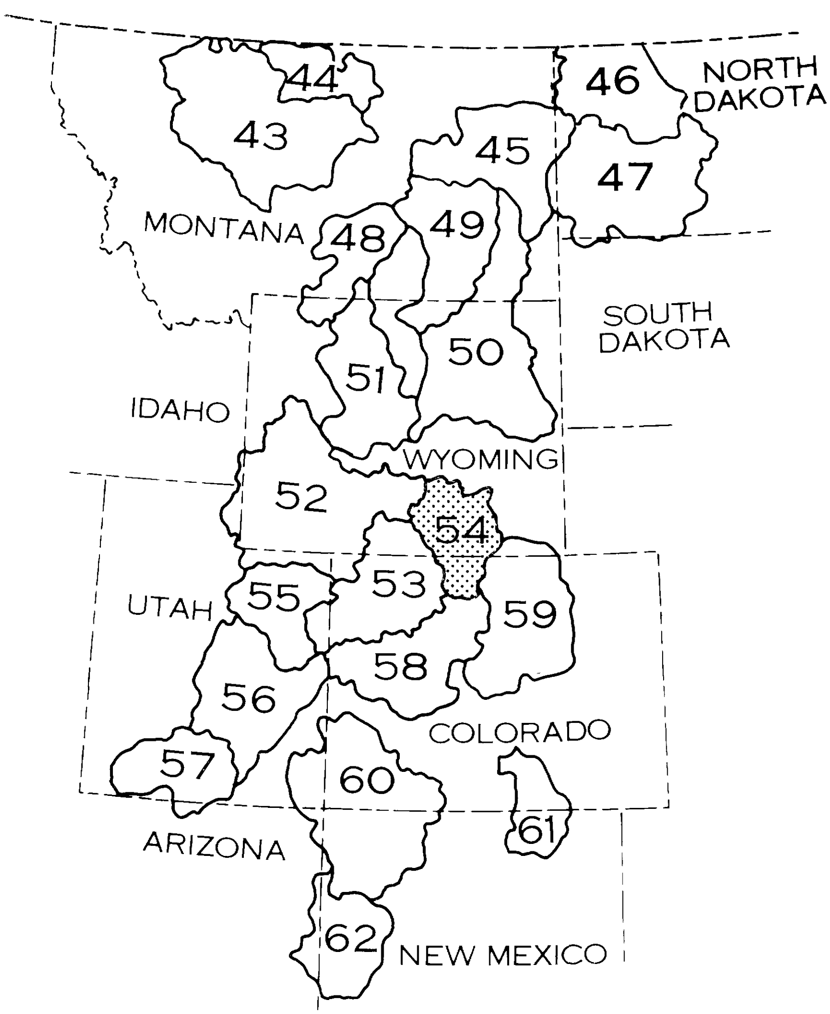
HYDROLOGY OF AREA 54, NORTHERN GREAT PLAINS, AND ROCKY MOUNTAIN COAL PROVINCES, COLORADO, AND WYOMING



- NORTH PLATTE RIVER
- LARAMIE RIVER
- MEDICINE BOW RIVER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS
OPEN FILE REPORT 83-146

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

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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:

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meters (m^3)
	0.001233	cubic hectometers (hm^3)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meters per second per square kilometer [$(m^3/s)/km^2$]
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
inches (in)	25.4	millimeters (mm)
inches per hour (in/h)	25.4	millimeters per hour (mm/h)
	2.54	centimeters per hour (cm/h)
micromhos per centimeter at 25° Celsius (μmhos/cm)	100	microsiemens per meter at 25° Celsius (μS/m)
miles (mi)	1.609	kilometers (km)
million gallons per day (mgal/d)	0.04381	cubic meters per second (m^3/s)
square miles (mi^2)	2.590	square kilometers (km^2)
tons per square mile per year [$(ton/mi^2)/yr$]	0.3503	metric tons per square kilometer per year [$(t/km^2)/a$]

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

HYDROLOGY OF AREA 54, NORTHERN GREAT PLAINS, AND ROCKY MOUNTAIN COAL PROVINCES, COLORADO, AND WYOMING

BY
GERHARD KUHN, PAMELA B. DADDOW, GORDON S.CRAIG, JR., AND OTHERS

Abstract

A nationwide need for information characterizing hydrologic conditions in mined and potential mine areas has become paramount with the enactment of the Surface Mining Control and Reclamation Act of 1977. This report, one in a series covering the coal provinces nationwide, presents information thematically by describing single hydrologic topics through the use of brief texts and accompanying maps, graphs, or other illustrations. The summation of the topical discussions provides a description of the hydrology of the area.

Area 54, in north-central Colorado and south-central Wyoming, is 1 of 20 hydrologic reporting areas of the Northern Great Plains and Rocky Mountain coal provinces. Part of the Southern Rocky Mountains and Wyoming Basin physiographic provinces, the 8,380-square-mile area is one of contrasting geology, topography, and climate. This results in contrasting hydrologic characteristics.

The major streams, the North Platte, Laramie, and Medicine Bow Rivers, and their principal tributaries, all head in granitic mountains and flow into and through sedimentary basins between the mountain ranges. Relief averages 2,000 to 3,000 feet. Precipitation in the mountains may exceed 40 inches annually, much of it during the winter, which produces deep snowpacks. Snowmelt in spring and summer provides most streamflow. Precipitation in the basins averages 10 to 16 inches annually, insufficient for sustained streamflow; thus, streams originating in the basins are ephemeral.

Streamflow quality is best in the mountains where dissolved-solids concentrations generally are least. These concentrations increase as streams flow through sedimentary basins. The increases are mainly natural, but some may be due to irrigation in and adjacent to the flood plains. In the North Platte River, dissolved-solids concentrations are usually less than 300 milligrams per liter; in the Laramie and the Medicine Bow Rivers, the concentrations may average 500 to 850 milligrams per liter. However, water-quality stations on the Laramie and the Medicine Bow Rivers are farther removed from the mountain sources than the stations in the North Platte drainage.

Because of the semiarid climate of the basins, soils are not adequately leached. Consequently, flow in ephemeral streams usually has a larger concentration of dissolved solids than that in perennial streams, averaging 1,000 to 1,600 milligrams per liter.

Aquifers containing usable ground water are combined into three groups: (1) Consolidated and unconsolidated noncoal-bearing Quaternary and Upper Tertiary deposits, (2) Mesozoic and Paleozoic sedimentary rocks, and (3) Lower Tertiary and Upper Cretaceous sedimentary rocks containing coal. These aquifers are used for municipal, domestic, irrigation, and stock supplies. Well yields range from about 5 to 1,000 gallons per minute, and depend on type of aquifer, saturated thickness, and degree of fracturing.

The best quality ground water usually comes from the noncoal-bearing Quaternary and Upper Tertiary rocks or the Mesozoic and Paleozoic rocks; often it is dominated by calcium and bicarbonate ions. The coal-bearing formations have a large variability in water chemistry; dominant ions may be bicarbonate or sulfate and sodium, calcium, or magnesium. Dissolved-solids concentrations are generally larger than in the former two groups.

The U.S. Geological Survey operates a network of hydrologic stations to observe the streamflow and ground-water conditions. This network currently includes 31 surface-water stations and 35 observation wells; information is available for many other sites observed in the past. Data available include rate of flow, water levels, and water quality; much of the data are available in published reports or from computer storage through the National Water Data Exchange (NAWDEX) or the National Water Data Storage and Retrieval System (WATSTORE).

Five formations of Late Cretaceous and early Tertiary age contain coal. Wyoming's Hanna Coal Field has 60 minable coal beds whereas the North Park Coal Field of Colorado has only 3. More than 90 percent of the area's 1980 production of 11 million tons came from the Hanna Coal Field.

Hydrologic problems related to surface mining are erosion and sedimentation, decline in water levels, disruption of aquifers, and degradation of water quality. General lack of runoff from semiarid mine areas combined with buffer and dilution capacities of major streams minimizes the effects on surface water. However, effects on ground-water systems may be much more severe and long-lasting.

1.0 INTRODUCTION
1.1 Objective

Area 54 Report to Aid Preparation of Mining Permits

Existing hydrologic conditions are described and sources of hydrologic information are identified.

A need for hydrologic information and analysis on a scale never before required nationally was identified with the enactment of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). This need is partly met by this report which broadly characterizes the hydrology of Coal Area 54 in Colorado and Wyoming (fig. 1.1-1). One in a series of reports describing the coal provinces nationwide, this report presents hydrologic information thematically by describing single hydrologic topics (for example, low flow) through the use of brief texts and accompanying maps, graphs, or other illustrations. The summation of the topical discussions provides a description of the hydrology of the area.

Public Law 95-87 requires that mining-permit applicants make a "determination of the probable hydrologic consequences of the mining and reclamation operations" in and adjacent to surface mine areas. To aid the permittee in making this determination, the law specifies that "hydrologic information on the general mine area prior to mining" be made available by an "appropriate Federal or State agency." Information presented or available through sources identified in this report may be used in describing the hydrology of the "general area" of any proposed mine. With the expectation that this general hydrologic information will be supplemented by the lease applicant's specific site data as well as data from other sources, a more detailed appraisal of the hydrology in the vicinity of the mine can be determined.

The information contained in this report should be useful to surface-mine owners/operators, consultants, and others in the preparation of the mining-permit applications. Finally, the information also should be an aid to the regulatory authorities in appraising the adequacy of the applications with respect to determining and minimizing the "disturbances to the prevailing hydrologic balance" during the mining and reclamation process.

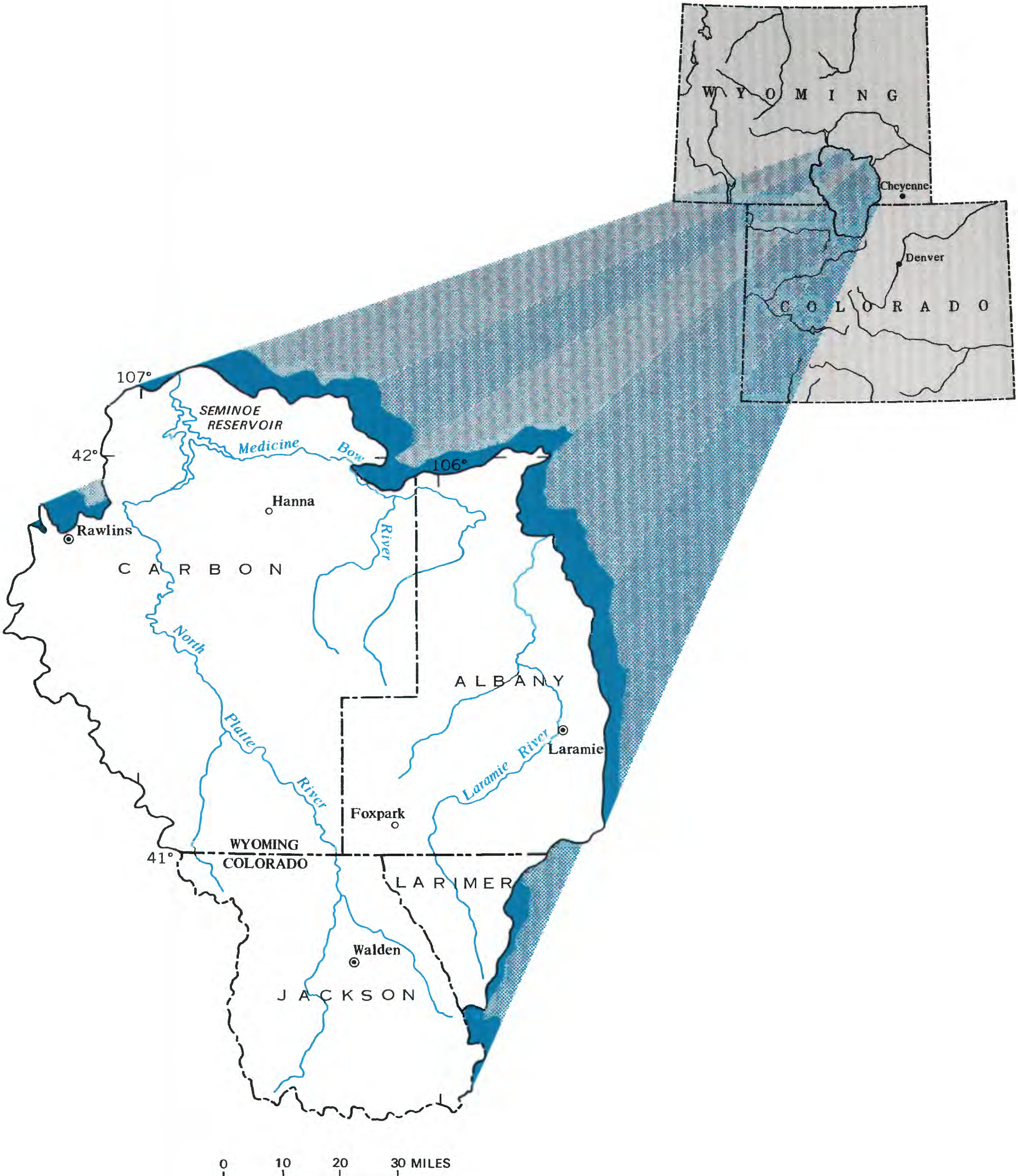


Figure 1.1-1 Location of Coal Area 54.

Area 54 has Diverse Physical Features and Sparse Population

The North Platte, the Laramie, and the Medicine Bow Rivers drain the 8,380-square-mile area which has a population of about 53,000.

Nationwide, the coal provinces have been divided into hydrologic reporting areas by combining hydrologic units (drainage basins) or parts of units on the basis of location, size, and presence of coal resources. Area 54, located in north-central Colorado and south-central Wyoming, is one of the reporting areas of the Northern Great Plains and Rocky Mountains Coal Provinces (see front cover). The 8,380-square-mile area is drained by the North Platte River and two of its tributaries, the Laramie and the Medicine Bow Rivers (fig. 1.2-1). Headwaters for all these rivers are within the area, and drainage is east of the Continental Divide that forms the western and southern boundaries.

The main stem of the North Platte River drains the western part of the area, following a northerly course from its headwaters in the mountains of Colorado to its impoundment by Seminoe Dam, Wyo. Seminoe Reservoir, a multipurpose reservoir, has a storage capacity of 1,026,000 acre-feet. The Laramie River, with a drainage area of 2,200 square miles, flows northeastward to its confluence with the North Platte River outside the report area. The drainage area of the Medicine Bow River is about 1,550 square miles, which does not include 980 square miles of tributary drainage from the Little Medicine Bow River, outside the area (fig. 1.2-1).

The region has diverse topography, geology, climate, and types of vegetation. Geologic strata ranging in age from Precambrian to Quaternary are at the surface. Elevation above NGVD of 1929 ranges from 6,000 feet in the canyon downstream from Seminoe Dam to about 13,000 feet in the Medicine Bow Mountains. Largely as a result of this varied elevation, the climate varies from semiarid with less than 12 inches annual precipitation to alpine with more than 40 inches annual precipitation. Because of the dramatic climate change, vegetation varies from northern desert shrub to spruce-fir forest (figs. 1.2-2 and 1.2-3). Subsequent sections of this report provide additional discussion of cultural and physical features.

In Colorado, the area includes all of Jackson and the northwest part of Larimer Counties; large parts of Albany and Carbon Counties are included in Wyoming. Census figures for 1980 show the following county populations: Albany, 29,062; Carbon, 21,896; and Jackson, 1,863. The area has a low population density, with most population concentrated in the following incorporated areas--in Wyoming, Laramie, 24,410; Rawlins, 11,547; Saratoga, 2,410; Hanna, 2,288; and in Colorado, Walden, 947. These five cities and towns have about 80 percent of the area's population. Northwest Larimer County probably has fewer than 200 residents, and the percentage of the populations of Albany and Carbon Counties outside the report area is also very small.

The economy is also diverse. Coal mining, oil and gas production, lumbering, cattle and sheep ranching, agriculture, railroading, recreation, and tourism are some of the economic activities. In addition, the University of Wyoming is located in Laramie.

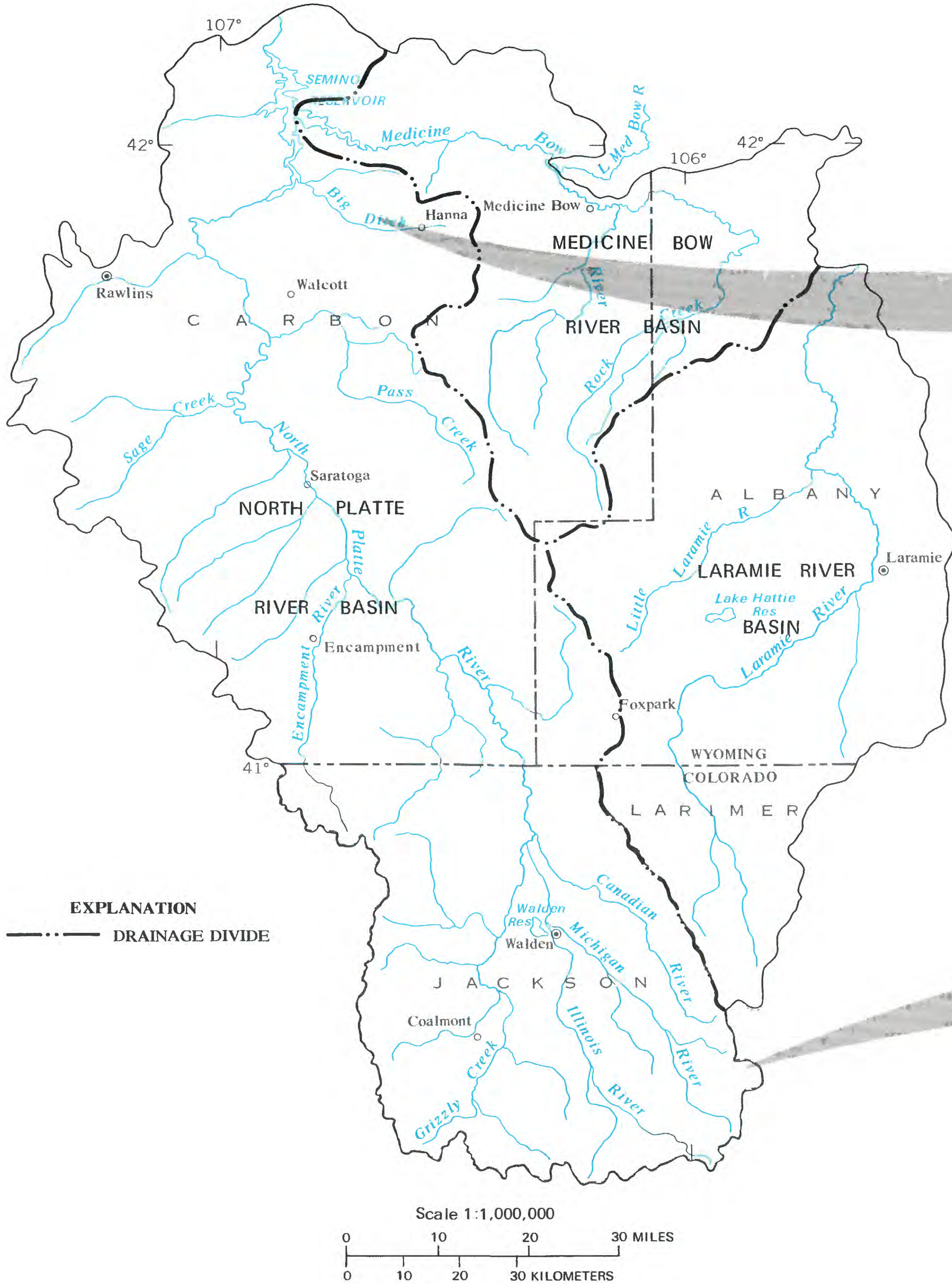


Figure 1.2-1 Drainage basins.

Figure 1.2-2 Shrub vegetation and topography in Hanna basin.

Figure 1.2-3 Spruce-fir vegetation and topography in Medicine Bow Mountains.

Quality of Surface Water Can Be Degraded

Erosion, sedimentation, and degradation of surface-water quality are typical problems associated with surface coal mining.

Surface mining results in dramatic changes, at least temporarily, in the landscape of previously undisturbed land. Landscape changes, such as removal of vegetation, excavation, and formation of large areas of unconsolidated and unweathered spoil material will result in some changes in the hydrologic characteristics of the mine areas. Hydrologic changes can affect the amounts of suspended sediment carried by streams and the amounts of dissolved solids and dissolved or total recoverable trace elements in surface water.

The hydrologic setting of Area 54, with respect to coal mining, is somewhat similar to that of other coal areas in the Rocky Mountain Coal Province. The major rivers--the North Platte, the Medicine Bow, and the Laramie Rivers and their principal tributaries--all have their headwaters in mountains some distance from the coal areas, whereas streams that originate in the coal areas are ephemeral. These mountains supply most of the water to the river systems from deep snowpacks that melt during late spring and summer. The mountains, generally igneous and metamorphic rock, are very different geologically than the coal areas, which are in sedimentary rock. Most of the water and its associated quality is foreign to the coal-region environment through which the water is transported; this is more true in Colorado than in Wyoming. The water quality of the Medicine Bow River, the major river in the Wyoming coal area, is influenced much more by flow through sedimentary rocks than streams in the Colorado coal area. These factors, in part, help to reduce the impacts from mining because runoff from the mine areas is relatively small and the larger streams usually have a large dilution capacity. However, observation of the system is more difficult because both the major streams and the small tributaries draining the coal areas must be observed.

A characteristic of ephemeral streams in this area is that they often have larger concentrations of suspended sediment than do the perennial streams (fig. 1.3.1-1). The loss of vegetative cover and the formation of areas of unconsolidated spoil material provides some opportunity for increased suspended-sediment concentrations in these streams. These areas would be especially susceptible to increased erosion during occasional intense thunderstorms. Because of the overall lack of water in these streams, the potential for increased sediment yield usually can be controlled by careful management and the use of settling ponds.

Dissolved-solids concentrations also are much larger naturally in ephemeral streams than in perennial streams. Soluble salts and minerals tend to accumulate in the soils of these semiarid areas because precipitation and runoff are insufficient to provide adequate leaching. An additional source of soluble mineral salts and trace elements is the unweathered rock material exposed by mining. Runoff from these areas may have larger concentrations of dissolved solids and dissolved or total recoverable trace elements.

One of the most common water-quality problems in the eastern United States is acid mine drainage; however, the problem is largely unknown in western coal mines. Iron sulfides (pyrite and marcasite) commonly occur in coals and associated noncoal strata. Once exposed to the atmosphere by mining, these minerals are readily oxidized, producing sulfuric acid and iron hydroxide precipitate. Increased acidity in the water, in turn, results in increased dissolution of additional minerals. Such water draining a mined area generally has pH values ranging from 2.5 to 5.0 and large sulfate, trace-metal, and dissolved-solids concentrations.

In the report area the chemical-weathering reaction is the same, but the native waters are buffered by carbonate and bicarbonate (alkalinity), normally preventing the development of acid waters and large concentrations of dissolved trace elements. The semiarid climate also aids in preventing the formation of acid water. Overall, some increases in dissolved solids, particularly sulfate, and increases in total recoverable trace-element concentrations are likely as a result of mining. But because the pH of the water is neutral to basic and because bicarbonate is abundant, trace elements largely remain in the suspended phase, sorbed to the fine-grained sediment. Increases in total recoverable trace-element concentrations, then, are usually associated with increases in suspended-sediment concentration.

Figure 1.3.1-1 Suspended sediment in ephemeral stream.

Quantity and Quality of Ground Water Can Be Impacted by Surface Mining

Decline in water levels and degradation of ground-water quality are typical problems associated with surface coal mining.

The effects of mining on the ground waters probably will be much more severe and have a longer duration than the effects on surface waters. However, in parts of the coal areas, ground-water and surface-water systems may be connected. Effects on ground water, such as degradation of quality, may then be reflected in the surface water of the area, resulting in poorer quality streamflow.

Aquifers in the coal areas can occur in alluvium, overburden, coal seams, and beds underlying coal seams. One of the major impacts is the total or partial loss of an aquifer by removal of overburden or coal. After reclamation, these aquifers may or may not be reestablished in the spoil material. Dewatering of aquifers adjacent to mines (fig. 1.3.2-1) results in a decline in water levels in those aquifers and water-supply wells could be affected. Conversely, ground-water levels may rise with time in undisturbed areas downdip from the mined areas. This may result from increased recharge in the reclaimed mine areas.

Disruption of aquifers and related effects due to surface mining also will affect ground-water quality. The rock material exposed and fragmented by mining is largely unweathered. As water moves through the spoils, increases in dissolved solids and trace elements are likely. The water usually is in contact with the spoils for a long time and dissolved solids may increase significantly in aquifers in mine spoils. Also, prior to mining, two or more aquifers with very different water-quality characteristics may be separated by relatively impermeable layers. Disruption by mining could effectively join these aquifers, resulting in degradation of water quality in some aquifers.

The effects of mining on the aquifers of Area 54 have not been studied; however, studies in other areas show that increases in dissolved-solids concentrations may be noted in waters in mine-spoil aquifers (Van Voast, 1974; Van Voast and others, 1977; and McWhorter and others, 1977). In their study of the effects of mining on the hydrology of a small watershed in northwestern Colorado, McWhorter and others (1977, p. 5) concluded that "dissolved solids concentration in overland flow runoff is very small compared to that in subsurface runoff" and that "concentration of dissolved solids in subsurface drainage from a bank of mine spoils cannot be expected to decline for many decades." Van Voast and others (1977, p. 42) suggest that water from mine spoils in southeastern Montana may have dissolved-solids concentrations ranging between 1,000 and 5,000 milligrams per liter. Dissolved-solids concentrations ranging from 328 to 8,160 milligrams per liter have been noted in ground-water samples from the Wyoming coal area (Freudenthal, 1979); however, none of these samples were from mine spoils. It is not certain if any of the larger concentrations observed here are due to mining, or whether dissolved-solids concentrations in mine-spoil aquifers of the report area will be similar or different from that observed in undisturbed aquifers.

Figure 1.3.2-1 Water in mine pit from dewatering of aquifer.

2.0 DEFINITION OF TERMS

Terms Used in Hydrologic Reports Defined

Technical terms that are used in this hydrologic report are defined.

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

Anion is a negatively charged ion.

Anticline is a fold that is convex upward, with the older rocks toward the center of curvature.

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.

Alluvial aquifer is an aquifer located in unconsolidated stream deposits of comparatively recent time.

Base flow (or base runoff) is sustained or fair-weather runoff composed largely of ground-water discharge.

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

Cation is a positively charged ion.

Cells per volume refers to the number of cells of any organism which is counted by using a microscope and grid or counting cell. Many planktonic organisms are multicelled and are counted according to the number of contained cells per sample volume, usually milliliters (ml) or liter (L).

Coefficient of determination (r^2), in linear regression, is the square of the correlation coefficient. The coefficient of determination x100 provides a measure of the percentage of the variation of the dependent variable explained by variation of the independent variable.

Conglomerate is a rock consisting of rounded, water-worn fragments of other rock or pebbles cemented together by another mineral.

Cubic foot per second (cfs, ft^3/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.

Dewatering, in this report, refers to the artificial discharge of water from an aquifer because the aquifer is exposed in a mine pit. Removal of such water from the mine pit also may be termed dewatering.

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

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

Mean discharge is the arithmetic mean of individual discharges during a specific period of time.

Dissolved refers to that material in a representative water sample which passes through a 0.45-micrometer membrane filter. This may include some very small (colloidal) suspended particles as well as the amount of substance present in true chemical solution. Determinations of "dissolved" constituents are made on subsamples of the filtrate.

Dissolved oxygen (DO) is the dissolved-oxygen content of water in equilibrium with air and is a function of atmospheric pressure and temperature and dissolved-solids concentration of the water. The capacity of water for dissolved oxygen decreases as dissolved solids or temperature increase or as atmospheric pressure decreases.

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 stream above 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 a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

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

Evapotranspiration is the water withdrawn from a land area by evaporation from water surfaces and moist soil and by plant transpiration; the loss of water from leaf and stem tissues of growing vegetation.

Gaging station is a particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained. When used in connection with a discharge record, the term is applied only to those gaging stations where a continuous record of discharge is computed.

Hydrograph is a graph showing discharge, water level, or other property of water with respect to time.

Hydrologic unit is a geographic area representing part or all of a surface drainage basin or distinct hydrologic feature as delineated by the Office of Water Data Coordination on the State Hydrologic Unit Maps; each hydrologic unit is identified by an eight-digit number.

Igneous rock is one that formed by solidification from molten or partially molten materials.

Ion is an atom, group of atoms, or molecule that has acquired a net electrical charge.

Lithology is the physical character of a rock, generally determined by observation with the unaided eye or with the aid of a low-power magnifier.

Load is the amount of material, whether dissolved, suspended, or on the bed, which is moved and transported by a flowing stream.

Metamorphic rock is a rock which has been altered in composition, texture, or internal structure in response to pronounced changes of temperature, pressure, and chemical environment.

Micrograms per liter (μg/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 one 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 mg/L, and is based on the mass of sediment per liter of water-sediment mixture.

Moles per liter is a unit expressing the concentration of chemical constituents in solution. A mole is a mass, expressed in grams, equivalent to the molecular weight.

Orogeny is the process of mountain formation.

Oxidation is the removal of one or more electrons from an element or ion, thus increasing its positive charge or decreasing its negative charge.

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

Perennial stream is one which flows continuously.

Plankton are any organisms, usually minute in size, floating, or drifting in water.

Phytoplankton is the plant part of the plankton. They are usually microscopic, and their movement is subject to the water currents. Phytoplankton growth is dependent upon solar radiation and nutrient substances. Because they are able to incorporate as well as release materials to the surrounding water, the phytoplankton have a profound effect upon the quality of the water. They are the primary food producers in the aquatic environment, and are commonly known as algae.

Blue-green algae are groups of phytoplankton organisms having blue pigment, in addition to the green pigment called chlorophyll. Blue-green algae often cause nuisance conditions in water.

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

Zooplankton is the animal part of the plankton. Some zooplankton are capable of extensive movements within the water column, and are often large enough to be seen with the unaided eye. Zooplankton are secondary consumers feeding upon bacteria, phytoplankton, and detritus. Because they are the grazers in the aquatic environment, the zooplankton are a vital part of the aquatic food web.

Picocurie (PC, pCi) is one trillionth (1×10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7×10^{10} radioactive disintegrations per second. A picocurie yields 2.22 disintegrations per minute (dpm).

Proximate analysis is, in the case of coal and coke, the determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash.

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

Runoff is that part of the precipitation that appears in surface streams.

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

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 sediments per liter of water-sediment mixture (mg/L).

Sedimentary rock is a rock formed by the accumulation of sediment in water or from the air. The sediment may consist of rock fragments of various sizes, of the remains or products of animals and plants, of the product of chemical action or evaporation, or a mixture of these materials.

Solute is any substance derived from the atmosphere, vegetation, soil, or rocks and is dissolved in water.

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

Standard error of estimate in linear regression, is the standard deviation of the residuals. A residual is the difference between the actual value and the value predicted from the regression equation. Standard error of estimate has the same units as the dependent variable and indicates how reliably it may be estimated from a given value of the independent variable.

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

Syncline is a fold that is convex downward, with the younger rocks toward the center of curvature.

Tectonic activity (tectonism) is any form of instability in or deformation of the Earth's crust.

Total recoverable is the amount of a given constituent that is in solution after a representative water-suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances. Complete dissolution of all particulate matter is not achieved by the digestion treatment, and thus the determination represents something less than the "total" amount (that is, less than 95 percent) of the constituent present in the dissolved and suspended phases of the sample. To achieve comparability of analytical data, equivalent digestion procedures would be required of all laboratories performing such analyses because different digestion procedures are likely to produce different analytical results.

Trace element is any constituent of water which generally occurs in concentrations of less than 1 milligram per liter. However, some trace elements may at times exceed this concentration.

Ultimate analysis is, in the case of coal and coke, the determination of carbon and hydrogen in the material, as found in the gaseous products of its complete combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference.

Land Form Characterized by Synclinal Basins Between Granitic Mountains

Twelve physical divisions of the Southern Rocky Mountains and Wyoming Basin physiographic provinces are defined.

Area 54 is within two of Fenneman's (1931, p. 92) physiographic provinces of the "Rocky Mountain System," the Southern Rocky Mountains and the Wyoming Basin. These and the 12 lesser physical subdivisions defined for the area are shown in figure 3.1-1. The following physiographic descriptions are largely based on chapters 2 and 3 of "Physiography of Western United States" by Fenneman (1931).

Generally, the Southern Rocky Mountains constitute a group of broad, deeply eroded granitic anticlines between which lie several synclinal basins, or parks, consisting of sedimentary deposits. The northernmost of these synclinal basins, North Park, is a 1,000-square-mile gently rolling, treeless area with elevations ranging from 8,100 to 8,400 feet. The park is a part of a larger structural basin bisected by the Rabbit Ears Range, which forms the southern boundary of North Park. The Never Summer Mountains, the Medicine Bow Mountains and the Sierra Madre (Park Range in Colorado) rim the park on the remaining three sides; the mountains rise abruptly from the floor of the park to elevations generally between 10,500 to 12,000 feet. The latter two ranges and the Laramie Mountains, which generally have elevations less than 9,000 feet, extend into Wyoming where they decrease in elevation and become buried by surrounding sedimentary deposits. This sedimentary-granitic rock contact serves as the approximate boundary between the Southern Rocky Mountains and the Wyoming Basin.

Fenneman (1931, p. 133) describes the Wyoming Basin as an interruption or, more precisely, a sag in the Rocky Mountain System. Here, sedimentary rocks continuous with those of the Great Plains and Colorado Plateau have partly buried the low-lying mountain core. Within Area 54, the Wyoming Basin consists of four subordinate basins: The Laramie, Carbon, and Hanna Basins and the Saratoga Valley. These basins are bounded or separated by uplifts of the Southern Rocky Mountains or by two uplifts of the Wyoming Basin--the Rawlins Uplift and the Sweetwater Arch--which are a complex of several small mountain ranges. Local relief in the basins usually is less than 300 feet; however, general elevation increases from 6,500 feet in the northern Hanna Basin to 7,500 feet in the southern Laramie Basin and Saratoga Valley. Elevations of the adjacent mountains are less than those rimming North Park; north of the Hanna Basin, they are only about 8,000 feet.

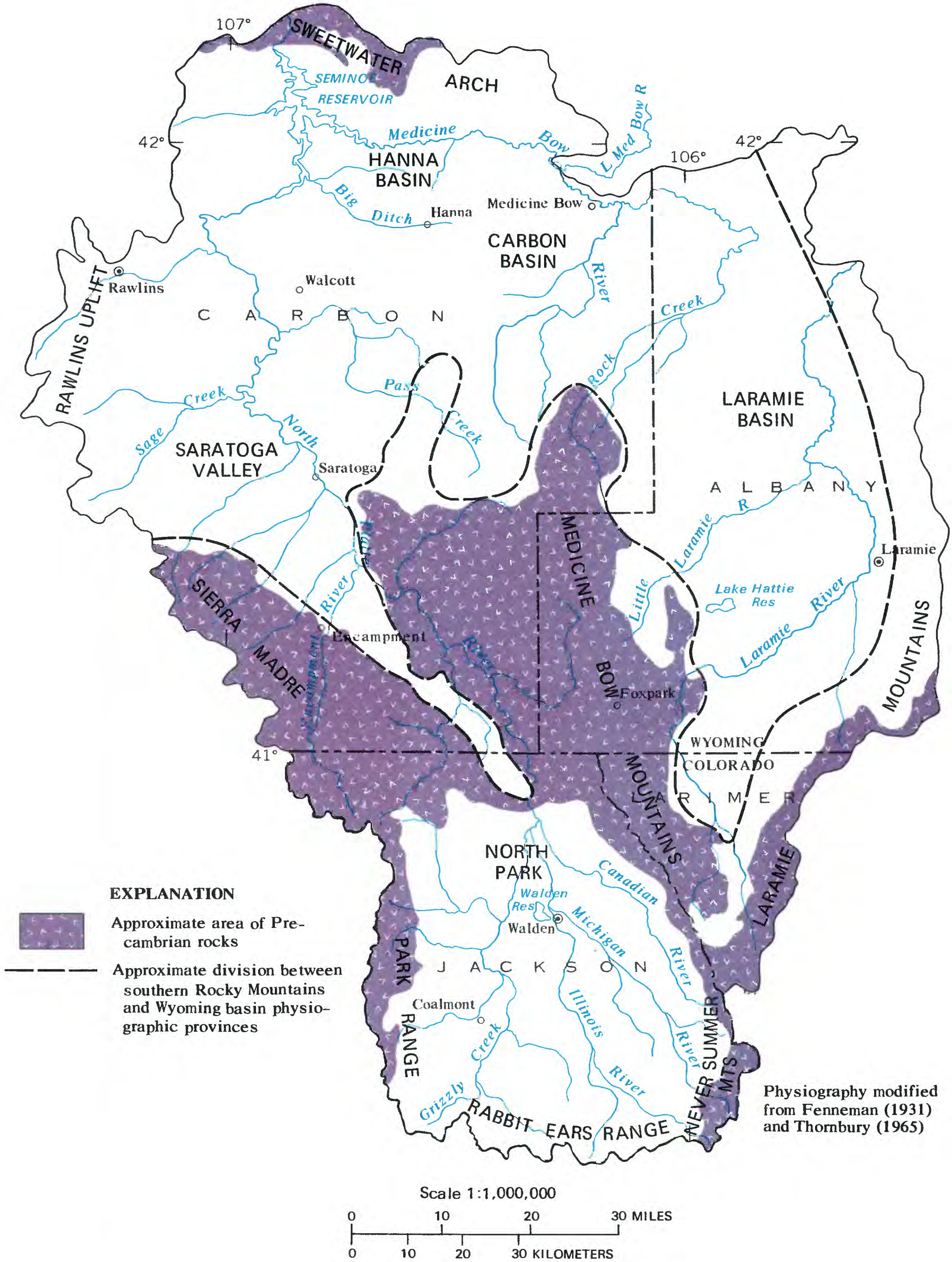


Figure 3.1-1 Physiographic divisions.

Precambrian to Quaternary Geologic Formations Are at Surface

Tectonic activity of the Laramide Orogeny is primarily responsible for the general geologic framework of the area.

As a part of the complex Rocky Mountain System, the region has a long, complex history of sedimentation, erosion, and tectonic activity. Shown in generalized form in figure 3.2-1, the many geologic formations exposed range in age from Precambrian to Quaternary. The five formations (the Coalmont, Hanna, Ferris, and Medicine Bow Formations and Mesaverde Group) known to contain coal resources are shown individually on the geologic map, whereas the remaining formations are combined into one of three other map units (undivided Quaternary and Tertiary deposits, undivided Mesozoic and Paleozoic rocks, and Precambrian rocks) based on age and rock type.

Although no tectonic or structural features are shown in figure 3.2-1, they are an important aspect of the area's geology and relate directly to the physiographic features previously discussed. The forces of the most recent period of tectonic activity, the Laramide Orogeny, are also the most important in shaping the area's basic structure--synclinal basins and anticlinal mountains. Beginning in Late Cretaceous time (about 72 million years ago according to Tweto, 1980, p. 129), the orogeny marked the end of an extended period of minor tectonic activity and mostly marine deposition during alternate transgression and regression of shallow seas over the region during the Mesozoic Era (Thomas, 1949; Berman and others, 1980; and Maughan, 1980). The period of the Laramide Orogeny, a time of major faulting, folding, and uplift and subsidence, was primarily a period of continental deposition. The uplifted areas were rapidly eroded, especially their sedimentary cover (Tweto, 1980, p. 134), and the eroded material was deposited in the subsiding basins. The amount of erosion and deposition was significant; an unconformity under the Paleocene Hanna Formation represents the removal of more than 20,000 feet of rock (Gill and others, 1970, p. 47), while the thickness of Laramide-age deposits in the Hanna Basin area is as much as 33,000 feet (Ryan, 1977, p. 1). Tectonic activity and sedimentation continued well into the Cenozoic Era, ending as late as Miocene and Pliocene time in some areas (Montagne, 1957; and Tweto, 1980). Erosion of the uplifts, a continuing process, culminated in the Pleistocene glaciation that developed many of the present-day features of the higher mountain ranges.

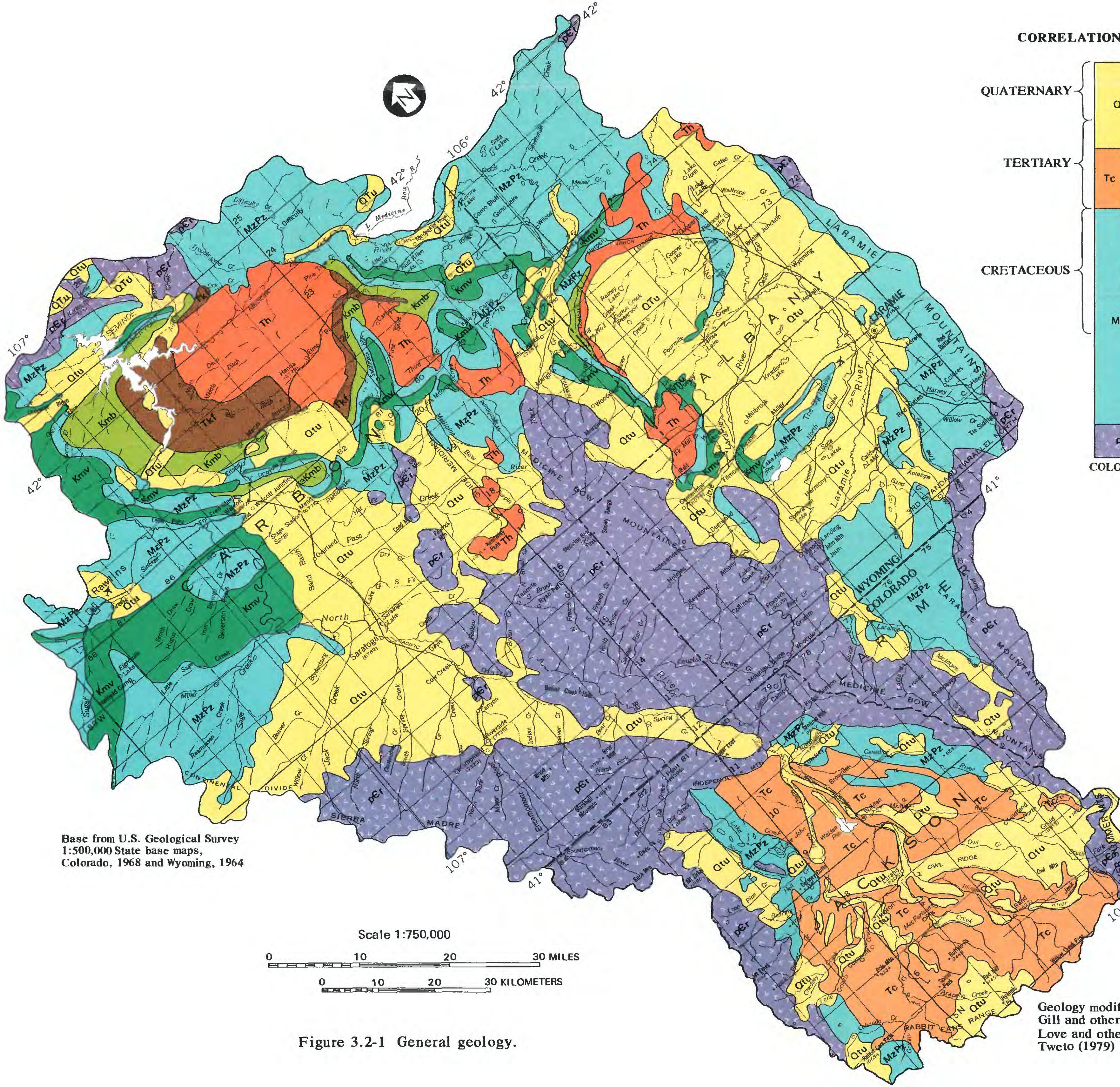
The Upper Cretaceous Mesaverde Group, predominantly of marine origin, is the oldest and, stratigraphically, the lowest coal-bearing formation of the area. In south-central Wyoming the Mesaverde Group was divided by Gill and others (1970, p. 11) into the following formations in ascending order: Haystack Mountains Formation, Allen Ridge Formation, Pine Ridge Sandstone, and Almond Formation. The maximum aggregate thickness of the Mesaverde Group would be about 6,000 feet, but because of unconformities and thinning of beds (Gill and others, 1970, p. 11-36), the average thickness in the Hanna Basin area is about 2,200 to 2,700 feet (Dobbin and others, 1929a, p. 18). Only the Almond Formation, described by Gill and others (1970, p. 31) as a "thick sequence of sandstone, shale, and minor coal," and the Pine Ridge Sandstone contain coal resources. Above the Mesaverde Group are the Lewis Shale, Fox Hills Formation, and Lance Formation, but they contain no coal resources and are not individually mapped in figure 3.2-1. The Medicine Bow Formation, also of Late Cretaceous age, occurs above these formations. This formation is a 6,200-foot-thick continental deposit of "fluviatile sandstone, siltstone and shale with persistent beds of coal in the lower part" (Gill and others, 1970, p. 43).

The Ferris Formation overlies the Medicine Bow Formation and the Hanna Formation overlies the Ferris. The lower 1,100 feet of the Ferris Formation, of Late Cretaceous age, consist of conglomeratic sandstone, sandstone, and shale with no coal, whereas the upper 5,400 feet, of Paleocene age, consist entirely of sandstone and coal beds. The Paleocene Hanna Formation consists of alternating conglomerates, sandstones, shales, and coal beds throughout its reported 7,000- to 13,500-foot thickness (Dobbin and others, 1929a, p. 24-25; Gill and others, 1970, p. 46-47; and Ryan, 1977, p. 5-6).

The only coal-bearing unit found in North Park is the Coalmont Formation of Paleocene and Eocene age. Hail (1968, p. 42) describes the Coalmont as a "heterogeneous mixture of nonmarine sandstone, conglomerate, claystone or mudstone, carbonaceous shale and coal. These rocks are probably flood plain, alluvial, and swamp deposits." The possible total thickness of 12,000 feet has not been verified because of faulting and limited exposures.

The numerous other geologic formations exposed in the area contain no coal resources and are grouped into three undifferentiated map units (fig. 3.2-1). Precambrian granitic and metamorphic rocks are exposed in the higher mountainous uplifts while the mostly marine Paleozoic and Meoszoic sedimentary rocks are found in areas of lesser uplift and in areas between the basins and uplifts. Consolidated and unconsolidated Tertiary and Quaternary deposits are found primarily in the basin areas.

The references given above and at the end of this report will provide a beginning of additional information on the complex geology of the area. These references, in turn, may lead to other sources of information.

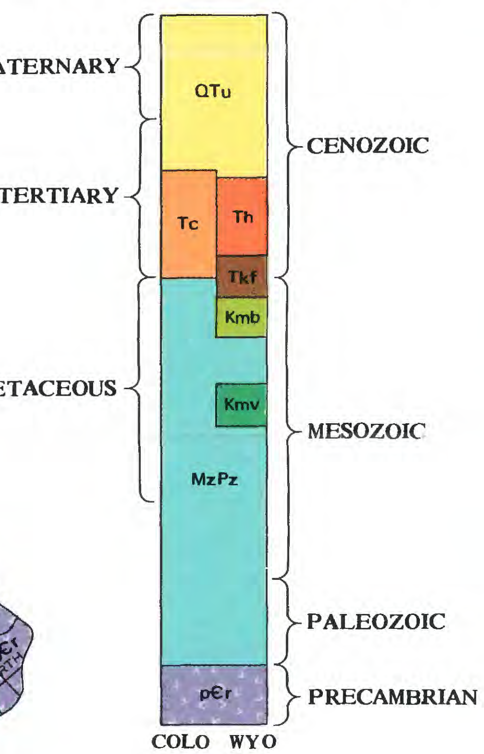


Base from U.S. Geological Survey 1:500,000 State base maps, Colorado, 1968 and Wyoming, 1964

Geology modified from Gill and others (1970), Love and others (1955), Tweto (1979)

Figure 3.2-1 General geology.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

QTu QUATERNARY DEPOSITS—Alluvium, colluvium, glacial drift, and eolian sand in both Colorado and Wyoming

TERTIARY ROCKS (INCLUDES NORTH PARK FORMATION, WHITE RIVER FORMATION, AND IGNEOUS ROCKS IN COLORADO. INCLUDES NORTH PARK FORMATION, BROWNS PARK FORMATION, WHITE RIVER FORMATION, WIND RIVER FORMATION, AND UNNAMED ROCKS IN WYOMING)—Sandstone, siltstone and conglomerate; basalt, tuff, breccia, and porphyries

Tc COALMONT FORMATION (EOCENE AND PALEOCENE)—Arkosic sandstone, conglomerate, carbonaceous shale, and coal beds

Th HANNA FORMATION (PALEOCENE)—Brown and gray sandstone, shale, conglomerate and coal. Beds of giant boulders near Medicine Bow Mountains

Tkf FERRIS FORMATION (PALEOCENE AND UPPER CRETACEOUS)—Brown and gray sandstone and shale; sparse carbonaceous shale and coal beds, thin lenticular pebble conglomerate

Kmb MEDICINE BOW FORMATION (UPPER CRETACEOUS)—Brown and gray sandstone and shale; thin carbonaceous shale and coal beds

MzPz LANCE FORMATION, FOX HILLS SANDSTONE OR FORMATION, LEWIS SHALE (UPPER CRETACEOUS) – Brown and gray sandstone and shale; light-colored sandstone and gray sandy shale; gray soft marine shale with lenticular sandstone beds. Not individually mapped but included in MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS

Kmv MESAVERDE GROUP (UPPER CRETACEOUS)—Gray to tan sandstone and sandy shale; some coal beds in Almond Formation and Pine Ridge Sandstone members

MzPz MESOZOIC AND PALEOZOIC SEDIMENTARY ROCKS (INCLUDES PIERRE SHALE, COLORADO GROUP, DAKOTA SANDSTONE, MORRISON FORMATION, SUNDANCE FORMATION, CHUGWATER FORMATION, CASPER FORMATION AND LOWER PART OF FOUNTAIN FORMATION IN COLORADO. INCLUDES STEELE SHALE, CODY SHALE, NIOBRARA FORMATION, FRONTIER FORMATION, MOWRY SHALE, THERMOPOLIS SHALE, CLOVERLY FORMATION, MORRISON FORMATION, SUNDANCE FORMATION, CHUGWATER GROUP, GOOSE EGG FORMATION, PHOSPHORIA FORMATION, FORELLE LIMESTONE SATANKA SHALE, CASPER FORMATION, TENSLEEP SANDSTONE, AMSDEN FORMATION, AND MADISON LIMESTONE IN WYOMING)—Tan to light gray to red sandstone and siltstone, shale and limestone. Gray to black shale, sandstone, claystone and limestone

pЄr PRECAMBRIAN ROCKS—Metamorphic schist and gneiss; granite and monzonite

About 800 Million Tons of Strippable Coal Resources Are in the Area

More than 60 minable coal beds, some as much as 40 feet thick, are identified in Wyoming's Hanna Coal Field; Colorado's North Park Coal Field has two important coal beds, 20 to 80 feet thick.

The most extensive strippable coal beds are in the Hanna and Ferris Formations in the Hanna and Carbon Basins. Glass and Roberts (1979) provide an in-depth evaluation of the coal resources in the Hanna Coal Field, which is divided into the Hanna, Seminoe, Carbon, and Corral Creek mining districts (fig. 3.3-1). They report that the Hanna Formation has 32 coal beds thicker than 5 feet and that 8 of these are 20 to 38 feet thick. The Ferris Formation reportedly has 28 minable coal beds. These beds generally are 5 to 10 feet thick, with three beds in the 22- to 40-foot range. Strippable coals of the Hanna Formation are found in the Hanna and Carbon mining districts, whereas those of the Ferris Formation are restricted to the Seminoe mining district.

Three strippable coal beds exist in the Medicine Bow Formation; the Penn-Wyoming bed (9 feet) is the thickest of the three. The Almond Formation of the Mesaverde Group has seven 5- to 10-foot-thick coal beds suitable for surface mining. The coal beds of these two formations are found throughout the Hanna Coal Field; however, these beds are not considered minable except in the Corral Creek mining district because of dips generally exceeding 25° (Glass and Roberts, 1979, p. 67-70). A summary, by mining district, of the measured and inferred coal reserves of the Hanna Coal Field is presented in table 3.3-1.

Information regarding the coal resources of the Rock Creek and Kindt Basin Coal Fields is minimal. In the Rock Creek Coal Field, a few coal beds are in the Pine Ridge Sandstone of the Mesaverde Group and in the Hanna Formation (Berryhill and others, 1950, p. 23). From the data of Berryhill and others (1950), Glass (1978b, p. 80) estimates 305 million tons of coal are in the Rock Creek Coal Field; this estimate includes beds as thin as 2 feet and with 3,000 feet of overburden. Coal in the Kindt Basin, actually a part of the Green River Coal Region west of Area 54, is mentioned by Veatch (1907) and Berryhill and others (1950), but neither estimates the quantity of coal because of insufficient data. Present (1982) indications are that neither of these two coal fields will be mined by surface methods.

Strippable coal beds of the North Park Coal Field are in the Tertiary Coalmont Formation, with a single different coal bed predominating in each of the two mining districts of the field (fig. 3.3-1). The Riach coal bed, with a reported thickness of 25 to 80 feet (Erdmann, 1941, p. 1) predominates in the Coalmont district, whereas the Sudduth coal bed, as thick as 58 feet (AAA Engineering and Drafting, Inc., 1980c, p. 9; and Beekly, 1915, p. 96), predominates in the McCallum district. Although other coal beds are known in both mining districts (Beekly, 1915; Erdmann, 1941; and Madden, 1977a, 1977b), the only other bed of considerable economic importance is the 3- to 13-foot-thick Capron coal bed in the McCallum mining district (AAA Engineering and Drafting, Inc., 1980b, 1980e).

The tonnage of recoverable coal in the two mining districts is not clearly established. A detailed analysis of the coal resources available in the area covered by six quadrangle maps--two in the Coalmont district and four in the McCallum district--is provided by AAA Engineering and Drafting, Inc. (1980a-1980f). These maps, however, include only areas of unleased Federal coal ownership (ranging from 26 to 59 percent of the quadrangles) and do not provide complete coverage of the mining districts. The figures presented by AAA Engineering and Drafting, Inc., are 15 million tons of strippable coal for the unleased Federal coal land in the Coalmont mining district and 58 million tons for the unleased Federal coal land in the McCallum mining district. For comparison, Speltz (1976, p. 47-48) estimates that 123 million tons are strippable in the Coalmont mining district and 10 to 15 million tons are strippable in the McCallum mining district. Differences in these estimates can be attributed to: (1) Different areal coverage, (2) different or improved data base, (3) different criteria for estimating, (4) alternative or improved mining methods, and (5) other factors.

