

HYDROLOGY OF AREA 50, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, WYOMING AND MONTANA

BY

MARLIN E. LOWRY, JAMES F. WILSON, JR., AND OTHERS

U.S. GEOLOGICAL SURVEY

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

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

<u>Multiply</u>	<u>By</u>	<u>To obtain</u>
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per square mile (acre ft/mi ²)	476	cubic meter per square kilometer
British thermal unit per pound (BTU/lb)	2.326	joule per gram
cubic foot (ft ³)	0.02832	cubic meter
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second square kilometer
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.06309	liter per second
gallon per second (gal/s)	3.785	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381 3,785	cubic meter per second cubic meter per day
pound (lb)	453.6	gram
pound per cubic foot (lb/ft ³)	16.02	kilogram per cubic meter
square foot (ft ²)	0.09290	square meter
square mile (mi ²)	2.590	square kilometer
ton (short, 2,000 pounds)	0.9072	metric ton
ton per day (ton/d)	0.0105 0.9072	kilogram per second metric ton per day

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

$$^{\circ}\text{F} = 9/5(^{\circ}\text{C}) + 32$$

$$^{\circ}\text{C} = 5/9(^{\circ}\text{F} - 32)$$

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

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Abstract

Area 50 includes the entire Powder River Basin and the upstream parts of the Belle Fourche and Cheyenne River basins--a total of 20,676 square miles. The information in this report will be useful to Federal agencies in leasing and management of Federal coal lands, to surface-mine owners, operators and others preparing permit applications, and to regulatory authorities. The report represents a summary of the results to date of the water-resources investigations of the U.S. Geological Survey, conducted in cooperation with State and other Federal agencies.

The area has abundant deposits of coal, but water is scarce. Increased population, industrial development, and water-based recreation are expected to have a much greater impact on water resources than the mining and transportation of the coal. However, the most likely effect of reclamation will be to inset into the existing hydrologic system a unit having hydrologic properties that are completely different from the undisturbed bedrock and overburden. The changes could be beneficial in some ways and detrimental in others.

The climate is semiarid in most of the area. The terrain varies from forested mountains to sand dunes, but most of the strippable coal deposits are located in the semiarid plains and the tablelands near the center of the area. Ephemeral and interrupted streams drain 80 percent of the area and yield 40 percent of the runoff. Soils of the plains cover 94 percent of the area. In the plains areas a mixture of grasses and sagebrush are the predominant vegetation; trees are scarce except in the mountains.

The area coincides approximately with the Powder River structural basin. Rocks representing all geologic periods are present; the coal was deposited during the Cretaceous and Tertiary Periods. Most coal beds are within the Fort Union and Wasatch Formations. The near-surface deposits generally are nearly flat-lying and uninterrupted by major faults. The average thickness of the coal bed being mined during 1983 was 70 feet. Nearly all of the near-surface coals are of subbituminous rank, averaging about 8,000 British thermal units per pound, with about 0.5 percent sulfur content. State and Federal governments own less than one-half of the land surface; however, the Federal government owns most of the coal.

Nearly 90 percent of the land is used for agricultural purposes--mostly livestock grazing; 92 percent of the water used is for irrigation. Energy-minerals development has resulted in intense competition between agriculture and industry for land and water.

All active coal mining in the area is in the outcrop of the Wyodak coal bed in eastern Campbell County, Wyoming. Annual coal production has increased from less than 1 million tons in 1970 to 81.2 million tons in 1982; the projected production in 1990 is 122 million tons. Other important mineral resources include oil, natural gas, uranium, bentonite, gypsum, limestone, and metals.

Surface-water data are available for 168 locations on streams in Area 50; 132 have streamflow data, 81 have chemical-quality data, 42 have fluvial-sediment data, and 67 have biological data. In mountain areas average-annual runoff exceeds 200 acre-feet per square mile; in the plains areas it is less than 10 acre-feet per square mile. Most plains streams are dry most of the time, because they flow only in response to rainstorms and snowmelt. Mountain streams seldom go dry.

Intense summer thunderstorms cause most of the floods in the plains streams, while rapid spring snowmelt is the common cause of floods in mountain streams. Simultaneous flooding on all streams in the area is rare. Values of the 100-year floods are available for 37 stations; graphs are provided for estimating the 100-year flood at ungaged sites, and a procedure is described for synthesizing hydrographs for small streams. Analysis of streamflow and water-level data indicates that discharge to streams from local ground-water systems is greater than that from a regional ground-water system.

Average dissolved-solids concentrations are significantly greater than the national secondary drinking-water standard of 500 milligrams per liter at nearly all stations and exceed 2,000 milligrams per liter in samples at nearly one-half of the stations. Dissolved-solids concentrations generally vary seasonally with stream discharge. Streams draining the Bighorn Mountains are the least mineralized. Average concentrations in the Belle Fourche River are significantly smaller downstream from Keyhole Reservoir than upstream.

Average alkalinity concentrations exceed 100 milligrams per liter at all sampling stations and 200 milligrams per liter at most stations; the risk of acid mine drainage is thus minimized in Area 50. This large buffering capacity of the area's streams is accompanied by uniformly high pH values--nearly all measurements are above 7 but less than 9. Sodium and sulfate generally are the dominant ions, except in mountain streams, in which calcium, magnesium, and bicarbonate are predominant. Concentrations of calcium and magnesium are large enough in most streams, however, to make the water very hard.

Total-phosphorus concentrations, associated with large concentrations of suspended sediment, are large in most streams, especially the Powder River, where they average 0.58 milligrams per liter. Although the Belle Fourche River often has large concentrations of total phosphorus, algal growth is not a problem in Keyhole Reservoir. Trace metals generally are not a problem in the area's streams; exceptions are large concentrations of selenium in the South Fork Powder River and large concentrations of manganese and iron in some samples throughout the area.

The discharge-weighted concentration of suspended sediment in the Powder River at Arvada, Wyoming was more than 22,000 milligrams per liter during the 1978 water year, in contrast with an average of about 8,000 milligrams per liter for the 1979-80 water years. Sediment loads transported by the Powder River are large, eroded mostly from the Wyoming reach and partly deposited in the Montana reach. Sediment loads are smaller in the Belle Fourche and Cheyenne Rivers, increase significantly in the downstream direction, and are trapped in Keyhole and Angostura Reservoirs. Clay-size particles comprise between 38 and 97 percent of the sediment transported out of Area 50; less than 8 percent is sand.

Bacteria concentrations in streams are small throughout the area, indicating little pollution from warm-blooded animals. The productivity and relative abundance of various species of algae in many streams indicate some organic enrichment--probably the result of natural conditions and waste from livestock and wildlife.

The invertebrate communities in Clear Creek downstream from Buffalo and in Donkey Creek downstream from Gillette reflect degradation of the water by sewage effluent. In the Belle Fourche River, invertebrate communities were diverse and as densely populated downstream from a coal mine as upstream. Invertebrates also can be used to indicate relative volume and pattern of streamflow.

Trout and other cold-water game fish are found in mountain streams, but generally not plains streams; catfish, bass, and other warm-water game fish are found in a few plains streams, but not in mountain streams. Most of the coal mines are near ephemeral or intermittent streams that do not support a fishery resource; the Little Powder River is an exception.

Stream temperature affects rates of chemical reactions and biological processes. In Area 50 stream temperatures range from 0 degrees Celsius (32 degrees Fahrenheit) in winter to about 25 degrees Celsius (77 degrees Fahrenheit) in summer.

Ground-water data--water levels, well yields, and water quality--are available for about 3,000 wells in Area 50. Water levels in 800 wells completed in the Wyodak-Anderson coal were collected during 1981 by mining companies and others, resulting in a compilation of water-level data for the coal and overburden in the mine areas of Campbell County, Wyoming.

Ground-water supplies suitable 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. The Madison Limestone usually is considered where large supplies are sought; however, because the permeability of the formation is principally secondary, large-yield wells are not always obtained. Recharge to aquifers occurs mainly in the outcrop areas near their southern, western, and eastern extents. Small quantities of water flow northward out of the area through the Madison and Lower Cretaceous aquifers. Movement in the coal aquifers is complex.

Eighty-four percent of the wells and springs sampled yield water with dissolved-solids concentrations greater than the recommended national secondary drinking-water standard of 500 milligrams per liter. Nearly all sources sampled, however, yield water suitable for livestock. Manganese and iron concentrations in water from some aquifers are large enough to be objectionable for domestic supplies because of taste and staining problems. The chemical quality of the ground water is controlled by the solubility of the minerals that comprise the rocks, the reactions that occur as water moves through the rocks, the water temperature and pH, and the length of time during which the water is in contact with the rocks.

1.0 INTRODUCTION

1.1 Objective

Report Summarizes Available Hydrologic Data

Existing hydrologic conditions and sources of hydrologic information are identified to aid in the preparation and appraisal of environmental impact studies and mine-permit applications and in making leasing decisions.

Hydrologic information and analyses are needed to aid in making decisions to lease Federally owned coal and for the preparation of the necessary environmental assessments and impact study reports. This need has become even more critical with the enactment of Public Law 95-87, "Surface Mining Control and Reclamation Act of 1977". This Act requires an appropriate regulatory agency to issue mining permits partly on the basis of the assessment of the hydrologic impacts in the mining-permit application. This need is partly fulfilled by a series of reports that broadly characterize the hydrology of drainage basins within coal provinces nationwide. This report is part of that series. A similar report is available for Area 49, which is adjacent to the northwestern border of Area 50 (Slagle and others, 1983).

Area 50 includes the entire Powder River drainage basin and the upstream parts of the Belle Fourche and Cheyenne River basins. The Powder River drainage basin does not coincide with the Powder River structural basin (fig. 1.1-1). Most of Area 50, which includes 20,676 square miles in Montana and Wyoming, is in the Northern Great Plains Coal Province; the remainder is in the Rocky Mountain Coal Province.

This report provides general hydrologic information by means of a brief text with accompanying map, chart, graph, or other illustration, for each of a series of water-resources-related topics. Collectively the topical discussions represent a description of the hydrology of the area. The information contained herein will be useful to Federal agencies in the leasing and management of Federal coal lands, to surface-

mine owners, operators, and others preparing permit applications, and to regulatory authorities evaluating the adequacy of the applications.

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

This report represents a summary of the results of water-resources investigations to date in northeastern Wyoming and southeastern Montana. The U.S. Geological Survey has collected hydrologic data and made interpretive hydrologic studies in the area for decades. Much of the work has been done in cooperation with State and other Federal agencies—particularly the Wyoming State Engineer, Wyoming Department of Agriculture, Wyoming Highway Department, Wyoming Department of Environmental Quality, Montana Bureau of Mines and Geology, Montana Department of Natural Resources and Conservation, U.S. Bureau of Land Management, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and U.S. Department of Energy. To a large extent this cooperation has been responsible for achieving the present state of knowledge of the hydrology of Area 50 and will be an important factor in increasing that knowledge in the years ahead.

1.0 INTRODUCTION--Continued

1.2 Perspective

Abundant Coal, Scarce Water

Development of the area's vast coal deposits spans nearly a century, but modern development is significantly affected by the scarcity of water.

The Powder River indirectly was named because of the coal in the area. Fires, generally caused by spontaneous combustion, have burned extensive areas, leaving baked and fused red rock that is locally called clinker or scoria. The Reynolds survey of 1859 reported, "*** Powder River, (which derives its name from the sulphurous vapors rising from burning beds of lignite in its vicinity,) ***" (Reynolds, 1868, p. 8).

The coal resources captured the imagination of some on the earliest expeditions into the area. One of the first recorded proposals for development of the coal and water in the Lake De Smet area is given in Palmer's account of the expedition of Connor in 1865, where he suggested the following: "Seven miles from Clear Fork we came to a very pretty lake, about two miles long and about three-fourths of a mile wide, which Major Bridger told us was De Smet Lake, named for Father De Smet. The lake is strongly impregnated with alkali, in fact so strong that an egg or potato will not sink if thrown into the water; large red bluffs are to be seen on both sides, and underneath the lake is an immense coal vein. Not many miles from this lake is a flowing oil well. A scheme might be inaugurated to tunnel under this lake, pump the oil into the lake, set the tunnel on fire and boil the whole body of alkali water and oil into soap."¹ Lake De Smet has since been developed into an off-stream reservoir and still is prominent in plans for the development of the 200-foot coal bed that partly underlies the lake.

"The Virginian" of Owen Wister's novel of the same name, who was the prototype for western heroes, also had plans for coal development in the Powder River Basin. The Virginian planned for the changes in ranching which he envisioned and said, "I am well fixed for the new conditions. And then, when I took up my land, I chose a place where there is coal. It will not be long before the new railroad needs that." (Wister, 1902, p. 433).

Although the area has abundant coal, little water is readily available to develop the coal and to supply the resulting increased population. Area 50 comprises about 2 percent of the area of the Mississippi drainage basin, but contributes only about 0.1 percent of the flow to the Mississippi River. The quotations on the facing page (fig. 1.2-1) emphasize that coal is abundant, water is deficient, and although there is a need for development, care is needed to develop the resources wisely.

The shortage of water for energy development in the area is perhaps best shown by two projects, the 330,000-kilowatt Wyodak steam-electric powerplant and the Energy Transportation Systems Incorporated (ETSI) proposed coal-slurry pipeline. The Wyodak plant is the world's largest (1983) air-cooled, steam-electric plant. The decision for building an air-cooled system, which requires a larger capital investment and is less efficient than water-cooled systems, was made because of the abundance of coal and the scarcity of water. The 200 to 300 gallons of water per minute required by the plant is principally effluent from the Gillette sewage-treatment facility.

The ETSI slurry pipeline was originally intended to use ground water to transport pulverized coal from the Powder River Basin to Arkansas. The use of ground water was approved by the Wyoming Legislature in 1974. The ensuing battle, often emotional and sometimes bitter, centered on two issues: the transport of "scarce" Wyoming water, via the pipeline, to other States; and the alleged potential for lowering water levels in western South Dakota. The State of South Dakota threatened legal action against the State of Wyoming if ground water were used for the coal slurry. Present (1983) plans are to obtain water for the slurry line by building a pipeline from the Oahe Reservoir, which is on the Missouri River in South Dakota. This plan is being opposed in the courts by States downstream from the reservoir.

¹ Quoted text reprinted with permission of the publishers, The Arthur H. Clark Company, from *Powder River Campaigns and Sawyer Expedition of 1865*, edited by L. R. Hafen and A. W. Hafen (1961, p. 124).

“AND YET, ANCIENT AS ARE THE ORIGINS OF THESE FOUNDATIONS OF OUR CURRENT PROSPERITY THE REMARKABLE THING IS THAT THE PROVISION FO THEIS BOUNTIFUL PLANET HAS BEEN SUCH THAT THERE IS A GREATER DIFFERENCE BETWEEN OUR PRESENT LIFE STYLE AND THAT OF THE EARLY NINETEENTH CENTURY, THAN THERE WAS BETWEEN THAT ERA AND THE PERIOD OF THE LIFE OF CHRIST. THE REASON FOR THIS IS THE INCREASINGLY SUCCESSFUL EXPLOITATION OF THE CRUST OF THE PLANET ON WHICH WE LIVE. LIFE EXPECTANCY AS RECORDED IN ONE OF THE OLDER CENSUSES BASED ON SWEDEN IN THE MIDDLE OF THE 18TH CENTURY WAS 19 YEARS IN TOWNS AND VILLAGES. IN THOSE SAME PLACES, IT IS NOW 70 YEARS AND THE DIFFERENCE THAT HAS ARISEN IN THAT BRIEF TIME SPAN RESULTS FROM FOUR PARTICULAR DISCOVERIES AND APPLICATIONS: MEDICAL CARE, AND ADEQUATE DIET, CLEAN WATER SUPPLIES, AND AN EFFECTIVE SYSTEM OF WASTE DISPOSAL. AND ALL THOSE THINGS ULTIMATELY DEPEND UPON MATERIALS PROVIDED BY THE SURFACE OF THE PLANET ON WHICH WE LIVE.

THE DEVELOPMENT DURING THE 17TH AND 18TH CENTURIES OF CHEAP FORMS OF POWER AND THE INVENTION OF THE BLAST FURNACE TO PRODUCE INEXPENSIVE IRON AND STEEL HAVE REVOLUTIONIZED THE WORLD IN WHICH WE LIVE. IT IS SOMEWHAT DIFFICULT TO REALIZE THE TOTALITY OF OUR DEPENDENCE ON THE EARTH. THE BUILDINGS IN WHICH WE LIVE ARE BUILT OF MATERIAL MANUFACTURED FROM THE EARTH’S CRUST. HEATING, COOLING, AND LIGHTING SYSTEMS INVOLVE THE USE OF ENERGY DERIVED FROM MATERIALS IN THE CRUST, ENERGY STORED FROM THE SUN BY PLANTS AND ANIMALS MILLIONS OF YEARS AGO. MOST OF THE CLOTHING WE WEAR, THE FOOD WE EAT, GASOLINE, CARS, RADIO, TV—ALL THESE ARE TRIUMPHS OF EXTRACTION OF CRUDE MATERIALS FROM THE CRUST OF THE EARTH; DULL, UNPROMISING ROCKLIKE MATERIALS, DISCOVERED, EXTRACTED, CONCENTRATED, REFINED, AND THEN MANUFACTURED INTO SOMETHING OF IMMEDIATE VALUE.

* * *

FOR SOME OF OUR MOST ESSENTIAL COMMODITIES—OIL, GAS, MERCURY, TIN, SILVER, AMONGST THEM—THE END OF EXPLOITATION LOOMS. RESERVES DWINDLE, YET DEMAND INCREASES. OUR NONREPLENISHABLE RESOURCES, OUR BURGEONING POPULATION, OUR UNEQUAL PATTERNS OF PROSPERITY AND OUR CARELESS TECHNOLOGY—ALL THESE REPRESENT BOTH THREAT AND CHALLENGE TO OUR SURVIVAL.”

*RHODES AND STONE (1981 P. 357-359)
(WITH PERMISSION OF PUBLISHER, PERGAMON PRESS)*

WORLD COAL RESOURCE STANDINGS

- 1) CHINA
- 2) RUSSIA
- 3) UNITED STATES
- 4) WYOMING—IF IT WERE AN INDEPENDENT COUNTRY
- 5) CAMPBELL COUNTY, WYOMING—IF IT WERE AN INDEPENDENT COUNTRY

*GARY B. GLASS, WYOMING STATE GEOLOGIST
(TALK GIVEN TO CHEYENNE GEOLOGIC ASSOCIATION, 1980)*



Photograph by Susan Hogg
Wyoming Department of
Environmental Quality



Photograph by R. Rothschild
U. S. Bureau of Land Management

The Wyodak coal bed in Campbell County, Wyoming has an average thickness of about 70 feet, with 5 to 50 feet of overburden.

“IN SUMMARY, THERE IS PROBABLY SUFFICIENT SURFACE WATER IN THE UPPER MISSOURI BASIN TO SUPPORT FULL ENERGY DEVELOPMENT (I.E., SYNFUELS, COAL-FIRED GENERATING PLANTS, SLURRY PIPELINES). ACTUAL DEVELOPMENT, HOWEVER, WOULD NECESSIATE LARGE SCALE DIVERSIONS WITHIN THE BASIN WHICH WILL RESULT IN MANY EMOTIONAL, POLITICAL, AND LEGAL REPURCUSSIONS.

NORTHEAST WYOMING SEEMS TO BE THE AREA MOST DEFICIENT IN WATER RESOURCES.
* * *

THE NEXT FEW DECADES WILL BE CRITITCAL FOR THE WATER RESOURCES OF THE UPPER MISSOURI BASIN. THE IMPENDING ENERGY DEMAND MUST BE MANAGED WITH CARE. SENSITIVITY AND TECHNICAL INNOVATION TO AVOID A TOTAL DISTRUPTION OF THE HYDROGEOLOGY OF THE AREA.”

RICHARD AND LARSON (1982. P. 436-437)

Figure 1.2-1 Qoutations emphasizing the need for wise development of resources, the abundancy of coal, and the scarcity of water.

1.0 INTRODUCTION--Continued

1.3 Hydrologic Effects of Coal Mining

1.3.1 Regional Effects

Increased Population, Not Mining, Will Have Largest Hydrologic Impact

Water development for the increased population, industrial development, and water-based recreation may result in greatest hydrologic impacts.

The largest impact on the hydrology probably will be caused by the increases in population and land use, rather than actual mining activities. The largest increase in population because of coal development has been and will continue to be in Campbell County, Wyo., but adjoining service areas will have significant increases also. The population trends for Gillette and Campbell County, Wyo., are shown in figure 1.3.1-1. Water for municipal use is projected to increase from 3,990 acre-feet per year during 1975 to 11,290 acre-feet per year by 1990 (U.S. Department of the Interior, 1979d, p. R1-19). Use of water for coal mines is projected to increase, in the same period, from 170 to 3,500 acre-feet per year. Water-based recreation will increase more than 100 percent. As of March 1983 no complaints had been filed with the Office of the Wyoming State Engineer about effects of coal mining on water resources. However, ground water for individual domestic supplies, trailer courts, and housing developments was being developed to such a large extent that the State Engineer started an investigation in the summer of 1982 (Richard G. Stockdale, Office of the Wyoming State Engineer, oral commun., 1983).

Because the area is semiarid, water supplies from outside the area will have to be developed; the impacts of such development will extend beyond Area 50. The City of Gillette has developed water from the Madison Limestone, about 40 miles north-east of the town, to meet the increased demand for municipal supplies. Most water-based recreation is outside Area 50.

The impacts on hydrology of the different alternatives for coal conversion in the area and for transporting coal from the area differ, but some alternatives would cause larger hydrologic impacts than actual mining. A comparison of the impacts of four coal-use processes using 12.5 million tons of coal per year on selected aspects of the environment for the Colorado part of the Yampa River basin is reproduced in table 1.3.1-1. Although these are not the only possible alternatives, the table indicates that hydrologic impacts are largely dependent on coal-use processes and on population. This table is used,

rather than data for projects proposed in the area, because it is based on a common coal tonnage for comparison.

Airborne residuals may enter the hydrologic cycle either by washout, by precipitation, or by direct settling on the surface and later being incorporated in runoff. There are proposals to dispose of solid residuals in surface mines; therefore, some residue could enter the ground-water system.

The scale of planned mining of the Wyodak-Anderson coal bed is large; therefore, some areal hydrologic consequences of mining will occur. It can be assumed that eventually the strippable coal will be mined and that such large-scale mining will have an impact on the hydrology. An example of what could happen to drainage in surface-mined areas is shown in figure 1.3.1-2. Surface-mining regulations preclude the drastic change in drainage illustrated. However, the reclaimed spoil will have different hydrologic properties from the undisturbed bedrock. Also, it will not always be possible, nor necessarily desirable, to re-establish the original topography. Although infiltration, runoff, and aquifer properties can be engineered in a variety of ways, the most likely effect of reclamation will be to inset into the existing hydrologic system a unit having completely different hydrologic properties. The changes could be beneficial or detrimental, or beneficial to some and detrimental to others. For example, if infiltration were increased, less runoff would flow to streams. During intervals of low flow, this decrease could have an adverse impact on downstream users; during floods the decrease could lessen the possibility of flooding and could benefit downstream landowners.

The impact of mining on ground water has caused some concern. Regionally, however, there probably will be no measureable impact on the quantity of flow because flow is dominantly local, rather than regional, in the upper several hundred feet of the coal-bearing rocks. The possible impacts on quality of water have not been adequately assessed.

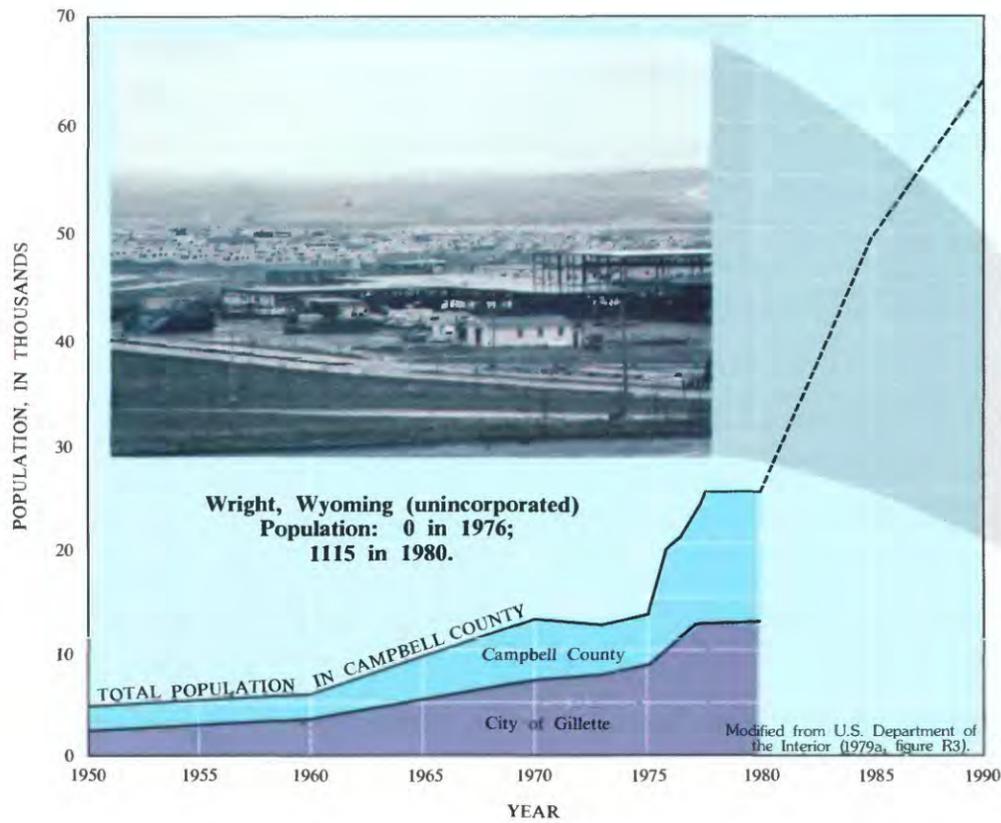
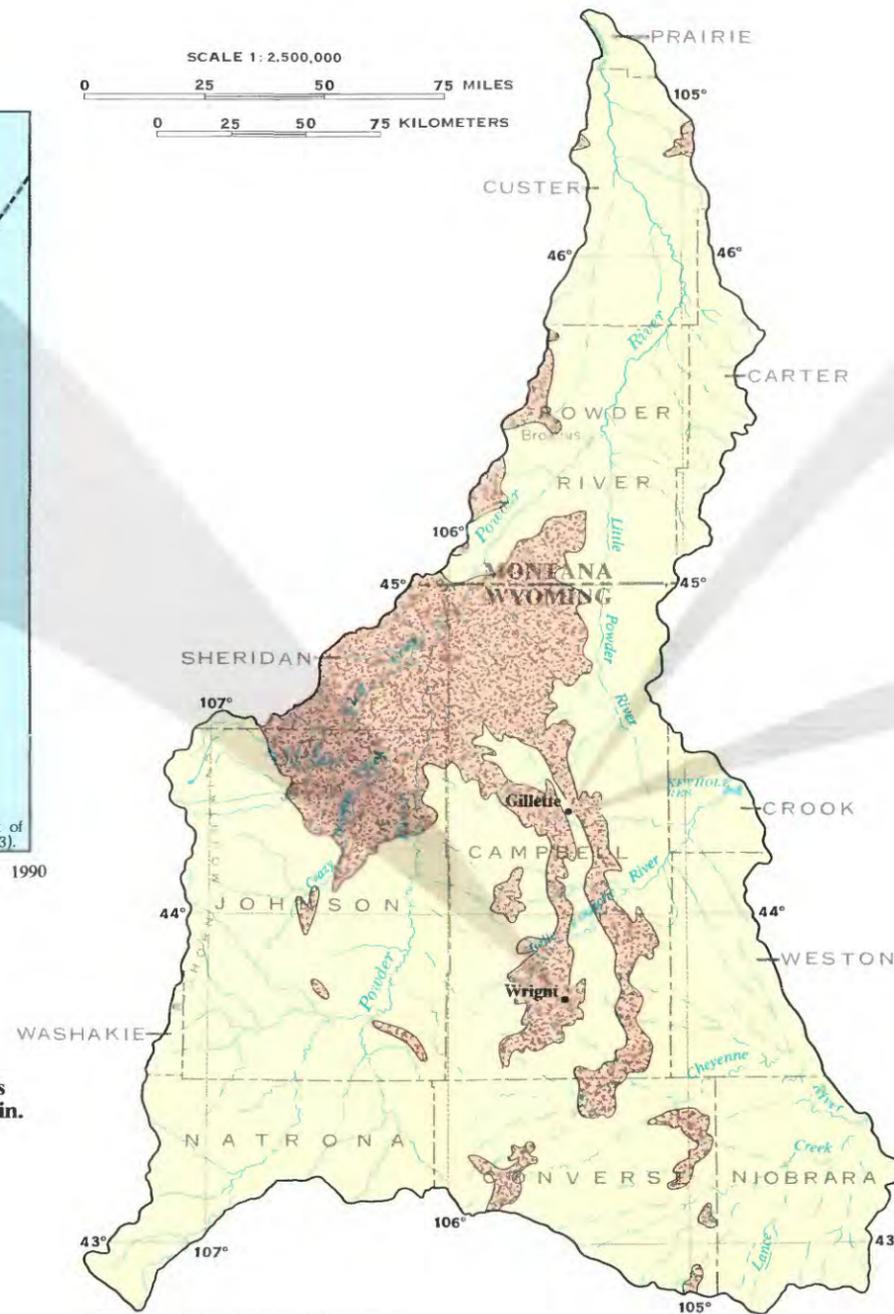


Figure 1.3.1-1 Population of Campbell County and the City of Gillette, 1950-80, and projected population of Campbell County, 1980-90.

Table 1.3.1-1 Comparison of the impact of four alternative coal-use processes on selected aspects of the environment, Colorado part of the Yampa River basin.

Item	Existing (1975)	Process using 12.5 million tons of coal			
		Electric power-plant	Gasification plant	Slurry-pipeline export	Unit-train export
Population-----	17,897	23,203	27,505	20,058	19,806
Water withdrawals (acre-feet per year)-	406,785	464,227	442,550	424,284	415,021
Water consumption (acre-feet per year)-	142,267	197,999	175,518	158,598	149,392
Residuals discharged (tons per year):					
Solid:					
Ash-----	73,926	733,725	723,036	73,926	73,926
Other solids-----	25,666	142,009	178,210	27,243	27,059
Airborne:					
Total suspended particulates-----	122,225	135,810	130,529	128,852	131,721
Hydrocarbons-----	5,682	7,371	6,518	5,756	5,875
Nitrogen oxides-----	22,193	147,366	47,784	22,310	22,490
Sulfur oxides-----	11,635	55,479	17,559	11,665	11,827
Carbon monoxide-----	7,790	12,983	9,227	7,880	8,054
Waterborne:					
Biochemical oxygen demand-----	2,152	2,180	2,202	2,163	2,162
Chemical oxygen demand-----	7,145	7,152	7,158	7,148	7,147
Nitrogen-----	130	141	151	134	134
Phosphorus-----	199	203	206	200	200
Suspended solids-----	13,276	38,312	38,340	38,291	38,289
Dissolved solids-----	62,790	63,026	63,220	62,888	62,876

From Steele and Hillier (1981, table 3).



Base from U.S. Geological Survey State base maps 1:2,500,000; Montana 1966, Wyoming 1964

EXPLANATION

 AREA WITH IDENTIFIED, NEAR-SURFACE, THICK OR ABUNDANT COAL BEDS

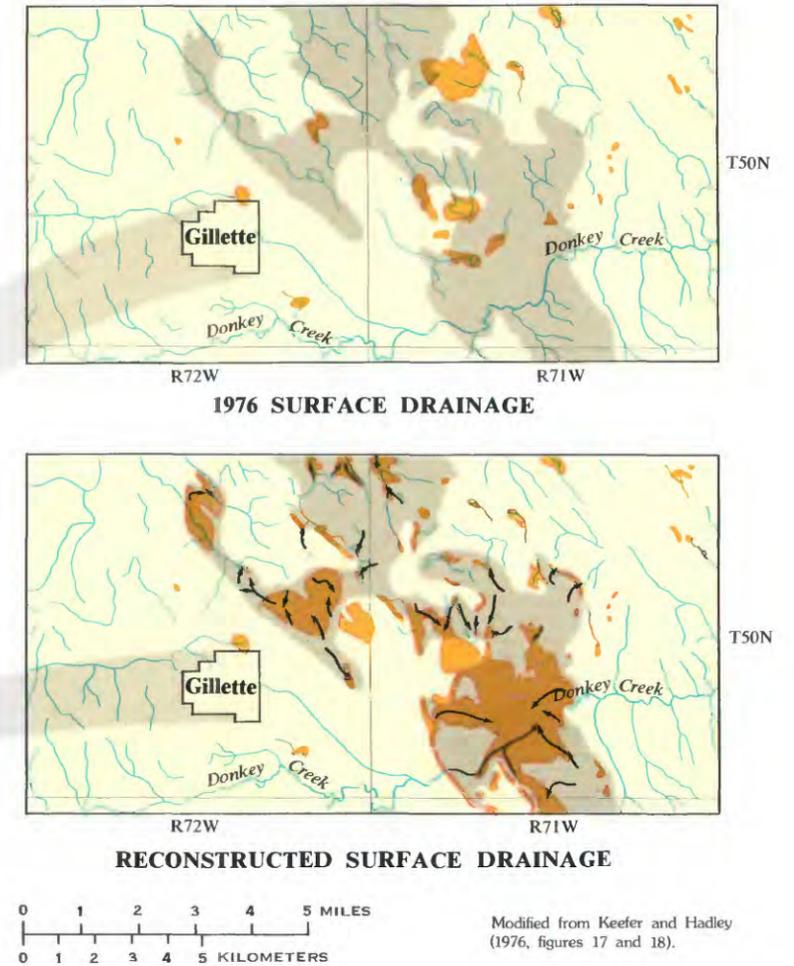


Figure 1.3.1-2 1976 surface drainage, Gillette and vicinity, and reconstructed surface drainage, if all coal is extracted from the strippable zone of the Wyodak-Anderson deposit according to the following assumed methods of mining and reclamation. 1) Overburden is replaced on a cut-by-cut basis as mining proceeds from east to west on 200-foot-wide north trending panels; 2) spoils are smoothly graded; 3) high walls are graded to 3:1 slopes; 4) overburden swells 20 percent; and 5) no attempt is made to re-establish through-flowing drainage. Strippable coal zone is shown by grey area. Topographic depressions marking areas of internal drainage within the mined-out tract are shown by yellow-orange area. Arrows indicate direction of streamflow. Based on a detailed reconstruction of the post-mining terrain by F.R. Shawe (U.S. Geological Survey, written commun., 1975). All drainage are intermittent except parts of Donkey Creek shown as heavy line.

1.0 INTRODUCTION--Continued

1.3 Hydrologic Effects of Coal Mining--Continued 1.3.2 Local Effects

Some Hydrologic Effects Beneficial; Some Detrimental

Water from mines may be developed for beneficial use; however, water levels will be lowered in the undisturbed coal and overburden and may never recover to pre-mining levels.

Water from some surface and underground mines has been developed for beneficial use. The water discharged from a mine into a stream at times may be the only flow in a stream and may have less dissolved solids than normal flow; such water commonly is put to beneficial use by ranchers in the area. The hydrographs in figure 1.3.2-1 illustrate flow in the Belle Fourche River upstream and downstream from the Cordero Mine in response to rainfall and snowmelt runoff and flow at the downstream site beginning in late August as the result of pumping from the mine. The bar graph shows that the water pumped from the mine contained less dissolved solids than are present in water during periods of normal flow.

Large amounts of water accumulate in abandoned coal mines and this water has been developed from springs at old mine entrances and from wells bored into flooded mine workings (Lowry and Cummings, 1966, p. 40). (See figure 1.3.2-2.) A mined area to the west of Area 50 has flooded and has been stocked with trout and bass by the Wyoming Game and Fish Department.

There are many different hydrologic settings where coal may be mined. Therefore, local hydrologic effects of mining cannot be generalized for Area 50. In applying for a mining permit, the operators of a proposed mine are required to describe the local hydrologic effects of mining and reclamation methods they intend to use.

Changes in hydrology will occur because of the changes in the physical conditions caused by mining.

These can be broadly classed into the effects on quantity and quality of ground and surface water in time and in space. The only effect that will certainly result is: where surface mining begins at the edge of the coal and extends some distance beyond the point where the water table is intercepted, the water levels in adjoining aquifers will be permanently lowered. There may or may not be other significant effects.

To date, the lowering of water levels has not been severe. Richard Stockdale, Hydrologist for the Office of the Wyoming State Engineer (oral commun., Mar. 1983), states that his office has received no complaints of water-level decline as the result of surface mining of coal. Since extensive mining began in mid-1970's, the lowering of water levels may not have extended beyond the mine property. However, the lowering of the water level near the Wyodak Mine, which began operation in the 1920's, has not extended westward more than 1,600 feet (Everett, 1979, p. 157). The lowering of the water level at the west face of the north pit probably is about 100 feet.

There has not been, nor is there presently planned (1983), large-scale underground mining in Area 50. The mine previously mentioned from which water has been developed by wells, the Krezlock Mine, produced only about 19,000 tons of coal between 1919 and 1950 (Mapel, 1959, p. 92). However, in the Tongue River basin, adjacent to Area 50, underground mining was extensive prior to 1950 and subsidence has occurred in many areas (Dunrud and Osterwald, 1980). Hydrologic effects of underground mining in Area 50 have not been described.

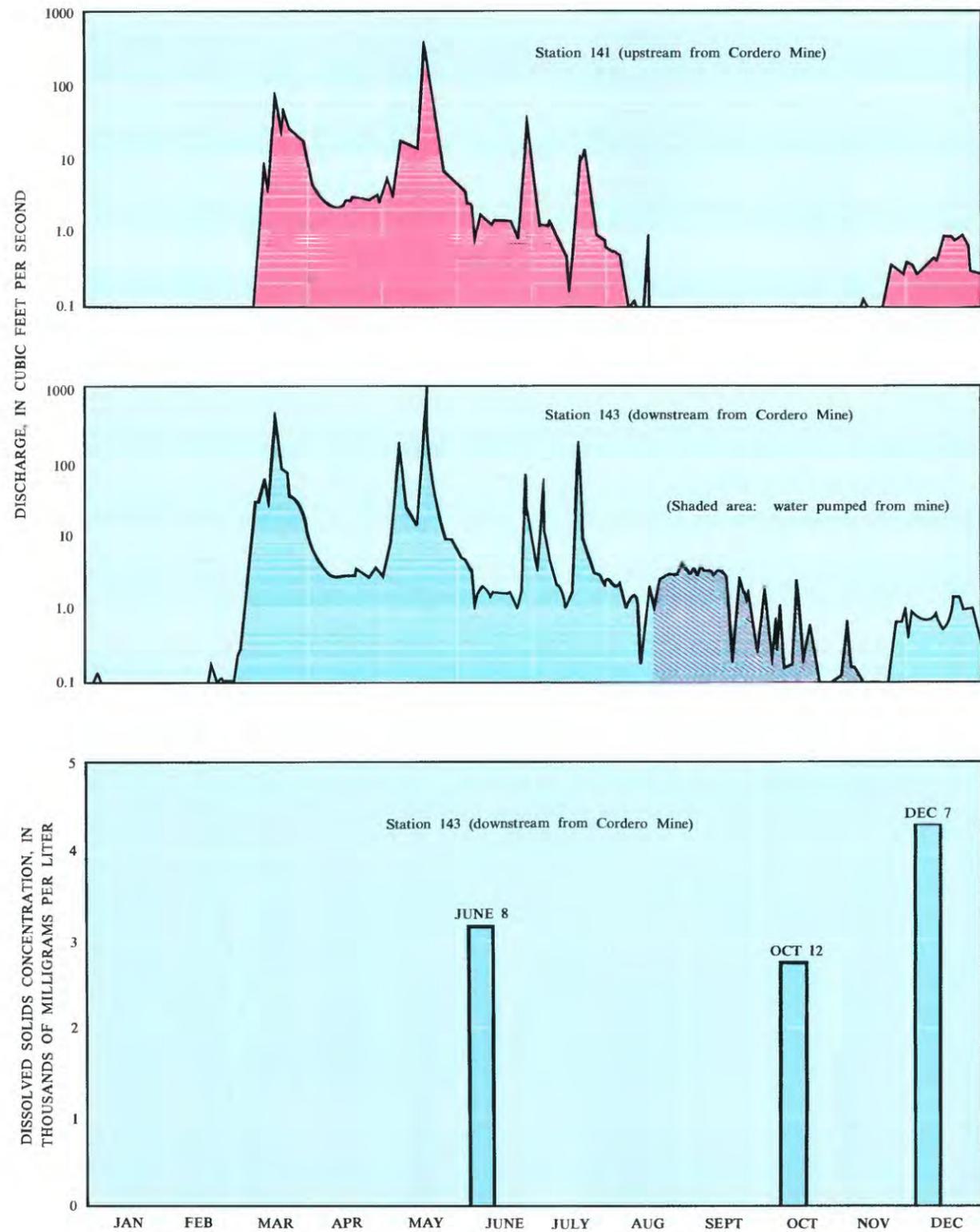
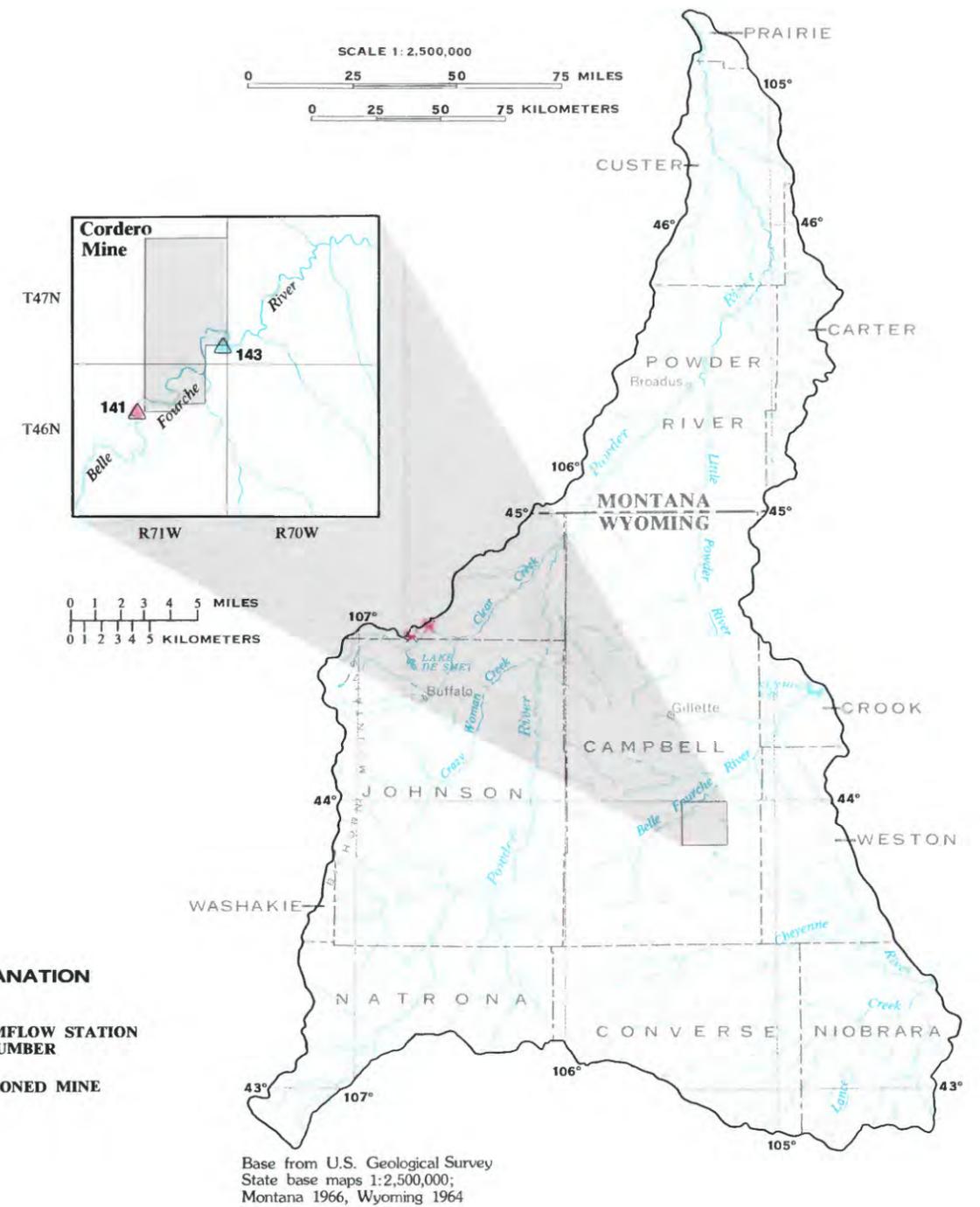


Figure 1.3.2-1 Daily discharge and dissolved solids of water in the Belle Fourche River, 1978.



Location of stations 141 and 143 and location of abandoned mines where water supplies have been developed.

2.0 DEFINITION OF TERMS

Terms in Report Defined

Technical terms that occur in this hydrologic report are defined

Algae are single-celled, colonial, or multi-celled plants, containing chlorophyll and lacking roots, stems, and leaves.

Blue-green algae are a Division (Cyanophyta) of phytoplankton organisms having a blue pigment, in addition to the green pigment called chlorophyll. Blue-green algae commonly cause nuisance conditions in water.

Diatoms are the unicellular or colonial algae having a siliceous shell. Diatoms comprise most of the Division Chrysophyta. Their concentrations are expressed as number of cells per milliliter of sample.

Euglenoids are a Division (Euglenophyta) of algae commonly associated with organic wastes in water. Their concentrations are expressed as number of cells per milliliter of sample.

Green algae have chlorophyll pigments similar in color to those of higher-order green plants. Some forms produce algal mats or floating "moss" in lakes. Their concentrations are expressed as number of cells per milliliter of sample.

Alluvium is clay, silt, sand, gravel, or similar detrital material deposited by flowing water.

Aquifer is a geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base flow is sustained or fair-weather runoff. In most streams, base flow is composed largely of ground-water effluent. The term base flow is often used in the same sense as base runoff (see Langbein and Iseri, 1960).

Cubic foot per second (ft³/s) is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meters per second.

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

Average discharge is the arithmetic mean of individual daily average discharges during a specific period.

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

Peak discharge (peak flow) is the maximum instantaneous discharge that occurs during a specified time interval. The series of annual peak discharges at a gaging station is used to determine the recurrence interval (frequency) and exceedance probability of floods.

Discharge-weighted concentration is the ratio of the total discharged dry weight of sediment, for a time period, to the total discharge by volume, for the same time period, of the water-sediment mixture, expressed as milligrams per liter.

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

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the river upstream from the specified point. Figures of drainage area given herein include all closed basins, or noncontributing areas, within the area unless otherwise noted.

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

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

Evapotranspiration is water withdrawn from a land area by evaporation from water surfaces and moist soil and by plant transpiration.

Exceedance probability is the mathematical expression of the probability that a flood equal to or greater than a given magnitude will occur in any given year. It is the inverse of the recurrence interval. For example, a 100-year flood has an exceedance probability of 0.01 (1-percent chance in any year).

Flood is an overflow or inundation that comes from a river or other body of water and causes or threatens damage; any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream.

Fluvial sediment is sediment that is transported by, suspended in, or deposited from water.

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

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

Hydrograph is a graph showing stage, flow, velocity, or other property of water with respect to time.

Infiltration is the downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is movement of water through soil layers or other surficial material.

Intermittent stream is a stream that flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow.

Interrupted stream is a stream that contains alternating reaches that are either ephemeral, intermittent, or perennial.

Micrograms per liter ($\mu\text{g/L}$) is a unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter.

Milligrams per liter (mg/L) is a unit for expressing the concentration of chemical constituents in solution. Milligrams per liter represent the mass of solute per unit volume (liter) of water. Concentration of suspended sediment also is expressed in milligrams per liter, and is based on the mass (dry weight) of sediment per liter of water-sediment mixture.

Parent material is the unconsolidated organic and mineral material from which soils form. Consolidated bedrock is not parent material by this concept.

Particle size is the diameter, in millimeters, of any given sediment particle. It may be determined by sieve or sedimentation methods. (See particle-size classification.)

Particle-size classification is a system of dividing the sediment particles into groups, each group having minimum and maximum dimension limits. The classification used by the U.S. Geological Survey follows that used by the American Geophysical Union Subcommittee on Sediment Terminology as follows:

Classification	Dimension limits, in millimeters
Clay	0.00024 - 0.004
Silt	0.004 - 0.062
Sand	0.062 - 2.00
Gravel	2.00 - 64.0

Particle-size distribution is the proportion of material of each particle-size class present in a given sample.

Perennial stream is a stream that flows continuously.

Permeability is a measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Porosity is the property of a rock or soil that refers to the interstices or voids that the material contains. It may be expressed quantitatively as the ratio of the volume of the interstices to the total volume of the material.

Potentiometric surface is the surface defined by the level to which water will rise in tightly cased wells completed in an aquifer or in a stratum within an aquifer.

Recharge is the process by which water is absorbed and added to the saturated zone (an aquifer), either directly into a formation or indirectly by way of another formation. Also, the quantity of water that is added to the saturated zone.

Recurrence interval is the average interval of time within which a flood of given magnitude will be equaled or exceeded once. For example, the 100-year flood at a stream station or site is the instantaneous peak discharge that has a recurrence interval of 100 years. The recurrence interval is the inverse of the exceedance probability.

Sediment is fragmented solid material that originates mostly from disintegrated rocks. It may also include chemical and biochemical precipitates and decomposed organic material, such as humus.

Site is a location on a stream where one or more miscellaneous measurements of discharge have been made and(or) one or more miscellaneous water-quality samples collected. (See station.)

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

Specific weight is the weight per unit volume of a substrate, such as sediment.

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

Station is a location on a stream where a continuous or repetitive record of streamflow and (or) water quality has been collected. (See site.)

Streamflow is the discharge that occurs in a natural channel. Although the term “discharge” can be applied to a flow of a canal, the word “streamflow” uniquely

describes the discharge in a surface stream course. The term “streamflow” is more general than “runoff” as stream flow may be applied to discharge whether or not it is affected by diversion or regulation.

Sublimation is the process whereby snow is changed to water vapor without melting.

Substrate is the physical surface upon which an organism lives.

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

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

Suspended-sediment discharge is the rate at which suspended sediment is transported through a cross section of a stream.

Suspended-sediment load is the quantity of sediment that is transported through any cross section of a stream in a unit of time.

Terrace is a berm or discontinuous segments of a berm, in a valley at some height above the flood plain, representing a former abandoned flood plain of the stream.

Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Turbidity is the optical property of a suspension with reference to the extent to which the penetration of light is inhibited by the presence of insoluble material.

3.0 PHYSIOGRAPHY

3.1 Climate

Topography Affects the Climate

Average precipitation in the mountains exceeds 25 inches per year; the plains receive 10 to 16 inches.

The climate of the area is affected significantly by the mountains along the Pacific coast and the Rocky Mountains. Westerly winds prevail, and the air masses generally move into the area from the Pacific Ocean. The mountain ranges cause much of the moisture in the air to precipitate before reaching the area. Continental air masses from Canada occasionally move into the area. During winter, these air masses wedge under the air in place, forcing it upward and thus causing snow.

The distribution of average annual precipitation is shown in figure 3.1-1. Most precipitation from November through April occurs as snow. Annual snowfall averages from 30 to 75 inches in the plains and 100 inches or greater in the mountains. Much of the snow in the open plains is sublimated; some snow remains as drifts in draws and shaded areas. Precipitation during the summer occurs as light showers and occasional intense thunderstorms. The distribution of normal monthly precipitation at two National Weather Service stations, Arvada 3 N and Midwest 1 SW, is shown in figure 3.1-2.

The amount of precipitation that occurs each year is extremely variable. During 1936-75, the weather station at Arvada 3 N recorded an annual maximum of 17.1 inches during 1944 and an annual minimum of 7.0 inches during 1966. During 1923-79, the station at Midwest 1 SW recorded an annual maximum of 19.8 inches during 1972 and an annual minimum of 8.4 inches during 1951.

Normal air temperature is minimum during late January and is maximum during late July. Average monthly air temperatures at Arvada 3 N and Midwest 1 SW are shown in figure 3.1-2. Soil temperatures at a depth of 6 feet vary much less than air temperatures; the change in soil temperature lags changes in the air temperature by about 1 month.

Evapotranspiration is greatest during July, but continues to be significant well into the fall because of the warm soil. Sunshine averages about 65 percent of possible on an annual basis, ranging from about 55 percent possible during winter to about 75 percent during late summer.

Wind is significant to the climate, with westerly winds prevailing. Wind velocity averages about 13 miles per hour annually, ranging from an average of 10 miles per hour during July and August to an average of 16 miles per hour during November through April. Daytime winds generally are stronger than nighttime winds. Occasional storms cause brief periods with wind gusts greater than 75 miles per hour.

The foregoing description of climate is based on a report prepared by J. D. Alyea (written commun., 1980). Climatological data are published monthly by the National Oceanic and Atmospheric Administration, National Climatic Center, Asheville, N.C.

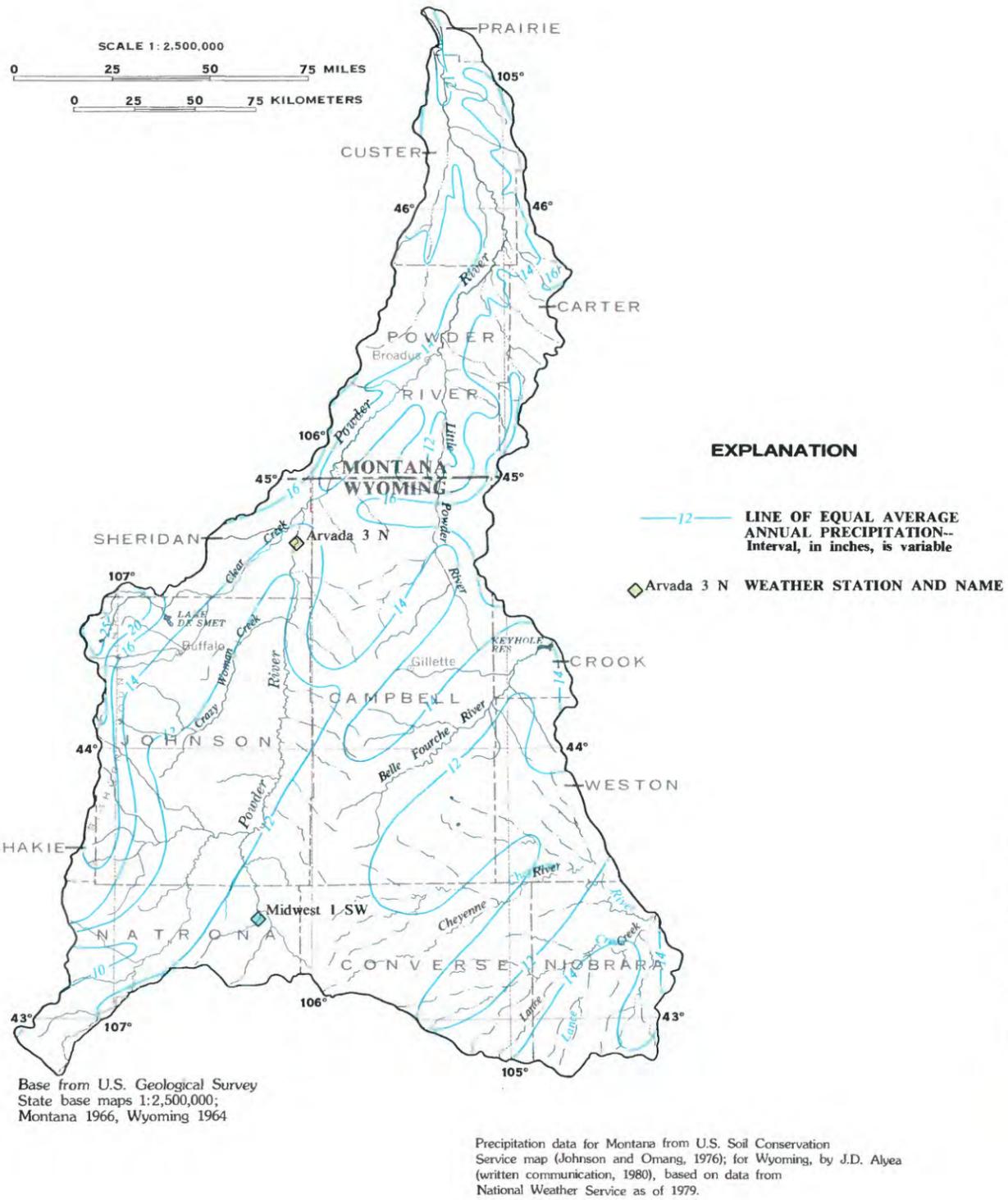
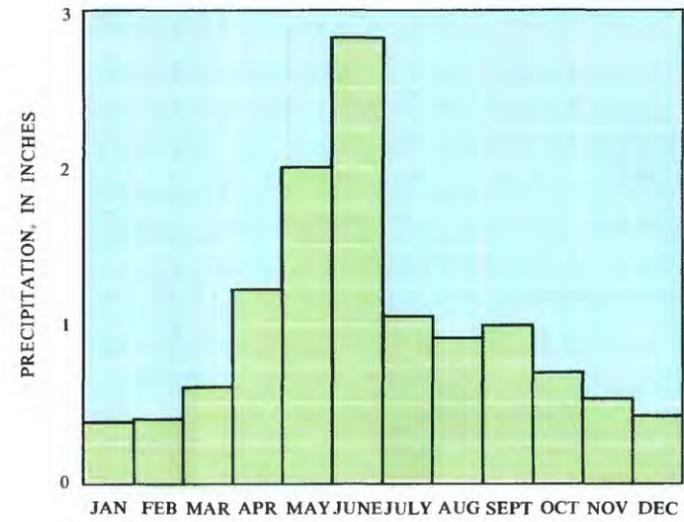
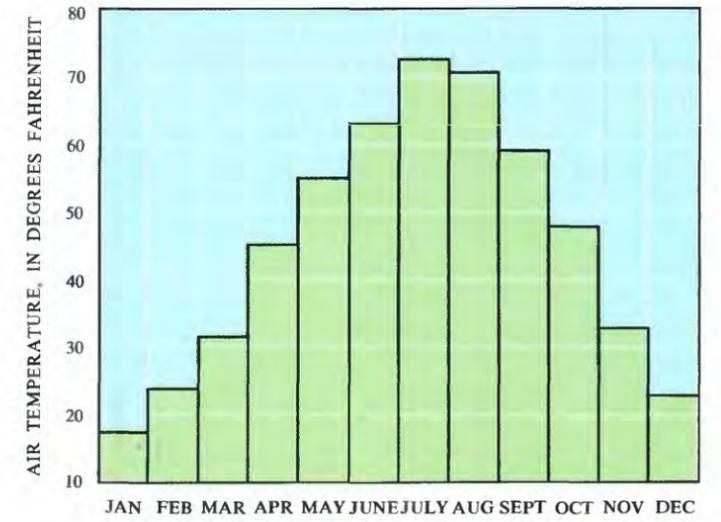


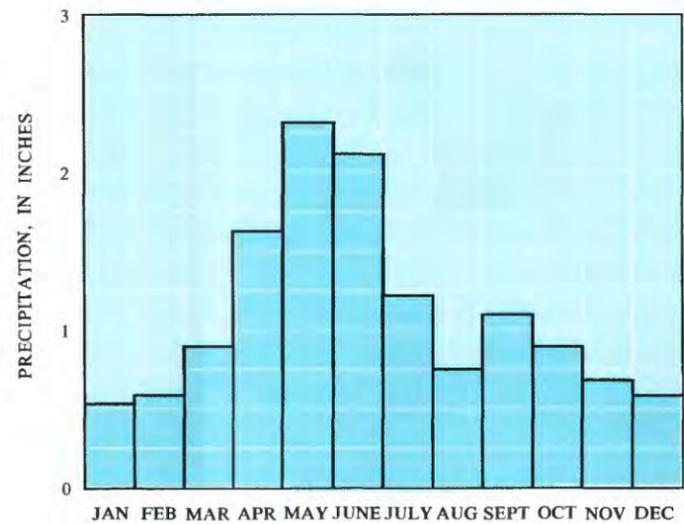
Figure 3.1-1 Average annual precipitation.



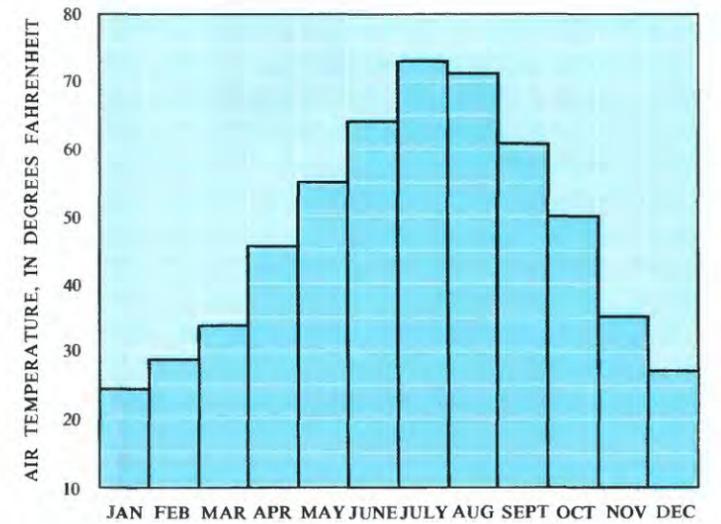
Normal monthly precipitation at weather station Arvada 3 N, Wyoming.



Average monthly air temperature at weather station Arvada 3 N, Wyoming.



Normal monthly precipitation at weather station Midwest 1 SW, Wyoming.



Average monthly air temperature at weather station Midwest 1 SW, Wyoming.

Figure 3.1-2 Monthly precipitation and air temperature based on records for 1941-70, from National Oceanic and Atmospheric Administration (1973).

3.0 PHYSIOGRAPHY--Continued

3.2 Landforms

Plains, Tablelands, and Open (Treeless) High Hills Predominate

The terrain of Area 50 varies from forested mountains to sand dunes, with most of the strippable coal deposits located in the semiarid plains and tablelands near the center of the area.

Viewing Area 50 from a vantage point at Gillette, Wyo., near the center of the area, one would see the varied terrain and colors resulting from a semiarid climate (figure 3.2.1). To the southeast from Gillette are plains, rolling hills, and tablelands as far as the eye can see. Rivers and streams dissect the area. A dense carpet of grass covers the landscape, green in the spring and golden brown in the summer. Cattle, sheep, buffalo, and antelope graze on the land.

The view to the west and northwest includes the Powder River breaks, where the river has eroded deeply into the plains. Farther south, in the area of South Fork Powder River and Salt Creek, there are large areas where shales have been dissected into badlands. A few sand dunes can be seen along the southern edge of the area.

The lofty, snow-covered Bighorn Mountains, with peaks rising to 12,000 feet, rim the western edge of the area. Pine-forested mountainsides and valleys drained by cascading streams are the principal source areas of surface water for Area 50.

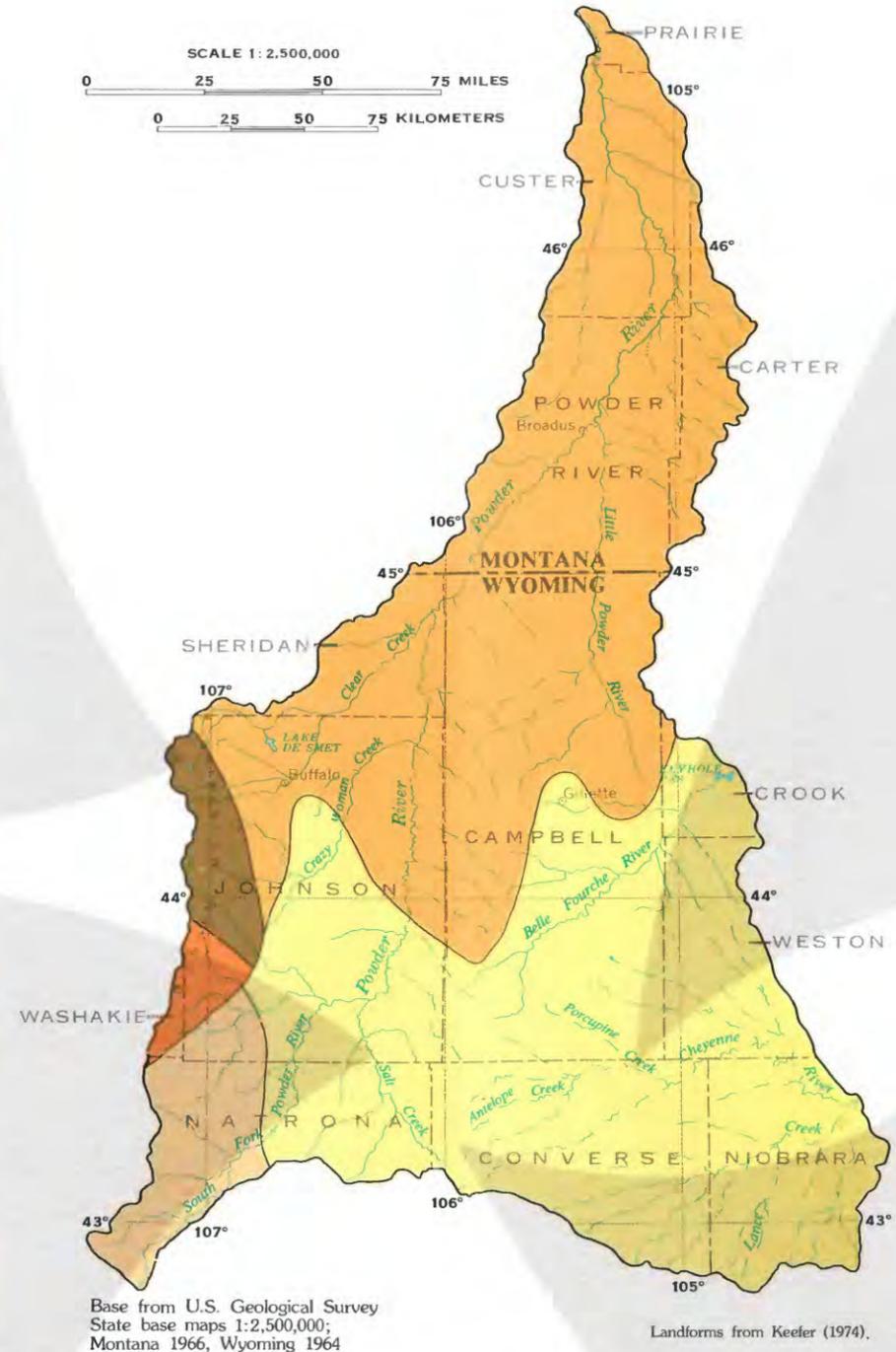
To the north in Wyoming and southern Montana are open high hills, with pine-forested escarpments along the Powder and Little Powder Rivers. Numerous red clinker-topped buttes accent the area. Majestic cottonwood trees with yellow-green leaves line the river valleys. In spring, green grasses cover the area, except for the scenic badlands along the eastern side of the Powder River in Montana, which remain bare.



