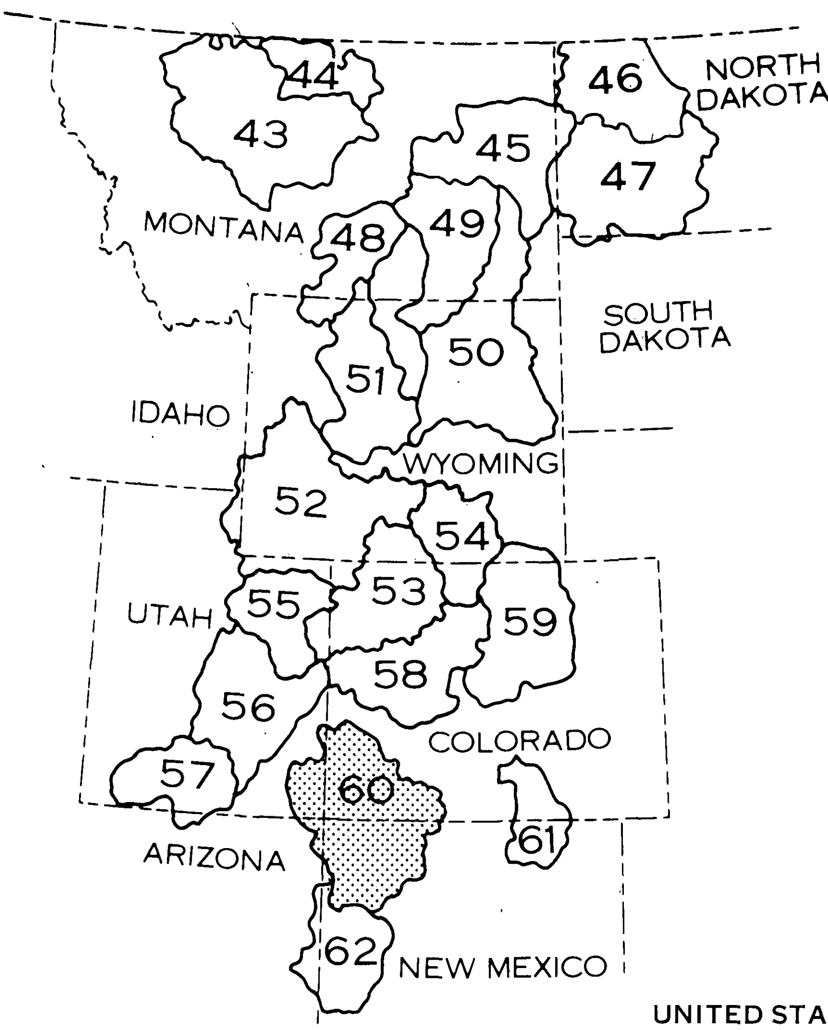
HYDROLOGY OF AREA 60, NORTHERN GREAT PLAINS, AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO, COLORADO, UTAH, AND ARIZONA



- DOLORES RIVER
- SAN MIGUEL RIVER
- SAN JUAN RIVER
- ANIMAS RIVER
- CHACO RIVER
- LA PLATA RIVER

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS
OPEN FILE REPORT 83-203

HYDROLOGY OF AREA 60, NORTHERN GREAT PLAINS, AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO, COLORADO, UTAH, AND ARIZONA

BY
F. EILEEN ROYBAL AND OTHERS

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SALT LAKE CITY, UTAH
SEPTEMBER, 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *SECRETARY*

GEOLOGICAL SURVEY

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CONTENTS

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
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acre-feet per square mile (acre-ft/mi^2)	4.761	cubic meters per hectare (m^3/hectare)
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]
gallons per minute (gal/min)	0.06309	liters per second (L/s)

$$°C = (°F - 32)/1.8$$

$$°F = (1.8 \times °C) + 32$$

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.

HYDROLOGY OF AREA 60, NORTHERN GREAT PLAINS, AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO, COLORADO, UTAH, AND ARIZONA

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Abstract

An expansion of coal-mining activity is planned for Coal Area 60, which is one of 20 hydrologic reporting areas in the Northern Great Plains and Rocky Mountain Coal Provinces. The division of these coal areas is based on drainage basins, coal resources, and geology. Hydrologic drainage basins or parts of basins are combined to form each area. Coal Area 60 includes approximately 20,000 square miles and is located at the southern end of the Rocky Mountain Coal Province in northwestern New Mexico, southwestern Colorado, southeastern Utah, and northeastern Arizona. Area 60 includes parts of the Dolores and San Juan River basins.

Coal mining can cause detrimental effects on the hydrologic system. The hydrologic changes that may occur with surface coal mining are land erosion, increased sedimentation in streams, destruction of stream channels, decline in ground-water levels, and changes in water quality.

Land in Area 60 is owned primarily by the Federal Government in Colorado and Utah and by the Navajo Indians in New Mexico and Arizona. The altitude ranges from approximately 4,300 feet to more than 14,000 feet, and average annual precipitation ranges from about 8 inches at lower altitudes to about 55 inches in the high mountains. The driest month is June and the wettest month is August. Average monthly temperatures are least during January and greatest during July.

Rocks that crop out range in age from Precambrian to Quaternary but are predominantly late Paleozoic and Mesozoic. Major geologic structures in Area 60 are the San Juan and Paradox Basins, the Four Corners platform, and the San Juan uplift.

Area 60 is divided into the San Juan Basin and the Dakota Sandstone coal regions. The greatest coal mining activity presently is in the San Juan Basin, where the primary coal-bearing units are the Mesaverde Group and Fruitland Formation.

Most streams draining the southern part of the area are ephemeral and flow only after summer thunderstorms. Perennial streams draining the northern part of the area exhibit greatest streamflows during the months of April, May, and June as a result of snowmelt in the mountainous areas.

Water-quality characteristics are based on data from 67 surface-water stations and 49 ground-water stations. Dissolved-solids concentrations in perennial rivers such as the San Juan River commonly are less than 500 milligrams per liter. Dissolved-solids concentrations of 2,000 milligrams per liter or more are present in the flows of ephemeral channels such as the Chaco River. Calcium and bicarbonate ions are the predominant ions in headwater flows, whereas sodium and sulfate ions become increasingly more dominant in the downstream direction. Concentrations of dissolved iron, manganese, and other trace elements in surface water generally are less than the limits set in drinking-water and mining regulations; however, the total recoverable concentrations from water-sediment mixtures may exceed these limits. Suspended-sediment concentrations exceeding 10,000 milligrams per liter are present in the flow of arroyos that drain areas with sparse vegetation.

The chemical-quality characteristics of ground water are similar to those of surface water except that the dissolved-solids concentration in ground water from all formations, especially shale deposits, may exceed 3,000 milligrams per liter. Sulfate concentrations are small in the ground water associated with coal deposits. Large concentrations of fluoride are present in ground water from all formations; large concentrations of lead, selenium and nitrate are associated with certain formations. Large alkalinity concentrations are found in the surface waters and ground waters of Area 60.

Report Summarizes Available Hydrology Data

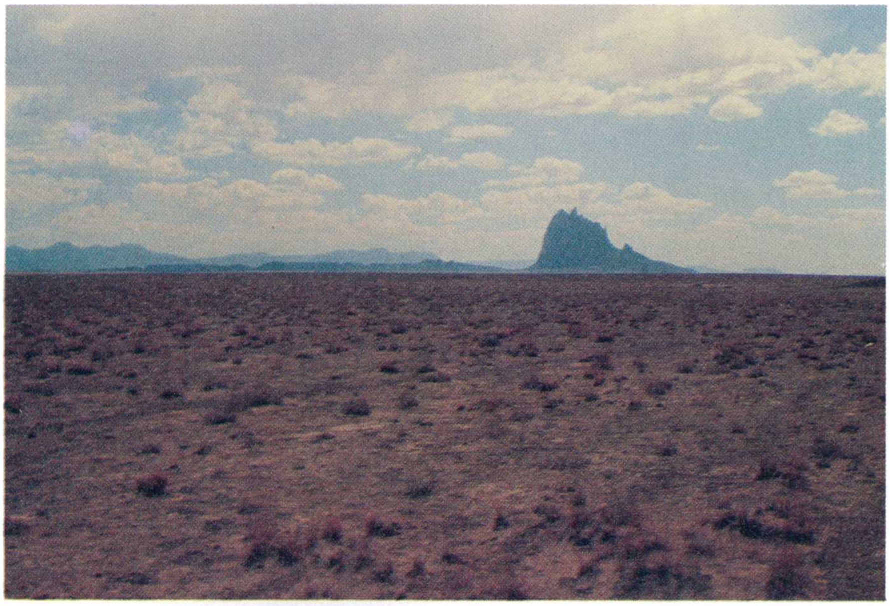
Existing hydrologic conditions and sources of information are identified to aid leasing decisions, and preparation and appraisal of environmental impact studies and mine-permit applications.

Hydrologic information and analysis are needed 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 60 in New Mexico, Colorado, Utah, and Arizona. This report is one of a series that describes coal provinces nationwide. Selected photographs of Area 60 are shown in figure 1.1-1.

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.

San Juan Mountains in Colorado.



Landscape - Shiprock in background, San Juan County, New Mexico.

Figure 1.1-1 Area 60.

Area 60 Includes Parts of New Mexico, Colorado, Utah, and Arizona

This report describes the general hydrology and water resources of Area 60 in the southern end of the Rocky Mountain Coal Province.