Table 3.3-1 *Strippable coal resources of the Hanna Coal Field by mining district (in millions of tons)*
[Source: Glass and Roberts (1979)]

Mining district (weighted average thickness of coal)	Thickness of overburden, in feet					
	Measured reserve base[1]		Indicated reserve base[1]		Total reserve base[1]	
	0-100	100-200	0-100	100-200	0-100	100-200
Hanna (14.2 feet)	86.18	85.67	43.87	58.16	130.05	143.83
Carbon (11.1 feet)	29.05	20.53	13.60	55.68	42.65	76.21
Seminoe (9.8 feet)	76.15	64.94	32.25	59.13	114.40	124.07
Corral Creek (5.9 feet)	7.44	4.51	2.58	2.55	10.02	7.06
Total for Hanna Coal Field (11.8 feet)	198.82	175.64	98.30	175.52	297.12	351.17

[1]Explanation of coal-resource classification given in U.S. Bureau of Mines and U.S. Geological Survey.

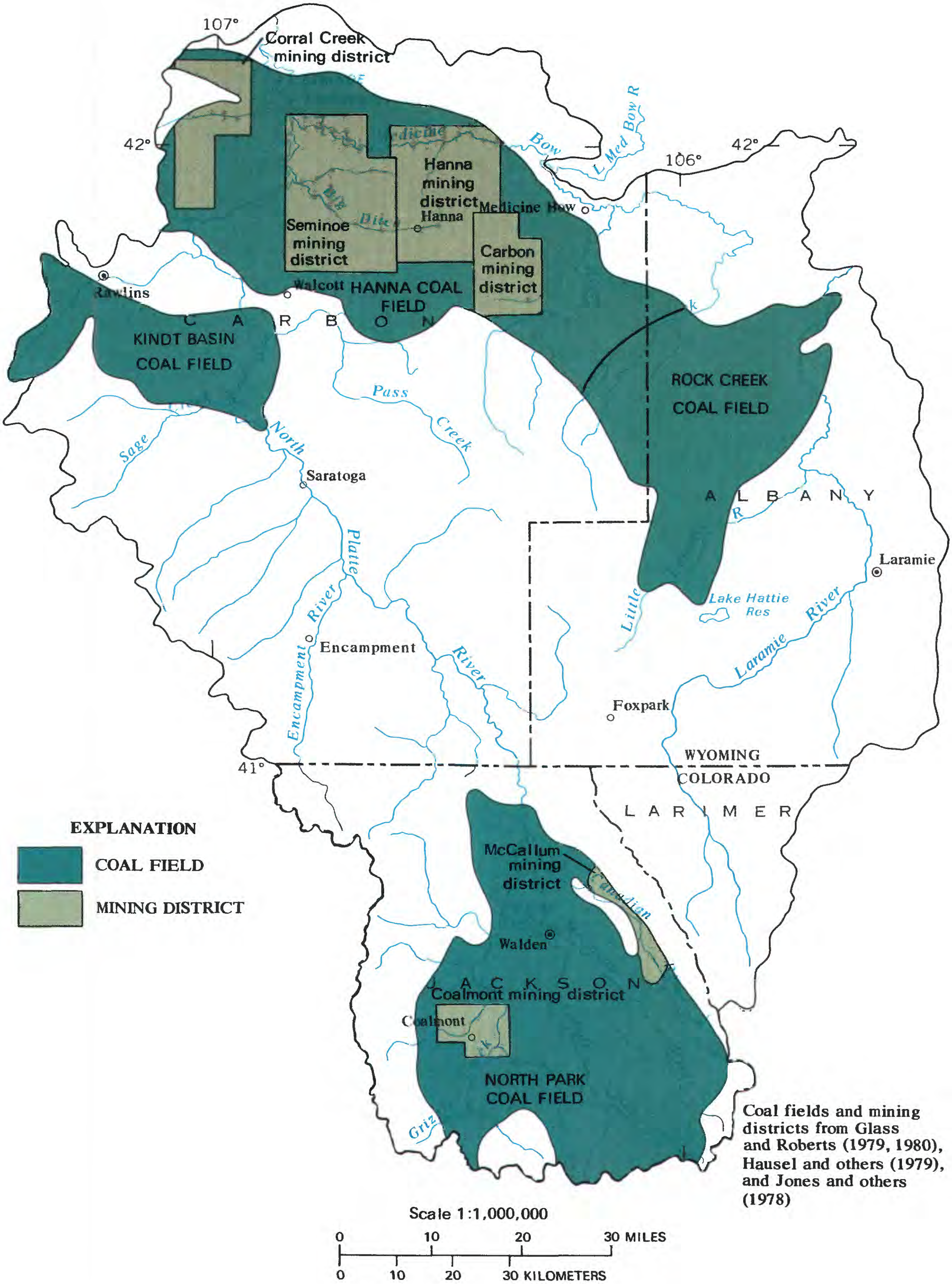


Figure 3.3-1 Coal fields and mining districts.

Hanna Coal Field Accounted for 98 Percent of Area's 215 Million Tons of Coal Production Through 1980

Since the late 1960's, surface mines have accounted for more than 90 percent of the annual coal production, which was 10.9 million tons during 1980.

Recorded coal production dates from 1864 in Colorado and from 1865 in Wyoming. From the small-scale pick-and-shovel mining operations of this early time, the coal industry in the two States grew steadily; by 1906, annual production was about 10 million tons in Colorado and 6 million tons in Wyoming. Production generally remained the same until 1930, decreased somewhat during the 1930's, and increased during World War II (1941-45). After the war, coal production decreased again, reaching recent lows of 2.9 million tons (1954) in Colorado and 1.6 million tons (1958) in Wyoming. Underground mining accounted for nearly all of the coal produced until the late 1950's.

During the 1960's and 1970's, the demand for low-sulfur coals for power generation and increasing prices for crude oil resulted in a rapid increase in the amount of coal produced; most of this increased production came from strip mines. During 1980, 69.5 percent of the 18.77 million tons of coal produced in Colorado and about 99 percent of the 93.98 million tons produced in Wyoming was surface mined (summarized from Berryhill and others, 1950; Colorado Division of Mines, (annual) 1974 to 1980; Glass, 1978b; Landis, 1959; and Wyoming State Inspector of Mines, (annual) 1979 and 1980).

In Area 54, commercial coal mining began in 1889 with the opening of two underground mines in the vicinity of Hanna (Berta, 1951, p. 88); cumulative production from these and other mines was about 35 million tons through 1950 (p. 91). Strip mines appeared in the area about this time; during 1980 there were five strip mines and two underground mines operating in the Hanna Coal Field (fig. 3.4-1). Cumulative production through 1978 for the field was 189.6 million tons, of which 79.7 million tons were removed by strip mines (Glass and Roberts, 1980). Production for 1979 and 1980, by individual mine, is presented in table 3.4-1.

Commercial development of coal in the North Park Coal Field began during 1909 with the opening of a mine near Coalmont (Erdmann, 1941, p. 2). Underground mining was combined with the primarily surface-mine operations, which reportedly were the largest in Colorado before their abandonment in 1963 (U.S. Bureau of Mines, 1971, p. 33). Mining, however, was small-scale and sporadic; total production through 1963 was only about 1.3 million tons (Jones and Murray, 1976, p. 26). Mining was renewed during 1974, but was restricted primarily to the McCallum mining district, where two strip mines produced 1.6 million tons from 1974 to 1978 (Colorado Division of Mines, (annual) 1974 to 1980). Production for 1979 and 1980 is presented in table 3.4-1.

All the coals of the area generally have been classified as subbituminous except those of the Mesaverde Group, which are classified as high volatile C bituminous (Berryhill and others, 1950; and Landis, 1959). Glass and Roberts (1980, p. 24), though, report that recent analysis of coals of the Hanna Formation also show an "apparent" rank of high volatile C bituminous. However, they qualify their findings by stating that many of the coal samples were not collected according to the methods prescribed by the American Society for Testing and Materials (1974).

A summary of proximate, ultimate, and heat-value analyses of the coals is presented in table 3.4-2. The American Society for Testing and Materials (1974) provides information regarding the various types of analyses and classification of coals. Additional information regarding analysis of the coals is given in Glass (1978a), Glass and Roberts (1979), and Hatch and others (1979), as well as in other references cited in this and the previous section.

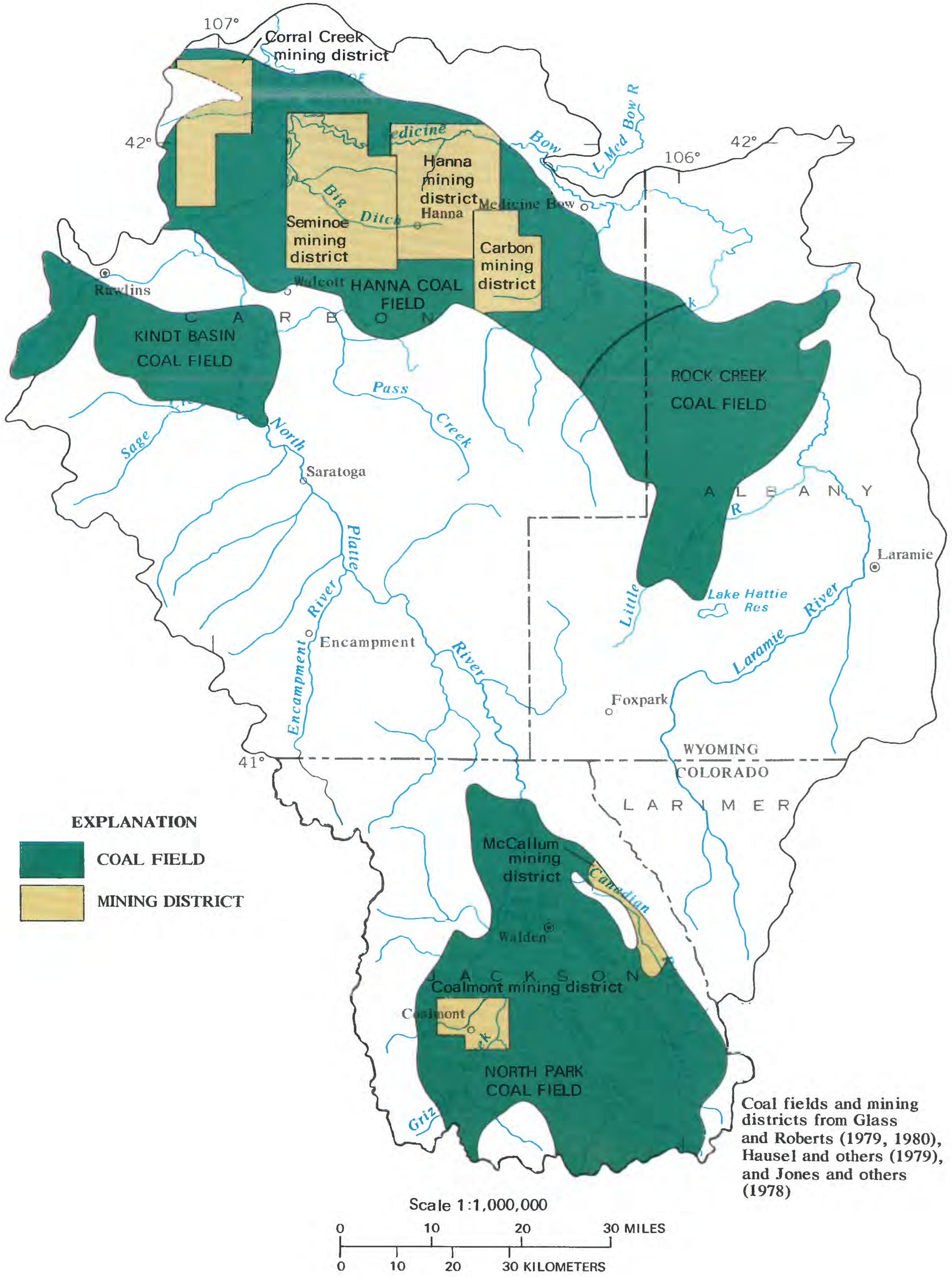


Figure 3.4-1 Coal fields and mining districts.

Table 3.4-1 *1979 and 1980 coal production in Area 54 (thousands of tons)*

Mine name (type)	Mining district	Producing formation	1979 production	1980 production
Carbon No. 1 (underground)	Hanna	Hanna	96	527
Medicine Bow (strip)	Seminoe	Ferris	2,346	1,820
Rimrock No. 1 and No. 2 (strip)	Seminoe	Ferris	596	692
Rosebud (strip)	Hanna	Hanna	2,396	1,890
Seminoe No. 1 (strip)	Seminoe	Ferris	2,285	2,500
Seminoe No. 2 (strip)	Hanna	Hanna	2,720	1,829
Vangard No. 2 (underground)	Seminoe	Ferris	345	878
Total for Hanna coal field			10,784	10,136
Bourg (strip)	McCallum	Coalmont	-----	4
Canadian (strip)	McCallum	Coalmont	98	44
Marr (strip)	McCallum	Coalmont	687	759
Total for North Park Coal Field			785	807

Source: Colorado Division of Mines (annual, 1974 to 1980), Wyoming State Inspector of Mines (annual, 1979 and 1980), and Glass and Roberts (1980)

Table 3.4-2 *Arithmetic mean of proximate, ultimate, and heat value analyses for Area 54 coals (number of samples varied from 2 to 198)*

Producing formation	Proximate (percent)				Ultimate (percent)					Heat value (British thermal units per pound)
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
Coalmont	14.9	35.0	41.5	8.6	5.7	57.1	0.8	27.3	0.4	9,930
Hanna (Hanna mining district)	12.8	36.7	41.8	8.8	5.7	60.4	1.1	24.1	0.8	10,420
Hanna (Carbon mining district)	10.0	36.7	39.6	13.7	4.8	46.8	1.0	16.6	2.7	10,190
Ferris	12.6	34.3	45.2	7.9	5.3	59.3	1.0	25.2	0.5	10,140
Medicine Bow	13.5	35.5	47.2	3.8	5.5	60.6	1.5	28.3	0.5	10,810
Almond (Mesaverde Group)	12.1	34.6	45.7	7.6	5.4	52.6	1.2	32.2	0.5	10,818

Source: Boreck and others (1977) and Glass and Roberts (1980)

Almost 50 Percent of the Land Is Federally Owned

Land ownership is 46.2 percent Federal, 46.3 percent private, and 7.5 percent State.

The dominant feature of land ownership in the western United States is the large proportion of federally owned land; for Colorado and Wyoming, it amounts to 35.4 and 48.4 percent, respectively, of their total areas. Originally most of the Nation's land was owned by the Government, but over a period of time the Government relinquished claim to 62 percent of that land, or more than 1.14 billion acres. Title to Federal lands, commonly known as the public domain, was transferred to States, citizens, corporations, and other entities through the enactment of numerous "land laws." The Government, however, retained ownership of large tracts of land, primarily in the West; excluding Alaska, about 87 percent of the 411 million acres of public domain are in the 11 western States (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming).

The General Land Office was established in 1812 to administer the public domain lands and the laws enacted for their disposition. During the late 1800's and early 1900's, jurisdiction of large tracts of Federal land was transferred to other branches of Government as a method of reserving some of this land for permanent public ownership and use. Thus, the National Forests, Parks and Monuments, and Wildlife Refuges were established, as well as agencies necessary to administer them.

By 1930 much of the public domain remaining under the control of the General Land Office was used largely as grazing land. The Taylor Grazing Act of 1934 established a Grazing Service to ensure proper management of these lands. In 1946 the two agencies were combined to form the U.S. Bureau of Land Management which administers about half of all Federal land. The U.S. Department of the Interior, which includes the Bureau of Land Management, National Park Service, and Fish and Wildlife Service, administers about 70 percent of Federal land. The U.S. Forest Service (U.S. Department of Agriculture) has jurisdiction over about 25 percent of the public domain.

Large parts of the previously all-public domain were put into private ownership as a result of the Homestead Act of 1862 and its successors. Grants to railroads to provide financial incentive for constructing new rail routes were also an important method of Federal land disposal. Alternate (odd-numbered) sections of land for about 20 miles on each side of the Union Pacific main line were granted to the railroad. Land grants also were made to the individual States, primarily to provide financial aid in support of education. (The foregoing discussion has been derived from the following sources: U.S. Bureau of Land Management, 1979, p. 1-33; Carstensen, 1962, p. 181-187, 449-454, 461-463; and Townsend, 1951, p. 92-95.)

General land ownership is shown in figure 3.5-1; the scale of the map does not permit an accurate depiction of land ownership. Table 3.5-1 gives the approximate acreage of the various categories of land ownership in Colorado, Wyoming, and the counties in Coal Area 54. The figures are approximate because the categories are not always broken down to a county level; no two sources ever gave the same figure, and ownership of land is changeable. More detailed land-ownership information is available from appropriate county, State, or Federal agencies.

Ownership of the minerals (mineral rights) on a particular parcel of land is of primary interest to those developing coal. Mineral ownership is about as complex as ownership of the surface land, and the two do not always coincide. A series of planimetric maps depict in considerable detail the surface and mineral ownership of lands in the report area (fig. 3.5-2 and table 3.5-2). These maps are published at a scale of 1:126,720 (½ inch = 1 mile). A new series of maps (not illustrated) at a scale of 1:100,000 (metric) is also being published now (1982), and may be available for some areas. Cost of the maps (as of October 1982) varies from $2.00 to $3.25. These maps, or additional information, are available from the U.S. Bureau of Land Management at 1037 20th Street, Denver, CO 80202 or P.O. Box 1828, Cheyenne, WY 82001.

Table 3.5-1 *Approximate land ownership for Colorado, Wyoming, and counties in Coal Area 54 (thousands of acres)*

State name	Total area	Private	State	U.S. Bureau of Land Management	U.S. Forest Service	Other Federal land
Colorado	66,718	38,671	3,021	7,994	14,415	1,199
Wyoming	62,665	26,518	3,645	17,793	9,253	3,283
County						
Albany	2,799	1,816	227	298	457	3
Carbon	5,048	1,991	325	2,120	611	--------
Jackson	1,042	376	123	194	334	14
Larimer (within report area only)	249	50	8	27	164	--------

Source: U.S. Bureau of Land Management (1975, 1979); Speltz (1976); Wyoming Department of Administration and Fiscal Control (1977); Waters (1965); Personal communication with the U.S. Bureau of Land Management, U.S. Forest Service, Arapahoe National Wildlife Refuge, and Jackson County

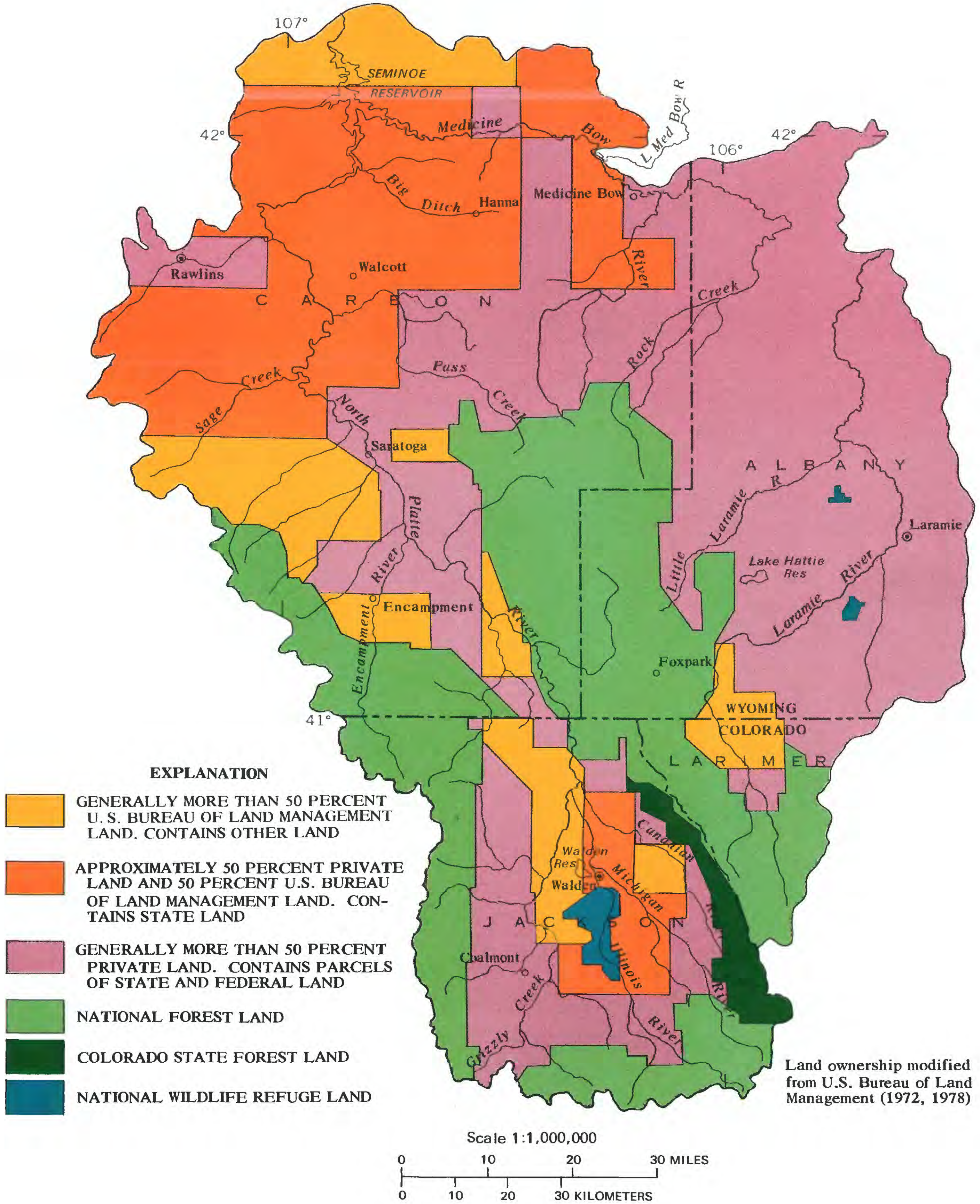


Figure 3.5-1 Generalized land ownership.

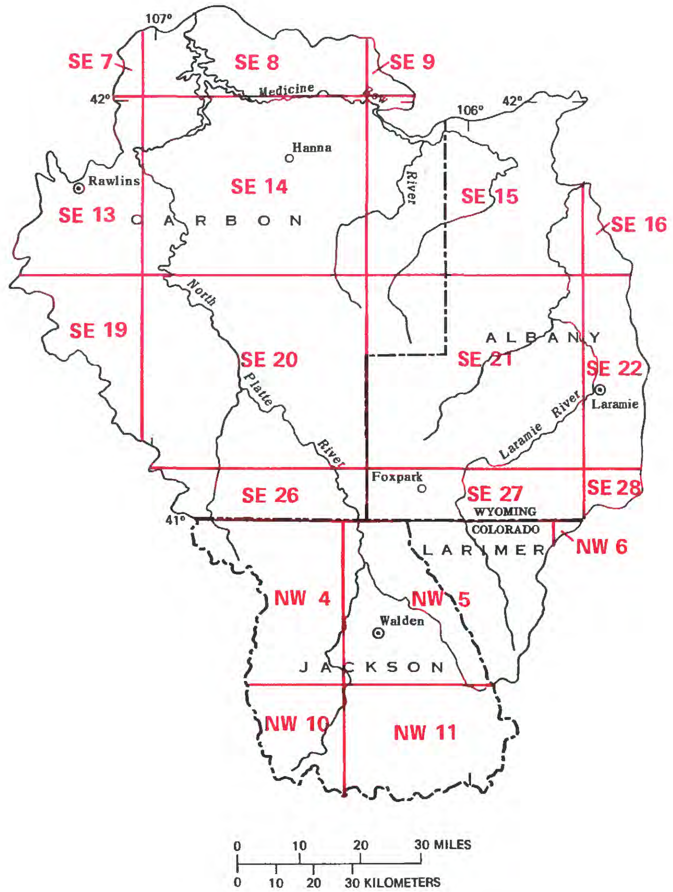


Figure 3.5-2 Index map for U.S. Bureau of Land Management land and mineral status maps.

Table 3.5-2 *Key to U.S. Bureau of Land Management land and mineral status maps*

Map No.	Map Name	Map No.	Map Name
SE 7	Ferris Mountains	SE 22	Laramie
SE 8	Shirley Basin	SE 26	Blackhall Mountain
SE 9	Marshall	SE 27	Woods Landing
SE 13	Rawlins	SE 28	Borie
SE 14	Hanna Basin	NW 4	Hahns Peak
SE 15	Medicine Bow	NW 5	Walden
SE 16	Ferguson Corner	NW 6	Red Feather Lakes
SE 19	Tullis	NW 10	Steamboat Springs
SE 20	Saratoga	NW 11	Rand
SE 21	Hatton		

Climate Characterized by Semiarid Basins and Humid Mountains

Mountains cause uneven precipitation patterns, and high elevation causes large temperature variation.

Climate generalizations for the area are: (1) Low relative humidity, (2) abundant sunshine, (3) large daily and seasonal temperature variations, and (4) increasing precipitation with elevation (Waters, 1965, p. 484). These conditions are produced by two major factors: (1) A midlatitude continental location far removed from any significant moisture sources, and (2) a high elevation combined with large local topographic variations.

The remoteness from moisture sources and high elevation result in low humidity and a generally semiarid climate. The low humidity and high elevation allow large inflows of solar radiation and also considerable outflow of heat at night, resulting in large daily temperature variations. Also, the midlatitude continental location produces marked seasonal temperature variations (McKee and others, 1981, p. 4). The orographic effect of the mountains, which causes increased condensation of atmospheric moisture at higher elevations because of cooler temperatures, results in much greater precipitation in the mountains than in the lowlands. Some temperature and precipitation means and extremes illustrating increase of precipitation with elevation are presented in table 3.6-1 (compare Laramie and Foxpark, which are about 35 miles apart but have elevations differing by nearly 2,000 feet). The differences in precipitation among Rawlins, Laramie, and Walden are largely due to geographic location, not elevation.

Mean annual precipitation (fig. 3.6-2) ranges from about 10 to 16 inches in the semiarid basins to 40 inches or more in the humid mountains. Seasonally, the basins receive a greater percentage of their precipitation during the summer (May-September), whereas the mountain precipitation is more uniformly distributed throughout the year (fig. 3.6-1). Winter precipitation, almost entirely snow, is generally produced by large storm systems moving in from the west or northwest. As the storms encounter the mountain barriers, snowfall is great because of orographic effects; but as the storms move across the basins, the precipitation amount is much less (see table 3.6-1 for mean annual snowfall). Snowfall is the most significant precipitation in that it accumulates in the mountains to depths of 5 to 10 feet; melting of the snowpack during April, May, and June usually provides 65 to 85 percent of the annual streamflow. Summer precipitation is generally produced by convective thunderstorms; but because moisture is lacking, the rainfall from these storms is not large--daily quantities seldom exceed 1 inch. The 10-year 24-hour rainfall intensities computed by the National Oceanic and Atmospheric Administration (Miller and others, 1973) are shown in figure 3.6-3.

Daily temperature variations at Walden, Colo., are reported to average about 25°F during winter and to increase to nearly 40°F in midsummer and fall (McKee and others, 1981, p. 4); variations are probably similar elsewhere in the area. Annual temperature extremes, occasionally as large as 145°F (table 3.6-1), generally average 70° to 80°F as shown in figures 3.6-4 and 3.6-5. The freeze-free period in Laramie and Rawlins, Wyo., averages 91 and 102 days, respectively; in Walden, Colo., and Foxpark, Wyo., the freeze-free period averages only 33 and 12 days, respectively, primarily because of increased elevation. Overall, the area has cold to very cold winters and mild summers; the seasonal temperature extremes, especially the summer highs, are somewhat moderated by the low humidity. During the winter, frequent and strong winds (Alyea, no date; and McKee and others, 1981, p. 17) are common throughout the area, increasing windchill.

In all areas, except perhaps the higher mountains, evaporation exceeds precipitation. Data reported for Laramie in 1979 show a pan evaporation of nearly 40 inches during June through September, while precipitation was 4.76 inches (National Oceanic and Atmospheric Administration, 1980). The May-September average evaporation estimated for the North Park area by McKee and others (1981, p. 18) is about 35 inches. The large evaporation and correspondingly small precipitation will probably limit successful revegetation of strip-mined areas (McKee and others, 1981, p. 2).

Because most streamflow is derived from mountain snowpacks, there is considerable interest in the depth of these snowpacks and their water content. Monthly snow surveys during winter and early spring have been conducted for many years; streamflow forecasts are made on the basis of the surveys. Snow-survey data and streamflow forecasts are published monthly, February through May, by the U.S. Department of Agriculture (Casper, Wyo., and Denver, Colo.) as "Water Supply Outlook for Wyoming (Colorado and New Mexico)." Long-term snow-survey data are published for Wyoming (1918-78) in Hagland and others (1979) and for Colorado (1936-77) in Washichek and others (1972, 1978). Snow-survey data are also available from computer storage through the U.S. Department of Agriculture computer center at Fort Collins, Colo.

Daily precipitation and temperature data are published monthly as "Climatological Data for Colorado (Wyoming)" by the National Oceanic and Atmospheric Administration (NOAA), National Climate Center, Asheville, N.C. Also published by NOAA (1978), "Climates of the States" presents summaries, means, and extremes of climatic data at selected stations as well as a narrative of each State's climate. Statistical analysis and information on precipitation are presented in NOAA Atlas 2, "Precipitation-Frequency Atlas of the Western United States" (Miller and others, 1973).

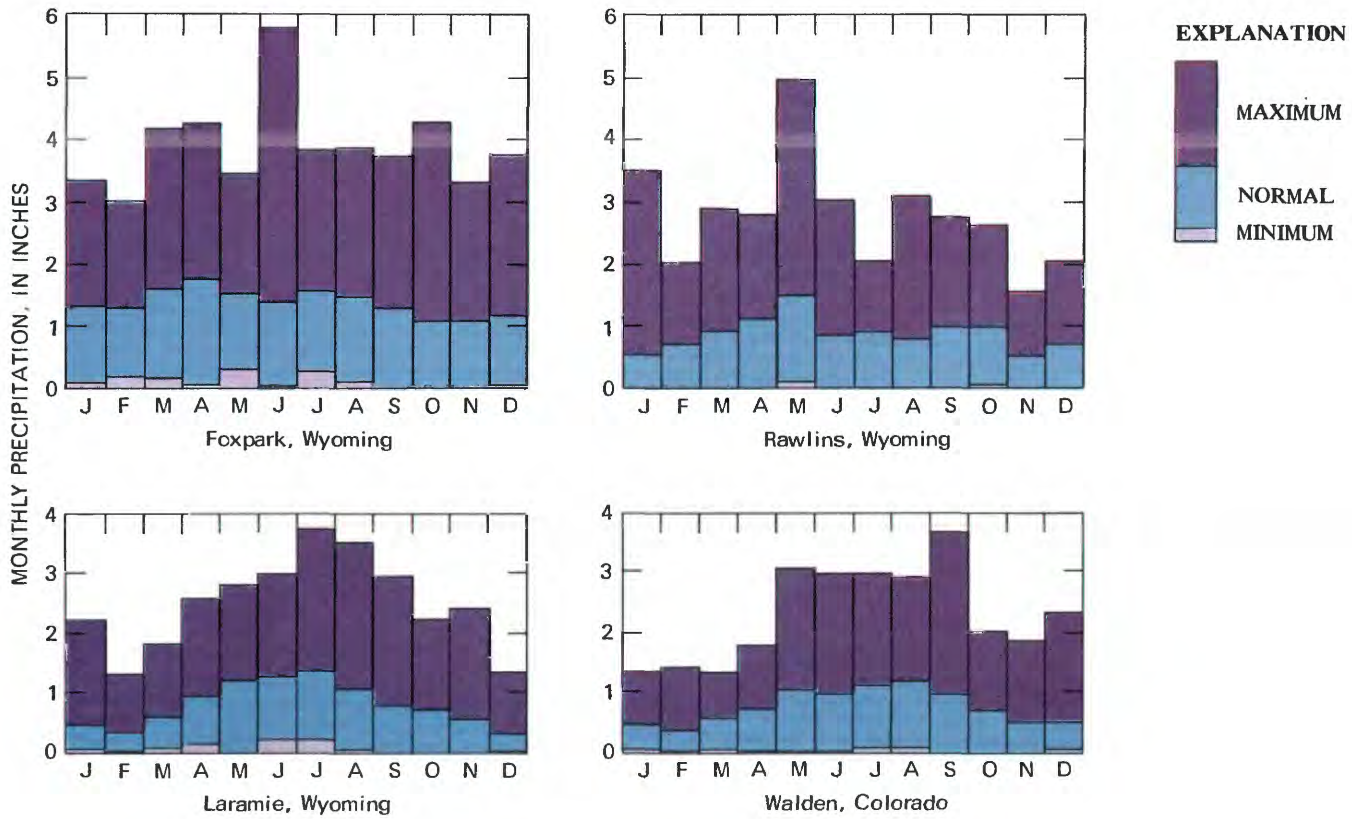


Figure 3.6-1 Monthly precipitation for select stations.

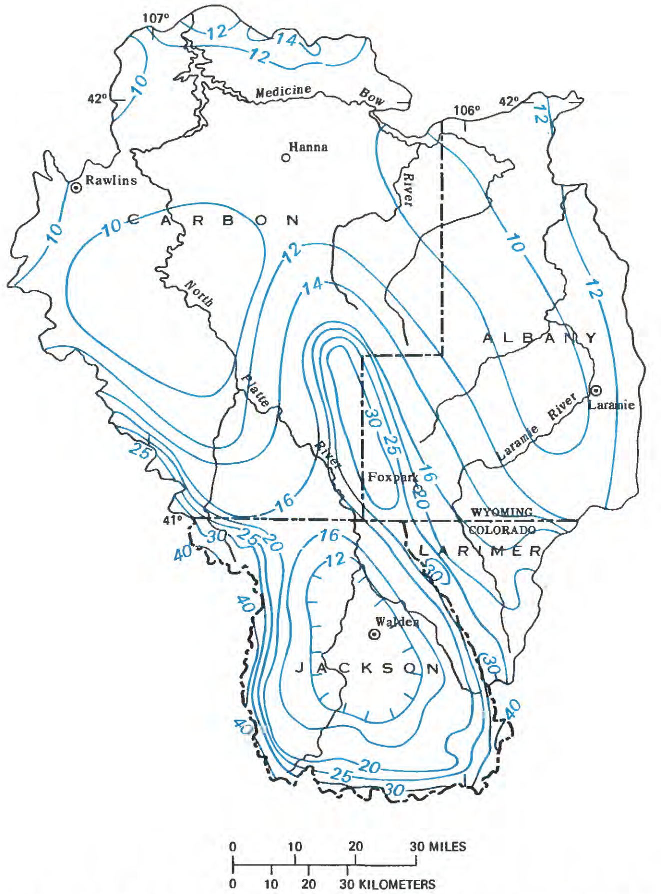


Figure 3.6-2 Mean annual precipitation, in inches. (Source: Wyoming State Engineer (1967) and the U.S. Weather Bureau 1967). Contour interval is variable.

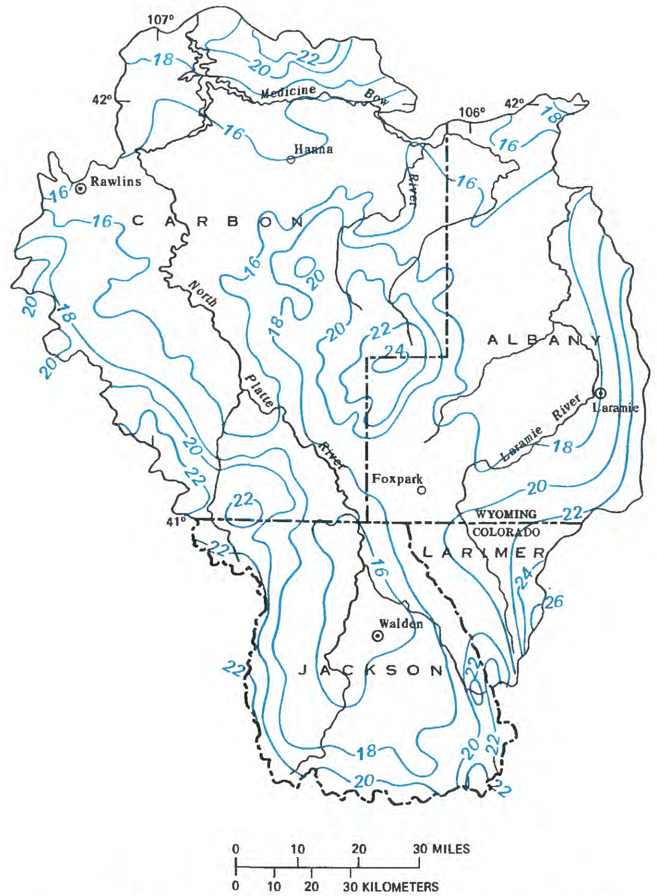


Figure 3.6-3 10-year, 24-hour precipitation, in tenths of an inch. (Source: Miller and others 1973). Contour interval two-tenths of an inch.

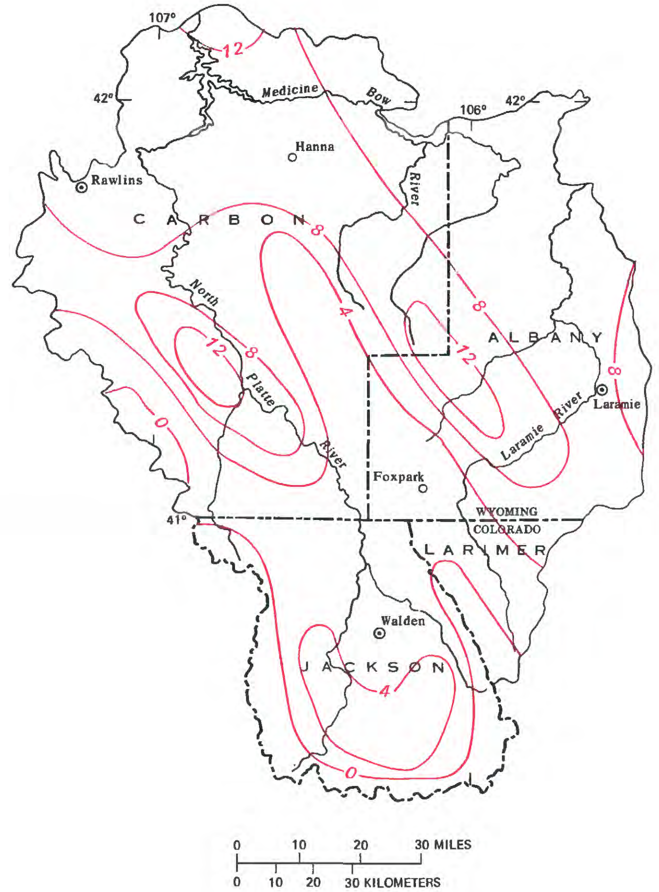


Figure 3.6-4 Mean minimum January temperature, in degrees Fahrenheit. (Source: National Oceanic and Atmospheric Administration, 1978). Contour interval 4 degrees.

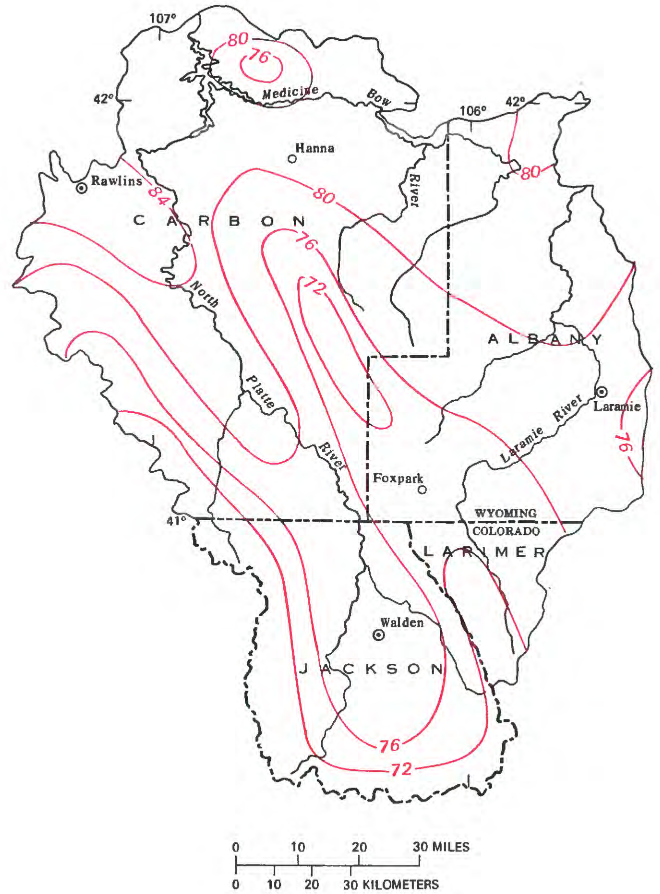


Figure 3.6-5 Mean maximum July temperature, in degrees Fahrenheit. (Source: National Oceanic and Atmospheric Administration, 1978). Contour interval 4 degrees.

Table 3.6-1 *Climatic means and extremes*

Station (Period of analysis)	Elevation (Feet)	Temperature (°F) Mean annual	Temperature (°F) Extremes (high/low)	Precipitation (inches) Mean annual	Precipitation (inches) Maximum monthly	Precipitation (inches) Maximum daily	Snow, sleet (inches) Mean annual	Snow, sleet (inches) Maximum monthly
Foxpark, Wyoming (1912-73)	9045	33.4	90/-52	17.09	6.01	[1]1.67	159.9	[1]68.0
Laramie, Wyoming (1943-74)	7266	40.7	94/-50	10.11	3.81	2.28	45.0	[2]28.0
Rawlins, Wyoming (1898-1960)	6736	43.0	102/-36	11.07	5.15	[3]2.60	47.2	[3]27.9
Walden, Colorado (1938-79)	8120	36.5	96/-49	9.50	3.75	2.19	51.3	31.0

[1]1951-73

[2]1951-74

[3]1926-60

Sources for figure 3.6-1 and table 3.6-1: Alyea (no date); National Oceanic and Atmospheric Administration (1978); U.S. Department of Commerce (1958, 1965, 1976); and the U.S. Weather Bureau (no date)

Rangeland Is Most Common Land Type

About 50 percent of Area 54 is rangeland, 30 percent forest land, and 10 percent agricultural land.

The land use and land-cover classifications shown in figure 3.7-1 are based on the system of Anderson and others (1976). This system is intended to be used with remote-sensor data and is used in preparing the U.S. Geological Survey Land Use and Land Cover map series. These maps show two levels of land classification; figure 3.7-1, derived from these maps, shows only one level. However, the level-II categories are included in the explanation to aid in visualizing the possible land types in the level-I categories. Land use and land-cover data compatible to figure 3.7-1 currently are not available north of the 42d parallel in the report area.

Rangeland constitutes about 50 percent of the area; it is found throughout the basin areas (figs. 1.2-2 and 1.3.1-1 show examples). Rangeland consists of a variety of shrubs and grasses, but sagebrush (*Artemesia* sp.) is common to much of this land. Large areas of rangeland are unused except as browse for livestock and habitat for wildlife. The coal areas are also in rangeland.

Forest land, about 30 percent of the area, is restricted to the mountains down to elevations of about 8,500 feet (fig. 1.2-3). Most forest land is within the boundaries of the National Forests. The forests include large tracts of lodgepole pine (*Pinus contorta*) and some aspen (*Populus tremuloides*) at lower elevations. At higher elevations, spruce (*Picea* sp.) and fir (*Abies* sp.) are more common. Treeline is about 11,000 feet, but may vary locally by a few hundred feet, depending on slope, aspect, and other factors. The forest lands, being in the mountains, serve as catchment areas for snow, which provides most streamflow. They also are used for timber and recreation.

Agricultural land is primarily in and adjacent to the major perennial streams; this is clearly shown in figure 3.7-1. Most of these lands are flood irrigated for the production of hay crops; North Park is the largest native hay-producing area in Colorado. About 560,000 acres are irrigated in the report area.

The remainder is composed of other land types. Tundra, above treeline in the mountains, constitutes about 2.5 percent. The water category includes numerous small mountain lakes, streams, and Seminoe Reservoir, Wyo., the largest body of water. Barren land includes strip-mine areas; probably no more that 0.5 percent of the area (about 42 mi^2 as of 1981) has been strip mined.

Land use and land-cover information and maps of greater detail are available from the U.S. Geological Survey (1980a-1980c). Additional information also may be available from the National Cartographic Information Center, Box 25046, Mail Stop 504, Denver Federal Center, Denver, CO 80225.

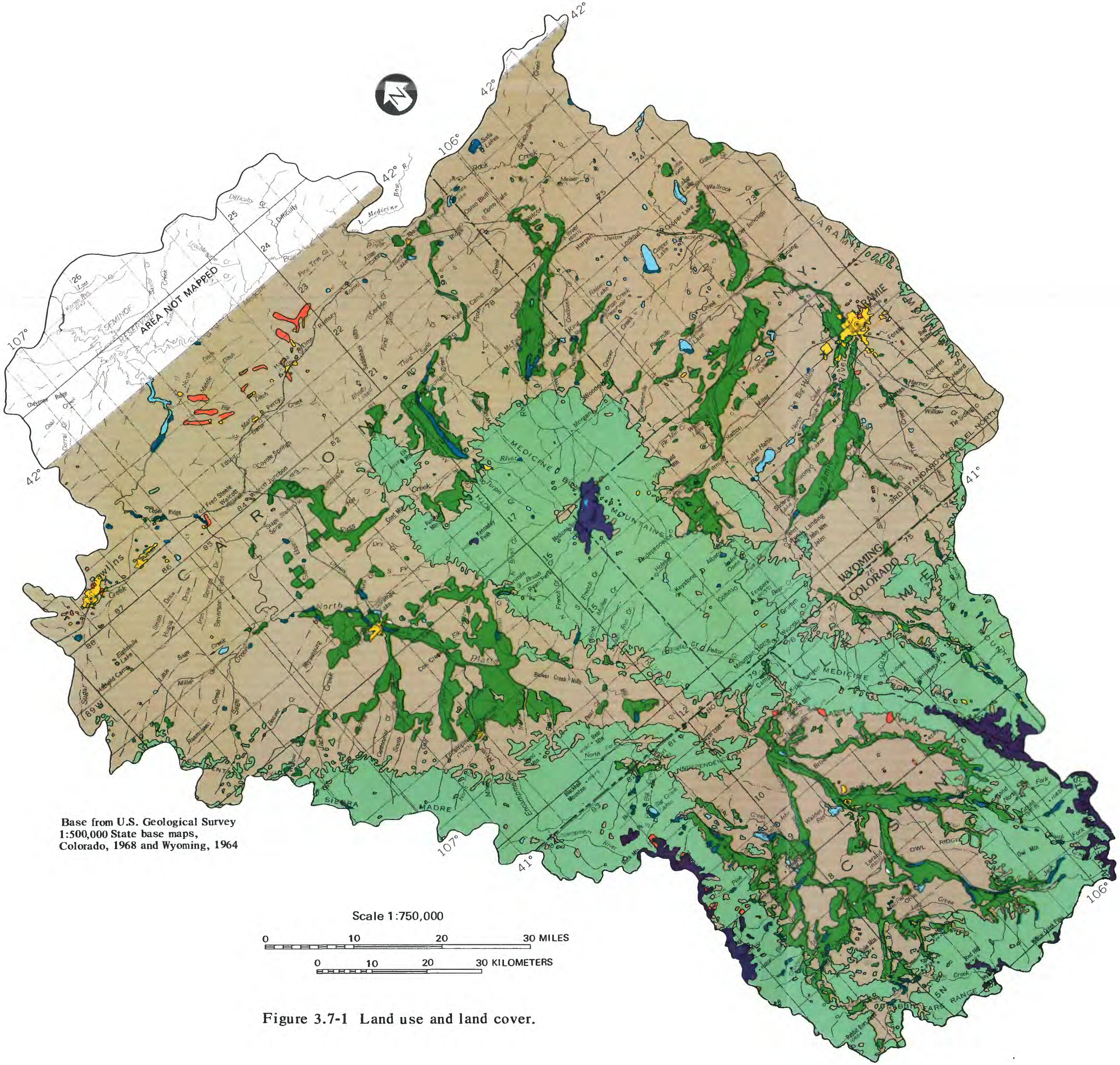


Figure 3.7-1 Land use and land cover.

EXPLANATION

LEVEL I	LEVEL II
Urban or built-up land	Residential Commercial and services Industrial Transportation, communications, and utilities Industrial and commercial complexes Mixed urban or built-up land Other urban or built-up land
Agricultural land	Cropland and pasture Orchards, groves, vineyards, nurseries, and ornamental horticultural areas Confined feeding operations Other agricultural land
Rangeland	Herbaceous rangeland Shrub and brush rangeland Mixed rangeland
Forest land	Deciduous forest land Evergreen forest land Mixed forest land
Water	Streams and canals Lakes Reservoirs Bays and estuaries
Wetland	Forested wetland Nonforested wetland
Barren land	Dry salt flats Beaches Sandy areas other than beaches Bare exposed rock Strip mines, quarries, and gravel pits Transitional areas Mixed barren land
Tundra	Shrub and brush tundra Herbaceous tundra Bare ground tundra Wet tundra Mixed tundra

Level I categories in figure 3.7-1 may include one or more Level II categories

Land use and land cover from U.S. Geological Survey (1980a - 1980c)

Soils Are Moderately Permeable, Slightly Acidic to Slightly Basic, and Subject to Moderate Erosion

Soil properties summarized on a regional basis indicate that soils meet the general requirements of plant growth; specific soil information is available from appropriate sources.

The formation of soil is complex, involving the interaction of a parent material with climate, vegetation, and topography over a given length of time (Young and Singleton, 1977, p. 1-3). Previous topics of this report have described the complexity and variety of topography, geology, climate, and vegetation. Because these factors are components of soil development, the soils of Area 54 are also complex and varied.

The soil-classification system in use in the United States (U.S. Department of Agriculture, 1975) has six classification levels: Order, suborder, great group, subgroup, family, and series. There are 10 recognized orders, which is the most broadly defined level; the most narrowly defined level, the series, has more than 10,500 members. The soil associations shown in figure 3.8-1 are identified at the great group level, which has 185 recognized categories. The soil map units are generally grouped on the basis of similar parent material, topography, and climate. This does not necessarily ensure that soils, in narrower classification levels, with similar engineering and hydrologic properties, will always be grouped together. General soil information on a regional basis is provided in figure 3.8-1 and table 3.8-1. For specific onsite soil properties, the reader may seek additional information from the sources identified herein.

Permeability, a measure of the ability of a soil to transmit air or water, ranges from moderately slow (0.2 to 0.6 inch per hour) to moderately rapid (2.0 to 6.0 inches per hour), with some exceptions (table 3.8-1). Values for available water capacity indicate the availability of soil moisture for use by most plants. The ranges of available water capacity are similar for individual soil associations in table 3.8-1; however, the values range considerably within the associations from very low (0 to 0.05 inch per inch) to high (>0.15 inch per inch). Soil reaction, or pH, is also important in support of plant life (table 3.8-2) and is generally near neutral.

The soil erodibility "K" factor is a part of the universal soil-loss equation; K values greater than 0.40 indicate a high susceptibility to erosion, whereas values less than 0.24 indicate a low susceptibility to erosion. The K values for soils of the report area indicate a low to moderate soil erodibility. Useful information on the use and application of the univeral soil-loss equation and its parameters is presented in a report by Wischmeier and Smith (1978).

Some general requirements of reclaimed land in reference to support of plant life are given in table 3.8-2. Comparison of the values for soil depth, available water capacity, and pH given in table 3.8-1 with those in table 3.8-2 indicated that, with respect to these soil properties, undisturbed soils meet the general requirements of plant growth. However, the soil properties of disturbed soils in a reclaimed mine area could be different from those of an undisturbed soil.

Detailed information on the engineering, hydrologic, and other characteristics of soils at the series level is available in soil-survey reports for Jackson and Larimer Counties in Colorado (Fletcher, 1981; and Mooreland, 1980); similar reports are in preparation for Albany and Carbon Counties in Wyoming. Additional soils information is available from State and county offices of the U.S. Soil Conservation Service and from the Agricultural Experiment Stations of Colorado State University and the University of Wyoming. Discussion of soil taxonomy and associated topics is available from the U.S. Department of Agriculture (1975). Information useful to reclamation of land disturbed by mining is available from Cook and others (1974) and Schaller and Sutton (1978).

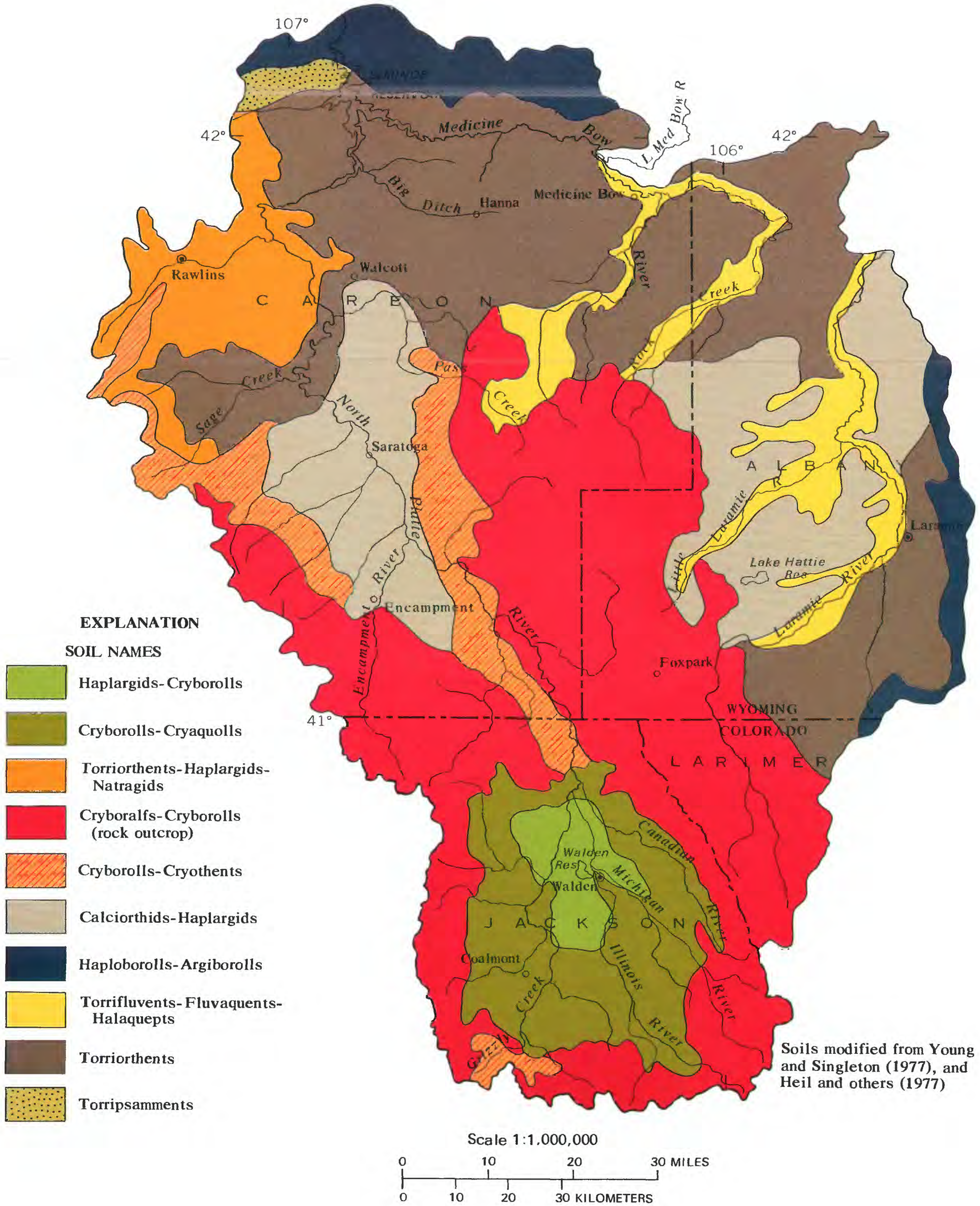


Figure 3.8-1 Generalized soil associations.

