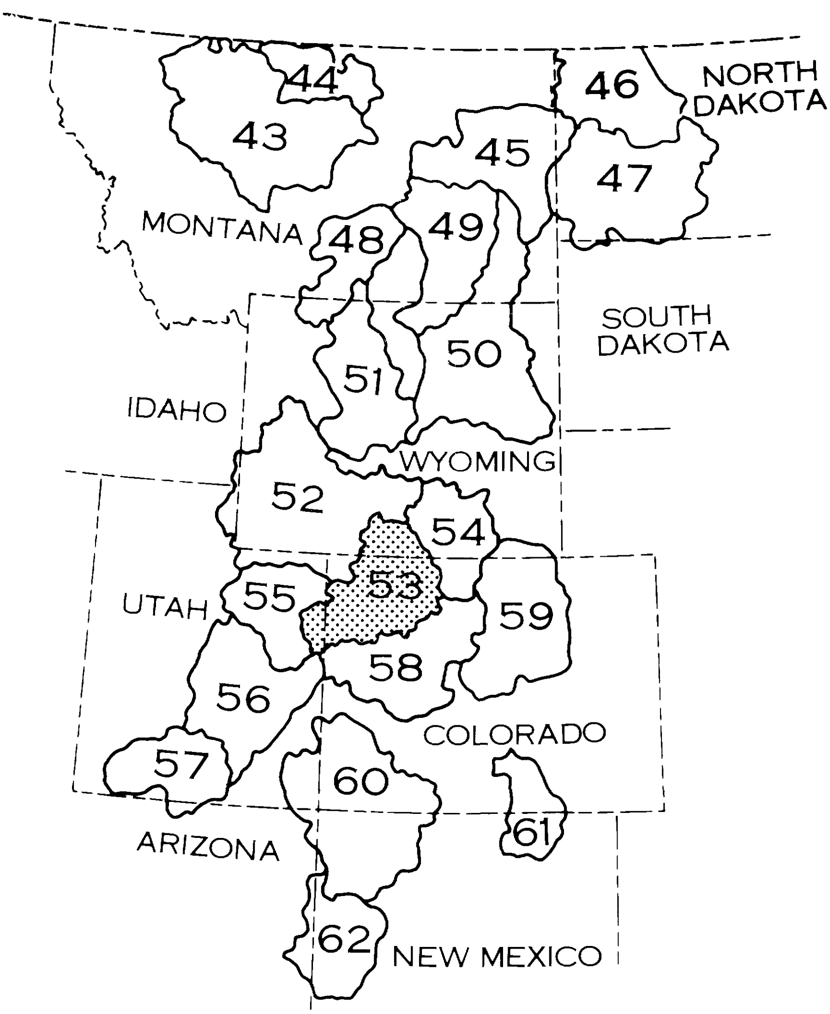
HYDROLOGY OF AREA 53, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, COLORADO, WYOMING AND UTAH



- YAMPA RIVER
- WHITE RIVER
- LITTLE SNAKE RIVER
- PICEANCE CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-765

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LAKEWOOD, COLORADO
SEPTEMBER, 1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *SECRETARY*

GEOLOGICAL SURVEY

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

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

Multiply	By	To obtain
acre-feet (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)
acre feet per square mile per year [$(acre\text{-}ft/mi^2)/yr$]	476.1	cubic meters per square kilometer per year [$(m^3/km^2)/a$]
gallons per minute (gal/min)	0.06309	liters per second (L/s)
gallons per minute per square mile [$(gal/min)/mi^2$]	0.02436	liter per second per square kilometer [$(L/s)/km^2$]
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)
square miles (mi^2)	2.590	square kilometers (km^2)
tons, short	0.9072	metric tons (t)

$$°F = 1.8 \times °C + 32$$

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

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Abstract

Hydrologic information and analysis are needed to aid in decisions to lease Federally owned coal and for the preparation of the necessary Environmental Assessments and Impact Study Reports. This need has become even more critical with the enactment of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). This report, one in a series of nationwide coal province reports, presents information thematically by describing single hydrologic topics through the use of brief texts and accompanying maps, graphs, or other illustrations. The report broadly characterizes the hydrology of Area 53 in northwestern Colorado, south-central Wyoming, and northeastern Utah.

The report area, located primarily in the Wyoming Basin and Colorado Plateau physiographic provinces, consists of 14,650 square miles of diverse geology, topography, and climate. This diversity results in contrasting hydrologic characteristics.

The two major rivers, the Yampa and the White Rivers, originate in humid granitic and basaltic mountains, then flow over sedimentary rocks underlying semiarid basins to their respective confluences with the Green River. Altitudes range from 4,800 to greater than 12,000 feet above sea level. Annual precipitation in the mountains, as much as 60 inches, is generally in the form of snow. Snowmelt produces most streamflow. Precipitation in the lower altitude sedimentary basins, ranging from 8 to 16 inches, is generally insufficient to sustain streamflow; therefore, most streams originating in the basins (where most of the streams in coal-mining areas originate) are ephemeral.

Streamflow quality is best in the mountains where dissolved-solids concentrations generally are small. As streams flow across the sedimentary basins, mineral dissolution from the sedimentary rocks and irrigation water with high mineral content increase the dissolved-solids concentrations in a downstream direction. Due to the semiarid climate of the basins, soils are not adequately leached; consequently, flows in the ephemeral streams usually have larger concentrations of dissolved solids than those in perennial streams.

Ground-water supplies are restricted by the low yields of wells due to small permeability. Most ground-water use is for domestic and stock-watering purposes; it is limited by the amount and type of dissolved material.

The ground-water ionic composition is highly variable. Dissolved-solids concentrations for aquifers sampled in Area 53 range from a minimum of 46 milligrams per liter to a maximum of 109,000 milligrams per liter. Trace element concentrations generally are not a problem.

An estimated 82 billion tons of coal exist above a depth of 6,000 feet in the Colorado parts of the area. The coal beds of greatest economic interest occur in the sedimentary deposits of the Upper Cretaceous Iles and Williams Fork Formations of the Mesaverde Group and the Upper Cretaceous Lance Formation and the Fort Union and Wasatch Formations of Tertiary age. The coal characteristically has a low sulfur content.

Hydrologic problems related to surface mining are erosion, sedimentation, decline in water levels, disruption of aquifers, and degradation of water quality. Because the semiarid mine areas have very little runoff and the major streams have large buffer and dilution capacities, the effects of mining on surface water are minimal. However, effects on ground water may be much more severe and long lasting.

1.0 DEFINITION OF TERMS

Terms Used in Hydrologic Reports Defined

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

Alkalinity is the capacity of a solution to neutralize acid. It can be attributed principally to the presence of bicarbonate and carbonate ions, which are formed largely by the dissolution of carbonate minerals, such as calcite. Actual concentrations of bicarbonate and carbonate ions are not always available from routine chemical analyses; therefore, alkalinity is normally expressed in terms of an equivalent concentration of calcium carbonate.

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.

Bituminous coal is a coal which ranks below anthracite, containing about 80 percent carbon and 10 percent oxygen.

Cation is a positively charged ion.

Coefficient of determination (r^2), in linear regression, is the square of the correlation coefficient. The coefficient of determination $\times 100$ provides a measure of the percentage of the variation of the dependent variable explained by variation of the independent variable.

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 correctly, volume of water 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.

Dispersion is the three-dimensional diffusion of waterborne materials in the stream channel. First, vertical and then lateral dispersion occurs depending upon stream width and velocity variations. Most importantly, longitudinal dispersion, having no boundaries, continues indefinitely.

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. The major cations involved are calcium, sodium, magnesium, and potassium; the major anions are bicarbonate, sulfate, and chloride.

Diversity is the relationship between the number of individuals or organisms representing each kind or major group. In general, clean, unpolluted water will support many kinds of bottom fauna, but because of natural predation and competition effects, the number of individuals representing each kind will be low (high diversity). However, most forms of stress reduce or simplify the complexity of the aquatic ecosystem, with the reduction of sensitive species and increase in number of tolerant organisms (low diversity).

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.

Flood-frequency curve is a cumulative distribution curve of peak flow that would expect to be equaled or exceeded at given recurrence intervals.

Flow-duration curve is a cumulative frequency curve showing the percentage of time that streamflows were equaled or exceeded in a given period.

Functional groups are a conceptual grouping of organisms described according to their adaptations for food acquisition. Benthic invertebrates generally are categorized into five distinct functional (feeding) groups. These groups are the shredders, scrapers, collector-gatherers, collector-filterers and predators .

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.

Ground-water underflow is when an aquifer may be discharged by underflow to a nearby, hydraulically connected aquifer.

Hogback is a long sharp-crested ridge carved by differential erosion from a steeply dipping layer or series of layers of resistant rocks.

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 past a point in a given period of time such as a day, month, or year.

Low-flow frequency curve is a cumulative frequency distribution curve that shows the minimum average flow during a given consecutive time period that would be expected at a given recurrence interval and generally is based on the climatic year (April 1 to March 31).

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 solution. One thousand micrograms per liter is equivalent to one milligram per liter.

Micromho (μmho) is one-millionth of a mho which is the practical unit of specific conductance equal to the reciprocal of the ohm.

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 solution.

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 quality data are collected systematically over a period of years for use in hydrologic analyses.

Perennial stream is one which flows continuously.

Permeability is the property or state of allowing gases or fluids to pass through.

pH is the negative base-10 logarithm of the hydrogen-ion concentration (activity) in moles per liter. A pH of 7.0 indicates neutral water, less than 7.0 indicates acidic water, and larger than 7.0 indicates basic water.

Reaeration is the physical absorption of oxygen from the atmosphere by the flowing stream in order to replace the dissolved oxygen consumed in the oxidation of organic wastes.

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.

Recurrence interval is (1) The average time interval between actual occurrences of a hydrologic event of a given or greater magnitude; (2) in an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum; and (3) in partial duration series, the average interval between floods of a given size, regardless of their relationship to the year or any other period of time.

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 dissolved in water.

Specific conductance is a measure of the ability of water to conduct an electrical current. It is expressed in micromhos per centimeter at 25 degrees Celsius. 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.

Subbituminous coal is a coal of rank between lignite and bituminous.

Surface geophysics, in this report, is the application of electrical and seismic methods at the ground surface to the exploration for underground supplies of water.

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.

Taxon is any classification category of organisms, such as phylum, class, order, or species.

Time of travel is the movement of water or waterborne materials from point to point in a stream for steady or gradually varied flow conditions.

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 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.

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

Volatile is the capability of being readily evaporated at relatively low temperatures.

2.0 INTRODUCTION

2.1 Study Area

Area 53 in Northern Great Plains and Rocky Mountain Coal Provinces

The Yampa and the White Rivers drain Area 53, an area of diverse physical features, and a clustered population distribution.

Coal provinces have been divided nationwide into hydrologic reporting areas consisting of hydrologic units (drainage basins) selected according to size, location, and presence of coal resources. Area 53, located in northwestern Colorado, south-central Wyoming, and northeastern Utah, is one of the report areas in the Northern Great Plains and Rocky Mountain coal provinces (see front cover). The Yampa River and its three main tributaries--the Little Snake and the Elk Rivers and the Williams Fork--and the White River and its major perennial tributary, Piceance Creek, drain the 14,650-square-mile area (fig. 2.1-1). Area 53 only consists of the Yampa River and the White River basins. The study area encompasses all or parts of the following counties: Moffat, Rio Blanco, Garfield, and Routt in Colorado; Sweetwater and Carbon in Wyoming; and Uintah in Utah.

Major perennial streams in the Yampa River basin 9,530 mi^2 (square miles) originate in the Sierra Madre and The Flat Tops along the eastern and southeastern edges of the basin. The Yampa River primarily flows from east to west through the Colorado towns of Steamboat Springs and Craig to its confluence with the Green River in Dinosaur National Monument in the extreme northwest corner of Colorado. The Little Snake River subbasin (approximately 3,770 mi^2), the largest subbasin in the Yampa River basin, originates in the Wyoming part of the Sierra Madre and flows to the southwest to its confluence with the Yampa River in the northwest part of Colorado. The Elk River subbasin (approximately 425 mi^2) originates in the Colorado part of the Sierra Madre and flows southward to its confluence with the Yampa River near Steamboat Springs. The Williams Fork subbasin (approximately 341 mi^2) originates in The Flat Tops and flows northwest to its confluence with the Yampa River west of Craig.

The White River (5,120 mi^2) has its headwaters in The Flat Tops and flows westward through Meeker, Colo., and Rangely, Colo., to its confluence with the Green River in Utah. The Piceance Creek subbasin (approximately 630 mi^2) has its headwaters in the Roan Plateau and flows northward to its confluence with the White River west of Meeker.

The physical features of these two basins are diverse. The surface geology includes formations from Precambrian to Quaternary age. Altitudes in the Yampa River basin range from 5,000 feet near the confluence of the Yampa and the Green Rivers to 12,354 feet on The Flat Tops. In the White River basin altitudes range from 4,810 feet at the confluence of the White River with the Green River to 11,998 feet on Shingle Peak in The Flat Tops.

As a result of large altitude differences, the climate varies from semiarid with as little as 8 inches of precipitation per year to subalpine zones with as much as 60 inches of precipitation per year. As a result of varied climate, vegetation varies from sagebrush to conifer; moisture most frequently is the limiting factor in the distribution of the vegetation.

The population of Area 53 is distributed among many small to medium-sized rural communities. The population figures from the 1980 census are as follows: Garfield County--22,514; Moffat County--13,133; Rio Blanco County--6,255; Routt County--13,404; Carbon County--21,896; Sweetwater County--41,723; and Uintah County--20,506. Most of the population of Garfield, Carbon, Sweetwater, and Uintah Counties is outside the study area. Well over one-half of the area's population is found in the Colorado towns of Craig and Steamboat Springs; Meeker and Rangely are the next two largest towns. During summer and winter recreation months, this region receives large influxes of persons not included in the census figures.

The economic base of the Yampa and the White River basins traditionally has been agricultural, primarily dominated by cattle and sheep ranching and by crop productions including corn, wheat, oats, barley, rye, hay, and potatoes. In recent years, recreational activities such as skiing, hunting, camping and rafting have stimulated the local economy. As a result retail business supports 20 percent of the regional work force. The timber industry provides some jobs in the Yampa River basin. In recent years, coal and petroleum production and associated conversion facilities have significantly affected the local economy. According to U.S. Soil Conservation Service (1966), mining is the most important economic activity in northwestern Colorado. If interest in oil and gas exploration and oil-shale development is renewed, additional population increase in the White River basin is likely.

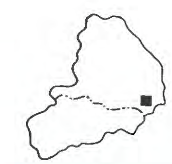
Further readings on the general features of Area 53 are found in U.S. Bureau of Land Management (1976, 1980), Melancon and others (1980), and Steele and others (1979). Extensive literature is available for this area.

nd Creek in the Snake River subbasin, Wyo.

avy snows during May in The Flat Tops
lderness Area near Trappers Lake, Colo.

Figure 2.1-1 Drainage basins and subbasins.

Piceance Creek subbasin, Colo., with the Roan Plateau in the background



Coal spoils by the ephemeral Foidel Creek in the semi-arid valleys near Hayden, Colo.

Report Summarizes Available Hydrology Data

Existing hydrologic conditions and sources of information are identified to aid leasing decisions, and preparation and appraisal of Environmental Impact studies and mine-permit applications.

Hydrologic information and analysis are needed to aid in decisions to lease Federally owned coal and for the preparation of the necessary Environmental Assessments and Impact Study Reports. This need has become even more critical with the enactment of Public Law 95-87, the "Surface Mining Control and Reclamation Act of 1977." This Act requires an appropriate regulatory agency to issue mining permits based on the review of permit application data to assess hydrologic impacts. This need is partly fulfilled by this report, which broadly characterizes the hydrology of Area 53 in Colorado, Wyoming, and Utah, a part of the Northern Great Plains and Rocky Mountain Coal Provinces (fig. 2.2-1). This report is one of a series that describes coal provinces nationwide.

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

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

ecipitation in the form of snow, as shown here on The Flat Tops, the principle source of streamflow in Area 53

oal trains, which deliver coal to power plants in the area and Denver, e loaded at the coal tipple in Foidel Creek drainage

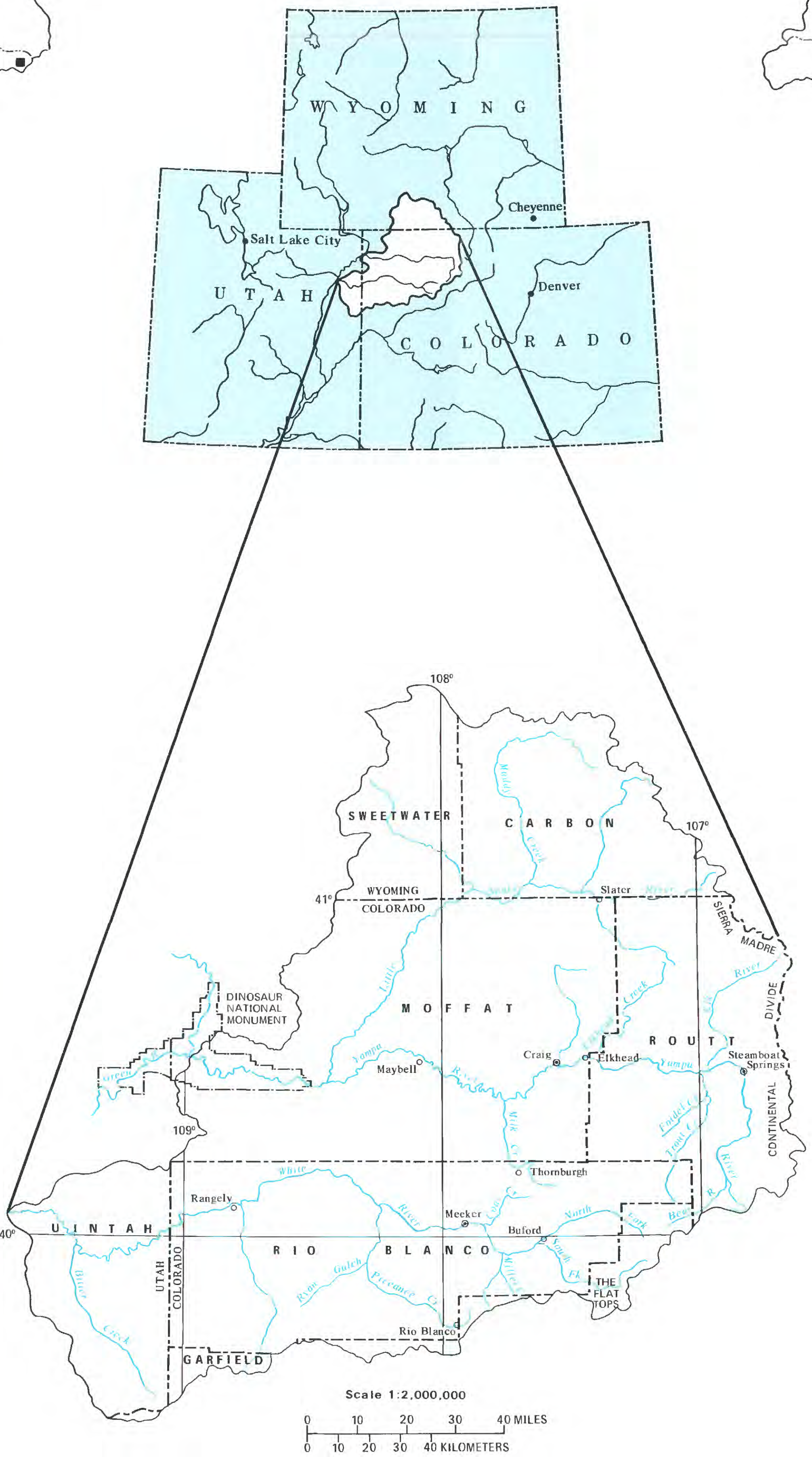


Figure 2.2-1 Location of Area 53.

Coal is strip mined in Trout Creek Valley with the Sierra Madres in the background

Streams meandering through broad, hilly terrain are charcteristic of Area 53

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. These hydrologic changes can affect amounts of suspended sediment carried by streams and amounts of dissolved solids and dissolved or total recoverable trace elements in surface water.

The hydrologic setting of Area 53 with respect to coal mining is similar to that of other coal areas in the Rocky Mountain coal province. The major rivers--the Yampa and the White Rivers--and their principal tributaries all have headwaters in mountains some distance from the coal areas. Streams originating in the coal areas generally 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, which are generally composed of igneous and metamorphic rock, are very different geologically from the coal areas, which are in sedimentary rock. Most of the water quantity and its associated water quality, then, are foreign to the coal region environment through which the water merely is transported. These factors, in part, help to reduce the impacts from mining because runoff from mine areas is relatively small and the larger streams usually have a large dilution capacity. On the other hand, analysis of the system is more difficult because both the major streams and the small tributaries draining the coal areas must be analyzed singly and combined.

A characteristic of ephemeral streams in this area is that they often have larger concentrations of suspended sediment than the perennial streams. The loss of vegetative cover and the formation of areas of unconsolidated spoil material provide 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 runoff management and the use of settling ponds.

Dissolved-solids concentrations in this area also are much larger naturally in ephemeral streams than in perennial streams. Soluble salts and minerals tend to accumulate in the soil 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 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 non-coal 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 occurrence 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.

Landscape changes, such as vegetation removal, excavation, and formation of large areas of unconsolidated and unweathered spoil material, will result in some changes in the hydrologic characteristics of the mine area

This view of a settling pond at the headwaters of Haggerty Creek shows acid mine drainage from an abandoned copper mine (courtesy of Wyoming Fish and Game Commission)

Quality and Quantity of Ground Water can be Affected by Surface Mining

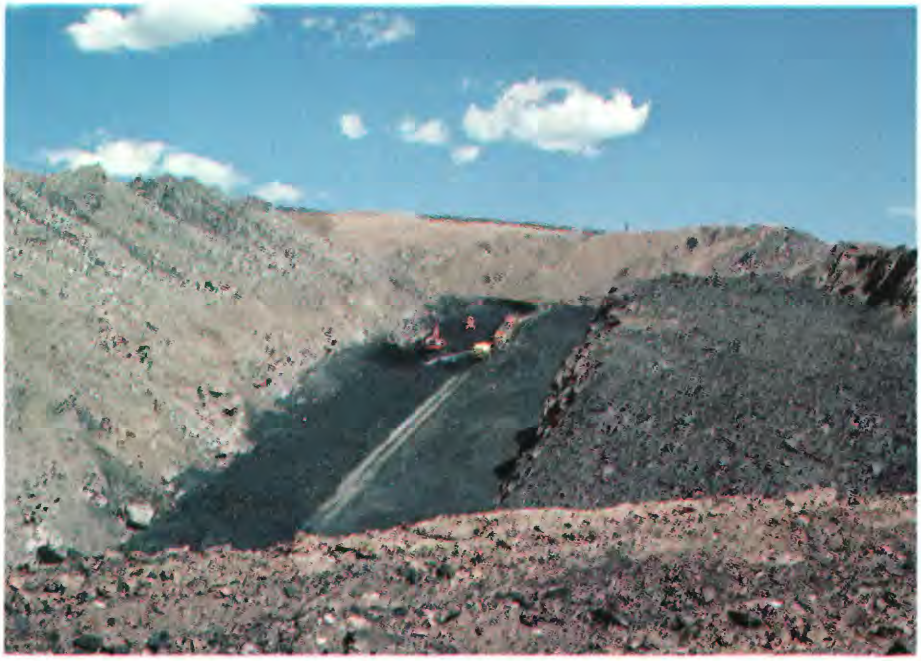
Degradation of ground-water quality and decline in water levels are typical problems associated with surface coal mining.

The effects of mining on ground water generally will be much more severe and have a longer duration than the effects on surface water. However, in parts of the coal areas, ground-water and surface-water systems may be con nected. Effects on ground water, such as degradation of quality, then may 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 results in a decline in water levels for some distance out in those aquifers, and adjacent wells could be affected. After mining and reclamation, ground-water levels may rise with time in undisturbed areas downgradient and laterally 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 the water 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 water-quality degradation or improvement in some aquifers.

The effects of mining on the aquifers of Area 53 currently are being studied. Available literature on the effects of mining in the area includes McWhorter and others (1977), Hounslow and others (1978), and Saunders (1983). 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 the ground water and that the large concentration of dissolved solids in ground-water discharge from a bank of mine spoils would not be likely to decline for many decades. Spoil pile aquifers in northwestern Colorado have dissolved-solids concentrations ranging from 2,200 to 2,600 milligrams per liter while natural aquifers in the area have dissolved-solids concentrations around 1,000 milligrams per liter (R. S. Williams, Jr., U.S. Geological Survey, oral commun., 1983).



One of the major impacts of surface mining is the total or partial loss of an aquifer by removal of overburden or coal

Increases in dissolved solids and trace elements are likely as water moves through the area of disturbed and reclaimed materials

Diverse Physiographic Features of Mountains, Basins, Plateaus, Badlands, and Ridges

Area 53 is in four physiographic provinces; the primary two are the Wyoming Basin and Colorado Plateau.

Most of Area 53 is within the Wyoming Basin and Colorado Plateau physiographic provinces which consist of many basins, plateaus, and uplifts. The area also is bounded on the east and northwest by the Southern Rocky Mountains and Middle Rocky Mountains physiographic provinces, respectively (Fenneman, 1931). The Yampa River basin lies mostly within the southern part of the Wyoming Basin (fig. 3.1-1), characterized by a plateau area partially bordered by abrupt mountain slopes and containing isolated ridges. The White River basin, which lies primarily within the northeastern part of the Colorado Plateau province, is characterized by distinctive, individual plateaus bounded by receding escarpments. The Sierra Madre and the White River Plateau are in the Southern Rocky Mountains province. These features occupy narrow areas along the eastern and southeastern margins respectively of Area 53. The Uinta Mountains, a broad anticlinal fold, are in the Middle Rocky Mountains province and comprise the southwestern part of the Yampa River basin.

The Wyoming Basin, according to Thornbury (1965), represents a major break in the continuity of the Rocky Mountains. The basin is not only continuous with the Great Plains, but also connects with the Colorado Plateau province through a sag east of the Uinta Mountains. The Wyoming Basin is nearly surrounded by mountains. The Wyoming Basin, which consists of a number of basins separated from each other by uplifts, contains six major physiographic subdivisions within Area 53 shown in figure 3.1-1: Washakie Basin, Sand Wash Basin, Axial Basin, Danforth Hills, Williams Fork Mountains, and Elkhead Mountains.

The Washakie and Sand Wash Basins are shallow synclinal structures. The Axial Basin, formed by the Axial uplift, is developed on an eroded anticlinal structure which connects the White River Plateau with the Uinta Mountains. The low Danforth Hills, rising about 2,000 feet above the adjacent valleys, form the south margin of the Yampa River basin. The Williams Fork Mountains, northeast of the Axial Basin, are a ridge formed by resistant sandstone layers. The Elkhead Mountains consist primarily of flat-lying soft sedimentary rocks capped by basalt flows.

The part of the Yampa River basin that lies within the Wyoming Basin province contains diverse topography of broad plains, badlands, and gently sloping ridges interspersed with low mountains and ridges. The altitude ranges from 6,500 to 7,500 feet.

The Colorado Plateau province is a conglomerate of individual plateaus with distinctive characteristics. About 90 percent of the province is drained by the Colorado River and its tributaries. The province contains two major physiographic subdivisions in Area 53--Uinta Basin and Piceance Basin, depicted in figure 3.1-1. The Uinta and Piceance Basins are both part of a great east-west asymmetrical syncline near the base of the Uinta Mountains.

The part of the White River basin within the Colorado Plateau is topographically a combination of rugged, intricately dissected plateaus with broad tabular upland tracts between valleys. Most of the area is between altitudes of 5,000 and 7,500 feet.

The Southern Rocky Mountains province forms the eastern and southeastern boundary of Area 53, and is marked with hogback foothills, deeply dissected plateaus, and mountainous terrain. Altitudes range from 7,500 to more than 12,000 feet. The two major physiographic subdivisions of the province are White River Plateau and Sierra Madre, known in Colorado as the Park Range. These two subdivisions form the headwaters for most of the major streams in the Yampa and the White River basins. The White River Plateau, a monoclinal range, consists of basalt uplands rising to altitudes of 10,000 to 12,000 feet. The Sierra Madre, the northern-most range of the Southern Rocky Mountains province, consists mainly of broad mountain slopes of 10,000 feet with some glaciated peaks rising to more than 12,000 feet.

The eastern edge of the Uinta Mountains, which are a subdivision of the Middle Rocky Mountains province, extends eastward into the southwest corner of the Yampa River basin. This physiographic feature consists of a central platform with broad slopes 8,000 feet high and is bordered by abrupt slopes on the north and south.

This discussion on physiographic features was primarily derived from the following references: Fenneman (1931), Steele and others (1979), and Thornbury (1965).

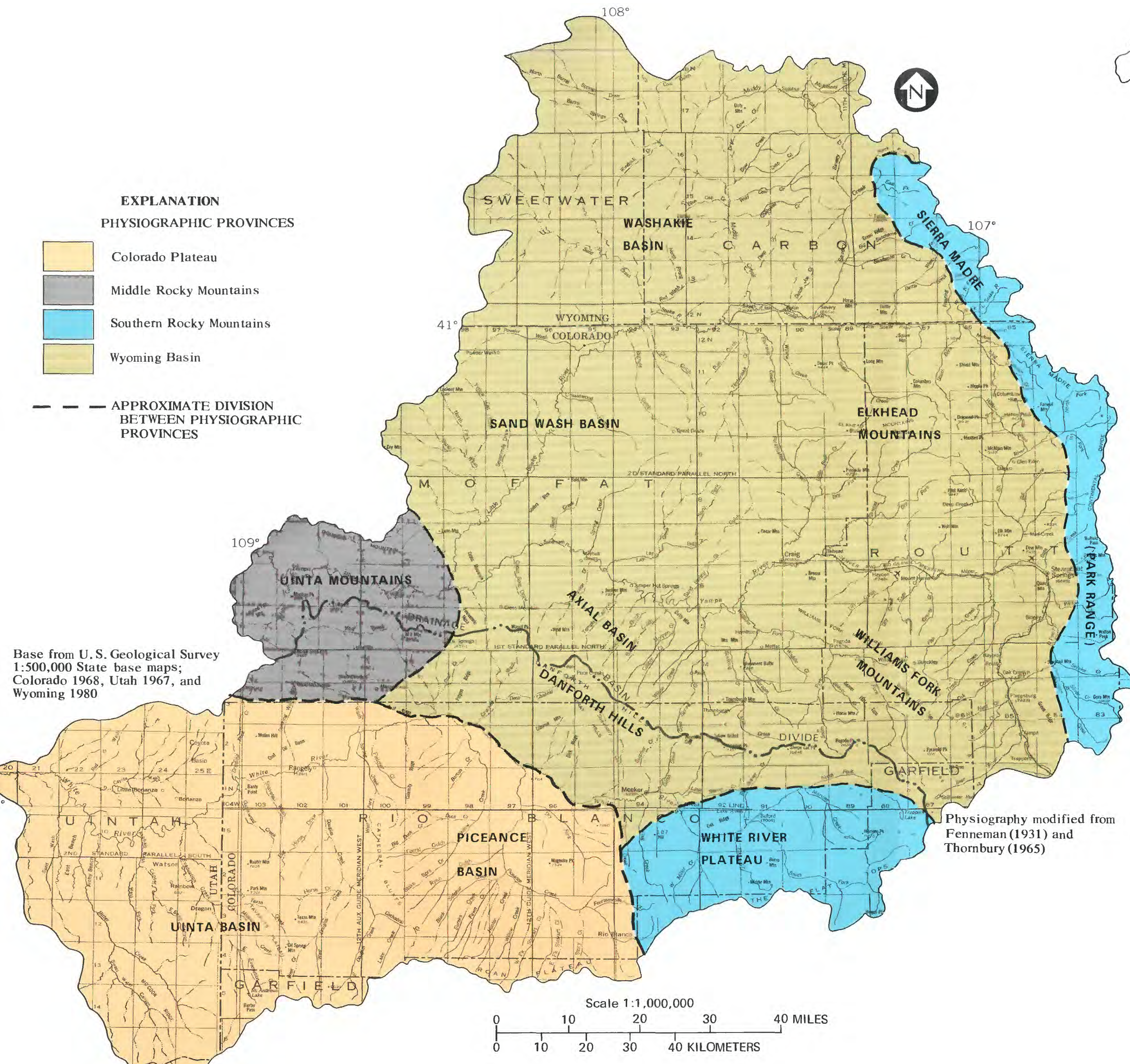


Figure 3.1-1 Physiographic divisions.

The broad plains of the Piceance basin are within the Colorado Plateau physiographic province

Yampa River valley with the Sierra Madre in the background contains diverse topography

Outcrops Date from Precambrian to Quaternary Age

The Laramide Orogeny was responsible for many of the present-day structural features in the study region.

The study area has a complex history of tectonic and sedimentary patterns. The surface outcrops of the six major economical coal-bearing formations, the coal-bearing and oil-shale host rock, and the remaining formations grouped into one of four map units based on age and rock type are shown in figure 3.2-1. These geologic formations date from Precambrian to Quaternary age. Although no structural features are depicted in figure 3.2-1, they are important aspects of the area's geology and are directly related to the physiographic divisions previously discussed. Regional geologic maps of the study area were compiled by Burbank and others (1967), Miller (1975), Tweto (1976, 1979), Love and others (1955), and Hintze (1980).

Mountains were created locally in Late Cretaceous and Cenozoic time (the Laramide Orogeny) by folding of the Earth's crust. The Sierra Madre uplift had begun (Curtis, 1962). In Eocene time a shallow lake formed southwest of the Sierra Madre. In the lake, marlstone and calcareous shales of the Green River Formation were formed, while around its edges the fluvial and deltaic Wasatch Formation was formed. Many present-day structural features were formed during the period of orogeny from Late Cretaceous to early Tertiary times (Quigley, 1965). Uplift and smoothing to a low order relief occurred during Oligocene time. During Miocene time, deposition of the Browns Park Formation was followed by volcanism. Greater moisture during the Pleistocene Epoch increased stream erosion and produced vigorous mountain glaciation in the region.

The regional stratigraphy of Area 53 is diverse. The oldest exposed rocks are Precambrian in age. Those in the Uinta Mountains are described by Hansen (1965, 1969); at Juniper Mountain by Abrassart and Clough (1955); and at Cross Mountain by Dyni (1968) and McKay (1974).

The strata younger than the Precambrian rocks are almost entirely of sedimentary origin. The most common change in the stratigraphic units, which vary in thickness and lithology throughout the study area, is from nonmarine coal-bearing strata to marine noncoal-bearing strata. Haun (1962) discusses Paleozoic strata of chiefly marine limestone dolomites, quartzites, and interbedded shales. Strata of early and middle Mesozoic age are primarily of continental origin but do not contain significant amounts of coal.

The oldest strata that have coal beds of economic interest in the study area are formations of late Mesozoic age. The Iles and Williams Fork Formations, which are within the Mesaverde Group, were deposited in terrestrial environments, including swamps, where organic materials accumulated ultimately to be changed to the present coal beds. Descriptions of the Mesaverde Group are given for the Yampa coal fields (Bass and others, 1955), for the Axial and Monument Butte areas (Hancock, 1925), for the Meeker area (Hancock and Eby, 1930), for the Rangely area (Cullins, 1968, 1971), for southern Wyoming (Gill and others, 1970), for the Piceance Creek basin and the Uinta Basin (Gill and Hail, 1975), and for southwestern Wyoming and northwestern Colorado (Miller, 1977).

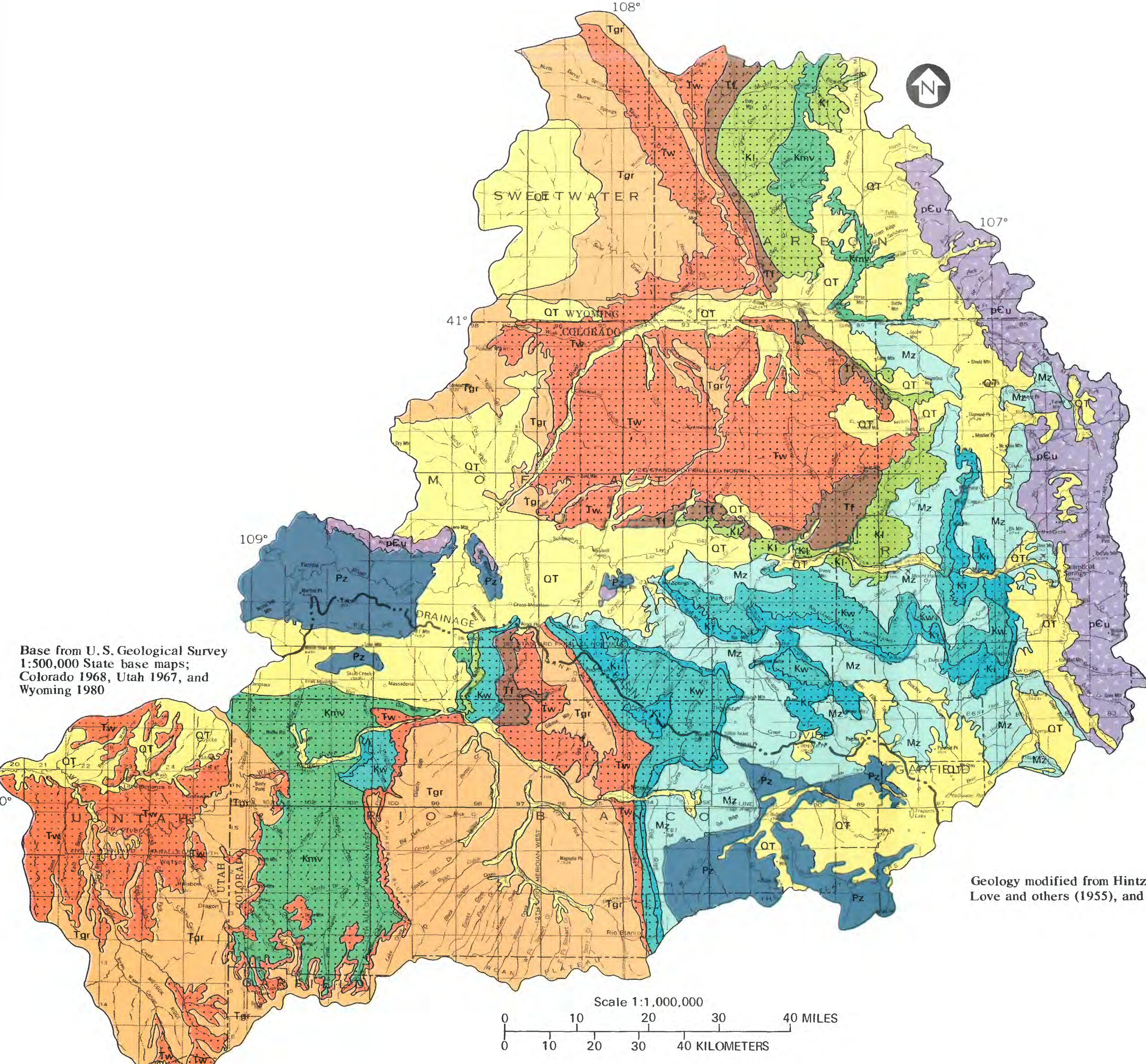
The Lance Formation, the latest Cretaceous sediment, was deposited in a marginal marine environment. The coal beds of this formation were formed from organic debris which accumulated in swamps. A brief history of the end of the Cretaceous and early Cenozoic time in this region is provided by Ritzma (1955).

During early Tertiary time, in the Paleocene Epoch, organic material accumulated in swamps and became coal beds of the Fort Union Formation. This formation varies in thickness from 800 feet in the southwest to 2,500 feet north of the Sand Wash Basin discussed in section 3.1 (McKay and Bergin, 1974; Masters, 1961). The Fort Union Formation extends southwest to an area between Meeker and Rangely; the formation is approximately 1,675 feet thick in the area (Hail, 1973).

The Wasatch Formation is the youngest coal-bearing formation that is economical to mine in the study area. The Wasatch consists of sandstone, mudstone, and some carbonaceous shale (Hornbaker and Holt, 1973; Speltz, 1976).

Just north of the Wasatch Formation across the State boundary in Wyoming, the Green River Formation contains three coal beds, but none of economic interest (Rohler, 1973). The Green River Formation is economically important for its large deposits of oil shale.

The geologic references mentioned in this text are only a sample of the vast literature available on this subject in the study area.



Base from U.S. Geological Survey 1:500,000 State base maps; Colorado 1968, Utah 1967, and Wyoming 1980

Geology modified from Hintze (1980), Love and others (1955), and Tweto (1979)

Figure 3.2-1 General geology.

EXPLANATION

QT	QUATERNARY DEPOSITS - Alluvium, colluvium, glacial drift, and eolian sand in Colorado, Utah, and Wyoming TERTIARY ROCKS, UNDIVIDED, (INCLUDES BROWNS PARK FORMATION, UINTA FORMATION, AND BRIDGER FORMATION IN COLORADO. INCLUDES UINTA FORMATION IN UTAH. INCLUDES BROWNS PARK FORMATION AND BRIDGER FORMATION IN WYOMING.) - Sandstone, siltstone, claystone, mudstone, marlstone, and conglomerate
Tgr	GREEN RIVER FORMATION (EOCENE) - Marlstone, sandstone, oil shale, claystone, and shale
Tw	WASATCH FORMATION (EOCENE AND PALEOCENE) - Claystone, shale, sandstone, conglomerate, and coal beds
Tf	FORT UNION FORMATION (PALEOCENE) - Brown to gray sandstone, gray to black shale, carbonaceous shale and thin coal beds
Kl	LANCE FORMATION (UPPER CRETACEOUS) - Gray and brown sandstone and shale, thin coal beds, massive cliff-forming white to yellow sandstone at base
Mz	LEWIS SHALE (UPPER CRETACEOUS) - Gray, soft marine shale with many gray and brown lenticular sandstone lenses. Not individually mapped but included in MESOZOIC SEDIMENTARY ROCKS
Kmv	MESAVERDE GROUP (PART) (UPPER CRETACEOUS) - Gray to tan sandstone and sandy shale with major coal beds
Kw	WILLIAMS FORK FORMATION OF MESAVERDE GROUP (UPPER CRETACEOUS) - Sandstone, shale, and major coal beds
Ki	ILES FORMATION OF MESAVERDE GROUP (UPPER CRETACEOUS) - Sandstone, shale, Trout Creek Sandstone Member at top and coal beds in upper half
Mz	MESOZOIC SEDIMENTARY ROCKS, UNDIVIDED, (INCLUDES MANCOS SHALE, AND ITS FRONTIER SANDSTONE AND MOWRY SHALE MEMBERS, DAKOTA SANDSTONE, BURRO CANYON FORMATION, MORRISON FORMATION, CURTIS FORMATION, ENTRADA SANDSTONE, GLEN CANYON SANDSTONE, CHINLE FORMATION AND MOENKOPI FORMATION IN COLORADO.) - Sandstone, siltstone, shale, claystone, and limestone
Pz	PALEOZOIC SEDIMENTARY ROCKS, UNDIVIDED, (INCLUDES PARK CITY FORMATION, WEBER SANDSTONE, MAROON FORMATION, MORGAN FORMATION, ROUND VALLEY LIMESTONE, MADISON LIMESTONE, MANITOU FORMATION, DOTSERO FORMATION, AND LODORE FORMATION IN COLORADO.) - Sandstone, limestone, shale, chert, dolomite, and quartzite
p€u	PRECAMBRIAN ROCKS - Quartzite, conglomerate, and shale; metamorphic schist and gneiss, granite
(dotted)	COAL-BEARING FORMATIONS

82 Billion Tons of Coal are in Study Area

The coal beds of greatest economic interest are in the Iles and Williams Fork Formations of the Mesaverde Group and in the Lance, Fort Union, and Wasatch Formations. Total coal production for 1980 was 12.7 million tons.

Coal resources of the area occur entirely within the Rocky Mountain coal province, and are located in the Green River and Uinta coal regions (fig. 3.3-1). The Green River region contains the Yampa coal field in Colorado and the Little Snake River coal field in Wyoming. The Uinta coal region consists of the Danforth Hills and Lower White River coal fields in Colorado.

The Yampa coal field, located in Moffat and Routt Counties of northwestern Colorado, contains extensive coal resources. Virtually all of the coals mined in the Green River region are in the Iles and Williams Fork Formations of the Mesaverde Group of Late Cretaceous age. The Mesaverde coals are primarily high-volatile C bituminous in rank and range in thickness from approximately 3 to 20 feet (Murray, 1980, p. 16). Younger coal-bearing rocks of the Lance Formation of Late Cretaceous age, the Fort Union Formation of Paleocene age, and the Wasatch Formation of Eocene and Paleocene age are located towards the interior of the basin, away from the outcrops of the Mesaverde. The Lance coals, which have been mined in the past but are not currently being mined, are subbituminous B or C and are as much as 10 feet thick. The overlying Fort Union coals reach thicknesses greater than 40 feet. These coals are subbituminous B or C in rank when sampled near the surface. The Wasatch coals have been mined at several ranches on both sides of the Colorado and Wyoming State boundary; however, little information is available on these coals. It is believed that the coals are subbituminous B or C in rank and range from several feet to 20 feet thick (Murray, 1980, p. 16).

Historically the Yampa coal field has produced more than 100 million tons of coal from 192 coal mines on record (Boreck and Murray, 1979). In 1979 alone, the Colorado part of the Green River region coal production exceeded 10 million tons from 13 mines; this represents more than half of the entire State production of about 18 million tons from 57 mines for the same period (Colorado Division of Mines, 1980). According to Boreck and Murray (1979), the remaining demonstrated reserve base of coal in the Green River region is over 6.5 billion tons. Total inplace coal reserves in the Colorado part of the Green River region probably exceed 60 billion tons above a depth of 6,000 feet (Murray, 1980, p. 16). Speltz (1976, p. 15) estimates that nearly one billion tons of potential surface-mineable coal may exist in this part of the region. Present production is from 8 surface and 6 underground mines (fig. 3.3-1). Surface-minable coal predominates in actual volume; in 1980, 83 percent of the total coal production in the Yampa coal field was from surface mines.

Most of the low-sulfur coal in the Green River region is or will be burned at either the Hayden, Colo. or Craig, Colo. steam-electric generating powerplant or at powerplants in the Denver area. Some of the coal also is exported to other States such as Illinois, Nebraska, Iowa, and Texas (Murray, 1980).

The Little Snake River coal field in Carbon County, Wyo. also contains strippable deposits of bituminous coal (Glass, 1980, p. 1). The China Butte mine, (map No. 14, fig. 3.3-1, and table 3.3-1), is the single coal mine in this field and is proposed with a design capacity of 3 million tons per year (Hausel and others, 1979). Abandoned underground mines scattered throughout Carbon County are depicted in figure 3.3-1. The coals at these sites lie within the Mesaverde Group and Fort Union Formation.

The Danforth Hills coal field of the Uinta coal region extends from Axial south to Meeker and is situated in Rio Blanco and southern Moffat Counties in Colorado. The Iles and Williams Fork Formations of the Mesaverde Group contain numerous good-quality bituminous coal beds, primarily high-volatile C in rank. Some of the coal beds exceed 20 feet in thickness (Murray, 1980, p. 21). As many as 32 separate beds of coal exist, of which only a few are of minable thickness (Speltz, 1976). Original inplace coal resources to a depth of 6,000 feet total more than 10.5 billion tons (Hornbaker and others, 1976). Approximately 164 million tons of strippable bituminous coal reserves are estimated to have been present originally (Speltz, 1976, p. 25). The coal production at the Danforth Hills field in 1978 was greater than 1.07 million tons, a significant increase over the 0.3 million tons produced during 1977. Two mines currently are active in the Danforth Hills field.

The Lower White River field, which includes the western Piceance basin and much of the Douglas Creek area, lies chiefly in Rio Blanco County, with a small part located in southern Moffat County, Colo. All the coal-bearing rocks in the field are in the Mesaverde Group. The lower Iles Formation contains minor coal beds, while the Williams Fork Formation contains the principal coals (Speltz, 1976). To date mining has been primarily along the flanks of a large breached anticline in the Rangely area. Coal beds are high-volatile C bituminous in rank and range in thickness from 6 to 12 feet (Murray, 1980, p. 22). Between the land surface and a depth of 6,000 feet, coal resources have been estimated at 11.76 billion tons. An estimated 89 million tons of bituminous coal amenable to strip mining are present in the Lower White River field (Speltz, 1976, p. 27).

Extensive literature is available for coal activities in the area. A Utah publication (Lines, 1981) and a Colorado publication (U.S. Geological Survey, 1976) describe hydrologic studies of the U.S. Geological Survey related to coal development in their respective States.