The Northern Great Plains and the Rocky Mountain Coal Provinces are divided into 20 hydrologic reporting areas. The division is based on hydrologic factors, location, size, and mining activity. Hydrologic drainage basins or parts of basins are combined to form each area. Area 60 is located at the southern end of the Rocky Mountain Coal Province, in northwestern New Mexico, southwestern Colorado, southeastern Utah, and northeastern Arizona (fig. 1.2-1).

Area 60 encompasses approximately 20,000 square miles and includes all or part of McKinley, Rio Arriba, Sandoval, and San Juan Counties, New Mexico; Archuleta, Dolores, Hinsdale, La Plata, Mineral, Montezuma, Montrose, San Juan, San Miguel, Conejos, Mesa, Ouray, and Rio Grande Counties, Colorado; San Juan County, Utah; and Apache County, Arizona.

The two major drainages in Area 60 are parts the San Juan River and Dolores River basins. The headwaters of the San Juan River are near the Continental Divide northeast of Pagosa Springs, Colorado. The San Juan River flows westward through the Four Corners area and is tributary to the Colorado River, which is west of the study area.

The Dolores River and its principal tributary, the San Miguel River, originate in the high slopes of the San Juan Mountains near Telluride, Colorado. The Dolores River flows southwestward through Dolores, Colorado, and then northwestward. The San Miguel River flows northwestward to where it joins the Dolores River near Uravan, Colorado.

Area 60 is sparsely populated; most of the population is concentrated along the San Juan River and its tributaries. The population of selected towns in Area 60 is shown in table 1.2-1.

Table 1.2-1. Population of selected towns.

New Mexico		Colorado		Utah	
Aztec	5,512	Bayfield	724	Blanding	3,118
Bloomfield	4,881	Cortez	7,095	Monticello	1,929
Crownpoint	1,134	Dolores	802		
Dulce*	1,648	Durango	11,426		
Farmington	31,222	Pagosa Springs	1,331		
Shiprock*	7,237	Telluride	1,047		

SOURCE: U.S. Department of Commerce, Bureau of the Census, 1980 Census of Population

*Census-Designated Place - population not within incorporated area.

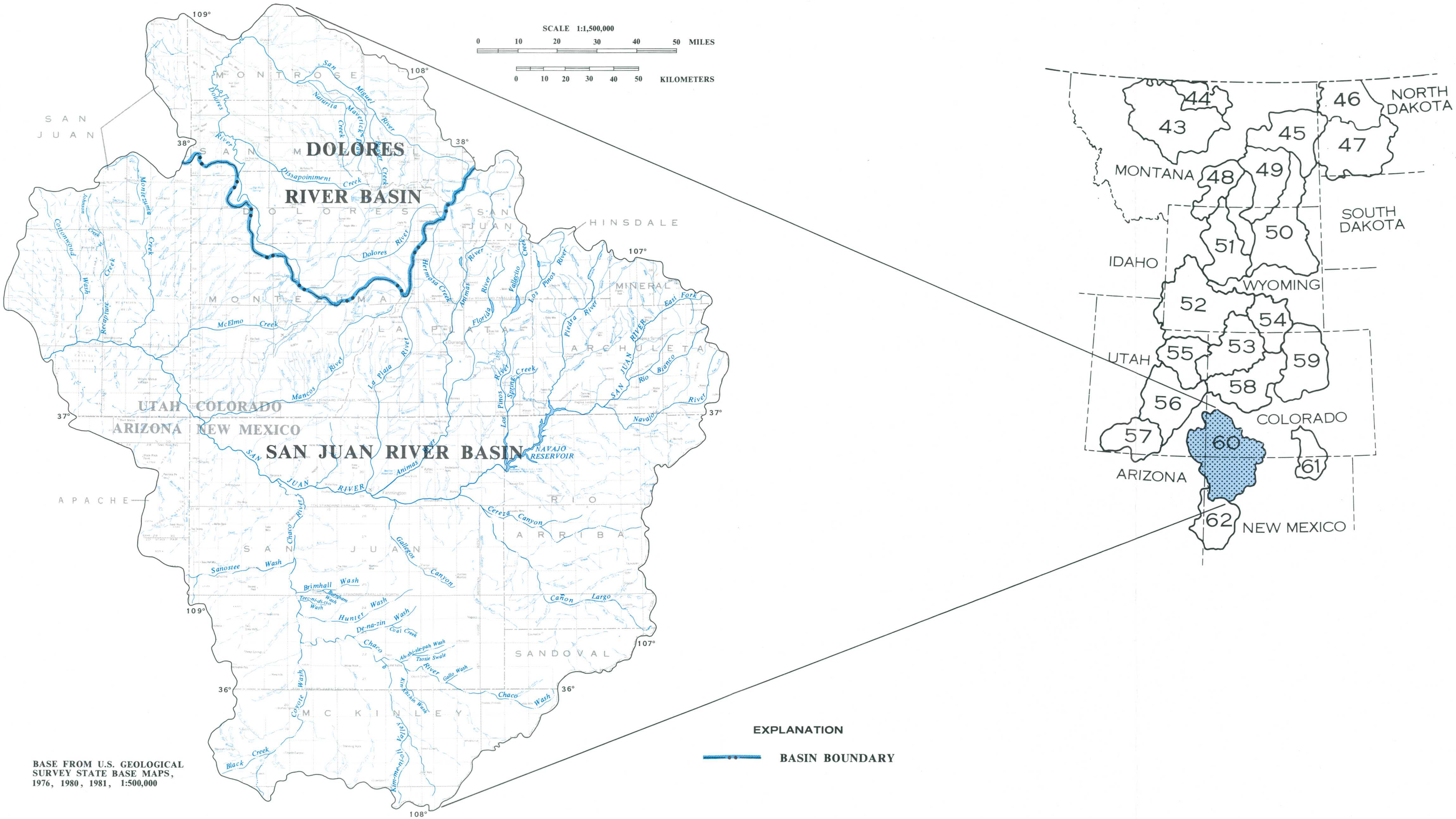


Figure 1.2-1 Study Area 60 in New Mexico, Colorado, Utah, and Arizona.

Hydrologic Environment Can Be Adversely Altered by Surface Coal Mining

Erosion, sedimentation, destruction of stream channels, decline in water level, and degradation of water quality may be the major problems associated with surface coal mining.

Surface mining drastically alters, at least temporarily, the environment of previously undisturbed lands. If the areas are not reclaimed, there can be long-term detrimental environmental consequences. Vegetation removal provides the potential for increased erosion and sedimentation. In the arid part of Area 60, where precipitation is less than 10 inches, water supplies for irrigation of reclaimed land may be difficult to obtain. The destruction of stream channels due to the excavation of coal will cause changes in runoff characteristics. Surface-water resources are limited and fully appropriated in this arid to semiarid region. Water supplies for future energy development in the San Juan Basin must be obtained by either purchase of surface water or by development of ground-water sources (Stone and others, 1983).

Declines in ground-water levels can take place in and near surface-mining areas when excavation extends below the water table. These declines can disrupt the hydrologic gradient and cause wells and springs to go dry (fig. 1.3-1). If the spoil piles are improperly treated, there could be ground-water and surface-water contamination (fig. 1.3-2) (Rickert and others, 1979, p. 38-39).