Table 3.8-1 *Soil association features*

Name	Description	Soil depth (Inches)	Permeability (Inches per hour)	Available water capacity (Inches per inch)	Soil reaction or pH	Soil erodibility "K" factor
Haplargids-Cryborolls	Deep, well-drained, mostly alluvial soils	20->60	0.06-6.0	0.03-0.14	5.6-9.0	0.15-0.32
Cryborolls-Cryaquolls	Deep upland soils formed mostly from transported materials (with some residuum)	>60	0.6-6.0	0.05-0.21	6.1-9.0	0.10-0.37
Torriorthents-Haplargids-Natrargids	Well-drained soils formed from alluvium or sedimentary rock	20-60	0.6-6.0	0.06-0.20	6.6-8.4	0.10-0.49
Cryboralfs-Cryborolls (rock outcrop)	Well-drained, upland slope soils formed mostly from glacial till or weathered bedrock	10->60	0.6-2.0	0.05-0.12	4.5-7.8	0.10-0.20
Cryborolls-Cryothents	Well-drained, upland soils formed from transported or residual sedimentary rock	10->60	0.06-2.0	0.05-0.19	6.1-9.0	0.17-0.37
Calciorthids-Haplargids	Deep, well-drained soils formed on gently sloping alluvium	>60	0.6-2.0	0.05-0.20	6.6-9.0	0.20
Haploborolls-Argiborolls	Well-drained, upland soils formed from residuum or transported materials	10->60	0.2-2.0	0.04-0.16	6.1-9.0	0.15-0.32
Torrifluvents-Fluvaquents-Halaquepts	Deep, alluvial soils formed on flood plains or stream terraces	>60	0.2-6.0	0.14-0.20	7.4-8.4	0.24-0.28
Torriorthents	Well-drained, intermountain basin soils formed over sedimentary rock	10->60	0.2-2.0	0.14-0.20	7.4-9.0	0.32-0.43
Torripsamments	Deep, well-drained soils formed from transported sand (partly sand dunes)	>60	6.0-20	0.04-0.08	6.6-8.4	0.15

Modified from Fletcher (1981), Heil and others (1977), Mooreland (1980), U.S. Department of Agriculture (1974-75, 1977, 1979-80), and Young and Singleton (1977)

Table 3.8-2 *Suitability rating of soil (to a depth of 3.28 feet) for use as a plant growth medium in drastically disturbed land*

Factors affecting use	Degree of suitability		
	Good	Fair	Poor (Virtually unsuitable)
Electrical conductivity (micromhos per centimeter at 25° Celsius)	<8	8-16	>16
Sodium absorption ratio	<2	2-12	>12
Exchangeable sodium percentage	<2	2-15	>15
pH	5.0-8.5	3.5-5.0	<3.5;>8.5
Coarse fragments more than 3 inches in diameter (percent by volume)	<15	15-35	>35
Available water capacity (inches per inch)	>0.1	0.1-0.05	<0.05
Depth to bedrock or cemented pan (inches)	>40	20-40	<20
Slope (percent)	<8	8-15	>15

Modified from U.S. Department of the Interior (1977)

Information on Surface Water Is Available for 147 Locations

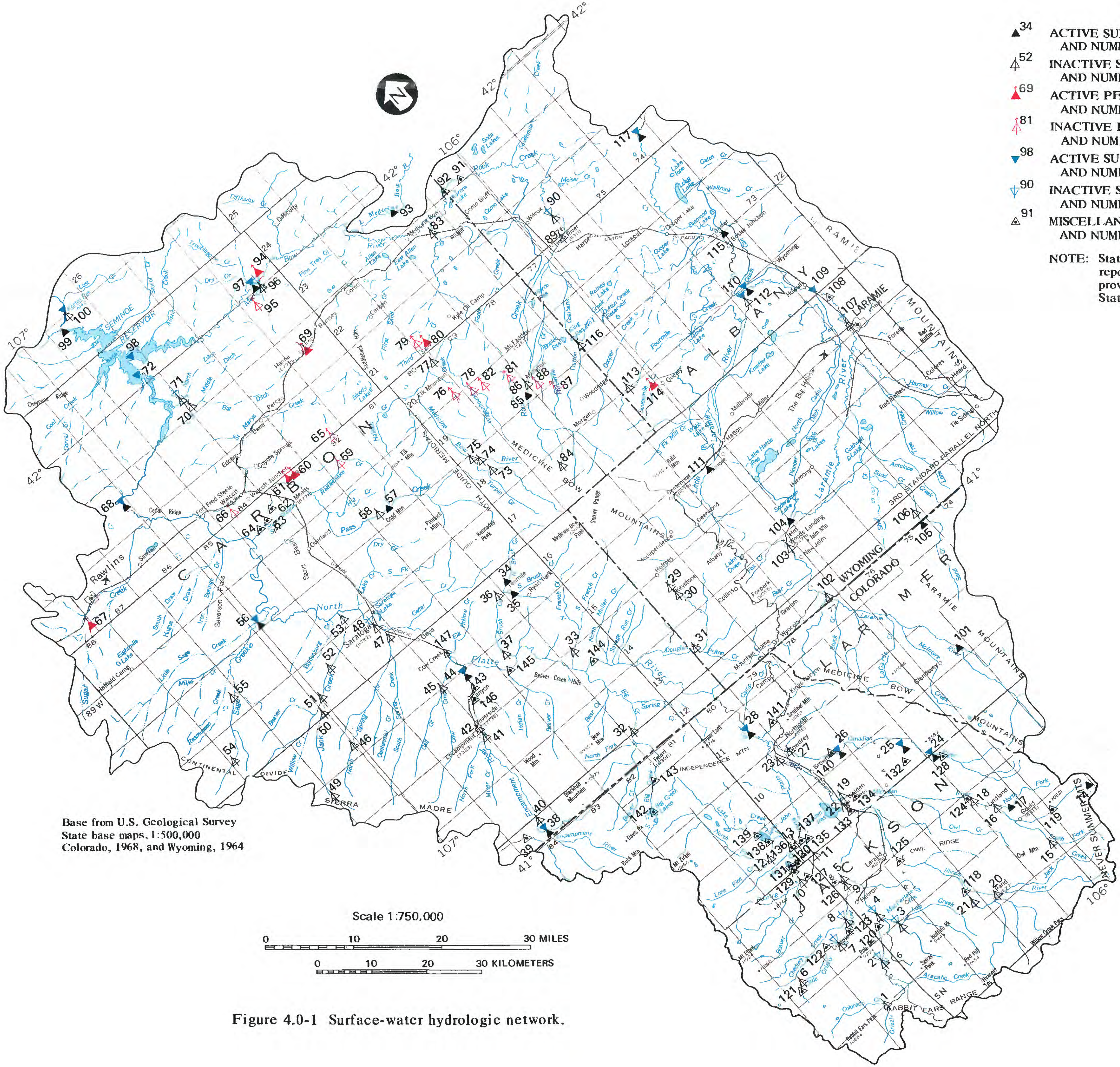
Information is currently being obtained at 31 surface-water locations--23 are streamflow stations, 15 of which are also water-quality stations.

Streamflow and water-quality information is available for 147 sites in Area 54; the location of the stations is shown in figure 4.0-1. Thirty-one of these are active streamflow or water-quality stations. The first recorded observations of streamflow in the area began in 1890 on the Laramie River at Woods Landing, Wyo. Information on streamflow at that early date probably was needed for administration of water rights and for development of irrigated cropland. The overall lack of water and a continuing and increasing demand for water resources resulted in the establishment of numerous streamflow and water-quality stations since 1890; many of these stations are no longer active.

Continuous or seasonal records of streamflow quantity are being obtained at 23 of the 31 active stations; in addition, water-quality information is being obtained at 15 of these stations. Water-quality data only are being obtained at one station on the North Platte River, two stations on the Laramie River, and two sites on Seminoe Reservoir, Wyo. A station at Seminoe Dam provides records of daily reservoir contents. Finally, 2 of the 31 stations are partial-record stations, where records of annual peak flow are obtained.

Thirty-seven of the 147 surface-water sites are miscellaneous stations. These sites are usually established for short-term studies; no systematic data collection occurs at these stations. Reports by Britton (1979) and Britton and Wentz (1980) present data obtained at some of these sites in Jackson County, Colo.

Additional information regarding the type and length of record available at surface-water stations is presented in the Supplemental Information section. Characteristics of streamflow, such as mean flow, peak flow, and low flow are presented for some of the stations in the next five sections. Much of the data available for these stations has been published in annual U.S. Geological Survey reports, "Water Resources Data for Colorado" and "Water Resources Data for Wyoming." These data are also available from computer storage through the National Water Data Exchange (NAWDEX) and the National Water Data Storage and Retrieval System (WATSTORE); these systems are described elsewhere in this report.



EXPLANATION

- ▲34 ACTIVE SURFACE-WATER QUANTITY STATION AND NUMBER
- △52 INACTIVE SURFACE-WATER QUANTITY STATION AND NUMBER
- ▲69 ACTIVE PEAK-FLOW MEASUREMENT STATION AND NUMBER
- △81 INACTIVE PEAK-FLOW MEASUREMENT STATION AND NUMBER
- ▼98 ACTIVE SURFACE-WATER QUALITY STATION AND NUMBER
- ▽90 INACTIVE SURFACE-WATER QUALITY STATION AND NUMBER
- △91 MISCELLANEOUS SURFACE-WATER STATION AND NUMBER

NOTE: Station numbers are for purposes of this report. Supplemental information section provides additional station information. Status of stations as of October 1, 1981

Base from U.S. Geological Survey
State base maps, 1:500,000
Colorado, 1968, and Wyoming, 1964

Scale 1:750,000

0 10 20 30 MILES

0 10 20 30 KILOMETERS

Figure 4.0-1 Surface-water hydrologic network.

Snowmelt Is Primary Source of Streamflow

Most perennial streams receive 66 percent or more of their annual flow from snowmelt during April, May, and June.

Streamflow variations are caused by variations in elevation, precipitation, vegetation, temperature, and consumptive use by man. Areally, these variations result in perennial streams originating in the mountains and ephemeral streams originating in the lowlands. With respect to a particular site, these variations result in most streamflow on perennial streams being derived from snowmelt during spring and early summer, whereas most streamflow on ephemeral streams may be derived from spring snowmelt or summer rainfall.

The location of four selected streamflow stations and their drainage basins is shown in figure 5.1-1. Station 17, North Fork Michigan River near Gould, Colo., is on a small natural-flow stream, and stations 28, North Platte River near Northgate, Colo., and 97, Medicine Bow River above Seminoe Reservoir, Wyo., are on larger, regulated rivers. Diversions for irrigation are the primary regulation, although some transbasin diversion is made from the North Platte River. These diversions usually are seasonal and made from May through September. Station 71, North Ditch near Coyote Springs, Wyo., is on a small ephemeral stream.

Variation in monthly mean discharge at station 28 is illustrated in figure 5.1-2. Even during years of drought, the months of April, May, and June have the larger minimum flows. The seasonal nature of snowmelt runoff also is illustrated in figure 5.1-3, which shows the average monthly discharge as a percent of the average annual discharge at stations 17, 28, and 97. Generally, regardless of the size or location of a drainage basin, 66 percent or more of the annual streamflow at perennial streams is during April, May, and June.

When there is sufficient snow at lower elevations, ephemeral streams also may obtain much of their total runoff from snowmelt. Low-elevation snowmelt, which precedes high-elevation snowmelt by 2 to 3 months, is illustrated in figure 5.1-4 for station 71. Comparison of maximum daily air temperature and daily depth of snow on the ground at Rawlins, Wyo., shows decreasing snow depth with increasing temperature, thus producing the early runoff. The snowmelt runoff illustrated provided 97.5 percent of the runoff at station 71 for the 1980 water year. However, during other years the percentage of runoff due to snowmelt at ephemeral streams may be less, and during some years the runoff from rainfall may exceed that from snowmelt. North Ditch is about 25 miles northeast of Rawlins, at a slightly higher elevation, and is located in a rolling area of narrow valleys and gullies. Probably somewhat more snow accumulated here and runoff would be expected to occur a week or two later than at Rawlins. On very small drainage basins (less than 11 square miles), excluding mountainous areas, Craig and Rankl (1978) found that thunderstorm activity and high-intensity rainfall cause the large runoff events. Snowmelt runoff is usually not significant on small drainage basins at lower elevations.

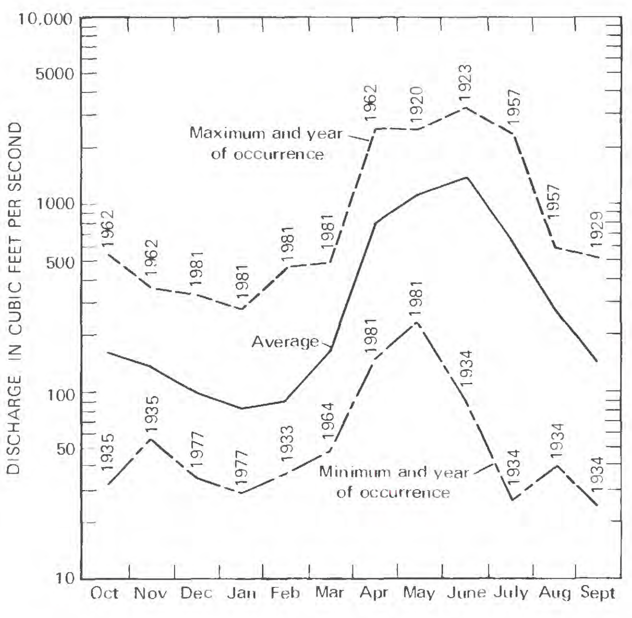


Figure 5.1-2 Variation in average monthly discharge at station 28, North Platte River near Northgate, Colo.

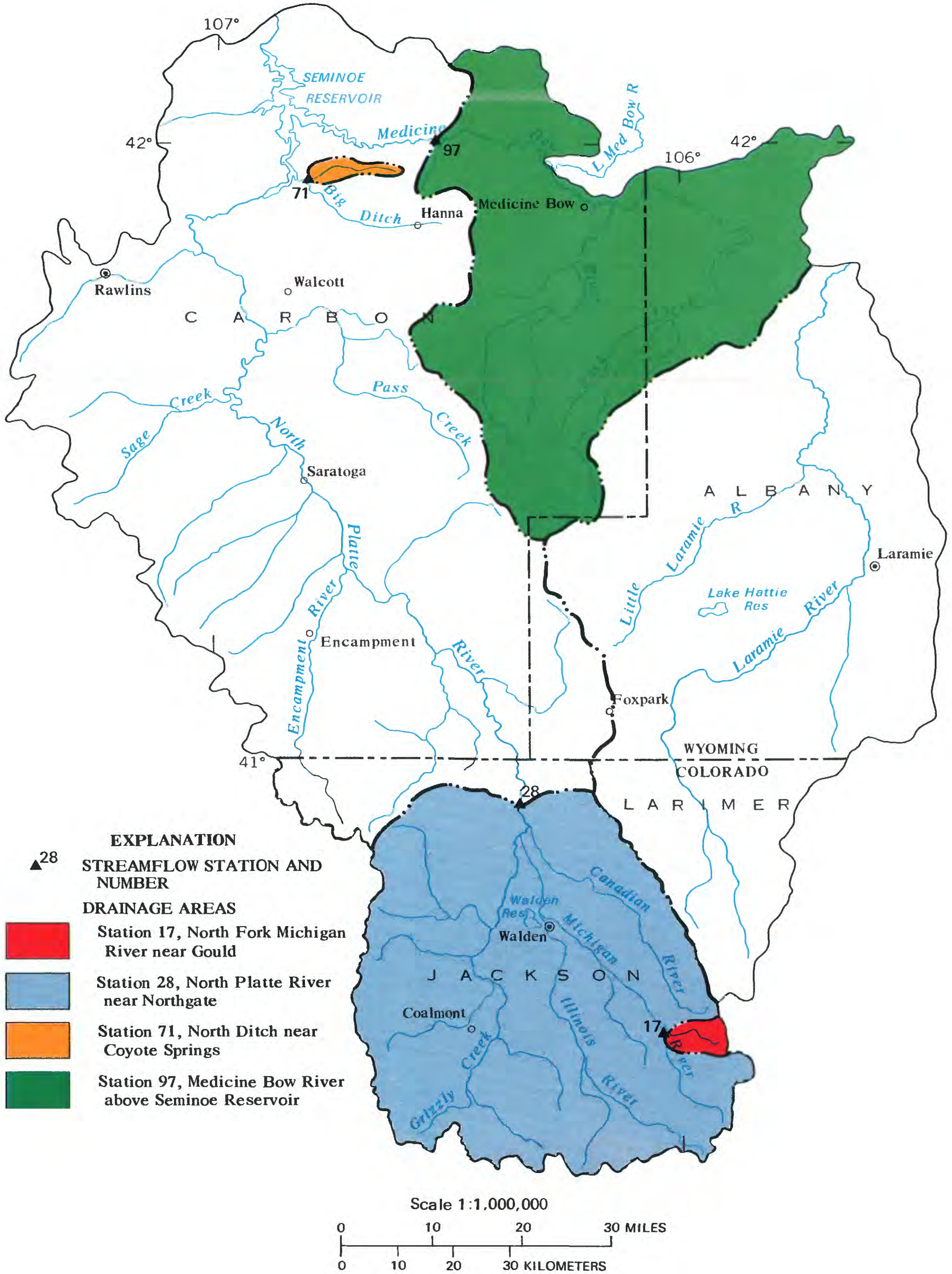


Figure 5.1-1 Drainage areas of selected streamflow stations.

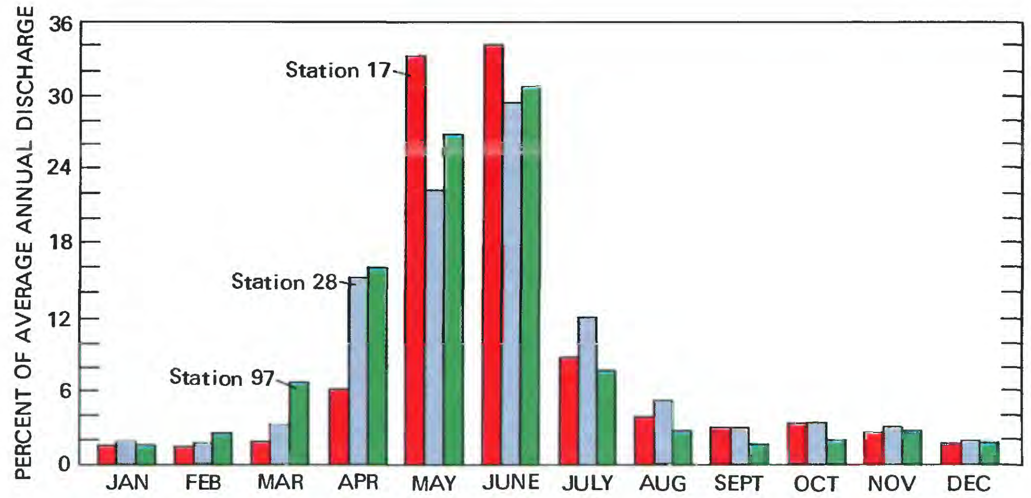


Figure 5.1-3 Average monthly discharge as a percent of average annual discharge.

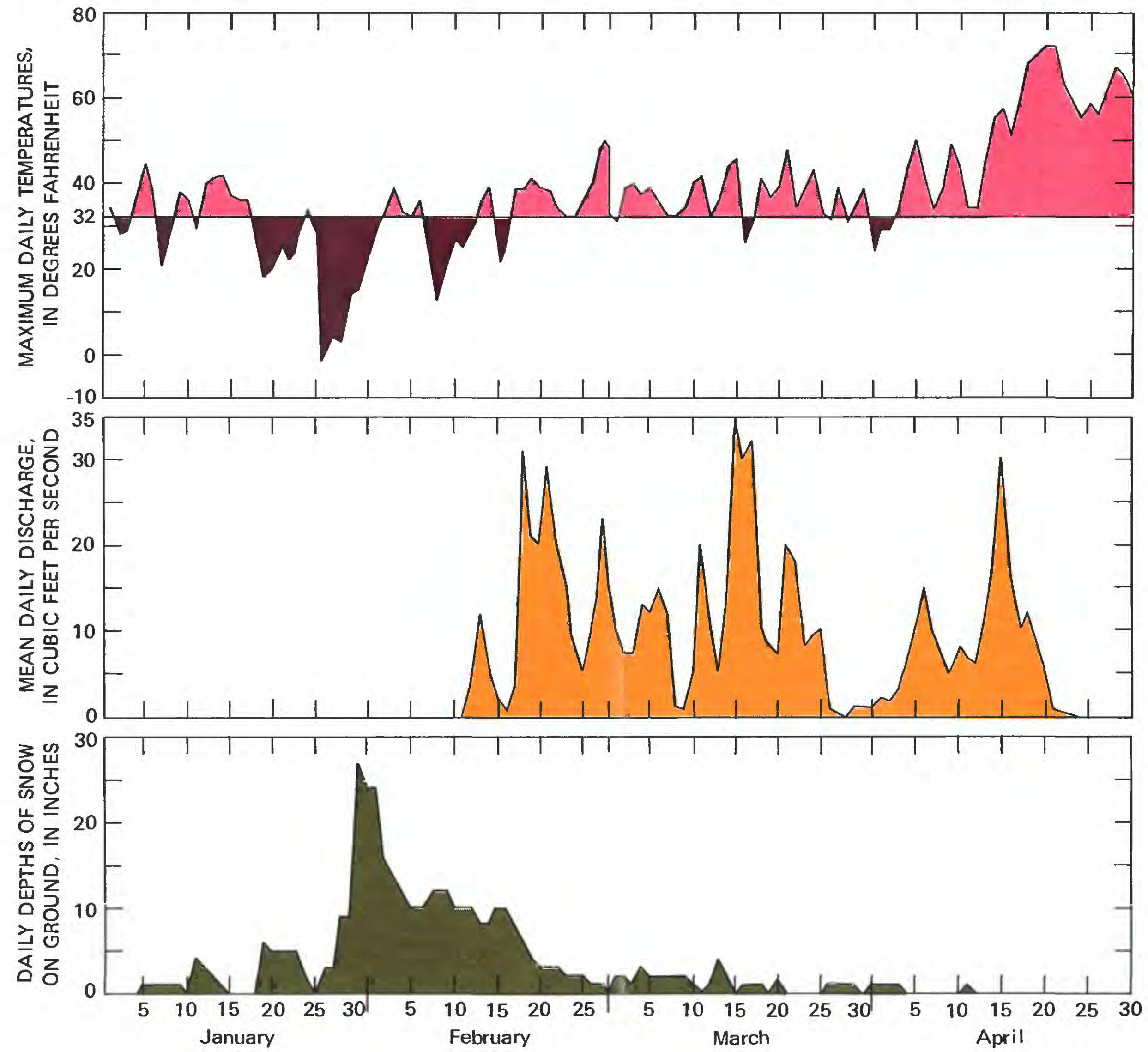


Figure 5.1-4 Maximum daily air temperatures and snow depths for 1980 at Rawlins, Wyo. as an indicator of snowmelt runoff at North Ditch near Coyote Springs, Wyo.

Mean Annual Flow Can Be Estimated

Mean annual flow can be estimated at ungaged sites using predictive equations developed for Colorado and Wyoming.

Predictive equations are available to estimate mean annual flow (Q_A), in cubic feet per second, for ungaged sites in Area 54. Lowham (1976) developed relations for Wyoming streams and was able to define the following regions reflecting primary source of streamflow: Region 1, mountains (snowmelt runoff); region 2, plains and valleys (rainfall runoff); and region 4, subdued mountains (rainfall and snowmelt runoff). Region 3 is not present in Area 54.

The relation for region 1 is defined using two significant variables--drainage area (A), in square miles, and mean basin elevation (E), in thousands of feet above mean sea level. The equation:

$$Q_A = 0.0036A^{0.96} E^{2.57}$$

has an average standard error of estimate of 59 percent and is applicable for perennial streams within the area shown in figure 5.2-1.

The relations for regions 2 and 4 are defined using drainage area as the single variable. The equation for region 2:

$$Q_A = 0.244A^{0.56}$$

applies to only intermittent and ephemeral streams in the part of Area 54 shown in figure 5.2-1. The equation for region 4:

$$Q_A = 0.162A^{0.98}$$

is applicable only to perennial streams (fig. 5.2-1). The latter two equations were developed by graphical regression of a very limited amount of data and no standard error of estimate is presented; the estimates of streamflow from these relations should be considered to be very approximate (Lowham, 1976, p. 3). The relationships developed by Lowham for Regions 1, 2, and 4 are illustrated in graphical form in figure 5.5-2.

Livingston (1970) presents several relations for estimating mean annual flow in the mountainous area of Colorado, utilizing different numbers and combinations of variables. A two-variable equation:

$$Q_A = 0.0009A^{0.94} P^{2.12}$$

where A = drainage area, in square miles, and P = mean annual precipitation, in inches, gives generally better estimates of mean annual flow, in comparison to that determined from actual station records in North Park, than his primary four-variable equation (p. 25). The standard error of estimate of the simpler equation is 48 percent, compared to 47 percent for the four-variable equation. The two-variable equation can be considered to be similar in form to the Wyoming region-1 equation, since elevation and precipitation are often correlated in this area. Nonetheless, the equation for Wyoming mountains (region 1) estimates a mean annual flow about two times as large as that estimated by the simpler equation for Colorado mountains.

Since the hydrologic characteristics of the mountains of Colorado and Wyoming should not be significantly different from each other, especially in the vicinity of the State line, the differences in streamflow estimated by the two equations are probably due to the assumptions and methodologies used in deriving the equations for each State. The relations developed by Livingston (1970) are for the entire mountain region of Colorado, which is not entirely homogeneous and, therefore, has localized hydrologic differences. Several intermontane basins, such as North Park, are included in the mountain area of Colorado. Drainage area of streams flowing through these basins may increase appreciably, but because precipitation is much less than in the surrounding mountains, streamflow does not increase correspondingly; Wyoming mountain areas generally do not have these intermontane basins. Streamflow stations in the Colorado part of Area 54 used in Livingston's (1970) analysis were almost always in the North Park basin--not in the mountains proper; streamflow stations in the Wyoming region-1 part of Area 54 were almost always well into the mountains for the analysis by Lowham (1976).

The streamflow on most streams in North Park is not entirely natural. Diversion for irrigation may, at some locations or during some years, have a significant effect on streamflow. This is not the case for streams in the mountains, whether in Colorado or Wyoming. Finally, the physiographic nature of Wyoming mountains provides for better distinction between mountains and plains, whereas the distinction between mountains and plains in Colorado is more difficult--on the east because of foothills and on the west because of plateaus. These reasons may, in part, explain the differences between the two equations.

In applying these relations within Area 54, especially on a drainage basin crossing the Colorado-Wyoming boundary, the user may want to make a precursory determination of the hydrologic characteristics of the basin. The determination as to whether the basin is entirely in the mountains or in the intermontane areas or whether there is diversion of streamflow will aid in determining which equation to apply. If some doubt remains, the following method may be used:

(1) Determine Q_A for the entire basin using each equation for both Colorado and Wyoming;

(2) Weight Q_A for each State by the percent of the drainage area in the State; and

(3) Sum the weighted values for a weighted mean annual flow.

Mean annual flows computed from station-record data at 49 streamflow stations are listed in the Supplemental Information section of this report.

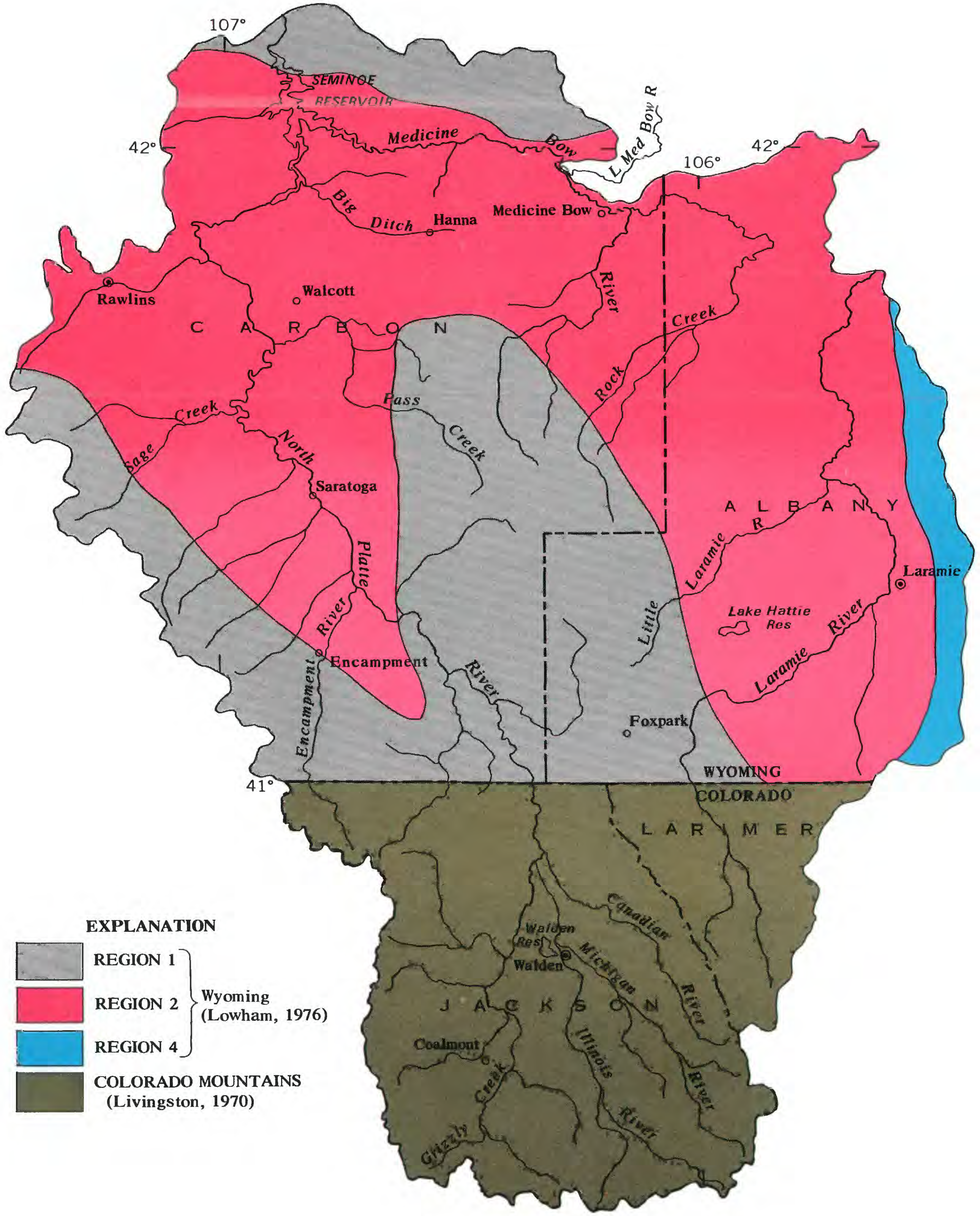


Figure 5.2-1 Defined areas where predictive equations are applicable for determining mean annual flow.

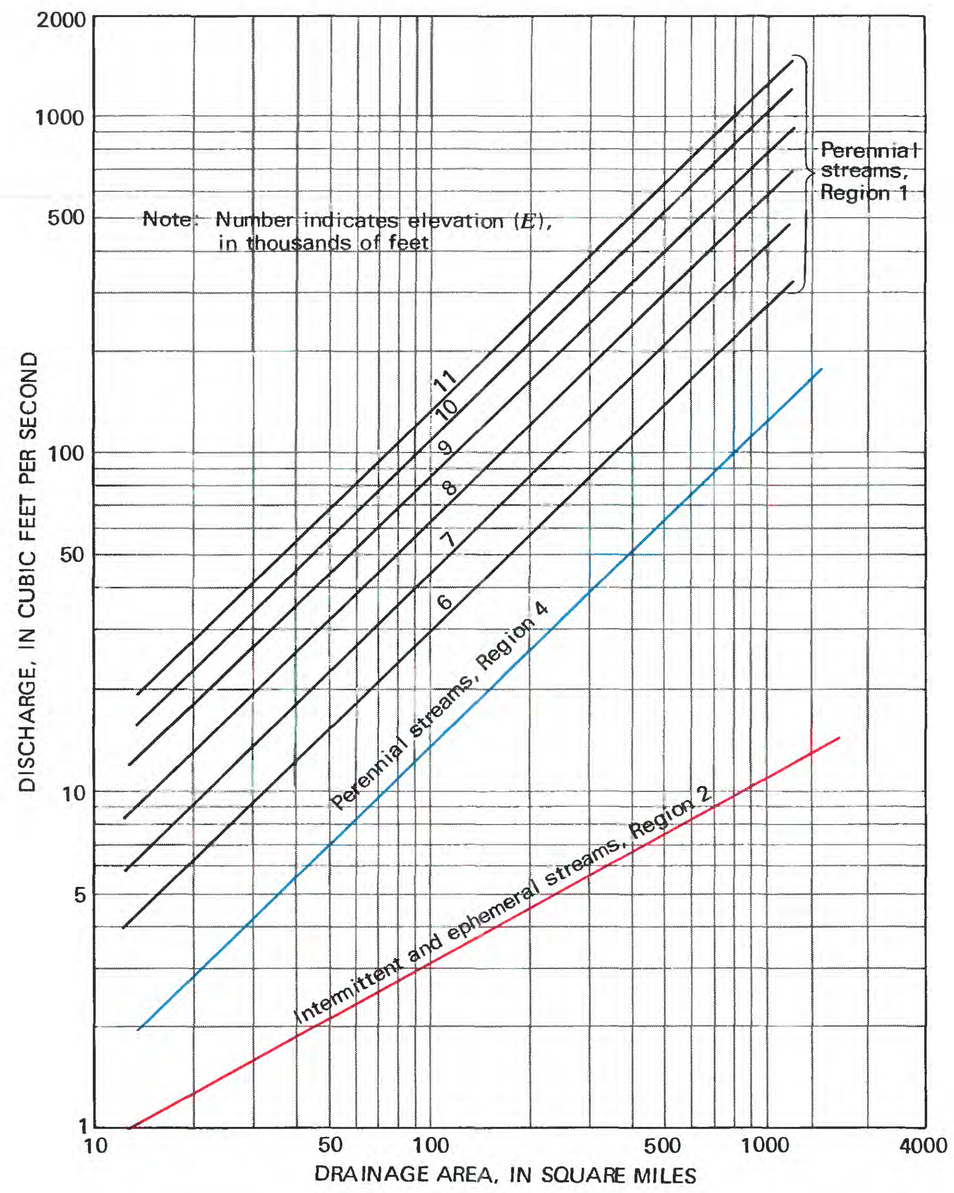


Figure 5.2-2 Method of determining mean annual flow for regions 1,2, and 4 (Lowham, 1976).

Duration Curves from Large and Small Drainage Areas Are Similar in Shape

Streamflow is primarily from snowmelt runoff, probably accounting for similarly shaped flow-duration curves at most gaging stations.

Flow-duration curves are cumulative frequency curves that show the percentage of time during which specified discharges were equaled or exceeded in a given period (Searcy, 1959). A flow-duration curve represents the flow characteristics of a stream throughout the range of discharge. The average slope of the duration curve is indicative of the magnitude of natural storage in the drainage basin. The shape of the lower end of the curve is a measure of the average ground-water conditions.

Duration curves for selected stations (fig. 5.3-1) are illustrated in figure 5.3-2 (small drainage areas) and figure 5.3-3 (large drainage areas). The steep slopes of the center part of the curves in figure 5.3-2 indicate a minimum of natural storage within each basin while the sustained lower end indicates a consistent ground-water discharge to the streams. The larger streams, as shown in figure 5.3-3, have a milder slope for the center part of the curves, indicating some natural storage within each basin. Ground-water discharge also is reflected in the sustained lower end of the curves.

Flow-duration curves for ephemeral streams are not shown. Stations on ephemeral streams usually are operated seasonally, resulting in incomplete records for computing flow duration. Furthermore, duration curves for ephemeral streams have little meaning.

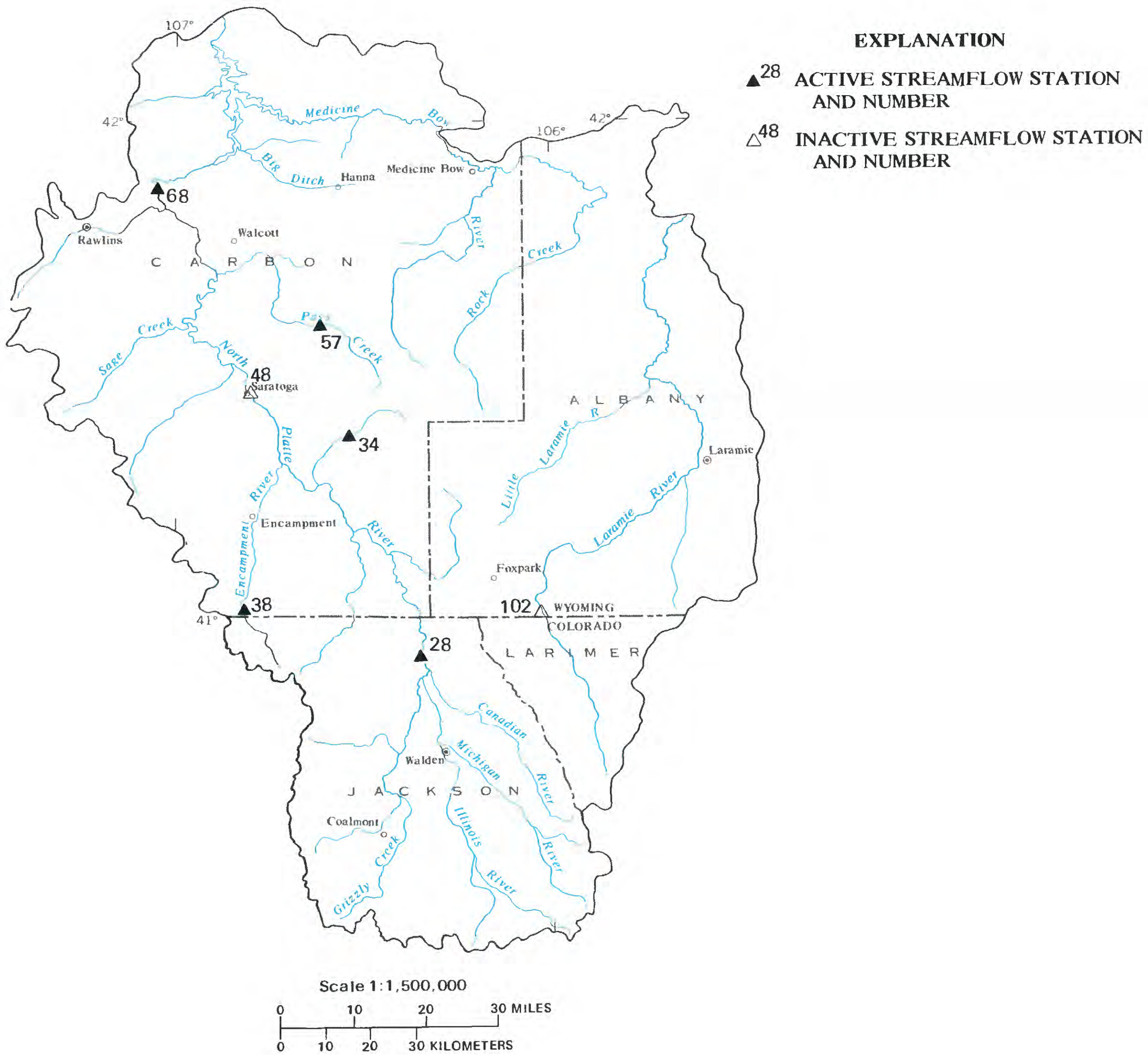


Figure 5.3-1 Location of flow-duration stations.

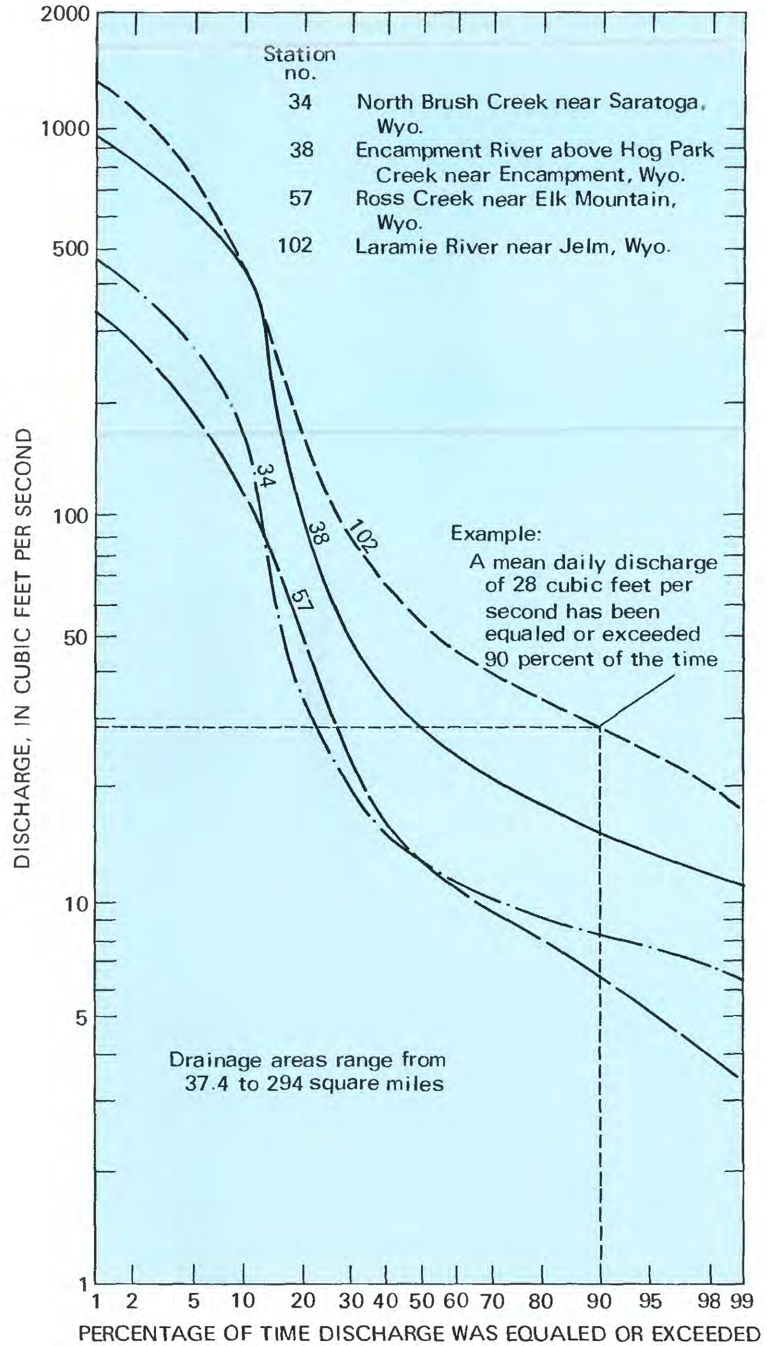


Figure 5.3-2 Flow-duration curves of mean daily flow for selected stations on tributaries of the North Platte River.

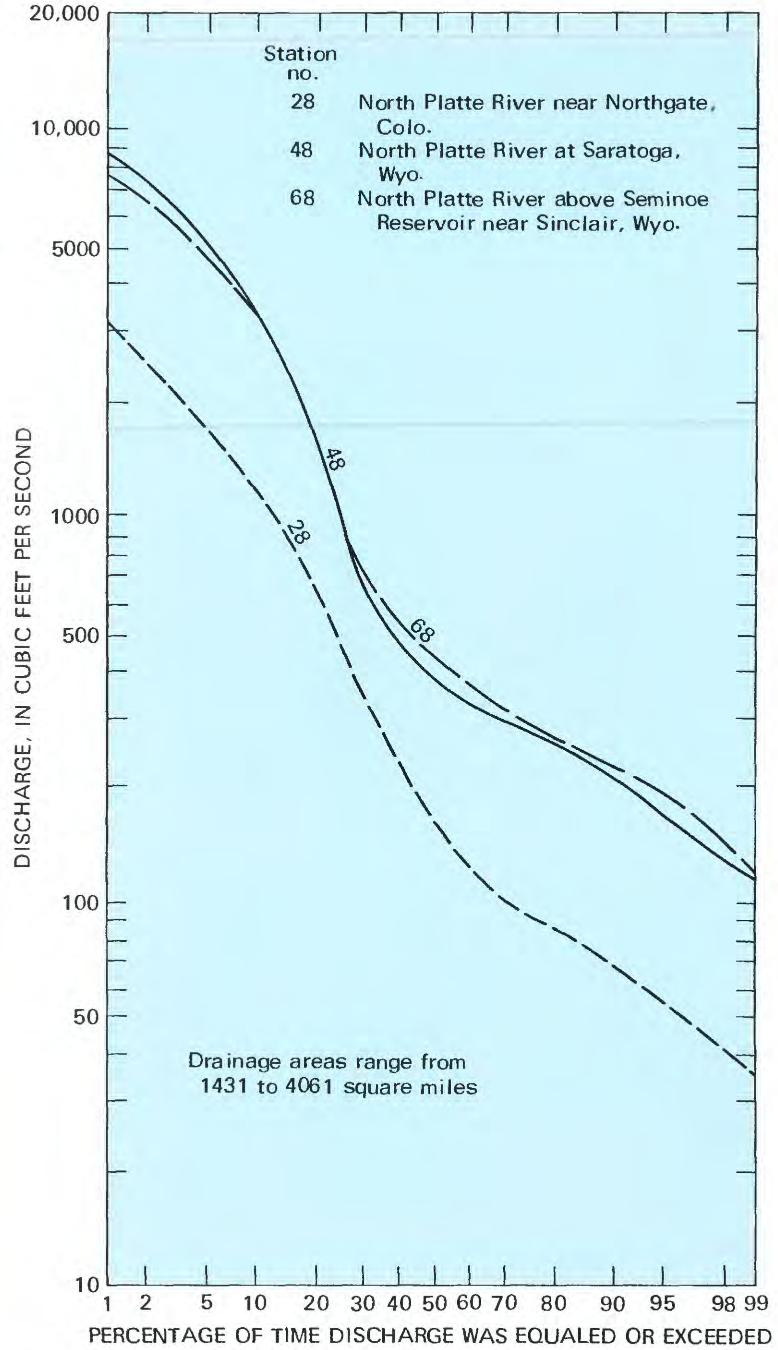


Figure 5.3-3 Flow-duration curves of mean daily flow for selected stations on the North Platte River.

Flood Flows Can Be Estimated for Small Ephemeral Streams

Estimates of the magnitude and frequency of flood peaks and of the corresponding volumes of flow on small ephemeral streams can be made, based on the results of a recent study of small-stream floods in Wyoming.

Equations are available for predicting the magnitude and frequency of flood peaks and flood volumes at ungaged sites. Because the areas of strippable coal are characterized by small, usually ephemeral, streams, the procedures developed for such streams in Wyoming by Craig and Rankl (1978) are emphasized in this section. Methods for predicting flood flows on ephemeral streams in the mountains of Colorado are not currently available.

Magnitudes of flood discharges are described in terms of recurrence intervals of 2, 5, 10, 25, 50, and 100 years. A 2-year flood is expected to be equaled or exceeded, on the average, once in 2 years, a 10-year flood once in 10 years, or a 100-year flood once in 100 years. Expressed another way, a 2-year flood has a 50-percent chance of being equaled or exceeded in a given year, a 10-year flood has a 10-percent chance, and a 100-year flood has a 1-percent chance. However, changes in climatic patterns can increase or decrease the magnitude of a designated recurrence.

Since 1959, peak-flow data have been obtained for many ephemeral streams and are now used to develop flood-frequency relations. The regional analysis by Craig and Rankl (1978), based on long-term rainfall records, provides a means of estimating flood-frequency relations for drainage basins of less than 11 square miles. Mountainous areas were excluded from the study. Figure 5.4-1 shows the part of Area 54 included in the study and the locations of six small ephemeral streams in or near defined coal fields.

Predictive equations for the cross-hatched area shown in figure 5.4-1 involve four important variables: Drainage area (A), in square miles; basin slope (S_B), in feet per mile; maximum basin relief (R_m), in feet; and main channel slope ($S_{10/85}$), in feet per mile. These terms are defined in the report by Craig and Rankl (1978). Equations for the 10-year, 50-year, and 100-year flood peaks, in cubic feet per second, are:

$$Q_{10} = 32.99\,A^{1.094}\,S_B^{\;1.080}\,R_m^{\;-1.308}\,S_{10/85}^{\;0.603}$$

$$Q_{50} = 43.88\,A^{1.084}\,S_B^{\;0.962}\,R_m^{\;-1.118}\,S_{10/85}^{\;0.616}$$

and

$$Q_{100} = 50.25\,A^{1.082}\,S_B^{\;0.914}\,R_m^{\;-1.047}\,S_{10/85}^{\;0.615}$$

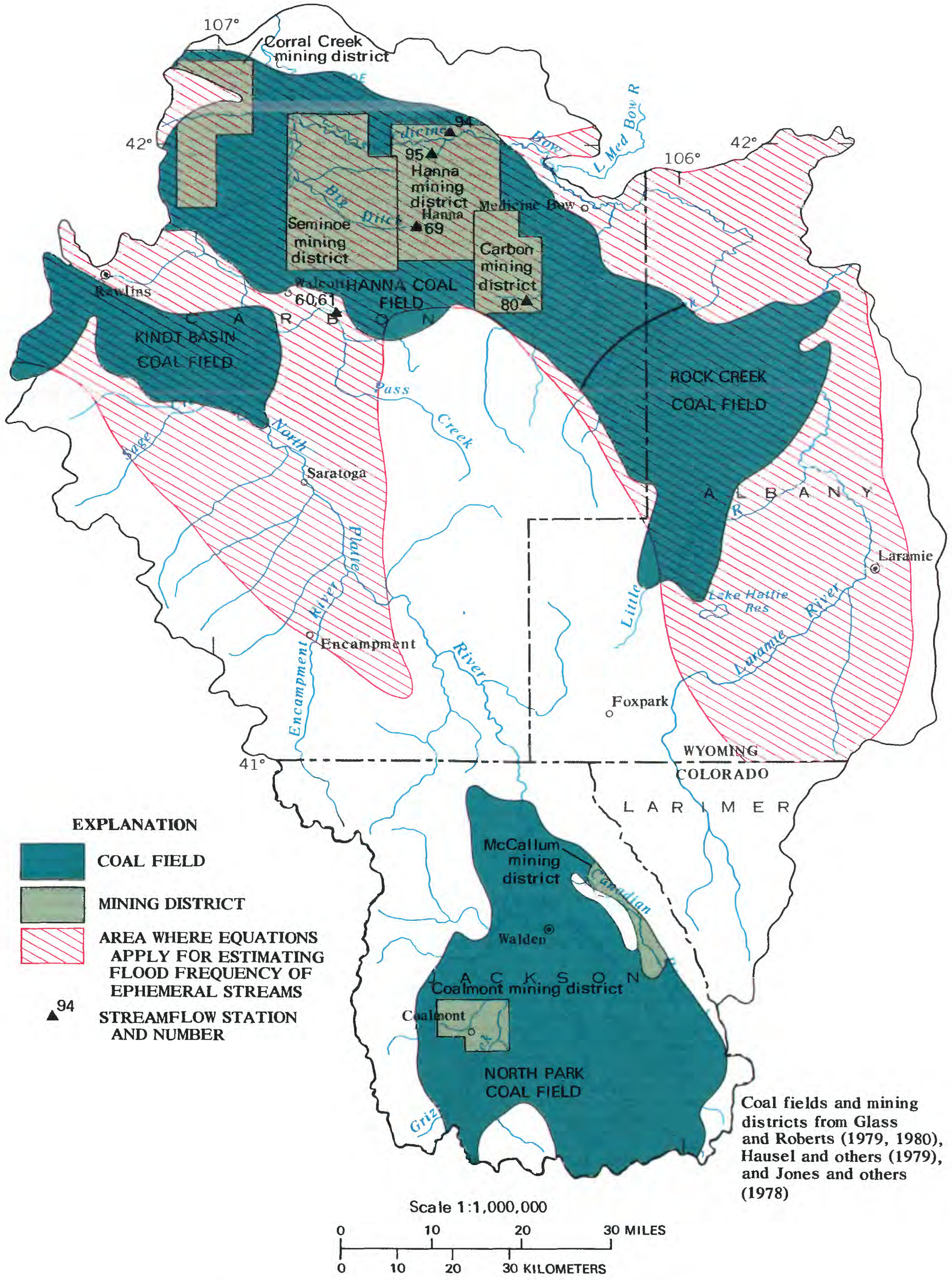
The respective average standard errors of estimate are 32, 34, and 37 percent.

The equations were the result of a study of seasonal (April-September) rainfall. Peak flows on small drainage basins are caused primarily by high-intensity rainfall from thunderstorm activity. For some areas, where summer rainfall is minimal and snowmelt runoff is more predominant, the above equations would predict peak flows higher than actually occur.

Table 5.4-1 lists the estimated flood frequencies for six selected small ephemeral streams. These results are shown graphically in figure 5.4-2. Three streams have frequencies developed from annual peak-flow records of 19 to 22 years, and three have frequencies developed from a synthetic peak-flow record of 73 years obtained from a computer model and utilizing a 73-year rainfall record. The station-record flood frequencies were obtained using methods developed by the U.S. Water Resources Council (1981). Although the frequency curves for the three stations with short records show steeper slopes, it is probable that with additional years of record the slopes would flatten out and become more consistent with the frequency curves for stations with longer records.

A relationship between flood peaks and runoff volume is shown in figure 5.4-3. This is a means of determining a flood volume corresponding to a flood peak of given magnitude. However, this does not imply a specific frequency to a volume so determined.