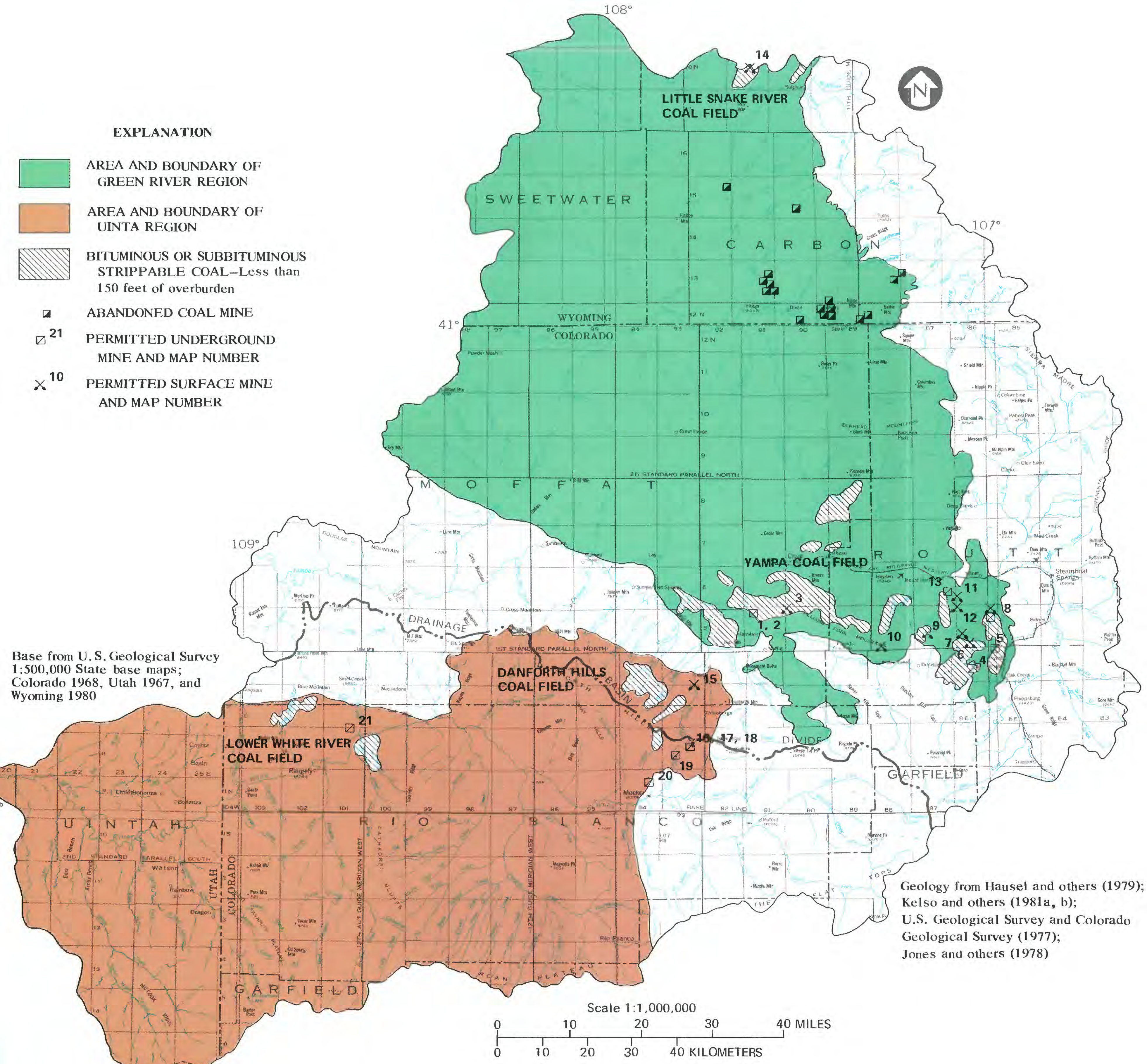


Figure 3.3-1 Coal resources and active coal mines.

Table 3.3-1 *Summary of permitted coal mines and production*

Map No.	Mine name	County and State	Coal field	Geologic unit	Coal beds	Rank of coal
1	Eagle No. 5	Moffat, Colo.	Yampa	Williams Fork	C,E,F,D	subbituminous
2	Eagle No. 9	-----do.-----	-----do.-----	------do.------	C,E,F,P	Do.
3	Trapper	-----do.-----	-----do.-----	------do.------	H,I,Q,R	Do.
4	Apex No. 2	Routt, Colo.	-----do.-----	Iles	Lower Annacle	bituminous
5	Edna Strip	-----do.-----	-----do.-----	Williams Fork	Lennex, Wadge, Wolfcreek	-------------
6	Energy No. 1	-----do.-----	-----do.-----	------do.------	Wadge	subbituminous
7	Energy No. 2	-----do.-----	-----do.-----	------do.------	Fish Creek	Do.
8	Energy No. 3	-----do.-----	-----do.-----	Mesaverde Group	Wadge	Do.
9	Grassy Creek No. 1	-----do.-----	-----do.-----	Iles	Pinnacle, Blocksmith	-------------
10	Hayden Gulch	-----do.-----	-----do.-----	Williams Fork	Fivebeds	subbituminous
11	Meadows No. 1	-----do.-----	-----do.-----	Iles	Pinnacle	bituminous
12	Seneca II	-----do.-----	-----do.-----	Williams Fork	Lennox, Wadge, Wolfcreek	Do.
13	Trout Creek No. 2	-----do.-----	-----do.-----	Iles	Blocksmith	Do.
14	China Butte	Carbon, Wyo.	Little Snake	Fort Union	--------------	-------------
15	Colowyo	Moffat, Colo.	Danforth Hills	Williams Fork	Y_3,Y_2,A,B,C,D,E,F	subbituminous and bituminous
16	Northern No. 1	Rio Blanco, Colo.	-----do.-----	------do.------	FF	subbituminous
17	Northern No. 2	-----do.-----	-----do.-----	------do.------	P	-------------
18	Northern No. 3	-----do.-----	-----do.-----	------do.------	P	-------------
19	Rienau No. 2	-----do.-----	-----do.-----	Mesaverde Group	G	bituminous
20	Sulphur Creek	-----do.-----	-----do.-----	------do.------	Fairfield, Major, Sulphur Creek	-------------
21	Deserado Mine	-----do.-----	Lower White River	Williams Fork	B,B/C,D	subbituminous

Map. No.	Overburden thickness (feet)	Heat Value (British thermal units per pound)	1979 production (tons x 1,000)	1980 production (tons x 1,000)	Cumulative production thru June, 1981 (tons x 1000)
1	0-900	------	556	474	1,771
2	0-900	------	173	180	454
3	30-140	9,600	2,329	2,014	18,781
4	450	12,000	0	4	166
5	0-200	------	1,166	1,026	18,025
6	0-140	11,300	2,353	3,338	22,588
7	0-80	11,000	654	0	4,366
8	0-800	11,000	425	270	2,442
9	-------	11,400	127	227	489
10	9-50	10,000	379	553	1,233
11	40-50	11,200	201	28	509
12	-------	12,000	1,612	1,779	12,400
13	0-1,500	12,000	0	0	0
14	-------	------	0	0	0
15	0-400	10,500	1,699	2,683	7,189
16	-------	10,400	6	63	112
17	-------	10,700	0	0	0
18	-------	11,400	0	0	0
19	-------	11,100	83	145	392
20	-------	10,200	0	0	0
21	-------	10,700	0	0	0

Climate, Topography, Vegetation, and Parent Rock Influence Soils

The soils generally are clayey to loamy, slowly to moderately permeable, and neutral to moderately alkaline.

The soils in the study area have been grouped into 10 soil association map units (fig. 3.4-1) on the basis of similarities in climate, topography, vegetation, and parent material. Depth of the soil, pH, and permeability are presented in table 3.4-1 as general ranges of values for each soil association. Soil pH values generally range from neutral to moderately alkaline. Soil pH may influence nutrient absorption and plant growth in two ways: (1) through the direct effect of the hydrogen ion; or (2) through its influence on nutrient availability and the presence of toxic ions. Soil permeability is that quality of the soil that enables it to transmit water or air. It can be measured as percolation under gravity with 72-inch head of water and is expressed in inches per hour. Soil permeability in Area 53 ranges from very slow (0.06 to 0.2 inch per hour) to moderately rapid (2.0 to 6.0 inches per hour).

Formation of soil is the product of climate, topography, vegetation, and parent material working together over long periods of time (Wilson and others, 1975). Climate and topography are discussed in detail in other parts of this report; however, vegetation and parent material, as related to soil formation, are addressed here.

Major woodland areas are in high mountains (8,000 to 11,000 feet); the dominant vegetative type is conifer. Dominant soils are Cryboralfs-Cryoborolls, Cryoborolls-Cryaquolls, and Cryoborolls-Cryothents (fig. 3.4-1). Aspen areas have an understory of assorted grasses, forbs, and shrubs. Usually organic-matter content is highest and thickest in soil formed under aspen; therefore, topsoil for reclamation would be more abundant where aspens had been present before mining. Dominant soils are Cryoborolls-Cryaquolls, Cryoborolls-Cryothents, and Haploborolls-Argiborolls. Woodland areas at lower elevations of 5,000 to 8,000 feet have shallow soils, commonly located on south and west slopes. Pinon-juniper woodlands are the Torriorthents-Calciorthids Natrargids, Torriorthents-Haplargids Natrargids.

The mountain-shrub vegetation dominates in middle altitudes (6,500 to 8,000 feet). This vegetative type consists of a complex of sagebrush, aspen, river bottom vegetation, and pinon-juniper. Cryboralfs-Cryoborolls, Cryborolls-Cryaquolls, Cryborolls-Cryothents and Haploborolls-Argiborolls are the dominant soils.

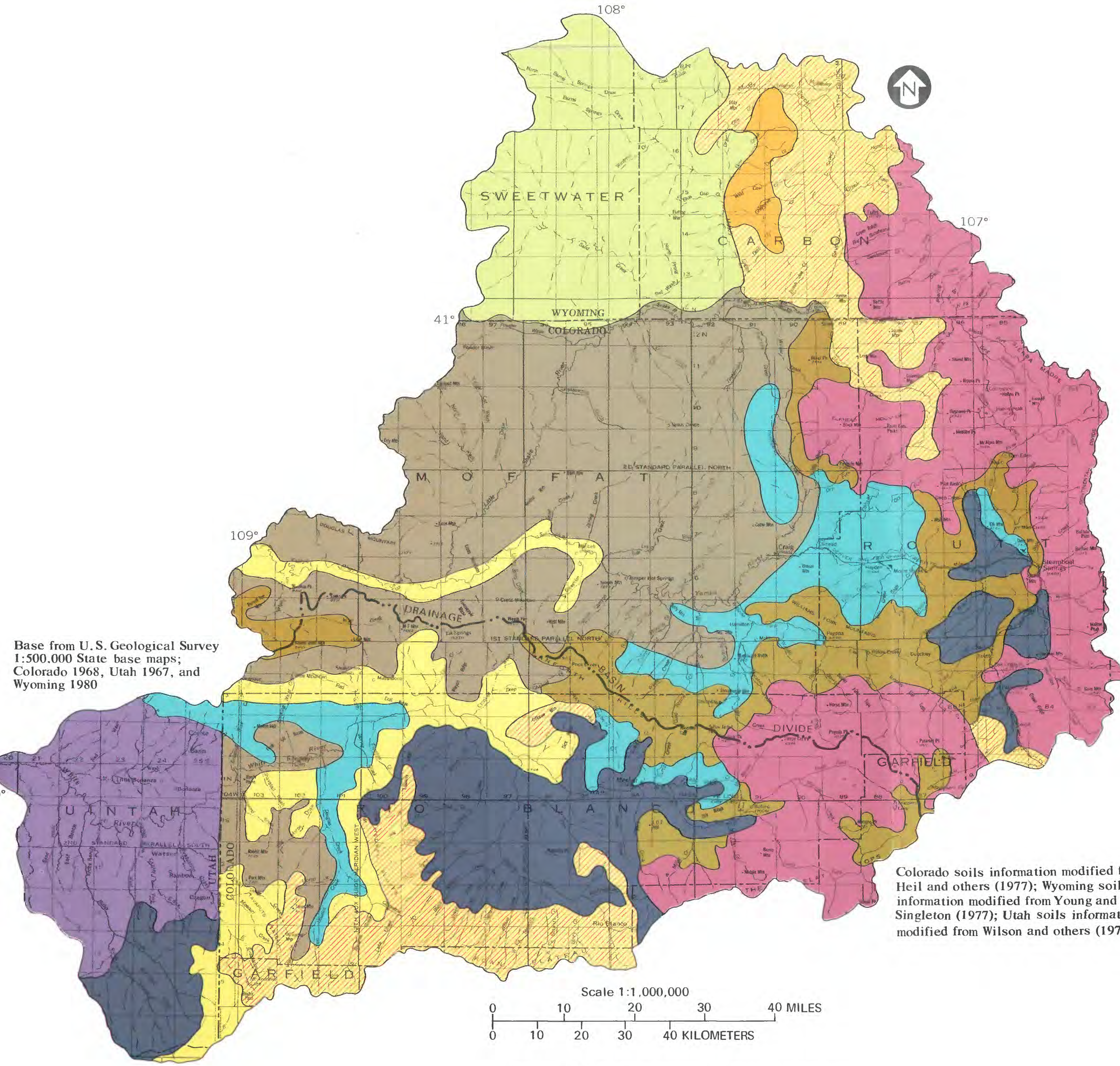
Sagebrush-vegetated areas can occur at elevations of 6,000 to 9,000 feet. Dominant soils are Camborthids, Haplargids, Cryborolls-Cryaquolls, Cryborolls-Cryothents, and Haploborolls-Argiborolls soil associations shown in figure 3.4-1.

Areas with primarily big sagebrush and greasewood occur at 5,000 to 8,000 feet altitude. The Torriorthents, Torriorthents-Haplargids Natrargids, Torriorthents-Camborthids Haplargids, Torriorthents-Calciorthids Natrargids, Camborthids, and Haplargids soil-association units in figure 3.4-1 are the dominant soils. In the Torriorthents-Haplargids Natrargids and Torriorthents-Calciorthids Natrargids areas on the soil map, large concentrations of sodium are found in the subsoil; these soils will definitely affect vegetative growth and survival. They generally were observed outside the present coal-mined areas.

The most common rocks that serve as a source of parent material for soils in the study region are sedimentary rocks that have been altered by wind, water, and ice. Soils have developed on residual material and on alluvial, glacial drift, and eolian deposits.

Sedimentary rocks consist of sandstones, shales, mudstones, and siltstones. Sandstones are dominant in the area and weather into soils that are loamy in texture, consisting primarily of sand. Shales weather to soils that are clayey in texture, dominated by clay. Mudstones and siltstones weather to soils that are silty or loamy in texture. The alluvial valleys contain sediments derived from coarse-grained sandstones to fine-grained shales; the mixture results in loamy soils.

Much of the above discussion was taken from reports by the U.S. Bureau of Land Management (1976) and Wilson and others (1975). Additional detailed 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, Utah State University, and University of Wyoming. Information that would be useful to reclamation of land disturbed by mining is available from Cook and others (1974) and Schaller and Sutton (1978).



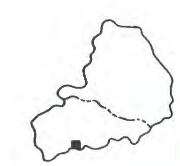
Base from U.S. Geological Survey 1:500,000 State base maps; Colorado 1968, Utah 1967, and Wyoming 1980

Colorado soils information modified from Heil and others (1977); Wyoming soils information modified from Young and Singleton (1977); Utah soils information modified from Wilson and others (1975)

Figure 3.4-1 Generalized soil associations.

Table 3.4-1 *Soil association features*

Map unit	Name	Description	Soil depth (inches)	pH	Permeability (inches per hour)
	Camborthids	Deep, well-drained, upland slope soils formed from residual weathered shale	20->60	7.9-9.0	.2-2.0
	Haplargids	Deep, well-drained soils formed from alluvium or sedimentary rock	20->60	6.6-8.4	.6-6.0
	Cryoborolls-Cryaquolls	Deep, upland soils formed from transported or residual material	>60	6.1-9.0	.6-6.0
	Cryoborolls-Cryothents	Well-drained, upland slope soils formed from transported or residual sedimentary rock	10->60	6.1-9.0	.6-2.0
	Cryboralfs-Cryoborolls (rock outcrop)	Well-drained, upland slope soils formed mostly from glacial till or weathered bedrock	10->60	4.5-7.8	.6-2.0
	Torriorthents	Well-drained soils formed mostly from alluvium or sedimentary rock	10->60	7.4-9.0	.2-2.0
	Torriorthents-Calciorthids Natrargids	Well-drained, highly erodible shallow soils located in desert areas	20	7.9-8.4	.06-.20
	Torriorthents-Camborthids Haplargids	Deep soils formed from residual or alluvial material	10->60	6.6-8.4	.6-2.0
	Torriorthents-Haplargids Natrargids	Well-drained soils formed from alluvium or sedimentary rock	20-60	6.6-8.4	.6-6.0
	Haploborolls-Argiborolls	Well-drained, upland slope soils formed from residual or transported material	10->60	7.4-9.0	.2-2.0



Aspen indicate areas of deep, well-formed soils

Altitude is Dominant Factor in Climate of Area

The climate is generally semiarid, and most of the precipitation falls as snow between November and April.

The climate varies from an arid desert environment in the lower western part of the study area to a cold, moist alpine zone along the Continental Divide to the east. These extremes result from large variations in altitude and exposure. Because much of the area is in basins with average altitudes between 6,000 and 8,000 feet, the climate generally is semiarid with relatively warm summers and cold winters.

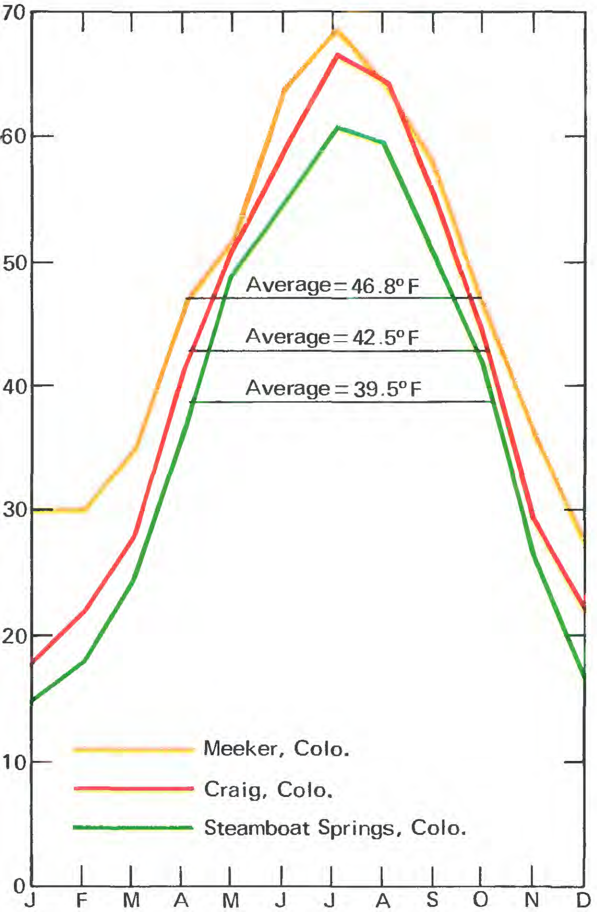
Air temperatures fluctuate with altitude and seasons. The average annual air temperature at Steamboat Springs, Colo. is 39.5°F (degrees Fahrenheit), with average extremes of -21°F to 90°F. At Craig, Colo., the average annual air temperature is 42.5°F with average extremes of 11°F to 93°F. Meeker, Colo. has an average annual air temperature of 46.8°F with average temperature extremes of -10°F to 93°F (National Climatic Center 1981). Irrigated lands near Yampa, Colo. and Steamboat Springs have an average annual growing season (period of year with average air temperatures above 36°F) of 102 days and areas near Craig average 125 days (Colorado Water Conservation Board, 1969). Seasonal variation in air temperatures at Craig, Meeker, and Steamboat Springs is depicted in figure 3.5-1.

Average annual precipitation ranges from more than 60 inches along the Continental Divide to less than 8 inches in the arid areas of Utah. Areal variations in average annual precipitation for the study area are shown in figure 3.5-2. Most of the precipitation falls as snow from November through April. Total annual snowfall averages 164 inches at Steamboat Springs and 101 inches at Yampa, while the arid areas receive less than 30 inches of snow annually (Colorado Water Conservation Board, 1969). Seasonal distributions of snowfall at Steamboat Springs and Yampa are shown in figure 3.5-3.

Winter snow accumulation in the mountains serves as the principal source of streamflow. Steamboat Springs receives nearly one-half of its annual precipitation as snow during December through April, whereas Craig receives more than one-third of its average annual precipitation as snow during the same period (Steele and others, 1979).

Steamboat Springs receives only one-fifth of its total precipitation during the peak growing season (July and August), whereas Craig receives greater than one-third of its total precipitation during the same period. Summer precipitation throughout the study area occurs as rain showers which contribute little to overall water availability. These storms seldom yield greater than 1 inch of rain. The 10-year, 24-hour rainfall intensities computed by National Oceanic and Atmospheric Administration (1980) and National Climatic Center (1980) are depicted in figure 3.5-4.

Evaporation in the study area decreases with increasing altitude. Evaporation losses from existing small ponds and reservoirs in lower altitudes range from 17 to 20 inches per year. Evaporation is greatest during the months of June and July.



igure 3.5-1 Seasonal variation of average monthly air tempertures at Craig, Meeker, and Steamboat Springs, Colo. (modified from Steele and others, 979, and National Oceanic and Atmospheric Administration, 1981).

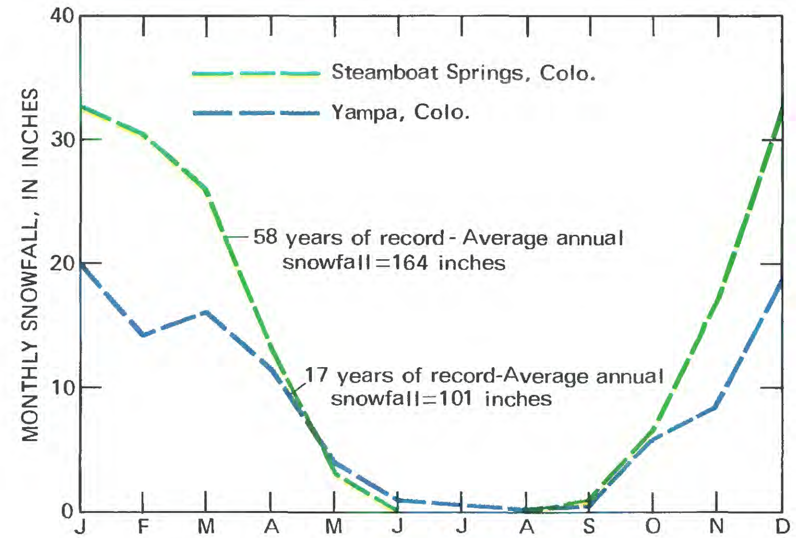
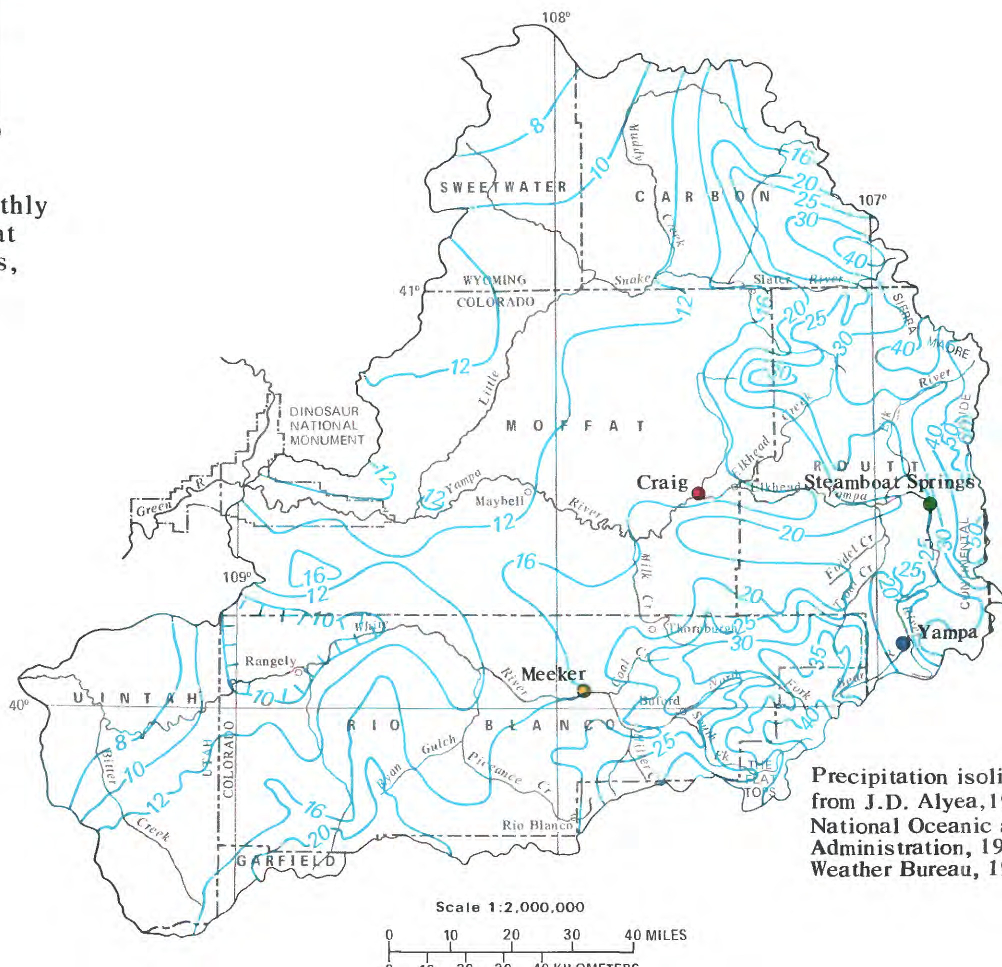


Figure 3.5-3 Seasonal distribution of average monthly snowfall, Steamboat Springs and Yampa, Colo. (from Steele and others, 1979).

Precipitation is related to altitude, with the mountains receiving up to 60 inches per year

EXPLANATION

—12— LINE OF EQUAL AVERAGE ANNUAL PRECIPITATION– Contour interval, in inches, is variable

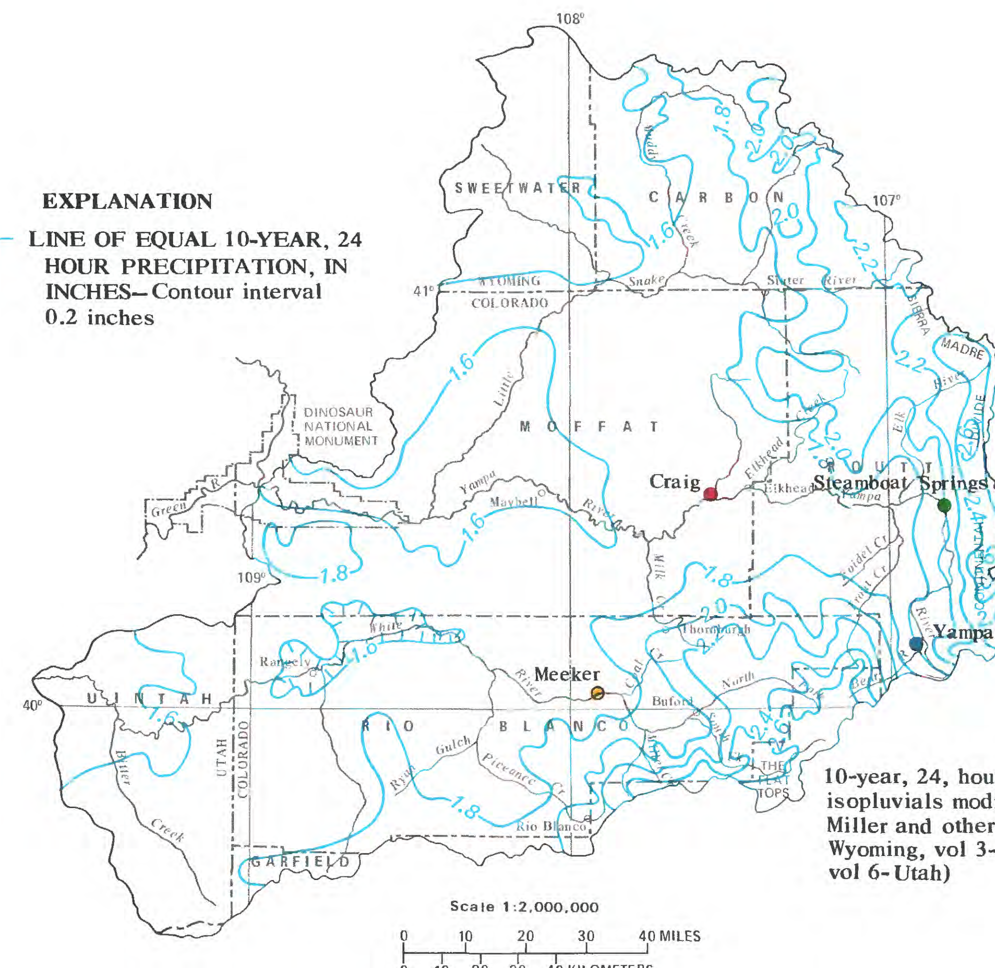


Precipitation isolines modified from J.D. Alyea,1980 (Wyoming); National Oceanic and Atmospheric Administration, 1978 (Utah); U.S. Weather Bureau, 1967 (Colorado)

Figure 3.5-2 Average annual precipitation.

EXPLANATION

—1.6— LINE OF EQUAL 10-YEAR, 24 HOUR PRECIPITATION, IN INCHES– Contour interval 0.2 inches



10-year, 24, hour precipitation isopluvials modified from Miller and others, 1973 (vol 2- Wyoming, vol 3- Colorado, vol 6- Utah)

Figure 3.5-4 Ten-year, 24 hour precipitation.

Livestock Grazing Primary Land Use

Land ownership is 60-percent Federal, 34-percent private, and 6-percent State; livestock operators, timber harvesters, and miners use public and private lands.

The major land uses in the study area include livestock grazing, timber harvesting, farming, mineral production, residential use, and recreational use. Although there often are overlapping land uses, such as mineral exploration or recreation on grazing land, generally there is one principal use on each particular tract of land. The U.S. Geological Survey (1980a, 1980b, 1980c) has published land-use and land-cover maps for this area.

The primary land use is for livestock grazing (fig. 3.6-1). Most livestock operators have either U.S. Bureau of Land Management, U.S. Forest Service, or State leases or permits to graze their livestock on public lands, to supplement grazing on their own land. Cattle and sheep generally summer on ranges on the higher and more remote federally owned lands and winter on ranges on lower and more accessible private lands, where winters are less severe.

In recent years some land use, primarily in Routt County, Colo., has changed from grazing to mineral production or residential use. New and expanding coal-strip mines have temporarily removed some grazing land from livestock use. In the Steamboat Springs area, Colorado, mountain forest and rangeland have been developed into recreational homesites due to the popularity of skiing in the area.

The eastern part of the study area is used conjunctively for grazing and timber production. Much of the land is within the Routt and Medicine Bow National Forests which are managed by the U.S. Forest Service. These forested lands consist of deciduous and evergreen trees. Timber-harvesting contributes significantly to the regional economy.

Because of inadequate precipitation, lack of irrigation water, and short growing seasons, less than 10 percent of the study region is in crop production (fig. 3.6-1). Principal crops are hay and wheat. Most hay is grown in irrigated river valleys, while most wheat is dryland farmed.

Farmlands are generally privately owned or leased from the State. Frequently, mineral rights are separate from surface rights, and mineral rights beneath farmlands may be either federally or State owned and subject to leasing. If coal desposits beneath farmlands are at a depth that can be strip mined, economics generally dictate that the farmer must sacrifice a part of his operation, at least temporarily (U.S. Bureau of Land Management, 1976).

The occurrence of mineral resources throughout the region has encouraged exploration and development of minerals since the early 1900's. The most important minerals in the area are coal, oil, and gas. Sections 3.3 and 3.7 discuss mineral resources in detail.

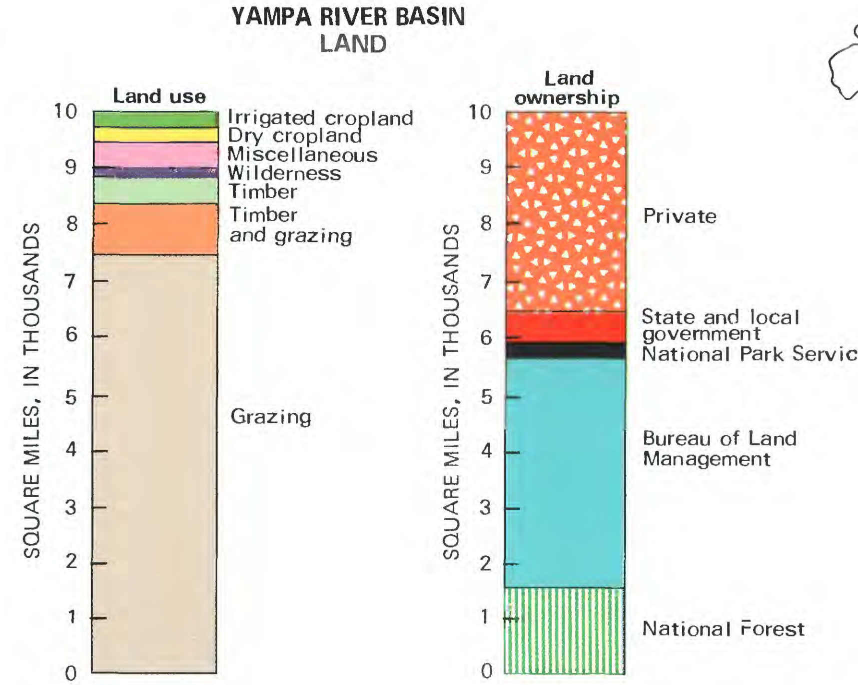
Residential land is centered around the Colorado towns: Craig, Steamboat Springs, Hayden, Oak Creek, Yampa, Meeker, Rangely, Maybell, and Dinosaur. In addition to recreation-oriented subdivisions, lands adjacent to Steamboat Springs, Craig, Meeker, and Rangely are being studied for residential use to accommodate anticipated growth from increased mineral production.

Recreational resources in Area 53 are extensive and varied. National forests, State parks, Dinosaur National Monument, and public lands managed by the U.S. Bureau of Land Management offer recreational activities including camping, hiking, boating, hunting, and fishing. Winter sports, primarily alpine and nordic skiing, have brought an economic boom to the town of Steamboat Springs and adjacent areas.

Sixty percent of the land in the Yampa and the White River basins is managed by the U.S. Bureau of Land Management, the U.S. Forest Service, and the U.S. National Park Service (fig. 3.6-1). About 34 percent of the land is privately owned, and less than 6 percent is owned or controlled by the State and local governments. Detailed land-ownership information is available from appropriate Federal, State, or county agencies.

The above discussion was primarily derived from the following sources: U.S. Bureau of Land Management (1976, 1980a), Steele and others (1979), and Melancon and others (1980). Two land status maps are useful references (U.S. Bureau of Land Management, 1972; 1978). Public land statistics are summarized by U.S. Bureau of Land Management (1979a).

heep grazing on National Forest lands



Horsepacked camping expedition in The Flat Tops Wilderness Area

armlands and the city of Craig in the Yampa River basin, Colorado

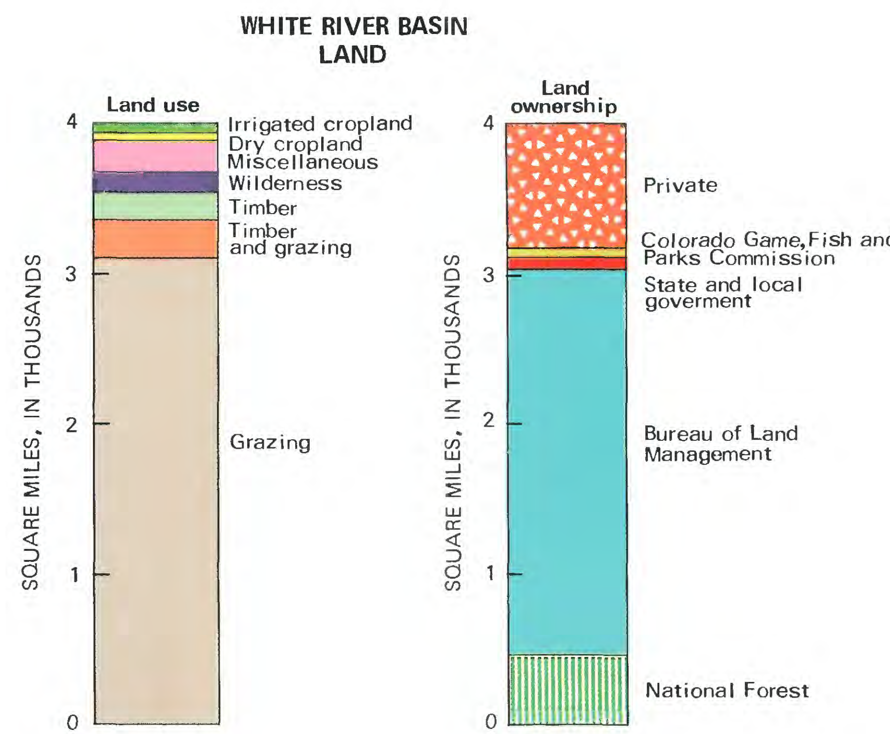


Figure 3.6-1 Use and ownership of land resources in the Yampa River basin (Colorado and Wyoming) and the White River basin (Colorado) (modified from U.S. Economic Research Service and others, 1966, 1969).

Rafting on the Yampa River near Dinosaur National Monument

Area Rich in Energy Minerals

Area 53 contains reserves of petroleum, natural gas, coal, uranium, and oil shale, as well as nonfuel resources of gold, copper, zinc, iron, vanadium, lead, molybdenum, fluorite, silver, sand and gravel. Federal ownership of minerals is extensive.

Fuel and nonfuel mineral resources are located throughout the Yampa and the White River basins. This area contains reserves of petroleum, natural gas, coal, uranium, and oil shale along with nonfuel mineral resources of gold, copper, zinc, iron, vanadium, lead, molybdenum, fluorite, silver, sand and gravel (U.S. Soil Conservation Service, 1966; 1969). Dawsonite and nahcolite--two sodium minerals associated with oil shales of the Piceance basin--also are present in commercial quantities (Melancon and others, 1980).

Production of oil and gas is a major industry in the White and the Yampa River basins (fig. 3.7-1). In 1973, a large number of oil and gas fields in Moffat, Rio Blanco, and Routt Counties, Colo. produced 22 million barrels of crude oil and 54,786 million cubic feet per day of natural gas. These three counties accounted for 60 percent of the total petroleum production and 30 percent of the natural gas production in Colorado; value of this oil and gas amounted to $120 million in 1973 compared to only $20 million from 1973 coal production in the study area (U.S. Bureau of Land Management, 1976).

Oil and gas fields are located throughout the study area (fig. 3.7-1). Most of the fields are developed at the crest of anticlines, whereas coal development in the same area is mostly on the flanks of these structures. Areas for exploration, however, are shifting from anticlinal traps to fault and sedimentary traps (U.S. Bureau of Land Management, 1980a). Potential for resource recovery conflicts with coal is greater; however, resources can be recovered sequentially from the same location with careful planning.

Coal development is primarily centered in the Yampa and the White River basins in the State of Colorado (fig. 3.7-1). Colorado is ranked eighth in the Nation in bituminous coal reserves (Speltz, 1976). An indepth discussion on coal reserves and production in the study area is presented in section 3.3.

Oil-shale deposits are found throughout the United States, but the richest reserves exist in the Green River Formation in Colorado, Utah, and Wyoming (fig. 3.7-1). Approximately 80 percent of the high-grade shale in the formation is located in the Piceance basin (Gold and Goldstein, 1978). An estimated 600 billion barrels of oil equivalent are available in the shale deposits of the Green River Formation (Slawson and Yen, 1979). This amount of oil is equivalent to a 100-year petroleum supply for the United States at 1977 consumption rates (Harbert and Berg, 1978).

Although uranium mineralization is widespread throughout the study area, the major reserves in the Yampa and the White River basins lie in the Browns Park Formation of Tertiary age west of Craig, Colo. and north of Rangely, Colo. near the Colorado-Utah State boundary (Melancon and others, 1980). Most of the uranium overlies principal coal-bearing beds which must be extracted with underground techniques. Differences in depths of the two minerals are sufficient that extraction of one probably would not interfere with later mining activities of the other (U.S. Bureau of Land Management, 1976).

Federal ownership of oil, gas, coal, oil shale, and uranium rights in the two basins is more extensive than Federal ownership of land. Ownership of mineral rights and land ownership for the Yampa and the White River basins has been graphically presented by the U.S. Bureau of Land Management (1979b, c, d, e; 1980b, c) in a series of "Surface-minerals management quadrangle" maps at a scale of 1:100,000. Privately owned mineral rights are concentrated primarily in homesteaded agricultural lands in the Yampa River Valley (Steele and others, 1979). The U.S. Bureau of Land Management is responsible for administering Federal mineral rights. In some areas, a consolidation of Federal, State, and private mineral rights is necessary to efficiently mine available coal resources.

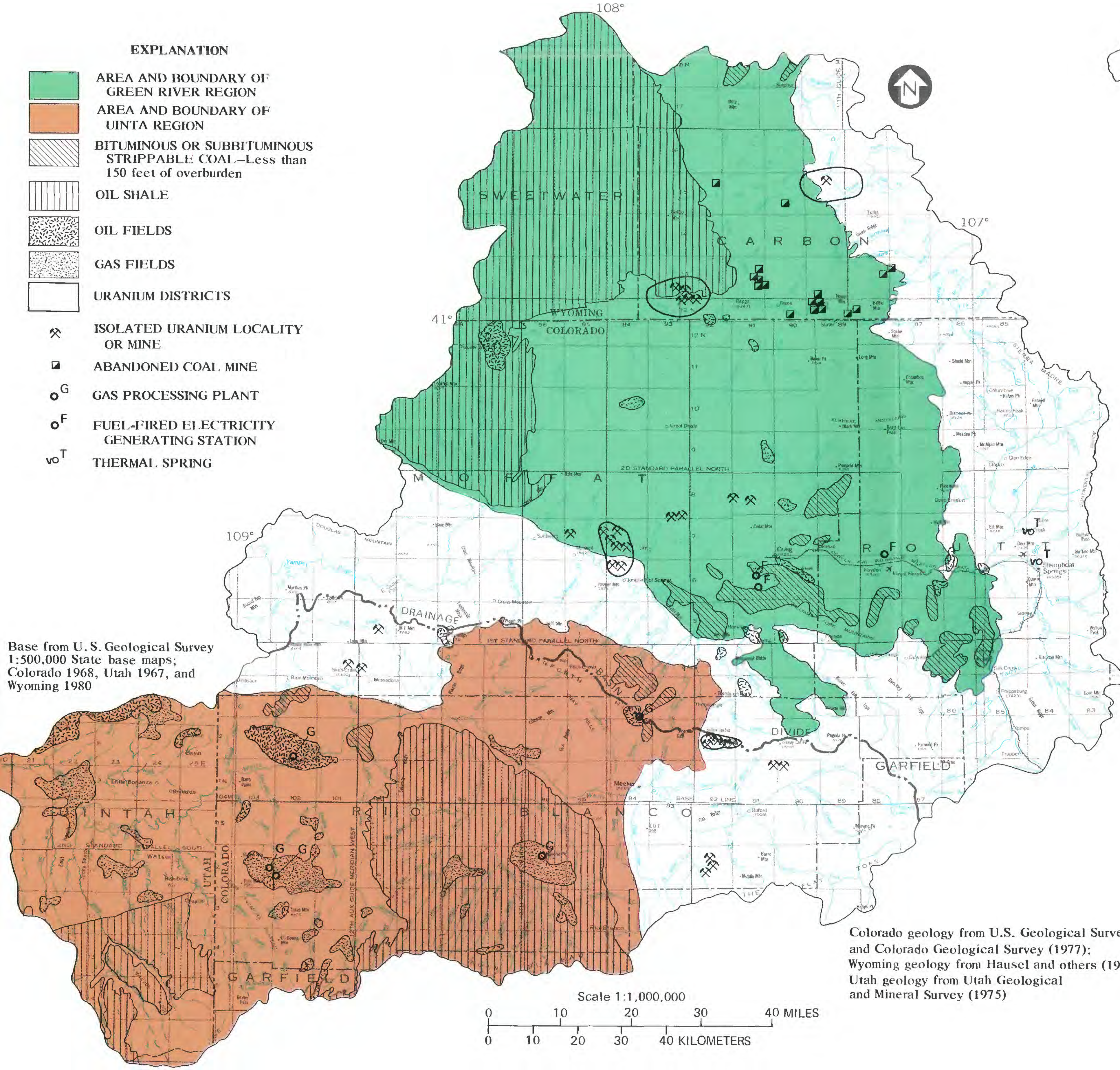


Figure 3.7-1 Mineral resources.

Generating of electricity is one of the primary uses of coal in the area

Drilling rigs explore for oil shale, oil, gas, or other mineral resources in the Piceance basin

Streamflow or Water-Quality Data Available for 197 Locations

There are 197 stations in the surface-water hydrologic network: 148 have continuous streamflow data, 55 have both streamflow and water-quality data, 25 have water-quality data only, and 18 have miscellaneous data.

The Yampa and the White River basins comprise all of Area 53. The selection of network stations in these basins was based on at least one of two criteria. The streamflow stations were selected if they had any daily streamflow data. Continuous streamflow data have been collected at 148 of the 197 surface-water stations, and 46 of these are currently active.

The criterion for inclusion of a water-quality station was a minimum of five analyses of dissolved solids. There are 80 water-quality stations in the network, of which 55 are combined streamflow and water-quality stations and 25 are water-quality stations only. Eighteen additional stations in the network have miscellaneous data; 1 is a sediment station, 4 are inactive partial-record stations where records of annual peak flow were obtained for use in flood studies, and 13 are biological stations.

The surface-water station network in the Yampa and the White River basins is indicated by station and numbers 1-197 on figure 4.0-1. These numbers are listed with an index of the U.S. Geological Survey station number and name, latitude, longitude, type of data, and period of record for each station in section 14.1.

The surface-water station network in this report contains 197 of the 476 surface-water stations in the Yampa and the White River basins. Data for all stations are available from the U.S. Geological Survey's water-quantity and water-quality files described in section 12.3.

The streamflow station 127 on the White River near Meeker, Colo. dates from 1901 and has the longest record in Area 53. The earliest water-quality station in Area 53 is station 23 on the Yampa River, downstream from a diversion near Hayden, Colo., and has water-quality data dating from 1944. Abundant data and long periods of record are available for many of the perennial streams in Area 53. However, long periods of record are unavailable at most stations on intermittent and ephemeral streams, where most coal mines in the area are located.

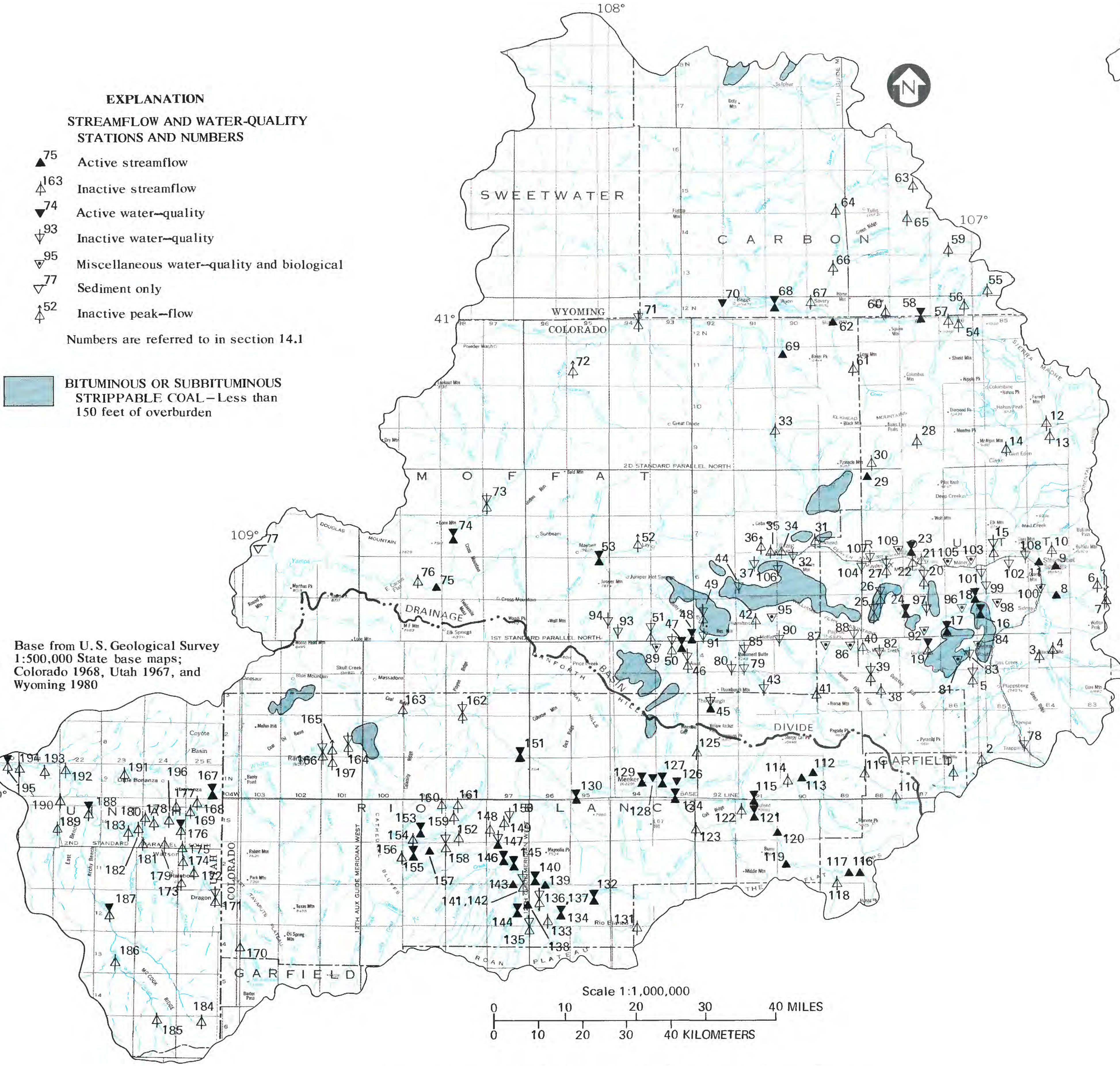
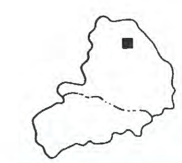


Figure 4.0-1 Location of streamflow and water–quality stations.

