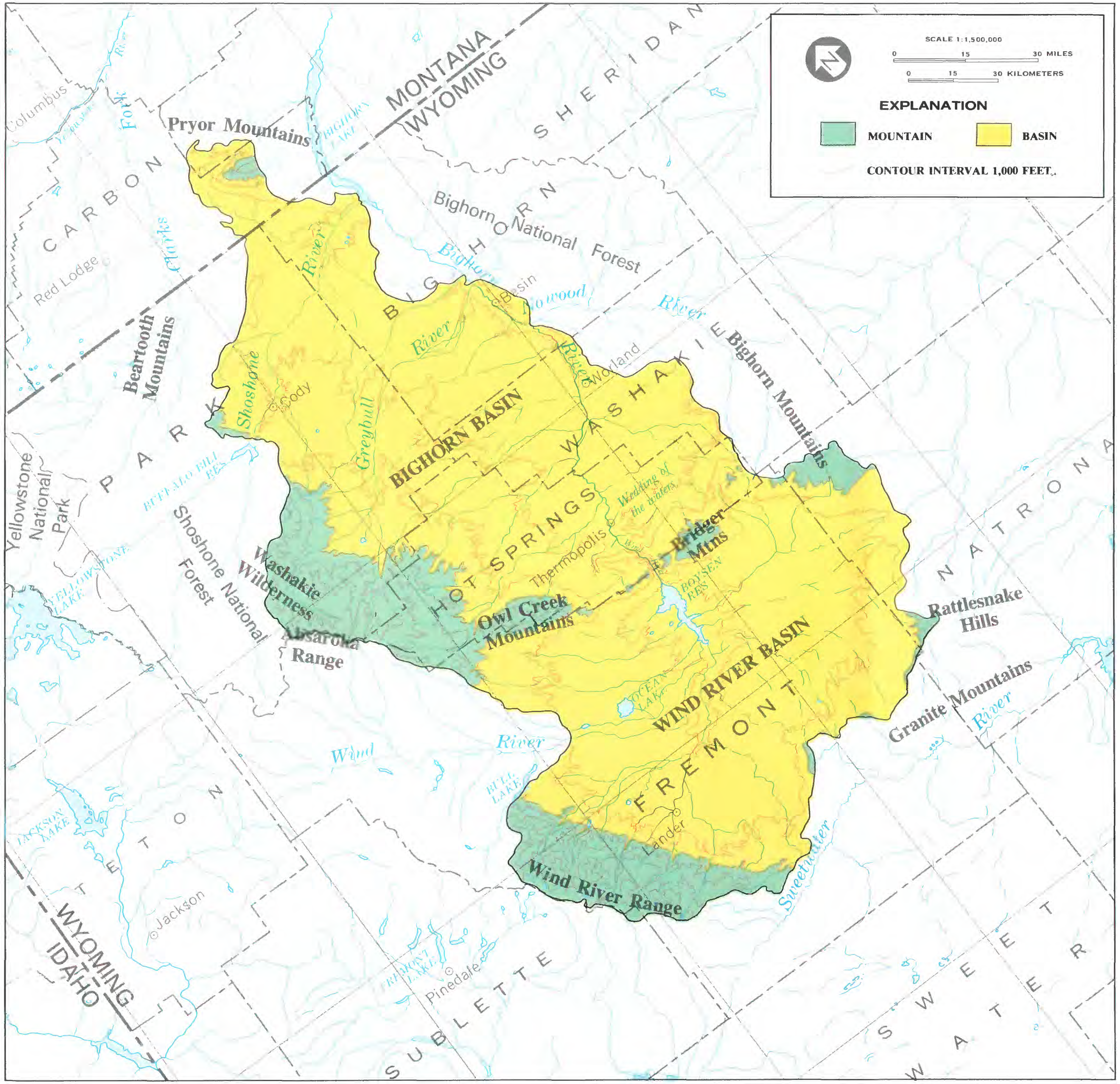


Figure 2.1-1 General index map of Area 51 and adjacent areas. Mountain and basin boundaries within the study area are defined by the 7,000-foot contour.

**Greybull River flows through Shoshone National Forest.
(Photo courtesy of Wyoming Travel Commission.)**

**Absaroka Range viewed from Anchor Dam.
(Photo courtesy of Wyoming Travel Commission.)**

Figure 2.1-2 Varied landforms in Area 51.

Precipitation Related to Altitude

Average precipitation in the mountains exceeds 25 inches per year; average precipitation in the plains is less than 11 inches per year.

Climate of the study area is more closely related to altitude than latitude. Altitudes above sea level range from less than 3,900 feet (ft) near Basin, Wyoming, to greater than 13,000 ft in the Wind River Range. Because of the range of altitudes in the study area, the climate varies greatly. However, the climate can be broadly generalized as follows: (1) cool, semiarid deserts in the intermontane basins; (2) cold, subhumid taiga on the mountainsides; and (3) very cold, humid tundra in the high mountains.

Rather than latitude, precipitation is related to altitude and, to a lesser extent, location. Precipitation increases with altitude in the mountains. The mountains surrounding the Wind River Basin draw available moisture from approaching air masses. Consequently, the Wind River Basin receives less than 11 inches (in.) of precipitation per year. Precipitation on the plains of the Bighorn Basin, however, is less influenced by the proximity of mountains and receives more precipitation than some higher altitudes further south. Average precipitation in the mountains exceeds 25 in. per year.

The distribution of average annual precipitation is shown in figure 2.2–1. Most precipitation from November through April occurs as snow (fig. 2.2–2) and is the most important source of streamflow in the area. Annual snowfall averages from 14 to 40 in. over most of the basin areas, as much as 90 in. over the southern Wind River Basin, and even more in the mountains (Wyoming State Engineer, 1972, p. 22). Precipitation during the summer occurs as light showers and occasional in tense thunderstorms. The distributions of normal monthly precipitation at two National Weather Service stations, at Basin and Lander, Wyo., are shown in figure 2.2–3.

The amount of precipitation that occurs from year to year is highly variable. The weather station at Lander (1892–1980) recorded a high of 21.89 in. during 1957 and a low of 7.25 in. during 1902 (Alyea, written commun., 1980). The station at Basin (1899–1980) recorded a high of 11.09 in. during 1924 and a low of 2.63 inches during 1902 (U.S. Department of Commerce, 1984).

Temperature varies as a result of changing seasons, as well as vertical temperature inversions, movement of air masses, and altitude. Normal air temperature is lowest during late January and highest during late July. Temperature extremes recorded at Basin range from −51 to 114° Fahrenheit. The growing season near Basin is greater than 160 days; however, the growing season at altitudes higher than 7,000 ft is less than 60 days (Wyoming Department of Administration and Fiscal Control, 1983). Soil temperature at a depth of 6 ft varies much less than air temperature and lags behind the air temperature by about one month.

Evapotranspiration, which is moderately high in the study area, is greatest during July but continues to be significant well into the fall because of the warm soil temperature. Clear, sunny skies are present about 65 percent of the possible time, on an annual basis. Skies are clear and sunny 50 to 55 percent of the available time during winter months, 75 to 80 percent of the available time during summer months.

Climatological data are published monthly by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, North Carolina.

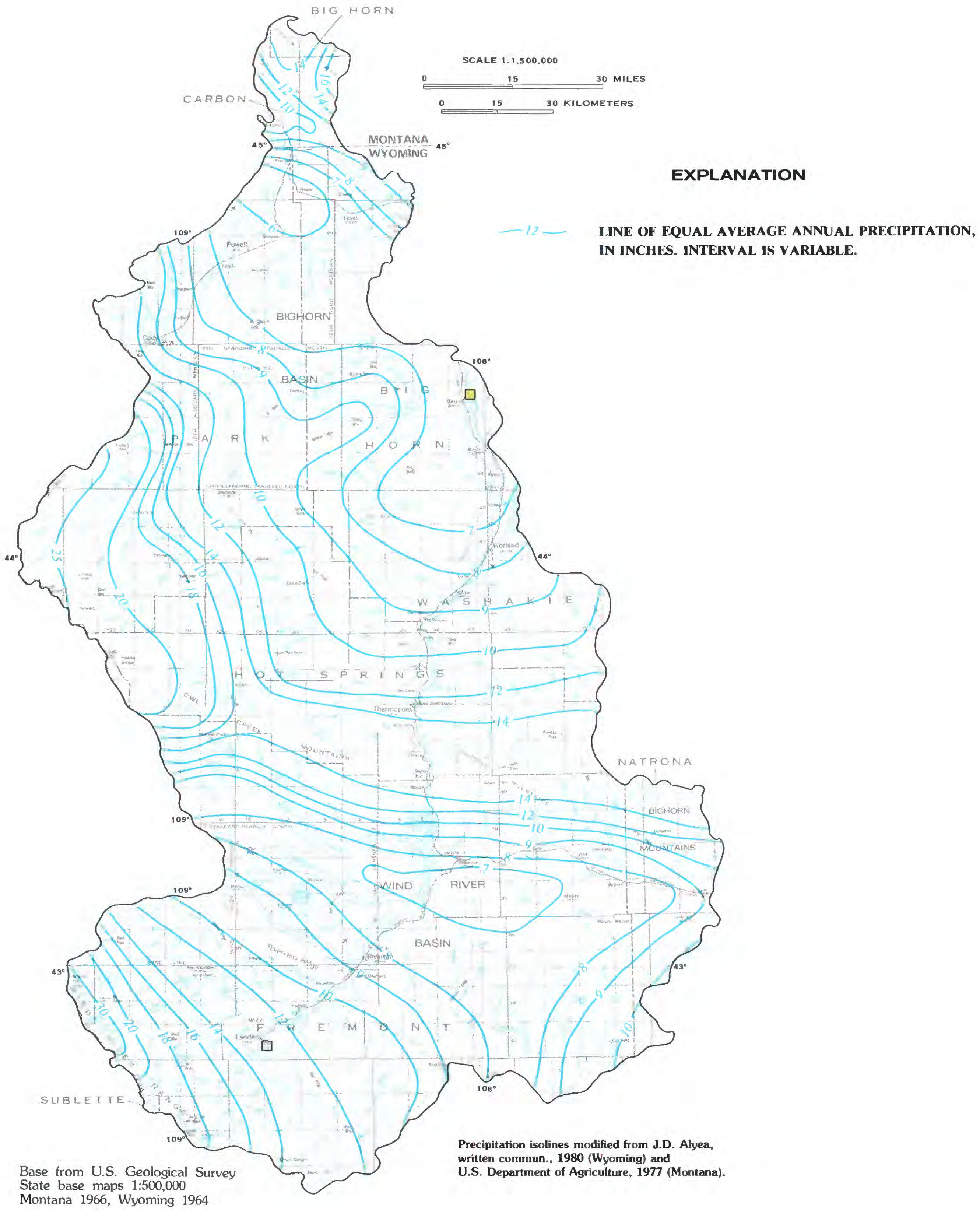


Figure 2.2-1 Average annual precipitation is related to altitude and location.

Figure 2.2-2 Mountain snowpack is critical for water supply to the basins.

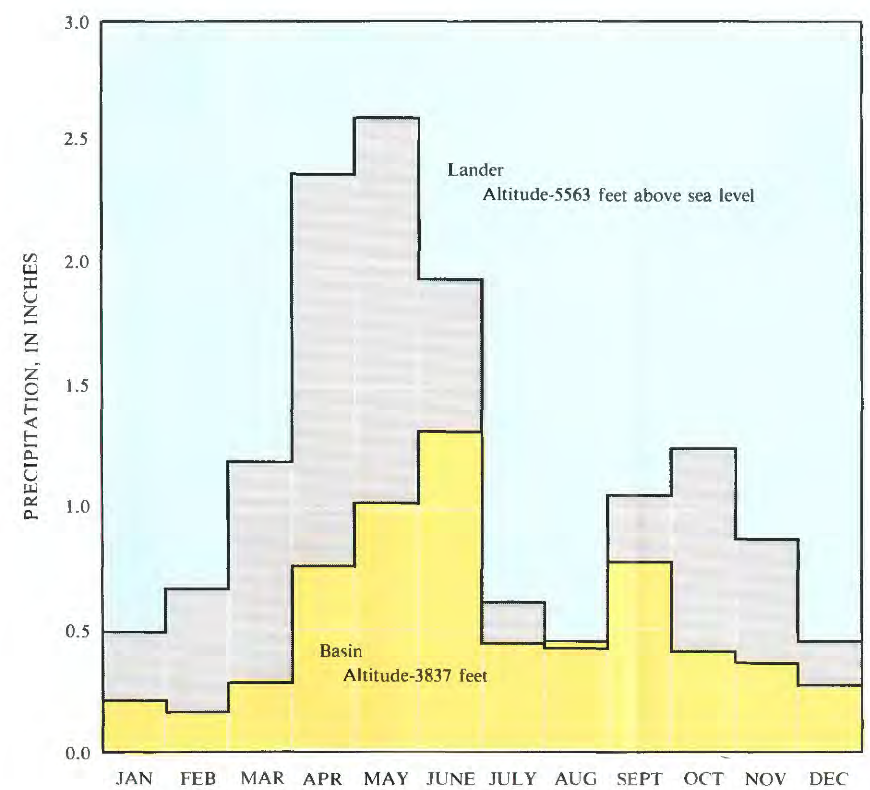


Figure 2.2-3 Warming of atmosphere causes relatively large amounts of precipitation to occur during April through June (National Oceanic and Atmospheric Administration, 1973).

Sagebrush and Grasses are the Predominant Vegetation

The plains support a mixture of sagebrush and grasses; the mountainsides support coniferous forests; high mountains support alpine tundras.

Native vegetation is extremely varied in the study area. Plant species and density are influenced primarily by elevation, soil, exposure, and rainfall. A map of vegetative aspect is shown in figure 2.3–1. Vegetative aspect is the visually dominant kind of vegetation such as alpine, brush, crops, grasses, or forest. Large water surfaces and barren areas are also shown.

Plains comprise most of the study area and support primarily sagebrush with some grasses (fig. 2.3–2). Sagebrush tends to dominate the vegetative aspect of all low precipitation zones in the area. Although vegetation appears to be sparse in the plains, extensive root systems compete for the available moisture. As precipitation becomes more plentiful with elevation, short and intermediate grasses and grasslike plants become more dominant. Grassland and woodland species are listed for each precipitation zone of the area in table 2.3–1. Boxelder, cottonwood, and willow trees are present along major rivers and streams of the plains and floodplains.

Most of the brush and grass lands and some of the land with trees is used for livestock grazing and is considered rangeland. Some of the rangeland plant communities have been converted to agricultural crops. Stands of trees on some floodplains have been cleared for irrigated crops. However, the vegetation is, for the most part, native and wild, interrupted only occasionally by pasture and cropland.

Forests of lodgepole pine and ponderosa pine predominate in the mountain foothills, giving way to taiga forests of alpine fir, aspen, and Douglas fir at higher altitudes (fig. 2.3–3). Above timberline (about 10,000 feet above sea level), tundra areas support alpine grasses. Taiga and tundra areas are important water-yielding areas, and some are covered with permanent snowfields.

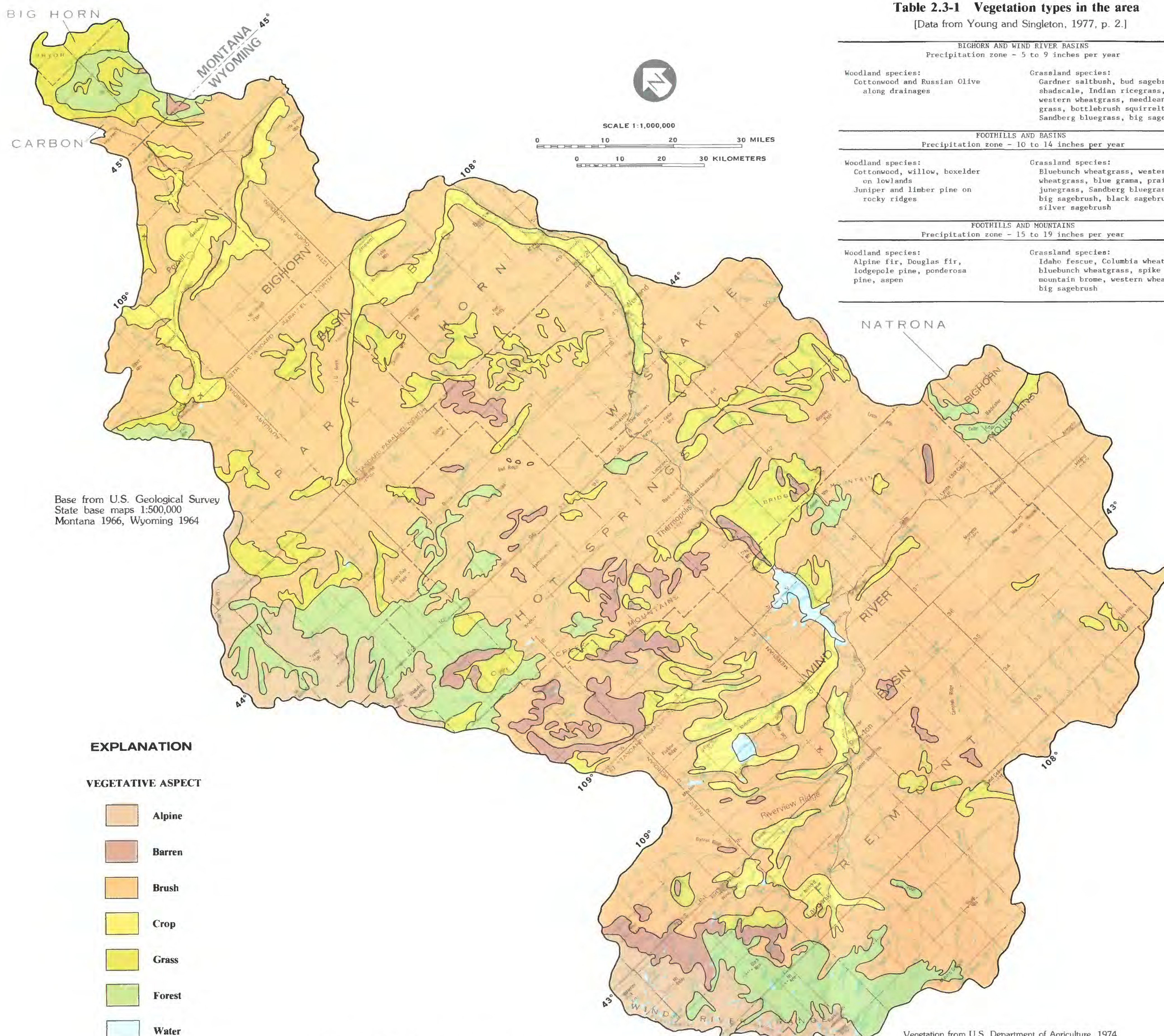


Figure 2.3-1 Vegetative aspect.

Table 2.3-1 Vegetation types in the area

[Data from Young and Singleton, 1977, p. 2.]

BIGHORN AND WIND RIVER BASINS Precipitation zone - 5 to 9 inches per year	
Woodland species: Cottonwood and Russian Olive along drainages	Grassland species: Gardner saltbush, bud sagebrush, shadscale, Indian ricegrass, western wheatgrass, needleandthread grass, bottlebrush squirreltail, Sandberg bluegrass, big sagebrush
FOOTHILLS AND BASINS Precipitation zone - 10 to 14 inches per year	
Woodland species: Cottonwood, willow, boxelder on lowlands Juniper and limber pine on rocky ridges	Grassland species: Bluebunch wheatgrass, western wheatgrass, blue grama, prairie junegrass, Sandberg bluegrass, big sagebrush, black sagebrush, silver sagebrush
FOOTHILLS AND MOUNTAINS Precipitation zone - 15 to 19 inches per year	
Woodland species: Alpine fir, Douglas fir, lodgepole pine, ponderosa pine, aspen	Grassland species: Idaho fescue, Columbia wheatgrass, bluebunch wheatgrass, spike fescue, mountain brome, western wheatgrass, big sagebrush

Figure 2.3-2 Sagebrush predominates in the basins. (Photo courtesy of Wyoming Game and Fish Department.)

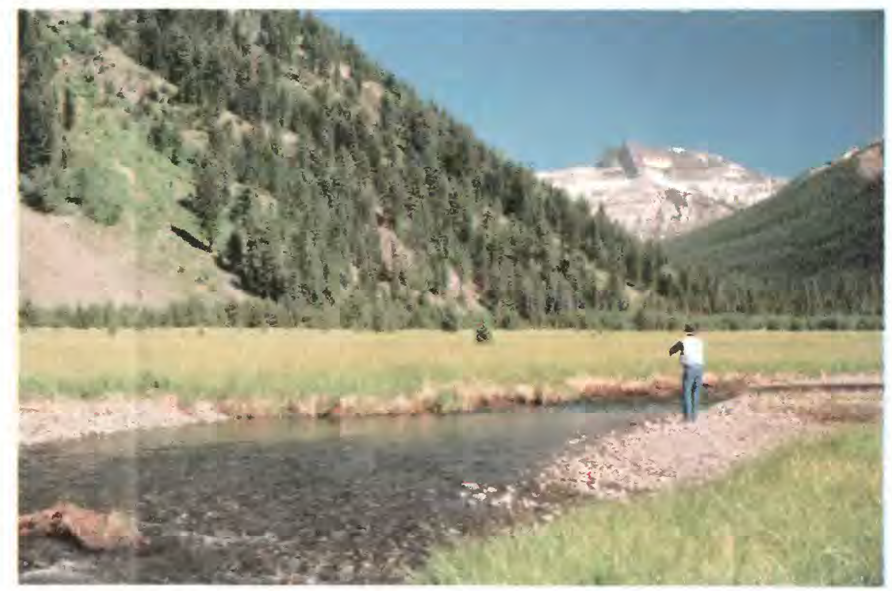


Figure 2.3-3 Washakie Wilderness has a variety of vegetation types. (Photo courtesy of Wyoming Travel Commission.)

Differences of Soils are Mainly Due to Differences in Geologic Origin and Climatic Conditions

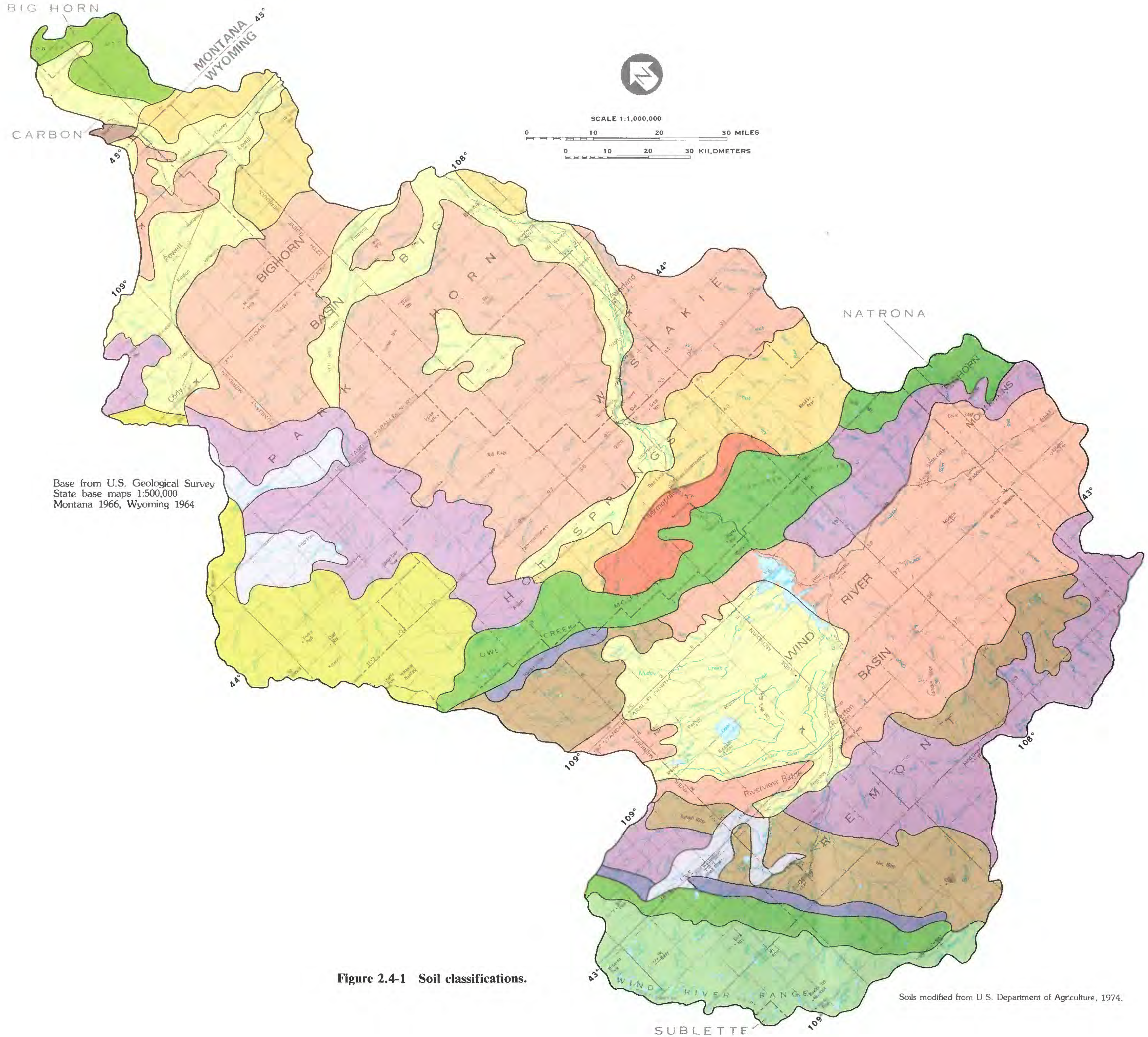
Soils that developed from shales and sandstones are predominant in Area 51.

Soils in Area 51 are shown on a generalized soil map (fig. 2.4–1). Soils in the area are classified into three broad groups primarily on differences in geologic origin and climatic conditions. The groups include (1) mountains, mountain valleys, and mountain foothills; (2) mountain foothills and desertic basins; and (3) desertic basins and uplands. The map units are designated to indicate kinds of soil that may be found in a delineation but are not intended to show exact locations of soil types.

The mountain soils are located on rolling to steep mountainous landscapes, are derived from igneous rocks, and consist of grayish-brown loams or sandy loams. These soils are quite often stony and shallow. Being within a zone of greater precipitation, they support more vegetation than other soils of the study area and, thus, have a higher humus content. The shallower and rockier soils support timber growth while the more fertile soils often support grassland (Scovel and Harmston, 1955, p. 14).

Soils of the mountain foothills and desertic basins are largely formed from shales. These soils are characterized by shallow, stony loams, grayish-brown loams, and alkali clays and loams. Soils in this group vary from badlands not suited for grazing to lands with a high productive capacity (Scovel and Harmston, 1955, p. 14). Most of the coal deposited in Area 51 is associated with this soil group. Locally, mined-land revegetation efforts may be seriously hampered because of high salinity and alkalinity conditions in these soils.

Information on soils is important to the planning of mined-land reclamation. A detailed description of soils is required by the regulatory agencies prior to the granting of a mine permit; soil surveys have been completed for mines that have already been granted permits. Detailed soil surveys are not currently (1984) completed for most of the area; however, many surveys are in progress. Additional soil information is available from Young and Singleton (1977) and the offices of the U.S. Soil Conservation Service and the U.S. Bureau of Land Management.



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

Figure 2.4-1 Soil classifications.

Soils modified from U.S. Department of Agriculture, 1974.

EXPLANATION

SOILS OF THE MOUNTAINS, MOUNTAIN VALLEYS, AND MOUNTAIN FOOTHILLS

C-1 CRYOBOROLLS-CRYOBORALFS--Rock outcrop association: steep and very steep, shallow and moderately deep, well-drained soils and rock outcrops on tops and sides of mountains

C-2 CRYOBORALFS--Rock outcrop association: steep and very steep, shallow to deep, well-drained soils on sides and foothills of mountains

C-3 CRYOBOROLLS--Rock outcrop association: steep, shallow to deep, well-drained soils on dissected mountain fronts and rounded knolls and ridges of mountains

SOILS OF THE MOUNTAIN FOOTHILLS AND DESERTIC BASINS

F-1 HAPLARGIDS-ARGIBOROLLS ASSOCIATION--Nearly level to steep, deep, well-drained soils on terraces, fans and till plains of the mountain foothills

F-2 HAPLARGIDS-CAMBORTHIDS-TORRIORTHENTS ASSOCIATION--Rolling and steep, shallow to deep, well-drained soils on dissected mountain foothills and on uplands in desertic basins

F-3 TORRIORTHENTS-Rock outcrop association:Rolling and steep, shallow to deep, well-drained soils on mountain foot slopes

F-4 HAPLARGIDS-TORRIORTHENTS ASSOCIATION--Rolling and steep, shallow to deep, well-drained soils on mountain foothills and on uplands in desertic basins

SOILS OF THE DESERTIC BASINS AND UPLANDS

M-1 HAPLARGIDS-TORRIFLUVENTS-TORRIORTHENTS ASSOCIATION--Nearly level to sloping, deep, well-drained soils on floodplains, terraces, and fans of desertic basins and uplands

M-2 TORRIORTHENTS-CAMBORTHIDS ASSOCIATION--Nearly level to steep, shallow to deep, well-drained soils on uplands of desertic basins

M-3 HAPLARGIDS-NATRAGIDS-TORRIORTHENTS ASSOCIATION--undulating to steep, shallow to deep, well-drained soils in desertic basins and uplands

M-4 CAMBORTHIDS-TORRIORTHENTS ASSOCIATION--Rolling and steep, shallow to deep, well-drained soils on dissected uplands in desertic basins

M-5 TORRIORTHENTS ASSOCIATION--Nearly level to steep, shallow to deep, well-drained soils on uplands

Rocks Representing All Geologic Eras are Exposed

The oldest exposed rocks in the area are more than 2.5 billion years old.

Rocks representing all geologic periods shown in figure 2.5.1–1 are present in the area. The oldest rocks in the area, which are metamorphic, have been intruded by granite that is more than 2.5 billion years old (Houston, 1971, p. 20). The geologic record is missing between intrusion of the granite and the Cambrian Period; however, by the Cambrian Period, erosion had reduced the area to a relatively flat surface, and seas encroached into the area from the west, depositing the oldest sedimentary rocks present in the area. The contact between the Precambrian granite and the Cambrian sedimentary rocks exposed in a road cut in the Wind River Canyon is shown in figure 2.5.1–2. The location of the Wind River Canyon is shown on figure 2.1–1.

By the end of the Paleozoic Era about 2,500 feet (ft) of marine sandstone, shale, and carbonates were deposited in the area. During the Permian Period carbonates were deposited in most of the area. Red siltstone, shale, and gypsum, which are locally called the redbeds, were deposited in the extreme eastern part of the area. Redbeds were also deposited during the Triassic Period; redbed and gypsum were deposited in Middle Jurassic. The total thickness of what is predominantly a redbed sequence is 1,500 to 2,000 ft in places within Area 51.