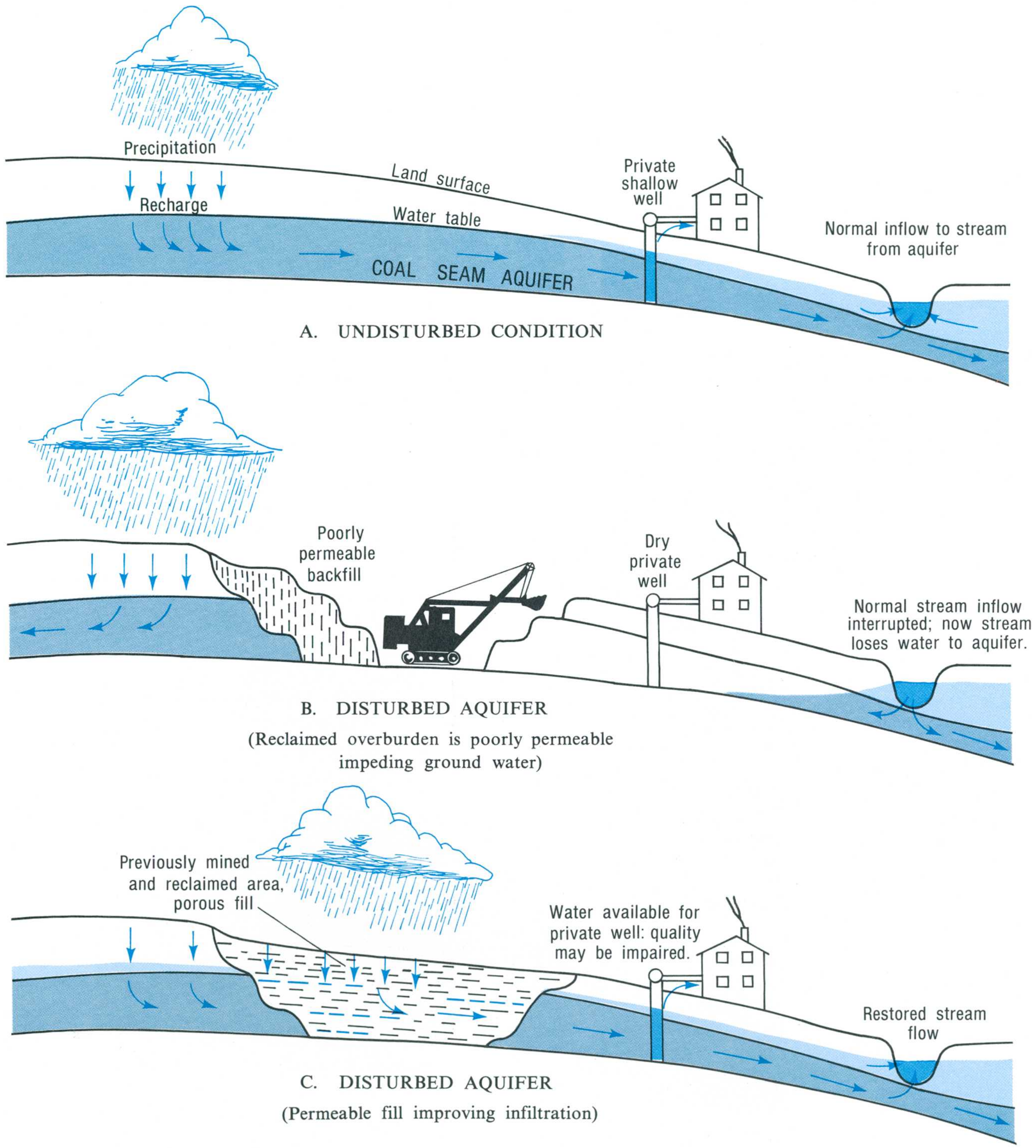
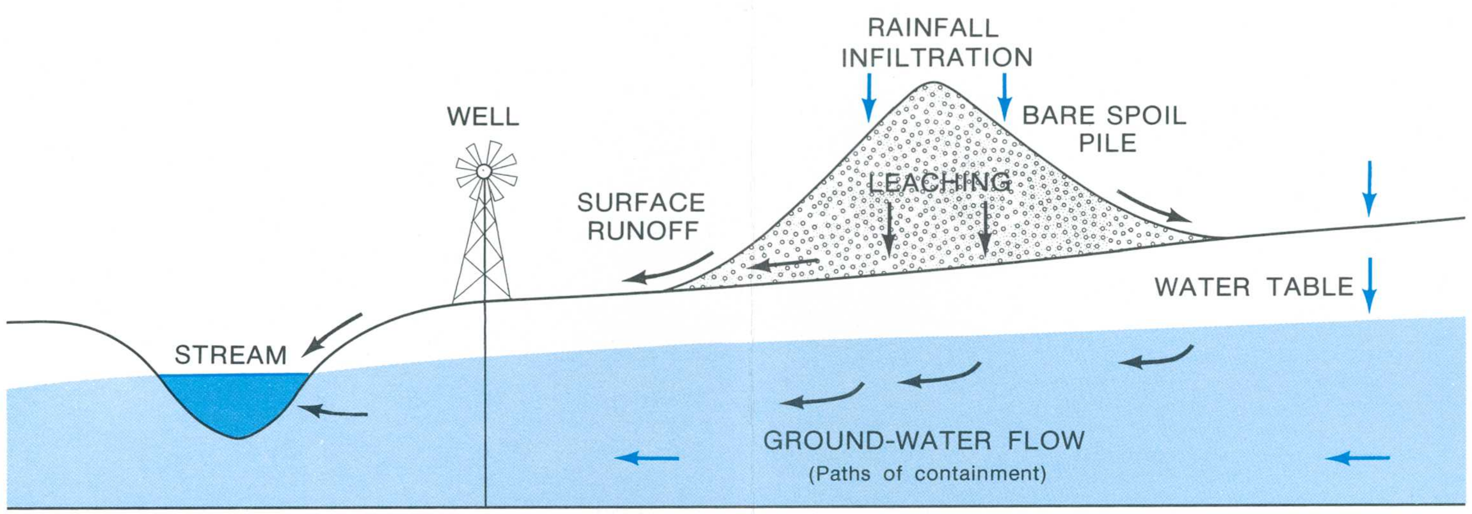


Figure 1.3-1 Possible impacts of mining aquifers.



From SYNTHETIC FUELS DEVELOPMENT by U.S. Dept. of Int. and U.S.G.S.

Figure 1.3-2 Dissolved substances leaching from soils.

Federal and Indian Lands Comprise Most of Area 60

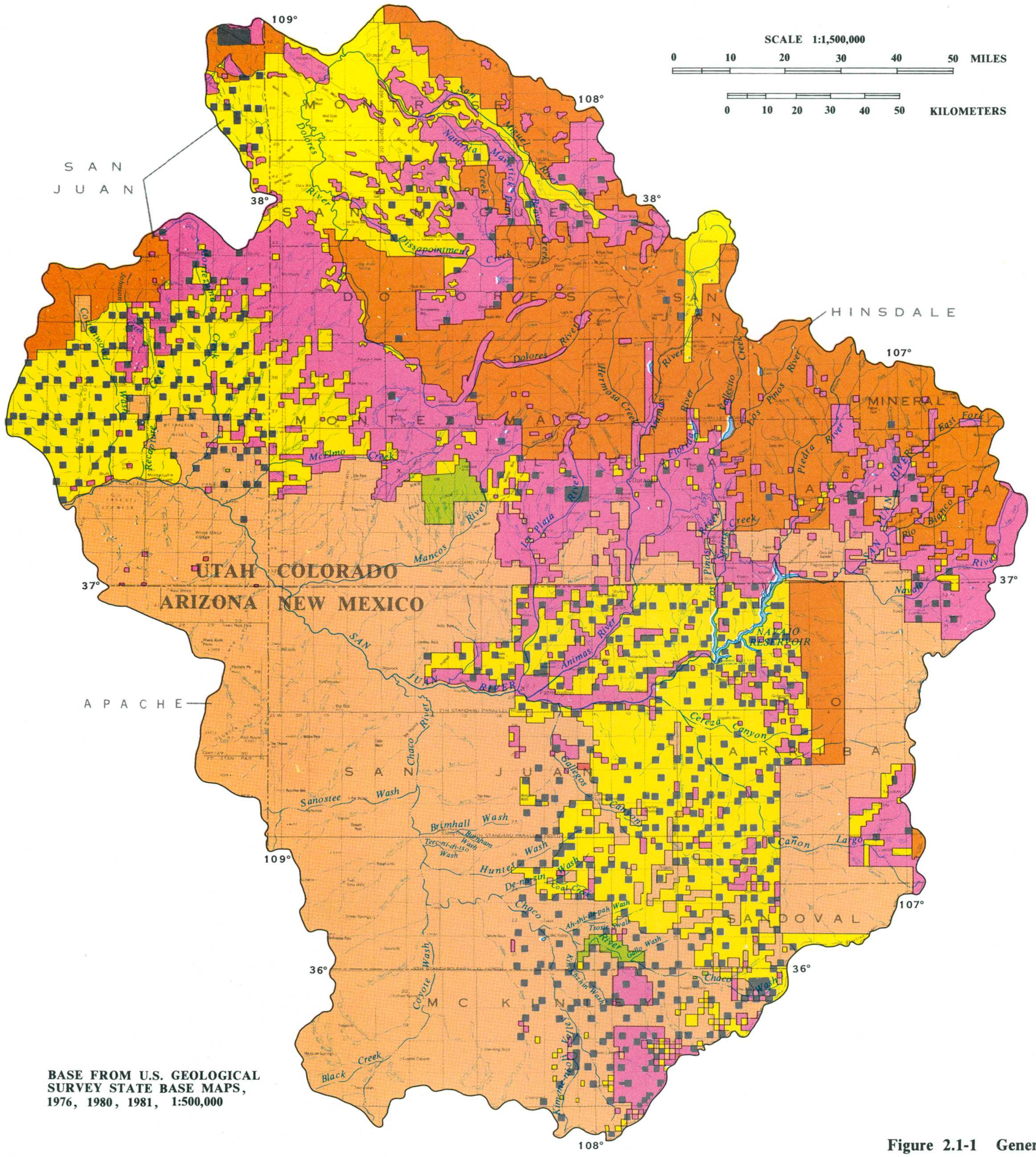
The majority of the land in Colorado and Utah is owned by the Federal Government; in New Mexico and Arizona, most of the land is owned by Indian tribes.

Federal land in Area 60 is administered by the U.S. Forest Service, the U.S. Bureau of Land Management, and the National Park Service. Parts of five National Forests are included in the area; these are: the San Juan and Uncompahgre in Colorado, the Carson and Santa Fe in New Mexico, and the Manti-La Sal in Utah and Colorado (fig. 2.1-1). The Bureau of Land Management is responsible for Federal land in the "checkerboard" areas in New Mexico and Utah, as well as large unified tracts in Colorado. National monuments administered by the Park Service are Chaco Canyon (fig. 2.1-2) and Aztec Ruins in New Mexico, Mesa Verde in Colorado, and parts of Hovenweep in Utah and Colorado.

There are four Indian reservations in Area 60: the Navajo Reservation in New Mexico, Utah, and Arizona; the Jicarilla Apache Reservation in New Mexico; the Southern Ute Reservation in Colorado; and the Ute Mountain Reservation in Colorado and New Mexico. The Indian lands shown in figure 2.1-1 include trust, private, and Federal lands, but there is no separation into these categories on the map.