Streamflow and water–quality data are collected at this flume and surface–water station at Wilson Creek near the Danforth Hills coalfield (station 47)



Water–quality sampling of a tributary of the Little Snake River

Streamflow has Marked Seasonal Variations

Most annual streamflow is from snowmelt runoff during spring and early summer; irrigation diversions affect streamflow during the summer growing season.

Natural streamflow variations between basins result primarily from differences in basin physiography and other physical characteristics, such as climate, altitude, vegetation, and geology. Man also can have an influence on streamflow variations through diversions for irrigation and use of water for stock and domestic purposes. Seasonal streamflow variations within a basin primarily are the result of type and timing of precipitation and temperature. In Area 53, most streamflow results from snowmelt. The rate the snowpack melts depends on temperature, altitude, slope, aspect, and vegetation cover. Average monthly flow data from station 130, White River below Meeker, Colo., indicate that 60 percent of the annual streamflow occurs in April, May, June, and July. At station 53, Yampa River near Maybell, Colo., more than 77 percent of the annual discharge occurs in April, May, and June.

Hydrographs of average monthly flow at selected streamflow stations are shown in figures 5.1-1 to 5.1-4. Station locations are shown on the map in figure 5.1-5. Hydrographs for two stations on both the Yampa River and the White River, respectively, are shown in figures 5.1-1 and 5.1-2. Both figures show that large seasonal variations are typical of streams in this area. Though general curve shapes and base flows are similar for the downstream stations on the Yampa River (station 53) and the White River (station 130), the Yampa River curve has a higher peak and, in general, reaches the peak discharge in May. On the other hand the curve for station 130 on the White River generally shows a peak discharge in June. These differences primarily result from the larger drainage area above the downstream Yampa River station 53 compared with the drainage area above the downstream White River station 130. Peak discharges at station 53 on the Yampa River are generally earlier than peak discharges at station 130 on the White River. In part, this is due to a larger, lower altitude drainage area where the snowpack melts earlier.

Man also has an effect on the streamflow of both rivers. Water is diverted from both the Yampa and the White Rivers for irrigation in summer months. Actual effects of these diversions on average monthly discharge is unknown.

Average monthly discharge hydrographs for selected smaller tributary streams in Area 53 are shown in figures 5.1-3 and 5.1-4, and their locations are shown in figure 5.1-5. Station data shown in figure 5.1-3 represent the mountainous region of Area 53, and station data in figure 5.1-4 represent the semiarid region. Assuming drainage area and other factors are similar, higher peak discharges generally occur on streams from the more mountainous areas. This is due to greater precipitation at higher altitudes. The hydrograph for station 1, Bear River near Toponas, Colo. (fig. 5.1-3), has a flatter curve as the result of stream regulation by man. The shape of the curves for station 123, Miller Creek near Meeker, Colo., and station 147, Piceance Creek below Ryan Gulch, near Rio Blanco, Colo. (fig. 5.1-4), is affected by irrigation and mine dewatering.

Average monthly flow information is useful, as it not only shows the average amount of water to be expected in any given month, but also shows when there may be an abundance or shortage of water. Though their hydrographs are not depicted in figures 5.1-1 through 5.1-4, many ephemeral streams are present in the area. Many coal mines in Area 53 are in ephemeral stream basins. Most of these streams receive the majority of their average annual discharge from snowmelt, although local thunderstorms also may contribute greatly--especially on streams in the drier western part of the area.

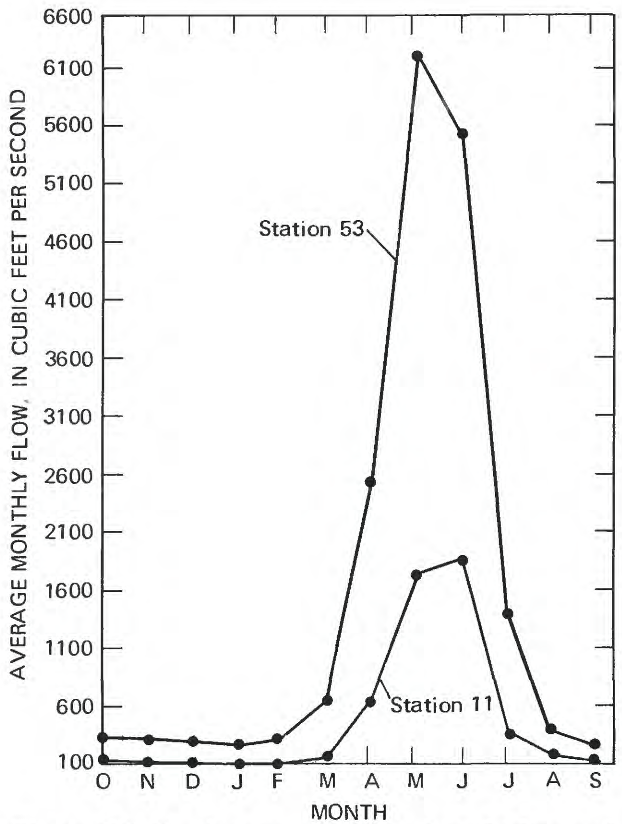


Figure 5.1-1 Average monthly flow hydrographs for stations on the Yampa River.

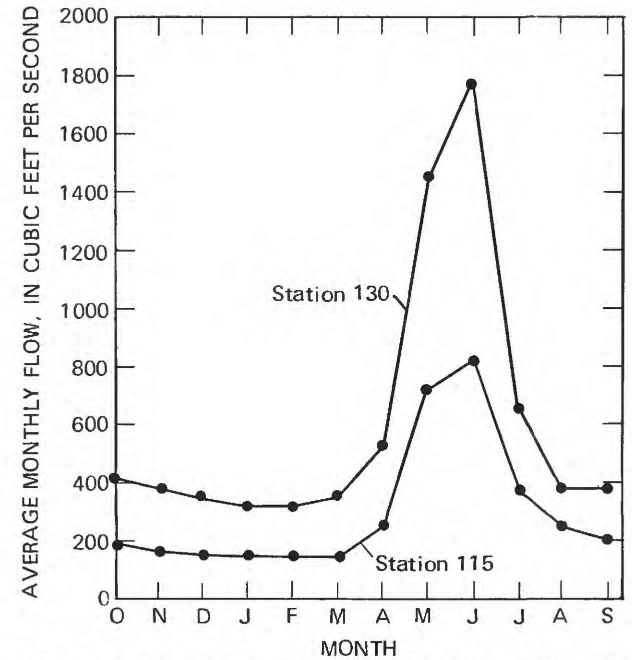


Figure 5.1-2 Average monthly flow hydrographs for stations on the White River.

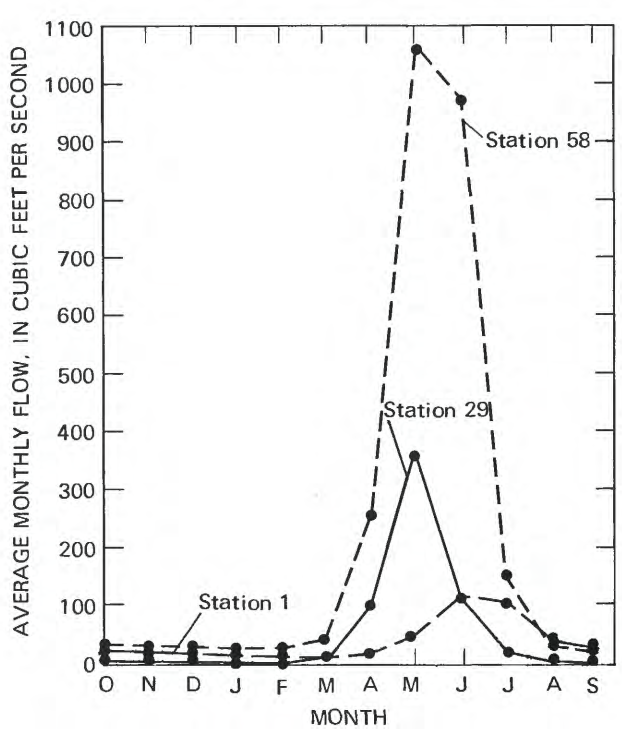


Figure 5.1-3 Average monthly flow hydrographs for stations in the mountainous part of Area 53.

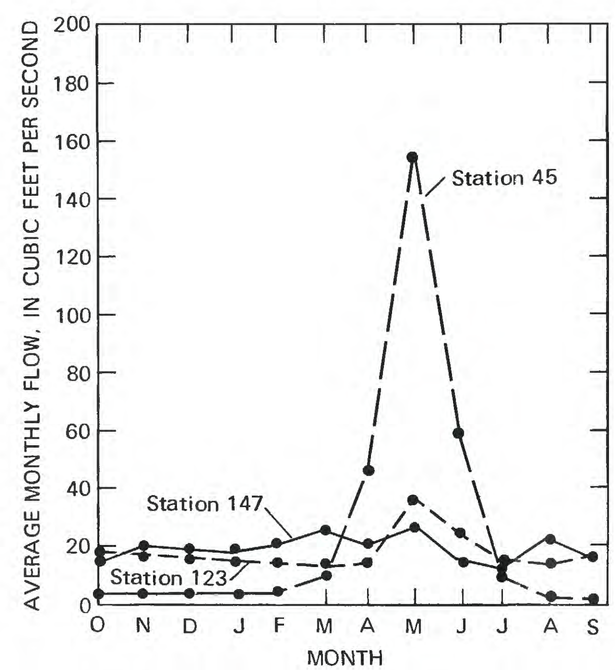


Figure 5.1-4 Average monthly flow hydrographs for stations in the semiarid part of Area 53.

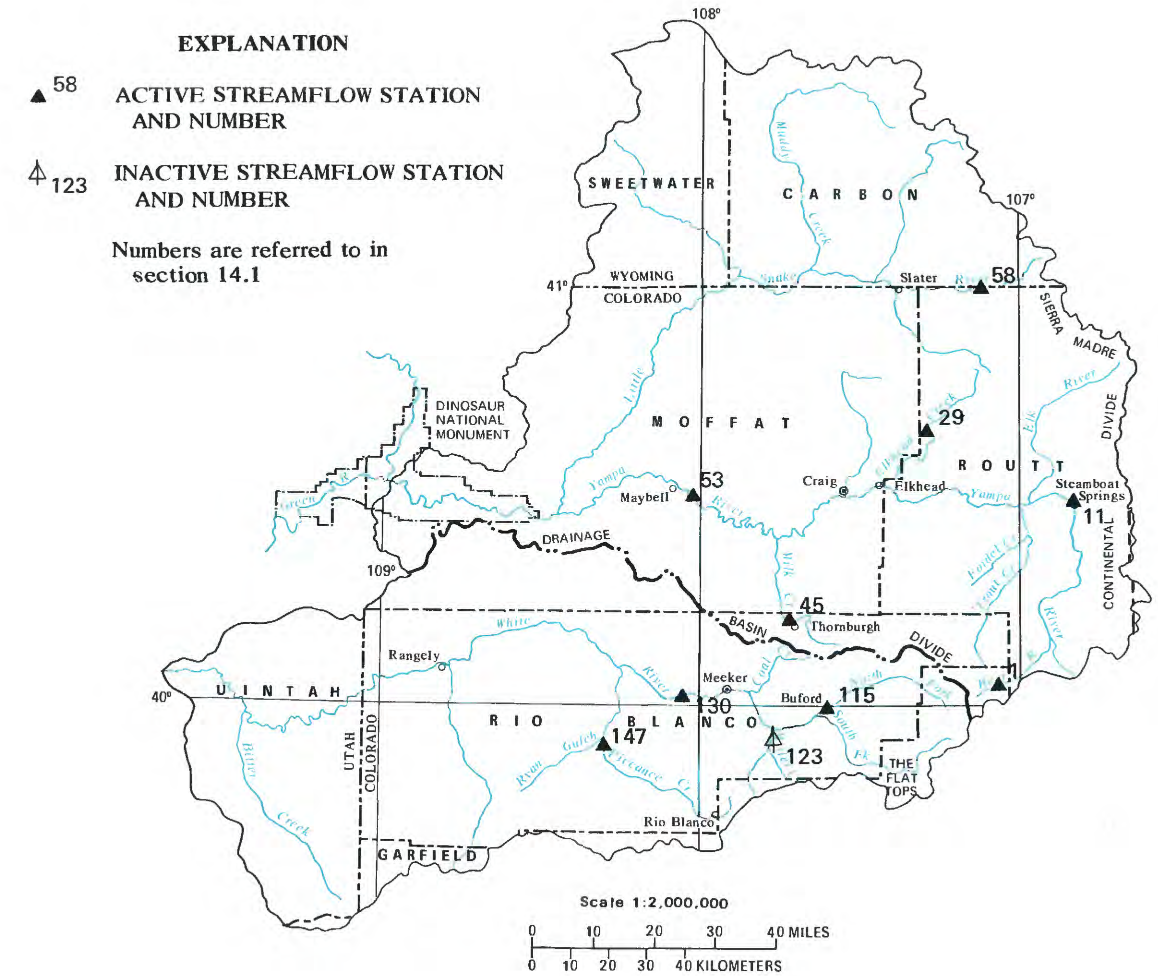


Figure 5.1-5 Location of stations used for average monthly flow hydrographs.

Runoff is Greatest in Streams Draining the Mountains

Average annual flow varies with drainage area and altitude; average annual flows can be predicted.

Average annual flow information is useful in determining water-supply sources. Principal factors influencing average annual flow in Area 53 are drainage area and altitude. Average annual flow, drainage area, and station altitude for selected streamflow stations in Area 53 are shown in table 5.2-1. Locations of these stations are shown on the map in figure 5.2-1.

Drainage area is a major factor in determining average annual flow at a station. This can be seen by comparing upstream and downstream streamflow stations on the same river. Average annual flow at station 11, Yampa River at Steamboat Springs, Colo., to station 53, Yampa River near Maybell, Colo., increases by 1,079 cubic feet per second with an increase in drainage area of 3,106 square miles (table 5.2-1). Similarly, average annual flow on the White River increases by 319 cubic feet per second with an increased drainage area of 764 square miles.

Also shown in table 5.2-1 is average annual flow per square mile of drainage area. This value shows the effect of altitude on average annual flow. Plots of average annual flow per square mile versus altitude are shown in figure 5.2-2. For the stations selected, there seem to be two different relations--one for streams in the mountainous part (A) of Area 53 and one for streams in the semiarid part (B). Streams in the mountainous part have a greater average annual flow per square mile than streams in the semiarid part. This is due to the effects on streamflow of the mountains from which most streams in the eastern part of the area flow. The major effect of the mountains probably is to change the altitude-precipitation relation, but other factors also are involved, such as less evapotranspiration at higher altitudes. The influence of irrigation on streamflow is evident at station 147, Piceance Creek below Ryan Gulch, near Rio Blanco, Colo., where average annual flow is 0.04 cubic feet per second per square mile--the lowest value of the selected streams. Also, lower elevation, less precipitation, and different geology contribute to the low average annual flow at station 147.

Average annual flow for other stations in Area 53 may be obtained from the U.S. Geological Survey WATSTORE computer file as described in section 12.3. Other values of average annual flow for stations in Area 53 are presented in Livingston (1970) for 16 Colorado stations and in Lowham (1976) for 6 Wyoming stations.

Equations are available to estimate average annual flow for ungaged sites in Area 53. Livingston (1970) presents relationships for estimating average annual flow in the mountainous area of Colorado. A relationship containing all variables determined to be significant is:

$$Q_A = 0.00140\, A^{0.956}\, S_t^{\,0.192}\, P^{2.010}\, t_i^{\,-0.189} \qquad (1)$$

where:

Q_A = average annual flow, in cubic feet per second;

A = drainage area, in square miles;

S_t = area of lakes and ponds, as a percentage of drainage area (plus 1 percent);

P = average mean annual precipitation, in inches; and

t_i = average mean minimum January temperature, in degrees Fahrenheit (plus 11 degrees Fahrenheit).

This relation has a standard error of estimate of 47 percent and was developed for mountainous basins where the mouth of the streams are above about 6,500 to 7,000 feet. A relation was not developed for streams in the plains or low plateau regions of Colorado due to a lack of data (Livingston, 1970).

Lowham (1976) developed average annual flow relations for Wyoming streams and defined regions reflecting primary streamflow sources. Two of these regions are in Area 53--region 1 (the mountainous areas subject to snowmelt runoff) and region 2 (plains prone to storm runoff). The boundary between the two is at an altitude of about 7,500 feet. The relation for region 1 is:

$$Q_A = 0.0036\, A^{0.96}\, E^{2.57}, \qquad (2)$$

where:

Q_A and A are as previously defined, and

E = average basin altitude, in feet.

The relation applies only to perennial streams. The relation for region 2 using drainage area as the single variable is:

$$Q_A = 0.244\, A^{0.56}, \qquad (3)$$

and is applicable only to intermittent and ephemeral streams. The relation for region 2 was developed from very limited data, hence, estimates from it should be considered approximate (Lowham, 1976, p. 3).

Relations for estimating average annual flow have not been developed in Utah. However, average annual flow may be estimated from channel geometry characteristics using a procedure developed by Fields (1975).

It may be necessary to apply estimating procedures to streams which cross state lines. If it is unclear which relation gives the best estimate, the following procedure should be used:

1. Determine average annual flows from both procedures; and

2. Use the average value of the two procedures.

ble 5.2-1 *Average annual flow for selected streamflow stations in Area 53*

ion	Station No.	Average annual flow (cubic feet per second)	Drain- age area (square miles)	Average annual flow per square mile (cubic feet per second per square mile)	Station altitude (feet)
a River at eamboat rings, Colo---------	11	464	604	0.77	6,695
a River near ybell, Colo---------	53	1,543	3,410	0.45	5,900
h Fork White ver at Buford, lo------------------	115	296	260	1.14	7,010
e River below eker, Colo----------	130	615	1,024	0.60	5,928
River near ponas, Colo---------	1	40	23	1.72	9,700
ead Creek near khead, Colo---------	29	54	64.2	0.84	6,895
le Snake River ar Slater, Colo-----	58	221	285	0.78	6,831
Creek near ornburgh, Colo------	45	25	65	0.39	6,599
er Creek near eker, Colo----------	123	18	57.6	0.32	6,710
ance Creek below an Gulch near o Blanco, Colo------	147	20	506	0.04	6,070

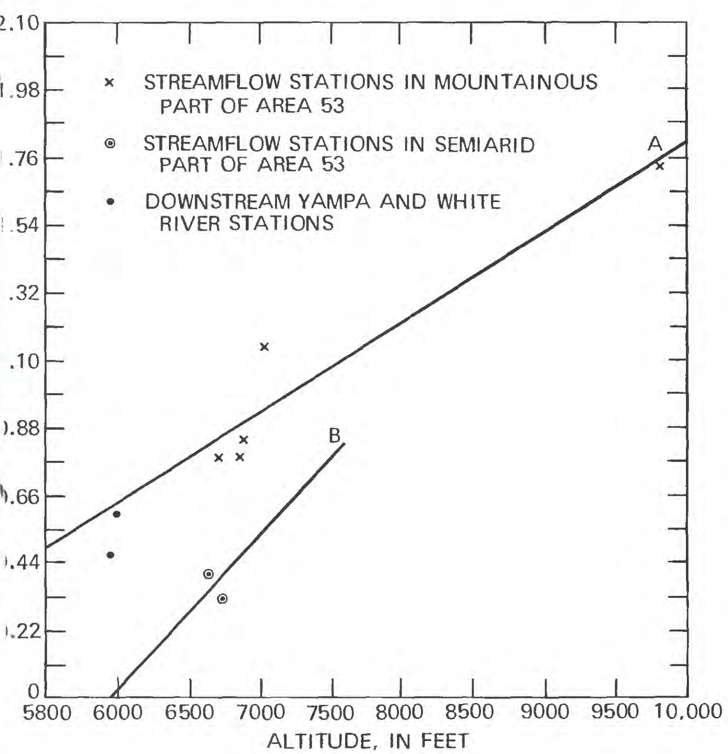


Figure 5.2-2 Variation of average annual flow with altitude in Area 53.

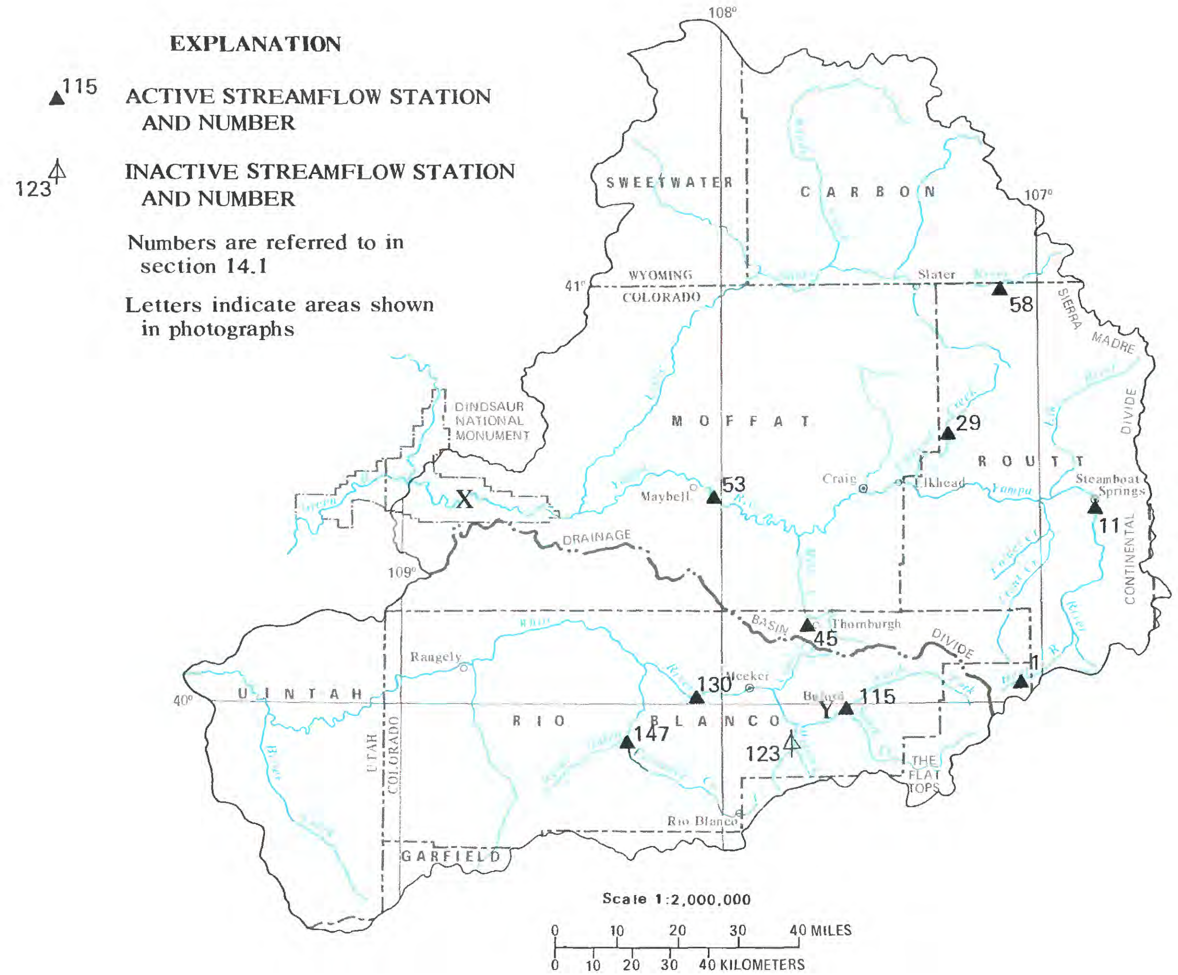
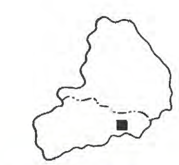
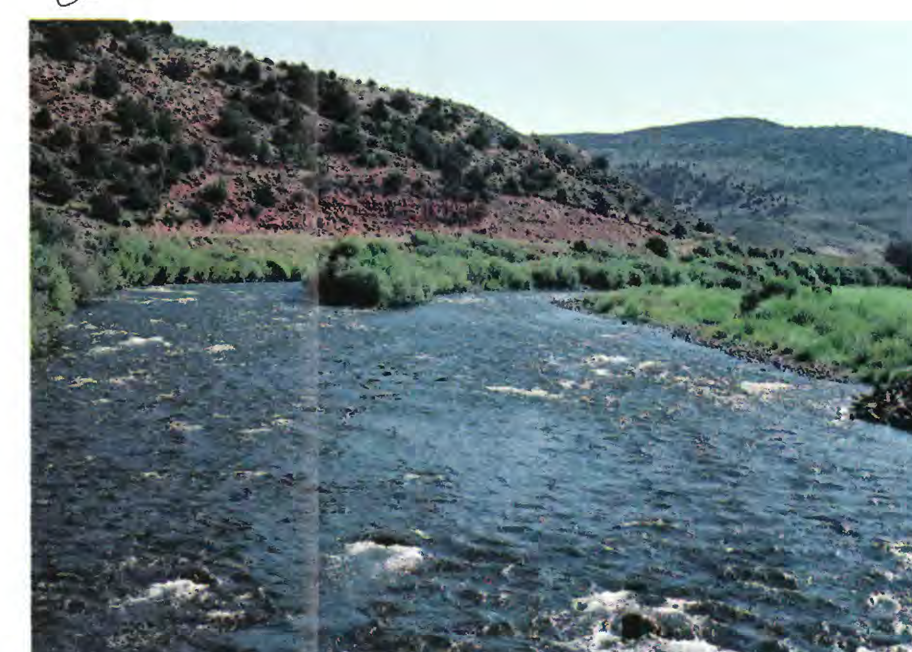


Figure 5.2-1 Location of stations used for average annual flow analysis.

Yampa River in Dinosaur National Monument, Colo.. Flow derived from mountains many miles to the east. Near site X in figure 5.2-1





Confluence of the North and South Forks of the White River. Near site Y in figure 5.2-1

Low-Flow Characteristics Reflect Ground-Water Inflows

Melting snowpacks and reservoir releases also may help augment low flow on some streams.

Low flows on perennial streams are sustained primarily by ground-water inflows, although melting snowpacks and reservoir releases also may help augment low flow on some streams. Low-flow frequency information is helpful in evaluating a stream for water supply or as an indication of its waste-dilution capacity. Low-flow frequency curves, defined in section 1.0, show the minimum average flow during a given consecutive time period that would be expected at a given recurrence interval and generally are based on the climatic year (April 1 to March 31). The low-flow discharge at the 2-year recurrence interval represents the median annual, or normal low flow, of a stream. The 7-day 10-year low flow often is used in water-quality studies. This value is the minimum average flow for a consecutive 7-day period that would be expected once every 10 years.

Seven-day low-flow frequency curves for stations on selected streams in Area 53 are shown in figures 5.3-1 to 5.3-4. Locations of these stations are shown on the map in figure 5.3-5. Curves for two stations on the Yampa River are shown in figure 5.3-1, and curves for two stations on the White River are shown in figure 5.3-2. For example, at station 53, Yampa River near Maybell, Colo., the 7-day 10-year low flow is 37.6 cubic feet per second, and at station 130, White River below Meeker, Colo., the 7-day 10-year flow is about 166 cubic feet per second. The relative steepness of the curves for the two Yampa River stations compared with the two White River stations shows that the flow of the Yampa River is less sustained by ground-water inflows. Curves for the downstream stations on both the Yampa and the White Rivers converge with and cross the curves for the upstream stations, even though the downstream station on the Yampa River has more than five times the drainage area of the upstream station and the downstream White River station has almost four times the drainage area of the upstream station. This probably is the result of loss of flow downstream from evapotranspiration, irrigation, and other diversions.

Curves for stations in the mountainous part of the area are shown in figure 5.3-3. Station 29, Elkhead Creek near Elkhead, Colo., has less sustained flows than the other streams, with 7-day average flows less than 0.1 cubic foot per second expected once every 15 years. The flattening of the lower end of the curve for station 1, Bear River near Toponas, Colo., is the result of regulation.

Low-flow frequency curves for stations located in the semiarid part of the basin are shown in figure 5.3-4. In comparing the curves of figure 5.3-4 with those in figure 5.3-3, it appears that streams in the semiarid part of Area 53 generally are less sustained than those in the mountainous part. This is due in part to the higher altitude of the stations in figure 5.3-3. Irrigation may affect some of the low flows. For example, station 147, Piceance Creek below Ryan Gulch near Rio Blanco, Colo., has a substantial amount of water diverted upstream for irrigation use.

Many ephemeral streams are in the area. However, low-flow frequency curves are virtually meaningless on ephemeral streams. Therefore, no examples are shown in the figure. Low-flow frequency curves for other stations in the area can be obtained from the U.S. Geological Survey's WATSTORE computer files, as described in section 12.3.

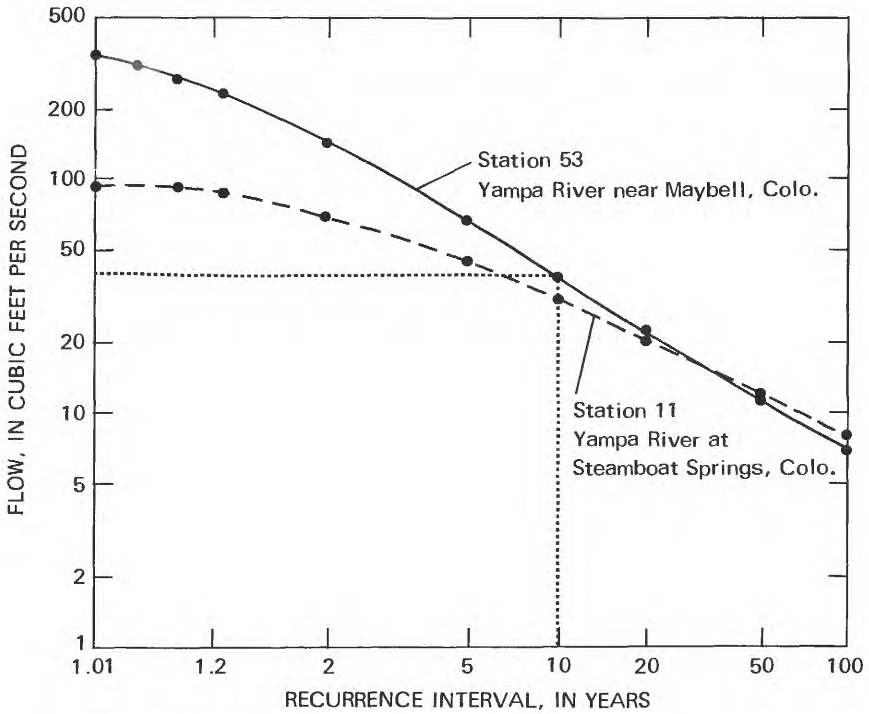


Figure 5.3-1 7-day low-flow frequency curves for streamflow stations on the Yampa River.

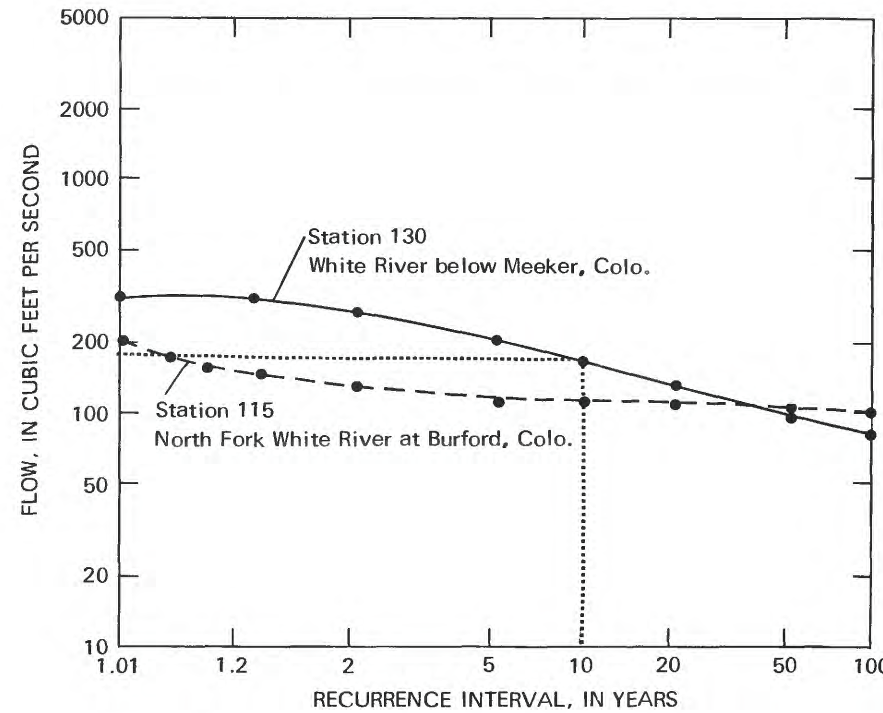


Figure 5.3-2 7-day low-flow frequency curves for streamflow stations on the White River.

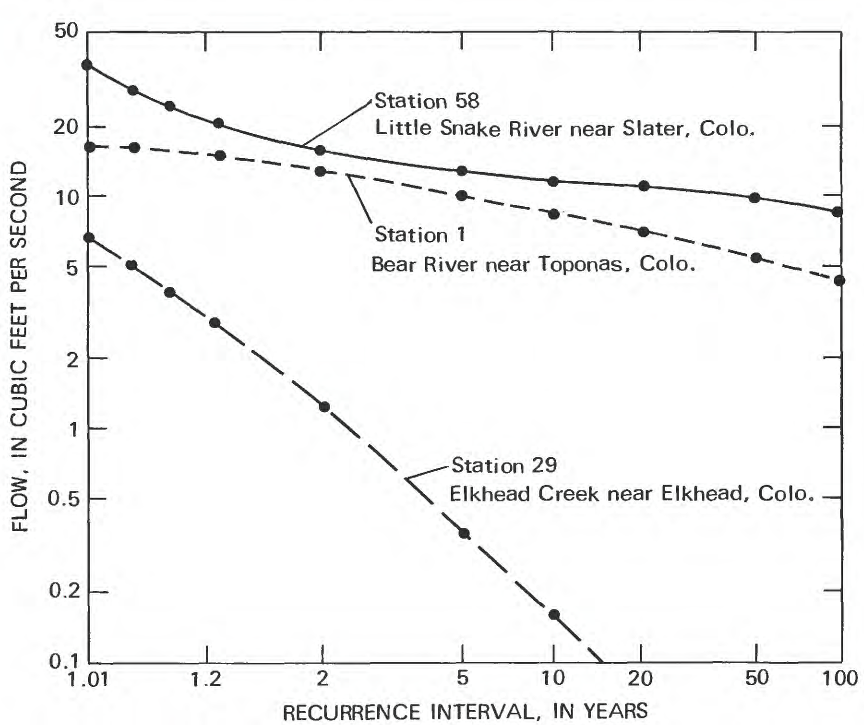


Figure 5.3-3 7-day low-flow frequency curves for streamflow stations in the mountainous part of Area 53.

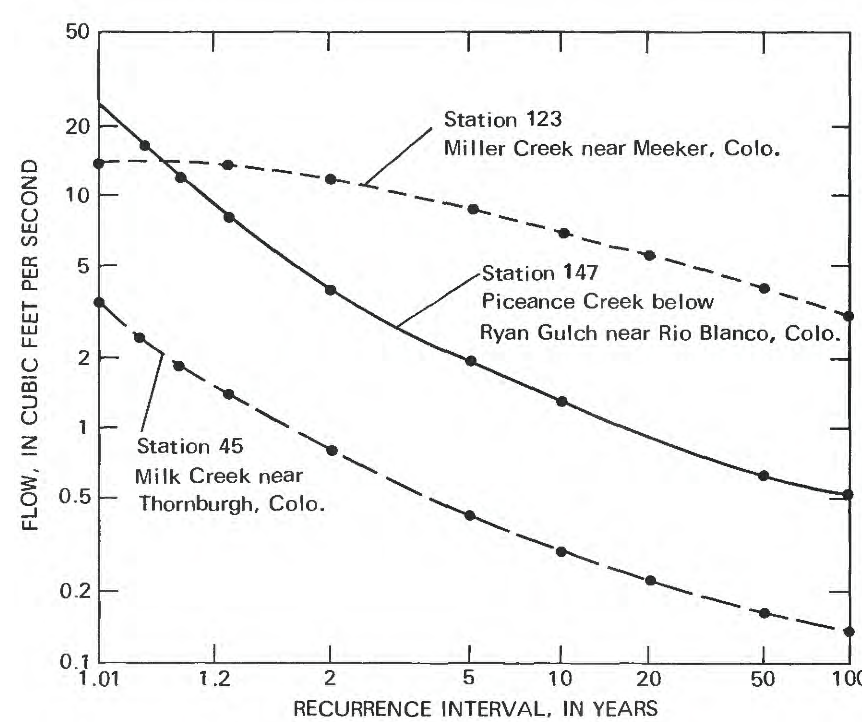


Figure 5.3-4 7-day low-flow frequency curves for streamflow stations in the semiarid part of Area 53.

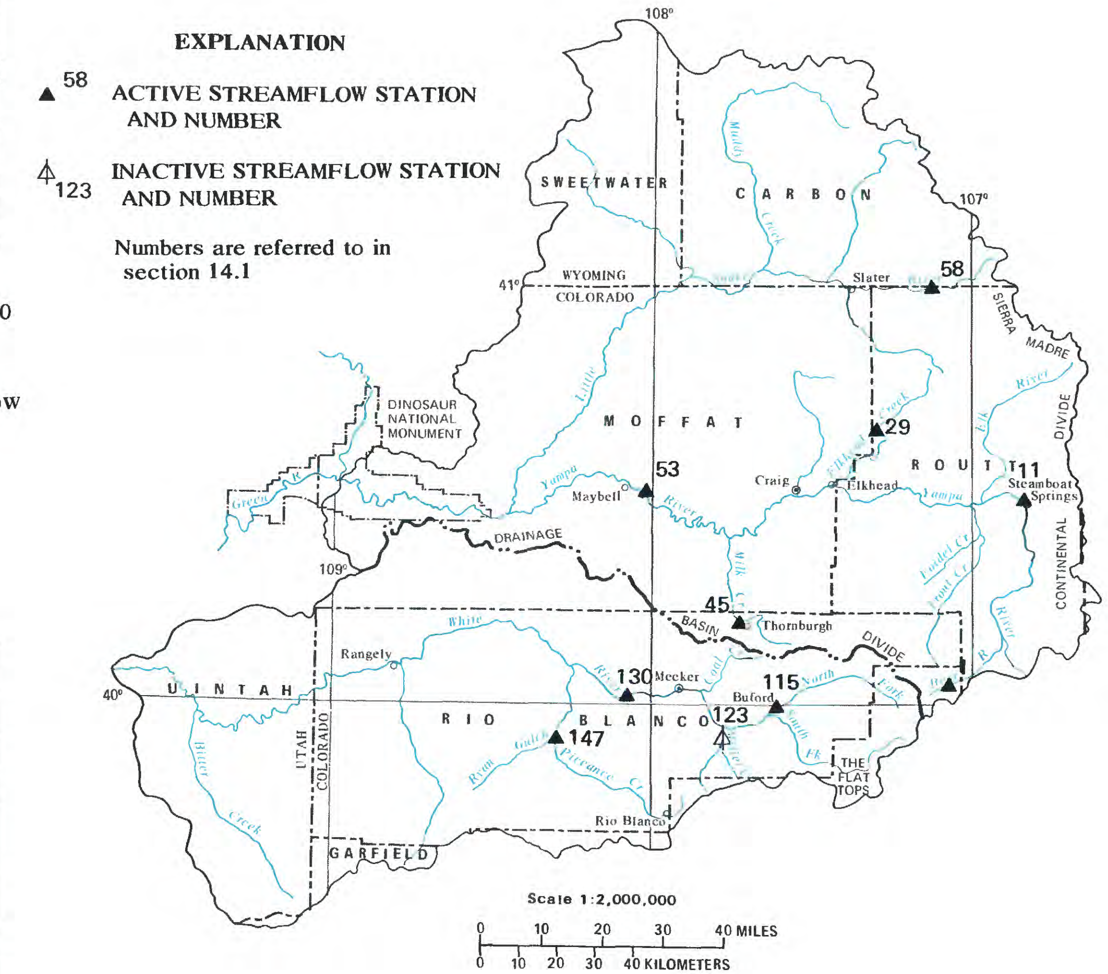


Figure 5.3-5 Location of stations used for low-flow frequency analysis.

Most Annual Peaks Occur in Spring

Most peak flows occur in the spring months as a result of snowmelt or rainfall runoff with snowmelt; the magnitude and frequency of flood peaks can be estimated.

Peak- and flood-flow information is valuable for determining when most peak flows are expected and for engineering design of settling ponds and structures such as culverts. Of the streams selected for analyses more than 88 percent of the peak flows occurred in May and June and almost 97 percent occurred from March to July. This indicates that for Area 53, nearly all recorded peak flows are the result of snowmelt runoff or rainfall runoff in conjunction with snowmelt runoff. This is not to suggest that peak flows from rainfall runoff cannot or have not occurred. In most cases, however, a peak flow from rainfall runoff in this area would be an extreme event, as most annual peak flows occur in the spring runoff period.

The recorded peak flow for stations selected for analyses are reported in table 5.4-1. For these stations, the largest recorded flow occurred May 19, 1917, at station 53, Yampa River near Maybell, Colo. This flow was 17,900 cubic feet per second, or more than 8 million gallons per minute. The largest recorded flow per unit area for these stations occurred at Station 29, Elkhead Creek near Elkhead, Colo., on May 17, 1978, with more than 1,870 cubic feet per second, or about 13,000 gallons per minute per square mile of drainage area.

Flood-frequency curves, defined in section 1.0, for two stations on the Yampa River (stations 11 and 53) are shown in figure 5.4-1, and two stations on the White River (stations 115 and 130) are shown in figure 5.4-2. The relative flatness of the curves in both figures is caused by most peak flows occurring from snowmelt runoff. Flood-frequency curves for streams in which most peak flows are the result of rainfall runoff tend to have a steeper slope. The relatively large drainage area for these stations also is a factor responsible for the flatter slope. Flood-frequency curves for stations in the mountainous part of the area are shown in figure 5.4-3, and flood-frequency curves for stations in the semiarid part of Area 53 are shown in figure 5.4-4. The curves for the semiarid stations (fig. 5.4-4) have a steeper slope than do those in figure 5.4-3. One reason for the steeper slope is the smaller drainage areas of station 45, Milk Creek near Thornburgh, Colo., and station 123, Miller Creek near Meeker, Colo. Another reason for the steeper slope is that the stations shown in figure 5.4-4 have a greater peak flow from rainfall runoff than do the stations in the mountainous part of the basin (fig. 5.4-3). Streams used for analyses are shown in figure 5.4-5.

Relations for estimating flood-peak magnitude and frequency at ungaged sites in Colorado, Wyoming, and Utah are available. McCain and Jarrett (1976) present relations for estimating 10-, 50-, 100-, and 500-year floods at sites on natural-flow streams in Colorado. They define relations for four regions in Colorado, two of which--mountain and northern plateau--are present in Area 53. The relations for both regions are defined in terms of drainage area and average annual precipitation.

Two studies have been made in Wyoming to determine flood magnitude and frequency. Lowham (1976) developed relations for regions based on primary source of streamflow. Region 1 (mountains subject to snowmelt runoff) and region 2 (plains prone to rainfall runoff) are in Area 53. Both relations are applicable to perennial and ephemeral streams and provide estimates for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The region 1 relation is defined by drainage area and average basin altitude. The relation for region 2 uses only drainage area. Craig and Rankl (1978) presented relations for small, mostly ephemeral streams in the plains and valley areas of Wyoming. Their relations provide estimates for the 2-, 5-, 10-, 25-, and 100-year floods and are defined in terms of drainage area, basin slope, maximum relief, and mainchannel slope.

In Utah, Thomas and Lindskov (1983) developed relations for estimating flood-peak magnitude and frequency. The relations for the Uinta basin are applicable both to perennial and ephemeral streams and provide estimates for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. The relations are defined in terms of drainage area and average basin altitude.

If a stream flows across a State boundary or is near a State line, and it is unclear which of the above estimating procedures to use for the best prediction of flood-peak magnitude and frequency, the following procedure is suggested:

1. Predict the flood peak using both procedures; and

2. Use the average value of the two procedures.

Flood frequency and magnitude information for other streams in Area 53 is described in section 12.3.

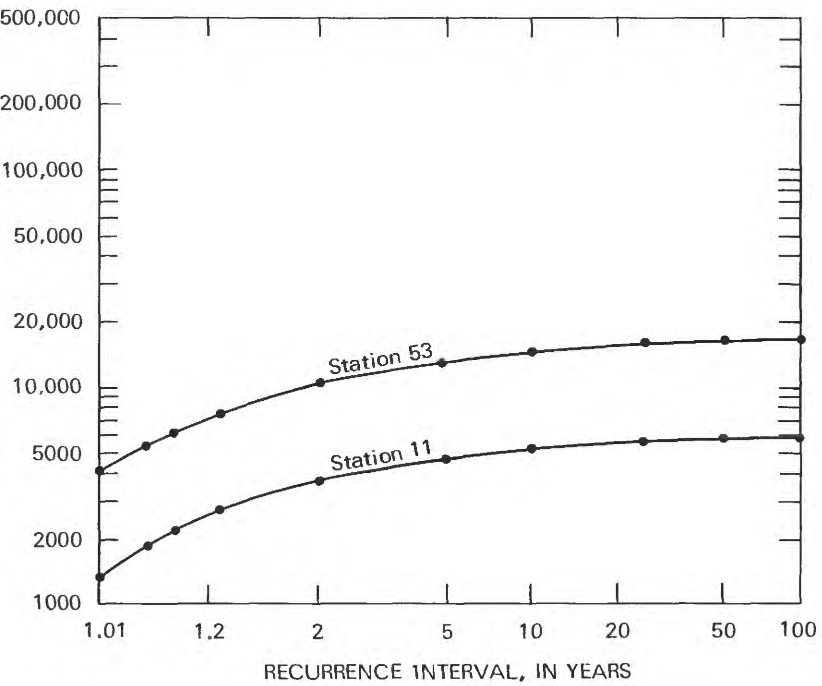


Figure 5.4-1 Flood-frequency curves for streamflow stations on the Yampa River.

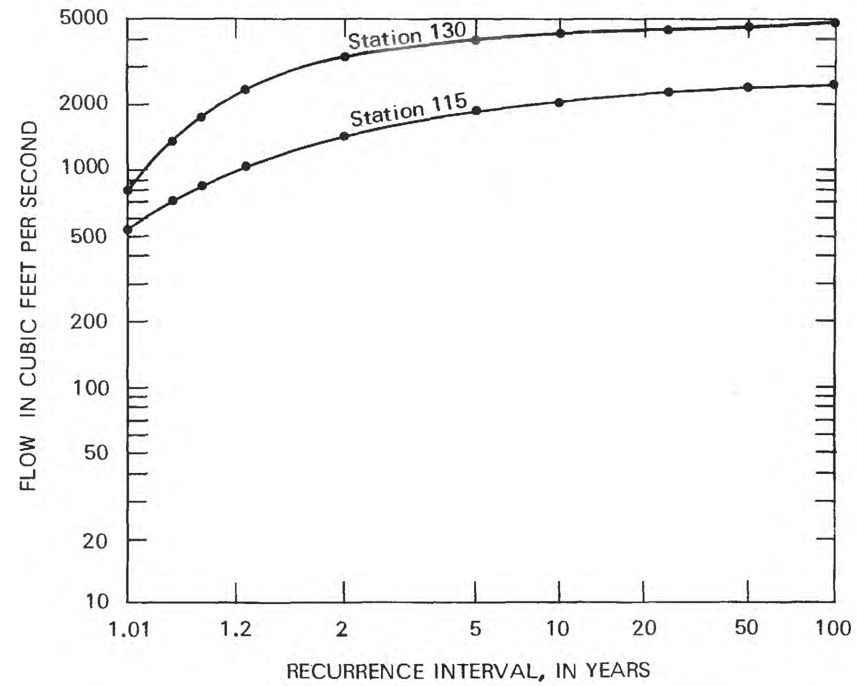


Figure 5.4-2 Flood-frequency curves for streamflow stations on the White River.