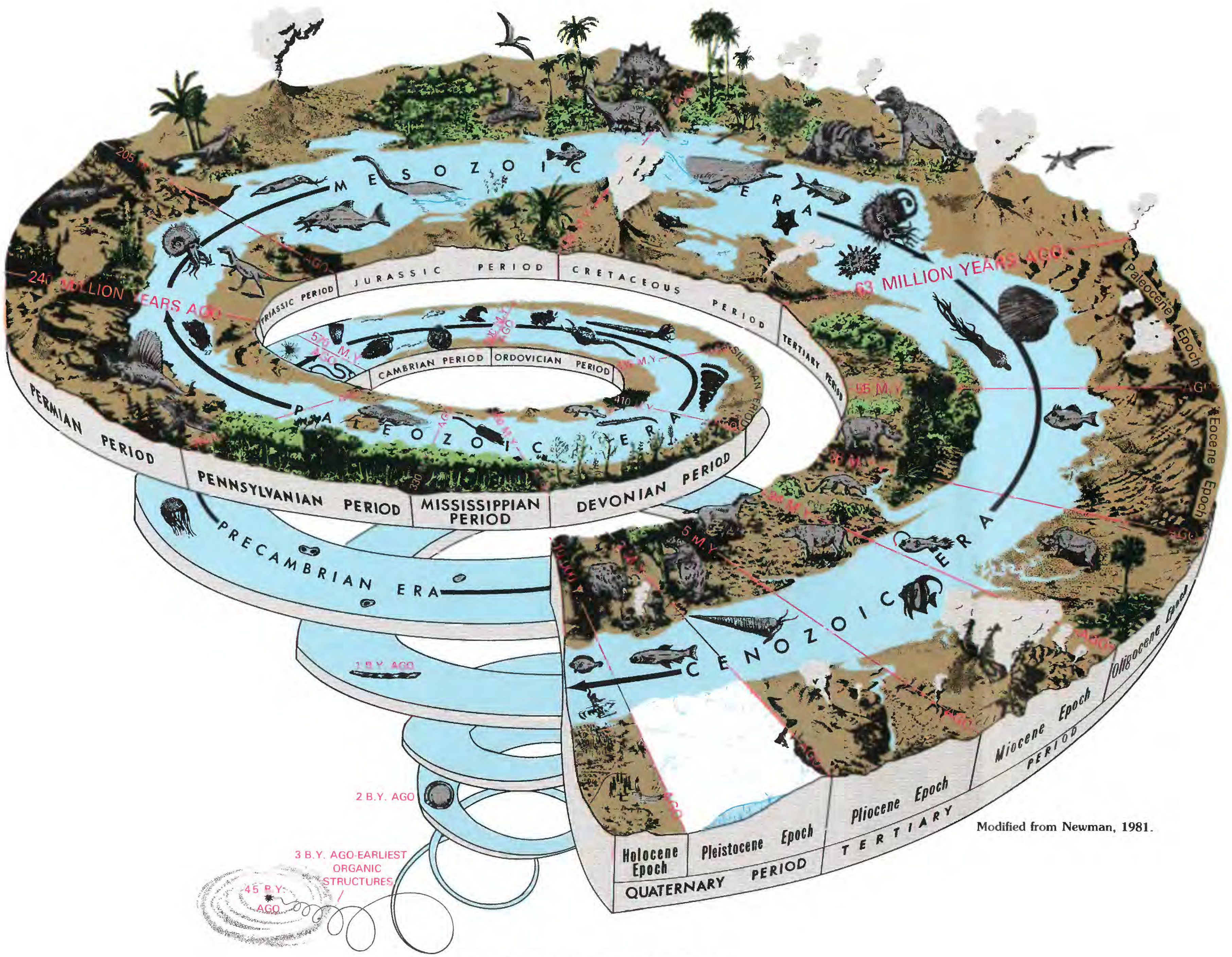
Overlying the redbeds is a sequence consisting of marine limestone, sandstone, and shale of Late Jurassic age overlain by continental deposits. Deposition of continental deposits continued into the Cretaceous Period. Rocks deposited during the two periods cannot be distinguished in part of the area. The sequence is about 1,000 ft thick.

Later in Early Cretaceous time, seas encroached into the area, depositing marine shale. During Late Cretaceous there were oscillations of the sea from the area eastward that resulted in intertonguing continental and marine deposits in the area. The oldest coal in the area was deposited at this time. The sequence of marine and intertonguing marine and continental deposits is as much as 8,000 ft thick.

Differential movement of the surface occurred in the area throughout geologic time; erosional and depositional differences resulted. However, near the end of the Late Cretaceous Epoch, intense folding and faulting of the area began. At that time, some of the areas of present-day uplifts (figure 2.5.1–3), were eroding and providing sediments to the basins. The outlines of the Wind River and Bighorn Basins were well established by early in the Tertiary Period. The Paleocene and early Eocene deposits, which are as much as 17,000 ft thick in the Wind River Basin, consist of fluvial and lacustrine deposits. Coal presently being mined in the Bighorn Basin, the Fort Union coal bed, was deposited during this time. Marine deposits may occur in the Wind River Basin (Keefer, 1965, p. A1). During the middle of the Eocene Epoch, volcanic activity increased in the area and in Yellowstone National Park; several thousand feet of volcaniclastic rocks were deposited near the centers of volcanic activity. Distant from the centers, deposits of equivalent age are thinner and contain a smaller proportion of volcanic debris. These deposits remain only in the Absaroka volcanic center, the Owl Creek Mountains, and Beaver Rim; elsewhere these deposits have been removed by erosion. Locations of these sites are shown on figure 2.1–1.

The youngest deposits in the area are those deposited during the Quaternary Period and consist of glacial, alluvial, and wind-blown deposits. Glacial deposits occur only in the mountains. Alluvial deposits, which are the most extensive Quaternary deposits, occur beneath the flood plains and cap terraces. Flood-plain deposits occur along most drainages but the thickness of the deposits is generally less than 100 ft. Wind-blown deposits occur principally in the Wind River Basin.

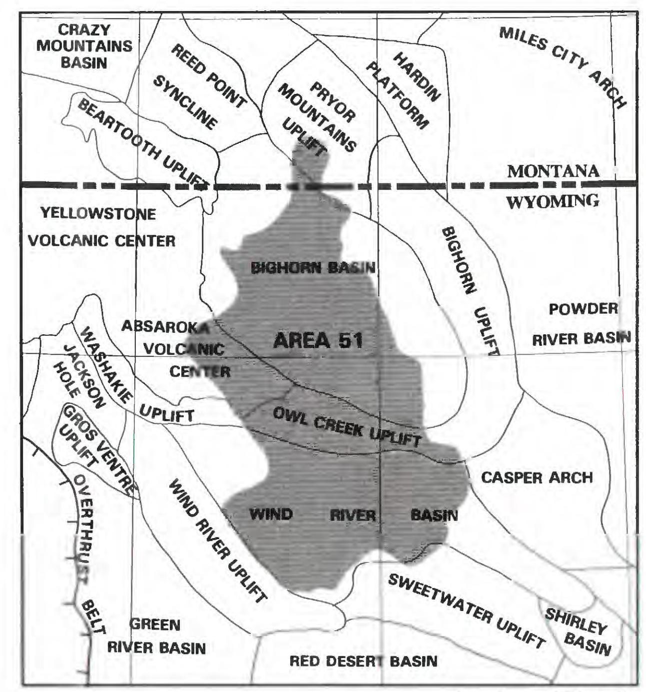
The stratigraphy and structure described in this section have been greatly simplified for the purpose of giving the reader a general knowledge of the geology. The combinations of stratigraphic units used are those most useful in describing the ground-water resources of the area. Much of the material in this section was abstracted from the Geologic Atlas of the Rocky Mountain Region (Rocky Mountain Asociation of Geologists, 1972) and the reader is referred to the publication for more detail.



Modified from Newman, 1981.

Figure 2.5.1-1 Relative and atomic geologic time.

Figure 2.5.1-2 Contact between the Precambrian granite and the Cambrian sedimentary rocks in the Wind River Canyon, Wyoming.



From Grose, 1972, p. 37.

Figure 2.5.1-3 Geologic structures in and near Area 51.

The Distribution of Rocks that Contain Mineral or Water Resources can be Inferred from Geologic Maps

Detailed maps of most of the area are available to provide information about the distribution and depth to a rock unit that may contain a mineral resource.

Inferences about the distribution of rocks and their physical and structural relations to one another for a small area can be ascertained from outcrops such as occur at Red Canyon (fig. 2.5.2–1). The location of Red Canyon is shown on figure 2.1–1. Many spectacular outcrops occur in Area 51, although few are as conveniently marked as those in the Wind River Canyon (fig. 2.5.2–2). However, to understand the geology of a large area, a map or other graphic portrayal is necessary. Geologic mapping of the area has been done in much greater detail than is possible to show in this report. An index of maps that includes the area has been compiled by McIntosh and Eister (1979).

The geologic units shown in figure 2.5.2–3 have been grouped for simplified discussion of the ground water; however, information about the geologic history, possible location of mineral and water resources, and geologic processes can be inferred from the figure. Changes in deposition throughout geologic history are shown by the layering of the units, particularly in the southwest part of the area. The folding that formed the present mountains and basins is indicated by the exposure of older rocks at the margins of the basins. Volcanic activity after most of the folding is indicated by the presence of volcaniclastic rocks on upturned, older units in the Absaroka volcanic center and in the Owl Creek and Sweetwater uplifts. Volcaniclastic and equivalent age rocks were present throughout most of the area at one time but were removed by downcutting streams. The course of the Wind River was established on these rocks and erosion of the rocks from most of the area resulted in the incision of the river into the more resistant rocks in the Wind River Canyon. The location of the Wind River Canyon is shown on figure 5.4–1.

Figure 2.5.2-1 Red Canyon south of Lander, Wyoming. The red beds are in the Triassic Chugwater group.

Figure 2.5.2-2 Outcrop of the Permian Phosphoria Formation in the Wind River Canyon, Wyoming.

Figure 2.5.2-3 Surficial geology.

EXPLANATION

- QUATERNARY DEPOSITS
- MIDDLE TERTIARY DEPOSITS
- LOWER TERTIARY AND UPPER CRETACEOUS CONTINENTAL DEPOSITS
- UPPER AND LOWER CRETACEOUS MARINE SHALE AND MARGINAL MARINE AND CONTINENTAL SANDSTONE
- LOWER CRETACEOUS AND JURASSIC MARINE AND NON-MARINE SANDSTONE, SHALE, AND JURASSIC, TRIASSIC, PERMIAN RED-BED GYPSUM SEQUENCE
- PALEOZOIC SANDSTONE AND CARBONATE DEPOSITS
- PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

Federal Government Largest Owner of Land Surface and Mineral Rights

The U.S. Bureau of Land Management administers most of the federal holdings.

The proportions of governmental and private ownership of land surface rights differ from county to county within Area 51, but the predominance of government surface ownership can be seen in figure 3.1–1. The mineral rights ownership pattern in the area often is identical to the land surface rights ownership pattern.

The ownership patterns can be understood more clearly through the history of the area. The Federal Government retained ownership of the surface and mineral rights to all unclaimed lands, with the exception of the school sections, when Wyoming was admitted to the Union. This was also true in Montana, except the Federal Government at first withheld the mineral rights and later released them. The rights to sections 16 and 36 of every township, called school sections, were granted to the States upon admission to the Union. Revenues from these lands were to be used for education.

The surface and mineral rights to the Wind River Indian Reservation are shared by the Shoshone and Arapahoe Indian tribes. The reservation was established by the Fort Bridger Treaty of 1863.

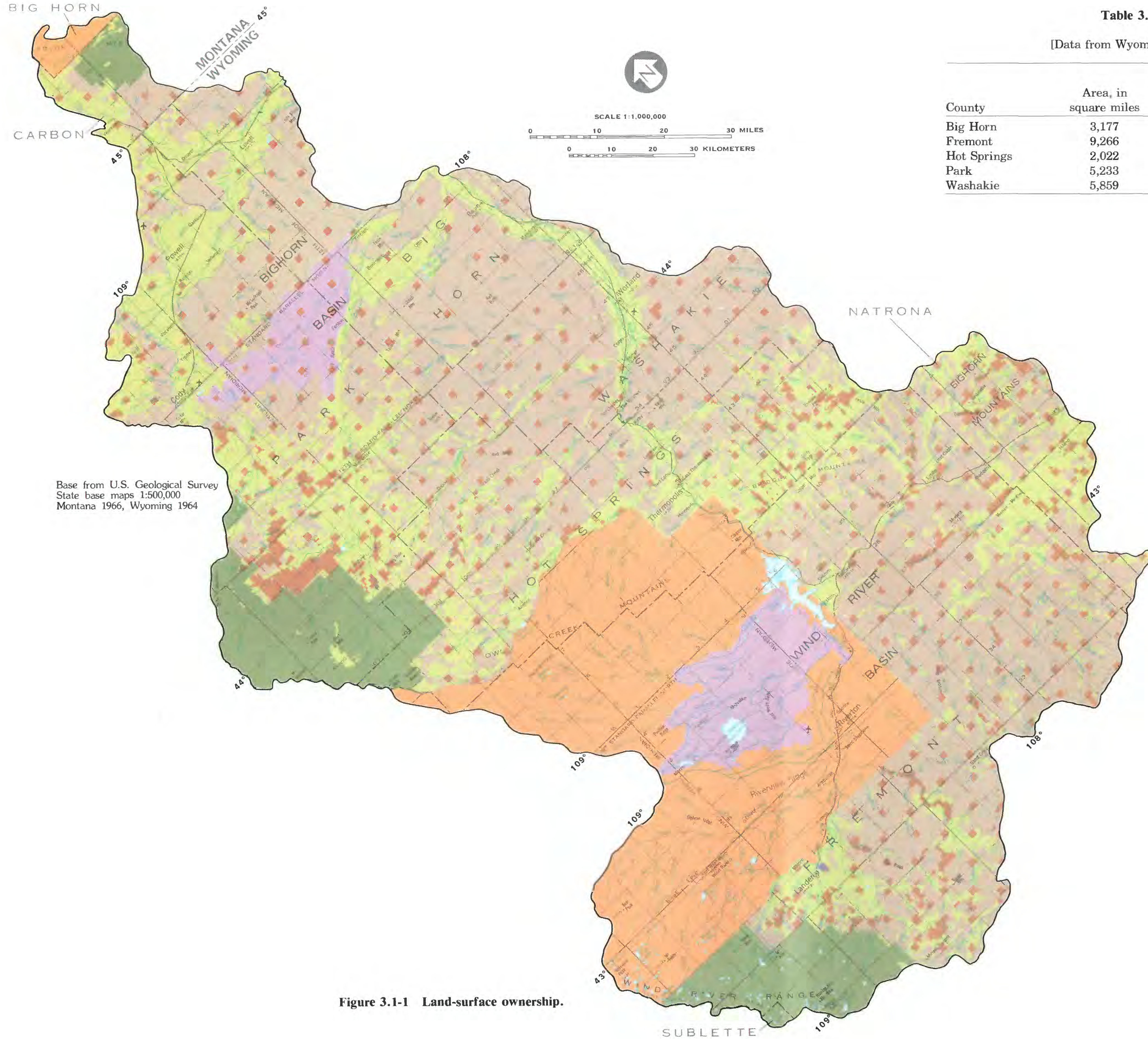
The pattern of private land surface ownership, shown in figure 3.1–1, developed in two ways. Lands along river valleys were homesteaded or bought during settlement of the area because of the availability of water for irrigation and household use. The early homesteaders were granted the mineral rights to their land, but the Federal government retained the mineral rights to private lands claimed after the Homestead Act of 1916. The checkerboard pattern of private and Federal ownership along the northern edge of the area resulted from the Federal grant to the Union Pacific Railroad of the odd-numbered sections in a band 20 miles wide along each side of the railroad. The grant was an incentive to build a transcontinental railway.

Jurisdiction of the Federal holdings has been assigned largely through congressional legislation. Widespread overgrazing and misuse of Federal land in the Western United States prompted passage of the Taylor Grazing Act of 1934. The Act placed substantial areas of Federal land surface under the jurisdiction of an agency, which is now the U.S. Bureau of Land Management, in order to promote sound land-use practices. The U.S. Bureau of Land Management also evaluates Federally owned mineral tracts and conducts leasing programs to make the coal, oil and gas, and other minerals available to the public. The U.S. Bureau of Reclamation has assumed jurisdiction of land surface near Ocean Lake, the Greybull River, and several smaller areas in order to facilitate irrigation projects. The Shoshone National Forest was delineated and placed under U.S. Forest Service jurisdiction by Presidential proclamation. The Washakie Wilderness was later partitioned from the Shoshone National Forest. Land ownership patterns in the Rocky Mountains are described in more detail by Calef (1960) and Foss (1960).

Table 3.1-1 Land ownership in five counties of the area

[Data from Wyoming Department of Administration and Fiscal Control, 1983]

County	Area, in square miles	Ownership, in percent Federal	State and local	Indian	Private
Big Horn	3,177	78	5	0	17
Fremont	9,266	52	3	32	13
Hot Springs	2,022	41	15	13	31
Park	5,233	73	5	0	22
Washakie	5,859	67	10	0	23



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

EXPLANATION

- PRIVATE
- U.S. BUREAU OF LAND MANAGEMENT
- U.S. BUREAU OF RECLAMATION
- U.S. FOREST SERVICE
- MILITARY
- INDIAN RESERVATION
- STATE

Figure 3.1-1 Land-surface ownership.

Livestock Grazing the Most Common Land Use

Much of the land is used as wildlife habitat.

Livestock grazing is the primary use of private land and of public land leased from the Federal and State governments. The ratio of rangeland to cropland is large, due in part to the need to irrigate crops. Most cropland is used for pasture and for hay production to help support livestock (Missouri River Basin Commission, 1978, p. 37). Ratios of rangeland to cropland in five counties are shown in figure 3.2–1. The average ranch size in those five counties ranges from 992 acres in Big Horn County to 8,651 acres in Hot Springs County (Wyoming Department of Administration and Fiscal Control, 1983, p. 109, 137). The ranch sizes are a reflection of the sparse vegetation, which supports only small livestock densities. The total value of agricultural products (primarily livestock) sold in Big Horn, Fremont, Hot Springs, Park, and Washakie Counties during 1978 exceeded $160 million (Wyoming Department of Administration and Fiscal Control, 1983).

Use of the land as wildlife habitat is important in the study area. Lands ranging from rough alpine peaks to vast grassland to sagebrush plains provide habitats for a wide variety of birds and animals. Big game hunting is especially popular in the mountains. Antelope, deer, elk, moose, mountain goats, and mountain lions depend on winter habitat in the study area. Bighorn sheep are natives of the mountains surrounding the Bighorn Basin. The moose winter habitat in Area 51 is considered critical for survival of the species. The peregrine falcon, a species classified as threatened, is resident in the area. Activities of the black-footed ferret (fig. 3.2–2), an endangered species, are currently being monitored in the area.

The amount of land used for urban areas and transportation is small, because of the low population density of the area. The average population density of Big Horn, Fremont, Hot Springs, Park, and Washakie Counties is 3.8 persons per square mile; the largest city in the study area is Riverton (population 8,588) (Wyoming Department of Administration and Fiscal Control, 1983).

The only active (1984) surface coal mine in the area is operated in Hot Springs County (Unit 3.4). Several oil and gas fields and two refineries are operated in the area. Uranium, bentonite, phosphate, copper, and feldspar are economically important in the area, timber harvest is not.

Camping, fishing, hunting, pack trips, and scenic opportunities are abundant (fig. 3.2–3). National forests and primitive areas in the mountain ranges surrounding the basins attract visitors year-round. Bighorn National Forest, although outside the study area to the east, is of national importance; visitors pass through en route to Yellowstone National Park. Resources dispersed throughout the area include geologic, scenic, and archeological areas.

Area 51 contains numerous archeological sites. Evidence of mammoths and Folsom man has been found in the Bighorn Basin. Indian artifacts including weapons and tepee rings and communal bison-kill sites are fairly common in the Bighorn Basin. Numerous petroglyph and pictograph sites also are in the area (Frison and Wilson, 1975, p. 33).

The likelihood of increased production of coal from Area 51 is not known. However, increased mining of coal will cause changes in land uses, not only for coal and transportation facilities, but also for related effects from the increased work force, such as intensified recreational land use. The potential to increase agricultural production, enlarge the timber industry, and provide more recreational facilities in the study area is large. Proper management, conservation, and in-depth land-use plans will facilitate improved efficient use of the land.

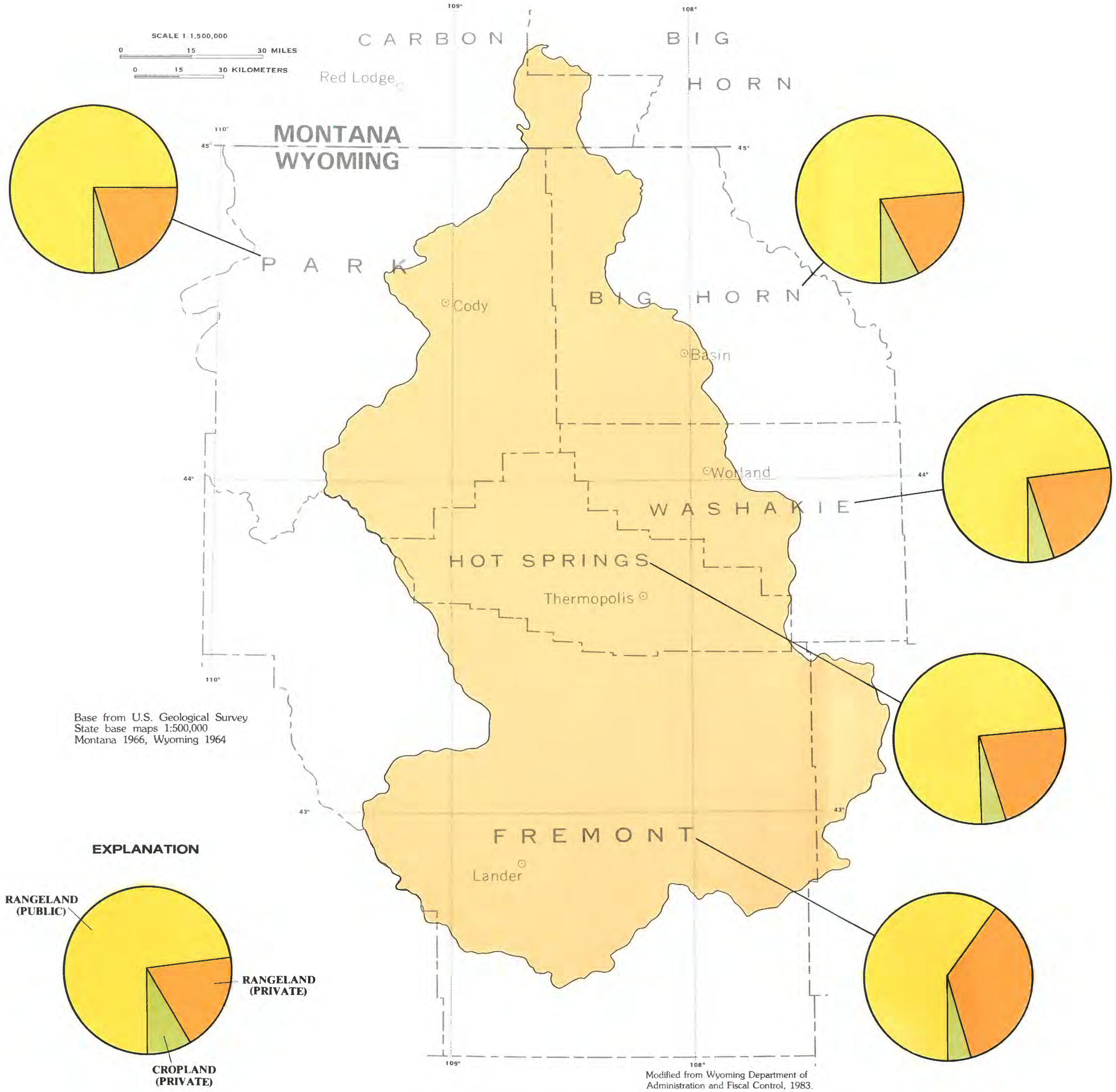


Figure 3.2-1 Ratios of rangeland to cropland, by county.

Figure 3.2-2 Black-footed ferrets are protected by the Threatened and Endangered Species Act of 1973. (Photo courtesy of Wyoming Game and Fish Department.)

Figure 3.2-3 Recreational opportunities are available in the basins as well as in the mountains. (Photo courtesy of Wyoming Game and Fish Department.)

Irrigation Consumes the Largest Amount of Water

Recreation, fish and wildlife habitat, and hydroelectric production are important water uses that are largely nonconsumptive.

The Wind/Bighorn River system provides water supplies for irrigation, industrial, and municipal uses as well as for fish and wildlife habitat and water-based recreation. Because the Wind River and Bighorn Basins are semiarid regions, the supply and use of surface water derived from the melting snow in adjacent mountains are of extreme importance and reservoirs contribute a great deal to stability of flow.

A mosaic of infrared imagery taken from a Landsat satellite is shown in figure 3.3–1. The imagery uses false colors that highlight certain features such as vegetation and soils. The forested mountain areas show in dark red. Irrigated areas are bright red or pink. Sparsely vegetated areas are light gray.

About 90 percent of the present consumptive use of surface water is for irrigation (fig. 3.3–2); evaporation from reservoirs accounts for 9 percent (Wyoming State Engineer, 1972, p. 110). In fact, more than 50 percent of all available surface water is used for irrigation (U.S. Department of Agriculture, 1974, p. II–11); the demand for water greatly exceeds the supply. Most of the irrigated lands are located near the larger perennial streams. Nearly all water used for irrigation is diverted from streams and reservoirs.

Other consumptive uses of water include industrial, municipal, rural domestic, and livestock. The largest industrial consumptive use of water is in the oil and gas industry. Water volumes presently consumed for other industries, including coal mining, in the area are minimal. About 61 percent of the towns use surface water as a source of supply, while the remaining 39 percent use ground water (Wyoming State Engineer, 1972, p. 131). Rural domestic water and stock water are supplied from lakes, streams, ponds, ditches, water wells, and reservoirs.

Reservoirs are used primarily for irrigation, recreation, hydroelectric production, and stabilization of streamflow. Table 3.3–1 lists the principal reservoirs in the area. Hydroelectric-generating plants are operated at two reservoirs in Area 51, Boysen and Pilot Butte.

Water-based recreation is largely a nonconsumptive use. Boating, fishing, and swimming are popular water uses in the area. Lowland reservoirs such as Boysen Reservoir (fig. 3.3–3) and Ocean Lake receive the greatest fishing pressure in terms of fisherman-days. The second most popular type of fishing is from streams, followed by alpine lakes, alpine reservoirs, and lowland lakes (Wyoming State Engineer, 1972). The predominant trout species caught are rainbow, brook, cutthroat, and German brown trout. Walleye and sauger are the most sought after warm-water game fish, while largemouth bass, crappie, perch, bluegill, and bullhead contribute significantly to the fishermen's limits. Although year-round fishing is permitted in the area, most of the fishing is done during May through September.

According to the agreement arrived at in the Yellowstone River Compact, Wyoming is entitled to 80 percent of the total divertable unused water in the Bighorn River. In other words, all existing rights are recognized and Wyoming may take 80 percent of the remainder (Rechard and Ragsdale, 1971, p. 5). The Yellowstone River is shown on figure 2.1–1.

Water is available in the area to meet future water needs. However, there are areas, especially along tributaries, where locally available water supplies are insufficient to meet even the present needs.

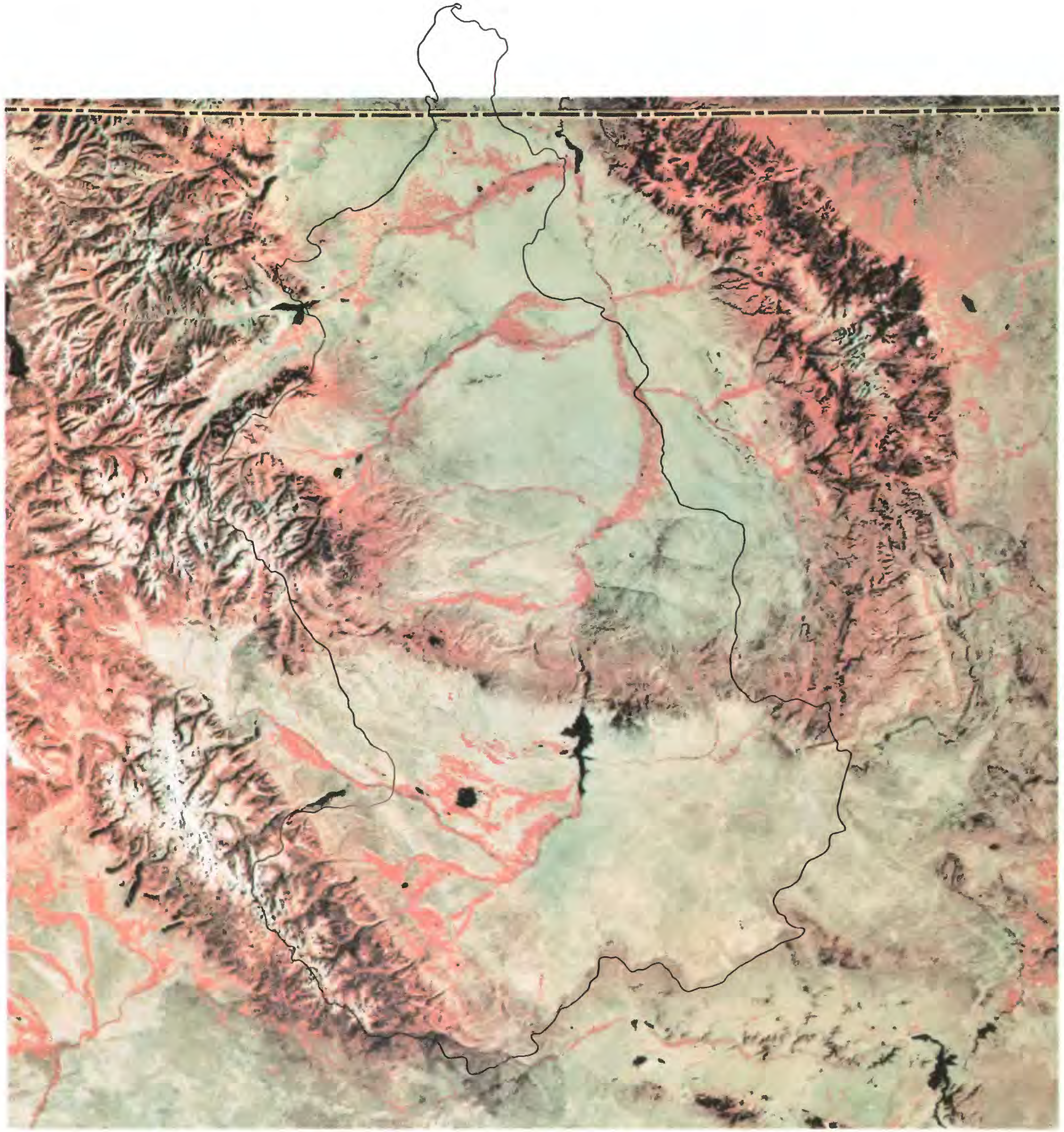


Figure 3.3-1 Infrared imagery obtained from Landsat Satellite highlights mountainous areas of dense vegetation and irrigated areas.

EXPLANATION

FALSE-COLOR INFRARED IMAGERY--

Forested areas show as dark red.
Irrigated areas show as red or pink.
Sparsely vegetated areas show as gray.

Figure 3.3-3 Reservoirs provide for several nonconsumptive uses. (Photo courtesy of Wyoming Travel Commission.)