The remainder of the land in the area is either privately or State owned. The majority of private land holdings in Area 60 are in Colorado. State-owned lands are scattered throughout the area except in Arizona.

Figure 2.1-2 Federal land at Chaco Canyon National Monument, New Mexico.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

EXPLANATION

LAND OWNERSHIP STATUS

- LANDS ADMINISTERED BY THE U.S. BUREAU OF LAND MANAGEMENT: WITHDRAWALS AND RESERVATIONS PRIMARILY UNDER BUREAU OF LAND MANAGEMENT JURISDICTION AND VACANT PUBLIC LANDS.
- PRIVATELY OWNED LAND, PATENTED, RAILROAD, MINING AND SMALL HOLDING CLAIMS, CORPORATIONS, AND CITIES.
- NATIONAL FOREST LANDS, ADMINISTERED BY THE U.S. FOREST SERVICE.
- STATE OWNED LANDS, INCLUDING THOSE UNDER CONTROL AND TITLE OF STATE FISH AND GAME DEPARTMENTS.
- INDIAN RESERVATIONS AND LANDS.
- NATIONAL PARKS AND MONUMENTS.

Generalized land ownership modified from Colorado Water Conservation Board and U.S. Department of Agriculture (1972, 1974)

Figure 2.1-1 Generalized land ownership.

Most of the Area Lies Within the Colorado Plateaus Physiographic Province

Area 60 is an area of diverse land forms, including mesas, buttes, plateaus, plains, valleys, gently sloping ridges, hogback ridges, high dome mountains, badlands, and canyons.

Most of Area 60 lies within the Colorado Plateaus physiographic province, which is divided into the Navajo and Canyon Lands sections (fig. 2.2-1). The largest part of the area lies within the Navajo section (fig. 2.2-2), an area characterized by mesas, buttes, cuesta ridges, and rock terraces separated by broad, open valleys and occasional canyons, badlands, and hogbacks. The Canyon Lands section of the Colorado Plateaus province is located in the northwestern part of the area. The Southern Rocky Mountains physiographic province, which includes the San Juan Mountains, lies along the northeastern margin of the area. Altitudes range from about 4,300 feet at Bluff, Utah, on the downstream reach of the San Juan River to more than 14,000 feet in the San Juan Mountains north of Durango, Colorado.

The major physiographic features in the area are the Uncompahgre Plateau and La Sal Mountains on the north, the Carrizo, Lukachukai, and Chuska Mountains on the west, the Zuni and San Mateo Mountains on the south, and the San Juan and San Pedro Mountains on the east. The area is drained by the San Juan and Dolores Rivers and their tributaries.

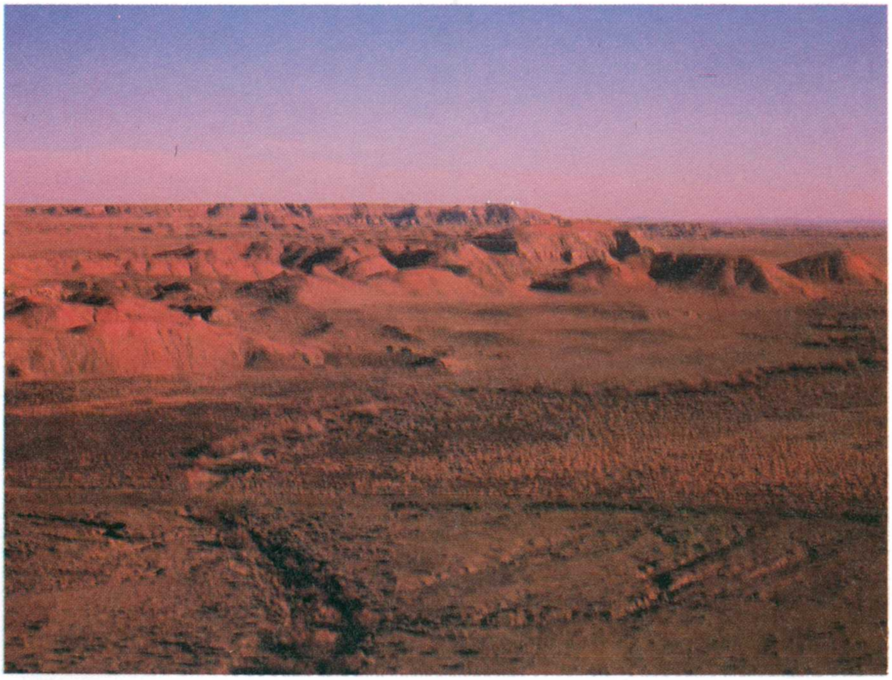
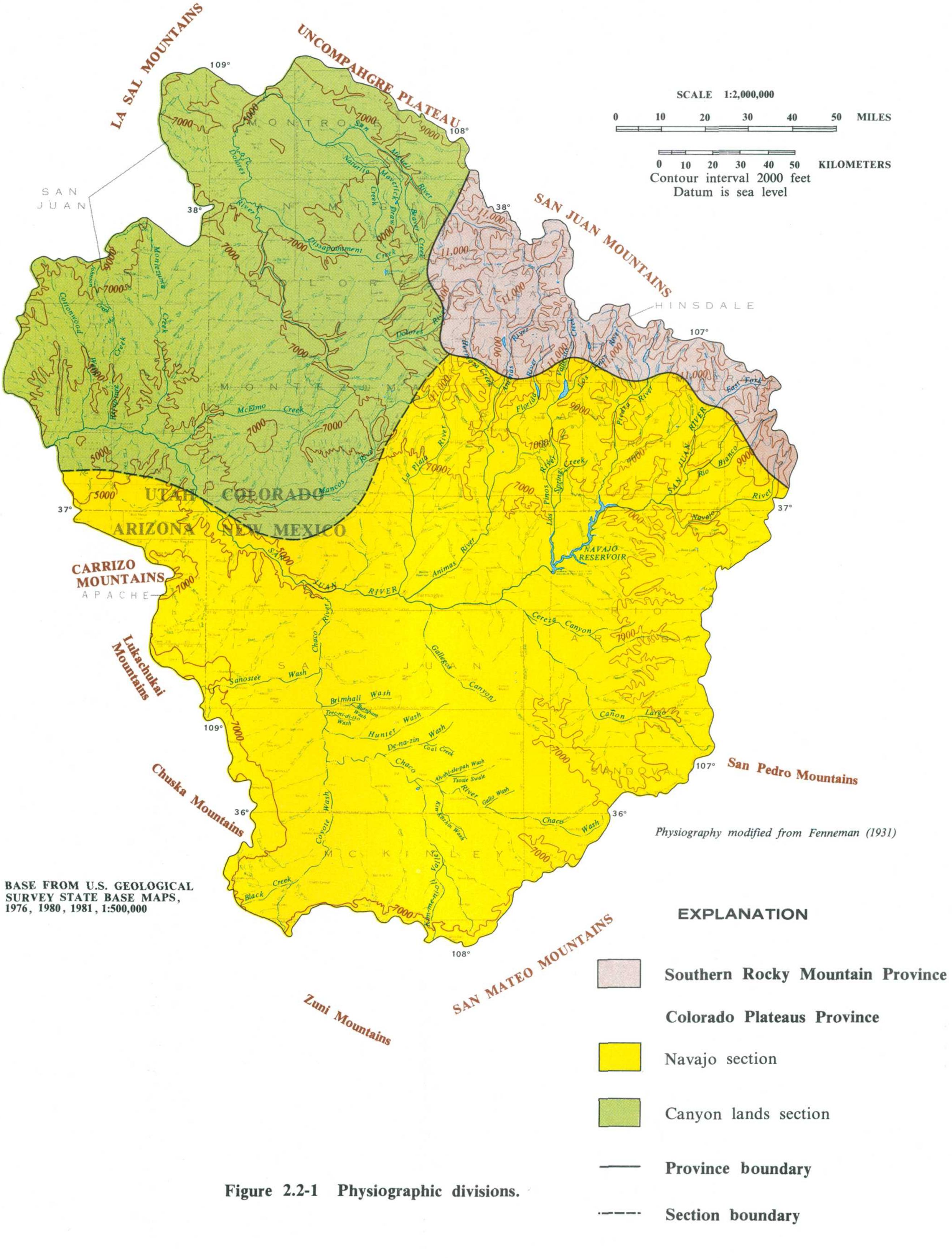


Figure 2.2-2 Typical terrain of Navajo Section in San Juan County, New Mexico.



EXPLANATION

- Southern Rocky Mountain Province
- **Colorado Plateaus Province**
- Navajo section
- Canyon lands section
- Province boundary
- Section boundary

Figure 2.2-1 Physiographic divisions.