Table 5.4-1 *Peak flow at selected streamflow stations*

Station	Station No.	Peak flow (cubic feet per second)	Date	Drainage area (square miles)	Flood peak flow per square mile (cubic feet per second per square mile)
Yampa River at Steamboat Springs, Colo----------	11	6,820	6-14-21	604	11.3
Yampa River near Maybell, Colo----------	53	17,900	5-19-17	3,410	5.25
North Fork White River at Buford, Colo------------------	115	2,350	6-29-57	260	9.04
White River below Meeker, Colo----------	130	4,750	6-17-78	1,024	4.64
Bear River near Toponas, Colo----------	1	436	7-2-57	23	19.0
Elkhead Creek near Elkhead, Colo----------	29	1,870	5-17-78	64	29.2
Little Snake River near Slater, Colo-----	58	4,180	4-25-74	285	14.7
Milk Creek near Thornburgh, Colo------	45	1,050	5-10-74	65	16.1
Miller Creek near Meeker, Colo----------	123	204	5-28-79	58	3.5
Piceance Creek below Ryan Gulch near Rio Blanco, Colo------	147	400	3-9-66	506	0.79

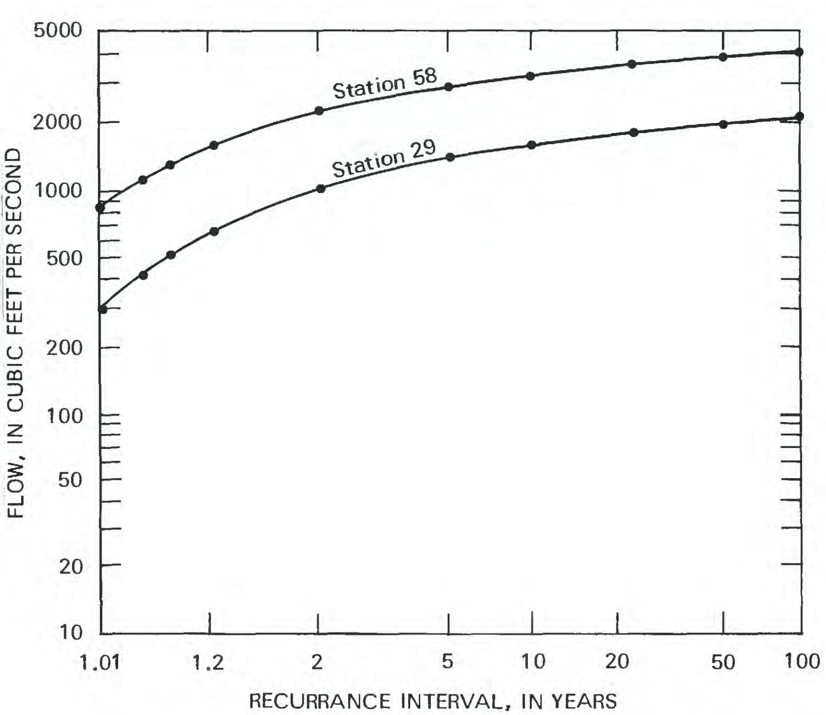


Figure 5.4-3 Flood-frequency curves for streamflow stations in the mountainous part of Area 53.

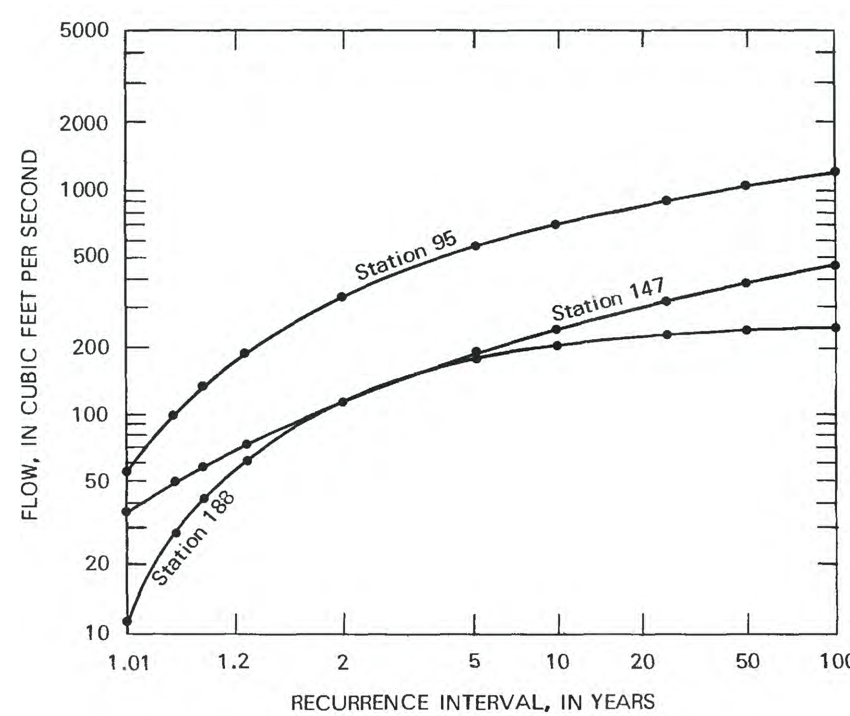


Figure 5.4-4 Flood-frequency curves for streamflow stations in the semiarid part of Area 53.

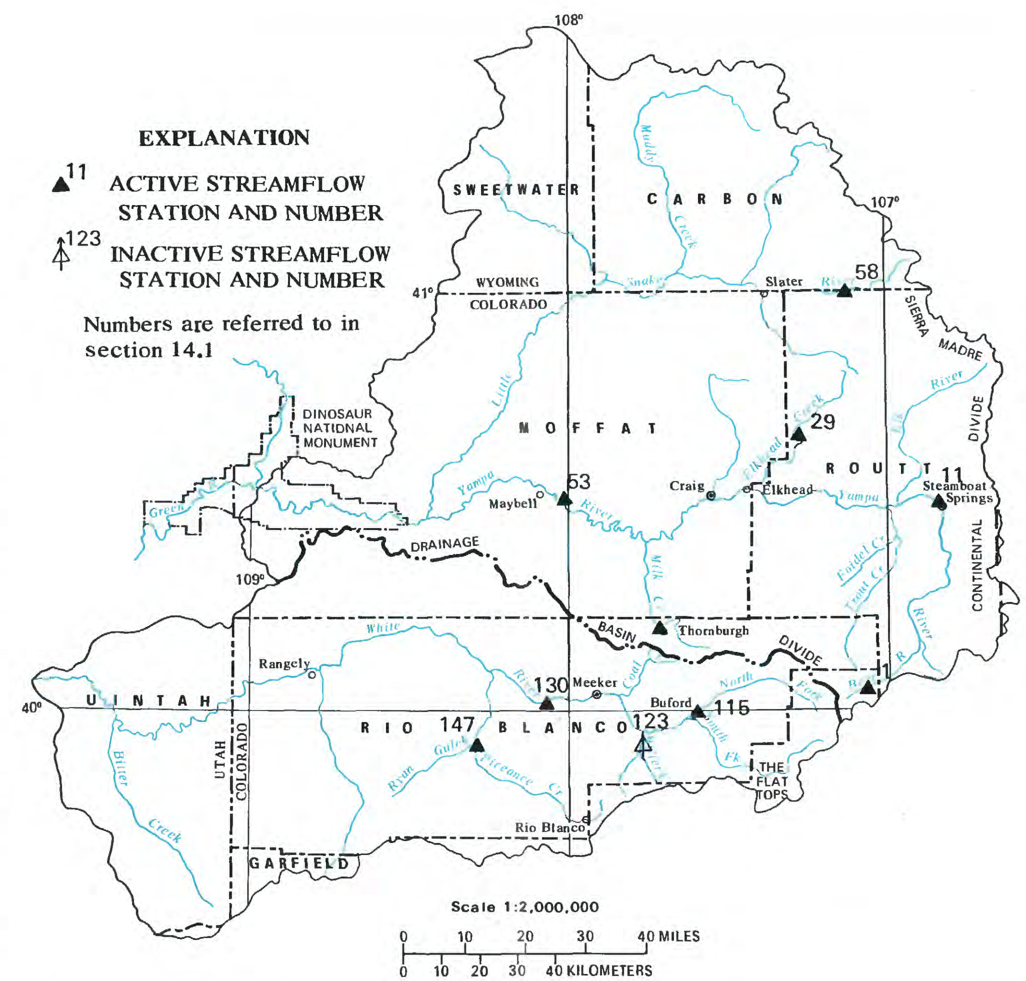


Figure 5.4-5 Location of streamflow stations used for peak and flood-flow analysis for Area 53.

Streamflow of the White River is More Sustained than Streamflow of the Yampa River

Climatic, hydrologic, and geologic characteristics of drainage basins as well as regulation affect streamflow duration.

Flow-duration information is useful for obtaining a general idea about the hydrology of a basin and to detect differences in the flow characteristics between basins. The shape of a flow-duration curve, defined in section 1.0, reflects the climatic, hydrologic, geologic, and flow-regulation characteristics of the drainage basin and is useful in predicting the availability and variability of future flow. A curve having a steep slope lower end of the curve indicates sustained base flow, whereas a steep slope indicates negligible base flow (Searcy, 1959).

Flow-duration curves for stations 11 and 53 on the Yampa River are shown in figure 5.5-1, and flow-duration curves for stations 115 and 130 on the White River are shown in figure 5.5-2. Comparing the curves for the Yampa River stations (fig. 5.5-1) and the White River stations (fig. 5.5-2), the White River stations are much flatter on the lower end. This indicates that the lower flows on the White River are much better sustained by ground-water inflows than those on the Yampa River. The flatter slope on the upper end of the curves in both figures reflects snowmelt runoff. In addition, the curves for the stations having the larger drainage area (upper curve in each figure) on both the Yampa River and the White River show a steeper slope at the lower end than do the lower curves. This is caused primarily by losses from natural causes such as evapotranspiration and effects of man's diversions of water between stations for irrigation use. On the Yampa River between the two stations shown, there is an estimated 35,000 irrigated acres. Between the two stations on the White River, there are more than 10,000 irrigated acres.

Flow-duration curves for stations in the mountainous part of Area 53 are shown in figure 5.5-3. These curves have a flatter slope at the upper Elkhead, Colo., has a much steeper slope at the lower end than do the curves for the other two stations, implying that flow on this stream is less sustained by ground-water inflow.

Flow-duration curves for stations in the semiarid part of the area are shown in figure 5.5-4. Again, these curves have a flatter slope at the upper end, implying snowmelt runoff supplies most higher flows. However, the slopes at the upper end are somewhat steeper than those in figure 5.5-3, implying that rainfall runoff has more influence at the upper end of these indicates that streams in the northeastern part of the area generally have better sustained flow by ground-water inflow, as demonstrated by flatter slopes on the lower end of the curves. However, the curves within each area are different, reflecting the importance of local geology influencing ground-water contributions and the influence of irrigation as in the case of station 147, Piceance Creek below Ryan Gulch near Rio Blanco, Colo. Locations of stations are shown in figure 5.5-5.

Though not shown in the examples, most of the many ephemeral streams in the area probably would have flow-duration curves shaped similarly to those shown. Most would have a somewhat flatter slope on the upper section of the curve, implying snowmelt runoff. The most noticeable difference would be at the lower section where the curves would be steep with only a small flatter area before the flow went to zero.

Flow-duration curves for other streamflow stations in Area 53 may be obtained from the U.S. Geological Survey's WATSTORE computer files, as described in section 12.3.

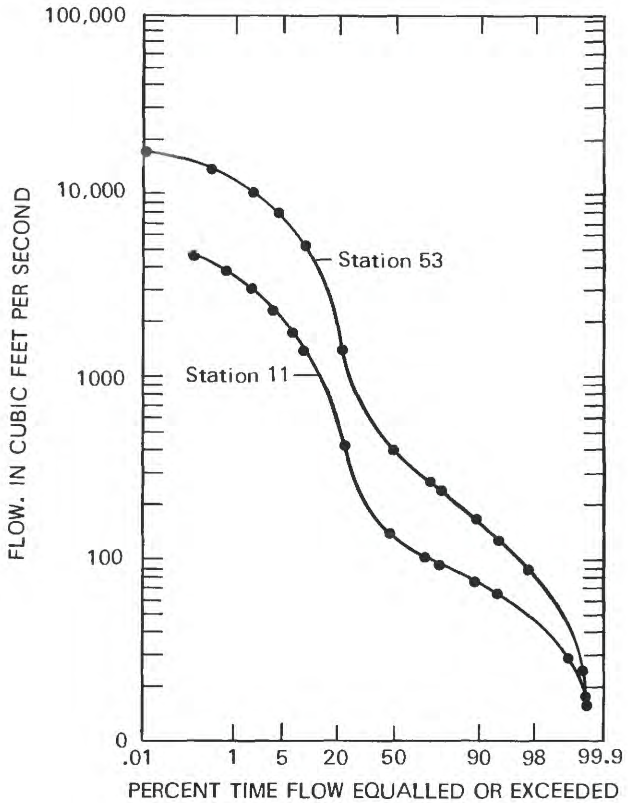


Figure 5.5-1 Flow-duration curves for streamflow stations on the Yampa River.

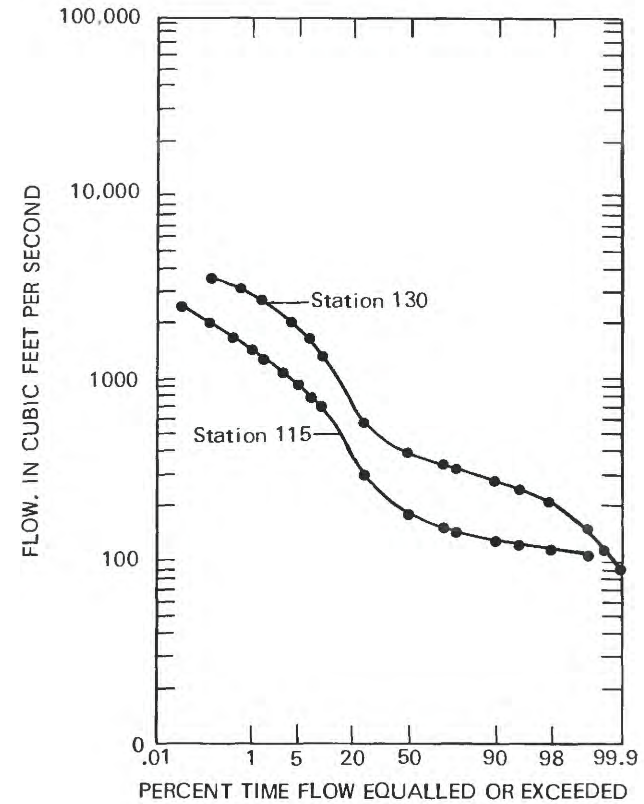


Figure 5.5-2 Flow-duration curves for streamflow stations on the White River.

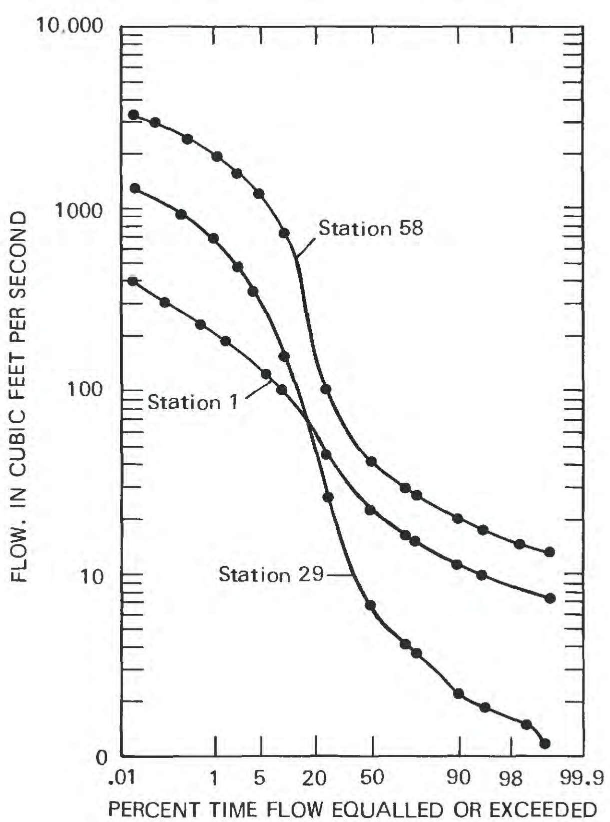


Figure 5.5-3 Flow-duration curves for streamflow stations in the mountainous part of Area 53.

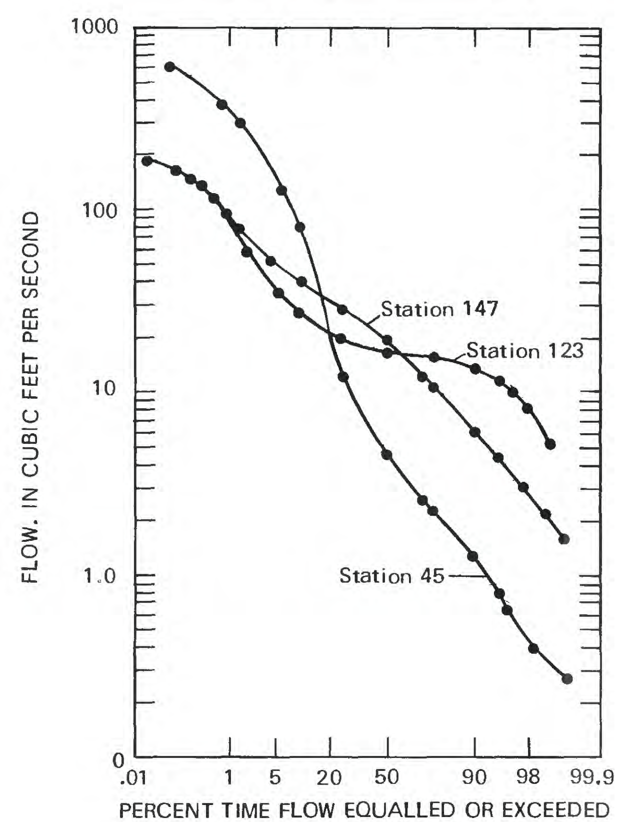


Figure 5.5-4 Flow-duration curves for streamflow stations in the semiarid part of Area 53.

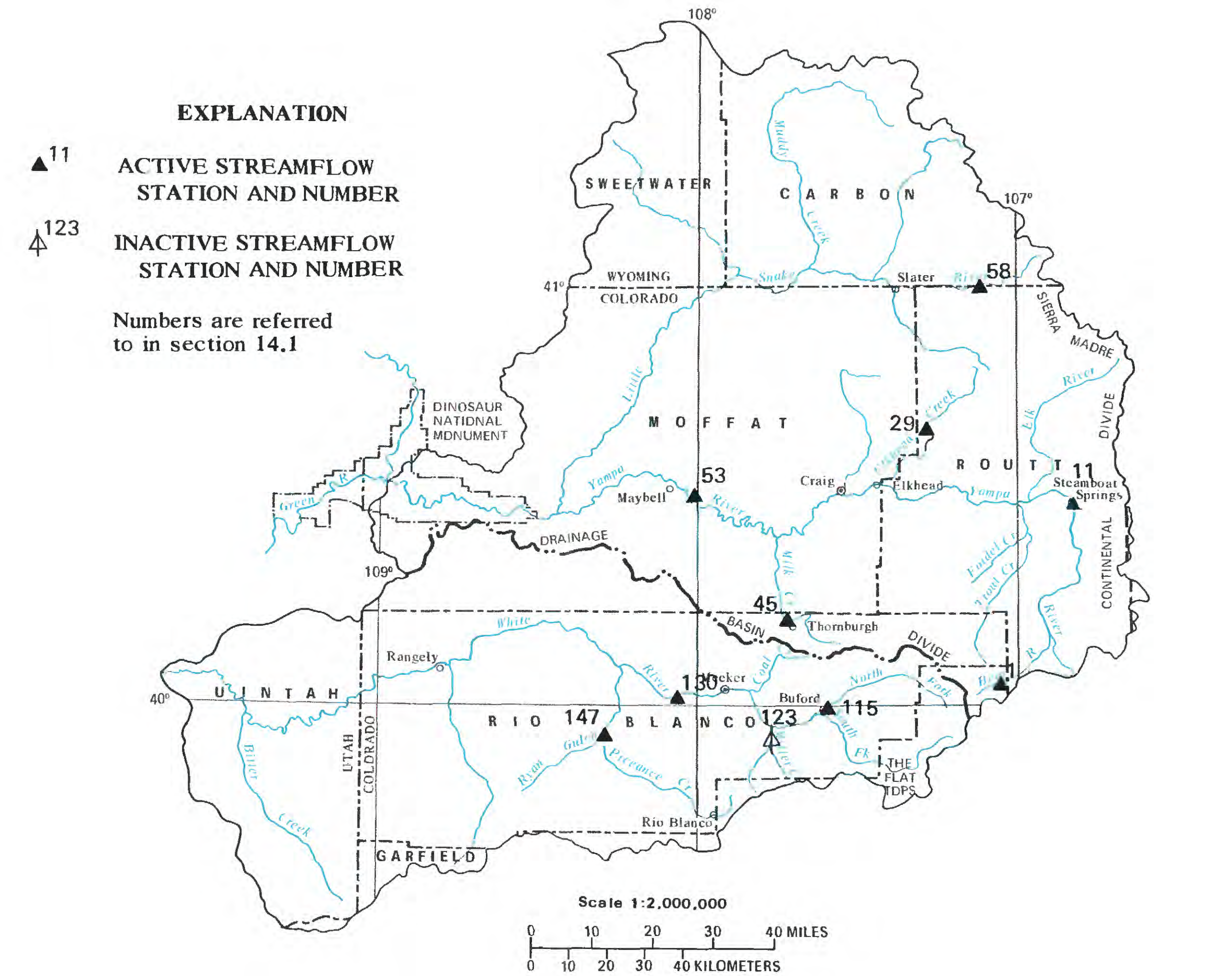


Figure 5.5-5 Location of streamflow stations used for flow duration analysis.

Most Larger Lakes and Reservoirs have Multiple Uses

Lakes and reservoirs are used for irrigation, fishery, recreation, and stock watering.

Lakes having a surface area greater than 100 acres and reservoirs having a storage capacity greater than 100 acre-feet are listed in table 5.6-1. The table number for the lake or reservoir corresponds to its location on figure 5.6-1. Steamboat Lake (Upper Willow Creek Reservoir) is the largest reservoir (capacity 23,060 acre-feet), and Trappers Lake is the largest natural lake (surface area 300 acres) in Area 53. Most larger reservoirs have multiple uses including irrigation, fishery, and recreation.

In addition to the larger lakes and reservoirs included in table 5.6-1, there are hundreds of smaller water bodies. These include natural lakes or beaver ponds (generally occurring at higher altitudes) and stock ponds (generally located at lower altitudes on ephemeral streams). Most of the stock ponds are owned by individuals or by irrigation and ditch companies. Many of these smaller lakes at lower altitudes normally are not accessible to the general public.

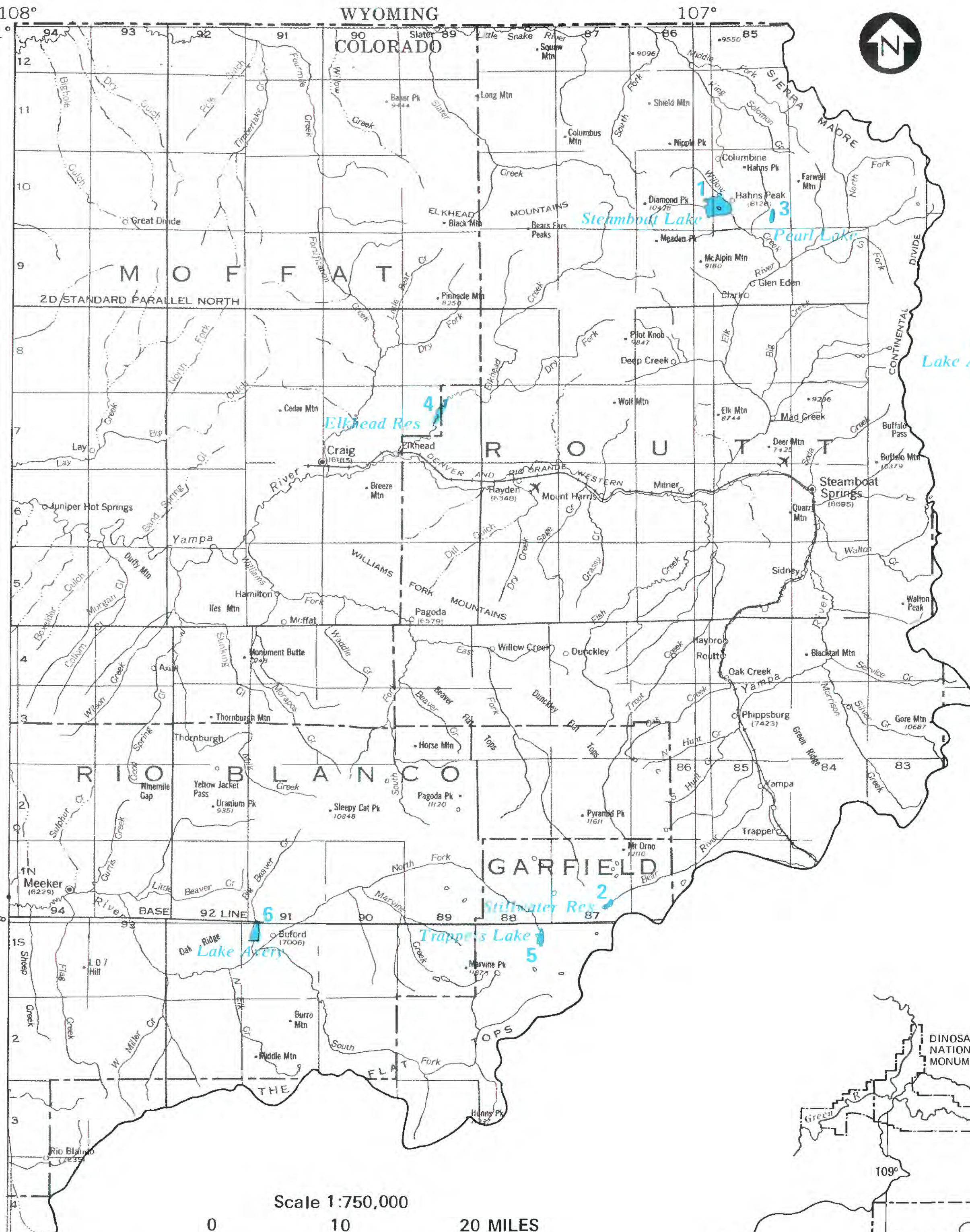
The U.S. Geological Survey has several publications on lakes and reservoirs in Area 53: Steele and others (1979), Britton and Wentz (1980), and Veenhuis and Hillier (1982). Additional information can be gathered from private irrigation companies, Federal, State, and local agencies.

Table 5.6-1 *Larger lakes and reservoirs in Area 53*[1]

[modified from Steele and others, 1979. Use: I, irrigation; F, fishery; R, recreation; O, other]

Number	Name	Stream	Use	Reservoir storage capacity (acre-feet)	Lake surface area (acres)	Location
1	Steamboat Lake (Upper Willow Creek Reservoir)	Willow Creek	F,R,I	23,060	---	NWNE32-10N-85W
2	Stillwater Reservoir----	Bear River	F,R,I	6,390	---	NWSE26- 1N-87W
3	Pearl Lake (Lester Creek Reservoir)	Lester Creek	F,O	5,660	---	NESW 2- 9N-85W
4	Elkhead Creek Reservoir-	Elkhead Creek	F,R	5,390	---	SWSE16- 7N-89W
	Three reservoirs (capacity of each between 1,000 and 1,200 acre-feet)	---	---	3,350	---	
	Twenty-four reservoirs (capacities of each between 100 and 1,000 acre-feet)	---	---	10,210	---	
5	Trappers Lake	Fraser Creek	R	------	300	NWSW 2-1S-88W
6	Lake Avery (Big Beaver Reservoir)	Big Beaver Creek	R,I	7,660	---	SWNE18-1S-91W

[1]Lakes with over 100 acres surface area or reservoirs with over 100 acre-feet storage capacity.



Scale 1:750,000

0 10 20 MILES

0 10 20 KILOMETERS

Base from U.S. Geological Survey 1:500,000 State base map, 1968

EXPLANATION

6 *Lake Avery* LAKES AND RESERVOIRS– Number corresponds to number in table 5.6-1

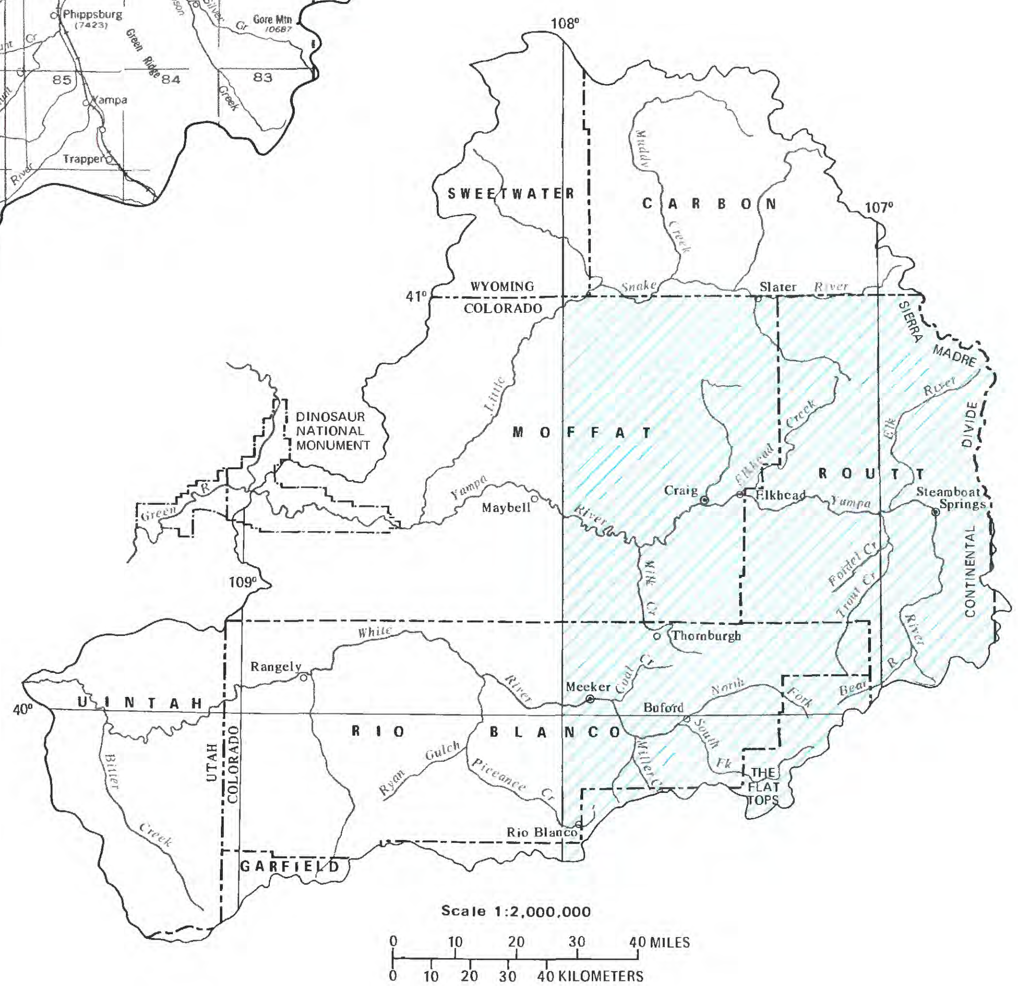


Figure 5.6-1 Location of larger lakes and reservoirs.

Trappers Lake (No. 5) in the White River basin, Colo.

High altitude lakes in The Flat Tops Wilderness Area, Colo.

Time-of-Travel and Reaeration Data Available for Several Streams

Time-of-travel data were collected on several streams at various flows; reaeration data were collected on some of the same streams at low flow.

Time-of-travel, dispersion, and reaeration, all defined in section 1.0, were measured on several streams in the Yampa and the White River basins (fig. 5.7-1). These measurements indicate how soluble contaminants will travel and disperse in the river and the capacity of the streams to receive wastes without excessive dissolved oxygen depletion. This information is valuable to planners and managers in tracing the movement of toxic spills and designing waste treatment facilities.

On each stream, time-of-travel measurements were made during a minimum of two flow conditions because time-of-travel and dispersion characteristics vary with flow and need to be defined throughout a range of flows. The dye, rhodamine-WT, was used to simulate the movement of a soluble waste because it is a solute that behaves like the water molecules. Therefore, measurement of the dye movement will, in effect, be a measurement of the motion and dispersion characteristics of the stream.

The dye was slug injected at various points on each stream and sampled at several sites downstream. The concentration-time curve (fig. 5.7-2) shows that as the dye cloud travels downstream, the peak concentrations decrease, and the longitudinal dispersion or length of dye cloud increases. A modified computer model (McQuivey and Keefer, 1976; Bauer and others, 1978) was used to simulate time-of-travel curves for the Yampa and the Little Snake Rivers (figs. 5.7-3 and 5.7-4). From these graphs, time-of-travel of the dye peak between sites at various flows can be estimated. The leading edge of the dye cloud travels faster than the peak and thus arrives sooner. Due to longitudinal dispersion, the dye cloud will also persist for some time after the peak-concentration occurrence.

Bauer and others (1978) 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. Time-of-travel can be estimated on other streams in the basins by use of equations developed by Boning (1974). Data collection and analyses for the time-of-travel studies followed the procedures and methods in Wilson (1968) and Hubbard and others (1982).

Reaeration coefficients were measured on sections of the Yampa River (Bauer and others, 1978), the Williams Fork, Trout Creek, and the White River (fig. 5.7-1). The coefficient, K^2, quantifies the reaeration process, which is the physical absorption of oxygen from the atmosphere by the flowing stream in order to replace the dissolved oxygen consumed in the oxidation of organic wastes. The reaeration coefficient is often a necessary parameter in water-quality modeling and can be used to determine how much waste can be discharged into a stream without seriously depleting the dissolved-oxygen content.

Several short reaches of the streams were studied at low flow using a modified tracer technique. The measurement of reaeration coefficients entails continuously injecting a tracer gas and determining a desorption coefficient for the gas from measurements of the gas concentrations at various sampling points downstream. The rate at which the tracer gas is desorbed from the stream is related to the rate at which oxygen is absorbed. Details of the technique are given by Rathbun and others (1975) and Rathbun and Grant (1978). Measured reaeration coefficients are listed for the Yampa River (table 5.7-1).

These studies are part of a time-of-travel and reaeration program of the U.S. Geological Survey, designed to collect data on various streams in energy-development areas. Data for the Little Snake River and part of the Yampa River are available in Bauer and others (1978). The remaining data are preliminary and subject to revision and will be published in future reports.

Table 5.7-1 *Reaeration coefficients determined using measured data on selected subreaches of the Yampa River (from Bauer and others, 1978)*

Subreach as defined by site numbers	Reaeration coefficient
3-4	30.5
4-5	22.7
5-6	11.4
3-6	18.1
8-9	10.8
9-11	3.28
8-11	9.25
13-14	7.32

EXPLANATION

TIME-OF-TRAVEL REACH

TIME-OF-TRAVEL AND REAERATION REACH

▲58 STREAMFLOW STATION AND NUMBER
Number is referred to in section 14.1.

3 TIME-OF-TRAVEL AND REAERATION SITES AND NUMBERS FOR LITTLE SNAKE RIVER

3 TIME-OF-TRAVEL AND REAERATION SITES AND NUMBERS FOR YAMPA RIVER

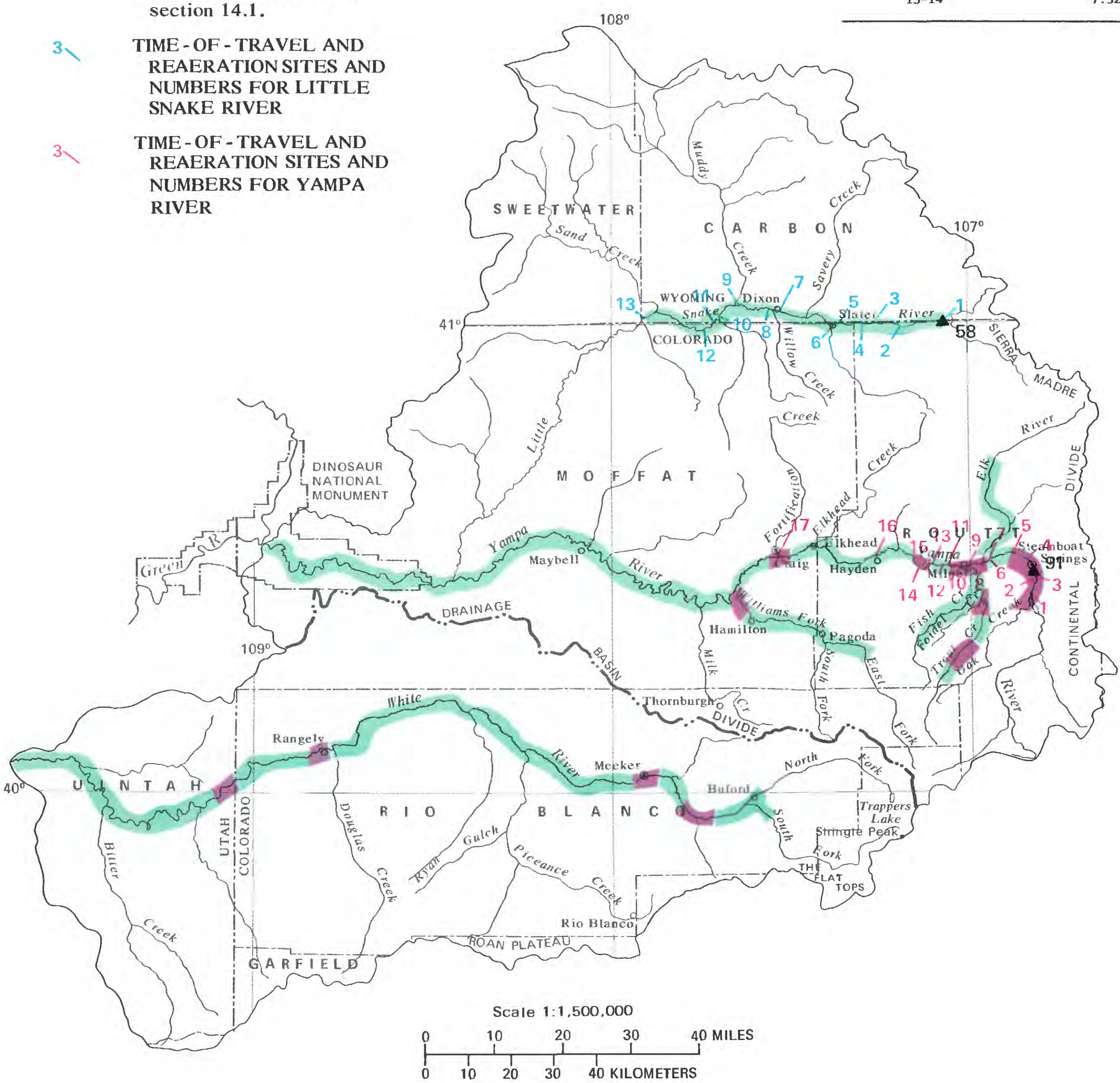


Figure 5.7-1 Location of study reaches in the Yampa and the White River basins.

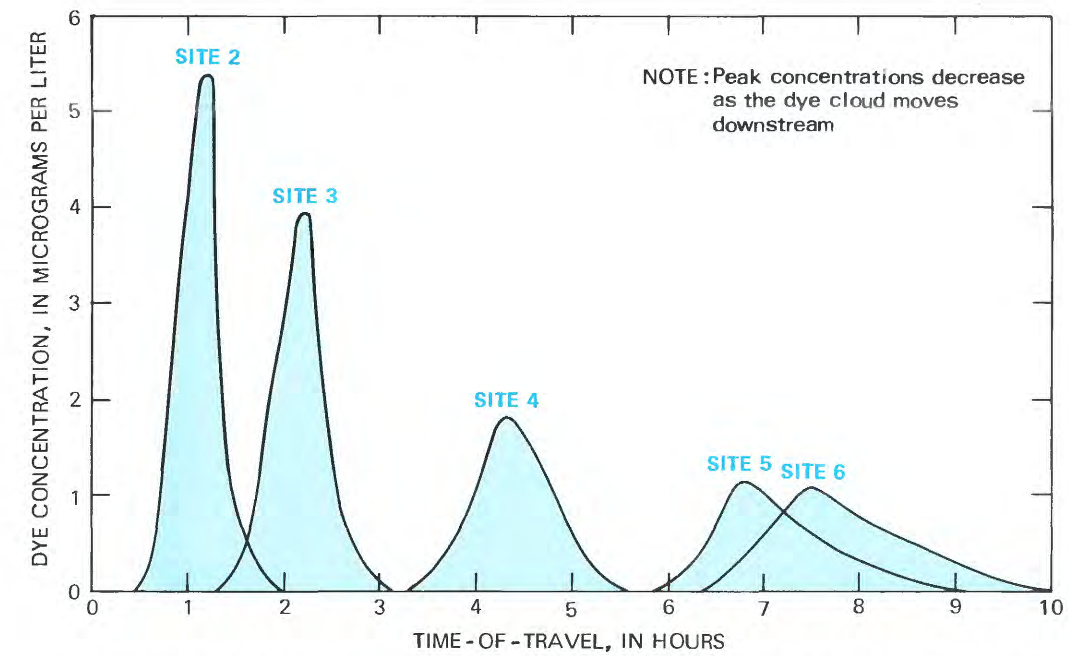


Figure 5.7-2 Downstream movement and dispersion of dye cloud, Little Snake River, Colo. and Wyo., May 1977 (from Bauer and others, 1978).

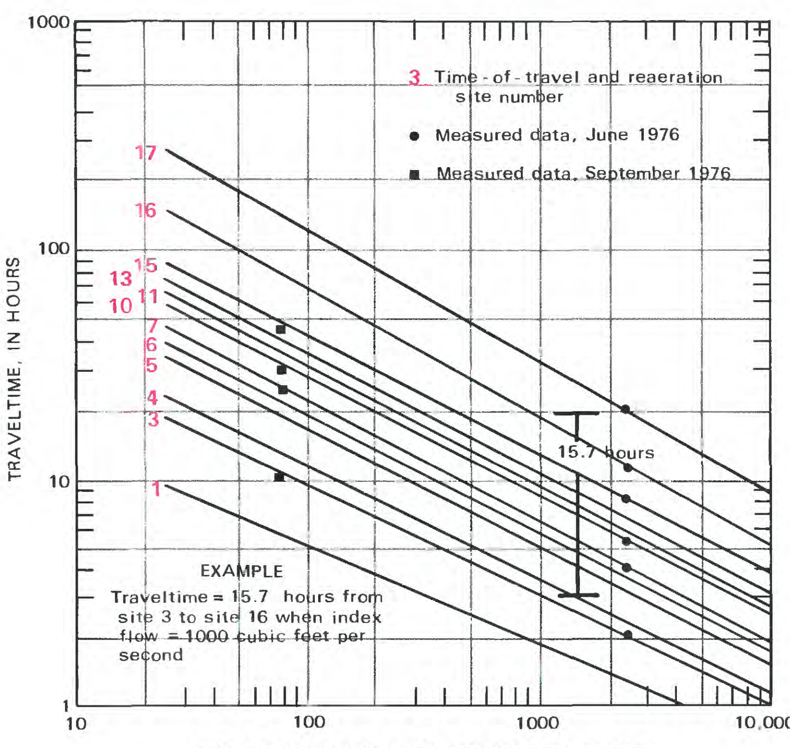


Figure 5.7-3 Simulated cumulative time-of-travel curves for the Yampa River, using station 11, Yampa River at Steamboat Springs, Colo. (from Bauer and others, 1978).

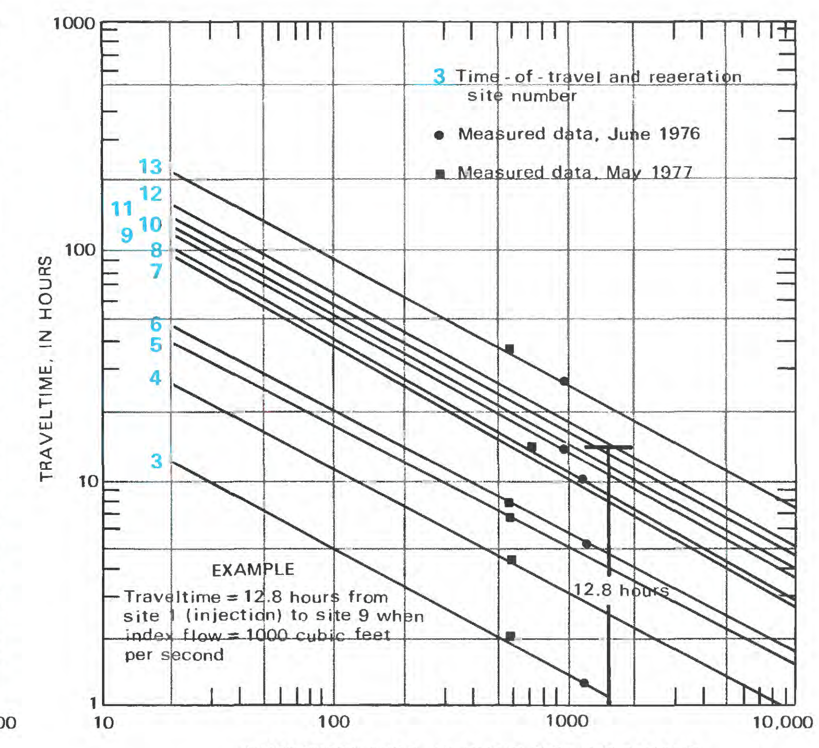


Figure 5.7-4 Simulated cumulative time-of-travel curves for the Little Snake River, using station 58, Little Snake River near Slater, Colo. (from Bauer and others, 1978).

Abundant Water-Quality Data are Available

Water-quality data including dissolved solids, specific conductance, alkalinity, pH, sulfate, and selected trace elements are available for 80 stations in the Yampa and the White River basins.

Based on the minimum of five measurements of dissolved solids at a station, data from 80 water-quality stations were selected for analysis. More than 6,540 samples were collected at these 80 water-quality stations during their respective periods of record through September 30, 1982. The water-quality statistics used in the surface-water quality sections were developed from this data base. The water-quality stations and numbers are plotted on a map of the Yampa and the White River basins (fig. 6.1-1). In addition to the 80 water-quality stations, 13 biological stations are plotted on figure 6.1-1. More detailed information on these stations is presented in section 14.1.

Thirty-six of the 80 water-quality stations in the hydrologic network are currently active, and 28 of these are streamflow stations in addition to being water-quality stations. Nineteen of the 44 inactive water-quality stations are also streamflow stations.

Evaluating the effects of coal mining on surface-water quality requires a knowledge of water-quality characteristics most likely to be affected by coal mining activities. The water-quality constituents and properties discussed in this report were selected on the basis of their potential for change due to coal mining activities (Melancon and others, 1980, p. 103). These constituents and properties include dissolved solids, specific conductance, alkalinity, pH, sulfate, and selected trace elements.

Dissolved-solids concentration, a commonly used indicator of water quality, is related in a general way to specific conductance, a frequently and inexpensively measured property of water (Hem, 1970, p. 96). Dissolved-solids concentrations in streams of Area 53 could increase or decrease from coal-mining spoils leachate or from mine effluent discharge to these streams (Wentz and Steele, 1980, p. 104; Melancon and others, 1980, p. 76).

The pH of water is a measure of the degree of acidity or basicity. In coal-mining areas pH could change due to the common occurrence of pyrite and other sulfide minerals in sedimentary rocks and associated coal deposits. Oxidation of these minerals may cause a decrease in pH. This process of acid mine drainage is not common in the study area because of the buffer capacity of streams and the semiarid climate. Bicarbonate ions are the primary source of alkalinity in the surface waters of Area 53.

Increased sulfate concentrations might also be expected as a result of coal-mining activities, since this ion is present in acid mine drainage. However, because sulfate is a ubiquitous constituent in the soils of the area, caution must be used in applying sulfate concentration as an indicator of acid mine drainage in Area 53. Sulfate concentration must be evaluated on a site-specific basis because natural sulfate concentrations in the Yampa and the White River basins can be quite large (Wentz, 1974, p. 36).

Increased acidity can also result in the dissolution of certain trace elements in amounts greater than natural concentrations. Trace elements discussed in sections 6.5, 6.6, and 6.7 are found in coal and overburden formations in significant concentrations (Melancon and others, 1980, p. 77).

EXPLANATION

WATER-QUALITY STATIONS AND NUMBERS

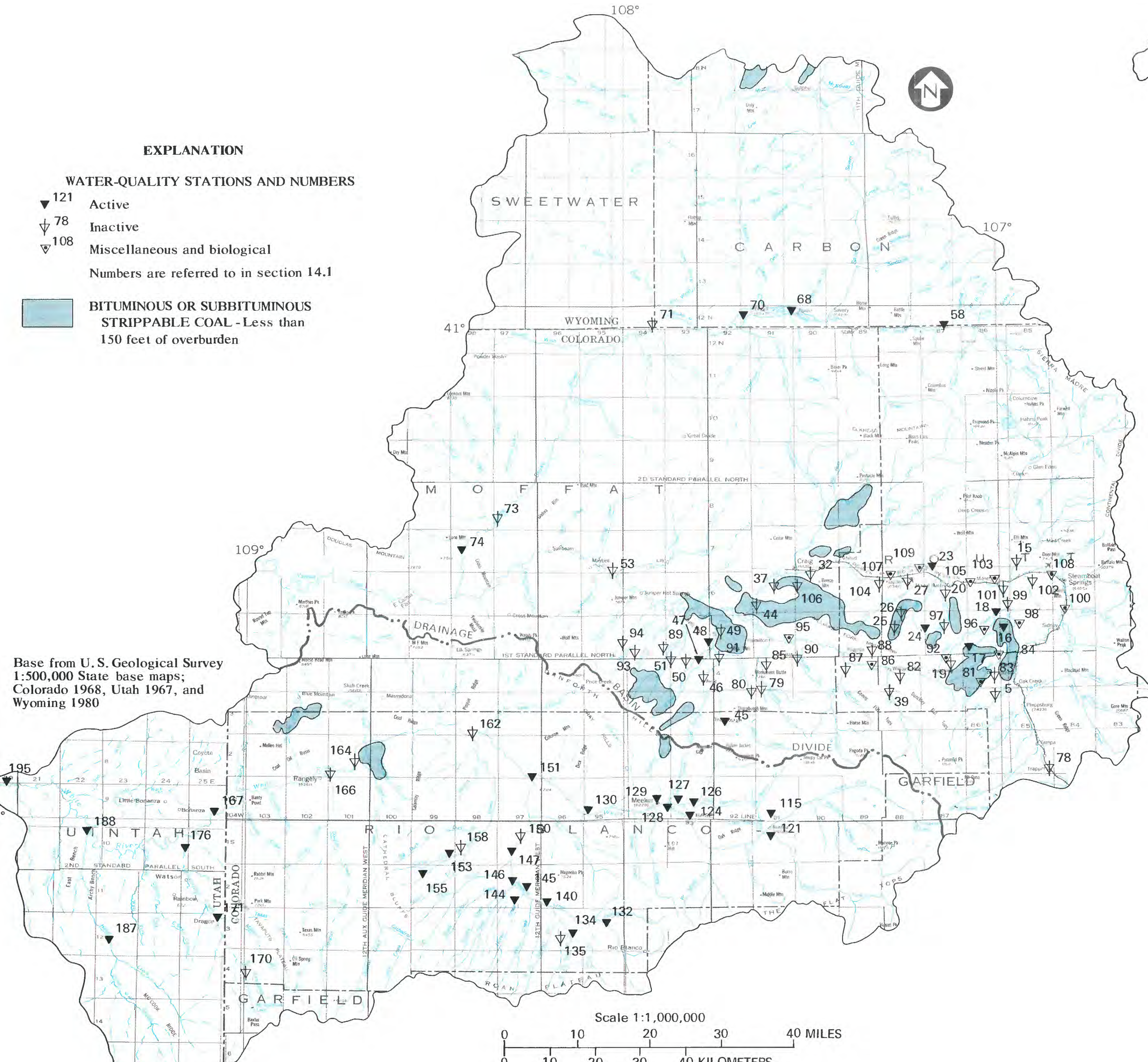
▼121 Active

▽78 Inactive

▽108 Miscellaneous and biological

Numbers are referred to in section 14.1

BITUMINOUS OR SUBBITUMINOUS STRIPPABLE COAL - Less than 150 feet of overburden



Base from U.S. Geological Survey 1:500,000 State base maps; Colorado 1968, Utah 1967, and Wyoming 1980

Figure 6.1-1 Location of water-quality stations.