Equations for predicting magnitudes and frequencies of flood peaks in Wyoming on drainage basins larger than 11 square miles are given by Lowham (1976). These equations are defined by regions identical to those for mean annual flow (see section 5.2) and may apply to perennial and ephemeral streams. Equations for predicting magnitude and frequency of flood peaks on perennial streams in Colorado are presented by McCain and Jarrett (1976). These equations apply only to perennial streams, since, in the mountain area, only perennial streams were used in their regression analysis. The equations presented by Lowham (1976) for Wyoming region 1 (mountains) estimate flood peaks which are about two times as large as those estimated by the equations presented by McCain and Jarrett (1976) for Colorado mountains. These differences can, in part, be similarly explained as those for mean annual flow presented in section 5.2. The weighting technique presented in that section also may be applied to the equations for estimating flood peaks.



Coal fields and mining districts from Glass and Roberts (1979, 1980), Hausel and others (1979), and Jones and others (1978)

Figure 5.4-1 Location of coal fields, mining districts, and streamflow stations on ephemeral streams.

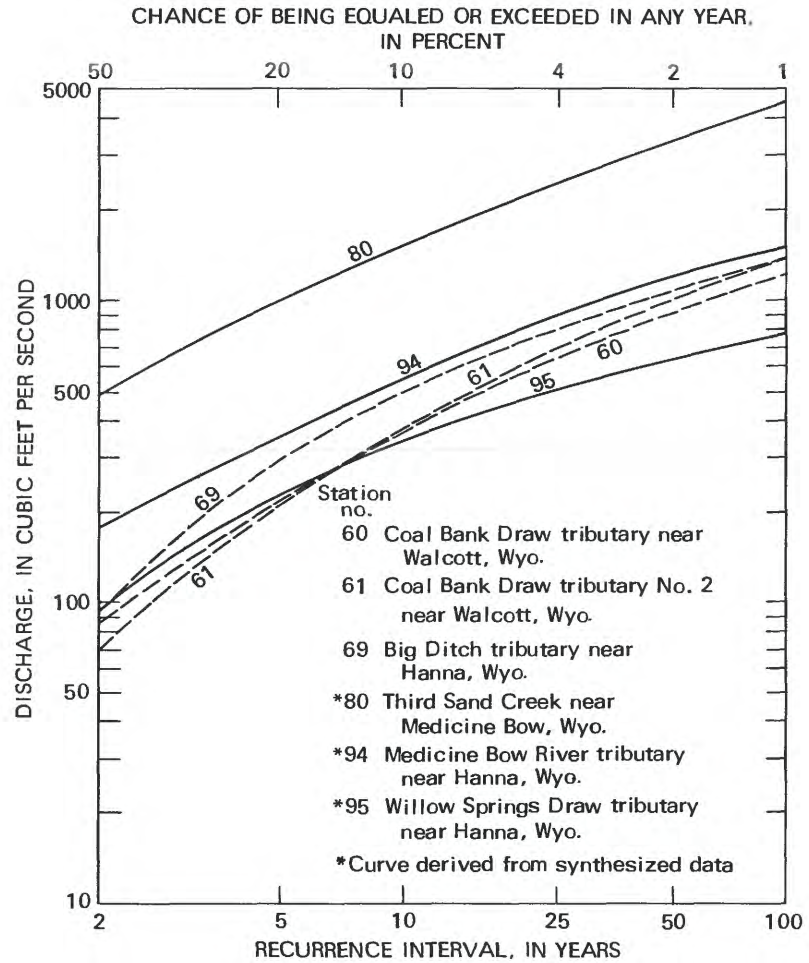


Figure 5.4-2 Peak-flow frequency curves for selected small ephemeral streams.

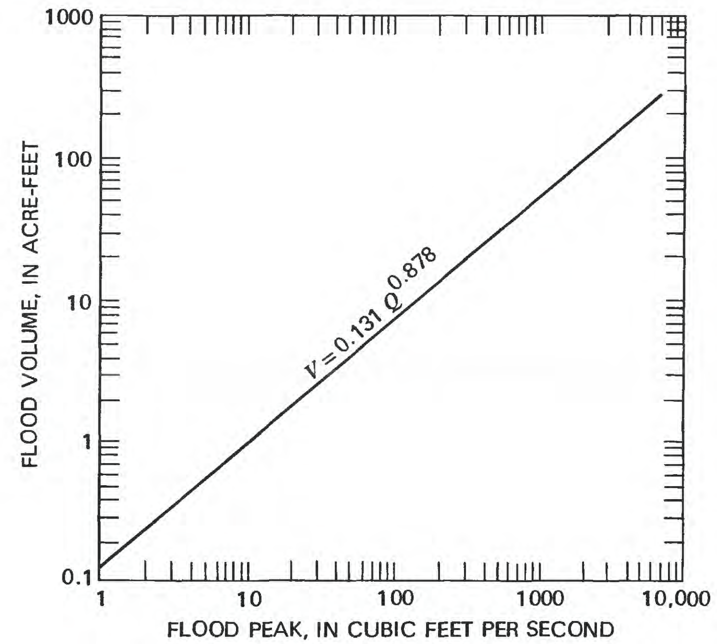


Figure 5.4-3 Flood volume corresponding to a flood peak of given discharge.

Table 5.4-1 *Flood peaks, in cubic feet per second, for given recurrence intervals at selected small ephemeral streams*

Station	Drainage area (square miles)	Years of peaks	Recurrence interval				
			5 years	10 years	25 years	50 years	100 years
60	3.65	19	215	359	634	927	1,318
61	2.41	19	208	368	676	1,000	1,422
69	7.42	22	295	499	826	1,111	1,422
80	10.8	*73	1,006	1,514	2,404	3,291	4,411
94	3.01	*73	367	549	865	1,175	1,564
95	1.98	*73	225	335	495	625	762

*Peak record synthesized from long-term rainfall record (Craig and Rankl, 1978)

Low-Flow Frequencies Not Predictable for Area 54

Effects of regulation and diversion on perennial streams in study area disrupt natural low-flow trends. Ephemeral streams are dry most days each year.

Low-flow relationships for streams in Area 54 have not been defined on an areal basis because most streams are subject to varying effects of regulation or diversion. While the effects of regulation or diversion on flood flows may not be significant, they become very significant when involved with low flows.

Attempts at regionalizing low-flow relationships by Wahl (1970) for Wyoming and by Livingston (1970) for Colorado proved unsatisfactory. Regression techniques could not adequately determine consistent results relating streamflow to the basin characteristics available for each study. The ability to predict low-flow frequency at ungaged sites in Colorado and Wyoming even today cannot be done with any degree of confidence.

Low-flow data for perennial streams within Area 54 are presented in table 5.5-1. A common statistic, the 7-day, 10-year low flow (Q7,10), is the discharge at 10-year recurrence intervals taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days. The probability is 1 chance in 10 that the 7-day low flow in any 1 year will be less than the 7-day, 10-year low flow. The 7-day, 10-year low flow presented for 33 stations with at least 10 years of record was obtained using a U.S. Geological Survey computer program (Hutchinson, 1975) to provide the statistical analysis. Also listed are the number of zero days or days (not necessarily consecutive) when no flow occurred for the given period of record. These are perennial streams, and the large number of no-flow days indicated for eight stations results primarily from depletion due to diversions and regulation. The zero days listed are for the period of record indicated; actual days or periods of no flow are available from appropriate offices of the U.S. Geological Survey in Lakewood, Colo., or Cheyenne, Wyo. Ephemeral streams--those that are dry most days each year--cannot be meaningfully analyzed for low-flow frequency.

Low-flow frequency curves for four selected stations are illustrated in figure 5.5-1. Minimum flows for consecutive periods of 1 day, 7 days, 30 days, 90 days, and 120 days are shown for recurrence intervals of from 2 to 20 years.

According to Riggs (1972), more than 20 years of record are considered desirable to adequately define the 20-year recurrence-interval annual minimum flow. The four stations illustrated in figure 5.5-1 have periods of record ranging from 23 years to 60 years.

Table 5.5-1 *Estimates of 7-day, 10-year low flow for stations in Area 54 with a minimum of 10 years of record*

Station				7-day, 10-year low flow	
Number	Name	Years record	Drainage area (square miles)	$Q_{7,10}$ (cubic feet per second)	Number of zero days
5	Grizzly Creek near Walden, Colo.	22	258	0.27	200
9	Little Grizzly Creek near Hebron, Colo.	15	98.6	.42	109
10	Roaring Fork near Walden, Colo.	25	79.1	6.41	0
11	North Platte River near Walden, Colo.	25	469	11.4	0
13	North Fork North Platte River near Walden, Colo.	14	160	7.00	0
*17	North Fork Michigan River near Gould, Colo.	30	21.2	1.31	[a]142
19	Michigan River at Walden, Colo.	24	182	2.35	0
22	Illinois Creek at Walden, Colo.	24	259	.05	134
27	Canadian River at Cowdrey, Colo.	10	180	.58	2
*28	North Platte River near Northgate, Colo.	64	1,431	34.6	0
31	Douglas Creek near Foxpark, Wyo.	26	120	2.98	0
33	French Creek near French, Wyo.	13	59.6	7.19	0
*34	North Brush Creek near Saratoga, Wyo.	19	37.4	5.83	0
*35	South Brush Creek near Saratoga, Wyo.	11	22.8	1.33	0
*38	Encampment River above Hog Park Creek, near Encampment, Wyo.	15	72.7	10.9	0
42	Encampment River at Encampment, Wyo.	16	211	10.9	0
*44	Encampment River at mouth, near Encampment, Wyo.	39	265	16.7	0
48	North Platte River at Saratoga, Wyo.	59	2,840	97.8	0
*57	Pass Creek near Elk Mountain, Wyo.	23	91.5	2.74	0
*68	North Platte River above Seminoe Reservoir, near Sinclair, Wyo.	41	4,175	101	0
83	Medicine Bow River above Rock Creek, near Medicine Bow, Wyo.	12	436	0	491
*85	Rock Creek above King Canyon Canal, near Arlington, Wyo.	15	62.9	6.33	0
86	Rock Creek at Arlington, Wyo.	32	64.5	4.00	0
90	Rock Creek below Rock River, Wyo.	10	218	.15	165
*97	Medicine Bow River above Seminoe Reservoir, near Hanna, Wyo.	41	2,338	2.77	1
*101	Laramie River near Glendevey, Colo.	67	101	9.42	0
102	Laramie River near Jelm, Wyo.	60	294	14.5	0
*104	Laramie River and Pioneer Canal near Woods Landing, Wyo.	59	434	13.3	3
107	Laramie River at Laramie, Wyo.	20	1,071	2.42	0
110	Laramie River at Two Rivers, Wyo.	52	1,224	1.17	39
*111	Little Laramie River near Filmore, Wyo.	55	157	8.34	0
112	Little Laramie River at Two Rivers, Wyo.	25	376	.10	1,742
*117	Laramie River near Lookout, Wyo.	38	2,174	.82	474

*Currently active gaging stations

[a]Period of total diversion to fill a recreation lake

Note: Location of these stations is shown in figure 4.0-1

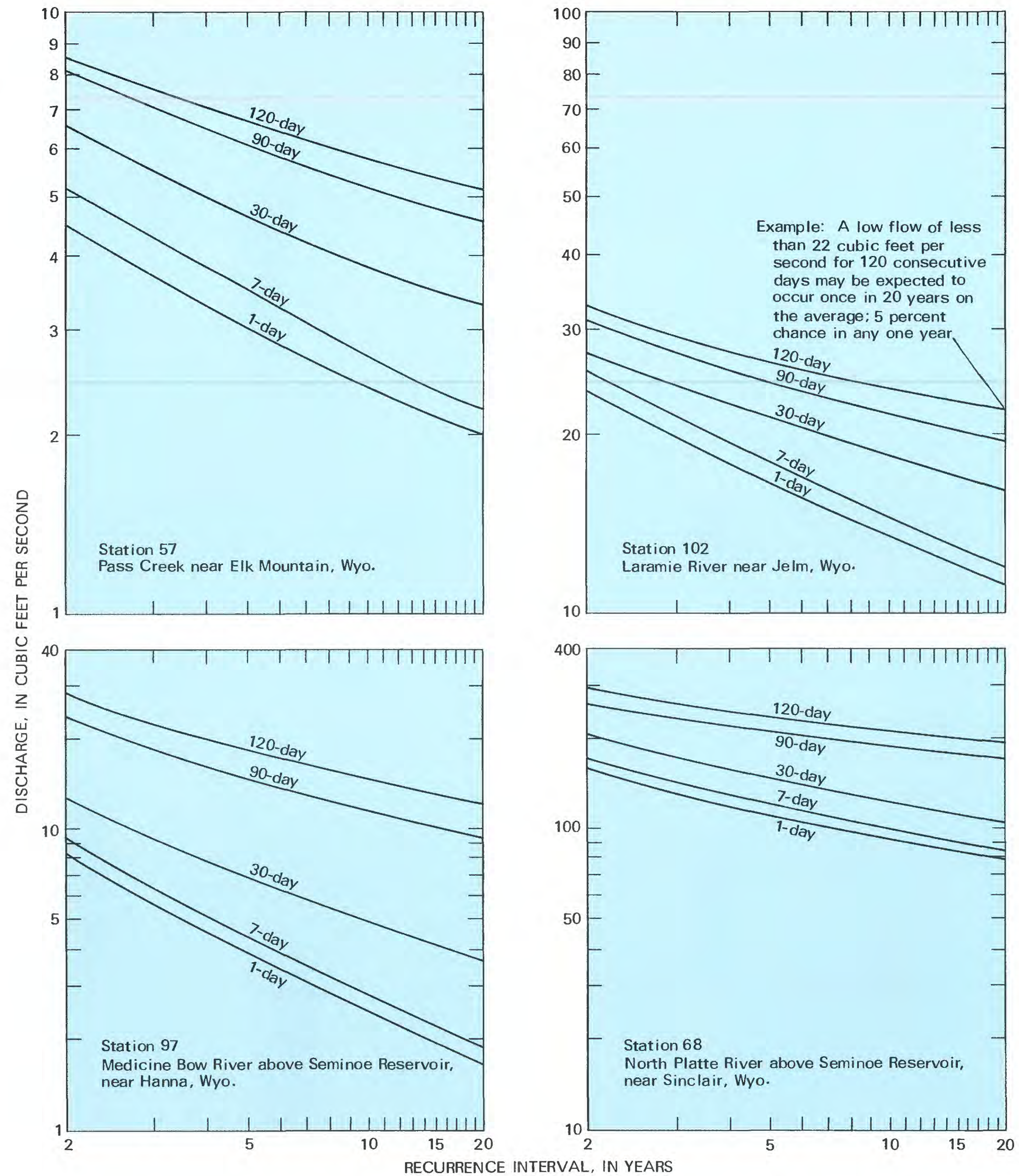


Figure 5.5-1 Low-flow frequency curves for selected streamflow stations.

Time-Of-Travel Data Available for Canadian River

Time-of-travel was determined for medium- and high-flow conditions on the Canadian River; irrigation affects time-of-travel during medium flow.

Time-of-travel, dispersion, and concentration of tracer dye were measured on two reaches of the Canadian River during medium and high flows (fig. 5.6-1). These reaches are primarily in agricultural areas. The river originates in mountainous forested terrain and flows through agricultural and rural ranch areas in its downstream reaches. Traveltime data for only the downstream reach are presented herein.

Time-concentration curves are shown for the downstream reach on the Canadian River during high flow (fig. 5.6-2). These curves illustrate the dispersion, decrease in peak concentration, and increase in traveltime as the dye tracer moves downstream.

Time-of-travel results for the downstream reach during medium and high flows are shown in figures 5.6-3 and 5.6-4. The traveltimes of the leading edge, peak concentration, and the trailing edge of the dye cloud were defined by sampling; therefore, the length of the dye cloud and duration of the dye presence can be determined at a given site. During medium-flow conditions (fig. 5.6-3), a multiple injection was necessary because of the long traveltime from the injection site to the first measurement site. This was due to a large percentage of the streamflow being diverted for irrigation. Subsequently, a substantial amount of dye also was diverted, and the remainder of the dye was delayed by the pool created by the diversion structure. This resulted in a lengthy, low-concentration dye curve. During high-flow conditions (fig. 5.6-4), a single injection was possible due to higher stream velocities.

Data collection and analyses for the traveltime study on the Canadian River followed the methods in Wilson (1968) and Hubbard and others (1982). Time-of-travel can be estimated on other rivers by the use of equations developed by Boning (1974). Bauer and others (1979) describe how time-of-travel measurements can be used to predict arrival time, concentration, and duration of spills of soluble contaminants and length of stream affected by such spills.

This study was part of a traveltime and reaeration program of the U.S. Geological Survey, designed to collect data on various streams in energy-development areas. These data are preliminary and subject to revision and will be published in a pending report. The data are available from the U.S. Geological Survey, Box 25046, Mail Stop 415, Denver Federal Center, Lakewood, CO 80225.

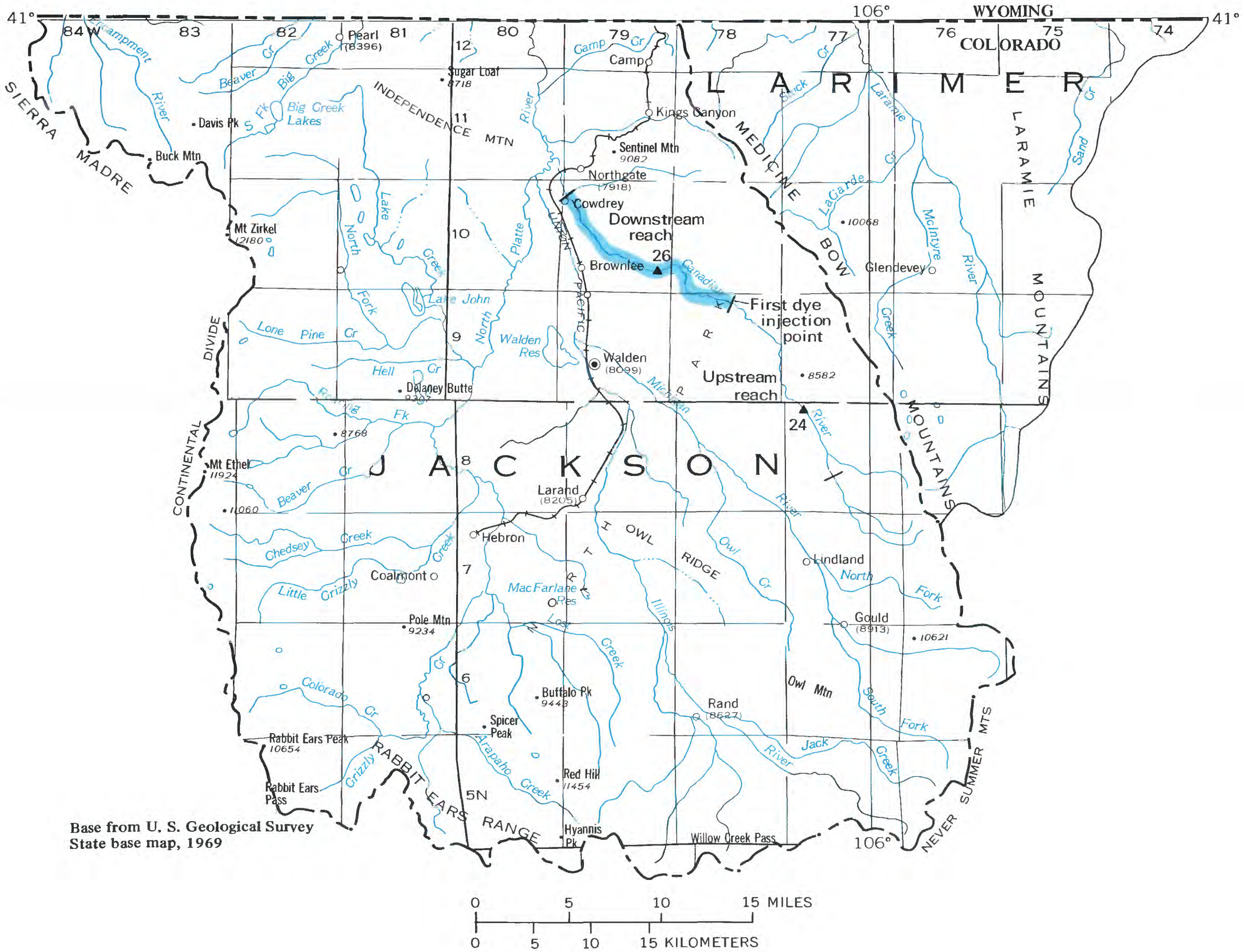


Figure 5.6-1 Location of time-of-travel reaches.

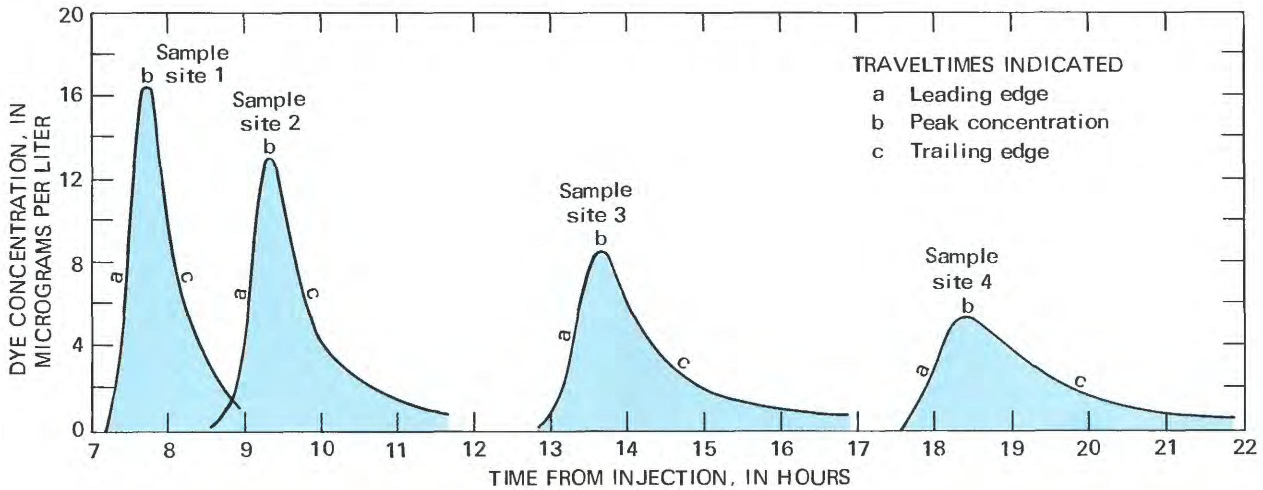


Figure 5.6-2 Time-concentration curves for downstream reach of Canadian River during high flow (130-135 cubic feet per second).

EXPLANATION

▲26 ACTIVE SURFACE-WATER STATION AND NUMBER

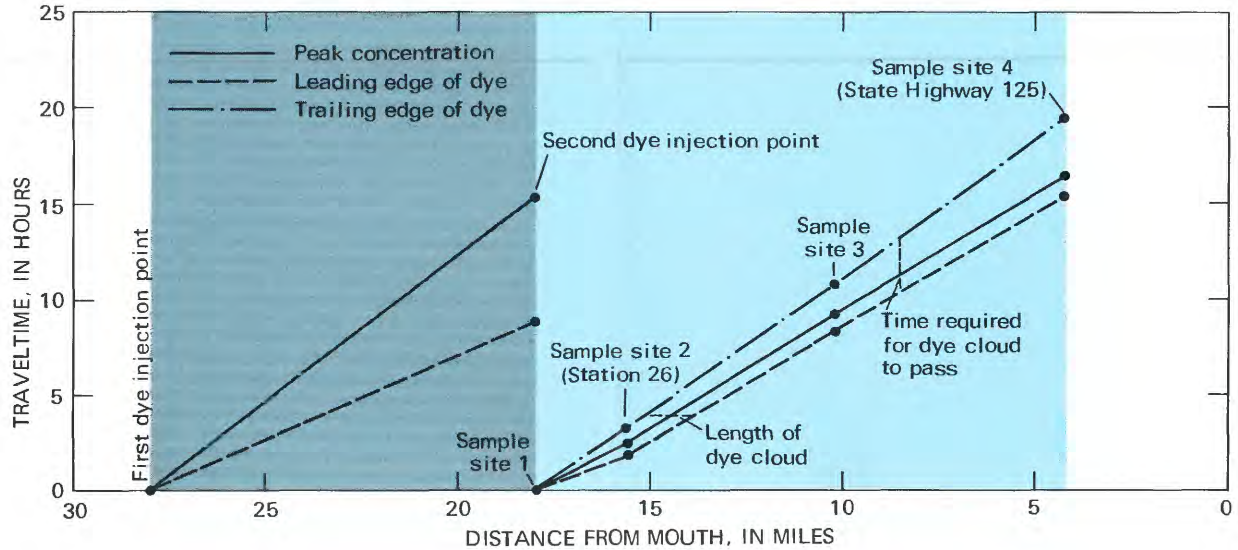


Figure 5.6-3 Traveltime-distance curves for downstream reach of Canadian River for a multiple-dye injection at medium flow (25-40 cubic feet per second).

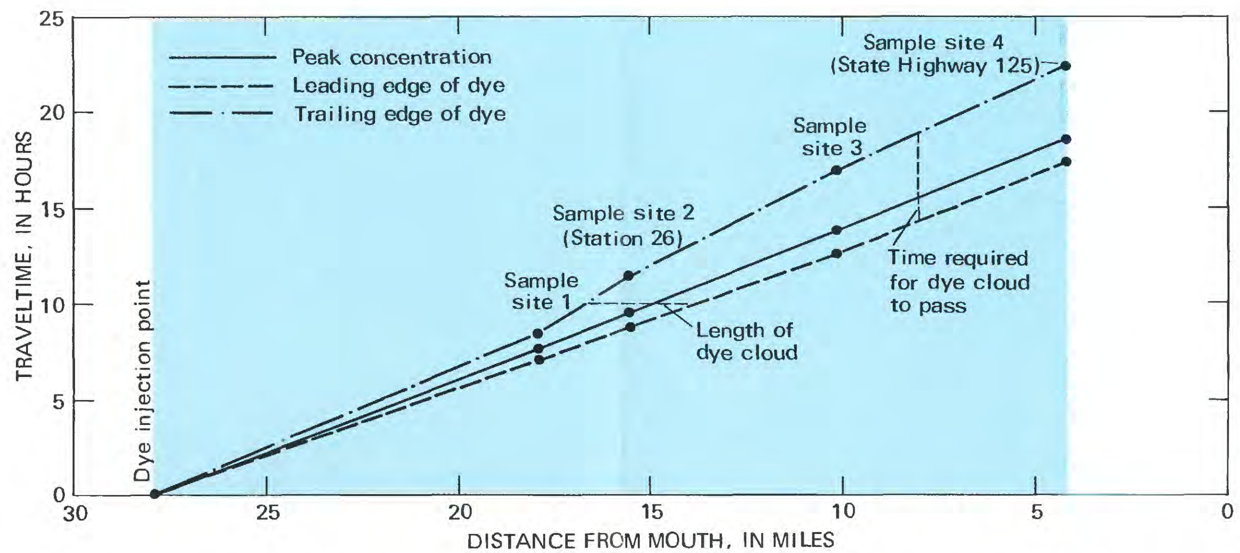


Figure 5.6-4 Traveltime-distance curves for downstream reach of Canadian River for a single-dye injection at high flow (130-135 cubic feet per second).

Large Buffering Capacity and Semiarid Climate Prevent Acid Mine Drainage in Area 54

Alkalinity buffers water against pH changes to which aquatic life may be exposed, decreases toxicity of metals, and helps prevent acid mine drainage.

Alkalinity is defined as the capacity of a solution to neutralize acid; most determinations of alkalinity are made by titrating the solution with standard acid to a pH of 4.5. Alkalinity can be attributed to several solute species, but it is due principally to the presence of carbonate and bicarbonate ions. These two ions are formed largely by the dissolution of carbonate minerals, such as calcite, and, to a lesser extent, by the solution of carbon dioxide. Actual concentrations of carbonate and bicarbonate ions are not always available from routine chemical analyses; therefore, alkalinity is normally expressed in terms of an equivalent concentration of calcium carbonate.

pH is a measure of the degree of acidity, or basicity; a pH of 7.0 indicates neutral water, less than 7.0 indicates acidic water, and larger than 7.0 indicates basic water. In pure water, acidity is due to hydrogen ions, but they usually are present in such small amounts that their concentration cannot be easily expressed in milligrams per liter. A convenient method of expression, then, is pH, defined as the negative base-10 logarithm of the hydrogen-ion concentration in moles per liter. The solution of carbon dioxide, which produces alkalinity, also produces hydrogen ions (acidity). In natural waters, though, other chemical processes also affect pH. Additional discussion on carbonate-bicarbonate equilibria and pH is provided by Hem (1970) and Garrels and Christ (1965).

The range of alkalinity observed at water-quality stations in Area 54 (fig. 6.1-1) is depicted as a frequency distribution in figure 6.1-2. Somewhat more than half the values range from 81 to 160 milligrams per liter as calcium carbonate, and about 95 percent of the values are less than 200. Hem (1970, p. 158) reports that the concentration of bicarbonate in most streams is less than 200 milligrams per liter, equivalent to an alkalinity of 164 milligrams per liter as calcium carbonate (p. 81). Alkalinity in water is desirable and important because it, among other things, buffers water against pH changes to which fish and other aquatic life may be exposed, and it may complex some metal ions, decreasing their potential toxicity (U.S. Environmental Protection Agency, 1976a, p. 7). They also report that alkalinity of as much as 400 milligrams per liter is not considered a problem to human health.

The range of pH observed at the stations also is shown as a frequency distribution (fig. 6.1-2). About 85 percent of the values are in the near neutral to slightly basic pH range of 7.2 to 8.3; the extreme values are 5.9 and 9.3. Most of the pH values are within the general range of 6.5 to 8.5 reported by Hem (1970, p. 93) for unpolluted water and the 6.5 to 9.0 range recommended for the support of freshwater aquatic life (U.S. Environmental Protection Agency, 1976c, p. 180).

The ranges of alkalinity and pH at individual stations are shown in figure 6.1-3. Alkalinity has considerable variation between stations and also at specific stations. The ranges of pH are much more uniform; the median in particular varies little and is usually close to 7.8. Alkalinity, although variable, generally maintains pH within the range of 7.2 to 8.3.

Bicarbonate ions, which are the primary source of alkalinity in the surface waters of Area 54, buffer water against changes in pH because they can react with either hydrogen ions (acids) or hydroxide ions (bases). The larger the concentration of bicarbonate, the larger the buffer capacity of water; consequently, more hydrogen or hydroxide ions can be consumed with little change in pH.

In areas of coal mining, buffer capacity is an important consideration because sedimentary rocks associated with coal deposits and the coal itself commonly contain pyrite and other sulfide minerals. When exposed to the atmosphere in spoil material, these minerals are oxidized (weathered), producing sulfate and hydrogen ions. The acidity thus produced may be neutralized by any available alkalinity; however, if the production of hydrogen ions is large, the pH may be decreased, possibly to 4.5 or less. This process of acid mine drainage is much more complex than this description and is discussed considerably in the literature (for example, Wentz, 1974).

Acid mine drainage is common to many coal-mine areas of the eastern United States, but seldom occurs in the western coal regions. This is primarily due to the buffer capacity of streams and the semiarid climate, as ample water is necessary for significant and rapid oxidation of pyrite. The data in figure 6.1-3 show that the minimum pH observed at streams draining active mine areas in the Hanna Basin (stations 70, 71, and 96) was not lower than 7.0, indicating an absence of acid mine drainage. However, acid mine drainage is possible in the semiarid west; it has been reported at a location in Routt County, Colo. (Wentz, 1974, p. 98, and Wentz and Steele, 1980, p. 48, 89-90). The acid drainage at this location apparently originates in an abandoned underground coal mine and is not associated with nearby surface mining.

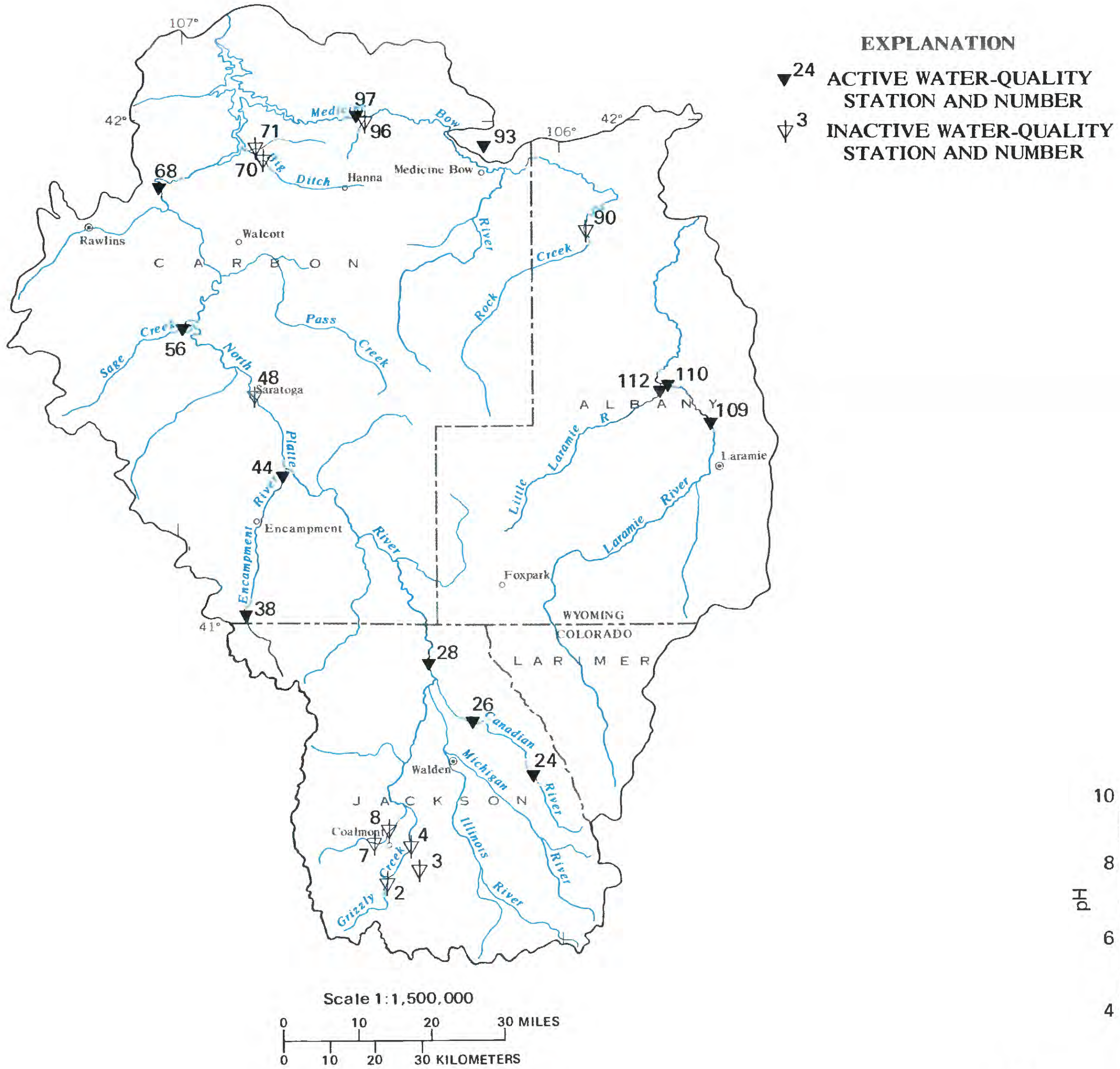


Figure 6.1-1 Location of water-quality stations for alkalinity and pH.

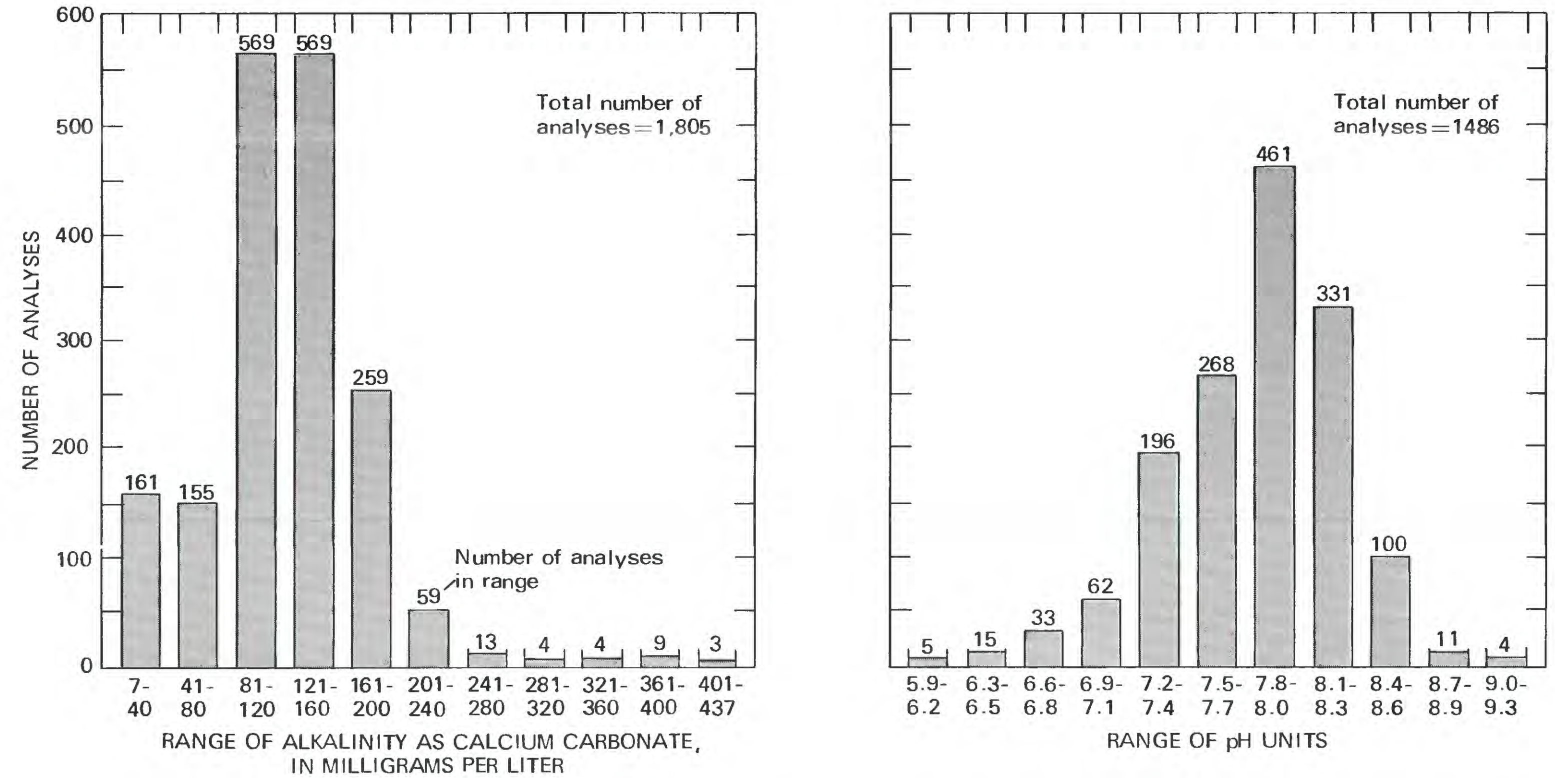


Figure 6.1-2 Frequency distributions of alkalinity and pH values measured at water-quality stations.

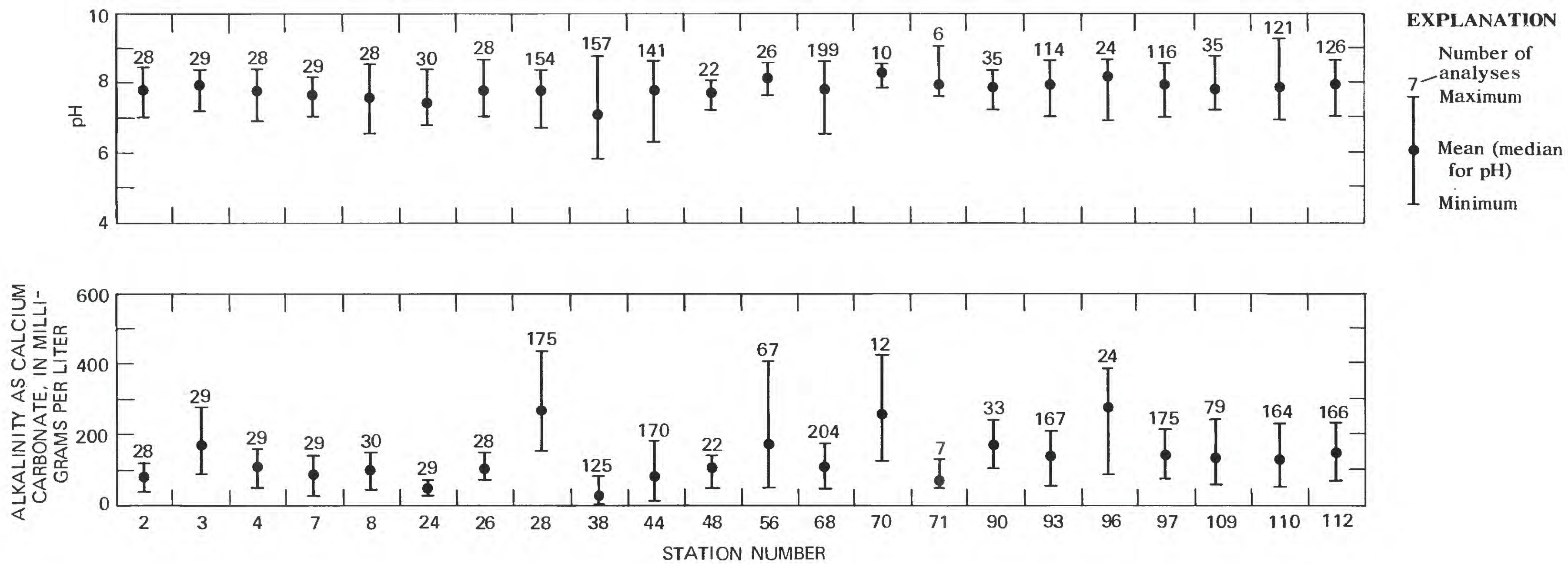


Figure 6.1-3 Maximum, minimum, mean, and median values for alkalinity and pH at individual water-quality stations.

Dissolved-Solids Concentration Is Related to Specific Conductance

Three statistical models relating specific conductance to dissolved solids were developed which provide a means of determining dissolved-solids concentrations at specific sites.

Specific conductance of water is a measure of its ability to conduct an electric current. The ability to conduct an electric current generally increases as the concentration of electrically charged ions (or quantity of dissolved solids) increases. However, the two do not have a direct relation, in either simple, single-salt solutions or in the complex, multiple-salt solutions of natural water; the relation is also not valid for an unlimited range of specific-conductance values (Hem, 1970, p. 96-102). Nevertheless, a relation between specific conductance and dissolved solids is a useful, practical method of determining general dissolved-solids concentrations.

Data from 22 water-quality stations in Area 54 (fig. 6.2-1) were used to develop three statistical models (fig. 6.2-2) relating specific conductance to dissolved-solids concentration. The first model (fig. 6.2-2a) was developed from specific conductances less than 500 micromhos. Almost all specific-conductance values observed at stations within the North Platte River main-stem drainage system fit this model. The notable exception is station 56, Sage Creek near Saratoga, Wyo., whose minimum observed specific conductance is 588 micromhos (fig. 6.2-3).

The drainage area of this stream is mainly in sedimentary rock--principally the Steele Shale--and does not have its headwaters in granitic mountains as do most streams in the upper North Platte River basin. Therefore, Sage Creek has generally larger dissolved-solids concentrations. The remainder of the streams upstream from station 68 generally should have dissolved-solids concentrations of about 300 milligrams per liter or less. Water-quality stations in the Laramie River and the Medicine Bow River drainages have some specific conductances less than 500 micromhos, which also should fit this model. These smaller values usually happen during the runoff season when snowmelt from the headwaters of these basins is available for dilution.

A second model (fig. 6.2-2b) was computed for specific conductances between 500 and 2,200 micromhos. This model generally applies to perennial streams in those parts of the Laramie River and the Medicine Bow River drainages in the sedimentary deposits of the Carbon, Hanna, and Laramie Basins. The streams in these areas generally have larger specific-conductance values because more solutes are available in sedimentary rock. However, farther upstream and closer to the mountains, where no water-quality data are available, dissolved-solids concentrations and specific-conductance values could be smaller, possibly fitting the first model. The larger specific-conductance values observed in the North Platte River drainage also fit the second model.

The third model developed (fig. 6.2-2c) applies exclusively to the ephemeral streams of the Hanna Basin. This type of stream generally has a large supply of solutes available, and consequently this model has a steeper slope than the second model, both of which include a similar range of values. A few specific conductances observed at the Hanna Basin stations were less than 500 micromhos, but these were included in the first model. These smaller values generally are produced by large runoff volumes sufficient to dilute the dissolved-solids concentrations; thus, they fit the first model. The coefficient of determination (r^2) of this model is smaller than that of the first two models; yet it explains 90 percent of the variation in the dissolved-solids concentrations. The standard error of estimate is considerably larger for the third model mainly because the values show more deviation from the model at the upper end than at the lower end. There are specific-conductance values (fig. 6.2-3) larger than the upper limits of the last two models, but the data are insufficient to adequately define the relations.

These models, then, can be used to give a reasonable estimate of the dissolved-solids concentrations at a particular site from a determination of specific conductance. The value of dissolved solids from that determination is not the absolute value for that particular determination, even within the limits of the standard error of estimate given herein, either at one of the stations used in developing the models or at another site. Although the models have a significant degree of correlation between specific conductance and dissolved solids, probably not every possible water-quality situation is included in these models. Many areas, such as the mountain areas and smaller streams in the basin areas, whether within or outside of coal-mining areas, have no water-quality information. Finally, the determination of the dissolved solids by the use of these models gives no indication what individual constituents are present in the water or what their relative concentrations are. In short, these models are practical tools, but the user needs to be aware of their limitations.

Development of a relation between specific conductance and a particular constituent would be the next step. This type of relation is generally developed for a particular site and does not necessarily have as much regional application as the relation between specific conductance and dissolved solids. Models of this type have been developed for some of the water-quality stations in Area 54 (Kuhn, 1982; and Rucker and DeLong, 1982).

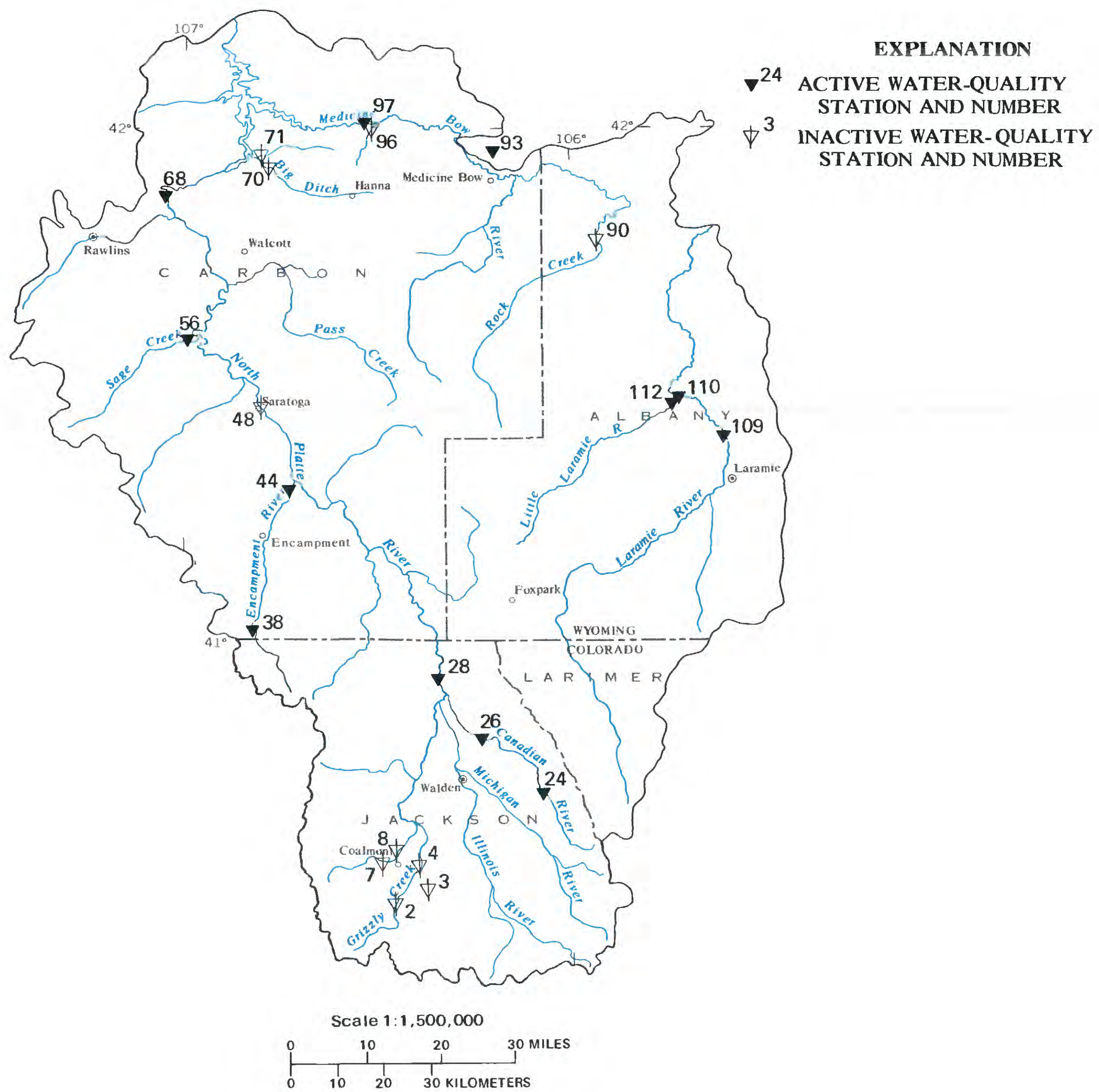


Figure 6.2-1 Location of water-quality stations for specific conductance and dissolved solids.

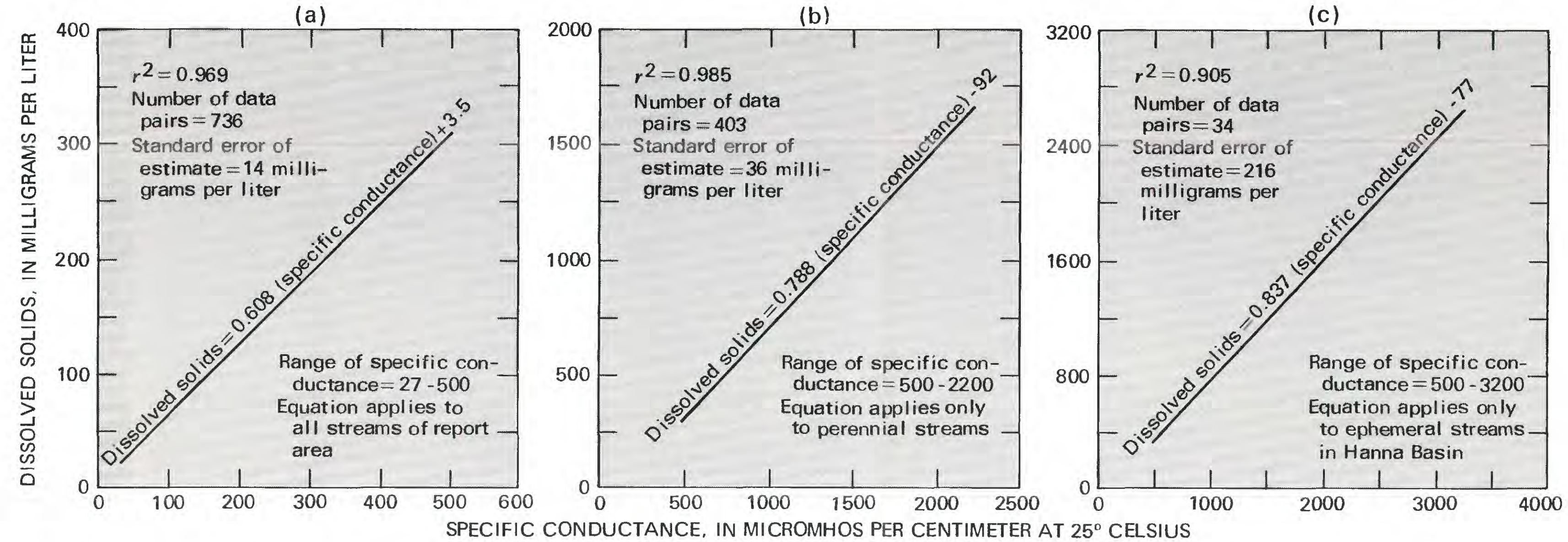


Figure 6.2-2 Relation between specific conductance and dissolved solids for different ranges of the specific conductance of samples from perennial and ephemeral streams.

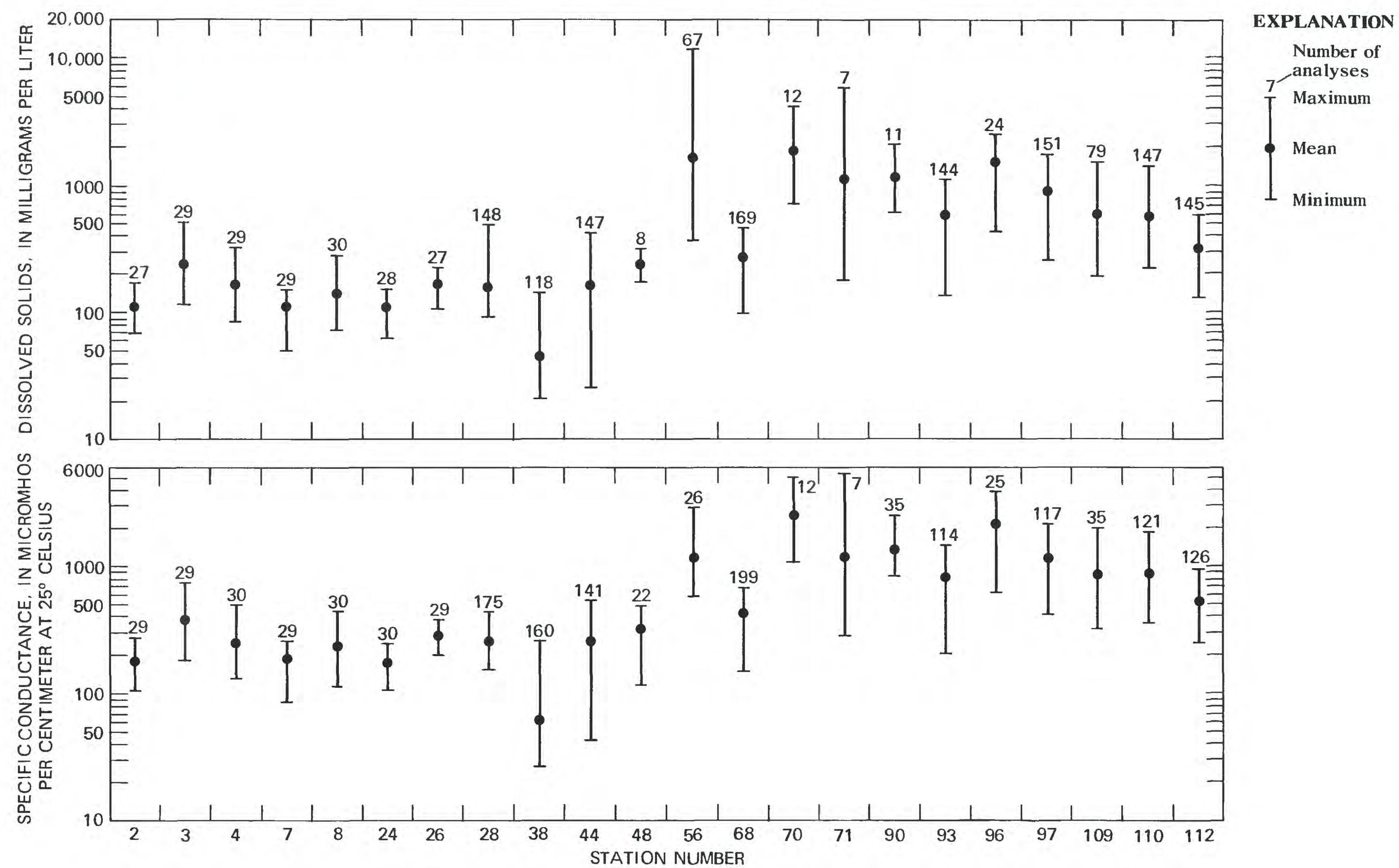


Figure 6.2-3 Maximum, minimum, and mean values for specific conductance and dissolved solids at individual water-quality stations.