High mountain country.



Grasslands in the Salt Creek drainage.



EXPLANATION

- | | |
|--|---|
|  PLAINS AND TABLELANDS, MODERATE RELIEF |  OPEN HIGH HILLS |
|  PLAINS WITH HIGH HILLS |  LOW MOUNTAINS |
| |  HIGH MOUNTAINS |



Antelope Creek at mouth of Porcupine Creek.



Sand dunes at the headwaters of the Cheyenne River.

Figure 3.2-1 Distribution of landforms.

3.0 PHYSIOGRAPHY--Continued

3.3 Drainage

Ephemeral and Interrupted Streams Drain Most of the Area

Ephemeral and interrupted streams drain 80 percent of the area and yield 40 percent of the runoff.

The Cheyenne River and Lance Creek, ephemeral streams with interrupted reaches, originate near the center of the area. Most of the drainage of the two streams is underlain by continental deposits of shale, sandstone, and coal. The two streams and their major tributaries have wide, sand channels that are bordered by three terraces (fig. 3.3-1): the Lightning terrace at about 6 feet, the Moorcroft terrace at about 14 feet, and the Kaycee terrace at about 33 feet above the channel (Leopold and Miller, 1954). Streamflow primarily is from rainstorms and melting snow, with little contribution from ground water; however, the stream channels intercept the ground-water table in several reaches. Annual runoff is about 8.5 acre-feet per square mile.

The Belle Fourche River originates in and drains an area underlain by continental deposits of shale, sandstone, and coal. The channel is relatively narrow, has a silt and clay bottom, and in places is grass-covered (fig. 3.3-1). The alluvial terraces are much lower than those found in the Cheyenne River drainage. The Moorcroft terrace is missing in the upstream part of the drainage basin (Leopold and Miller, 1954). Streamflow is primarily from thunderstorms and snowmelt. The ground-water table is intercepted by the channel in many reaches, thus forming pools, but very little ground water is contributed to the streamflow. Most of the ground water evaporates from the pools. Annual runoff is about 10 acre-feet per square mile.

Channel-bottom material of the Little Powder River consists of clay, silt, and some clinker gravel. The stream flows northward through an alluvial valley 1½ miles wide, bordered by high escarpments. The stream is perennial and has an average annual runoff of about 15 acre-feet per square mile.

Clear Creek, Crazy Woman Creek, and the upstream reaches of the Powder River, which originate in the Bighorn Mountains, are perennial. These streams drain granitic and limestone areas. Precipitation in the mountains is about twice that in the plains. Annual runoff in many of the areas of the mountains exceeds 200 acre-feet per square mile.

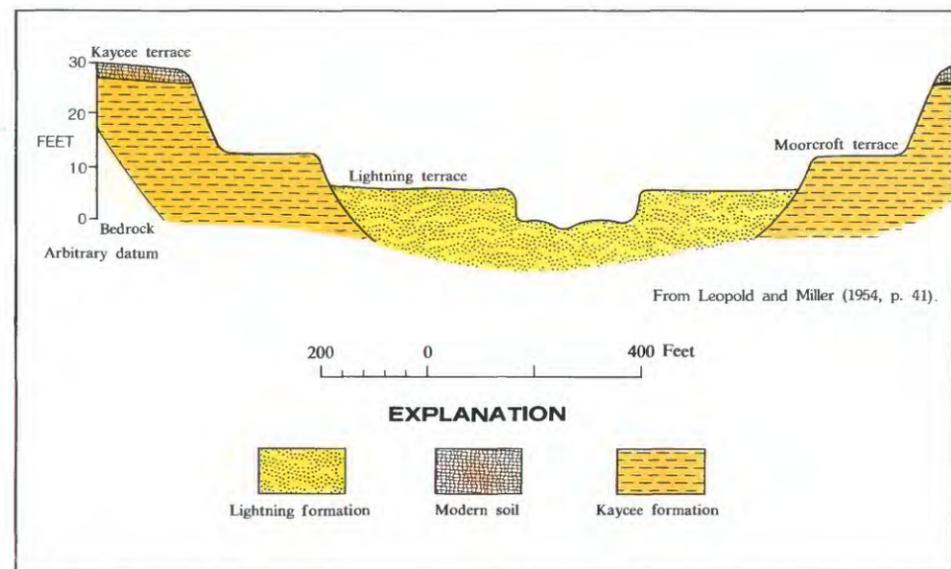
Although the Powder River from Sussex, Wyo., to the mouth flows through a semiarid area, it is a perennial stream. Runoff for this reach includes sustained flow from the headwater areas in the mountains and direct runoff from rainstorms and snowmelt in the remainder of the drainage basin. The river has a wide, sandy channel. Three terraces are present: the Lightning terrace at about 5 feet, the Moorcroft terrace at about 16 feet, and the Kaycee terrace at about 45 feet above the stream channel (Leopold and Miller, 1954). The three terraces exist at the gaging station at Moorhead, Mont. (see photograph in figure 3.3-1).



Powder River at Moorhead, Montana.



Belle Fourche River below Rattlesnake Creek near Piney, Wyoming.



Cross section of a valley in the Cheyenne River Basin.

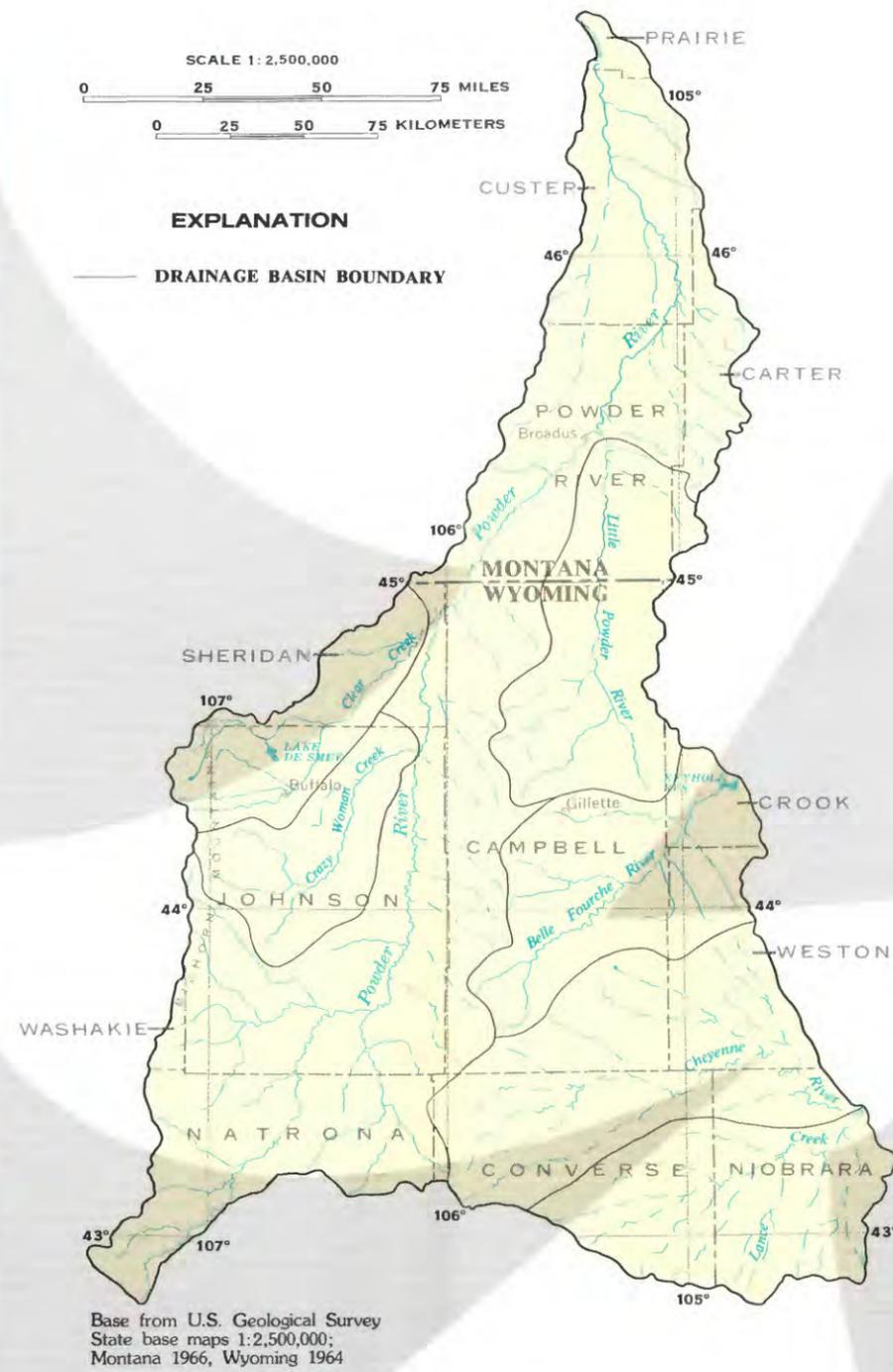


Figure 3.3-1 Drainage basins and terraces of principle streams.



Lance Creek near Bright, Wyoming.

3.0 PHYSIOGRAPHY--Continued

3.4 Soils

Soils of the Plains Cover 94 Percent of the Area

Soils of the plains are classified by the land slope and the type of parent material from which they are derived; soils of the mountains, which cover 6 percent of the area, are unclassified.

Soils of the plains area generally contain little organic material, are fine grained, and are alkaline. The soils have a low-to-moderate permeability and a moderate-to-high potential for precipitation runoff. The sandy soils in the southern part of the area have a low potential for precipitation runoff. Most of the soils are moderately erodible by water. Sandy soils are not easily eroded by water but are easily eroded by wind.

Soils in mountain areas contain more organic material than the soils of the plains; they are coarser grained, and have less potential for precipitation runoff. These soils range from acidic to alkaline; the reaction depends on whether the parent material is acidic or basic. Soils of the mountains also have steeper slopes than soils of the plains.

The soils shown in figure 3.4-1 are classified by physiographic area, source of parent material, and land slope. Physiographic area is a broad classification group that separates soils of mountain areas from soils of plains areas. Soils of the plains are divided into those derived from transported material and those derived from residual material. These soils are further subdivided by land slope.

Climate, parent material, and slope affect the development of a soil. The mountain climate is characterized by cold winters, cool summers, generally more than 20 inches of precipitation, and 60 or fewer frost-free days. The plains climate is characterized by cold winters, warm summers, 12 to 18 inches of precipitation, and 110 to 140 frost-free days.

Silts and sands transported by floods and deposited on flood plains of streams are the primary source of transported material. Most of the soils in Area 50 are formed from residual materials. In the plains, these materials are derived from weathered flat-lying sandstone, siltstone, and shale. Most soils of the mountains are formed from residuum of igneous, metamorphic, and carbonate rocks.

Land slope affects runoff and erosion, which in turn affect the development and accumulation of soils. Land slopes have been divided into six classes. There are single slopes and complex slopes in each class, and each type of slope has its own descriptor. The slopes in Area 50 range from level (0 to 3 percent) to very steep (45 to 90 percent).

- EXPLANATION**
- SOIL TYPES**
- SOILS OF THE MOUNTAINS**
 - Cryoborolls-Cryoboralfs
 - Cryoborolls-Rock Outcrop
 - SOILS OF THE PLAINS**
 - Transported Material**
 - Level to gently sloping**
 - Camborthids-Torrifluents-Torriorthenents
 - Torrifluents-Haplargids-Torriorthenents
 - Rolling to hummocky**
 - Ustipsamments association
 - Nearly level to steep slopes**
 - Calciborolls-Calciorthids
 - Residual Material**
 - Nearly level to rolling**
 - Camborthids-Torriorthenents (shallow)
 - Camborthids-Torriorthenents
 - Haplargids-Camborthids-Natrargids
 - Haplargids-Paleargids-Torriorthenents
 - Haplargids-Torriorthenents
 - Strongly sloping**
 - Torriorthenents (shallow)
 - Torriorthenents-Camborthids
 - Torriorthenents (shallow)-Camborthids-Torriorthenents
 - Torriorthenents (shallow)-Torriorthenents-Camborthids
 - Torriorthenents-Natrargids
 - Torriorthenents-Haplargids
 - Torriorthenents-Torriorthenents (shallow)
 - Torriorthenents-Torriorthenents, shallow Rock Outcrop
 - Torriorthenents
 - Steep and very steep slopes**
 - Badland-Torriorthenents

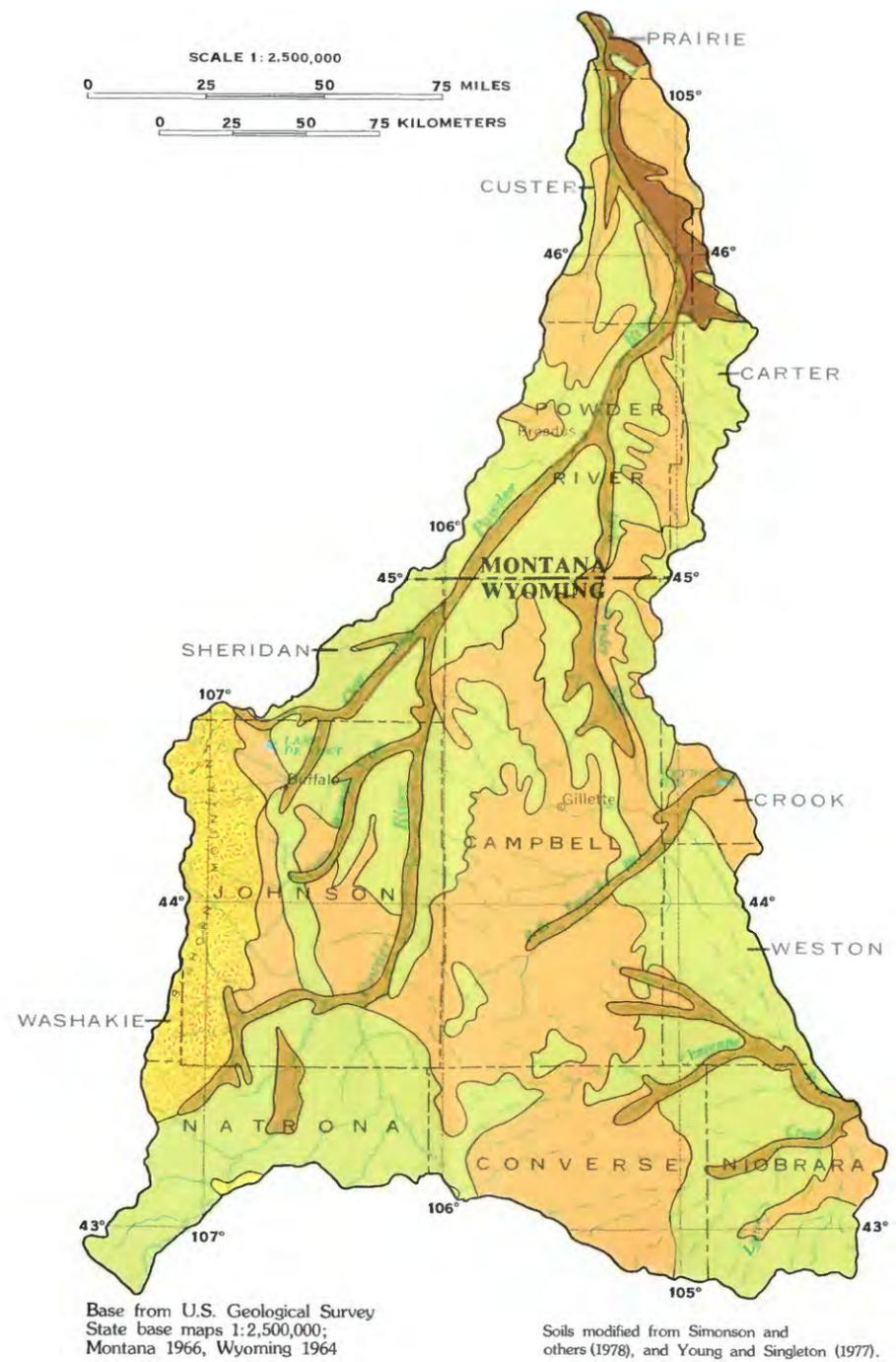


Figure 3.4-1 Distribution of soil types.

Table 3.4-1 Description of soil groups and land types.

[Modified from Simonson and others, 1978]

<p>Badland: Mainly very steep, nearly barren areas. Areas of this land type are characterized by nearly vertical escarpments, narrow ridges isolated buttes, and deeply entrenched coulees. These areas were formed by the active geologic erosion of soft, multicolored sedimentary beds of loamy sand, sandy loam, silt loam, clay loam, and silty clay.</p>
<p>Calciborolls: Dark-colored soils of cool, semiarid and subhumid grasslands that are calcareous at or near the surface and have subsoil horizons with large calcium carbonate accumulation. These are mostly loamy soils on gravelly terraces and piedmont glacial moraines derived from limestone.</p>
<p>Calciorthids: Light-colored soils of cool, arid and semiarid grasslands. These soils are calcareous and have subsoil horizons with large calcium carbonate accumulation. Most have loamy textures and are on gravelly piedmont terraces.</p>
<p>Camborthids: Light-colored soils of cool, arid and semiarid grasslands. They have had only slight alteration during formation. Some are calcareous throughout but have no large accumulations of calcium carbonate.</p>
<p>Cryoboralfs: Cold, light-colored, acid soils of subhumid and humid mountains and high foothills. The vegetation is mainly coniferous forest. These extensive soils have brownish subsoil horizons of clay accumulation. They formed in material derived from a variety of rock types and, commonly, in glacial till. Some are calcareous in the lower part if formed in limey material.</p>
<p>Cryoborolls: Cold, dark-colored soils of subhumid and humid grasslands. These soils may or may not have horizons of clay accumulation. Structure is mostly moderate and the lower horizons commonly have accumulations of calcium carbonate. They are on the high foothills, piedmont terraces and moraines, and mountain slopes.</p>
<p>Lithic Cryoborolls are less than 20 inches deep to hard bedrock and shallow cryoborolls are less than 20 inches deep to soft bedrock. These are mainly steep and very steep soils.</p>
<p>Haplargids: Light-colored soils of cool, arid and semiarid grasslands. These soils have brownish subsoil horizons with large structure and clay accumulation. The lower horizons have accumulations of calcium carbonate. Haplargids are mostly on stable surfaces of smooth uplands and terraces.</p>
<p>Natrargids: Light-colored, sodium-affected soils of cool, arid and semiarid grasslands. These soils typically have columnar structured, clayey, sodium-dispersed shallow subsoil horizons of clay accumulation. Some are calcareous throughout and some have accumulations of soluble salts, carbonates, or both in lower horizons. Natrargids are commonly in the landscape as a complex pattern of nearly barren "slick spots."</p>
<p>Paleargids: Light-colored, strongly weathered soils of cool, semiarid grasslands. These soils have brownish horizons of clay accumulation abruptly beneath loamy surface horizons. Lower horizons of calcium carbonate accumulation are generally present.</p>
<p>Rock outcrop: A land type indicating bare bedrock exposures. The rock is soft, such as shale exposures in the badlands, or hard as is common in the foothills and mountains. It is a prominent, though minor, component of many steep dissected soil landscapes and is a major part of alpine areas, badland, and very steep canyon walls.</p>
<p>Torrifluents: Light-colored, stratified soils on flood plains and recent alluvial fans of cool, arid and semiarid regions. These soils are commonly calcareous and some are salt affected. Torrifluents are mostly loamy, many are gravelly, and some are clayey. They are near stream channels and on fans. Most of these soils are subject to flooding.</p>
<p>Torriorthenents: Light-colored soils of cool, arid and semiarid grasslands. These soils are very little altered from the material in which they have formed. Most Torriorthenents are calcareous. They are extensive on steep and very steep slopes of dissected sedimentary bedrock plains.</p>
<p>Ustipsamments: Light-colored, sandy soils of cool, semiarid and subhumid grasslands. These soils are on recent sand dunes and other very sandy deposits, or are shallow over sandstone bedrock.</p>

3.0 PHYSIOGRAPHY--Continued

3.5 Vegetation

Grasses and Sagebrush are the Predominant Vegetation

The plains support a mixture of grasses and sagebrush, whereas the mountains and breaks support trees, grasses, and sagebrush.

The natural vegetation of most of Area 50 is a mixture of grasses and sagebrush. A map of vegetation types is shown in figure 3.5-1.

Common plants of the plains grasslands include prairie sandreed grass, needleandthread grass, western wheatgrass, blue grama grass, little bluestem grass, big sagebrush, and greasewood. Cottonwood trees commonly grow along stream bottoms in the plains, whereas breaks and upland areas may support thin stands of ponderosa pine and juniper. Examples of plains grassland are shown in figure 3.5-2.

Although vegetation appears to be sparse in the

plains, the extensive root systems compete for the available moisture. Annual forage requirements for grazing land are estimated to be about 30 to 60 acres per cow.

The vegetation of the western edge of Area 50 reflects greater precipitation on the mountains than on the plains. Trees, such as Douglas fir, alpine fir, and aspen, are the predominant vegetation in the mountains; pines predominate in the foothills. Bluebunch wheatgrass, columbia needlegrass, spike fescue, and big sagebrush are common plants in the clearings between the trees.

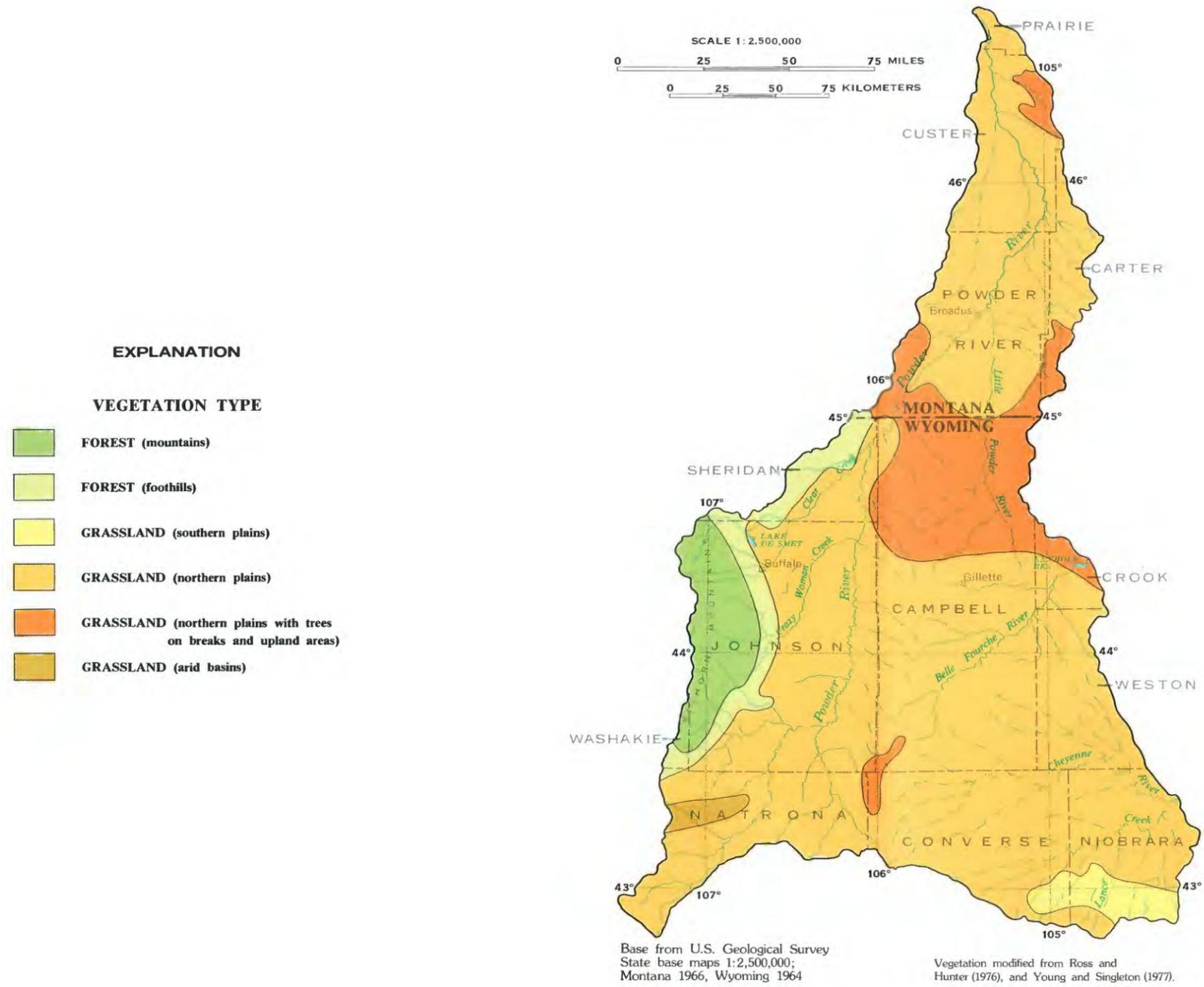


Figure 3.5-1 Distribution of vegetation types.



Figure 3.5-2 Examples of northern plains grassland.

3.0 PHYSIOGRAPHY--Continued

3.6 Geology

3.6.1 Structure and Stratigraphy

Much of the Coal is Nearly Flat-Lying

Rocks representing all geologic periods are present; coal was deposited during the Cretaceous and Tertiary Periods.

Area 50 is located principally within the Powder River structural basin, but part of the area is in the Wind River basin, which is separated from the Powder River Basin by the Casper arch. The Casper arch also separates the Rocky Mountain Coal Province from the Northern Great Plains Coal Province. Parts of the area extend into the Bighorn Mountains and the Sweetwater and Hartville uplifts (fig. 3.6.1-1).

Few major faults are present in the central part of the Powder River basin, where most economic coal deposits are located; hence the coal beds are not greatly disrupted by faulting. On the east side of the basin, dips are slight (fig. 3.6.1-2) and the coal is nearly flat-lying.

The oldest rocks are igneous and metamorphic rocks of Precambrian age. Next oldest are the lower Paleozoic rocks--marine sandstone, carbonates, and shale; carbonates such as the Madison Limestone are the predominant rock type (fig. 3.6.1-3). The upper Paleozoic rocks are more complex and include thick sandstone overlain by red shale intertongued with limestone; evaporites also are present. Deposition of red shale intertongued with limestone and evaporites continued during the early part of the Mesozoic, subsequently being replaced by alternating and intertonguing marine and continental deposition.

During Early Cretaceous time, a thick sequence of marine shale was deposited over most of the area. The shale is interfingered with marine sandstone and some continental deposits in the western part of the area. Some limestone was deposited in the eastern

part of the the area. The oldest coal in the area is in these rocks.

During Late Cretaceous time, the sea withdrew from the area, depositing the Fox Hills Sandstone, and deposition of continental shale, sandstone, and coal in a tropical, near-sea-level environment began. This deposition continued through early Tertiary time, when the present basin shape was established and the mountains had risen high above the surrounding terrain.

Later during the Tertiary Period there was regional uplift, and arid conditions prevailed (Van Houten, 1964, p. 79). Basin filling continued until only the highest mountain peaks were above the general land surface. The deposits were partly sand, siltstone, and near the mountains, some boulder conglomerates. Some of the clastics were derived from volcanics. Igneous rocks were intruded in the extreme southwest part of the area at this time. Subsequent erosion has removed most of the upper Tertiary rocks from the area, leaving only remnants such as Pumpkin Buttes in southwestern Campbell County, Wyo.

Continental ice sheets did not extend into the area. Alpine glacial deposits, however, are present in the highest parts of the Bighorn Mountains. Although many streams flow on bedrock, alluvium is present, even in minor drainages. The general fine-grained character of the alluvium has been described by Leopold and others (1964, p. 438).

3.0 PHYSIOGRAPHY--Continued

3.6 Geology--Continued

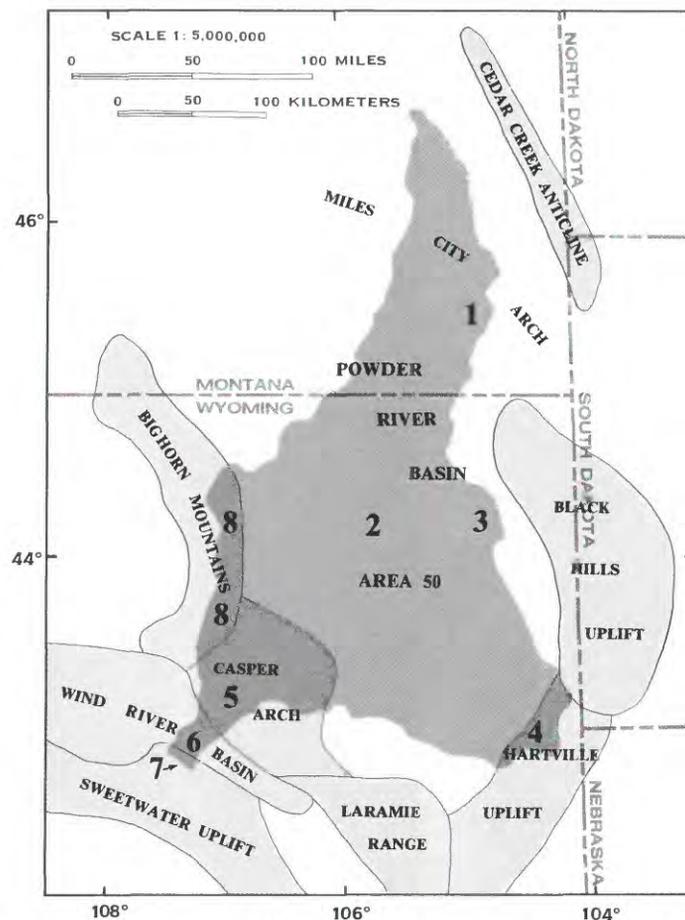
3.6.2 Surficial Geology

Distribution of Surficial Rocks Reflects Geologic Structure

Surficial geology is similar to that which preceded deposition of Oligocene rocks.

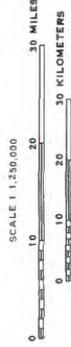
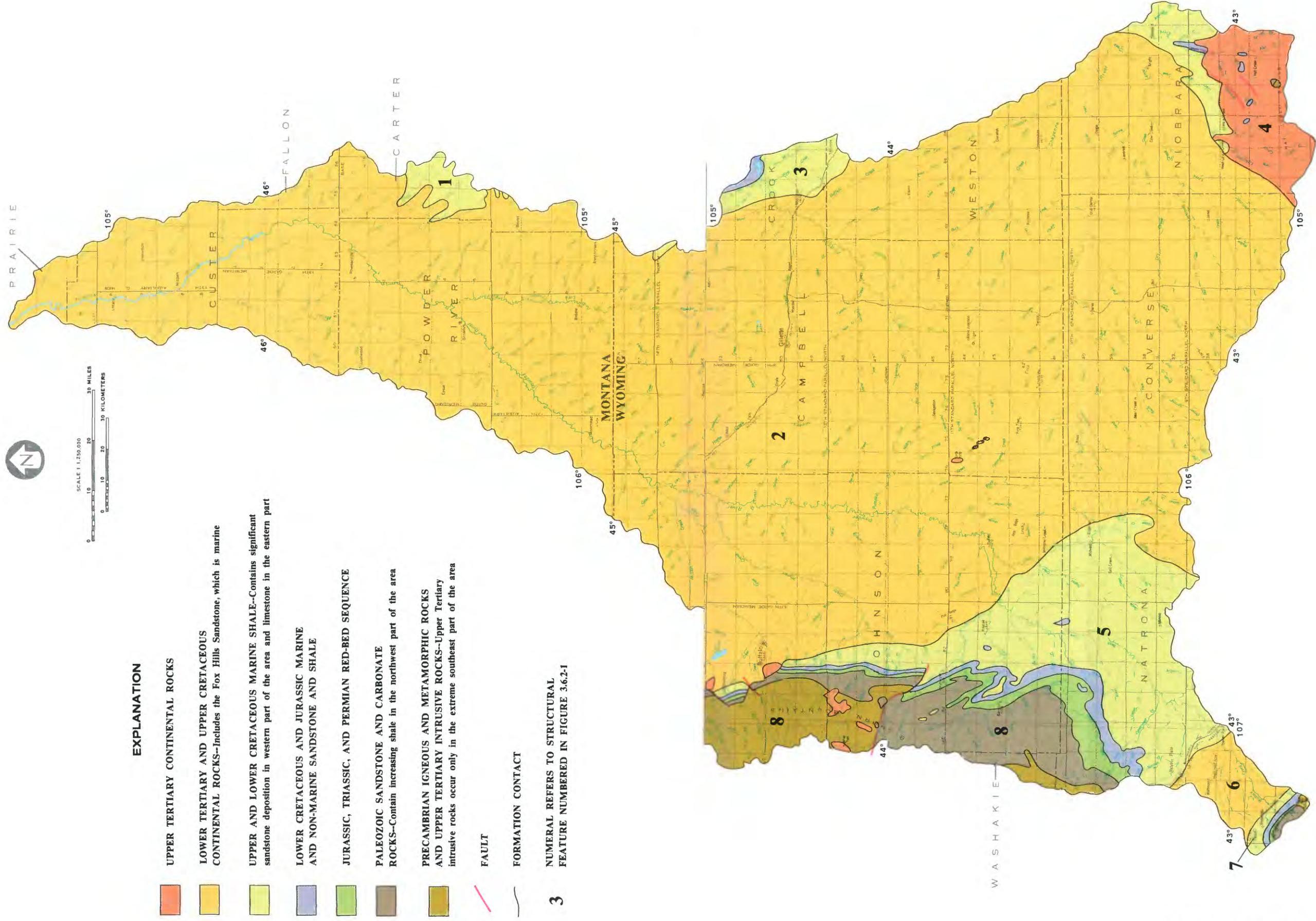
The predominant surficial rocks in Area 50 are those of the coal-bearing sequence, which are exposed throughout most of the Powder and Wind River basins. Differential uplift and erosion, however, have resulted in exposure of older rocks along the margin of Area 50. The principal geologic structures are numbered in figure 3.6.2-1 and the same number is shown at the corresponding location in the map of the surficial geology (fig. 3.6.2-2).

The present surficial geology is similar to that which was present before the deposition of the Upper Tertiary continental deposits. These deposits subsequently have been nearly all removed by erosion and are present as erosional remnants only in and near the Bighorn Mountains, at Pumpkin Buttes, and in the southeastern part of the area.



Modified from Grose (1972, p. 37), with permission of the publisher, Rocky Mountain Association of Geologists.

Figure 3.6.2-1 Structural features in and near Area 50. Location of numbers correspond to the same number on Figure 3.6.2-2.



EXPLANATION

- UPPER TERTIARY CONTINENTAL ROCKS
- LOWER TERTIARY AND UPPER CRETACEOUS CONTINENTAL ROCKS--Includes the Fox Hills Sandstone, which is marine
- UPPER AND LOWER CRETACEOUS MARINE SHALE--Contains significant sandstone deposition in western part of the area and limestone in the eastern part
- LOWER CRETACEOUS AND JURASSIC MARINE AND NON-MARINE SANDSTONE AND SHALE
- JURASSIC, TRIASSIC, AND PERMIAN RED-BED SEQUENCE
- PALEOZOIC SANDSTONE AND CARBONATE ROCKS--Contain increasing shale in the northwest part of the area
- PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS AND UPPER TERTIARY INTRUSIVE ROCKS--Upper Tertiary intrusive rocks occur only in the extreme southeast part of the area
- FAULT
- FORMATION CONTACT

3 NUMERAL REFERS TO STRUCTURAL FEATURE NUMBERED IN FIGURE 3.6.2-1

3.0 PHYSIOGRAPHY--Continued
 3.6 Geology--Continued
 3.6.2 Surficial Geology

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

Modified from Keifer (1974).

Figure 3.6.2-2 Surficial geology.

3.0 PHYSIOGRAPHY--Continued

3.6 Geology--Continued

3.6.3 Coal

Extensive Coal Deposits Are in the Area

Most coal beds are within the Fort Union and Wasatch Formations; the average thickness of the only coal bed mined during 1983 was 70 feet.

The coal deposits in Area 50 are within three major coal-bearing areas: The Powder River Coal Basin, the Fort Union Coal Region, and the Wind River Coal Basin (fig. 3.6.3-1). Most of Area 50 is within the Wyoming part of the Powder River Coal Basin, but the northward extension of the area, into Montana, is almost entirely in the Fort Union Coal Region. Both the Powder River Coal Basin and the Fort Union Coal Region are part of the Northern Great Plains Coal Province. Only the small coal-bearing area in the extreme southwestern corner of Area 50 is part of the Wind River Coal Basin, which is in the Rocky Mountain Coal Province.

In the early 1900's, these three major coal-bearing areas were divided into numerous coal fields. More recent studies by the U.S. Geological Survey, the Montana Bureau of Mines and Geology, and The Geological Survey of Wyoming have identified the coal geology in detail. Glass (1976, 1980b, 1982) summarizes the coal geology of north-eastern Wyoming, which includes Area 50, and provides lists of references; Cole and others (1980, 1982) and Matson and Blumer (1973) provide similar summaries for Montana as well as lists of pertinent references.

Coals are reported in the Upper Cretaceous Mesaverde and Lance (Hell Creek) Formations in the southern part of Area 50. However, the thickest and most important coal beds are in the Paleocene Fort Union Formation and the overlying Eocene Wasatch Formation (fig. 3.6.1-3). Within the Fort Union Formation, which is 2,000 to 3,000 feet thick, the most persistent and thickest coal beds are in the 1,500- to 1,800-foot-thick upper member, the Tongue River Member. Tongue River Member coal beds are best developed in the central and eastern parts of Area 50, where they have an almost imperceptible westward dip of 2 to 3 degrees.

Of the seven to nine major minable coals reported in the Tongue River Member in Area 50 (fig. 3.6.3-2), only the Wyodak coal bed is mined; in fact, this is the only coal bed mined in Area 50. The outcrop of the Wyodak coal bed, though naturally burned in many places, has been mapped for more than 100 miles along the eastern side of Area 50. Coals equivalent to the Wyodak also are tentatively correlated into the Sheridan, Wyo. area, 80 miles west of Gillette (fig. 3.6.3-2).

The subbituminous Wyodak coal bed is 25 to 175 feet thick, and probably averages 70 feet in thickness. The coal has variously been called the Wyodak-Anderson and Anderson-Canyon coal bed. Because of correlation problems,

the Wyodak coal bed was erroneously called the Roland-Smith coal bed in the older reports.

To the west of Gillette, the Wyodak coal bed separates into the Anderson and Canyon coal beds, with the two beds each 10 to 65 feet thick (fig. 3.6.3-2). North from Gillette, the Wyodak separates into an Upper Wyodak and Lower Wyodak. In places, the Upper Wyodak separates into the Smith, Swartz, and Anderson coal beds and the Lower Wyodak separates into the Canyon and Cook coals (Kent and others, 1980). When the Wyodak separates into five or more beds, the individual coal beds are 3 to 38 feet thick and separated by a few feet to 200 feet of claystone, shale, or sandstone. The Wyodak also separates into the Anderson coal (D bed) and the Canyon (E bed) southward from Gillette (fig. 3.6.3-2).

The Eocene Wasatch Formation, which is 1,000 to 2,000 feet thick, is the second most important coal-bearing formation in the Powder River Coal Basin. The Wasatch Formation crops out in most of the western part of Area 50 and generally has dips of less than 3 degrees.

The Wasatch Formation contains as many as eight thick, persistent coal beds (fig. 3.6.3-2). The thickest Wasatch coal bed occurs at Lake DeSmet on the west side of Area 50. There, the Lake DeSmet coal bed locally exceeds 200 feet in thickness (Mapel, 1958; Obernyer, 1980). Wasatch coals have been mapped and correlated for tens of miles along outcrops in many areas but these coals are thicker and more persistent in the northwestern and central parts of Area 50.

Currently (1983) no Wasatch coals are mined in Area 50, although some companies have recently proposed to mine Wasatch coals in the vicinity of Lake De Smet. Wasatch coals--the subbituminous School and Badger coal beds, however, are mined just south of Area 50 in Converse County, Wyo., and the mining will progress into the area.

With the exception of the Paleocene lignites in the Fort Union Coal Region, all the near-surface coals in Area 50 are reportedly of subbituminous rank, including the Cretaceous coals. It is possible, however, that the more deeply buried coals, and the Cretaceous coals in particular, may be bituminous at depth. A summary of the content and heat value of coal samples from the Wyodak, School, and Badger coal beds and the thickness of the coals is given in table 3.6.3-1.

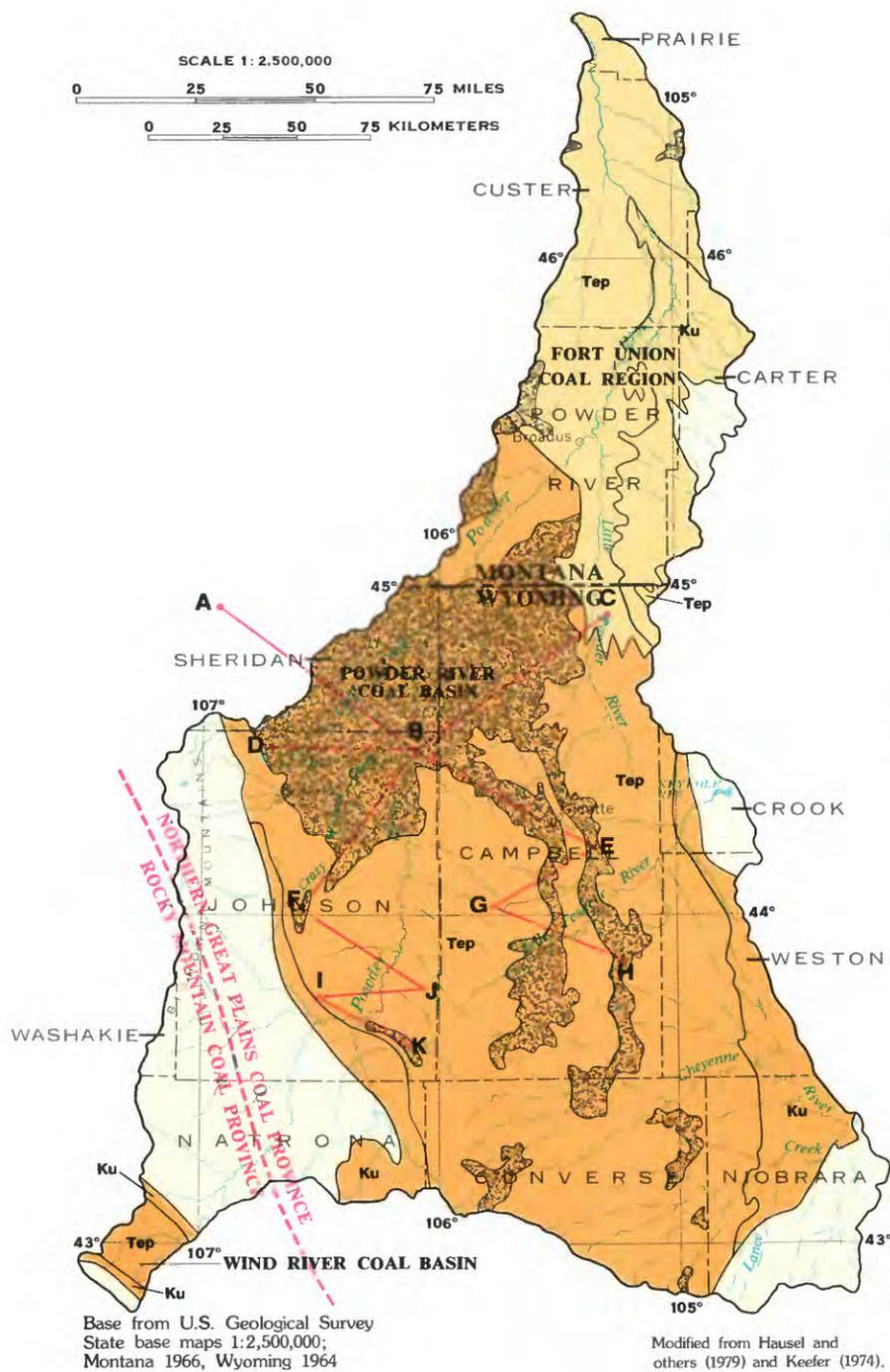


Figure 3.6.3-1 Coal-bearing parts of Area 50 and rank of coal.

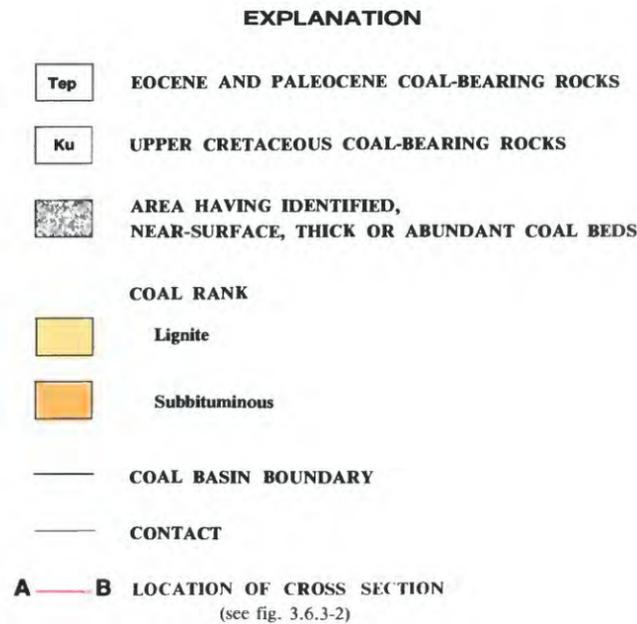


Table 3.6.3-1 Characteristics of coals currently mined in or adjacent to Area 50.

[Source: Glass (1982)]

Coal-bed name:	Wyodak Paleocene Fort Union Subbituminous		School Eocene Wasatch Subbituminous		Badger Eocene Wasatch Subbituminous	
Age:	Fort Union		Wasatch		Wasatch	
Rank:	Subbituminous		Subbituminous		Subbituminous	
	Range ²	Average ²	Range ³	Average ³	Range ⁴	Average ⁴
Moisture (percent) ¹	21.1-36.9	29.8	19.5-26.4	22.2	22.7-29.3	27.4
Volatile matter (percent) ¹	26.5-35.5	30.7	34.4-38.1	35.9	31.7-34.5	33.3
Fixed carbon (percent) ¹	29.6-41.4	33.5	28.3-33.6	30.5	28.5-32.6	31.4
Ash (percent) ¹	3.9-12.2	7.9	8.8-15.7	11.4	6.6- 9.8	7.9
Sulfur (percent) ¹	0.2- 1.2	.5	0.5- 0.7	.6	0.4- 0.5	.45
Heat value (British thermal unit per pound) ¹	7,420-9,600	8,220	7,830-8,870	8,180	7,610-8,290	7,950
Thickness (feet)	25-175	70	22-38	35	17-20	18.5

¹ As-received basis
² Based on five analyses
³ Based on three analyses
⁴ Based on 59 analyses

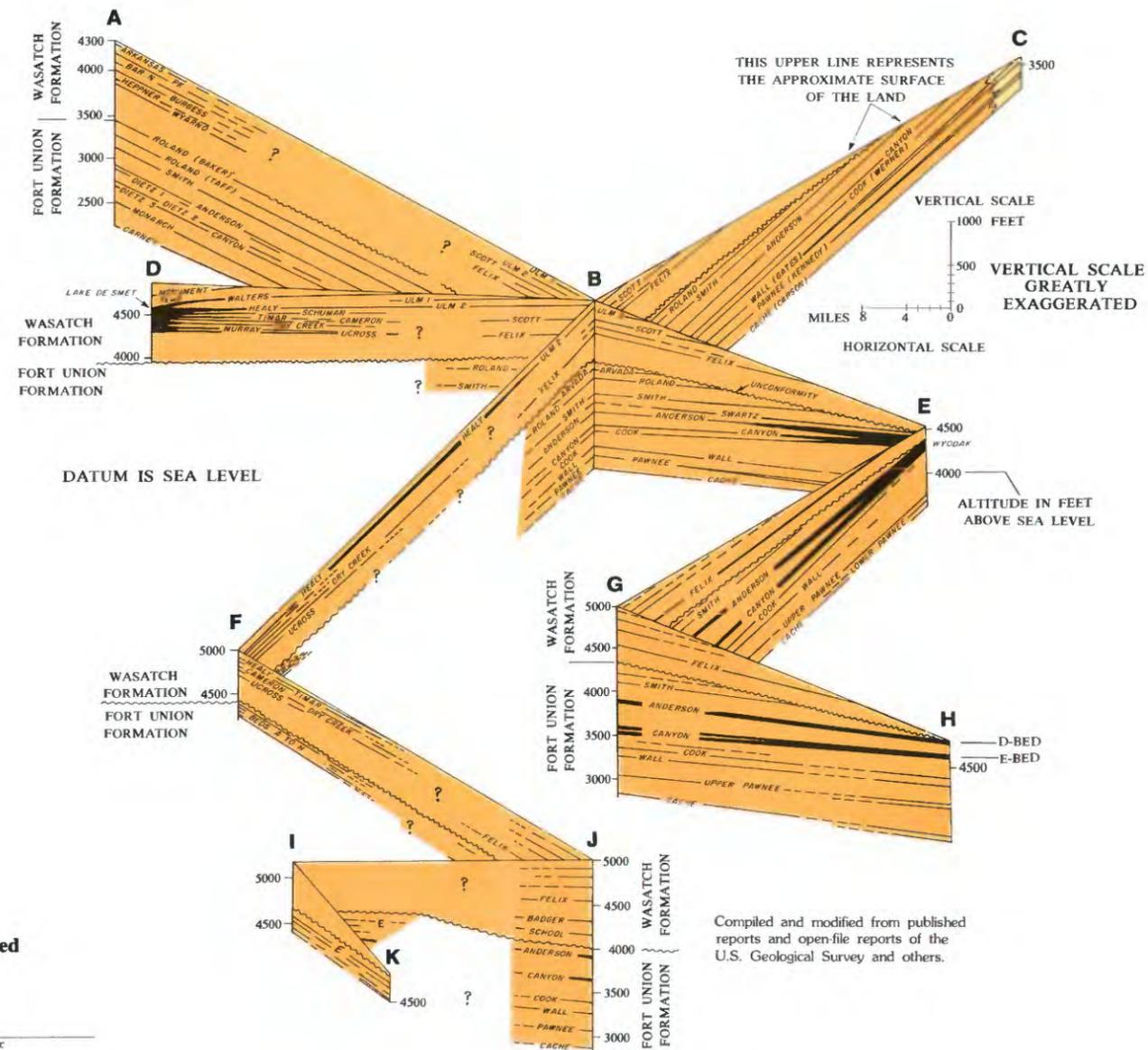


Figure 3.6.3-2 Correlation of principal coal beds. Location shown in Figure 3.6.3-1.

4.0 ECONOMIC DEVELOPMENT

4.1 Surface Ownership

Most of the Land Surface is Privately Owned

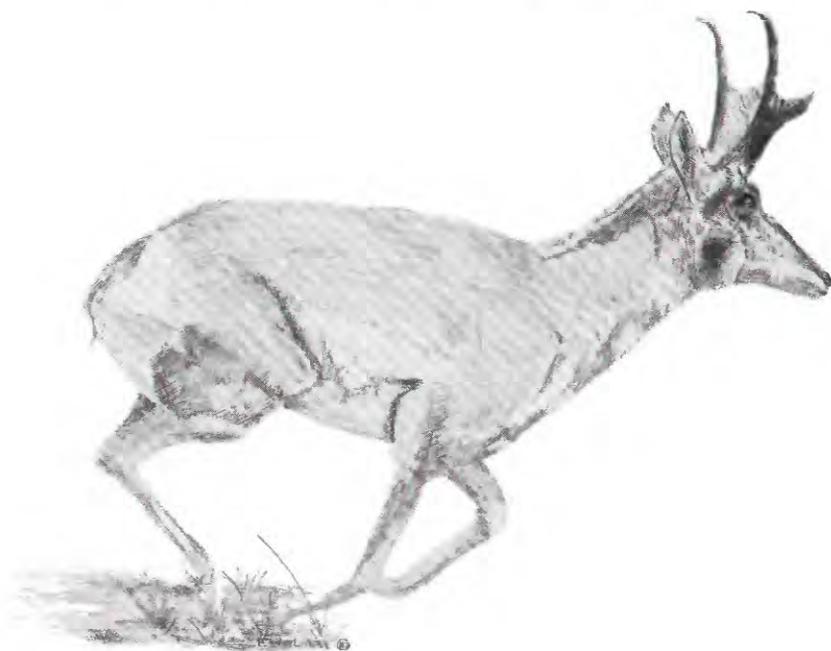
State and Federal Governments own less than one-half the land surface.

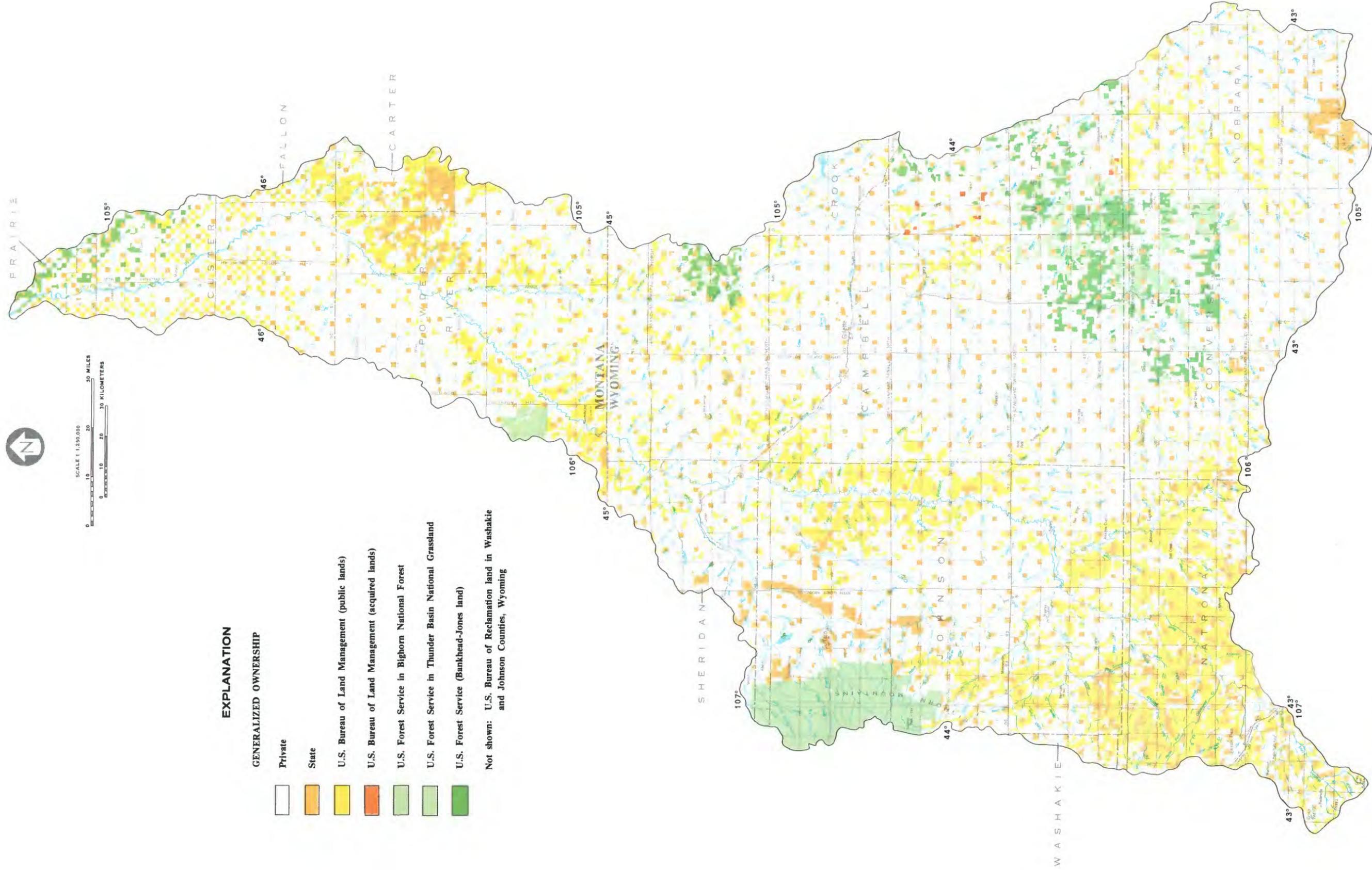
Private and government land-surface ownership differs greatly from county to county within Area 50, as shown in figure 4.1-1. Approximately 80 percent of the land surface in Campbell County is privately owned (Wyoming Department of Administration and Fiscal Control, 1981); Campbell County is the center of active coal mining in Area 50. Of the privately owned land surface in Campbell County, individual ranchers own 60 percent, ranch companies and coal companies own 35 percent (Gary B. Glass, written commun., 1983). The government owners are primarily the States of Wyoming and Montana, and the Federal government.

Sections 16 and 36 of every township, called school sections, were granted to Montana and Wyoming upon admission to the Union. Revenues from these lands were to be used for education. This pattern of ownership, shown in figure 4.1-1, is different only where trades, purchases, or sales by have been made by the States.

Nearly all the land surface owned by the Federal government is under the jurisdiction of the U.S. Forest Service and the U.S. Bureau of Land Management. The Forest Service administers the Bighorn National Forest, the Thunder Basin National Grassland, and Bankhead-Jones land. The Bankhead-Jones Act of 1937 and the Taylor Grazing Act of 1934 were enacted to promote sound land-use practices. The Taylor Grazing Act placed substantial areas of Federal land under the jurisdiction of an agency that is now the Bureau of Land Management.

The checkerboard pattern of Federal land ownership in the northern part of the area resulted from the Federal grant of the odd-numbered sections of land to the Northern Pacific Railroad. The grant was an incentive to build a northern transcontinental railway to benefit the settlement of the West. Land-ownership patterns in Wyoming are described in more detail by Calef (1960) and in the Rocky Mountain region by Foss (1960).





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

Compiled from U.S. Bureau of Land
Management Surface Management Status
maps for Wyoming and Montana.

Figure 4.1-1 Land-surface ownership.

4.0 ECONOMIC DEVELOPMENT--Continued
4.2 Minerals Ownership

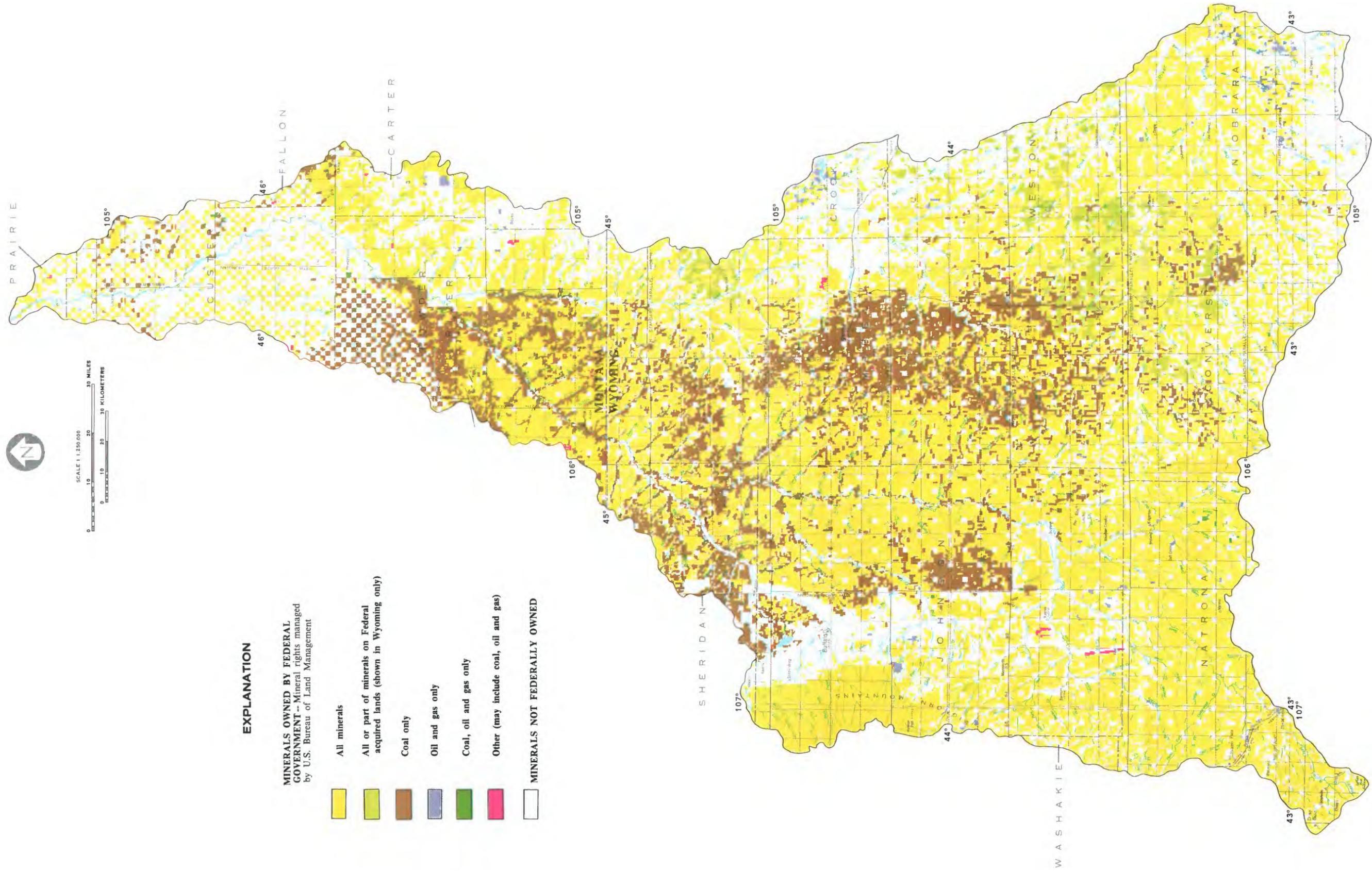
Federal Government Owns Most of the Coal

Private ownership of minerals was granted with the earliest homesteads, most of which are along major streams and near the mountains, and with land granted to the State and to the railroads.

The pattern of mineral ownership of the States and the checkerboard pattern of land given to the railroads (fig. 4.2-1) is the same as that of surface ownership described in section 4.1; the mineral estate was included with surface ownership for the earliest homesteads. Subsequently, however, a difference between land- and mineral-ownership patterns began to develop, as mineral rights increasingly were reserved by the Federal government. Finally, the Homestead-Grazing Act of 1916 was passed, which reserved all mineral rights on homestead lands for the Federal government. The result of this change in homestead laws is indicated on the map by more private ownership of minerals on some of more desirable agricultural land, such as along major streams and near the mountains, in contrast to the rest of the area. The Surface Mining Control and Reclamation Act of 1977, however, includes special mining regulations for protection of alluvial valley floors. Furthermore, the land near the mountains

does not have extensive coal beds such as are present in the basin. Therefore, less surface mining of coal will occur where the minerals are privately owned.

The large proportion of Federal mineral ownership will affect the future of the area, because of the method in which coal tracts are selected for leasing. The U.S. Bureau of Land Management makes tract selections and evaluates the tracts according to several suitability criteria. Scenic value, critical habitat for endangered or threatened plant and animal species, alluvial valley floors, and municipal watersheds are only a few of the many items considered in determining if a Federal coal tract is suitable for mining. On April 28, 1982, in the largest sale of Federal coal leases in the history of the United States, 2.24 billion tons of coal in the Powder River structural basin were offered for sale by the Bureau of Land Management.



EXPLANATION

MINERALS OWNED BY FEDERAL GOVERNMENT -- Mineral rights managed by U.S. Bureau of Land Management

- All minerals
- All or part of minerals on Federal acquired lands (shown in Wyoming only)
- Coal only
- Oil and gas only
- Coal, oil and gas only
- Other (may include coal, oil and gas)
- MINERALS NOT FEDERALLY OWNED

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

Compiled from U.S. Bureau of Land Management Mineral Status maps for Wyoming and Montana.

Figure 4.2-1 Minerals ownership.

4.0 ECONOMIC DEVELOPMENT--Continued

4.3 Land and Water Use

Agriculture Greatest User of Land and Water

Nearly 90 percent of the land in Area 50 is used for agricultural purposes-- mostly livestock grazing; 92 percent of the water used is for irrigation.