Measuring dissolved oxygen of a water sample

Strip mining of coal as shown in the Trout Creek basin can affect surface-water quality

6.0 SURFACE-WATER QUALITY

6.1 Introduction

Dissolved Solids and Specific Conductance Values Tend to be Higher in the White River Basin than the Yampa River Basin

The average dissolved-solids concentration of water from the White River basin is nearly three times the salinity hazard-limit.

The average concentrations of dissolved solids, defined in section 1.0, at each water-quality station are shown in figure 6.2-1. Regionally, dissolved-solids concentrations are generally greater west of the mountains which are located along the eastern border of the study area. The smaller dissolved-solids concentrations are in the mountains.

A frequency graph of dissolved-solids concentrations (fig. 6.2-2) in Area 53 shows the distribution of concentrations throughout the area. The data in this graph is biased toward those stations with a larger number of measurements. The average dissolved-solids concentration in Area 53 is 978 mg/L (milligrams per liter). Slightly more than 45 per cent of the dissolved-solids concentrations are 500 mg/L or less, and 91 percent of the concentrations are 2,000 mg/L or less.

The average concentration of dissolved solids in the Yam pa River basin is 467 mg/L. This concentration is just under the 500 mg/L salinity hazard-limit for irrigation practices set by the National Technical Advisory Committee (1968, p. 170). The average dissolved-solids concentration of water from the White River basin is 1,440 mg/L, which is nearly three times the salinity hazard-limit.

The average dissolved-solids concentration of water from the White River basin is in a range which may have adverse effects on many crops and requires careful management practices. The limit established by the National Technical Advisory Committee (1968, p. 134) for dissolved solids in water consumed by livestock is 5,000 mg/L, which may be present in highly alkaline waters containing sodium and calcium carbonates. Currently there is no promulgated standard for dissolved solids in drinking water, although 500 mg/L has been said to be a desirable limit (U.S. Environmental Protection Agency, 1977a).

Documented studies in the area have shown that dissolved-solids concentrations increase due to coal mining. McWhorter and Rowe (1976) found that mined areas which represent only 14 percent of the area contributed 52 percent of the dissolved-solids load leaving the basin. McWhorter, Skogerboe, and Skogerboe (1975, p. 2) found that dissolved-solids production from a specific coal mine spoils by Trout Creek is more than 10 times greater per unit area than in the upstream watershed. Melancon and others (1980, p. 76) state that by 1990 the dissolved-solids load from the Yampa River basin will be 4.5 million kilograms per year and will increase the dissolved-solids concentration in the Colorado River below Hoover Dam by one milligram per liter.

The average value of specific conductance, defined in section 1.0, is 1,320 μmhos (micromhos per centimeter at 25° Celsius) for both the Yampa and the White River basins combined. Just over 29 percent of the specific conductance measurements are 500 μmhos or less, and 60 percent are 1,000 μmhos or less. The maximum measured value out of 6,546 measurements is 18,900 μmhos, the smallest value is 59 μmhos. This is in marked contrast to the 11 to 480 μmhos range quoted for Area 24 in the eastern coal province of Alabama and Georgia (Harkins and others, 1982, p. 38).

The development of a relationship between specific conductance and dissolved solids can be useful in determining general dissolved-solids concentrations. Specific conductance can be used to indicate the approximate amount of dissolved solids in solution. The concentration of dissolved solids, in mg/L, typically is between 0.55 and 0.75 times the specific conductance, in μmhos, but can range from 0.54 to 0.96 times the specific conductance (Hem, 1970, p. 99).

At stations where considerable data are available, a regression relationship between concentrations of dissolved solids or individual ions and specific conductance can be developed. These relationships can then be used to estimate concentrations of the ions or dissolved solids from specific conductance measurements. Regression equations for dissolved solids and specific conductance have been developed for streams in the Yampa River basin by Wentz and Steele (1980, p. 27) and for specific conductance and individual ions by Turk and Parker (1981, p. 6). Boyle and others (1984) have developed similar equations for streams in the White River basin. Delong (1977, p. 32) developed regression relationships for the Little Snake River, a major tributary to the Yampa River.

A plot of specific conductance versus dissolved solids for station 16, Middle Creek near Oak Creek, Colo., is shown in figure 6.2-3. Based on this curve, a water sample with a specific conductance of 500 μmhos would be expected to have a dissolved-solids concentration of 310 mg/L.

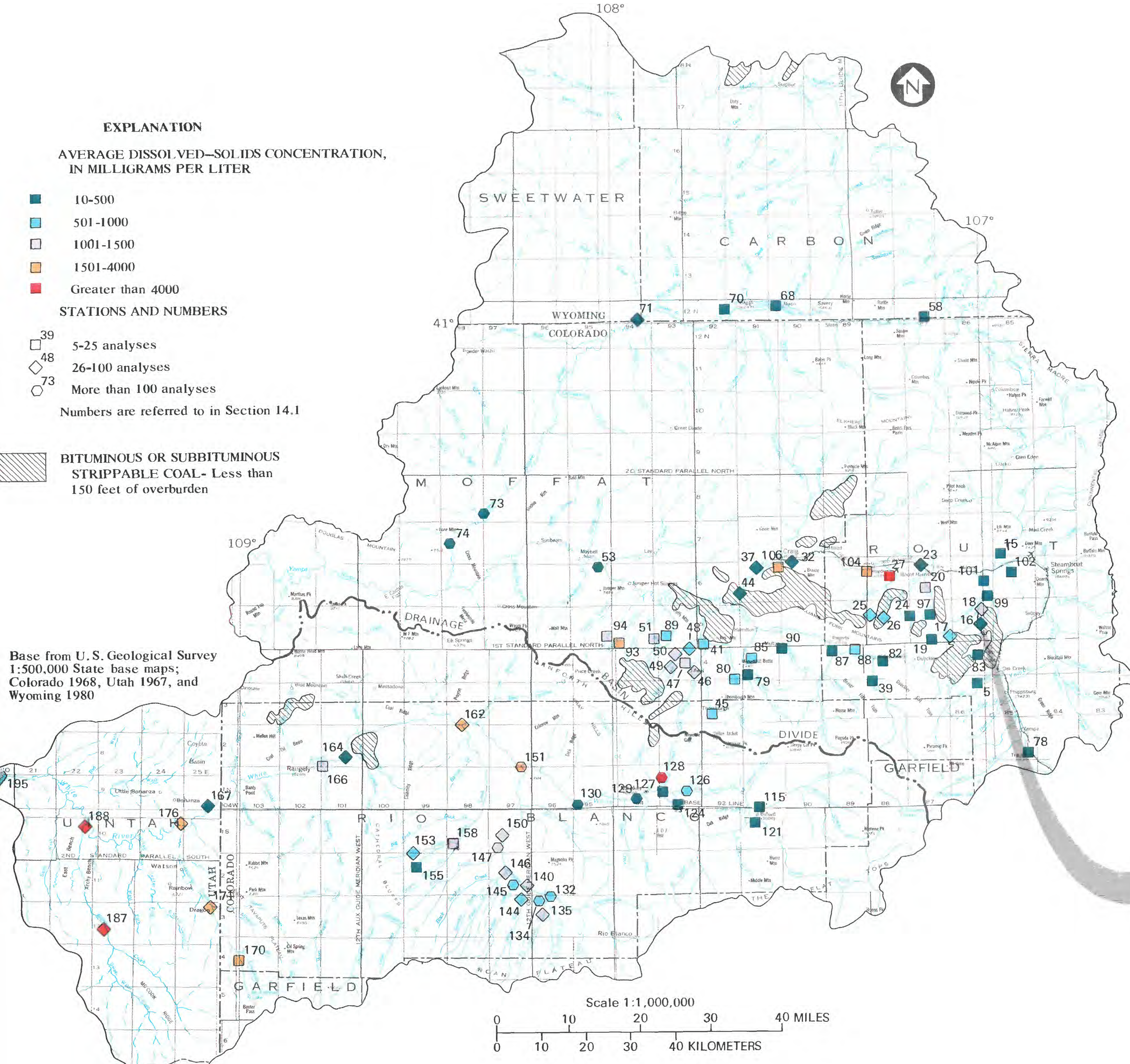


Figure 6.2-1 Average dissolved–solids concentrations at water–quality stations.

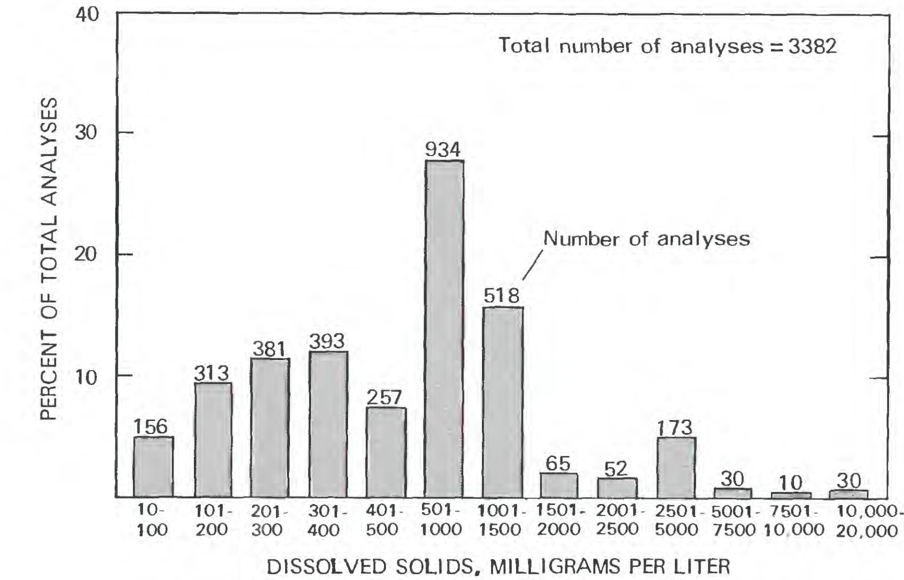


Figure 6.2-2 Frequency distribution of dissolved–solids concentrations.

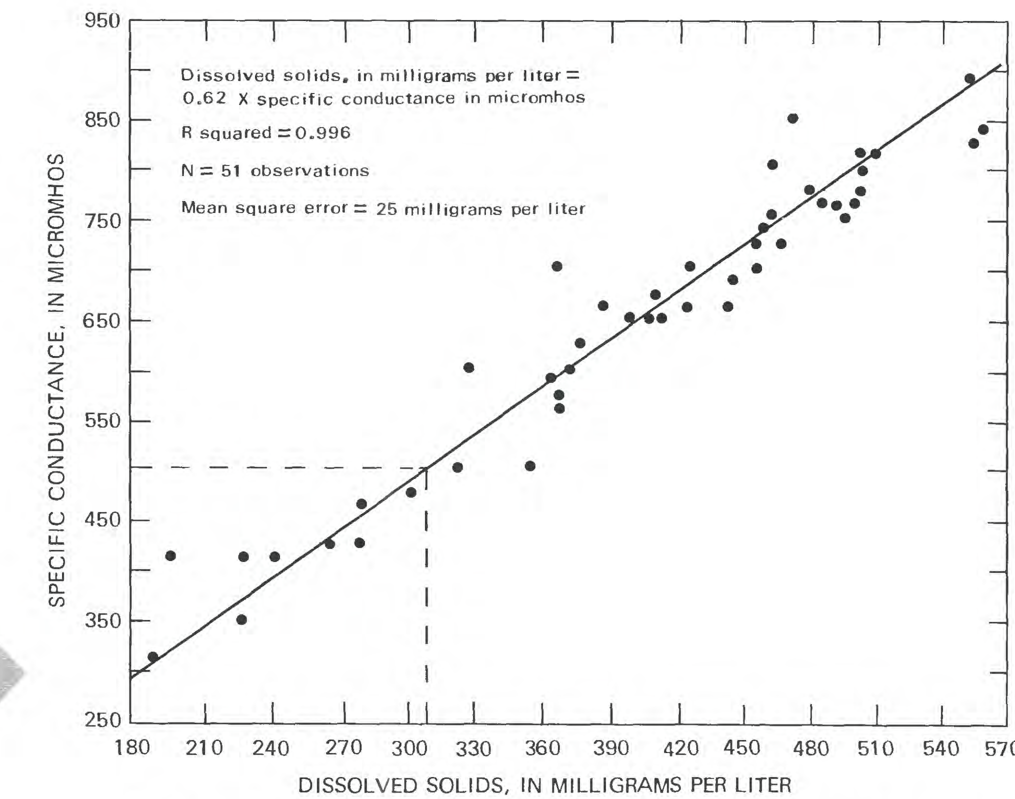


Figure 6.2-3 Plot of dissolved solids versus specific conductance for station 16– Middle Creek near Oak Creek, Colo..

Large Buffering Capacity of Streams and a Semiarid Climate Prevent Acid Mine Drainage

Alkalinity buffers water against pH changes that may affect aquatic life, decreases toxicity of metals, and helps prevent acid mine drainage.

The average concentration of alkalinity, in mg/L (milligrams per liter) as calcium carbonate, measured at water-quality stations in Area 53 is shown in figure 6.3-1. Alkalinity, defined in section 1.0 and measured at most stations, averages less than 400 mg/L; the U.S. Environmental Protection Agency (1976, p. 7) reports that values this large are not considered a problem to human health. A frequency distribution of all alkalinity con centrations measured in the area (fig. 6.3-2) shows that 72 percent are less than 400 mg/L. The largest concentrations were measured in streams in the Piceance and Yellow Creek basins, where stations 140, 151, and 162 have average alkalinity concentrations of 739 mg/L, 1,010 mg/L, and 1,400 mg/L, respectively. The maximum concentration, 3,850 mg/L, was measured at station 151, Piceance Creek at White River, Colo., which also has a maximum dissolved-solids concentration of 5,280 mg/L. By comparison, station 188, Bitter Creek at mouth near Bonanza, Utah, which has a maximum dissolved-solids concentration of 15,500 mg/L, has a maximum alkalinity concentration of only 691 mg/L. The large amount of alkalinity in streamflow in the Piceance and Yellow Creek basins is largely a result of the abundance of carbonate minerals in the sedimentary rocks of these two basins.

Measurements of pH, defined in section 1.0, in Area 53 also are shown as a frequency distribution in figure 6.3-3. About 85 percent of the measurements are in the near neutral to slightly basic pH range of 7.4 to 8.4; only about 1 percent are either less than 7.0 or greater than 8.9. The extremes are 6.0 and 9.8. About 93 percent of the pH measurements are within the general range of 6.5 to 8.5 reported by Hem (1970, p. 93) for unpolluted water, and about 99 percent are in the 6.5 to 9.0 range recommended for the support of freshwater aquatic life (U.S. Environmental Protection Agency, 1977b, p. 180). The frequency distributions are somewhat biased because some stations have many more analyses than other stations.

Bicarbonate ions, which are the primary source of alkalinity in the surface waters of Area 53, 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 buffering capacity of the water; consequently, more hydrogen or hydroxide ions can be consumed with little change in pH. Additional discussion on carbonate-bicarbonate equilibria and pH is provided by Hem (1970, p. 83-95, 152-161) and Garrels and Christ (1965, p. 74-92).

In areas of coal mining, buffering 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 brief description and is discussed thoroughly in the literature (for example, Wentz, 1974, p. 15-20).

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 buffering capacity of streams and the semiarid climate, as ample water is necessary for significant and rapid oxidation of pyrite. The lack of any highly acidic pH measurements (fig. 6.3-3) indicates that acid mine drainage is not a problem in Area 53. However, acid mine drainage associated with coal mining 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 (in the vicinity of station 5, fig. 6.3-1) apparently originates in an abandoned underground coal mine and is not associated with nearby surface mining.

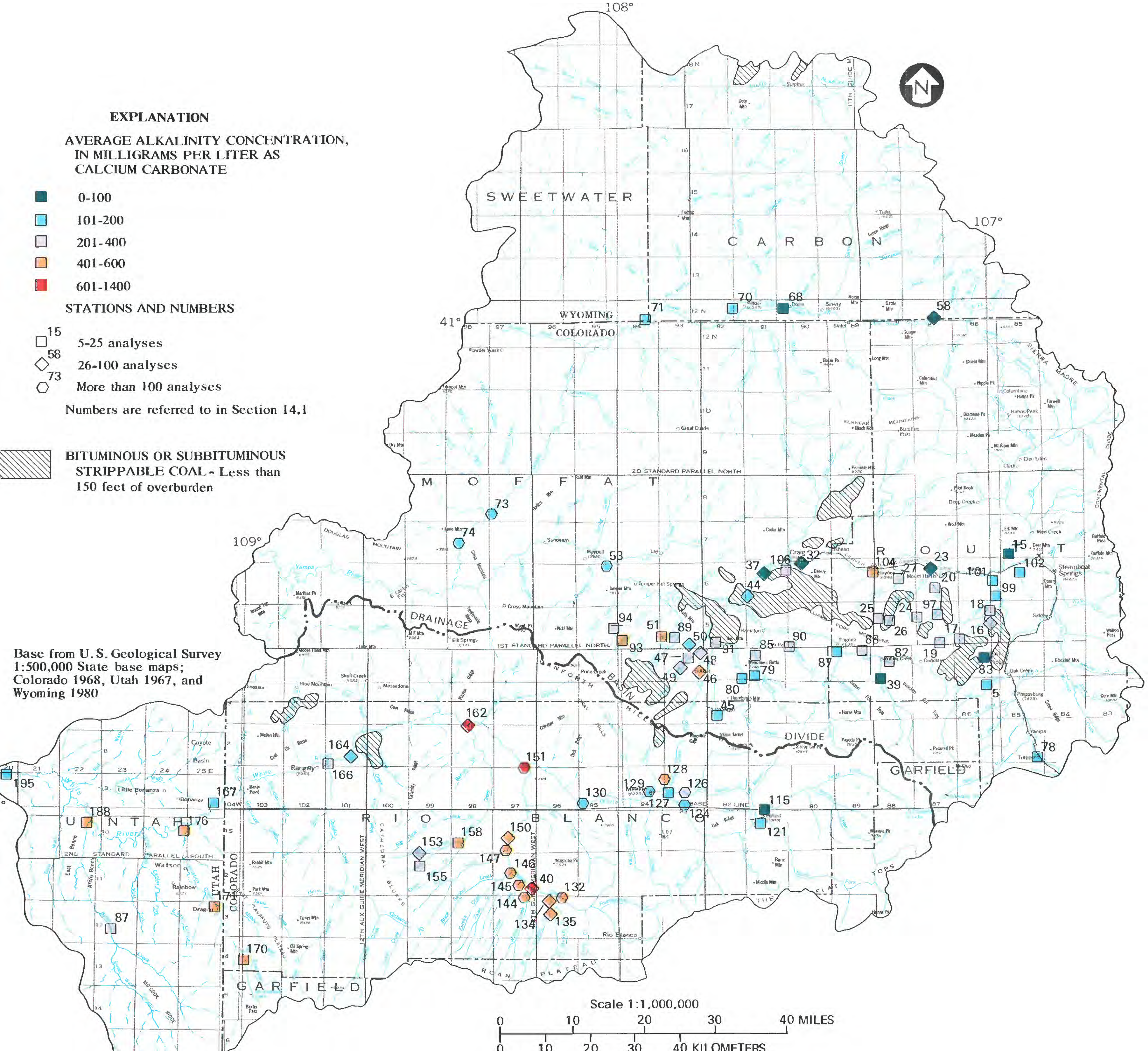


Figure 6.3-1 Average alkalinity concentrations at water-quality stations.

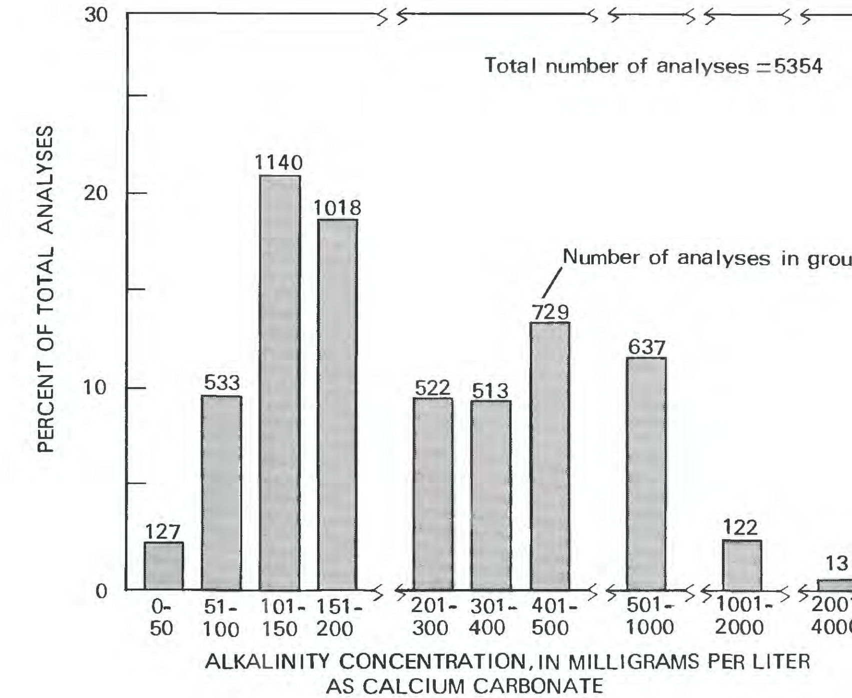


Figure 6.3-2 Frequency distribution of alkalinity concentrations.

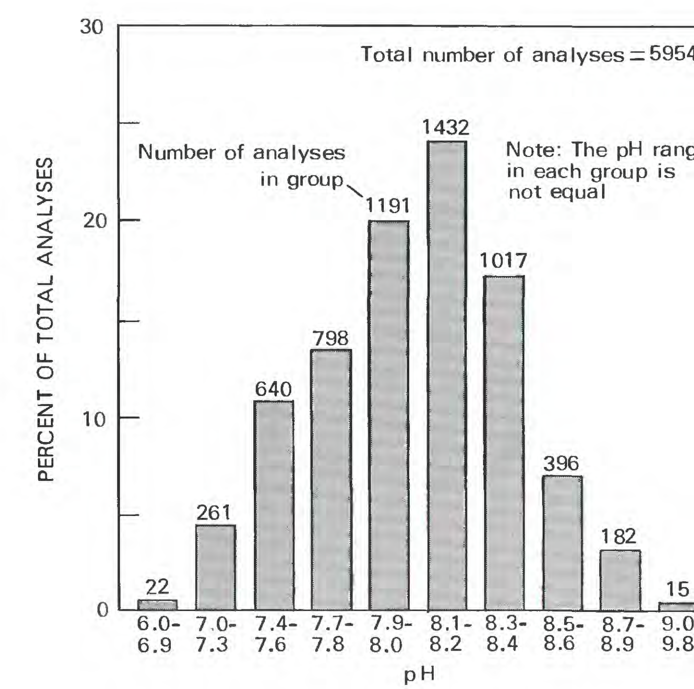


Figure 6.3-3 Frequency distribution of pH values.

Most Sulfate Concentrations are Less than the 250 Milligrams per Liter Maximum Concentration Recommended for Domestic Water Supply

Most sulfate concentrations in Area 53 are naturally produced; therefore, sulfate generally is not useable as an indicator of acid mine drainage.

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.

In order to determine if sulfate concentration has increased due to mining at a particular site, it is necessary to: (1) Know the natural, background concentration at that site, or (2) determine the sulfate concentration upstream and downstream of the mine area. Unfortunately, sulfate concentration data prior to the start of mining are not available for most water-quality stations in Area 53, and, as Wentz (1974, p. 35-36) noted, large background concentrations of sulfate are common. Use of the second method requires knowledge of the effect, if any, of other factors, such as geology or ground water, on the surface-water chemistry between the two stations; often this is not known adequately. For these reasons, sulfate generally is not useable as an indicator of acid mine drainage in Area 53.

Average sulfate concentration and number of analyses at water-quality stations in Area 53 are shown in figure 6.4-1. The average concentration at stations on the Yampa River, and at stations on the upstream reaches of its major tributaries (such as Oak, Trout, and Fish Creeks, the Williams Fork, and the Little Snake River) generally have sulfate concentrations less than 100 mg/L (milligrams per liter). The downstream reaches of some of the major tributaries and lesser perennial tributaries have average sulfate concentrations between 100 mg/L and 500 mg/L. Most ephemeral tributaries have average concentations greater than 1,000 mg/L.

Two principal factors account for larger sulfate concentrations: (1) The presence of either the Mancos or Lewis Shales (or other undifferentiated shale beds) in the basins upstream from these stations; and (2) whether the stream is perennial or ephemeral. Sulfate-producing minerals, such as gypsum, pyrite, and marcasite are common in the shales in this area. When water contacts these minerals sulfate is produced; but, because of buffering, the pH remains slightly basic. Soils in ephemeral stream basins are not adequately leached of soluble minerals and salts; thus, they generally have even larger sulfate (and dissolved-solids) concentrations than perennial streams with similar geology. For example, stations 93 and 94 are on ephemeral streams and have average sulfate concentrations of 1,190 mg/L and 660 mg/L, respectively. Nearby, stations 51 and 90 are on perennial streams and have respective average sulfate concentrations of only 470 mg/L and 198 mg/L. All of these streams have a somewhat similar basin geology. Despite the fact that many tributaries of the Yampa River have large sulfate concentrations, the average concentration in the river itself remains below 100 mg/L because the discharge of these tributaries is very small in comparison to the discharge of the Yampa River.

Sulfate concentrations in the upper White River basin are similar to those in the Yampa River basin, averaging less than 100 mg/L. However, sulfate and dissolved-solids concentrations increase significantly in the White River near Meeker, Colo. These increases are apparently a result of leakage of water from a saline aquifer in the lower part of the Meeker Dome, a small structural feature just northeast of Meeker (U.S. Environmental Protection Agency, 1972). The major perennial tributary of the White River, Piceance Creek, and also its tributaries have average sulfate concentrations between 100 mg/L and 500 mg/L. Ephemeral streams have average concentrations greater than 1,000 mg/L for the same reasons described above. The large sulfate concentration at station 128, Curtis Creek near Meeker, Colo., is mostly due to the presence of the Mancos Shale in the basin upstream.

A frequency distribution of all sulfate analyses (fig. 6.4-2) shows that 64 percent of the concentrations are less than the 250 mg/L maximum concentration recommended for domestic water supply (U.S. Environmental Protection Agency, 1977b, p. 205). Eighty-six percent of the analyses are less than 500 mg/L, and 93 percent are less than 1,000 mg/L, showing that extremely large sulfate concentrations are uncommon in streams of Area 53. As noted above, the large concentrations occur mostly in ephemeral streams. The frequency distribution is somewhat biased because some stations have many more analyses than other stations.

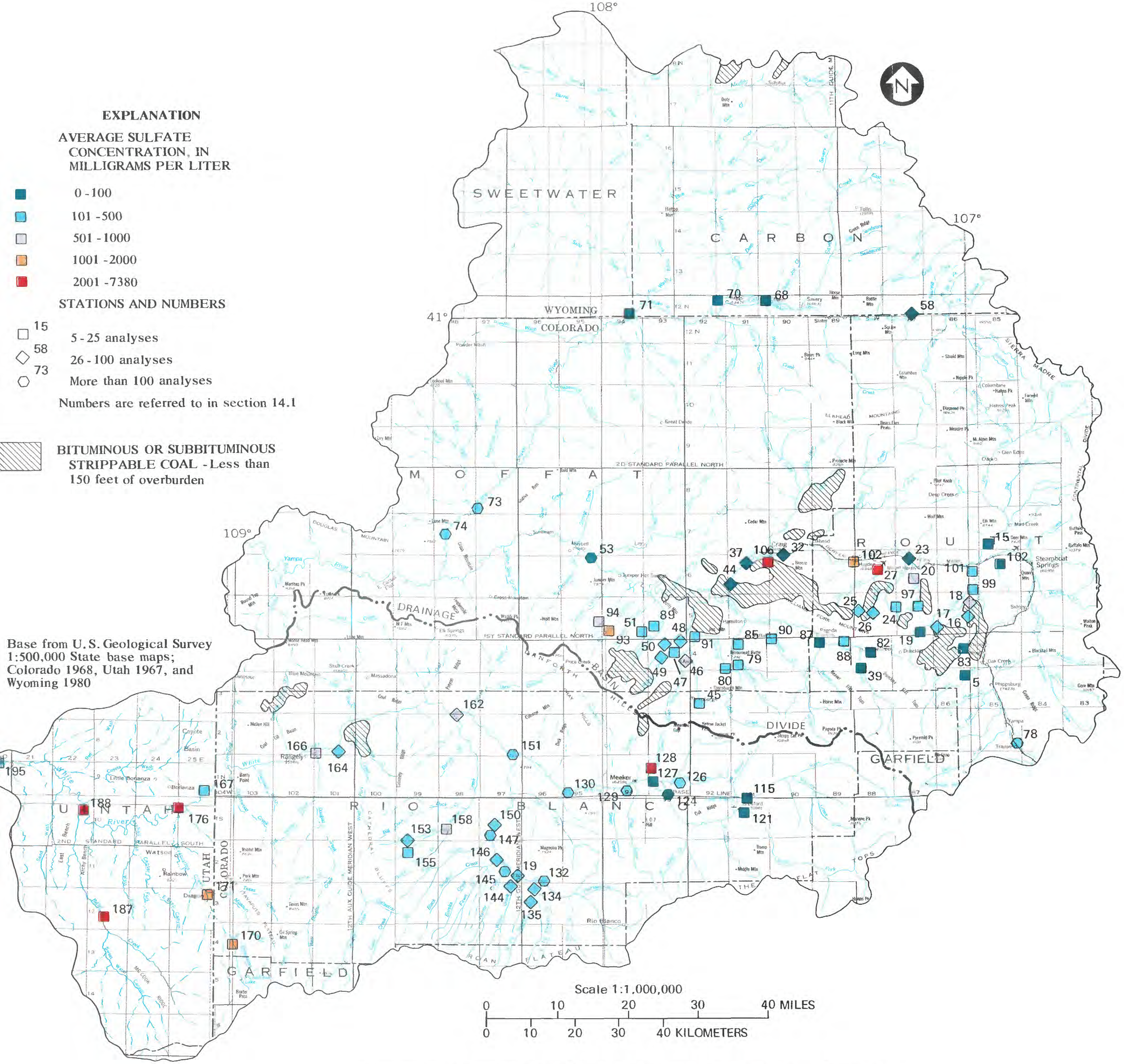


Figure 6.4-1 Average sulfate concentrations at water-quality stations.

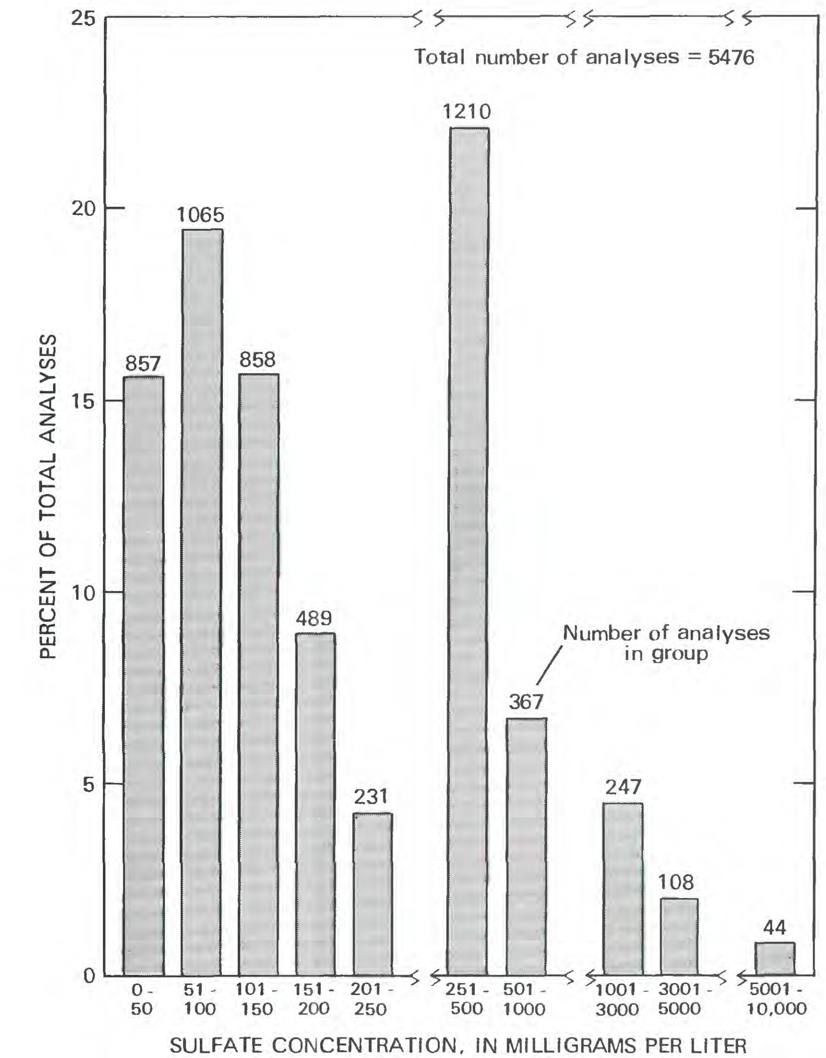


Figure 6.4-2 Frequency distribution of sulfate concentrations.

Total Recoverable Iron Concentrations Commonly Exceed Domestic Water Criterion

Total recoverable iron concentrations exceed the domestic water-supply criterion of 300 micrograms per liter in 65 percent of the analyses, but dissolved iron concentrations exceed the criterion in only 2 percent of the analyses.

Iron is the fourth most abundant element, by weight, in the Earth's crust; it occurs in a wide variety of minerals, such as biotite, magnetite, siderite, marcasite, and pyrite, which are associated with igneous, metamorphic, and sedimentary rocks. Therefore, large amounts of iron in soils and sediment are not uncommon, and because iron is a required nutrient for plants and animals it is present in organic materials. Iron, then, usually is the most common metallic trace element dissolved in surface waters.

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. Excessive concentrations of iron in water impart an objectionable taste and may cause discoloration of or deposits on objects in contact with such water.

In coal mining the greatest potential for degradation of water quality occurs where the overburden contains appreciable concentrations of pyrite (FeS_2). When in contact with oxygen and water, oxidation of pyrite and of iron released from pyrite can take place. If the geological materials are incapable of buffering the solution, the pH of the water can decline sometimes to values as low as 2 or 3. However, in the Western United States the overburden material is extremely alkaline and therefore neutralizes the acidic solution.

Average total recoverable iron concentrations at water-quality stations in the report area are shown in figure 6.5-1. Only three stations have an average value less than 300 micrograms per liter; an additional eight stations have an average concentration less than 1,000 micrograms per liter. The U.S. Environmental Protection Agency (1977b, p. 78) recommends that iron concentration not exceed 300 micrograms per liter in water used for domestic supplies, and that it not exceed 1,000 micrograms per liter for the protection of freshwater aquatic life. The above reference does not specify whether the criteria apply to dissolved, total recoverable, or some other category of concentration; however, William Warthol (U.S. Environmental Protection Agency, oral commun., May 1983) indicated that the criteria apply to total concentrations. It is necessary to keep in mind, though, that average values are shown in figure 6.5-1; the domestic water-supply criterion is exceeded in at least one analysis at all stations, and the freshwater-life criterion is exceeded in at least one analysis at all stations except stations 15, 23, 68, and 71.

Frequency distributions of both total recoverable and dissolved iron concentrations measured in the area are shown in figure 6.5-2. Although the number of total recoverable analyses is much less than the number of dissolved analyses, the total recoverable concentrations exceed the water-quality criteria much more frequently. Sixty-five percent of the total recoverable iron concentrations exceed the domestic water-supply criterion, but only 2 percent of the dissolved concentrations exceed that standard. For the freshwater-life criterion, 44 percent of the total recoverable concentrations exceed the standard; only a single analysis for dissolved iron exceed that criterion. The frequency distributions are somewhat biased because some stations have many more analyses than other stations.

Large concentrations of total recoverable iron, as well as other trace elements, are frequently associated with large concentrations of suspended sediment. These elements are found in the minerals comprising the rocks and soils of the drainage basins. Large flows resulting from spring snowmelt and summer thunderstorms have the ability to transport considerable quantities of soil particles (sediment); thus, large concentrations of total recoverable trace elements are associated with large concentrations of suspended sediment. The relation between concentrations of total recoverable iron and suspended sediment at several stations is shown in figure 6.5-3. The stations used for this analysis (fig. 6.5-1), are on small perennial and ephemeral tributaries of the Yampa River. Although total recoverable concentrations of iron (and other trace elements) can become quite large, the dissolved concentration does not appreciably increase (fig. 6.5-2), largely because the pH is on the basic side and because of buffering by bicarbonate ion, which tends to keep these trace elements sorbed to the fine-grained sediment.

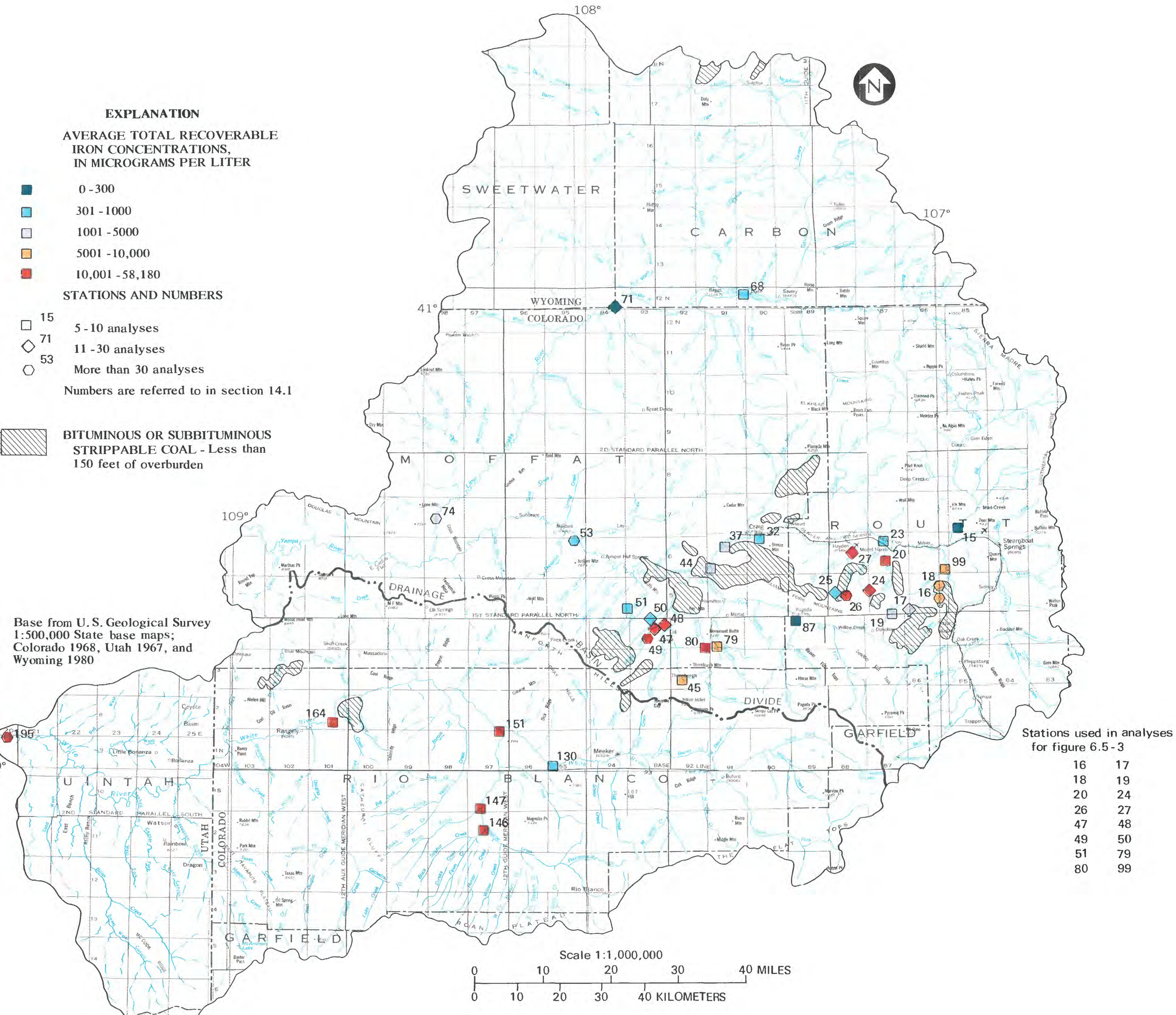


Figure 6.5-1 Average total recoverable iron concentrations at water-quality stations.

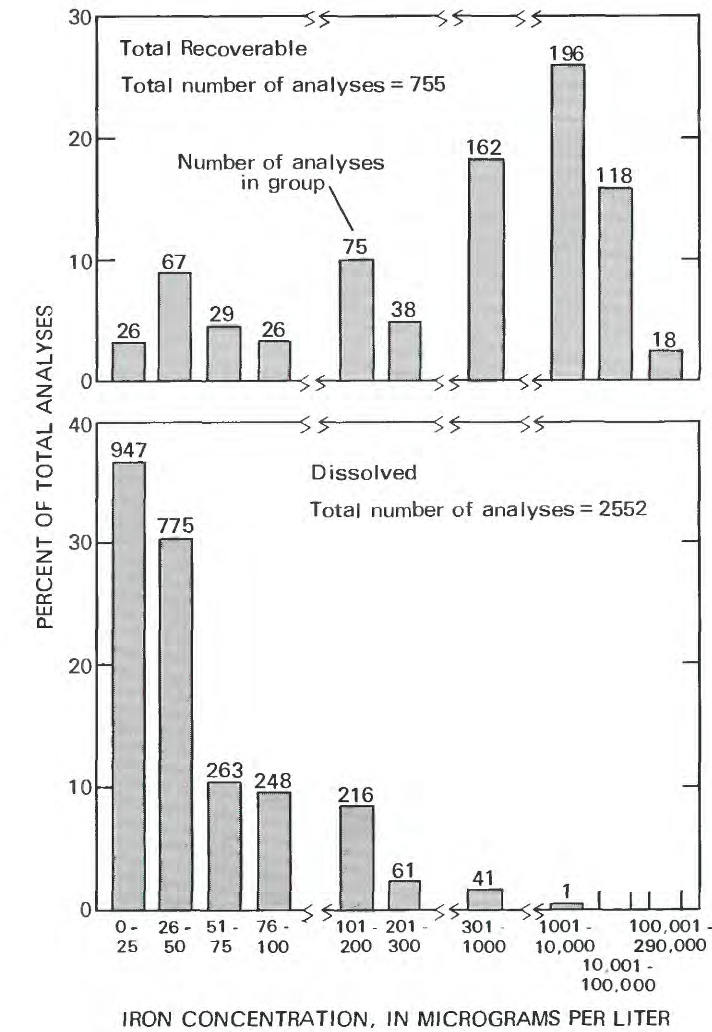


Figure 6.5-2 Frequency distributions of total recoverable and dissolved iron concentrations.

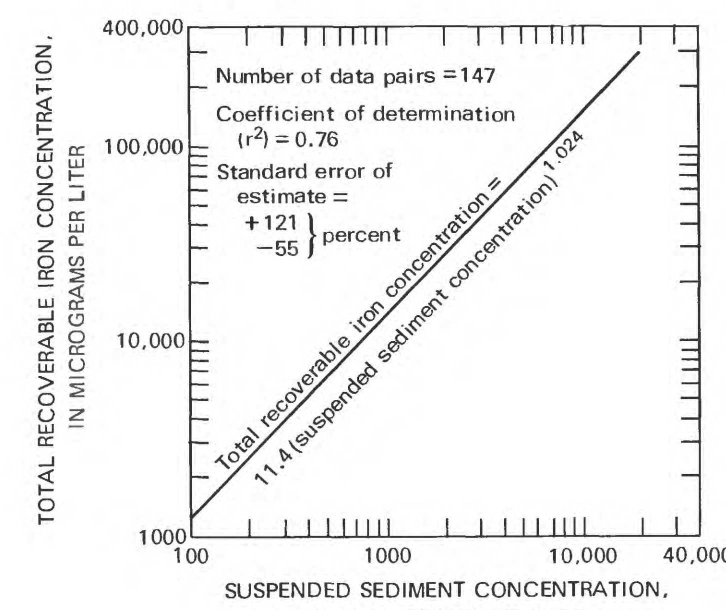


Figure 6.5-3 Relation between total recoverable iron and suspended-sediment concentrations.

6.0 SURFACE-WATER QUALITY--Continued

6.5 Iron

Total Recoverable Manganese Concentrations Commonly Exceed Domestic Water Criterion

Sixty-nine percent of the total recoverable manganese concentrations exceed the domestic water-supply criterion of 50 micrograms per liter; 30 percent of the dissolved manganese concentrations exceed that criterion.

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--objectionable 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.

High dissolved-manganese concentrations in streams draining mined areas can be produced by accelerated weathering of manganese minerals present in mine spoils. Manganese is often present to the extent of more than 1 milligram per liter in streams that have received acid drainage from coal mines. In the Western United States, however, acid mine drainage is not a problem because of the high buffering capacity of the carbonate rocks.

Average total recoverable manganese concentrations at water-quality stations in Area 53 are shown in figure 6.6-1. Seven stations have an average concentration less than 50 micrograms per liter--the recommended maximum concentration for domestic water supply (U.S. Environmental Protection Agency, 1977b, p. 95). All stations, though, except station 15, have at least one analysis for total recoverable manganese exceeding the above criterion. Reported tolerance levels to manganese for freshwater aquatic life range from 1.5 to more than 1,000 milligrams per liter (U.S. Environmental Protection Agency, 1977b, 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; however, William Warthol (U.S. Environmental Protection Agency, oral commun., 1983) indicated that the criteria apply to total concentrations.

Frequency distributions of both total recoverable and dissolved manganese concentrations measured in the area are shown in figure 6.6-2. Sixty-nine percent of the total recoverable concentrations and 30 percent of the dissolved concentrations exceed the domestic water-supply criterion. But, because there were fewer total recoverable analyses, the actual number of total recoverable manganese concentrations exceeding the standard is less than the number of dissolved concentrations in exceedence. The frequency distributions are somewhat biased because some stations have many more analyses than other stations.

The relation between concentrations of total recoverable manganese and suspended sediment at several stations is shown in figure 6.6-3. The stations used for this analysis (fig. 6.6-1) are on small perennial and ephemeral tributaries of the Yampa River. The discussion relating concentrations of total recoverable iron and other trace elements and suspended sediment (section 6.5) applies equally well to manganese.