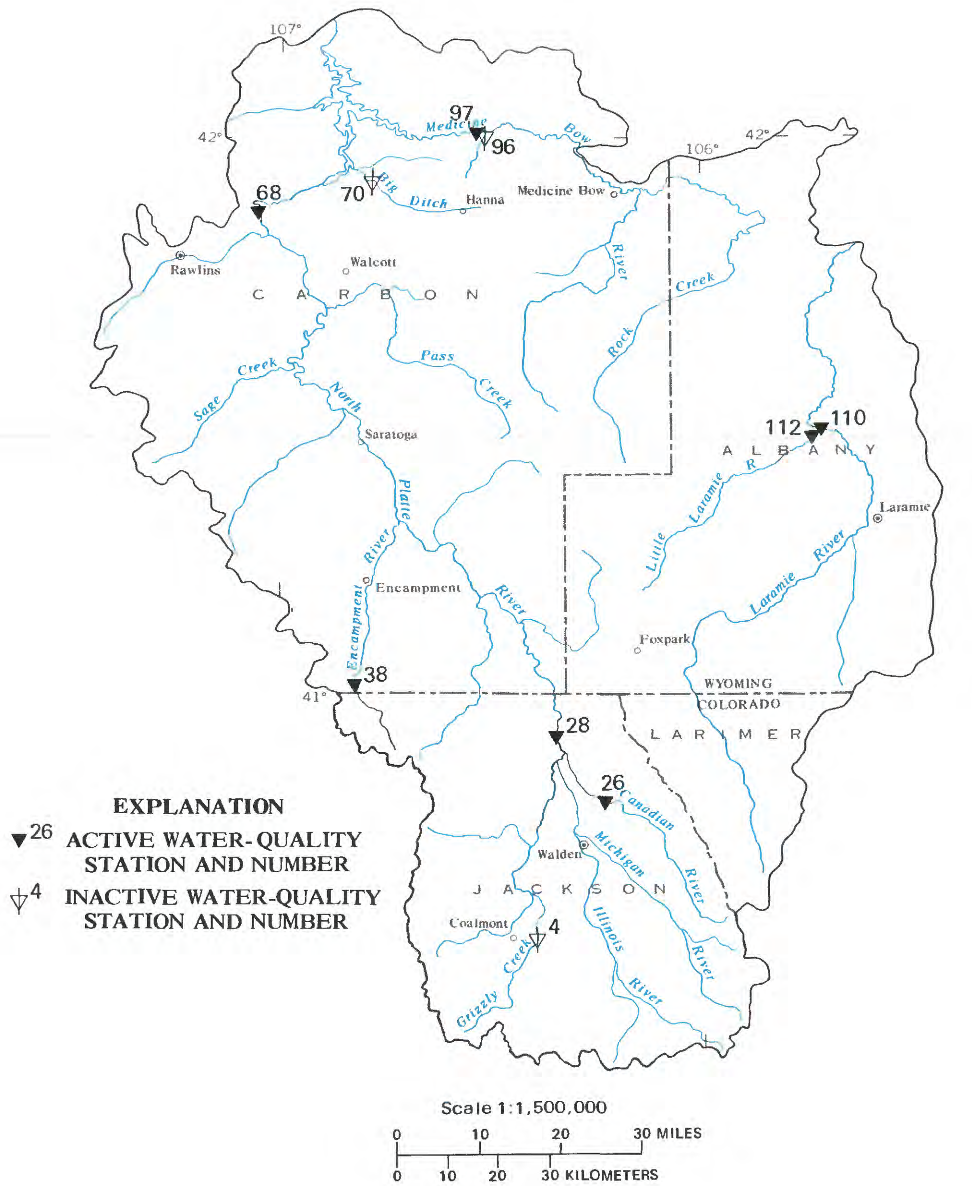


Figure 6.3-1 Location of stations for determination of regional water-quality variations.

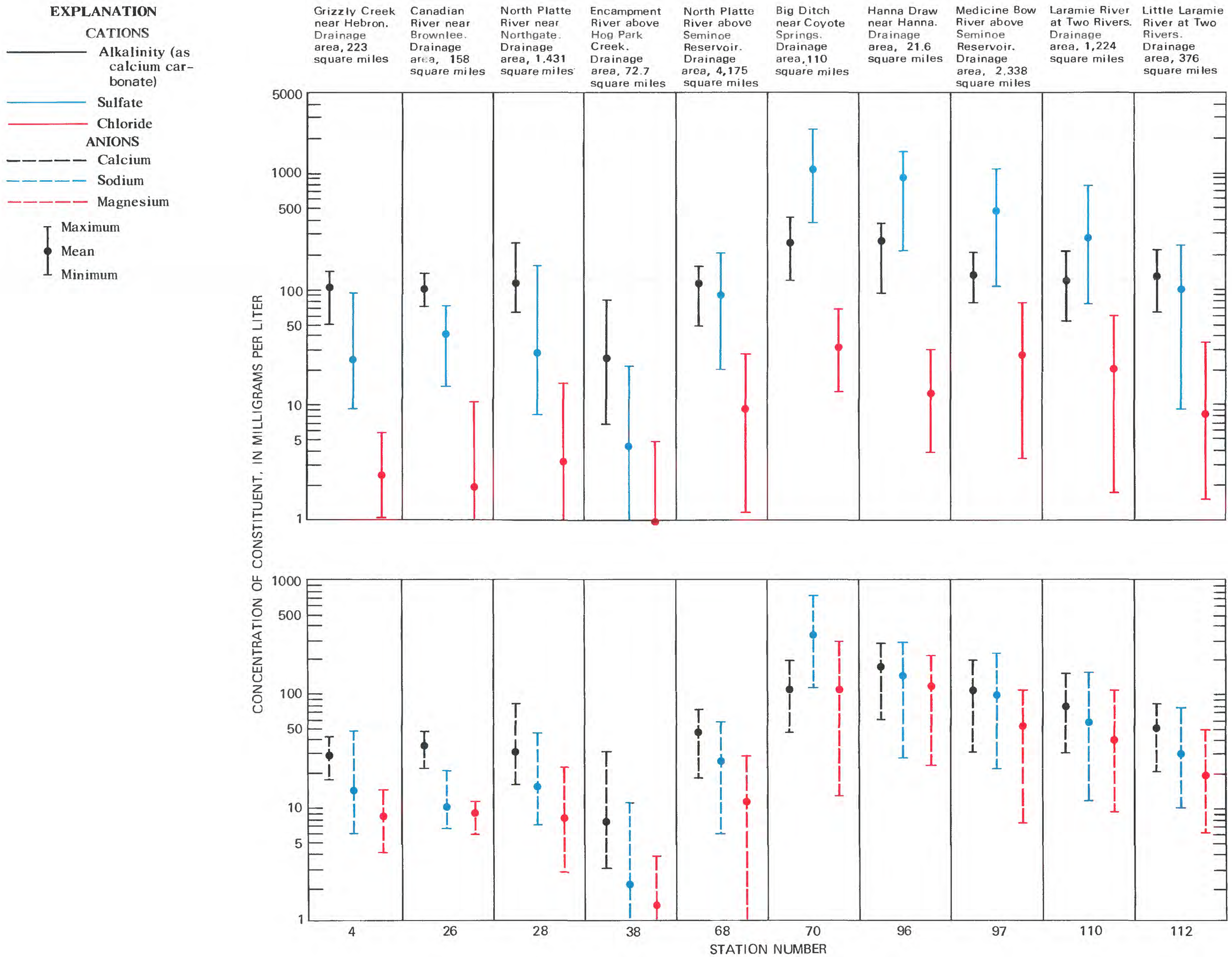


Figure 6.3-2 Maximum, minimum, and mean concentrations of major inorganic constituents at selected water-quality stations.

Snowmelt Runoff Causes Seasonal Dilution of Dissolved-Solids Concentrations

Concentration of dissolved solids generally decreases during April, May, and June due to snowmelt; in some streams irrigation also may have an effect on dissolved-solids concentration.

From August or September to March or April, the average concentration of dissolved solids and individual constituents at five selected water-quality stations (fig. 6.4-1) is fairly uniform (fig. 6.4-2). These months generally coincide with the base-flow period when streamflow does not vary greatly and is sustained primarily by ground-water discharge from alluvial aquifers in stream valleys. An exception to this is station 110 which shows an increase in the dissolved-solids concentration during late summer. Then during runoff (April, May, and June), dissolved-solids concentration decreases because snowmelt discharge, which usually has less dissolved solids than base-flow discharge, dilutes the concentrations of dissolved solids (fig. 6.4-2).

Reasons for the lack of a significant decrease in concentrations of dissolved solids at stations 28 and 110 during the runoff period are not definitely known. It may be that the dilution effect of snowmelt is offset somewhat by an increase of dissolved solids due to extensive flood-irrigation in and adjacent to the alluvial valleys of North Park and the Laramie Basin. About 130,000 acres upstream from station 28 and about 51,000 acres upstream from station 110 are irrigated, primarily for hay crops. In North Park, irrigation also is augmented by the snowmelt floods, which often overflow the banks of stream channels. Diverted irrigation water, or bank overflow, flows across the flood plains or infiltrates into the soil; some of it eventually is returned to the streams, most probably with a larger dissolved-solids concentration. There also may be other factors contributing to the small decrease in dissolved solids at these two stations during runoff.

The acreage irrigated upstream from station 110 is less than 50 percent of that irrigated upstream from station 28, but the mean annual runoff at station 110 (111 cubic feet per second) is only about 25 percent of that at station 28 (431 cubic feet per second). So, with respect to the amount of water available for irrigation, water demand probably is greater in the Laramie Basin than in North Park. This demand is more acute after the snowmelt recession, the peak of the growing season. Therefore, a greater percentage of the available discharge is diverted for irrigation in the Laramie Basin than in North Park. This condition may, in part, result in the increase of dissolved solids at station 110 during late summer, whereas the water at station 28 does not undergo a similar increase. At the end of the growing season, the concentration of dissolved solids at station 110 shows a significant decrease, indicating a return to more normal base-flow conditions.

The effects of snowmelt dilution on dissolved-solids concentration are much more evident from the concentration curves for stations 38, 68, and 97. The demand for irrigation water is less at stations 68 and 97, and most likely water quality at these stations is affected less by irrigation. No diversion or irrigation occurs in the basin upstream from station 38.

Concentration of dissolved solids also increases slightly during baseflow. This results because ground water discharging into streams during late winter has been in the alluvial aquifers for a longer time than ground water discharged during early fall. Water with the longer contact time usually has a larger concentration of dissolved solids.

When the concentration of dissolved solids is weighted by the discharge (fig. 6.4-3) with an appropriate conversion factor, the load can be computed. Load also varies seasonally but is regulated much more by water discharge than by dissolved-solids concentration. Discharge often is a function of drainage area, so load also may be a function of drainage area. For example, the concentration of dissolved solids at station 97 is much greater than at station 68, but station 68, with the greater discharge, has the greater load. Additional information regarding the load characteristics at these five water-quality stations is available in a report by Rucker and DeLong (1982).

Quality of Surface Waters Varies with Water Source Area and Distance from Source

Ten streamflow stations illustrate regional similarities and differences in water quality, depending on the geology and climate of headwaters area and distance from headwaters area.

The water-quality characteristics of a given area or stream are determined by the combination of factors such as: (1) Type of rock, soil, climate, and vegetation; (2) length of time water is in contact with the rock or soil; (3) amount of ground water contributed to streamflow; (4) amount of surface water available for dilution; (5) chemical relationships; and (6) activities of man. An introductory discussion to these and other water-quality topics is provided by Hem (1970).

Ten stations were selected to illustrate some similarities and differences in the quality of surface waters in Area 54 (figs. 6.3-1 and 6.3-2). The first five stations (4, 26, 28, 38, and 68) illustrate the water-quality characteristics of the North Platte River and some of its tributaries. Stations 70 and 96 illustrate the water quality of the ephemeral streams in the Hanna Basin, whereas the last three (97, 110, and 112) depict the water quality at stations on the Medicine Bow and the Laramie Rivers.

Station 38, on the Encampment River, has its drainage area entirely in the mountains and could be considered to be the most "upstream" of the water-quality stations. The concentration bars for this station indicate the type of water quality that probably is representative of streams draining granitic mountain areas, where most major streams have their headwaters. The smallest concentrations of the six ions depicted in figure 6.3-2 were determined at station 38. Streams in the mountains generally have smaller amounts of dissolved solids because solutes are less available in the granitic rock environment, direct snowmelt runoff provides considerable dilution, and the activities of man are minimal.

Stations 4, 26, and 28 illustrate the water quality of streams in North Park and could be considered to be "downstream" of the water-quality characteristics at station 38. The discharge at the North Park stations is still derived mostly from snowmelt in the granitic mountains, but ion concentrations have increased relative to those at station 38. These increases can be attributed in part to: (1) Increased availability of soluble minerals and salts in the sedimentary rocks and alluvial stream valleys of North Park, (2) inflow of either ground or surface waters containing larger concentrations of dissolved solids, and (3) flood-irrigation practices in the alluvial valleys of North Park. Mean concentration values for individual ions vary only slightly between stations 4, 26, and 28, indicating that streams in North Park may have a somewhat uniform water quality.

Further downstream on the North Platte River, at station 68, concentrations of the various ions also have increased; these increases are due partly to the reasons mentioned above. Also, downstream from the vicinity of Saratoga, Wyo., tributary streams of the North Platte River generally have a larger proportion of their drainage area in sedimentary rock, especially with respect to their headwaters. Consequently, these streams may have considerably larger dissolved-solids concentrations. For example, Sage Creek (station 56, fig. 6.2-1), a tributary in this area, has an average dissolved-solids concentration of 1,760 milligrams per liter. However, the much larger discharge of the North Platte River dilutes the larger concentration of ions in these tributary streams, which have a relatively small discharge.

The water quality of the ephemeral streams in the Hanna Basin is illustrated by the concentration bars for stations 70 and 96 (fig. 6.3-2). The following paragraph from Hem (1970, p. 165) helps explain the situation: "In semiarid and arid regions, the soils are usually not fully leached, and surplus solutes may accumulate near the surface. The amount of drainage water that leaves such an area is a small fraction of the total received in precipitation. Because of these factors, the supply of solutes is relatively large in proportion to the water volume in which it can be carried away. As a result, surface and underground waters in semiarid regions tend to be comparatively high in dissolved solids. Sulfate is a predominant anion in many places."

Although all water-quality stations depicted in figure 6.3-2, except station 38, are in semiarid basin areas, the above statement has more applicability to these ephemeral streams. This is because they flow only occasionally, and their runoff is derived entirely within the sedimentary basins. Although the two stations are downstream from active strip mines, the effect of mining on the water quality of these streams cannot be determined with the available data.

The concentration bars for stations 97, 110, and 112 illustrate water quality at stations on the Medicine Bow and the Laramie Rivers. Here the effects of the processes increasing dissolved solids are much more evident than at stations on the North Platte River. Of the four main-stem stations (28, 68, 97, and 110), station 97 on the Medicine Bow River has the largest proportion of its drainage basin in sedimentary rock, and it has the largest average concentration of dissolved constituents. Station 110, on the Laramie River, has smaller ion concentrations, but they are still more than twice those at station 68. Station 112, on the Little Laramie River, however, is nearer to the mountains, and the concentration range of ions at this station was similar to that at station 68 on the North Platte River.

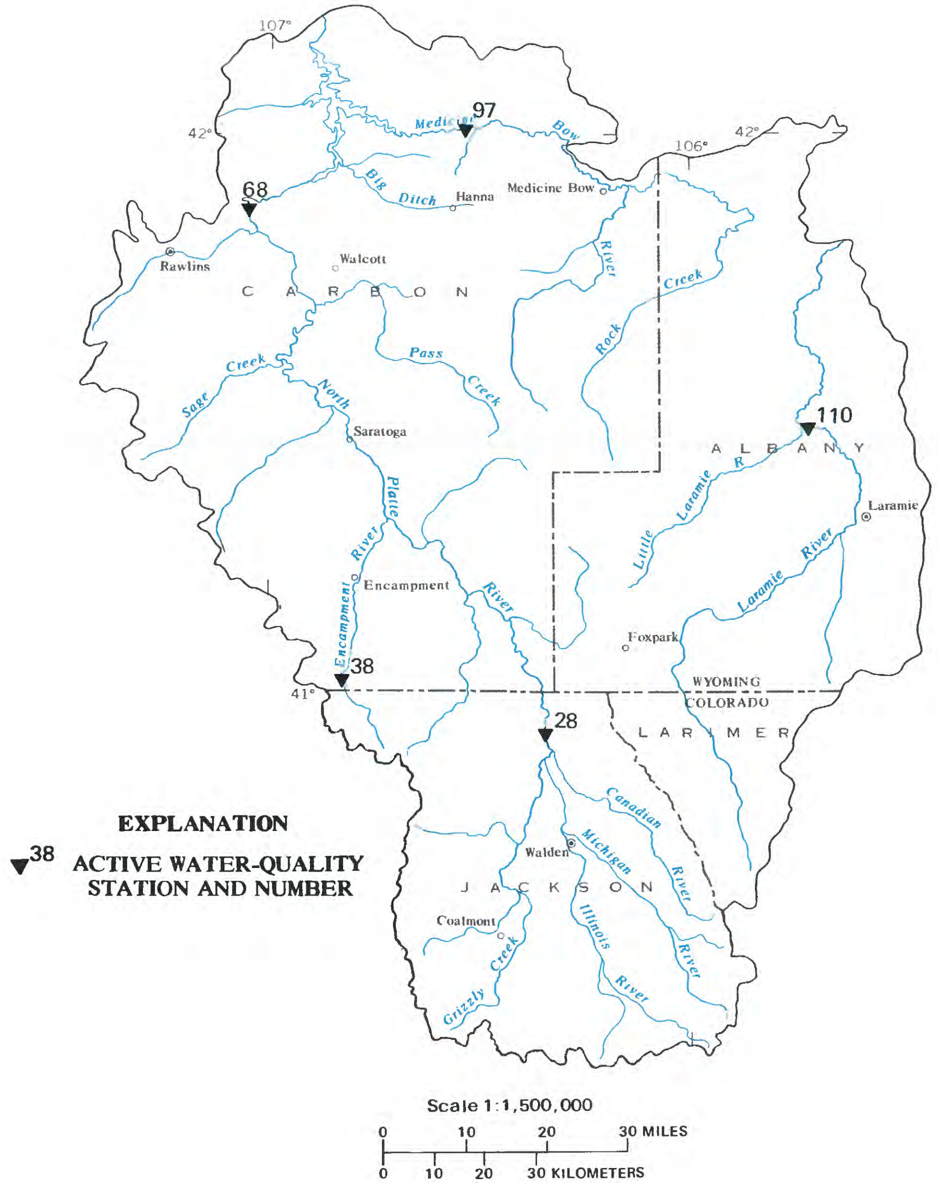


Figure 6.4-1 Location of water-quality stations.

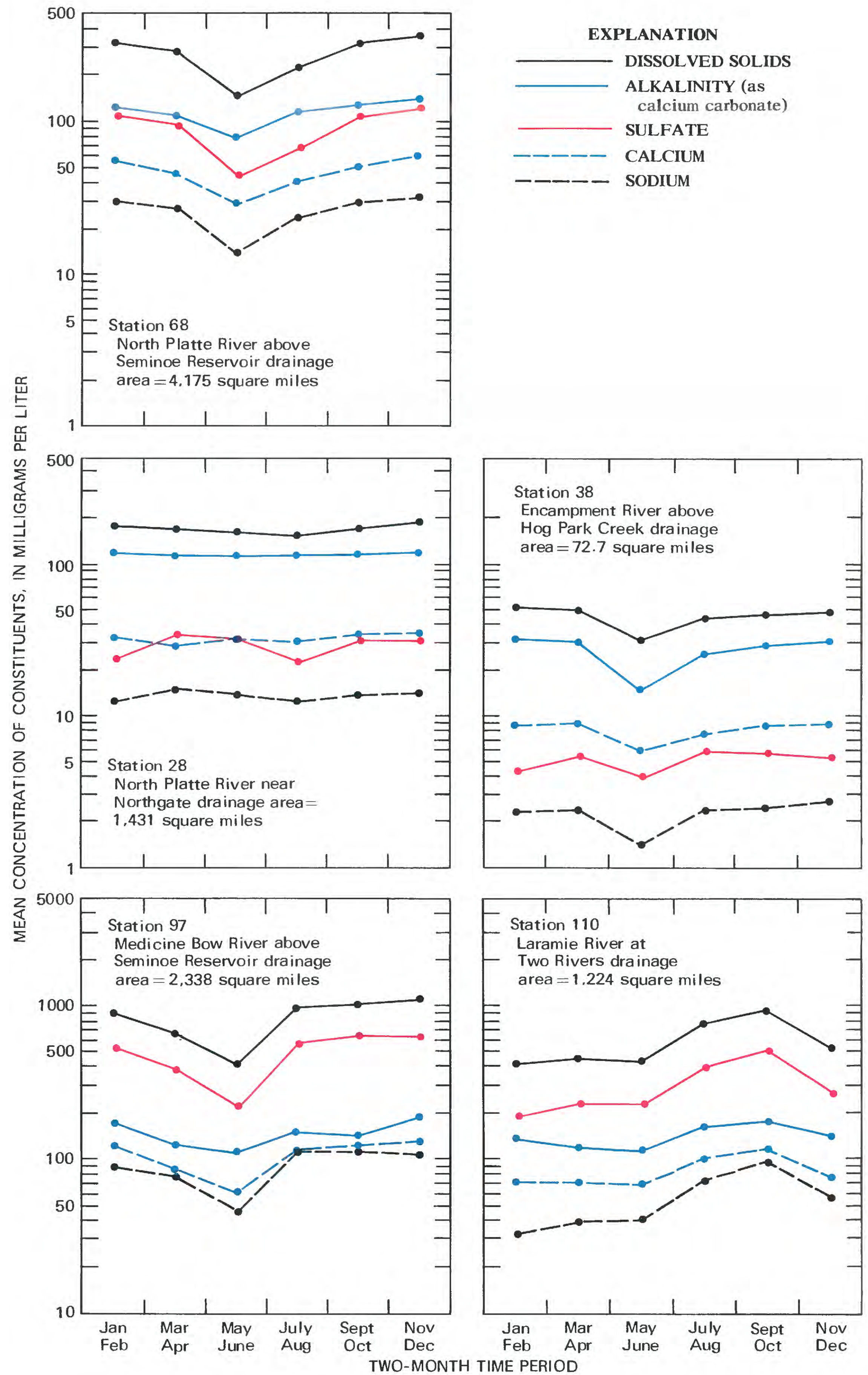


Figure 6.4-2 Seasonal variation in mean concentration of alkalinity, sulfate, calcium, sodium, and dissolved solids at selected water-quality stations.

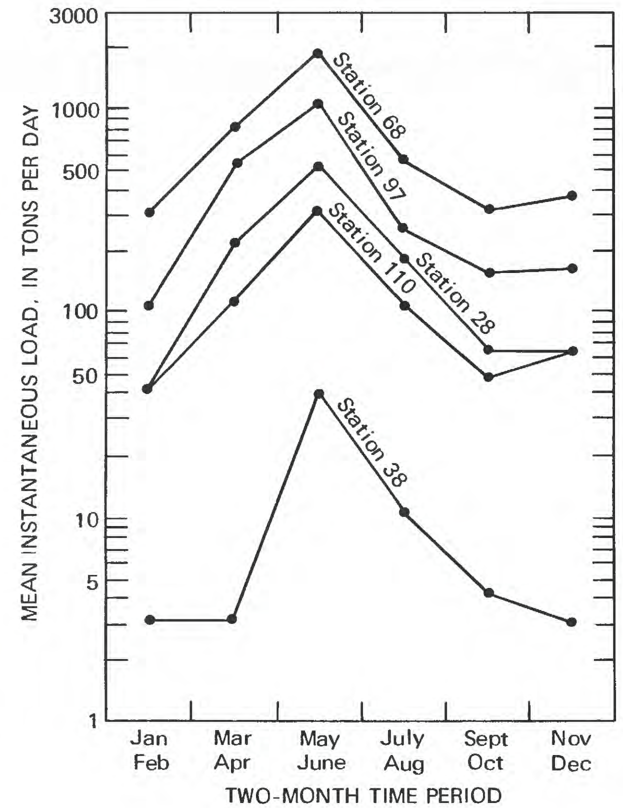


Figure 6.4-3 Seasonal variation in mean value of instantaneous dissolved-solids load at selected water-quality stations.

Sulfate Concentration Ranges from 0 to 6,900 Milligrams per Liter

Sulfate generally is not a reliable indicator of mine drainage in Area 54; most sulfate concentrations are naturally produced.

Sulfate ions in water are derived mainly from the oxidation of metallic sulfides in igneous and sedimentary rocks, and also from the solution of gypsum if available. Sulfides of iron (pyrite and marcasite) are common in coal deposits and associated noncoal strata; weathering of these minerals may result in large concentrations of sulfate downstream from mine areas. This situation is especially common in the humid eastern United States where large sulfate concentrations have been used as an indicator of mine drainage (Harkins and others, 1981; and Zuehls and others, 1981).

Nearly all active surface mining in Coal Area 54 is in the Hanna Basin, and the streams of this area do have large sulfate concentrations (as seen for stations 70, 71, and 96 in figs. 6.5-1 and 6.5-2). However, as noted in section 6.3, the supply of solutes in this area exceeds the rate of their removal, and sulfate is a major, naturally occurring constituent in these solutes. In addition, some large concentrations of sulfate have been determined in numerous ground-water samples of the area (Freudenthal, 1979). Finally, Wentz (1974, p. 35-36), in evaluating many areas of Colorado possibly affected by either metal or coal mining, concluded that large concentrations of sulfate commonly are due to the natural occurrence of sulfur. Sulfate, then, generally is not a reliable indicator of mine drainage in the report area, and probably the greater proportion of the large concentrations of sulfate in the ground and surface waters is naturally produced.

Sulfate concentrations average less than 100 mg/L (milligrams per liter) throughout most of the North Platte River drainage system upstream from station 68 (figs. 6.5-1 and 6.5-2). The downstream reaches of the Medicine Bow and the Laramie Rivers, streams in the Hanna Basin, and some tributaries of the North Platte River between Saratoga and Seminoe Reservoir have larger concentrations of sulfate, averaging 500 to 1,000 mg/L. Ephemeral streams in the Hanna Basin (stations 70, 71, and 96) and station 56, on Sage Creek, have occasional sulfate concentrations exceeding 1,500 mg/L. The largest sulfate concentration, 6,900 mg/L, was determined for station 56, which has no mining upstream from it. The large sulfate concentrations at this station are primarily a result of the large percentage of shale in the basin.

A frequency distribution (fig. 6.5-3) of sulfate concentration shows that about 50 percent of the values are less than 100 mg/L and about 67 percent are less than 200 mg/L. Less than 2.5 percent of the analyses showed a concentration greater than 1,000 mg/L; most of these were from ephemeral streams and station 56. Large sulfate concentrations in the area may not necessarily indicate mine drainage, but they are indicative of large concentrations of dissolved solids. A major consideration of large values of dissolved solids is in regard to livestock watering. The National Academy of Sciences and National Academy of Engineering (1974, p. 308) recommend that water used for livestock watering normally have dissolved-solids concentrations less than 3,000 mg/L. Dissolved-solids concentrations in the report area may exceed that value when the sulfate concentration is about 2,000 mg/L, an infrequent occurrence.

Three regression models relating sulfate concentration to specific conductance are presented on the opposite page. The first two models are applicable to perennial streams of the area; one (fig. 6.5-4a) applies to specific conductances between 250 and 750 micromhos, and the other (fig. 6.5-4b) applies to specific conductances between 750 and 2,200 micromhos. This division is somewhat different than that used for the models relating specific conductance to dissolved solids previously presented. Sulfate concentration is especially variable for specific conductances less than 250 micromhos; extending the first model to 750 micromhos resulted in a better model than for the range of 250 to 500 micromhos.

The third model (fig. 6.5-4c) applies to ephemeral streams of the Hanna Basin. Sulfate concentration in these streams normally is larger than that in the perennial streams for equal values of specific conductance. The differences in concentration are less noticeable for larger values of specific conductance because the factors that produce the larger sulfate concentrations in the perennial streams (second model) are the same factors producing the larger sulfate concentrations in the ephemeral streams. Guidelines for use of models presented in section 6.2 are equally applicable to models relating specific conductance to sulfate.

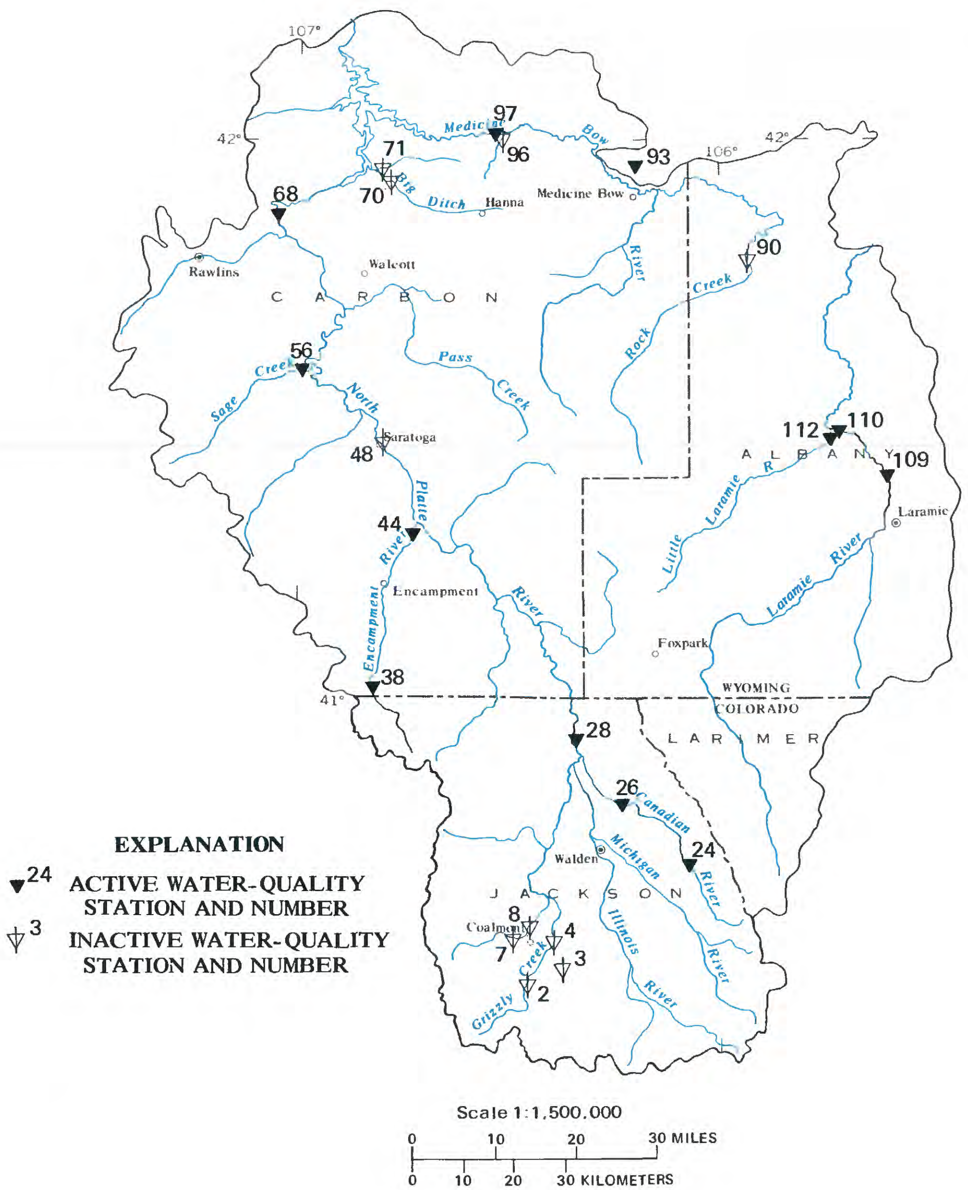


Figure 6.5-1 Location of water-quality stations for sulfate.

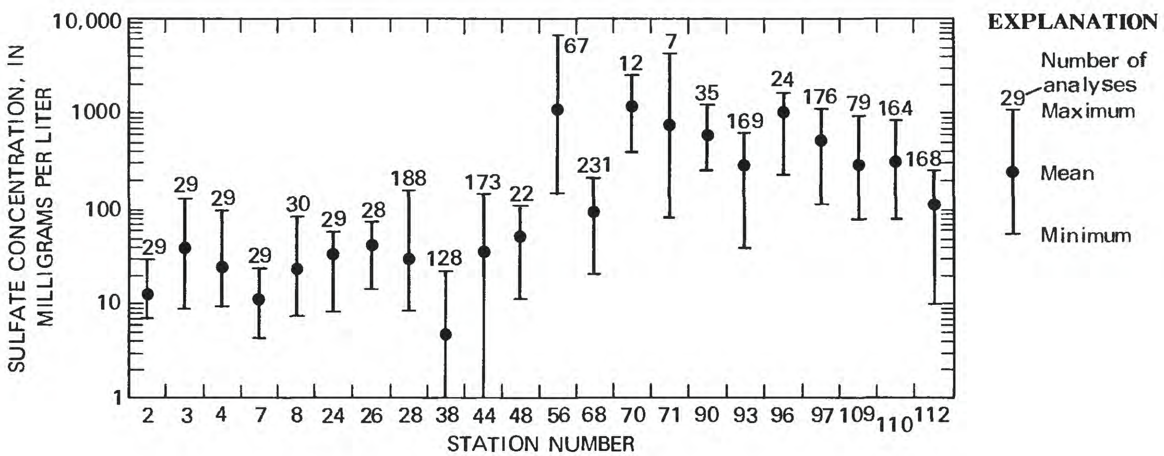


Figure 6.5-2 Maximum, minimum, and mean values of sulfate concentration at individual water-quality stations.

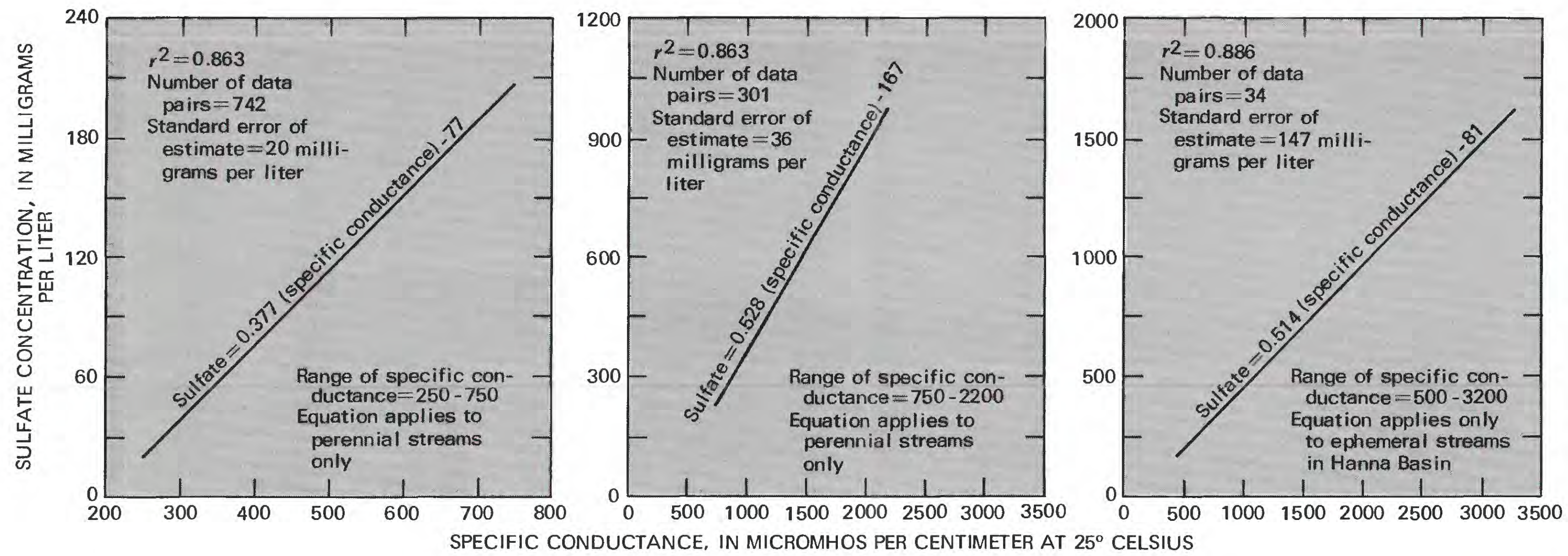


Figure 6.5-4 Relation between specific conductance and sulfate for different ranges of specific conductance of samples from perennial and ephemeral streams.

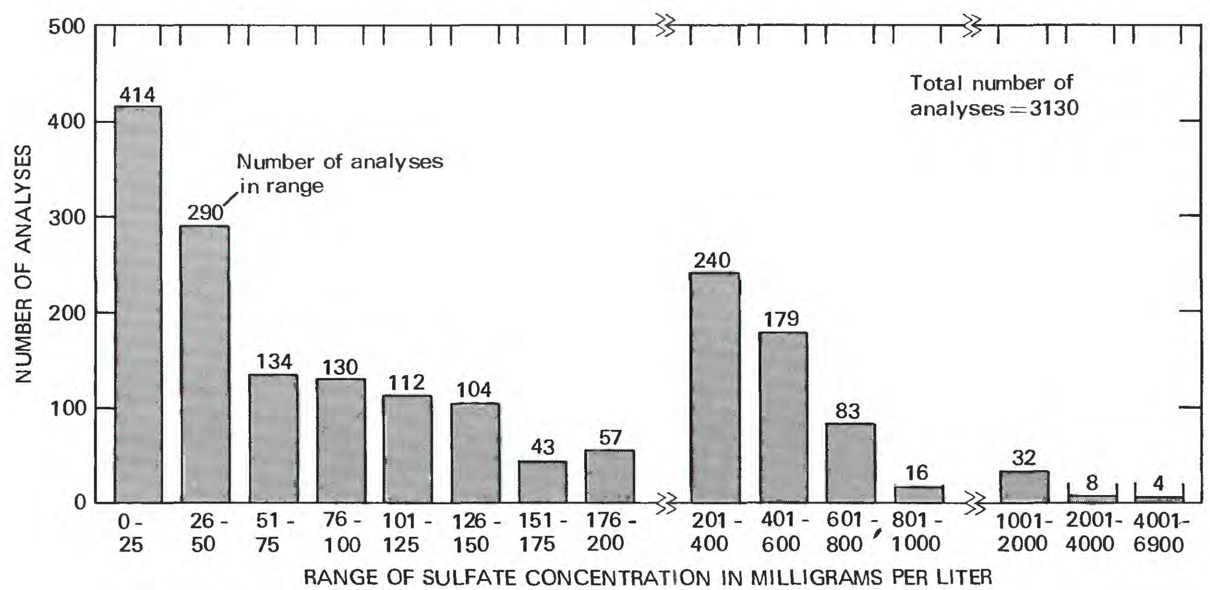


Figure 6.5-3 Frequency distribution of sulfate concentration.

Suspended-Sediment Discharge Is Highly Variable in Area 54

Discharge-weighted concentrations are generally less than 50 milligrams per liter in the mountains and as large as 2,730 milligrams per liter in the plains.

Subareas of similar suspended-sediment discharge are delineated in figure 6.6-1. Discharge-weighted concentrations for measured stations ranged from 730 to 2,730 milligrams per liter in subarea 1 and from 7 to 46 milligrams per liter in subarea 2. No suspended-sediment discharge data are available for subarea 3; however, because of environmental similarities, the discharge here may be similar to subarea 2.

The relation between suspended-sediment concentration and water discharge is shown in figure 6.6-2. The figure shows that as water discharge increases, suspended-sediment concentration also increases--but at a faster rate for subarea 1 than for subarea 2, or possibly for subarea 3.

Particle-size distribution of suspended sediment transported during high flow is predominantly silt and clay (89 percent finer than 0.062 millimeter) for subarea 1. No particle-size data are available for subarea 2. Composition of material on streambeds and quantity of material transported as bedload was unmeasured and was not included in reports of sediment discharge.

The interrelated processes of erosion, transportation, and deposition of sediment particles are controlled by gravity, geology, topography, climate, soils, vegetation, and land use. The first six of these depend on the forces of nature while the last is subject to the activities of man, which may variably alter some of the effects of the first six.

Subarea 1 is structurally an intermontane basin characterized by low topographic relief, scant precipitation, and sparse vegetal cover. The surficial geology is sandstone, siltstones, shales, and some coals. Resistant sandstone forms ridges, and shales form strike valleys having unconsolidated soil masses adjacent to channels. Land use varies from agriculture to surface coal mining.

Subarea 2 is characterized by tree-covered mountain ridges of granites, schists, and gneisses with wide grass-covered alluvial plains between. Precipitation is considerably more than in subarea 1, and soil masses adjacent to channels are consolidated with grass cover. Land use is generally limited to agriculture and recreation.

Subarea 3 may be characterized similar to subarea 2 except that the northern half has low topographic relief. Soil masses in the wide valleys are consolidated with extensive grass cover, and land use is generally agriculture and recreation.

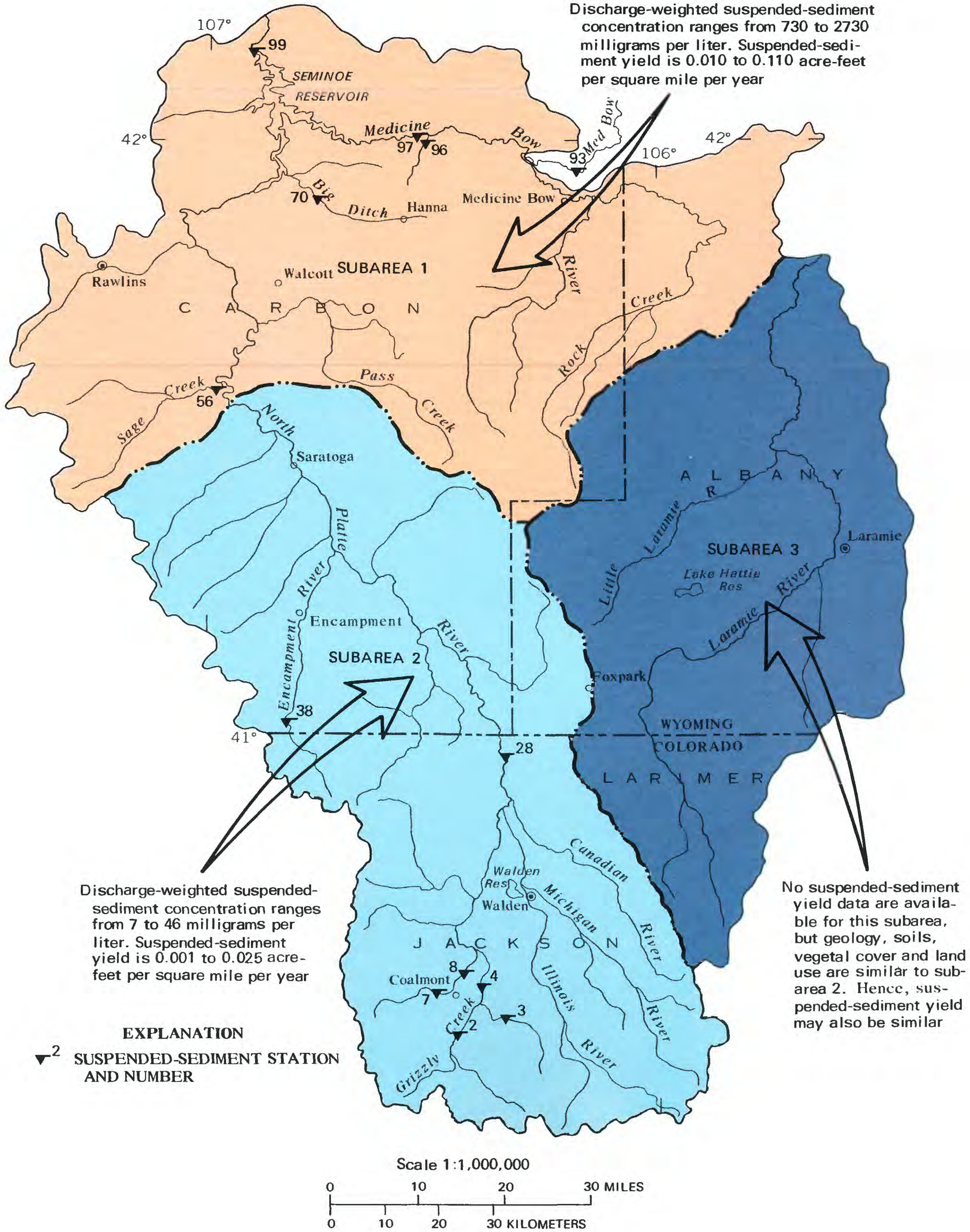


Figure 6.6-1 Subareas where suspended-sediment yields are similar.

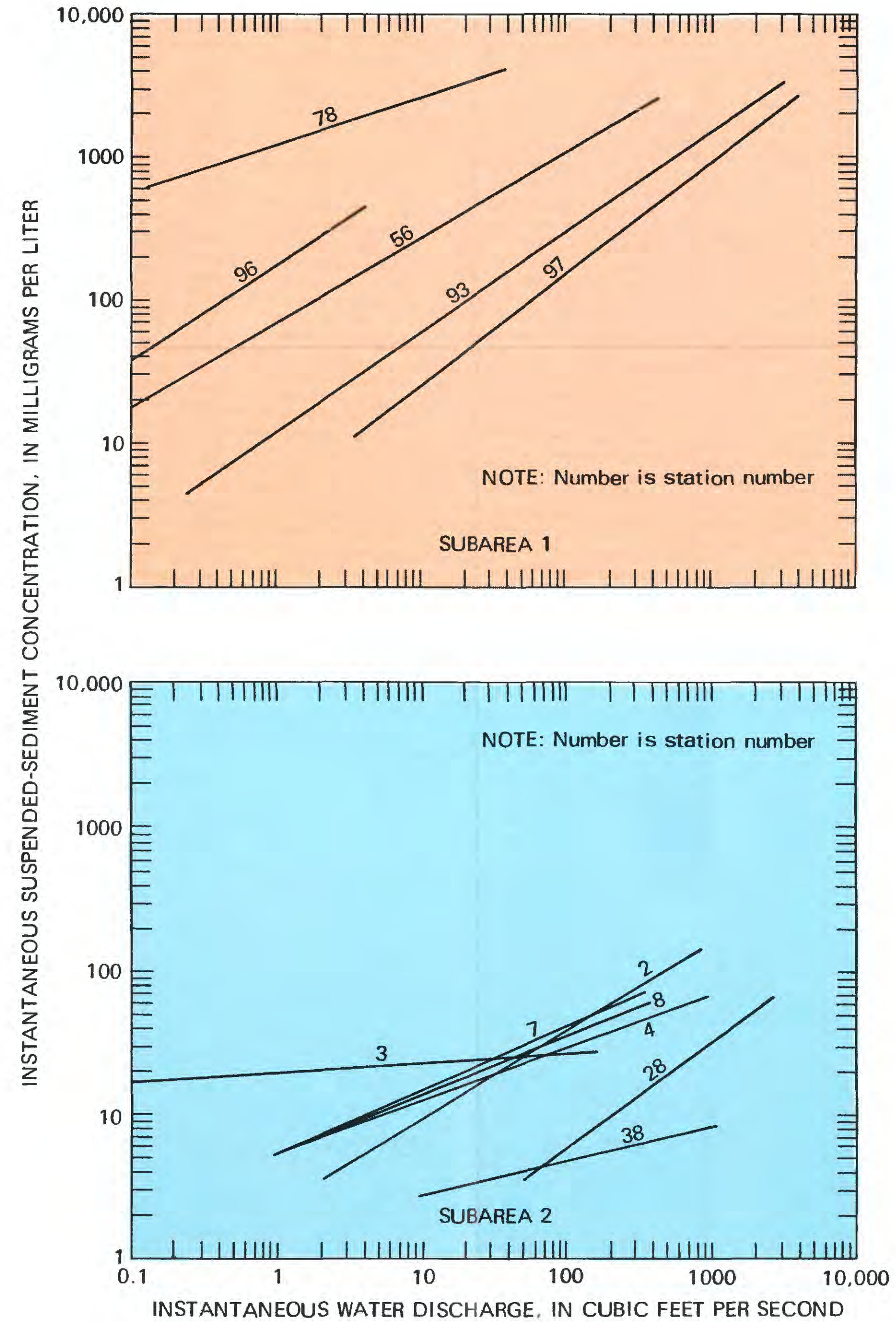


Figure 6.6-2 Relation between suspended-sediment concentration and discharge.

Iron and Manganese are the Most Common Trace Elements

Concentrations of dissolved and total recoverable iron and manganese are usually less than the maximum concentrations established for the protection of freshwater aquatic life.

Iron is the fourth most abundant element, by weight, in the Earth's crust; generally it also is the most common metallic trace element dissolved in surface waters. Iron occurs in a wide variety of minerals, such as biotite, magnetite, siderite, marcasite, and pyrite, which are associated with igneous, metamorphic, and sedimentary rocks. Iron is a required nutrient for many plants and animals and, therefore, commonly is present in soils and organic materials. Excessive concentrations of iron in water impart an objectionable taste and may cause discoloration of or deposits on objects in contact with such water. Dissolved iron occurs mainly as the ferrous-ion form (Fe^{+2}); the ferric-ion form (Fe^{+3}) generally is insoluble. Most flowing streams at a near-neutral pH contain only minor concentrations of free ferrous ion; most of it is complexed with organic substances, or it is oxidized to the insoluble ferric form.

The presence of manganese in the Earth's hydrologic system is similar to that of iron. It commonly is in the same minerals as iron, and it also is an important nutrient. The problems of excessive dissolved manganese--problems of taste, discoloration, and deposition--also are similar to those of iron. However, the chemistry of manganese in water is not similar to that of iron (see Hem, 1970, for an introduction to the aqueous chemistry of trace elements). Hem reports (p. 129) that at near-neutral pH, dissolved manganese is largely in the form of the Mn^{+2} ion; as pH is increased, other forms, Mn^{+3} and Mn^{+4}, may increase in concentration.

The U.S. Environmental Protection Agency (1976c, p. 78) recommends that iron concentrations not exceed 300 micrograms per liter and that manganese concentrations (p. 95) not exceed 50 micrograms per liter in water used for domestic supply. For the protection of freshwater aquatic life, the criterion for iron is 1.0 milligram per liter (p. 78). Reported tolerance levels to manganese for freshwater aquatic life range from 1.5 to more than 1,000 milligrams per liter (p. 96); thus no specific criterion is given. No information is given in the above reference to indicate whether the water-quality criteria apply to dissolved concentration, total recoverable concentration, or some other category of concentration.

Frequency distributions of dissolved and total recoverable iron and manganese concentrations at selected water-quality stations (fig. 6.7.1-1) are shown in figure 6.7.1-2. For dissolved concentrations, the criteria for the protection of freshwater aquatic life were exceeded only by three analyses of iron and by one analysis of manganese; the criteria were exceeded by total recoverable concentrations somewhat more frequently. The domestic water-supply criteria were exceeded in about 20 percent of the analyses for dissolved concentrations and in 37 percent of the analyses for total recoverable concentrations.

The range of iron and manganese concentrations at individual stations is shown in figure 6.7.1-3. Total recoverable concentrations generally increase as the concentration of suspended sediment increases, whereas the dissolved concentration may not increase accordingly. For perennial streams, suspended sediment and total recoverable iron and manganese concentrations are largest during snowmelt runoff; larger discharges have the capacity to carry much more suspended material than smaller discharges. Concentrations of total recoverable iron and manganese at most perennial streams, though, usually do not greatly exceed the dissolved concentrations because material to be carried in suspension is less available in the granitic mountains.

Streams in the Hanna Basin, however, have total recoverable concentrations much larger than dissolved concentrations (stations 70, 71, and 96, and, to a lesser extent, stations 93 and 97). The previous section of this report showed that discharge-weighted suspended-sediment concentration in the Hanna Basin may be more than 50 times as large as elsewhere. Thus, concentrations of total recoverable iron and manganese are much larger than the dissolved concentrations.