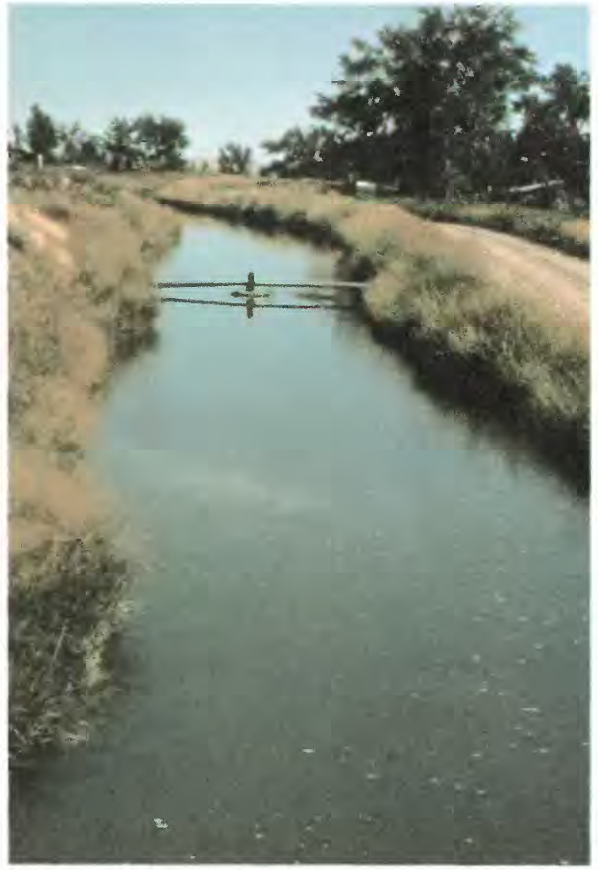


Figure 3.3-2 Irrigation is the primary consumptive water use.

Table 3.3-1 Principal reservoirs in the area

[Reservoirs of over 1,000 acre-foot capacity. Modified from Wyoming State Engineer, 1972, p. 111]

Reservoir	Water use
Anchor	Domestic, irrigation, recreation, and stock water
Boysen	Domestic, industrial, irrigation, mining, municipal, power, recreation, and stock water
Christina Lake	Domestic, irrigation, and stock water
Cody	Municipal, power, and recreation
Enterprise	Domestic, irrigation, recreation, and stock water
Fairview	Domestic, irrigation, recreation, and stock water
Lake Creek	Irrigation and recreation
Louis Lake	Power and recreation
Lower Sunshine	Domestic, industrial, irrigation, power, recreation, and stock water
Perkins and Kinney	Irrigation and recreation
Pilot Butte	Industrial, irrigation, municipal, power, and recreation
Sage Creek	Irrigation and recreation
Shoshone	Irrigation, recreation, and stock water
Teapot	Irrigation and recreation
Upper Sunshine	Domestic, industrial, irrigation, recreation, and stock water
Worthen Meadow	Domestic, irrigation, municipal, and recreation

Millions of Tons of Strippable Coal are Available

A strippable deposit of low sulfur, bituminous coal is in the Bighorn Basin.

The estimated strippable coal-reserve base of the Bighorn Basin is 18,600,000 short tons of bituminous-rank coal (Glass, 1982, table 9). In addition, subbituminous coal beds underlie much of the area in the Bighorn and Wind River Basins (figure 3.4–1). The deposit in the Wind River Basin, which is relatively thin, steeply dipping beds, is economically insignificant compared to that of the Bighorn Basin, which in turn, is small compared to deposits in other parts of Wyoming and Montana.

The bituminous coal mined in the Bighorn Basin is good quality, because of its heat value and low-sulfur content. The coal has an average heat value of nearly 11,000 British thermal units per pound and an average sulfur content of 0.4 percent (Glass, 1978, p. 70).

The quality of coal from the study area is compared to the quality of coal from other parts of the United States in table 3.4–1. The quality factors listed as most important by Zimmerman and Glass (1984) include the following:

Heat value—An important indicator of potential energy available from the burning of coal. Heat value generally is reported in British thermal units on an as-received basis.

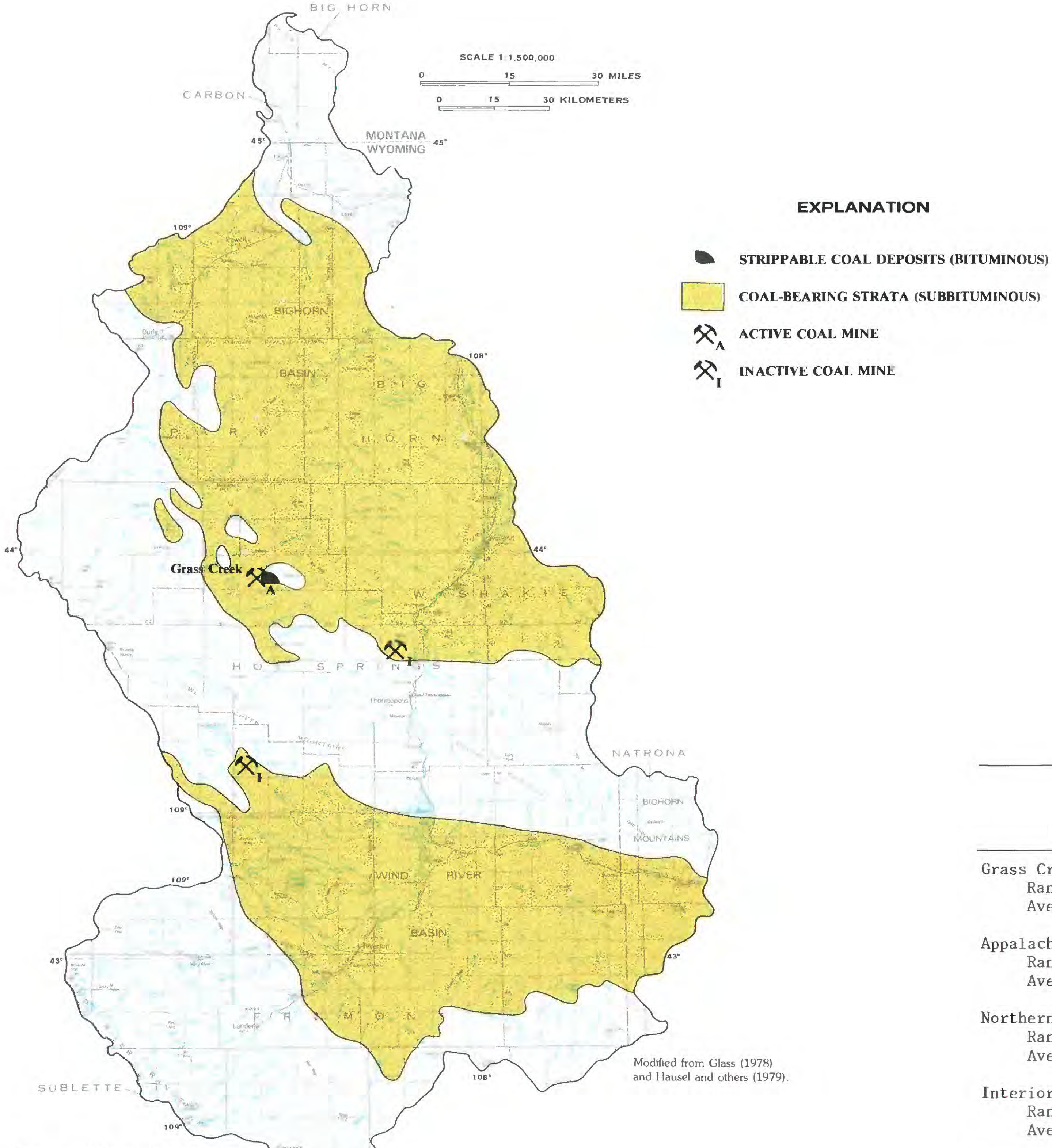
Ash—An undesirable residue, generally reported as a percentage by weight. The percentage is about the same in coal from Area 51 as in coal from other regions.

Sulfur—Produces an acid-forming gas, sulfur dioxide, when burned. Sulfur is reported as a percentage by weight. Coal from Area 51 is low in sulfur compared to most coal from other regions.

Moisture—Can cause slaking (disintegration) and spontaneous combustion in stored coal. Moisture is reported as a percentage by weight.

The coal deposits of the area occur in formations of Late Cretaceous and Tertiary age. Historically, coal from the Mesaverde Formation of Late Cretaceous age has been the most important for mining operations, but interest in coal from the Fort Union Formation of Tertiary age has heightened recently (Glass and others, 1975, p. 221–222).

Only the Grass Creek surface mine (fig. 3.4–2) is active (1984) in the area. Mine production during 1982 was 66,711 short tons (Wyoming State Inspector of Mines, 1982, p. 24). The coal is mined from the Mayfield coal bed of the Fort Union Formation. The estimated strippable reserve base for the Mayfield coal bed is 15 million tons (Stewart, 1975). Locations of the Grass Creek mines and deep mines in the Bighorn Basin are described by Glass and others (1975, p. 221–227); abandoned surface mines and deep mines in the Wind River Basin are described by Glass and Roberts, (1978, p. 363–375).



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

Figure 3.4-1 Coal deposits.

Figure 3.4-2 Grass Creek surface mine.

Table 3.4-1 Characteristics of coal from Area 51 and other major coal regions

[Btu/pound, British thermal unit per pound. All analyses on an as-received basis. Modified from Zimmerman and Glass (1984), and Glass (1982, p. 663.)]

Coal-bearing area	Heat value (Btu/pound)	Ash (percent, by weight)	Sulfur (percent, by weight)	Moisture (percent, by weight)
Grass Creek field, Bighorn coal basin[1]				
Range	10,730 - 11,246	5.0 - 9.4	0.3 - 0.6	10.7 - 12.8
Average	10,970	7.4	0.4	12.3
Appalachian region[2]				
Range	6,700 - 15,000	2.4 - 45.2	0.5 - 15.0	0.7 - 15.1
Average	12,890	11.0	2.3	2.8
Northern Great Plains province[3]				
Range	6,330 - 9,900	4.2 - 21.9	0.2 - 4.9	17.8 - 36.9
Average	8,480	8.3	1.2	24.5
Interior province (Mid-Continent)[4]				
Range	6,670 - 14,770	1.7 - 36.7	0.4 - 13.5	1.3 - 18.6
Average	11,580	12.6	3.9	7.2

[1] Fort Union coal
[2] Pennsylvania, Ohio, Maryland, West Virginia, Kentucky, Tennessee, and Alabama
[3] North Dakota, Montana, and Wyoming
[4] Michigan, Indiana, Iowa, Nebraska, Missouri, Kansas, Oklahoma, and Arkansas

Resources Abundant in Area

Wells tap supplies of oil, gas, and geothermal water; uranium, bentonite, and gypsum are mined in the area.

Oil and gas production accounts for a major percentage of the valuation of minerals produced from the area. Oil and gas wells are located throughout the area, in addition to the major oil and gas fields that are shown in figure 3.5–1. The Oregon Basin and the Elk Basin fields have been among the largest producers in the area since the early 1900's. The Elk Basin field, for example, has produced 413 million barrels of oil since 1915 (Wyoming Oil and Gas Conservation Commission, 1983a, p. 23). Total production figures for the study area are not available, but figures are available for three counties which comprise much of the study area. During 1982 wells in Fremont, Hot Springs, and Park Counties produced more than 40 million barrels of oil and 74 billion cubic feet of natural gas (Wyoming Oil and Gas Conservation Commission, 1983b, p. 1). Production in the Bighorn Basin generally is from stratigraphic traps in Jurassic or older formations; production in the Wind River Basin is from stratigraphic or structural traps in Tertiary and Cretaceous formations, and from structural traps in Jurassic or older formations (Ver Ploeg, 1982, p. 3).

Geothermal water rises to the surface at several locations in the study area (Breckenridge and Hinckley, 1978), but the most notable is Hot Springs State Park near Thermopolis. Numerous springs in the park produce about 4,800 gallons per minute of 115- to 132-degree Fahrenheit water (Hinckley and others, 1982, p. 5). The travertine terraces formed by the springs and the variously colored algae and bacteria that inhabit the terraces are well known for their aesthetic value (figure 3.5–2). Within the park, water from Big Spring also supplies nearby pools at public and private establishments. Several Thermopolis area residences are heated with geothermal water (Hinckley and others, 1982, p. 36). Geothermal waters also occur at depth in much of the study area (Heasler and others, 1983, map).

Uranium is mined in the southeastern fringe of the area. The locations of eight uranium mines that were active as of 1979 are shown in figure 3.5–1. Declining market conditions after 1979 caused several mines to cease operation. The three mines operating during 1982 produced an annual total of 764,000 short tons of ore (Wyoming State Inspector of Mines, 1982, p. 32–34). Only one mine was operating as of 1983 (Harris, 1983, p. 9).

Bentonite, a swelling clay, is mined at four locations in the area. Bentonite mines are operated intermittently, depending on the properties of the individual deposit and the current requirements. Total production from the area during 1982 was 181,238 short tons (Wyoming State Inspector of Mines, 1982, p. 38). Bentonite is used in the manufacture of drilling fluid and foundry castings, for pelletizing taconite, and in many minor industrial products.

Gypsum is quarried at two locations in the area. The gypsum is quarried from the Gypsum Spring Formation of Middle Jurassic age (Bullock and Wilson, 1969, p. 2–5). Total production of the two quarries was 308,332 short tons during 1982 (Wyoming State Inspector of Mines, 1982, p. 57–58). The quarries operate in conjunction with a mill that produces drywall, also called gypsum board.

Feldspar was mined on the south flank of Copper Mountain, in the central part of the area, during the 1970's, and was milled at a plant located at Bonneville. The feldspar was used for the manufacture of household cleanser and porcelain products.

Miscellaneous operations and prospects include sand and gravel, clay, limestone, dolomite, zeolites, talc, sulfur, pumice, and shale quarries. Metals, such as copper, gold, titanium, rare earths, and silver, have been found in the area, but are not currently (1984) mined. The Absaroka, Owl Creek, and Bridger mountain ranges contain many ore deposits of potential economic value, and are currently being explored and mapped by the Geological Survey of Wyoming as well as private companies. The mineralogy of some of the ore deposits in the area has been described by Hausel (1982) and Wilson (1964).

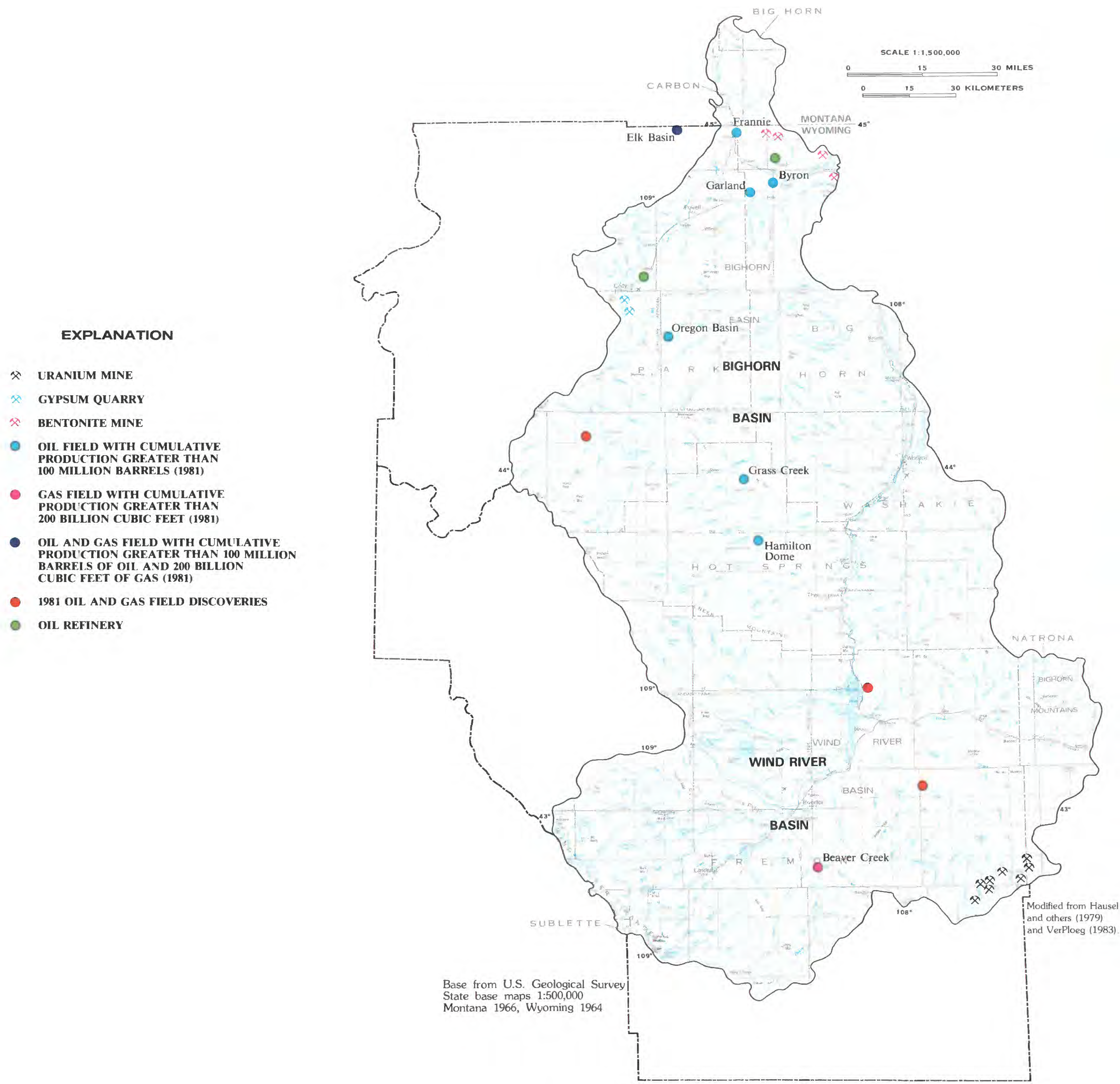


Figure 3.5-1 Mineral resources, other than coal.

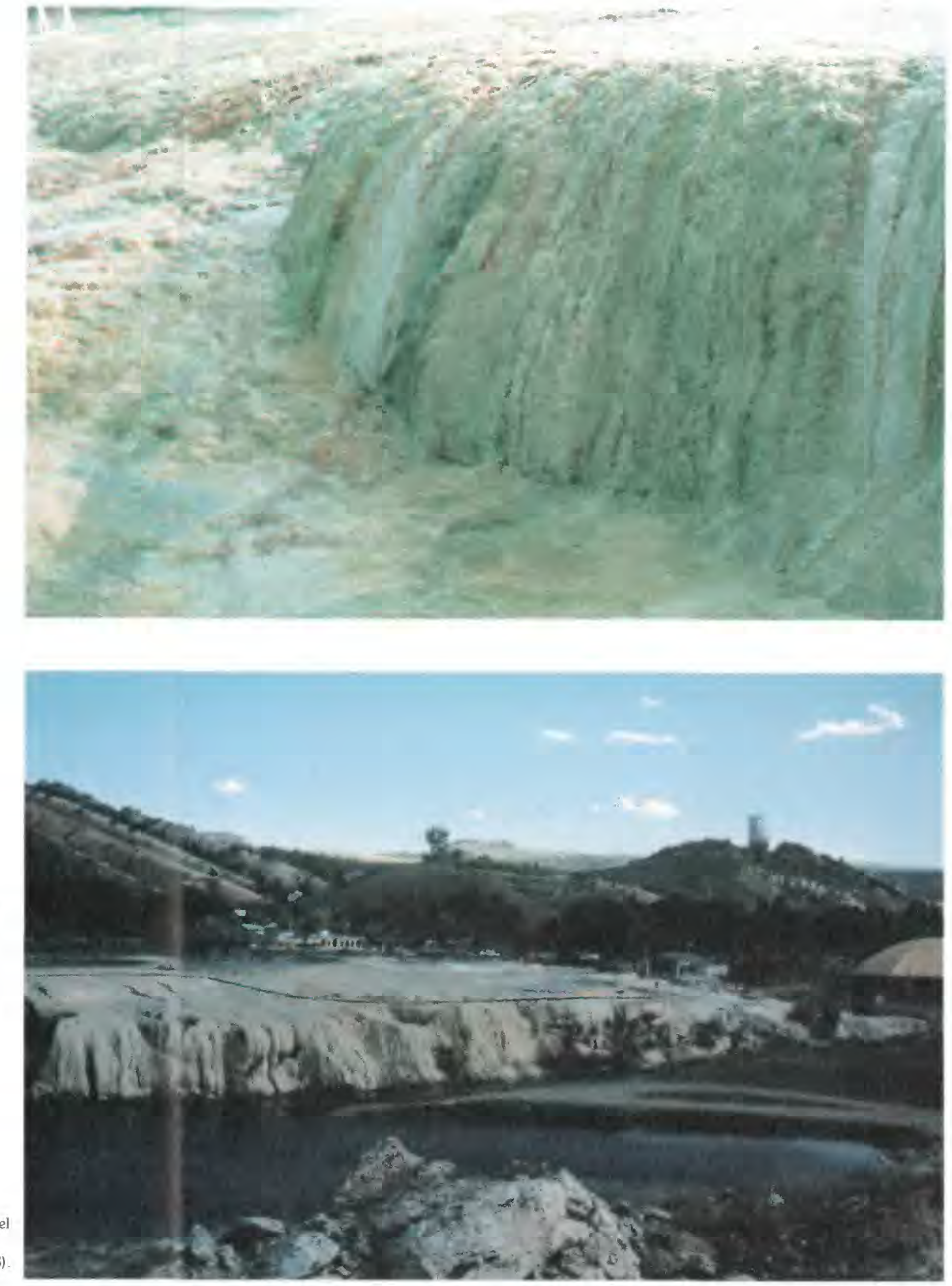


Figure 3.5-2 The algae and bacteria that inhabit the terraces at Hot Springs State Park are dependent on water temperature.

Network Contains 173 Stations

Surface-water quantity and/or quality were systematically determined at the stations.

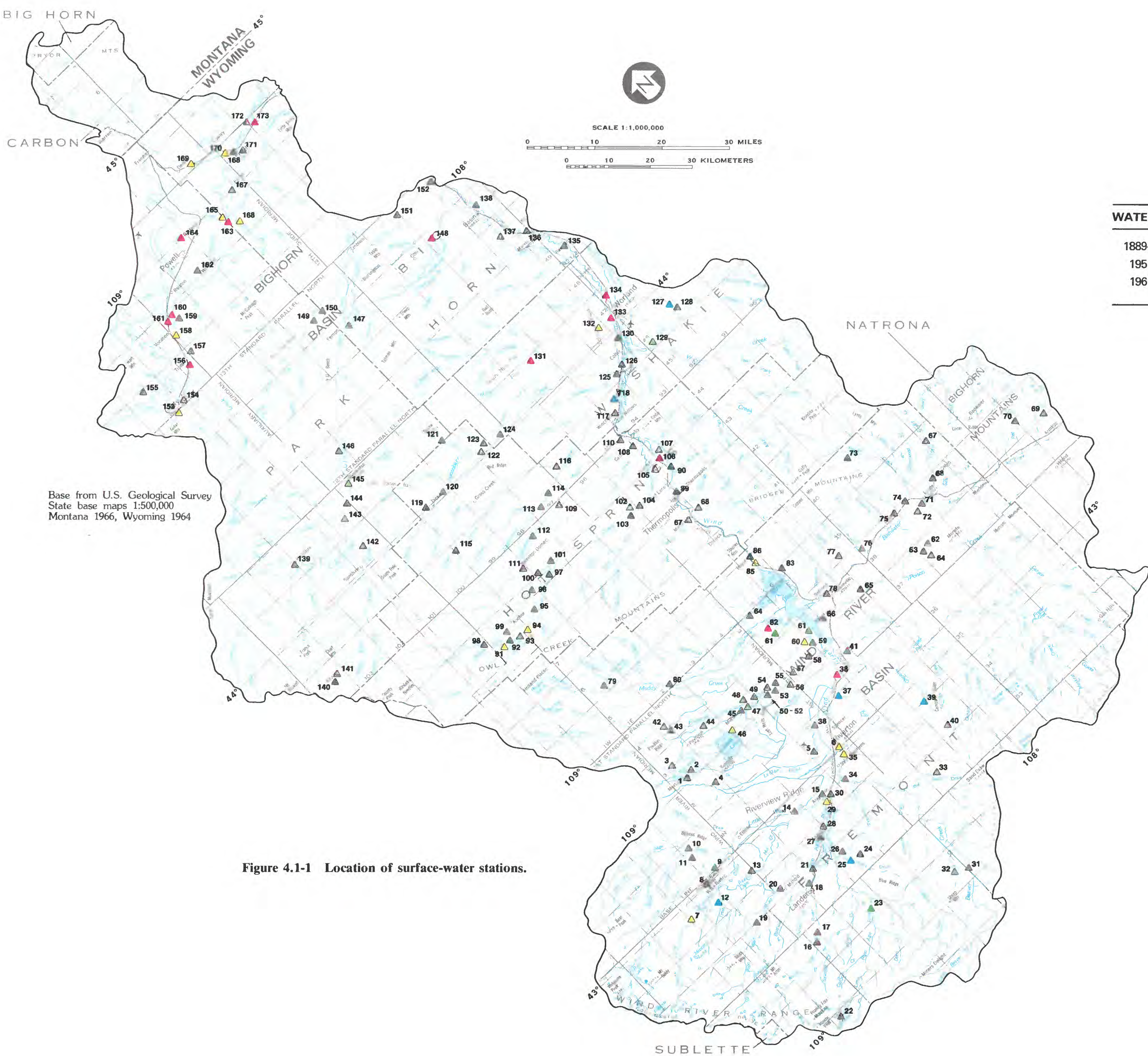
A surface-water station is a location where discharge measurements and/or water-quality samples are collected on a systematic basis, often at a monthly or quarterly frequency. Station locations are shown in figure 4.1–1. For this report, sequential numbers are assigned to the stations instead of the eight-digit station identification numbers that are customarily used by the U.S. Geological Survey. The sequential and corresponding eight-digit station numbers, a description of the location, and the type and length of record for each station are listed in Unit 10.1.

The available surface-water-quantity data include continuous streamflow records, peak-flow measurements, and instantaneous-streamflow measurements. At continuous-record stations, a shelter houses a recorder and water-level sensing equipment. The daily mean streamflow is calculated from the continuous water-level records and periodic measurements of instantaneous streamflow. Daily streamflow data are utilized in many ways, such as by the Wyoming State Engineer for management of water for irrigation.

At peak-flow stations, either a crest-stage indicator (CSI), or a stage-rainfall gage (SR gage) are operated. A peak-flow station is used when information is needed about peak flows, such as for bridge and culvert design.

Available surface-water-quality data include chemical quality, suspended sediment, daily measurements of temperature and specific conductance, or combinations of these. The sampling frequency of chemical quality and suspended sediment often is monthly or quarterly, and is done in conjunction with measurement of instantaneous discharge. Most of the chemical-quality data include analyses of dissolved solids, principal ions, nutrients, and physicochemical measurements, such as dissolved oxygen and pH. Trace metal, radiochemical, biological, and herbicide data are available for some stations. The suspended-sediment data include concentrations, loads, and particle-size analyses. Suspended-sediment samples are collected by automated samplers at some stations. The daily water-temperature and specific-conductance measurements are obtained from either automated recorders or observers.

Data for stations shown in figure 4.1–1 can be retrieved from the computer files of the U.S. Geological Survey. Information about computer storage and retrieval of the data is given in Unit 9.3. Users should refer to the eight-digit station number when requesting data for a particular station. The data also are available in printed form. Data for October 1965 through September 1983 have been published in annual reports of the U.S. Geological Survey (see Section 11.0). Data prior to October 1965 have been published in three reports, which are listed in table 4.1–1. The data are compiled by water year, which is October 1 through September 30 of the following year. For example, water year 1950 is October 1, 1949 through September 30, 1950.



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

Figure 4.1-1 Location of surface-water stations.

Table 4.1-1 Reports listing data prior to October, 1965

[WSP; U.S. Geological Survey Water-Supply Paper.]

WATER YEARS	REPORT	AUTHOR
1889-1950	WSP 1309	U.S. Geological Survey, 1959
1951-60	WSP 1729	U.S. Geological Survey, 1964
1961-65	WSP 1916	U.S. Geological Survey, 1969

EXPLANATION

- ACTIVE (1982) STREAMFLOW-GAGING STATION
- ACTIVE (1982) WATER-QUALITY STATION
- ACTIVE (1982) STREAMFLOW-GAGING AND WATER-QUALITY STATION
- ACTIVE (1982) PEAK-FLOW STATION
- DISCONTINUED STATION
- 129 STATION NUMBER

Unit 10.1 provides additional station information.

Network Contains 44 Miscellaneous Sites

Samples of surface-water quality were collected at the sites.

A miscellaneous site is a location where a limited number of water-quality samples were collected on an occasional basis. Locations of miscellaneous sites and site numbers used for this report are shown in figure 4.2–1. The site numbers and a description of the location of each site are listed in Unit 10.2. The sequential number assigned to each miscellaneous site for this report corresponds to a fifteen-digit site-identification number customarily used by the U.S. Geological Survey.

The miscellaneous sites shown in figure 4.2–1 were established for studies that required information at locations where stations were nonexistent. For example, surface-water-quality samples were collected at miscellaneous sites by Cooley and Head during their studies of hydrogeologic features of alluvial deposits in the Greybull River valley (1979) and the Owl Creek valley (1982). These two reports include the results of measurements of specific conductance and chemical quality at miscellaneous sites. Data from miscellaneous sites also may be retrieved from computer storage (Unit 9.3).