Livestock grazing on private and public lands is common throughout the area. The large proportions of land used for agriculture in Johnson and Campbell Counties are illustrated in figure 4.3-1; the proportions are similar in others parts of the area. The average ranch size in Campbell County is 7,451 acres (U.S. Department of Commerce, 1981). The average livestock densities are small, because 50 acres or more of rangeland may be required to meet the annual forage requirements for one cow. Agricultural and other land uses for the eastern one-half of Area 50 have been mapped at a scale of 1:250,000 (U.S. Geological Survey, 1979a, 1979b, 1979c, 1979d, 1980a, 1982).

Urban areas comprise a small proportion of the land use. The largest city in the area is Gillette (population 12,134), in Campbell County, Wyo. The population of Campbell County nearly doubled between 1970 and 1980; the average population density in the county as of 1980 was 5.1 persons per square mile (Wyoming Department of Administration and Fiscal Control, 1981). The magnitude of population growth resulting from energy-minerals development has caused an increased emphasis on regional, county, and city land-use planning. Examples of land-use plans are the City of Gillette/Campbell County Comprehensive Planning Program (City of Gillette/Campbell County Planning Commission and City of Gillette/Campbell County Department of Planning and Development, 1978), and Wyoming Land Use Decisions (U.S. Bureau of Land Management, 1979).

Recreational land uses such as hunting, fishing, and fuelwood gathering in the Bighorn Mountains are popular on public and private lands. For example, Strickland (1981) reported more than 16,000 hunter-days and a success rate of more than 80 percent for antelope hunters in Johnson and Campbell Counties.

The most common industrial land use in the area is for mineral development. The 12 mines operating during 1980 will disturb 52,143 acres of the land surface during mining. The area of mining at any

one time, however, is much less, and reclamation follows initial disturbance by about 5 years. A north-south railroad across Area 50 was built beginning in the early 1970's specifically for coal development. The 113-mile line is the longest continuous, new track built in the United States since the 1930's. Two coal-fired powerplants in the area are supplied from nearby mines. Oil-and-gas fields are located throughout the basin, but are most numerous in the eastern part. Naval Petroleum Reserve Number 3 (which was the focus of the Teapot Dome oil scandal during the 1920's) is located in the southern part of the area, near the town of Midwest. Bentonite clay is mined near Kaycee.

More than 90 percent of the total water use in Area 50 is for irrigation. Surface- and ground-water use for irrigation, municipal, rural, and industrial supplies is illustrated in figure 4.3-2. The surface water used for irrigation is usually applied to hayfields along stream channels. Very few other irrigated crops are grown. Dryland winter wheat is grown in a few areas.

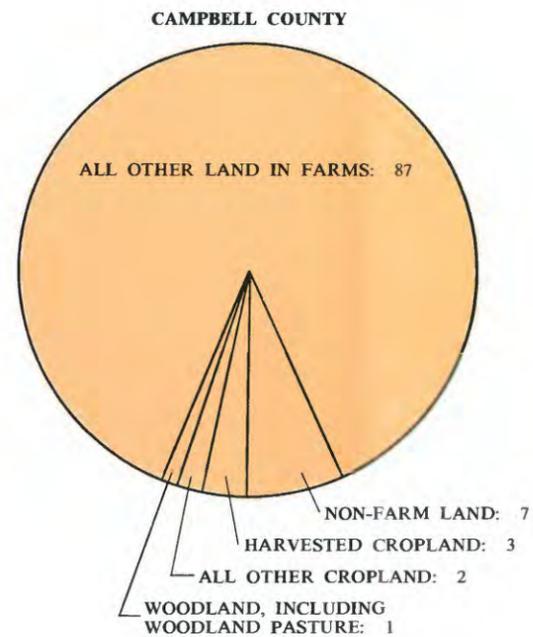
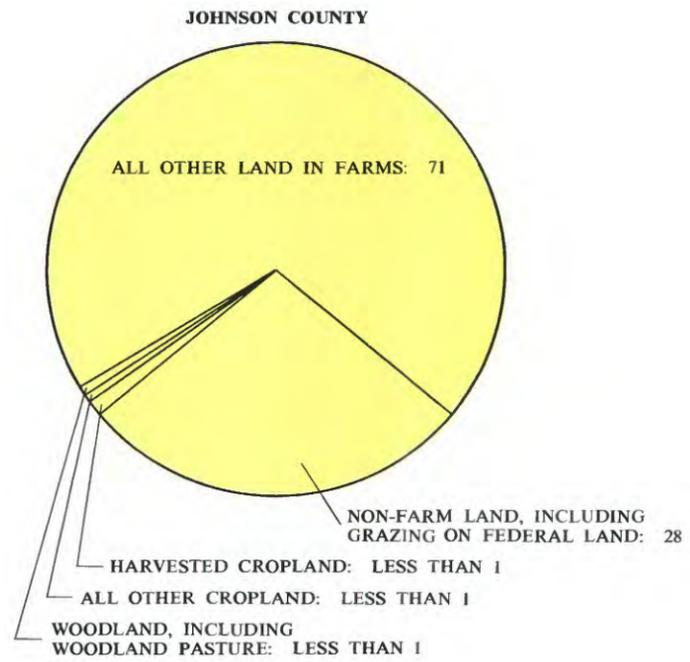
Water use for municipal and rural supplies is relatively small. Most municipal supplies are obtained from ground water; rural supplies are obtained in approximately equal proportions from ground water and surface water.

Water for industrial use is drawn mostly from ground water. Water may be injected in wells to increase oil production or to dispose of saline wastewater. The principal source of water for the Wyodak powerplant near Gillette is sewage effluent from Gillette.

Agricultural and industrial land and water uses commonly overlap (fig. 4.3-3). Jacobs and others (1982) prepared a detailed assessment of the transfer of land from agriculture to industry, the competition between agriculture and the coal industry for land and water, and the physical and economic impacts on agriculture as the result of coal development in the Powder River Basin.



Figure 4.3-1 Land use in Johnson and Campbell Counties, Wyoming.



LAND USE BY COUNTY, IN PERCENT
Percentages modified from Wyoming
Department of Administration and Fiscal Control (1981).

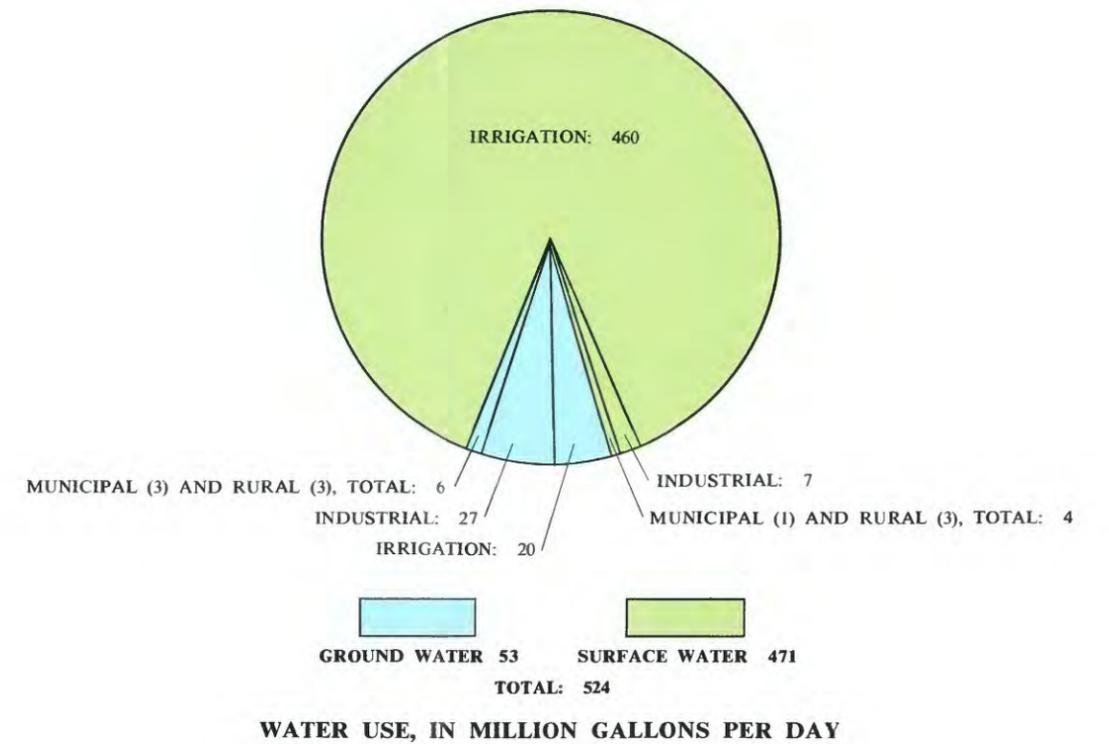


Figure 4.3-2 Approximate water use during 1980.



Figure 4.3-3 Agricultural and industrial uses of land and water commonly overlap.

4.0 ECONOMIC DEVELOPMENT--Continued

4.4 Coal

Area 50 Contains More Coal than Any Other Hydrologic Area in the Nation

Coal production has increased from less than 1 million tons in 1970 to 81.2 million tons in 1982; production in 1990 is projected to be 122 million tons.

Coal resources underlying Area 50 probably exceed 500 billion tons. Of this estimated resource, at least 24.5 billion tons are currently (1983) defined as strippable reserve base; that is, that part of the resource from which recoverable strippable reserves will be derived (Glass, 1982; Matson and Blumer, 1973). These 24.5 billion tons are a conservative estimate that will increase as more detailed geologic reports are published.

The reserve base for coal that may be recoverable by underground mining techniques also is extremely large in the area--about several tens of billions of tons. Because the last comprehensive coal-resource estimate for this area was made in 1950 (Berryhill and others, 1950), more accurate estimates of resources and reserve base must await new studies based on private and government coal drilling during the last 15 years and on extensive oil-and-gas drilling records for the last 30 or more years. New coal-resource estimates, however, are available for some smaller parts of the area (Denson and Keefer, 1974; Denson and others, 1978; and Grazis, 1977a, 1977b, 1977c, 1977d).

Coal production from Area 50 has increased phenomenally during the last 12 years. (See figure 4.4-1.) In 1970, two strip mines were active in the area. Of the 640,000 tons produced by those two mines, the Wyodak Mine accounted for all but 2,179 tons. By 1982, 13 large strip mines were active in the area, and collectively, these mines produced 75 percent (81.2 million tons) of Wyoming's total coal production (108 million tons) during that year (fig. 4.4-2). Two of these strip mines (Thunder Basin Coal Company's Black Thunder Mine and Amax Coal Company's Belle Ayr Mine) produced 16.8 million tons and 15.2 millions, respectively. These two mines, incidentally, are the largest coal mines in the United States. Although the Belle Ayr mine shown in figure 4.4-3 was the second largest mine in 1982, its 1978 production of 18.1 million tons is still the Nation's record annual production from a single coal mine. Although demand for coal from Area 50 is forecast to exceed 122 million tons per year by

1990, annual mine capacity in the area could approximate 200 millions tons by that same year (Glass, 1980a).

All the active coal mining in the area is restricted to the outcrop of the Wyodak coal bed in eastern Campbell County, Wyo. (fig. 4.4-2). Strip-mine operations extracted 81.2 million tons of coal from this bed during 1982, which is the largest tonnage from a single coal bed in the Nation. This annual production also ranks Campbell County as the largest coal-producing county in the United States--a title the county could hold for many decades, if not centuries. During 1981 only four coal-producing States (Kentucky, West Virginia, Wyoming, and Pennsylvania) produced more coal than Campbell County.

The present demand for Area 50 coals began during the late 1960's as electric utilities searched for low-sulfur coals that they could burn in their powerplants and meet mandated emission standards. Today, nearly all the coal mined in this area is burned in coal-fired electrical powerplants in at least 16 States as far west as Oregon, as far east as Ohio, and as far south as Texas and Louisiana. Only about 1.5 million tons, or 1.8 percent of the coal from the area, are used for industrial purposes (beet sugar, bentonite, and cement industries) or retail sales for home, business, and municipal heating.

Although only one coal-fired powerplant (330-megawatt Wyodak plant) is located in the area, others have been proposed. In addition, the area has been named as a possible site for several proposed coal-conversion plants (a facility that converts coal into synthetic gas or into synthetic liquids or both). At two separate test sites in the area (Lawrence Livermore's Hoe Creek site and Atlantic Richfield's Rocky Hill No. 1 site) thick Tertiary coals have been converted into low-energy synthetic gas by in situ (underground) combustion experiments (fig. 4.4-2). The huge coal resources of the area will continue to make Area 50 a potential site for such facilities.



Figure 4.4-3 Belle Ayr Coal Mine. Average production for 1973-82 was 11.7 million tons per year. Peak production in 1978 was 18.1 million tons, a record for the Nation.

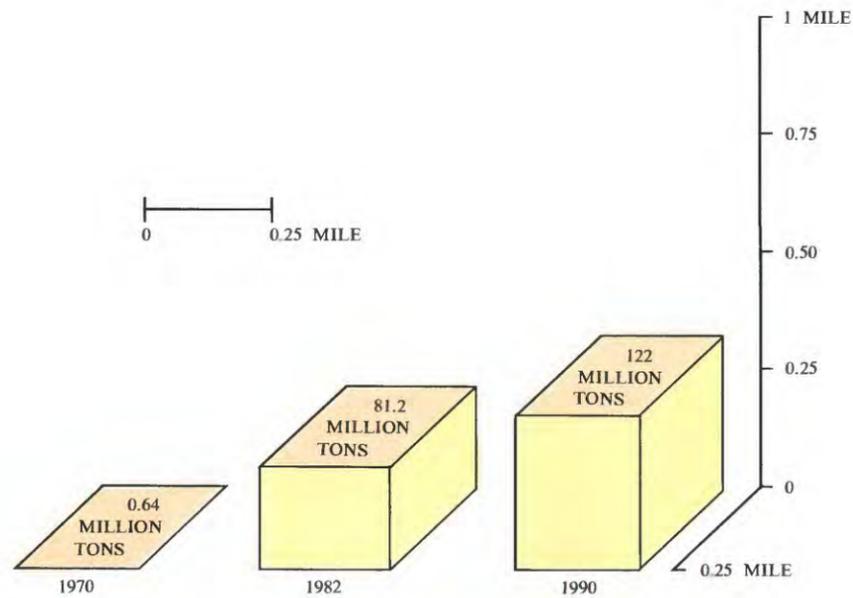


Figure 4.4-1 Tonnage and approximate volume of coal produced in 1970 and 1982 and projected production for 1990.

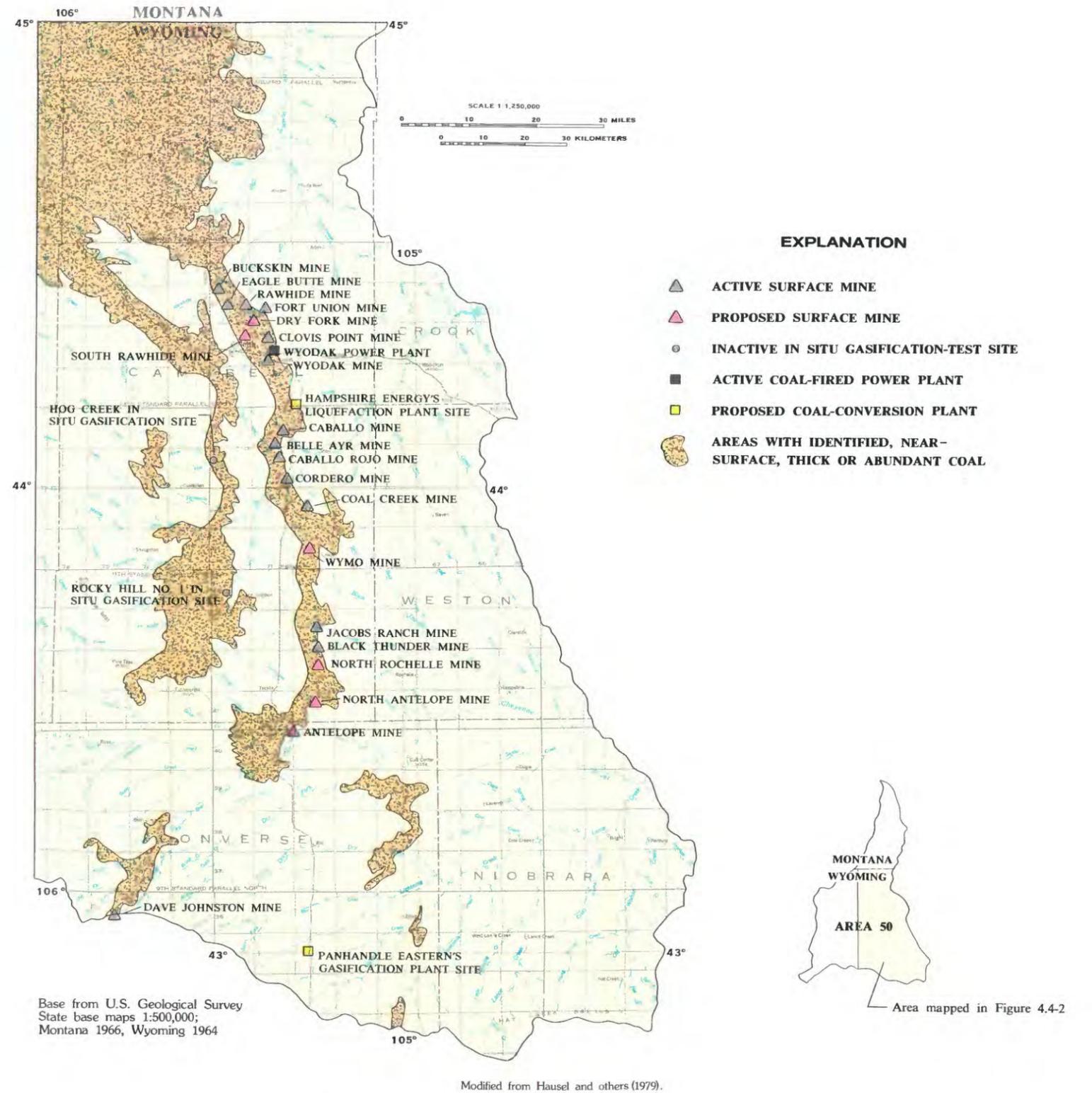


Figure 4.4-2 Minerals ownership.

4.0 ECONOMIC DEVELOPMENT--Continued

4.5 Other Mineral Resources

Oil, Natural Gas, Uranium, Bentonite, Gypsum, Limestone, and Metals also are Important Resources in the Area

Petroleum products are produced from wells and underground mines; uranium is produced from surface and underground mines as well as from in situ leaching processes.

During 1981, about 47 million barrels of petroleum and about 54 billion cubic feet of natural gas were produced in Area 50 from fields shown in figure 4.5-1. These amounts were about 38 percent of the State's oil production and about 12 percent of the State's gas production. The production was from about 500 oil-and-gas fields, which are located mostly in the eastern one-half of the area (fig. 4.5-1). Oil and natural gas exploration in this area has been so prolific in recent years that at least one new field has been discovered each month. Although drilling has decreased since 1982, more wells are drilled in this area each year than in any other area of the State. For a recent summary of the oil-and-gas industry in Wyoming, see Ver Ploeg (1982).

All the oil and natural gas that has been commercially developed was from formations older than the Upper Cretaceous Fox Hills Sandstone. Oil and gas wells completed in these formations also produced more than 250 million barrels of water each year. Although some of this water is simply reinjected into disposal wells, most of the water is used for secondary and tertiary waterflood projects.

Recently there has been commercial interest in the gas in thick Tertiary age coal beds that underlie the area. The coal gas is principally methane with some light hydrocarbons (Whitcomb and others, 1966, p. 70-71; Lowry and Cummings, 1966, p. 46-48). Some coal gas that is discharged from water wells has been reported to be used for domestic use, but most gas that is produced that way escapes into the atmosphere. The ignited gas at a stockwater tank in southeastern Sheridan County, Wyo., is shown in figure 4.5-1.

The area also contains the sites of one active and another proposed underground mine for the recovery of heavy oil. Conoco's underground mine in the North Tisdale field near Kaycee, Wyo. (fig. 4.5-1), produced 10,418 barrels of heavy oil during 1981. Conoco has a second mine under construction near Linch, Wyo., which is 20 miles east of their active mine.

Currently (1983) two uranium mines in the area are active; however, 10 mines that are closed or postponed can reopen or resume construction if the demand and price of uranium oxide increase (fig. 4.5-2). During 1981 six active mines or in-situ leach operations produced 1.3 million tons of uranium ore. By 1982 production decreased to an estimated 1 million tons. Numerous prospects and abandoned uranium mines from the 1950's and early 1960's are present in the southern part of the area, and many uranium-ore deposits have been reported (Hausel and others, 1979).

Bentonite is another important mineral resource in the area. This clay mineral is used primarily for well-drilling mud, for pelletizing taconite (iron ore), and for foundry castings. Kaycee Bentonite Company operates the active mines in the southwestern part of the area. Bentonite-bearing strata also crop out in the southeast along the Old Woman anticline and in the northeast along the western edge of the Black Hills uplift (fig. 4.5-2).

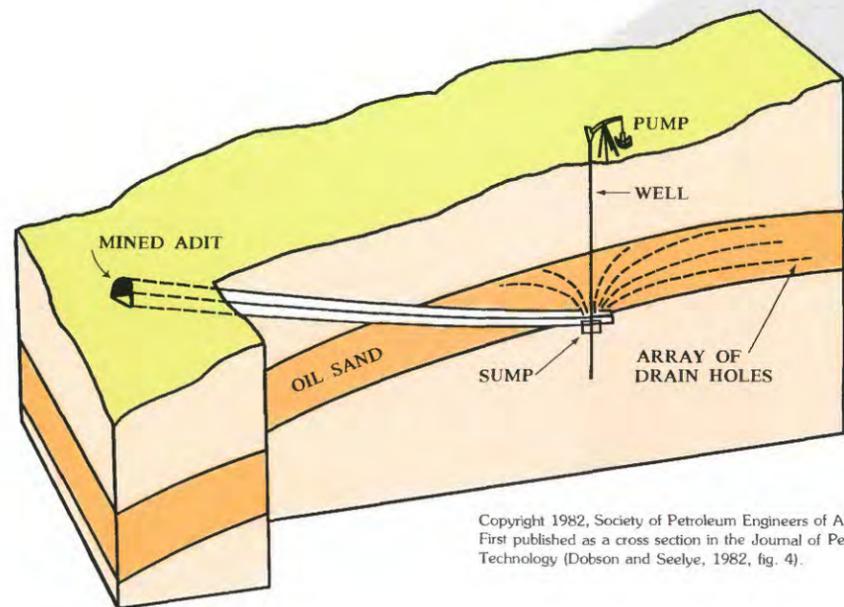
Gypsum-bearing rocks are present on the flank of the Bighorn uplift on the west side of the area (fig. 4.5-2). An abandoned gypsum mine is located in T. 53 N., R. 83 W. (Hausel and others, 1979). No gypsum is presently (1983) produced in Area 50; however, Wyoming's largest gypsum-producing region is just west of the Bighorn Mountains.

Limestone crops out along both the east and west margins of the area (fig. 4.5-2). Several small quarries are present in these units, but limestone is not presently (1983) produced within Area 50. These limestones are quarried in adjacent regions. Limestone is, however, an important resource of the area.

A few prospects for metals (gold, copper, tungsten, manganese, and rare earths) are found in the Bighorn Mountains on the west side of Area 50 (fig. 4.5-2). No major production has been reported from any of these prospects.

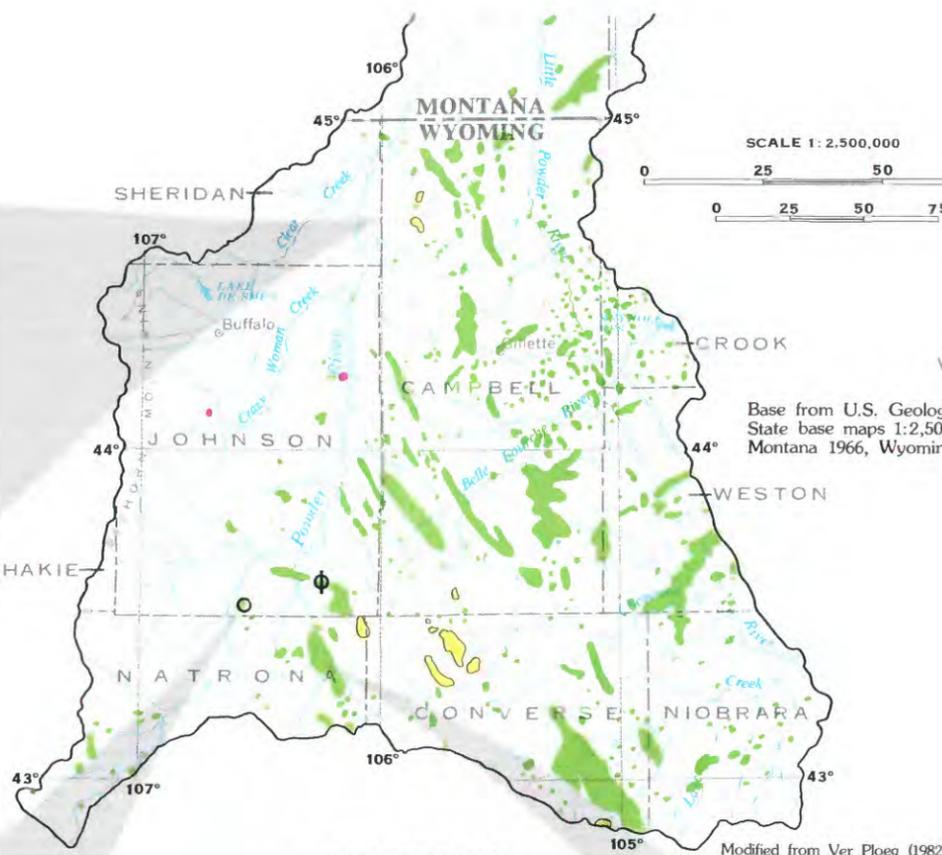


Burning coal gas at artesian water well in southeast Sheridan County, Wyoming.



Copyright 1982, Society of Petroleum Engineers of AIME. First published as a cross section in the Journal of Petroleum Technology (Dobson and Seelye, 1982, fig. 4).

Diagram of oil mine near Kaycee, Wyoming; not to scale.



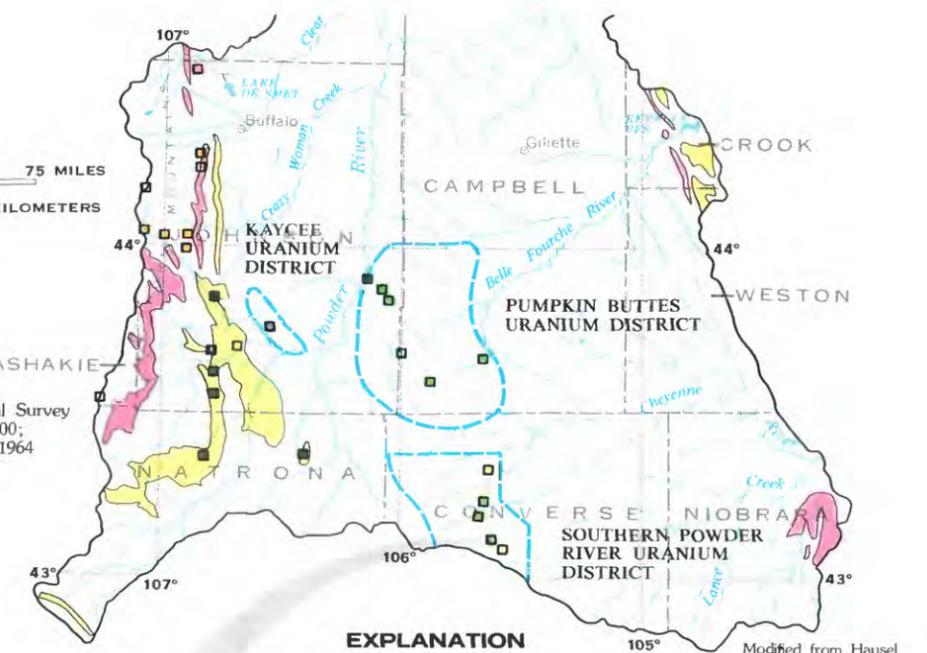
EXPLANATION

- OIL FIELD
- GAS FIELD
- OIL AND GAS FIELD
- UNDERGROUND MINE FOR HEAVY OIL
- Active
- ⊕ Proposed

Figure 4.5-1 Location of oil and gas fields.



Salt Creek oil field.



EXPLANATION

- URANIUM DISTRICT BOUNDARY
- Active uranium mine.
- Inactive uranium mine.
- ⊕ Proposed uranium mine.
- LIMESTONE OUTCROP AREA
- BENTONITE OUTCROP AREA
- Active bentonite mine.
- Inactive bentonite mine.
- INACTIVE GYPSUM MINE
- METALLIC-MINERAL PROSPECT (gold, copper, tungsten, manganese, and rare earths)

Figure 4.5-2 Location of uranium, limestone, bentonite, gypsum, and metallic-mineral resources.



Exxon's Highland uranium mine.

5.0 SURFACE-WATER DATA NETWORK

Hydrologic Data Available for 168 Surface-Water Locations

Surface-water data are available for 168 locations in Area 50; 132 have streamflow data, 81 have chemical-quality data, 42 have fluvial-sediment data, and 67 have biological data.

Data collection in Wyoming is a cooperative effort in which the planning and financial support are shared with the U.S. Geological Survey by State and local governments, and other Federal agencies. The locations of stations and sites where surface-water data have been collected are shown in figure 5.0-1. Additional information about the name, location, and records available for each station and site is given in section 10.3 of this report.

A station is a location where continuous or repetitive records of streamflow or water quality have been collected; a site is a location where miscellaneous discharge measurements or water-quality samples have been obtained. To simplify the identification of the locations shown on the maps in this report, including figure 5.0-1, the stations and sites have been assigned individual numbers, from 1 to 168. These numbers are used throughout this report, instead of the Geological Survey 8-digit station numbers (see list in section 10.3). For example, station 1 in figure 5.0-1 has a Geological Survey downstream-order station number 06309200; site 154 has none. When requesting additional information about the records for a station, use the Geological Survey station number.

Continuous records of streamflow have been collected at 117 gaging stations. At such installations a continuous record of gage height (stage) is recorded. Discharge is periodically measured with a current meter. The measurements are used to develop a stage-discharge relationship with which discharge can be determined for any stage of the stream. Application of the relationship to the continuous record of stage yields streamflow values that are expressed as average rates or volumes of flow for each day. Maximum and minimum instantaneous flow rates also are determined.

At some stations only peak-flow data are collected. These are known as crest-stage stations. A protected staff gage at these stations records the maximum stages of floods. A stage-discharge rela-

tionship is developed for each station and the peak discharge is determined for each maximum recorded stage.

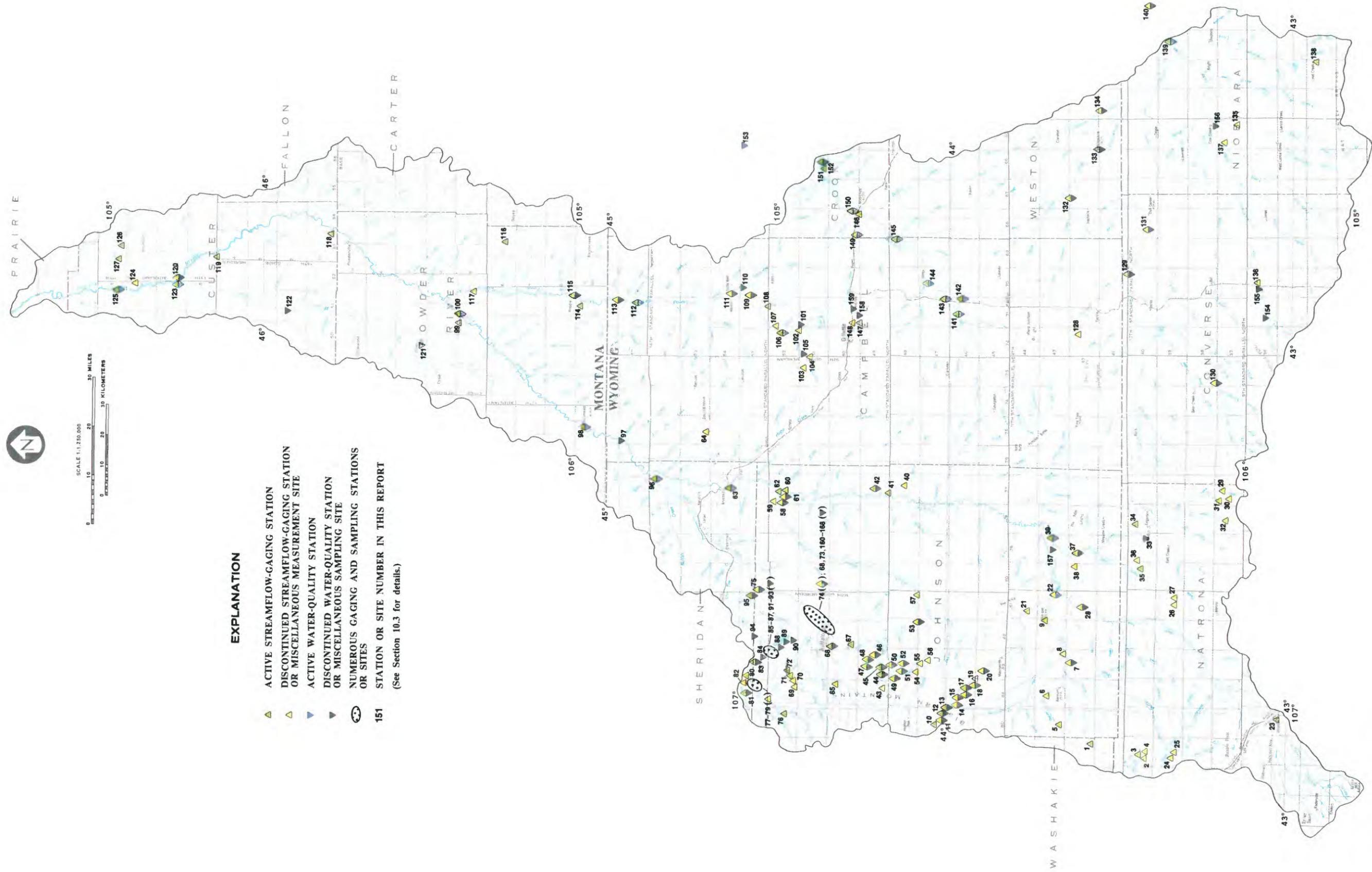
During 1965-73, a network of special gaging stations was operated as part of a study of flood hydrographs for small drainage basins. At these stations, continuous records of rainfall and resulting runoff were collected during the rainfall season, May through September (Rankl and Barker, 1977). A mathematical model was used to extend the records of floodflows at these sites (Craig and Rankl, 1978).

Special studies sometimes require discharge measurements to be made at sites where streamflow-gaging stations have not been installed. For example, seepage studies to determine water loss or gain through a particular reach of stream, and collection of water samples at ungaged sites generally require a measurement of discharge. Fifteen sites listed in section 10.3 have this type of streamflow record.

Water samples have been collected at many of the stations and sites shown in figure 5.0-1. Chemical-quality data are available for 81 locations, fluvial-sediment data for 42 locations, and biological data for 67 locations.

The concentrations of dissolved and suspended material in streamflow change with season of the year and magnitude of the discharge. A single sample defines the kinds and concentrations of material only at the time of sampling. For surface-water quality to be defined for a specified time and for a range of discharges, water samples generally are collected periodically.

Records of streamflow and water quality are published in annual reports of the U.S. Geological Survey (1983a, 1983b). They also may be retrieved through computerized systems that are described in section 9.0 of this report.



5.0 SURFACE-WATER DATA NETWORK

Figure 5.0-1 Surface-water data network, 1982.

6.0 SURFACE-WATER QUANTITY

6.1 Average Flow

Mountain Areas Produce Much Greater Runoff than Plains Areas

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

Average annual runoff, in acre-feet per square mile, was computed using streamflow data collected at 40 gaging stations in Area 50. Values of average annual runoff range from 2.21 to 760 acre-feet per square mile. The data were divided into six groups and each group was assigned a color; the results are presented in figure 6.1-1.

Average annual runoff in the mountain streams 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 average 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 the drainage area.

Average annual runoff of a plains-area stream is a function of quantity and intensity of precipitation,

drainage area, evaporation, 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 plains-area streams is minor. Man-made 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 50 by using regression equations developed by Lowham (1976, p. 23). He developed equations for the perennial streams in mountain areas by relating runoff to the drainage area and average basin elevation. Average annual runoff for plains-area basins was related only to drainage area. These equations were developed for Wyoming but are applicable to the Montana part of Area 50.

6.0 SURFACE-WATER QUANTITY--Continued

6.2 Streamflow Variability

Streamflow More Variable in Plains Areas than in Mountain Areas

The large variability of streamflow in the plains areas is a result of variable precipitation, little infiltration, and negligible moisture storage; mountain runoff is less variable because of moisture storage in snowpacks and aquifers.

Hydrographs of maximum, minimum, and average daily streamflows for an ephemeral stream in the plains area and a perennial stream in the mountain areas are compared in figure 6.2-1. The hydrographs for Lance Creek near Riverview, Wyo. (station 139), an ephemeral stream, show a large difference between the maximum and minimum runoff values, high sharp peaks, an early snowmelt runoff, and many days of zero flow. The hydrographs for North Fork Powder River near Hazelton, Wyo. (station 10), a perennial stream, show less variability of runoff and a later period of snowmelt runoff than the ephemeral stream.

Streamflow hydrographs for the 1979 water year for an ephemeral and a perennial stream are illustrated in figure 6.2-2. Dead Horse Creek near Buffalo,

Wyo. (station 42), an ephemeral stream that drains 151 square miles of plains, shows one snowmelt runoff in March and three periods of rainfall runoff in the summer. The perennial stream, Clear Creek near Buffalo, Wyo. (station 66), which drains 120 square miles of mountain area, shows sustained ground-water discharge in the fall and winter and a large snowmelt runoff from April through June.

Long-term variability of streamflow is illustrated in figure 6.2-3. During 1944 the annual flow of the Powder River near Locate, Mont. (station 125) was 250 percent of the average flow for the period of record (1939-81 water years). During 1961 the annual flow was only 13 percent of the average flow.

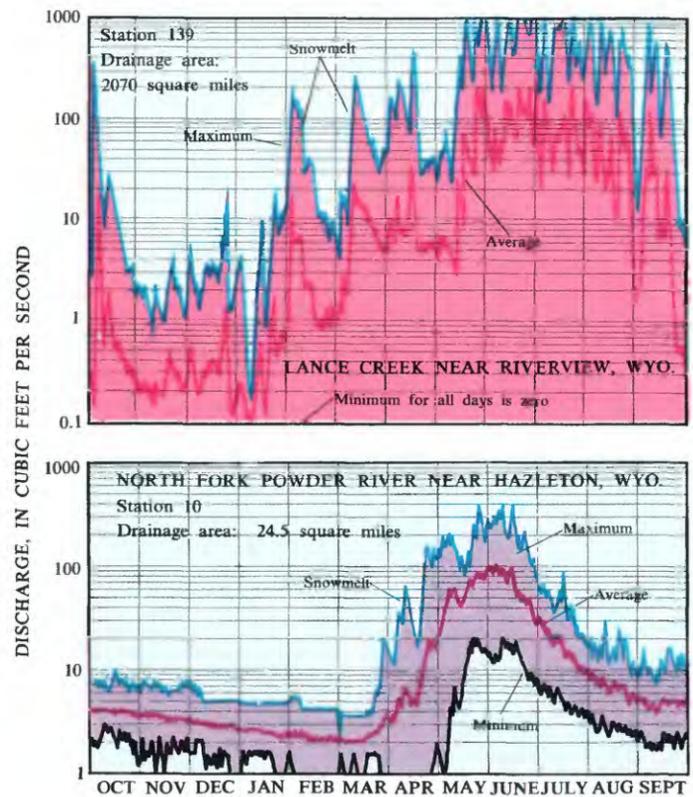
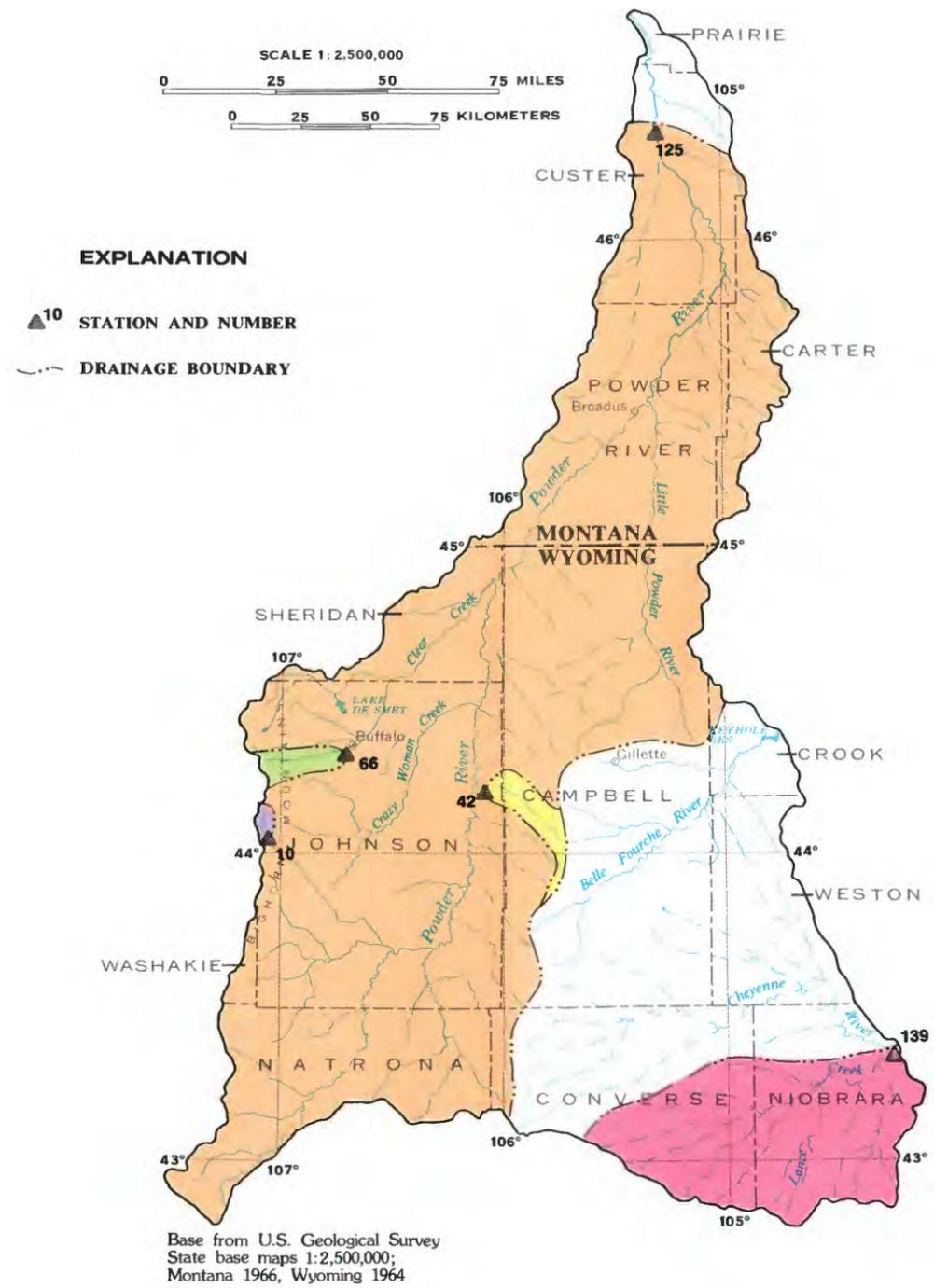


Figure 6.2-1 Maximum daily, minimum daily, and average daily streamflow hydrographs for selected stations, 1951-69 water years.



Base from U.S. Geological Survey
State base maps 1:2,500,000;
Montana 1966, Wyoming 1964

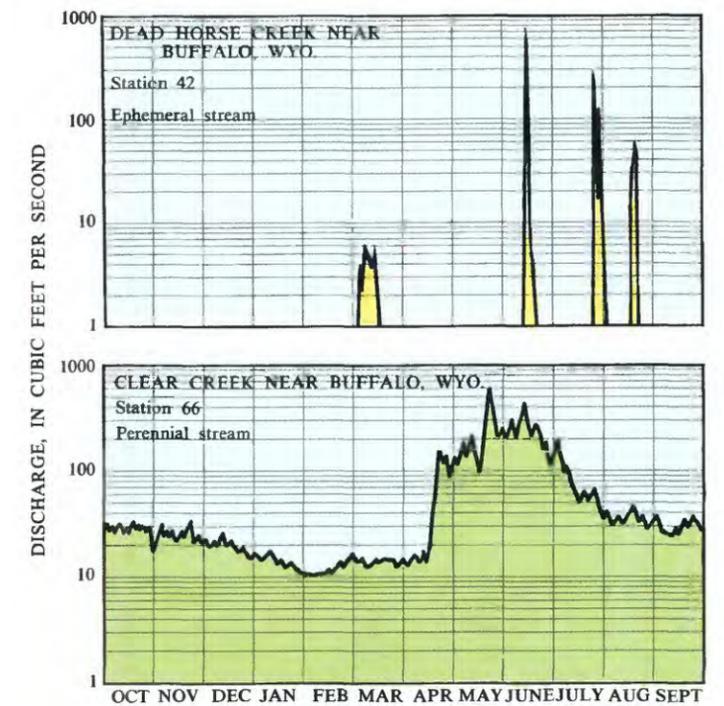


Figure 6.2-2 Streamflow hydrographs for 1979 water year for selected stations.

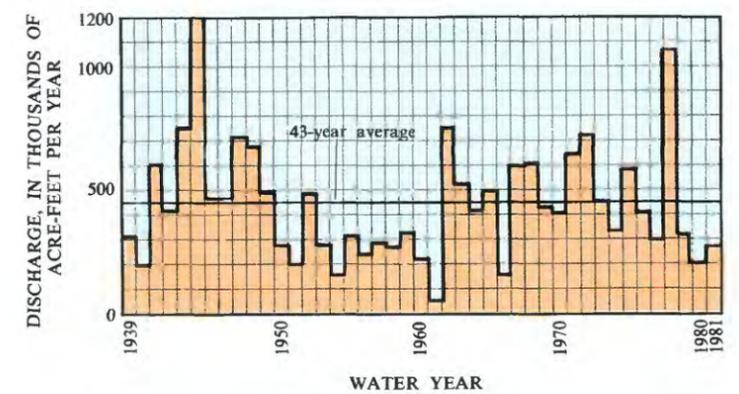


Figure 6.2-3 Annual discharge of Powder River near Locate, Montana (station 125), 1939-81 water years.

6.0 SURFACE-WATER QUANTITY--Continued

6.3 Low Flow

Low Flow is No Flow in Most Plains-Area Streams

Because most plains-area streams flow only in response to rainstorms and snowmelt they are dry most of the time; mountain streams flow during most dry seasons and droughts.

Most plains-area streams 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) on the plains intercept shallow aquifers or receive water from springs that provide perennial flows 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 mountains result from more precipitation, less evapotranspiration, and a larger capacity to store moisture. 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 19 or more years of record were analyzed for 7-day low-flow statistics. The results of these analyses are listed in table 6.3-1.

The Powder River maintains flow most of the time throughout its course from the mountains to the Yellowstone River, 29.4 miles downstream from station 125, but its low-flow characteristics change as illustrated by the 7-day low-flow statistics presented in figure 6.3-1. The concave probability curve for station 22 shows that the perennial source of water is the mountains. Streamflow losses to irrigation, evapotranspiration, and to alluvial aquifers between stations 22 and 63 are exemplified by the convex

shape of the low-flow probability curve at station 63 and the increase in the number of no-flow days.

A perennial source of water from the mountains enters the Powder River between stations 63 and 98. The results are a less convex low-flow probability curve and fewer no-flow days at station 98. Streamflow gains and losses between stations 98 and 125 are apparently about equal and, therefore, the low-flow statistics are similar for the two stations.

Low-flow statistics for station 81 are presented in figure 6.3-2 as an example of the type of information available for perennial streams in the area. These low-flow statistics provide information about water supply for municipal and industrial uses, irrigation, instream fisheries, and waste disposal.

Unfortunately, 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 so variable (section 6.1), the average annual flow of these streams (section 6.2) is also of little value when seeking a dependable water supply. A reservoir-storage frequency model has been developed by Glover (1984). The model evaluates the within-year and the between-year variability of streamflow for an ephemeral stream, and computes the probabilities of reservoir storage, including the risk of being unable to supply downstream demand.

Table 6.3-1 Seven-day low-flow statistics.

[Discharge, cubic feet per second]

Station number	Drainage area (square miles)	Length of record (years)	Recurrence interval (years)						Number of years of no flow ¹
			1.01	1.25	2	5	10	20	
Perennial streams									
10	24.5	34	2.68	1.90	1.48	1.10	0.93	0.80	0
20	106	32	20.0	16.9	14.3	11.3	9.78	8.53	0
28	1,150	20	5.49	4.76	3.06	1.14	.52	.23	0
56	82.7	29	10.4	6.79	5.00	3.50	2.85	2.37	0
66	120	42	32.3	7.07	2.46	.73	.37	.20	0
72	60.0	26	5.72	4.37	3.13	1.89	1.34	.97	0
77	69.4	24	20.1	14.9	11.2	7.64	5.99	4.78	0
81	36.8	29	7.97	5.98	5.02	4.18	3.78	3.48	0
83	118	40	21.5	11.7	8.24	5.75	4.75	4.05	0
95	267	31	29.0	19.1	11.1	4.69	2.60	1.48	0
96	1,110	41	56.4	21.0	9.25	2.26	.74	-	2
117	1,974	19	3.96	1.75	.56	.03	-	-	3
Ephemeral streams									
139	2,070	29	-	-	-	-	-	-	29
140	5,270	25	-	-	-	-	-	-	25
150	1,670	26	-	-	-	-	-	-	26
Powder River main stem									
22	980	31	31.1	3.72	1.10	.33	.17	.10	0
63	6,050	46	112	14.0	-	-	-	-	29
98	8,088	48	122	46.4	16.0	2.58	.47	-	3
125	13,189	41	155	53.0	20.0	4.62	1.00	-	2

¹ Seven or more consecutive days of no flow

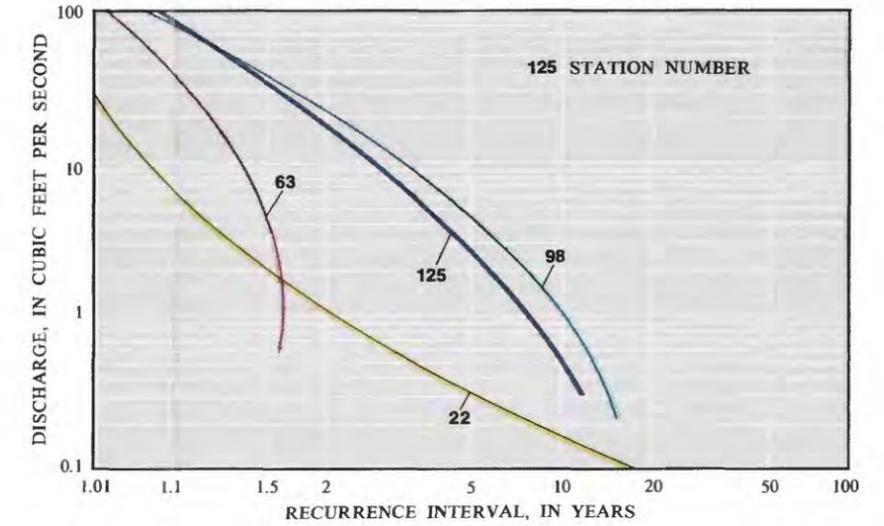
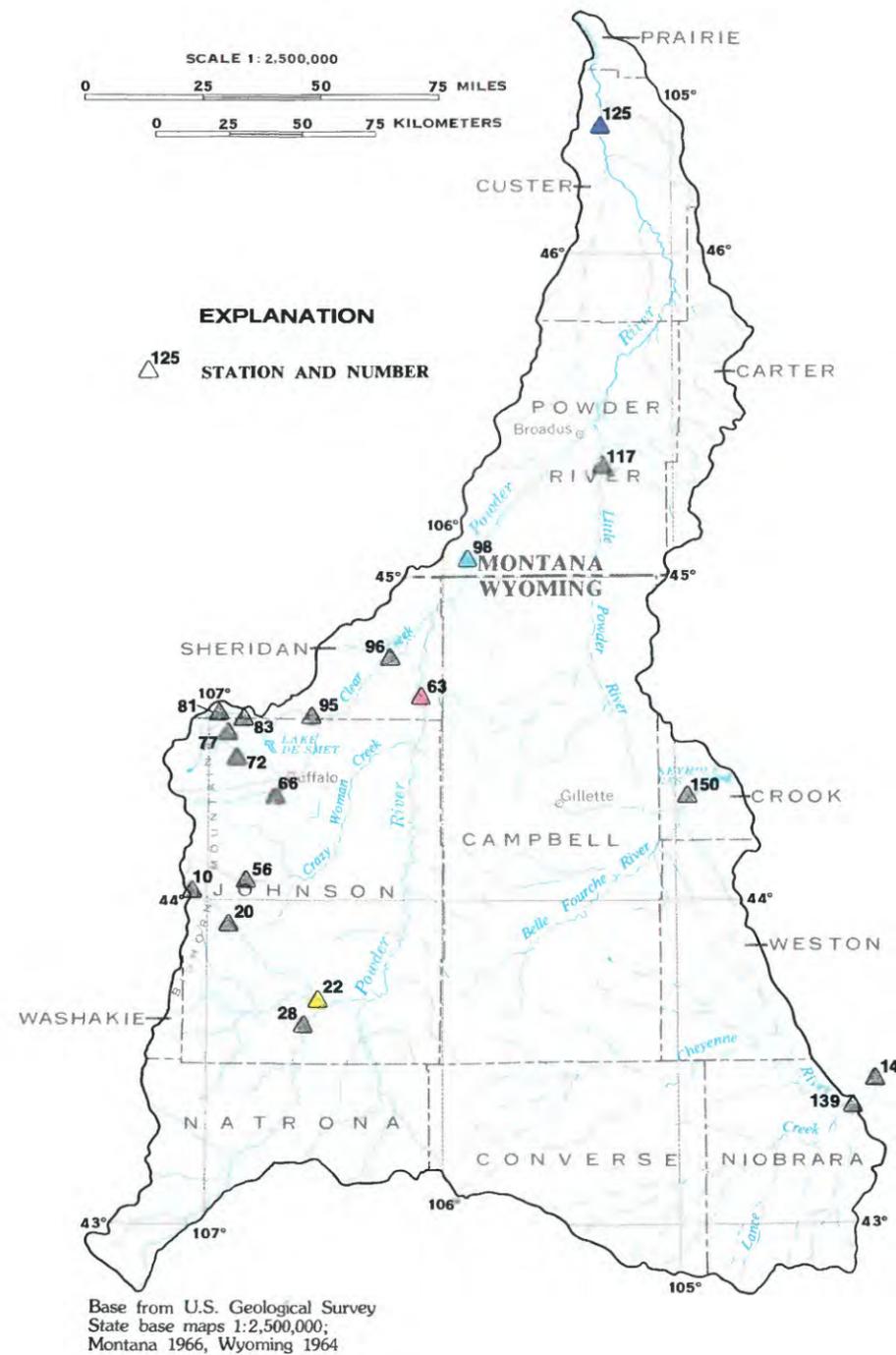


Figure 6.3-1 Seven-day low flow frequency curves for stations on the mainstem of the Powder River.

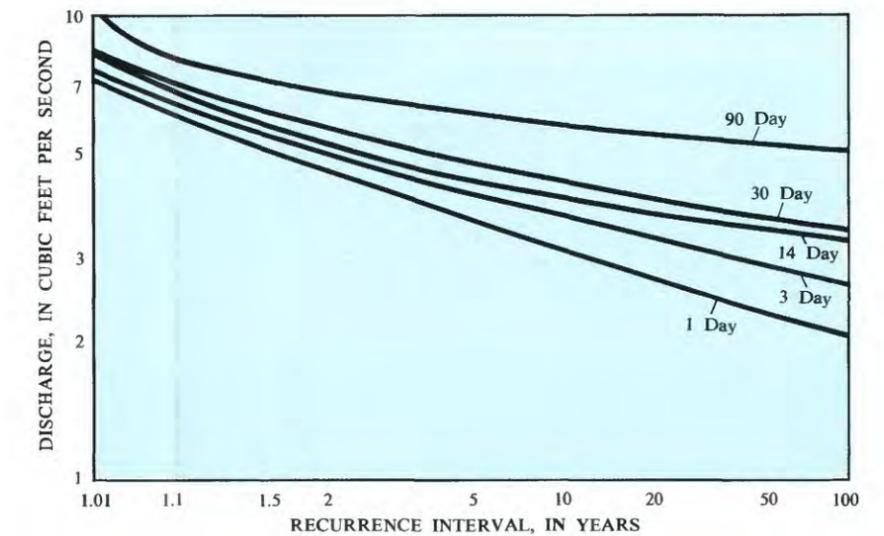


Figure 6.3-2 Low-Flow characteristics of station 81, North Piney Creek near Story, Wyoming.

6.0 SURFACE-WATER QUANTITY--Continued

6.4 Floods

6.4.1 Occurrence

Climatic Factors Determine Flood Flows

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

Mountain streams flood mainly in spring or early summer. The magnitude of the flood depends on the volume and water content of snow accumulated during the preceding winter, the rate of increase in air temperature, and the quantity of spring rain. A gentle, warming trend in the spring causes a prolonged runoff, with stream channels full, but seldom overflowing. A sudden, unseasonably warm spell, however, with temperatures at night near or above freezing, can cause a short-duration runoff of much greater magnitude. Extremely large flows result when there is a combination of deep snowpack, warm air, and rain.

Plains streams 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 in spring, summer, or fall 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 locally severe.

Significant floods occur somewhere in Area 50 nearly every year. It is rare to have severe flooding simultaneously on all major streams in the area. However, such flooding resulted from intense, area-wide rainfall, preceded by greater than average runoff due to snowmelt and greater than average precipitation in May 1978 (Parrett and others, 1978; Parrett and others, 1984). The floods of May 1978 on the smaller drainage basins generally were not exceptionally large, but the cumulative effect produced floods that were the highest of record for many stations on the Powder, Cheyenne, and Belle Fourche Rivers (fig. 6.4.1-1).

The term "flood" has many definitions, most of which refer to flows greater than some base level-bankful flow, for example. For statistical purposes, the annual maximum flow, or peak discharge, is a flood, whether or not the water overflowed the stream banks. A comparison of the seasonal distribution of annual peak discharges on mountain and plains streams is shown in figure 6.4.1-2.

The flood hydrographs in figure 6.4.1-3 illustrate the differences in runoff characteristics of mountain

and plains streams. The hydrograph for the mountain stream shows a gradual increase in daily discharge, followed by a gradual decrease. Daytime thawing and nighttime freezing of snowpack commonly superimpose diurnal variations on the general trend. The hydrograph for the plains stream (a large, ephemeral stream) shows more rapid increase and decrease in flow and a shorter duration of flow. Floods caused by thunderstorms on small, ephemeral streams usually peak quickly and last from a few hours to a few days. Practically all existing or planned coal mines in the area are in the plains areas.

In general, the relative magnitude of floods varies inversely with drainage area: the larger the area, the smaller the proportion of the area affected by snowmelt, by local thunderstorms, or by the most intense precipitation of large storm systems. Unit 100-year floods were calculated to illustrate this relationship (fig. 6.4.1-4). The unit 100-year flood is calculated by dividing the 100-year flood (1 percent exceedance probability in any year) by the drainage area.

The potential for damage to structures by floods is greater in or near the mountains than on the plains. Mountain roads and bridges commonly need to be constructed in locations where occasional flooding is unavoidable. Most towns in the area are located in the plains, except for Buffalo, which is near the base of the mountains. Towns commonly are established on or near a stream, in order to have an easily accessible water supply. Compared with the other towns the City of Gillette is a relatively large population center. Located near the head of a minor plains stream, some parts of Gillette are flooded by occasional fast-melting snow or by intense thunderstorms. Much of the flooding is caused by local drainage limitations. Elsewhere in the plains area, flash flooding generally causes loss of livestock and destruction of stock ponds; severe flooding may wash out roads and bridges or damage farmlands and pastures by erosion or by deposition of sediments. Flood damage in the plains areas sometimes is increased because of backwater and inundation caused by long fills used for approaches to bridges.



Figure 6.4.1-1 Flood of May 1978, Belle Fourche River near Moorcroft, Wyoming. (View is downstream from Interstate Highway I-90).



Base from U.S. Geological Survey State base maps 1:2,500,000; Montana 1966, Wyoming 1964

EXPLANATION

- MOUNTAIN AREA
- PLAINS AREA
- STATION AND NUMBER
- * PHOTO SITE

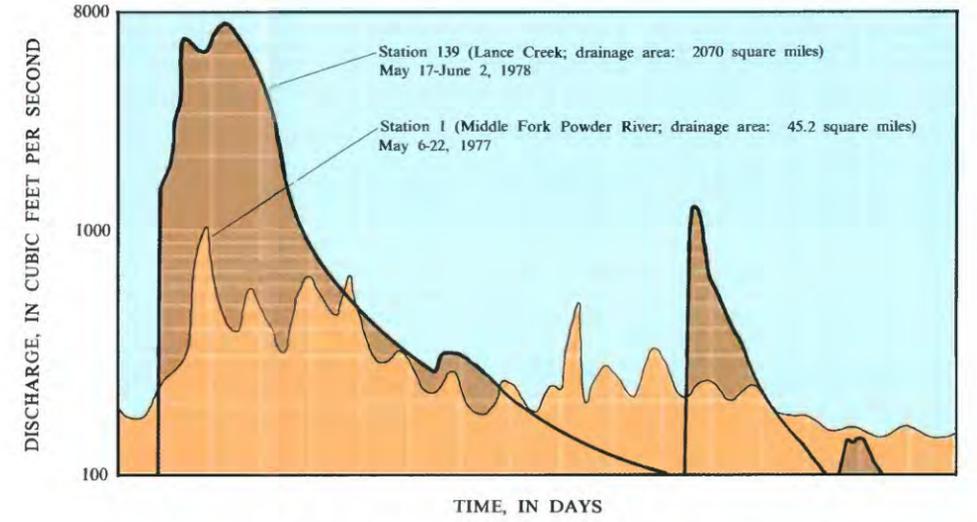


Figure 6.4.1-3 Flood hydrographs for a mountain stream (station 1) and a plains stream (station 139).

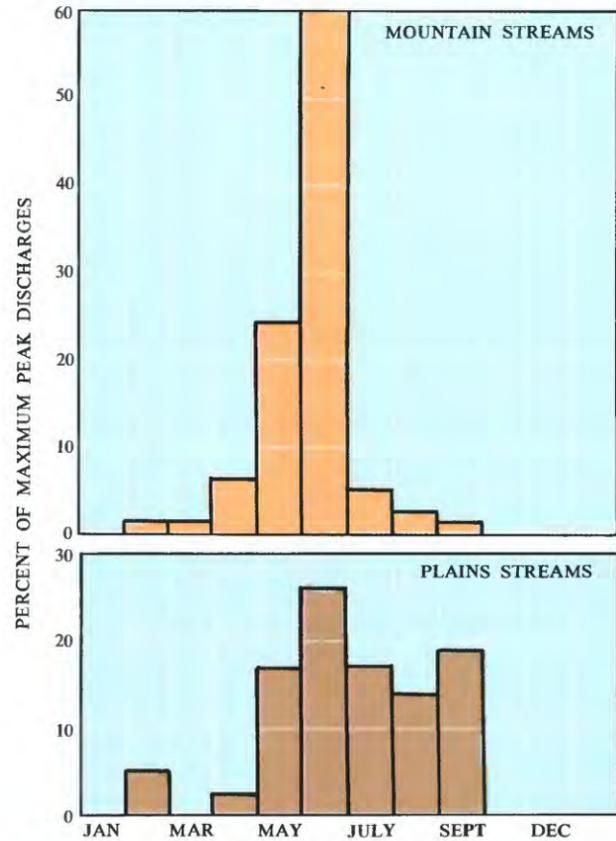


Figure 6.4.1-2 Seasonal occurrence of annual peak flows (after Lowham, 1976).

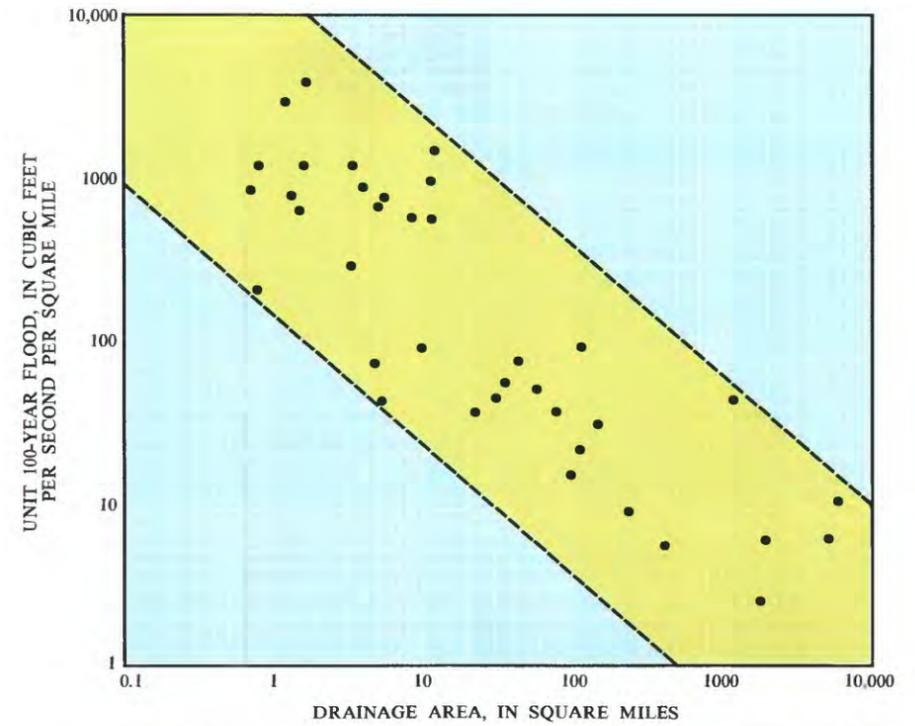


Figure 6.4.1-4 Generalized inverse relationship of relative magnitude of floods to drainage area for 37 stations in Area 50. Stations for both mountain and plains streams, perennial and ephemeral, are included.