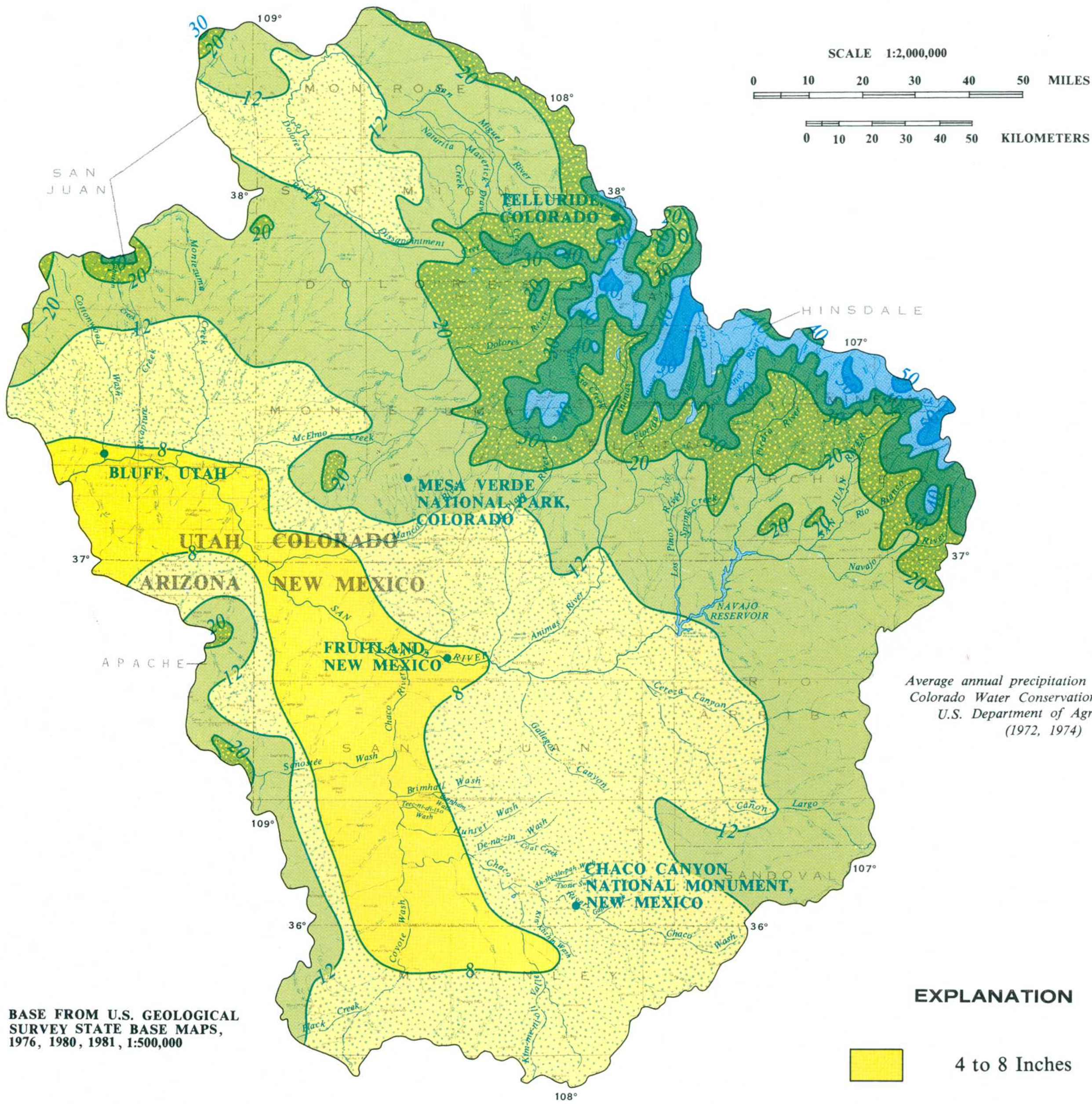
The Climate of Area 60 Generally is Semiarid to Arid

Average annual precipitation varies from less than 8 inches in the desert valleys to more than 50 inches in the mountains.

Most of the rainfall occurs in late summer as intense thunderstorms. The driest month is June and the wettest month is August. In the high mountainous areas, precipitation commonly ranges from 30 to 50 inches per year. The approximate areal distribution of average annual precipitation is shown in figure 2.3-1.

The large variation in precipitation and temperature is controlled by the altitude. Areas at high altitudes have greater precipitation and lower temperatures than areas at lower altitudes. For example, Telluride, Colorado, at an altitude of 8,800 feet, receives an average of 23 inches of precipitation annually and has an average annual temperature of 40° Fahrenheit; Bluff, Utah, at an altitude of approximately 4,300 feet, receives an average of 7.6 inches of precipitation per year and has an average annual temperature of 55° Fahrenheit. Average monthly temperatures are least during January and greatest during July. The average monthly precipitation and temperature for selected towns are shown in figure 2.3-2.

Daily precipitation data for New Mexico, Colorado, Utah, and Arizona are published monthly by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, N.C.



Average annual precipitation modified from Colorado Water Conservation Board and U.S. Department of Agriculture (1972, 1974)

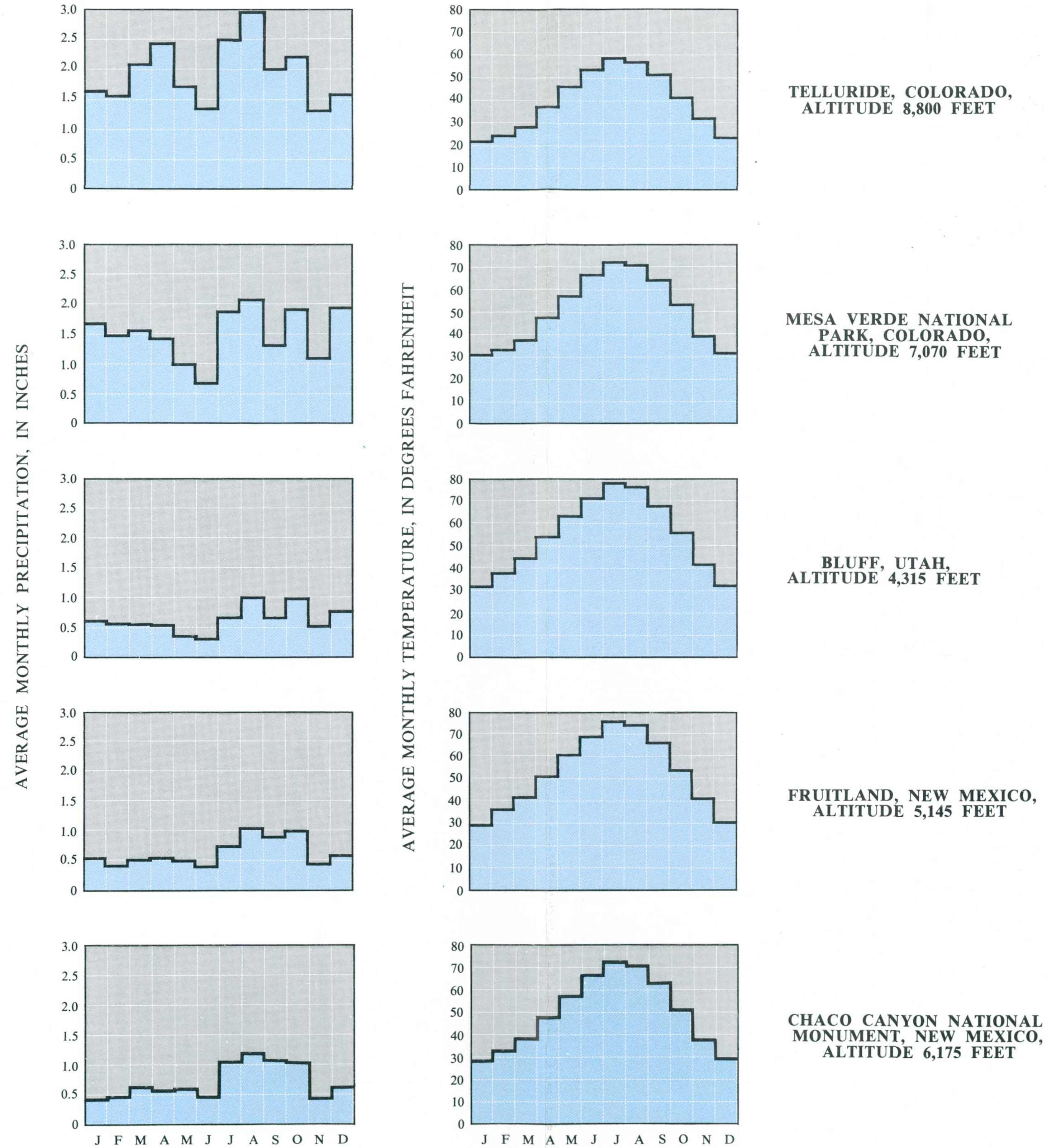
BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

EXPLANATION

- 4 to 8 Inches
- 8 to 12 Inches
- 12 to 20 Inches
- 20 to 30 Inches
- 30 to 40 Inches
- 40 to 50 Inches
- More than 50 Inches

—8— **Lines of equal precipitation in inches**
Interval, in inches, is variable.

Figure 2.3-1 Average annual precipitation.



Climatological data compiled from U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (1979, 1980a, 1980b, 1980c)

Figure 2.3-2 Selected average monthly precipitation and temperature.

Vegetation in Area is Very Diverse

The vegetation ranges from alpine plants above timberline in Colorado to southern desert shrubs and grasses at low altitude in Utah.

The wide range in altitude (and hence climatic conditions) is reflected by the diversity of vegetation present in Area 60. The types of vegetation shown in figure 2.4-1 are very generalized; several specific plant associations, which generally have an areal extent too small to show at the map scale, may be included in a general vegetation type. Although distinct vegetation boundaries are shown, such boundaries rarely exist in nature; transitions between vegetation types are gradational and include species from each type.