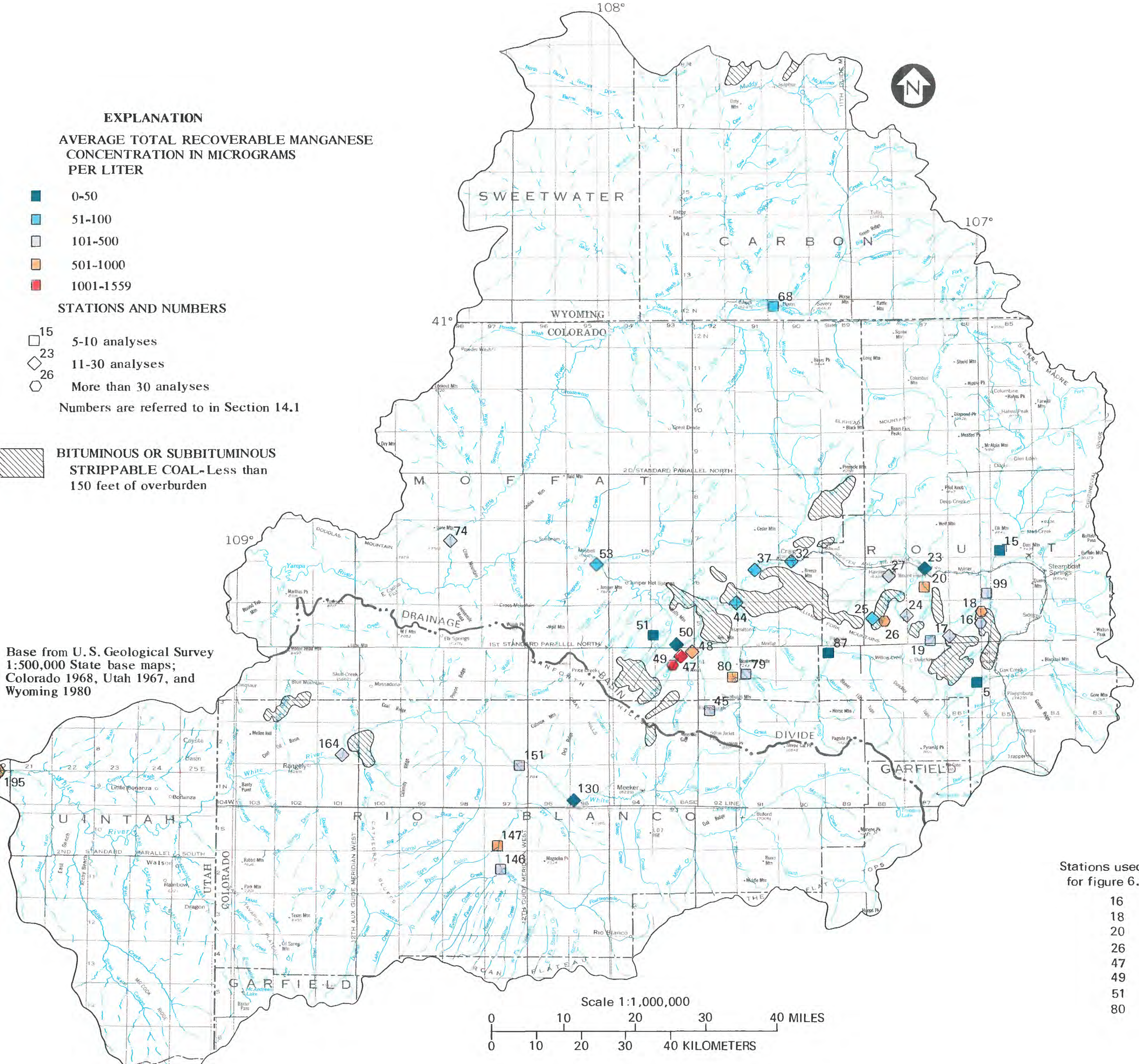


Figure 6.6-1 Average total recoverable manganese concentrations at water-quality stations.

Stations used in analysis for figure 6.6-3

16	17
18	19
20	24
26	27
47	48
49	50
51	79
80	99

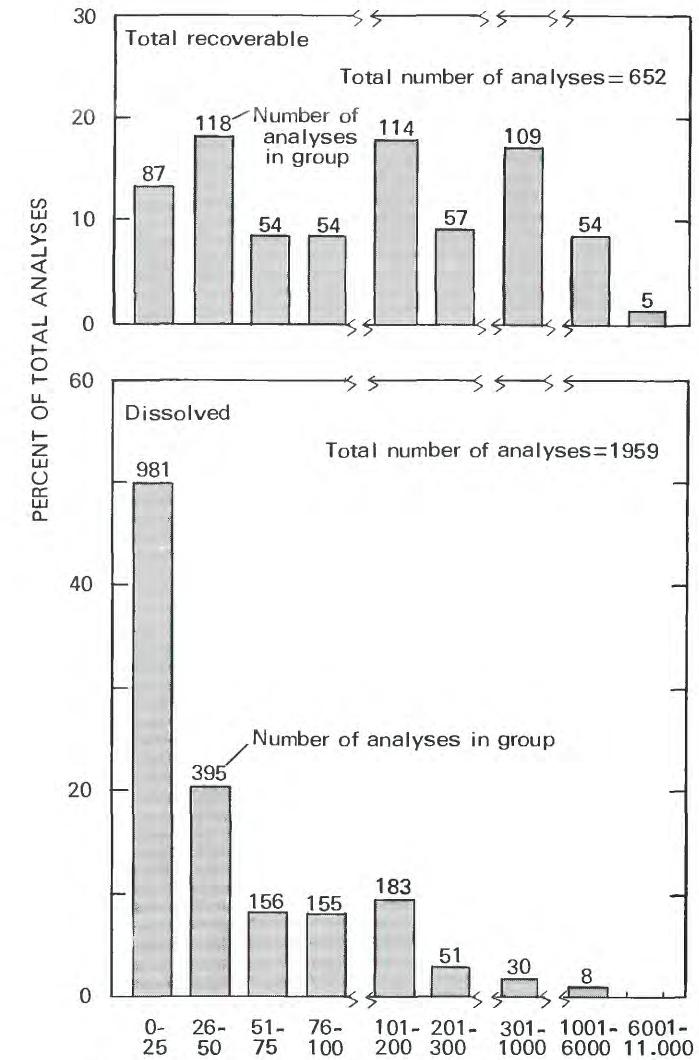


Figure 6.6-2 Frequency distributions of total recoverable and dissolved manganese concentrations.

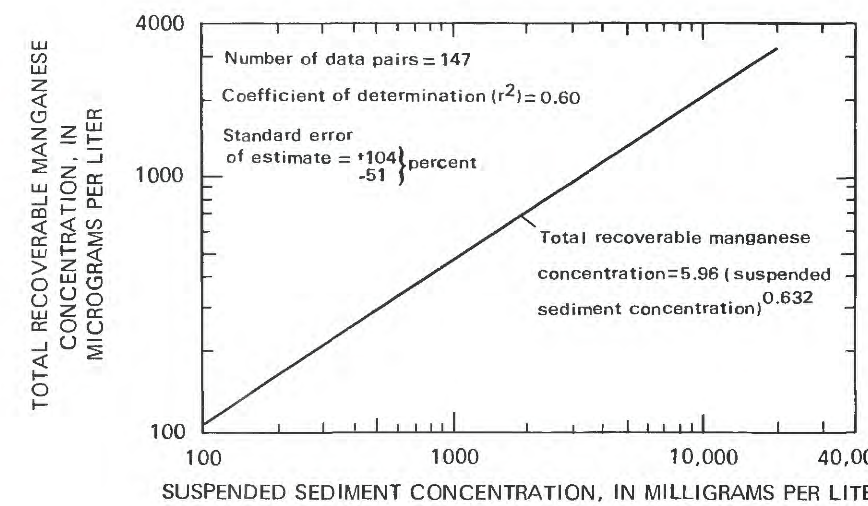


Figure 6.6-3 Relation between total recoverable manganese and suspended-sediment concentrations.

Trace-Element Concentrations Occasionally Exceed Water-Quality Criteria

Many trace elements are essential for plant growth and animal metabolism, but large concentrations of certain trace elements can be toxic; in Area 53 concentrations generally are within water-quality criteria.

Trace elements in surface water generally are derived from soils, geologic strata underlying the basin, and atmospheric fallout. Small concentrations of some trace elements, defined in section 1.0, are essential to plants, animals, and man; however, large concentrations can be toxic. Toxicity also may result from other factors such as the exposure time of the water to the soil and the chemical form of the element. Trace-element concentrations are generally small in streamflow that is not significantly affected by pollution. Large concentrations of trace elements can occur naturally in surface water; however, most large concentrations are associated with municipal- and industrial-waste discharge, mine drainage, or storm runoff from urban areas.

In coal-mine areas of the Eastern United States, accelerated weathering of pyrite present in coal-mine spoils produces acidic mine drainage, which enters the stream. The acid water reacts with other minerals and can produce large, possibly toxic concentrations of trace elements in mine drainage. In Area 53 acid mine drainage generally does not occur because the native waters are buffered by carbonate and bicarbonate as discussed in section 6.3.

Frequency distributions of total recoverable concentrations of aluminum, arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc and dissolved concentration of boron are depicted in figure 6.7-1. The total recoverable concentrations for the trace elements are used because the water-quality standards in U.S. Environmental Protection Agency (1977b) are based on total concentrations rather than dissolved concentrations (William Warthol, U.S. Environmental Protection Agency, oral commun., 1983). Both because the pH of the water is neutral to basic and because bicarbonate is abundant in Area 53, trace elements largely remain in the suspended phase, sorbed to fine-grained sediment. Increases in total recoverable trace-element concentrations usually are associated with increases in suspended-sediment concentrations. This relation is discussed in section 6.5 on iron. Dissolved concentration of boron is used because very few total recoverable boron concentrations were determined. The frequency distributions in figure 6.7-1 show that larger concentrations of these elements generally are uncommon. The frequency distribution is somewhat biased since some stations have been sampled for water quality more times than other stations.

In several analyses, total concentrations of arsenic, cadmium, chromium, and mercury exceed the domestic water-supply criteria (table 6.7-1). In about 30 or more analyses the criteria for selenium and lead are exceeded. Copper and zinc samples never exceed the domestic water-supply criteria. Both copper and zinc are essential micronutrients; lead and mercury, however, are nonessential, nonbeneficial elements recognized to be of high toxic potential (U.S. Environmental Protection Agency, 1977b). Selenium is an essential, beneficial element in trace amounts but is toxic to animals at small concentrations.

Because even low levels of selenium produce toxic levels in forages, the recommended maximum concentration in irrigation waters (U.S. Environmental Protection Agency, 1977b) is 20 micrograms per liter. Twenty-two samples exceed this criterion. Selenium occurs in the Little Snake River basin at a toxic level in indicator plants. Consequently, selenium has been a problem for grazing in this area.

Boron is an essential element for growth of plants. However, sensitive crops have shown toxic effects when 750 micrograms per liter of boron have been exceeded during long-term irrigation. In Area 53, however, no sensitive crops such as citrus are grown. Recommended maximum concentrations for plants irrigated throughout Area 53 are 1 milligram per liter for semitolerant plants and 2 milligrams per liter for tolerant plants. One hundred and nine samples exceed the 1 milligram per liter criterion.

Aluminum, which is more abundant in the Earth's crust than iron, is not involved in biologic metabolism. Recommended maximum concentrations are 5 milligrams per liter aluminum for continuous use on all soils and 20 milligrams per liter for use on fine textured, neutral to alkaline soils for a period of 20 years (National Academy of Sciences and National Academy of Engineering, 1973, p. 340). One hundred and sixteen samples exceed the 5 milligrams per liter criterion, while 41 samples exceed the 20 milligrams per liter criterion.

The freshwater aquatic life criteria for some trace element concentrations are expressed in terms of the 96-hour LC_{50} (table 6.7-1). This term is defined as the concentration of an element that will be fatal to 50 percent of the test organisms during a 96-hour exposure time (U.S. Environmental Protection Agency, 1977b). The actual concentration is variable for different aquatic species. Some of these data are presented in the above reference.

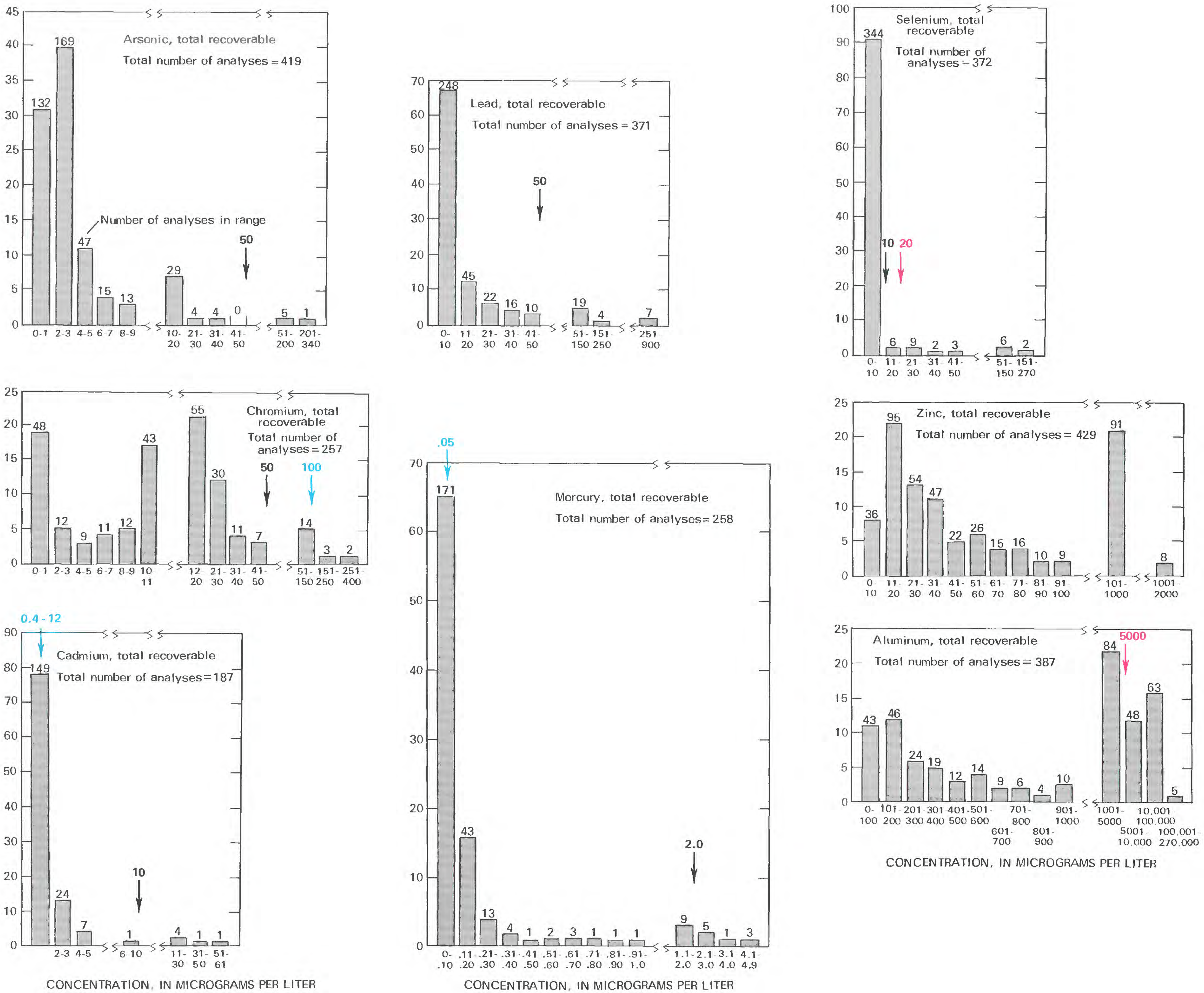


Table 6.7-1 *Recommended maximum concentrations of trace elements, in micrograms per liter*

[Source: U.S. Environmental Protection Agency, 1977b]

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}

EXPLANATION

50 DOMESTIC WATER SUPPLY — 100 FRESHWATER AQUATIC LIFE — 20 AGRICULTURE

The arrows and numbers refer to the concentration limits for water use established by U.S. Environmental Protection Agency (1977b) or National Academy of Sciences and National Academy of Engineering (1973)

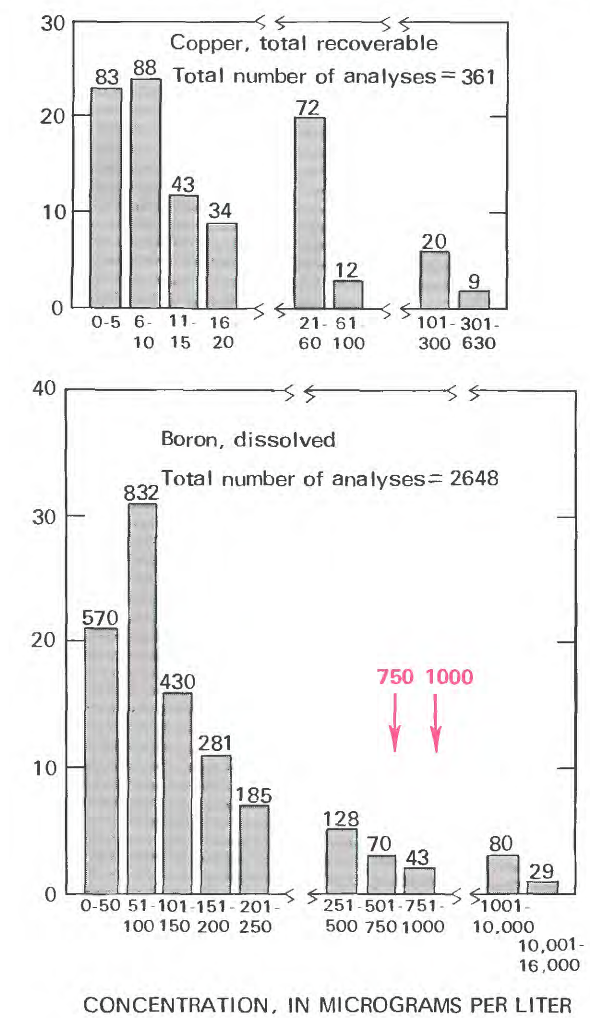


Figure 6.7-1 Frequency distributions of total recoverable and dissolved concentrations of selected trace elements.

Benthic Invertebrate Data Used to Evaluate Stream Water Quality

In most streams of Area 53, the upper reaches seem to have a healthy biotic community and a balanced taxonomic composition; however, diversity decreases downstream and is associated with changes in water quality.

Selected stations where benthic invertebrates, defined in section 1.0, have been collected in the study area are shown in figure 6.8-1. Also shown in figure 6.8-1 is the average number of organisms per square meter collected from the streams on approximately a bi-monthly basis in 1980-81. Data from the main stem Yampa River are based on replicate samples collected in September, 1975. In general, the average number of organisms increases downstream, and although not shown in the figure, the average number of taxa, or kinds of organisms, decreases downstream. No quantitative data were collected for the White River (stations 115, 121, 123, 127, 129, 130), but basically the more tolerant forms (fly larvae) were present only at the downstream stations. According to Eddy (1975), the diversity, defined in section 1.0, of benthic invertebrates collected from the Yampa River (stations 11, 100, 103, 105, 107, 108, 109) was significantly smaller directly downstream from point-source discharges.

Benthic invertebrates provide a means for detecting gradual changes in the aquatic environment because they are highly sensitive to changes in water quality. If a short-term exposure to poor water quality occurs, organisms that cannot tolerate the stress are destroyed and the community structure changes. However, biological data do not replace chemical and physical data but only provide another source of data that supplements other water-quality information.

Even though no two bottom fauna organisms react equally to pollution, certain types of organisms are intolerant to various types of pollution. Therefore, some organisms are often associated with certain water-quality conditions. This is the indicator organism concept. In general, immature or larval stages of mayflies, stoneflies, caddisflies, riffle beetles, and hellgrammites are quite sensitive, and environmental changes will often cause their elimination (Cairns and Dickson, 1971). In contrast, pollution-tolerant organisms such as sludgeworms, certain fly (Diptera) larvae (Chironomids), leeches, and certain snails usually increase in number under polluted conditions.

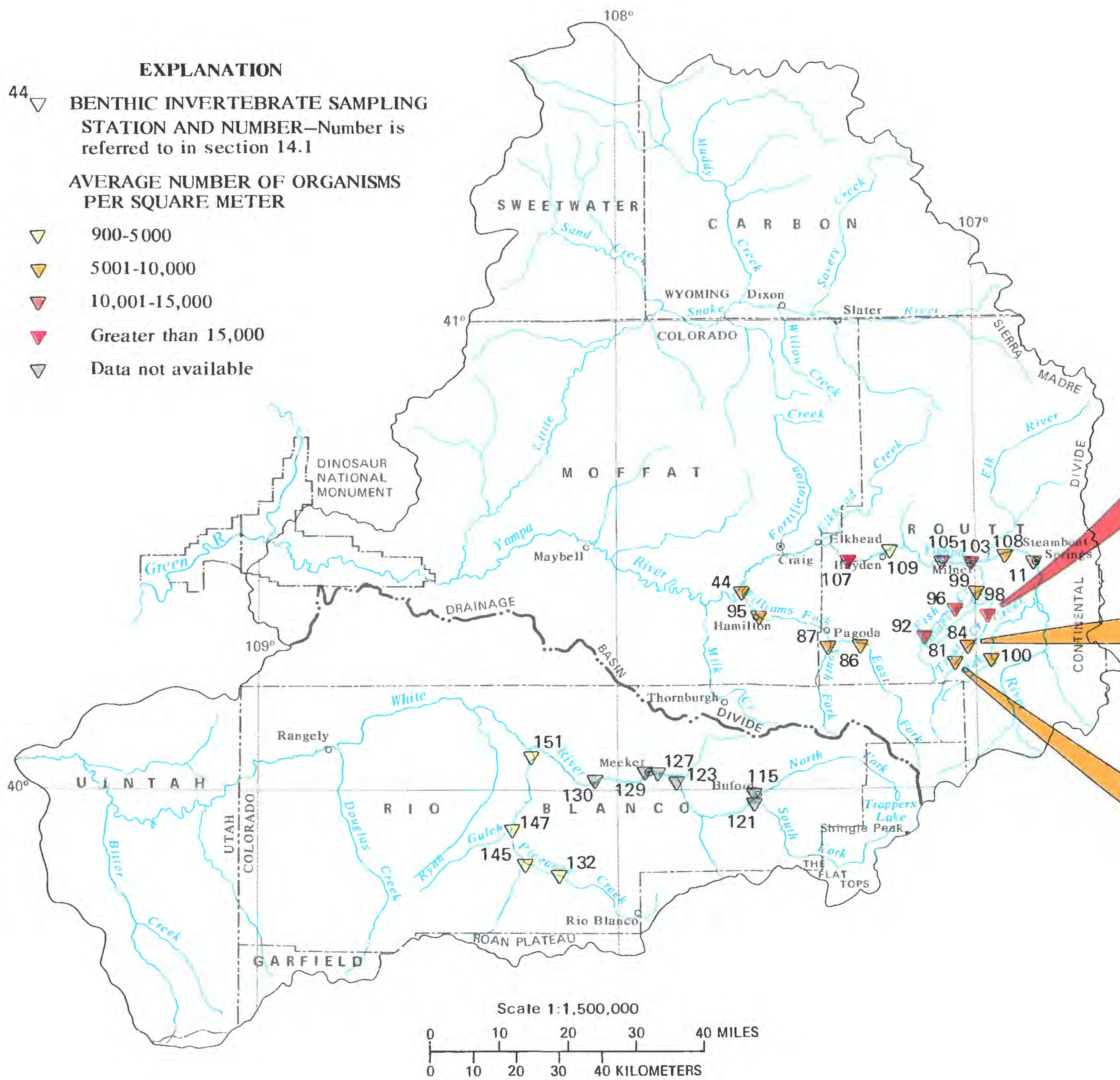


Figure 6.8-1 Location of benthic invertebrate sampling stations.

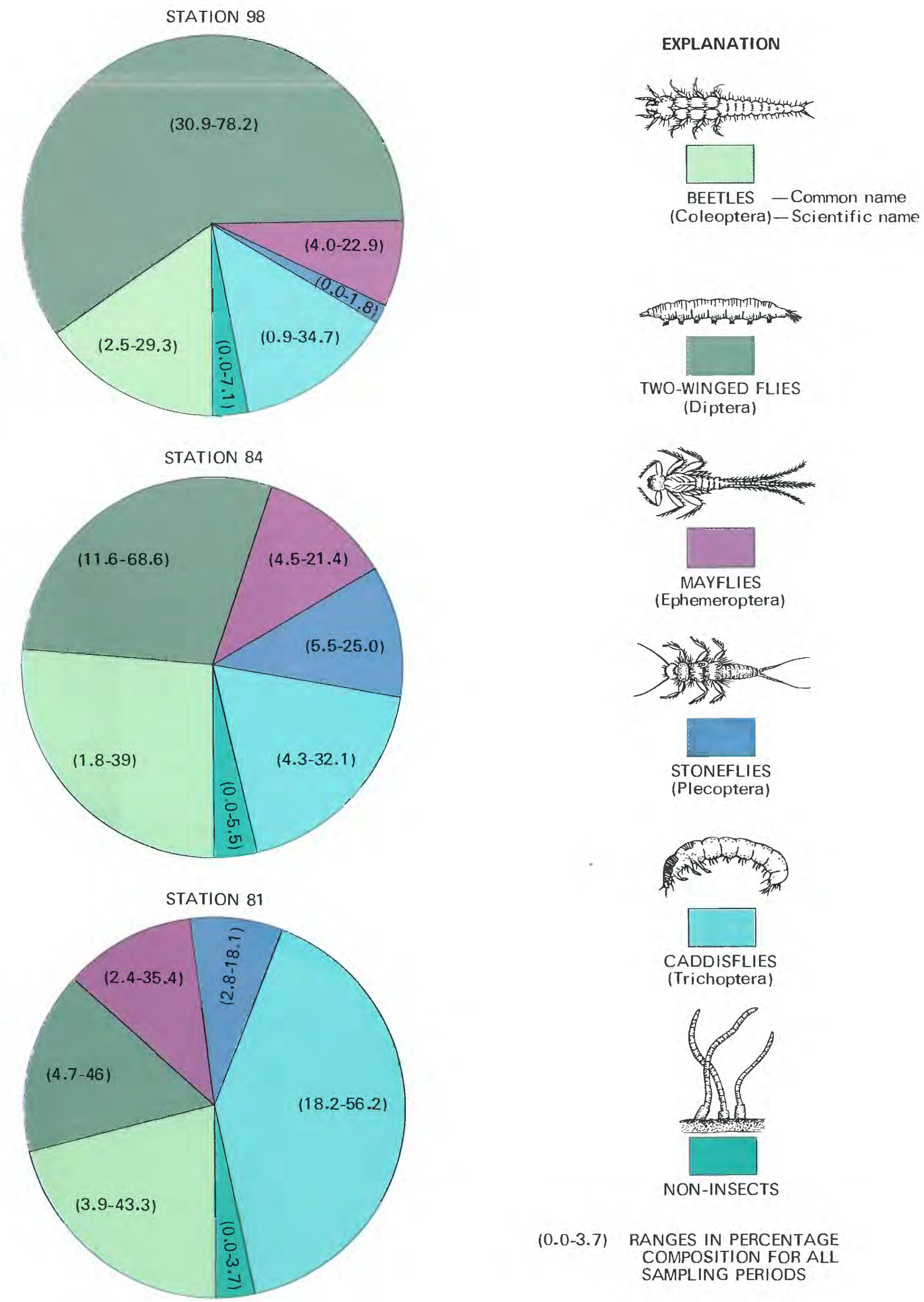


Figure 6.8-2 Average percentage composition of major benthic invertebrate taxonomic groups for Trout Creek (stations 81, 84, 98).

Total Sediment Load has been Measured at Several Stations in the Yampa River and the White River Basins

Sediment transport varies directly and increases dramatically with streamflow.

Sediment transported through and stored in a river reach affects water quality, channel cross section, and the hydraulics of flow of the reach. The total load of sediment transported by a stream may be subdivided into two components: (1) Suspended load, or that which is supported by turbulence and carried at about the same velocity as the flow; and (2) bedload, or that which bounces, rolls, or slides along the streambed and moves at a much slower rate. The size distribution of suspended sediment predominantly is clay, silt, and fine sand; bedload predominantly is sand size or larger. Sediment may be supplied to the stream from hillslope erosion or entrained directly from the streambed and banks (Kircher, 1982).

Suspended-sediment load is computed by combining suspended-sediment concentration with streamflow. Suspended-sediment concentrations have been measured and suspended-sediment loads computed at many streamflow stations in the Yampa and the White River basins. Some data also exist on the size distribution of suspended sediment sampled at these same stations. The location of 62 stations with 15 or more observations each of suspended-sediment concentration is presented in figure 7.1-1. Sediment data are stored in the U.S. Geological Survey WATSTORE Daily Values and Water Quality files. The Daily Values file contains average daily streamflows, in cubic feet per second; average daily suspended-sediment concentrations, in milligrams per liter; and average daily suspended-sediment discharges, in tons per day. The Water Quality file contains instantaneous streamflows, in cubic feet per second; instantaneous suspended-sediment concentrations, in milligrams per liter; and instantaneous suspended-sediment discharges, in tons per day.

Bedload may be measured in the field, but equipment available at this time is not considered standard by the U.S. Geological Survey. For this reason it is often estimated with computational techniques (Colby, 1964; Meyer-Peter and Muller, 1948; Einstein, 1950). Bedload data usually are not collected and filed in routine fashion, as are suspended-load data.

Total sediment loads for several stations in the Yampa River basin have been estimated by Andrews (1978), who computed bedload transport with the Meyer-Peter and Mueller (1948) equation and added that to measured suspended loads. Computed total sediment loads range from 1,400,000 tons per year at station 74, the Little Snake River near Lily, Colo., to 550 tons per year at station 46, Good Springs Creek near Axial, Colo. Suspended-sediment load as a percentage of total load for all the stations analyzed ranges from 30 percent to 98 percent with an average of 69 percent. Suspended-load, bedload, and total-load measurements have been made at station 76, Yampa River at Deerlodge Park, Colo. A preliminary analysis of data from this station indicates a total annual load of approximately 2,000,000 tons per year. Suspended load as a percentage of the total load is variable through the year at this station, ranging from 69 percent to 98 percent with an average of approximately 90 percent.

In many streams there is a positive correlation between average daily suspended-sediment load and average daily streamflow (fig. 7.1-2). Typically, there is a large degree of scatter in the data due to limitations of sample collection and record computation, fluctuation in hydraulic conditions, variation in sediment supply, and seasonality of suspended-sediment concentrations. As such, the relation between sediment load and streamflow is general; however, within the range of streamflow conditions sampled, the relation is useful for estimating sediment load when streamflow is known. Figure 7.1-2 shows how dramatically sediment transport increases with discharge. Discharge from 10 to 100 cubic feet per second produced a sediment increase from about 3 to 1,000.

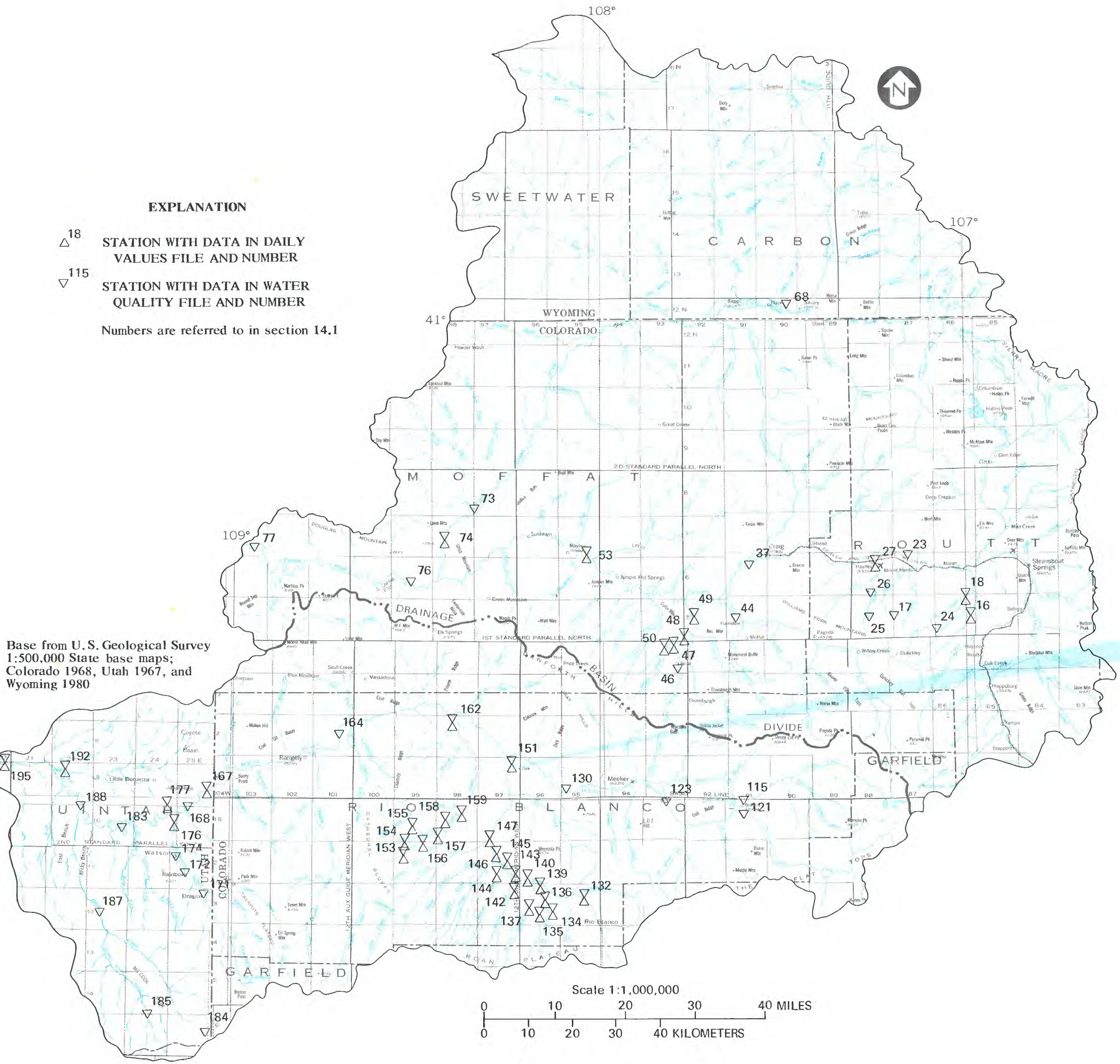


Figure 7.1-1 Sediment-sampling stations.

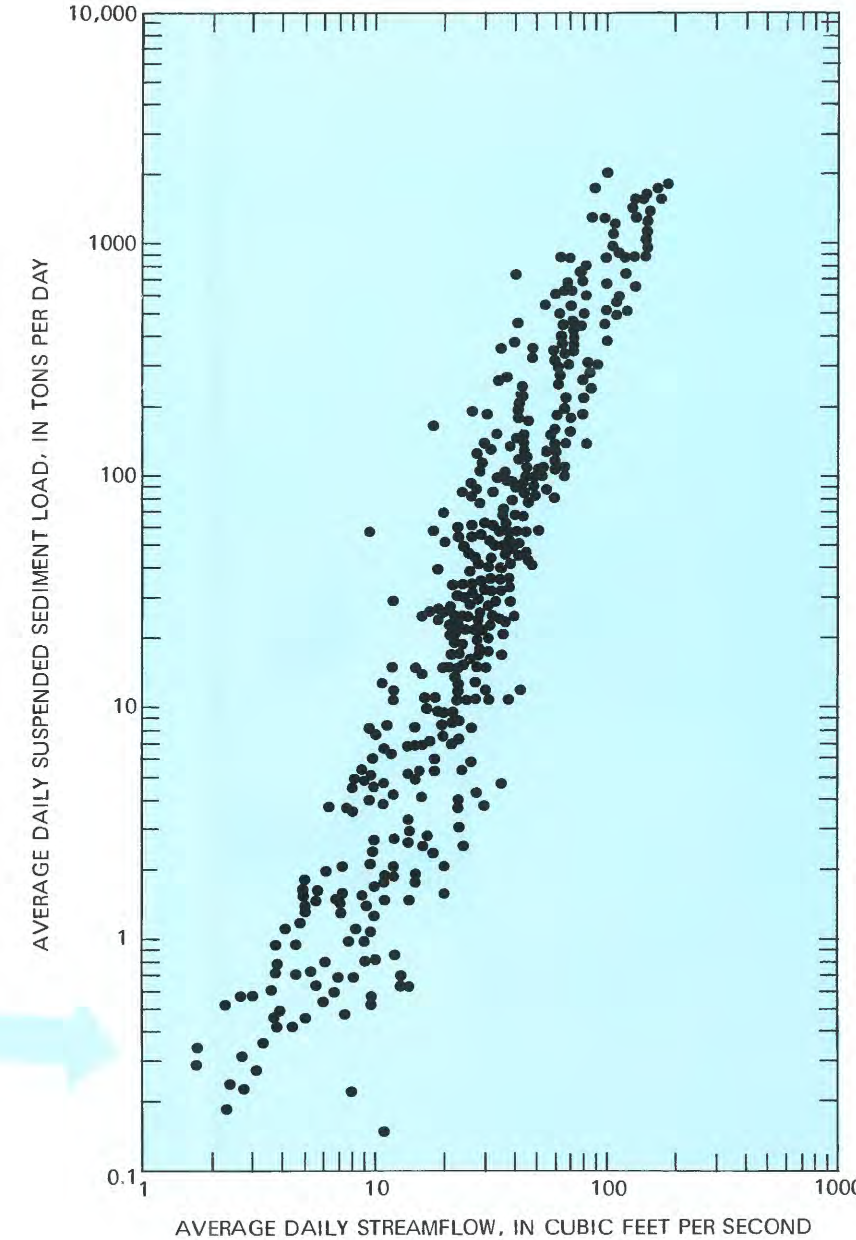


Figure 7.1-2 Variation of suspended-sediment load with streamflow, station 151.

Sediment Yields in Area 53 are Greatest in Areas of the Watershed having 10 to 14 Inches Annual Precipitation

Although two oil-shale tracts have been active since 1978 in the Piceance basin, no significant change was identified in sediment yields attributable to mining from suspended-sediment data collected at stations downstream from the oil-shale tracts; however, an almost fortyfold increase in sediment yield is indicated for unreclaimed surface-mined areas in part of the Yampa River basin.

Sediment yield refers to the amount of material removed from a specified drainage basin in a given time (Cooke and Doornkamp, 1974, p. 22). It is based on measurements of load past a point in the basin or on reservoir accumulations, and it may be expressed in terms of volume (acre-feet) per unit area per unit time or weight (tons) per unit area per unit time.

Sediment yields vary considerably throughout Area 53 (fig. 7.2-1). In the Colorado part of Area 53, annual sediment yield has been estimated by the Colorado Land Use Commission (1974) utilizing a technique developed by the Pacific Southwest Inter-Agency Committee (1968). Values of sediment yield range from less than 0.1 acre-foot of sediment per square mile per year in the wetter mountainous regions to almost 3.0 acre-feet per square mile per year in the lower, drier western parts of the basin. The Pacific Southwest InterAgency Committee method is used to develop a numerical rating of the potential erodibility of a part of a watershed. The erosion rate, or sediment yield, of this area is then estimated by comparing the numerical score with the measured erosion rate of drainage basins with a similar score. Results using the Pacific Southwest Inter-Agency Committee method are estimates of average sediment yields in various parts of the watershed but are not good estimates of the actual sediment yields at specific stations.

Schumm (1977, p. 18) identifies several variables that affect sediment yield. Among them are geology, climate, vegetation, drainage density, slope, and relief. Land use also is an important factor. Generally, sediment yield increases with slope (Hadley and Schumm, 1961) and decreases with drainage area (Strand, 1975).

Based on the sediment records of 17 streamflow stations in the Yampa River basin of Colorado and Wyoming, Andrews (1978) found that about 60 percent of the total sediment load at station 76, the Yampa River at Deerlodge Park, Colo., is contributed from the drainage area between station 68, the Little Snake River near Dixon, Wyo., and station 74, the Little Snake River near Lily, Colo. This area is less than 35 percent of the entire basin area and contributes less than 3 percent of the annual runoff. The lithology of this area is predominantly erodible Tertiary sedimentary rocks of the Green River and Wasatch Formations, and precipitation ranges from 10 to 12 inches per year.

Variations in annual precipitation may be the most significant variable affecting the distribution of sediment yields in the Yampa River basin. The largest sediment yields occur in those parts of the basin which receive from 10 to 14 inches of precipitation annually. As average annual precipitation increases from west to east across the Yampa River basin, sediment yields decrease. Langbein and Schumm (1958, p. 1076) explain this variation in sediment yield by the interaction of precipitation and vegetation on runoff and erosion. As precipitation increases above zero, sediment yields increase at a rapid rate. Opposing this tendency is that of vegetation, which becomes more abundant as annual precipitation increases. Above about 12 inches of precipitation, sediment yields decrease as vegetation becomes more effective in inhibiting erosion.

Although soil type and ground cover commonly influence sediment yields, these factors also are closely related to the distribution of precipitation in the Yampa River basin. The bedrock geology of much of the Yampa River basin is principally interbedded sandstone, mudstone, and shale. Likewise, hillslope relief generally is similar throughout the basin so that neither of these factors can be primarily responsible for the observed variations in sediment yields (Andrews, 1978, p. 31).

Energy resource development is another factor that can affect sediment yield; however, the degree to which activity of this type has altered sediment yields in Area 53 is not well documented. In the Piceance basin of the White River watershed, two oil-shale developments have been active since 1978. Kircher and Von Guerard (1982) could not identify a significant change in sediment yields attributable to mining from suspended-sediment data collected at stations downstream from the oil-shale tracts. Apparently the variability of the sediment-streamflow relation was too great for the period of record analyzed. Andrews (1978) estimated the potential change in sediment yield due to proposed surface mining of coal in the Yampa River basin by using the Pacific Southwest Inter-Agency Committee method. If soil profiles and ground cover are appreciably changed, an almost fortyfold increase in sediment yield is indicated for unreclaimed surface-mined areas in parts of the basin.

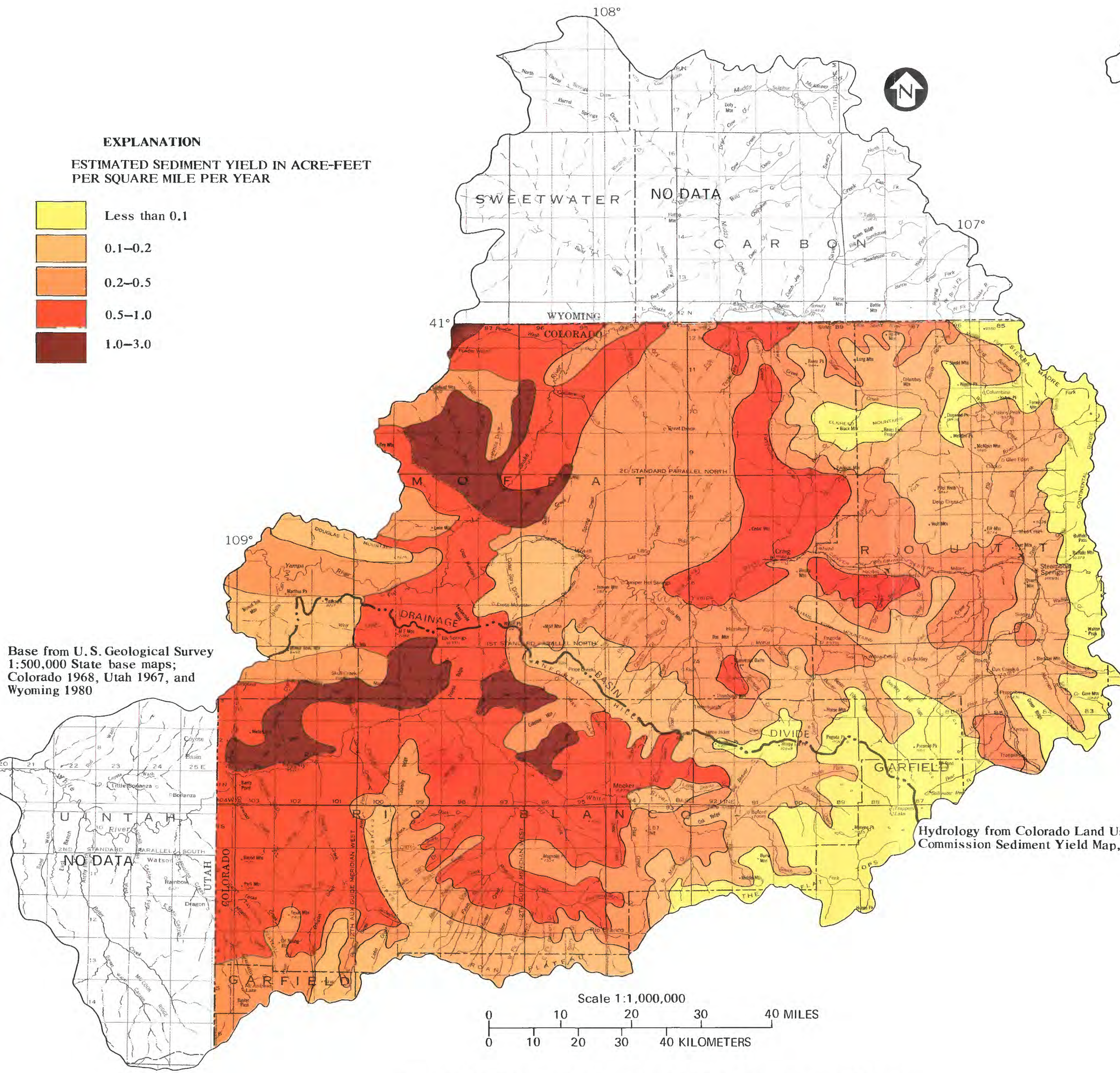


Figure 7.2-1 Estimated sediment yield in the Colorado part of Area 53.

Confluence of Sand Creek and Red Wash, Wyo.; two streams carrying a high sediment load

Terrace wall on Douglas Creek, Colo. shows the effects of erosional processes that contribute sediment to streams

8.0 GROUND-WATER HYDROLOGIC NETWORK

The Most Extensive Ground-Water Data in Area 53 are Available for the Coal and Oil-Shale Areas

The U.S. Geological Survey has collected a variety of ground-water data from about 1,500 wells in Area 53.

The U.S. Geological Survey has collected ground-water data since 1965 from more than 1,500 test holes and observation wells in Area 53. The types of data collected at these sites include water levels, water-quality analyses, yield measurements from wells and springs, aquifer characteristics, and well records. Most of these sites were established for areal ground-water studies, and no data were collected after the studies were completed. Therefore, the period of record for most of the ground-water data in the study area is brief; however, data are available for many of these wells, for water levels, the results of aquifer tests, and water quality.

Water levels are the most commonly collected data in ground-water studies. Throughout the Nation systematic water-level measurements are made by the U.S. Geological Survey at selected wells, which comprise the statewide observation-well network. The current (1983) Colorado statewide observation-well network in the study area includes 23 wells in Moffat County, 33 wells in Rio Blanco County, and 32 wells in Routt County. Utah has only one well in Area 53 in its statewide observation-well network; Wyoming has none. In Colorado extensive data are currently being collected from 21 bedrock wells, 17 alluvial wells, and 3 spoils wells associated with coal-mining studies in Routt County. The type of data being collected in these coal-mining areas are water levels, water quality, well yields, and well test data to characterize several of the aquifers. The direction of flow in the aquifers and the interaction of the bedrock, alluvial, and surface-water systems are being determined. The area of this current study is depicted in figure 8.0-1. One alluvial well (site 44) and one bedrock well (site 43) from this current study also are located on the map.

Water levels fluctuate as a result of changes in ground-water storage. The changes in storage can be due to pumping for domestic, stock, municipal, or irrigation purposes, variations in recharge to the aquifer, dewatering, evapotranspiration cycles of alluvial aquifers, or a combination of these factors. In Area 53 the primary cause for changes in bedrock storage and water levels is pumping for domestic or stock usage.

A hydrograph of an observation well in alluvium that may be surface mined for coal in Routt Country is shown in figure 8.0-2. The depth of the well is 30 feet and the alluvium, which typically is a silty clay, is 40 feet deep. The hydrograph shows a seasonal response in water levels due to recharge from precipitation in spring and early summer and discharge from evapotranspiration and discharge to a stream in the late summer and fall.

The hydrograph of an observation well in bedrock in the same area of Routt County is shown in figure 8.0-3. The well is 150 feet deep and is completed in the Mesaverde Group. The hydrograph shows minor seasonal variations and a minimal change in water levels. The bedrock aquifer in this area appears to be in a steady-state condition.

All of the Colorado and Utah statewide network sites, selected current data-collection sites, water-quality sites with geologic and hydrologic units identified, and other ground-water sites associated with coal mining are depicted in figure 8.0-1. Water levels or water-quality data are available for these ground-water sites. Data and period of record for each site are listed in section 14.2. Additional data for these sites are available from the U.S. Geological Survey NAWDEX and WATSTORE computer files described in sections 12.1, 12.2, and 12.3. Other information and data are available from the Wyoming Department of Environmental Quality in mining permit applications and from well-drilling permit completions filed with the Colorado, Utah, and Wyoming State Engineers.