6.0 SURFACE-WATER QUANTITY--Continued

6.4 Floods--Continued

6.4.2 Peak-Flow Frequency

100-Year Peak Discharges Can be Estimated

Values of the 100-year flood are available from flood-frequency data for 37 stations; graphs based on regionalized data may be used to estimate the 100-year flood on mountain and plains streams.

Thirty-seven streamflow stations in Area 50 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 6.4.2-1. 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. Another way of expressing it is the discharge that has a 1-percent chance of being equaled or exceeded in any given year. Floods of other frequencies, such as 10-year, 25-year, and so forth, are occasionally of interest; however, because most regulations concerning the effect of flooding are based on the 100-year flood, this discussion is limited to 100-year floods.

Equations or graphs for predicting the magnitude of the 100-year flood at ungaged sites are developed by regression techniques. Frequency curves for individual streamflow stations are first developed using the record of annual-maximum peak discharges at the stations. The methods used by the U.S. Geological Survey are those published by the U.S. Water Resources Council (1981). Values of discharge for the 100-year flood obtained from sufficiently long records at streamflow stations are used as the dependent variable in the regression analysis. Various basin and climatic characteristics are used as independent variables.

The graphs in figure 6.4.2-1 may be used to estimate the 100-year flood at ungaged sites in areas of corresponding color on the map. The boundaries shown on the map were modified from those developed by Lowham (1976). Somewhat more accurate estimates for sites in Montana may be obtained by using the equations developed by Parrett and Omang (1981), because they found that other independent variables, in addition to drainage area, improved the accuracy of the estimating equations. Hydrologists presently (1983) are revising the analyses for Wyoming, based on additional data obtained since the report by Lowham (1976) was prepared.

When an estimate of the 100-year flood is needed for a basin encompassing more than one colored area

on the map, an area-weighted average discharge needs to be used. This is done by: (1) Obtaining the discharge from each applicable graph, using the total drainage area; (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 25-year floods, for example, may be required for the design of diversion ditches. The reports by Lowham (1976) and Parrett and Omang (1981) contain graphs and equations for estimating floods of selected frequencies.

A special method applicable only to ephemeral streams with drainage areas less than 11 square miles was developed by Craig and Rankl (1978). The method is time-consuming, but is considered to be more accurate than the graphs in figure 6.4.2-1. Besides drainage area, three additional basin characteristics first need to be measured on topographic maps:

1. Basin slope, in feet per mile. Obtained by measuring the length, in miles, of all contours within the drainage boundary (100-foot intervals usually suffice); multiplying by the contour interval, in feet; and dividing by the drainage area, in square miles.
2. Maximum relief, in feet. The difference in altitude between the channel at the site of interest and the highest point in the basin.
3. Channel slope, in feet per mile. Determined from altitudes at points 10 and 85 percent of the distance along the channel from the site of interest to the drainage-basin divide.

Once the four independent variables have been determined, the nomograph in figure 6.4.2-2 can be used to estimate the 100-year peak discharge. The arrows, starting with drainage area at the bottom of the graph, indicate the sequence to follow.

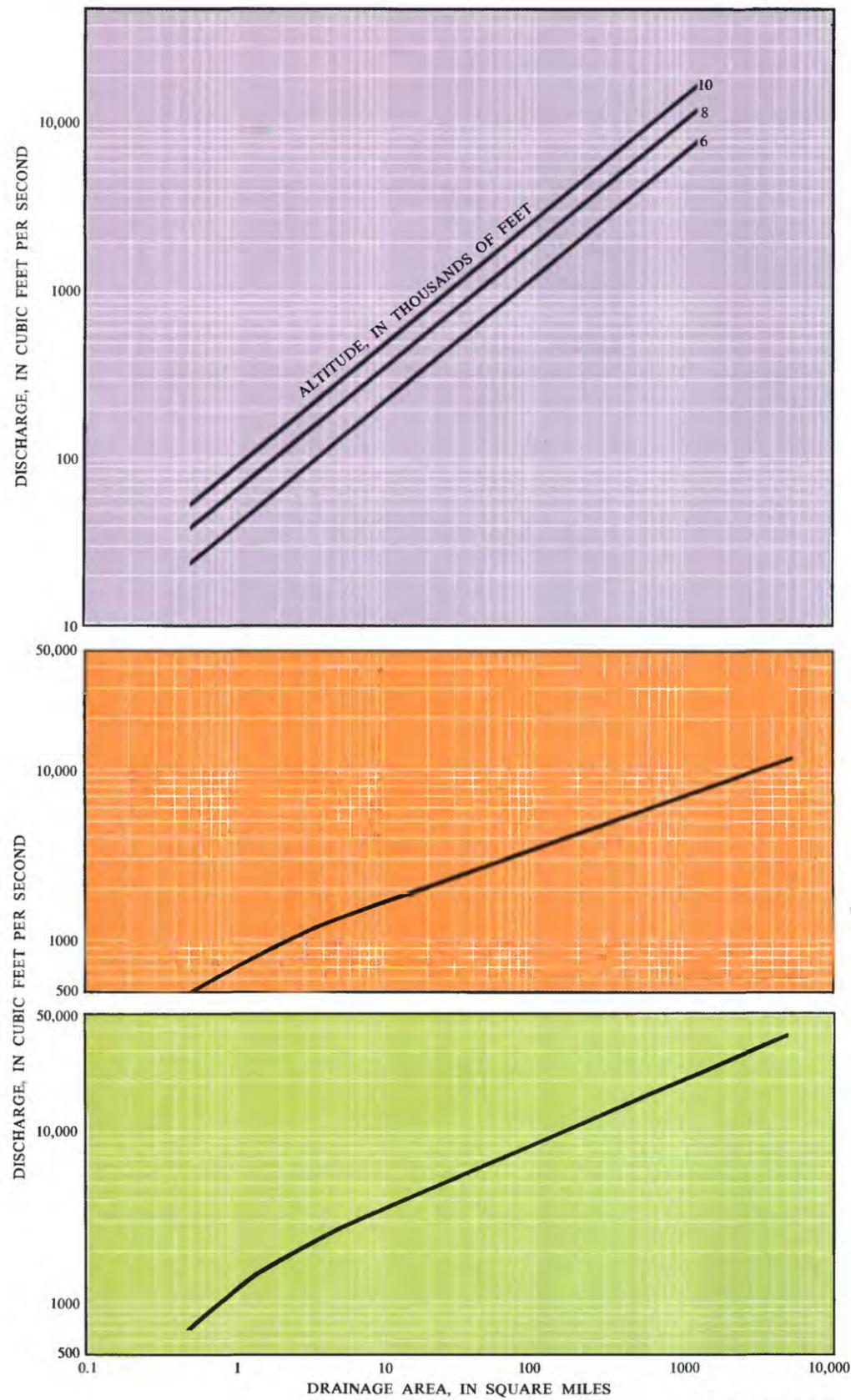
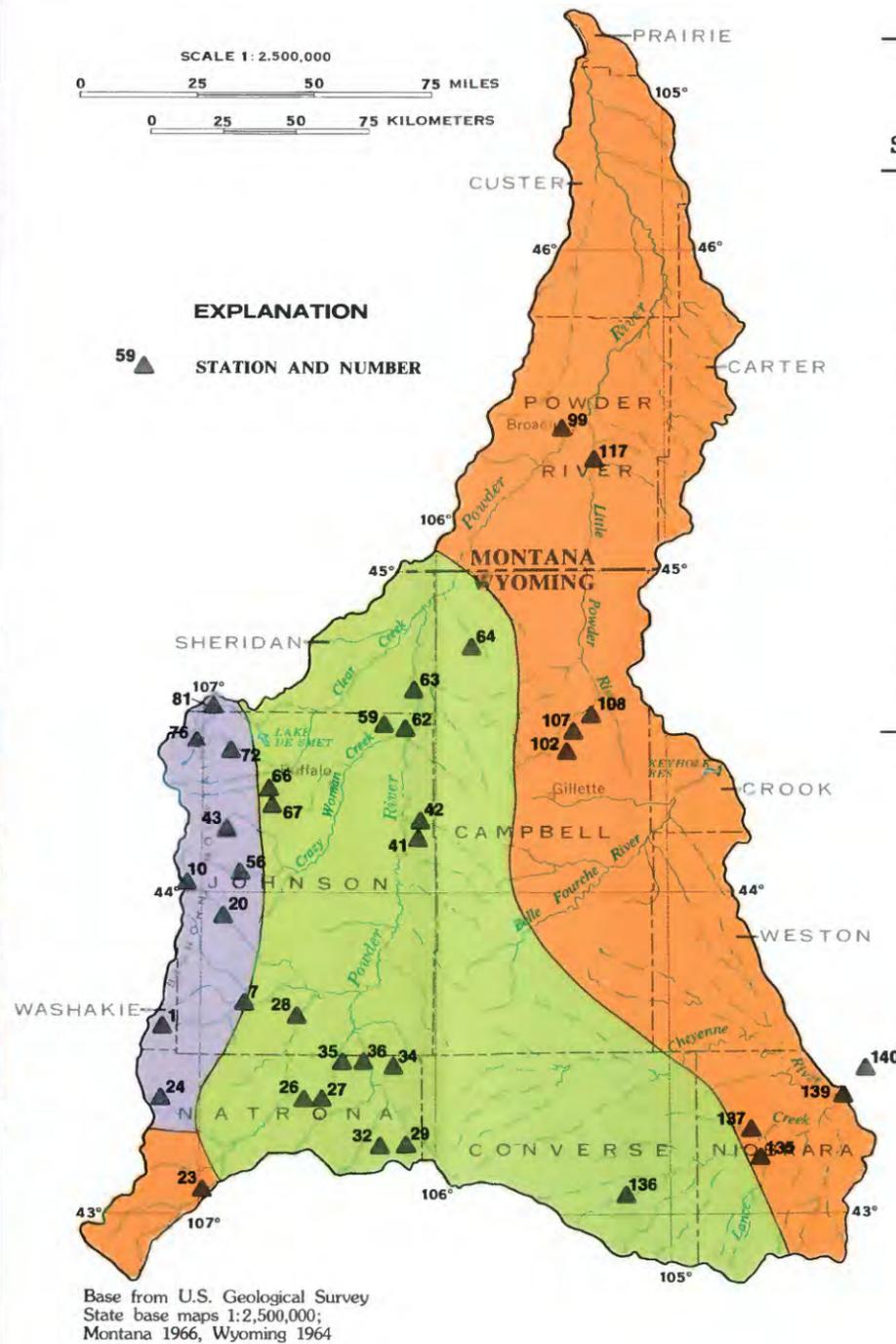


Figure 6.4.2-1 Relation of 100-year flood to drainage area for areas of corresponding color on map.

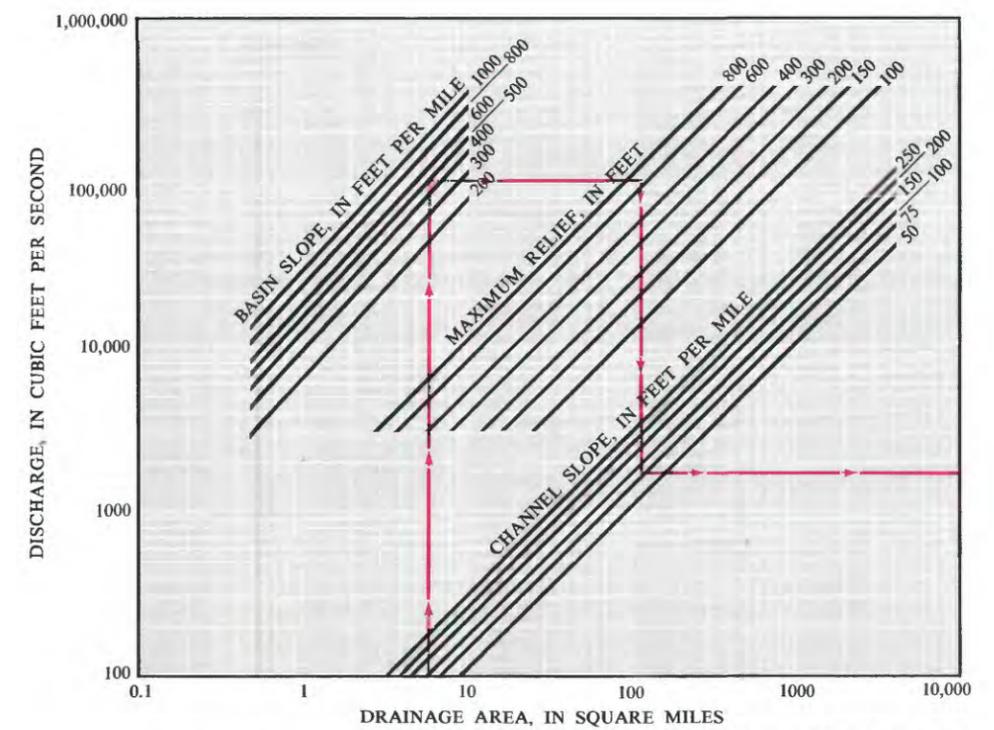


Base from U.S. Geological Survey
State base maps 1:2,500,000;
Montana 1966, Wyoming 1964

After Lowham (1976).

Table 6.4.2-1 100-year floods (P_{100}) for selected stations.

Station	Drainage area (square miles)	P_{100} (cubic feet per second)	Station	Drainage area (square miles)	P_{100} (cubic feet per second)
1	45.2	3,510	62	1.64	7,750
7	450	2,190	63	6,050	60,400
10	24.5	865	64	3.98	4,100
20	106	1,520	66	120	2,390
23	262	2,160	67	10.8	18,100
24	5.53	215	72	60.0	3,030
26	1.53	1,130	76	33.6	1,430
27	1.34	1,230	81	36.8	1,990
28	1,150	52,100	99	10.2	887
29	8.29	5,470	102	.81	163
32	5.44	4,840	107	3.45	1,070
34	11.4	7,520	108	.72	697
35	.80	1,130	117	1,970	4,220
36	1.60	2,300	135	1.20	4,530
41	10.8	12,500	136	112	10,200
42	151	4,490	137	5.10	4,030
43	5.08	359	139	2,070	11,000
56	82.7	3,050	140	5,270	28,900
59	3.32	4,790			



After Craig and Rankl (1978, p. 38)

Figure 6.4.2-2 Relation of 100-year peak discharge to drainage area, basin slope, maximum relief, and channel slope, for basins smaller than 11 square miles.

6.0 SURFACE-WATER QUANTITY--Continued

6.4 Floods--Continued

6.4.3 Hydrographs--Small Streams

Hydrographs Available for Small Ephemeral Streams

Rainfall-runoff data are available for six ephemeral streams with drainage areas smaller than 10 square miles; also, a method is available for preparing synthetic hydrographs for specified peak discharges.

Real or synthetic hydrographs of reliable accuracy for small streams commonly are needed in planning and design. Although such data are scarce, both types of hydrographs are available for the Wyoming part of Area 50. The hydrographs are a product of a study of runoff in small ephemeral streams in Wyoming (Craig and Rankl, 1978). Hydrograph data collected in the study by Craig and Rankl were compiled by Rankl and Barker (1977). Their report includes a tabulation of precipitation and discharge in 5-minute increments for 392 storms in 22 drainage basins. Six of the basins are in Area 50 (see fig. 6.4.3-1):

Station number	Drainage area (square miles)	Number of hydrographs
26	1.53	21
27	1.34	21
32	5.44	17
35	.80	24
59	3.32	12
137	5.1	25

Craig and Rankl (1978) also developed a dimensionless hydrograph that defines the characteristic shape of flood hydrographs for small ephemeral streams in Wyoming. The hydrograph is a composite of 298 real hydrographs for 28 small basins. Hydrographs synthesized from the dimensionless hydrograph were compared with corresponding real hydrographs for numerous other small basins in Wyoming, New Mexico, and Arizona. The comparisons were excellent in most instances. Although the dimensionless hydrograph was not tested with data for Montana streams, it may be used to synthesize hydrographs for streams in the Montana part of Area 50. The dimensionless hydrograph is shown in figure 6.4.3-2; the values of the discharge and time factors that form the hydrograph are listed in table 6.4.3-1.

The construction of a synthetic hydrograph requires estimates of two variables: peak discharge and a corresponding flow volume. The correlation of these two variables seems to be better for smaller

streams than for larger streams. The volume-discharge relation developed by Craig and Rankl (1978, p. 45-49) has a standard error of estimate of 55 percent, based on 105 hydrographs. The graph is shown in figure 6.4.3-3. If peak discharge is specified, the corresponding volume can be determined. Conversely, a peak discharge corresponding to a specified volume also may be determined from the graph. The frequency, or exceedance probability, of the dependent variable is not related to that of the independent variable. For example, if 1,000 cubic feet per second is the 100-year peak discharge (1 percent exceedance probability), the corresponding volume, 56 acre-feet (fig. 6.4.3-3) is not the 100-year volume. It simply is the volume associated with the 100-year peak discharge.

To determine plotting points (discharge, in cubic feet per second, and time, in minutes), multiply each value of the discharge factor (table 6.4.3-1) by the peak discharge, Q , and multiply each value of the corresponding time factor by the ratio of volume to discharge, V/Q . Construct the hydrograph by plotting and connecting the points as shown in the example (fig. 6.4.3-4).

The actual distribution of flow during a specified time, and hence the shape of the resulting hydrograph, depends on the distribution of precipitation on the basin and on the variation in the duration and rate of precipitation. Real hydrographs can have two or more peaks and can have runoff durations lasting much longer than those indicated by the synthetic hydrographs. For a given peak discharge and volume, however, Craig and Rankl (1978, p. 59) demonstrated that the fast-rising single-peak hydrograph is the most important type for evaluating possible backwater ponding at culvert sites. Although the experiments of Craig and Rankl were limited to the effects of culverts, the conclusion about hydrograph shape can apply to the hydraulic design of any structure--sediment ponds for example.

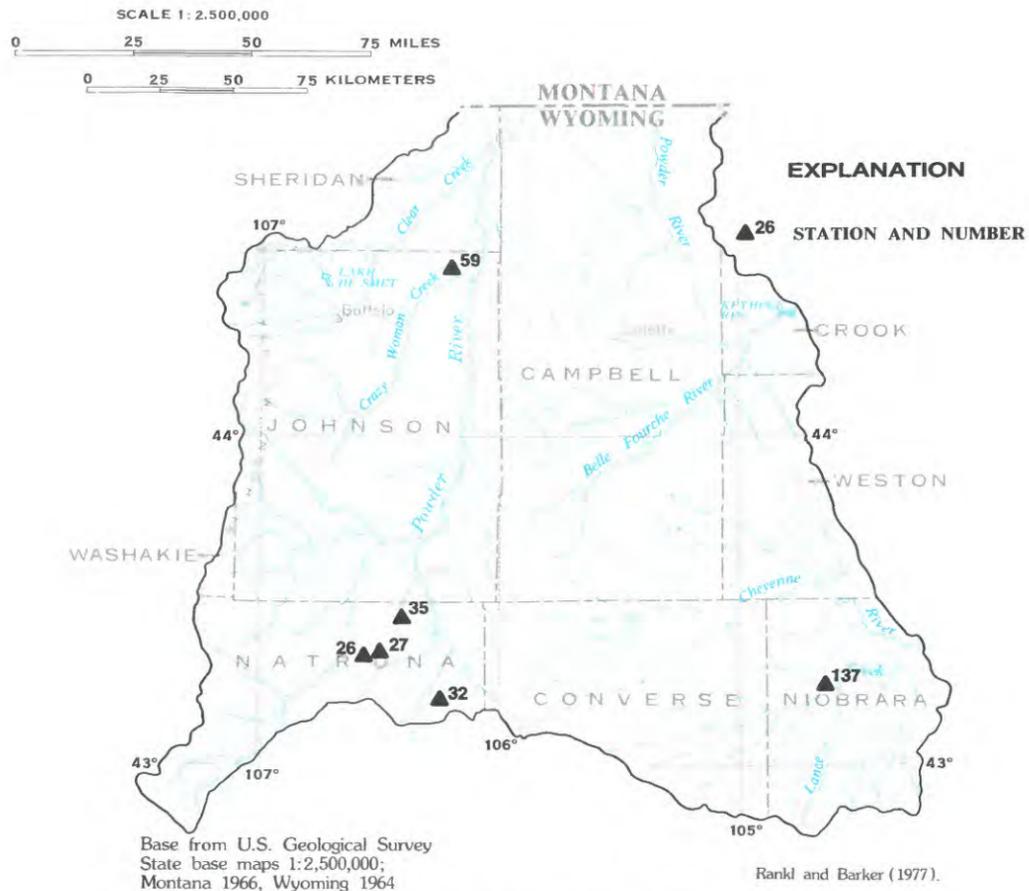


Figure 6.4.3-1 Location of sites on small ephemeral streams with published hydrograph data.

Table 6.4.3-1 Factors for calculating plotting points for synthetic hydrographs.

Discharge factor	Time factor
0	0
0.093	134.7
.217	224.5
.417	314.3
.817	449.0
.950	493.5
1.000	538.8
.983	583.7
.917	628.6
.633	808.2
.383	1,033
.200	1,347
.087	1,796
.033	2,245
.008	2,694
0	3,143

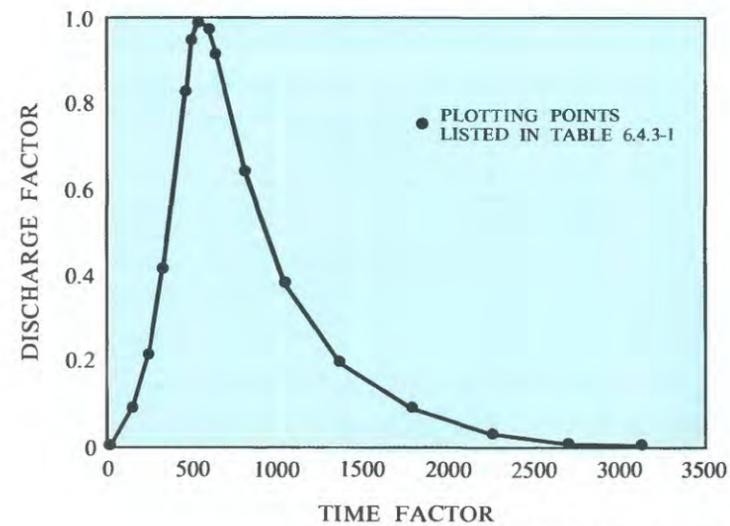


Figure 6.4.3-2 Dimensionless hydrograph for small plains streams.

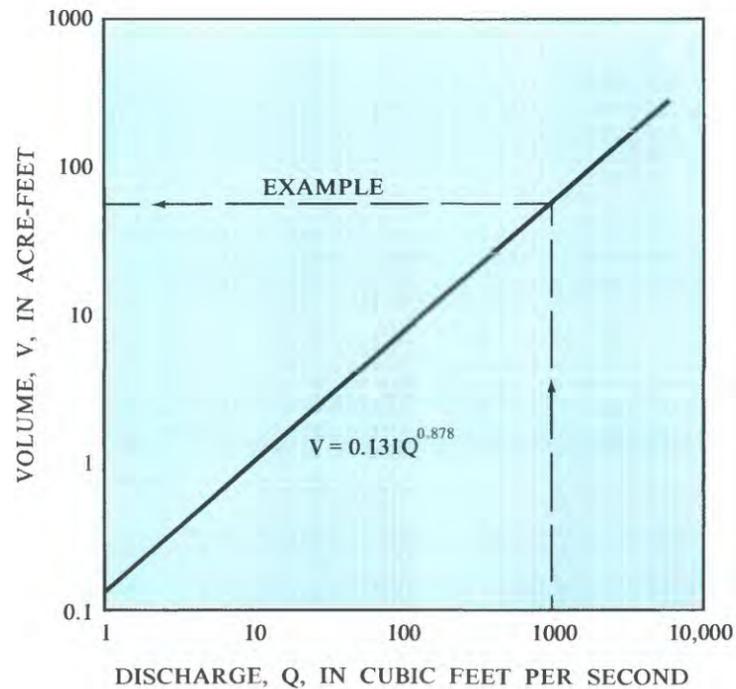


Figure 6.4.3-3 Relation of flood volume to peak discharge.

EXAMPLE:

CONSTRUCTION OF A SYNTHETIC HYDROGRAPH FOR A FLOOD WITH PEAK DISCHARGE (Q) OF 1000 CUBIC FEET PER SECOND

1. Corresponding volume (V) from Figure 6.4.3-3 = 56 acre-feet.
2. Ratio (V/Q) = 0.056
3. Hydrograph plotting points, using factors in table 6.4.3-1:

Discharge, in cubic feet per second (each discharge factor multiplied by Q)	Time, in minutes (each time factor multiplied by V/Q)
0	0
93	8
217	13
417	18
817	25
950	28
1000	30
983	33
917	35
633	45
383	58
200	75
87	101
33	126
8	151
0	176

4. Plotted hydrograph:

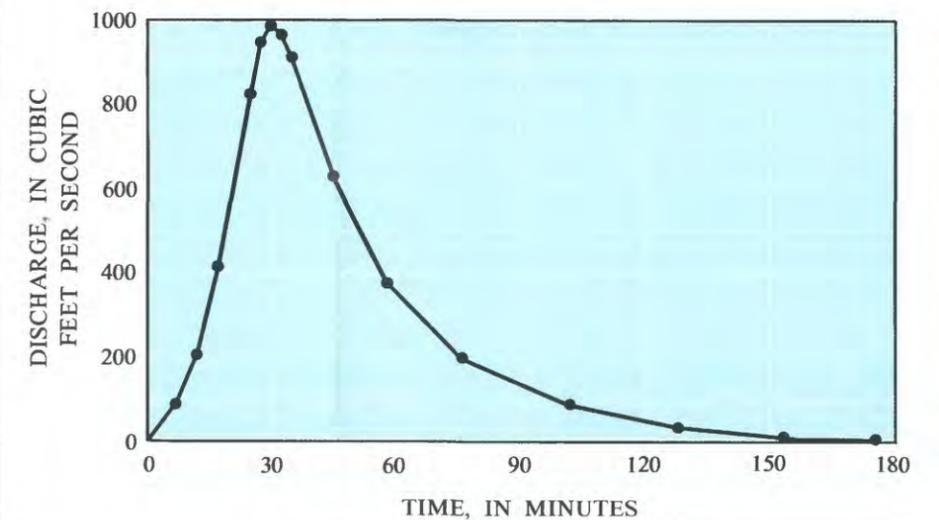


Figure 6.4.3-4 Example of construction of a synthetic hydrograph.

6.0 SURFACE-WATER QUANTITY--Continued

6.4 Floods--Continued

6.4.4 Flood-Prone Area Maps

Maps Available for Flood-Prone Areas

U.S. Geological Survey flood-prone area maps are available for the main stem of the Powder River and the City of Buffalo; National Flood Insurance Program maps also are available for a few communities and counties.

Flood-prone area maps have been prepared by the U.S. Geological Survey for 43 topographic quadrangles (scale, 1:24,000) in Area 50 (table 6.4.4-1 and fig. 6.4.4-1). In accordance with the recommendations contained in House Document 465, 89th Congress, hydrologists used information about depth of flooding at streamflow stations and other sites to delineate the boundaries of areas of potential flooding. The National Flood Insurance Act of 1968 required the Federal Insurance Administration (FIA) to identify areas subject to inundation by the 100-year flood (1-percent exceedance probability in any year); therefore, the Geological Survey delineated the boundaries of the 100-year flood on the maps. Because the nationwide task was to be accomplished in a short time, hydrologists used simplified procedures to extrapolate data from sites where flood depths were known to stream reaches where data about flood depths were lacking.

The flood-prone area maps prepared by the Geological Survey are not flood-insurance maps, but are intended to alert the public to areas of potential flooding. Black-and-white copies of the maps are available free of charge as follows:

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

Montana
Montana College of Mineral
Science and Technology
Butte, MT 59701

Telephone: (406) 496-4166

Under the National Flood Insurance Program, the FIA has prepared maps that are official documents for flood-insurance and other purposes, such as determining whether a proposed action by a Federal agency will occur in a flood-hazard area. Some of the FIA maps are based directly on Geological Survey flood-prone area maps; others are based on more detailed hydrologic investigations. FIA maps are available for the communities and counties listed below; the town of Edgerton, Wyo. is not presently (1983) participating in the National Flood Insurance Program.

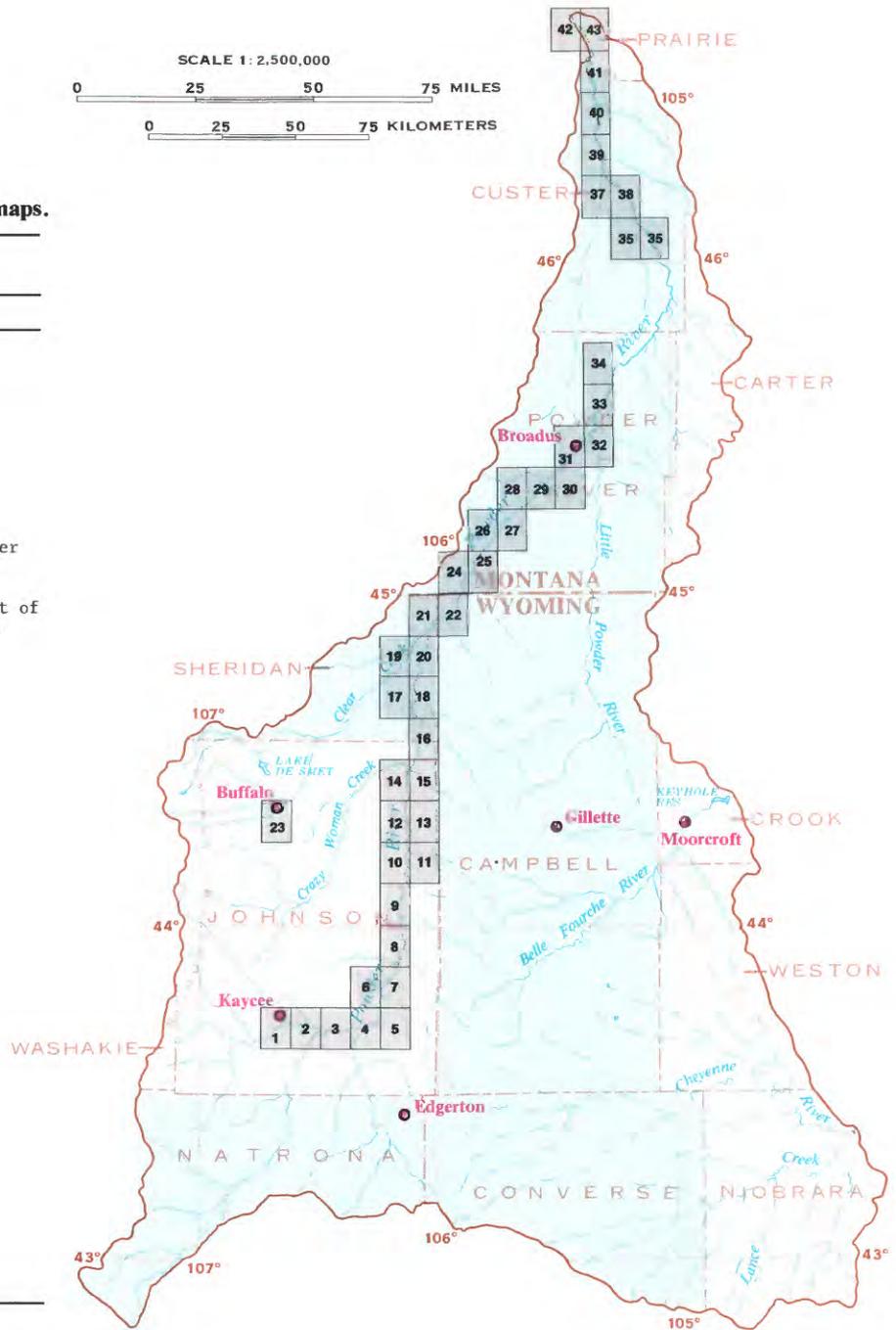
Communities	Counties (Unincorporated areas only)
Buffalo, Wyo.	Campbell (Wyo.)
Edgerton, Wyo.	Converse (Wyo.)
Gillette, Wyo.	Natrona (Wyo.)
Moorcraft, Wyo.	Sheridan (Wyo.)
Kaycee, Wyo.	Custer (Mont.)
Broadus, Mont.	Powder River (Mont.)

Copies of FIA maps are available from:

Federal Emergency Management Agency
National Flood Insurance Program
P. O. Box 34294
Bethesda, MD 20034
Telephone (800) 638-6620 (toll free)
(800) 492-6605 (toll free, Maryland only)
(301) 897-5900 (Washington, D.C.,
metropolitan area)

Table 6.4.4-1 List of U.S. Geological Survey flood-prone area maps.

Map no.	Map name
<u>Wyoming</u>	
1	Kaycee
2	Kaycee NE
3	Figure 8 Reservoir
4	Sussex
5	House Creek
6	Soldier Creek
7	Fort Reno
8	Hoe Ranch
9	Bowman Flat
10	Juniper Draw
11	Laskie Draw (a part of Juniper Draw map)
12	Somerville Flats West
13	Somerville Flats East (a part of Somerville Flats West map)
14	Mitchell Draw
15	Livingston Draw
16	Lariat
17	Arvada
18	Arvada NE
19	Fawn Draw
20	Cabin Creek SE
21	Cabin Creek NE
22	Black Draw
23	Buffalo
<u>Montana</u>	
24	Bradshaw Creek
25	Moorhead
26	Bloom Creek
27	Huckins School
28	Yarger Butte
29	Lonesome Peak
30	Eldon Mountain
31	Broadus
32	Monday Creek
33	Hawkey Creek
34	Cross S School
35	Bear Jaw Creek
36	Tepee Butte
37	Mizpah
38	Pennock Creek
39	Locate SE
40	Locate
41	Spring Draw
42	Zero
43	Zero NE



EXPLANATION

-  FEDERAL INSURANCE ADMINISTRATION MAP AVAILABLE FOR COMMUNITY INDICATED
-  FEDERAL INSURANCE ADMINISTRATION MAP AVAILABLE FOR COUNTY
-  U.S. GEOLOGICAL SURVEY FLOOD-PRONE AREA MAP AVAILABLE--
Map number corresponds to numbers in Table 6.4.4-1

Base from U.S. Geological Survey State base maps 1:2,500,000; Montana 1966, Wyoming 1964

Figure 6.4.4-1 Location of Federal Insurance Administration maps and U.S. Geological Survey flood-prone area maps.

6.0 SURFACE-WATER QUANTITY--Continued

6.5 Relationship to Ground Water

Most Base Flow is from Local Ground-Water Systems

Analysis of streamflow and water-level data indicates that discharge to streams from local ground-water systems is greater than discharge from a regional ground-water system.

Coal-bearing formations underlie the alluvium from the mouth of the Powder River to a point upstream from Sussex, Wyo. (station 39). Water levels in coal-bearing formations indicate that the downstream reach of the river should gain flow, at least as far upstream as Arvada, Wyo. (station 63). However, long-term records show that flow decreases even during winter months in the Powder River from Sussex, Wyo., to Locate, Mont. (fig. 6.5-1). The change in flow was determined by subtracting the average daily discharge at an upstream station from the average daily discharge at a downstream station. There is no diversion of water for irrigation outside the valley.

Annual and seasonal trends or changes in streamflow generally are masked by flow variability; therefore, hydrographs of average daily discharge are used to show flow conditions for the period of record. The hydrographs make it possible to determine long-term averages of base flow, streamflow losses, and changes in base flow due to evapotranspiration.

Another technique to determine the presence or absence of ground-water contribution to streamflow is to examine the shapes of flow-duration curves. The flow-duration curve has been described by Searcy (1959, p. 1) as "a cumulative frequency curve that shows the percent of time during which specified discharges were equaled or exceeded in a given period." Searcy (1959, p. 22) described the interpretation of the shapes of the flow-duration curves as follows: "A curve with a steep slope throughout denotes a highly variable stream whose flow is largely from direct runoff, whereas a curve with a flat slope reveals the presence of surface- or ground-water storage, which tends to equalize the flow." A change in slope of a flow-duration curve can provide as much or more information as the steepness or flatness of the slope. For example, a decrease in the slope in the lower part of the flow-duration curve may indicate a small quantity of ground-water discharge. An increase in slope indicates the depletion of surface- or ground-water storage.

Flow records of streams in the Powder River

Basin were analyzed using flow-duration curves and average-discharge hydrographs to determine the type of stream and the ground-water/surface-water interaction. The data in table 6.5-1 indicate that there is little base flow from ground water in streams originating in areas underlain by the Fox Hills-Wasatch sequence.

Flow-duration curves for Dead Horse Creek (station 42), the Little Powder River (station 117), and Black Thunder Creek (station 133) are shown in figure 6.5-2. The difference in flow for streams with base flow (station 117) and without base flow (stations 42 and 133) can be seen by comparing the flow-duration curves. Base flow in the nongrowing season was determined from the average-discharge hydrograph such as shown in figure 6.5-3 for the Little Powder River (station 117). The absence of measurable base flow in the Powder River and the presence of some base flow in the smaller streams in areas of coal-bearing formations indicate that discharge from the local ground-water systems is more important to base flow in streams than is a regional ground-water system.

The flow-duration curves (fig. 6.5-2) for North Fork Crazy Woman Creek (station 44) and Beaver Creek (station 6) show flow characteristics typical of granitic and limestone areas of the Bighorn Mountains. Granite stores and discharges less water than limestone; therefore, the duration curve for North Fork Crazy Woman Creek, which drains the granitic area, is steeper, indicating less base flow. Snow persists throughout the year in the higher parts of the Bighorn Mountains and contributes to the low flow of some streams. The flow-duration curve for Beaver Creek, which drains an area underlain by limestone, has a flatter slope, indicating more base flow. The streamflow across limestone rocks can vary significantly because of large sinks and springs. The Wyoming State Engineer's Office (1976, p. 95) reported a cumulative increase in flow of about 80 cubic feet per second in the principal streams crossing limestone on the east flank of the Bighorn Mountains in Wyoming.

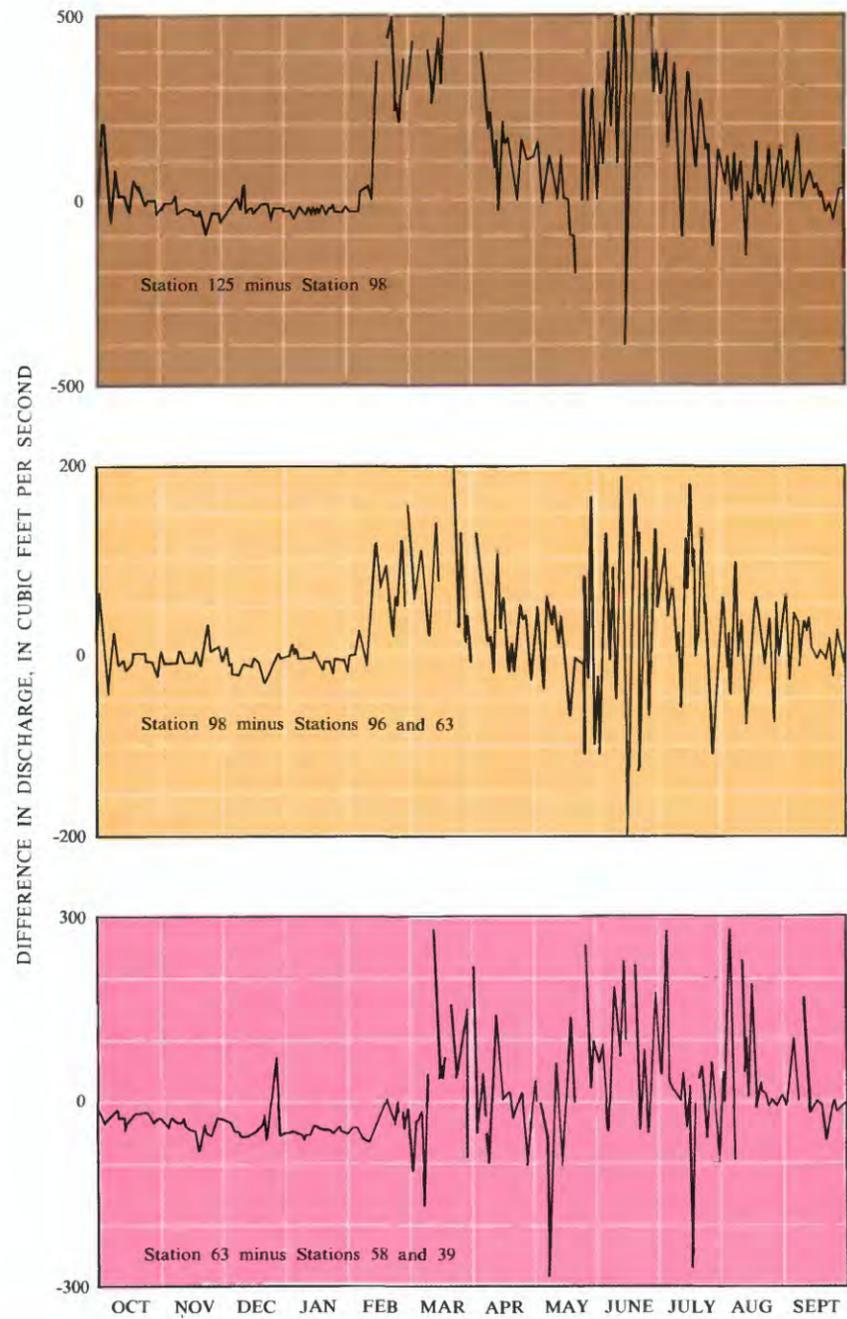


Figure 6.5-1 Differences in average discharge for the indicated reaches of the Powder River.

Table 6.5-1 Summary of ground-water/surface-water relationships of streams originating in areas underlain by the Fox Hills-Wasatch sequence.

Station number	Drainage area (square miles)	Ground water indicated	Base flow during nongrowing season (cubic feet per second)	Period of record
42	155	Yes	0	1971-77
112	1,230	Yes	1	1972-77
117	1,974	Yes	5	1957-72
133	535	No	0	1972-77
140	5,270	No	0	1948-77
150	1,670	Yes	0	1944-70

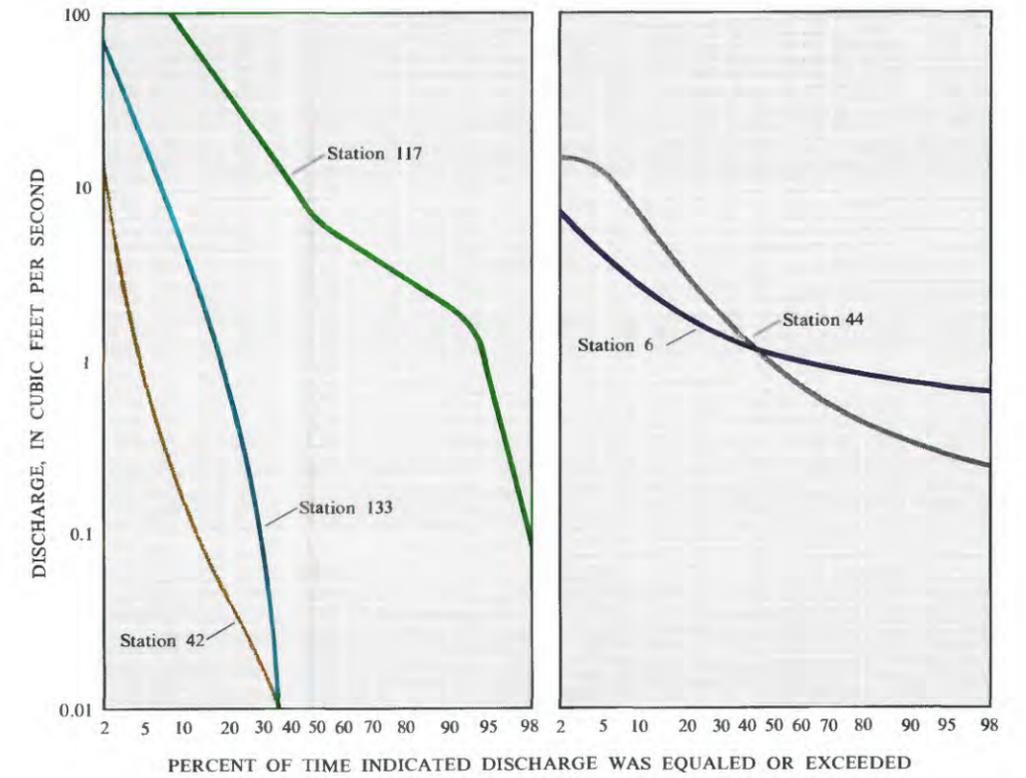
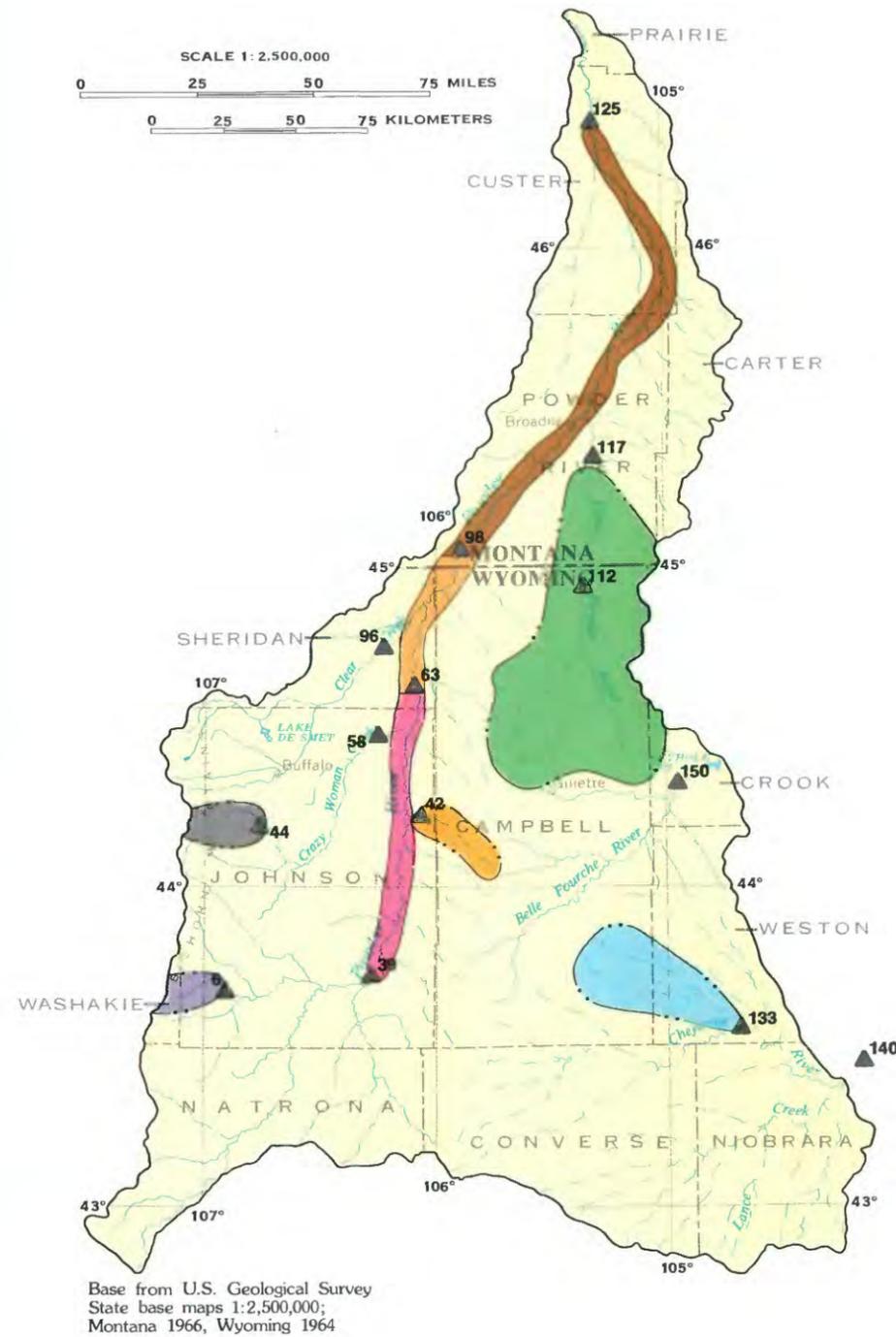


Figure 6.5-2 Flow duration curves at selected stations.

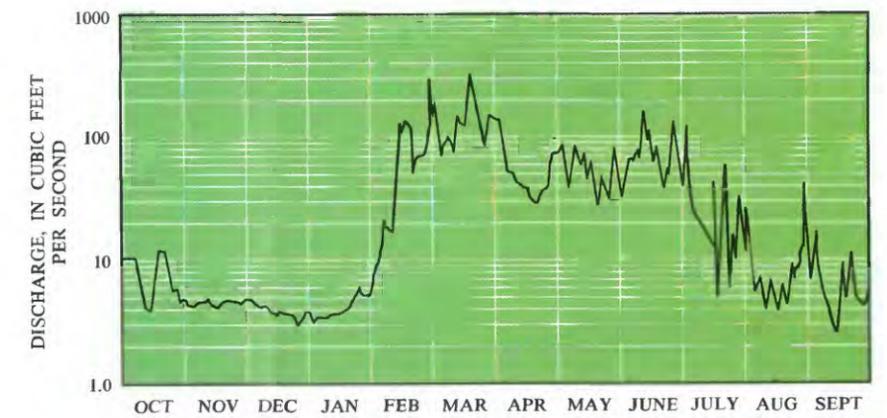


Figure 6.5-3 Average-discharge hydrograph for Little Powder River near Broadus, Montana (station 117) for the period 1958-72.

EXPLANATION

- STATION AND NUMBER
- DRAINAGE BOUNDARY
- RIVER REACH, DESCRIBED IN FIGURE 6.5-1

7.0 SURFACE-WATER QUALITY

7.1 Chemical Quality

7.1.1 Dissolved Solids

High Dissolved-Solids Concentrations Common in Most Streams

Average dissolved-solids concentrations at nearly all surface-water stations are significantly greater than the national drinking-water standard of 500 milligrams per liter. Nearly one-half of the stations have average and median concentrations exceeding 2,000 milligrams per liter. Streams draining the Bighorn Mountains have the lowest dissolved-solids concentrations.

Frequent high dissolved-solids concentrations are characteristic of most of the area's streams (fig. 7.1.1-1). The average dissolved-solids concentrations at most stations are significantly higher than the 500-mg/L (milligram per liter) national secondary drinking-water standard recommended by the U.S. Environmental Protection Agency (1979). Nearly one-half of the stations have average and median dissolved-solids concentrations greater than 2,000 mg/L. Two stations have maximum dissolved-solids concentrations greater than 7,000 mg/L. The highest determined dissolved-solids concentration at any of the area's surface-water stations was 7,870 mg/L (station 141 in the Belle Fourche basin). In contrast, many streams in the Eastern States have much lower dissolved-solids concentrations. For example, many of the streams in central West Virginia, a coal-mining area, have average dissolved-solids concentrations of less than 100 mg/L, and nearly all have dissolved-solids concentrations of less than 500 mg/L (Ehlke and others, 1982).

An important exception to the generally high dissolved-solids concentrations in the area's streams is evident at stations 22, 74, 75, 95, and 96 in the Powder River Basin. These stations are on streams that drain the Bighorn Mountains. Mountain streams are the source of the area's least mineralized water. They are important not only for the quality but also for the quantity of water they provide. The water from these streams is used primarily for irrigation but also provides important trout fisheries. However, Buffalo obtains its water from one of these mountain streams.

Another characteristic of the area's streams is the wide range of dissolved-solids concentrations at a station. The streams at some stations have a tenfold difference between minimum and maximum concentrations. Station 111 on the Little Powder River has a twentyfold difference between the minimum (222 mg/L) and the maximum (4,450 mg/L) analyzed dissolved-solids concentrations.

Dissolved-solids concentrations generally vary inversely with stream discharges. (See Rucker and DeLong, 1984.) The wide range in dissolved-solids concentrations at a station is primarily due to the wide range in stream discharges common in the area's streams.

Although the Little Powder, Belle Fourche, and Cheyenne are called rivers and have relatively large drainage areas (the size of Maryland or Rhode Island), they often have less streamflow than the use of the word "river" would imply. Most of the year these rivers could be stepped across without getting one's feet wet. During such low flows, the dissolved-solids concentrations are high. However, during periods of infrequent high flow, these streams do resemble rivers and have relatively low dissolved-solids concentrations. As a result, if a reservoir is constructed, the water in the reservoir would have a much lower dissolved-solids concentration than the average dissolved-solids concentration of the upstream stations would indicate. This is because concentrations of incoming water tend to be discharge-weighted, with more weight given to the larger volumes of water entering the reservoir during periods of high flow with low dissolved-solids concentrations than to smaller volumes entering during periods of low flow with high dissolved-solids concentrations.

Discharge-weighting may be explained by a hypothetical example. Imagine a stream flowing into an empty reservoir for 2 days. On the first day 1 volume enters the reservoir with a dissolved-solids concentration of 1,000 mg/L. On the second day 9 volumes of water entered the reservoir with a dissolved-solids concentration of 200 mg/L. On a "time-weighted" basis the average dissolved-solids concentration of the stream is $(1,000 + 200) \div 20$, or 600 mg/L. However, this would not be the concentration of the water in the reservoir. The concentration must be computed with a "discharge-weighted" average. Ten volumes entered the reservoir: 1 volume at 1,000 mg/L dissolved solids and 9 volumes at 200 mg/L dissolved solids. Therefore, the average dissolved-solids concentration in the reservoir would be:

$$\frac{(1 \text{ volume} \times 1,000 \text{ mg/L}) + (9 \text{ volumes} \times 200 \text{ mg/L})}{(10 \text{ volumes}), \text{ or } 280 \text{ mg/L}}$$

This discharge-weighting effect of Keyhole Reservoir on the Belle Fourche River explains why the dissolved-solids concentrations are less downstream from the reservoir (station 153) than upstream from the reservoir (station 141).

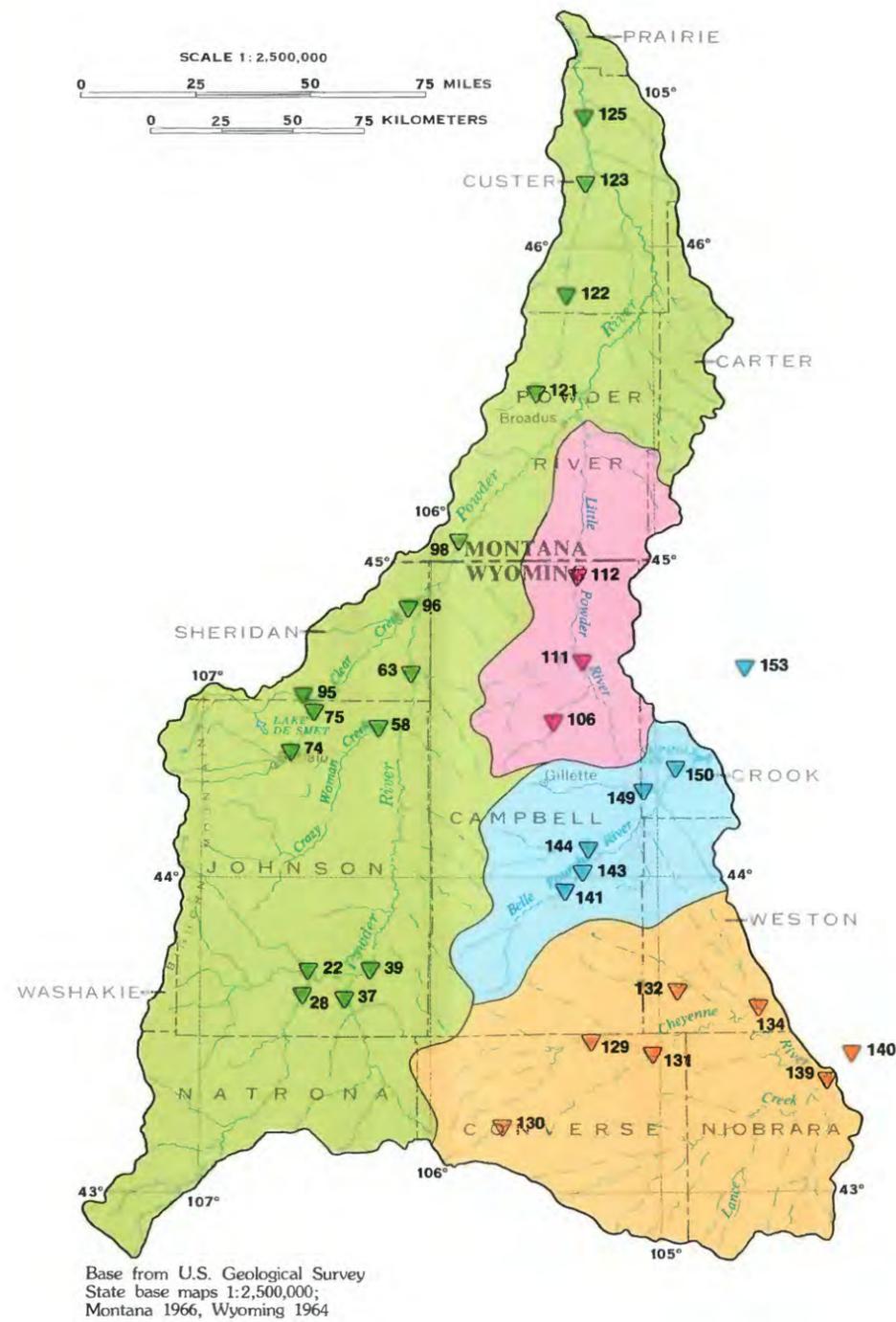
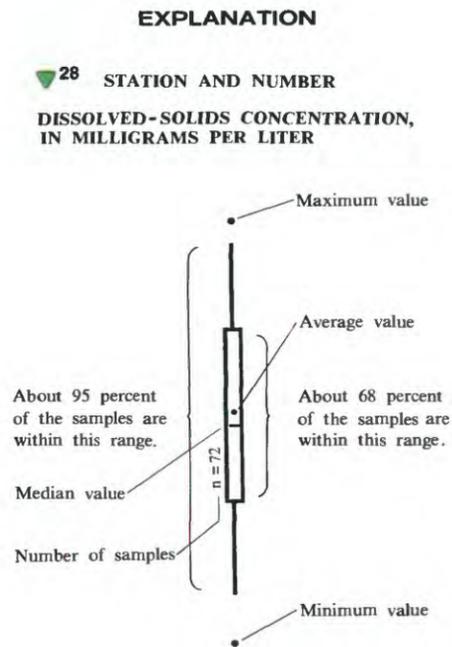
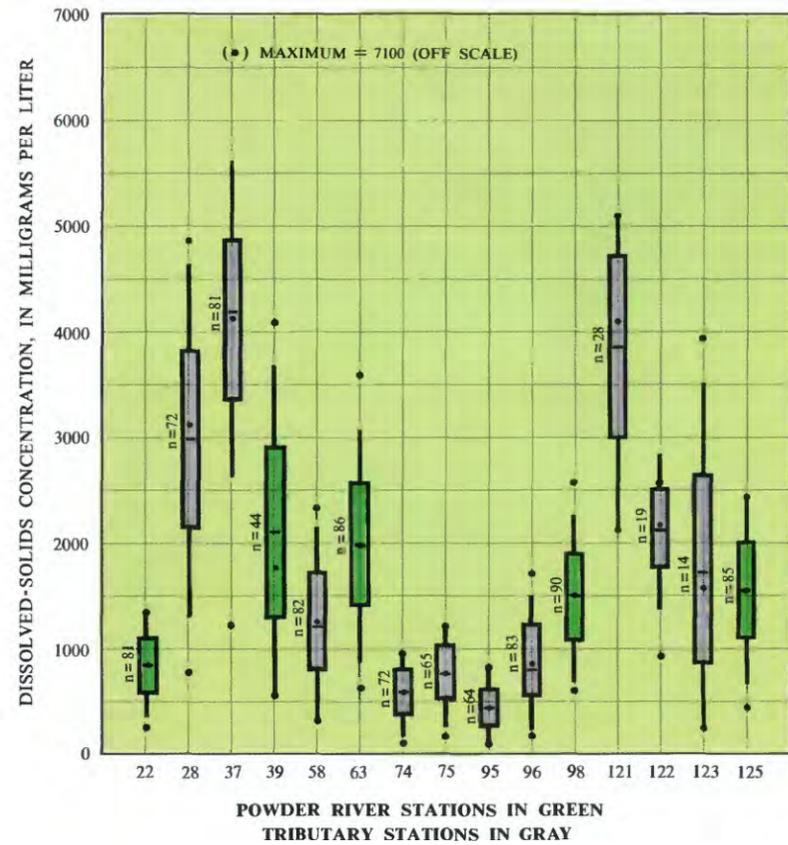
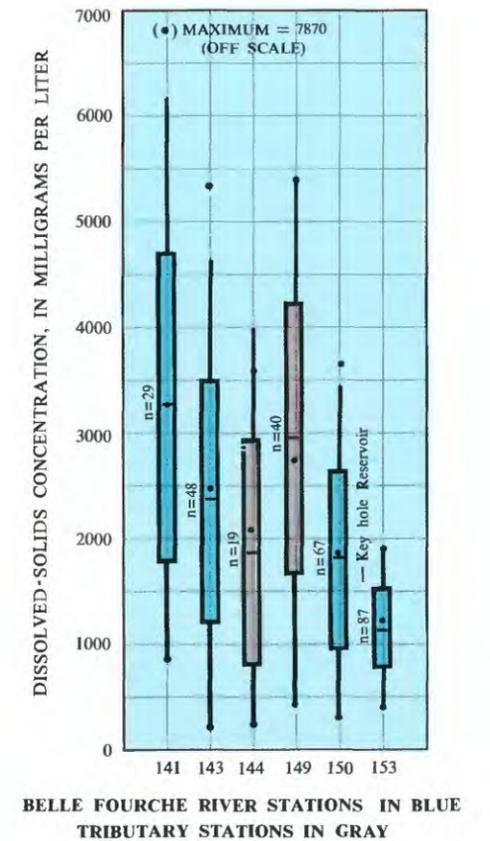
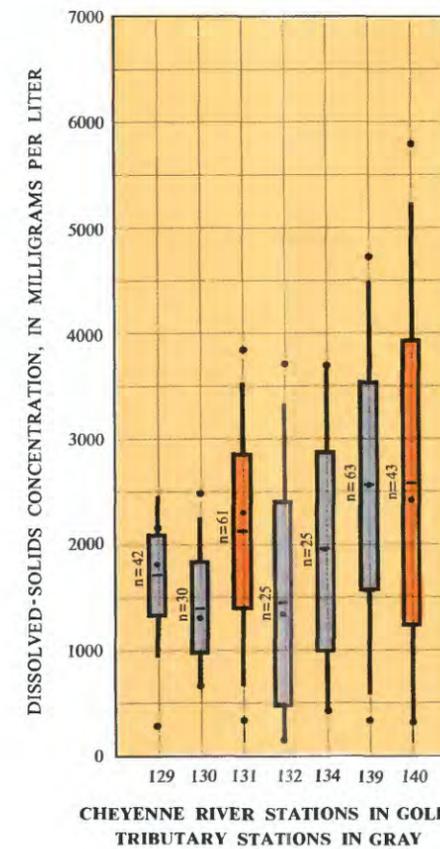
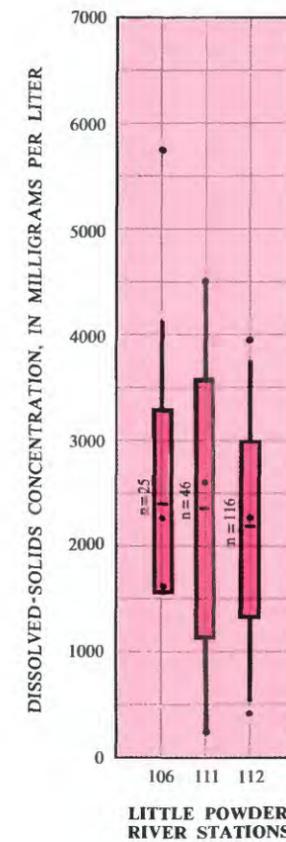


Figure 7.1.1-1 Dissolved-solids concentrations of the area's streams.



7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.2 Seasonal Variability

Dissolved-Solids Concentrations Vary Seasonally with Streamflow

Late spring and early summer snowmelt in the mountains increases streamflow in the mountain streams. Spring runoff and summer rainstorms are seasonal factors in streamflow for plains streams. Because dissolved-solids concentrations generally are inversely related to streamflow, dissolved-solids concentrations also vary seasonally.