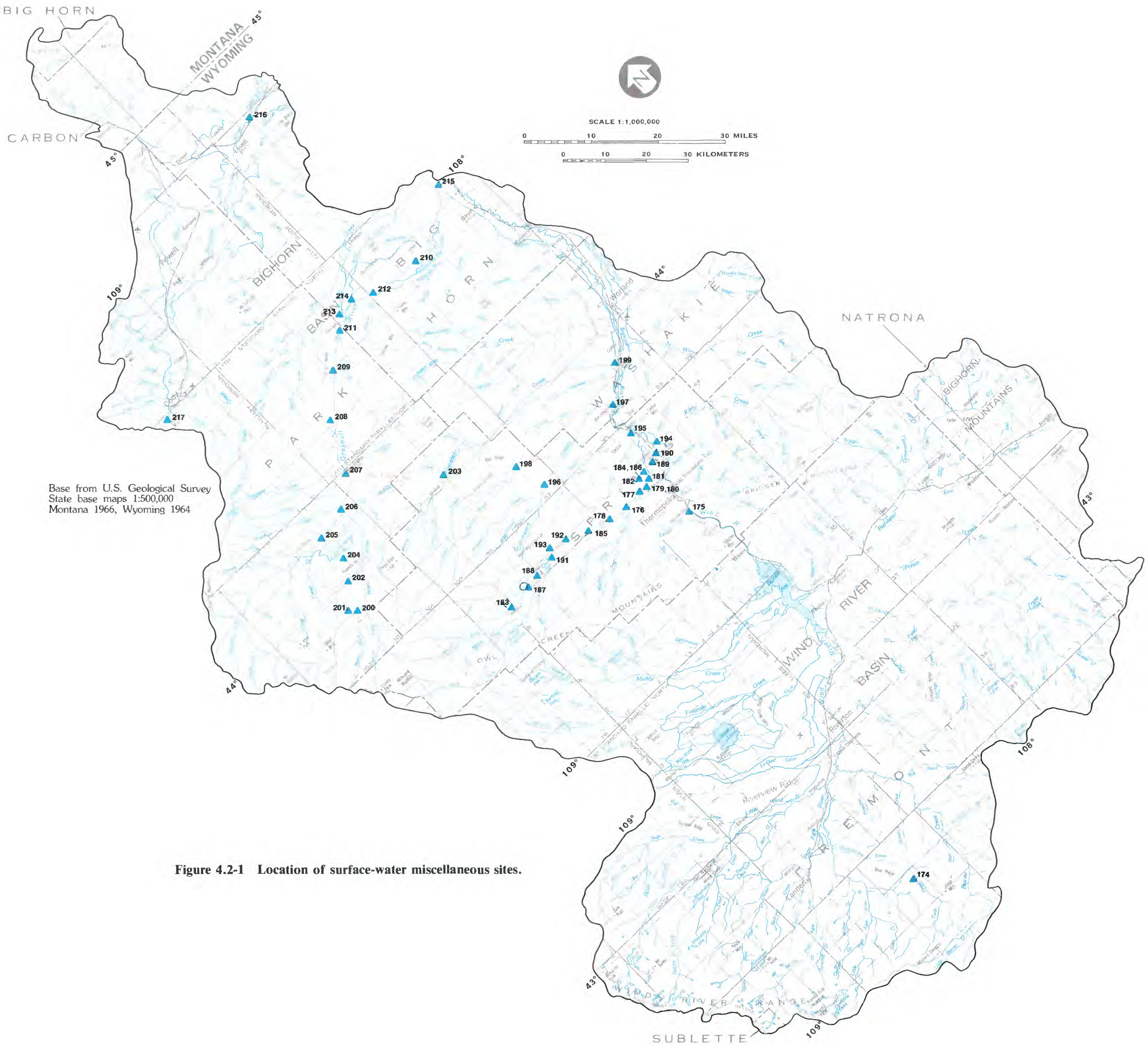


Figure 4.2-1 Location of surface-water miscellaneous sites.

EXPLANATION

▲194 SURFACE-WATER MISCELLANEOUS SITE AND NUMBER

Unit 10.2 provides additional site information.

Mountain Areas Produce Much Greater Runoff than Intermontane Basins

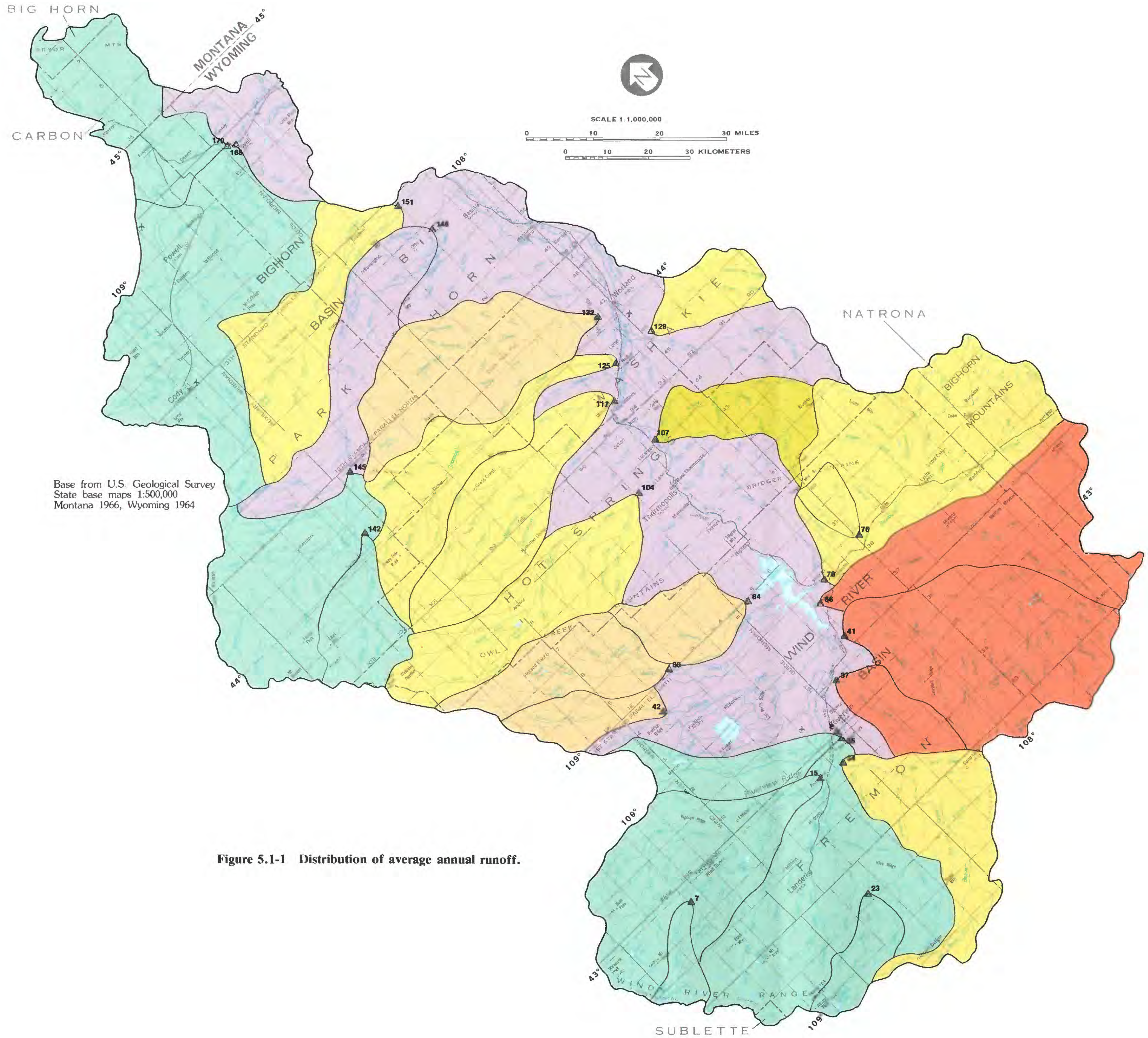
Average annual runoff per square mile exceeds 200 acre-feet in the mountain areas and is less than 10 acre-feet in the semiarid basins.

Average annual runoff, in acre-feet per square mile, was computed using streamflow data collected at 27 gaging stations in the area. Values of average annual runoff range from 0.39 to 970 acre-feet per square mile. The data were divided into six groups by magnitude of average annual runoff; the results are presented in figure 5.1–1.

Average annual runoff from the mountain areas is a function of climatic factors and physical characteristics of the basins. Important climatic variables are precipitation, temperature, wind, evaporation, and solar radiation. Climatic conditions of a mountain basin are related to the basin elevation and the basin's relative position in the mountain range. The most important physical characteristic is the drainage basin size. Moisture storage in the form of lakes, ponds, and aquifers has some effect on total runoff, but to a much lesser degree than the climatic conditions and drainage area.

Average annual runoff of streams originating in the semiarid areas of the Wind River Basin and the Bighorn Basin is a function of quantity and intensity of precipitation, drainage area, evapotranspiration and permeability of the surficial material. Rainstorm intensities or snowmelt rates that exceed the infiltration rate of moisture into the surficial material produce runoff. The contribution of discharge from ground water to streams originating in the Wind River Basin and the Bighorn Basin is minor. Manmade drainage structures, stock ponds, and irrigation works decrease the total runoff from a basin by increasing the time for water losses due to evaporation and evapotranspiration, as well as by retention of water for consumptive use.

Average annual flow, in cubic feet per second, can be estimated for ungaged sites in Area 51 by using regression equations developed by Lowham (1976, p. 23). Equations for perennial streams in mountain areas were developed by relating runoff to drainage area and basin elevation. Average annual runoff from basins in the semiarid areas was related only to drainage area. These equations were developed for Wyoming but are applicable to the Montana part of Area 51.



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

Figure 5.1-1 Distribution of average annual runoff.

EXPLANATION

▲ STATION AND NUMBER

〜 DRAINAGE BASIN BOUNDARY

AVERAGE ANNUAL RUNOFF FROM DRAINAGE AREA UPSTREAM FROM GAGING STATION IN ACRE-FEET PER SQUARE MILE PER YEAR

- 0-9.99
- 10-19.9
- 20-49.9
- 50-99.9
- 100-199
- 200 and greater

Low Flow is No Flow in Most Intermontane Streams

Because most semiarid streams flow only in response to rainstorms and snowmelt, they are dry most of the time; mountain streams flow even during most dry seasons and droughts.

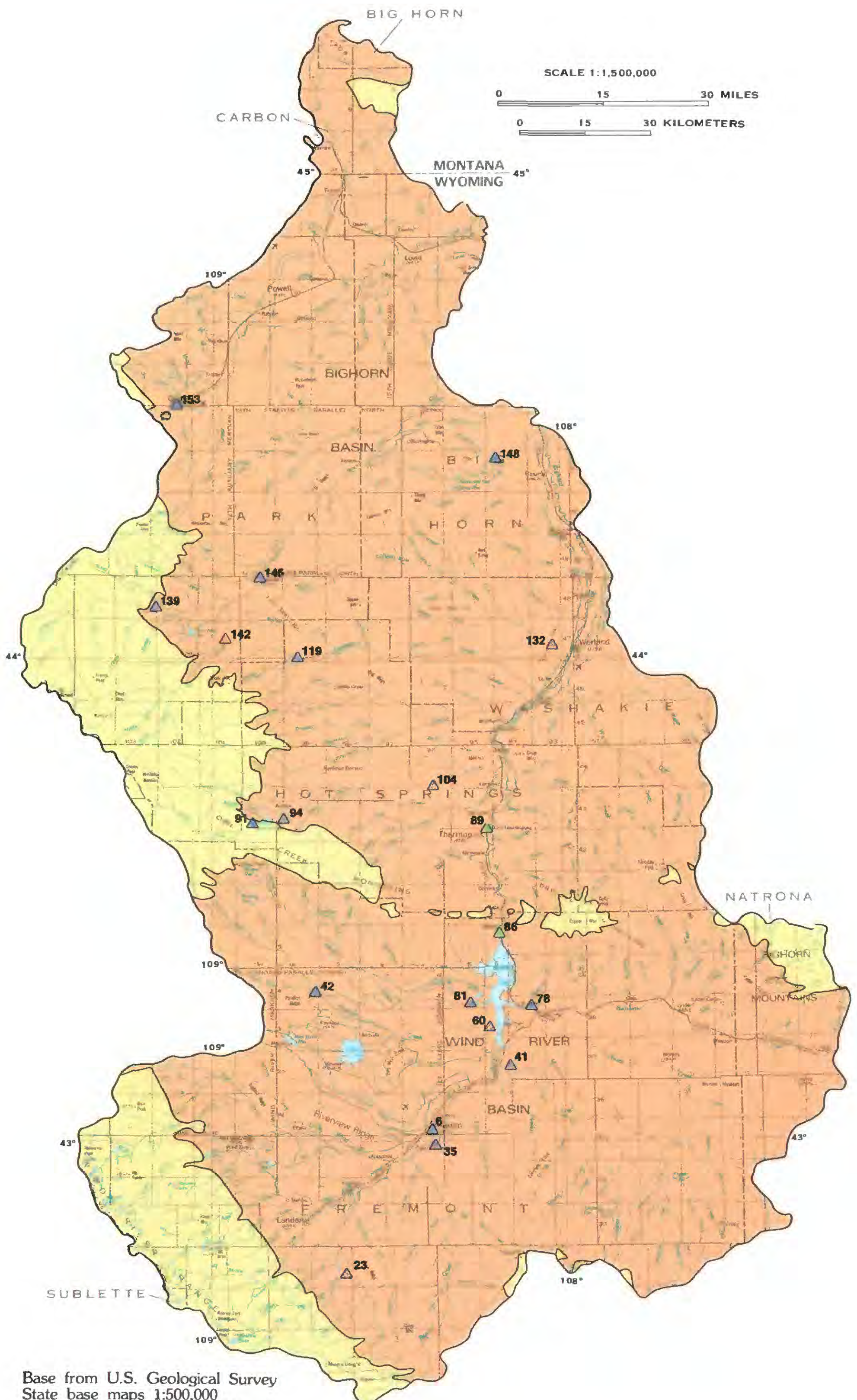
Most of the streams originating in the semiarid intermontane basins are ephemeral and have long periods of no flow. Only the largest streams maintain flow for extended periods during most years. Some streams (called interrupted streams) in the intermontane basins tap shallow aquifers or are fed by springs that provide perennial flow for relatively short reaches. Such flows do not continue far from their sources, because of infiltration and evapotranspiration; consequently, the streams cease flowing.

Minimum flows greater than zero in the mountain streams result from more precipitation, less evapotranspiration, and a larger capacity to store moisture than those streams originating in the semiarid areas. Moisture is stored in aquifers and near-permanent snowpacks and is released at a slow rate to sustain the streamflow.

Streamflow records for stations with 20 or more years of record (fig. 5.2–1) were analyzed for 7-day low-flow statistics. The results of these analyses are listed in table 5.2–1.

The Wind/Bighorn River is a perennial stream throughout its entire reach. Just upstream from where the Wind River enters Area 51, nearly 45 percent of the flow is diverted into the Wyoming Canal for irrigation in the Riverton Project. The low-flow analysis for station 6, Wind River at Riverton, shows the historical record of low-flow downstream from the diversion of water in to the Wyoming Canal and upstream from the return flow to the Wind River. Return flow from the irrigation project re-enters the river below Riverton via drains, Fivemile Creek and Muddy Creek. Low-flow analyses were made for 30-year periods before and after the installation of Boysen Reservoir. Flow data collected at station 89, Bighorn River at Thermopolis, were used to compute the low-flow statistics before the installation of Boysen Reservoir. Data collected at station 86, Wind River below Boysen Reservoir, were used to compute low flow after the installation of Boysen Dam. The increased low-flow discharge after the reservoir operation started is shown in figure 5.2–2.

Low-flow characteristics for station 142, Wood River at Sunshine, are illustrated (fig. 5.2–3) as an example of the type of information available for perennial streams that originate in the mountains. These low-flow characteristics provide information about water supplies for municipal and industrial uses, irrigation, instream fisheries, and waste disposal. Low-flow studies for ephemeral streams, which have zero flow for many days each year, have little value. Because streamflow in ephemeral and intermittent streams is extremely variable, the average annual flow of these streams (Unit 5.1) is also of little value when seeking a dependable water supply. A reservoir-storage frequency model has been developed by Glover (1984). This model computes the probabilities of reservoir storage including the risk of being unable to supply downstream demands. The model evaluates the within-year and the between-year variability of streamflow for an ephemeral stream.



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

EXPLANATION

△132 STATION AND NUMBER

BOUNDARIES BETWEEN MOUNTAINS AND INTERMONTANE BASINS

MOUNTAINS

INTERMONTANE BASINS

Figure 5.2-1 Geographic boundaries between mountains and basins and the location of stations used in the computation of low-flow statistics.

Table 5.2-1 Seven-day low-flow statistics

Station No.	Drainage area (square miles)	Length of record (years)	Discharge (cubic feet per second), Recurrence interval (years): 1.01	1.25	2	5	10	20	Number of years of no flow[1]
Tributaries to Wind/Bighorn River									
23	125	25	26.5	22.0	19.1	16.0	14.4	13.1	0
35	1,094	40	222	153	115	81.2	66.2	55.1	0
41	733	20	-----	-----	-----	-----	-----	-----	20
42	118	25	-----	-----	-----	-----	-----	-----	21
60	418	33	15.6	38.2	30.6	23.5	20.1	17.5	0
78	808	25	-----	-----	-----	-----	-----	-----	25
81	332	29	9.98	5.18	2.25	-----	-----	-----	11
91	87.0	21	7.27	3.42	1.61	.50	.40	-----	1
94	131	22	.86	.14	-----	-----	-----	-----	16
104	478	27	20.6	3.58	1.26	.42	.23	.14	0
119	95.0	20	8.04	1.90	.50	.04	-----	-----	2
132	518	24	-----	-----	-----	-----	-----	-----	24
139	282	21	25.5	21.6	18.0	13.8	11.6	9.87	0
142	194	26	34.1	31.7	25.4	15.4	10.4	6.89	0
145	681	39	82.1	59.8	47.2	35.7	30.3	26.2	0
148	1,115	42	65.8	24.3	10.4	3.07	1.12	-----	2
153	1,538	61	724	428	288	179	135	105	0
Wind/Bighorn River									
6	2,309	65	480	250	144	72.0	47.0	32.0	0
86	7,701	30	1,240	880	653	444	349	281	0
89	8,020	30	706	529	435	349	309	277	0

[1] Seven or more consecutive days of no flow

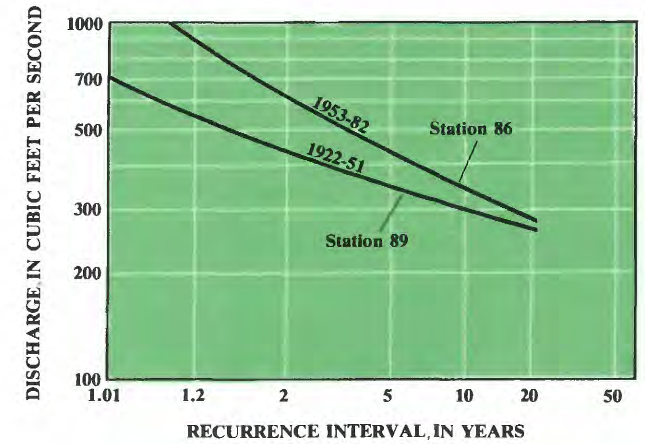


Figure 5.2-2 Frequency curves of annual minimum 7-day means for stations on the Wind/Bighorn River before and after the closing of gates on Boysen Dam.

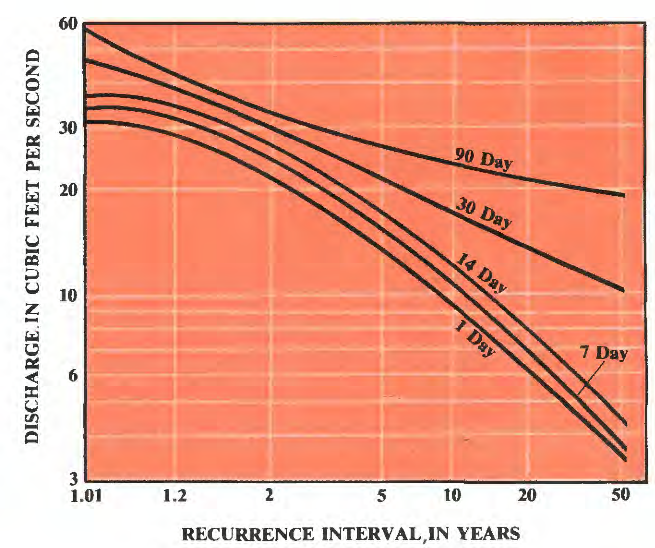


Figure 5.2-3 Low-flow characteristics of station 142, Wood River at Sunshine, Wyoming.

Climatic Factors Determine Flood Flows

Rapid spring snowmelt in the mountains and intense summer thunderstorms in the intermontane basins cause most of the floods in the area.

Mountain streams flood mainly during the spring or early summer. The magnitude of the flood depends on the volume and water content of the snow accumulated during the preceeding winter, air temperature, solar radiation, and the quantity of spring rain. A slow warming trend in the spring causes a prolonged runoff, with stream channels full, but seldom overflowing. An early warm spell however, with night temperatures near or above freezing with moderate winds, can cause a short-duration runoff of much greater magnitude. Extremely large flows result when a combination of deep snowpack, warm air, and rain occurs.

Streams originating in the intermontane basins may flood when accumulated snow is melted during a winter or spring thaw; spring rains and summer thunderstorms also may cause floods. Occasional intense thunderstorms produce the largest floods. Such storms typically pass over only part of a drainage area, but the magnitude of the floods, particularly in small streams, can be large.

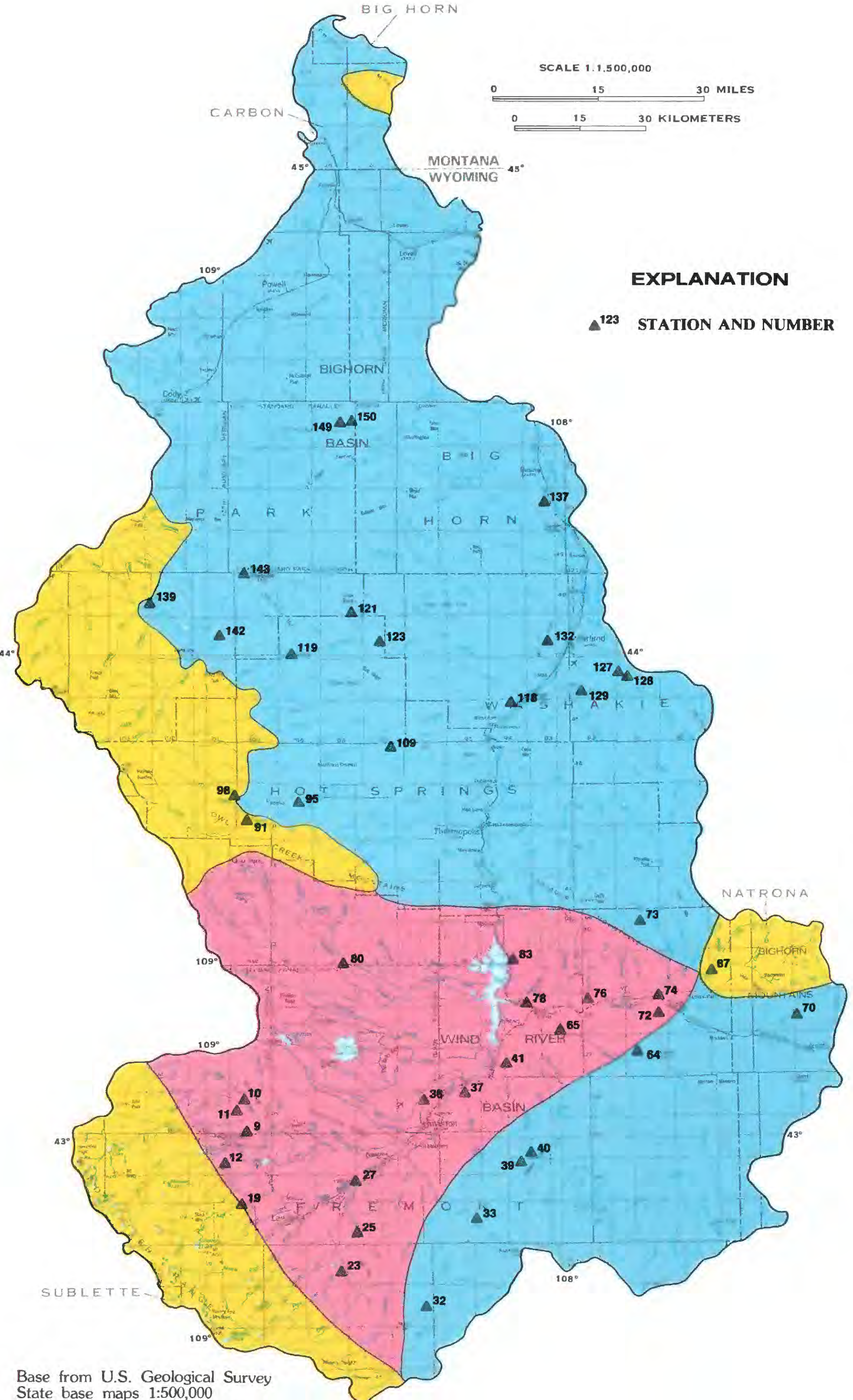
Forty-four streamflow stations in Area 51 have discharge records of sufficient length to determine the 100-year peak discharge, or 100-year flood. The station numbers, drainage areas, and discharges are listed in table 5.3–1. Locations of the stations are shown in figure 5.3–1. A 100-year flood is defined as the annual maximum instantaneous (peak) discharge that will be equaled or exceeded once in 100 years, on the average.

Equations and graphs for predicting the magnitude of the 100-year flood at ungaged sites have been developed by regression techniques. Values of discharge for the 100-year flood, such as those listed in table 5.3–1, were used as the dependent variable in the regression analysis. Various basin and climatic characteristics are used as independent variables.

The graphs in figure 5.3–2 may be used to estimate the 100-year flood at ungaged sites in areas of corresponding color on the map. The discharge relations in figure 5.3–2 and the boundaries on the map are from those developed by Lowham (1976). Hydrologists presently (1984) are revising the analyses for Wyoming, based on additional data obtained since the report by Lowham (1976) was prepared.

An area-weighted discharge method is used when a discharge is needed for an ungaged basin that is crossed by a color-area boundary. An estimate of the 100-year flood is computed by (1) obtaining the discharge from each application graph, using the total drainage; (2) multiplying each discharge by the ratio of the drainage area within the corresponding colored area to the total drainage area; and (3) obtaining the sum of the values in step 2.

For some purposes estimates of flood discharge for frequencies other than 100-year are required. Estimates of the 10-year and the 25-year floods, for example, may be required for the design of sediment-detention ponds. The report by Lowham (1976) contains graphs and equations for estimating floods of selected frequencies. A method applicable only to ephemeral streams with drainage areas less than 11 square miles was developed by Craig and Rankl (1978). The report provides methods for estimating volume and peak discharge for selected frequencies and for preparing synthetic hydrographs.



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

Figure 5.3-1 Flood-area boundaries and location of stations where the 100-year flood has been determined. Colors correspond to colors in figure 5.3-2.

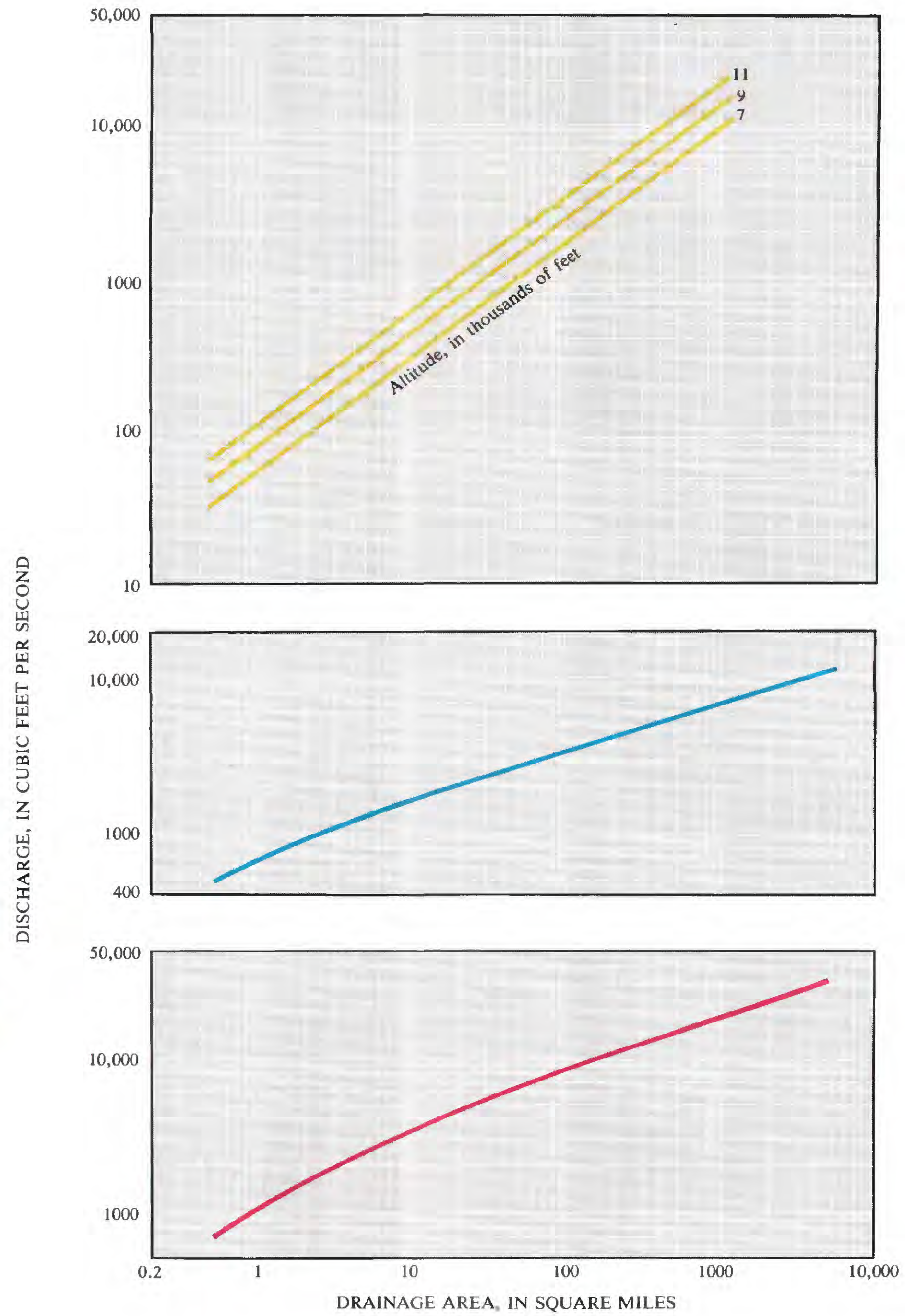


Figure 5.3-2 Relation of 100-year flood to drainage area of corresponding color on map (After Lowham, 1976).

Table 5.3-1 100-year floods (P-100) for selected stations

Station No.	Drainage area (square miles)	P-100 (cubic feet per second)	Station No.	Drainage area (square miles)	P-100 (cubic feet per second)
9	127	3,500	76	52.6	3,010
10	15.4	532	78	808	17,800
11	16.1	660	80	267	4,310
12	87.5	4,570	83	13.2	984
19	98.4	4,340	91	87.0	2,120
23	125	2,100	95	144	2,190
25	8.23	1,738	98	54.8	4,350
27	384	1,710	109	6.33	4,980
32	3.88	449	118	1.78	744
33	2.39	2,540	119	95.0	1,290
36	9.52	4,320	121	1.30	1,065
37	129	5,040	123	2.32	1,158
39	0.69	323	127	3.77	2,284
40	1.85	615	128	2.11	1,303
41	733	11,800	129	149	5,670
64	4.46	2,630	132	518	4,860
65	0.39	358	137	96.9	7,120
67	131	1,690	139	282	8,330
70	7.15	864	142	194	4,720
72	5.86	1,683	145	681	14,200
73	10.0	1,590	149	12.8	3,240
74	182	3,190	150	0.65	402

Time-of-Travel Information Available

Time of travel and dispersion of solutes in the Wind/Bighorn River can be estimated for the 113-river-mile reach between Boysen Dam and Greybull.

Time-of-travel and dispersion information is available for general use in evaluating transport of dissolved contaminants (solutes) in the Wind/Bighorn River or, if necessary, for taking protective measures at points downstream where water is withdrawn from the river. Surface drainage from the potential mine and mill areas and from population centers is toward the river. Increased development of coal and other resources in the area would increase the possibility of contaminants entering the river, either directly by accidental spillage, or indirectly by inflow from tributaries draining potential source areas of contaminants.

The information is based on two time-of-travel studies done in 1971 (Lowry and others, 1976). The first was done in March when the discharge in the river was about 2,000 cubic feet per second (ft^3/s). The second was done in June when the discharge was about 8,000 (ft^3/s). In both studies a tracer dye was injected as a single slug just downstream from Boysen Dam and monitored by sampling the water in the river at seven sites between Boysen Dam and Greybull, a distance of about 113 river miles (fig. 5.4–1).