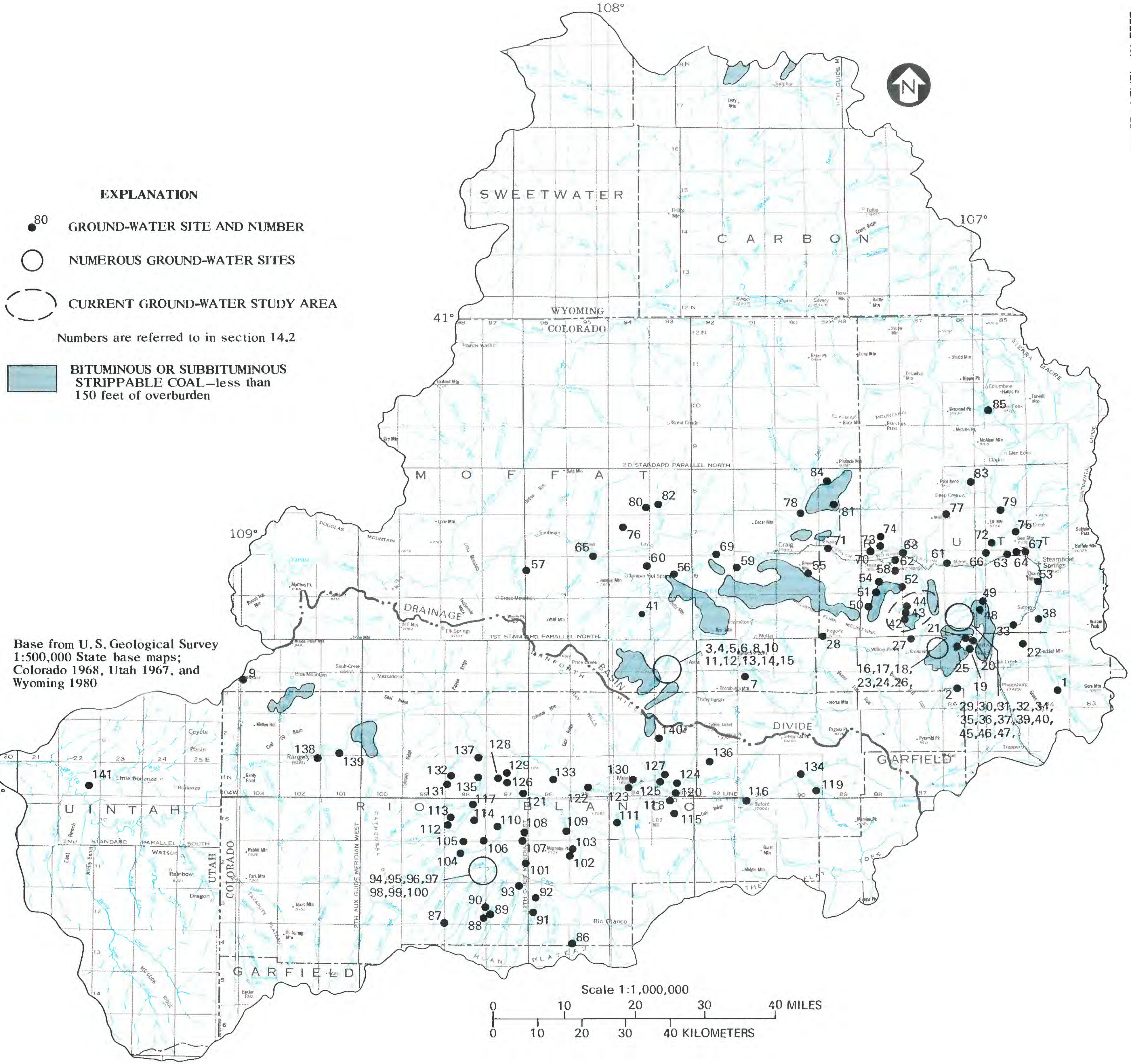


Figure 8.0-1 Location of ground-water sites.

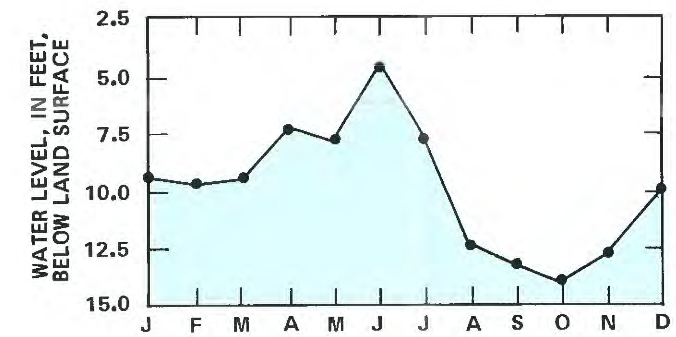


Figure 8.0-2 Hydrograph of alluvial well 44.

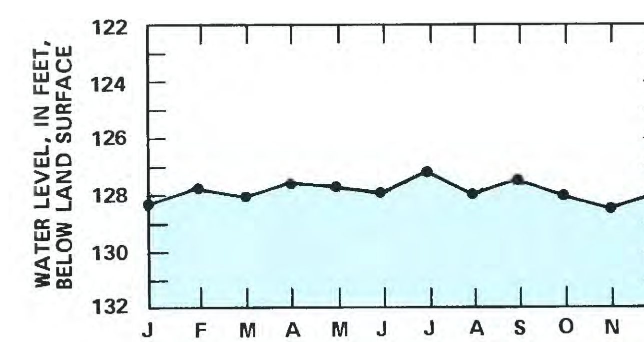


Figure 8.0-3 Hydrograph of bedrock well 43.

Bedrock well 43 (with a recorder on it to measure water levels) is shown with six other bedrock wells at a current ground-water study area. A network of alluvial wells, including alluvial well 44, are located in the valley below

Ground-Water Hydrologic Studies have Increased in Recent Years

Many published ground-water reports on Area 53 are by the U.S. Geological Survey.

Because of increased interest in mineral resources in Area 53, the number of ground-water studies and reports has increased in recent years. Many reports are available on previous ground-water hydrologic studies. Many reports on ground water in the study area have been published by the U.S. Geological Survey and are associated with energy-resource development.

Reconnaissance of ground-water resources in the Yampa River basin has been discussed in Boettcher (1972), Brogden and Giles (1977), Covay and Tobin (1981), Price and Arnow (1974), and Welder and McGreevy (1966). Ground-water reports associated with coal-resource development in the Yampa River basin include Colorado Water Conservation Board (1969), Ellis and Mann (1981), Melancon and others (1980), Steele and others (1979), U.S. Bureau of Land Management (1976, 1980), Warner and Dale (1982), and Williams and Driver (1982).

Ground-water reports in the White River basin have focused on oil-shale development in the Piceance basin. These reports include Alley (1982), Melancon and others (1980), Price and Arnow (1974), Robson and Saulnier (1981), Taylor (1982), and Teller and Welder (1983).

Currently, many ground-water studies associated with coal-resource development are being conducted in the Yampa River basin by the U.S. Geological Survey. The hydrologic units (drainage basins) in which the studies are located are shown in figure 9.0-1. The studies corresponding to each hydrologic unit are described in table 9.0-1. The hydrogeology of the upper part of the coal-bearing Mesaverde Group of Upper Cretaceous age is being studied in the Williams Fork Mountains of Routt and Moffat Counties, Colo. (study 1). An evaluation of surface geophysics as applied to an alluvial ground-water study is being performed in Routt County (study 2). Also in Routt County, the U.S. Geological Survey is studying an undisturbed alluvial and bedrock ground-water system of an area to be surface mined for coal (study 3). Soil-water content and geochemistry of coal spoil piles are being examined in another study in Routt County (study 4). The ground-water system in alluvium, bedrock aquifers, and spoils is being studied in an area currently being surface mined for coal (study 5).

Several ground-water studies of oil-shale development currently are being done in the White River basin. One project (study 6) is a reconnaissance of the alluvial aquifer in the White River basin between Agency Park and Rangely, Colo. The extent, saturated thickness, and hydraulic characteristics of the aquifer are being determined. Another study (study 7) involves ground-water modeling of the interrelationship of the bedrock system with the alluvial and surface-water system in the Piceance basin. A regional ground-water study of the Upper Colorado River Basin (study 8) includes analysis of the Yampa and the White River basins. The study involves collection and compilation of existing geologic, geophysical, hydrologic, and geochemical data on deep, major aquifers. Simulation models will assess hydrologic characteristics of the aquifer systems. Additional information on these studies is available from the District Chief, U.S. Geological Survey, Water Resources Division, Box 25046, MS 415, Denver Federal Center, Lakewood, CO 80225.

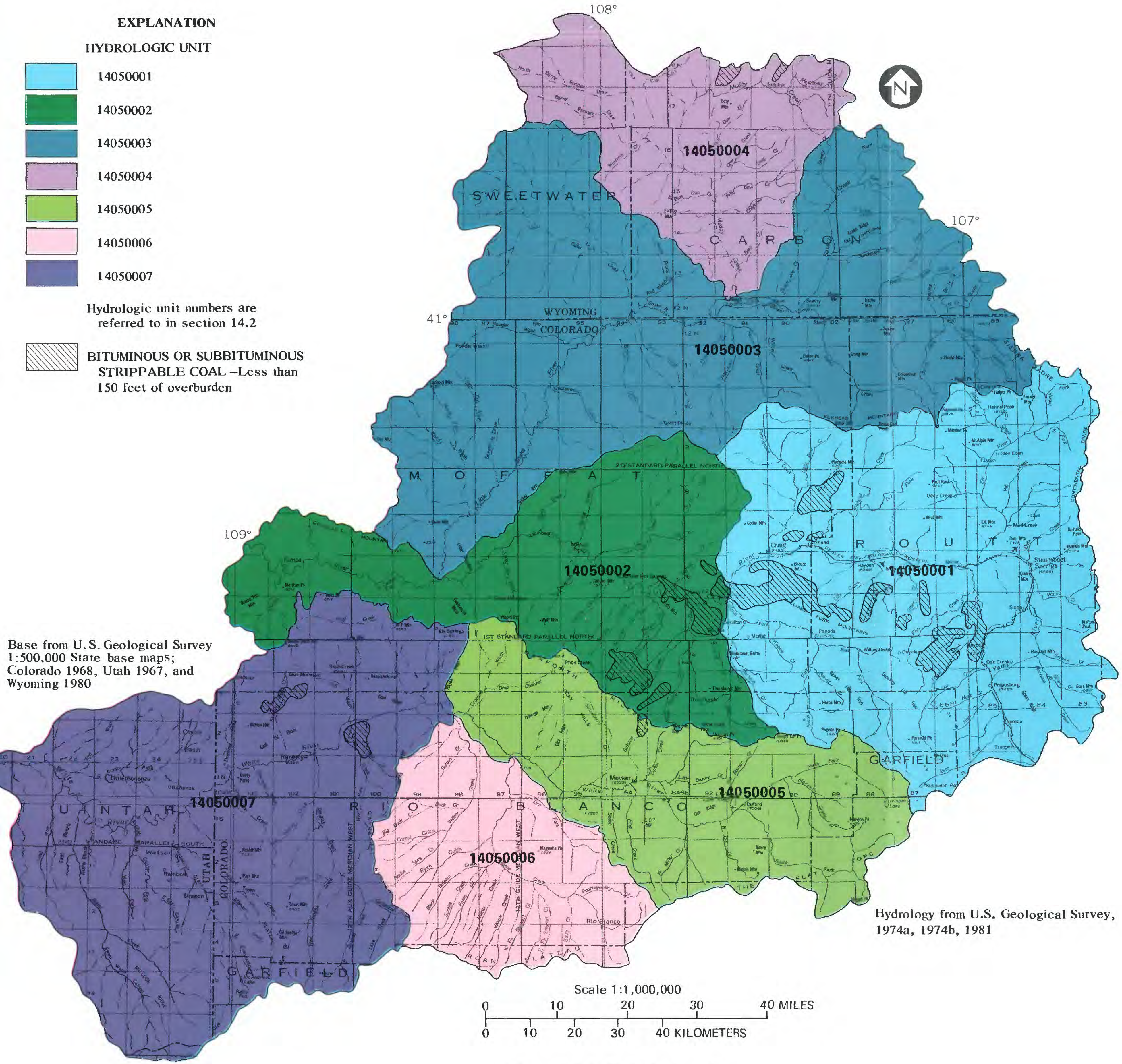
EXPLANATION

HYDROLOGIC UNIT

- 14050001
- 14050002
- 14050003
- 14050004
- 14050005
- 14050006
- 14050007

Hydrologic unit numbers are referred to in section 14.2

BITUMINOUS OR SUBBITUMINOUS STRIPPABLE COAL—Less than 150 feet of overburden



Base from U.S. Geological Survey 1:500,000 State base maps; Colorado 1968, Utah 1967, and Wyoming 1980

Hydrology from U.S. Geological Survey, 1974a, 1974b, 1981

Figure 9.0-1 Hydrologic units.

Table 9.0-1 *Description and location of current studies*

Study No.	Description of current U.S. Geological Survey studies	Hydrologic unit
1	Hydrogeology of Mesaverde Group in Williams Fork mountains	14050001 14050002
2	Evaluation of surface geophysics as applied to alluvial ground-water study	14050001
3	Evaluation of alluvial and bedrock ground-water system in natural conditions before surface mining for coal	14050001
4	Soil-water content and geochemistry of coal spoil piles	14050001
5	Evaluation of alluvial, bedrock, and spoils ground-water systems in area currently being surface mined	14050001
6	Reconnaissance of alluvial aquifer in White River basin	14050005 14050007
7	Ground-water modelling of alluvial and bedrock systems in Piceance basin	14050006
8	Regional ground-water study of the Upper Colorado River Basin	14050001 14050002 14050003 14050004 14050005 14050006 14050007

Three spoils wells in the distance and five bedrock wells (one with a water-level recorder on it) in the foreground are part of study no. 5

10.0 GROUND-WATER OCCURRENCE AND AVAILABILITY

Aquifers are in a Variety of Lithologic Units

Ground-water supplies are restricted by low yields of wells due to the small permeability of the rocks in the region.

Ground water occurs throughout the study area, but its availability is limited by the small permeability of the rocks. Ground-water use in the basins also is limited by the amount and kind of material dissolved in the water.

Most ground water in the Yampa and the White River basins is used for domestic and stock-watering purposes. Less than 1 percent of the ground water is used to irrigate land in the basins (Colorado Water Conservation Board, 1969). The public water supply for Baggs, Wyo., and Dinosaur, Colo., is provided from ground water. Industrial use of ground water is limited but does include oil-well, coal-mining, and railroad operations (Steele and others, 1979).

Alluvial aquifers are restricted to the valleys of the Yampa and the White Rivers and their principal tributaries. Withdrawal of water from the alluvium can induce surface water in the streams to flow into the alluvium. In this manner high yield, long-term wells can be developed in alluvial aquifers (Brogden and Giles, 1977); however, at this time no known ground-water sources from the alluvium are capable of the sustained high yields necessary for municipal supplies, powerplant cooling, coal gasification, or slurry pipelines.

Ground-water availability in Area 53 is shown in figure 10.0-1. Three categories are shown on the map: (1) Areas underlain by crystalline rocks, (2) areas underlain by thick marine shales, and (3) areas underlain by other sedimentary rocks (includes all of the coal-producing formations).

In general, yields from 2 to 20 gallons per minute of good quality water can be obtained locally from fractures in the crystalline rock. Thick marine shales generally produce small yields (1 to 5 gallons per minute) of poor quality water, and, because of the great thickness of the shales (1,000 to 5,000 feet), the prospect for obtaining good water supplies below them is unfavorable. If sandstone members are encountered within about 200 feet of the surface, the ground water may be useable for watering livestock.

Other sedimentary rocks covering the remainder of the study area generally include saturated permeable sandstones within at least 1,000 feet of the surface. In most places a well can be completed at a depth less than 500 feet (U.S. Bureau of Land Management, 1976). These sedimentary rocks (that generally yield less than 25 gallons per minute) include the Mesaverde Group of Late Cretaceous age and the Fort Union, Wasatch, Green River, and Browns Park Formations of Tertiary age and are major sources of ground water in the two basins.

The Mesaverde Group generally is buried deeply in the study area, and the ability of pumping to readily affect recharge and discharge is limited; therefore, ground-water development would result in large water-level declines. Because of their thickness and permeability, the Fort Union, Wasatch, and Green River Formations are considered to be relatively important sources of ground water in the arid parts of the basins. However, large water withdrawals from these formations would result in extensive water-level declines (Steele and others, 1979). In the thickest parts of the Browns Park Formation, large-scale ground-water development may be possible.

Aquifers near the surface are recharged from percolation of snowmelt and precipitation and from seepage losses from streams. Deep aquifers are recharged by these same processes in outcrop areas and from leakage from overlying and underlying aquifers.

Ground-water discharge in the basins occurs through evapotranspiration, flow from springs and seeps, ground-water underflow, and discharge into streams. Because discharge to wells is small relative to the above discharges, essentially steady-state conditions exist in the present ground-water regime.

The interaction between ground- and surface-water systems primarily depends on the bedrock geology. In reaches where streams flow over exposed sandstone beds, described as other sedimentary rocks in figure 10.0-1, or through unconsolidated alluvial deposits, the hydrologic connection is great. However, in areas where streams flow over exposed shale layers, the hydrologic connection to underlying sandstone aquifers is small, and the ground- and surface-water systems have less influence on each other.

At several coal mines in the area, wells have been drilled to a depth of 500 feet for drinking-water supplies; however, small yields of the aquifers have prevented intensive use of the ground water. Ground water and surface water that flow into holding ponds at the mine sites are used for suppressing dust on the haul roads.

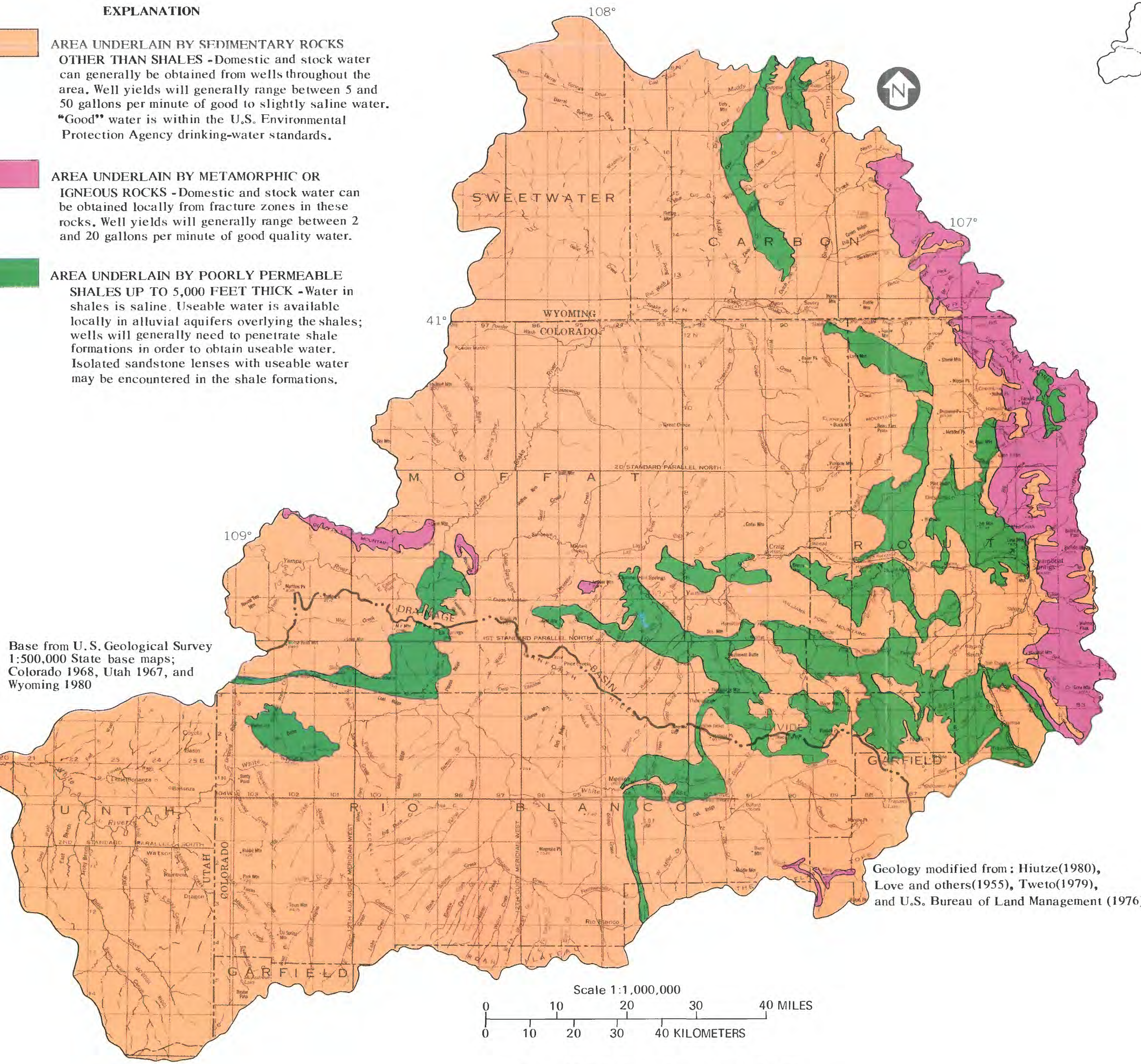


Figure 10.0-1 Ground–water availability.

A holding pond was formed when an aquifer was encountered during strip mining of coal in the Grassy Creek watershed

Parshall flumes are used by hydrologists to measure the discharge of springs

10.0 GROUND-WATER OCCURRENCE AND AVAILABILITY

The Average Dissolved-Solids Concentration is Well Above the National Drinking Water Standard

The dissolved-solids concentration for aquifers sampled ranges from 46 milligrams per liter to 109,000 milligrams per liter; coal mining may increase the dissolved-solids concentration.

The dissolved-solids concentration for 93 percent of the 698 ground-water samples from Area 53 is less than or equal to 5,000 mg/L (milligrams per liter). The average dissolved-solids concentration is 2,430 mg/L which is well above the National drinking water standard (U.S. Environmental Protection Agency, 1977a). A histogram of dissolved-solids concentrations is shown in figure 11.1-1. The frequency distribution is somewhat biased because some wells have been sampled for water quality more times than other wells.

Generally, the longer water has been moving through a geologic unit, the greater the dissolved-solids concentration and the poorer the chemical quality. The minerals present in the rocks will affect the ionic composition of the water.

The natural chemical evolution of dissolved solids in ground water, as described above, can be drastically changed by the surface mining of coal. Many surface coal mines are present in hydrologic unit 14050001 (fig. 11.1-2). Coal mining may affect the water quality of this hydrologic unit as well as other units in Area 53.

A very simplified, idealized, and hypothetical mine site will now be described along with a few assumptions about the hydrology. Although many variations are possible, the site described is fairly typical of the mine sites in hydrologic unit 14050001 (fig. 11.1-2).

The hypothetical site to be mined is the only place where recharge occurs in the basin. An aquifer, characterized by calcium and bicarbonate ions, is present in the overburden and the coal. The dissolved-solids concentration is 750 mg/L. During mining, this aquifer is dewatered, and therefore, no ground water flows downgradient from the hypothetical mine to the undisturbed bedrock. Water flowing into the mine pit is used for dust suppression or pumped to a holding pond.

After mining, the spoil pile is replaced and reclaimed. The hypothetical spoil pile is more permeable at this site than the natural strata and has no layering. As a result, water enters the spoil pile, flows downward to the base of the spoil pile, and then flows downgradient until undisturbed strata are encountered. If the strata encountered are dry, they may become saturated. If the strata contain an aquifer, then water from the spoil will move away from the mine, and mixing of waters will begin.

A major concern is the quality of the water flowing from the spoil pile. Water containing dissolved oxygen enters the spoil pile and reacts with pyrite to form sulfuric acid. The acid then dissolves the carbonate rocks (calcite and dolomite) in the spoil pile, and calcium, magnesium, and sulfate concentrations reach saturation. The concentration of the dissolved solids is then about 3,500 mg/L, which is considerably greater than the original 750 mg/L. Also, the ionic composition of the water has shifted from being characterized by calcium and bicarbonate ions to being characterized by calcium, magnesium, and sulfate ions.

Although changes in ionic makeup may be a concern, the greater concern is the increased dissolved-solids concentration. The increased dissolved-solids concentration can deleteriously affect local ground-water supplies. Also, surface-water quality may be degraded where it receives water from spoil-pile sources.

For the hydrologic unit as a whole, it can be seen in figure 11.1-3 that the water quality of each of the existing aquifers may be degraded if the water moves from the spoil pile into the aquifer.

The ground-water quality in Area 53 has been evaluated in many reports. The actual or potential impacts from domestic, municipal, and industrial uses of water also have been discussed in a variety of reports. Various ground-water topics have been discussed by the following authors: Boettcher (1972), Brogden and Giles (1977), Covay and Tobin (1981), Ficke and others (1974), Gaydos (1980), Giles and Brogden (1978), Hounslow and others (1978), Robson and Saulnier (1981), Steele and others (1979), Steele and Hillier (1981), Turk (1982), Weeks (1978), Weeks and others (1974), Weeks and Welder (1974), and Wymore (1974).

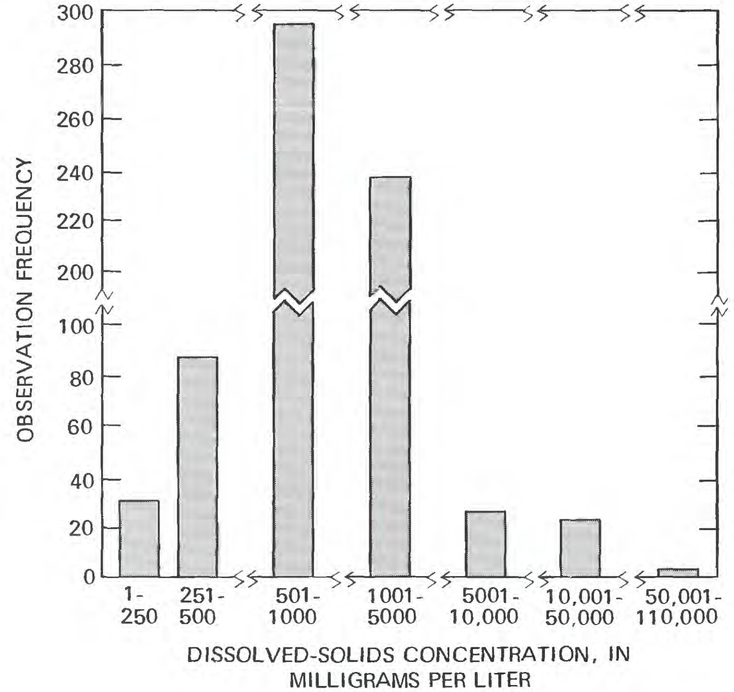


Figure 11.1-1 Frequency of dissolved-solids concentration.

Well in hydrologic unit 14050001 is being sampled for water-quality analysis. Specific conductance, pH, and dissolved-oxygen content are determined on site. Major cations and anions and trace elements are determined in the laboratory

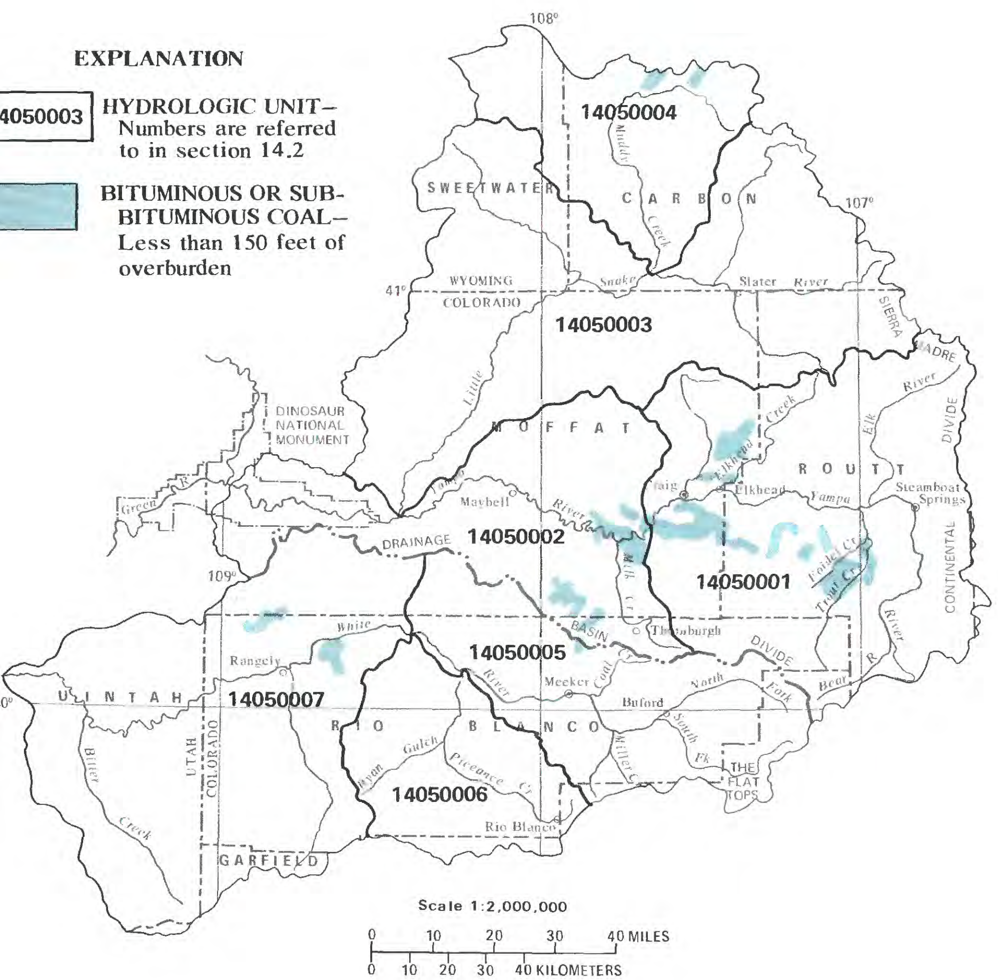


Figure 11.1-2 Hydrologic unit map of Area 53.

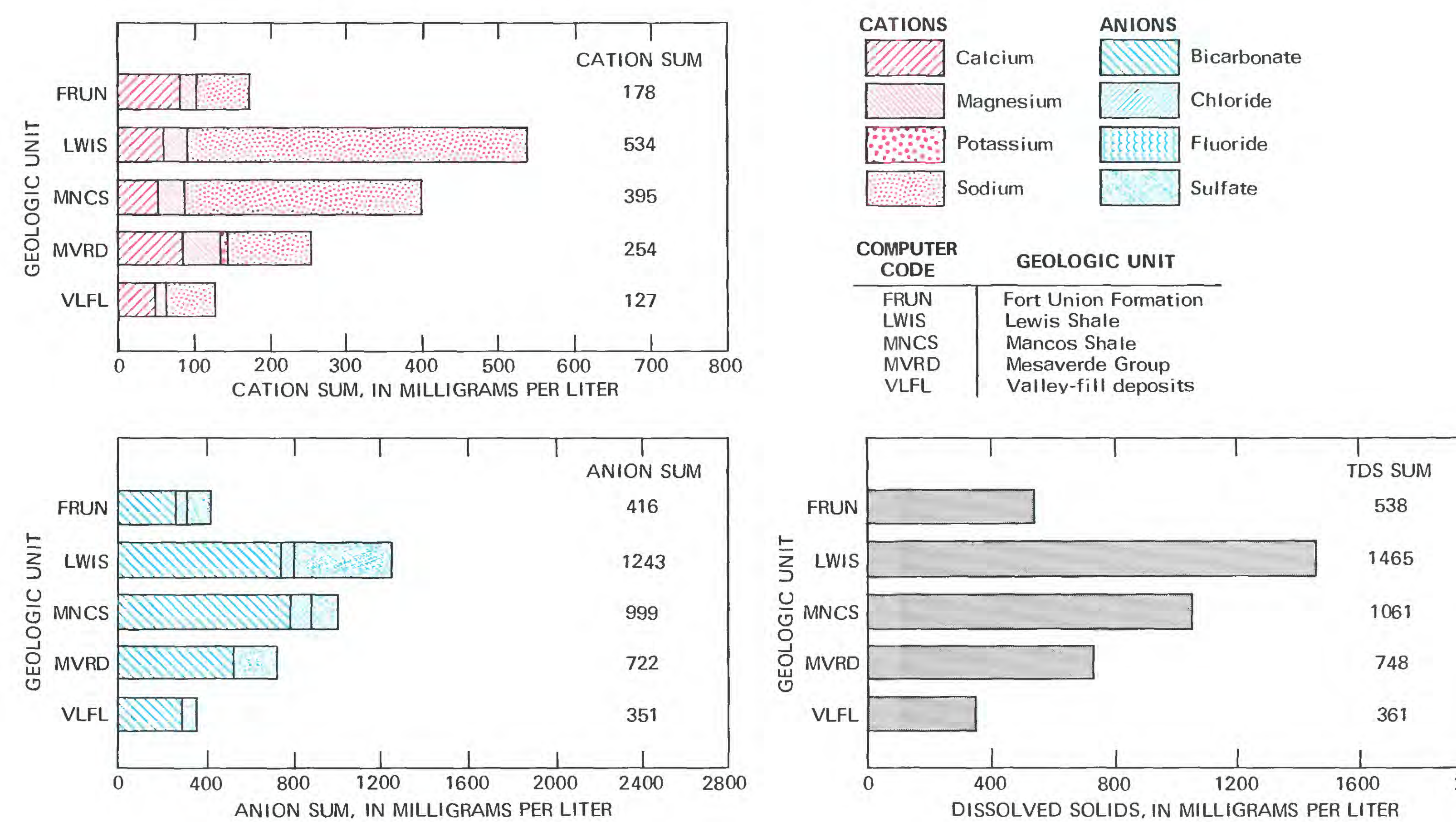


Figure 11.1-3 Average concentration of ions in ground water, hydrologic unit 14050001, Yampa River basin.

Trace Elements are Generally Not a Problem

Except for iron and manganese, trace elements analyzed generally do not exceed the National drinking water standard.

Averitt (1969) states that coal contains "...small quantities of essentially all metallic and nonmetallic elements...." He also describes four ways by which the elements can be introduced into the coal:

1. As inert material washed into the coal swamp at the time of plant accumulation.

2. As a chemical precipitate from the swamp water.

3. As a minor constituent in the original plant cells.

4. As a later addition, introduced after coal formation, primarily by ground water in undisturbed aquifers moving downward and laterally.

Breger (1958) and Szilagi (1971) also note that secondary enrichment of trace elements occurs in coal.

Averitt (1969) states, "Most of the minor elements occur in coal in about the same concentration as the Earth's crust." However, a few elements such as arsenic and boron can occur in vastly greater concentrations, and other elements such as lead can occur in significantly greater concentrations. Breger (1958) further notes that a specific trace element may be enriched in one area and may have a lower than normal value in another area.

The concentration of most trace elements is generally less than the U.S. Environmental Protection Agency (1976, 1977b) maximum level for drinking water. Frequency distribution of dissolved concentrations of select trace elements are shown in figure 11.2-1. Recommended maximum concentrations of trace elements are given in table 11.2-1. The low concentration of these trace elements is generally due to small, although ubiquitous, occurrences of the element or low solubility of the element. Although many trace elements are necessary for plant and animal growth, excessive concentrations of the trace elements can be injurious or lethal.

Iron and manganese are the trace elements whose concentrations are most likely to exceed drinking-water standards. These trace elements are found in both depositional environments and igneous or metamorphic rocks. Excessive boron concentrations (as much as 109,000 milligrams per liter) were found in a few brines.

Zinc is present in many water samples in large concentrations; however, these concentrations do not exceed the recommended drinking-water standards. If wells have galvanized pipes, some of the zinc could be attributed to contamination from the pipes.

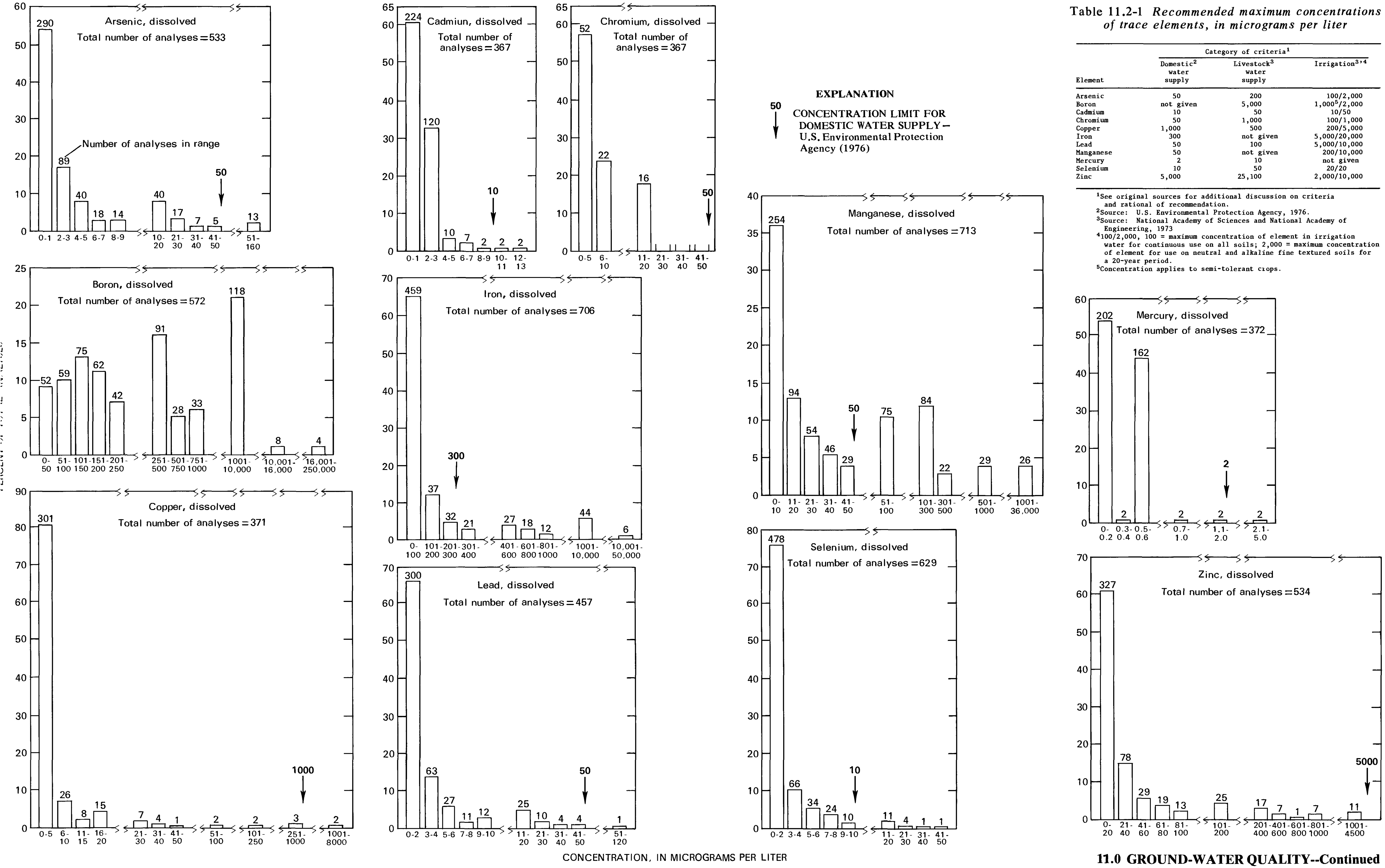


Figure 11.2-1 Frequency distribution of dissolved concentrations of select trace elements.

Table 11.2-1 *Recommended maximum concentrations of trace elements, in micrograms per liter*

Element	Category of criteria[1] Domestic[2] water supply	Livestock[3] water supply	Irrigation[3,4]
Arsenic	50	200	100/2,000
Boron	not given	5,000	1,000[5]/2,000
Cadmium	10	50	10/50
Chromium	50	1,000	100/1,000
Copper	1,000	500	200/5,000
Iron	300	not given	5,000/20,000
Lead	50	100	5,000/10,000
Manganese	50	not given	200/10,000
Mercury	2	10	not given
Selenium	10	50	20/20
Zinc	5,000	25,100	2,000/10,000

[1]See original sources for additional discussion on criteria and rational of recommendation.
[2]Source: U.S. Environmental Protection Agency, 1976.
[3]Source: National Academy of Sciences and National Academy of Engineering, 1973
[4]100/2,000, 100 = maximum concentration of element in irrigation water for continuous use on all soils; 2,000 = maximum concentration of element for use on neutral and alkaline fine textured soils for a 20-year period.
[5]Concentration applies to semi-tolerant crops.

12.0 WATER-DATA SOURCES

12.1 Introduction

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

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

Three activities within the U.S. Geological Survey help identify and improve access to the vast amount of existing water data.

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

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

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

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

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

NAWDEX Simplifies Access to Water Data

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

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

Services are available through a Program Office located at the U.S. Geological Survey's National Center in Reston, Virginia, and a nationwide network of Assistance Centers located in 45 states and Puerto Rico, which provide local and convenient access to NAWDEX facilities (see fig. 12.2-1). A directory is available on 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 79-423 (revised)].

NAWDEX can assist any organization or individual in identifying and locating needed water data and referring the requestor to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water Data Index (fig. 12.2-2), which identifies sites for which water data are available, the type of data available for each site, and the organization retaining the data. A Water Data Sources Directory (fig. 12.2-3) also is maintained that identifies organizations that are sources of water data and the locations within these organizations from which data may be obtained. In addition NAWDEX has direct access to some large water-data bases of its members and has reciprocal agreements for the exchange of services with others.

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

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

Program Office
National Water Data Exchange
(NAWDEX)
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 860-6031
FTS 928-6031
Hours: 7:45 - 4:15 EST

District Chief, WRD
U.S. Geological Survey
Mail Stop 415, Box 25046
Denver Federal Center
Lakewood, CO 80225
Telephone: (303) 236-4882
FTS 776-4882

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

District Chief, WRD
U.S. Geological Survey
Room 1016, Administration Building
1745 West 1700 South
Salt Lake City, UT 84104
Telephone: (801) 524-5663
FTS 588-5663

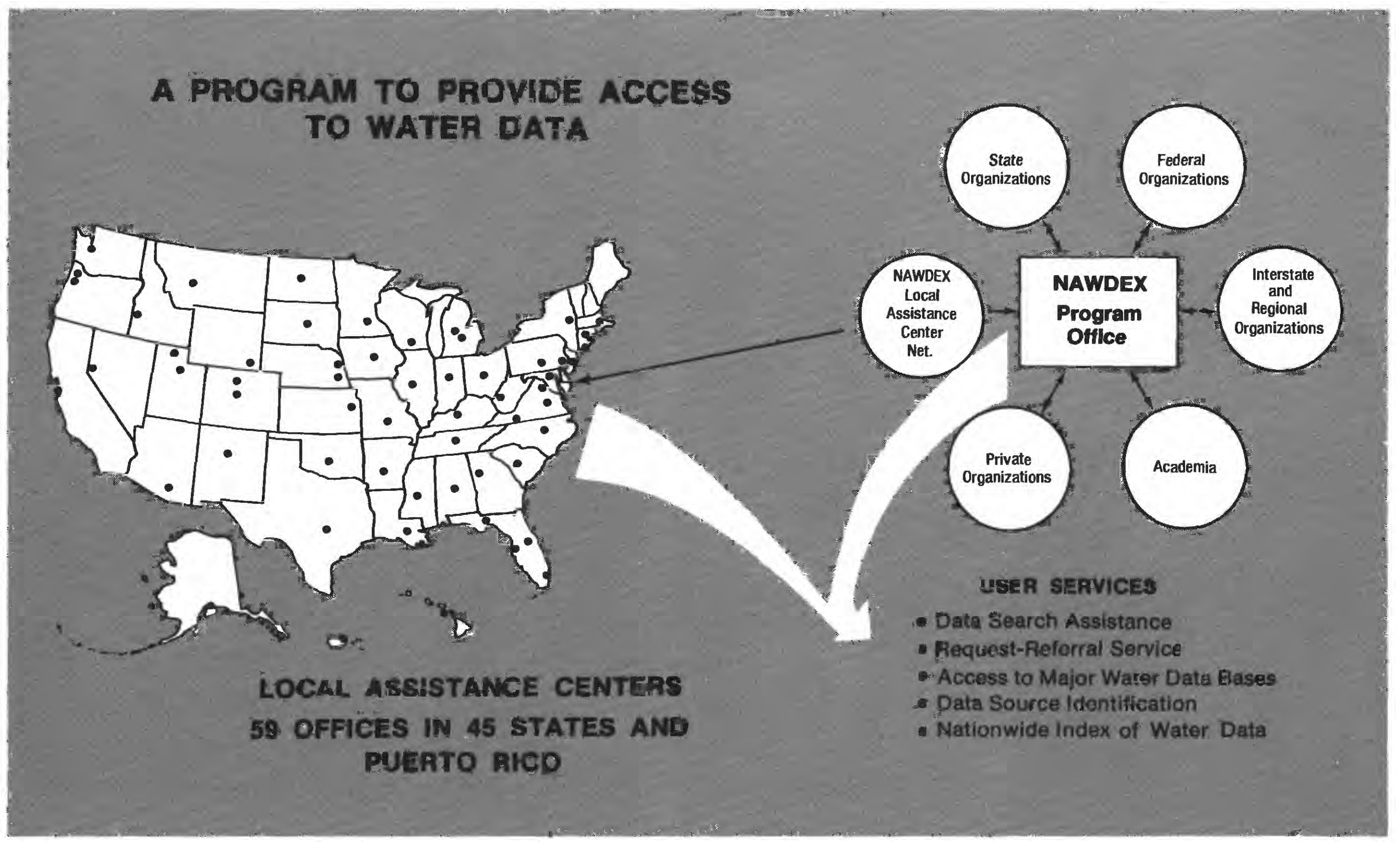


Figure 12.2-1 Access to water data.

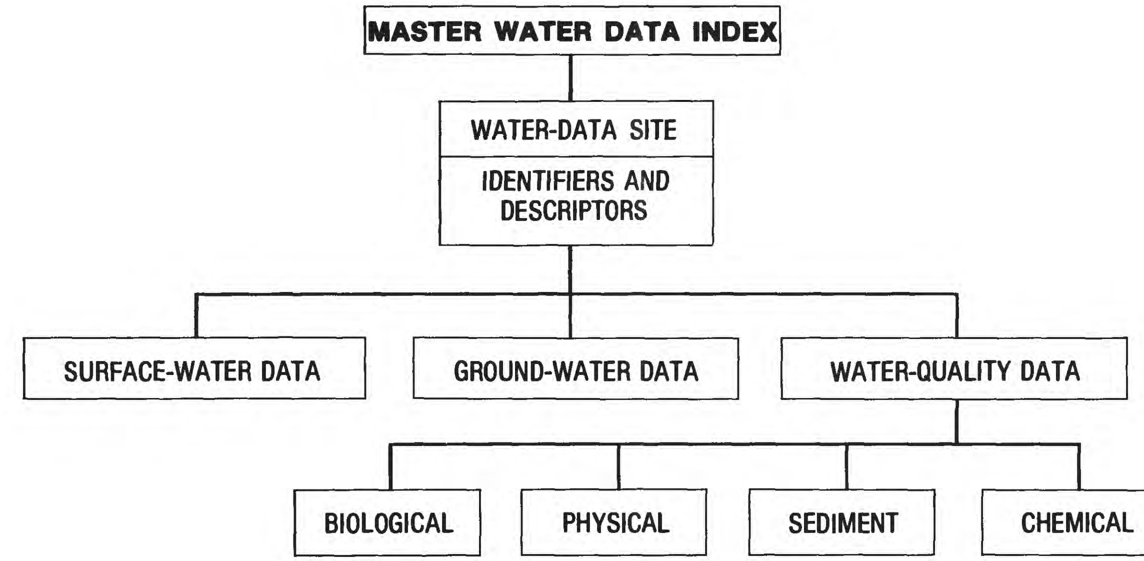


Figure 12.2-2 Master water-data index.

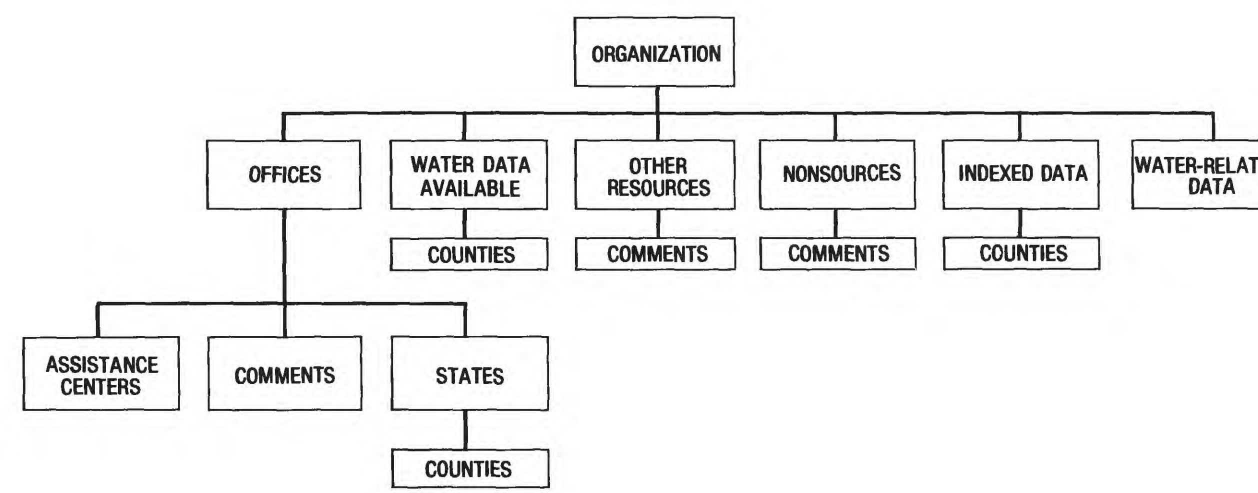


Figure 12.2-3 Water-data sources directory.

WATSTORE Automated Data System

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

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

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

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

U.S. Geological Survey
Water Resources Division
P.O. Box 1125
2120 Capitol Avenue, Room 4007
Cheyenne, WY 82003

U.S. Geological Survey
Water Resources Division
Room 1016, Administration Building
1745 West 1700 South
Salt Lake City, UT 84104

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

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system also is designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) Surface-water, quality-of-water, and ground-water measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 12.3-1). A brief description of each file is as follows.

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

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

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

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

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

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

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

Remote Job Entry Sites: Almost all 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 enter data into or retrieve data from the system within an interval of several minutes to overnight, depending upon the priority placed on the request. The number of remote job-entry sites is increased as the need arises.

Digital Transmission Sites: Digital recorders are used at many field locations to record values for parameters such as river stages, conductivity, water temperature, turbidity, wind direction, and chlorides. Data are recorded on 16-channel paper tape; the tape is removed from the recorder, and the data are transmitted over telephone lines to the receiver at Reston, Va. The data are re-recorded on magnetic tape for use on the central computer. Extensive testing of satellite data-collection platforms indicates their feasibility for transmitting real-time hydrologic data on a national scale. Battery-operated radios are used as the communication link to the satellite. About 500 data-relay stations are being operated currently (1983) by the Water Resources Division.