Seasonal variations in streamflow account for much of the variability in stream quality. The seasonal pattern of streamflow and its effect on dissolved-solids concentrations are shown in figure 7.1.2-1 for a mountain stream (station 74), for the Powder River (station 125), and for a plains stream (station 139). The graphs are plots of average daily discharges overlaid with plots of the dissolved-solids concentrations from the 1976 monthly samples. The 1976 discharges (fig. 7.1.2-1) were slightly greater than average for the mountain stream and the Powder River station, but considerably less than average for the plains stream station.

Snowmelt from the heavy snowpack that accumulates in the mountains during the fall, winter, and spring flows into the mountain streams during May, June, and July, greatly augmenting the base flow of these streams as shown by the 1976 hydrograph of station 74. Because snowmelt dilutes the dissolved-solids concentration of the base flow, dissolved-solids concentration also varies seasonally.

The May, June, and July monthly samples at station 74 had dissolved-solids concentrations of 210, 306, and 217 milligrams per liter--considerably lower than in samples collected throughout the rest of the year. Although station 74 is used as an example for a mountain stream, it is actually representative of a mountain stream as it enters the plains. Some 13,000 acres are irrigated upstream from the site. Had data been collected upstream from the irrigated area, the dissolved-solids concentrations would have been less because irrigation return flow increases the dissolved-solids concentration of the stream.

The seasonal pattern of streamflow in the Pow-

der River (station 125) is affected by runoff from both mountains and plains areas. The early peaks in streamflow during February, March, and April are due to increased runoff from the plains area from snowmelt and rainstorms. Even though streamflow increased during this period, the dissolved-solids concentrations remained relatively large because the runoff from the plains generally has a larger dissolved-solids concentration than the runoff from the mountains. In May and June the snowmelt from the mountain tributaries (such as station 74) was the source for most of the streamflow in the Powder River; the dissolved-solids concentrations decreased.

Station 139 is used as an example of a plains stream of the area. Runoff per unit area in the plains is much less than the runoff per unit area of the mountains. The semiarid plains do not normally accumulate a significant snowpack. Some years there may be none. Also, a significant base flow is lacking in plains streams, in contrast to the mountain streams. The 1976 hydrograph shown for station 139 had an average discharge of 7.4 cubic feet per second, considerably less than the 31-year average discharge (25.9 cubic feet per second). However, for consistency, the 1976 hydrograph is shown. An average year would likely have greater spring runoff from snowmelt and (or) spring rainstorms and a larger volume of runoff from summer rainstorms than that which occurred during 1976. Nonetheless, periods of both no flow and low flow are frequent in the plains streams. The graph for station 139 demonstrates two of the hydrologic problems for the plains area: (1) Not much surface water is available, and (2) the dissolved-solids concentrations of the streams generally are high.

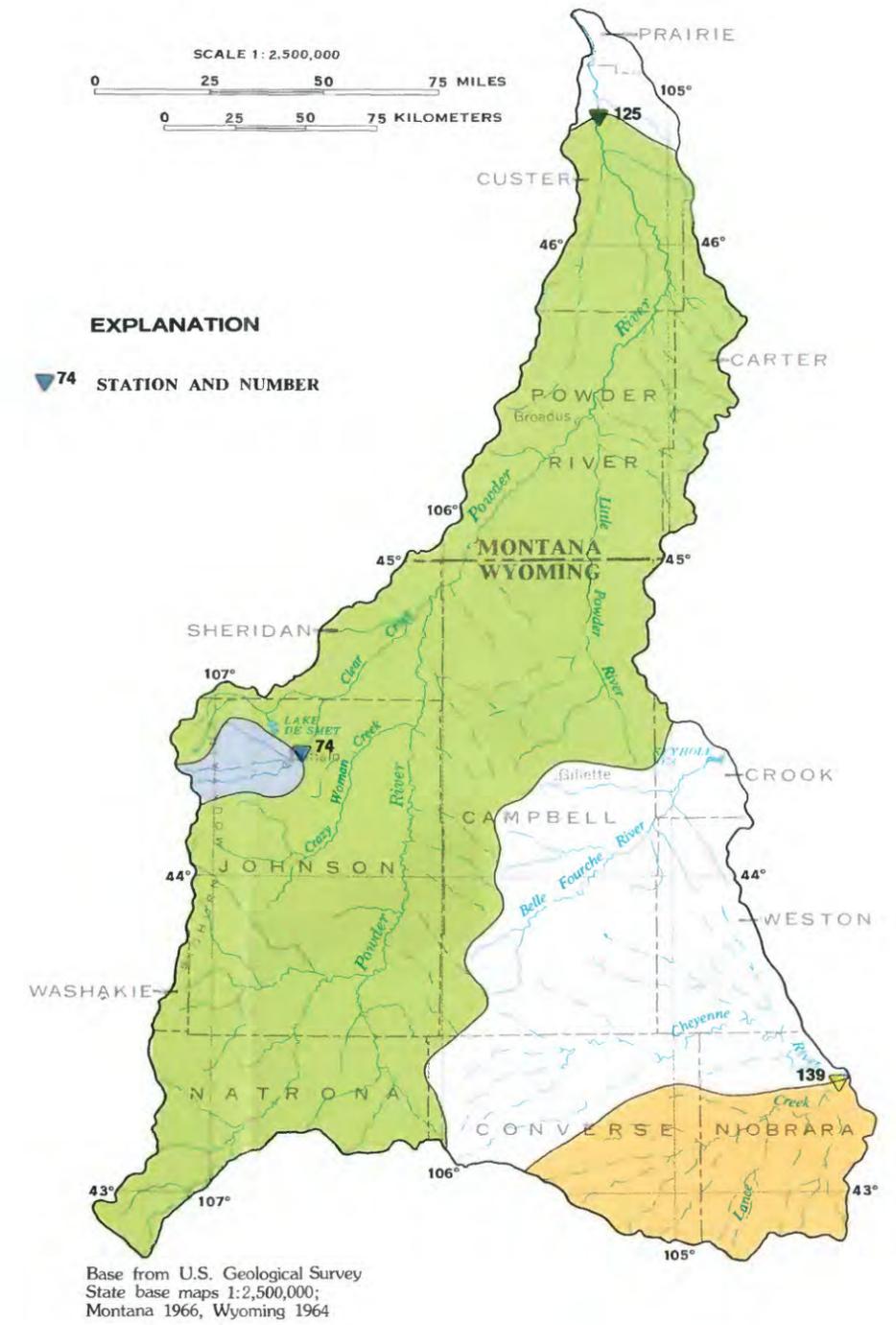
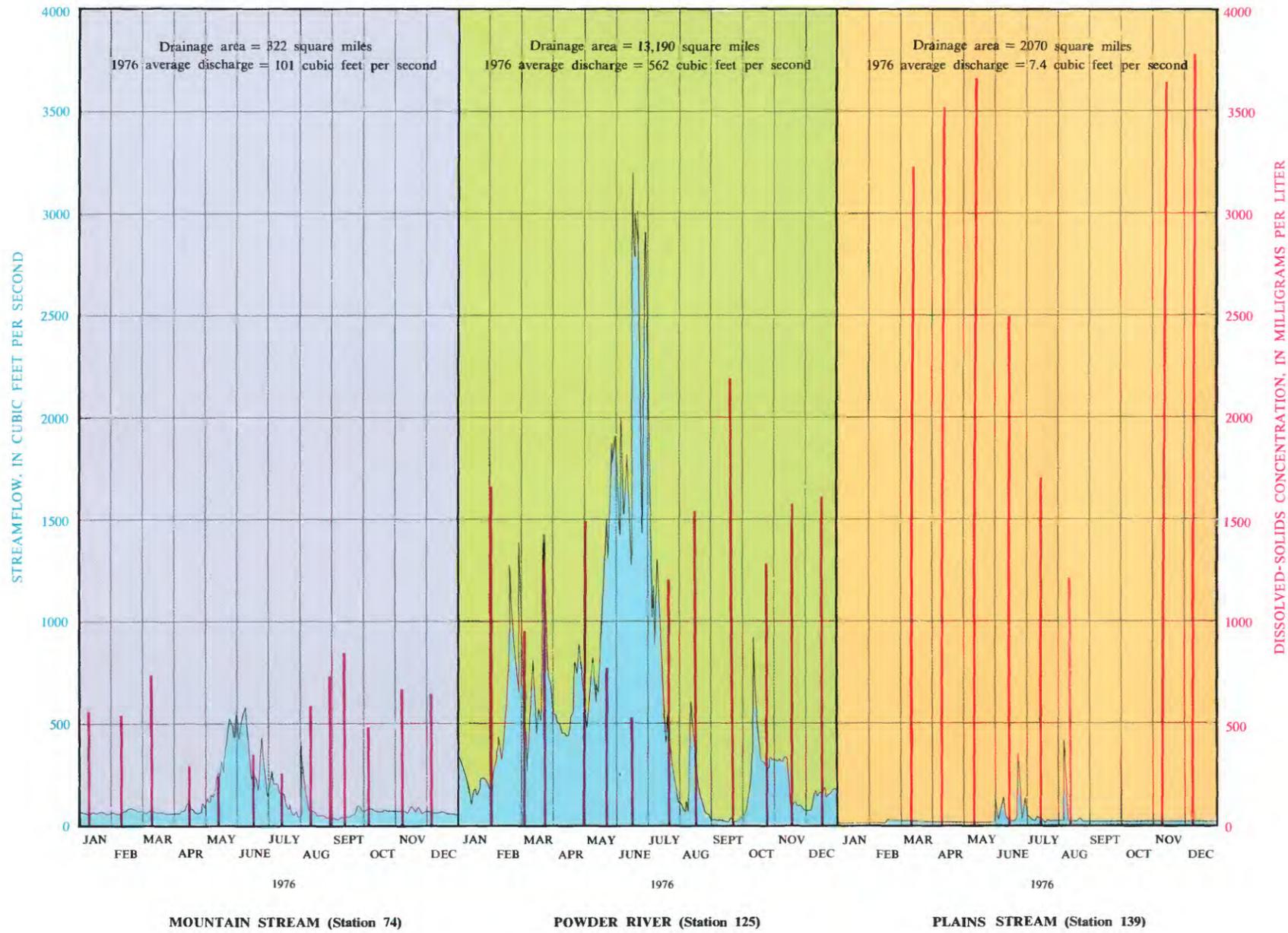


Figure 7.1.2-1 Seasonal variability of dissolved-solids concentrations and streamflow at three stations.

7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.3 Alkalinity

Alkalinity Concentrations Generally High Throughout the Area

Average alkalinity concentrations at all stations exceed 100 milligrams per liter; most stations have mean and median concentrations greater than 200 milligrams per liter. These high alkalinity concentrations reduce the risk of acid mine drainage.

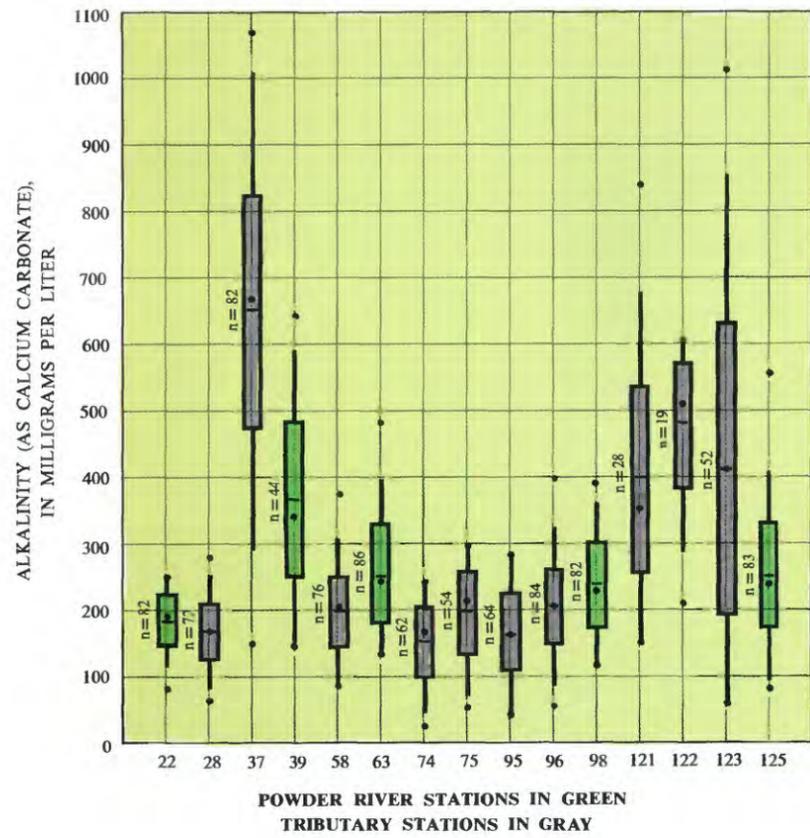
Alkalinity is a measure of the ability of water to neutralize an acid. In most natural waters alkalinity is almost entirely attributable to bicarbonate and carbonate ions. The concentrations of these ions in natural waters are extremely variable, ranging from almost none to greater than 1,000 mg/L (milligrams per liter). The principal sources of bicarbonate and carbonate ions in natural waters are soils and calcareous rocks such as limestone; the dissolution of atmospheric carbon dioxide also contributes some bicarbonate. Areas with thin soils and hard, crystalline bedrock are, therefore, more susceptible to damage from acid rain or acid mine drainage because the soils and surface waters do not have much capacity to neutralize acids.

The alkalinities of most of the area's streams are high. The mountain tributaries of the Powder River, however, have significantly lower alkalinities, especially during periods of high flow. All stations have average and median alkalinity concentrations in excess of 100 mg/L, as calcium carbonate (fig. 7.1.3-1). Alkalinity concentrations traditionally are reported as an equivalent concentration of calcium carbonate. Streams at most chemical-quality, surface-water sta-

tions in Area 50 have average alkalinity concentrations greater than 200 mg/L, as calcium carbonate. In comparison, the average alkalinity of streams in a coal-mining area of central West Virginia is 27 mg/L, with extremes ranging from 0 to 260 mg/L (Ehlke and others, 1982).

Acid mine drainage has not been a problem in Area 50, even though the ingredients required to produce sulfuric acid--pyrite (iron sulfide), moisture, and oxygen--are present. Any sulfuric acid produced by the oxidation of pyrite is neutralized by the high alkalinity of the area's streams.

Although acid mine drainage has not been a problem in the area's receiving streams, the Wyoming Department of Environmental Quality has identified a low-pH problem in soils. Acid production on some parcels of land reclaimed after coal mining has lowered the pH of the soil to the extent that revegetation efforts have been adversely affected (Dennis Fransway, written commun., 1983). The extent of this problem, however, is not well documented.



EXPLANATION

▼ 39 STATION AND NUMBER
ALKALINITY (AS CALCIUM CARBONATE),
IN MILLIGRAMS PER LITER

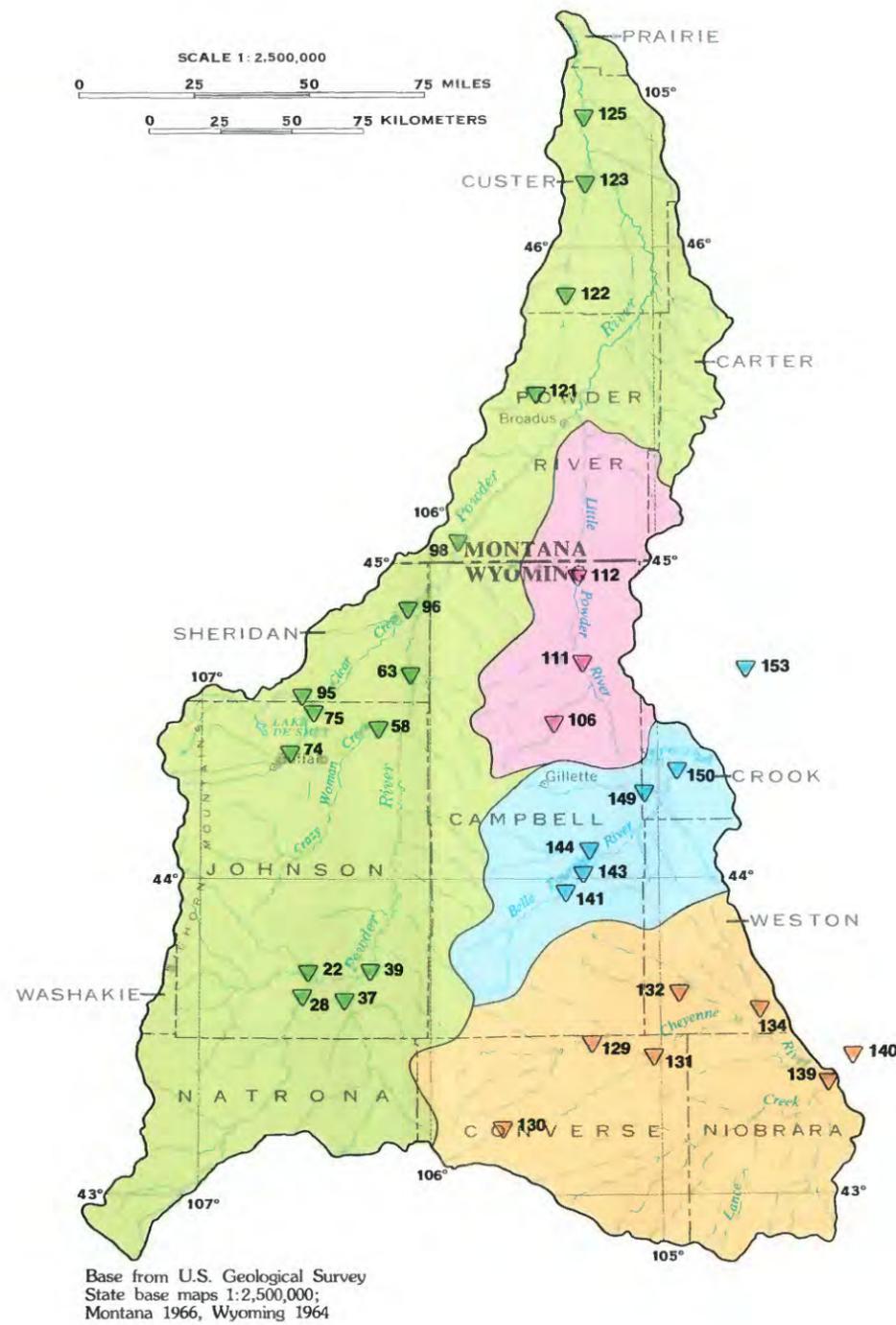
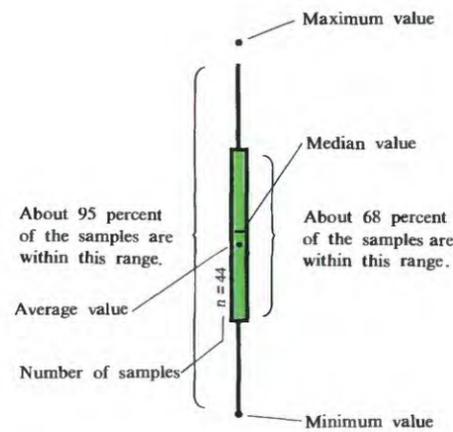
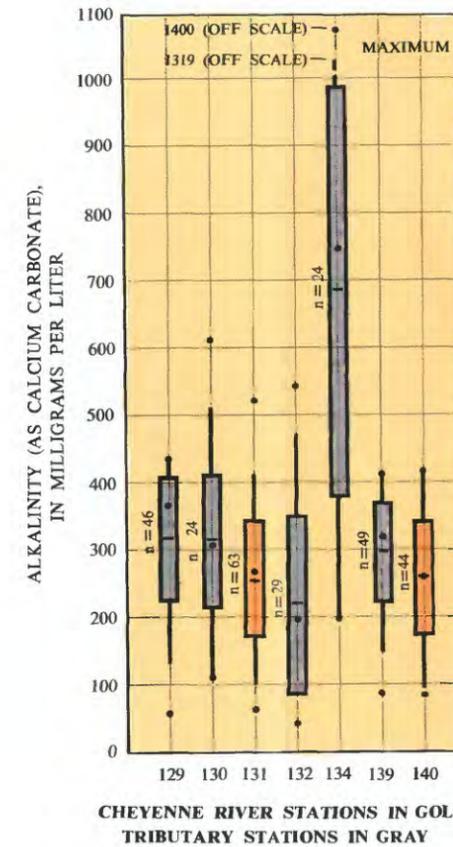
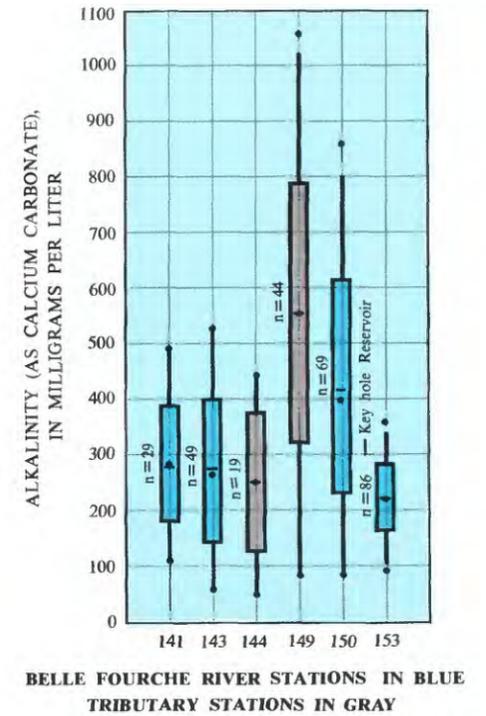
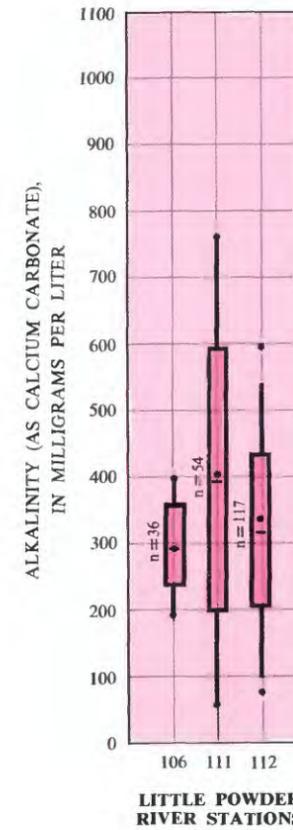


Figure 7.1.3-1 Alkalinity of the area's streams.



7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.4 pH

Acid Mine Drainage Not a Problem

Surface-water pH values tend to be alkaline, even downstream from mine sites. Nearly all pH measurements are above 7, and nearly all meet recommended criteria.

Unlike some coal areas in the Eastern States, acid mine drainage is not a problem in this area. The area's streams, even those that receive ground water directly from the coal mines, generally have high pH values, as shown in figure 7.1.4-1. The relatively high alkalinity of the area's soils, surface water, and ground water provides a large buffering capacity that tends to neutralize any sulfuric acid that might be formed through the oxidation of pyrite or other sulfide minerals that may accompany coal-mining operations.

The pH criterion for untreated water used as a source for public supplies specifies a permissible range of 5 to 9 pH units (U.S. Environmental Protection Agency, 1976). The pH of treated water is easily adjusted if the pH of the untreated water is within the 5-to-9 range. All surface waters measured in the area have a pH greater than 5 (none are below pH 6.1). A few isolated pH measurements were greater than 9.0 (the maximum pH value was 9.1).

To protect freshwater aquatic lifeforms, a pH range of 6.5 to 9.0 is recommended by the U.S. Environmental Protection Agency (1976). This pH range provides protection for fish as well as for aquatic biota in the food chain for fish. Nearly all surface-water pH measurements for this area meet this 6.5-to-9.0 criterion.

The pH of water is of concern not only for the direct effect of pH on water quality, but also because the toxicity of some substances is dependent on pH. For instance, hydrogen sulfide and hydrogen cyanide both become more toxic to fish with decreasing pH. In contrast, ammonia becomes more lethal as the pH increases.

It is important to keep in mind that pH is a measurement of the hydrogen-ion concentration. Pure waters and all water solutions dissociate to

some extent, normally producing minute concentrations of hydrogen (H^+) and hydroxyl (OH^-) ions. If the concentration of hydrogen ions is equal to the concentration of hydroxyl ions, the water is neutral ($pH = 7$). If the hydrogen-ion concentration is greater than the hydroxyl-ion concentration, the water is acidic ($pH < 7$). Conversely, it is basic (alkaline) if the hydroxyl ion concentration is greater ($pH > 7$). In a neutral solution, at 25° Celsius, the concentrations of both the hydrogen and hydroxyl ions are 0.0000001 moles per liter. (A mole is the molecular weight expressed in grams.) Because the hydrogen and hydroxyl ion concentrations normally are so low, their concentrations are more conveniently expressed as the negative logarithms, which are defined as pH and pOH, respectively:

$$pH = -\log_{10} [H^+],$$

where $[H^+]$ = the hydrogen-ion concentration in moles per liter.

$$pOH = -\log_{10} [OH^-],$$

where $[OH^-]$ = the hydroxyl-ion concentration in moles per liter.

The approximate relationships of pH, pOH, and the hydrogen-ion concentration to one another are given in table 7.1.4-1. Because pH is the negative logarithm of the hydrogen-ion concentration, an increase of 1 pH unit represents a tenfold decrease in the hydrogen-ion concentration; an increase of 2 pH units, a hundredfold decrease; and an increase of 3 pH units, a thousandfold decrease. Thus, the permissible pH range of 5 to 9 (for raw water for public supplies) allows a ten-thousandfold variation in the hydrogen-ion concentration. The pH scale ranges from 0 to 14, with a pH of 7 being neutral.

Table 7.1.4-1--Relationship (approximate) of pH, pOH, and hydrogen-ion concentrations (H).

	← Increasingly acidic							Neutral
pH	0	1	2	3	4	5	6	7
H ⁺ (moles per liter)	1	1x10 ⁻¹	1x10 ⁻²	1x10 ⁻³	1x10 ⁻⁴	1x10 ⁻⁵	1x10 ⁻⁶	1x10 ⁻⁷
H ⁺ (milligrams per liter)	1,000	100	10	1	.1	.01	1x10 ⁻³	1x10 ⁻⁴
pOH	14	13	12	11	10	9	8	7

	Increasingly basic →						
pH	8	9	10	11	12	13	14
H ⁺ (moles per liter)	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰	10 ⁻¹¹	10 ⁻¹²	10 ⁻¹³	10 ⁻¹⁴
H ⁺ (milligrams per liter)	10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	10 ⁻⁹	10 ⁻¹⁰	10 ⁻¹¹
pOH	6	5	4	3	2	1	0

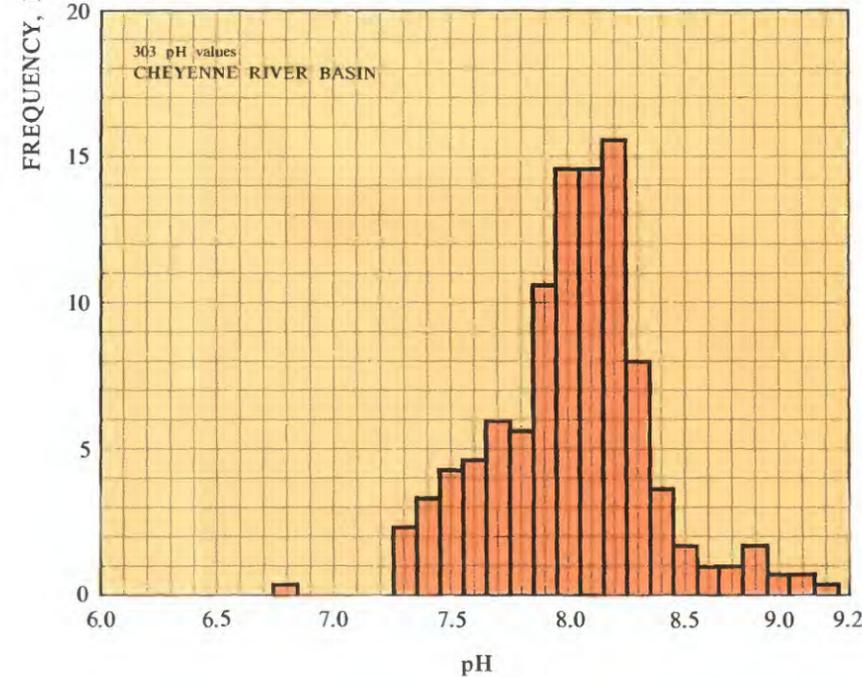
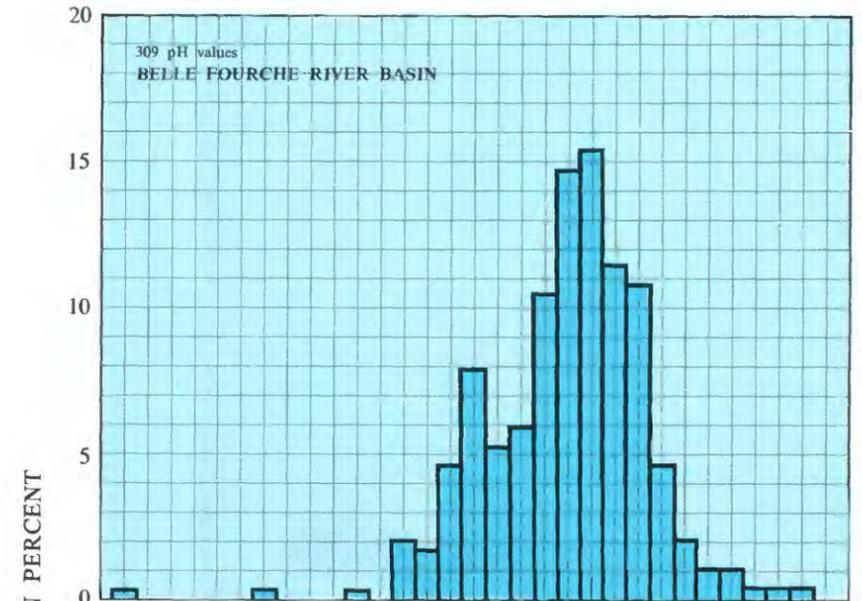
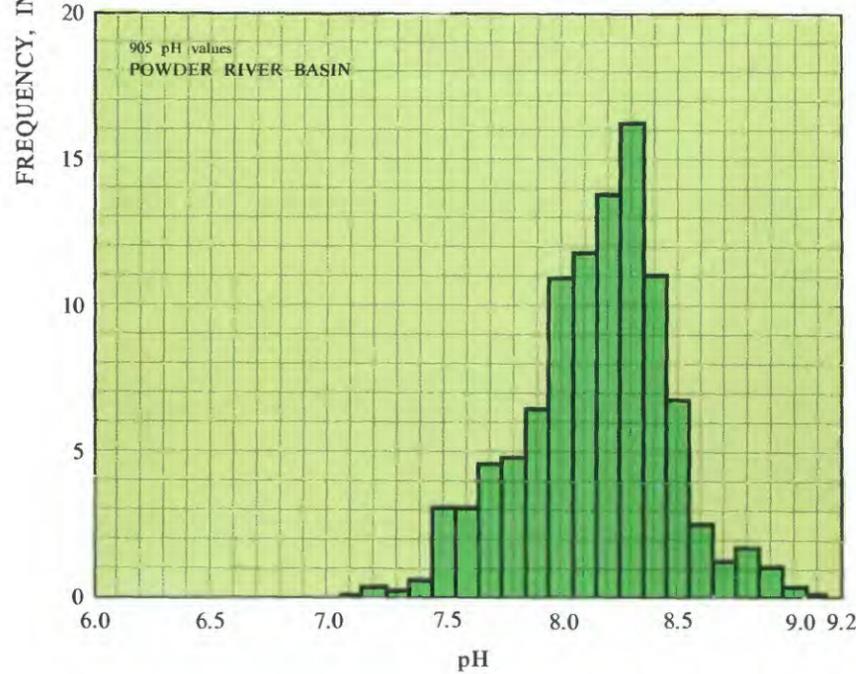
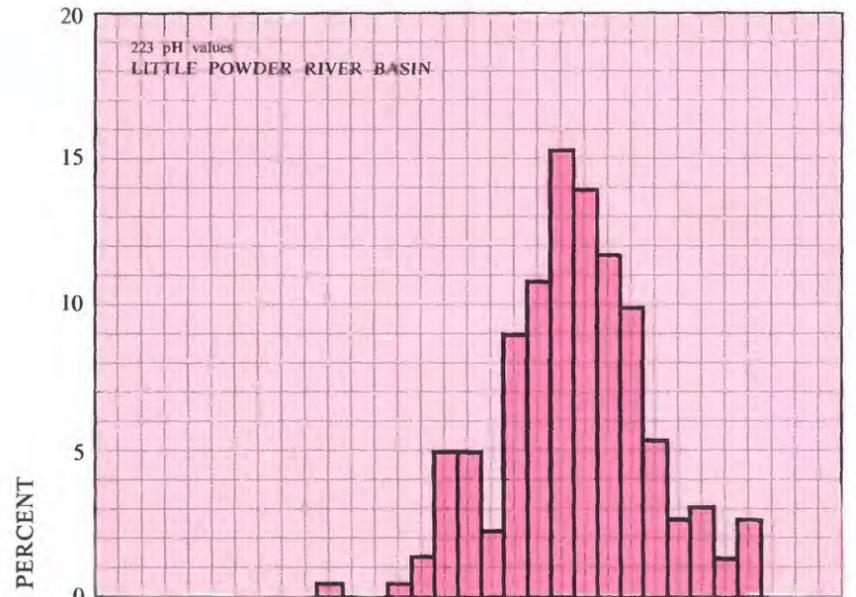
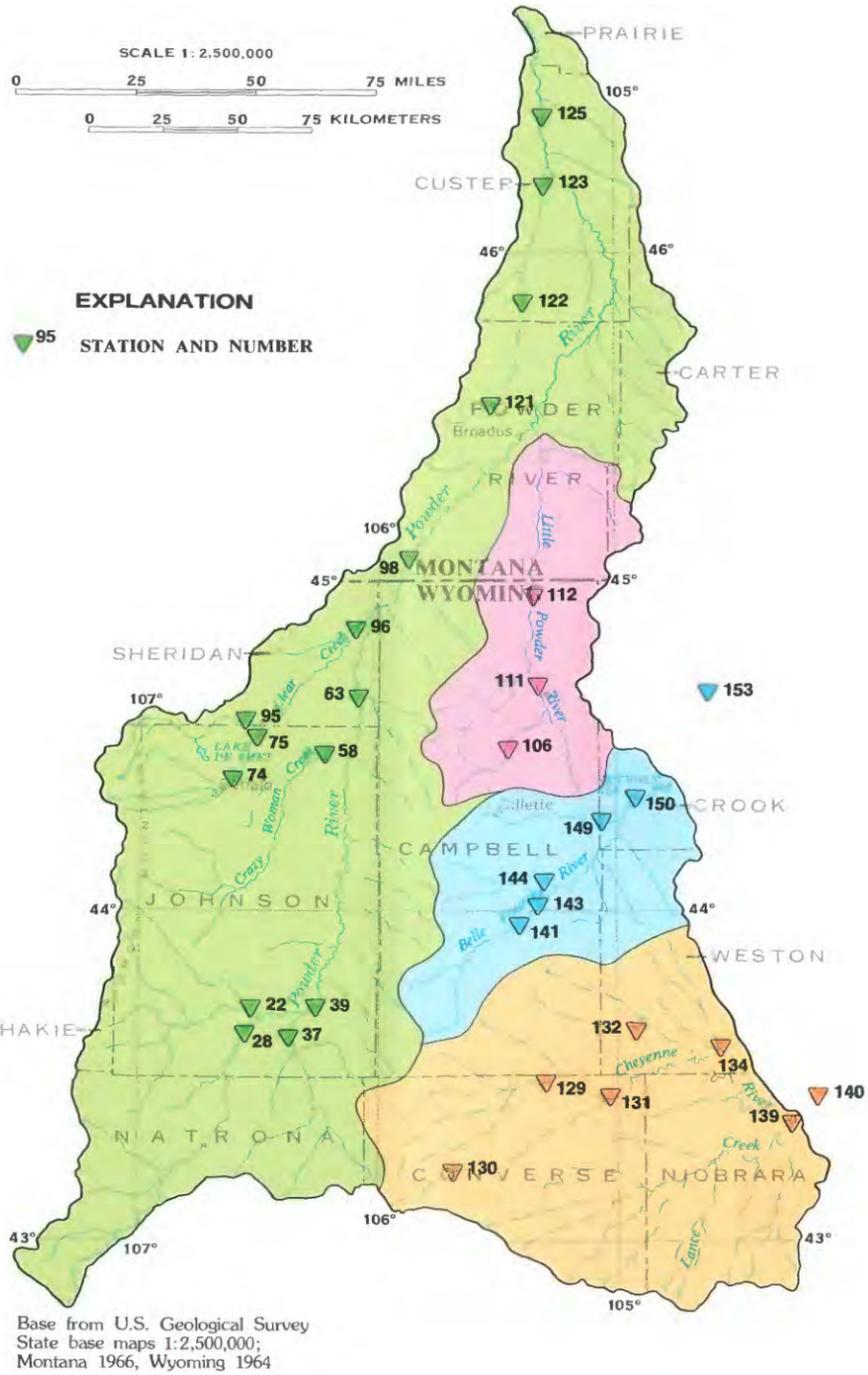


Figure 7.1.4-1 Histograms of pH values.

7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.5 Ionic Composition

Sodium and Sulfate Generally Dominant Ions

Sodium and sulfate generally are dominant ions, except in mountain streams, where calcium, magnesium, and bicarbonate are predominant. Chloride is the major anion in Salt Creek due to the inflow of oilfield-production water.

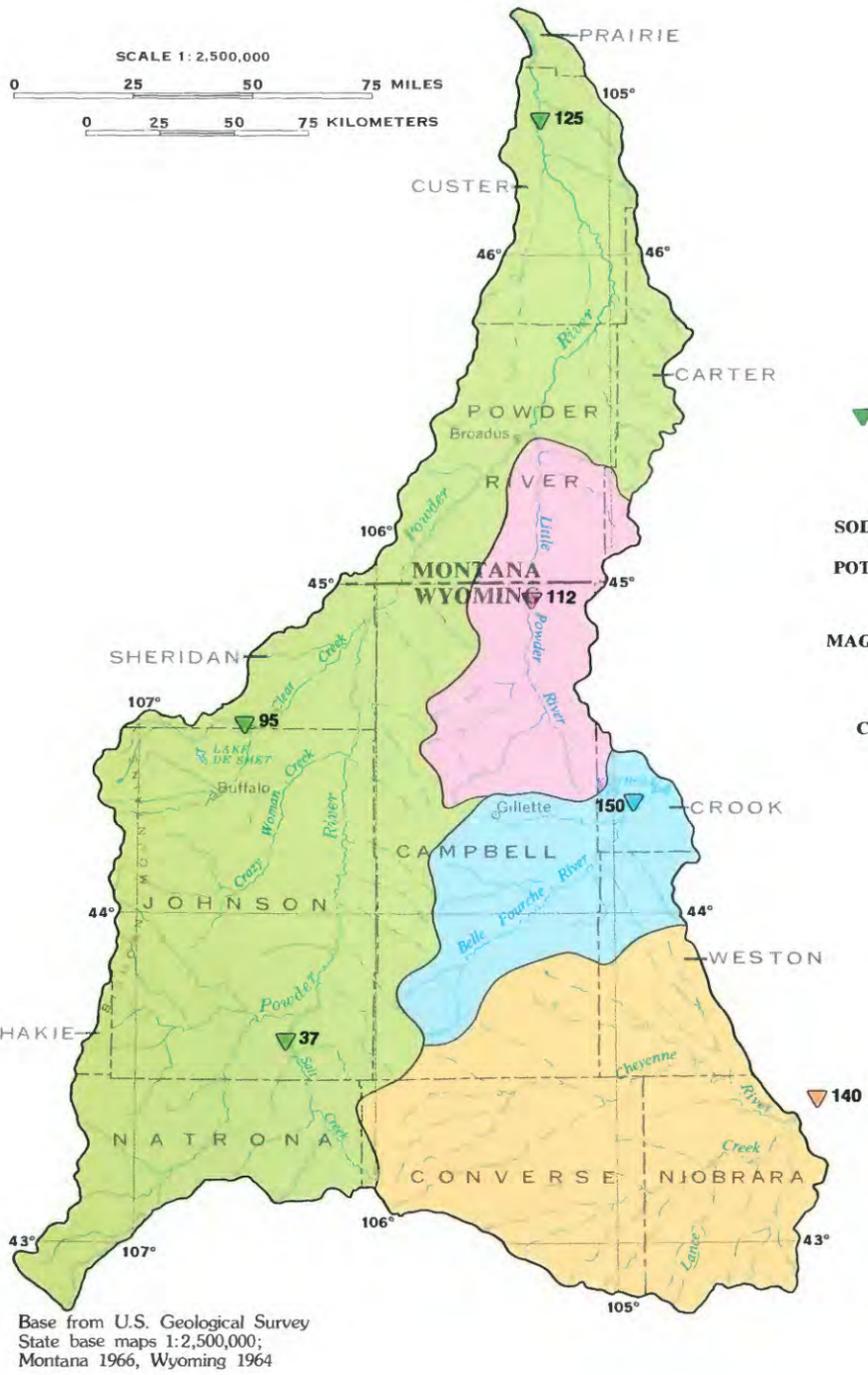
In most of the area's streams sodium is the major cation and sulfate the major anion. Median ionic compositions of some of the areas streams are shown in figure 7.1.5-1. Calcium and magnesium, though generally not the dominant ions, are present in high enough concentrations to make water from streams of the area very hard.

In the Eastern States, high sulfate concentrations in streams generally are indicative of acid mine drainage from coal mines. By eastern standards, the sulfate concentrations of this area's streams would be abnormally high. The median sulfate concentration at station 112 is 1,300 mg/L (milligrams per liter); however, the high sulfate concentrations at this and other stations are not accompanied by low pH values that are characteristic of acid mine drainage.

The area's mountain streams are represented by station 95 in figure 7.1.5-1. Mountain streams differ from the other streams in the area by having a much lower total-ionic concentration and by having a different ionic composition. The percentages of

magnesium, calcium, and bicarbonate ions are significantly higher and the percentages of sodium and sulfate ions are lower than those of the plains streams. However, mountain streams tend to become enriched in sodium and sulfate in their downstream reaches. Use of these streams for irrigation probably accelerates the normal downstream enrichment in sodium and sulfate ions, due to the relatively high concentrations of these ions in the irrigation return flow.

The ionic composition of Salt Creek (station 37) is unique for the area, due to the addition of oilfield-production water into the Salt Creek drainage. The high sodium and chloride concentrations in the production water alter the natural composition of Salt Creek. The chloride concentration is unusually high for streams of this area and even has considerable effect on the chloride concentration of Powder River downstream from Salt Creek, particularly when the flow of Powder River upstream from Salt Creek is low.



Base from U.S. Geological Survey
 State base maps 1:2,500,000;
 Montana 1966, Wyoming 1964

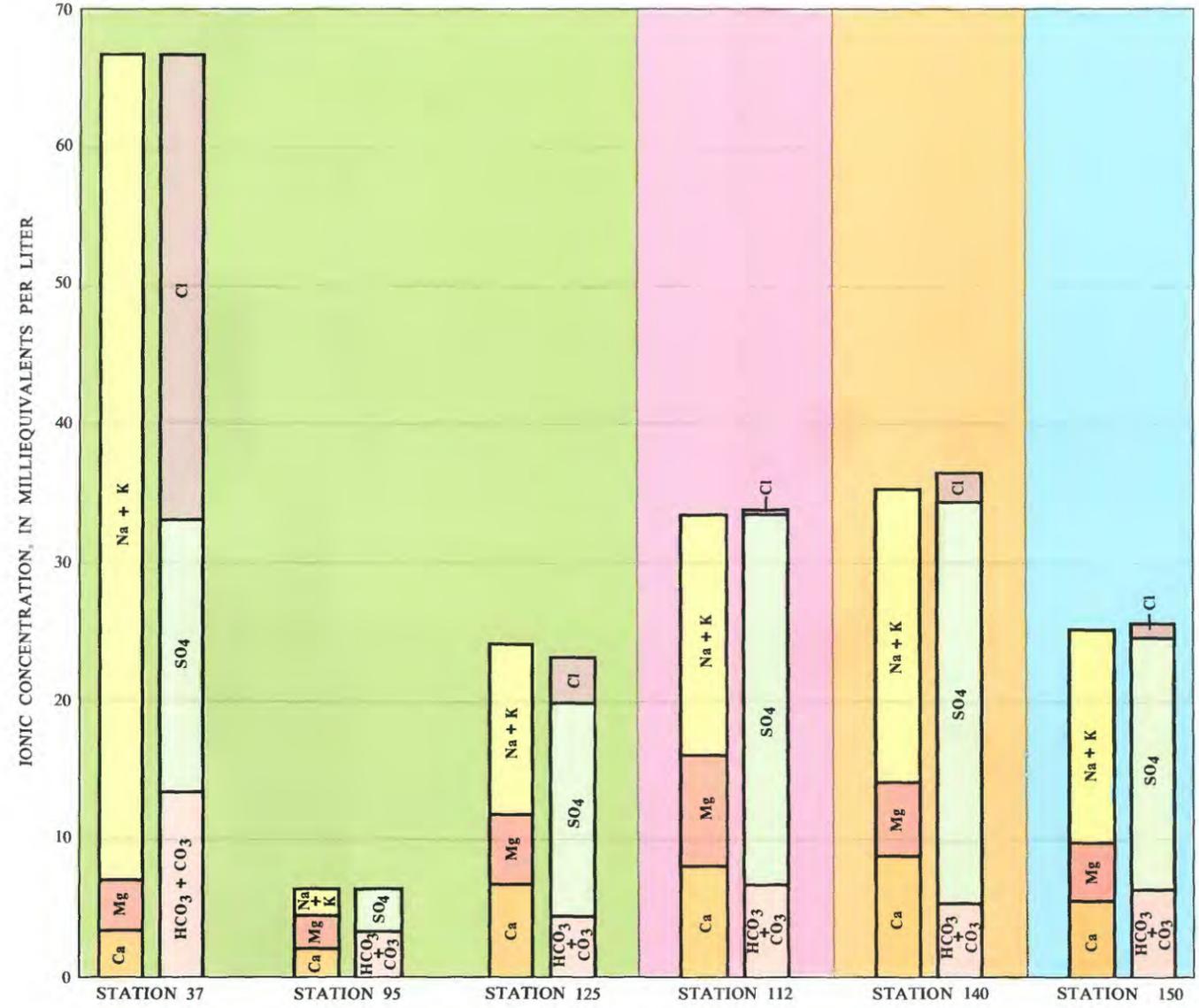
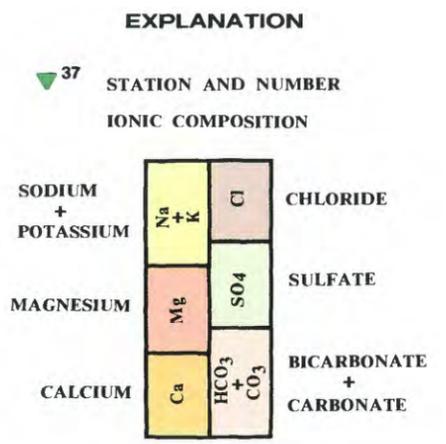


Figure 7.1.5-1 Median ionic composition of the area's streams.

7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.6 Total Phosphorus

Phosphorus Concentrations High in Most Streams

Total-phosphorus concentrations, associated with high suspended-sediment concentrations, are high in most streams, especially the Powder River. The total-phosphorus criterion to protect reservoirs frequently is exceeded by the water in the Belle Fourche River flowing into Keyhole Reservoir.

The Powder River is aptly named, for the stream transports a large sediment load. High sediment concentrations result in high total-phosphorus concentrations. The relationship of total-phosphorus concentrations to suspended-sediment concentrations for the Powder River stations is shown in figure 7.1.6-1.

Simple statistics for total-phosphorus concentrations in water for the streams of the area are shown in figure 7.1.6-2. Total-phosphorus concentrations for the stations on the main stem of Powder River average 0.58 mg/L (milligram per liter), significantly higher than the other drainages in the area and more than twice the average for the Nation's streams, which is about 0.24 mg/L (Briggs and Ficke, 1978). Most streams in the area have an increase in phosphorus concentration in the downstream direction. The principal exception is between stations 150 and 153. The decrease in phosphorus at station 153 is due to the presence of Keyhole Reservoir between the two stations. The reservoir is both a sediment and a phosphorus trap.

High concentrations of phosphorus are objectionable primarily because phosphorus promotes nuisance growth of algae and other aquatic plants in lakes, reservoirs, and streams. A maximum concentration of 0.1 mg/L total phosphorus (as phosphorus) has been suggested to protect streams which do not flow into lakes or reservoirs (Mackenthum, 1973). Lakes and reservoirs are more prone to algal problems than streams. To protect lakes and reservoirs, inflowing streams should not have

total-phosphorus concentrations in excess of 0.05 mg/L (U.S. Environmental Protection Agency, 1976). This criterion frequently is exceeded in the Belle Fourche River above Keyhole Reservoir (station 150); there, the mean total-phosphorus concentration is 0.23 mg/L and the median is 0.13 mg/L. However, because algal growth presently is not a problem at Keyhole Reservoir, other factors limiting algal growth evidently are involved.

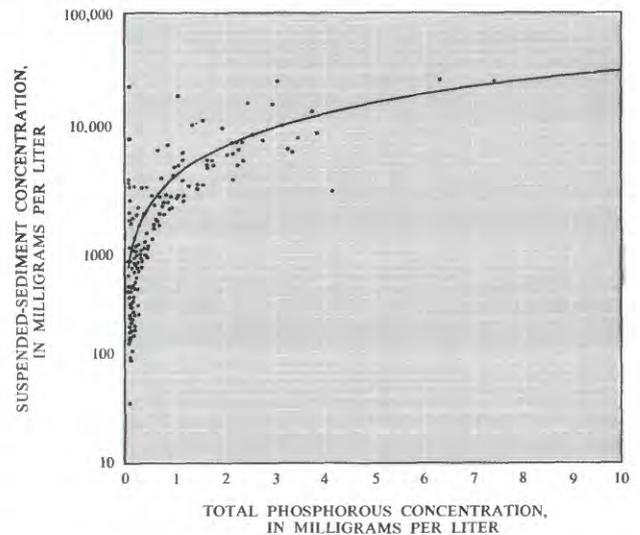


Figure 7.1.6-1 Total-phosphorus versus suspended-sediment concentrations (Powder River stations).

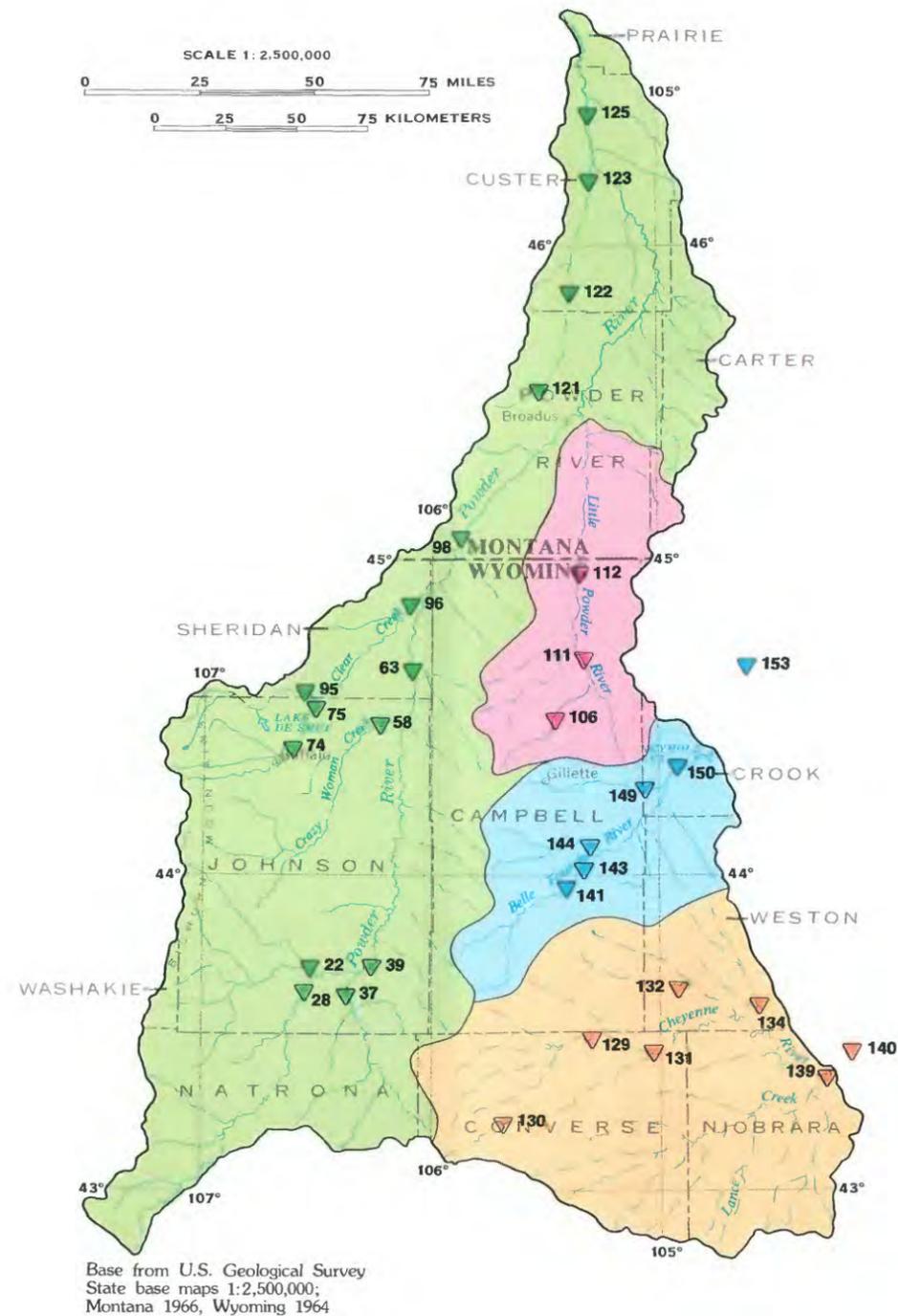
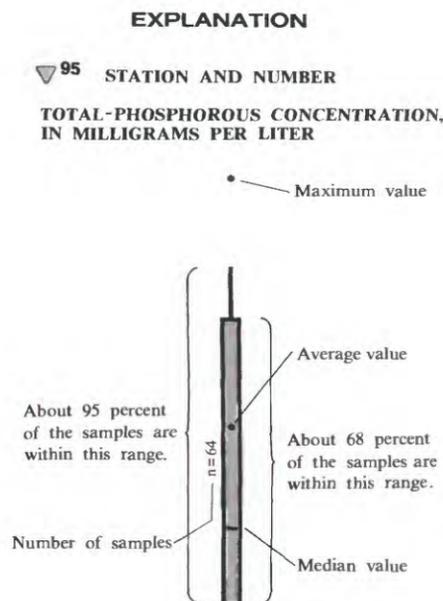
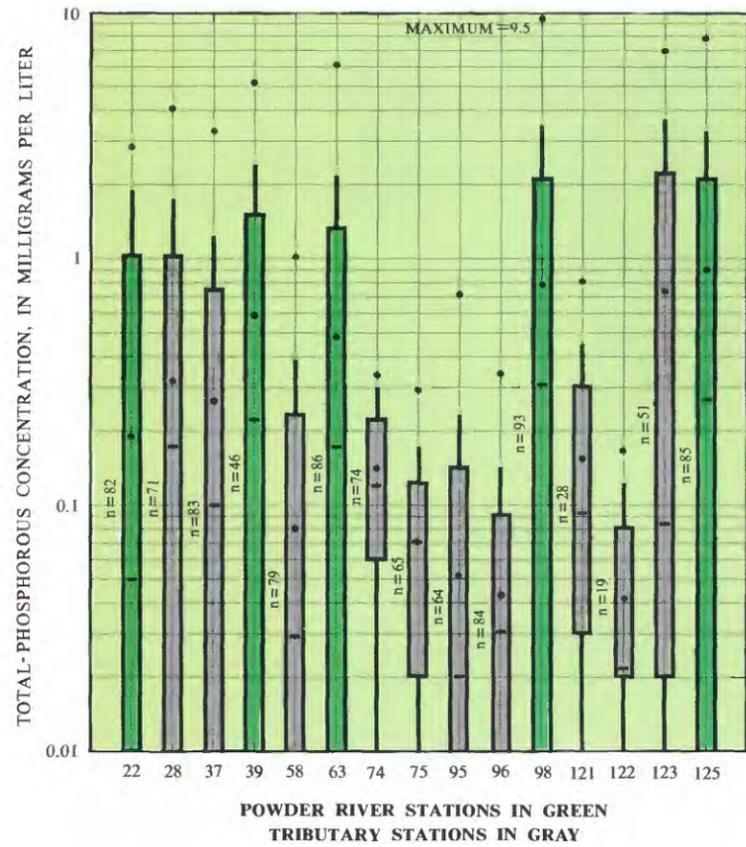
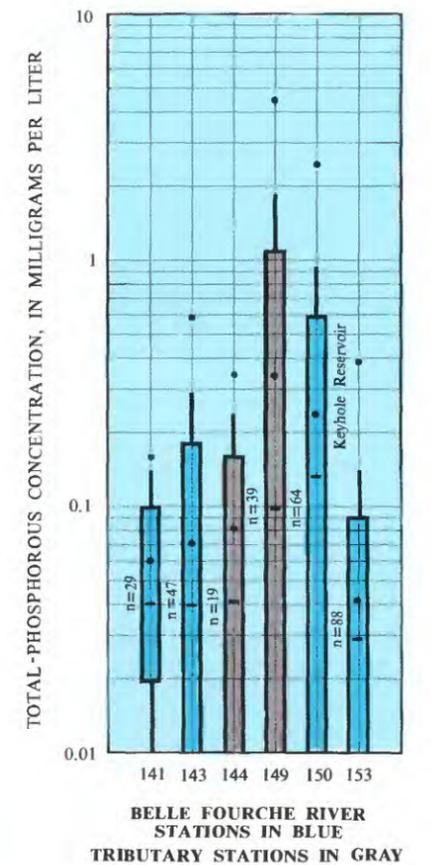
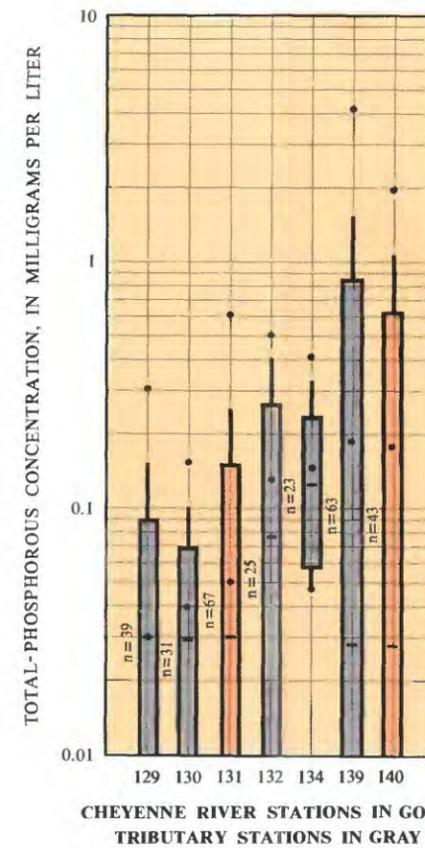
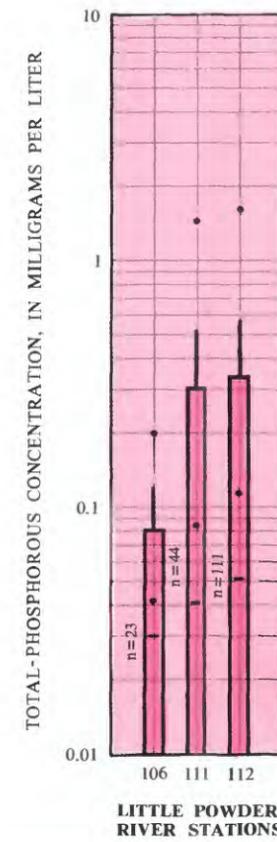


Figure 7.1.6-2 Total-phosphorus concentrations of the area's streams.



7.0 SURFACE-WATER QUALITY--Continued

7.1 Chemical Quality--Continued

7.1.7 Trace Metals

Selenium Concentrations High in South Fork Powder River

Trace metals generally are not a problem in the area's streams; exceptions are high concentrations of selenium in the South Fork Powder River and high concentrations of manganese and iron in some samples throughout the area.

Although only 8 of nearly 400 dissolved-selenium analyses (table 7.1.7-1) have concentrations greater than the 10 $\mu\text{g/L}$ (micrograms per liter) national primary drinking-water standard established by the U.S. Environmental Protection Agency (1977), the pattern of the occurrence of these high values indicates a local problem. Most of the samples with selenium concentrations greater than 10 $\mu\text{g/L}$ were collected at South Fork Powder River near Kaycee, Wyo., station 28 (fig. 7.1.7-1). Six of the eight samples collected at this station have concentrations greater than the drinking-water standard. Even though the selenium concentrations at this station generally exceed the drinking-water standard, it does not constitute a problem, because the water is not used for a public supply. Nor are the selenium concentrations high enough to cause a problem when the water is used for watering livestock. Selenium in water is not a documented cause of selenium poisoning of livestock. Nonetheless, a maximum concentration of 50 $\mu\text{g/L}$ is suggested by the National Academy of Sciences and National Academy of Engineering (1973) to protect livestock. High selenium concentrations in the basin's surface water indicate the presence of seleniferous soils. When these soils are present, certain plants take up and concentrate selenium to concentrations as high as several thousand parts per million (selenium to dry plant weight). Such plants are very toxic to animals that eat them, causing selenium poisoning that often is

fatal. Some of the analyses at station 28 also exceed the 20 $\mu\text{g/L}$ maximum selenium concentration recommended by the National Academy of Sciences and National Academy of Engineering (1973) for irrigation water.

Manganese concentrations exceeded the 50 $\mu\text{g/L}$ secondary drinking-water standard (U.S. Environmental Protection Agency, 1979) in about 56 percent of the samples. Iron values exceeded the 300 $\mu\text{g/L}$ secondary drinking-water standard (U.S. Environmental Protection Agency, 1979) in about 3 percent of the samples. High concentrations of manganese and iron could cause esthetic problems (bitter taste and staining of plumbing fixtures) if present in a domestic water supply; however, such problems can be alleviated by water treatment and storage. The manganese and iron concentrations do not pose problems for the watering of livestock or for irrigation of crops.

The other potentially toxic trace metals that occurred in concentrations higher than the national primary drinking-water standards--cadmium, lead, and mercury--occurred in high concentrations so infrequently and with such lack of definite pattern that it is probable that no persistent problem with these trace metals exists in the area's streams.

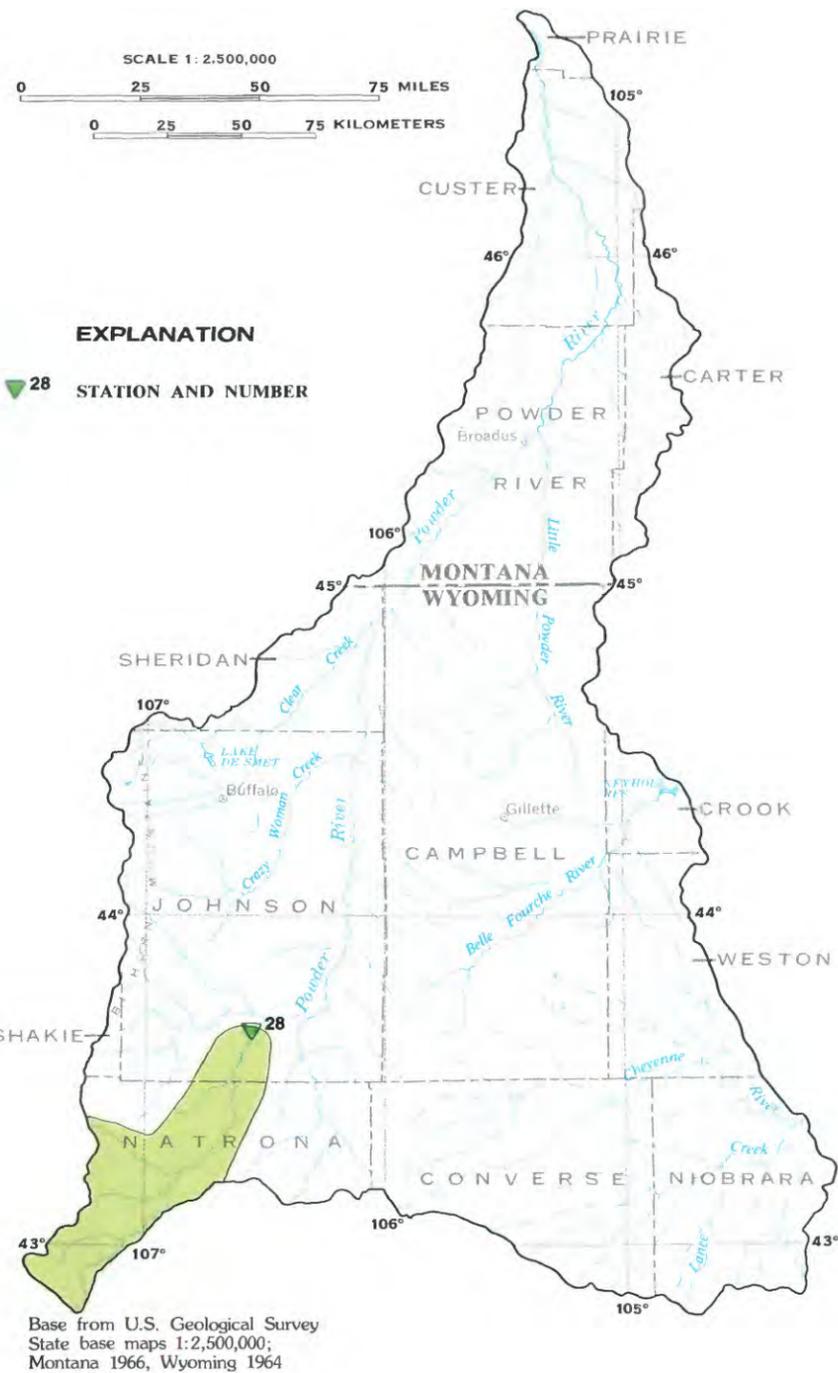


Table 7.1.7-1 Dissolved-trace metal concentrations in the streams of the area.