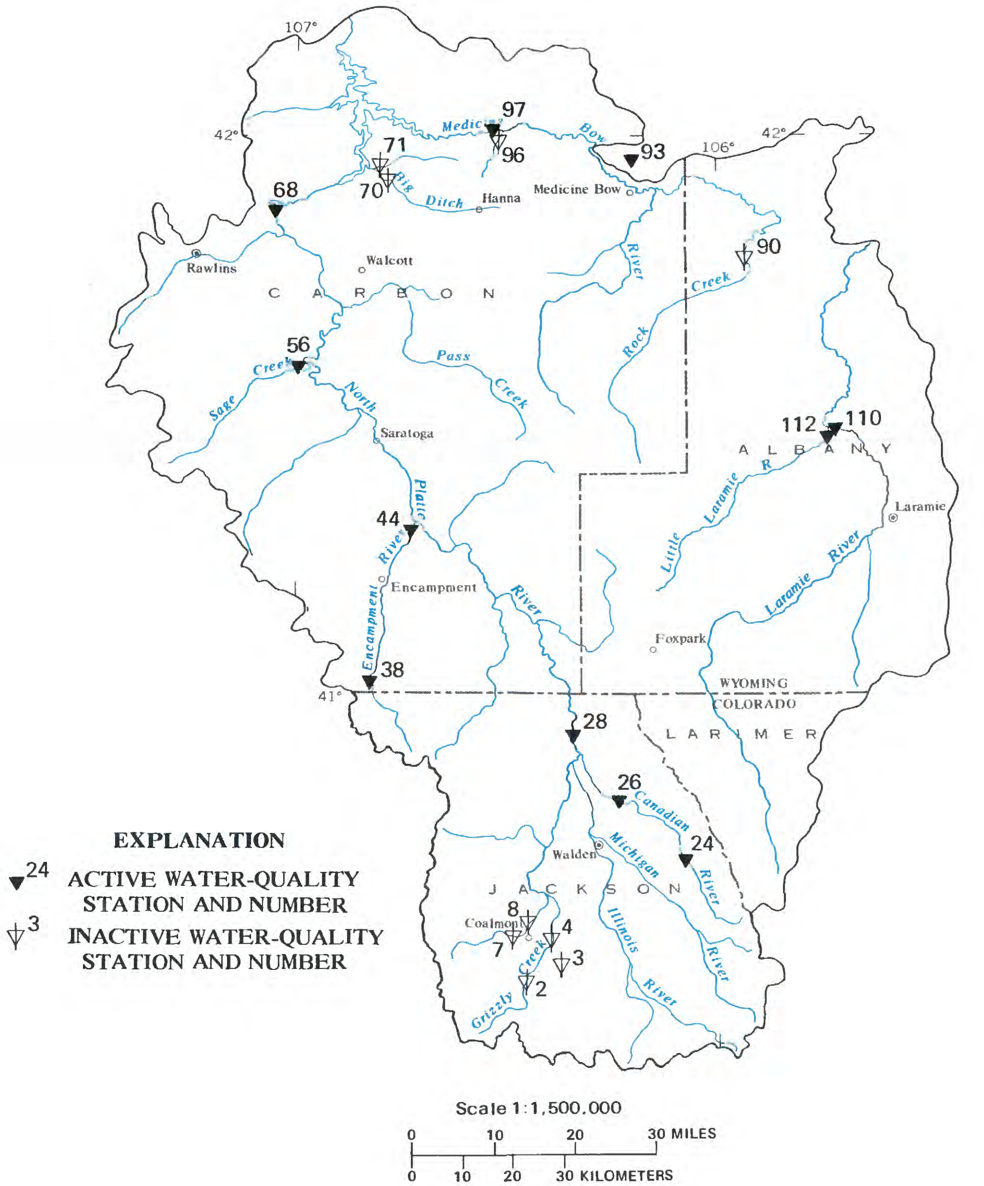


Figure 6.7.1-1 Location of water-quality stations for iron and manganese.

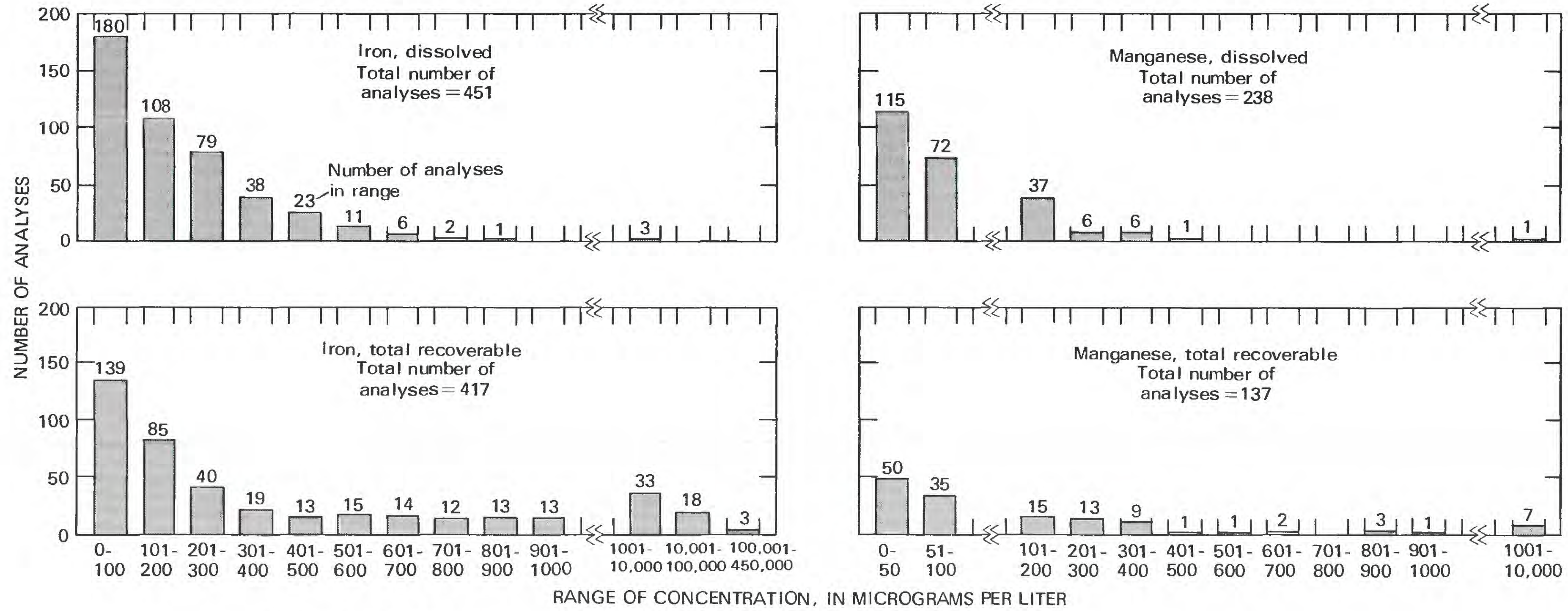


Figure 6.7.1-2 Frequency distributions of dissolved and total recoverable iron and manganese.

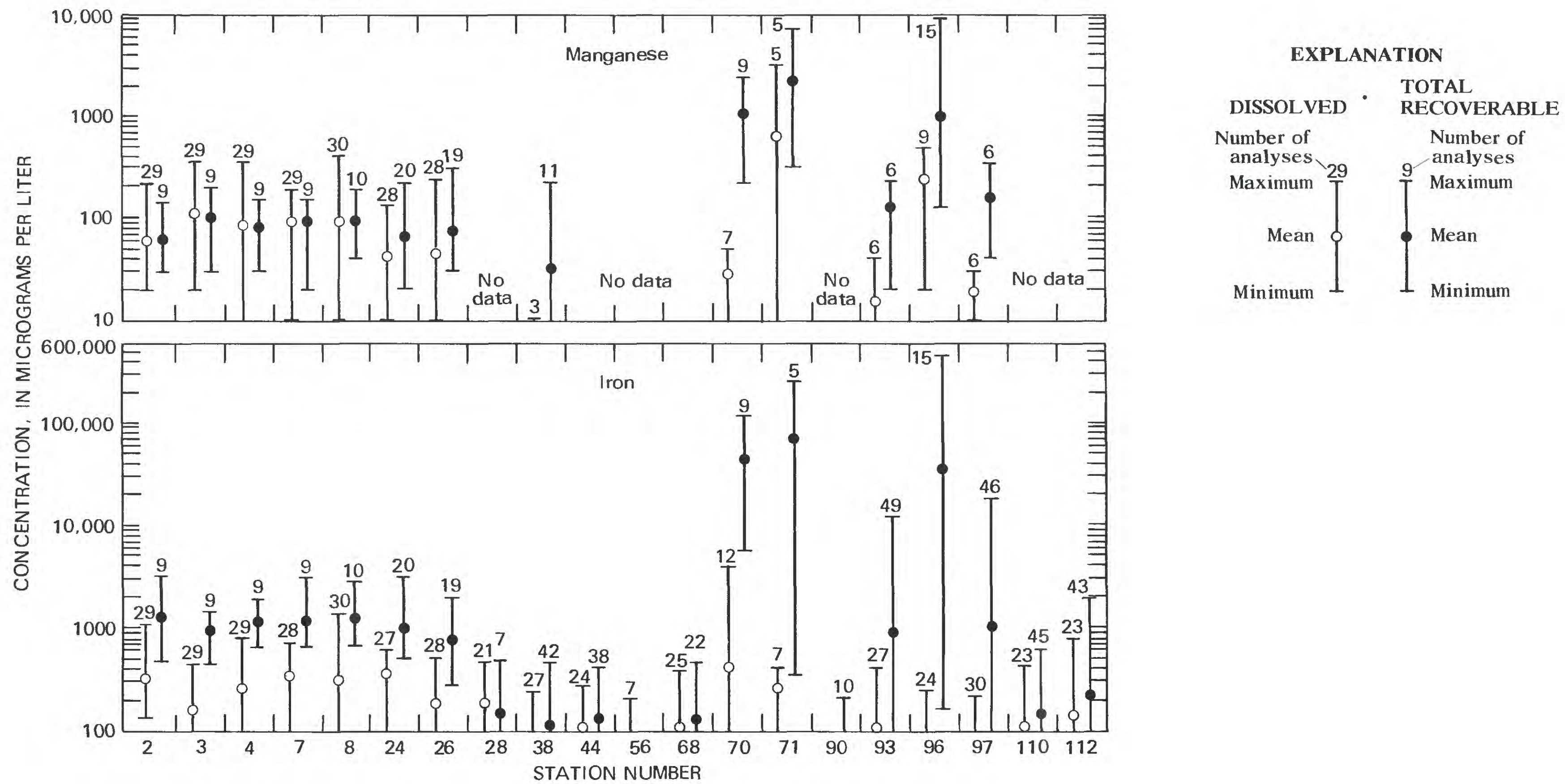


Figure 6.7.1-3 Maximum, minimum, and mean concentrations of dissolved and total recoverable iron and manganese at individual water-quality stations.

Trace-Element Concentrations Generally Do Not Exceed Water-Quality Criteria

Some trace elements are necessary plant and animal nutrients, but large concentrations of these elements may be toxic; concentrations generally are within established levels for domestic water supply.

Dissolved trace elements generally have very small concentrations in most surface waters not significantly affected by pollution. These elements are present to a minor extent in nearly all geologic strata and soils. However, the solubilities of most trace elements are very small, especially in the 6 to 9 pH range of most natural waters. Large concentrations of these elements can occur under some natural conditions, such as in thermal springs or in acidic ground waters, but most commonly they are associated with municipal or industrial wastes or with acid mine drainage.

Many trace elements are a necessary nutrient to a wide variety of life forms, including man; however, larger concentrations of these substances can be toxic. Toxicity, though, may be due to other factors such as the length of the exposure time and the chemical form of the element.

Frequency distributions of dissolved and total recoverable boron, aluminum, copper, lead, and zinc for selected water-quality stations (fig. 6.7.2-1) are shown in figure 6.7.2-2; total recoverable boron was not determined. The concentrations of five less commmon trace elements--arsenic, cadmium, chromium, mercury, and selenium--are summarized in table 6.7.2-1. The frequency distributions and table 6.7.2-1 show that the larger concentrations of these elements are uncommon. As with iron and manganese (previous section), the total recoverable concentrations generally increase as suspended-sediment concentration increases. Most of the very large concentrations, dissolved or total recoverable, are from the ephemeral streams of the Hanna Basin (stations 70, 71, and 96; fig. 6.7.2-1).

The domestic water-supply criteria for these elements (table 6.7.2-2) were almost never exceeded, by either the dissolved or the total recoverable concentrations. Lead is the notable exception; 3 analyses for dissolved and 25 analyses for total recoverable lead exceeded the criterion. Some of the analyses of total recoverable arsenic, cadmium, and chromium also exceeded the respective domestic water-supply criteria. The U.S. Environmental Protection Agency (1976c) does not specify to which concentration category the water-quality criteria apply.

Boron is an important nutrient to higher plants, including many agricultural crops. Therefore, there is considerable information in the literature regarding boron concentration. There often is only a small difference between required and toxic amounts of boron (Gough and others, 1979, p. 13).

Aluminum is more abundant than iron in the Earth's crust, but its solubility is much less than that of iron, and it generally is not involved in biologic metabolism. Aluminum toxicity in the marine environment has been known for some time (National Academy of Sciences and National Academy of Engineering, 1974, p. 242), but toxicity in freshwater, dependent largely on pH, is just being established (Ember, 1981).

Carbonate, sulfide, and oxide ores of copper, lead, and zinc are major sources of dissolved ions of these trace elements. Both copper and zinc are important in nutrient cycles, but there is no known nutritional benefit in lead (U.S. Environmental Protection Agency, 1976c).

The freshwater aquatic-life criteria of some of these substances is given in terms of the 96-hour LC_{50} (table 6.7.2-2). This term may be defined as the concentration of a substance that will be fatal to 50 percent of the test organisms during a 96-hour exposure time (U.S. Environmental Protection Agency, 1976c, p. 1). The actual concentration is variable for different forms of aquatic life and has been experimentally determined for numerous species. Some of these data are presented in the above reference.

Table 6.7.2-1 *Summary of dissolved and total recoverable concentrations, in micrograms per liter (µg/L), of select trace elements.*

	Dissolved					Total recoverable					
	Total number of analyses	Number of analyses exceeding:			Maximum concentration	Total number of analyses	Number of analyses exceeding:				Maximum concentration
Element		0 µg/L	2.0 µg/L	10 µg/L	(µg/L)		0 µg/L	2.0 µg/L	10 µg/L	50 µg/L	(µg/L)
Arsenic	87	77	8	0	5.0	76	74	24	6	2	250
Cadmium	88	67	10	0	4.0	75	47	23	17	0	20
Chromium	39	8	8	4	20	65	43	43	29	5	350
Mercury	81	66	0	0	1.8	78	64	0	0	0	1.3
Selenium	81	68	8	0	7.0	71	60	14	0	0	9.0

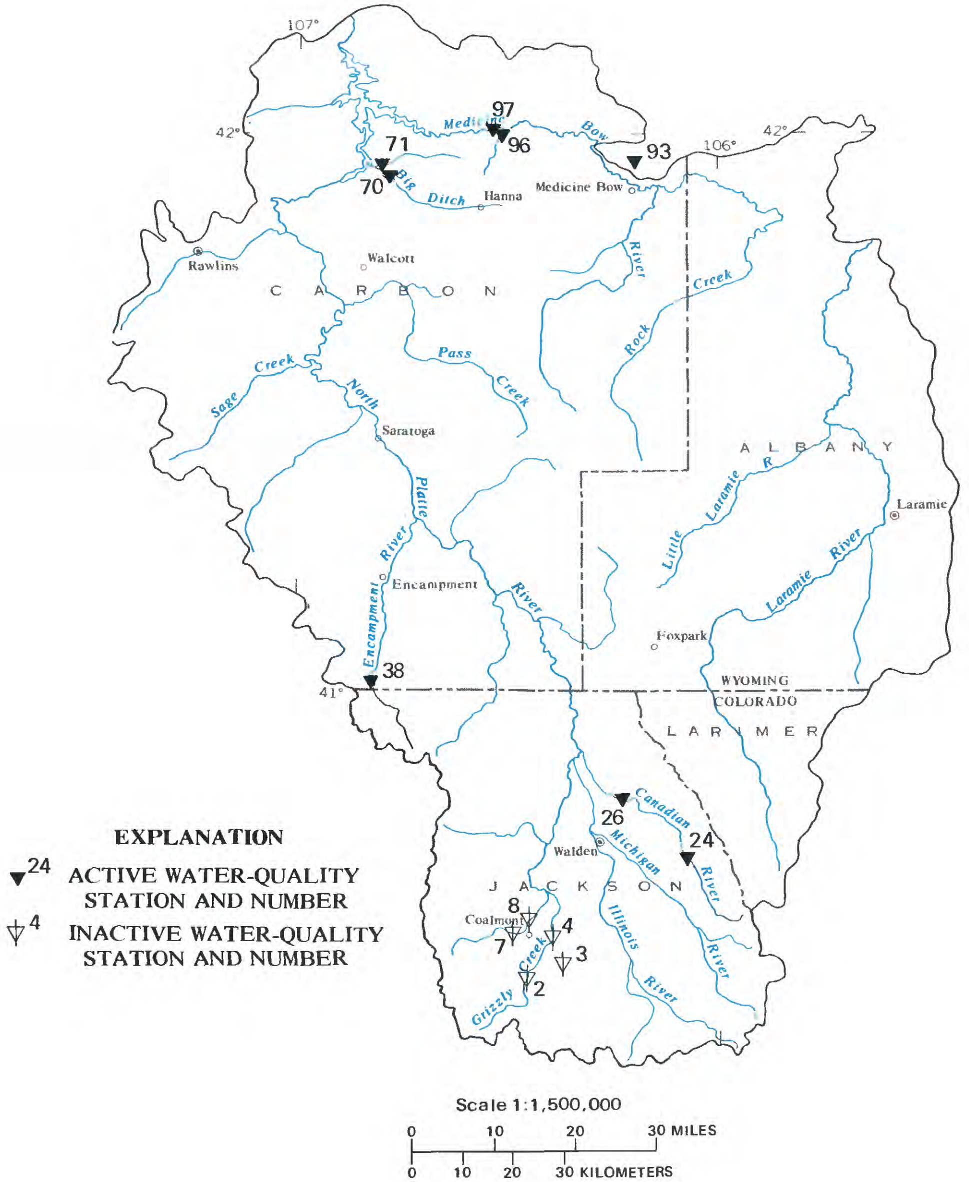


Figure 6.7.2-1 Location of water-quality stations for trace elements.

Table 6.7.2-2 *Recommended maximum concentrations of trace elements, in micrograms per liter*
(Source: U.S. Environmental Protection Agency, 1976c)

Element	Category of criteria[1] Domestic water supply	Freshwater aquatic life
Aluminum	Not given	Not given
Arsenic	50	Not given[1,2]
Boron	Not given[3]	Not given[3]
Cadmium	10	0.4 to 12[4]
Chromium	50	100
Copper	1,000	1/10 of 96-hour LC_{50}[1,5]
Lead	50	1/100 of 96-hour LC_{50}[1,5]
Mercury	2.0	0.05
Selenium	10	1/100 of 96-hour LC_{50}[1,5]
Zinc	5,000	1/100 of 96-hour LC_{50}[1,5]

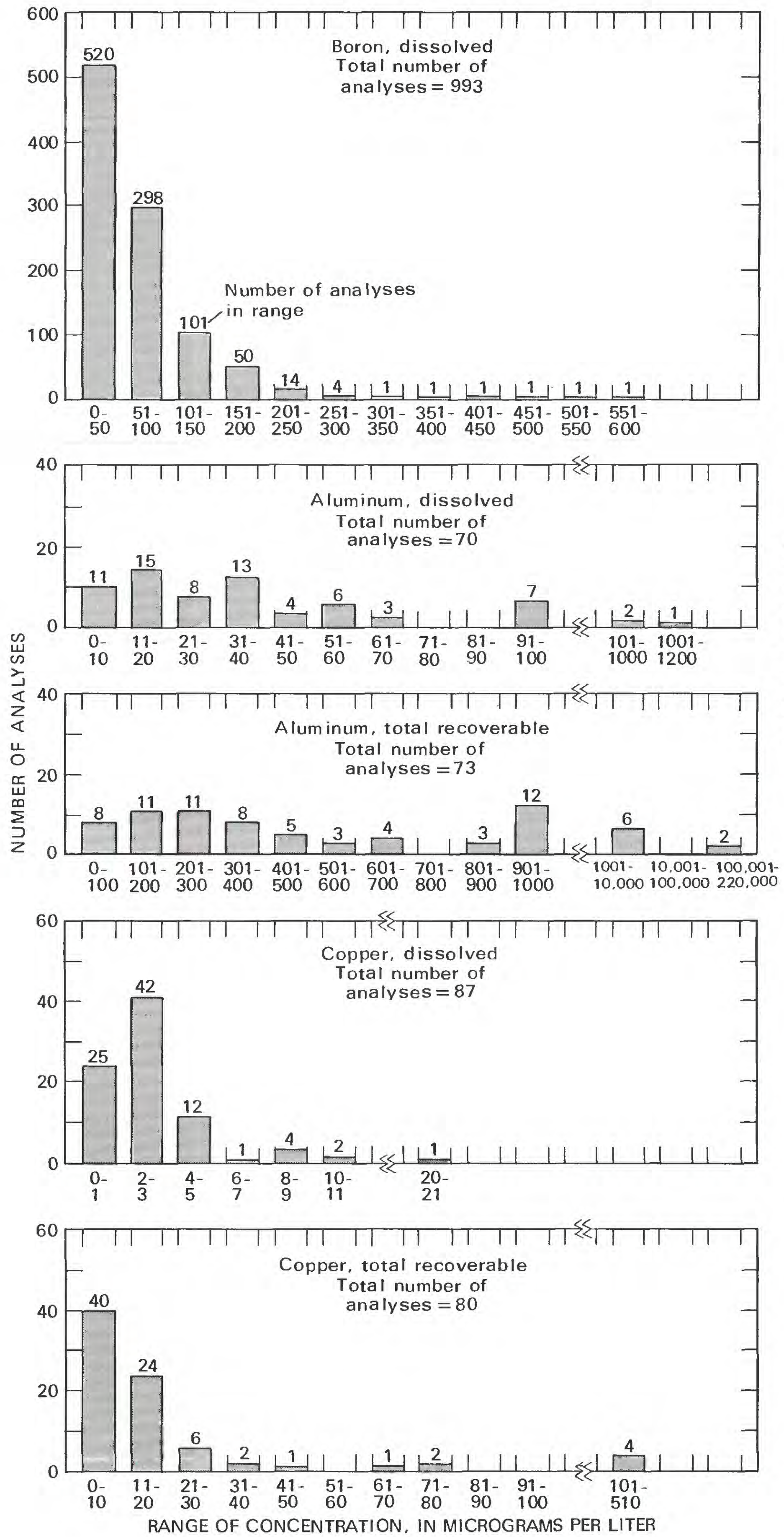
[1]See source for additional discussion of criteria and rationale of recommendation

[2]100 micrograms per liter for irrigation of crops

[3]750 micrograms per liter for long term irrigation of sensitive crops

[4]Depends on hardness of water and type of aquatic life

[5]See text for definition of 96-hour LC_{50}



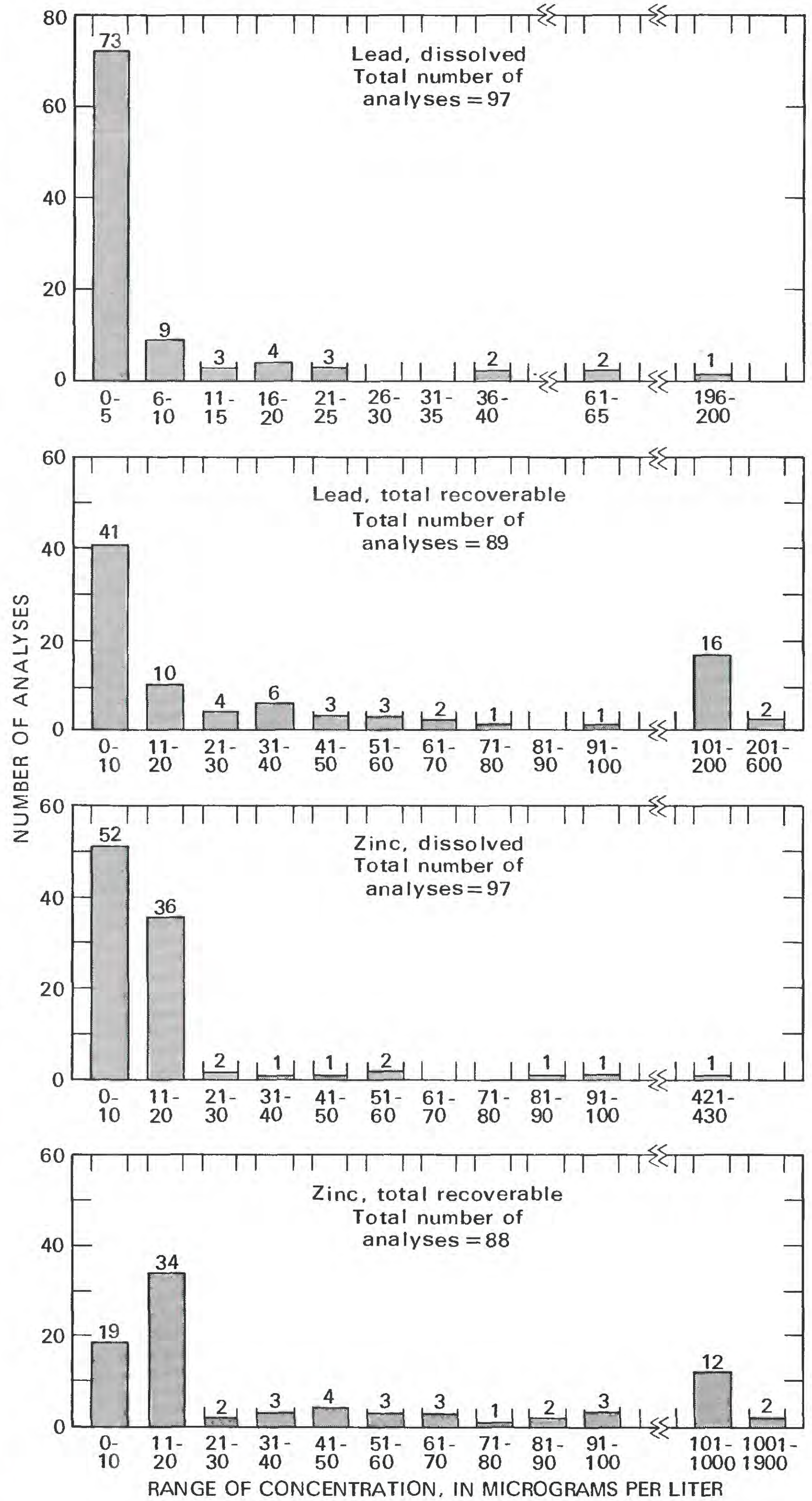


Figure 6.7.2-2 Frequency distributions of dissolved and total recoverable concentrations of selected trace elements.

Benthic-Invertebrate Data Available for Streams in North Park

Stream benthic-invertebrate data, including counts and species identification, indicate that monthly variations in taxa are prevalent on the Canadian River.

Stations sampled for benthic invertebrates (fig. 6.8.1-1) are located in North Park on the Canadian River (stations 26 and 128) and on Little Grizzly and Grizzly Creeks (stations 8, 120, and 121). The streams originate in mountainous, forested terrain, and then flow through agricultural and rural ranch areas in their downstream reaches; the sampled stream reaches are primarily in agricultural areas. At each station, benthic invertebrates were collected, and water temperature, specific conductance, pH, and dissolved oxygen were measured about bimonthly during the 1980 and 1981 growing seasons (April to November). These data are summarized in tables 6.8.1-1 and 6.8.1-2.

The number of organisms (table 6.8.1-1) is based on three 1-square-foot samples collected with a Surber sampler; the result is then converted to number of organisms per square meter. The number of species listed is simply the total number of species identified in the three samples. The diversity index is a calculation based on number of organisms and taxa identified in the samples, using the following formula:

$$d = \sum_{i=1}^{s} \frac{n_i}{n} \log \frac{n_i}{n}$$

where:

n_i = the number of individuals per taxon,

n = the total number of individuals, and

s = the total number of taxa in the sample.

Diversity-index values range from 0 to some positive number (generally 4.0); maximum diversity is where each individual in the sample belongs to a different taxa or species, and minimum diversity is when all individuals belong to the same species. Generally, unpolluted water has a smaller number of organisms comprised of a large number of taxa (high diversity) than polluted water.

Number of organisms and species for specified sampling times from the Canadian River, stations 26 and 128, are shown in figure 6.8.1-2. Variation in types of organisms (taxa) for these two stations is shown in figure 6.8.1-3. Monthly variations in taxa are prevalent at these two stations.

All data were collected by the U.S. Geological Survey following the methods given in Greeson and others (1977). Benthic-invertebrate samples were analyzed by a private contract laboratory. The data interpretations presented herein are preliminary, but will be completed in a forthcoming report. The data are available from U.S. Geological Survey, Box 25046, Mail Stop 415, Denver Federal Center, Lakewood, CO 80225.

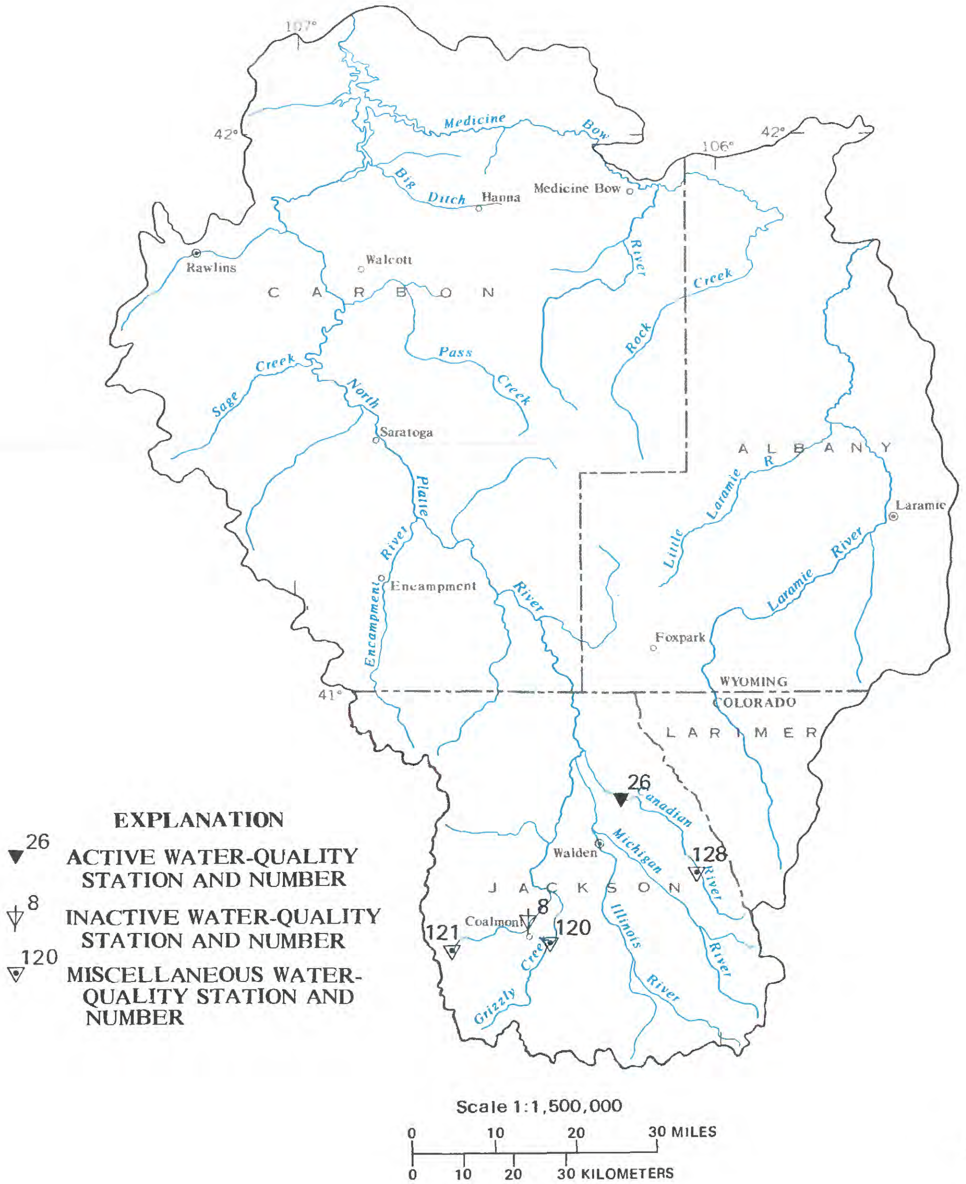


Figure 6.8.1-1 Location of water-quality stations at which benthic invertebrates were sampled.

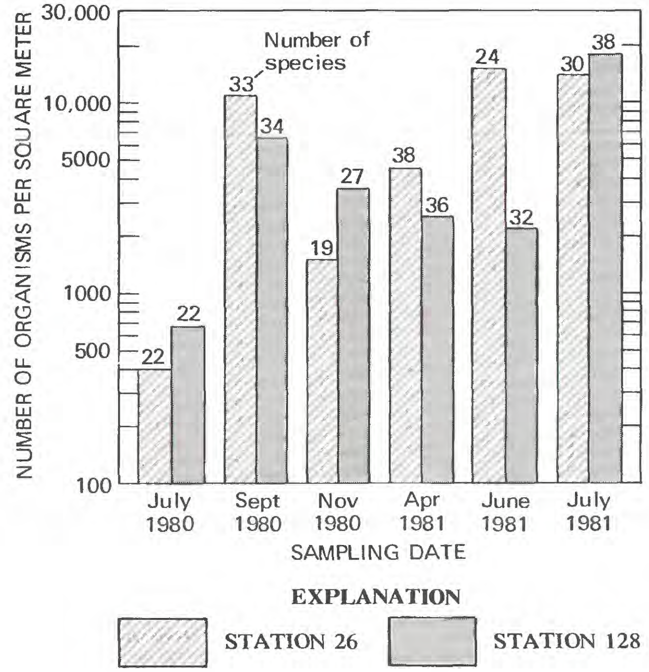


Figure 6.8.1-2 Number of organisms and species for the Canadian River.

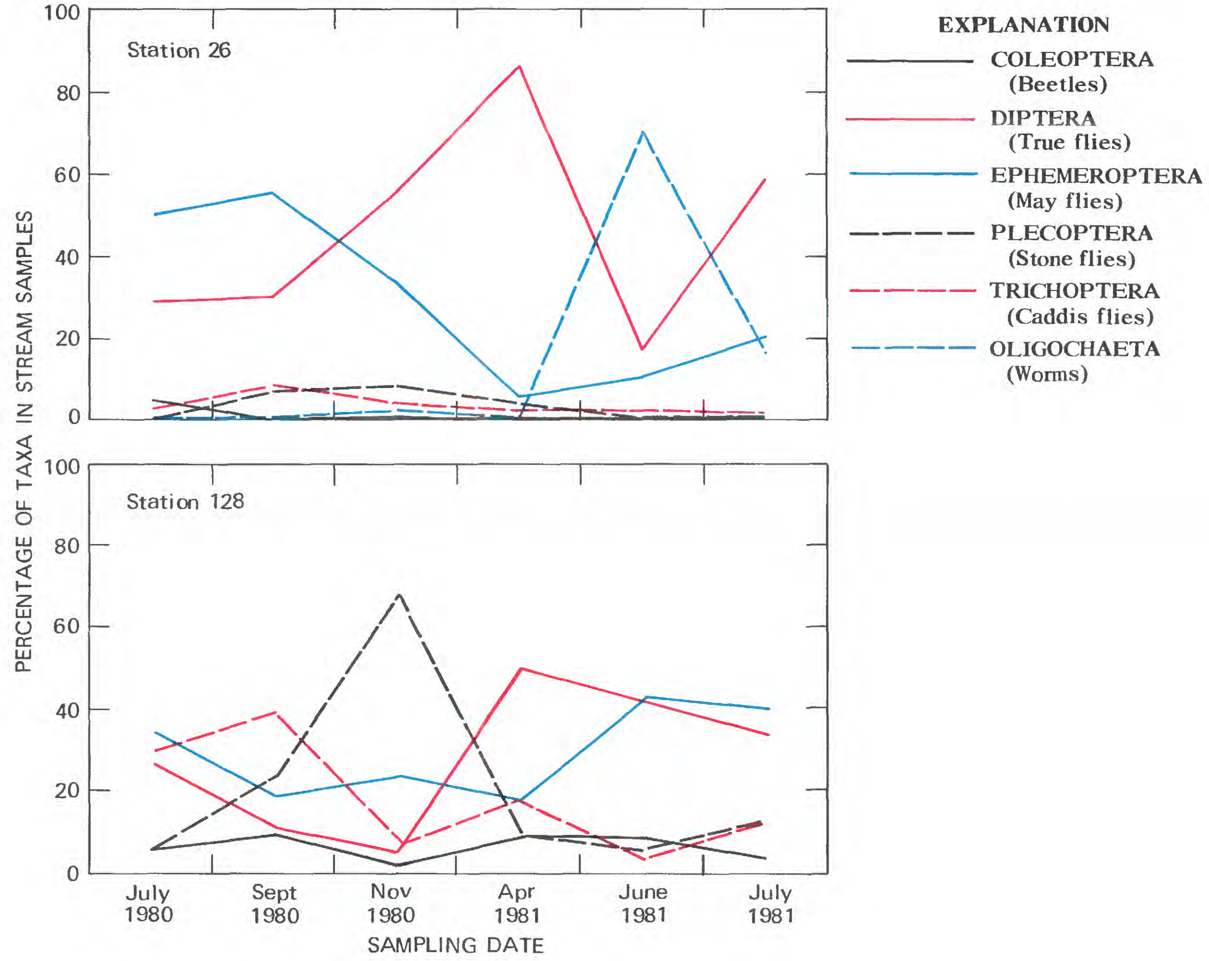


Figure 6.8.1-3 Percentage of taxa collected in samples from the Canadian River.

Table 6.8.1-1 *Ranges of number of organisms, number of species, and diversity-index values in samples of benthic invertebrates collected at stations from July 1980 to July 1981*

[Min = minimum, Max = maximum]

Station No.	Number of organisms per square meter			Number of species			Diversity index		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
121	730	16,000	5,400	31	39	35	3.15	4.17	3.81
8	630	19,000	9,200	20	41	30	2.50	3.54	3.13
120	390	4,400	2,200	18	29	25	2.70	3.66	3.14
128	670	17,000	5,400	22	38	32	2.19	4.23	3.44
26	390	16,000	8,200	19	38	28	1.83	3.67	2.82

Table 6.8.1-2 *Ranges in water-quality data collected at stations at which benthic invertebrates were sampled from July 1980 to July 1981*

[Min = minimum, Max = maximum]

Station No.	Temperature (degrees Celsius)			Specific conductance (micromhos per centimeter at 25° Celsius)			pH (units)			Dissolved oxygen (milligrams per liter)			Percent dissolved-oxygen saturation		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Median	Min	Max	Mean	Min	Max	Mean
121	0.0	20.0	9.0	21	100	60	6.4	7.6	7.3	6.6	10.4	8.3	87	106	97
8	.3	21.3	11.7	160	284	220	7.1	8.9	7.5	6.7	11.1	8.3	85	146	103
120	.2	18.8	12.3	154	286	216	7.3	8.1	7.5	5.2	10.4	7.0	67	97	87
128	.0	20.0	10.0	30	120	78	6.6	8.0	7.3	6.7	11.8	8.6	96	112	102
26	.0	22.2	13.3	216	373	287	7.5	8.6	7.7	6.9	10.3	8.1	94	116	103

Phytoplankton Blooms in Seminoe Reservoir

The blue-green alga Aphanizomenon is responsible for phytoplankton blooms on Seminoe Reservoir in late summer and early fall.

The water of Seminoe Reservoir, Wyo., is a pea-soup green color and appears to be strewn with grass clippings during "blooms" or large concentrations of phytoplankton (suspended algae) during late summer and early fall. Cell counts of the blue-green alga *Aphanizomenon* have exceeded 100,000 cells per milliliter during blooms. Phytoplankton counts versus depth at three stations on Seminoe Reservoir (fig. 6.8.2-1) on three selected dates during late summer are shown in figure 6.8.2-2.

Phytoplankton blooms impart an objectionable taste and odor to the water and can make a drinking-water supply unpotable. When the algae die, the dissolved oxygen in the water is depleted by the decaying cells, which can create a stress and possibly a lethal effect on fish.

Phytoplankton are not a nuisance in Seminoe Reservoir during most of the year. The diatoms, flagellated algae, and other algae that are common when *Aphanizomenon* is not blooming, form the base of the aquatic food chain. Zooplankton and benthic invertebrates form the next higher levels, and fish occupy the upper levels of the food chain. The zooplankton and benthic invertebrates were studied by LaBounty and others (1976, 1978). Fish in Seminoe Reservoir were studied by Peterson and Leik (1955) and Wesche and Skinner (1973).

Nutrients have a large effect on phytoplankton growth in any body of water. The nutrient supply in Seminoe Reservoir is affected by input from the tributaries and frequent windy conditions. Strong winds cause water-circulation patterns, which stir nutrients from the bottom sediments and make the nutrients available to phytoplankton near the surface.

Selected nutrient and physiochemical measurements are listed in table 6.8.2-1. Results of sampling for phytoplankton and other water-quality properties are published in annual U.S. Geological Survey reports "Water Resources Data for Wyoming." Seminoe Reservoir is described as mesotrophic or moderately biologically productive by LaBounty and others (1976). Additional information on nutrients in the reservoir is available from the U.S. Environmental Protection Agency (1977b).

Mining in the Hanna Coal Field has the potential to affect Seminoe Reservoir by direct or indirect drainage, due to the proximity of some of the coal mines to the reservoir. Phytoplankton growth could be increased or decreased, depending on the concentrations of nutrients, toxic compounds, and turbidity of the drainage from the mines.

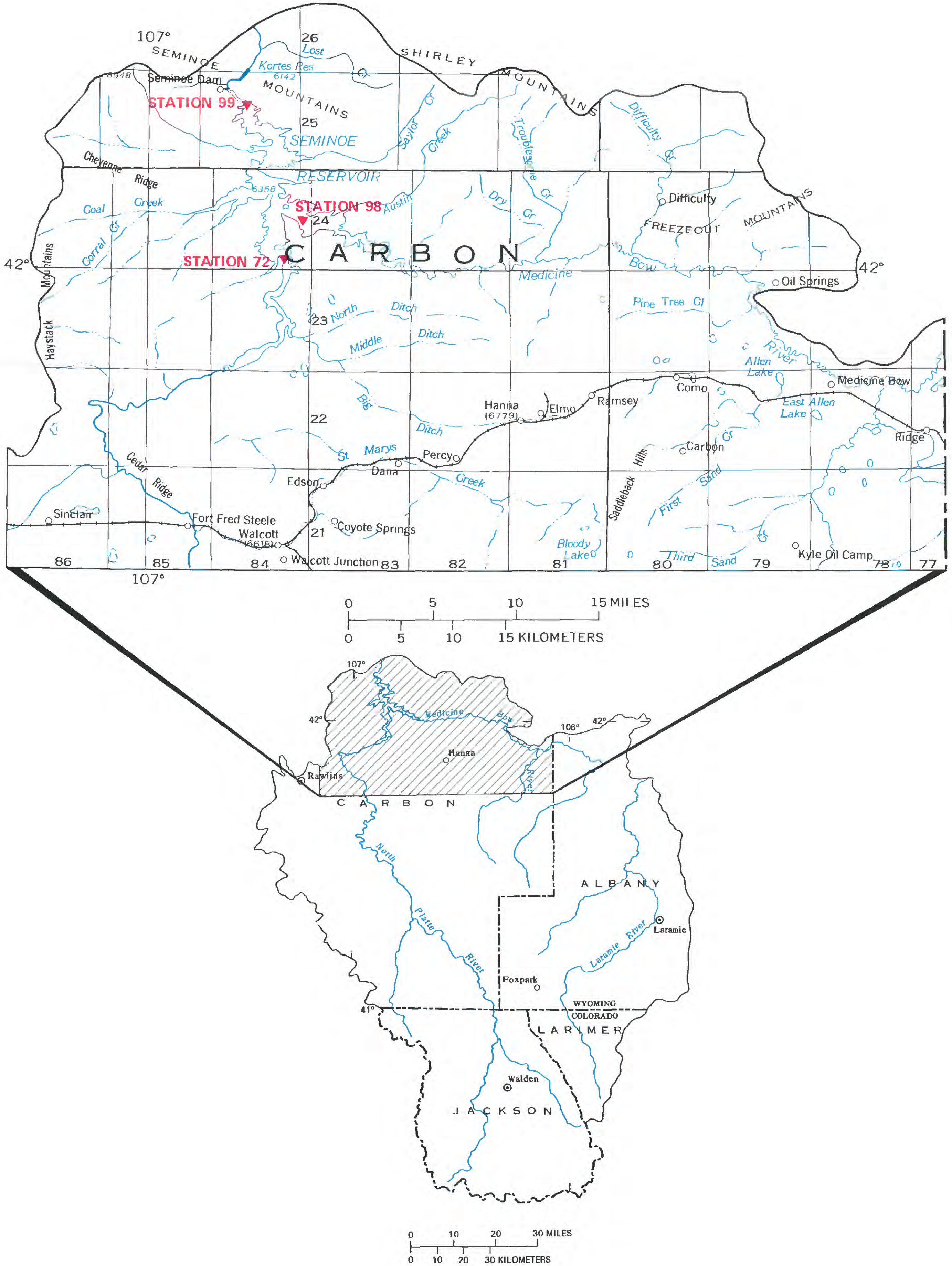


Figure 6.8.2-1 Location of Seminoe Reservoir and sampling stations.

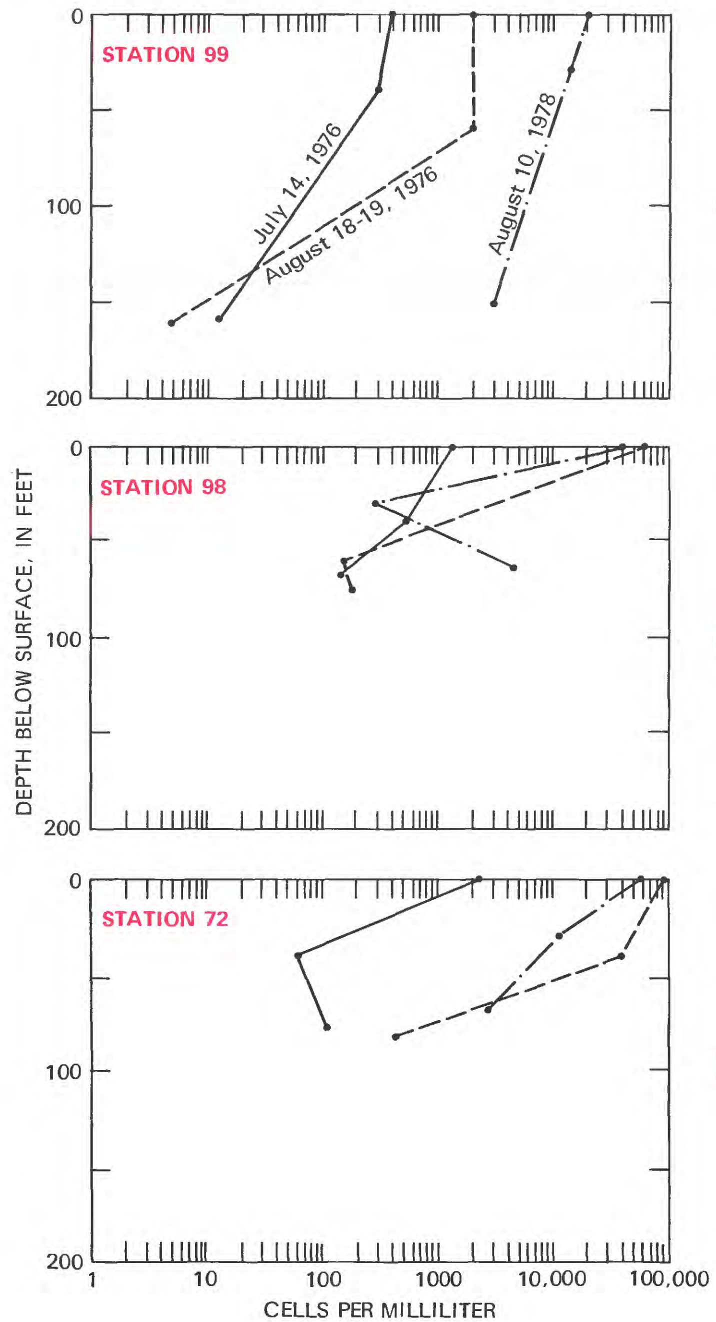


Figure 6.8.2-2 Phytoplankton counts on three selected dates.

Table 6.8.2-1 *Selected properties measured in Seminoe Reservoir*

Property or constituent	Number of samples	Range	Median
Phytoplankton (cells per milliliter)	25	5-120,000	890
Secchi disk (feet)	28	1.7-15.4	8.6
Dissolved solids (milligrams per liter)	66	180-421	282
Dissolved phosphorus (milligrams per liter)	34	0.00-0.11	0.01

Property or constituent	Number of samples	Range	Median
Phytoplankton (cells per milliliter)	18	120-85,000	1,400
Secchi disk (feet)	22	1.1-12.0	5.7
Dissolved solids (milligrams per liter)	51	119-333	241
Dissolved phosphorus (milligrams per liter)	28	0.00-0.09	0.02

Property or constituent	Number of samples	Range	Median
Phytoplankton (cells per milliliter)	21	23-130,000	5,900
Secchi disk (feet)	24	1.1-9.3	4.8
Dissolved solids (milligrams per liter)	51	178-388	280
Dissolved phosphorus (milligrams per liter)	31	0.00-0.32	0.01

7.0 GROUND-WATER HYDROLOGIC NETWORK

Extensive Ground-Water Data Available

The U.S. Geological Survey has collected ground-water data at about 1,000 sites within Area 54 since the 1940's.

The U.S. Geological Survey has collected ground-water data within Area 54 since the early 1940's. The ground-water data base resulting from these studies includes about 1,000 data-collection sites, hundreds of water levels and water-quality analyses, yield measurements from wells and springs, aquifer characteristics, and well records. However, many of these sites were established for various areal studies of ground water and have not been remeasured since the studies were completed. The current data-collection network includes 9 wells in the Colorado statewide network, 5 wells in the Wyoming statewide network, and 21 wells in an irrigation impact study in the Saratoga, Wyo., area.

Figure 7.0-1 shows all ground-water sites used in this report, additional sites in the Hanna and Carbon Basins coal mining area not used in this report, and those in the current data-collection networks. Data and period of record for each site are listed in section 14.0, Supplemental Information. Additional data for these sites are available from the U.S. Geological Survey's NAWDEX and WATSTORE computer files. Other information and data are available from the Wyoming Department of Environmental Quality in mining-permit applications, and from the Colorado and Wyoming State Engineers in well-drilling permit completions.

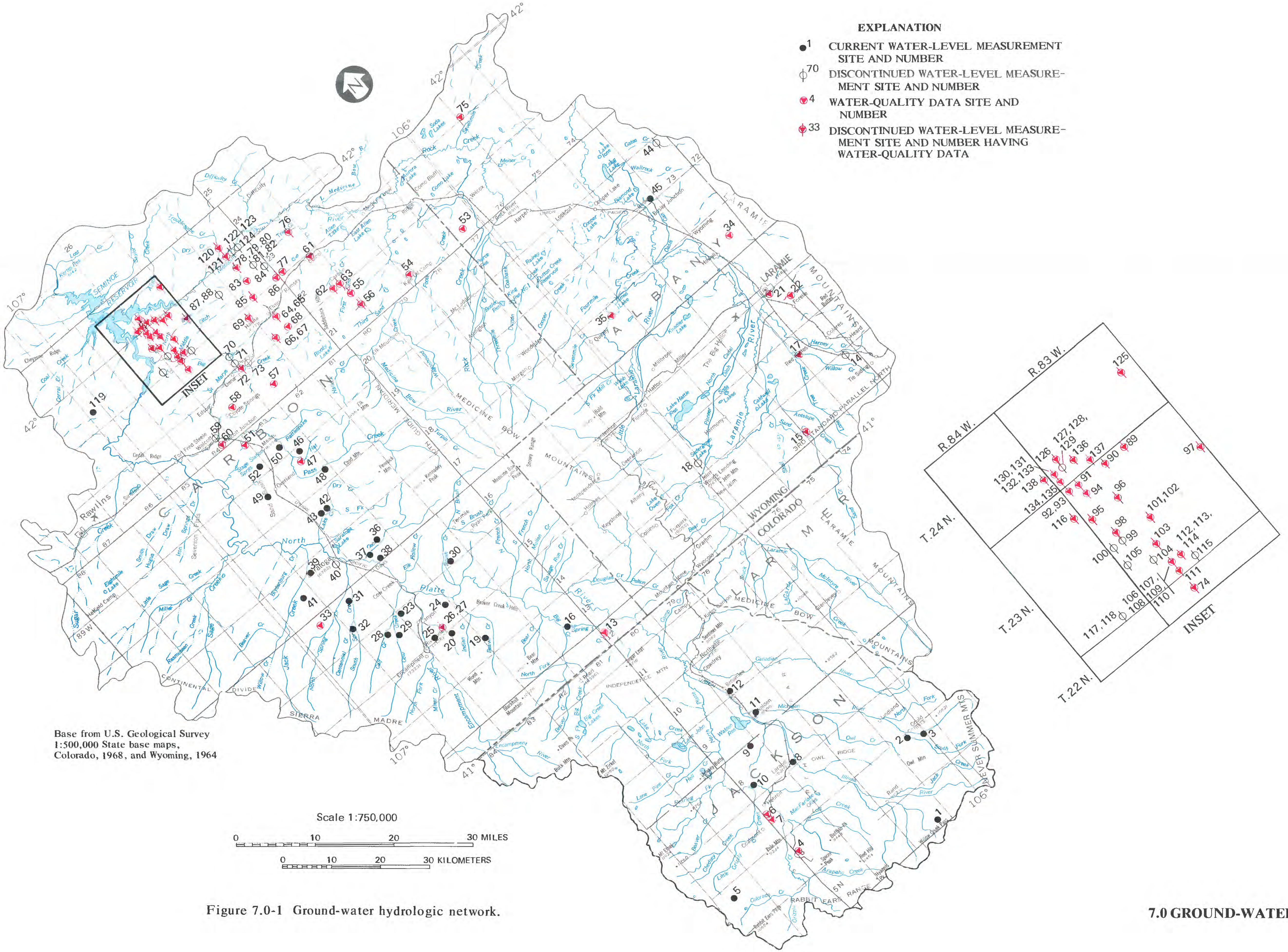


Figure 7.0-1 Ground-water hydrologic network.

7.0 GROUND-WATER HYDROLOGIC NETWORK

Ground-Water Hydrology Studied Since the 1940's

Most published ground-water reports in Area 54 are by the U.S. Geological Survey or the University of Wyoming.

Many reports describing the ground-water hydrology of various parts of Area 54 have been published since 1947. The locations of the study areas of some of these reports and a current (1982) study are shown in figure 8.0-1.

Published reports of U.S. Geological Survey water-resources studies of specific areas and studies of irrigation and municipal supply include Berry (1960), Littleton (1950), Morgan (1947), Visher (1952), and Voegeli (1965). The areal ground-water hydrology in the Wyoming portion is also described by Lowry and others (1973) and Welder and McGreevy (1966). Water-quality data from the U.S. Geological Survey Hanna and Carbon Basins study is published in Freudenthal (1979).