In Area 60, the type of vegetation present generally is dependent on the quantity of precipitation an area receives. This relation is illustrated by comparing figure 2.4-1 with figure 2.3-1 (average annual precipitation). In general, forests are present in areas that receive 20 or more inches of precipitation per year, piñon-juniper woodlands and northern desert shrubs in the areas of somewhat less precipitation, and grasslands in the areas of least precipitation.

The density of vegetative cover in Area 60 is extremely variable. Generally, forested and wooded areas have dense vegetation; the cover is less dense in the shrub and grass lands at lower altitudes. Areas with little or no vegetation (not delineated in figure 2.4-1), mainly present where there is little precipitation and rough topography, are easily eroded and contribute significant quantities of sediment to streams.

Cropland, though a land use rather than a vegetation type, is included in figure 2.4-1 because it encompasses a substantial area. Additional information about land use and extensive information about the vegetation present in Area 60 is available in the publications by the Colorado Water Conservation Board and the U.S. Department of Agriculture (1972, 1974).

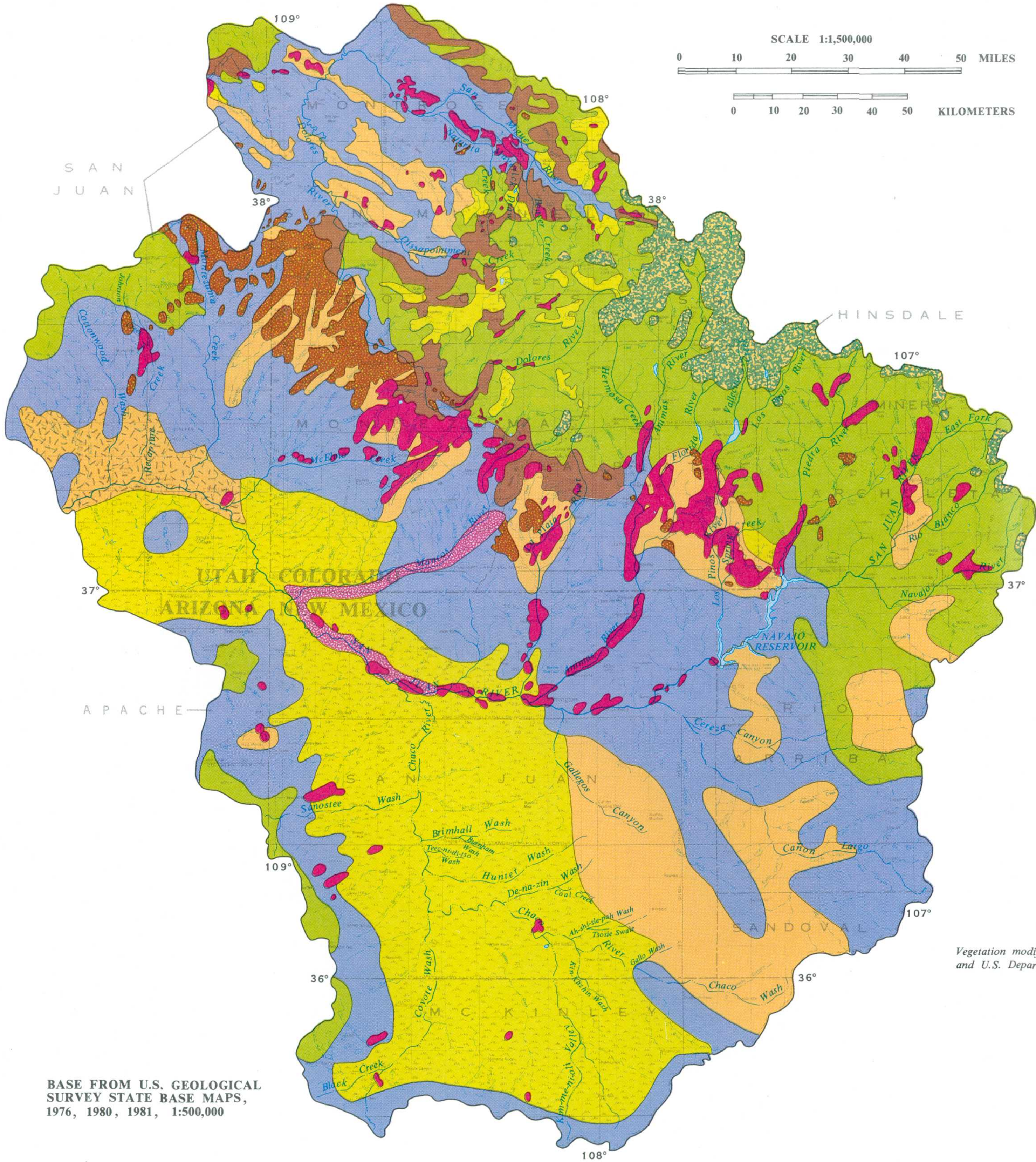


Figure 2.4-1 Vegetation.

Vegetation modified from Colorado Water Conservation Board and U.S. Department of Agriculture (1972, 1974)

EXPLANATION

VEGETATION TYPE	APPROXIMATE RANGE IN ALTITUDE, IN FEET	COMMON PLANT SPECIES
Alpine	Above 11,500	sedges, bluegrasses, bistort, willows, gentian.
Forest	6,500-11,500	Englemann spruce, fir (sp.), aspen, Ponderosa pine.
Mountain brush	6,000-9,000	oak, mountain mahogany, bitterbrush, sagebrush.
Piñon-juniper	5,500-7,500	Colorado piñon, juniper (sp.), oak, sagebrush.
Northern desert shrub	5,000-7,500	big sagebrush, rabbitbush, winterfat, snakeweed.
Southern desert shrub	Below 5,000	blackbush, creosote brush, yucca, fourwing saltbush.
Grassland	--	Blue Grama and gallenta below 6,500 feet; fescue, wheatgrass, sedges, needlegrass and squirreltail elsewhere.
Greasewood	4,500-6,000	greasewood, rabbitbush, saltgrass, shadscale.

Irrigated Cropland -- Generally hay and pasture, small areas of grain, vegetables, and fruit.

Dry Cropland -- Generally dry bean and winter wheat crops, also used for pasture.

Soils are Derived Principally from Sandstone and Shale

The principal soil groups are Torriorthents, Torrifluvents, and Cryoboralfs.

The general soil map shows eight different map units (fig. 2.5-1). In general, the soils of Area 60 are derived from sandstone and shale. Slopes are extremely variable, ranging from 0 to 80 percent. The soils are eroded easily when the vegetative cover is removed.

The soils in map unit 1 (dominantly Cryoboralf with Cryorthod or Cryochrept groups) are derived from sandstone, shale, gravelly outwash, and igneous materials. The surface soils generally are loamy, acidic, and light colored. About one-half of the soils are shallow and mainly are present on ridges and slopes. The remainder are deep, ranging from 20 to about 60 inches and extend over steep alpine slopes and moderately sloping, open parks. These soils are located within the greatest precipitation and highest altitude zones of Area 60.

The soils in map unit 2 (dominantly Argiboroll and Cryoboroll groups) are derived from sandstone, shale, gravelly and cobbly outwash, and igneous materials. These soils generally have organic-rich, loamy surface layers and subsoils in which clay has accumulated. The depth of soils generally ranges between 20 and 40 inches, but shallow soils are present on steep slopes and ridges. The soils are present on steep mountain slopes, plateaus, foothills, and benches.

The soils in map unit 3 (dominantly Haplargid group) are derived from sandstone, shale, and clayey alluvial deposits, and generally have light, loamy surface layers with little organic matter. Most of the soils are shallow and are alkaline within 24 inches of the surface. These soils are found on gently to moderately sloping uplands and valleys.