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

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

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

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

Statistical Analyses: WATSTORE interfaces with a proprietary statistical package called SAS (Statistical Analysis System, 1982) to provide extensive analyses of data such as regression analyses, analysis of variance, transformations, and correlations.

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

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

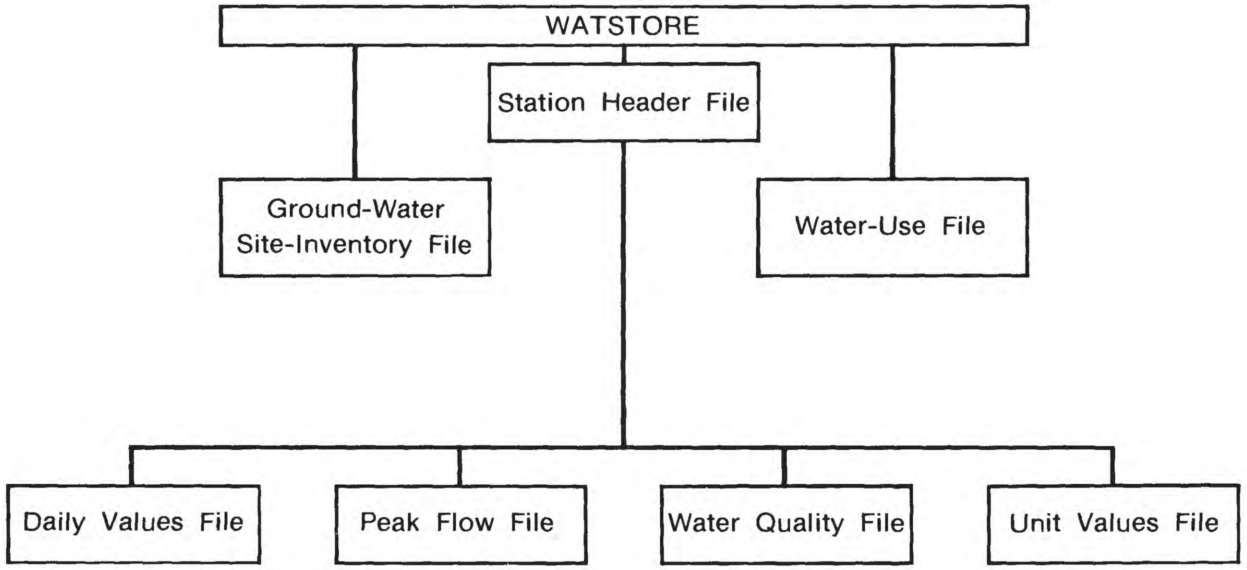


Figure 12.3-1 Index file stored data.

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

This special index consists of five volumes (fig. 12.4-1): Volume 1, 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 in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

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

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

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

U.S. Geological Survey
Water Resources Division
Mail Stop 415, Box 25046
Denver Federal Center
Lakewood, CO 80225
Telephone: (303) 236-4882
FTS 776-4882

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

U.S. Geological Survey
Water Resources Division
Room 1016, Administration Building
1745 West 1700 South
Salt Lake City, UT 84104
Telephone: (801) 524-5663
FTS 588-5663

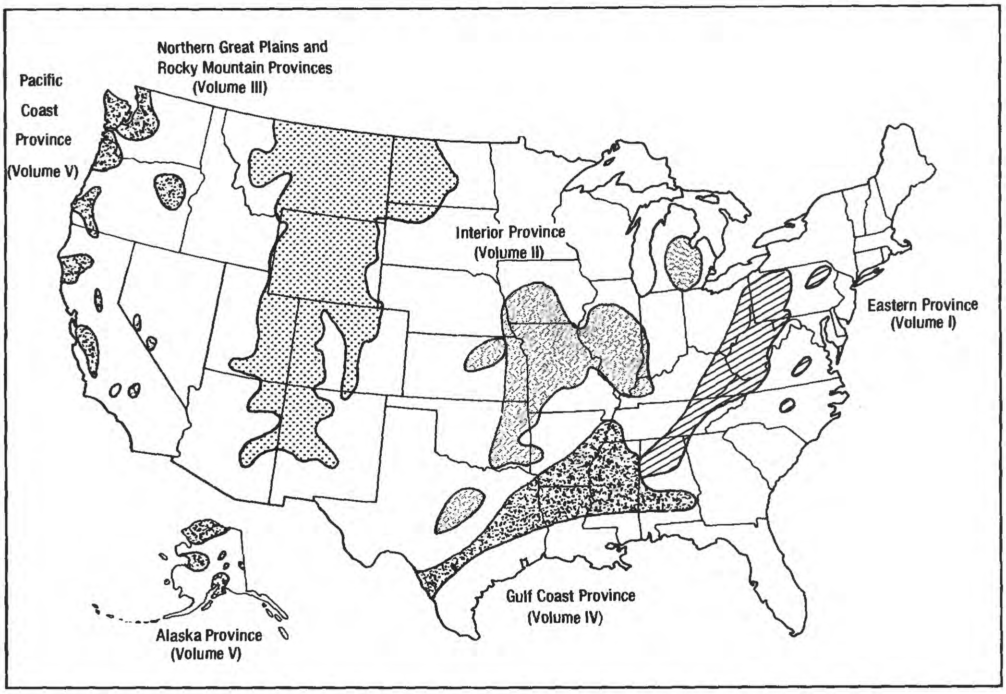


Figure 12.4-1 Index volumes and related provinces.

STORET Water-Quality Data Base System

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

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

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

About 1,800 water-quality parameters are defined with STORET's Water Quality File. In 1976 the data in the system represented more than 200,000 unique collection points. The groups of parameters and number of observations that are in the Water Quality File are illustrated in figure 12.5-1.

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

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

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

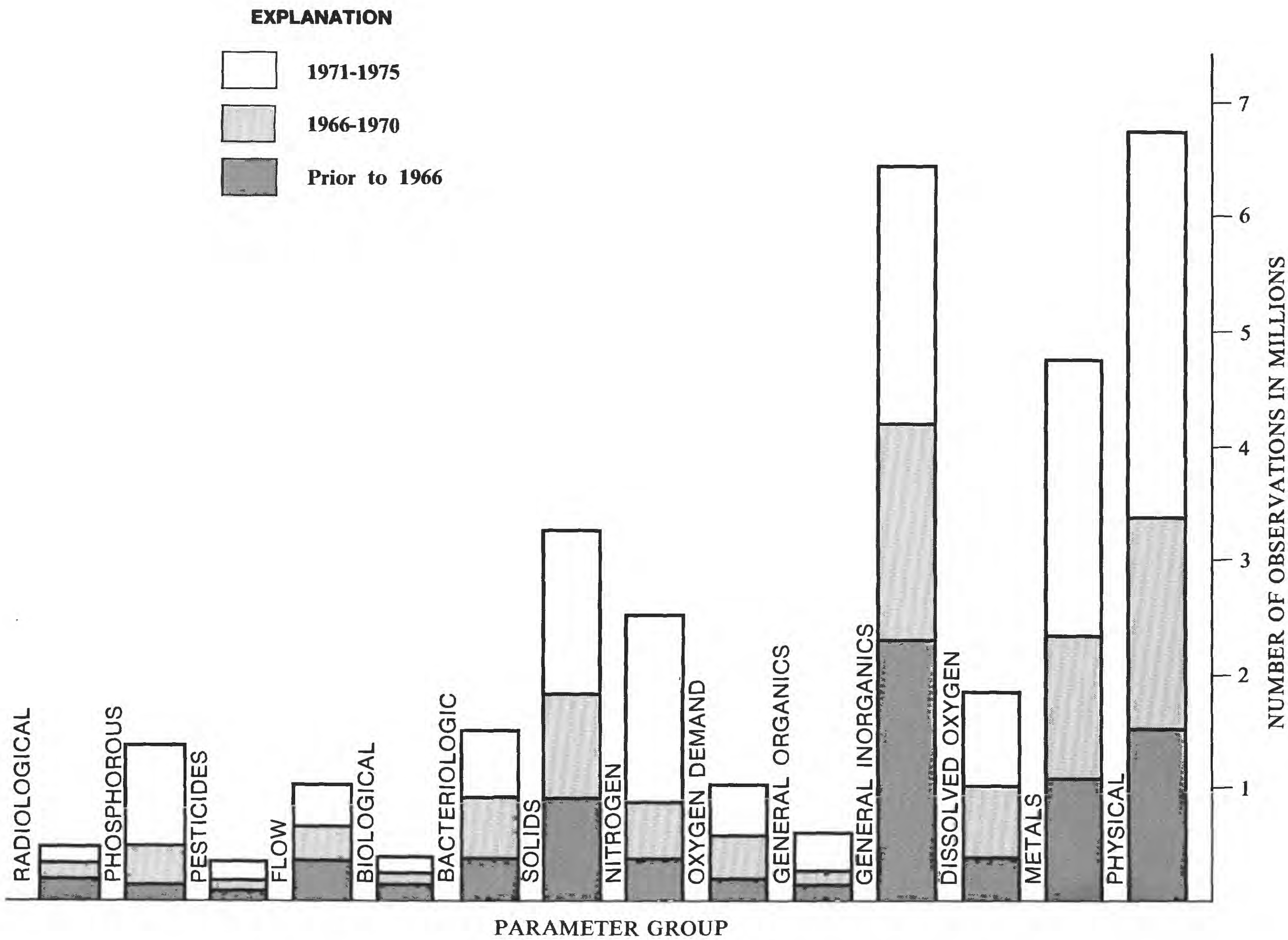


Figure 12.5-1 Parameter groups and number of observations in the Water Quality File.

13.0 TOPICAL LIST OF REFERENCES CITED

Study Area and Hydrologic Problems Related to Surface Mining

Hounslow, Arthur, Fitzpatrick, Joan, Cerrillo, Lawrence, and Freeland, Michael, 1978, Overburden mineralogy as related to ground-water chemical changes in coal strip mining: U.S. Environmental Protection Agency Report No. 600/7-78-156, 299 p.

McWhorter, D. B., Rowe, J. W., Van Liew, M. W., Chandler, R. L., Skogerboe, R. K., Sunada, D. K., and Skogerboe, G. B., 1977, Surface and subsurface water-quality hydrology in surface-mined watersheds, Part I, Text (Fulfillment of U.S. Environmental Protection Agency Grant No. RO3175 to Colorado State University): Cincinnati, U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Office of Research and Development, 313 p.

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Saunders, G. P., 1983, Aquifer dewatering and drawdown at an open mine pit in northwestern Colorado: Ground-water Monitoring Review, Winter 1983, p. 122-127.

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U.S. Bureau of Land Management, 1976, Northwest Colorado coal; Regional Analysis plus five site-specific analyses--Final environmental statement: v. 1, variously paginated.

______1980, Green River-Hams Fork; Regional Coal--Final environmental impact statement: v. 1, 358 p.

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14.0 SUPPLEMENTAL INFORMATION FOR AREA 53

14.1 Index of Surface-Water and Water-Quality Stations for the Yampa and the White River Basins

[D,daily discharge; Q,water quality; M,miscellaneous data; *interrupted record; B,biological data; S,sediment data; P,daily precipitation data; dashes indicate not computed; K,peak flow station]

YAMPA RIVER BASIN

Station No. for report	U.S. Geological Survey station No.	Station name	Lati-tude	Longi-tude	Drainage area, in in square miles	Data type	Period of record	
							Discharge	Water-quality
1	09236000	Bear River near Toponas, Colo.	400238	1070418	23.00	DQ	1952-82*	1961-82
2	09236500	Bear River near Yampa, Colo.	400415	1065950	41.60	D	1939-44	
3	09237500	Yampa River near Oak Creek, Colo.	401708	1064959	227.00	DQ	1939-72*	
4	09237800	Service Creek near Oak Creek, Colo.	401745	1064803	38.20	DQ	1965-73*	1965-73
5	09238000	Oak Creek near Oak Creek, Colo.	401438	1070053	14.00	DQSB	1952-57*	1975-81*
6	09238300	North Fork Walton Creek near Rabbit Ears Pass, Colo.	402344	1063857	0.71	DQB	1972-75	1972-76
7	09238350	Fishhook Creek near Rabbit Ears Pass, Colo.	402546	1064034	6.45	D	1972-75	
8	09238500	Walton Creek near Steamboat Springs, Colo.	402429	1064711	42.40	DQ	1965-82*	1947-82*
9	09238900	Fish Creek at Upper Station, near Steamboat Springs, Colo.	402830	1064711	25.80	DQ	1966-82*	1966-82
10	09239400	Spring Creek near Steamboat Springs, Colo.	402936	1064817	6.96	DQ	1965-72	1965-72
11	09239500	Yampa River at Steamboat Springs, Colo.	402901	1064954	604.00	DQSB	1904-82*	1950-82*
12	09240500	Elk River at Hinman Park, Colo.	404520	1064834	61.00	D	1913-18	
13	09240800	South Fork Elk River near Clark, Colo.	404443	1064824	33.70	DQ	1966-73	1966-73
14	09241000	Elk River at Clark, Colo.	404303	1065455	206.00	DQSB	1910-82*	1957-82*
15	09242500	Elk River near Trull, Colo.	403053	1065712	415.00	DQSB	1904-27*	1947-76
16	09243700	Middle Creek near Oak Creek, Colo.	402308	1065933	23.50	DQSB	1975-82	1975-82
17	09243800	Foidel Creek near Oak Creek, Colo.	402045	1070504	8.61	DQSB	1975-82	1975-82
18	09243900	Foidel Creek at mouth, near Oak Creek, Colo.	402325	1065939	17.50	DQSB	1975-82	1975-82
19	09244100	Fish Creek near Milner, Colo.	402003	1070819	34.50	DQSB	1955-73	1957-82
20	09244300	Grassy Creek near Mount Harris, Colo.	402649	1070842	25.80	DQSB	1958-66	1961-82
21	09244400	Yampa River near Hayden, Colo.	402921	1070933	1,430.00	DQB	1965-72	1965-79
22	09244405	Gibraltar Canal near Hayden, Colo.	402917	1070919	--------	DQ	1970-73	1966-73
23	09244410	Yampa River below diversion, near Hayden, Colo.	402918	1070933	1,430.00	DQSB	1965-82	1944-82
24	09244415	Sage Creek above Sage Creek Reservoir near Hayden, Colo.	402301	1071134	--------	DQSB	1981-82	1981-82
25	09244460	Watering Trough Gulch near Hayden, Colo.	402257	1071649	--------	DQSB	1979-81	1978-82
26	09244464	Hubberson Gulch near Hayden, Colo.	402328	1071615	--------	DQSB	1979-81	1978-82
27	09244470	Stokes Gulch near Hayden, Colo.	402806	1071447	13.60	DQSB	1978-81	1978-82
28	09244500	Elkhead Creek near Clark, Colo.	404356	1071008	45.40	DQ	1942-73*	1961-73
29	09245000	Elkhead Creek near Elkhead, Colo.	404011	1071705	64.20	DQSB	1953-82	1957-82*
30	09245500	North Fork Elkhead Creek near Elkhead, Colo.	404050	1071712	21.00	DQS	1958-73	1961-76
31	09246500	Elkhead Creek near Craig, Colo.	403152	1072608	249.00	DQSB	1910-18	1957-78*
32	09246550	Yampa River below Elkhead Creek, near Craig, Colo.	402950	1073034	--------	QSB		1975-80
33	09246900	Fortification Creek near Craig, Colo.	404523	1073245	34.30	DQ	1955-60	1957-58
34	09247000	Fortification Creek at Craig, Colo.	403051	1073227	258.00	D	1909-47*	
35	09247500	Yampa River at Craig, Colo.	402945	1073310	1,730.00	DQSB	1904-16*	1947-76*
36	09247520	Cedar Mountain Gulch at Craig, Colo.	403052	1073431	6.26	KMP	1973-76*	
37	09247600	Yampa River below Craig, Colo.	402904	1073623	--------	QS		1975-80
38	09248500	East Fork of Williams Fork near Willow Creek, Colo.	401321	1071558	96.00	D	1943-47	
39	09248600	East Fork of Williams Fork above Willow Creek, Colo.	401540	1071740	108.00	DQ	1956-72	1959-81
40	09249000	East Fork of Williams Fork near Pagoda, Colo.	401845	1071910	150.00	DQB	1953-71	1959-76
41	09249200	South Fork of Williams Fork near Pagoda, Colo.	401244	1072632	46.70	DQSB	1965-79	1965-79*
42	09249500	Williams Fork at Hamilton, Colo.	402212	1073631	341.00	DQ	1904-27*	1947-
43	09249700	Morapos Creek near Hamilton, Colo.	401307	1073451	13.70	DQ	1965-67	1965-67
44	09249750	Williams Fork at mouth, near Hamilton, Colo.	402614	1073850	--------	QSB		1957-80
45	09250000	Milk Creek near Thornburgh, Colo.	401137	1074354	65.00	DQSB	1952-83	1959-82
46	09250400	Good Spring Creek at Axial, Colo.	401725	1074722	40.00	DQSB	1974-78	1972-78
47	09250507	Wilson Creek above Taylor Creek, near Axial, Colo.	401853	1074758	--------	DQSB	1980-82	1981-82
48	09250510	Taylor Creek at mouth, near Axial, Colo.	401848	1074757	7.22	DQSB	1975-82	1975-82*
49	09250600	Wilson Creek near Axial, Colo.	401856	1074750	20.10	DQSB	1974-80	1974-81
50	09250610	Jubb Creek near Axial, Colo.	401845	1074918	7.53	DQSB	1975-81	1975-81
51	09250700	Morgan Gulch near Axial, Colo.	402009	1075306	---------	DQSB	1980-81	1980-81
52	09250900	Lay Creek tributary near Lay, Colo.	403131	1075528	0.99	KMP	1978-80	
53	09251000	Yampa River near Maybell, Colo.	403010	1080145	3,410.00	DQSB	1916-82	1947-82
54	09251500	North Fork Little Snake River near Battle Creek, Colo.	405926	1070237	120.00	DQ	1912-22	1976-
55	09251800	North Fork Little Snake River near Encampment, Wyo.	410300	1065730	9.64	D	1956-65	

YAMPA RIVER BASIN--Continued

Station No. for report	U.S. Geological Survey station No.	Station name	Latitude	Longitude	Drainage area, in square miles	Data type	Period of record: Discharge	Period of record: Water-quality
56	09251900	North Fork Little Snake River near Slater, Colo.	410055	1070120	29.30	DQSB	1956-63	1957-78
57	09252500	South Fork Little Snake River near Battle Creek, Colo.	405835	1070259	46.00	D	1913-20	
58	09253000	Little Snake River near Slater, Colo.	405958	1070834	285.00	DQSB	1942-82*	1957-82
59	09253400	Battle Creek near Encampment, Wyo.	410800	1070350	12.80	DQSB	1956-63	1978
60	09253500	Battle Creek near Slater, Colo.	410012	1071416	85.30	DQSB	1942-51	1975-78
61	09254500	Slater Fork at Baxter Ranch, near Slater, Colo.	405322	1071948	80.00	D	1913-20	
62	09255000	Slater Fork near Slater, Colo.	405854	1072258	161.00	DQSB	1931-82	1957-80
63	09255400	East Fork Savery Creek near Encampment, Wyo.	411620	1070930	7.91	D	1956-58	
64	09255500	Savery Creek at Upper Station, near Savery, Wyo.	411305	1072218	200.00	D	1940-71	
65	09255800	Big Sandstone Creek near Savery, Wyo.	411200	1071030	10.30	D	1956-58	
66	09256000	Savery Creek near Savery, Wyo.	410552	1072253	330.00	DQSB	1941-72	1957-78
67	09256500	Savery Creek at Savery, Wyo.	410129	1072638	354.00	DQS	1914-22*	1957-78
68	09257000	Little Snake River near Dixon, Wyo.	410142	1073255	988.00	DQSB	1910-80*	1957-82
69	09258000	Willow Creek near Dixon, Wyo.	405456	1073116	24.00	DQSB	1953-82	1957-80*
70	09259050	Little Snake River below Baggs, Wyo.	410143	1074114	--------	Q		1980-82
71	09259700	Little Snake River near Baggs, Wyo.	410011	1075511	3,020.00	DQSB	1961-68	1965-80*
72	09259750	Little Snake River tributary near Great Divide, Colo.	405310	1080547	3.42	KMP	1978-80	
73	09259950	Little Snake River above Lily, Colo.	403627	1082011	--------	DQS	1959-64	1950-70*
74	09260000	Little Snake River near Lily, Colo.	403250	1082525	3,730.00	DQSB	1921-82	1950-82*
75	09260025	Yampa River below Little Snake River, Colo.	402621	1082820	--------	Q		1977-80
76	09260050	Yampa River at Deerlodge Park, Colo.	402702	1083120	--------	QSB		1975-82*
77	09260150	Yampa River below Box Elder Park, near Dinosaur, Colo.	403108	1085738	--------	QS		1982-
78	400612106524800	Chimney Creek at Trapper, Colo.	400612	1065248	--------	QSB		1975-76
79	401601107375400	Morapos Creek near Iles Grove, Colo.	401601	1073754	16.80	QS		1981-82
80	401601107395300	Stinking Gulch near Thornburgh, Colo.	401601	1073953	8.43	QSB		1975-82
81	401640107030500	Trout Creek above Trout Creek School, Colo.	401640	1070305	--------	MB		1980-81
82	401747107161600	Willow Creek near Dunckley, Colo.	401747	1071616	19.60	QS		1981-82
83	401816107011000	Trout Creek near Oak Creek, Colo.	401816	1070110	31.10	Q		1981-
84	401823107003400	Trout Creek near Oak, Creek, Colo.	401823	1070034	--------	MB		1980-81
85	401829107375600	Deer Creek near Hamilton, Colo.	401829	1073756	27.90	QS		1981-82
86	401847107193500	East Fork Williams Fork below Willow Creek, Colo.	401847	1071935	--------	MB		1980-81
87	401857107243500	South Fork of Williams Fork at mouth, near Pagoda, Colo.	401857	1072435	56.60	MB		1980-81
88	401913107204100	Hayden Gulch near Pagoda, Colo.	401913	1072041	5.79	QB		1975-82
89	401925107523500	Collum Gulch near Axial, Colo.	401925	1075235	12.80	MB		1980-81
90	401944107322900	Waddle Creek near Hamilton, Colo.	401944	1073229	16.30	QS		1981-82
91	401948107445600	Milk Creek near Iles Grove, Colo.	401948	1074456	134.00	QS		1981-82
92	402010107082000	Fish Creek above Coyote Creek, Colo.	402010	1070820	--------	MB		1980-81
93	402038107585100	Maudlin Gulch near Axial, Colo.	402038	1075851	12.80	Q		1981-82
94	402145108001000	Jesse Gulch near Axial, Colo.	402145	1080010	2.12	Q		1981
95	402217107335600	Williams Fork near Hamilton, Colo.	402217	1073356	--------	MB		1980-81
96	402300107022700	Fish Creek below Yampa Coal Mine No. 2, Colo.	402300	1070227	--------	MB		1980-81
97	402330107082000	Grassy Creek at Grassy Gap, Colo.	402330	1070820	5.52	QSB		1975-82
98	402338106573600	Trout Creek above Fish Creek, Colo.	402338	1065736	--------	MB		1980-81
99	402530106585700	Fish Creek at mouth, near Milner, Colo.	402530	1065857	77.90	QSMB		1975-82
100	402544106493600	Yampa River below Oak Creek, near Steamboat Springs, Colo.	402544	1064936	--------	QSB		1975-76
101	402720106591200	Trout Creek above Milner, Colo.	402720	1065912	110.00	QSB		1981-82
102	402836106550100	Cow Creek near Steamboat Springs, Colo.	402836	1065501	14.40	QS		1982
103	402840107004200	Yampa River at Milner, Colo.	402840	1070042	--------	QB		1975
104	402845107185100	Smuin tributary creek near Hayden, Colo.	402845	1071851	1.30	Q		1981
105	402902107043600	Yampa River above Tow Creek Oil Field, Colo.	402902	1070436	--------	QB		1975
106	402911107323500	Flume Gulch near Craig, Colo.	402911	1073235	8.42	Q		1981
107	402930107174200	Yampa River below Hayden, Colo.	402930	1071742	--------	QB		1950-76*
108	402958106515200	Yampa River below sewage plant, below Steamboat Springs, Colo.	402958	1065152	--------	QB		1975
109	403051107124500	Yampa River below Morgan Creek, near Hayden, Colo.	403051	1071245	--------	QB		1975
110	09302400	North Fork White River below Trappers Lake, Colo.	395952	1071350	19.50	DQ	1956-65	1959-65
111	09302420	North Fork White River above Ripple Creek, near Trappers Lake, Colo.	400249	1071838	62.50	DQ	1965-73	1965-73
112	09302450	Lost Creek near Buford, Colo.	400301	1072806	21.50	DQSB	1964-82	1964-82*
113	09302500	Marvine Creek near Buford, Colo.	400218	1072915	59.70	DQSB	1972-82	1972-82*
114	09302800	North Fork White River near Buford, Colo.	400208	1073113	220.00	DQ	1903-73*	1959-73*
115	09303000	North Fork White River at Buford, Colo.	395915	1073650	260.00	DQSB	1910-82	1959-82*
116	09303300	South Fork White River at Budges Resort, Colo.	395036	1072003	52.30	DQ	1975-82	1975-81
117	09303320	Wagonwheel Creek at Budges Resort, Colo.	395034	1072010	7.36	DQ	1975-82	1975-81

Station No. for report	U.S. Geological Survey station No.	Station name	Latitude	Longitude	Drainage area, in in square miles	Data type	Period of record: Discharge	Period of record: Water-quality
118	09303340	Patterson Creek near Budges Resort, Colo.	394905	1072328	11.20	DQ	1975-82	1975-77
119	09303400	South Fork White River near Budges Resort, Colo.	395151	1073200	128.00	DQ	1976-82	1976-81
120	09303500	South Fork White River near Buford, Colo.	395518	1073304	152.00	DQSB	1903-82	1960-82*
121	09304000	South Fork White River at Buford, Colo.	395828	1073729	177.00	DQSB	1919-82	1959-82*
122	09304100	Big Beaver Creek near Buford, Colo.	395808	1073846	34.10	DQ	1955-64	1959-64
123	09304150	Miller Creek near Meeker, Colo.	395552	1074610	57.60	DQSB	1961-82	1961-82
124	09304200	White River above Coal Creek, near Meeker, Colo.	400018	1074929	648.00	DQB	1970-79	1970-81
125	09304300	Coal Creek near Meeker, Colo.	400529	1074610	25.10	DQ	1957-68	1959-68
126	09304480	Coal Creek below Little Beaver Creek, near Meeker, Colo.	400152	1074918	89.80	QB		1978-82*
127	09304500	White River near Meeker, Colo.	400201	1075142	755.00	DQSB	1901-82	1947-82*
128	09304550	Curtis Creek near Meeker, Colo.	400222	1075254	23.10	QB		1973-82*
129	09304600	White River at Meeker, Colo.	400200	1075505	808.00	DQMB	1978-82	1978-82
130	09304800	White River below Meeker, Colo.	400048	1080533	1,024.00	DQSB	1961-82	1961-82*
131	09305500	Piceance Creek at Rio Blanco, Colo.	394356	1075617	8.97	D	1952-57	
132	09306007	Piceance Creek below Rio Blanco, Colo.	394934	1081057	177.00	DQSB	1974-82	1974-82
133	09306015	Middle Fork Stewart Gulch near Rio Blanco, Colo.	394720	1081023	24.00	DQSB	1974-81*	1976-76
134	09306022	Stewart Gulch above West Fork near Rio Blanco, Colo.	394848	1081100	44.00	DQSB	1974-82	1974-82
135	09306025	West Fork Stewart Gulch near Rio Blanco, Colo.	394701	1081121	14.20	DQSB	1974-81	1974-80*
136	09306028	West Fork Stewart Gulch at mouth, near Rio Blanco, Colo.	394845	1081100	15.70	DQSB	1974-81	1975-80*
137	09306033	Sorghum Gulch near Rio Blanco, Colo.	394707	1081233	1.22	DQSB	1974-81	1975-80
138	09306036	Sorghum Gulch at mouth, near Rio Blanco, Colo.	394930	1081155	3.62	DQSB	1974-82	1975-80
139	09306039	Cottonwood Gulch near Rio Blanco, Colo.	394936	1081225	1.20	DQSB	1974-82	1974-80
140	09306042	Piceance Creek tributary near Rio Blanco, Colo.	395001	1081312	1.06	DQSB	1974-82	1976-82
141	09306045	Piceance Creek below Gardenhire Gulch, near Rio Blanco, Colo.	395008	1081314	--------	DQSB	1980-82	1980-81
142	09306050	Scandard Gulch near Rio Blanco, Colo.	394738	1081340	6.61	DQSB	1974-81	1974-80
143	09306052	Scandard Gulch at mouth, near Rio Blanco, Colo.	394851	1081435	7.97	DQSB	1974-82*	1974-80
144	09306058	Willow Creek near Rio Blanco, Colo.	395014	1081437	48.40	DQSB	1974-82	1974-82
145	09306061	Piceance Creek above Hunter Creek, near Rio Blanco, Colo.	395102	1081530	309.00	DQSB	1974-82	1974-82
146	09306175	Black Sulphur Creek near Rio Blanco, Colo.	395217	1081713	103.00	DQS	1974-82	1974-82
147	09306200	Piceance Creek below Ryan Gulch, near Rio Blanco, Colo.	395516	1081749	506.00	DQSB	1964-82	1964-82*
148	09306202	Horse Draw near Rangely, Colo.	395559	1081859	1.47	DQS	1977-81	1977-80
149	09306203	Horse Draw at mouth, near Rangely, Colo.	395612	1081753	2.87	DQS	1977-81	1977-80
150	09306210	Piceance Creek near White River, Colo.	395620	1081720	515.00	Q		1947-76
151	09306222	Piceance Creek at White River, Colo.	400516	1081435	652.00	DQSB	1964-82*	1965-82
152	09306230	Stake Springs Draw near Rangely, Colo.	395537	1082514	26.10	DQSB	1974-77	1976-77
153	09306235	Corral Gulch below Water Gulch, near Rangely, Colo.	395422	1083156	8.61	DQSB	1974-82	1974-82
154	09306237	Dry Fork near Rangely, Colo.	395520	1083155	2.74	DQS	1974-82	1975-81
155	09306240	Box Elder Gulch near Rangely, Colo.	395318	1083140	9.21	DQSB	1974-82	1974-82
156	09306241	Box Elder Gulch tribntary near Rangely, Colo.	395450	1082905	2.39	DQSB	1974-82	1975-82
157	09306242	Corral Gulch near Rangely, Colo.	395513	1082820	31.60	DQSB	1974-82	1974-82
158	09306244	Corral Gulch at 84 Ranch, Colo.	395602	1082535	37.80	DQSB	1975-77	1975-78
159	09306246	Yellow Creek tributary near 84 Ranch, Colo.	395802	1082315	5.53	DQSB	1975-77	1976-
160	09306248	Duck Creek at Upper Station near 84 Ranch, Colo.	395855	1082710	39.10	DQS	1975-77	1975-76
161	09306250	Duck Creek near 84 Ranch, Colo.	395849	1082427	50.00	DQS	1975-77	1975-76
162	09306255	Yellow Creek near White River, Colo.	401007	1082402	262.00	DQSB	1972-82	1965-82
163	09306290	White River below Boise Creek, near Rangely, Colo.	401047	1083353	--------	D	1982-83	
164	09306300	White River above Rangely, Colo.	400626	1084244	2,773.00	DQSB	1972-82	1948-82*
165	09306315	Gillam Draw near Rangely, Colo.	400531	1084445	13.60	KMP	1975-80	
166	09306380	Douglas Creek at Rangely, Colo.	400515	1084632	425.00	DQB	1976-78	1948-78*
167	09306395	White River near Colorado-Utah State line	400050	1090448	3,680.00	DQSB	1976-83*	1976-82*
168	09306400	White River above Hells Hole Canyon near Watson, Utah	395826	1090749	3,700.00	DQSB	1974-76*	1974-76
169	09306405	Hell's Hole Canyon at mouth, near Watson, Utah	395824	1090740	24.50	DQS	1974-82*	1975-80*
170	09306408	El-West Evacuation Creek near Dragon, Utah	394132	1085954	15.70	Q		1974-77

Station No. for report	U.S. Geological Survey station No.	Station name	Lati- tude	Longi- tude	Drainage area, in in square miles	Data type	Period of record	
							Discharge	Water-quality
171	09306410	Evacuation Creek above Missouri Creek, near Dragon, Utah	394752	1090426	100.00	DQSB	1974-83*	1974-82
172	09306415	Evacuation Creek below Park Canyon, near Watson, Utah	395054	1090748	246.00	DQSB	1974-76	1974-75
173	09306417	Thimble Rock Canyon near Watson, Utah	394930	1090937	1.70	D	1975	
174	09306420	Evacuation Creek at Watson, Utah	395258	1090924	259.00	DQSB	1974-76	1948-77
175	09306425	Evacuation Creek tributary near	395400	1090920	12.40	D	1975	
176	09306430	Evacuation Creek near mouth, near Watson, Utah	395708	1090931	284.00	DQSB	1974-81*	1974-82
177	09306500	White River near Watson, Utah	395846	1091041	4,020.00	DQSB	1904-79*	1949-79
178	09306600	White River below Southam Canyon, near Watson, Utah	395715	1091528	4,030.00	DQSB	1974-76	1974-76
179	09306605	Southam Canyon Wash near Watson, Utah	395421	1091216	2.50	DQS	1974-76	1976
180	09306610	Southam Canyon Wash at mouth, near Watson, Utah	395650	1091406	8.30	DQSB	1974-76	1976-82*
181	09306620	Asphalt Wash below Center Fork, near Watson, Utah	395426	1091555	94.40	DQS	1974-76	1976
182	09306625	Asphalt Wash near mouth, near Watson, Utah	395605	1091600	97.50	DQSB	1974-82	1975-79
183	09306700	White River below Asphalt Wash, near Watson, Utah	395532	1091730	4,130.00	DQSB	1974-77	1974-82
184	09306740	Bitter Creek above Dick Canyon, Utah	393203	1090559	11.70	DQSB	1974-78	1974-78
185	09306760	Sweetwater Canyon below South Canyon, near Watson, Utah	393206	1091321	22.60	DQSB	1974-78	1974-78
186	09306780	Sweetwater Canyon Creek near mouth, near Watson, Utah	393931	1091958	124.00	QSB	1974-78	1975-78
187	09306800	Bitter Creek near Bonanza, Utah	394512	1092115	324.00	DQSB	1970-82*	1971-81
188	09306850	Bitter Creek at mouth, near Bonanza, Utah	395756	1092459	398.00	DQSB	1974-83	1974-82
189	09306870	Sand Wash near Ouray, Utah	395601	1092946	59.70	DQ	1974-81*	1976-80
190	09306872	Sand Wash at mouth, near Ouray, Utah	395926	1092910	71.10	DQ	1976-81*	1974-77
191	09306875	Coyote Wash near Bonanza, Utah	400241	1091845	174.89	D	1977	
192	09306878	Coyote Wash near mouth, near Ouray, Utah	400315	1092836	228.49	DQS	1976-83*	1976-82
193	09306880	North Wash near Ouray, Utah	400248	1093123	--------	DQ	1980-81	1980-81
194	09306885	Cottonwood Wash near mouth, near Ouray, Utah	400321	1093630	70.60	DQS	1976-81	1978-80
195	09306900	White River at mouth, near Ouray, Utah	400354	1093806	5,120.00	DQSB	1969-83	1974-82
196	395846108104101	White River near Watson, Utah	395846	1091041	--------	D	1977	
197	400500108460002	Rangely 1E (Colo. Entry) - Colo. NWS 6832	400500	1084600	--------	MP		1974-82

14.0 SUPPLEMENTAL INFORMATION FOR AREA 53
14.2 Ground-Water Site Index

[dashes indicate information not available]

Map No. for report	Site identification No.	Local well No.	Hydrologic unit	Geologic unit	Depth of well	Period of record	
						Water levels	Water quality
1	401224106471301	SB00308426BBC	14050001	Browns Park Formation	1200.0	1973-82	
2	401340107030201	SB00308616CDB1	14050001	Valley-fill deposits	-------		1975
3	401425107492201	SB00309309DDB	14050002	Mesaverde Group	82.0	1975-82	
4	401444107482501	SB00309310ACD	14050002	Mesaverde Group	-------	1975-80	
5	401449107490601	SB00309310BCB2	14050002	Mesaverde Group	65.0	1975-80	
6	401453107500600	SB00309309BBD	14050002	Mesaverde Group	85.0	1974-82	
7	401503107263901	SB00309109ABA1	14050001	Mancos Shale	-------		1975
8	401506107474401	SB00309302CDC	14050002	Alluvial, flood plain	-------	1975-80	
9	401506108595401	SB00310307ABB1	14050002	Entrada Sandstone	745.0	1974-82	
10	401507107493001	SB00309304DCD	14050002	Mesaverde Group	217.0	1974-80	
11	401508107485401	SB00309303DCC	14050002	Mesaverde Group	-------	1975-76	
12	401535107472001	SB00309302ACC	14050002	Alluvial, flood plain	-------	1974-80	
13	401602107504301	SB00409332DCD	14050002	Mesaverde Group	-------	1975-82	
14	401619107502901	SB00409332DAB	14050002	Alluvial, flood plain	140.0	1980-82	
15	401621107493301	SB00409333DBA	14050002	Alluvial, flood plain	25.0	1980-82	
16	401804107062101	SB00408724DBD	14050001	Alluvial, flood plain	263.0	1977-82	
17	401826107070401	SB00408724BCB	14050001	Mesaverde Group	145.0	1975-82	1977, 1980
18	401837107054501	SB00408619BBD	14050001	Alluvial, flood plain	111.0	1975-77	1977, 1980
19	401847107003301	SB00408614CDD	14050001	Valley-fill deposits	-------		1975
20	401847107003101	SB00408614DCC1	14050001	Alluvial, flood plain	20.0	-------	
21	401850107003301	SB00408614CDD2	14050001	Iles Formation	140.0	-------	
22	401858106521401	SB00408513DCB	14050001	Browns Park Formation	60.0	1973-82	
23	401904107060800	SB00408713AAD	14050001	Mesaverde Group	-------		1975-76
24	401904107060801	SB00408713DAA	14050001	Browns Park Formation	173.0	1977-82	
25	401912107031301	SB00408616CBA	14050001	Iles Formation	122.0	1977-82	
26	401922107050701	SB00408618BDA	14050001	Iles Formation	180.0	1975-77	
27	401950107103300	SB00408709CBC	14050001	Mancos Shale	-------		1975
28	402013107245201	SB00508931DDC1	14050001	Mancos Shale	-------		1975
29	402015107015500	SB00408610BAD	14050001	Valley-fill deposits	-------		1975
30	402015107014501	SB00408610BAD	14050001	Alluvial, flood plain	100.0	1975-82	
31	402114107034300	SB00508629CDD1	14050001	Alluvial, flood plain	126.0	1975	
32	402114107034301	SB00508629CDD	14050001	Mesaverde Group	-------		1975, 1977
33	402120106535201	SB00508526CCC1	14050001	Valley-fill deposits	-------		1975
34	402156107015201	SB00508627BBC1	14050001	Valley-fill deposits	-------		1975
35	402202107022101	SB00508628ABB1	14050001	Valley-fill deposits	-------		1975
36	402204107012201	SB00508627BAA	14050001	Alluvial, flood plain	18.0	1976-82	
37	402205107013201	SB00508627BAB1	14050001	Valley-fill deposits	-------		1975
38	402208106493501	SB00508429AAA1	14050001	Alluvial, flood plain	14.0	1973-82	
39	402209107023101	SB00508621CDD	14050001	Alluvial, flood plain	282.0	1976-82	
40	402212107011801	SB00508622DCC1	14050001	Valley-fill deposits	-------		1975
41	402223107533601	SB00509424ABC1	14050002	Mesaverde Group	1600.0	1976-82	
42	402231107111602	SB00508719ABA1	14050001	Mesaverde Group	-------		1980-82
43	402231107111637	SB00508719DBA6	14050001	Mesaverde Group	151.0	1980-82	
44	402231107111647	SB00508718CAC2	14050001	Mesaverde Group	29.4	1980-82	
45	402236107025301	SB00508621BCC	14050001	Mesaverde Group	198.0	1976-82	
46	402239107040301	SB00508620BCB	14050001	Mesaverde Group	30.0	1976-77	
47	402257107015301	SB00508621AAA	14050001	Mesaverde Group	207.0	1976-82	
48	402327106590001	SB00508613ACC	14050001	Mesaverde Group	237.0	1975-77	
49	402346106590001	SB00508613ABB	14050001	Alluvial, flood plain	100.0	1975-82	
50	402356107171701	SB00508808CDC	14050001	Alluvial, flood plain	-------	1976-82	
51	402600107160001	SB00608833DBB	14050001	Alluvial, flood plain	205.0	1977-82	
52	402627107115900	SB00608731BBB	14050001	Lewis Shale	-------		1975
53	402639106493601	SB00608429DDD	14050001	Alluvial, flood plain	25.0	1973-82	
54	402643107153301	SB00608828DAD1	14050001	Lewis Shale	-------		1975
55	402812107271401	SB00609014DCD1	14050001	Lewis Shale	-------		1975
56	402814107490001	SB00609315DBB	14050002	Alluvial, flood plain	425.0	1982	
57	402838108131001	SB00609618BAA1	14050002	Browns Park Formation	332.0	1974-78	
58	402852107125801	SB00608814ADA1	14050001	Lewis Shale	-------		1975
59	402857107385101	SB00609118BAD1	14050001	Lewis Shale	-------		1975
60	402914107532801	SB00609112CCD	14050002	Browns Park Formation	265.0	1974-82	
61	402922107042301	SB00608607DBD2	14050001	Valley-fill deposits	30.0	1976-82	
62	403001107124401	SB00608801CDC1	14050001	Alluvial, flood plain	14.0	1973-82	
63	403012106542201	SB00608503CAD1	14050001	Valley-fill deposits	-------		1975
64	403017106523701	SB00608501CBC1	14050001	Valley-fill deposits	-------		1975
65	403024108023102	SB00609503AAB2	14050002	Browns Park Formation	68.0	1976-82	
66	403025106575201	SB00608506CAA1	14050001	Valley-fill deposits	-------		1975
67	403030106513801	SB00608406BCB1	14050001	Browns Park Formation	980.0	1974-82	
68	403032107115701	SB00608801ADC1	14050001	Valley-fill deposits	-------		1975
69	403040107420801	SB00709234DBD	14050002	Browns Park Formation	190.0	1974-78	
70	403055107165001	SB00708832DDC	14050001	Lewis Shale	55.0	1973-82	
71	403114107234901	SB00708932ACD1	14050001	Alluvial, flood plain	15.0	1973-82	
72	403129106570801	SB00708532BCB1	14050001	Mancos Shale	-------		1975
73	403132107152501	SB00708827CBC1	14050001	Lewis Shale	-------		1975
74	403200107152501	SB00708827CBC2	14050001	Mesaverde Group	75.0	1974-82	
75	403258106531300	SB00708523DBB	14050001	Mancos Shale	-------		1975

Map No. for report	Site identi- fication No.	Local well No.	Hydrologic unit	Geologic unit	Depth of well	Period of record	
						Water levels	Water quality
76	403359107572101	SB00709409CDC	14050002	Browns Park Formation	200.0	1976-82	
77	403516107042501	SB00708606DCD1	14050001	Mancos Shale	-------		1975, 1978
78	403534107281700	SB00709003DAB	14050001	Fort Union Formation	-------		1975
79	403542106554300	SB00708504BDD1	14050001	Alluvial, flood plain	7.0	1973-82	
80	403635107533201	SB00809425DCC1	14050002	Mesaverde Group	600.0	-------	
81	403646107223700	SB00808933ABD	14050001	Fort Union Formation	-------		1975
82	403654107513401	SB00809329CAA1	14050002	Mesaverde Group	655.0	1978-82	
83	403921107003101	SB00808614BBC1	14050001	Browns Park Formation	510.0	1973-82	
84	403949107235800	SB00808908DBB	14050001	Fort Union Formation	-------		1975
85	404815106572001	SB01008530AAA1	14050001	Browns Park Formation	110.0	1973-82	
86	394153108052400	SC00409518DDA	14050006	Green River Formation	937.00		1973
87	394444108255400	SC00309831ACCD	14050006	Green River Formation	2389.00		1973
88	394540108191201	SC00309730ACC1	14050006	Green River Formation	655.00		1975
89	394540108191202	SC00309730ACC2	14050006	Uinta Formation	655.0	1975-82	
90	394540108191203	SC00309730ACC3	14050006	Green River Formation	1040.0	1975-82	
91	394559108114201	SC00309629BAB	14050006	Uinta Formation	1086.0	1973-82	
92	394747108110901	SC00309617AAB	14050006	Green River Formation	1158.0	1973-82	
93	394859108135100	SC00309701CADA	14050006	Uinta Formation	-------		1977
94	395028108192700	SC00209730DCCB	14050006	Alluvial, flood plain	-------		1973
95	395105108185400	SC00209730AADD	14050006	Alluvial, flood plain	-------		1973
96	395130108184000	SC00209720CCAB	14050006	Alluvial, flood plain	-------		1973
97	395131108183800	SC00209720CBDD	14050006	Alluvial, flood plain	-------		1973
98	395136108183000	SC00209720CACA	14050006	Alluvial, flood plain	-------		1973
99	395136108210000	SC00209824CBB2	14050006	Green River Formation	640.0	1976-82	1975
100	395136108210003	SC00209824CBB3	14050006	Green River Formation	1160.0	1976-82	
101	395155108123102	SC00209619ACB2	14050006	Green River Formation	853.0	1975-80	
102	395310108050400	SC00209508CCA1	14050005	Green River Formation	1182.00		1975
103	395310108050401	SC00209508CCA2	14050005	Green River Formation	1575.00		1975
104	395327108232000	SC00209809DACC	14050005	Alluvial, flood plain	-------		1973
105	395439108223302	SC00209830DBA2	14050006	Green River Formation	1715.00		1975, 1979
106	395447108192100	SC00109731DCC	14050006	Uinta Formation	-------		1975
107	395515108130101	SC00109631CBB1	14050006	Green River Formation	2800.00		1975
108	395515108130102	SC00109631CBB2	14050006	Uinta Formation	895.0	1976-82	
109	395549108060900	SC00109531BBAB	14050006	Green River Formation	790.00		1976
110	395630108170601	SC00109728ABB2	14050006	Valley-fill deposits	42.0	1982	
111	395703107580101	SC00109420DBD1	14050005	Mesaverde Group	160.0	1981-82	
112	395712108243402	SC00109820AAC2	14050006	Green River Formation	1080.0	1975-82	
113	395712108243403	SC00109820AAC3	14050006	Green River Formation	1485.0	1975-82	1975
114	395755108211400	SC00109814ADC1	14050006	Green River Formation	1260.00		1975
115	395808107482601	SC00109314CBB1	14050005	Alluvial, flood plain	45.0	1982	
116	395931107364301	SC00109104CDD1	14050005	Valley-fill deposits	120.0	1982	
117	395935108211600	SC00109802DBAA	14050005	Alluvial, flood plain	-------		1973
118	400015107493201	SC00109303BBB1	14050005	Valley-fill deposits	121.0	1981	
119	400041107253301	SB00108931CBB1	14050005	Pennsylvanian System	135.0	1982	
120	400042107484901	SB00109334CAB1	14050005	Frontier Formation	80.0	1982	
121	400045108131401	SB00109736ADCC	14050005	Green River Formation	2400.0	1976-82	
122	400119108023601	SB00109527CCA1	14050005	Valley-fill deposits	76.0	1982	
123	400137107562001	SB00109428ACD1	14050005	Mesaverde Group	100.0	1982	
124	400150107482601	SB00109327ABD1	14050005	Frontier Formation	35.7	1982	
125	400207107502700	SB00109320DDD	14050005	Valley-fill deposits	41.0	1973-82	
126	400208108153901	SB00109722DCA1	14050006	Alluvial, flood plain	115.0	1982	
127	400209107502601	SB00109320DDA	14050005	Browns Park Formation	148.0	1973-82	
128	400218108170600	SB00109721CAD1	14050006	Uinta Formation	1060.0	1976-82	
129	400218108170603	SB00109721CAD3	14050006	Uinta Formation	1540.0	1976-82	
130	400221107552201	SB00109420DAC1	14050005	Mesaverde Group	-------		1975
131	400228108245402	SB00109820DBB2	14050006	Uinta Formation	1122.0	1976-82	
132	400228108245403	SB00109820DBB3	14050006	Green River Formation	1510.0	1976-82	
133	400231108081102	SB00109623CDC2	14050005	Alluvial, flood plain	38.0	1982	
134	400242107280101	SB00109015DDA1	14050005	Permian-Pennsylvanian System	94.0	1982	
135	400246108200801	SB00109824ABA	14050006	Valley-fill deposits	82.0	1982	
136	400427107424901	SB00109209BAD1	14050005	Mesaverde Group	-------		1975
137	400508108202000	SB00109801ACCB	14050005	Alluvial, flood plain	-------		1973
138	400524108463001	SB00110106BAC1	14050007	Valley-fill deposits	30.0	1982	
139	400605108430301	SB00210134BDA1	14050007	Valley-fill deposits	12.6	1982	
140	400723107504901	SB00209320DCB1	14050005	Mesaverde Group	-------		1975
141	395801109245801	(D-10-22)10ADA1	14050007	---------------------------	-------		1976-82