University of Wyoming graduate theses on ground-water resources include Burritt (1962), Lundy (1978), Reichenbaugh (1969), Robinson (1956), Saulnier (1958), and Thompson (1979). Additionally, the Wyoming Water Resources Research Institute has completed a study on the occurrence and characteristics of ground water in the area for the U.S. Environmental Protection Agency (Richter, 1981).

The only current (1982) study in the area by the U.S. Geological Survey is to determine the impact of irrigation on the ground-water resources of the Saratoga Valley. Additional information on this study and water-level data from the Hanna and Carbon Basins study is available from District Chief, U.S. Geological Survey, Water Resources Division, P.O. Box 1125, Cheyenne, WY 82001.

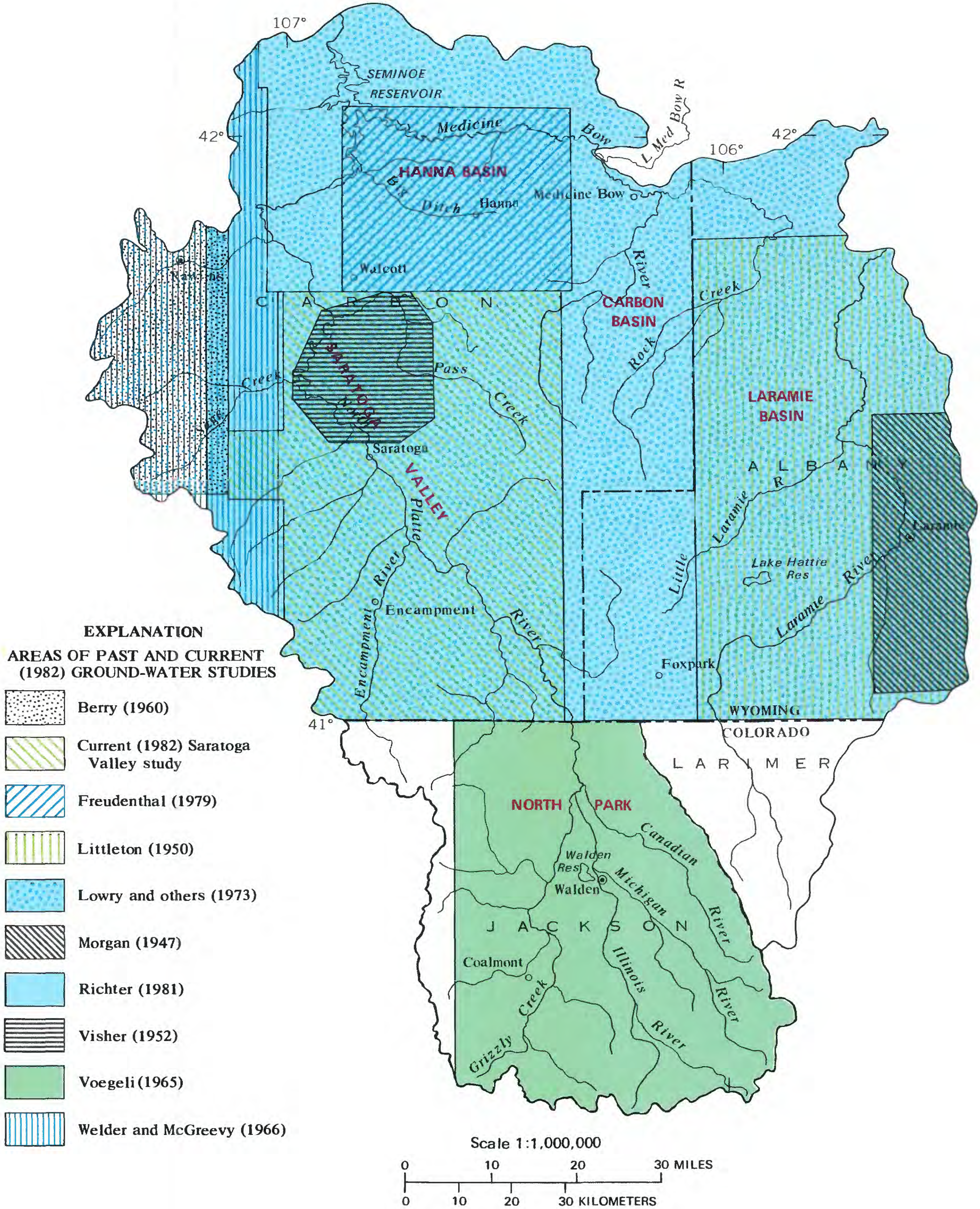


Figure 8.0-1 Areas of ground-water studies.

Much of Area 54 Depends on Ground Water for Municipal, Domestic, and Stock Supply

Four groups of rocks provide water supplies at rates from 5 to 1,000 gallons per minute in geologically distinct areas.

Aquifers ranging in age from Quaternary to Precambrian are used for water supply where they occur within about 500 feet from the surface in different parts of the area. The major aquifers--those with larger yields in each area--are shown in four groups of rocks in figure 9.1-1. These aquifers are in the Casper Formation in the Laramie Basin; the Hanna and Ferris Formations in the Hanna, Carbon, and northern Laramie Basins; and the Browns Park, North Park, and Wind River Formations in the Saratoga Valley, northern Laramie Basin, and North Park area.

Aquifers in the Hanna, Carbon, and northern Laramie Basins include sandstone, conglomerate, and coal beds of the Hanna, Ferris, and Medicine Bow Formations and Mesaverde Group. Generally, the yields are less than 50 gallons per minute (gal/min), except where fractures provide more water. Yields as much as 1,000 gal/min may be possible due to the large thickness of the unit (Lowry and others, 1973). The water is used for stock watering and domestic and mine supplies.

Water production in the Saratoga Valley is primarily from the Browns Park and North Park Formations. Water is produced from sandstone and conglomerate beds, with yields as much as 500 to 1,000 gal/min (Lowry and others, 1973). The water is used for irrigation, domestic supply, and stock watering.

The coal-bearing rocks have eroded away in the eastern Laramie Basin, and thin, mostly unsaturated alluvial deposits cover the Cretaceous and older rocks. The major aquifer in this area is the Casper Formation. The sandstone and limestone beds are the municipal water source for the city of Laramie, Wyo. Wells and springs yield 50 to 100 gal/min where the full section is saturated, and as much as 1,000 gal/min where the rock is fractured (Lowry and others, 1973). The Chugwater Group, Forelle Limestone, and Satanka Shale are also used for stock watering with yields of 5 to 10 gal/min.

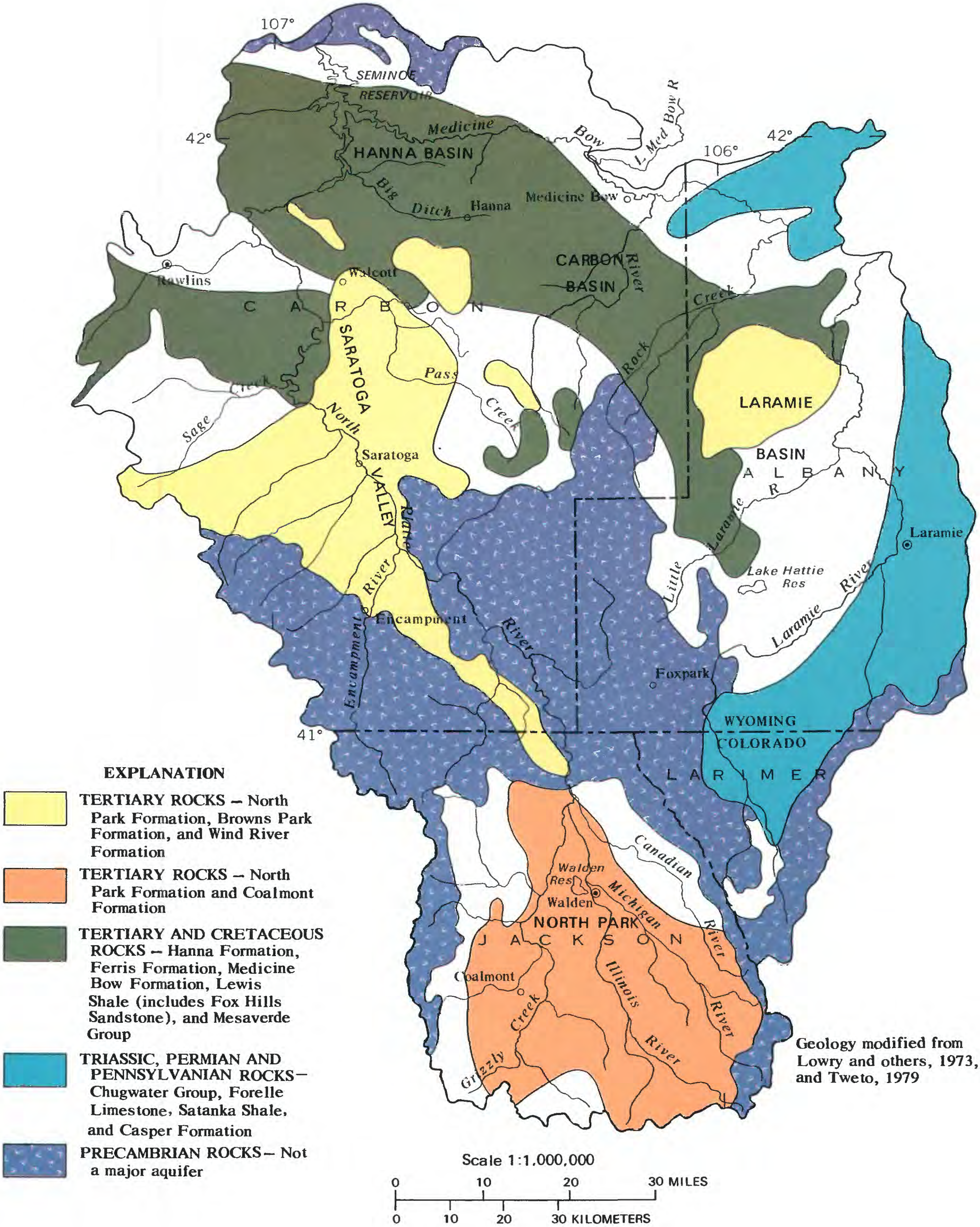


Figure 9.1-1 Rocks that include major aquifers.

Long-Term Water Levels Available for 18 Wells

Changes in water levels reflect changes in ground-water storage.

Changes in water levels reflect changes in the amount of water stored in an aquifer. These changes can be caused by variations in precipitation and recharge to the aquifer, pumping for irrigation or other use, dewatering, evapotranspiration cycles in alluvial aquifers, or combinations of these factors.

Water-level changes in selected wells (fig. 9.2-1) caused by different hydrologic stresses on aquifers are illustrated in figures 9.2-2 and 9.2-3. With municipal development in the Saratoga, Wyo., area, peaks in the hydrograph of site 40 (fig. 9.2-2) have changed from late fall to spring, and water levels have declined. The hydrograph for site 18 shows a seasonal response in the water level due to recharge from surface-water irrigation. The occurrence of peaks at the end of the irrigation season (September-October) probably results from a lag in the time of diversion from the Laramie River to the response in the well. The well is 0.3 mile from the nearest diversion ditch.

The hydrograph for site 25 (fig. 9.2-3) also shows a seasonal response to recharge from irrigation, and a long-term rise in water level in the North Park Formation. The hydrograph shows no apparent response to either monthly or annual precipitation; recharge from irrigation has a more dominant influence on the water level. Water levels are currently being observed in many wells in the Saratoga Valley to study the effects of irrigation on ground water (see section 8.0).

Water levels in 14 wells in Area 54 (fig. 9.2-1) are being measured on a continuing basis by the U.S. Geological Survey as part of statewide observation-well programs. The period of record and producing formations of these wells and four discontinued wells are listed in table 9.2-1. Data for wells in Wyoming are published in annual reports by Ringen (1973), Ballance and Freudenthal (1975, 1977), and Stevens (1978). Data for 1979-82 are available from the District Chief, U.S. Geological Survey, P.O. Box 1125, Cheyenne, WY 82001. Data for the wells in Colorado are available from the District Chief, U.S. Geological Survey, Box 25046, Mail Stop 415, Denver Federal Center, Lakewood, CO 80225. Water-level data for many other wells (some are listed in section 14.2) also are available from the U.S. Geological Survey WATSTORE computer files at the above addresses.

Table 9.2-1 *Wells measured in Colorado and Wyoming statewide observation-well programs*

Site No.	Formation	Period of record
Jackson County, Colo.		
1	Coalmont Formation	1976-81
2	Coalmont Formation	1976-81
3	Coalmont Formation	1976-81
5	Coalmont Formation	1976-81
8	North Park Formation	1974-81
9	North Park Formation	1975-81
10	North Park Formation	1976-81
11	Coalmont Formation	1976-81
12	Coalmont Formation	1974-81
Albany County, Wyo.		
14	Casper Formation	1966-68, 1970-73, 1975-77
18	Terrace deposits	1948-53, 1959-76
44	Forelle Limestone	1965-68, 1970-79
45	Steele Shale	1968, 1970-81
Carbon County, Wyo.		
25	North Park Formation	1967-68, 1970-81
40	Browns Park Formation	1967-68, 1970-75
41	North Park Formation	1967-68, 1977-81
50	North Park Formation	1950-81
120	Mesaverde Group	1967-68, 1970-81

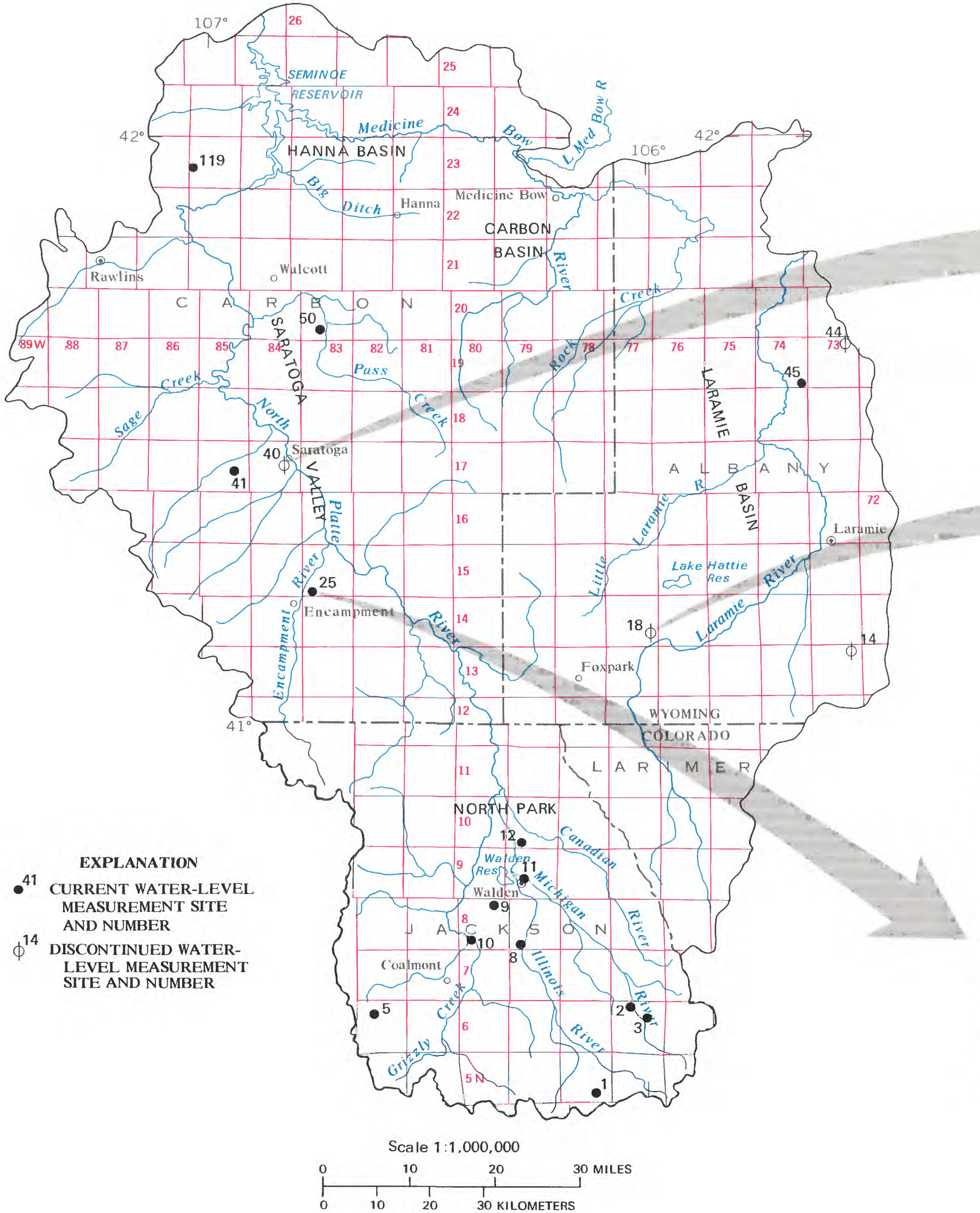


Figure 9.2-1 Location of wells in statewide observation-well programs.

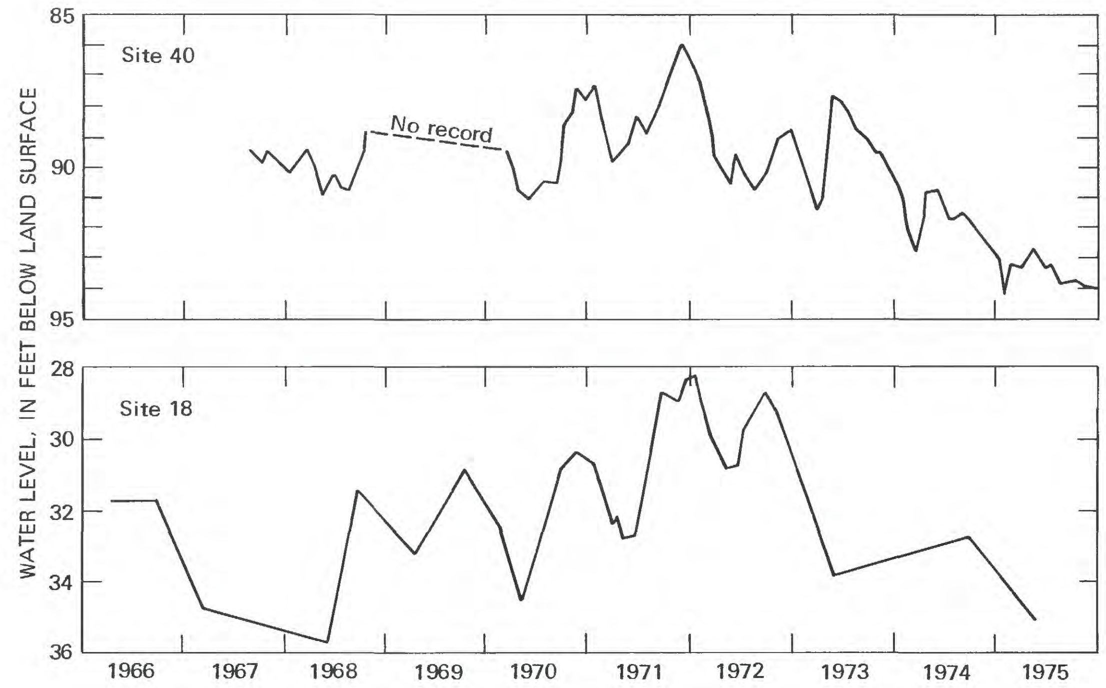


Figure 9.2-2 Hydrographs for wells at sites 40 and 18 from 1966 to 1975.

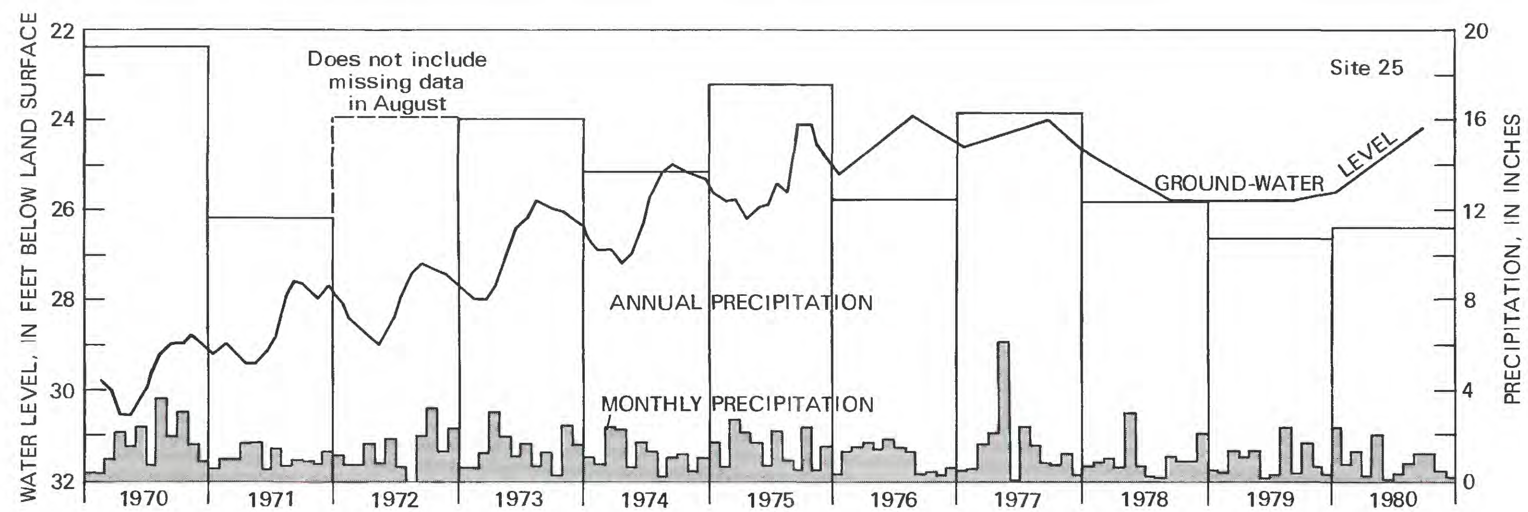


Figure 9.2-3 Hydrograph for wells at site 25, and precipitation at Encampment, Wyo., for 1970 to 1980.

Three Mines Dewatered in Hanna Coal Field

Water levels in some wells in and adjacent to mine areas show a response to dewatering.

Four of seven mines in the Hanna Coal Field (fig. 10.0-1) are dry; three other mines require dewatering. The Carbon County Coal Co. pumps water from their underground mine into a settling and evaporation pond; there has been no discharge from the pond to date (1981). Energy Development Co. pumps 300,000 gallons per day out of the Vanguard 2 underground mine into a series of four settling ponds, which discharge into Big Ditch, an ephemeral stream. Arch Mineral Corp.'s Medicine Bow surface mine requires pumping from the bottom of the pit only periodically. Since 1978, many days and entire months of zero discharge have been recorded. On days of pumping, discharge has ranged from 20,000 to 540,000 gallons per day into settling and evaporation ponds. When the dewatering volume is sufficient to fill the ponds, the water is discharged into Big Ditch. Flow discharged from the settling ponds of either mine rarely reaches the U.S. Geological Survey streamflow-gaging station on Big Ditch (station 70, fig. 10.0-2), 7 miles downstream from the Vanguard 2 mine and 2 miles downstream from the Medicine Bow mine.

The complex, faulted bedrock of the Hanna Basin has prevented a clear understanding of the effects of dewatering on the water levels in the sandstone and coal aquifers. Water levels were measured in many wells in the Hanna Basin from 1974-80 by the U.S. Geological Survey. Water levels in some wells near the mine pits being dewatered have declined, while other water levels have not been affected.

A diagram of the Medicine Bow mine and vicinity with well locations is shown in figure 10.0-2. Hydrographs of water levels in wells in and near the dewatered mine pits are shown in figure 10.0-3. Water levels declined in these wells during the mining process, which eventually destroyed most of these wells. The water-level decrease was as much as 60 feet at site 107. The wells were completed in coal and sandstone zones above the lowest coal bed mined.

The response of water levels in wells further from the pit dewatering illustrates the complexity of the geohydrology (fig. 10.0-4). Site 111, 0.3 mile from the pit being dewatered, is completed in a thick sandstone below the level of the coal which was mined and dewatered, and the water level showed no response to dewatering, indicating low vertical permeability. Site 103, 0.5 mile from the pit, is separated from the pit by a fault. This hole is finished in sandstone at a depth of 150 feet, and also showed no response to dewatering. Although only a single, major fault is shown in figure 10.0-2, the area contains numerous other faults (see Blanchard and Comstock (1980) and Glass and Roberts (1979) for mapping of faults).

The stratigraphic relations between the aquifers at site 96, site 98, and the larger mine pit are not known. However, both wells are across a fault and completed in an interval that is within the same altitude interval as the overburden and the coal in the pit. Site 96 is 2.5 miles from the pit, completed in sandstone at 412 feet, and showed a large response to dewatering--40 feet of water-level decline in 1.5 years. Site 98, completed in sandstone at a depth of 275 feet, showed no response to dewatering. The mine in section 17 between sites 96 and 98 did not require dewatering and may not have affected water levels as greatly as the larger mine to the south. The only supply well in the area--site 99--supplies a small amount of water for office and shop use, and seems to have no effect on nearby water levels.

The ground water being removed from the mines usually has larger concentrations of dissolved solids and trace metals than the surface water in this area. The major effect of dewatering on water quality is the response of surface-water quality to the introduction of the ground water pumped from the mines. This has not been studied, but the coal companies are required to report monthly analyses of iron, pH, total suspended solids, and oil and grease, along with instantaneous discharge measurements when water is discharged to Big Ditch. These data are available from the Water Quality Division, Wyoming Department of Environmental Quality, Cheyenne, Wyo.

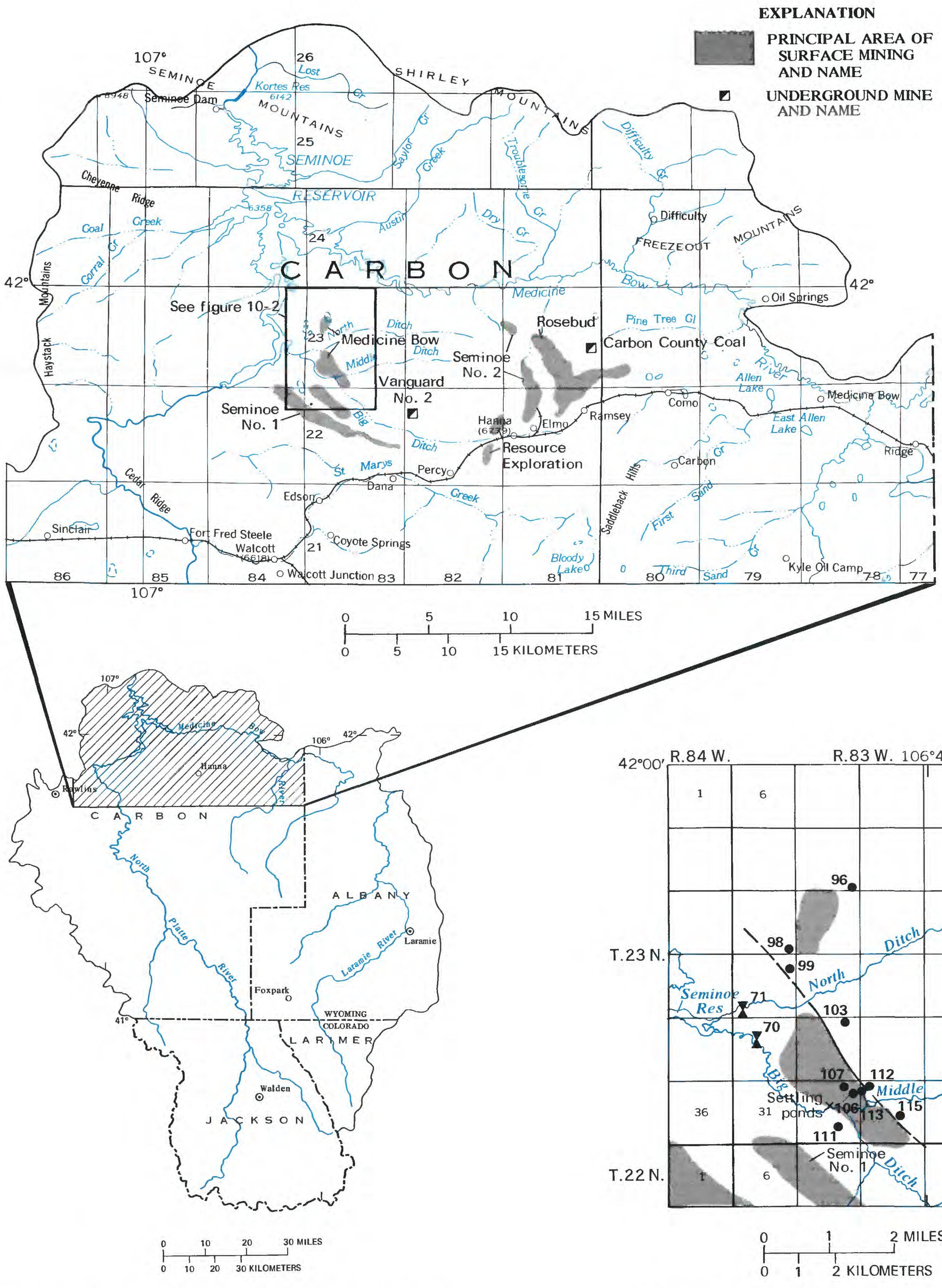


Figure 10.0-1 Location of active coal mines in the Hanna Coal Field (1981).

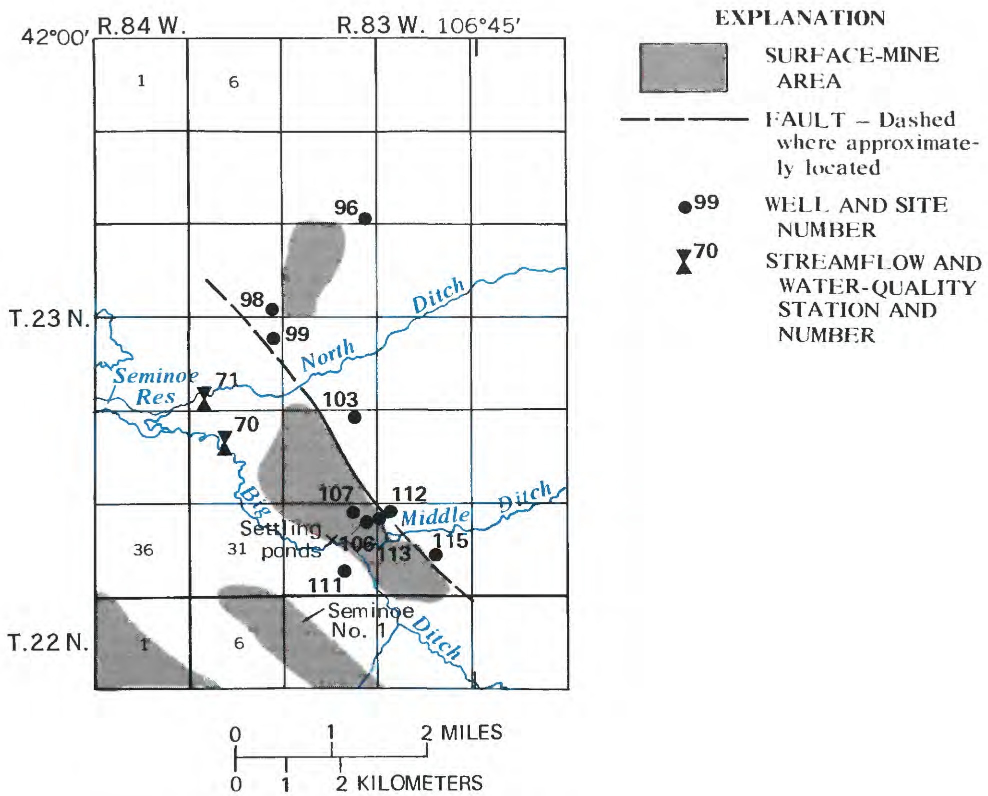


Figure 10.0-2 Medicine Bow mine pits and vicinity.

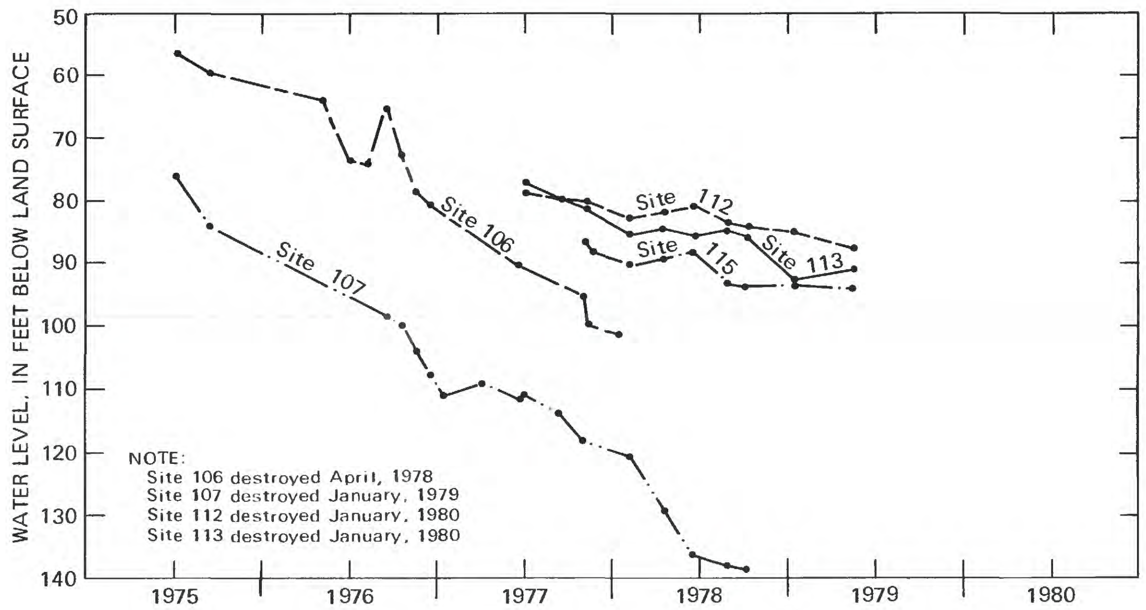


Figure 10.0-3 Hydrographs for wells at the Medicine Bow mine pits.

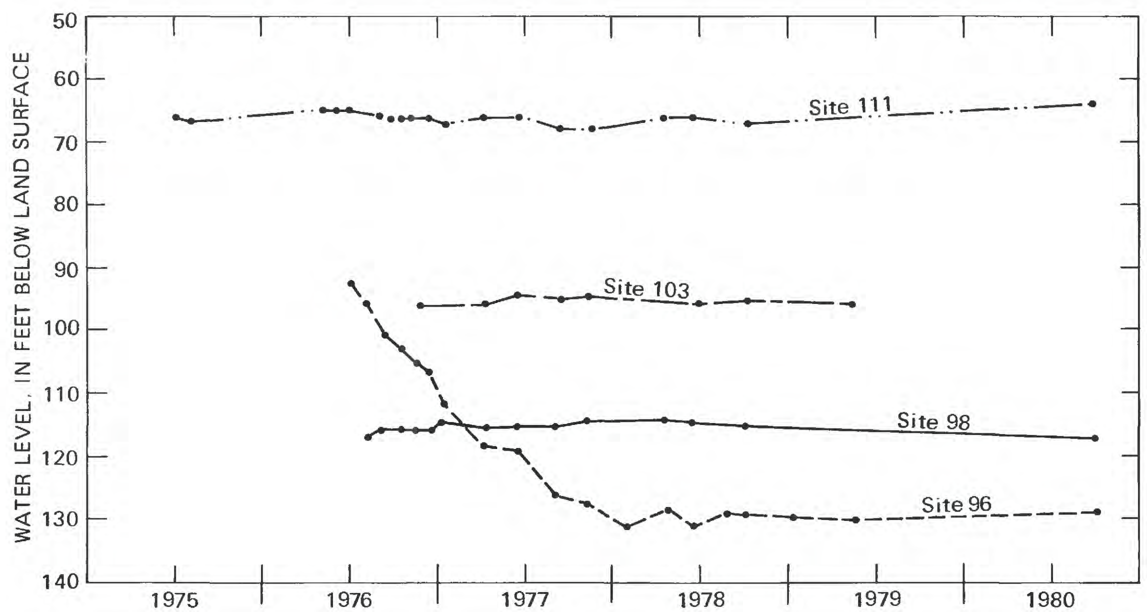


Figure 10.0-4 Hydrographs for wells near the Medicine Bow mine pits.

Ground-Water Quality is Variable

The aquifers used for water supply yield waters of varied dissolved-solids concentrations and many different chemical compositions, the most unusual being from the coal-associated aquifers.

The ground-water quality of aquifers in Area 54 is variable both in dissolved-solids concentrations and in chemical composition. Aquifers in the Hanna Basin coal area are characterized by larger dissolved-solids concentrations (up to 8,160 milligrams per liter) than other aquifers. The chemical composition within most aquifers is generally uniform; the same cation and anion combinations dominate most analyses from wells in a formation. Aquifers of the Hanna Basin, however, do not show this uniformity.

Chemical composition of the water reflects the lithologic variability, mineralogy, and time-of-residence in the formations. Precambrian granite and many sandstone aquifers contain relatively insoluble minerals and yield water with small dissolved-solids concentrations. Lithologies with more soluble minerals, especially the coal, carbonaceous shale, shale, and sandstone sequences, yield water containing larger dissolved-solids concentrations. The larger the dissolved-solids concentration, the poorer the quality of water.

The circle diagrams in figure 11.1-1 show representative chemical quality of ground water in selected formations in Area 54. The size of the circle represents the dissolved-solids concentration, while the dominant cation and anion are shown by colors. Where two cations or anions were almost equal, both are shown in the circle.

The North Park, Browns Park, and Coalmont Formations, Mesaverde Group, Chugwater Group, and the Casper Formation yielded a consistent water composition in many samples. Three analyses of the dominant water composition for each aquifer are depicted in figure 11.1-1. Several chemical compositions are depicted for the analyses from wells in the Hanna and Ferris Formations, where no single chemical composition dominated the analyses.

The Hanna Formation yielded water dominated by sulfate (green) in 11 of 20 analyses; the other 9 analyses were dominated by bicarbonate (blue) in 3 and by both bicarbonate and sulfate in 6 analyses. The cations were dominated by sodium (red) in nine analyses, calcium (orange) in three, sodium and magnesium (red and yellow) in two, and by a mixture of the three cations in six analyses.

Sulfate (green) also dominated the anionic ground-water composition in the Ferris Formation in 23 of 29 analyses. The dominant cation was sodium (red) in 12 analyses, magnesium (yellow) in 5, magnesium and sodium in 9, and a mixture of magnesium, sodium, and calcium in 3.

The dissolved-solids concentration often limits the use of ground water for domestic, agriculture, and livestock use. The Wyoming Department of Environmental Quality (1980) established 500 milligrams per liter as the maximum dissolved-solids concentration for domestic use of ground water, 2,000 milligrams per liter for agriculture use, and 5,000 milligrams per liter for livestock use.

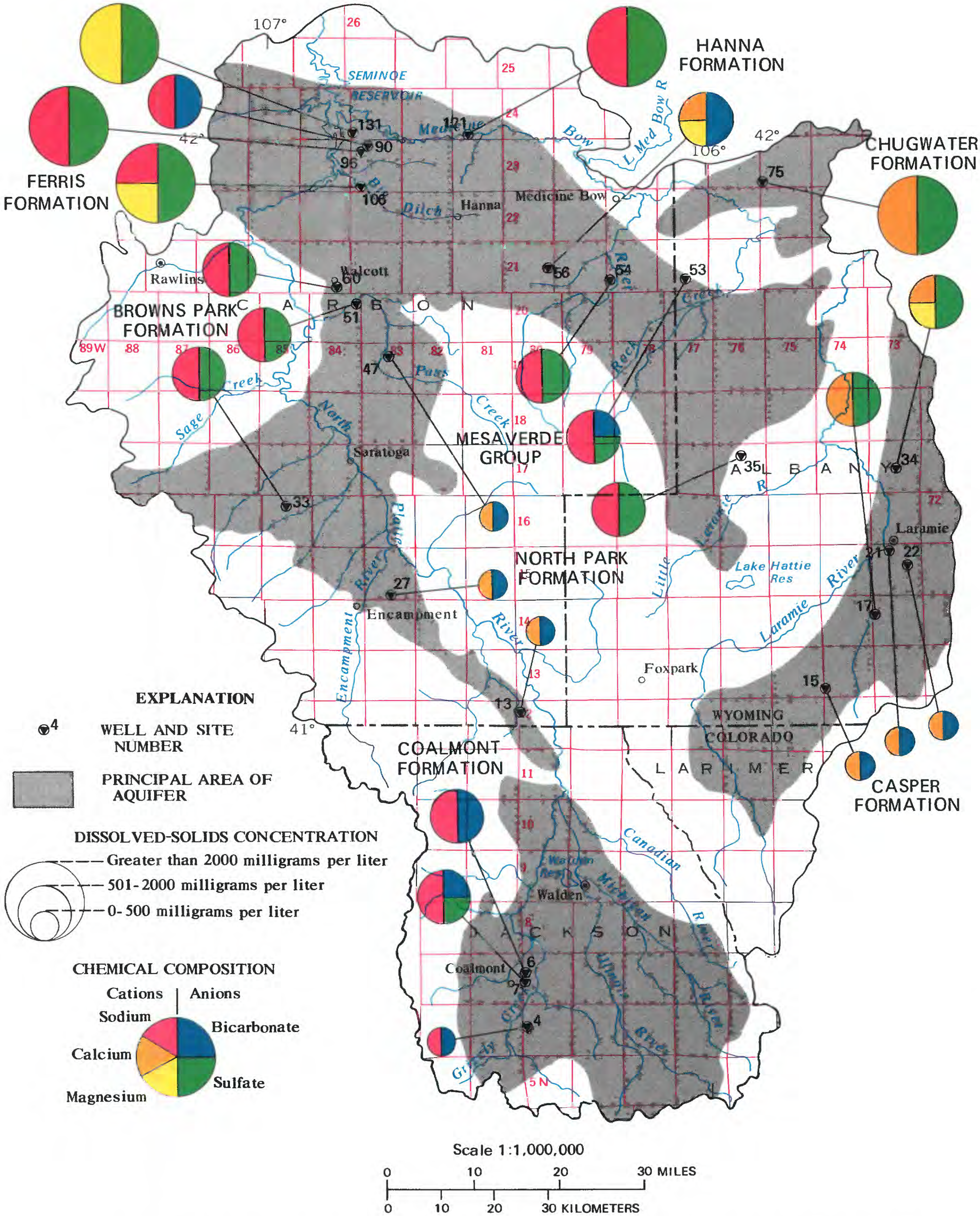


Figure 11.1.1 Dissolved-solids concentration and chemical composition in selected wells in selected geologic formations.

Trace-Element Analyses Summarized for the Hanna Basin Area

Concentrations of some trace elements in ground water exceed concentration limits for use.

Ground water in the Hanna Basin coal area (fig. 11.2-1) contains larger concentrations of iron and manganese than of other dissolved trace elements in samples analyzed from wells in that area. Frequency distributions of dissolved concentrations of boron, chromium, fluoride, iron, manganese, selenium, and zinc are shown in figure 11.2-2. Data for these and additional trace elements are published in Freudenthal (1979).

The Wyoming Department of Environmental Quality (1980) has adopted the U.S. Environmental Protection Agency's drinking-water standards and recommendations (1976b, 1976c, and 1977a) and has added additional standards for domestic, agriculture, and livestock use. The domestic, agriculture, and livestock water-supply concentration limits are marked on the graphs in figure 11.2-2 with color-coded arrows. Any analysis with a concentration graphed to the right of an arrow exceeds that standard. For most trace elements, concentration limits were exceeded by only 1, 2, or 3 analyses out of 48 to 60 analyses. However, limits for iron and manganese were exceeded in many analyses. The water-quality standards do not specify whether they apply to dissolved or total recoverable concentrations. Generally, total recoverable concentrations of trace elements are larger than dissolved concentrations, and many more analyses would exceed the standards using total recoverable concentrations.

The dissolved concentrations of arsenic, cadmium, copper, and lead were generally less than 10 micrograms per liter, with a maximum of 29 micrograms per liter, as shown in table 11.2-1. Concentrations of all four elements are less than the concentration limits established for domestic, agriculture, and livestock use. The low concentrations of cadmium and lead are due to the rare occurrence of cadmium in rocks and to the low solubility of lead.

The concentration of mercury, also a rare element in rocks, was less than 0.5 microgram per liter in 47 analyses. One analysis exceeded the domestic water-supply standard of 2.0 micrograms per liter with a concentration of 2.1 micrograms per liter.

Many of the wells sampled for trace-element analyses are observation wells with no use of the water, but some are used for domestic and livestock water supply. The observation wells are completed in a variety of lithologies, including coal, shale, clinker, and sandstone.

Trace elements are present in nearly all geologic strata, but they exist in small amounts and their solubilities are very small, especially in the 6 to 9 pH range of most natural waters. Thus, trace elements occur naturally in ground water, dissolved from the rocks through which it flows; trace-element concentrations in ground water are generally less than 1 milligram per liter. Many trace elements are essential to plant and animal metabolism in small concentrations, but can be toxic in larger concentrations.

Table 11.2-1 *Summary of dissolved concentrations of selected trace elements, in micrograms per liter (μg/L)*

Element	Total number of analyses	Number of analyses less than or equal to 2 μg/L	5 μg/L	10 μg/L	Maximum concentration, in μg/L
Arsenic	48	39	45	47	29
Cadmium	48	45	48	48	5
Copper	48	33	40	44	20
Lead	48	23	40	47	22
Mercury	48	47	48	48	2.1

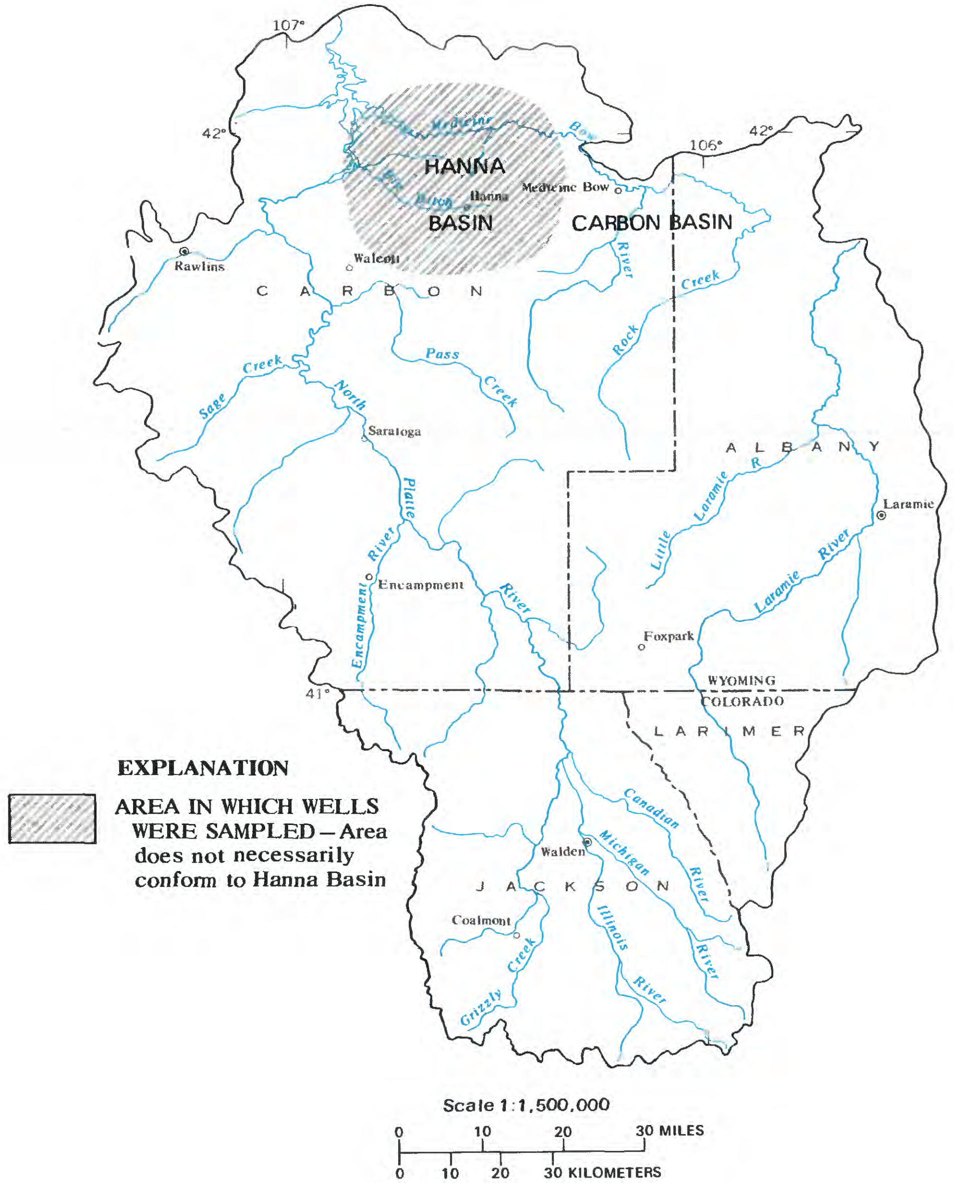


Figure 11.2-1 Area where wells were sampled for trace elements.

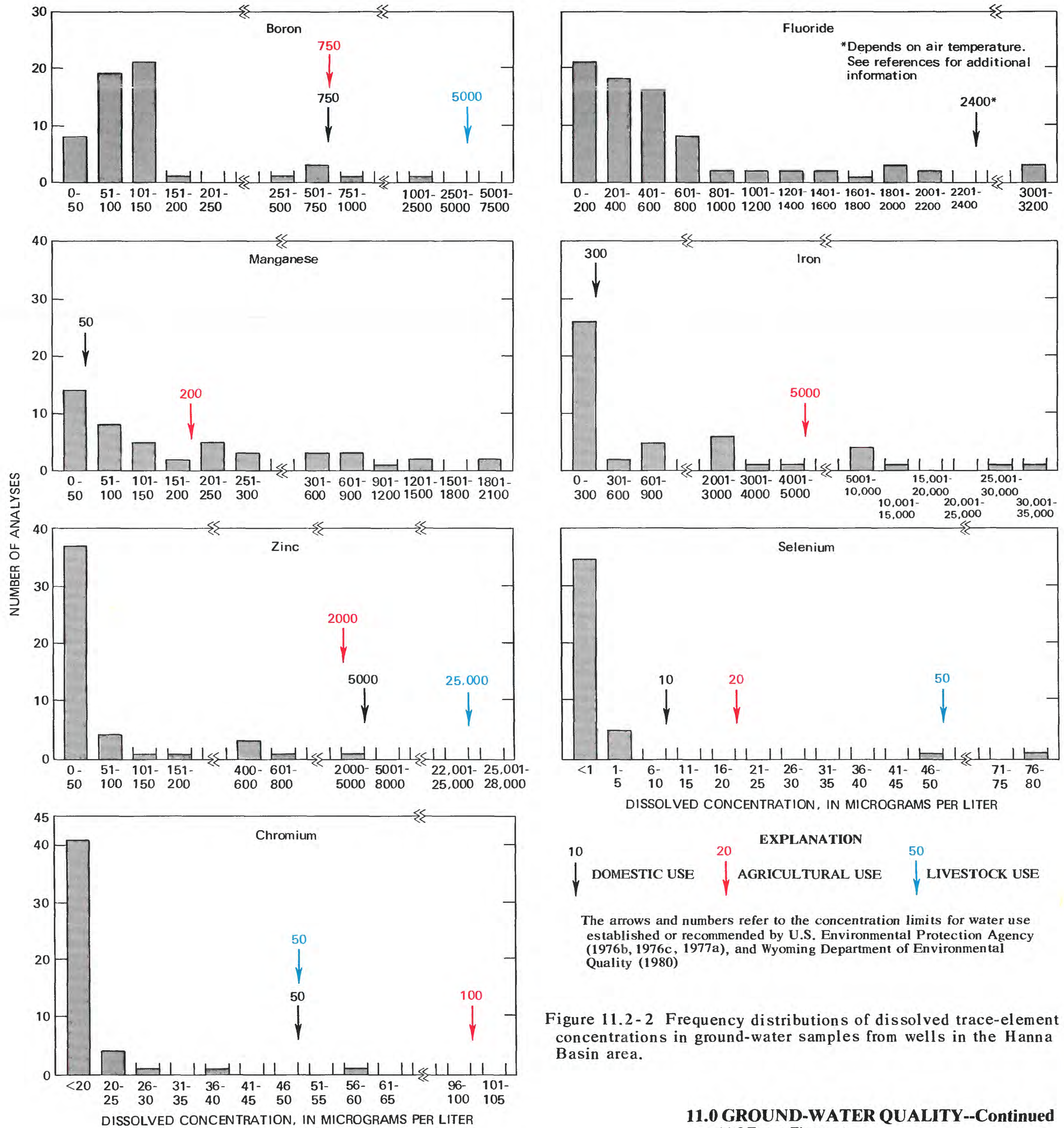


Figure 11.2-2 Frequency distributions of dissolved trace-element concentrations in ground-water samples from wells in the Hanna Basin area.

Radionuclides Analyzed in Water from 15 Welss

No excessive radionuclide concentrations were present in 20 samples from 15 wells.

Radium and uranium occur naturally in ground water, and neither element was present in excessive concentrations in the Hanna and Carbon Basins where radionuclides were analyzed in 20 samples from 15 wells (fig. 11.3-1). The maximum radium-226 concentration was 2.1 picocuries per liter, and the maximum natural dissolved uranium concentration was 14 micrograms per liter. Both values were less than the drinking-water, agriculture, and livestock limits of 5,000 micrograms per liter of uranium and 5 picocuries per liter of radium (U.S. Environmental Protection Agency, 1976a; and Wyoming Department of Environmental Quality, 1980). The analyses are published in Freudenthal (1979) and are summarized in table 11.3-1.