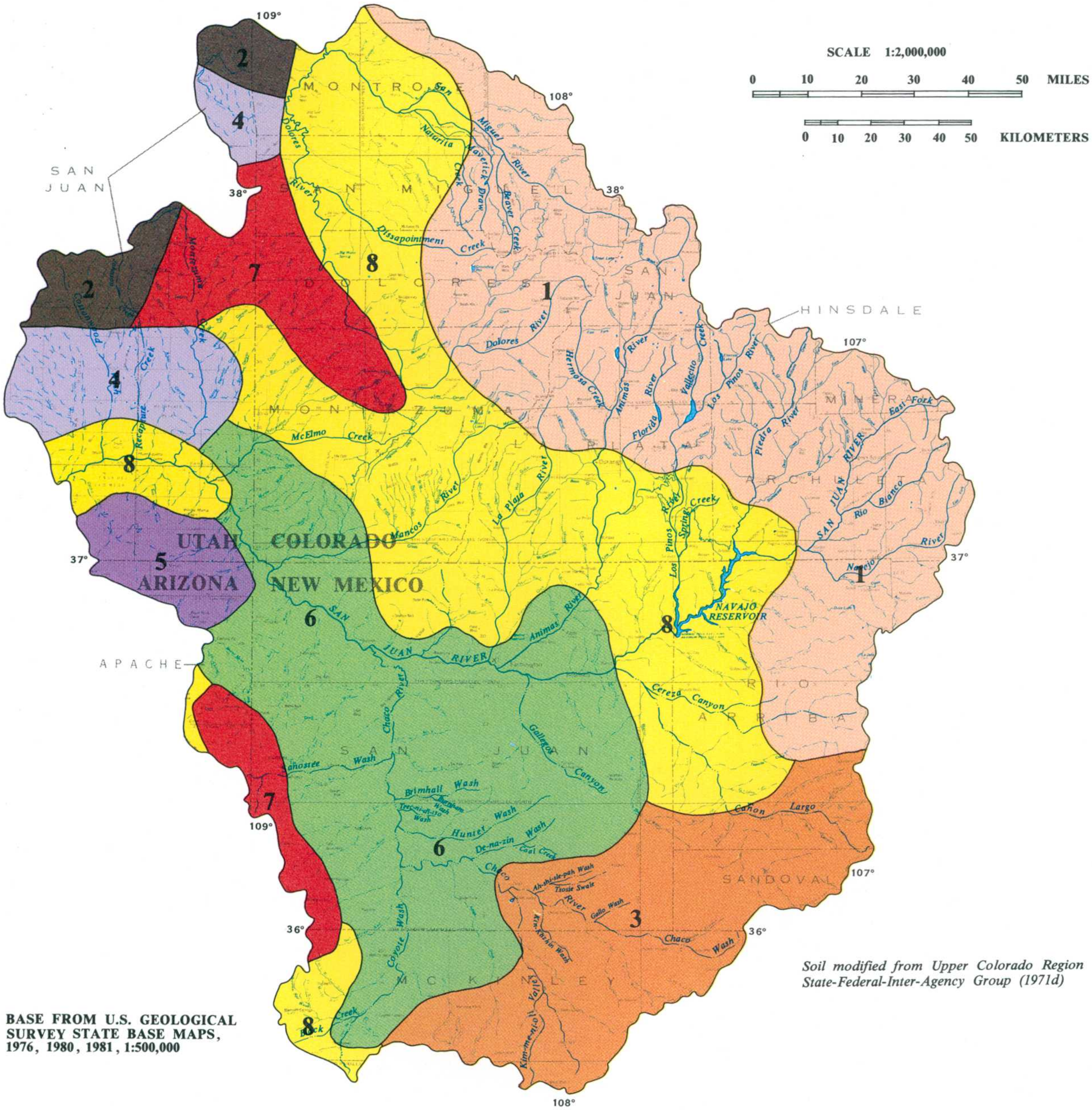
The soils in map unit 4 (dominantly Calciorthid group) are derived from wind deposits, sandstone, and shale. Soils generally have loamy surface layers with little organic matter. The depth of soil ranges from 20 to about 60 inches. The soils of this map unit are present on gently to moderately sloping plateaus and mesas.

The soils in map unit 5 (dominantly Camborthid group) are derived from wind and alluvial deposits. Most of the soils of this unit are deep and have loamy or sandy surface layers that contain little organic matter. The soils are found on plateaus and mesas bordered by cliffs and steep slopes.

The soils in map unit 6 (dominantly Torriorthent and Torrifluvent groups) are derived from sandstone, shale, siltstone, and mudstone. The majority of the soils are alkaline. The depth of soil ranges from 20 to 60 inches. These soils extend over gently sloping valley floodplains, benches, mesas, and steep foothills and are located within the least precipitation zone of Area 60.

The soils in map unit 7 (dominantly Argiustall and Haplustoll groups) are derived from sandstone, shale, and alluvial deposits. These soils generally have dark-colored, friable surface layers that are rich in organic matter. Depth of the soil ranges from 20 to more than 60 inches. The unit extends over gently to steeply sloping mesas, plateaus, and mountain slopes.

The soils in map unit 8 (dominantly Torriorthent or Ustorthent groups) are derived from sandstone and shale. This map unit contains a significant proportion of shallow soils (less than 20 inches thick). These soils are alkaline and have light-colored surface layers. The unit is present in canyonlands, mountain slopes, valleys, rock outcrops, and shale badlands.



EXPLANATION

1 — **COOL, USUALLY MOIST, LIGHT-SURFACE SOILS** -- Dominantly Cryoboralfs with Cryorthods or Cryochrepts.

2 — **COOL, USUALLY MOIST, DARK-SURFACE SOILS** -- Dominantly Argiborolls and Cryoborolls.

3 — **WARM, USUALLY DRY, LIGHT-SURFACE SOILS WITH HORIZONS OF CLAY ACCUMULATION** -- Dominantly Haplargids.

4 — **WARM, USUALLY DRY, LIGHT-SURFACE SOILS WITH HORIZONS OF CALCIUM CARBONATE OR GYPSUM ACCUMULATION** -- Dominantly Calciorthids.

5 — **WARM, USUALLY DRY, LIGHT-SURFACE SOILS WITH WEAKLY DEVELOPED HORIZONS** -- Dominantly Camborthids.

6 — **WARM, USUALLY DRY, DOMINANTLY DEEP SOILS WITHOUT DISTINCT HORIZONS** -- Dominantly Torriorthents and Torrifluvents.

7 — **WARM, INTERMITTENTLY DRY, DARK-SURFACE SOILS** -- Dominantly Argiustolls and Haplustolls.

8 — **WARM OR COOL, USUALLY DRY, DOMINANTLY SHALLOW SOILS WITHOUT DISTINCT HORIZONS** -- Dominantly Torriorthents or Ustorthents (shallow).

Figure 2.5-1 General soil map.

Precambrian Through Quaternary-Age Rocks Underlie the Area

Crystalline and sedimentary rocks that underlie Area 60 comprise a structurally complex region.

The rocks that crop out consist mostly of igneous and metamorphic rocks of Precambrian age, volcanic rocks of Tertiary age, and a thick sequence of sedimentary rocks of Paleozoic and Mesozoic age (fig. 2.6-1). The older rocks generally are exposed in the regionally uplifted areas where the younger rocks have been removed by erosion. The younger rocks generally are exposed in the relatively lower synclinal areas.

The Precambrian crystalline rocks are mostly granite with some schist and gneiss. The Paleozoic rocks consist of quartzite, shale, limestone, sandstone, conglomerate, and mudstone.

Mesozoic-age rocks mostly consist of alternating beds of sandstone, siltstone, shale, and some coal. Principal coal-bearing units in the area are associated with upper Mesozoic rocks.

Cenozoic rocks in the southern part of the area consist of shale and sandstone. In the northern part of the area, igneous flows and pyroclastic rocks predominate. The most recent Cenozoic rocks (Quaternary age; not shown on map) are represented by relatively thin fluvial and eolian sediments, landslide deposits, rock glaciers, and talus deposits.

Major positive structural areas in the San Juan and Dolores River basins are the Uncompahgre uplift, the San Juan uplift (fig. 2.6-2), the Nacimiento uplift, the Zuni uplift, the Defiance uplift, and Monument uplift. The three principal structural basins are the San Juan Basin in the southern part of the area, the Blanding Basin in the western part of the area, and the Paradox Basin in the northern part of the area. Situated between the basins is the Four Corners platform (fig. 2.6-3).