Dissolved-trace metal	Number of analyses exceeding drinking-water standards	Percent of analyses exceeding drinking-water standards	Drinking-water standard (micrograms per liter)	Median value (micrograms per liter)	Maximum value (micrograms per liter)	Number of analyses
Arsenic	0	0	¹ 50	1	50	373
Barium	0	0	¹ 1,000	100	400	140
Cadmium	5	1.4	¹ 10	2	20	370
Chromium	0	0	¹ 50	0	20	374
Copper	0	0	² 1,000	3	70	397
Iron	45	3.4	² 300	40	1,800	1,316
Lead	5	1.1	¹ 50	2	200	370
Manganese	256	55.8	² 50	70	6,600	459
Mercury	4	1.1	¹ 2	0.1	4.0	380
Selenium	8	2.1	¹ 10	1	26	381
Zinc	0	0	² 5,000	20	180	382

¹ National interim primary drinking-water standards (U.S. Environmental Protection Agency, 1977)
² National secondary drinking-water regulations (U.S. Environmental Protection Agency, 1979)

Figure 7.1.7-1 Drainage basin upstream from station 28, where selenium concentrations generally exceed 10 micrograms per liter.

7.0 SURFACE-WATER QUALITY--Continued

7.2 Suspended Sediment

7.2.1 Concentration

Suspended-Sediment Concentrations Much Larger During High Flows

Larger concentrations of suspended sediment during high flow are the result of increased energy of flowing water, larger area of streambanks being inundated, and greater vulnerability of soil to erosion by rainfall or snowmelt.

Concentrations of suspended sediment in streams vary directly with streamflow—small concentrations generally are associated with low flows and large concentrations are associated with high flows. The relation between suspended-sediment concentration and water discharge for the Powder River at Arvada, Wyo. is illustrated in figure 7.2.1-1. This relation differs somewhat among data-collection stations, but in all instances within Area 50 the trend towards increasing concentrations for increasing discharges is similar.

Annual discharge-weighted concentrations are shown in figure 7.2.1-2 for four groups of stations: (1) On the Powder River, (2) on streams tributary to the Powder River, (3) on the Belle Fourche River, and (4) on the Cheyenne River. These graphs compare concentrations for an extreme flood year, 1978, with the average of two subsequent years, 1979-80, when flows were substantially smaller. The lack of 1978 data at some stations is noted on the graphs.

The quantity of sediment in transport can be computed from sediment concentration and discharge by using the formula,

$$Q_s = 0.0027 Q_w \times C_s,$$

where Q_s = sediment discharge, in tons per day; Q_w = water discharge, in cubic feet per second; C_s = suspended-sediment concentration, in milligrams per liter; and 0.0027 is a conversion coefficient.

Suspended sediment is the major cause of turbidity. Excessive turbidity blocks sunlight that aquatic plants need for photosynthesis (the synthesis of carbohydrates from water and carbon dioxide in the presence of light). Large quantities of fine sediment

can clog the gills of invertebrates and fish. Deposition of fine sediment in voids between sand and gravel particles destroys habitat for invertebrates and fish eggs. Excessive turbidity also decreases the esthetic quality of the water.

Suspended-sediment particles provide the surface onto which moderately soluble chemicals in water may sorb and be transported. Thus, chemically enriched sinks can form in sediment deposition areas. Sediment also provides a substrate on which aqueous chemical reactions can take place. The presence of suspended sediment in a flowing stream also limits the capability of that stream to acquire and transport additional sediment. Conversely, a reduction of sediment (particularly in a stream that previously transported large amounts of sediment) enhances the capability of that stream to acquire and transport additional sediment.

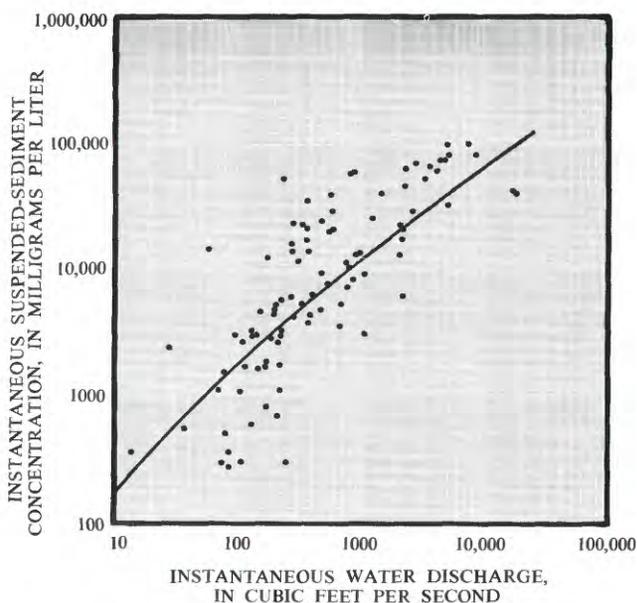


Figure 7.2.1-1 Relation between suspended-sediment concentration and water discharge for Powder River at Arvada, Wyoming (station 63).

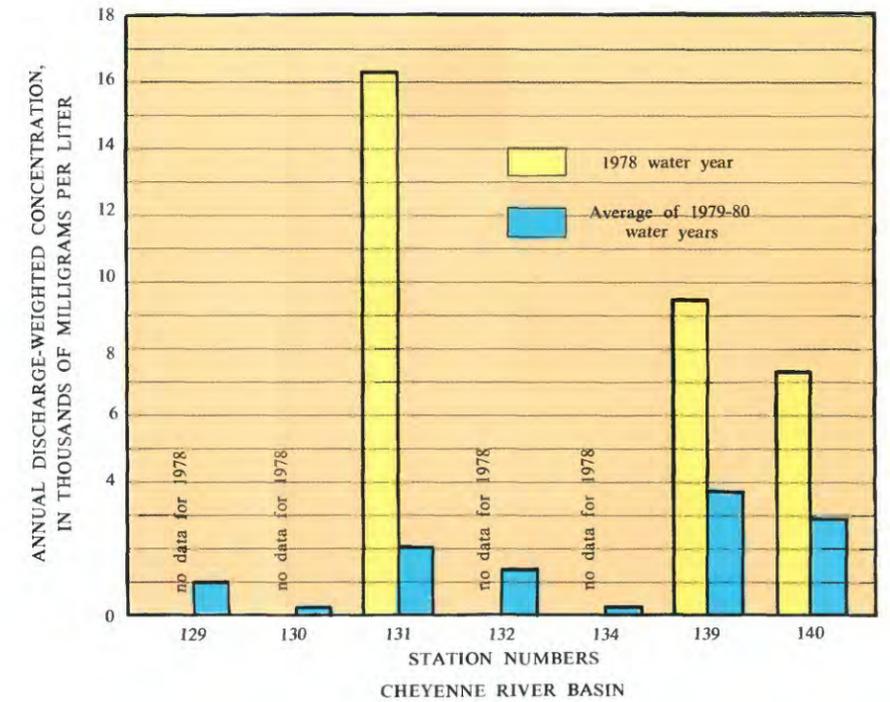
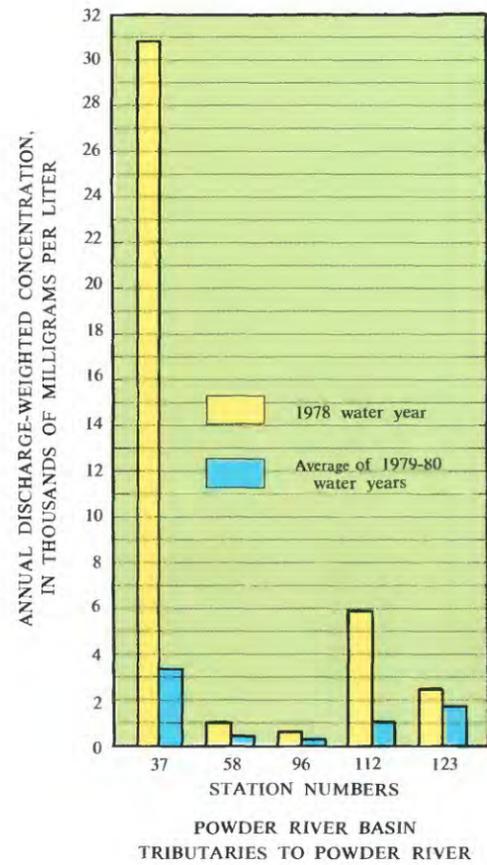
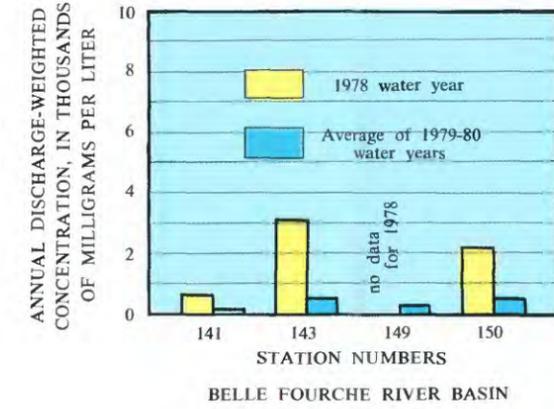
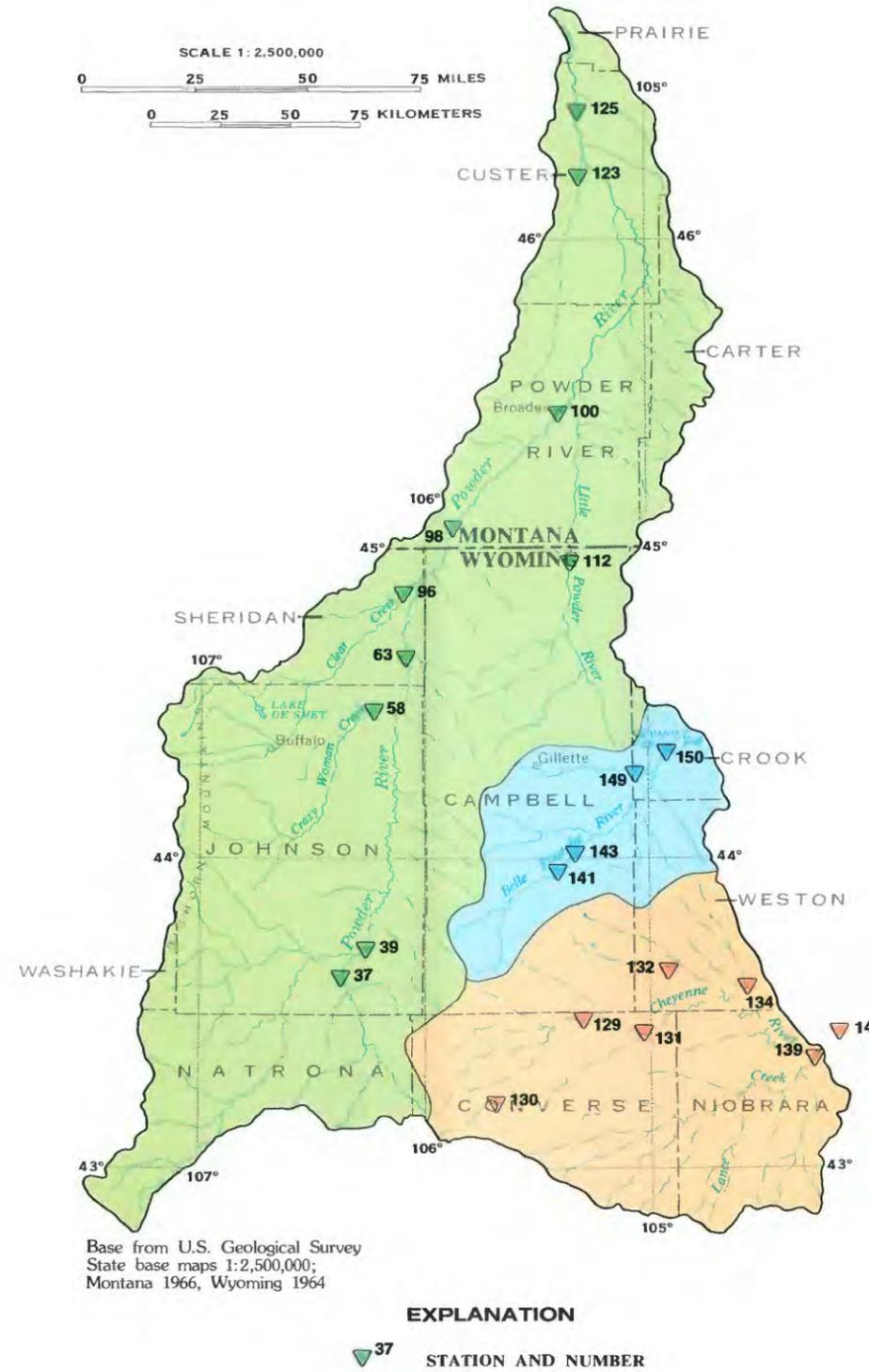
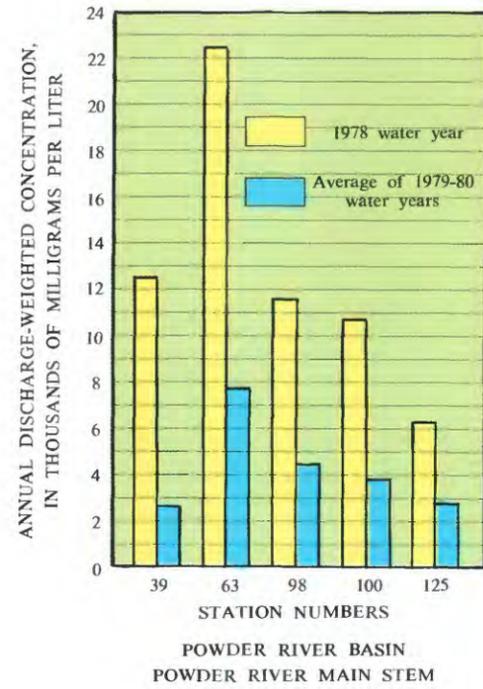


Figure 7.2.1-2 Annual discharge-weighted suspended-sediment concentrations, 1978 and the average of 1979-80 water years.

7.0 SURFACE-WATER QUALITY--Continued

7.2 Suspended Sediment--Continued

7.2.2 Loads--Powder River

Sediment Load in Powder River is Mostly from Wyoming

Sediment loads transported by the Powder River are large, are eroded mostly from the Wyoming reach, and are partly deposited in the Montana reach.

"Too thick to drink and too thin to plow." This very early description of the Powder River is appropriate, because at times the streamflow consists of a mixture that is 10 percent sediment and 90 percent water.

Records of suspended-sediment load obtained at five data-collection stations on the main channel and at one station on each of its five main tributaries (fig. 7.2.2-1) are given in table 7.2.2-1. The average (24 years) amount of suspended sediment transported past Arvada, Wyo. (station 63) is 4,710,000 tons per year, which is the equivalent of 129 railroad carloads each day, each car transporting 100 tons. On the average, only 2,700,000 tons per year are transported past Locate, Mont. (station 125), indicating that about 2,010,00 tons per year are deposited in the reach between Arvada and Locate. This hypothesis is supported by Martinson (1982) who surveyed cross sections of the river between Moorhead (station 98) and Broadus (station 100) and found that the stream channel was aggrading. Martinson and Meade (1983) documented changes in the river channel between

Moorhead and Broadus during the period, 1938-78. This same effect--scour, or increasing loads, in the upstream reach of a large river and deposition, or decreasing loads, in the downstream reach--was noted for the Yellow River in China (Long and Xiong, 1981). The graph of variation in loads along the Powder River (fig. 7.2.2-2) illustrates that this hypothesis also must be true for the reach between Arvada (station 63) and Moorhead (station 98). The rate of deposition in that reach probably is greater than that between Moorhead and Broadus. The contribution of suspended sediment from the five main tributaries represents 8 percent of the load in the main stream during years of low flow and 16 percent during years of high flow.

Photographs of the Powder River in the vicinity of Arvada, Wyo., following the major flood of May 18-22, 1978 are shown in figures 7.2.2-3 and 7.2.2-4. Scour into a road by the river is shown in figure 7.2.2-3 and deposition resulting from river overflow onto the flood plains is shown in figure 7.2.2-4.

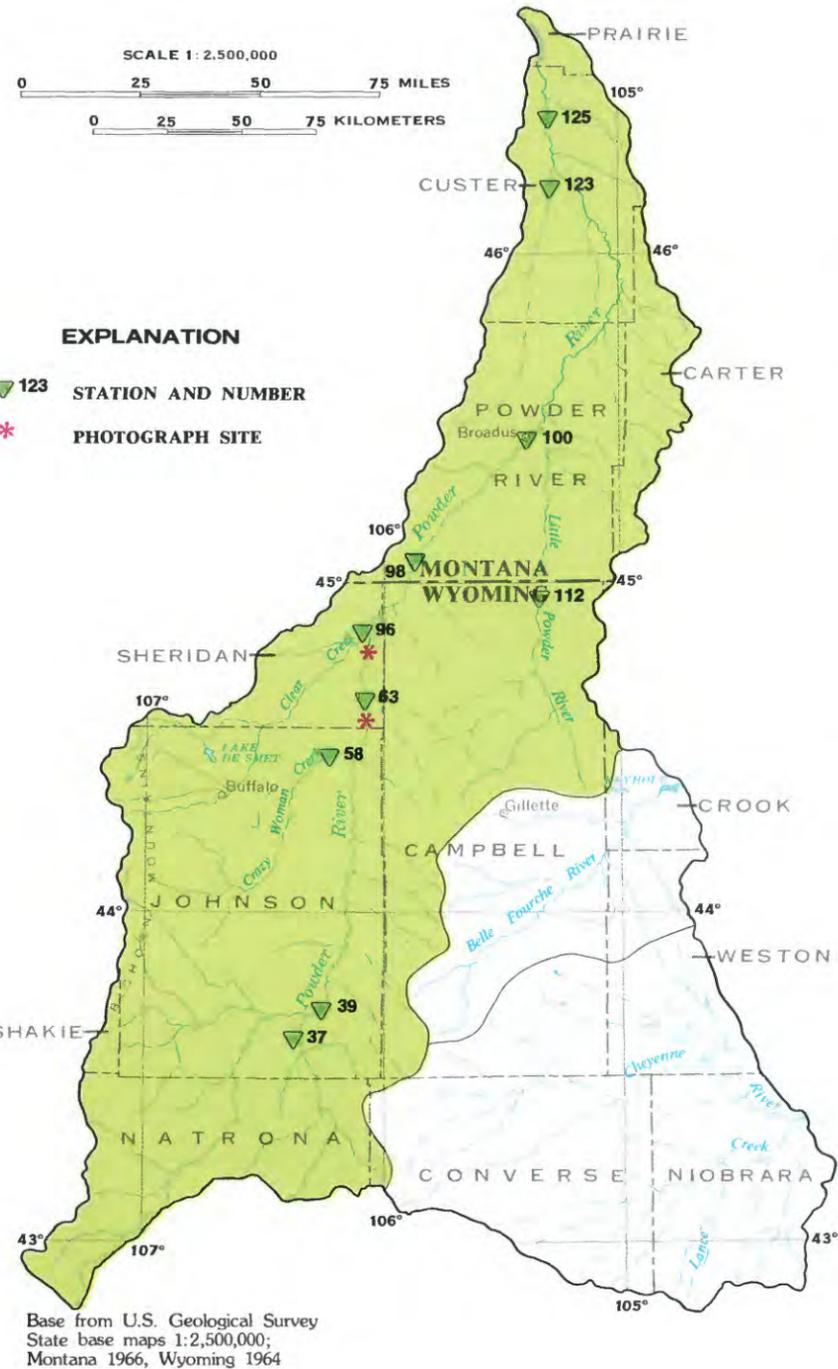


Figure 7.2.2-1 Location of suspended-sediment stations in the Powder River Basin.



Figure 7.2.2-3 Eroded bank at bend in the Powder River near Arvada, Wyoming, after flood of May 1978.

Table 7.2.2-1 Annual suspended-sediment loads, in tons.

Station number	1978 water year	Average of 1979-80 water years
Powder River Basin		
37	2,521,000	130,000
39	5,996,000	492,000
58	109,000	11,200
¹ 63	16,270,000	1,786,000
96	159,000	5,780
98	12,490,000	1,235,000
100	11,720,000	1,128,000
112	715,000	7,340
123	104,000	22,300
125	9,200,000	1,000,000

¹ 24-year average is 4,710,000 tons

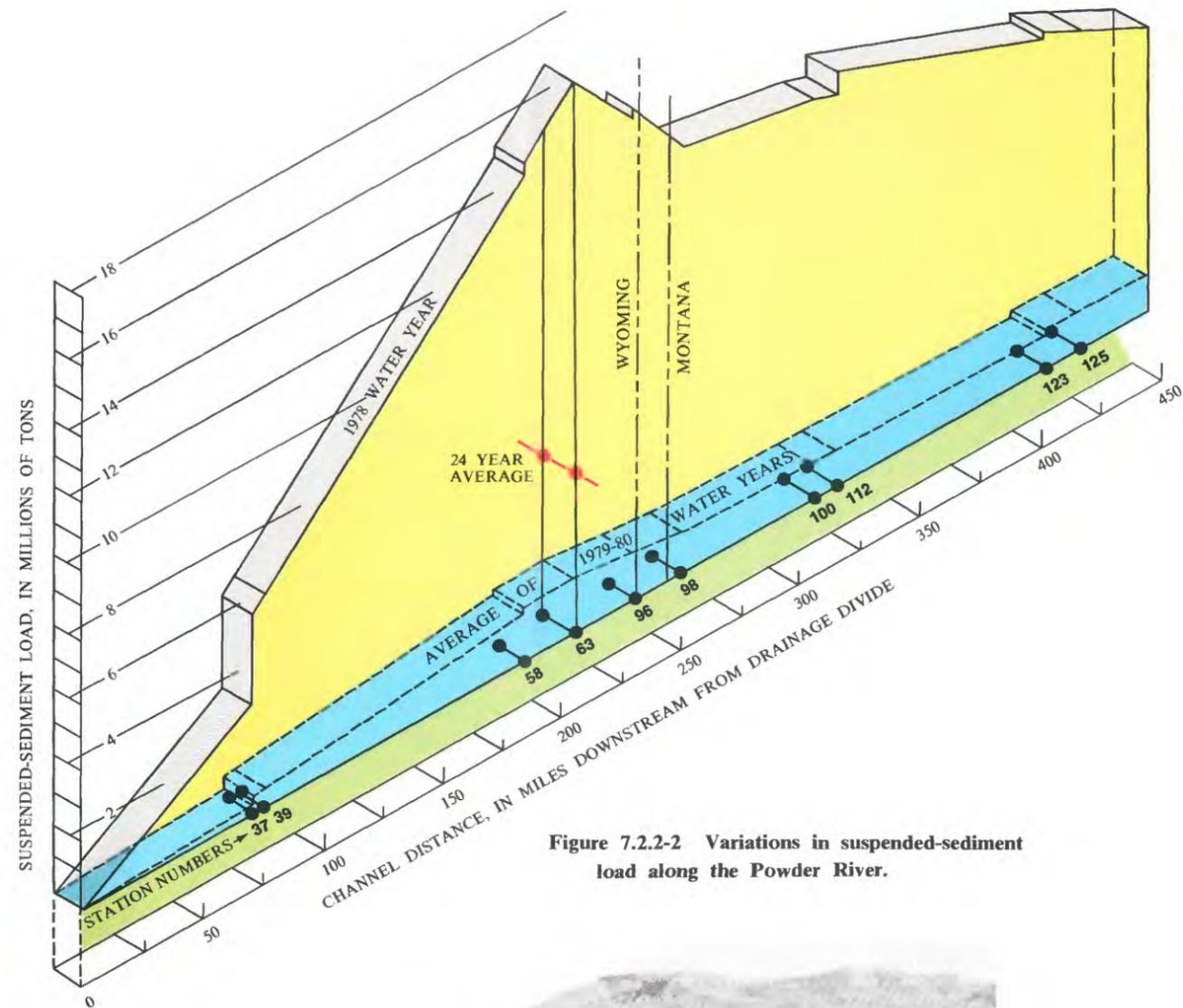


Figure 7.2.2-2 Variations in suspended-sediment load along the Powder River.



Figure 7.2.2-4 Deposition on flood plain of Powder River about 15 miles downstream from Arvada, Wyoming.

7.0 SURFACE-WATER QUALITY--Continued

7.2 Suspended Sediment--Continued

7.2.3 Loads--Belle Fourche and Cheyenne Rivers

Sediment Loads in Belle Fourche and Cheyenne Rivers Increase Downstream

Sediment loads transported by the Belle Fourche and Cheyenne Rivers are significantly less than loads transported by the Powder River; sediment is trapped in Keyhole Reservoir on the Belle Fourche River and in Angostura Reservoir on the Cheyenne River.

The quantity of sediment transported by a stream is directly related to the quantity of water discharged by that stream. Because the quantity of water in the Belle Fourche and Cheyenne Rivers is less than that in the Powder River, the sediment loads measured at stations shown in figure 7.2.3-1 are significantly less than that transported by the Powder River (section 7.2.2). The sediment loads transported by the Belle Fourche and Cheyenne Rivers increase downstream (fig. 7.2.3-2) in a manner similar to the increase in the upstream reach of the Powder River (section 7.2.2).

The average loads transported by the Belle Fourche and Cheyenne Rivers during the 1979-80

water years are listed table 7.2.3-1. The flow during 1979 and 1980 was significantly less than the long-term average; hence, the loads transported during these years also were less than the estimated 26-year average.

Sediment discharged from the drainage basin of the Belle Fourche River upstream from Keyhole Reservoir and that from the area contiguous to the reservoir are trapped in the reservoir. Sediment discharged from the Cheyenne River basin in Area 50 is trapped in Angostura Reservoir (located on-channel, about 60 river miles downstream from the edge of Area 50).

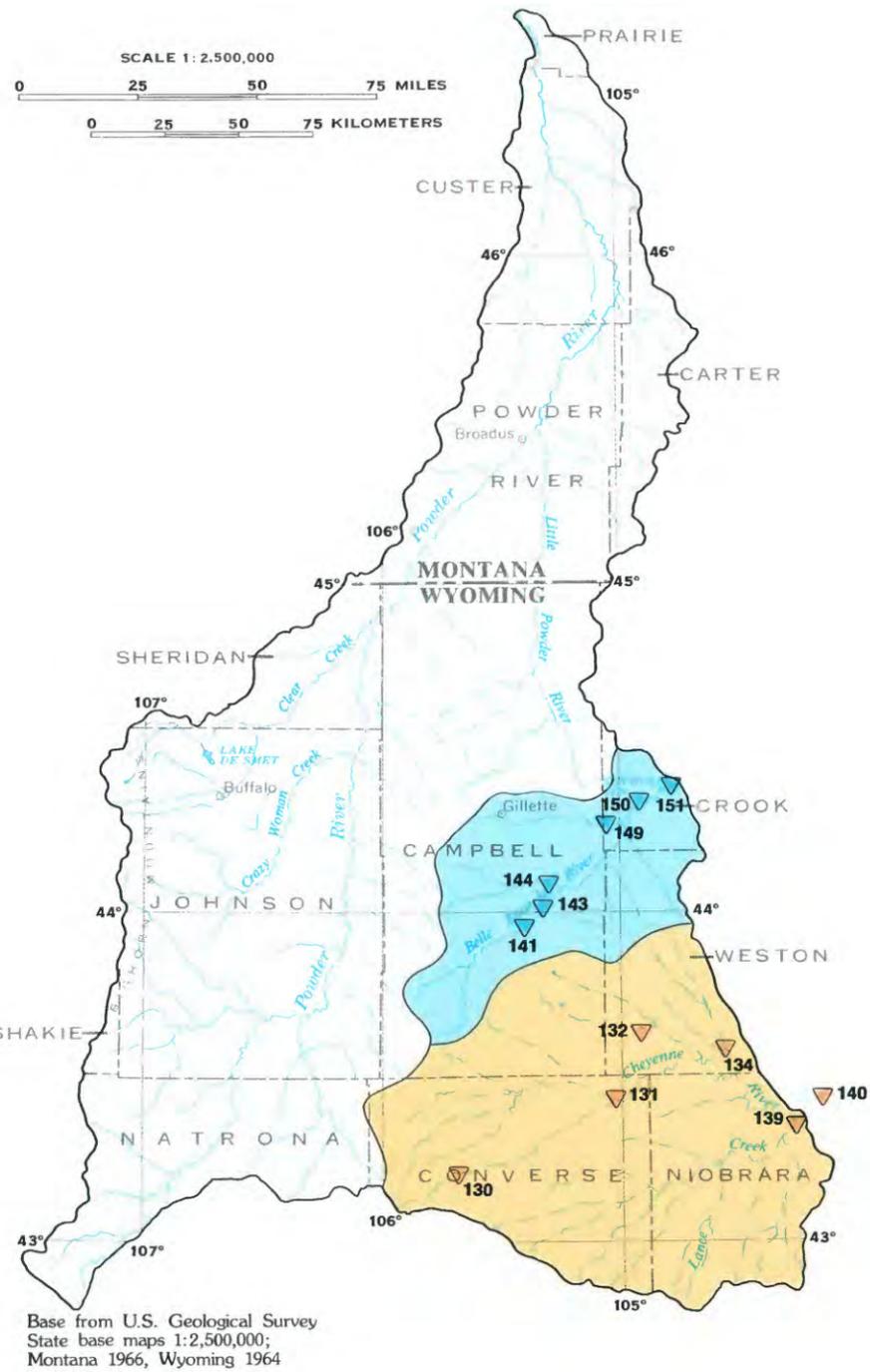


Figure 7.2.3-1 Location of suspended-sediment stations in Belle Fourche and Cheyenne River basins.

Table 7.2.3-1 Annual suspended-sediment loads, in tons.

Station number	Average of 1979-80 water years	26-year average
Belle Fourche River		
141	265	--
143	1,240	--
144	192	--
149	674	--
150	8,230	49,300
151	42,700	256,000
Cheyenne River		
130	101	--
131	17,300	--
133	2,190	--
134	133	--
139	102,000	235,000
140	294,000	1,220,000

EXPLANATION
 STATION AND NUMBER

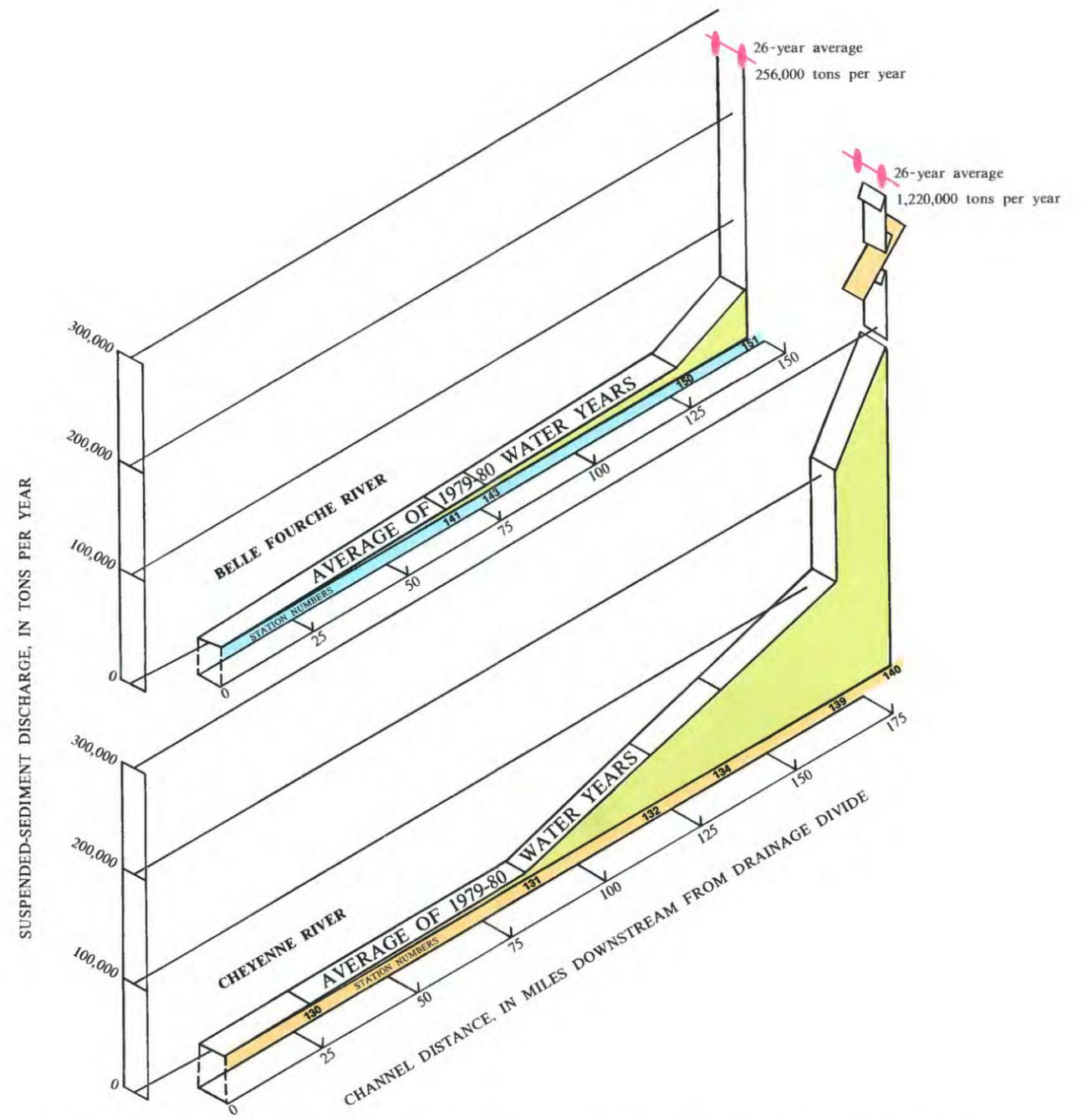


Figure 7.2.3-2 Variations in suspended-sediment load along the Belle Fourche and Cheyenne Rivers.

7.0 SURFACE-WATER QUALITY--Continued

7.2 Suspended Sediment--Continued

7.2.4 Particle Size

Suspended Sediment is Mostly Clay

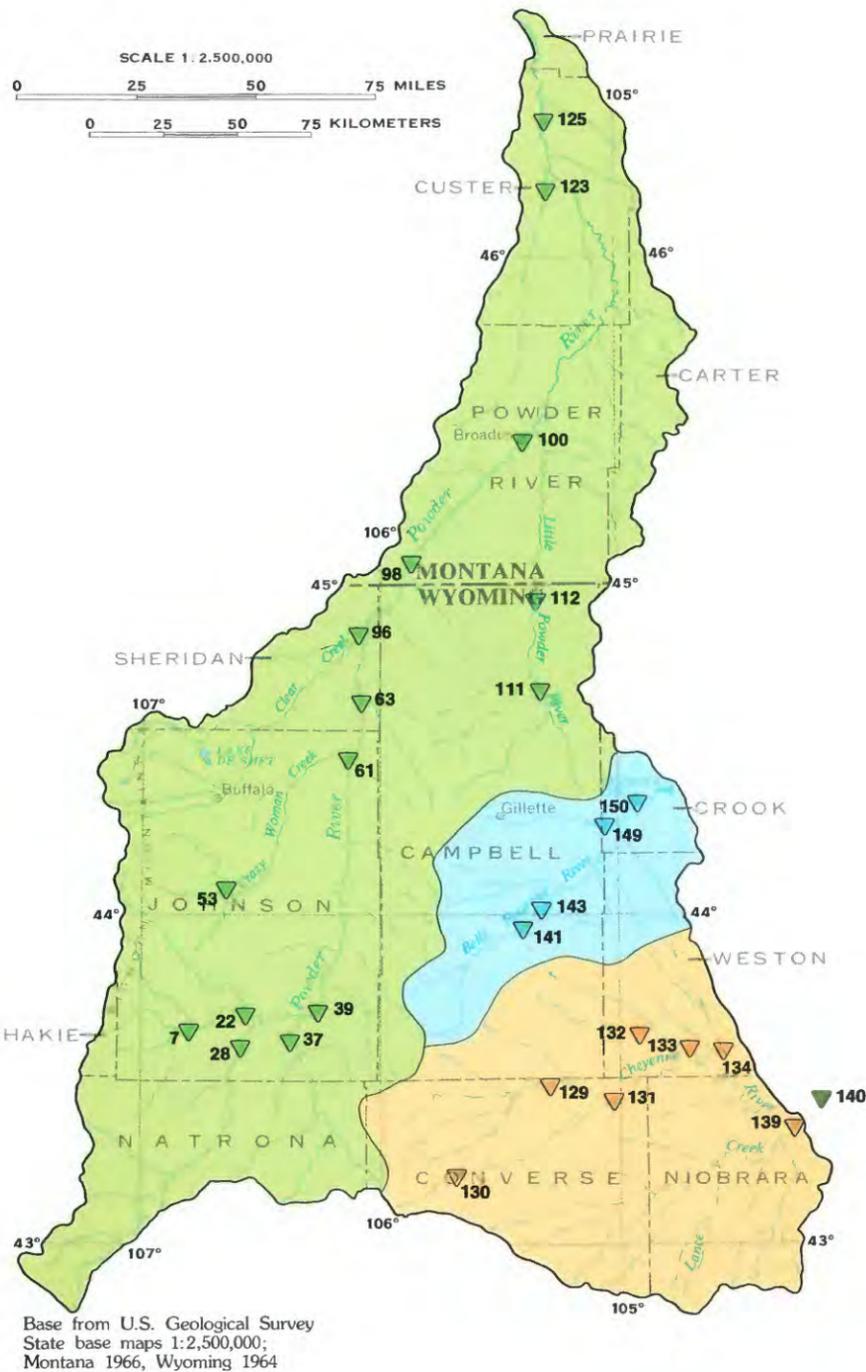
Clay-size particles comprise between 38 and 97 percent of the sediment transported out of Area 50; an average of less than 8 percent is sand.

Silt and clay comprise an average of 89 percent of the suspended sediment transported in streams of the Powder River Basin, 94 percent in the Belle Fourche, and 97 percent in the Cheyenne River basin. These values are unweighted averages from all samples (table 7.2.4-1) analyzed during the period of record at each station shown in figure 7.2.4-1. Further analysis of available data indicates that clay composes 58 percent of the suspended sediment in transport in the Powder River Basin, 77 percent in the Belle Fourche River basin, and 80 percent in the Cheyenne River basin.

Computation of the volume occupied by sediment deposited by a stream requires knowledge of the size distribution of the sediment. The location of deposition within the streambed or reservoir and determination of hydraulic characteristics of that

deposit may be inferred from particle-size data. Information regarding sediment sources and the flow characteristics of the stream also may be obtained.

Particle sizes in deposits tend to become more uniform as median particle size decreases; therefore, deposits of material where sediment particles are about clay-size generally have greater porosity and smaller initial specific weight than deposits composed mostly of sand sizes. A clay deposit also will generally occupy a larger volume per given weight of material than will a sand deposit. The number of suspended-sediment samples for each sampling station for which particle-size distributions, the average composition of the samples, and the specific weight of a deposit of that composition were determined are listed in table 7.2.4-1.



Base from U.S. Geological Survey
State base maps 1:2,500,000;
Montana 1966, Wyoming 1964

Figure 7.2.4-1 Size distribution of fluvial sediment.

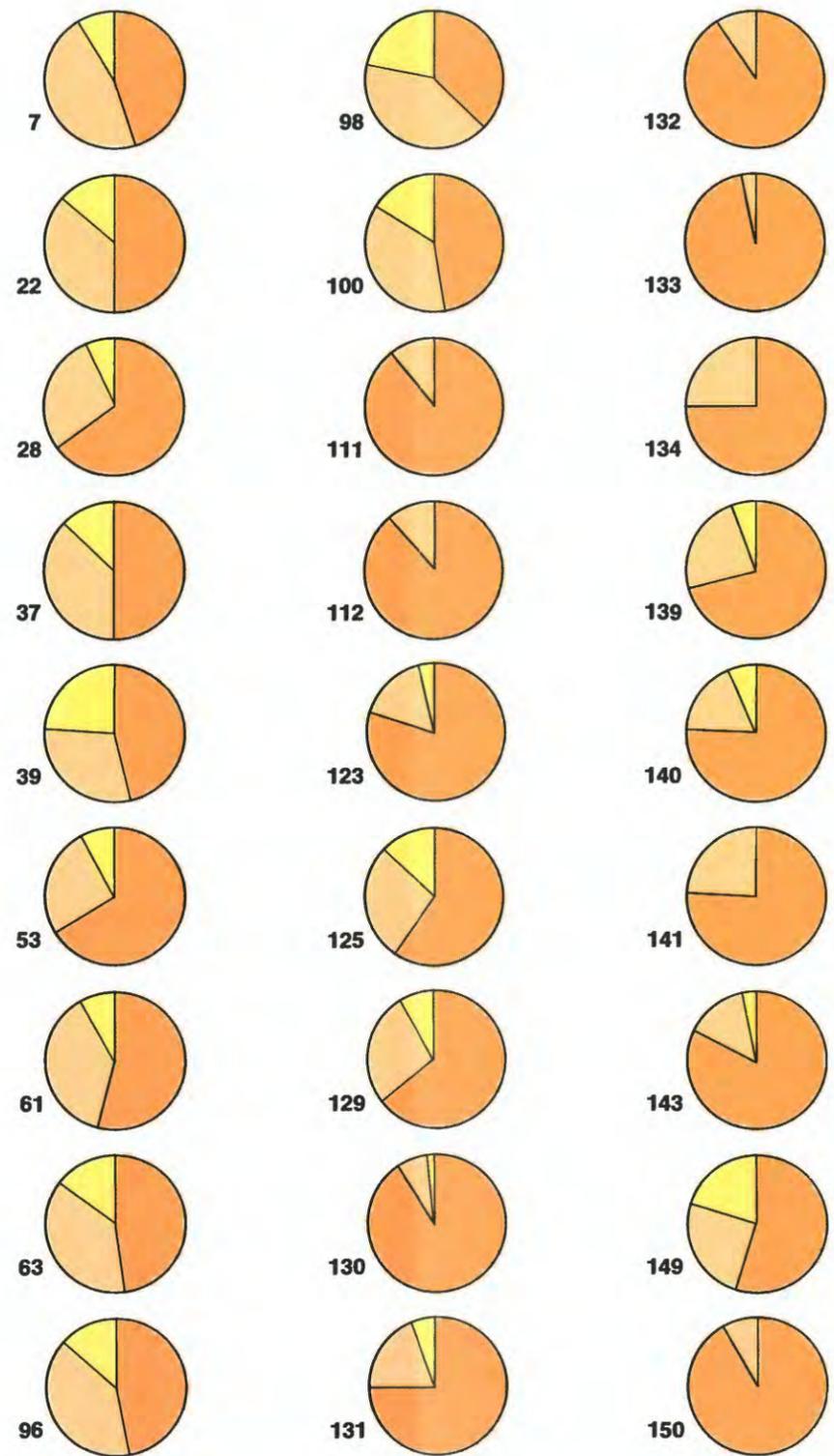


Table 7.2.4-1 Size distribution and specific weight of fluvial sediment.

Station number	Number of samples	Average composition (percent)			Specific weight ¹ (pounds per cubic feet)
		Clay	Silt	Sand	
Powder River Basin					
7	64	42	49	9	53
22	52	50	38	12	51
28	101	64	30	6	44
37	12	50	38	12	50
39	87	46	35	19	54
53	8	66	26	8	44
61	45	54	38	8	48
63	300	47	38	15	58
96	42	47	39	14	52
98	7	38	40	22	58
100	27	47	37	16	53
111	6	89	11	0	34
112	12	87	13	0	35
123	18	78	18	4	39
125	80	60	26	14	48
Belle Fourche River basin					
141	6	76	24	0	38
143	3	88	10	2	35
149	3	54	25	21	52
150	33	90	10	0	34
Cheyenne River basin					
129	2	64	28	8	45
130	3	91	8	1	33
131	8	74	20	6	41
132	4	90	10	0	34
133	1	97	3	0	31
134	1	75	25	0	39
139	119	70	25	5	42
140	40	77	16	7	40

¹ Based on average composition

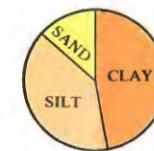
EXPLANATION

PARTICLE SIZE BASED ON DIAMETER

Sand--Coarser than 0.062 millimeter

Silt--0.004 to 0.062 millimeter

Clay--Finer than 0.004 millimeter



STATION AND NUMBER

7.0 SURFACE-WATER QUALITY--Continued

7.3 Biology

7.3.1. Bacteria

Bacteria Concentrations are Small Throughout Area

Small concentrations of fecal coliform and fecal streptococci bacteria indicate little pollution from warm-blooded animals.

The median value of fecal coliform bacteria did not exceed 600 colonies per 100 milliliters of water, and the median value of fecal streptococci bacteria did not exceed 400 colonies per 100 milliliters at the stations shown in figure 7.3.1-1. The median value is the value for which 50 percent of the sample values are greater and 50 percent are smaller.

The two primary sources of fecal bacteria in Area 50 are fecal waste from livestock and wildlife, and human waste from sewage plants or individual septic systems. Because there are relatively few people and livestock in the area, fecal pollution contributed to streams by humans and animals is small. The probable sources of fecal bacteria at most stations are fecal wastes of livestock and wildlife that graze in the area and drink from streams.

Fecal coliform and fecal streptococci bacteria originate in the gastrointestinal tract of warm-blooded animals, and are not adapted to aquatic environments. Their presence does not constitute a health hazard; they are sampled as indicators of the

possible presence of pathogens, or disease-causing organisms. The half-life (length of time during which one-half of the remaining bacteria are destroyed) of fecal coliform and fecal streptococci bacteria outside the gastrointestinal tract is about 24 hours (Mallard, 1981). Therefore, the bacteria measured in samples were deposited a relatively short time prior to sampling. The distance of the sample bacteria from their source is dependent on the time of travel of the water in the stream.

Bacteria concentrations in the streams of the area will be affected to a greater degree by the population increase associated with increased mining of coal and other energy minerals than by the mining itself. Owing to the short life-span of the bacteria and the ephemeral flow of many of the streams, increased sewage effluent in streams will cause local, rather than regional, increases in bacteria concentrations. There is a demand for the sewage effluent of Gillette for industrial uses and by the local ranchers for irrigation.

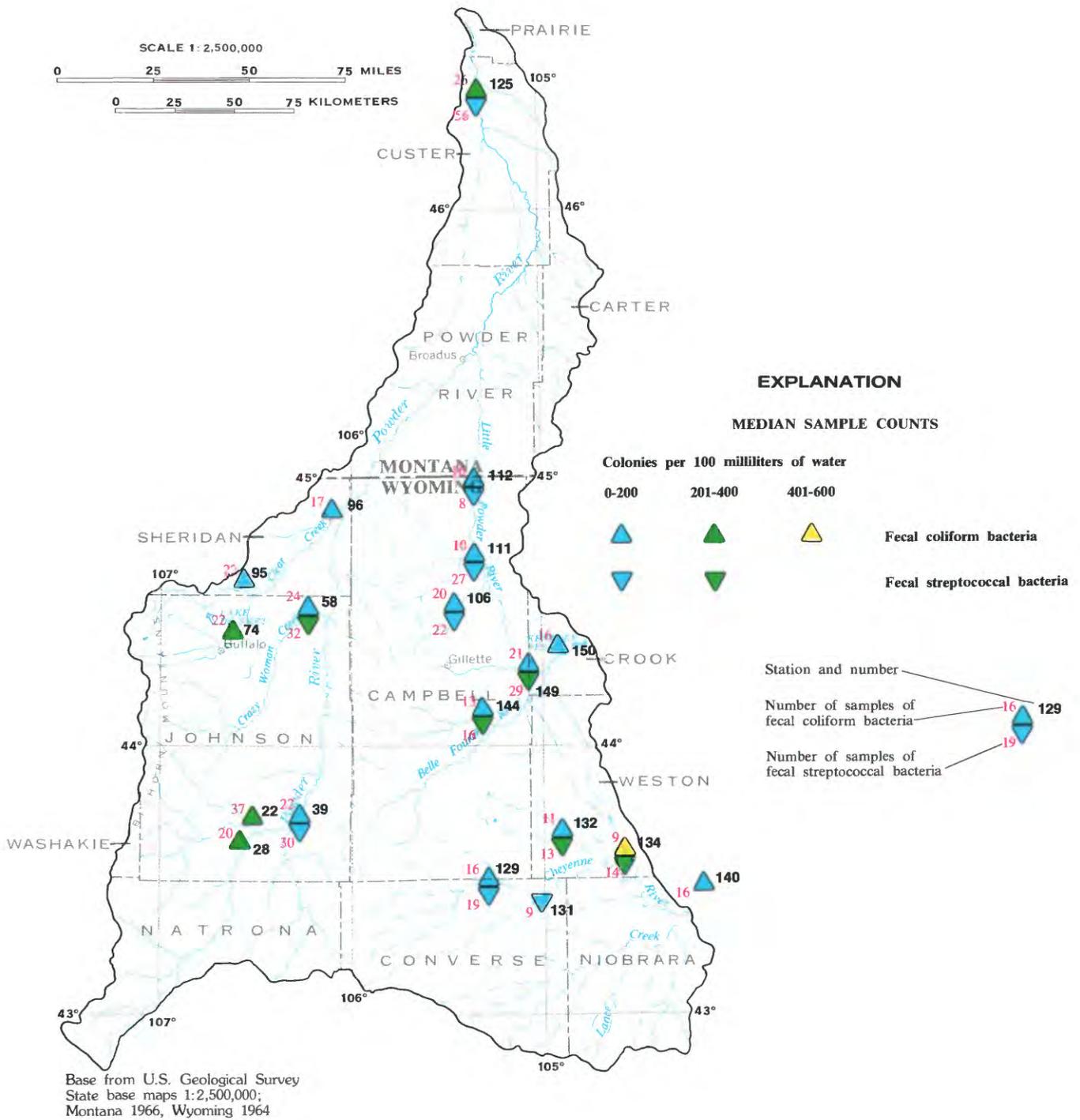


Figure 7.3.1-1 Fecal coliform and fecal streptococcal bacteria concentrations.

7.0 SURFACE-WATER QUALITY--Continued

7.3 Biology--Continued

7.3.2 Algae

Algae are Indicators of Water Quality

The productivity and relative abundance of diatoms, green algae, blue-green algae, and euglenoids within the periphyton and phytoplankton communities indicate organic enrichment in many streams of the area.

Diatoms are a common algae in periphyton and phytoplankton communities of the area, and commonly dominate the communities of perennial streams. Green algae, blue-green algae, and euglenoids commonly dominate the periphyton and phytoplankton communities of ephemeral and intermittent streams and perennial streams that receive sewage effluent from towns. Dominance of an algal community by green and blue-green algae or euglenoids generally is considered to be a sign of organic enrichment, particularly nutrients, whereas a relatively diverse diatom community generally predominates in unenriched environments. Because few of the streams in the area receive sewage effluent, the commonness of green and blue-green algae, and euglenoids probably is a result of the natural environmental conditions and fecal waste from livestock and wildlife. The location of stations sampled for phytoplankton (algae suspended in the water) and periphyton (algae attached to objects, such as rocks and logs) is shown in figure 7.3.2-1.

Phytoplankton concentrations in samples from two sites, one on an ephemeral stream reach and one on a perennial stream reach, are indicated in figure 7.3.2-2. The ephemeral stream reach contains stagnant pools that serve as waterholes for livestock; the

perennial stream reach also receives livestock use, but the effects are diluted by the flowing water. Nutrients contributed by the livestock stimulate algal growth, particularly the growth of green and blue-green algae, and euglenoids.

The types or concentrations of algae in periphyton and phytoplankton communities could be affected by coal mining through changes in water quality or quantity. In a study of streams in southeastern Montana, Bahls (1980) found that salinity (as indicated by specific-conductance values of less than 6,400 micromhos) did not appear to adversely affect periphyton community structure; he also identified previous work (Bahls, 1979) that showed negative effects on diatom diversity from salinity (as indicated by specific-conductance values in excess of 7,500 micromhos). It is important to know how coal mining might affect algae, because algae are at the base of the aquatic food chain. Through photosynthesis, algae are the primary producers. Algae are a part of the diet of many fish; algae also serve as food for animals, such as insects in streams or zooplankton in lakes, which in turn are food for larger animals, such as fish.

7.0 SURFACE-WATER QUALITY--Continued

7.3 Biology--Continued

7.3.3 Invertebrates

Invertebrate Communities are Indicators of Water Quality and Quantity

The invertebrate communities of streams receiving sewage effluent are different from the communities of other streams; the invertebrate communities inhabiting ephemeral streams are different from those of perennial and intermittent streams.

The invertebrate communities of Clear Creek and Donkey Creek reflect degradation of water quality by inflow of sewage effluent. Two invertebrate taxa (Tubificid worms and Chironomid bloodworms) that adapt to oxygen-deficient, organically enriched environments dominated invertebrate samples collected at site 158 on Donkey Creek. The invertebrate community composition in Clear Creek downstream from a sewage treatment plant (sites 165-168) was different from that upstream (sites 160-163), but the differences were less pronounced than for Donkey Creek because of dilution of the sewage by Clear Creek. The locations of invertebrate sampling stations and sites are shown in figure 7.3.3-1.

The invertebrate communities of streams in the area can be used as indicators of the water quantity--the relative volume and pattern of flow. The communities inhabiting ephemeral streams are adapted to life in lentic (standing water) habitats, such as pools. The body structure, feeding habits, and respiratory system of invertebrates adapted to lentic habitats are different from those of invertebrates adapted to life in lotic (flowing water) habitats, such as riffles in perennial or intermittent streams. Invertebrates adapted to lentic habitats can survive in the pools of perennial or intermittent streams, but invertebrates adapted to lotic habitats have a large mortality rate in lentic habitats.

Densities and community composition of invertebrates upstream and downstream from a coal mine are shown in figure 7.3.3-2. Although not

tested statistically, the density and diversity of the invertebrate community generally appear to be at least as large downstream from the mine as upstream. Between the stations, the stream receives intermittent flow from a tributary, is diverted around the mine, and receives infrequent discharge pumped from the mine pit. Any one or a combination of these actions may have an effect on the invertebrate communities at the station downstream from the mine. The communities at either station are not atypical of communities in lentic habitats in other streams of the area.

In contrast to coal areas in the eastern United States, mine pumpage or leachate from coal mines in Area 50 generally does not contain toxic compounds in concentrations large enough to be lethal to invertebrates. Wangsness (1977) and Rockett (1976) found that invertebrate communities had developed in strip-mine ponds during the 20 to 30 years after they had been abandoned, but some differences still existed between the communities of natural ponds in the area and those of the abandoned mine ponds.

The invertebrate communities of small streams within or near Area 50 have been studied by Baril and others (1978), Wesche and Johnson (1980), and Wangsness and Peterson (1980). A photograph of an invertebrate, a caddisfly larva, from a small stream is shown in figure 7.3.3-3. Rehwinkel (1978) noted that invertebrates are not abundant in the Powder River in Montana.

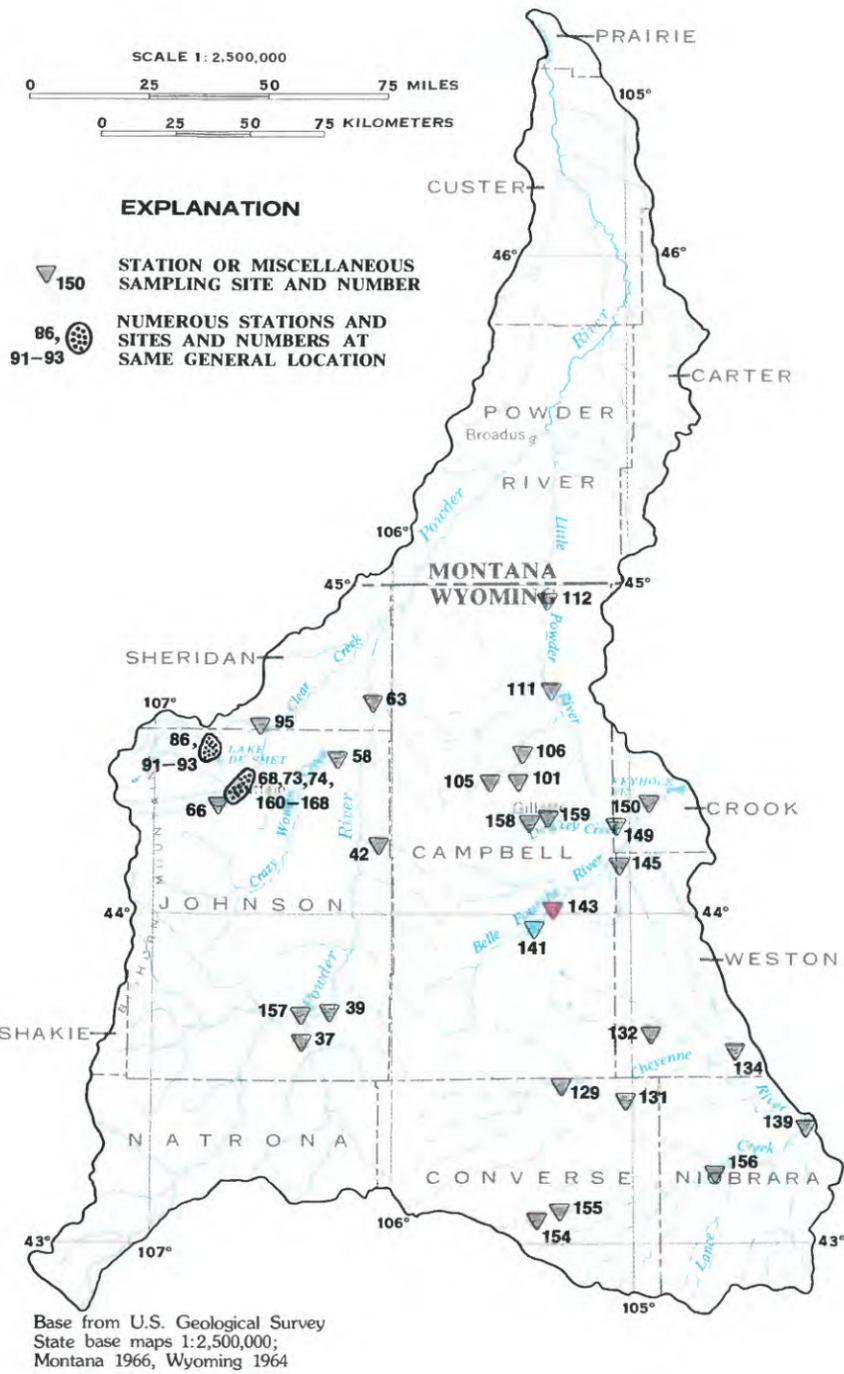


Figure 7.3.3-1 Location of stations or miscellaneous sampling sites for invertebrates.

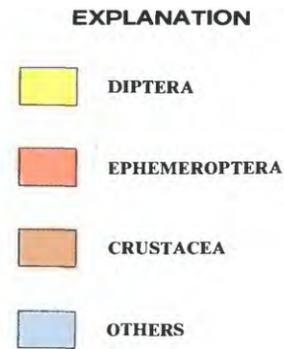


Figure 7.3.3-3 A caddisfly larva (x4) removed from its case. Found in Box Creek (site 154).

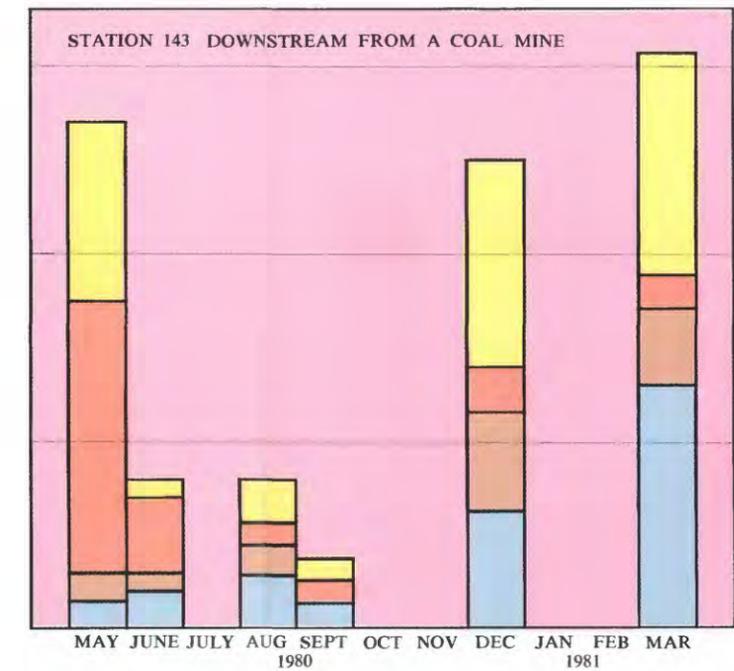
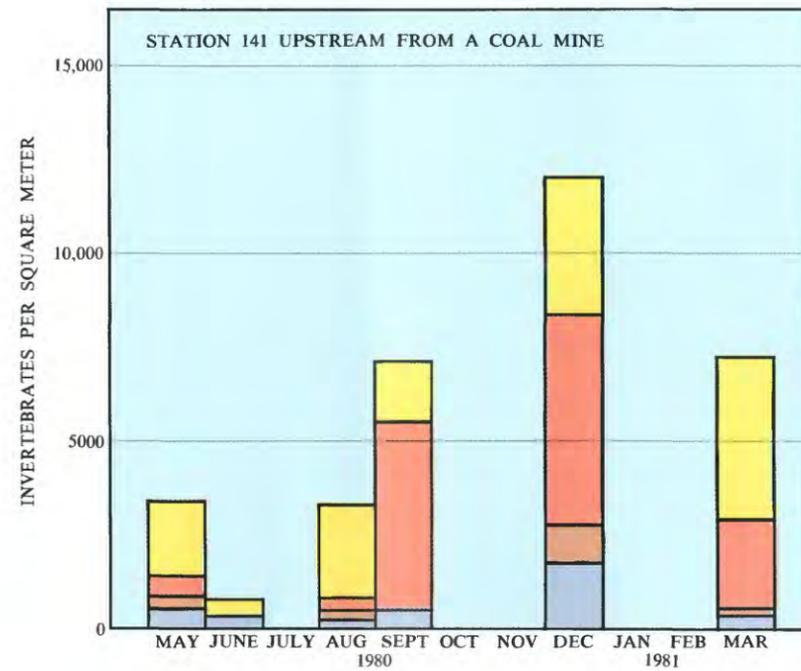


Figure 7.3.3-2 Invertebrate densities and community compositions of two ephemeral stream reaches of the Belle Fourche River.

7.0 SURFACE-WATER QUALITY--Continued

7.3 Biology--Continued

7.3.4 Fish

Mountain Streams Support Cold-Water Game Fish

Cold-water game fish are found in mountain streams, but generally not in plains streams; warm-water game fish are found in a few plains streams, but not in mountain streams.

Streams in the Bighorn Mountains support cold-water game fish such as rainbow trout, brown trout, brook trout, whitefish, and grayling. The mountain streams have the best ratings as fishery resources, based on the stream-classification system shown in figure 7.3.4-1. The classification system was designed by the U.S. Fish and Wildlife Service in cooperation with the Wyoming Game and Fish Commission (U.S. Fish and Wildlife Service, 1978) and with the Montana Department of Fish, Wildlife, and Parks (U.S. Fish and Wildlife Service, 1980). The system includes the following criteria to evaluate permanent streams, their tributaries, and certain intermittent streams as fishery resources: (1) The presence of endangered or threatened species as designated by the States or Federal government, (2) species of high interest to the State, and (3) habitat restoration or mitigation potential. The Middle Fork Powder River, the only stream to receive a Class I designation (highest value as a fishery resource), has been inventoried by the National Park Service for possible designation as a National Wild and Scenic River. The Middle Fork of the Powder River also received a Class I designation (highest) from a rating system used by the Wyoming Department of Environmental Quality (1982).

A few perennial streams in Area 50 support

warm-water game fish, but most plains streams, especially intermittent and ephemeral plains streams, do not support a fishery resource. Warm-water game fish found in the plains streams include channel catfish, black bullheads, largemouth bass, bluegills, and sunfish. Non-game fish such as white suckers, carp, redhorse, and bait minnows also are found in plains streams. Baxter and Simon (1970) noted the presence of about 20 species of fish in plains streams of this area. Rehwinkel (1978) found that flathead chubs and sturgeon chubs were the most common species in the Powder River, and that warm-water game fish were present in small numbers.

The ephemeral or intermittent character of the streams in areas of active coal mining inhibits the development of a fishery resource, with the exception of the Little Powder River. The Little Powder River is perennial, drains an area of active coal mining (fig. 7.3.4-1), and supports a limited fishery resource. Wesche and Johnson (1980) studied four small streams near the areas of active coal mining and concluded that they could not be considered practicable as sport fisheries, even though warm-water game fish were present, because of the small numbers and sizes of the fish.