Because measurements were made at two different discharges, it is possible to estimate the time of travel between any two sites in the study reach for a wide range of discharges by interpolation of the graph in figure 5.4–2. The graph is based on the time of travel of the peak concentration, which always is slightly less than the average time of travel. The discharge in the river can be obtained by contacting the U.S. Geological Survey office in Riverton, Wyo., or the U.S. Bureau of Reclamation at Boysen Dam. Streamflow stations are operated below Boysen Dam and at Kane, Wyo., just upstream from Bighorn Lake and about 24 river miles downstream from the boundary of Area 51 near Greybull.

When a solute enters a stream as a single slug, the solute forms a cloud with a dispersion pattern similar to that shown in figure 5.4–3. As the material travels downstream the dimensions of the dispersion pattern change: the peak concentration decreases and the passage time increases.

Passage time, the time required for a solute cloud to pass a site on the river, can be estimated. Passage time (T), in hours, is a function of the distance traveled (L), in river miles:

$$T = L^a$$

The exponent, a, varies with discharge in the Wind/Bighorn River as follows:

Discharge (cubic feet per second)	a
2,000	0.55
4,000	0.50
6,000	0.45
8,000	0.40
10,000	0.35

For example, at a discharge of 6,000 (ft^3/s), a solute cloud will take about $30^{0.45}$, or 4.6 hours to pass a site 30 river miles downstream from the injection site.

If the peak concentration ($C1$) and time of travel ($T1$) are known (measured) at a site downstream from the injection site, the peak concentration ($C2$) at a site farther downstream can be estimated as follows:

$$C2 = C1(T1/T2)^{0.5}$$

where $T2$ is the estimated time of travel (using fig. 5.4–2) to the site of interest.

For example, a spill in Wind River Canyon, 5.7 river miles downstream from Boysen Dam, is monitored at Thermopolis, where the peak concentration ($C1$) is found to be 100 milligrams per liter and the elapsed time ($T1$) since the spill is 4 hours. The average discharge is 6,000 (ft^3/s). The time of travel ($T2$) from the spill site to Worland is estimated to be 18.3 hours (fig. 5.4–2). The peak concentration at Worland is estimated to be $100(4/18.3)^{0.5}$, or 47 milligrams per liter. Such estimates can be used for planning protective measures, even though the estimates are very rough and do not allow for variations in the physical and chemical characteristics of specific contaminants.

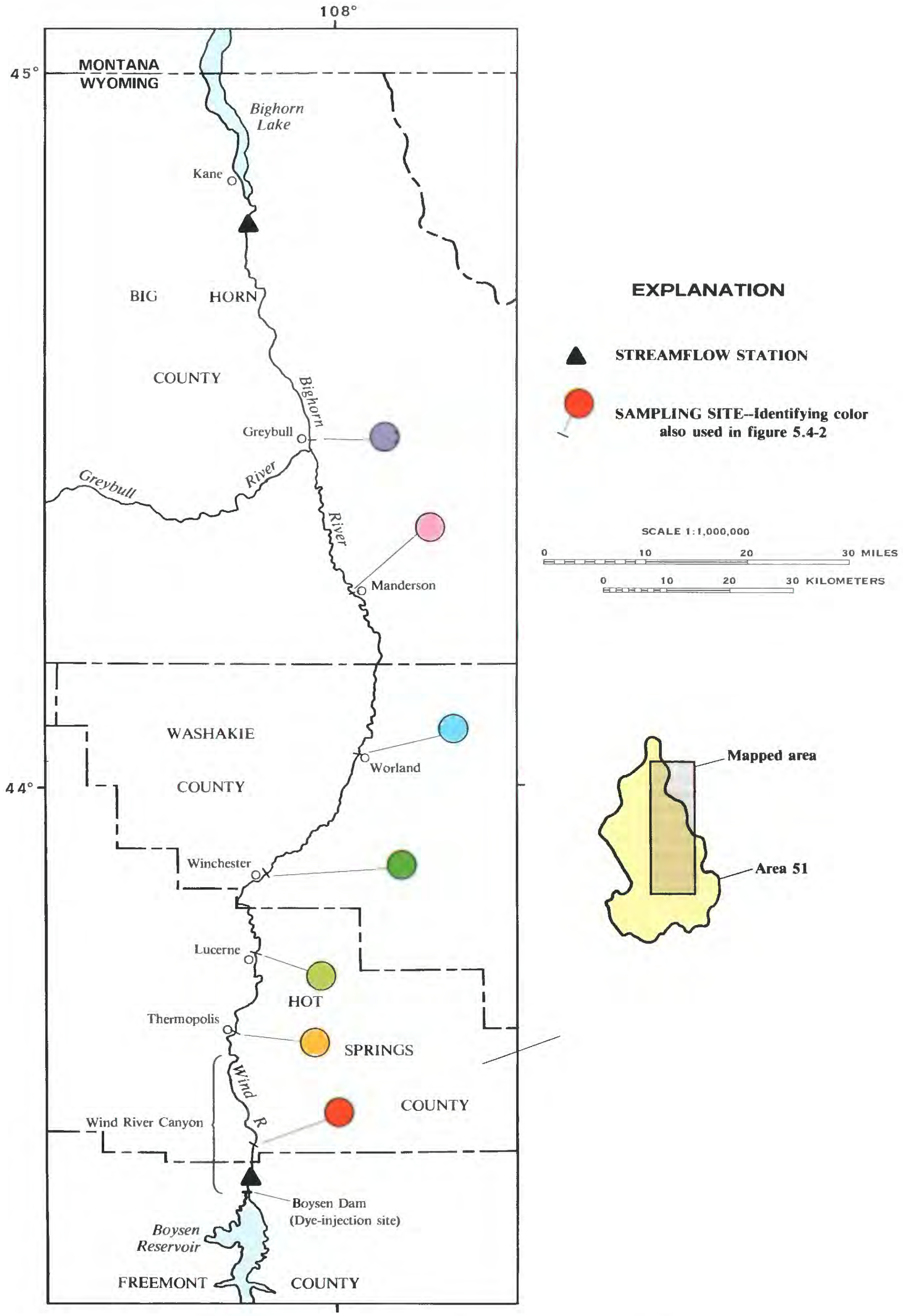


Figure 5.4-1 Locations of dye-injection and sampling sites, 1971 time-of-travel study, Wind/Bighorn River.

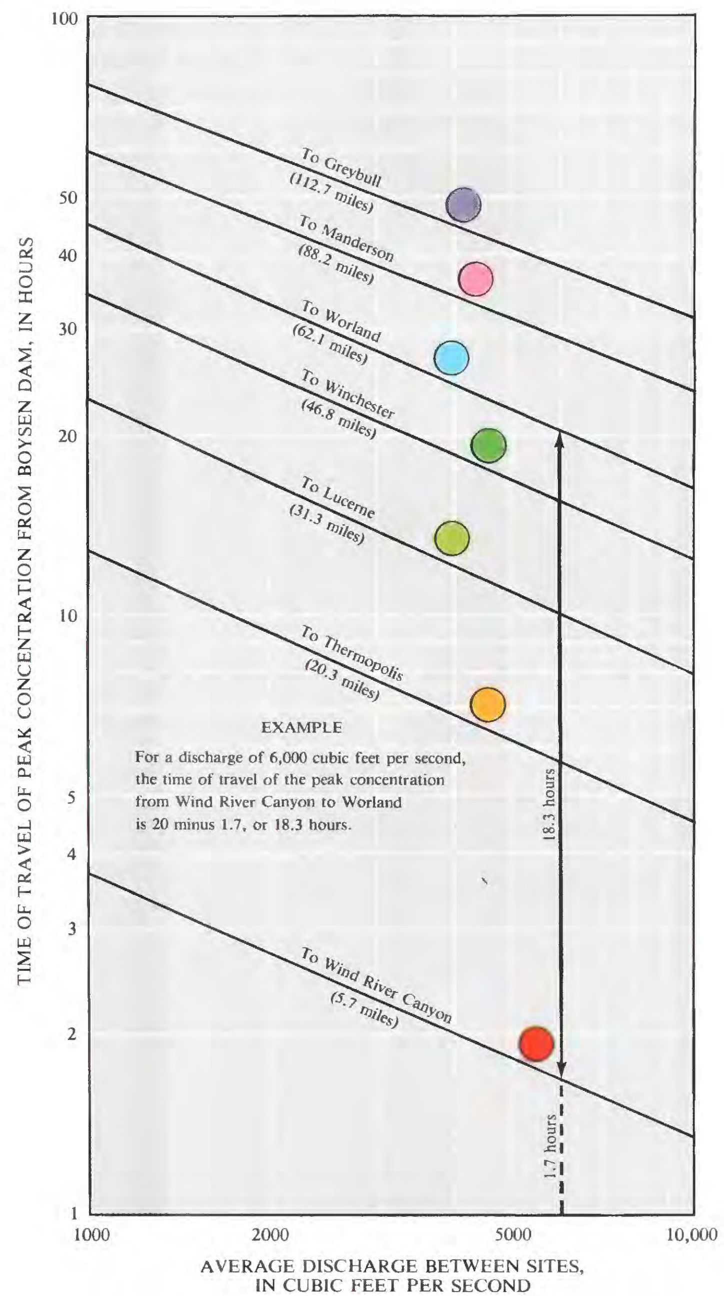


Figure 5.4-2 Relation of time of travel to discharge in the Wind/Bighorn River (from Lowry and others, 1976, sheet 2). Time of travel between intermediate sites is determined by subtraction, as shown in the example.

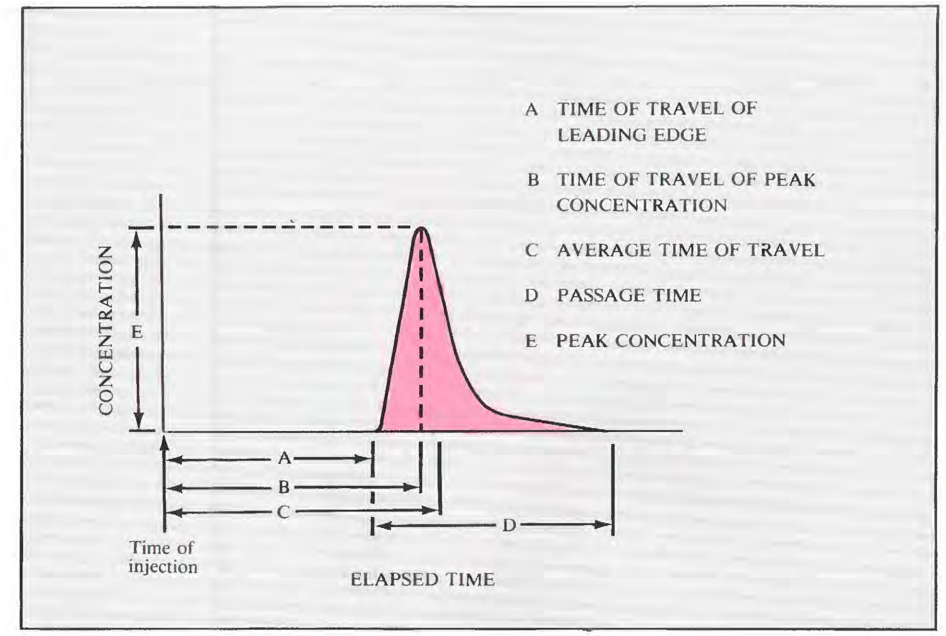


Figure 5.4-3 Typical concentration curve for a solute cloud passing a point in a stream.

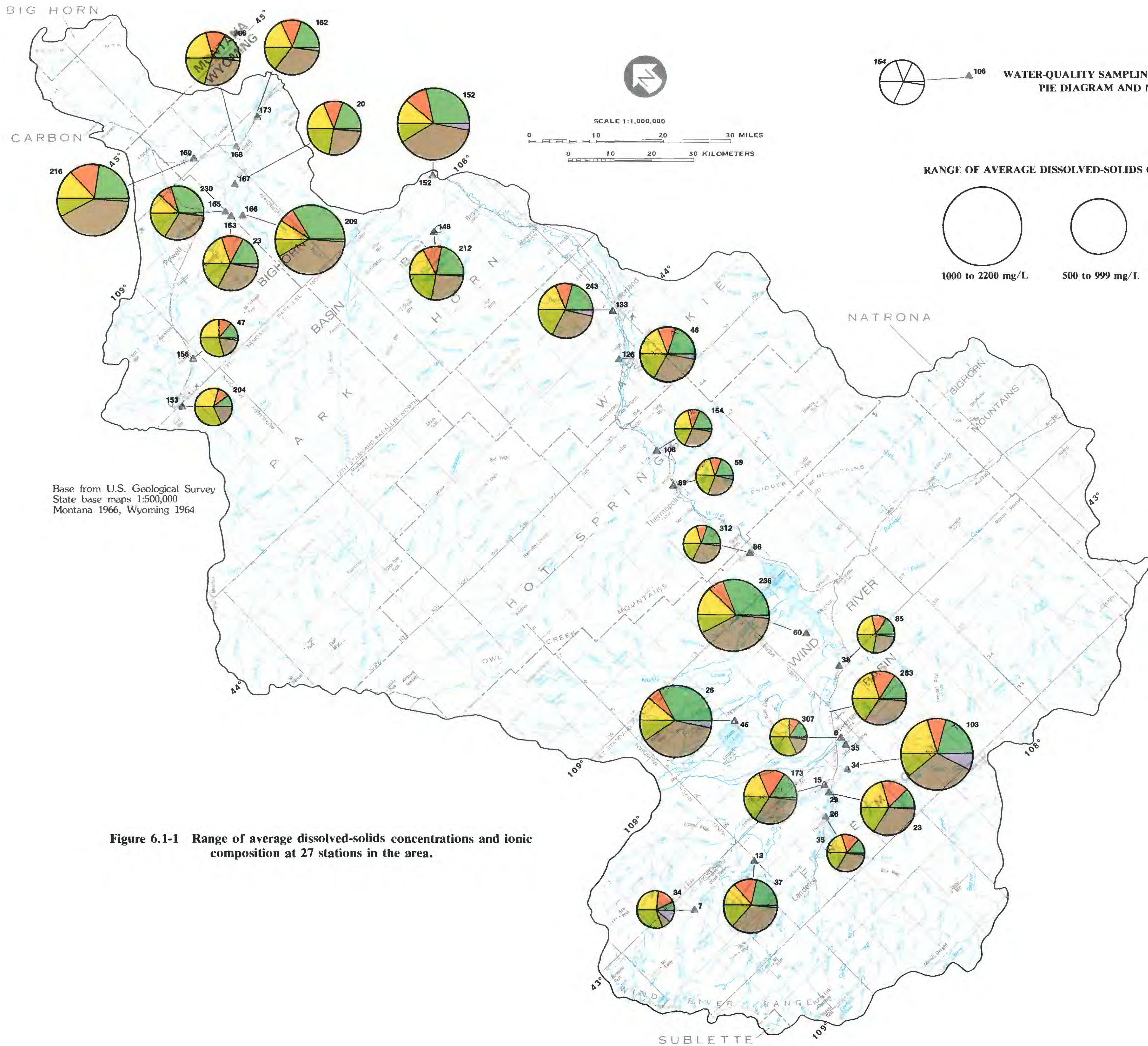
Concentrations of Dissolved Solids are Largest in Plains Streams

The concentrations of dissolved solids generally are larger in streams originating in the plains than in streams originating in the mountains.

The concentrations of dissolved solids often are greater than 1,000 milligrams per liter in streams originating in the plains. In contrast, the concentrations generally are less than 1,000 milligrams per liter (mg/L) in streams originating in the mountains. The range of average concentrations of dissolved solids at stations in the area is shown in figure 6.1–1. Examples of streams originating in the plains are Beaver Creek and Dry Creek; an example of a stream originating in the mountains is the Wind/Bighorn River. The concentration of dissolved solids in the Wind/Bighorn River increases as the river flows through the plains. The mean concentrations in the river gradually increase from 254 mg/L at station 6, near the Wind River Range, to 587 mg/L at station 133, more than 220 river miles downstream.

A rating of water quality largely depends on the intended use of the water and availability. The dissolved-solids classification listed in table 6.1–1 is given for general reference.

Several ions constitute most of the dissolved solids in the water. The principal cations are calcium, magnesium, sodium, and potassium; the principal anions are bicarbonate, sulfate, and chloride. The proportions of the ions at selected stations in the area are shown in figure 6.1–1. Calcium generally is the predominant cation, and either bicarbonate or sulfate are the predominant anion in streams with mean concentrations of dissolved solids less than 500 mg/L. The proportions of sodium and sulfate, relative to calcium and bicarbonate, tend to become larger as the concentrations of dissolved solids become larger. Either calcium or sodium are the predominant cation at stations with mean concentrations of dissolved solids of 500 to 1,000 mg/L. Sodium is the predominant cation at stations with mean concentrations of dissolved solids greater than 1,000 mg/L. Sulfate is the predominant anion at all stations with mean concentrations of dissolved solids greater than 500 mg/L.



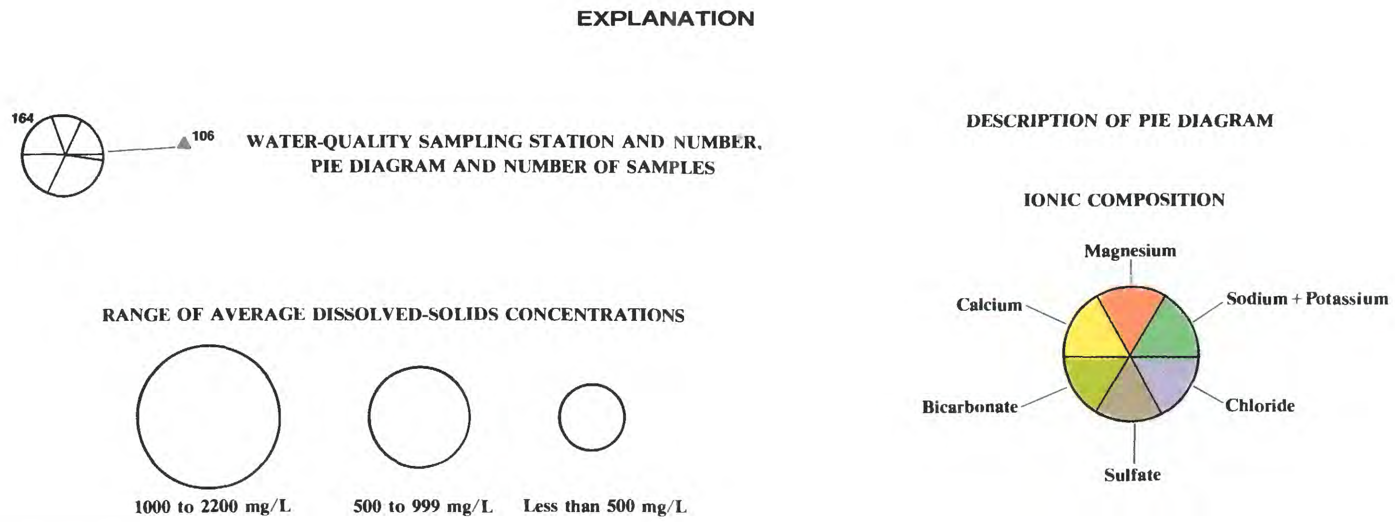


Figure 6.1-1 Range of average dissolved-solids concentrations and ionic composition at 27 stations in the area.

Table 6.1-1 Recommended dissolved-solids concentrations for various water uses

Water use	Dissolved-solids concentration, in milligrams per liter
Drinking water[1]	
National secondary drinking-water standard	< 500
Irrigation[2]	
Water from which no detrimental effects on crops will usually be noticed	500
Water which can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000
Livestock and poultry[3]	
Excellent for all classes of livestock and poultry	< 1,000
Very satisfactory for all classes of livestock and poultry	1,000-2,999
Satisfactory for livestock, but poor for poultry	3,000-4,999
Reasonably safe for livestock, excepting pregnant or lactating animals; not acceptable for poultry	5,000-6,999
Considerable risk for pregnant, lactating, or young livestock; older animals may subsist on this, under certain conditions	7,000-10,000
Not recommended for livestock or poultry	> 10,000

[1] U.S. Environmental Protection Agency, 1979, p. 42195-42202.
[2] U.S. Environmental Protection Agency, 1976, p. 208.
[3] Modified from National Academy of Sciences and National Academy of Engineering, 1973, p. 308.

Large Phosphorus Concentrations Occur in Plains Streams

Median concentrations of phosphorus were larger in streams originating in the plains than in streams in or near the mountains.

The largest median concentrations of total phosphorus in streams were at sampling stations in the plains (figure 6.2–1). The smallest concentrations were measured in streams in or near the mountains. The sample analyses for total phosphorus included suspended and dissolved forms of phosphorus.

Phosphorus is contributed to streams by manmade and natural sources. The manmade sources include sewage outfalls and agricultural fertilizers. Phosphorus also is naturally present in soils and precipitation. Some of the phosphorus in streams is attached to particles of suspended sediment washed in from the soil.

Phosphorus concentrations in streams of the area exhibited a seasonal pattern. The peak concentrations generally occurred during the spring and summer, and the minimum concentrations generally occurred during the winter. For example, the seasonal pattern of phosphorus concentrations at station 38 on the Wind River is shown in figure 6.2–2. The seasonal peaks may be associated with runoff from applications of fertilizer to agricultural lands. Regressions of total phosphorus to suspended sediment and discharge showed generally poor correlations at the sampling stations.

Phosphorus often is considered to be the nutrient that limits algal growth in reservoirs and lakes. In excess of a critical concentration, phosphorus may stimulate algal growth and accelerate eutrophication. To prevent nuisance algal growths (blooms), the U.S. Environmental Protection Agency (1976, p. 356) suggests total phosphates as phosphorus should not exceed 0.050 milligrams per liter in streams that enter reservoirs and lakes. Mackenthun (1973) suggested total phosphorus should not exceed 0.100 milligrams per liter to prevent plant nuisances in streams not discharging directly to reservoirs and lakes. In practice, the critical concentration varies, depending on factors such as water temperature and turbidity. Inorganic turbidity interferes with algal growth in Ocean Lake (Pederson, 1984) and in many other waters in the area.

Nuisance algal growths occur regularly in the area, but the role of phosphorus in these growths is not well documented. Streamers of filamentous algae grow in the Bighorn River below Boysen Dam and the irrigation canals supplied by the river. The algae normally grow attached to the substrate, but often break loose, float downstream, and tend to clog irrigation-diversion structures. Mechanized algae collectors have been installed at many of the diversion structures, to remove the algae from the water. Algal blooms occur in lakes and reservoirs in the area during late summer, but the blooms have not caused serious problems.

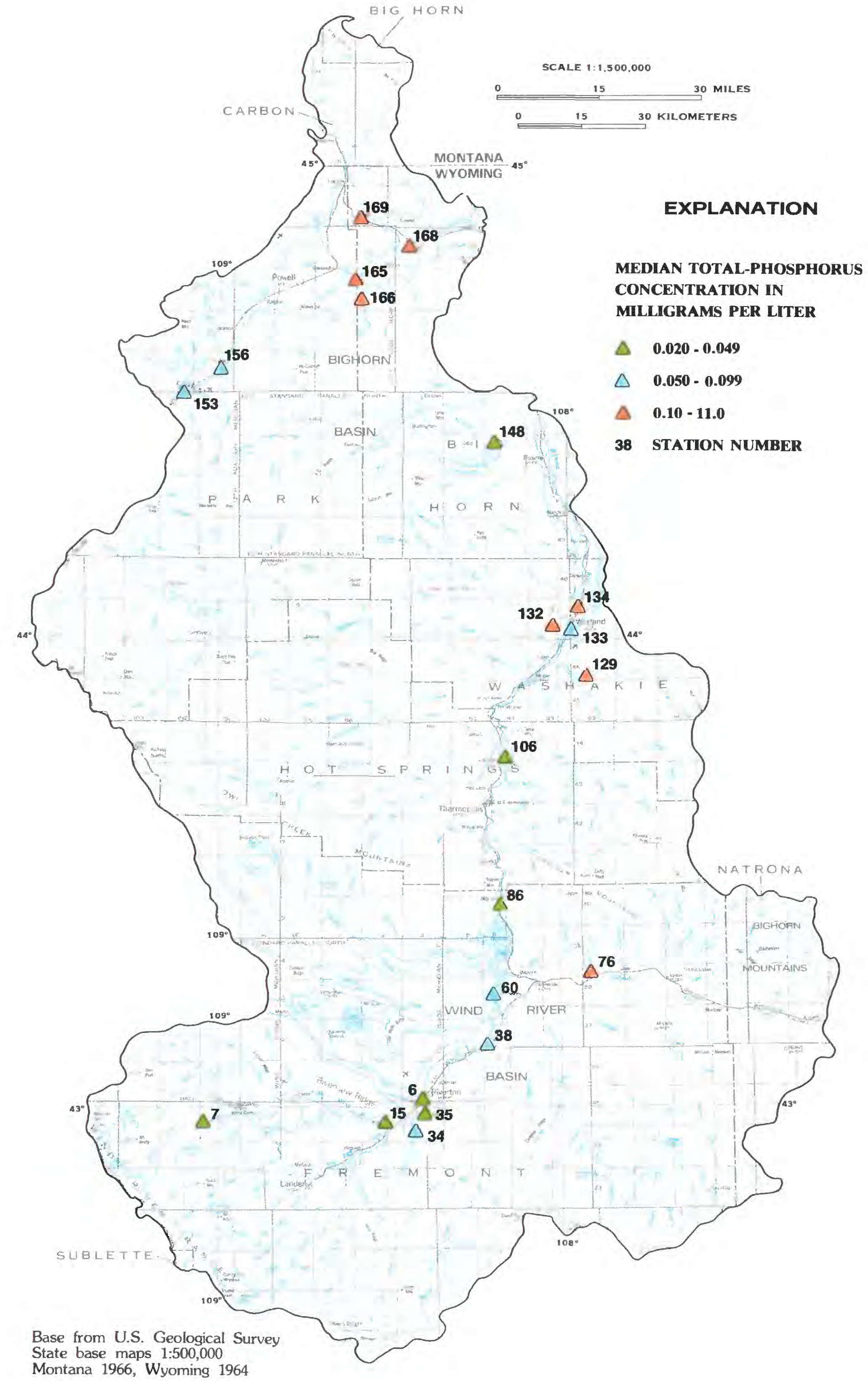


Figure 6.2-1 Median total-phosphorus concentrations.

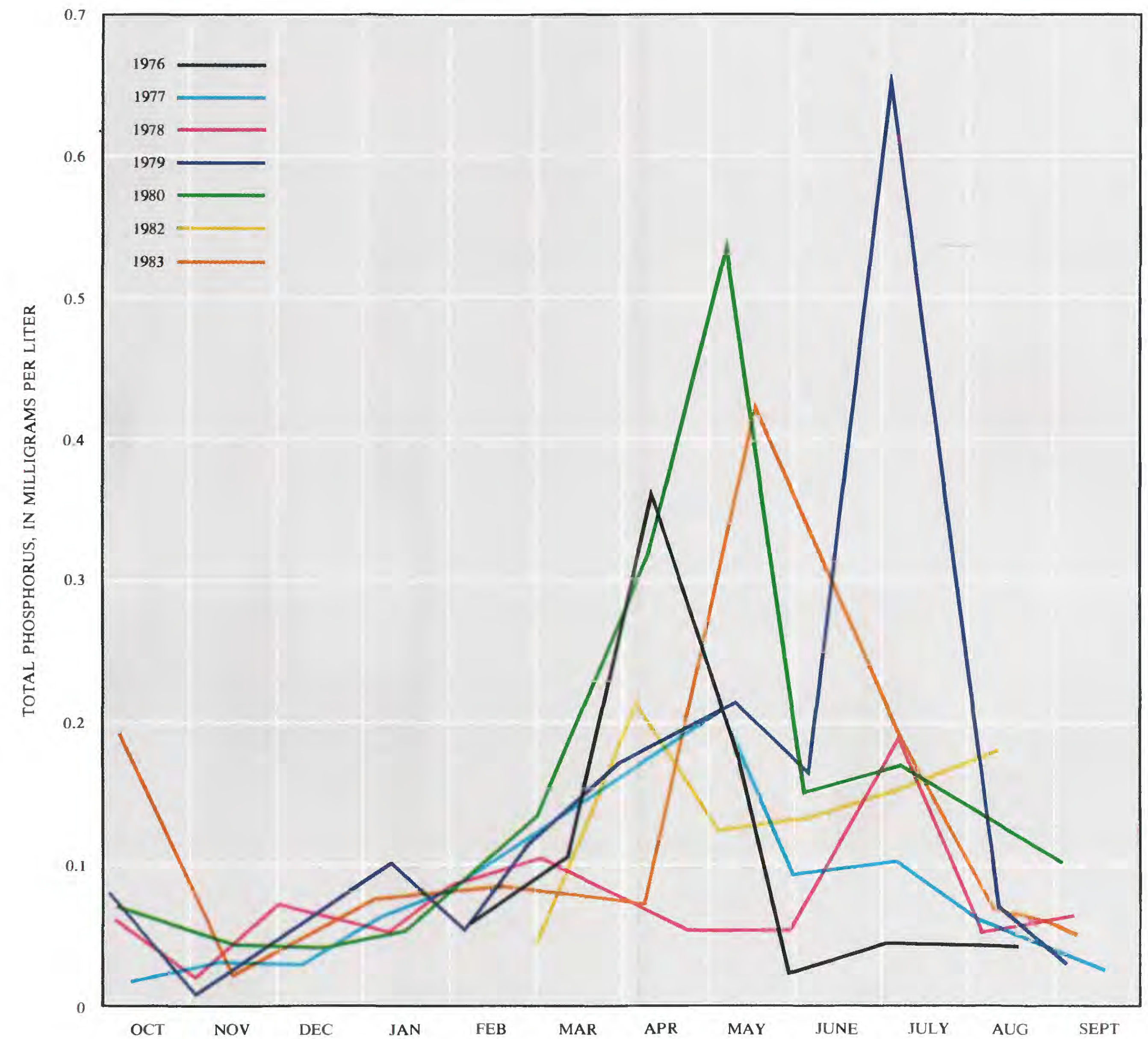


Figure 6.2-2 Total-phosphorus concentrations of periodic samples collected at station 38 on the Wind River, above Boysen Reservoir.

Boysen Reservoir and Erosion Control Reduce Suspended-Sediment Load in the Bighorn River and Tributaries

Suspended-sediment discharge in the Bighorn River at Thermopolis was 80 percent less during 1952 water year than 1951 water year, due to Boysen Dam closure, and 90 percent less during 1969 water year than 1950 water year in Fivemile Creek near Shoshone, due to erosion-control practices.