Table 11.3-1 *Radionuclide data from Hanna and Carbon Basins*

	Range	Median	Number of analyses
Gross alpha, dissolved (micrograms per liter as uranium-natural)	5.3-140	<28	20
Gross alpha, suspended total (micrograms per liter as uranium-natural)	<.4-240	21.0	20
Gross beta, dissolved (picocuries per liter as cesium-137)	<2.1-40	8.7	20
Gross beta, suspended total (picocuries per liter as cesium-137)	<.4-70	10.5	20
Gross beta, dissolved (picocuries per liter as strontium/Yttrium-90)	<1.9-35	7.65	20
Gross beta, suspended total (picocuries per liter as strontium/Yttrium-90)	<.4-65	9.05	20
Radium 226, dissolved, radon method (picocuries per liter)	.07-2.1	.34	20
Uranium natural dissolved (micrograms per liter as uranium)	<.4-14	1.0	14
Uranium dissolved, extraction (micrograms per liter)	.15-1.3	.63	6

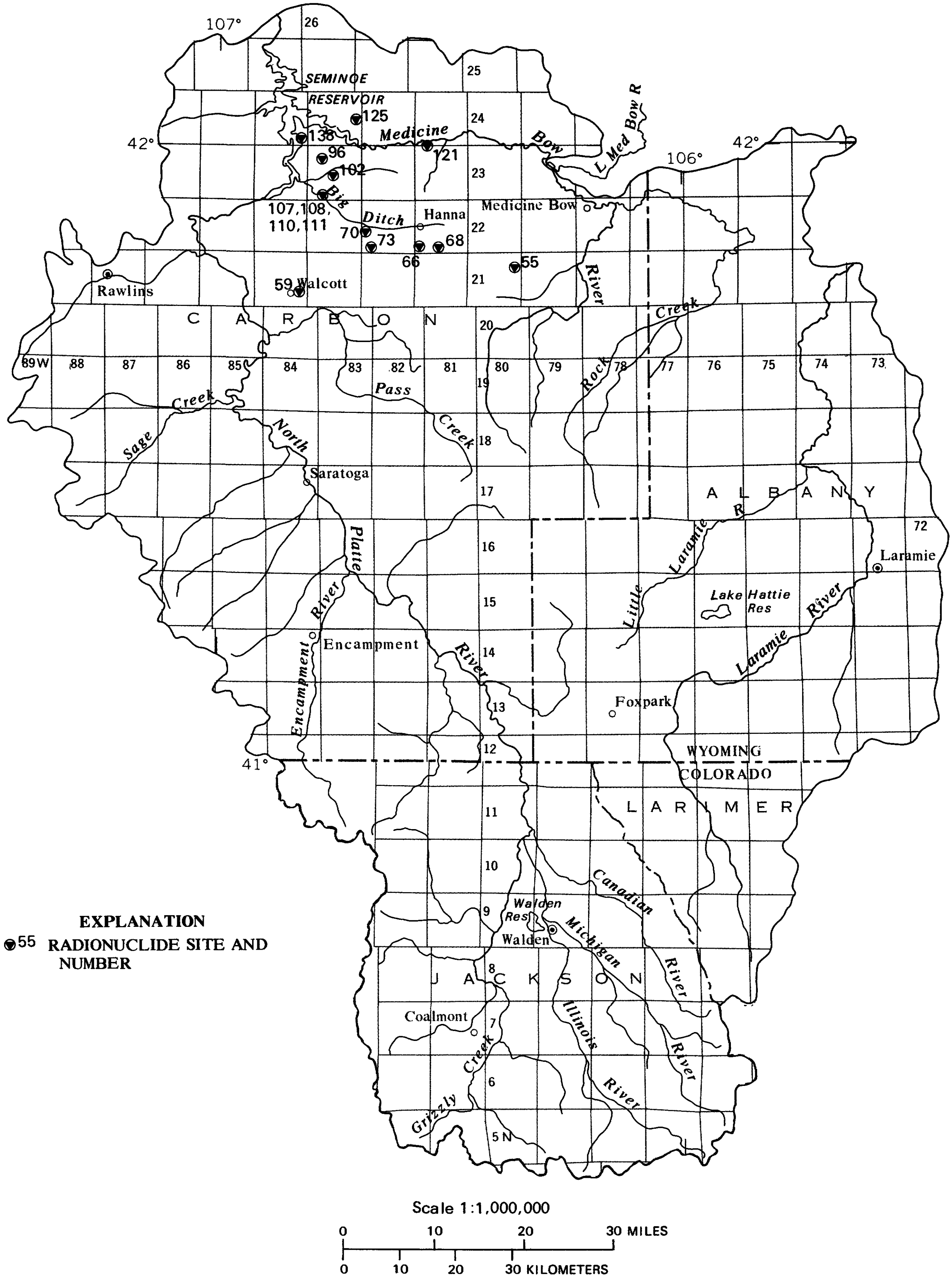


Figure 11.3-1 Location of radionuclide sampling sites.

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

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

Three activities within the U.S. Geological Survey help to identify and improve access to the vast amount of existing 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 needing data to determine what information is available.

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

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

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

More detailed explanations of these four activities are given in sections 12.2, 12.3, 12.4, and 12.5.

National Water-Data Exchange 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 accessible and to facilitate a more efficient exchange of water data.

Services are available through a Program Office at the U.S. Geological Survey's National Center in Reston, Va., and a nationwide network of Assistance Centers in 45 States and Puerto Rico, which provide local and convenient access to NAWDEX facilities (fig. 12.2-1). A directory is available upon request that provides names of organizations and persons to contact, addresses, telephone numbers, and office hours for each of these locations [Directory of Assistance Centers of the National Water-Data Exchange (NAWDEX), U.S. Geological Survey Open-File Report 80-1193].

NAWDEX can assist any organization or individual in identifying and locating water data and referring the requester to the organization that retains the data required. To perform this service, NAWDEX maintains a computerized Master Water-Data Index (fig. 12.2-2) that identifies sites for which water data are available, the type data available for each site, and the organization retaining the data. A Water-Data Sources Directory (fig. 12.2-3) also is maintained that identifies organizations 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. 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, however estimates will be automatically provided when costs are anticipated to be substantial.

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

Program Office
National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

Telephone: (703) 860-6031
FTS 928-6031

Hours: 7:45 to 4:15 Eastern Standard Time

or

COLORADO
U.S. Geological Survey
Water Resources Division
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

or

WYOMING
U.S. Geological Survey
Water Resources Division
P.O. Box 1125
Cheyenne, WY 82001

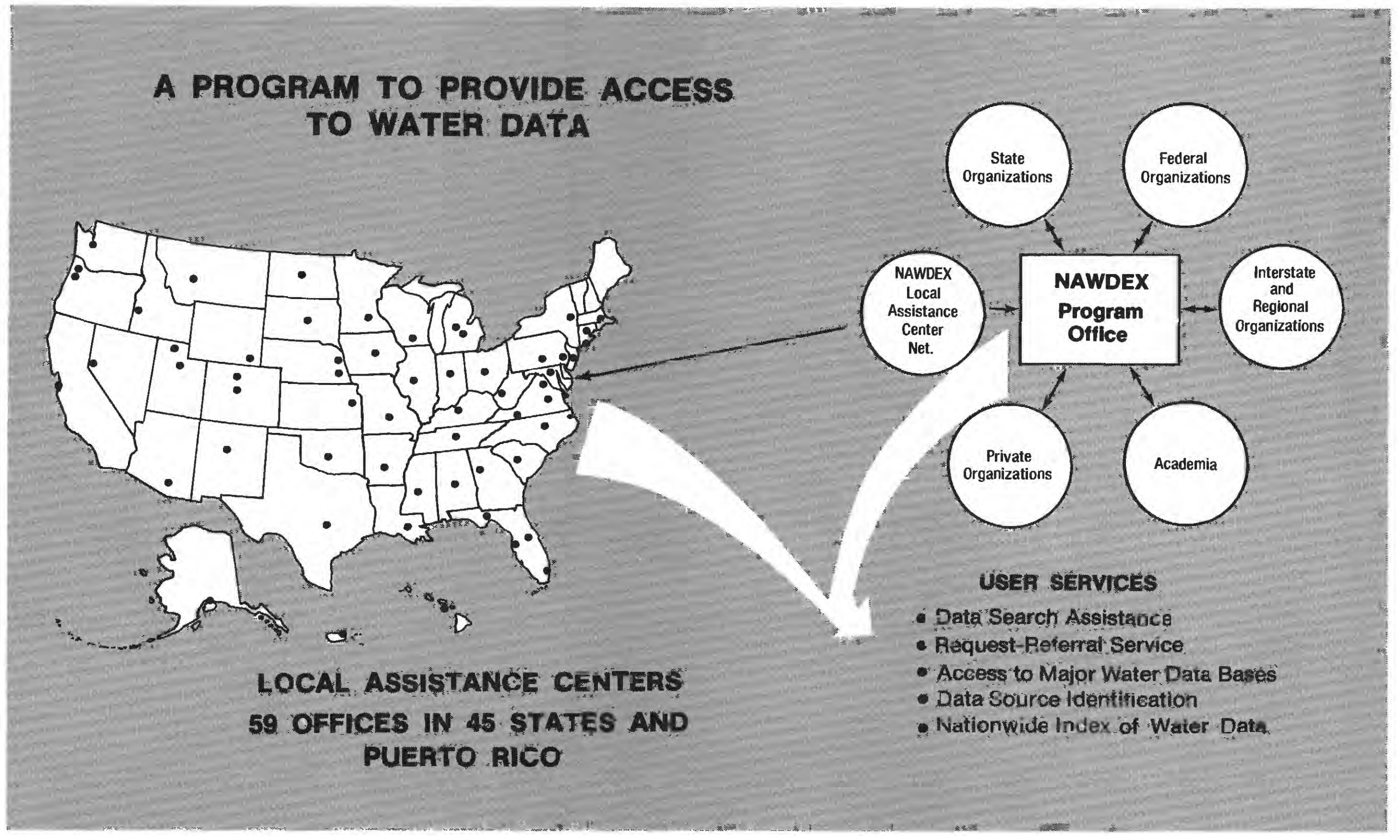


Figure 12.2-1 Access to water data.

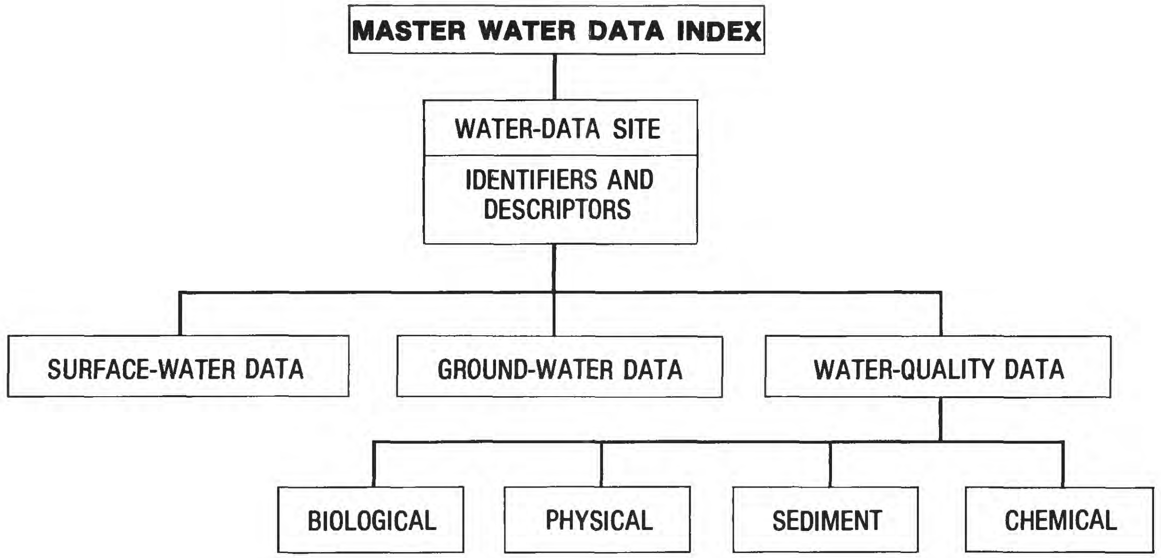


Figure 12.2-2 Master water-data index.

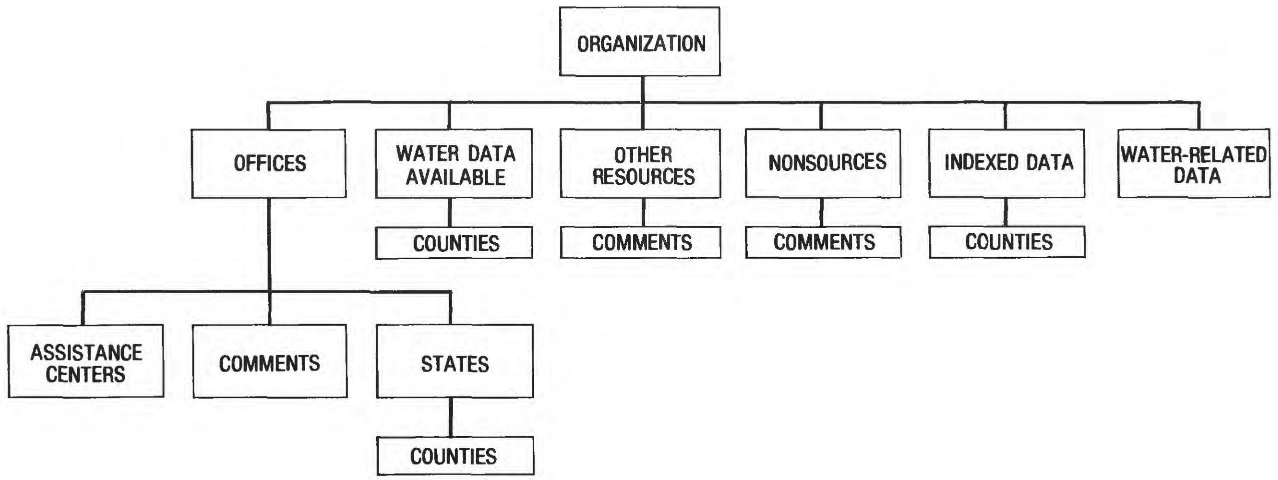


Figure 12.2-3 Water-data sources directory.

WATSTORE Automated System

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

The National Water-Data Storage and Retrieval System (WATSTORE) was established in November 1971 to computerize the U.S. Geological Survey's existing water-data system and to provide 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, Va. Data may be obtained from WATSTORE through the Water Resources Division's 46 district offices. General inquiries about WATSTORE may be directed to:

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

or

District Chief
U.S. Geological Survey
Water Resources Division
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

or

District Chief
U.S. Geological Survey
Water Resources Division
P.O. Box 1225
Cheyenne, WY 82001

The Geological Survey currently (1982) collects data at approximately 16,000 stream-gaging stations, 1,000 lakes and reservoirs, 5,200 surface-water quality stations, 1,020 sediment stations, 30,000 water-level-observation wells, and 12,500 ground-water-quality wells. Each year many water-data collection sites are added and others are discontinued; thus, large amounts of information, 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, water-quality, and ground-water data measured daily or continuously; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water stations; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water stations. In addition, an index file of stations for which data are stored in the system is also maintained (fig. 12.3-1). A brief description of each file is as follows:

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

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

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

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

Unit Values File: Water parameters measured on a schedule more frequent than daily are stored in this file. Rainfall, stream discharge, and temperature data are examples of the types of data stored in the Unit Values File.

Ground-Water Site-Inventory File: This file is discussed above, but it is cross-referenced to the Water-Quality File and the Daily Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for nearly 70,000 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 or retrieved from WATSTORE at a number of locations that are part of a nationwide telecommunication network.

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

Digital-Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chlorides. Data are recorded on 16-channel paper tape, which is removed from the recorder and transmitted over telephone lines to the receiver at Reston, Virginia. The data are recorded on magnetic tape for use on the central computer. Extensive testing of satellite data collection platforms indicates their feasibility for collecting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 200 data relay stations are being operated currently (1980).

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

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

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

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

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

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

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

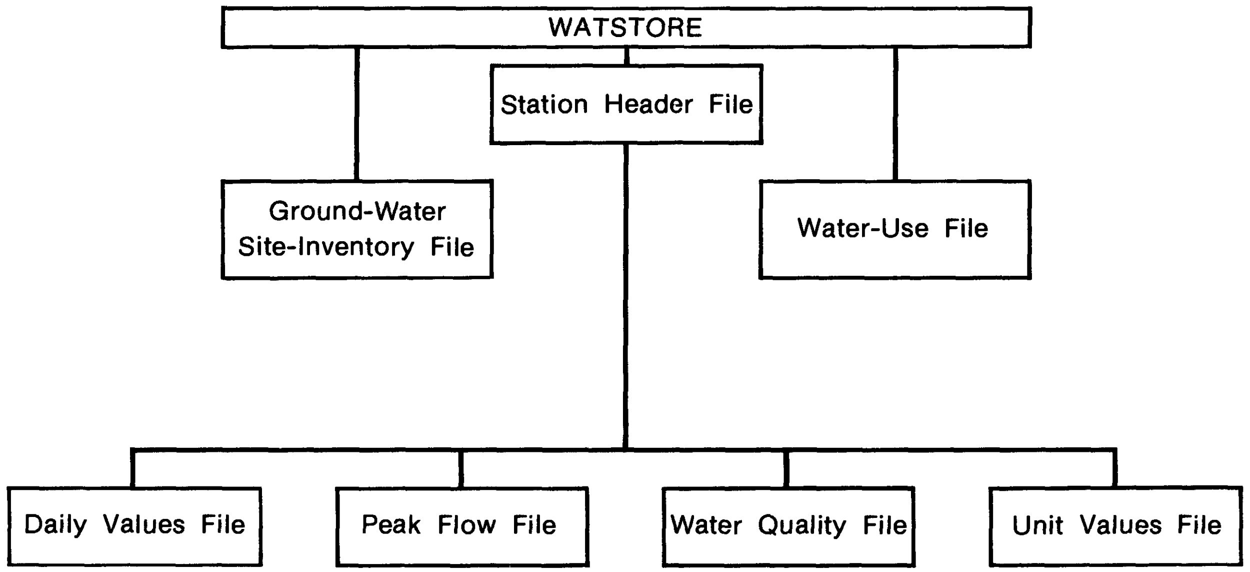


Figure 12.3-1 Index file stored data.

Water Data Indexed for Coal Provinces

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

The "Index to Water-Data Activities in Coal Provinces of the United States" was prepared to assist those involved in developing, managing, and regulating the Nation's coal resources by providing information on the availability of water-resources data in the major coal provinces of the United States. The index 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. 12.4-1): 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 hydrologic investigations and water-data activities not included in other parts of the index. The agencies that submitted the information, agency codes, and the number of activities reported by type are included.

Those who need additional information from the Catalog File or who need assistance in obtaining water data should contact the National Water Data Exchange (NAWDEX). (See section 12.2.)

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

District Chief
U.S. Geological Survey
Water Resources Division
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

or

District Chief
U.S. Geological Survey
Water Resources Division
P.O. Box 1225
Cheyenne, WY 82001

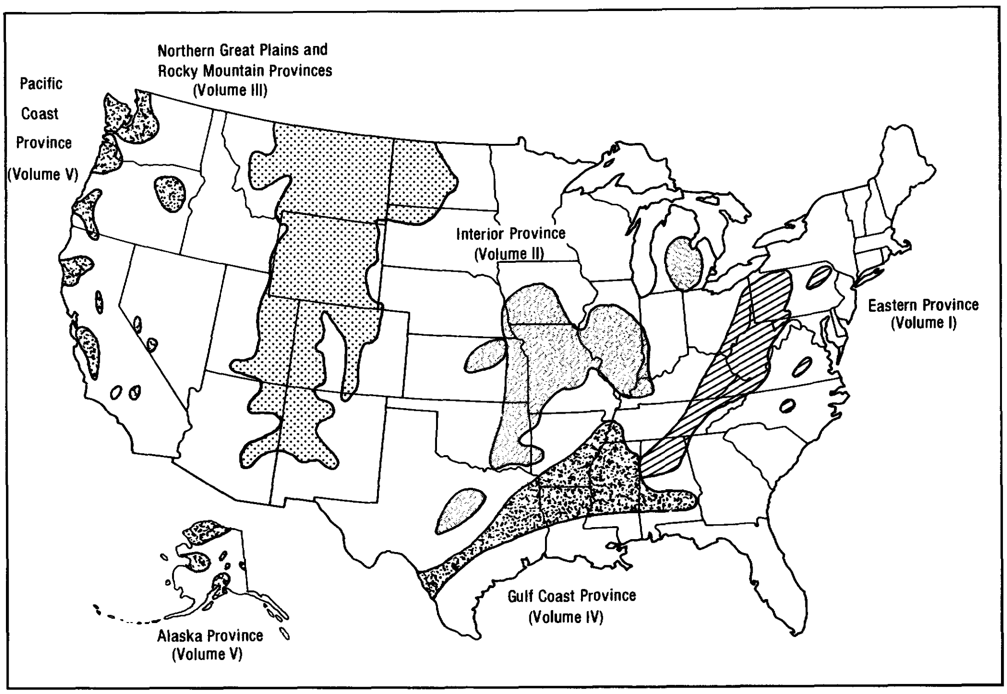


Figure 12.4-1 Index volumes and related provinces.

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

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

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

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

There are 1,800 water-quality parameters defined within STORET's WQF. In 1976 there were data from more than 200,000 unique collection points in the system. Figure 12.5-1 illustrates the groups of parameters and the number of observations that are in the WQF.

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

Director
Surveillance and Analysis Division
Environmental Protection Agency
1660 Lincoln Street Suite 103
Denver, CO 80295
(303) 837-2226

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

13.0 REFERENCES

AAA Engineering and Drafting, Inc., 1980a, Coal resource occurrence and coal development potential maps of the Eagle Hill quadrangle, Jackson and Larimer Counties, Colorado: U.S. Geological Survey Open-File Report 79-188, 24 p., 9 oversize sheets, scale 1:24,000.

_________1980b, Coal resource occurrence and coal development potential maps of Gould NW quadrangle, Jackson County, Colorado: U.S. Geological Survey Open-File Report 79-191, 25 p., 11 oversize sheets, scale 1:24,000.

_________1980c, Coal resource occurrence and coal development potential maps of Johnny Moore Mountain quadrangle, Jackson County, Colorado: U.S. Geological Survey Open-File Report 79-192, 21 p., 9 oversize sheets, scale 1:24,000.

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14.0 SUPPLEMENTAL INFORMATION FOR AREA 54

14.1 Surface-Water Station Index

SURFACE-WATER STATION INDEX

[D=discharge, Q=water quality, M=miscellaneous, and P=peak flow. (bio)=biological data also, (sed)=sediment data also]

Station No.	Station identification No.	Station name	Latitude	Longitude	Drainage area, in square miles	Type	Average discharge, in cubic feet per second	Maximum discharge, in cubic feet per second	Period of record: Discharge	Period of record: Water quality
1	06611000	Colorado Creek near Spicer, Co.	402631	1063005	25.8	D	23.5	408	1951-55	-------------
2	06611100	Grizzly Creek near Spicer, Co.	402037	1062657	118	D,Q	--------	864	1977-79	1977-80 (sed)
3	06611200	Buffalo Creek near Hebron, Co.	403123	1062207	56.3	D,Q	--------	180	1977-80	1977-80 (sed)
4	06611300	Grizzly Creek near Hebron, Co.	403327	1062322	223	D,Q	--------	1,130	1977-80	1977-80 (sed)
5	06611500	Grizzly Creek near Walden, Co.	403808	1062346	258	D	52.5	1,340	1904-05, 1923, 1926-47	-------------
6	06611700	Little Grizzly Creek near Coalmont, Co.	403305	1063657	10.1	D	20.2	300	1967-73	-------------
7	06611800	Little Grizzly Creek above Coalmont, Co.	403424	1063034	35.4	D,Q	--------	394	1977-79	1977-80 (sed)
8	06611900	Little Grizzly Creek above Hebron, Co.	403457	1062658	52.2	D,Q	--------	469	1977-80	1977-80 (sed)
9	06612000	Little Grizzly Creek near Hebron, Co.	403743	1062410	98.6	D	54.7	592	1904-05, 1931-45	-------------
10	06612500	Roaring Fork near Walden, Co.	404059	1062736	79.1	D	57.1	790	1904-05, 1924-47	-------------
11	06613000	North Platte River near Walden, Co.	404156	1062454	469	D	186	1,940	1904-05, 1924-47	-------------
12	06613500	North Fork North Platte River at Higho, Co.	404424	1062911	80.8	D	--------	380	1904-05	-------------
13	06614000	North Fork North Platte River near Walden, Co.	404340	1062441	160	D	74.9	694	1924-28, 1937-45	-------------
14	06614800	Michigan River near Cameron Pass, Co.	402946	1055152	1.53	D	2.85	44	1974-	-------------
15	06615000	South Fork Michigan River near Gould, Co.	402744	1060029	14.9	D	17.2	450	1951-58	-------------
16	06615500	Michigan River near Lindland, Co.	403313	1060228	61.4	D	37.3	663	1931-41	-------------
17	06616000	North Fork Michigan River near Gould, Co.	403258	1060114	21.2	D	17.2	290	1950-	-------------
18	06616500	Michigan River at Haworth School, near Lindland, Co.	403646	1060504	96.1	D	--------	580	1937-39	-------------
19	06617100	Michigan River at Walden, Co.	404428	1061644	182	D	55.7	1,070	1904-05, 1923-47	-------------
20	06617500	Illinois Creek near Rand, Co.	402745	1061035	70.8	D	32.8	745	1931-40	-------------
21	06618000	Willow Creek near Rand, Co.	402811	1061301	55.9	D	9.68	200	1931-40	-------------
22	06618500	Illinois Creek at Walden, Co.	404335	1061724	259	D	36.1	2,520	1923-47	-------------
23	06619000	Michigan River near Cowdrey, Co.	405142	1062012	479	D	50.2	1,010	1904-05, 1937-47	-------------
24	06619400	Canadian River near Lindland, Co.	404143	1060356	44	D,Q	--------	177	1978-	1978- (sed)
25	06619420	Williams Draw near Walden, Co.	404418	1060649	3.95	D,Q	--------	21	1979-	1979- (sed)
26	06619450	Canadian River near Brownlee, Co.	404829	1061409	158	D,Q	--------	352	1978-	1978- (sed)
27	06619500	Canadian River at Cowdrey, Co.	405147	1061839	180	D	29.8	802	1904-05, 1929-32, 1937-47	-------------
28	06620000	North Platte River near Northgate, Co.	405610	1062021	1,431	D,Q	431	6,720	1904, 1915-	1965- (bio)
29	06620400	Douglas Creek above Keystone, Wy.	411100	1061610	22.1	D	35.2	865	1955-60	-------------
30	06620500	Douglas Creek near Keystone, Wy.	411040	1061600	25.6	D	--------	840	1912-17	-------------
31	06621000	Douglas Creek near Foxpark, Wy.	410452	1061825	120	D	78.7	1,630	1946-72	-------------
32	06622000	Big Creek at Big Creek Ranger Station, Wy.	410300	1063130	106	D	99.2	1,300	1913-24	-------------
33	06622500	French Creek near French, Wy.	411230	1063100	59.6	D	89.4	1,680	1909-24	-------------
34	06622700	North Brush Creek near Saratoga, Wy.	412210	1063122	37.4	D	50	1,120	1960-	-------------
35	06622900	South Brush Creek near Saratoga, Wy.	412038	1063133	22.8	D	31.8	559	1960-74, 1976-	-------------
36	06623000	Brush Creek at upper station, near Saratoga, Wy.	412130	1063310	77	D	--------	989	1941-47	-------------
37	06623500	Brush Creek at lower station, near Saratoga, Wy.	411620	1063720	107	D	--------	2,120	1909-16	-------------
38	06623800	Encampment River above Hog Park Creek, near Encampment, Wy.	410125	1064927	72.7	D,Q	113	1,680	1965-	1967-
39	06623820	Hog Park Creek below Hog Park Reservoir, near Encampment, Wy.	410201	1065133	--------	M	--------	--------	1967-75	-------------
40	06623900	Encampment River near Encampment, Wy.	410150	1064930	105	D	156	2,290	1957-64	-------------
41	06624000	Encampment River above Encampment, Wy.	411200	1064640	205	D	--------	3,920	1940-44	-------------
42	06624500	Encampment River at Encampment, Wy.	411250	1064640	211	D	295	4,680	1900, 1909-32	-------------
43	06624900	Encampment River above Rainbow Canyon, near Encampment, Wy.	411628	1064338	--------	M	--------	--------	--------	1967
44	06625000	Encampment River at mouth, near Encampment, Wy.	411812	1064253	265	D,Q	240	4,510	1940-	1966-
45	06625500	Cow Creek near Saratoga, Wy.	411840	1064640	60	D	--------	290	1911-12	-------------
46	06626000	North Spring Creek near Saratoga, Wy.	412010	1070000	24.5	D	--------	370	1913-15	-------------
47	06626500	Spring Creek near Saratoga, Wy.	412540	1064800	152	D	--------	685	1911-12	-------------
48	06627000	North Platte River at Saratoga, Wy.	412718	1064816	2,840	D,Q	1,142	18,000	1903-06, 1909, 1911-70	1967-68
49	06627300	Jack Creek at Jack Creek Park, near Saratoga, Wy.	411800	1070703	12.2	D	--------	195	1967-68	-------------
50	06627500	Jack Creek at Matheson River, near Saratoga, Wy.	412400	1070000	41.2	D	23.2	334	1913-24	-------------
51	06627600	Jack Creek below Lower Jack Creek, near Saratoga, Wy.	412523	1065947	98.2	D	--------	546	1957-58, 1967-68	-------------
52	06628000	Jack Creek at Blydenburghs Ranch, near Saratoga, Wy.	412710	1065540	113	D	--------	735	1912-15	-------------
53	06628500	Jack Creek near Saratoga, Wy.	413000	1065000	138	D	--------	318	1911-12	-------------
54	06628700	Sage Creek below Adams Reservoir, near Rawlins, Wy.	412645	1071244	24.3	D	--------	80	1967-68	-------------
55	06628750	Sage Creek near Rawlins, Wy.	413105	1070815	52	D	--------	72	1967-68	-------------

Station No.	Station identification No.	Station name	Latitude	Longitude	Drainage area, in square miles	Type	Average discharge, in cubic feet per second	Maximum discharge, in cubic feet per second	Period of record	
									Discharge	Water quality
56	06628800	Sage Creek near Saratoga, Wy.	413453	1065917	263	D,Q	--------	1,800	1973-81	1972-81 (sed)
57	06628900	Pass Creek near Elk Mountain, Wy.	413510	1063637	91.5	D	40	1,180	1957-	-------------
58	06629000	Pass Creek near Saratoga, Wy.	413540	1063840	106	D	--------	450	1929-32	-------------
59	06629100	Rattlesnake Creek near Wolcott, Wy.	414156	1063734	13.9	P	--------	125	1962-74	-------------
60	06629150	Coal Bank Draw tributary near Wolcott, Wy.	414405	1064318	3.65	P	--------	787	1962-81	-------------
61	06629200	Coal Bank Draw tributary No. 2 near Wolcott, Wy.	414419	1064336	2.41	P	--------	839	1962-81	-------------
62	06629510	Pass Creek at Highway 130 Branch, Wy.	414246	1064923	--------	M	--------	--------	--------	1967
63	06629520	Pass Creek above Stage Station Springs, near Wolcott, Wy.	414211	1065029	--------	M	--------	--------	--------	1967
64	06629521	Pass Creek below Stage Station Springs, near Wolcott, Wy.	414151	1065029	--------	M	--------	--------	--------	1967
65	06629650	Kenny Creek near Hanna, Wy.	414412	1063619	.46	P	--------	15	1962-67	-------------
66	06629700	St. Mary Creek tributary near Sinclair, Wy.	414433	1065157	.46	P	--------	282	1959-71	-------------
67	06629800	Coal Creek near Rawlins, Wy.	414544	1071607	7.32	P	--------	436	1959-81	-------------
68	06630000	North Platte River above Seminoe Reservoir, near Sinclair, Wy.	415220	1070325	4,175	D,Q	1,106	14,500	1939-	1960- (bio)
69	06630200	Big Ditch tributary near Hanna, Wy.	415145	1063135	7.42	P	--------	470	1959-81	-------------
70	06630300	Big Ditch near Coyote Springs, Wy.	415607	1064801	110	D,Q	--------	396	1975-81	1975-81
71	06630330	North Ditch near Coyote Springs, Wy.	415644	1064806	22.6	D,Q	--------	49	1976-81	1975-81
72	06630350	Seminoe Reservoir at North Platte arm, near Seminoe Boat Club, Wy.	420035	1065019	--------	Q	--------	--------	--------	1972- (bio)
73	06630440	Medicine Bow River at Bow Ranger Station, near Elk Mountain, Wy.	413112	1062256	28.7	D	--------	1,120	1971-75	-------------
74	06630480	East Fork Medicine Bow River near Elk Mountain, Wy.	413255	1062346	17.8	D	--------	620	1971-75	-------------
75	06630500	Medicine Bow River near Elk Mountain, Wy.	413400	1062400	65.6	D	--------	660	1946-47	-------------
76	06630800	Bear Creek near Elk Mountain, Wy.	413911	1062041	8.93	P	--------	141	1962-74	-------------
77	06631000	Medicine Bow River near Medicine Bow, Wy.	414300	1061900	190	D	122	2,810	1911-17, 1919-25	-------------
78	06631100	Wagonhound Creek near Elk Mountain, Wy.	413824	1061817	25.6	P	--------	330	1962-74	-------------
79	06631140	Third Sand Creek tributary near Medicine Bow, Wy.	414500	1061900	.78	P	--------	189	1965-70	-------------
80	06631150	Third Sand Creek near Medicine Bow, Wy.	414500	1061900	10.8	P	--------	1,580	1965-81	-------------
81	06631200	Foote Creek near Arlington, Wy.	413702	1061356	5.49	P	--------	32	1962-68	-------------
82	06631260	Foote Creek tributary near Arlington, Wy.	413745	1061632	2.10	P	--------	22	1962-70	-------------
83	06631500	Medicine Bow River above Rock Creek, near Medicine Bow, Wy.	415255	1060905	436	D	52.4	1,340	1951-63	-------------
84	06632000	Deep Creek near Arlington, Wy.	412710	1061630	3.13	D	--------	116	1914-18	-------------
85	06632400	Rock Creek above King Canyon Canal, near Arlington, Wy.	413507	1061320	62.9	D	82.3	2,590	1966-	-------------
86	06632500	Rock Creek at Arlington, Wy.	413512	1061316	64.5	D	--------	1,720	1911-18, 1939-65	-------------
87	06632600	Threemile Creek near Arlington, Wy.	413318	1061019	6.31	P	--------	863	1962-74	-------------
88	06632700	Onemile Creek near Arlington, Wy.	413508	1061126	3.59	P	--------	210	1962-74	-------------
89	06633000	Rock Creek near Rock River, Wy.	414400	1055600	187	D	--------	1,350	1911-12, 1928-33	-------------
90	06633500	Rock Creek below Rock River, Wy.	414635	1055548	218	D,Q	29.2	1,490	1940-42, 1951-68	1966-68
91	06633800	Rock Creek above State Fish Hatchery, near Medicine Bow, Wy.	415502	1060112	--------	M	--------	--------	--------	1966-70
92	06633820	Rock Creek below State Fish Hatchery, near Medicine Bow, Wy.	415538	1060320	--------	M	--------	--------	--------	1968
93	06634600	Little Medicine Bow River near Medicine Bow, Wy.	415712	1060938	963	D,Q	60.2	9,500	1974	1965 (sed)
94	06634910	Medicine Bow River tributary near Hanna, Wy.	420032	1062932	3.01	P	--------	856	1965-	-------------
95	06634950	Willow Springs Draw tributary near Hanna, Wy.	415830	1063150	1.98	P	--------	255	1965-73	-------------
96	06634990	Hanna Draw near Hanna, Wy.	420022	1063030	21.6	D,Q	--------	385	1975-81	1974-81 (sed)
97	06635000	Medicine Bow River above Seminoe Reservoir, near Hanna, Wy.	420035	1063045	2,338	D,Q	178	6,590	1939-	1965- (sed)
98	06635100	Seminoe Reservoir at Medicine Bow River arm, near Seminoe Boat Club, Wy.	420233	1064933	--------	Q	--------	--------	--------	1972- (bio)
99	06635500	Seminoe Reservoir near Leo, Wy.	420921	1065429	7,230	D	--------	--------	1939-	-------------
100	06636000	North Platte River above Pathfinder Reservoir, Wy.	421042	1065233	7,241	D,Q	1,491	18,800	1914-39, 1951-59	1969-
101	06657500	Laramie River near Glendevey, Co.	404802	1055240	101	D	73.2	2,240	1904-05, 1910-	-------------
102	06658500	Laramie River near Jelm, Wy.	410008	1060051	294	D	160	4,200	1904-05, 1910-71	-------------
103	06659000	Laramie River at Woods Landing, Wy.	410640	1060040	392	D	343	4,500	1890-92, 1895-1911	-------------
104	06659500	Laramie River and Pioneer Canal near Woods Landing, Wy.	410817	1055849	434	D	--------	5,060	1912-24, 1926-27, 1931-	-------------
105	06659580	Sand Creek at Colorado-Wyoming State line	405944	1054536	29.2	D	--------	6,710	1968-	-------------
106	06659600	Sand Creek near Tie Siding, Wy.	410047	1054519	39.9	D	7.60	253	1957-68	-------------
107	06660000	Laramie River at Laramie, Wy.	411936	1053627	1,071	D,Q	105	3,250	1933-72	1968
108	06660070	Laramie River above Howell, Wy.	412205	1053540	--------	D,Q	--------	--------	1980-	1980-
109	06660100	Laramie River at Howell, Wy.	412450	1053656	--------	Q	--------	--------	--------	1901, 1974-
110	06660500	Laramie River at Two Rivers, Wy.	412822	1054330	1,224	D,Q	--------	2,990	1909-28, 1932-	1966-
111	06661000	Little Laramie River near Filmore, Wy.	411742	1060203	157	D	103	3,450	1902-03, 1911-26, 1932-	-------------
112	06661500	Little Laramie River at Two Rivers, Wy.	412807	1054356	376	D,Q	44	2,440	1903, 1910-27, 1933-72	1965-
113	06661530	Fourmile Creek near Centennial, Wy.	412829	1060255	7.34	D	--------	1,040	1963-68	-------------
114	06661580	Sevenmile Creek near Centennial, Wy.	412729	1060036	11.2	P	--------	528	1962-	-------------
115	06661585	Laramie River near Bosler, Wy.	413317	1054058	1,790	D	152	1,820	1973-	-------------
116	06661600	Dutton Creek near McFadden, Wy.	413418	1060454	19.9	D	1.87	186	1958-63	-------------
117	06662000	Laramie River near Lookout, Wy.	414544	1054116	2,174	D,Q	131	3,340	1912-17, 1921-27, 1932-	1976-
118	402918106125600	Willow Creek below Rand, Co.	402918	1061256	--------	M	--------	--------	--------	1976-77
119	402953105581000	Michigan River below Seven Utes Mountain, near Gould, Co.	402953	1055810	--------	M	--------	--------	--------	1976-77
120	403246106240600	Grizzly Creek near Coalmont, Co.	403246	1062406	--------	M	--------	--------	--------	1976-77
121	403256106343200	Little Grizzly Creek above Doran Creek, near Coalmont, Co.	403256	1063432	--------	M	--------	--------	--------	1980-81
122	403425106311500	Little Grizzly Creek above Chedsey Creek, near Coalmont, Co.	403425	1063115	--------	M	--------	--------	--------	1976
123	403440106270000	Little Grizzly Creek near Coalmont, Co.	403440	1062700	--------	M	--------	--------	--------	1976-77
124	403647106050400	Michigan River below Gould, Co.	403647	1060504	--------	M	--------	--------	--------	1976-77
125	403657106165000	Illinois River near Larand, Co.	403657	1061650	--------	M	--------	--------	--------	1976
126	403832106250600	North Platte River below Grizzly Creek, near Hebron, Co.	403832	1062506	--------	M	--------	--------	--------	1976-77
127	404059106273800	Roaring Fork River below Beaver Creek, near Walden, Co.	404059	1062738	--------	M	--------	--------	--------	1976
128	404143106035700	Canadian River above Muddy Creek, Co.	404143	1060357	--------	M	--------	--------	--------	1976-77
129	404208106272000	South Delaney Lake, Co.	404208	1062720	--------	M	--------	--------	--------	1975
130	404242106265900	East Delaney Lake, Co.	404242	1062659	--------	M	--------	--------	--------	1975
131	402445106275900	North Delaney Lake, Co.	404245	1062759	--------	M	--------	--------	--------	1975
132	404317106073501	Williams Draw 1.5 miles above station 06619420, Co.	404317	1060735	--------	M	--------	--------	--------	1979
133	404335106172300	Illinois River near Walden, Co.	404335	1061723	--------	M	--------	--------	--------	1976-77
134	404346106154800	Michigan River near Walden, Co.	404346	1061548	--------	M	--------	--------	--------	1976-77
135	404346106235300	North Platte River below North Fork North Platte River, near Walden, Co.	404346	1062353	--------	M	--------	--------	--------	1976
136	404351106271200	Hell Creek near mouth, near Walden, Co.	404351	1062712	--------	M	--------	--------	--------	1976
137	404406106251000	North Fork North Platte River above mouth, near Walden, Co.	404406	1062510	--------	M	--------	--------	--------	1976
138	404555106275300	Lake John, Co.	404555	1062753	54.6	M	--------	--------	--------	1975
139	404729106283700	Lake John, Co.	404729	1062837	--------	M	--------	--------	--------	1975
140	404828106141300	Canadian River at Dunways Bridge, near Walden, Co.	404828	1061413	--------	M	--------	--------	--------	1976-77
141	405447106172600	Pinkham Creek near Northgate, Co.	405447	1061726	--------	M	--------	--------	--------	1976
142	405607106363500	Lower Big Creek Lake, Co.	405607	1063635	50	M	--------	--------	--------	1975
143	405750106340600	South Fork Big Creek near Pearl, Co.	405750	1063406	--------	M	--------	--------	--------	1976
144	411009106285801	North Platte River below Mullen Creek, near Encampment, Wy.	411009	1062858	--------	M	--------	--------	--------	1977-78
145	411523106382201	North Platte River above Beaver Creek, near Encampment, Wy.	411523	1063822	--------	M	--------	--------	--------	1977-78
146	411555106443501	Encampment River at Baggot Bridge, near Encampment, Wy.	411555	1064435	--------	M	--------	--------	--------	1977-78
147	412117106433201	North Platte River at Wyoming Highway 130, near Saratoga, Wy.	412117	1064332	--------	M	-------	--------	--------	1977-78

GROUND-WATER SITE INDEX

Site No.	Site identification No.	Local well No.	Principal aquifer	Depth of well, in feet	Period of record	
					Water levels	Water quality
1	402246106060101	SB05N 078W 26AAD01	Coalmont Formation	70	1976-81	----------
2	403106106021701	SB06N 077W 04CAA01	Coalmont Formation	40	1976-81	----------
3	403032106001301	SN06N 077W 11BAC01	Coalmont Formation	52	1976-81	----------
4	402900106245301	SB06N 080W 18DCD01	Coalmont Formation	-----	--------	1979
5	403022106362701	SB06N 082W 09BDD01	Coalmont Formation	100	1976-81	----------
6	403440106252801	SB07N 080W 18BCC01	Coalmont Formation	-----	--------	1979
7	403449106251501	SB07N 080W 19BCD01	Coalmont Formation	-----	--------	1979
8	403702106164601	SB08N 079W 32DBD01	North Park Formation	52	1974-81	----------
9	404155106203301	SB08N 080W 02BAC01	North Park Formation	68	1975-81	----------
10	403814106233001	SB08N 080W 29ACD01	North Park Formation	30	1976-81	----------
11	404419106165201	SB09N 079W 21BCC01	Coalmont Formation	28	1976-81	----------
12	404718106164601	SB10N 079W 32DDD01	Coalmont Formation	97	1974-81	----------
13	410145106253801	12N 080W 07BAA01	North Park Formation	145	--------	1967
14	410725105325301	13N 073W 02CAA01	Casper Formation	110	1966-77	----------
15	410417105444201	13N 074W 30BBC01	Casper Formation	80	--------	1968
16	410439106292301	13N 081W 22CCB01	North Park Formation	-----	1980-81	----------
17	411102105371501	14N 073W 18ACD01	Chugwater Group	-----	--------	1968
18	410847105585201	14N 077W 25DCD01	Holocene alluvium	75	1948-53, 1959-76	----------
19	411016106384401	14N 082W 19ADA01	North Park Formation	85	1967, 1980-81	----------
20	411234106424601	14N 083W 03CAB01	North Park Formation	58	1980-81	----------
21	411750105350001	15N 073W 04DB 01	Casper Formation	952	--------	1943
22	411602105322801	15N 073W 14DAC01	Casper Formation	165	--------	1958
23	411808106464001	15N 083W 06BBC01	North Park Formation	101	1980-81	----------
24	411448106401701	15N 083W 24DCC01	North Park Formation	153	1967, 1980-81	----------
25	411307106442601	15N 083W 32DDD01	North Park Formation	92	1967-81	----------
26	411353106425701	15N 083W 34BAB01	North Park Formation	61	1980-81	----------
27	411306106425701	15N 083W 34CDC01	North Park Formation	91	1965, 1968, 1980	1966
28	411707106491301	15N 084W 10ADB01	North Park Formation	330	1980-81	----------
29	411602106480101	15N 084W 14ADC01	North Park Formation	-----	1980-81	----------
30	411858106423101	16N 083W 34ABD01	Holocene alluvium	-----	1980-81	----------
31	412202106511401	16N 084W 09CBC01	North Park Formation	202	1968, 1980-81	----------
32	411914106523101	16N 084W 30DDA01	North Park Formation	130	1980-81	----------
33	412211106560001	16N 085W 10ADD01	Browns Park Formation	100	--------	1967
34	412534105342101	17N 073W 22CCD01	Chugwater Group	100	--------	1943
35	412737105552901	17N 076W 10CBB01	Mesaverde Group	67	--------	1968
36	412610106420401	17N 083W 23BAC01	North Park Formation	85	1980-81	----------
37	412501106442901	17N 083W 28BCD01	North Park Formation	54	1980-81	----------
38	412416106425201	17N 083W 34ACB01	North Park Formation	136	1980-81	----------
39	412731106514501	17N 084W 08DAD01	Browns Park Formation	-----	1980-81	----------
40	412626106482401	17N 084W 14DDB01	North Park Formation	150	1967-68, 1970-75	----------
41	412610106552401	17N 085W 23AAC01	North Park Formation	156	1967-68, 1977-81	----------
42	413147106440401	18N 083W 16DBD01	North Park Formation	63	1949, 1980-81	----------
43	413148106453701	18N 083W 17CAC01	North Park Formation	92	1980-81	----------

Site No.	Site identification No.	Local well No.	Principal aquifer	Depth of well, in feet	Period of record: Water levels	Period of record: Water quality
44	413816105325601	19N 073W 02CDD01	Forelle Limestone	100	1965-79	----------
45	413419105391301	19N 074W 36CCA01	Steele Shale	800	1968, 1970-81	----------
46	413837106415101	19N 083W 02DCB01	North Park Formation	195	1980-81	----------
47	413812106431601	19N 083W 10BDB01	North Park Formation	-----	--------	1950, 1967
48	413501106411701	19N 083W 25CCC01	North Park Formation	175	1967, 1980-81	----------
49	413701106494701	19N 084W 15DBD01	Browns Park Formation	600	1950-54, 1958-69, 1980-81	----------
50	414104106442701	20N 083W 28BAB01	North Park Formation	33	1950-81	----------
51	414325106480501	20N 084W 12BCA01	Browns Park Formation	130	--------	1968
52	414103106473401	20N 084W 25AAB01	Browns Park Formation	135	1980-81	----------
53	414538106030501	21N 077W 27CBC01	Mesaverde Group	80	--------	1968
54	414554106130301	21N 078W 30ACB01	Mesaverde Group	2,121	--------	1968
55	414828106205601	21N 080W 12ACA01	Hanna Formation	310	1977-80	1977
56	414657106213601	21N 080W 24BBA01	Hanna Formation	200	1977-80	1977
57	414643106384701	21N 082W 21BDA01	North Park Formation	200	--------	1967, 1978
58	414709106450701	21N 083W 16DDA01	Mesaverde Group	1,503	--------	1967, 1978
59	414542106503001	21N 084W 26CAB01	Lewis Shale	80	1965-68	----------
60	414459106502101	21N 084W 35BDA01	Browns Park Formation	160	--------	1968
61	415401106223601	22N 080W 02CDC01	Ferris Formation	120	--------	1968, 1978
62	414932106232201	22N 080W 34DCD01	Hanna Formation	310	1976-80	1977
63	414928106215601	22N 080W 35DDC01	Hanna Formation	175	1977-80	1977
64	415209106312801	22N 081W 21AAB01	Hanna Formation	150	1976-80	----------
65	415210106312602	22N 081W 21AAB02	Hanna Formation	150	1976-80	1977
66	414942106340401	22N 081W 31CCD01	Hanna Formation	140	1976-80	1977
67	414942106340602	22N 081W 31CDD02	Hanna Formation	260	1976-80	1977
68	414938106312201	22N 081W 33DDC01	Hanna Formation	120	--------	1977
69	415336106345501	22N 082W 12ACD01	Hanna Formation	240	1976-79	1977
70	415144106403801	22N 082W 19DAB01	Ferris Formation	210	1976-78	----------
71	415102106413301	22N 082W 30BCB01	Ferris Formation	220	1976-80	----------
72	415005106411701	22N 082W 31BCD01	Ferris Formation	140	1976-80	1977
73	415026106391201	22N 082W 32AAA01	Ferris Formation	250	1976-80	----------
74	415408106463001	22N 083W 05DDB01	Ferris Formation	-----	1967, 1974-80	1968, 1976
75	415525105514801	23N 075W 31ACD01	Chugwater Group	418	--------	1968
76	415750106225001	23N 080W 14CBA01	Medicine Bow Formation	110	1976-78	1977
77	415542106271501	23N 080W 31BAB01	Hanna Formation	208	--------	1977
78	415831106320101	23N 081W 09CAC01	Hanna Formation	300	1976-80	----------
79	415830106320302	23N 081W 09CAC02	Hanna Formation	200	1976-80	----------
80	415830106320503	23N 081W 09CAC03	Hanna Formation	175	1976-80	1977
81	415752106293101	23N 081W 14BDD01	Hanna Formation	480	1978-80	----------
82	415730106294501	23N 081W 14CDB01	Hanna Formation	390	1978-80	----------
83	415700106244401	23N 081W 21BDD01	Hanna Formation	185	--------	1977
84	415656106282001	23N 081W 24DBB01	Hanna Formation	281	1978-80	----------
85	415529106332501	23N 081W 32AAA01	Hanna Formation	200	1977-80	1977
86	415514106280901	23N 081W 36ABB01	Hanna Formation	254	--------	1977
87	415740106361901	23N 082W 14DBC01	Hanna Formation	160	1978-80	----------
88	415740106361902	23N 082W 14DBC02	Hanna Formation	170	1978-80	----------
89	415939106443901	23N 083W 03BDC01	Hanna Formation	126	1976-80	1976
90	415937106461301	23N 083W 04BCC01	Ferris Formation	387	1976-80	1977

Site No.	Site identification No.	Local well No.	Principal aquifer	Depth of well, in feet	Period of record: Water levels	Period of record: Water quality
91	415945106474401	23N 083W 06ACA01	Ferris Formation	303	1976-80	1977
92	415958106482901	23N 083W 06BBB01	Ferris Formation	146	1974-80	1974, 1977
93	415938106482101	23N 083W 06BCD01	Ferris Formation	265	1976-80	1977
94	415908106472701	23N 083W 06DDD01	Ferris Formation	200	1974-80	1974, 1977
95	415838106480701	23N 083W 07CAA01	Ferris Formation	124	1967, 1974-80	1976
96	415816106461501	23N 083W 08DDD01	Ferris Formation	412	1976-80	1977
97	415808106413701	23N 083W 13AAD01	Hanna Formation	-----	1967, 1976-80	1968
98	415727106473101	23N 083W 18DDD01	Ferris Formation	275	1976-80	1977
99	415657106472501	23N 083W 19ADD01	Ferris Formation	380	1974	----------
100	415716106482601	23N 083W 19BDB01	Ferris Formation	195	1974-80	----------
101	415722106455301	23N 083W 21BAB01	Ferris Formation	140	1976-80	1977
102	415710106454601	23N 083W 21BDA01	Hanna Formation	-----	1967, 1974-80	----------
103	415631106462601	23N 083W 29AAB01	Ferris Formation	150	1976-79	1977
104	415548106465201	23N 083W 29CDA01	Ferris Formation	171	1974-77	----------
105	415607106480101	23N 083W 30BDD01	Holocene Alluvium	24	1975-80	----------
106	415530106461601	23N 083W 32AAD01	Ferris Formation	140	1975-78	1975, 1977
107	415539106463301	23N 083W 32ABA01	Ferris Formation	130	1975-78	1975, 1977
108	415530106463301	23N 083W 32ABD01	Ferris Formation	200	-------	1977
109	415513106463501	23N 083W 32ACD01	Ferris Formation	130	1974-78	----------
110	415521106461801	23N 083W 32ADA01	Ferris Formation	115	1974-76	1975
111	415506106464201	23N 083W 32DBC01	Ferris Formation	300	1975-80	1975, 1977
112	415537106461101	23N 083W 33BBB01	Ferris Formation	320	1977-79	1977
113	415533106460901	23N 083W 33BBC01	Ferris Formation	198	1977-79	1977
114	415532106455901	23N 083W 33BDB01	Ferris Formation	-----	1974-80	----------
115	415509106453801	23N 083W 33DBC01	Ferris Formation	148	1977-79	----------
116	415852106490301	23N 084W 12ACB01	Ferris Formation	121	1974-79	1974
117	415508106494401	23N 084W 35DAA01	Ferris Formation	220	1976-79	----------
118	415508106494602	23N 084W 35DAA02	Ferris Formation	236	1976-78	----------
119	415652107014201	23N 085W 19DBD01	Mesaverde Group	119	1967-81	----------
120	420139106313901	24N 081W 26ABA01	Hanna Formation	120	1977-78	1967
121	420022106313301	24N 081W 33DBA01	Hanna Formation	193	1976-80	1977
122	420026106303001	24N 081W 34ACD01	Holocene alluvium	35	1975-80	----------
123	420035106304501	24N 081W 34BDA01	Holocene alluvium	15	1975-80	----------
124	420009106285701	24N 081W 35DAD01	Hanna Formation	231	1976-79	1977
125	420203106421901	24N 083W 24CAA01	Hanna Formation	274	1967-68, 1977-78	1977
126	420052106472801	24N 083W 30DDD01	Ferris Formation	205	1974-80	1974,1976, 1977
127	420051106475301	24N 083W 31ABB01	Ferris Formation	210	1976-78	----------
128	420051106475402	24N 083W 31ABB02	Ferris Formation	200	1976-78	----------
129	420052106475483	24N 083W 31ABB03	Ferris Formation	150	1976-78	----------
130	420049106480701	24N 083W 31BAA01	Ferris Formation	95	--------	1977
131	420048106480901	24N 083W 31BAB01	Ferris Formation	116	1977-79	1977
132	420035106480301	24N 083W 31BAD01	Ferris Formation	220	1976-78	----------
133	420035106480402	24N 083W 31BAD02	Ferris Formation	220	1976-79	----------
134	420019106481201	24N 083W 31CAB01	Ferris Formation	317	1977-78	1977
135	420019106481202	24N 083W 31CAB02	Ferris Formation	320	1977-78	----------
136	420044106465201	24N 083W 32BAA01	Ferris Formation	250	1976-79	1977
137	420001106461501	24N 083W 32DDD01	Ferris Formation	97	1974-80	1974, 1976
138	420027106484301	24N 084W 36ADC01	Ferris Formation	300	1976-80	1977

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