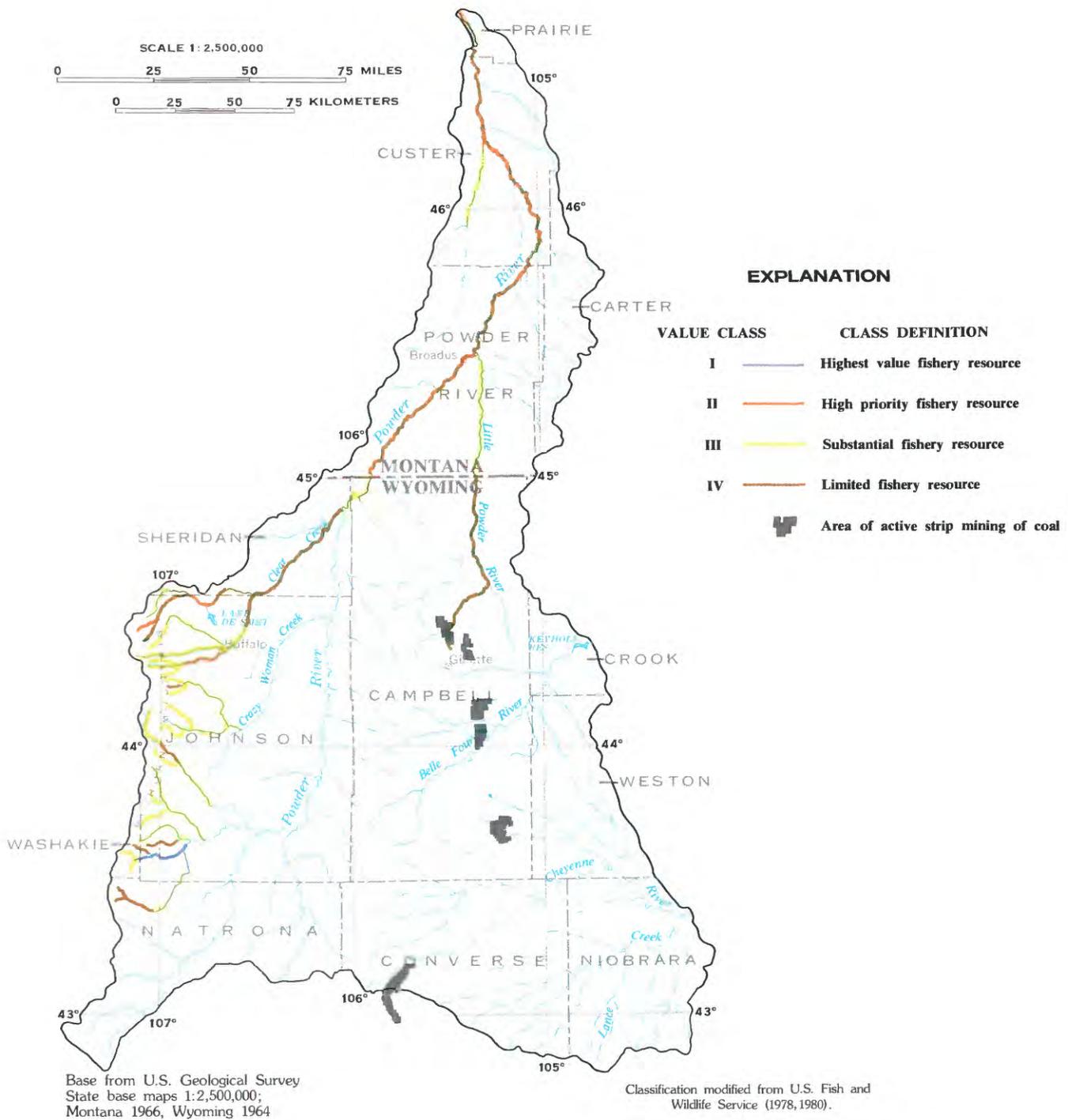


Figure 7.3.4-1 Fishery-resource classification.

7.0 SURFACE-WATER QUALITY--Continued

7.4 Temperature

Temperature is a Significant Factor of Water Quality

Stream temperature affects rates of chemical reactions and biological processes; in Area 50 temperatures can range from 0 degrees Celsius in winter to about 25 degrees Celsius in summer.

Observations of water temperature are made at surface-water stations whenever discharge measurements are made. These measurements generally are made monthly; a summary of the temperature data was prepared by Lowham and others (1975). Water temperatures also are obtained daily, monthly, or less frequently when water-quality samples are collected. These data are published in annual reports of the U.S. Geological Survey (1983a, 1983b).

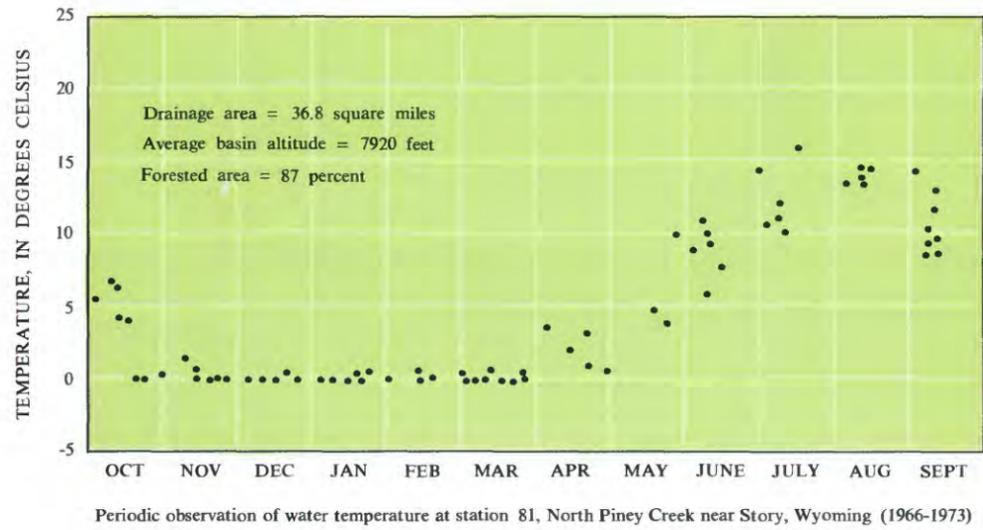
The temperature of water in streams of Area 50 can range from 0 degrees Celsius during winter to 25 degrees Celsius or more during late summer. Observations of water temperature for two example streams are shown in figure 7.4-1. North Piney Creek (station 81) drains a mountainous area of relatively high altitude, whereas Lance Creek (station 139) drains an area of lower altitude in the plains. Water temperatures of North Piney Creek are lower and have less variability than those of Lance Creek because of differences in the climatic and physical conditions of their drainage basins.

Temperature determines the physical form of water (solid, liquid, or vapor) and also affects most physical processes and chemical reactions that take place in water. For example, as water temperature increases, dissolved oxygen decreases because of the

decreased saturation capacity of the water and 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, temperature affects water use and aquatic life.

Water temperature is important to many water users. It is important to the sportsman, as it is a vital factor affecting fish life. It is important to agricultural users, as temperature of irrigation water can affect crop production. Industrial water users commonly use water for cooling purposes and need to consider stream temperature in plant design and operation.

The temperature of water in streams is significantly affected by the surrounding conditions. Climatic conditions that affect water temperature include solar radiation, wind speed, air temperature, and vapor pressure. Important physical conditions 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.



EXPLANATION

▽ 81 STATION AND NUMBER

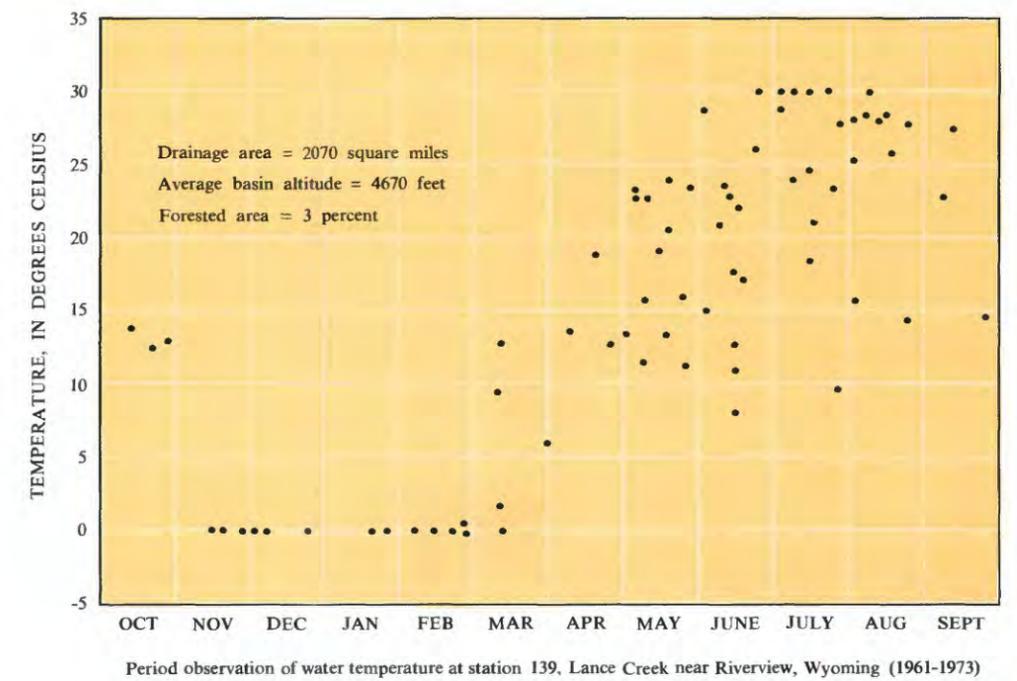
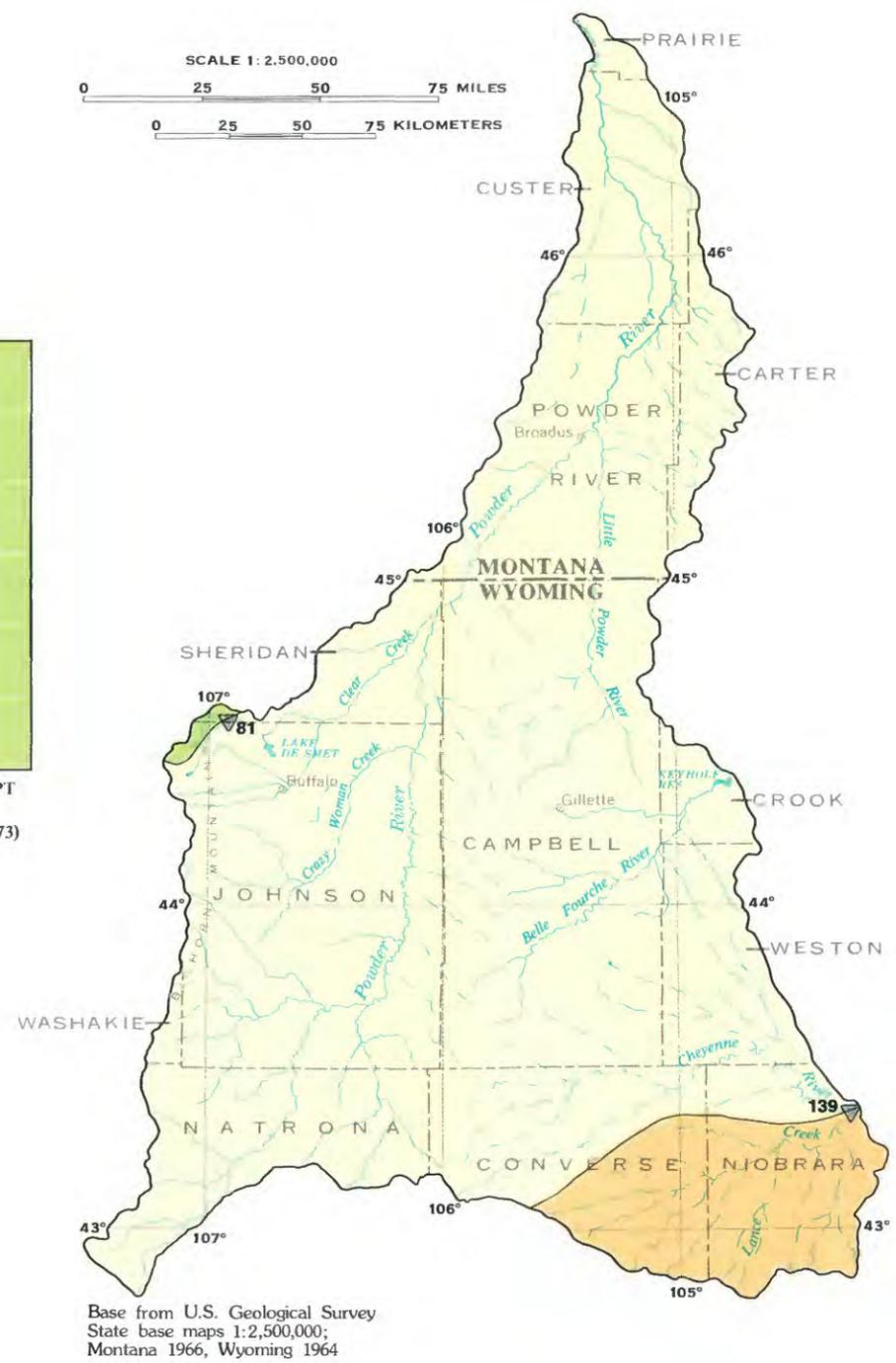


Figure 7.4-1 Observations of water temperature for two example streams.

8.0 GROUND WATER

8.1 Ground-Water Data

Data Available for about 3,000 Wells

Data collected since the mid-1970's emphasize hydrology of small areas and regional aquifer systems.

The distribution of ground-water-data sites in Area 50 is indicated in figure 8.1-1. The sites shown are those for which quality-of-water, well-yield, water-level, or geologic data are stored in the computer files of the U.S. Geological Survey as of September 1982. These files are continually expanded and revised as the result of studies in the area, but to date (1983) not all the available data are in the files.

Most ground-water data were collected during interpretive studies. The earliest studies in the area by the Geological Survey were by Renick (1924) and Riffenburg (1926). During the mid-1950's, several ground-water studies in Montana and Wyoming were completed by the Geological Survey as part of a special Federal program for the development of the Missouri River Basin. A description of the ground-water resources near Kaycee, Wyo., by Kohout (1957) was the only one of these studies that included part of Area 50.

The Montana Bureau of Mines and Geology conducted some of the earliest studies in the area, including those by Perry, (1931, 1932, and 1935). A cooperative program between the Geological Survey and the Montana Bureau of Mines and Geology began in 1956. Studies that included part of Area 50 were those of the Cedar Creek anticline in eastern Montana (Taylor, 1965) and ground-water resources of the northern Powder River valley (Taylor, 1968).

A cooperative program between the Wyoming State Engineer and the Geological Survey began in 1945. As part of this program, reconnaissance ground-water studies, which include all or part of Area 50, were completed in Crook County (Whitcomb and Morris, 1964); Johnson County (Whitcomb and others, 1966); Natrona County (Crist and Lowry, 1972); and Sheridan County (Lowry and Cummings, 1966). A similar study of Campbell County was started; however, because the State Engineer recognized the need for prompt reconnaissance coverage of a larger area to provide information needed for coal development, the study was expanded to include all northeastern Wyoming. The result was a report by Hodson and others (1973) (fig. 8.1-2).

With the subsequent increase in coal development in the area, a large quantity of ground-water data was collected by industry, universities, and government agencies.

Most of these data were collected to support studies to describe the hydrology and possible environmental impacts in relatively small areas, such as a proposed mine. The government agencies and universities that were most active in acquiring ground-water data are listed in section 10.2.

Much of the ground-water data collected in Campbell County, Wyo., is pooled through the Gillette Area Ground Water Monitoring Organization (GAGMO), an organization consisting principally of mining companies. Water levels in 800 wells completed in the Wyodak-Anderson coal were reported to the organization in 1981, resulting in a compilation of water-level data for most of Campbell County, Wyo., close to the coal outcrop. A copy made of this report is in the Wyoming State Library in Cheyenne.

The Madison Limestone was recognized as a potential source of water for coal development (U.S. Geological Survey, 1975); consequently, during 1975-80, the Geological Survey studied the regional aquifer in parts of Montana, North and South Dakota, Wyoming, and Nebraska (fig. 8.1-2). This regional study was a forerunner of Regional Aquifer System Analysis (RASA) studies by the Geological Survey. The results of the Madison Limestone study are described in a series of reports. Data for the Geological Survey test wells were reported by Blankennagel and others (1977) and by Brown and others (1977). The geology, geochemistry, and hydrology of the aquifer system will be described in Geological Survey Professional Paper 1273. Two chapters have been published: MacCary and others (1983) and Thayer (1983). Five remaining chapters have been released to the open files, pending publication: MacCary (1981), Peterson (1981), Brown and others (1982), Downey (1982a), and Busby and others (1983).

The Northern Great Plains RASA (fig. 8.1-2) was selected as one of the first of the series of RASA studies because of the extensive energy resources in the study area (U.S. Geological Survey, 1979e). This RASA project was completed in 1982. A few of the principal reports about results of the Northern Great Plains study are still in preparation (1983). Selected reports of results to date are: Lobmeyer (1980), Levings (1981a, 1981b), Levings and others (1981), Downey (1982a, 1982b), Larson and Daddow (1984), and Lenfest (1984).

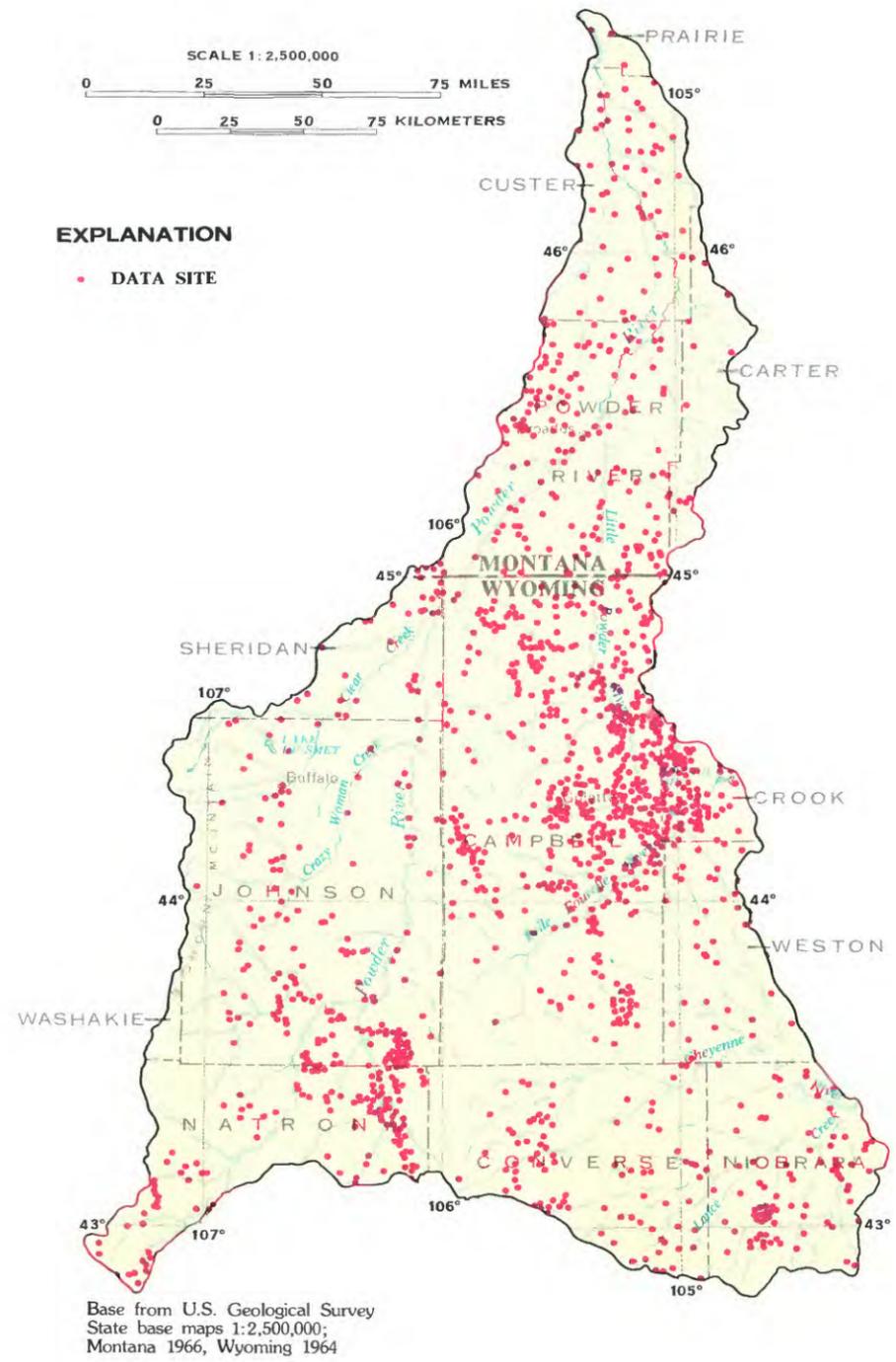


Figure 8.1-1 Location of ground-water data sites in Area 50.

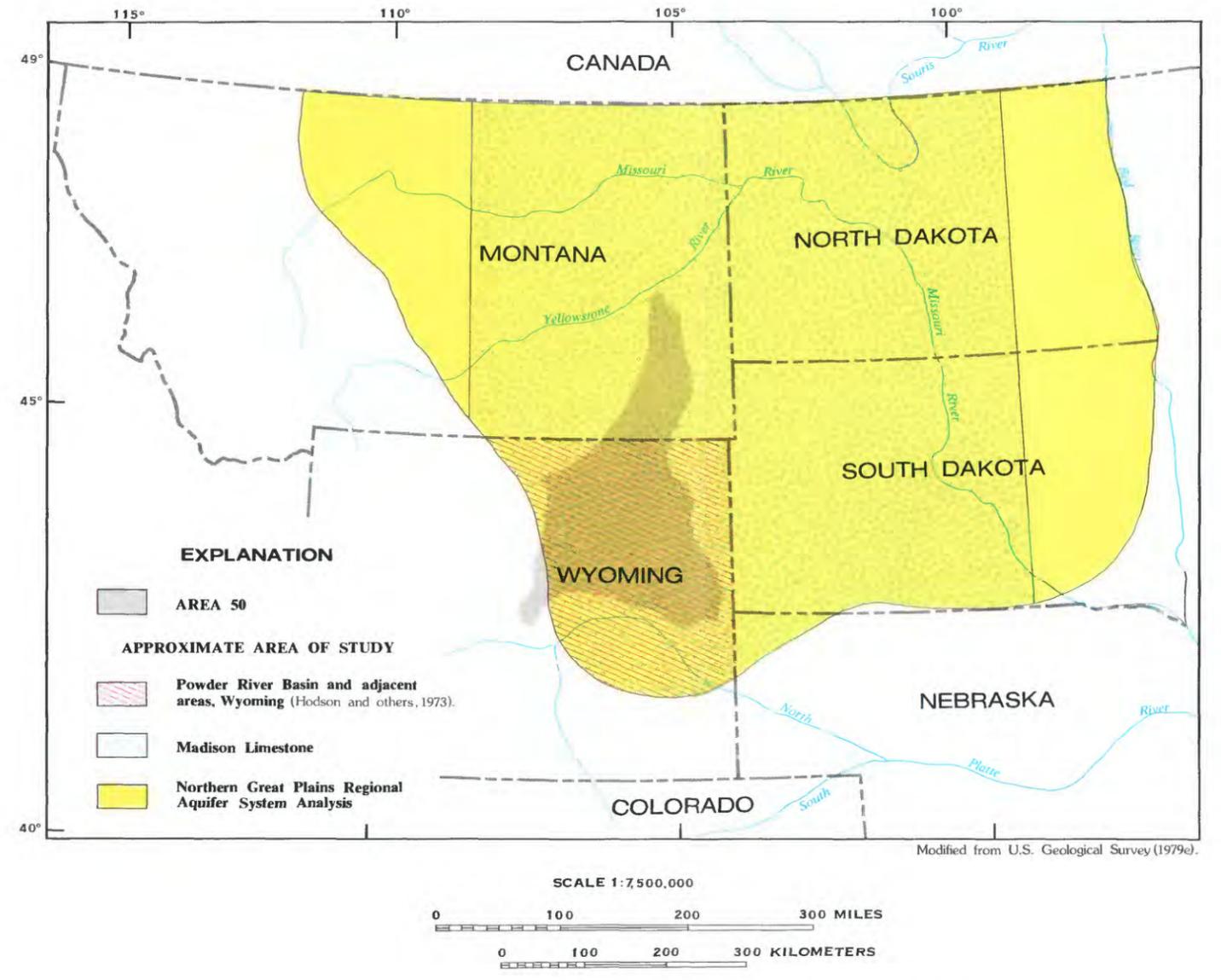


Figure 8.1-2 Location of Area 50 and large-scale ground-water studies that included most of the area.

8.0 GROUND WATER--Continued

8.2 Availability

Ground Water is Available Throughout Area 50

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.

The shallowest bedrock in most of the area consists of lower Tertiary and Upper Cretaceous sedimentary rocks. Enough water for stock and domestic use can be obtained in most of the area from wells less than 500 feet deep. Wells commonly are drilled deeper, however, to produce yields such as shown in figure 8.2-1. Flowing wells can be developed principally in the valleys of the major streams such as the Powder, Little Powder and Cheyenne Rivers. Yields greater than 200 gallons per minute can be developed locally from wells less than 1,000 feet deep, and nearly everywhere in Area 50 (except in the mountains) from deeper wells because of the large saturated thickness of the rocks.

Paleozoic sandstone and carbonate rocks, which include the Madison Limestone, are usually considered where large ground-water supplies are sought. Flows of 7,000 and 3,400 gallons per minute were reported for two artesian wells completed in the Madison Limestone at Midwest in northeastern Natrona County, Wyo. (Crist and Lowry, 1972, p. 42). Although yields from the carbonate rocks can be several thousand gallons per minute, they also can be only several tens of gallons per minute. The large yields from carbonate rocks in Area 50 and adjoining areas are possible only as a result of large secondary permeability (which does not occur everywhere) or because of large artesian head above land surface, which occurs at places near the mountains.

The Upper and Lower Cretaceous shale on the east side of Area 50 has the least potential for developing a water supply in the area. The rocks on the western side of the basin have a somewhat greater water-yielding potential than those on the eastern side, because they include the Frontier and Mesa-verde Formations, which contain thick sandstone. In most of the area, wells for stockwater are about 1 mile apart. Deep water wells are drilled through shale on the east side of the area into the Lakota Formation. Distribution systems for stock water, commonly tens of miles long, are then constructed from a single well. Because of the great depth to the older rocks in most of the area, water wells have not been drilled into them in the deep parts of the basin. Therefore, the availability of water from these rocks is relatively unknown.

Alluvial deposits are found along even the smallest streams but are too narrow to show in figure 8.2-1. The thickest and coarsest-grained alluvium occurs near the mountains where well yields of as much as 500 gallons per minute are possible. The alluvium distant from the mountains is mostly fine grained and the saturated thickness is generally less than 20 feet, so large water yields are not possible. The largest reported yield from the alluvium of the Powder River is 90 gallons per minute (Whitcomb and others, 1966, p. 47).



Fish hatchery spring near Story, Wyoming.



Artesian flow from lower Tertiary sandstone.

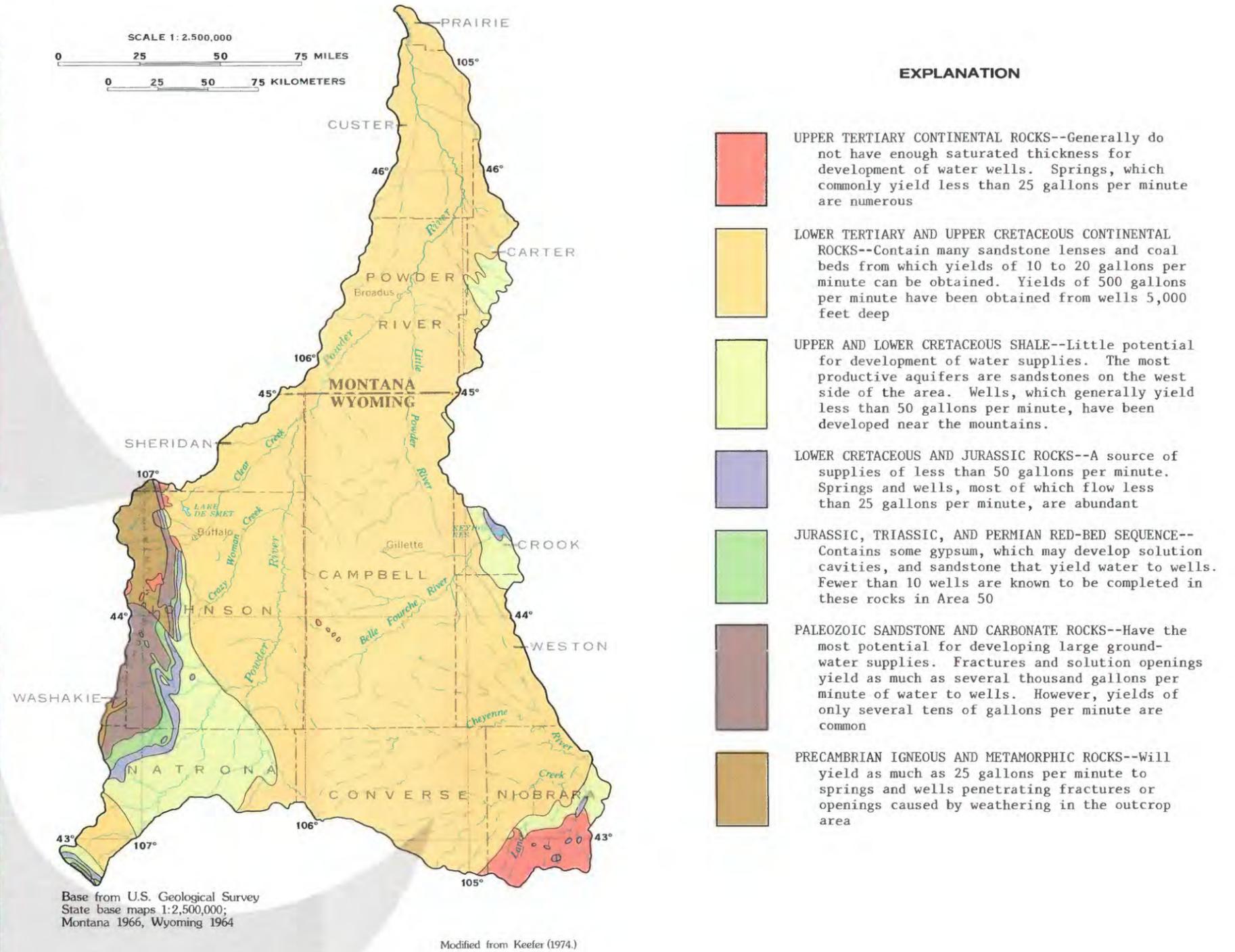


Figure 8.2-1 Availability of ground water.

8.0 GROUND WATER--Continued

8.3 Recharge and Movement

Three Aquifers Show Distinctive Patterns of Ground-Water Movement

Recharge to the principal aquifers occurs mainly in the outcrop areas near the southern, western, and eastern boundaries of Area 50. Small quantities of water probably move out of the area in the Madison and Lower Cretaceous aquifers; movement in the coal aquifers is complex.

Water movement in an aquifer generally is inferred from potentiometric-surface maps such as shown in figure 8.3-1. Movement from recharge area to discharge area generally is at right angles to the potentiometric contours. However, in very permeable zones such as the fractures and solution openings that occur in the Madison aquifer, movement of water may follow the fractures and in some instances may be nearly parallel to the contours.

The Madison aquifer includes the Mission Canyon and Lodgepole Limestones of the Madison Group in Montana, and the Madison and Pahasapa Limestones in Wyoming. The map of the potentiometric surface of water in the Madison aquifer (fig. 8.3-1) shows that recharge to the aquifer occurs in the uplifted areas of the Black Hills and the Bighorn and Laramie Mountains in or adjacent to the study area.

Water movement in the Madison aquifer is locally controlled by structural features associated with zones of high permeability along the Bighorn Mountains and the Black Hills. West of the Black Hills, fracture zones that are very transmissive seem to divert the water to the north and south (Fitzwater, 1981) and therefore restrict the amount of flow into the center of the basin. Also, east of the Bighorn Mountains, in Johnson County, Wyo., faulting has broken the hydrologic continuity between the outcrop area and the aquifer in the basin, restricting flow into the basin (Blackstone, 1981). The potentiometric surface of the Madison aquifer seems to be flat, based on a limited quantity of data for the center of the basin. According to Swenson and others (1976), the flatness could indicate either a small quantity of flow or a larger transmissivity. A small quantity of flow could be due to a combination of (1) less movement because of the large permeability zones diverting the flow northward, and (2) discharge into the overlying Lower Cretaceous aquifer. Larger transmissivity would result from the high water temperatures and northward thickening of the formation. The principal discharge area for the Madison aquifer is in eastern North and South Dakota and the Province of Manitoba, Canada (Downey, 1982a). Leakage into the overlying Lower Cretaceous aquifer also accounts for some discharge from the Madison aquifer.

The Lower Cretaceous aquifer includes stratigraphic units from the Muddy and Newcastle Sandstones down to the Cloverly Formation and Lakota Sandstone (see fig. 3.6.1-3). Recharge to this aquifer is principally due to leakage from the underlying Madison aquifer, as indicated

in a study by Dwight T. Hoxie and Kent C. Glover (U.S. Geological Survey, written commun., 1983) and shown in figure 8.3-2. The Lower Cretaceous aquifer is also recharged in the uplifted areas of the Black Hills and the Bighorn and Laramie Mountains in or adjacent to the study area. The closed circles in the potentiometric surface at the Wyoming-Montana State line are a low-pressure anomaly. This anomaly is the principal control of water movement in the aquifer. Hoxie and Glover (written commun., 1983) report that 76 percent of the water movement in the Lower Cretaceous aquifer is toward the low-pressure anomaly. In the trough in southeastern Johnson County, Wyo., ground water moves to replace oil pumped from the Lower Cretaceous formations at the Salt Creek oil field in northeastern Natrona County, Wyo.

Water movement in the shallow aquifers in the Powder River Basin, Wyoming (most of Area 50) is best described by movement in the coals, as these are the most extensive aquifers. Maps of the potentiometric surfaces for the School coal bed in Converse County, Wyo., and the Wyodak-Anderson coal bed elsewhere in the area are shown in figure 8.3-3. Most of the water-level data along the coal outcrops were obtained from the coal companies operating there. Recharge to the School and Wyodak-Anderson coal beds occurs along the outcrops, as shown on the map.

The potentiometric-surface map for the School coal bed indicates ground-water flow to the north and east. The potentiometric-surface map for the Wyodak-Anderson coal bed in figure 8.3-3 indicates movement to the north along the eastern outcrop with some discharge in the Gillette area. However, near the Wyoming-Montana border, movement is to the west in the aquifer. Because water-level data are not available to determine how the northward flow and westward flow are related, this may not be a true representation of the potentiometric surface describing regional flow.

Potentiometric maps published between 1980 and 1983 for all or a part of Area 50, in addition to those mentioned previously, include maps of the Lower Cretaceous aquifer in Montana, North Dakota, South Dakota, and Wyoming (Lobmeyer, 1980), the Judith River aquifer in Montana (Levings, 1982a), the Lakota aquifer in Montana (Levings, 1982b), the Fox Hills-lower Hell Creek aquifer in Montana (Levings, 1982c), and the Eagle Sandstone aquifer in Montana (Levings, 1982d).

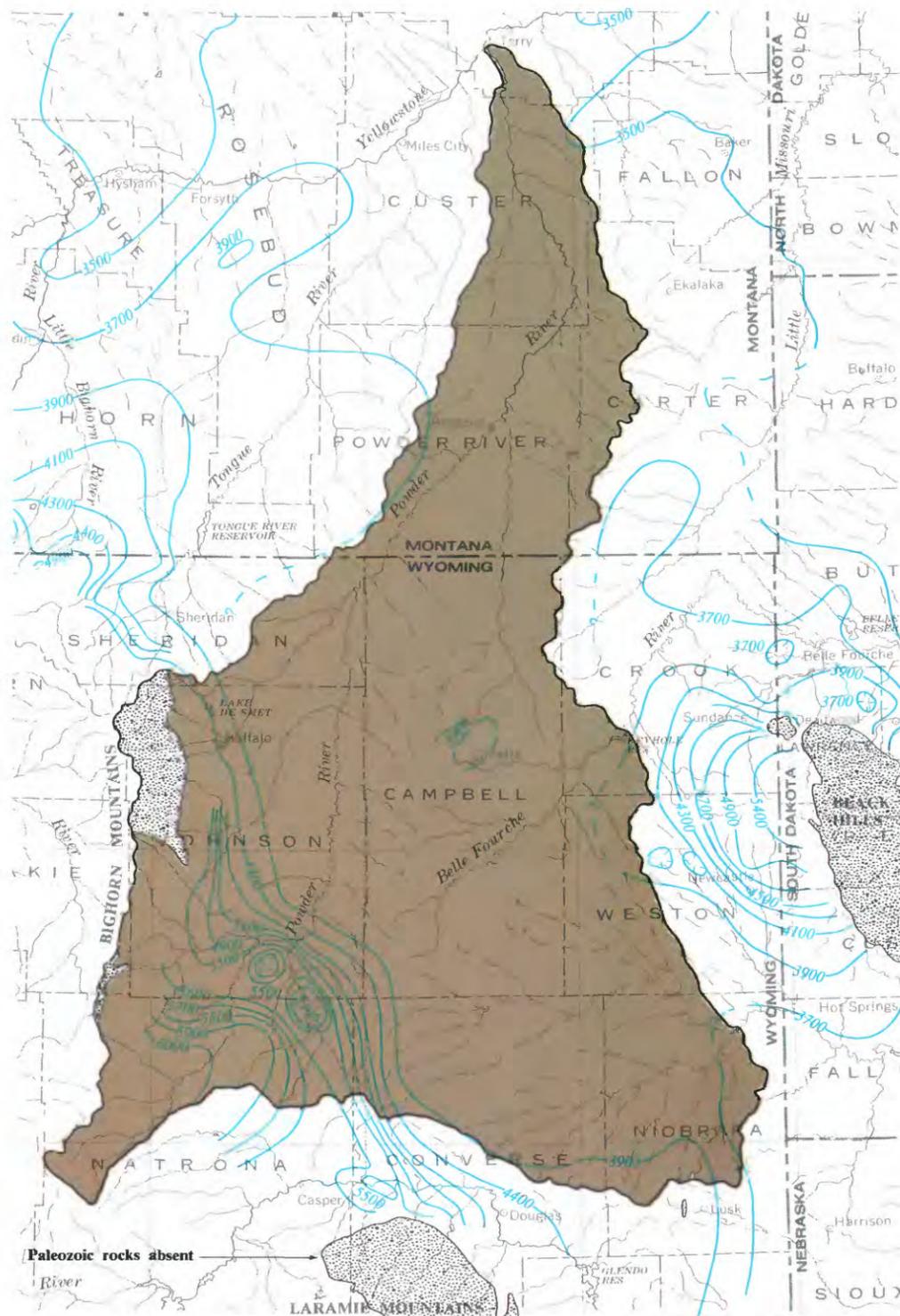


Figure 8.3-1 Potentiometric-surface map of water in the Madison Limestone.

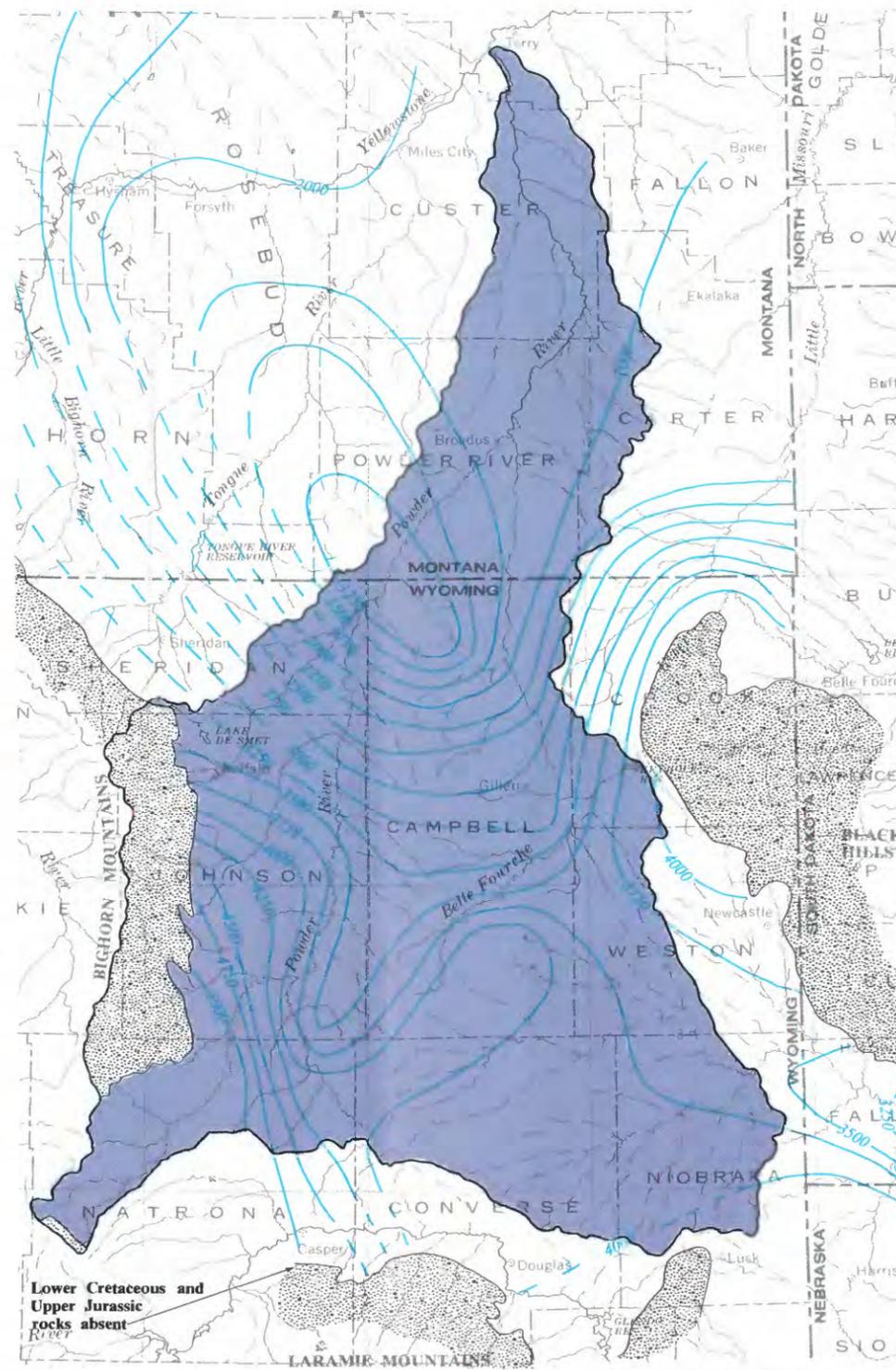


Figure 8.3-2 Potentiometric-surface map of water in the Lower Cretaceous aquifer.

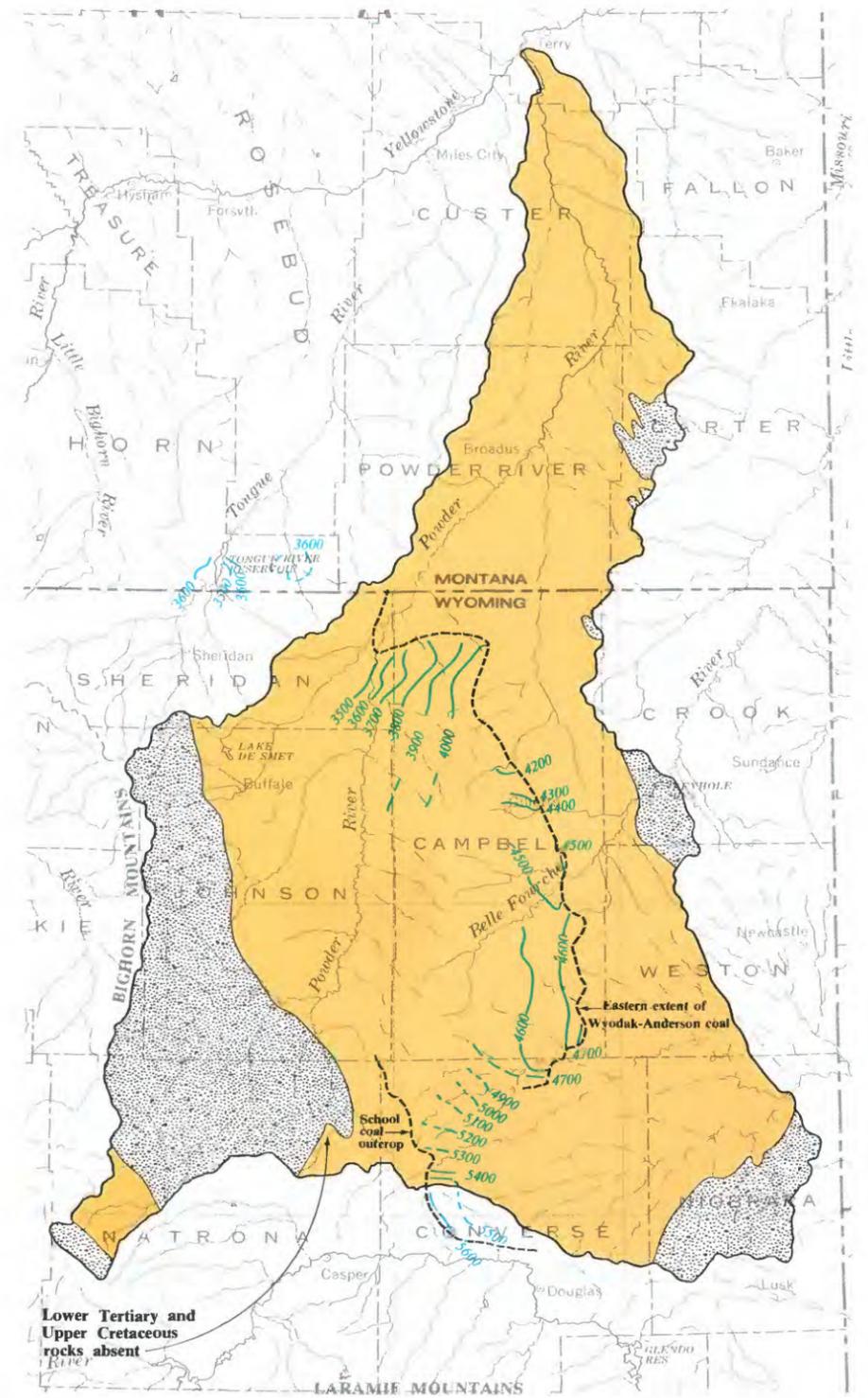


Figure 8.3-3 Potentiometric-surface map of water in the School coal bed (altitudes 4900 feet and greater) and in the Wyodak-Anderson coal bed elsewhere.

EXPLANATION
For All Figures

—4500— GENERALIZED POTENTIOMETRIC CONTOUR— Shows altitude of equivalent fresh-water head in well completed in the formation mapped. Dashed where approximately located. Contour interval, in feet, varies. Datum is sea level

8.0 GROUND WATER--Continued

8.4 Chemical Quality

8.4.1 Dissolved Solids

High Dissolved-Solids Concentrations in Most Ground-Water Supplies

Eighty-four percent of the wells and springs have water with dissolved-solids concentrations greater than the recommended national drinking-water standard of 500 milligrams per liter. Nearly all sources sampled, however, are suitable for watering livestock.

The histogram for dissolved-solids concentrations from the area's wells and springs (fig. 8.4.1-1) shows that concentrations are less than the 500-mg/L (milligrams per liter) maximum recommended by the National Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1979) in only 110 of 693 samples (about 16 percent). The secondary regulations are not mandatory, however, and the recommended 500-mg/L maximum for drinking water commonly is exceeded in the arid West because a practical alternative source is not available. Many rural dwellers are pleased to have wells that yield water with dissolved-solids concentrations of 1,000 mg/L or less. About 45 percent of the samples are in this category.

Most of the wells and springs in the area are used for watering livestock. Salinity (dissolved-solids) standards for livestock, published by the National Academy of Sciences and National Academy of Engineering (1973), may be summarized as follows:

0 - 999 mg/L	Excellent
1,000 - 2,999 mg/L	Very satisfactory
3,000 - 4,999 mg/L	Satisfactory for animals accustomed to such water
5,000 - 6,999 mg/L	Reasonably safe except for pregnant and lactating animals
7,000 - 10,000 mg/L	Unfit or only usable with considerable risk

Based on these standards, 98 percent of the samples were satisfactory or better for livestock watering.

To some extent the well samples for salinity have a built-in bias because the wells have not been drilled at random. Wells are not likely to be drilled in areas known to have dissolved-solids concentrations that are hazardous to livestock. In addition, if a well were

drilled and the water was too saline, the rancher would abandon the well. Furthermore, the analyses of samples in Geological Survey files generally do not include oil-field data that represent deeper aquifers that yield more saline water. For these reasons the samples are biased toward less mineralized ground water and are not truly representative of the area.

A statistical summary of dissolved-solids concentrations for aquifers with 10 or more samples is shown in table 8.4.1-1. Generally, the water in each aquifer has a considerable range in dissolved-solids concentrations. Samples from the Wasatch Formation contained from 227 to 8,200 mg/L of dissolved solids, whereas those from the Fort Union Formation contained from 209 to 5,620 mg/L. Together, these two formations account for 65 percent of all samples.

Although other factors are involved, the length of flow time or the length of the flow path from recharge to discharge or withdrawal is probably the dominant factor affecting the dissolved-solids concentration in most aquifers. Wells close to recharge areas generally have the lowest dissolved-solids concentrations, whereas wells remote from the recharge areas have high dissolved-solids concentrations. The samples from the Tensleep Sandstone have the lowest median concentration (254 mg/L) of all the aquifers sampled, because most samples were collected from wells and springs near the Bighorn Mountains, where the formation crops out and where recharge occurs. However, a sample from the Tensleep Sandstone obtained near the middle of the basin, far from the recharge site, had a dissolved-solids concentration of 6,820 mg/L.

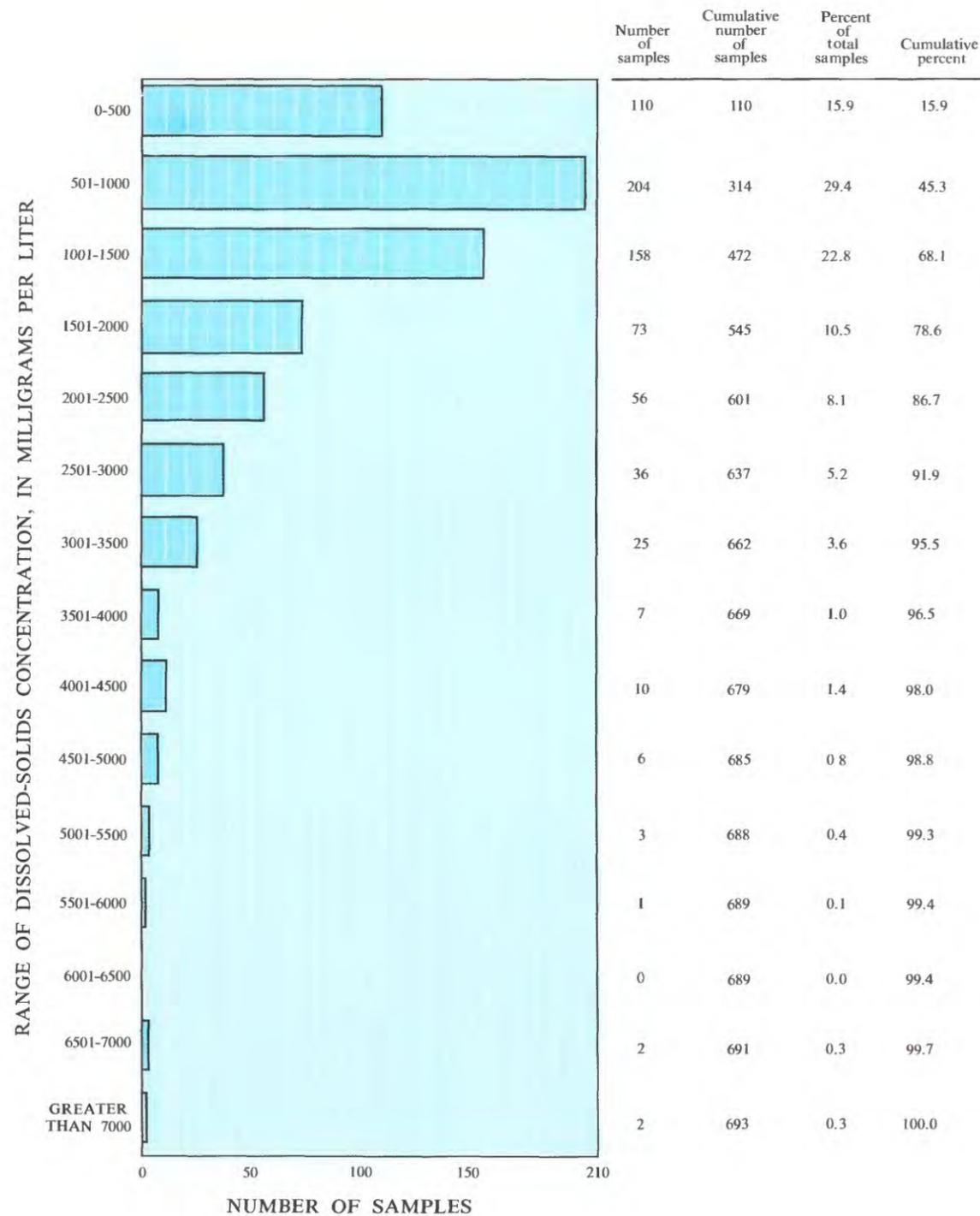


Figure 8.4.1-1 Histogram of dissolved-solids concentrations.

Table 8.4.1-1 Median, average, minimum, and maximum dissolved-solids concentrations in water from the area's major aquifers.

Aquifer	Dissolved-solids concentration (milligrams per liter)				Number of samples
	Median	Average	Minimum	Maximum	
Alluvium	1,700	2,128	106	6,610	38
Wasatch Formation	1,010	1,298	227	8,200	191
Fort Union Formation	1,260	1,464	209	5,620	257
Fox Hills-Hell Creek Formations	691	790	340	2,850	24
Fox Hills Sandstone	943	1,494	451	5,450	26
Hell Creek Formation	800	978	408	2,390	23
Lance Formation	977	1,218	251	2,850	31
Tensleep Sandstone	254	874	230	6,820	15
Madison Group	987	1,503	65	3,240	25

8.0 GROUND WATER--Continued
8.4 Chemical Quality--Continued
8.4.2 Trace Metals

High Manganese and Iron Concentrations--A Common Problem

Manganese concentrations exceed the recommended drinking-water standard in about 43 percent of the wells sampled and iron concentrations exceed the standard in about 35 percent of the wells. High selenium concentrations in some wells may indicate a problem.

Both manganese and iron concentrations in the area's ground-water samples frequently exceed the maximum allowable concentration when used for domestic supplies (table 8.4.2-1). The National Secondary Drinking Water Regulations recommend a maximum concentration of 50 $\mu\text{g}/\text{L}$ (micrograms per liter) for manganese and 300 $\mu\text{g}/\text{L}$ for iron (U.S. Environmental Protection Agency, 1979). Domestic supplies and stock watering are both important uses for ground water in the area. For domestic use high manganese and high iron concentrations cause taste and staining (laundry and plumbing fixtures) problems. For stock watering, however, high manganese and iron concentrations are not problems.

Selenium concentrations exceeded the national primary drinking-water standard in 4 out of 159 ground-water samples (table 8.4.2-1). The National Interim Primary Drinking Water Regulations list a maximum allowable selenium concentration of 10 $\mu\text{g}/\text{L}$ (U.S. Environmental Protection Agency, 1977). (The primary drinking-water regulations are mandatory and are designed to safeguard the consumer's health, in contrast to the secondary standards, which are not mandatory but are only recommended for esthetic or economic reasons.) High selenium concentrations in some of the area's ground-water samples are not unexpected, because local selenium problems are known to exist in the area.

Plant uptake and concentration of selenium

from seleniferous soils in parts of Wyoming have caused alkali disease (selenium poisoning) in foraging livestock. However, selenium poisoning of livestock from drinking water has not been documented (Beath, 1943). Nonetheless, a maximum concentration of 50 $\mu\text{g}/\text{L}$ selenium in livestock water has been recommended (National Academy of Sciences and National Academy of Engineering, 1973). The maximum selenium concentration determined from the area's ground-water samples was 31 $\mu\text{g}/\text{L}$. Besides soils, irrigation water is also a recognized source of selenium. In order to prevent a hazardous buildup of selenium in forage crops a maximum selenium concentration of 20 $\mu\text{g}/\text{L}$ is recommended (National Academy of Sciences and National Academy of Engineering, 1973). Despite the toxicity of high concentrations, selenium is now recognized to be an essential trace element in animal diet.

In 6 out of 165 samples lead concentration exceeded the primary drinking-water standard. The National Primary Interim Drinking Water Regulations list a maximum allowable lead concentration of 50 $\mu\text{g}/\text{L}$ (U.S. Environmental Protection Agency, 1977). Most high lead concentrations are not due to natural conditions, but are the result of corrosion (U.S. Environmental Protection Agency, 1976). Contamination from paint on acid ampoules used in preserving the water samples may also be responsible for some high lead concentrations.

Table 8.4.2-1 Trace-metal concentrations in ground water in Area 50.

Dissolved-trace metal	Number of analyses	Number of analyses exceeding drinking-water standards	Percent of analyses exceeding drinking-water standards	Drinking-water standard (micrograms per liter)	Median value (micrograms per liter)	Maximum analyzed value (micrograms per liter)
Arsenic	154	1	0.6	¹ 50	1	120
Barium	95	1	1.0	¹ 1,000	100	1,100
Cadmium	165	1	.6	¹ 10	2	17
Chromium	116	0	.0	¹ 50	10	50
Copper	123	0	.0	² 1,000	1	104
Iron	366	56	15.3	² 300	100	120,000
Lead	165	6	3.6	¹ 50	2	180
Manganese	257	100	38.9	² 50	40	4,800
Mercury	122	0	.0	¹ 2	.4	1.5
Selenium	159	4	2.5	¹ 10	1	31
Zinc	141	0	.0	² 5,000	20	1,800

¹ National interim primary drinking-water standards (U.S. Environmental Protection Agency, 1977)

² National secondary drinking-water regulations (U.S. Environmental Protection Agency, 1979)

8.0 GROUND WATER--Continued

8.4 Chemical Quality--Continued

8.4.3 Ground-Water-Quality Controls

Lithology, Chemical Reactions, and Other Factors Control Water Quality

Dissolved-solids concentrations in water usually increase with depth; in the coal-bearing rocks dissolved-solids concentrations in water decrease with depth.

The chemical quality of ground water is controlled by the solubility of the rocks and minerals that comprise the aquifer, the reactions that occur as the water moves through the aquifer, the pH and temperature of the water, pressure, and, to some extent, the length of time that the water is in contact with the rocks. The differences in chemical quality that result from water moving through different rock types are illustrated by three curves in figure 8.4.3-1. Specific conductance, a measure of the electrical conductance of water, is closely related to the concentration of dissolved solids in the water. The data used in the figure are from all of Natrona County, Wyo. (Crist and Lowry, 1972), not just the part in Area 50. The only difference between the rock sequences used in figure 8.4.3-1 and those used elsewhere in this report is that the Fox Hills Sandstone is included with the Upper and Lower Cretaceous shale in figure 8.4.3-1. The differences between the three curves are attributed principally to differences in the lithology of the units and to the chemical reactions that occur as the water moves through the rocks. The increase in specific conductance of water from wells and springs in the upper Tertiary sequence illustrates the increase in dissolved solids that normally occurs as water moves through an aquifer. The sample with the smallest specific conductance was collected from a spring near the recharge area; samples from wells farther from the recharge area have larger specific conductances; and the samples that have specific conductances larger than 900 microsiemens were collected in an area where ground water is discharged into playa lakes and the dissolved solids are concentrated. Travelers on the Oregon Trail gathered salts deposited in those lakes for baking soda. Natrona County was named for the salt that is deposited in playas: Natron is sodium carbonate ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$); trona is a combination of sodium carbonate and bicarbonate, ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$).

In contrast to the increase in dissolved-solids concentration that normally occurs as water moves through an aquifer, there is a decrease in dissolved-solids concentration in water moving through the lower Tertiary and

Upper Cretaceous continental rocks (fig. 8.4.3-2). The chemical quality of water in these deposits has been described by Riffenburg (1926), Thorstenson and others (1979), and Lee (1979). The dominant reactions that control the quality of water in these rocks are cation-exchange softening and sulfate reduction. Cation exchange is a reaction in which the calcium and magnesium in the water are exchanged for sodium from solids such as clay, resulting in soft water. Sulfate reduction is a reaction whereby sulfate in the water is chemically reduced in the presence of organic material to form bicarbonate and sulfide. Water from shallow wells has large concentrations of calcium and magnesium, sulfate, and total solids; water from deep wells has small concentrations of calcium and magnesium, sulfate, and solids. Trace-metal concentrations in the water are small because trace metals in solution react with the sulfide resulting from sulfate reduction to form a precipitate that is relatively insoluble at the pH of the water.

The chemical quality of water in the alluvium varies with the composition of the alluvium and with the proximity to the mountains. The alluvium derived from the more-resistant rocks in the mountains generally contains water with smaller dissolved-solids concentrations than occur in alluvium derived from rocks in the plains. Water in alluvium of streams that originate in the mountains is of better quality in the mountains than it is in the plains. This is in part because of increased transpiration on the broader flood plains, which results in concentration of dissolved solids in the water, and in part because of the downstream increase in fine-grained sediment derived from rocks in the plains.

The quality of water in each of the geologic sequences is summarized in figure 8.4.3-3. However, the reader is cautioned that this summary is a gross generalization and that the quality of water from aquifers in deep parts of the area is not well known.

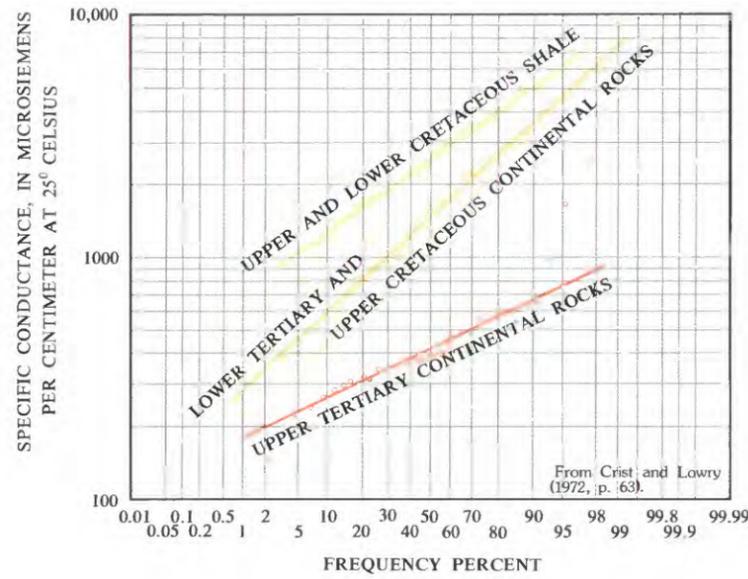


Figure 8.4.3-1 Differences in specific conductance within and between the indicated rock sequences.

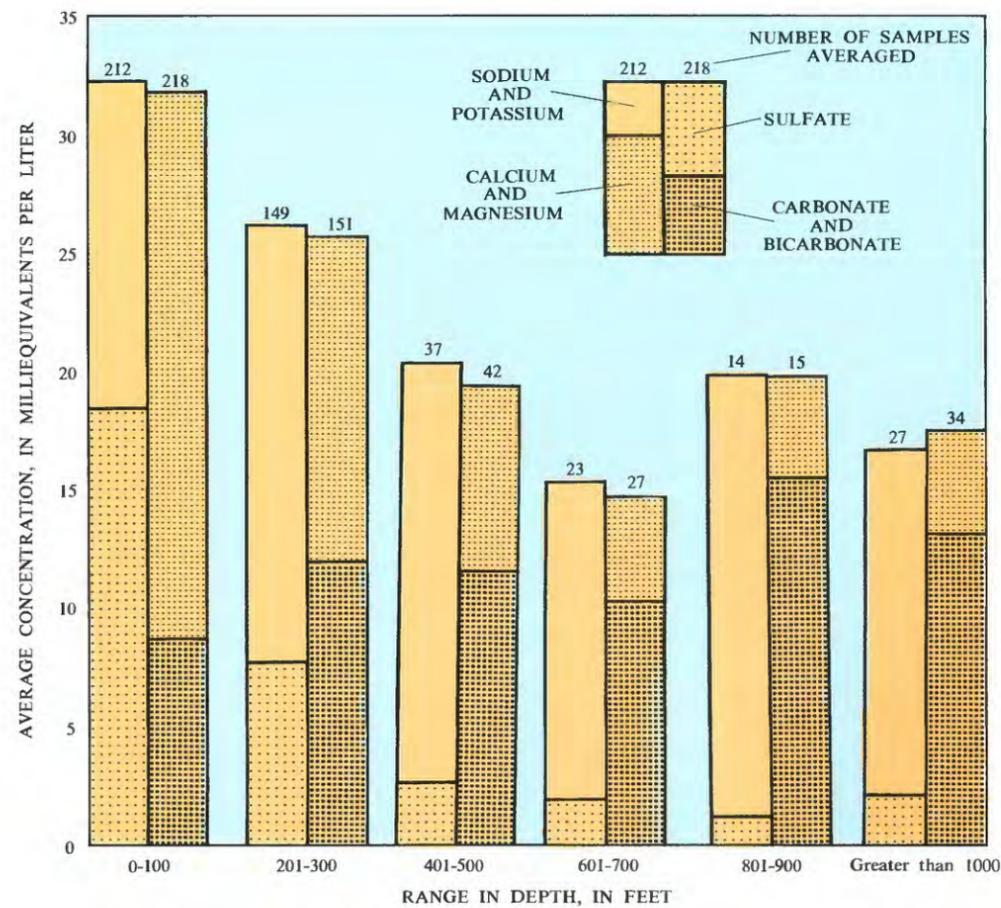


Figure 8.4.3-2 Comparison of average concentrations of major ions in water from springs and wells in the Lower Tertiary and Upper Cretaceous rocks.