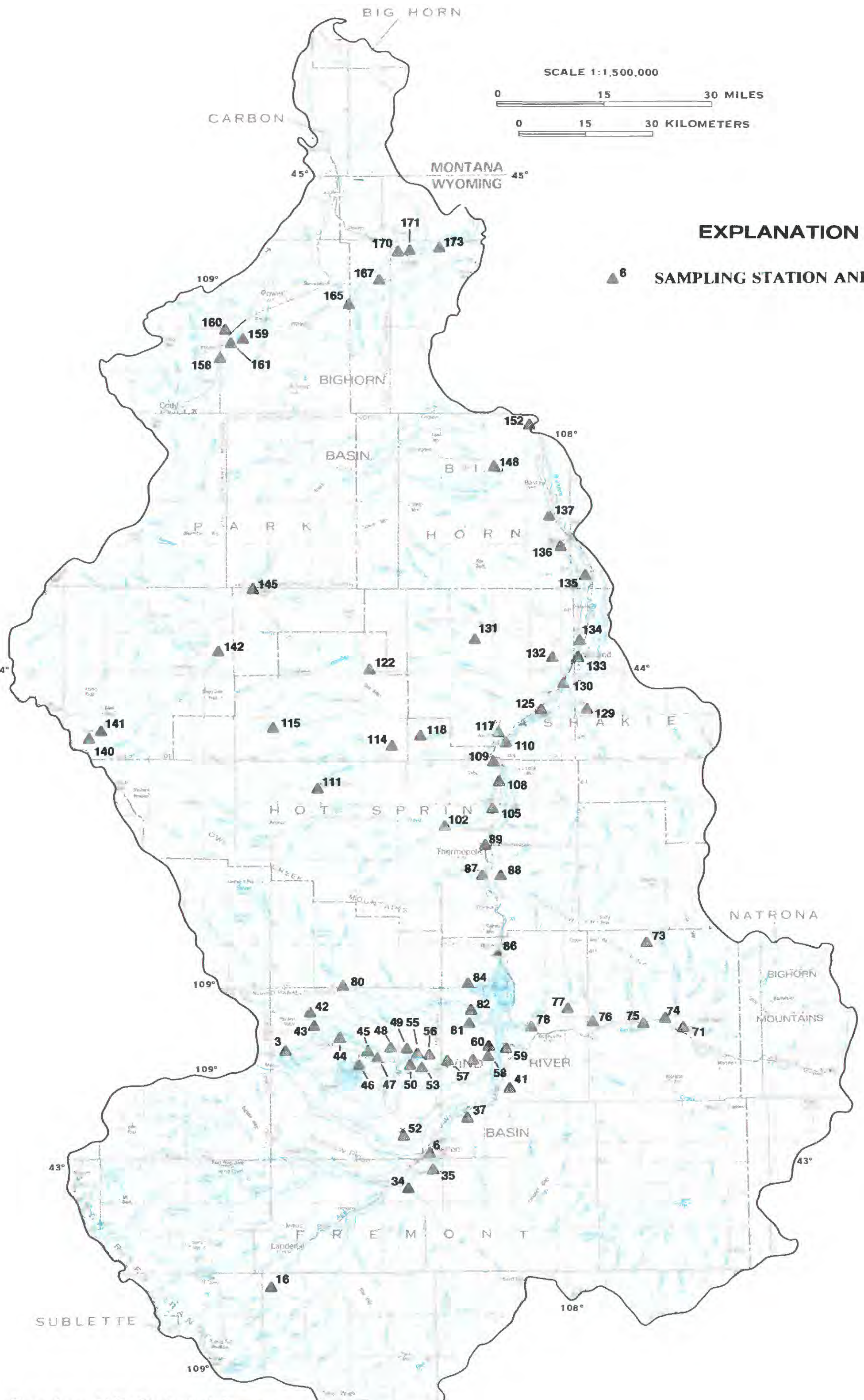
The pattern of suspended-sediment discharge in the Wind/Bighorn River is determined from records obtained at 13 stations in the area (fig. 6.3–1). Only small amounts of suspended sediment are discharged by the Wind River upstream from Riverton; however, the suspended-sediment discharge increases downstream. During water years 1949–56, the annual discharge in the Wind River at Riverton (station 6) averaged 446,656 tons (discharge-weighted concentration, 564 mg/L (milligrams per liter)). Irrigation return flow from Fivemile and Muddy Creeks (stations 60 and 81) plus ephemeral flow from Kirby Draw (station 37), Muskrat Creek (station 41), Badwater Creek (station 78), and Cottonwood Creek (station 84) significantly increased the suspended-sediment discharge of the Wind River. For example, Fivemile Creek alone discharged 2,384,111 tons (discharge-weighted concentration, 43,300 mg/L) of sediment to the Wind River in 1951 (table 6.3–1).

The storage of water in Boysen Reservoir, beginning in 1952, caused a dramatic decrease in suspended-sediment discharge downstream from Boysen Dam (fig. 6.3–2). Records show that the suspended-sediment discharge in the Wind River at Thermopolis (station 89) decreased from 4,666,791 tons during 1951 (discharge-weighted concentration, 2,140 mg/L) to 239,192 tons during 1952 (discharge-weighted concentration, 324 mg/L) (table 6.3–1). This reduced discharge has continued to the present (1984).

Erosion-control practices have greatly reduced suspended-sediment yield by Fivemile and Muddy Creeks from what it was during the late 1940's and early 1950's. The appearance of Fivemile Creek during 1952 and 1984 is shown in figures 6.3–3 and 6.3–4. The bank surfaces were harshly eroded in 1952; the banks now (1984) present a subdued, vegetated appearance. This is evidence that erosion has decreased.

Another example of how erosion-control practices have reduced suspended-sediment discharge in the Bighorn River is shown in figure 6.3–5. The accumulated suspended-sediment discharge for Fifteenmile Creek near Worland (station 132) is plotted against the accumulated water discharge for the same station. This figure represents water years 1951–72. A straight line throughout the range of plotted points would indicate that the suspended-sediment yield for a given amount of water discharge is unchanged. In this case, however, the line is straight in two separate segments, with the break in slope occurring around 1959. This indicates less suspended-sediment yield for the same amount of water discharge after 1959.

The U.S. Bureau of Land Management constructed spreader-dike systems on the floodplain of Fifteen mile Creek during 1958. These spreader systems caused a flattening of the energy slope of the flow and hence a deposition of sediments behind the dikes. To date, the spreader systems have been effective for reducing sediment discharges to the Bighorn River from Fifteenmile Creek.



EXPLANATION

▲6 SAMPLING STATION AND NUMBER

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

Figure 6.3-1 Location of suspended-sediment sampling stations in Area 51.

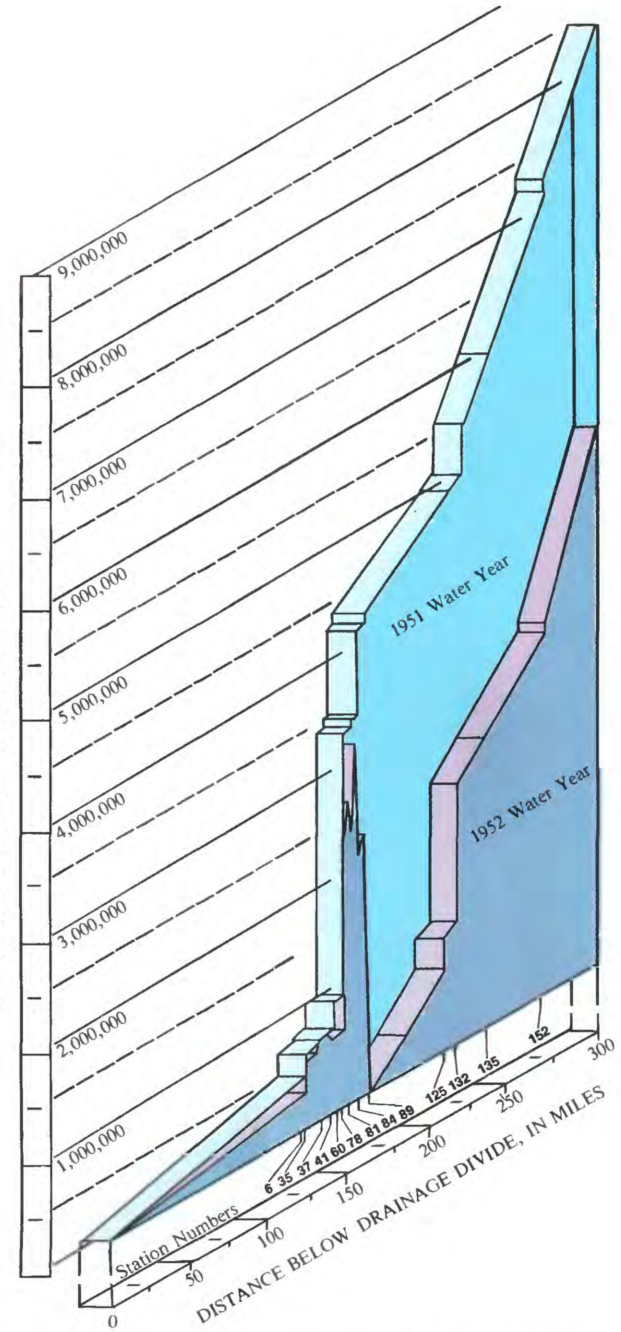


Figure 6.3-2 Suspended sediment discharged by the Wind-Bighorn River in Area 51.

Table 6.3-1 Suspended-sediment discharges and river miles for sites in Area 51 used to determine suspended-sediment discharge pattern

Map No.	Suspended-sediment discharge (tons) 1951	1952	Distance below drainage divide (miles)
006	453,791	288,743	121
035	196,576	304,602	123
037	2,400	5,810	133
041	240,948	1,590	141
060	2,384,111	2,010,819	147
078	79,042	58,625	150
081	755,330	718,389	151
084	77,737	231,989	156
089	4,666,791	239,192	180
125	1,617	170,748	210
132	455,506	1,200,872	218
135	5,848,117	2,622,446	235
152	84,157	108,257	269

Figure 6.3-3 Fivemile Creek near Shoshone (Station 81) at gaging station, 1952.

Figure 6.3-4 Fivemile Creek near Shoshone (Station 81) at gaging station, 1984.

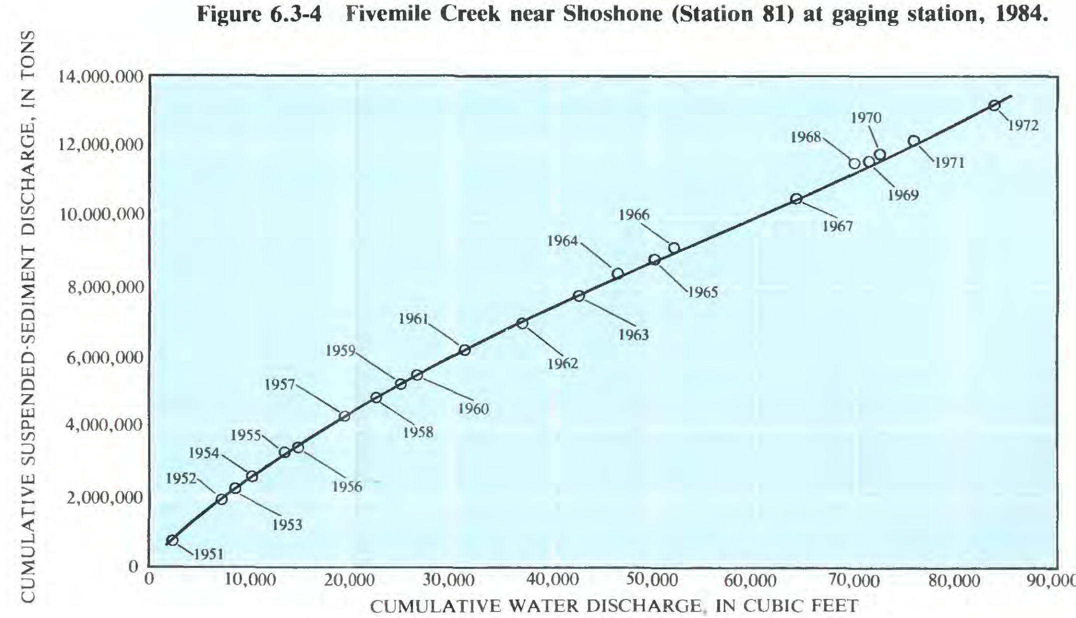


Figure 6.3-5 Double mass curve for Fifteenmile Creek near Worland (Station 132), 1951-72 water years.

Water Temperature is Important to Many Users

Temperature data are available for most of the surface-water stations and miscellaneous sites. Stream temperatures range from 0° Celsius during winter to greater than 25° Celsius in summer.

Temperature is an important factor of water quality. It determines the physical form of water and also affects most physical, chemical, and biological processes that take place in water. For example, as water temperature increases, dissolved oxygen decreases because of (1) the decreased saturation capacity of the water, and (2) the increased oxygen consumption of aquatic life. In contrast, the solubility of various substances in water increases with temperature. Because of its effect on water quality, stream temperature affects water use and aquatic life.

Water temperature is important to many water users. It is important to the sportsman because it is a vital factor affecting fish life. It is important to agricultural users because temperature of irrigation water can affect crop production. Industrial water users commonly use water for cooling purposes and need to consider the impact of potential temperature increases on receiving streams.

Stream temperature is significantly affected by the surrounding climatic and physical conditions. Climatic factors that affect water temperature include solar radiation, wind, air temperature, and vapor pressure. Important physical factors include shading, ground-water inflows, aspect of the stream, and stream width, depth, and velocity. Waste discharges and reservoirs also may have significant effects on the temperature of water in streams.

Measurements of water temperature are made at surface-water stations whenever discharge measurements are made. These measurements are made monthly, and a summary of the data has been compiled by Lowham and others (1975). Periodic measurements of water temperature made at a streamflow station on Fifteenmile Creek (station 132) are shown on the graph in figure 6.4–1. Water temperature is also measured whenever water-quality samples are obtained, and automatic monitors sometimes are installed that measure temperature continuously. Figure 6.4–2 shows daily temperatures measured at a water-quality station on the Shoshone River (station 168). Some temperature data are available for nearly all of the regular surface-water stations and miscellaneous sites operated by the U.S. Geological Survey (see Units 10.1 and 10.2 for a complete listing of these stations and sites). Stations where sufficient temperature measurements are available to define average seasonal variations are shown on the map in figure 6.4–3.

Stream temperatures in Area 51 may vary annually from 0° Celsius during winter periods to greater than 25° Celsius during late summer. Seasonal stream temperatures exhibit a cyclical pattern throughout the year, as shown by the graphs in figures 6.4–1 and 6.4–2.

In addition to seasonal fluctuations, temperatures also vary on a daily basis. Variation is greatest during summer and least during winter. The temperature during a summer day may vary as much as 20° Celsius in small plains streams but generally varies less than 5° Celsius in large perennial streams.

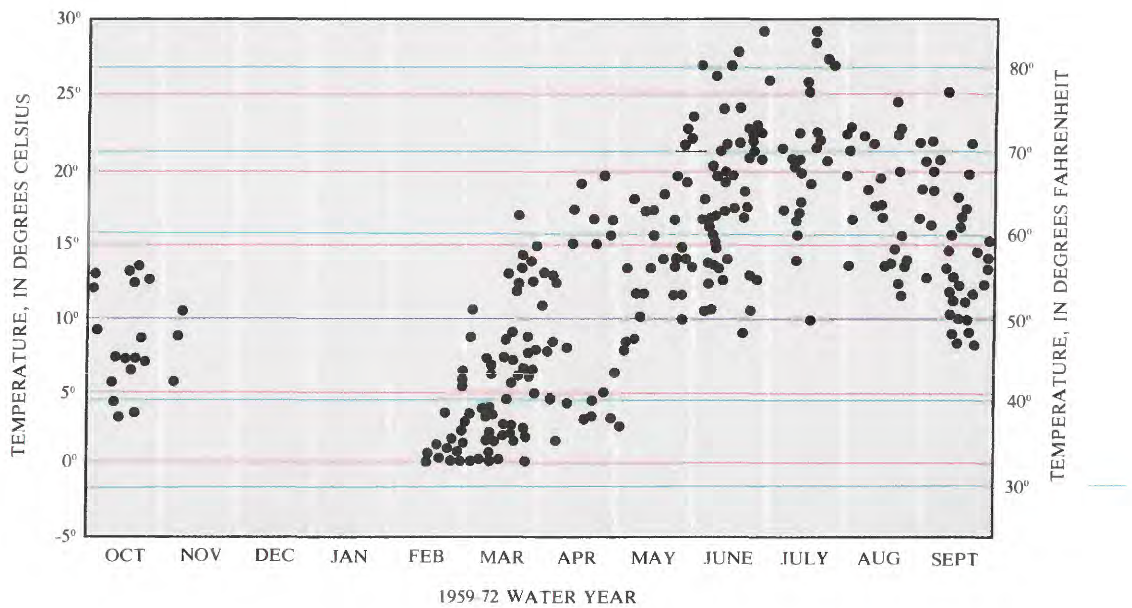


Figure 6.4-1 Periodic measurements of water temperature at Station 132 on Fifteenmile Creek.

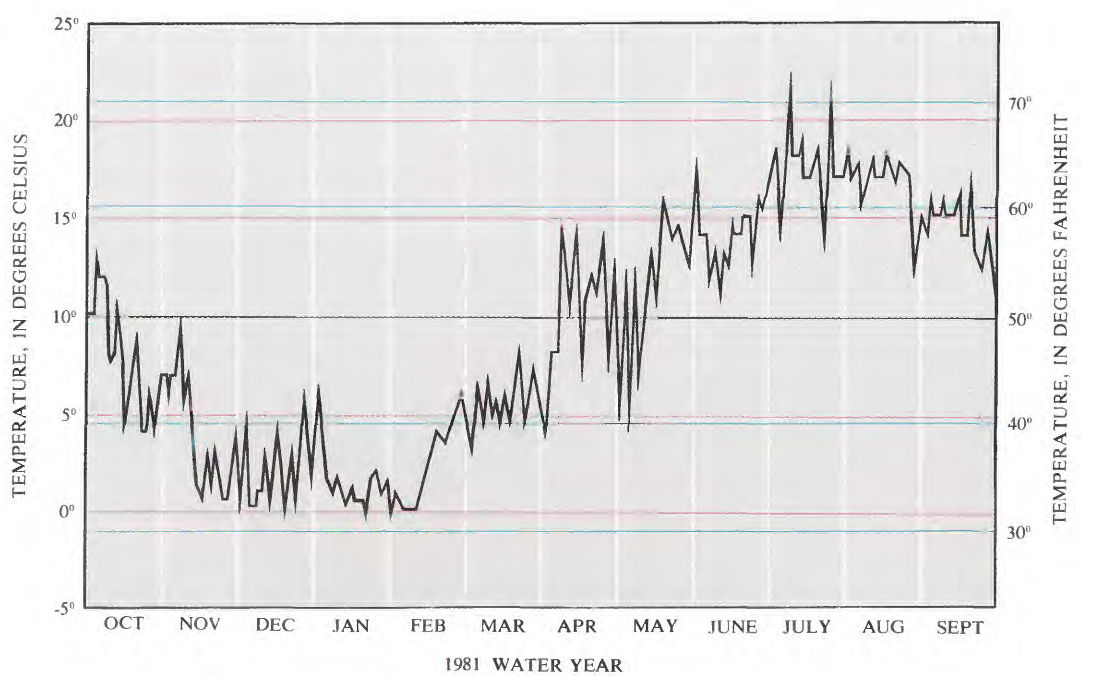


Figure 6.4-2 Daily measurements of water temperature of the Shoshone River at Station 168.

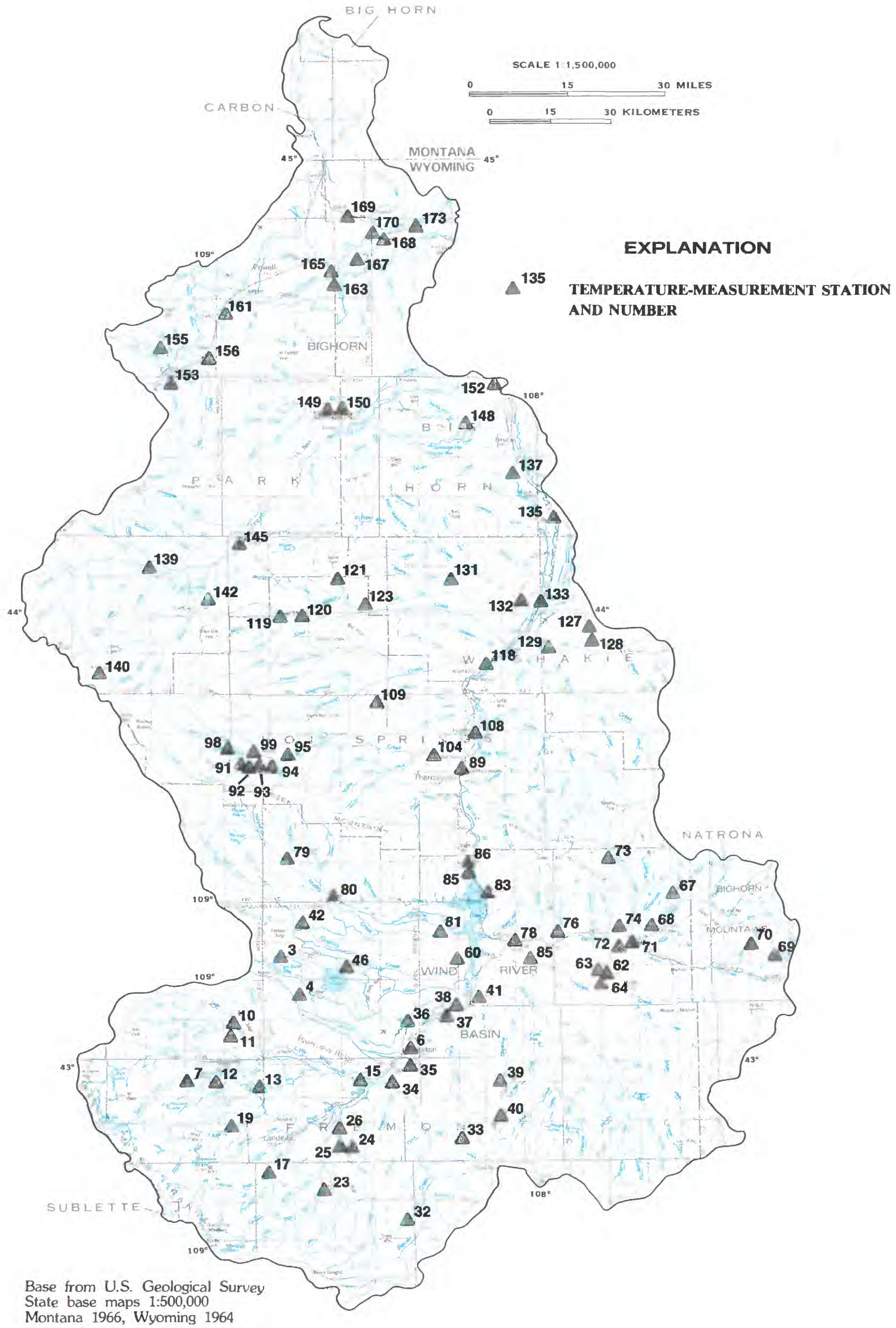


Figure 6.4-3 Location of measurement stations.

7.0 GROUND-WATER DATA NETWORK

Data are Available for About 1,300 Ground-Water Sites

The data include measurements of water levels and analyses of the chemical quality of the water.

Data for the ground-water sites shown in figure 7.0–1 are stored in the computer files of the U.S. Geological Survey. Instructions for accessing the data are given in Unit 9.3. Data concerning water levels, water quality, well depths, geologic units, or combinations of these are available for the sites. At some sites, instruments record the water level on a continuous basis. Graphs of continuous water-level records, such as the one shown in figure 7.0–2, are shown by Ragsdale (1982) for 1971 through part of 1980. Water-level data for 1940–71 are listed in Ringen (1973).

Most of the ground-water data were collected during reconnaissance studies or during project studies in a specific area, from existing wells. Many of the ground-water sites are located near streams, because irrigation wells are often drilled in the alluvium. The clusters of sites shown in figure 7.0–1 generally reflect data collected from wells in oil and gas fields.

The ground water in the southern half of the area was studied by Whitcomb and Lowry (1968); the northern half was studied by Lowry and others (1976). Cooley and Head (1979, 1982) collected water-quality samples from wells along two streams in the northern half of the area. The quality of ground water in Wyoming was described by Larson (1984).

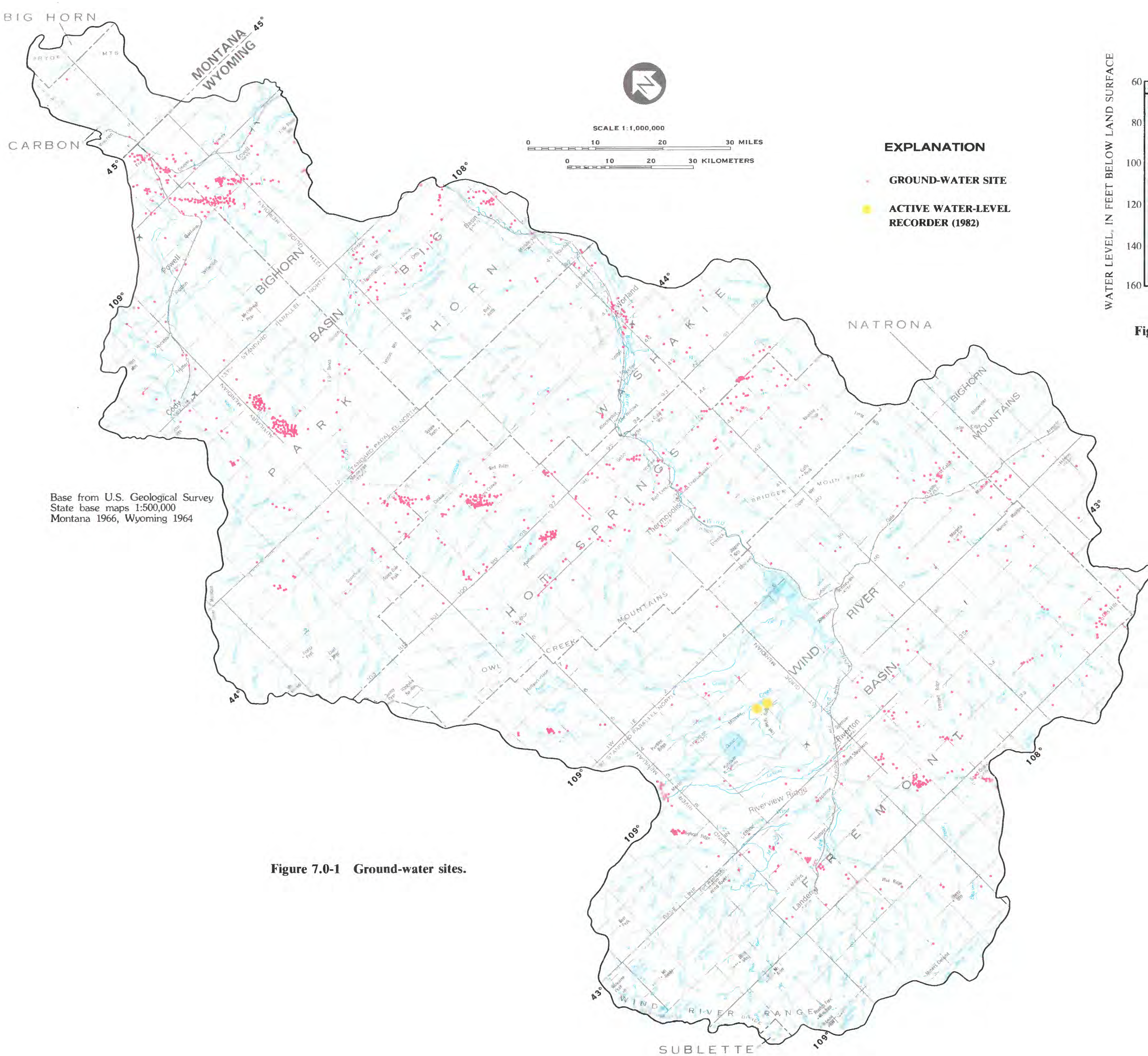


Figure 7.0-1 Ground-water sites.

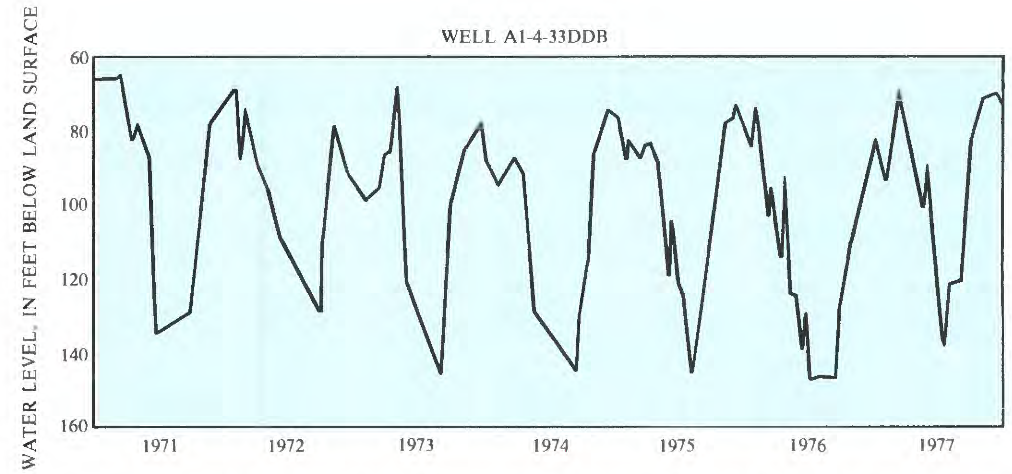


Figure 7.0-2 Water-level record from a well in Fremont County (from Ragsdale, 1982).

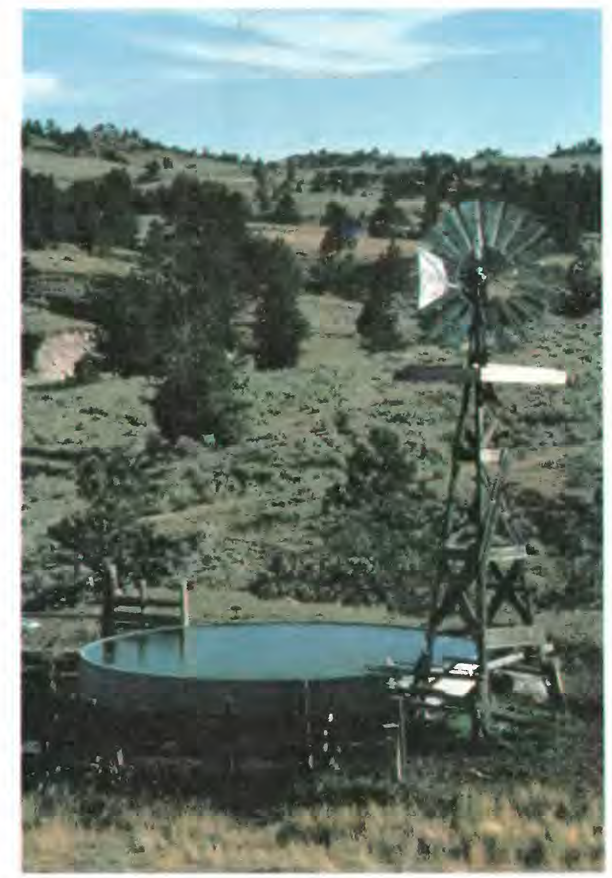


Figure 7.0-3 Data collected at windmills generally are from shallow aquifers (Photograph courtesy of the Wyoming Travel Commission).

Ground Water is Available Throughout Area 51

Artesian flows of more than 1,000 gallons per minute are possible.

The availability of water from the geologic units shown on figure 8.1–1 is summarized in table 8.1–1. Ground water for stock and domestic use can be developed in most of the area from wells less than 500 feet (ft) deep. Deeper wells generally are needed to obtain larger yields.