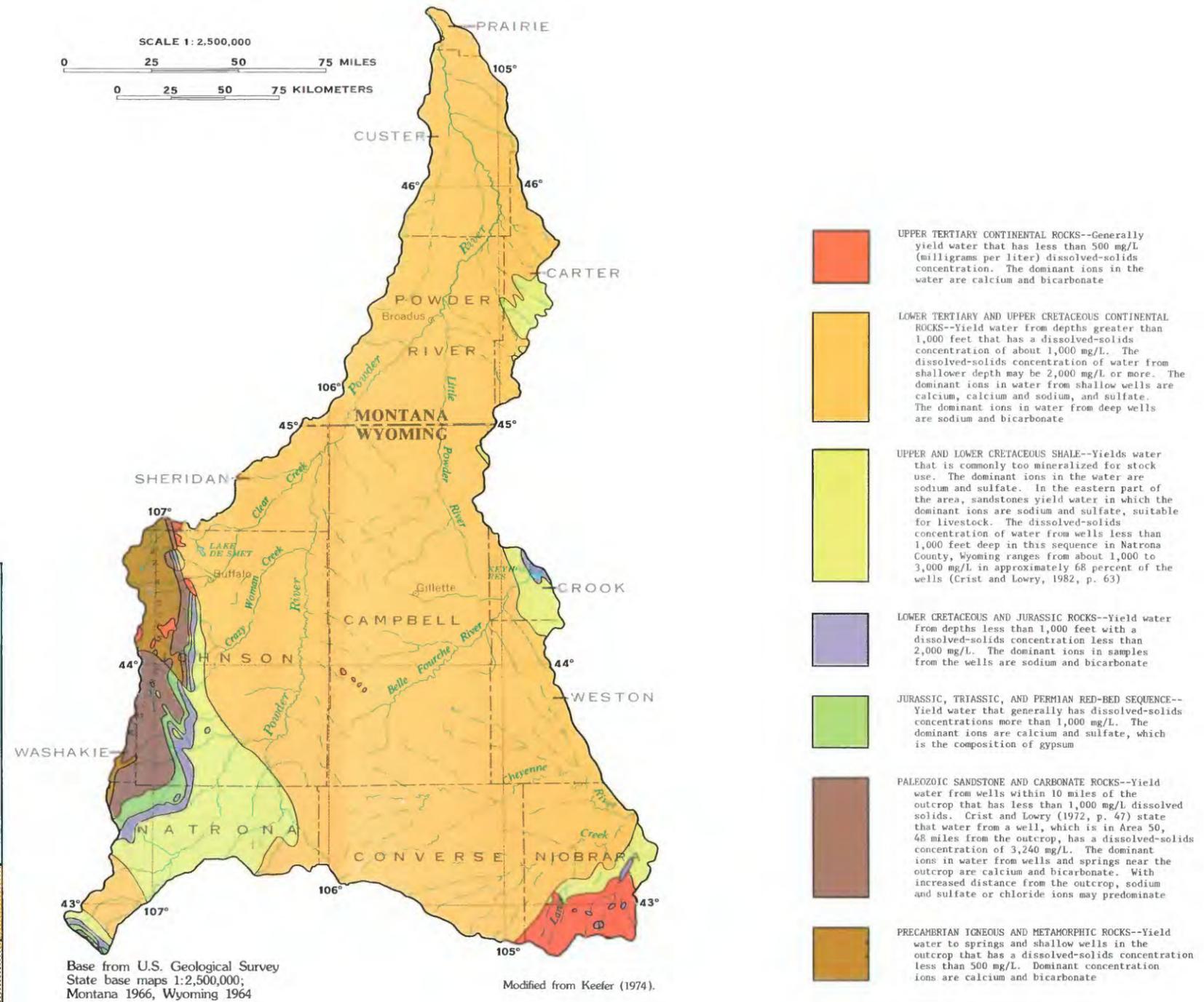


Figure 8.4.3-3 Summary of chemical quality of ground water.

9.0 WATER-DATA SOURCES

9.1 Introduction

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.

Three activities within the U.S. Geological Survey help 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 more than 400 organizations and serves as a central focal point to help those in need of water data to determine what information already is 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.

The U.S. Environmental Protection Agency operates a Water Quality Control Information System which includes a data base called STORET. This data base is used for the STOrage and RETrieval of data relating to the quality of water in waterways within and contiguous to the United States.

More detailed explanations of these four activities are given in sections 9.2, 9.3, 9.4, and 9.5.

9.0 WATER-DATA SOURCES--Continued
9.2 National Water Data Exchange (NAWDEX)

NAWDEX Simplifies Access to Water Data

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

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

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities (see fig. 9.2-1). A directory (Edwards, 1980) is available on request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations.

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requestor to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water-Data Index (fig. 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 (fig. 9.2-3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

Charges for NAWDEX services are assessed at the option of the organization providing the requested data or data service. Search assistance services are provided free by NAWDEX to the greatest extent

possible. Charges are assessed, however, for those requests requiring computer cost, extensive personnel time, duplicating services, or other costs encountered by NAWDEX in the course of providing services. In all instances, charges assessed by NAWDEX Assistance Centers will not exceed the direct costs incurred in responding to the data request. Estimates of cost are provided by NAWDEX upon request and in all instances 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)
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 860-6031
or FTS 928-6031
Hours: 7:45 - 4:15 EST

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

District Chief, WRD
U.S. Geological Survey
Federal Building, Drawer 10076
Helena, MT 59626
Telephone: (406) 449-5263
FTS 585-5263

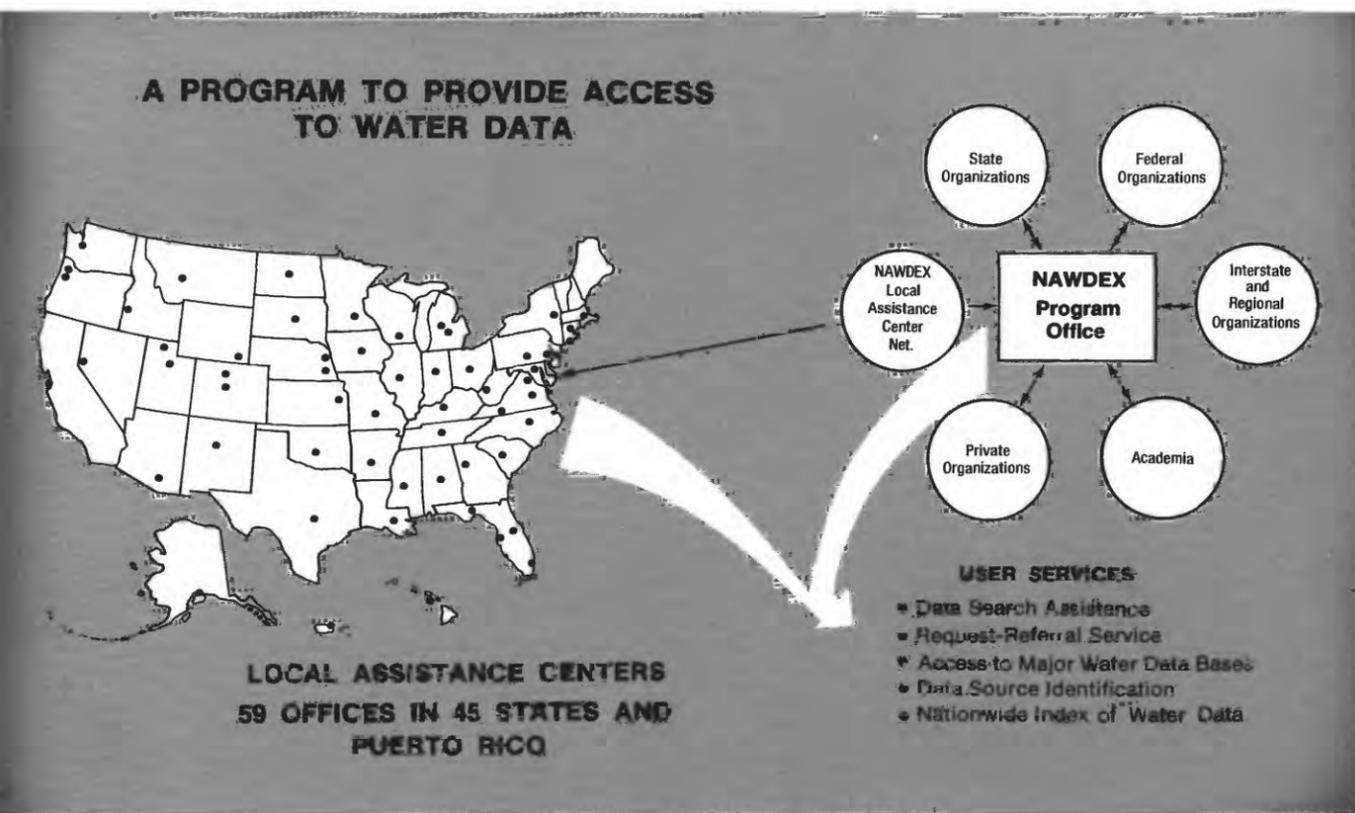


Figure 9.2-1 Function of NAWDEX Program Office.

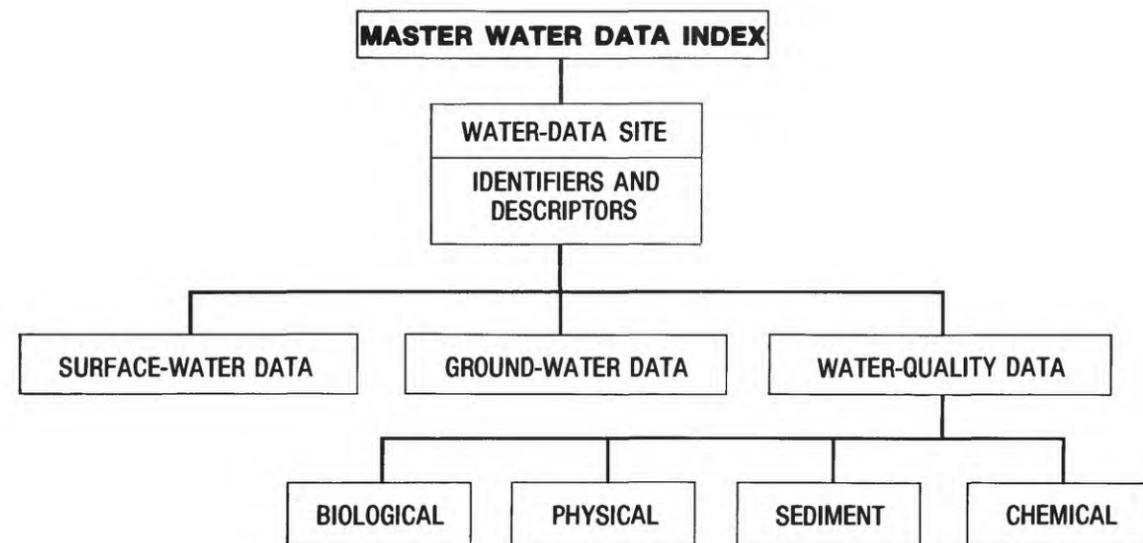


Figure 9.2.2 Master Water-Data Index.

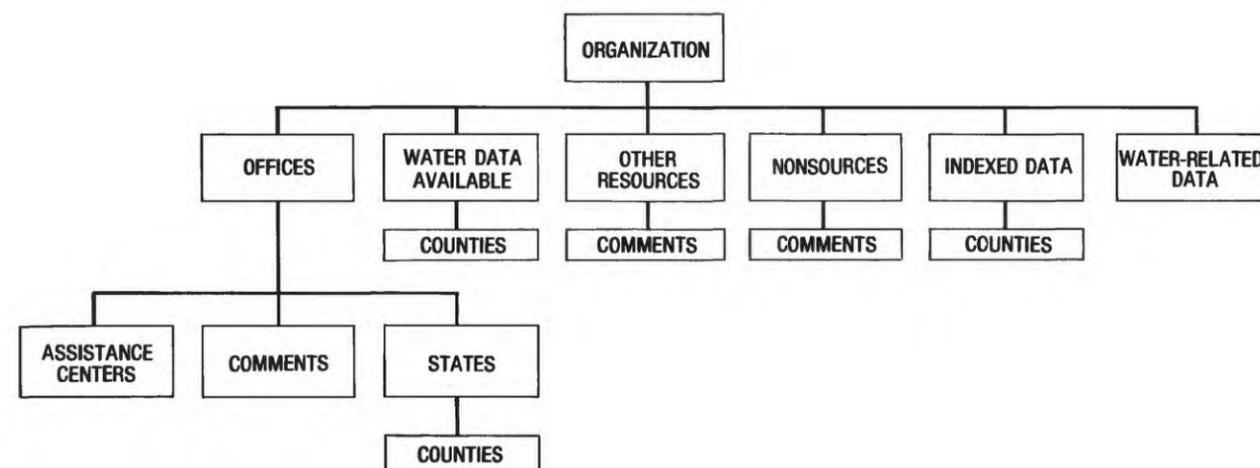


Figure 9.2-3 Water Data Sources Directory.

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.

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

U.S. Geological Survey
Water Resources Division
P.O. Box 1125
Cheyenne, WY 82003

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

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

on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 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 is contained in this file. All sites for which data are stored in the Daily Values, Peak Flow, Water Quality, and Unit Values files of WATSTORE are indexed in this file.

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

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

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

Unit Values File: Water parameters measured on

a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and 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 on-site measurements such as water temperature. The file is designed to accommodate 225 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 facilities of the Geological Survey at its National Center. However, data may be entered into and retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

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

Digital Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chloride concentration. 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 re-recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for transmitting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 500 data-relay stations are being operated currently (1983) by the Water Resources Division.

Central Laboratory System: The Water Resources Division's two water-quality laboratories, located in Denver, Colo., and Atlanta, Ga., analyze more than 150,000 water samples per year. These laboratories are equipped to automatically perform

chemical analyses ranging from determinations of simple inorganic substances, such as chloride, to complex organic compounds, such as pesticides. As each analysis is completed, the results are verified by laboratory personnel and transmitted via a computer terminal to the central computer facilities to be stored in the Water Quality File of WATSTORE.

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

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 called SAS (Statistical Analysis System, 1976) 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.

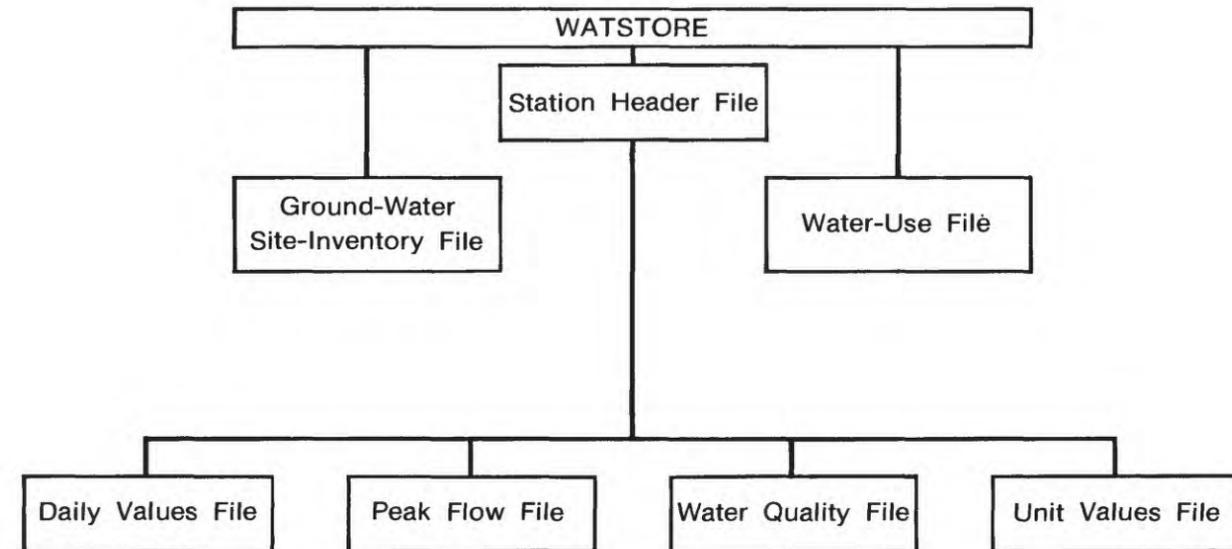


Figure 9.3-1 WATSTORE file system.

9.0 WATER-DATA SOURCES--Continued
9.4 *Index to Water-Data Activities in Coal Provinces*

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 (fig. 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 listed in a table.

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

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

U.S. Geological Survey
Water Resources Division
P.O. Box 1125
Cheyenne, WY 82003
Telephone: (307) 772-2153
FTS 328-2153

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

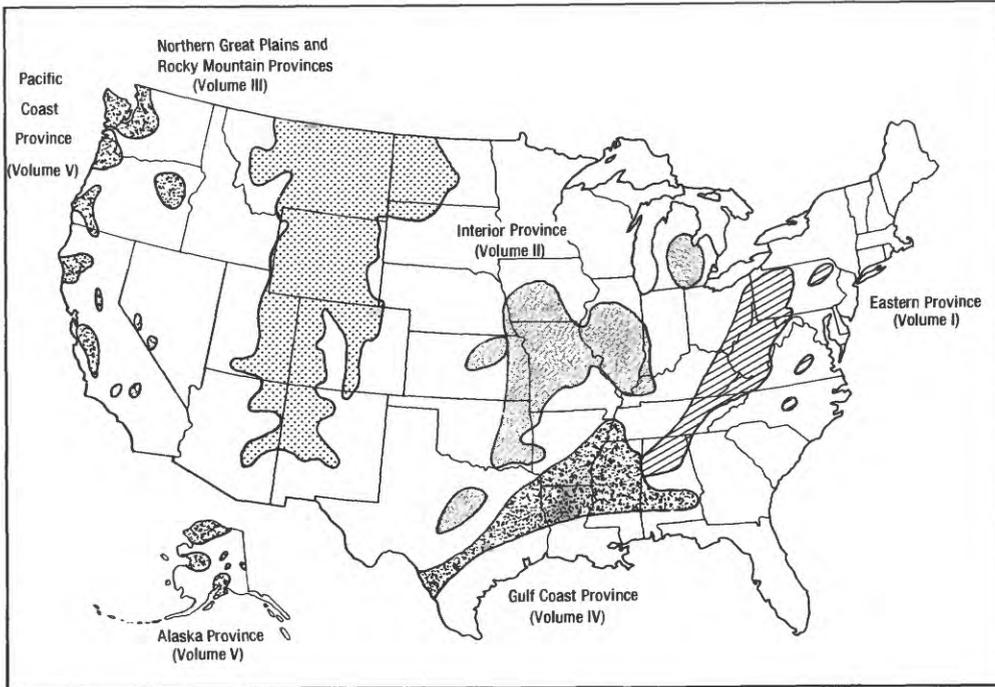


Figure 9.4-1 Index volumes and related provinces.

9.0 WATER-DATA SOURCES--Continued
9.5 STORET

**STORET is U.S. Environmental Protection Agency
Computerized Water-Data System**

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

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

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

There are 1,800 water-quality parameters defined within STORET's Water Quality File. In 1976 data from more than 200,000 unique collection points in the United States were stored in the system. The groups of parameters and number of observations that are in the Water Quality File are shown in figure 9.5-1.

State, Federal, interstate, and local government agencies can become STORET users. Information on becoming a user of the system can be obtained by contacting the Environmental Protection Agency. The contact for this area is:

Environmental Services Division
U.S. Environmental Protection Agency
1860 Lincoln Street, Suite 103
Denver, CO 80295
Telephone: (303) 844-2226

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

EXPLANATION

- 1971-1975
- 1966-1970
- Prior to 1966

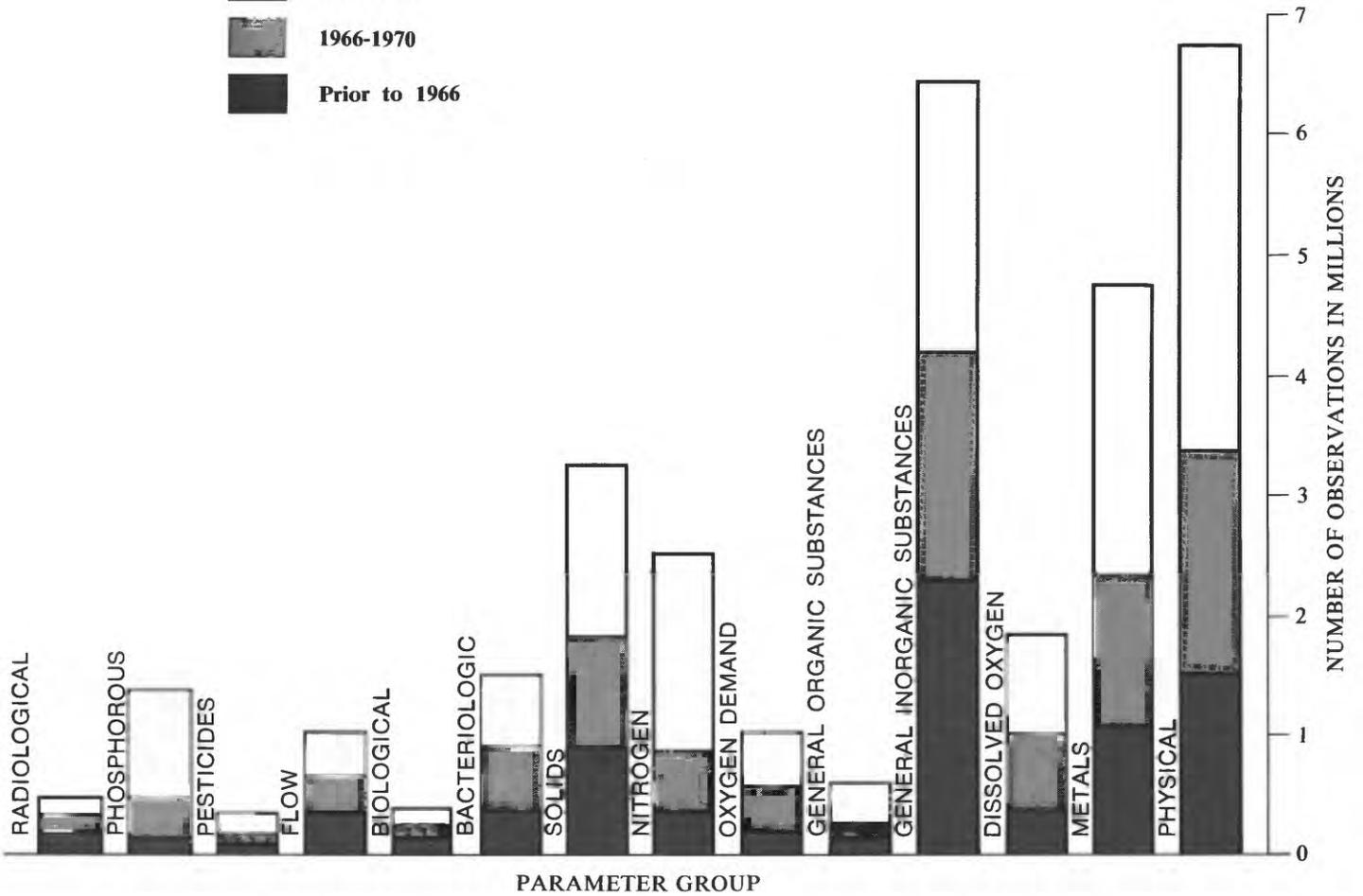


Figure 9.5-1 Parameter groups and number of observations in the Water Quality File.

10.0 SUPPLEMENTAL INFORMATION FOR AREA 50

10.1 Hydrologic Studies by the Geological Survey

Many Active Investigations in Area 50

The Wyoming and Montana Districts of the U.S. Geological Survey have many active hydrologic studies that will produce information about the water resources of Area 50; some are site-specific in scope and others are statewide or regional.

The U.S. Geological Survey projects described below are either active (data collection and analysis in progress) or complete except for report (final report in preparation). Projects for which the final reports are listed in the References (section 11.0) of this report are not described below. For each project listed, the Geological Survey project number, purpose, and geographic location are given. For additional information see Green (1983) and Roberts (1983).

WYOMING AND MONTANA

1. Surface-Water Stations (WY001 and MT001). A network of surface-water stations is operated and maintained, in order to collect, store, and publish short-term and long-term stream flow data for evaluation, planning, and management of surface-water resources. Statewide, Wyoming and Montana.

2. Ground-Water Stations (WY002 and MT002). A network of ground-water wells is operated and maintained in order to collect, store, and publish short-term and long-term water-level data for evaluation, planning, and management of ground-water resources. Statewide, Wyoming and Montana.

3. Water-Quality Stations (WY003 and MT003). A network of water-quality stations is operated and maintained, in order to collect, store, and publish short-term and long-term chemical, physical, and biological-quality data for surface and ground waters for evaluation, planning, and management of water resources. Statewide, Wyoming and Montana.

4. Sediment Stations (WY004 and MT004). A network of sediment stations is operated and maintained, in order to collect, store, and publish data, including concentration, discharge, and particle size of sediment transported by rivers and streams, for evaluation, planning, and management of water resources. Statewide, Wyoming and Montana.

5. Northern Great Plains Regional Aquifer-System Analysis in Parts of Montana, North Dakota, South Dakota, and Wyoming (CR230, WY049, and MT067). Assess the availability of ground water through a detailed study of the hydrologic characteristics of the major aquifers and develop predictive models to evaluate selected ground-water-management alternatives. Northeastern Wyoming, eastern Montana, North and South Dakota.

WYOMING

1. Flood Investigations in Wyoming (WY010). Collect flood information at partial-record stations and other sites; define the magnitude and frequency of floods using all available data. Statewide.

2. Precipitation, Infiltration, and Runoff Relations for Small Basins in Wyoming (WY054). Define infiltration-rate curves for soils and other surficial materials for use in a rainfall-runoff model, in order to provide a method for estimating flood discharges on small streams. Statewide.

3. Streamflow Characteristics of Energy-Mineral Areas in Wyoming (WY056). Develop improved techniques and relations for estimating monthly and annual runoff; refine relations for estimating peak flows. Statewide.

4. Biological Communities of Small Streams in Wyoming (WY057). Define the biologic communities and their interrelated stream environments; evaluate aquatic organisms as a means of identifying alluvial-valley floors; assess potential for re-establishment of biologic communities following disturbance. Northeastern Wyoming.

5. Ground-Water Hydrology of the Southern Powder River Uranium District, Wyoming (WY060). Define the existing hydrologic system and evaluate impacts of

uranium exploration and development. Northeastern Wyoming.

6. Potentiometric Maps of Shallow Aquifers in the Powder River Basin, Northeastern Wyoming (WY062). Prepare maps of potentiometric surfaces for shallow ground-water aquifers, including the Wyodak Coal. Northeastern Wyoming.

7. Sediment Yield From Natural and Reclaimed Small Ephemeral Stream Basins in Wyoming (WY066). Relate sediment yield to rainfall and runoff; evaluate possible changes in the relation due to surface mining; determine the importance of channel erosion and slope wash as sediment sources; investigate possible sediment-transport models. Northeastern and south-central Wyoming.

8. Low Flow of Streams in the Powder River Structural Basin, Wyoming (WY067). Analyze low-flow characteristics of streams as an indicator of the amount of water available without the use of artificial storage. Northeastern Wyoming.

9. Chemical Quality of Surface Water in the Powder River, Green River, Great Divide, and Hanna Basins, Wyoming (WY071). Summarize statistically the surface-water quality data previously collected in the principal coal areas and recommend future water-quality data-collection activities in these areas. Northeastern, south-central, and southwestern Wyoming.

10. Recharge of Shallow Aquifers Through Ephemeral Stream Channels in Wyoming (WY073). Determine the relationship of water in the alluvium to streamflow and to water in the bedrock aquifers; evaluate the use of streamflow hydrographs to determine seepage from ephemeral streams. Northeastern Wyoming.

11. Ground-Water Quality in Wyoming (WY074). Assemble and summarize existing information; assess the adequacy of the information for describing the quality of water of major aquifers and for evaluating future changes in water quality. Statewide.

12. The Fluvial System in Energy-Minerals Areas of Wyoming (WY076). Describe how the fluvial systems function; determine the effects of energy-related developments on the stability of stream channels and drainage networks. Northeastern, south-central, and southwestern Wyoming.

13. Hydrologic Properties of the Alluvial Deposits Along the Powder River Between Sussex, Wyoming and Moorhead, Montana (WY078). Describe the hydrology of the alluvial deposits; determine the potential for development of water from the alluvium. Northeastern Wyoming.

14. Evaluation of the Ground-Water Observation-Well Program for the Powder River Basin and Adjacent Area, Northeastern Wyoming (WY079). Evaluate the existing observation-well program; recommend a revised program to monitor ground-water levels. Northeastern Wyoming.

15. Evaluation of the Individual and Cumulative Impacts of Mine Operations on the Surface and Ground-Water Hydrology in the Eastern Powder River Basin of Wyoming (WY080). Northeastern Wyoming.

MONTANA

1. Water-Use Data System for Montana (MT007). Develop and maintain a water-use data system that is responsive to users at State and national levels. Statewide.

2. Peak-Flow Analysis for Small Drainage Areas, Montana (MT010). Obtain adequate data to enable definition of the magnitude and frequency of floods to be expected from any given small drainage basin in the State. Statewide.

3. Bridge-Site Investigations in Montana (MT023). Provide the Montana Department of Highways with sufficient data to permit the most economical and hydraulically safe bridge or culvert as possible. Statewide.

4. Special Investigations, Montana (MT030). Assist State and other Federal agencies in solving water-resource problems on short notice. Statewide.

5. Effects of Mining and Related Activities on the Shallow Ground-Water System (MT048). Define the ground-water flow systems above the Bearpaw Shale; develop predictive models to assess the effects of mining on the hydrologic system. Southeastern Montana.

6. Structure, Potentiometric-Surface, and Quality-of-Water Maps of the Madison Limestone Aquifer in Central and Eastern Montana (MT056). Compile data from wells and test holes; prepare maps describing the altitude

and configuration of the top of the aquifer, potentiometric surface, and quality of water. Central and eastern Montana.

7. Water-Resources Monitoring, Northern Powder River Coal Region, Montana (MT059). Determine characteristics of the regional water-resources system; detect and document any changes in the system as a result of coal mining. Southeastern Montana.

8. Limnological Reconnaissance of Small Reservoirs in Montana (MT064). Characterize the present physical, chemical, and biological conditions in selected reservoirs; evaluate the suitability of the reservoirs for various uses. Eastern Montana.

9. Streamflow Characteristics Related to Channel Geometry in Ephemeral Streams, Montana (MT070). Collect data on chemical characteristics; develop equations relating channel geometry to streamflow characteristics; determine the accuracy of the estimates. Statewide.

10. Regional Analyses of Surface-Water Quality in the Fort Union Coal Region, Montana (MT072). Compile and present data in a semi-interpretive format; review and modify the data-monitoring network. Eastern Montana.

10.0 SUPPLEMENTAL INFORMATION FOR AREA 50--Continued

10.2 List of Other Agencies

Resource Information Available from Other Agencies

Water, land, and coal resources in Area 50 are the concern of many State and Federal agencies; these agencies are important sources of information.

The names and addresses of principal State and Federal agencies that have additional information about water, land, and coal resources are listed below. Other agencies also have water-related missions. Those that are concerned primarily with construction of water projects, such as reservoirs, or with the use of water for specific purposes, such as recreation, are not included, unless they also serve as an important source of water-resources information. Also not included are coal and oil companies operating in the area that have nonproprietary information available.

FEDERAL AGENCIES

Wyoming State Office
U.S. Bureau of Land Management
P.O. Box 1828
Cheyenne, WY 82003

Montana State Office
U.S. Bureau of Land Management
Granite Tower, 222 N. 32nd
Billings, MT 59101

Casper District Office
U.S. Bureau of Land Management
951 Rancho Road
Casper, WY 82601

Miles City District Office
U.S. Bureau of Land Management
P.O. Box 940
Miles City, MT 59301

Wyoming State Office
U.S. Soil Conservation Service
P.O. Box 2440
Casper, WY 82602

Montana State Office
U.S. Soil Conservation Service
Post Office and Federal Bldg.
32 E. Babcock Street
Bozeman, MT 59715

U.S. Department of Energy
P.O. Box 2567

Grand Junction, CO 81502

Western Section, Branch of
Coal Resources
Geologic Division
U.S. Geological Survey
Mail Stop 972, Box 25046
Denver Federal Center
Lakewood, CO 80225

Surveillance and Analysis Division
U.S. Environmental Protection Agency
8ES-DA
1860 Lincoln Street
Denver, CO 80295

Western Technical Center
Office of Surface Mining
1020 - 15th Street
Denver, CO 80202

Thunder Basin National Grassland
U.S. Forest Service
809 South 9th Street
Douglas, WY 82633

Northern Regional Office
U.S. Forest Service
Federal Bldg., Post Office,
and Courthouse
200 E. Broadway Street
Missoula, MT 59801

STATE AGENCIES

Wyoming State Engineer
Herschler Building
Cheyenne, WY 82002

Wyoming State Geologist
The Geological Survey of Wyoming
Box 3008, University Station
Laramie, WY 82071

Water Quality Division
Wyoming Department of
Environmental Quality

Herschler Building
Cheyenne, WY 82002

Land Quality Division
Wyoming Department of
Environmental Quality
Herschler Building
Cheyenne, WY 82002

Wyoming Water Research Center
University of Wyoming
Box 3067, University Station
Laramie, WY 82071

Montana Bureau of Mines and Geology
Montana College of Mineral
Science and Technology
Butte, MT 59701

Water Resources Division
Montana Department of Natural
Resources and Conservation
32 South Ewing
Helena, MT 59601

Energy Division
Montana Department of Natural
Resources and Conservation
25 South Ewing
Helena, MT 59601

Water Quality Bureau
Montana Department of Health
and Environmental Sciences
Cogswell Building
Helena, MT 59601

Montana Water Resources
Research Center
Montana State University
Bozeman, MT 59717

Montana Department of State Lands
1625 - 11th Avenue
Helena, MT 59601

MAPS

Several of the agencies listed above have resource maps available. Water-resource, geologic, coal-resource, land-use, topographic, and other natural-resource maps of the U.S. Geological Survey are available for purchase from:

Western Distribution Branch
U.S. Geological Survey
Box 25286, Denver Federal Center
Lakewood, CO 80225

10.0 SUPPLEMENTAL INFORMATION FOR AREA 50

10.3 Index of Surface-Water Stations

Station or site no. in this report	U.S. Geological Survey station no.	Station name	Location (degrees, minutes, seconds)		Drainage area (square miles)	Period and type of record				
			Latitude	Longitude		Discharge	Chemical		Sediment	Biological
							Quality			
1	06309200	Middle Fork Powder River near Barnum, Wyo.	43 34 40	107 08 16	45.2	1961-82				
2	06309260	Buffalo Creek above North Fork Buffalo Creek near Armino, Wyo.	43 25 33	107 11 18	8.80	1974-79				
3	06309270	North Fork Buffalo Creek near Armino, Wyo.	43 26 11	107 10 58	8.10	1974-79				
4	06309280	Buffalo Creek below North Fork Buffalo Creek near Armino, Wyo.	43 25 08	107 09 59	18.6	1974-79				
5	06309450	Beaver Creek below Bayer Creek, near Barnum, Wyo.	43 39 55	107 03 48	10.9	1974-79				
6	06309460	Beaver Creek above White Panther ditch, near Barnum, Wyo.	43 41 52	106 56 52	24.2	1974-79				
7	06309500	Middle Fork Powder River above Kaycee, Wyo.	43 38 51	106 48 29	450	1949-54, 1965-68, 1970, 1977	1949-54, 1949-53, 1965-68, 1965-68, 1970			
8	06310000	Red Fork near Barnum, Wyo.	43 39 00	106 46 00	142	1929-32, 1950-53	1970, 1977			
9	06310500	Middle Fork Powder River at Kaycee, Wyo.	43 43 00	106 37 00	647	1911-13, 1929-32	1970, 1977			
10	06311000	North Fork Powder River near Hazelton, Wyo.	44 01 43	107 04 55	24.5	1946-82	1970		1974 ^m	
11	06311050	North Fork Powder River below Dull Knife Reservoir, near Hazelton, Wyo.	44 01 08	107 03 07		1970 ^m				
12	06311060	North Fork Powder River below Bull Creek, near Hazelton, Wyo.	44 00 29	107 01 08	32.3	1970-71 ^m	1970-71			
13	06311065	North Fork Powder River above Gammon Creek, near Hazelton, Wyo.	44 00 27	107 00 57		1970 ^m	1970			
14	06311100	North Fork Powder River below Johnson Creek, near Hazelton, Wyo.	43 58 40	106 59 22		1970 ^m	1970			
15	06311150	North Fork Powder River above Gardner Creek, near Hazelton, Wyo.	43 58 15	106 57 02		1970-71 ^m	1970-71			
16	06311220	North Fork Powder River below Gardner Creek, Wyo.	43 56 48	106 56 00		1971 ^m	1971			
17	06311240	North Fork Powder River above Pass Creek, Wyo.	43 55 56	106 54 27		1971 ^m	1971			
18	06311300	Pass Creek near Mayoworth, Wyo.	43 55 13	106 53 51		1971 ^m	1971			
19	06311400	North Fork Powder River below Pass Creek, near Mayoworth, Wyo.	43 54 41	106 53 20	100	1973-82				
20	06311500	North Fork Powder River near Mayoworth, Wyo.	43 53 50	106 52 40	106	1940-73	1971	1951		
21	06312000	North Fork Powder River near Kaycee, Wyo.	43 46 00	106 36 00	244	1911, 1929-32				
22	06312500	Powder River near Kaycee, Wyo.	43 41 35	106 31 48	980	1933-35, 1938-71, 1978-80	1946-47, 1949-54, 1968-82	1949-53	1973-82	
23	06312700	South Fork Powder River near Powder River, Wyo.	43 02 00	107 01 00	262	1961-82 ^p				
24	06312795	Sanchez Creek above reservoir, near Armino, Wyo.	43 20 23	107 10 48	5.53	1970-81 ^p				
25	06312800	Sanchez Creek near Armino, Wyo.	43 20 07	107 09 58	5.95	1961-76 ^p				
26	06312910	Dead Horse Creek tributary near Midwest, Wyo.	43 20 11	106 32 04	1.53	1965-72 ^p				
27	06312920	Dead Horse Creek tributary No. 2 near Midwest, Wyo.	43 01 19	106 31 35	1.34	1965-72 ^p				
28	06313000	South Fork Powder River near Kaycee, Wyo.	43 37 10	106 34 36	1,150	1911, 1938-40, 1950-69, 1978-79	1949-53, 1968-81	1949-53	1975-80	
29	06313020	Bobcat Creek near Edgerton, Wyo.	43 11 55	106 05 25	8.29	1965-73 ^s				
30	06313030	Coopers Draw near Edgerton, Wyo.	43 11 10	106 07 20	1.11	1973-81 ^p				
31	06313040	Seven L Creek near Edgerton, Wyo.	43 12 45	106 08 10	7.10	1965-73 ^p				
32	06313050	East Teapot Creek near Edgerton, Wyo.	43 10 50	106 12 40	5.44	1965-79 ^p				
33	06313090	Salt Creek below Midwest, Wyo.	43 25 40	106 17 30					1967	

10.0 SUPPLEMENTAL INFORMATION FOR
AREA 50--Continued

10.3 Index of Surface-Water Stations

Station or site no. in this report	U.S. Geological Survey station no.	Station name	Location (degrees, minutes, seconds)		Drainage area (square miles)	Period and type of record		
			Latitude	Longitude		Discharge	Chemical Quality	Sediment Biological
34	06313100	Coal Draw near Midwest, Wyo.	43 27 00	106 14 00	11.4	1961-82 ^P		
35	06313180	Dugout Creek tributary near Midwest, Wyo.	43 26 12	106 25 11	.80	1965-74, s 1974-82		
36	06313200	Hay Draw near Midwest, Wyo.	43 26 50	106 22 20	1.60	1968-70 ^P	1967-81	1975-81
37	06313400	Salt Creek near Sussex, Wyo.	43 37 19	106 22 04	769	1976-81		
38	06313450	North Spring Draw near Sussex, Wyo.	43 37 49	106 24 36	5.21	1980-81 ^P		
39	06313500	Powder River at Sussex, Wyo.	43 41 54	106 17 50	3,090	1938-40, 1950-57, 1977-82	1949-53, 1966-68, 1976-82	1976-81 1976-81
40	06313600	Bugher Draw near Buffalo, Wyo.	44 08 00	106 05 50	4.57	1961-71 ^P		
41	06313630	Van Houghton Draw near Buffalo, Wyo.	44 10 40	106 07 25	10.8	1971-81 ^P		
42	06313700	Dead Horse Creek near Buffalo, Wyo.	44 12 54	106 06 41	151	1958-71, ^P 1971-82	1976	1976, 1980-81
43	06313900	Caribou Creek near Buffalo, Wyo.	44 10 40	106 55 10	5.08	1961-74 ^P	1973	
44	06313950	North Fork Crazy Woman Creek below Pole Creek near Buffalo, Wyo.	44 11 11	106 51 12	43.4	1973-82		
45	06314000	North Fork Crazy Woman Creek near Buffalo, Wyo.	44 11 16	106 49 48	44.9	1942-49, 1973-82	1973	
46	06314500	North Fork Crazy Woman Creek below Spring Draw, near Buffalo, Wyo.	44 11 38	106 46 47	51.7	1949-72	1951	
47	06314510	Little North Fork Crazy Woman Creek near Buffalo, Wyo.	44 13 43	106 49 49		1973-75 ^m	1973	
48	06314520	Little North Fork Crazy Woman Creek at mouth of canyon, near Buffalo, Wyo.	44 13 34	106 49 00		1973-75 ^m	1973	
49	06314890	Muddy Creek above canyon, near Buffalo, Wyo.	44 09 36	106 52 24		1973-75 ^m	1973	
50	06314900	Muddy Creek at mouth of canyon, near Buffalo, Wyo.	44 09 45	106 49 10		1973-75 ^m	1973	
51	06314920	Billy Creek below Billy Creek Spring, near Buffalo, Wyo.	44 07 44	106 50 35		1973-75 ^m	1973	
52	06314930	Billy Creek at mouth of canyon, near Buffalo, Wyo.	44 08 05	106 48 54		1973-75 ^m	1973	
53	06315000	North Fork Crazy Woman Creek near Greub, Wyo.	44 04 50	106 39 40	174	1950-68	1964-68	
54	06315480	Poison Creek near Tetley Spring near Mayoworth, Wyo.	44 05 29	106 51 47	19.0	1974-76		
55	06315490	Poison Creek near Mayoworth, Wyo.	44 04 12	106 49 17	24.7	1974-76		
56	06315500	Middle Fork Crazy Woman Creek near Greub, Wyo.	44 03 29	106 48 07	82.7	1942-72		
57	06316000	Crazy Woman Creek near Buffalo, Wyo.	44 05 20	106 31 50	464	1929-32		
58	06316400	Crazy Woman Creek at upper station, near Arvada, Wyo.	44 29 15	106 10 25	945	1963-70, 1977-81	1966-67, 1976-81	
59	06316480	Headgate Draw at upper station, near Buffalo, Wyo.	44 31 00	106 10 00	3.32	1965-73 ^S		
60	06316490	Headgate Draw at lower station, near Buffalo, Wyo.	44 29 00	106 08 00	2.60	1965-73 ^S		
61	06316500	Crazy Woman Creek near Arvada, Wyo.	44 29 00	106 09 00	956	1939-43, 1950-64	1949-53	
62	06316700	Coal Draw near Buffalo, Wyo.	44 30 00	106 08 00	1.64	1965-73, ^S 1973-82 ^P		
63	06317000	Powder River at Arvada, Wyo.	44 38 45	106 08 00	6,050	1919-82	1946-53, 1955, 1967-82	1972-82
64	06317050	Rucker Draw near Spotted Horse, Wyo.	44 43 10	105 53 10	3.98	1961-81 ^P		
65	06317500	North Fork Clear Creek near Buffalo, Wyo.	44 19 12	106 54 35	29.0	1949-68		
66	06318500	Clear Creek near Buffalo, Wyo.	44 19 58	106 46 36	120	1894, 1896-99, 1917-27, 1938-82	1949-50, 1969-70, 1977	1977-78
67	06319100	Bull Creek near Buffalo, Wyo.	44 16 38	106 44 42	10.8	1969-82 ^P		
68	06319200	Clear Creek above Rock Creek, near Buffalo, Wyo.	44 21 39	106 39 36		1974-76	1978	1978
69	06319470	South Rock Creek at forest boundary, near Buffalo, Wyo.	44 26 37	106 55 12	40.3	1974-76		
70	06319480	South Rock Creek above Red Canyon, near Buffalo, Wyo.	44 26 36	106 54 36	40.5	1974-76		
71	06319500	South Fork Rock Creek near Buffalo, Wyo.	44 27 00	106 53 00	43.8	1941-43, 1950-53		
72	06320000	Rock Creek near Buffalo, Wyo.	44 27 22	106 52 42	60.0	1941-82		
73	06320170	Rock Creek at mouth, near Buffalo, Wyo.	44 21 49	106 40 04		1975-81	1978	1978
74	06320200	Clear Creek below Rock Creek, near Buffalo, Wyo.	44 21 44	106 39 13	322	1975-81	1975-81	1975-81
75	06320400	Clear Creek at Ucross, Wyo.	44 33 09	106 32 06	409	1976-81	1975-81	1975-81
76	06320500	South Piney Creek at Willow Park, Wyo.	44 27 59	107 02 03	33.6	1945-57, 1959-82		
77	06321000	South Piney Creek near Story, Wyo.	44 33 26	106 56 11	69.4	1951-80		
78	06321020	Mead-Coffeen ditch above fish hatchery, near Story, Wyo.	44 33 41	106 55 45		1974-79		
79	06321040	Mead-Coffeen ditch below fish hatchery, near Story, Wyo.	44 34 07	106 55 23		1974-79		
80	06321100	South Piney Creek below Mead-Coffeen ditch, near Story, Wyo.	44 33 29	106 55 50	69.5	1974-79		
81	06321500	North Piney Creek near Story, Wyo.	44 34 50	106 55 55	36.8	1951-82	1976	1976
82	06321800	Spring Creek near Story, Wyo.	44 34 07	106 55 29		1974-79		
83	06323000	Piney Creek at Kearny, Wyo.	44 32 08	106 49 18	118	1902-06, 1910-17, 1919-23, 1940-82	1975-76, 1978	1951, 1976, 1978
84	06323005	Piney Creek above Highline ditch diversion, at Kearny, Wyo.	44 32 08	106 48 59		1969-70		
85	06323015	Piney Creek at Senff ditch diversion, near Kearny, Wyo.	44 31 22	106 45 02		1969-70		
86	06323090	Shell Creek above Lake De Smet near Buffalo, Wyo.	44 30 10	106 47 10		1977-78	1977-78	1977-78
87	06323100	Piney Creek above Lake De Smet outlet, near Buffalo, Wyo.	44 31 28	106 46 35		1977		
88	06323101	Lake De Smet at dam, near Buffalo, Wyo.	44 29 22	106 45 58		1977		
89	06323102	Lake De Smet site 2 near Buffalo, Wyo.	44 28 17	106 44 47		1977-78		
90	06323103	Lake De Smet site 3 near Buffalo, Wyo.	44 27 20	106 43 45		1977		
91	06323105	Lake De Smet outflow to Piney Creek, near Kearny, Wyo.	44 31 00	106 46 49		1975-77		
92	06323110	Piney Creek below Lake De Smet outlet, near Buffalo, Wyo.	44 31 27	106 46 31		1977		
93	06323114	Piney Creek below Lake De Smet outlet, No. 5, near Buffalo, Wyo.	44 31 16	106 45 10		1977-78		
94	06323125	Piney Creek below Senff ditch, near Ucross, Wyo.	44 33 39	106 42 58		1976	1976	
95	06323500	Piney Creek at Ucross, Wyo.	44 33 45	106 32 25	267	1975-80	1975-80	1975-80
96	06324000	Clear Creek near Arvada, Wyo.	44 52 18	106 04 56	1,110	1917-23, 1950-82	1949-54, 1966-82	1950-53, 1974-80
97	06324410	Powder River below Fence Creek, near Moorhead, Mont.	44 57 56	105 55 40		1974		
98	06324500	Powder River at Moorhead, Mont.	45 04 04	105 52 10	8,088	1929-72, 1974-82	1951-53, 1955-57, 1969-72,	1975-82 1969-72, 1974-77

10.0 SUPPLEMENTAL INFORMATION FOR
AREA 50--Continued

10.3 Index of Surface-Water Stations

10.0 SUPPLEMENTAL INFORMATION FOR
AREA 50--Continued

10.3 Index of Surface-Water Stations

Station or site no. in report	U.S. Geological Survey station no.	Station name	Location		Drainage area (square miles)	Period and type of record		
			(degrees, minutes, seconds) Latitude	(degrees, minutes, seconds) Longitude		Chemical Quality	Sediment	Biological
99	66324700	Sand Creek near Broadus, Mont.	45 26 00	105 26 00	10.2	1974-82		
100	66324710	Powder River at Broadus, Mont.	45 25 40	105 24 15	8,748	1955-82 ^P 1975-82	1975-78, 1979-80	
101	66324790	Little Powder River at State Highway 59, near Gillette, Wyo.	44 26 08	105 27 19		1980		1980-81
102	66324800	Little Powder River tributary near Gillette, Wyo.	44 26 50	105 27 40	.81	1960-81 ^P		
103	66324810	Box Draw tributary near Gillette, Wyo.	44 26 00	105 37 00	.50	1965-72 ^P		
104	66324820	Rawhide Creek tributary near Gillette, Wyo.	44 25 00	105 34 00	2.60	1965-72 ^P		
105	66324830	Rawhide Creek at U.S. Highways 14 and 16, near Gillette, Wyo.	44 25 30	105 33 50		1975-78	1978	1975-76 1978
106	66324890	Little Powder River below Corral Creek, near Weston, Wyo.	44 29 40	105 28 00	204	1977-82	1977-82	1975-81
107	66324900	Cedar Draw near Gillette, Wyo.	44 31 00	105 26 40	3.45	1959-81 ^P		
108	66324910	Cow Creek tributary near Weston, Wyo.	44 32 35	105 21 40	.72	1971-82 ^P		
109	66324912	Little Powder River above Cottonwood Creek, near Weston, Wyo.	44 35 35	105 18 50		1975-76 ^m	1975-76	1975-76
110	66324918	Cottonwood Creek at mouth, near Weston, Wyo.	44 36 30	105 17 40		1969, ^m 1977-81	1976 1976-81	1975-76 1975-81
111	66324925	Little Powder River near Weston, Wyo.	44 39 00	105 18 50	540	1972-82	1975-82	1975-81
112	66324970	Little Powder River above Dry Creek, near Weston, Wyo.	44 55 45	105 21 06	1,235	1968 ^m	1969-70	
113	66324985	Little Powder River near Wyoming-Montana State line	44 59 00	105 20 40		1972-82 ^P		
114	66324995	Badger Creek at Biddle, Mont.	45 04 43	105 21 42	6.06	1938-43	1978	
115	66325000	Little Powder River at Biddle, Mont.	45 06 00	105 19 00	1,541	1974-82 ^P		
116	66325400	East Fork Little Powder River tributary near Hammond, Wyo.	45 18 04	105 05 50	3.45	1947-53, 1957-72, 1973-82 ^P		
117	66325500	Little Powder River near Broadus, Mont.	45 23 25	105 18 15	1,974	1928-33		
118	66325700	Powder River tributary near Powderville, Mont.	45 48 46	105 03 51	3.20	1976-82		
119	66325950	Cut Coulee near Mizpah, Mont.	46 08 38	105 10 05	2.23	1976-82		
120	66326000	Powder River near Mizpah, Mont.	46 15 00	105 16 00	12,132	1978		
121	66326050	Mizpah Creek at Olive, Mont.	45 32 30	105 31 40	129	1976-82		1976-79
122	66326200	Mizpah Creek near Volborg, Mont.	45 56 00	105 23 40	510	1976-78		1976-77
123	66326300	Mizpah Creek near Mizpah, Mont.	46 15 39	105 17 34	797	1976-82	1976-82	1976-79
124	66326400	Meyers Creek near Locate, Mont.	46 23 00	105 17 00	9.42	1962-76 ^P		
125	66326500	Powder River near Locate, Mont.	46 25 48	105 18 34	13,189	1938-82	1946, 1948-63, 1975-82	1950-53, 1974-82
126	66326507	Locate Creek near Ismay, Mont.	46 25 20	105 07 45		1979-82		
127	66326510	Locate Creek tributary near Locate, Mont.	46 25 52	105 10 51	.91	1973-82 ^P		
128	66326700	Porcupine Creek near Turnercreek, Wyo.	43 37 40	105 28 00	31.5	1959-76 ^P		
129	66326700	Antelope Creek near Teckla, Wyo.	43 29 07	105 13 29	959	1977-81	1977-81	1977-81
130	66326900	Dry Fork Cheyenne River near Bill, Wyo.	43 13 21	105 40 00	128	1976-81	1977-81	1977-81
131	66326900	Cheyenne River near Dull Center, Wyo.	43 25 45	105 02 43	1,527	1976-81	1975-81	1975-81
132	66327500	Little Thunder Creek near Hampshire, Wyo.	43 39 20	104 54 20	234	1977-81	1977-81	1977-81
133	663276300	Little Thunder Creek near Hampshire, Wyo.	43 34 51	104 43 04	535	1972-82	1977-81	1979-81
134	663278300	Lodgepole Creek near Hampshire, Wyo.	43 33 40	104 33 40	354	1977-81	1977-81	1977-81
135	663278640	Lance Creek tributary near Lance Creek, Wyo.	43 10 00	104 37 00	1.20	1965-73 ^P		
136	663279600	Box Creek near Bill, Wyo.	43 06 20	105 15 35	112	1956-59 1961-81 ^P		
137	663282200	Pritchard Draw near Lance Creek, Wyo.	43 12 00	104 41 00	5.10	1964-72 ^s 1972-81 ^P		
138	663285400	Cottonwood Creek at Hat Creek, Wyo.	42 56 15	104 21 55	14.5	1972-79 ^P		
139	663286000	Lance Creek near Riverview, Wyo.	43 22 00	104 16 00	2.070	1948-54.	1951-53.	1950-54.

Station or site no. in this report	U.S. Geological Survey station no.	Station name	Location (degrees, minutes, seconds)		Drainage area (square miles)	Period and type of record			
			Latitude	Longitude		Discharge	Chemical Quality	Sediment	Biological
140	06386500	Cheyenne River near Riverview, Wyo.	43 25 00	104 08 00	5,270	1956-82	1975-82	1957-59, 1976-82	
141	06425720	Belle Fourche River below Rattlesnake Creek, near Piney, Wyo.	43 59 04	105 23 16	495	1948-74	1975-82	1969-70, 1975-81, 1971-74	1975-80
142	06425750	Coal Creek near Piney, Wyo.	43 58 22	105 19 53		1980-82	1980-82	1980-82	1981
143	06425780	Belle Fourche River above Dry Creek, near Piney, Wyo.	44 01 30	105 19 35	594	1975-82	1975-82	1975-82	1975-82
144	06425900	Caballo Creek at mouth near Piney, Wyo.	44 04 48	105 15 59	260	1977-82	1977-82	1977-82	1978-80
145	06425950	Raven Creek near Moorcroft, Wyo.	44 10 04	105 05 11	76	1977-82	1977-82	1977-82	1978-80
146	06426000	Belle Fourche River near Moorcroft, Wyo.	44 16 30	104 58 35	1,380	1923-33			
147	06426195	Donkey Creek tributary above reservoir, near Gillette, Wyo.	44 16 57	105 25 38	.20	1970-82 ^P			
148	06426200	Donkey Creek tributary near Gillette, Wyo.	44 17 00	105 25 40	.28	1960-76 ^P			
149	06426400	Donkey Creek near Moorcroft, Wyo.	44 16 58	105 03 48	246	1977-81	1977-82	1977-81	1977-81
150	06426500	Belle Fourche River below Moorcroft, Wyo.	44 17 44	104 58 35	1,670	1943-70, 1974 ^m	1946-47, 1949-57, 1975-82	1946-47, 1947-52, 1976-82	1975-81
151	06427000	Keyhole Reservoir near Moorcroft, Wyo.	44 22 55	104 46 45	2,000	1975-82			
152	06427500	Belle Fourche River below Keyhole Reservoir, Wyo.	44 23 18	104 46 12	2,000	1951-82	1969		
153	06427850	Belle Fourche River at Devils Tower, Wyo.	44 35 22	104 42 12			1968-82		1978-81
154		Box Creek at County Road 32 near Bill, Wyo.	43 04 33	105 23 43					1980
155		Box Creek at Johnson Ranch near Bill, Wyo.	43 06 09	105 16 39					1978
156		Lightning Creek near Janet, Wyo.	43 14 00	104 37 25					1977
157		Powder River above Salt Creek, near Sussex, Wyo.	43 41 29	106 20 30					
158		Donkey Creek above Lee Draw, near Gillette, Wyo.	44 16 23	105 24 08					1978
159		Donkey Creek below Wyodak Mine, near Gillette, Wyo.	44 17 13	105 22 30			1975		1978
160		Clear Creek above Buffalo city park, Wyo.	44 21 01	106 40 33					1978
161		Clear Creek at Buffalo city park, Wyo.	44 21 02	106 40 40					1978
162		Clear Creek above Buffalo sewage plant, at Buffalo, Wyo.	44 21 04	106 41 01					1978
163		Clear Creek above Buffalo sewage plant, below stockpens, at Buffalo, Wyo.	44 21 05	106 40 57					1978
164		Buffalo sewage plant effluent at Buffalo, Wyo.	44 21 06	106 42 18					1978
165		Clear Creek below Buffalo sewage plant, at Buffalo, Wyo.	44 21 08	106 40 45					1978
166		Clear Creek at U.S. Highway 16, at Buffalo, Wyo.	44 21 17	106 40 03					1978
167		Clear Creek below Rumor Draw, near Buffalo, Wyo.	44 23 38	106 37 13					1978
168		Clear Creek above East Healy Draw, near Buffalo, Wyo.	44 24 07	106 36 30					1978

P Data on peak flows only.
s Stage-rainfall station operated during May through September.
m Record consists of periodic or miscellaneous discharge measurements.

10.0 SUPPLEMENTAL INFORMATION FOR AREA 50--Continued

10.3 Index of Surface-Water Stations

11.0 REFERENCES

11.1 Topic Listing

Bibliography Contains More Than 350 References

The scientific literature for Area 50 is extensive; the references listed in this report are summarized by major topic.

More than 350 references are listed in section 11.2, indicating the large amount of scientific information available. Because only about 145 of the references are cited in the text, the references are listed below by major topic. The topics correspond with primary and, in most instances, secondary headings used in this report. Every reference is listed at least once; some twice or more. The classification of the references is not exhaustive—a reference may include useful information about topics other than those for which the reference is listed. For example, the environmental impact statements are listed only under 1.0 INTRODUCTION; these reports commonly contain extensive information related to most of the other topics.

1.0 INTRODUCTION

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2.0 DEFINITION OF TERMS

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3.2 Landforms

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3.3 Drainage

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3.4 Soils

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3.5 Vegetation

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3.6 Geology

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6.0 SURFACE-WATER QUANTITY

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7.0 SURFACE-WATER QUALITY

7.1 Chemical Quality

Briggs and Ficke (1978), Conner and others (1976), Druse and others (1981), Ebens and Shacklette (1982), Ehlke and others (1982), Frickel and Shown (1974), Geugh and others (1979), Greeson (1981a), Hem (1970), Hembree and others (1952), Karp and Botz (1975), Karp and others (1975), Knapton and Ferreira (1980), Knapton and McKinley (1977), Lorens (1982), Mackenthum (1973), McKee and Wolf (1971), Melancon and others (1979), National Academy of Sciences and National Academy of Engineering (1973), Ringen and others (1979), Rucker and DeLong (1984), U.S. Environmental Protection Agency (1976, 1977, 1979), U.S. Geo-

logical Survey (1977, 1983a, 1983b), U.S. Public Health Service (1962).

7.2 Suspended Sediment

Hadley and Schumm (1961), Hembree and others (1952), Lagasse and others (1982), Langbein and Schumm (1958), Leopold and others (1964), Lidstone (1982), Long and Xiong (1981), Martinson (1982), Martinson and Meade (1983), Ringen and others (1979), Roach and Colby (1958), Rolfe and Hadley (1964), U.S. Bureau of Reclamation (1959), U.S. Geological Survey (1983a, 1983b).

7.3 Biology

Bahls (1979, 1980), Bahls and others (1981), Baril and others (1978), Baxter and Simon (1970), Gore and Johnson (1979), Greeson (1981a, 1981b, 1981c, 1981d, 1982), Klarich and Regele (1980), Klarich and others (1980), Knapton and Bochy (1976), Mallard (1981), McFeters and others (1974), Newell (1977), Rehwinkel (1978), Rockett (1976), U.S. Fish and Wildlife Service (1978, 1980), Wangsness (1977), Wangsness and Peterson (1980), Wesche and Johnson (1980), Wyoming Department of Environmental Quality (1982).

7.4 Temperature

Aagaard (1969), Lowham and others (1975), U.S. Geological Survey (1983a, 1983b).

8.0 GROUND WATER

8.1 Ground-Water Data

Ballance and Freudenthal (1975, 1976, 1977), Blankennagel and others (1977), Boner and others (1976), Botz and Bond (1966), Brown and others (1977, 1982), Busby and others (1983), Crist and Lowry (1972), Downey (1982a, 1982b), Gilbert and Buchanan (1982), Head and others (1979), Hodson (1971a, 1971b, 1974), Hodson and others (1973), Hopkins (1976), Kohout (1957), Larson and Daddow (1984), Lenfest (1984), Levings (1981a, 1981b, 1982a, 1982b, 1982c), Levings and others (1981), Lobmeyer (1980), Lobmeyer and others (1982), Lowry (1973), Lowry and Cummings (1966), Miller and others (1977), Perry (1931, 1932, 1935), Peterson (1981), Ragsdale (1982), Renick (1924), Riffenburg (1926), Ringen (1973, 1974), Slagle and Stimson (1979), Stevens (1978), Taylor (1965, 1968), Thayer (1983), U.S. Geological Survey (1975, 1979e, 1983a, 1983b), Wells (1982), Wells and others (1979), Whitcomb (1965), Whitcomb and Morris, (1964), Whitcomb and others (1966).

8.2 Availability

Anderson and Kelley (1976), Bergantino (1981), Crist and Lowry (1972), Downey (1982a), Feathers

and others (1981), Ground-water Subgroup of Water Work Group, Northern Great Plains Resources Program (1974), Head and Merkel (1977), Hodson and others (1973), King (1974), LaRocque (1966), Levings and others (1981), Lewis and Hotchkiss (1981), Lewis and Roberts (1978), Littleton (1950), Lowry and Cummings (1966), Lowry and Rankl (1984), McCary and others (1983), Meinzer (1923), Miller (1976, 1979, 1981), Montana Bureau of Mines and Geology and U.S. Geological Survey (1978), Morris (1956), National Research Council (1981), Perry (1931, 1932, 1935), Rahn (1975, 1976), Renick (1929), Robinson and Foley (1941), Stoner and Lewis (1980), Taylor (1965, 1968, 1978), Warner (1947), Whitcomb (1965), Whitcomb and Morris (1964), Whitcomb and others (1966), Wyoming Water Planning Program (1972, 1973a).

8.3 Recharge and Movement

Blackstone (1981), Boner and others (1976), Downey (1982a), Feltis (1980a), Fitzwater (1981), Huntoon (1976), Konikow (1976), Levings (1982a, 1982b, 1982c, 1982d), Lobmeyer (1980), Meinzer (1923), Miller and Strausz (1980a, 1980b), Stone and Snoeberger (1977), Swenson and others (1976), U.S. Office of Surface Mining (1981a), Van Voast and others (1978), Wyoming State Engineer's Office (1976).

8.4 Chemical Quality

Beath (1943), Busby and others (1983), Crist and Lowry (1972), Dockins and others (1980), Ebens and Shaklette (1982), Everett (1979), Feder and others (1977), Feltis (1980b, 1980c, 1980d), Hem (1970), Hodson (1971b, 1974), Hodson and others (1973), Keefer (1974), Kohout (1957), Larson and Daddow (1984), Lee (1979, 1981), Littleton (1950), National Academy of Sciences and National Academy of Engineering (1973), Powers and others (1974), Renick (1924), Riffenburg (1926), Thorstenson and others (1979), U.S. Environmental Protection Agency (1976, 1977, 1979), U.S. Geological Survey (1977), U.S. Public Health Service (1962), Van Voast and Bremmer (1976), Van Voast and others (1978), Wells and others (1979).

9.0 WATER-DATA SOURCES

9.2 National Water Data Exchange (NAWDEx)
Edwards (1980)

10.0 SUPPLEMENTAL INFORMATION

10.1 Hydrologic Studies by the Geological Survey
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