The shallowest bedrock throughout most of the area consists of lower Tertiary and Upper Cretaceous deposits. Water for stock and domestic use generally can be obtained from these deposits in wells less than 500 (ft) deep. However, the sandstones, which are the aquifers within the formations, are discontinuous and are not the dominant rocks. Therefore, wells at this depth are not always successful because some yield too little water.

Paleozoic sandstone and carbonate deposits, which include the Madison Limestone, usually are considered when large ground-water supplies are required. The second largest flowing well in the United States is a municipal supply well for the city of Worland. This well is located northeast of the city and flowed at the rate of 14,000 gallons per minute when first drilled. Although yields from the carbonate rocks can be spectacular, they also can be disappointing. The large yields from the carbonate rocks in the area, and adjoining areas, are possible only as the result of large secondary permeability often coupled with large artesian pressure. Neither condition occurs everywhere, and some wells yield less than 100 gallons per minute. Drilling costs for water wells in the carbonate rocks are prohibitive in most of the area because of the depth at which the rocks occur.

The Cretaceous marine and continental deposits have the least potential for development of ground-water supplies. The deposits contain a large percentage of shale; the water within the sandstone is too mineralized for most uses except very near the recharge areas. Many wells drilled in the area of outcrop of the marine Cretaceous deposits are drilled completely through the deposits into underlying aquifers in order to obtain a water supply. Because the quantity of water that can be developed is not suitable for most industrial uses and the quality generally is not suitable for agricultural or domestic uses, shallower wells in these deposits are not useful.

Ground water is available from the alluvium in the flood plains and underlying terraces. Alluvium in the flood plains is generally less than 50 (ft) thick and is coarse grained only along the principal streams that flow from the mountains. Therefore, yields larger than a few hundred gallons per minute generally are not possible. The alluvium in terraces is topographically high and generally contains sufficient saturation to yield water to wells only in areas where there is irrigation from surface-water sources. If the saturated thickness of alluvium is thin and water of adequate quality or quantity cannot be obtained from the bedrock, some communities use horizontal collector wells rather than conventional wells to obtain an adequate water supply.

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

Modified from Ross and others, 1955, Lowry and others, 1976, and Whitcomb and Lowry, 1968.

Figure 8.1-1 Surficial geology.

Table 8.1-1 Summary of water-bearing properties of geologic units

[gal/min, gallons per minute.]

	Quaternary deposits underlying the floodplains and irrigated terraces reportedly yield as much as 900 gal/min (Robinove and Langford, 1963, p. 74). However, yields generally are much less because of the small saturated thickness of the deposits that prevails in the area.
	Middle Tertiary deposits in the area of Beaver Rim yield adequate quantities of water for stock supplies. Neither wells nor springs are known to yield water from the deposits in the Bighorn Basin. Springs are common in the areas of the outcrops in the mountains; water quantities adequate for stock or domestic use could be developed from wells. Volcanic intrusive and extrusive rocks are present in the Absaroka volcanic center. The water-bearing properties of these rocks are similar to the properties of the Precambrian rocks.
	Lower Tertiary and Upper Cretaceous continental deposits contain many lenticular sandstone aquifers that yield adequate quantities of water for stock or domestic use. However, the sandstone aquifers are discontinuous; shale, siltstone, and claystone are the dominant lithology in the sequence. Therefore, wells as deep as 450 feet have been drilled without getting an adequate quantity of water for livestock (Lowry and others, 1976).
	Upper and Lower Cretaceous marine shale, marginal marine, and continental sandstone are, in general, the poorest aquifers in the area. A larger percentage of sandstones that yield water to domestic and stock wells were deposited in the western part of the area.
	Lower Cretaceous and Jurassic marine and non-marine deposits are potential sources of water for stock and domestic supplies. Yields of 100 gal/min could probably be developed. The Jurassic, Triassic, and Permian redbed and gypsum sequence yields only small supplies from the sandstones. Wells generally are not completed in the redbeds because of the large mineralization of the water.
	The Paleozoic sandstone and carbonate deposits yield more than 1,000 gal/min to some wells. However, the large yields are from zones of large secondary permeability, which are not present everywhere.
	The Precambrian igneous and metamorphic rocks yield as much as 25 gal/min to wells and springs from fractures or from the weathered zone. Because open fractures and weathering do not occur at large depths, deep drilling to increase the yield of a well usually is not effective.

Ground Water Flows Through the Sedimentary Rocks from the Bighorn Basin Northward and from the Wind River Basin Eastward

Ground-water discharge from the Tertiary rocks is within the structural basins and principally from seepage faces above stream level; therefore, ground-water discharge does not contribute significantly to flow in the streams.

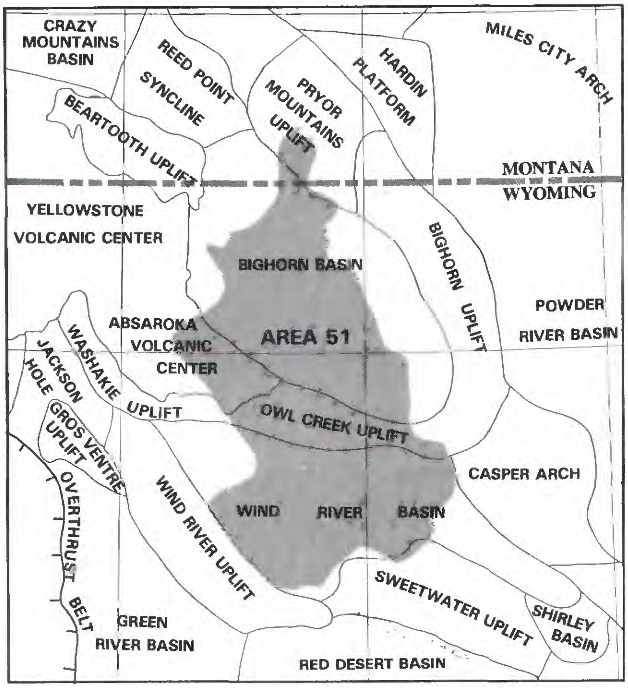
Ground water cannot flow out of the Bighorn Basin (fig. 8.2–1) through a single sedimentary unit in any direction except northward and from the Wind River Basin in any direction except eastward; the sedimentary sequence in these basins is not continuous in other directions. The potentiometric-surface map of the Tensleep Sandstone of Permian and Pennsylvanian age (Bredehoeft and Bennett, 1971) indicates that the water in the Tensleep Sandstone of the Bighorn Basin is moving toward the Bighorn River. However, there is a decrease in permeability with depth in the formation and therefore northward flow may predominate in the formation.

Recharge to the Paleozoic aquifers in the Bighorn Basin occurs at the margins of the basin. Some water is discharged from the Paleozoic aquifers by springs in the outcrop area and from upward movement along faults in the basin. The hot springs at Hot Springs State Park in the southern Bighorn Basin flow from Paleozoic aquifers at a faulted anticline where Triassic rocks are at the surface (Breckenridge and Hinckley, 1978, p. 39). Terraces deposited by the springs are shown in figure 8.2–2.

Recharge to the Paleozoic aquifers in the Wind River Basin occurs in the outcrop area, and discharge occurs in the outcrop area and from springs associated with structures. In the southern Wind River Basin, the entire flow of the Middle Popo Agie River disappears into Mississippian Madison Limestone and emerges from springs about one-half mile downstream. In the same area, hot springs, flowing about 150 gallons per minute, occur at the crest of a faulted anticline at Fort Washakie (Breckenridge and Hinckley, 1978, p. 19). A fault of large displacement has uncoupled the Paleozoic aquifers along the Casper Arch. However, maps of the potentiometric surface in the Madison Limestone of the Powder River Basin indicate ground-water movement from the Wind River Basin into the Powder River Basin (Swenson and others, 1976). Sulphur springs in township 39 north, range 90 west indicate that water is moving vertically along the fault.

Paleocene and younger bedrock formations have been eroded from the Casper Arch and, therefore, ground water does not move out of the Wind River Basin through these units. Much of the ground water discharged from the continental deposits in the Bighorn and Wind River Basins is from seepage faces where the formations crop out. The water discharged from seepage faces is evaporated or transpired during the summer and is stored as ice during the winter. Therefore, it does not contribute to base flow of streams.

In both basins, ground-water flow in the alluvium underlying the floodplains in both basins parallels the streams. Ground-water flow in the alluvium underlying the terraces is similar, but discharge occurs at the margins of the terraces in many places where the edges of the deposits do not abut bedrock.



From Grose, 1972, p. 37.

Figure 8.2-1 Geologic structures in and near Area 51.

Figure 8.2-2 Terraces deposited by flow from hot springs, Hot Springs State Park, Wyoming.

Excessive Dissolved-Solids Concentrations are a Widespread Problem in the Area

The concentrations of dissolved solids ranged from 205 to 11,100 milligrams per liter.

The excessive concentration of dissolved solids is probably the most widespread ground-water-quality problem in the area. The median concentration of dissolved solids in samples from wells in the area was 1,295 milligrams per liter. A total of 274 samples were collected from 255 wells and 3 springs (figure 8.3–1).

The concentrations of dissolved solids varied between aquifers, as well as within aquifers. The Tensleep Sandstone and Madison Limestone generally yielded water with small dissolved-solids concentrations at sites near their recharge areas. The alluvium yielded water with dissolved solids ranging from near the smallest to near the largest concentrations of those in the study area. In a study of the ground-water quality in Wyoming, Larson (1984) found the median concentration of dissolved solids in wells in Hot Springs County was much larger than median concentrations in Fremont, Big Horn, Park, and Washakie Counties.

The dissolved-solids concentration in more than 90 percent of the samples exceeded the 500-milligram-per-liter limit for domestic water supply recommended by the U.S. Environmental Protection Agency (1979, p. 42198). A histogram of the concentrations is shown in figure 8.3–2. Very few of the concentrations exceeded the 5,000-milligram-per-liter limit for pregnant or lactating livestock recommended by the National Academy of Sciences and National Academy of Engineering (1972, p. 308). Other guidelines for dissolved solids in water are listed in Unit 6.1. Water containing dissolved solids in excess of the concentration recommended for the intended use is often used in the area, because better water is not economically available.

The effect of coal mining on the ground-water quality in the area is difficult to assess. The only active (1984) mine in the area, the Grass Creek surface mine, has not intersected the water table.

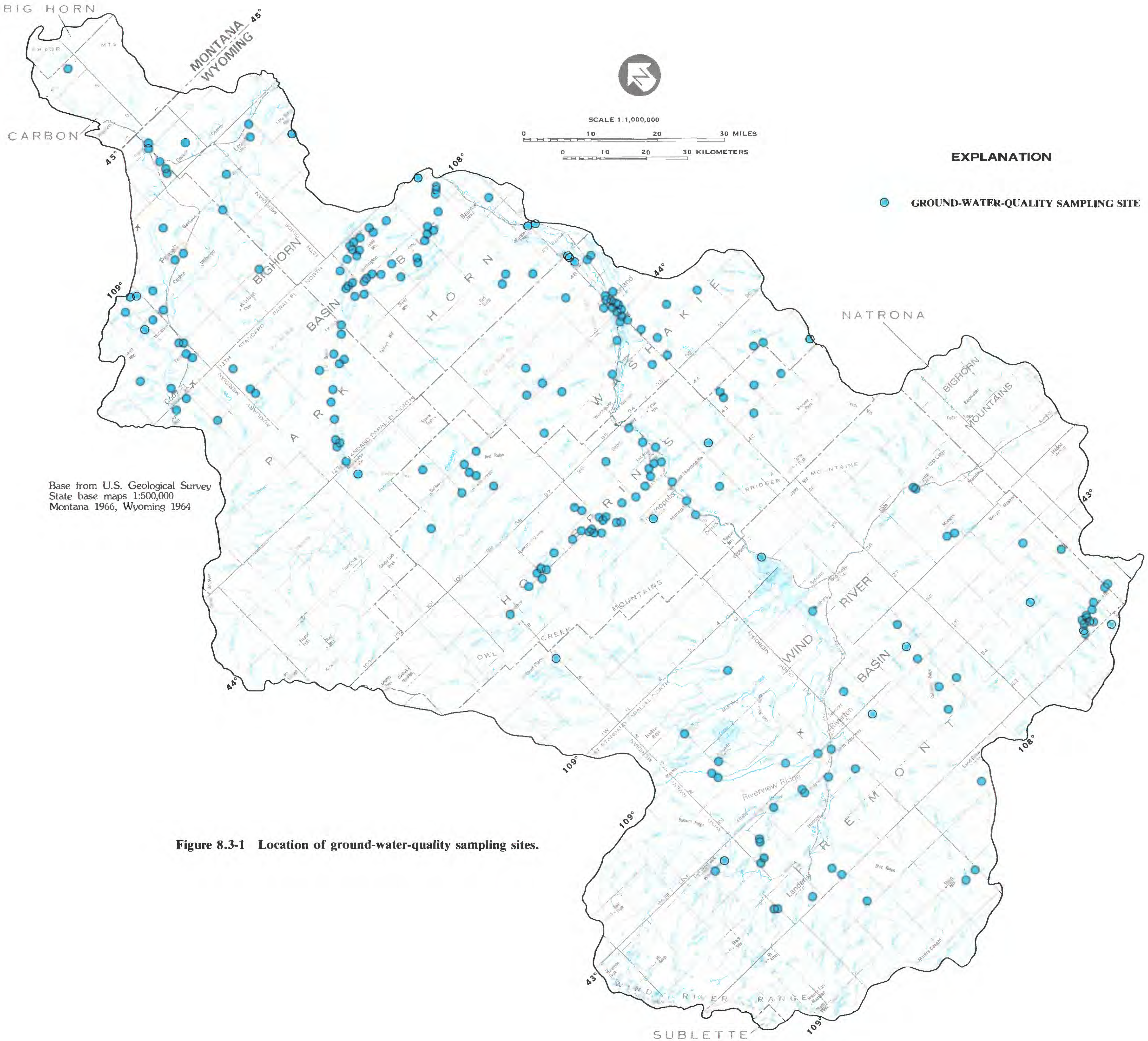


Figure 8.3-1 Location of ground-water-quality sampling sites.

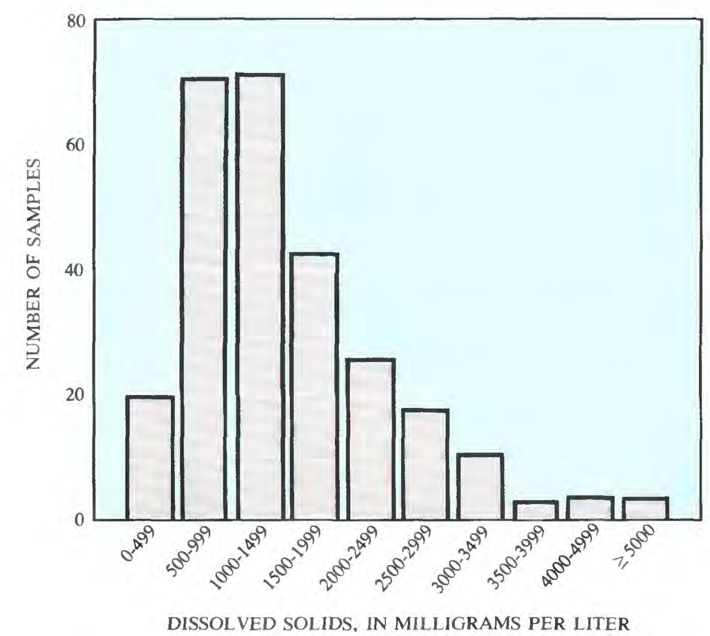


Figure 8.3-2 Many of the dissolved-solids concentrations were in the 500-999 and 1000-1499 milligrams-per-liter ranges.

National Water-Resource Data and Information are Available from Four Sources at the Federal Level

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

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

1. The National Water-Data Exchange (NAWDEX) indexes the water data available from over 400 organizations and serves as a central focal point to help those in need of water data by identifying information already available.

2. The National Water-Data Storage and Retrieval System (WATSTORE) serves as the central repository of water data collected by the U.S. Geological Survey and contains large volumes of data on the quantity and quality of both surface and ground waters.

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

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

A more detailed explanation of these three activities is given in sections 9.2, 9.3, 9.4, and 9.5.

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 at the U.S. Geological Survey's National Center in Reston, Va. and a nationwide network of Assistance Centers in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities. (See figure 9.2–1.) A directory, which is available on request, provides names of organizations and persons to contact and addresses, telephone numbers, and office hours for each of the organizations [Directory of Assistance Centers of the National Water-Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 80–1193].

NAWDEX can assist any organization or individual in identifying and locating needed water data and can refer the requester to the organization that retains the data required. To provide this service, NAWDEX maintains a computerized Master Water-Data Index (figure 9.2–2), 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 (figure 9.2–3), which also is maintained, 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 large water-data bases of some of its members and has reciprocal agreements for the exchange of services with others.

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

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

Program Office
National Water-Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 648-5663
FTS 959-5663
Hours 7:45 a.m. to 4:15 p.m. Eastern Time

or

District Chief
U.S. Geological Survey, WRD
P.O. Box 1125
2120 Capitol Ave., Room 4006
Cheyenne, WY 82003
Telephone: (307)772-2153
FTS: 328-2153

or

District Chief
U.S. Geological Survey, WRD
Federal Building, Room 428
301 S. Park Ave., Drawer 10076
Helena, MT 59626-5496
Telephone: (406)449-5496
FTS: 585-5496

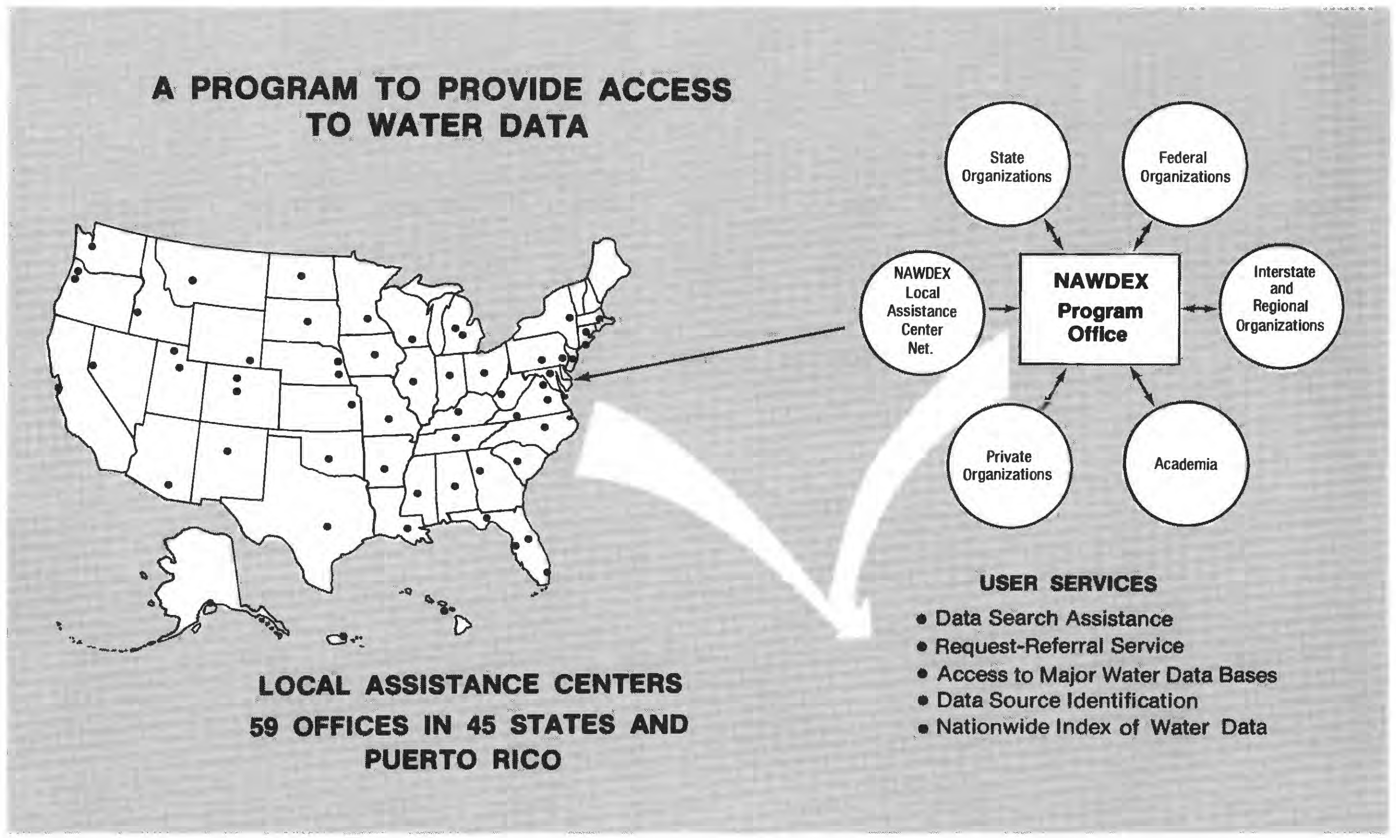


Figure 9.2-1 Access to water data.

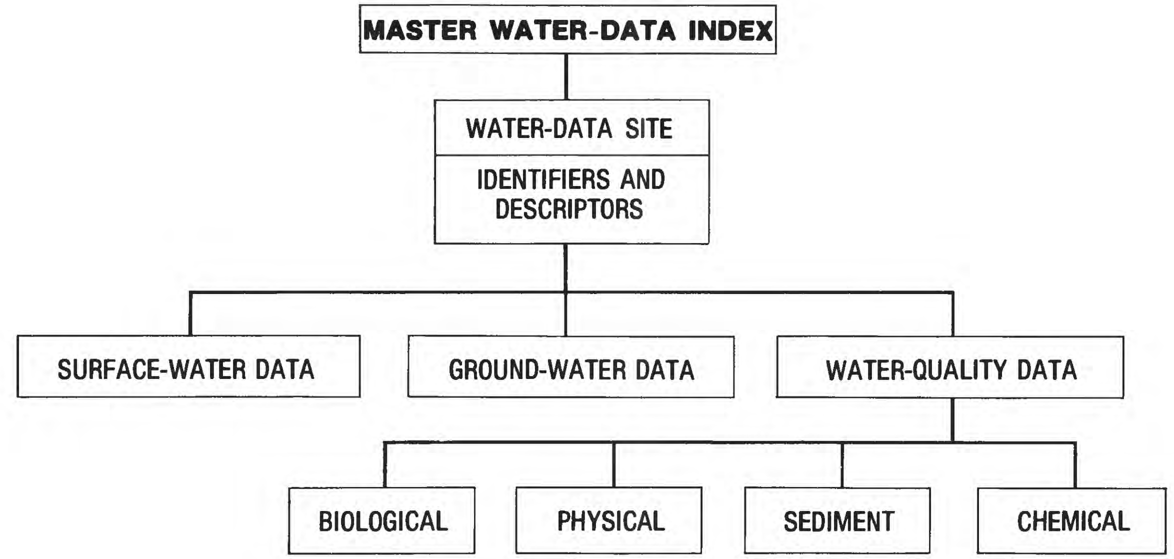


Figure 9.2-2 Master Water-Data Index.

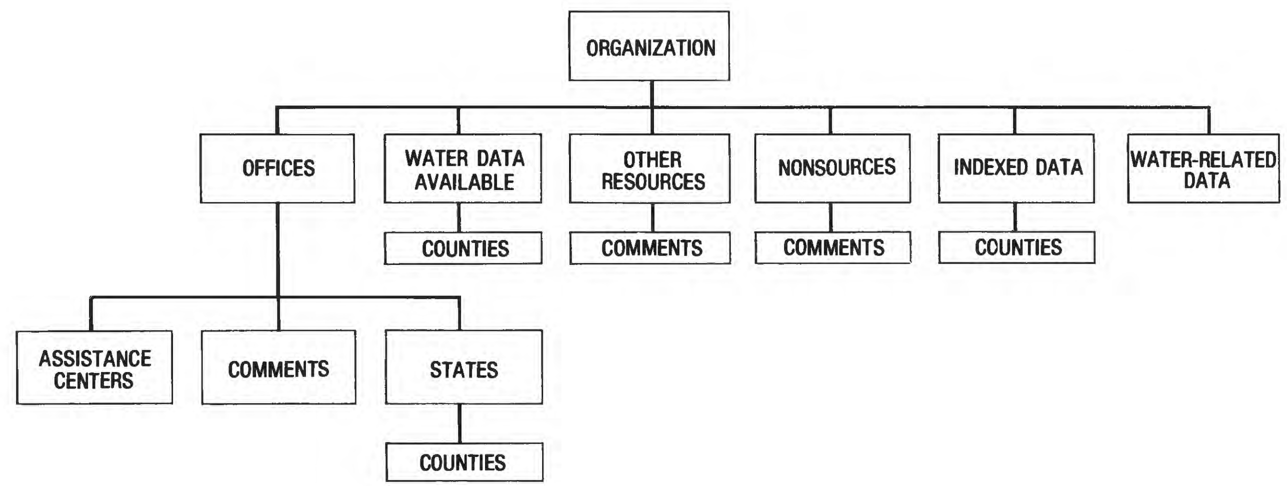


Figure 9.2-3 Water-Data Sources Directory.

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

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

or

District Chief
U.S. Geological Survey, WRD
Federal Building, Room 428
301 S. Park Ave., Drawer 10076
Helena, MT 59626-0076

or

District Chief
U.S. Geological Survey, WRD
P.O. Box 1125
2120 Capitol Ave., Room 4006
Cheyenne, WY 82003

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

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) Surface water, quality of water, and ground water 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 maintained (figure 9.3–1). A brief description of each file is as follows:

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

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

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

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

Unit-Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and 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 field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 700,000 sites.

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

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

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stage, conductivity, water temperature, turbidity, wind direction, and chloride concentraion. Data are recorded on 16-channel paper tape; the tape is removed from the recorder, and the data are transmitted over telephone lines to the receiver at Reston, Va. The data are 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 200 data-relay stations are being operated currently by the Water Resources Division.

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

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

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

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

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

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

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

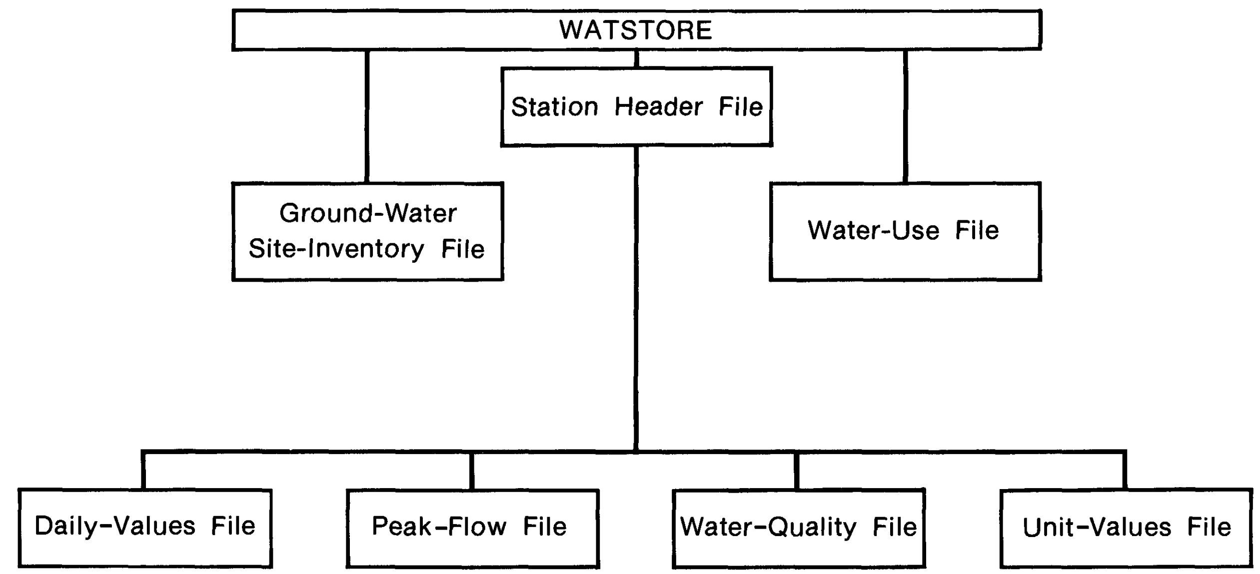


Figure 9.3-1 Index to file stored data.

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 on the availability of water-resources data in the major coal provinces of the United States. It is derived from the "Catalog of Information on Water Data," which is a computerized information file about water-data acquisition activities in the United States and its territories and possessions, with some international activities included.

This special index consists of five volumes (figure 9.4–1): volume I, Eastern Coal Province; volume II, Interior Coal Province; volume III, Northern Great Plains and Rocky Mountain Coal Provinces; volume IV, Gulf Coast Coal Province; and volume V, Pacific Coast and Alaska Coal Provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

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

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water-Data Exchange (NAWDEX). (See section 9.2.)

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

District Chief
U.S. Geological Survey, WRD
2120 Capitol Ave., Room 4006
P.O. Box 1125
Cheyenne, WY 82003
Telephone: (307) 772-2153
FTS: 328-2153

or

District Chief
U.S. Geological Survey, WRD
Federal Building, Room 428
301 S. Park Ave., Drawer 10076
Helena, MT 59626-0076
Telephone: (406) 449-5496
FTS: 585-5496

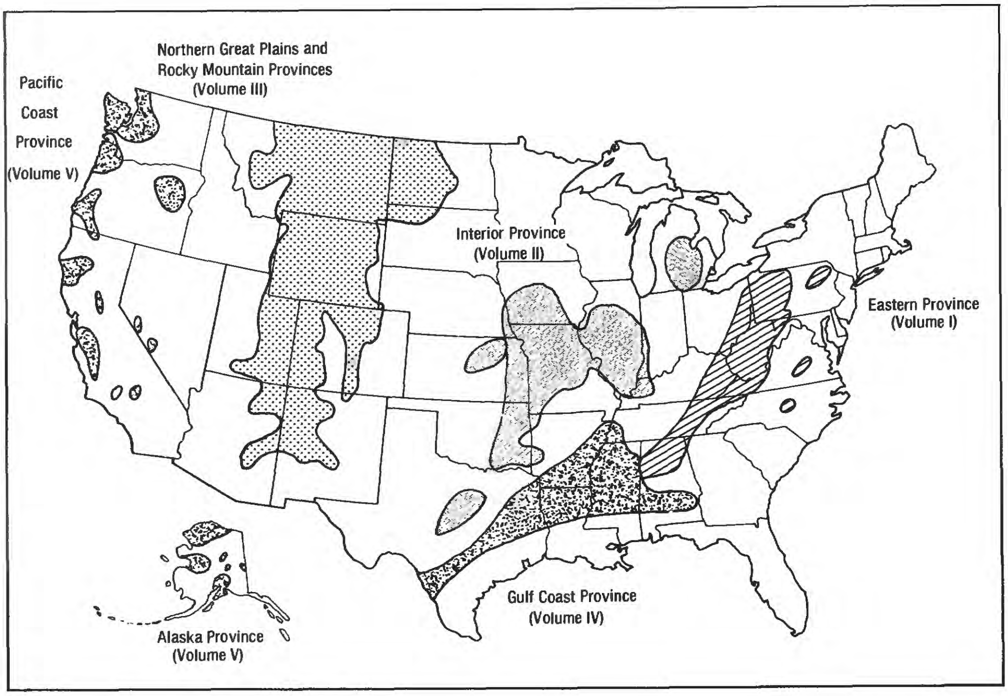


Figure 9.4-1 Index volumes and related provinces.

STORET is U.S. Environmental Protection Agency's Computerized Data-Base System

STORET is the computerized water-quality data-base system maintained by the U.S. Environmental Protection Agency.

STORET is a computerized data-base system maintained by the U.S. Environmental Protection Agency (1979) for the storage and retrieval of data relating to the quality of the 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 fishkills, waste-abatement needs, implementation schedules, and other water-quality related information. The Water-Quality File (WQF) is the most widely used STORET file.

The data in the WQF are collected through cooperative programs involving EPA, 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 Bureau of Reclamation, and the Tennessee Valley Authority all use STORET's WQF to store and retrieve data collected through their water-quality monitoring programs.

There are 1,800 water-quality parameters defined within STORET's WQF . In 1976 there were data from more than 200,000 unique collection points in the system. Figure 9.5–1 illustrates the groups of parameters and the number of observations that are in the WQF.

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 Region VIII is:

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

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

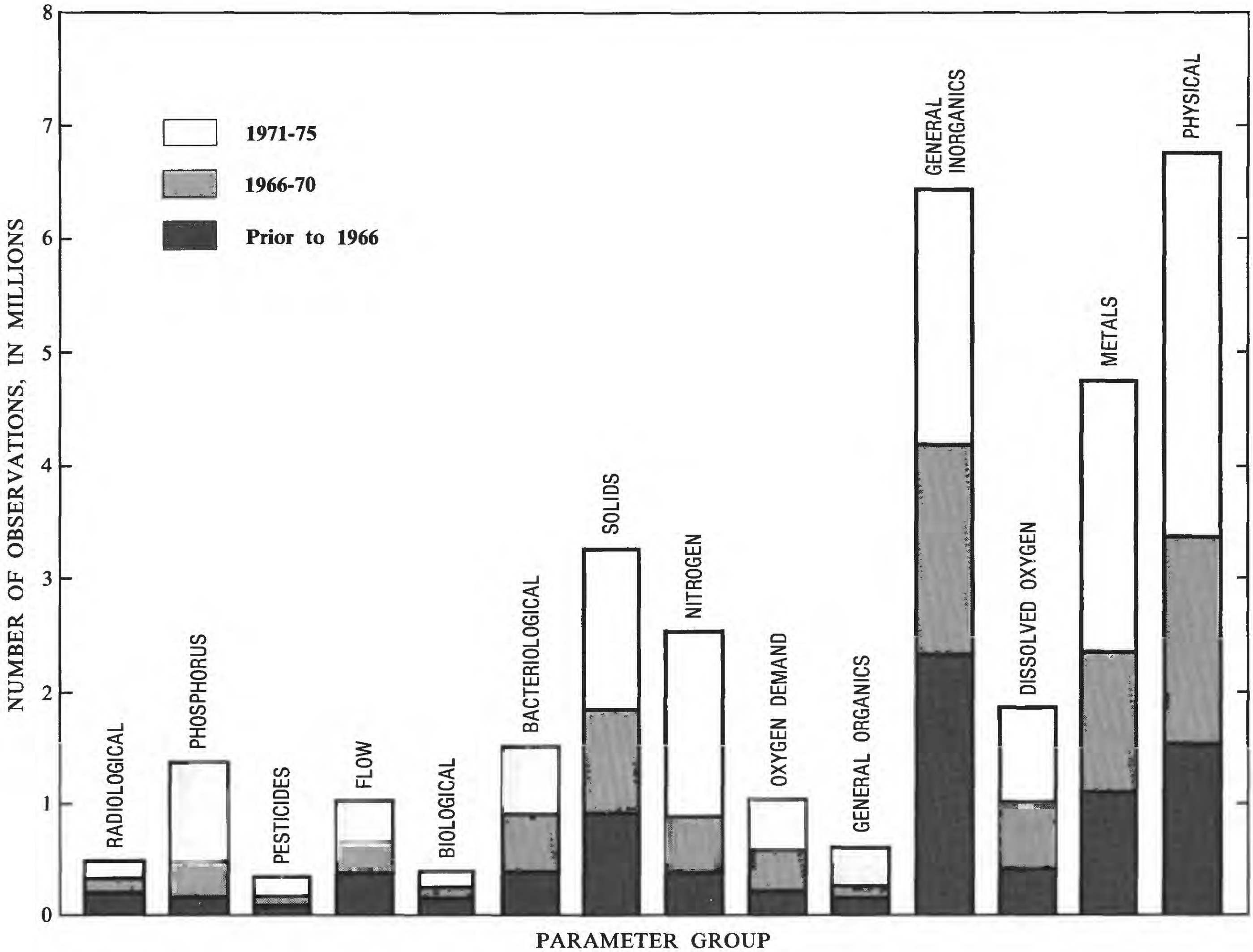


Figure 9.5-1 Parameter groups and number of observations in the Water-Quality File.

[Site number: Simplified site number used in this report to identify surface-water locations
Station number: Assigned by U.S. Geological Survey to locations where streams are measured or sampled on a regular basis. The first two digits identify the major basin in which the station is located (Missouri River Basin is 06). The remaining six digits identify the relative location of the station, with numbers increasing progressively in the downstream direction
Location: Latitude and longitude are given in degrees, minutes, and seconds
Discharge: Continuous record
Temperature: Daily measurement
p: Data on peak flows only
m: Miscellaneous measurement(s) or sample(s)]

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
1	06226500	Pilot wasteway near Morton	43 11 35	108 45 25		1949-53			
2	06227000	Pilot Canal near Morton	43 12 00	108 44 00		1949-53, 1974m, 1977m			
3	06227500	Wyoming Canal below Pilot diversion near Morton	43 14 00	108 46 00		1949-53, 1975-82m			1975-83
4	06227600	Wind River near Kinnear	43 08 34	108 42 32	2,194	1974-79			
5	06227700	Leclair Canal near Riverton	43 02 29	108 25 46		1976-77m			1976-77
6	06228000	Wind River at Riverton	43 00 38	108 22 32	2,309	1906-08, 1911-83	1947-58, 1960-83	1947-49, 1953-56, 1966-76	1949-65, 1977
7	06228350	South Fork Little Wind River above Washakie Reservoir near Fort Washakie	42 58 06	109 02 13	90.3	1976-83	1976-83		
8	06228500	Little Wind River near Fort Washakie	43 00 00	108 56 05	117	1921-40			
9	06229000	North Fork Little Wind River at Fort Washakie	43 00 40	108 53 10	127	1921-40			
10	06229700	Norkok Meadows Creek near Fort Washakie	43 04 56	108 54 12	15.4	1965-81P			
11	06229800	Sand Draw near Fort Washakie	43 03 42	108 54 44	.991	1961-81P			
12	06229900	Trout Creek near Fort Washakie	42 57 04	108 56 54	16.1	1961-68, 1970-83P			
13	06230300	Lake outlet near Fort Washakie	42 57 13	108 48 47		1960-70	1960-70	1962-68	
14	06230500	Little Wind River near Arapahoe	42 58 58	108 35 54	618	1950-53			
15	06231000	Little Wind River above Arapahoe	42 57 37	108 29 54	660	1906-09, 1911-18, 1979-83	1966-83		
16	06231500	Middle Popo Agie River near Lander	42 44 35	108 49 00	86.5	1911-12, 1918-24			
17	06231600	Middle Popo Agie River below Sinks near Lander	42 45 27	108 47 52	87.5	1959-68, 1969-70P			1965
18	06231950	Baldwin Creek at Lander	42 50 55	108 43 00			1981-82		
19	06232000	North Popo Agie River near Milford	42 51 50	108 54 25	98.4	1945-63			
20	06232500	North Popo Agie River near Lander	42 52 59	108 47 16	134	1938-53			
21	06232600	Popo Agie River at Hudson Siding near Lander	42 51 59	108 41 04			1983		
22	06232800	Little Popo Agie River near Atlantic City	42 35 32	108 55 08	5.99	1957-73			
23	06233000	Little Popo Agie River near Lander	42 43 00	108 38 34	125	1946-83			
24	06233340	Monument Draw at upper station near Hudson	42 48 57	108 33 04	5.50	1965-72P			
25	06233360	Monument Draw at lower station near Hudson	42 49 15	108 34 59	8.380	1965-83P			
26	06233440	Coal Mine Draw tributary near Hudson	42 50 43	108 35 04	.631	1965-72P			

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
27	06233500	Little Popo Agie River at Hudson	42 54 04	108 35 12	384	1907-09, 1911-17, 1938-53			
28	06233600	Popo Agie River at Hudson	42 54 45	108 34 07		1966-69	1966-69		
29	06233900	Popo Agie River near Arapahoe	42 56 47	108 30 34		1979-83	1980-83		
30	06234000	Little Wind River below Arapahoe	42 57 20	108 29 15	1,464	1906-09, 1911-18			
31	06234500	Beaver Creek near Lander	42 37 50	108 21 10	113	1938-41			
32	06234700	South Fork Hall Creek near Lander	42 38 44	108 23 23	3.88	1959-72P			
33	06234800	Bobcat Draw near Sand Draw	42 49 34	108 13 18	2.89	1969,P 1971-81P			
34	06235000	Beaver Creek near Arapahoe	42 57 16	108 25 39	354	1950-53, 1967-73^{m}	1951 1967-81		1950-53
35	06235500	Little Wind River near Riverton	42 59 51	108 22 29	1,904	1941-83	1949-58, 1960-64, 1966-83	1949, 1953, 1956, 1965-76	1949-54, 1956-65, 1969, 1971
36	06235700	Haymaker Creek near Riverton	43 04 54	108 22 46	9.52	1961-64P, 1966-73P			
37	06236000	Kirby Draw near Riverton	43 05 29	108 16 06	129	1951-53, 1961-83P			1951-53
38	06236100	Wind River above Boysen Reservoir near Shoshoni	43 07 43	108 13 28	4,390	1973-83^{m}	1973-83		
39	06238760	West Fork Dry Cheyenne Creek at upper station near Riverton	42 57 12	108 06 16	.691	1965-83P			
40	06238780	West Fork Dry Cheyenne Creek tributary near Riverton	42 53 03	108 06 12	1.85	1965-73P			
41	06239000	Muscrat Creek near Shoshoni	43 08 53	108 09 27	733	1950-58, 1959-73			1950-58, 1960-73
42	06244500	Fivemile Creek above Wyoming Canal near Pavillion	43 18 05	108 42 08	118	1949-58, 1961-75	1950-52, 1954, 1974-76	1951, 1962, 1965-73	1950-58, 1960-75
43	06245000	Fivemile Creek near Pavillion	43 17 56	108 41 50	118	1948-49			1949
44	06245500	Powerline wasteway near Pavillion	43 15 00	108 37 00		1949-50			1949-50
45	06246000	Pavillion drain near Pavillion	43 13 00	108 30 00		1948-50		1949	1949-50
46	06246500	Ocean drain at Ocean Lake outlet, near Pavillion	43 11 56	108 34 08		1948-53, 1978-83	1947, 1949-51, 1978-83		1949-51
47	06246800	Ocean Drain near Midvale	43 12 41	108 28 33		1979-82			1979-82
48	06247000	Ocean Drain near Pavillion	43 13 00	108 28 00		1948-53		1949	1949-51
49	06247500	Dudley wasteway near Pavillion	43 13 00	108 27 00		1949-50			1949-50
50	06248000	Kellett drain near Pavillion	43 12 00	108 25 00		1948-50		1948-49	1948-50
51	06248500	Dewey drain near Pavillion	43 12 00	108 25 00		1948-50		1948-49	1948-50
52	06249000	Fivemile 76 drain near Riverton	43 12 00	108 25 00		1949-50		1949	1949-50
53	06249500	Sand Gulch drain and wasteway near Riverton	43 12 00	108 24 00		1949-50		1949	1949-50
54	06250000	Fivemile Creek near Riverton	43 12 14	108 23 54	356		1950-52	1951-58, 1961-65	1950-58, 1960-65
55	06250500	Lost Wells Butte drain near Riverton	43 12 00	108 23 00		1949-50			1949-50
56	06251000	Coleman drain near Shoshoni	43 11 00	108 21 00		1948-50		1948-49	1948-50
57	06251500	Sand Gulch near Shoshoni	43 11 38	108 18 50	18.6	1948-53		1948-49	1948-50
58	06252000	Eagle drain near Shoshoni	43 12 00	108 15 00		1948-50		1948-49	1948-50
59	06252500	Lateral P-34.9 wasteway near Shoshoni	43 13 00	108 13 00		1949-50			1949-50
60	06253000	Fivemile Creek near Shoshoni	43 13 20	108 13 06	418	1941-42, 1948-83	1947-83	1949-69, 1972	1948-75, 1978-83

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
61	06253500	Lateral P-36.8 wasteway near Shoshoni	43 14 00	108 12 00					1949-50
62	06255160	Dead Man Gulch tributary near Lysite	43 11 28	107 46 03	0.541	1965-72P			
63	06255190	Dead Man Gulch near Lysite	43 10 58	107 46 50	4.11	1965-73P			
64	06255200	Dead Man Gulch near Moneta	43 10 37	107 47 02	4.46	1958-69P			
65	06255300	Poison Creek tributary near Shoshoni	43 13 26	107 59 59	.391	1959-81P			
66	06255500	Poison Creek near Shoshoni	43 14 15	108 08 20	500	1949-53, 1955-56	1951	1949	1949-54, 1956, 1964^{m}
67	06256000	Badwater Creek at Lybyer Ranch near Lost Cabin	43 21 02	107 33 22	131	1948-68			
68	06256500	Badwater Creek at Lost Cabin	43 17 08	107 37 52	166	1945-48			
69	06256550	E-K Creek tributary near Arminto	43 12 53	107 15 08	.141	1960-68P			
70	06256600	Red Creek near Arminto	43 14 44	107 19 38	7.15	1963-81P			
71	06256650	Badwater Creek at Lysite	43 15 53	107 41 44	415	1965-73		1967-73	1966-73
72	06256670	Badwater Creek tributary near Lysite	43 15 30	107 42 55	5.86	1965-73P			
73	06256700	South Bridger Creek near Lysite	43 26 40	107 45 22	10.0	1960-81P			
74	06256800	Bridger Creek near Lysite	43 17 22	107 43 16	182	1965-74		1967-73	1965-73
75	06256830	Dolus Creek near Lysite	43 17 15	107 46 10		1966^{m}			1966^{m}
76	06256900	Dry Creek near Bonneville	43 16 52	107 54 45	52.6	1964-81	1976-79	1976-81	1965-81
77	06256940	Hoodoo Creek near Bonneville	43 18 20	107 58 35		1966^{m}			1966^{m}
78	06257000	Badwater Creek at Bonneville	43 16 09	108 04 46	808	1947-73	1951, 1953	1963-73	1947-73
79	06257300	Shotgun Creek tributary near Pavillion	43 27 35	108 44 37	2.57	1961-81P			
80	06257500	Muddy Creek near Pavillion	43 21 46	108 36 08	267	1949-73	1950-51	1949, 1955-58, 1962, 1965-72	1949-58, 1960-72
81	06258000	Muddy Creek near Shoshoni	43 17 10	108 16 30	332	1949-68, 1972-83	1949-51, 1953, 1983	1949, 1956-58, 1962-64, 1966	1949-68, 1983
82	06258010	Cottonwood Creek drain near Shoshoni	43 18 06	108 16 55					1979-82
83	06258400	Birdseye Creek near Shoshoni	43 22 27	108 07 38	13.2	1959-72P			
84	06258500	Cottonwood Creek near Bonneville	43 21 02	108 13 30	165	1949-53	1951^{m}		1949-53
85	06258900	Boysen Reservoir	43 25 00	108 10 37	7,700	1951-83			
86	06259000	Wind River below Boysen Reservoir	43 25 30	108 10 42	7,701	1951-83	1953-54, 1960-83	1954, 1960-82	1979-83
87	06259100	Red Canyon Creek near Thermopolis	43 35 23	108 13 27		1964^{m}			1964^{m}
88	06259300	Buffalo Creek near Thermopolis	43 35 36	108 10 41		1964^{m}			1964^{m}
89	06259500	Bighorn River at Thermopolis	43 38 46	108 12 08	8,020	1900-05, 1910-53	1947-54, 1970	1947-54	1947-53
90	06259600	Bighorn River below Black Willow Draw near Lucerne	43 41 53	108 09 25		1976		1976	
91	06260000	South Fork Owl Creek near Anchor	43 39 53	108 52 02	87.0	1932, 1939-43, 1959-83	1974-83		
92	06260200	Middle Fork Owl Creek above Anchor Reservoir	43 40 00	108 52 00	33.6	1959-65			
93	06260300	Anchor Reservoir	43 39 50	108 49 27	131	1960-83			
94	06260400	South Fork Owl Creek below Anchor Reservoir	43 39 57	108 47 34	131	1959-83	1974-83		
95	06260500	South Fork Owl Creek above Curtis Ranch north of Thermopolis	43 41 00	108 44 00	144	1943-59			
96	06261000	South Fork Owl Creek at Curtis Ranch near Thermopolis	43 43 00	108 42 00	149	1931-32, 1938-43			

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
97	06261500	South Fork Owl Creek near Thermopolis	43 43 00	108 38 00	180	1921-22, 1929-32			
98	06262000	North Fork Owl Creek near Anchor	43 42 00	108 55 00	54.8	1941-62			
99	06262300	North Fork Owl Creek above Basin Ranch near Anchor	43 41 21	108 50 24	61.0	1962-75[m]			
100	06262500	North Fork Owl Creek at Crann Ranch near Thermopolis	43 44 00	108 39 00	94.2	1938-39			
101	06263000	North Fork Owl Creek near Thermopolis	43 44 00	108 36 00	102	1930-32			
102	06263300	Owl Creek above Mud Creek near Thermopolis	43 41 31	108 19 22		1965[m]			1965[m]
103	06263500	Mud Creek near Thermopolis	43 41 00	108 20 00	101	1938-39			
104	06264000	Owl Creek near Thermopolis	43 41 09	108 18 08	478	1910-17, 1931-32, 1938-69			
105	06264500	Owl Creek near Lucerne	43 43 00	108 11 00	509	1932-33, 1938-53			1947
106	06264700	Bighorn River at Lucerne	43 44 10	108 09 38			1965-83		
107	06265000	Kirby Creek near Lucerne	43 44 00	108 09 00	199	1941-45			
108	06265180	Coal Draw near Kirby	43 47 08	108 11 08		1965[m]			1965[m]
109	06265200	Sand Draw near Thermopolis	43 48 30	108 28 00	6.33	1960-81P			
110	06265300	Sand Draw near Kirby	43 49 03	108 11 58		1965[m]			1965[m]
111	06265337	Cottonwood Creek at county bridge near Hamilton Dome	43 45 40	108 40 30			1977-78		1977-78
112	06265350	Cottonwood Creek above Hamilton Dome	43 48 30	108 36 30		1970[m]	1970[m]		
113	06265400	Cottonwood Creek below Hamilton Dome	43 49 46	108 30 30		1970[m]	1970[m]		
114	06265410	Cottonwood Creek at state highway 120 near Hamilton Dome	43 50 27	108 28 00		1977-78[m]	1977-78[m]		1977-78
115	06265435	Grass Creek above Little Grass Creek near Grass Creek	43 53 32	108 47 11		1977-78[m]	1977-78		1977-78
116	06265492	Grass Creek near mouth near Hamilton Dome	43 52 14	108 23 36		1977-78[m]	1977-78		1977-78
117	06265500	Cottonwood Creek at Winchester	43 51 45	108 09 10	416	1941-45, 1946-49[m]			1965-66[m]
118	06265600	Tie Down Gulch near Worland	43 53 15	108 07 45	1.78	1961-83P			
119	06265800	Gooseberry Creek at Dickie	44 00 00	108 45 25	95.0	1957-78			
120	06266000	Gooseberry Creek near Grass Creek	44 00 00	108 41 10	142	1945-57	1951		
121	06266320	Gillies Draw tributary near Grass Creek	44 04 53	108 34 52	1.30	1965-73P			
122	06266450	Gooseberry Creek at state highway 431 near Grass Creek	44 00 14	108 31 12		1977-78[m]	1977-78		1977-78
123	06266460	Murphy Draw near Grass Creek	44 00 52	108 30 08	2.32	1965-81P			
124	06266500	Gooseberry Creek near Dickie	44 00 18	108 27 18	289	1938-41			
125	06267000	Gooseberry Creek at Neiber	43 55 22	108 03 48	361	1941-53	1951	1951-52	1947, 1951-53, 1965-66[m]
126	06267050	Bighorn River at Neeber	43 55 12	108 03 23			1966-69		
127	06267260	North Prong east fork Nowater Creek near Worland	43 56 45	107 48 37	3.77	1964-83P			
128	06267270	North Prong east fork Nowater Creek tributary near Worland	43 56 37	107 48 20	2.11	1965-73P			
129	06267400	East Fork Nowater Creek near Colter	43 54 55	107 55 46	1.49	1971-83	1977-81		1977-81
130	06267420	Nowater Creek 4 miles south of Worland	43 58 26	107 59 28					1950-51 1953, 1966[m]
131	06267900	Middle Fork Fifteenmile Creek near Worland	44 04 12	108 13 43			1979-81		1979-82

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
132	06268500	Fifteenmile Creek near Worland	44 01 14	108 00 42	518	1951-72, 1978-83	1962-72, 1979-81	1961-72	1949-72, 1979-83
133	06268600	Bighorn River at Worland	44 00 53	107 58 08	10,810	1965-69	1965-83	1965-69	1965-69
134	06268640	Slick Creek near Worland	44 03 30	107 55 59			1981-83		1950-51
135	06269000	Bighorn River near Manderson	44 12 00	107 55 00	11,020	1949-53, 1955-56	1949^{m}, 1951-53, 1967-68, 1970-71	1949-53, 1956, 1972	1949-53, 1955-56
136	06269500	Bighorn River at Manderson	44 16 00	107 59 00	11,048	1941-49	1947-49		1947-49
137	06274250	Elk Creek near Basin	44 18 30	108 01 50	96.9	1959-81^{P}			1950-51, 1967^{m}
138	06274300	Bighorn River at Basin	44 23 00	108 02 08		1983^{m}	1983^{m}		
139	06274500	Greybull River near Pitchfork	44 06 31	109 09 36	282	1946-49, 1951-71			
140	06274800	Wood River near Kirwin	43 52 10	109 18 39	7.66	1970-75			1975
141	06274810	Wood River at Kirwin	43 52 33	109 17 52	11.4	1975-78			1975
142	06275000	Wood River at Sunshine	44 02 15	108 58 24	194	1945-83			1975
143	06275500	Wood River near Meeteetse	44 06 25	108 57 25	211	1910-12, 1914-16, 1917^{m}, 1929-49			
144	06276000	Greybull River near Meeteetse	44 07 30	108 55 15	659	1910-12, 1915-16, 1920			
145	06276500	Greybull River at Meeteetse	44 09 20	108 52 35	681	1897, 1903^{m}, 1920-83	1951-53, 1965-76	1955-56	1955-56, 1975
146	06276700	Greybull River below Meeteetse Creek near Meeteetse	44 13 14	108 49 48				1974-75	
147	06277000	Bench Canal near Burlington	44 24 00	108 33 00		1930-38			
148	06277500	Greybull River near Basin	44 24 24	108 11 10	1,115	1930-73	1951-53, 1965-83		1965-67^{m}
149	06277700	Twentyfour mile Creek near Emblem	44 27 32	108 36 30	12.8	1960-81^{P}			
150	06277750	Dry Creek tributary near Emblem	44 27 42	108 34 12	.651	1960-68^{P}, 1970-81^{P}			
151	06277950	Dry Creek near Greybull	44 29 48	108 12 33	432	1979-81	1979-81		
152	06278000	Dry Creek at Greybull	44 30 00	108 03 00	433	1951-53, 1955-60	1951, 1958-60, 1965	1952-53	1949-53, 1959-60, 1979-81
153	06282000	Shoshone River below Buffalo Bill Reservoir	44 31 00	109 05 50	1,538	1921-83	1947-49, 1965-83	1947-49, 1976-79	
154	06282500	Shoshone River at Cody	44 32 05	109 03 40	1,603	1902-09			
155	06282700	Cottonwood Creek tributary near Cody	44 36 00	109 07 50	.761	1961-73^{P}			
156	06282900	Shoshone River above Dry Creek near Cody	44 34 37	108 58 18			1951-53, 1974-83		
157	06283000	Shoshone River at Corbett Dam	44 35 00	108 56 00	1,793	1908-25			
158	06283800	Shoshone River above Willwood Dam near Willwood	44 38 29	108 56 19		1979-82			1979-82
159	06284000	Shoshone River at Willwood Dam	44 40 00	108 54 00	1,833	1925-26			1979-82
160	06284005	Willwood Canal near Ralston	44 40 21	108 54 34					1979-83
161	06284010	Shoshone River below Willwood Dam near Ralston	44 40 25	108 54 59			1972-78		1973, 1979-83
162	06284200	Shoshone River at Willwood	44 42 32	108 45 31	1,980	1974-78			
163	06284400	Shoshone River near Garland	44 44 20	108 35 38	2,036	1958-78	1959, 1968-71, 1974-76 1983		

Site No.	Station No.	Station name	Location: Latitude ° ' "	Location: Longitude ° ' "	Drainage area (square miles)	Type and period of record: Discharge	Chemical quality	Temperature	Sediment
164	06284450	Bitter Creek below sewage Lagoon near Powell	44 47 10	108 43 44			1981		
165	06284500	Bitter Creek near Garland	44 45 13	108 35 29	80.5	1950-53, 1957-60, 1968-83	1950-53, 1957, 1960, 1968-83	1969-75, 1977-83	1949-51
166	06284800	Whistle Creek near Garland	44 43 21	108 34 16	101	1958-60, 1968-83	1957-60, 1969-83	1969-75, 1977-83	
167	06285000	Shoshone River at Byron	44 47 00	108 31 00	2,345	1929-66	1947-50, 1965-66	1947-49	1951
168	06285100	Shoshone River near Lovell	44 50 20	108 26 00	2,350	1966-83	1967-83	1967-75, 1977-83	1971-82
169	06285400	Sage Creek at Sidon Canal near Deaver	44 53 08	108 33 01	341	1958-60, 1968-83	1957-60, 1969-83	1969-75, 1977-83	
170	06285500	Sage Creek near Lovell	44 51 00	108 27 00	381	1951-60	1950-53, 1965m, 1968-71	1953	1949-53
171	06286000	Shoshone River at Lovell	44 50 00	108 25 00	2,832	1897-98, 1899m			
172	06286020	Shoshone River below Big Fork Canal near Lovell	44 51 32	108 19 52				1969-70	
173	06286200	Shoshone River at Kane	44 51 31	108 19 52	2,989	1957-68	1950-53, 1959-68, 1976-83	1961-68	1959-64

Site number: Simplified site number used in this report to identify surface-water locations.
Miscellaneous site identification number: Assigned by the U.S. Geological Survey to locations where only one or a few measurements or samples have been obtained. The first six digits designate latitude of the site, the next seven digits designate longitude, and the last two digits are sequence numbers to distinguish between several sites that may be in close proximity of one another.
Location: Latitude and longitude are given in degrees, minutes, and seconds

Site No.	Miscellaneous site identification number	Location Latitude ° ' "	Location Longitude ° ' "	Station name
174	424018108300100	42 40 18	108 30 01	Twin Creek at Carr Reservoir outlet near Lander
175	433452108124500	43 34 52	108 12 45	Bighorn River at Wedding of the Water
176	434104108200500	43 41 04	108 20 05	Mud Creek at mouth near Thermopolis
177	434112108160800	43 41 12	108 16 08	Owl Creek 0.5 mile below Eagle Draw near Thermopolis
178	434128108233400	43 41 28	108 23 34	Owl Creek near Thompson Reservoir No. 1 near Thermopolis
179	434129108145400	43 41 29	108 14 54	Owl Creek 1.7 miles above Meeteetse Draw near Thermopolis
180	434134108150400	43 41 34	108 15 04	Owl Creek 3.1 miles below Eagle Draw near Thermopolis
181	434137108143500	43 41 37	108 14 35	Owl Creek 1.0 mile above Meeteetse Draw near Thermopolis
182	434152108141100	43 41 52	108 14 11	Owl Creek below Meeteetse Draw near Thermopolis
183	434204108473200	43 42 04	108 47 32	North Fork Owl Creek above Rattlesnake Creek near Anchor Dam
184	434206108133500	43 42 06	108 13 35	Owl Creek above Sunnyside Lane near Thermopolis
185	434207108281700	43 42 07	108 28 17	Owl Creek at Middleton School
186	434208108133000	43 42 08	108 13 30	Owl Creek at Sunnyside Lane near Thermopolis
187	434229108425500	43 42 29	108 42 55	South Fork Owl Creek near Ember Ranch
188	434250108401900	43 42 50	108 40 19	South Fork Owl Creek at Ember Ranch
189	434255108103200	43 42 55	108 10 32	Owl Creek at U.S. Highway 20 near Lucerne
190	434319108093100	43 43 19	108 09 31	Owl Creek at mouth near Lucerne
191	434326108355900	43 43 26	108 35 59	South Fork Owl Creek near mouth near Arapahoe Ranch
192	434327108320500	43 43 27	108 32 05	Owl Creek at Arapahoe Ranch
193	434336108352800	43 43 36	108 35 28	South Fork Owl Creek at mouth near Arapahoe Ranch
194	434419108081900	43 44 19	108 08 19	Kirby Creek at Black Mountain Road near Lucerne
195	434730108102600	43 47 30	108 10 26	Coal Draw at mouth at Kirby
196	435030108275300	43 50 30	108 27 53	Cottonwood Creek above Grass Creek near Hamilton Dome
197	435146108091000	43 51 46	108 09 10	Cottonwood Creek at mouth at Winchester
198	435445108291500	43 54 45	108 29 15	Grass Creek near mouth near Grass Creek
199	435524108035000	43 55 24	108 03 50	Gooseberry Creek at mouth at Neiber
200	435543109081600	43 55 43	109 08 16	Middle Fork Wood River near Kirwin
201	435608109083800	43 56 08	109 08 38	Deer Creek near Kirwin
202	435919109052800	43 59 19	109 05 28	Dick Creek near Kirwin
203	440033108395600	44 00 33	108 39 56	Gooseberry Creek at State Highway 120 near Dickie
204	440155109030000	44 01 55	109 03 00	Sunshine Reservoir tributary near Meeteetse
205	440540109032900	44 05 40	109 03 29	Greybull River at Pappapou Butte near Meeteetse
206	440630108572700	44 06 30	108 57 27	Wood River at mouth near Meeteetse
207	440930108522200	44 09 30	108 52 22	Greybull River at Meeteetse
208	441551108472800	44 15 51	108 47 28	Greybull River below Cottonwood Creek near Meeteetse
209	442017108410800	44 20 17	108 41 08	Greybull River below Coyote Canyon near Meeteetse
210	442302108161800	44 23 02	108 16 18	Greybull River near Otto
211	442327108345700	44 23 27	108 34 57	Greybull River at Fenton
212	442357108255400	44 23 57	108 25 54	Greybull River at county bridge near Burlington
213	442451108325100	44 24 51	108 32 51	Bench Canal near Fenton
214	442514108293700	44 25 14	108 29 37	Greybull River at Avent School near Burlington
215	442815108032600	44 28 15	108 03 26	Greybull River at mouth at Greybull
216	443039109084800	44 30 39	109 08 48	Shoshone River in Shoshone Canyon near Cody
217	445132108195000	44 51 32	108 19 50	Shoshone River below Sand Draw near Lovell

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