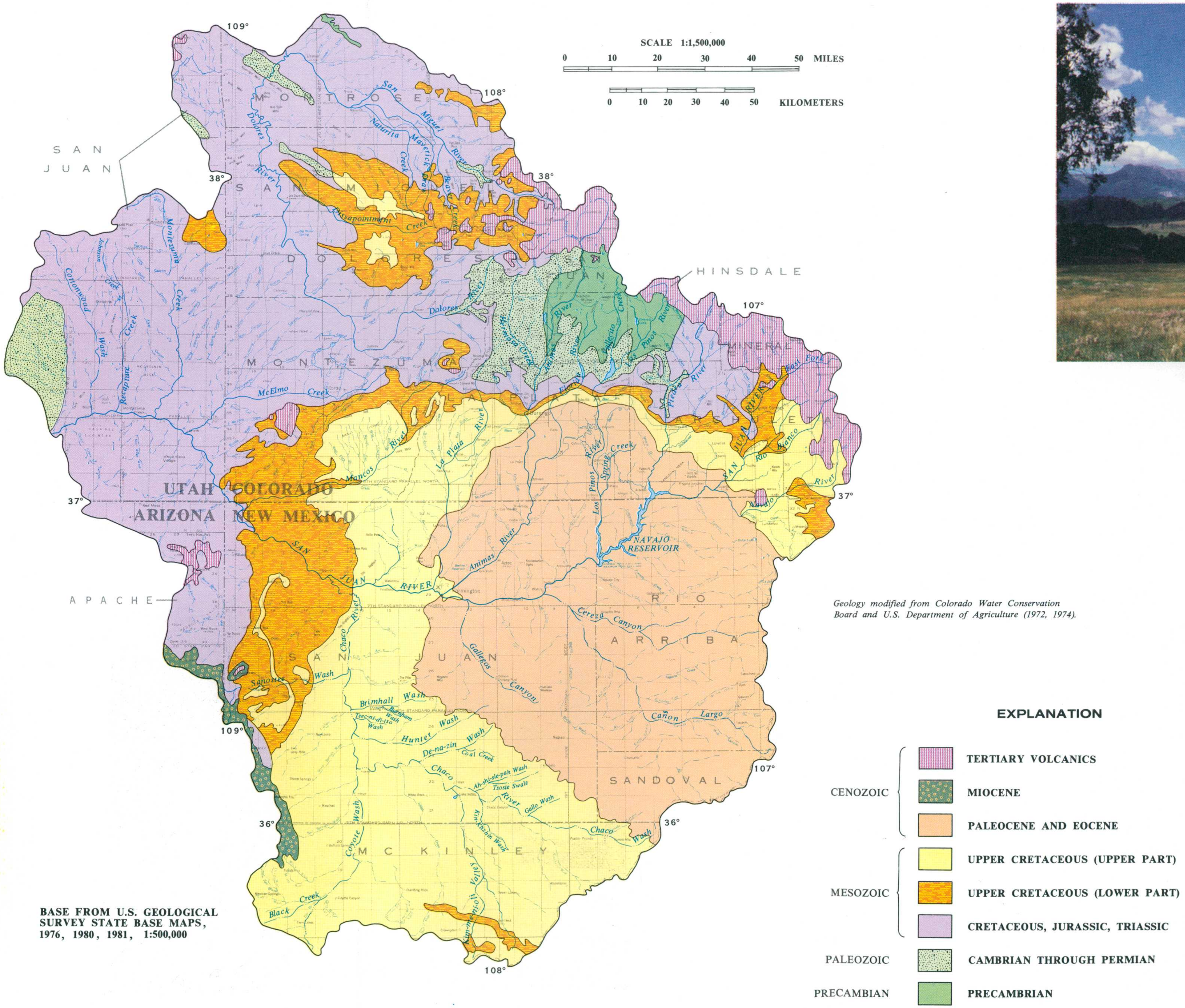
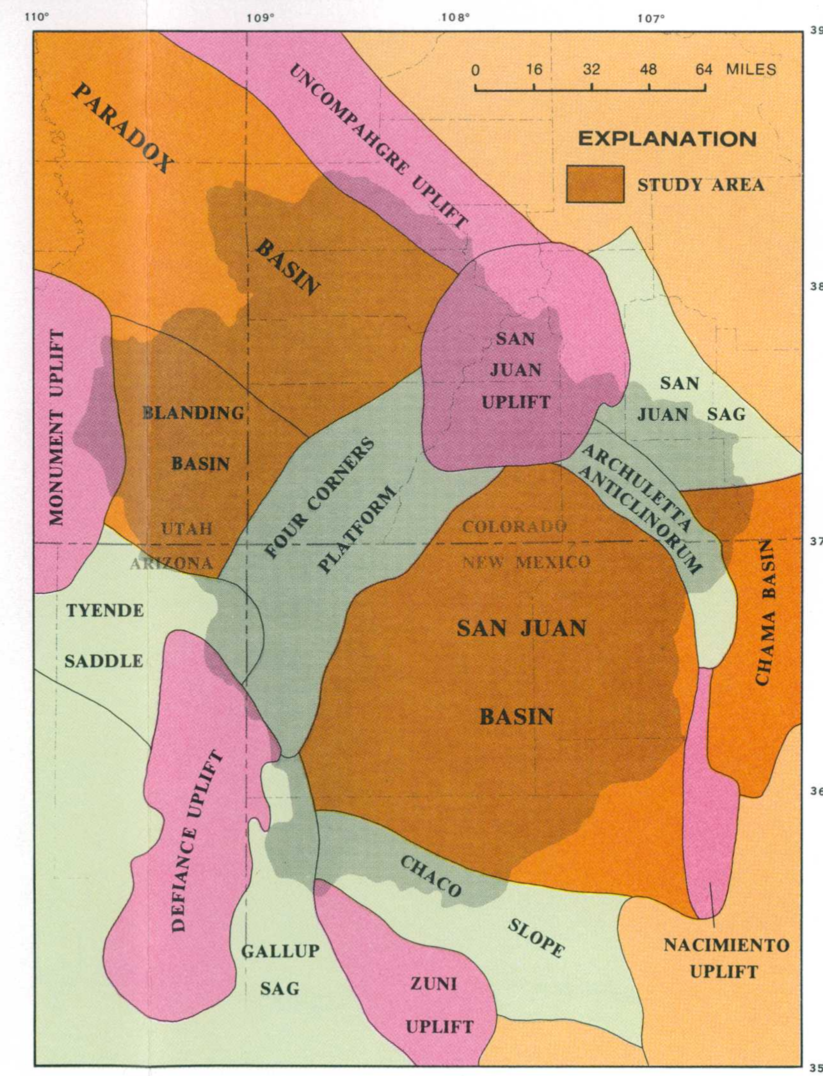


Figure 2.6-1 Generalized geology of study area.

Figure 2.6-2 Part of San Juan uplift.



Structural features modified from Kelley (1955)

Figure 2.6-3 Major geologic structural features.

Coal-Bearing Rocks Exist in Two Major Coal Regions

Economically important coal beds are present in three Cretaceous-age rock units.

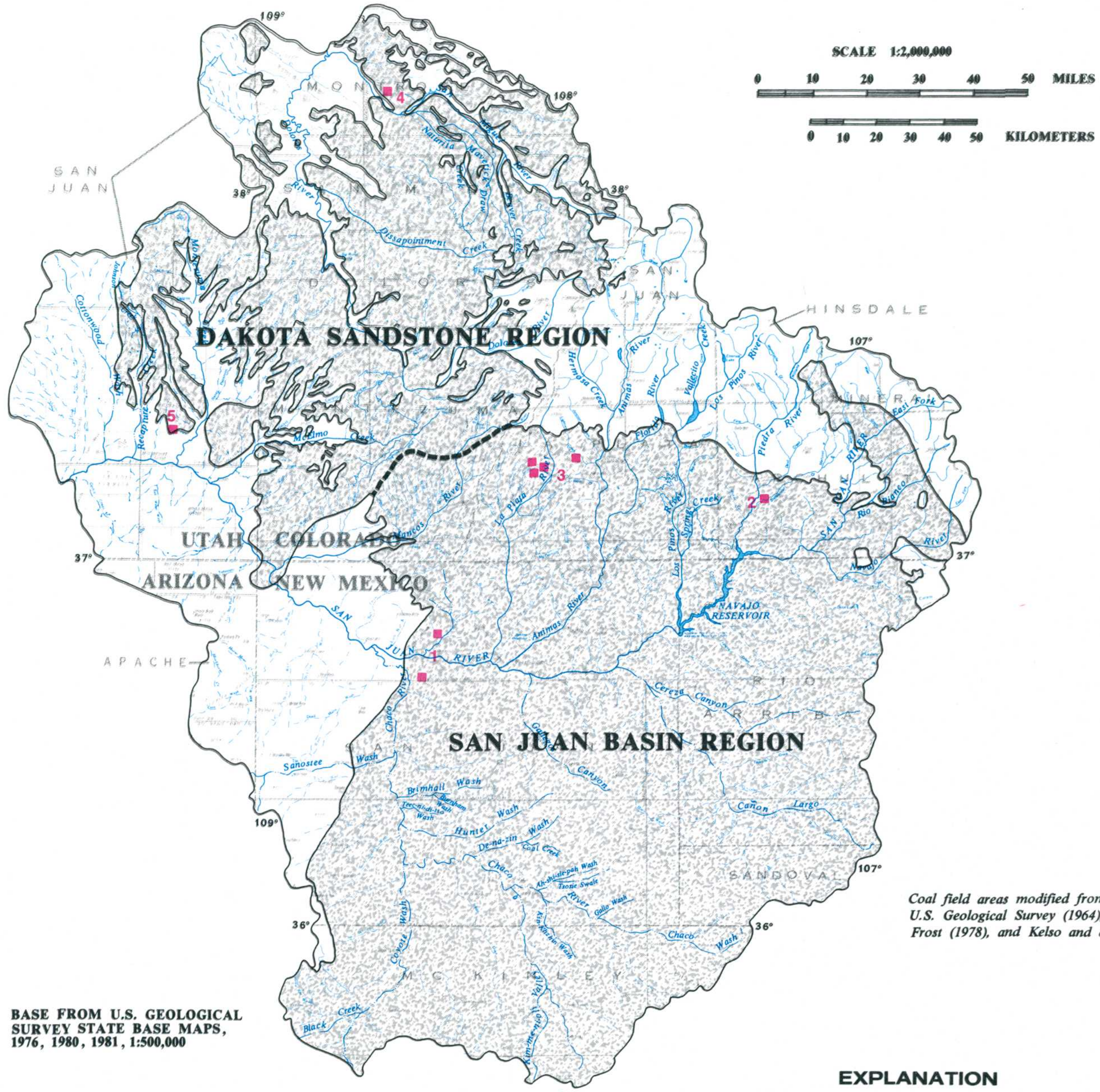
Two major coal regions are defined in Area 60. The San Juan Basin region is in the southern part of the area, and the Dakota Sandstone region in the northern part of the area (fig. 2.7-1).

The primary sources of coal in the San Juan Basin region are the Mesaverde Group, the Fruitland Formation, and the Dakota Sandstone. The three units are separated by strata of greatly varying thickness that are barren of coal. The principal areas of strippable coal are confined to the periphery of the basin. The depth to the coal-bearing rocks near the center of the basin ranges from 4,000 to 8,000 feet. The Mesaverde Group and the Fruitland Formation are the most productive coal-bearing units in the region. At the present time, the primary coal-leasing areas are in the vicinity of the Chaco River in the southern part of the area. A coal bed in the Chaco River basin is shown in figure 2.7-2.

The primary source of coal in the Dakota Sandstone region is the Dakota Sandstone; most of the Mesaverde Group and younger coal-bearing rocks have been removed by erosion. However, the depth to coal in this region varies greatly because of the extreme topographic relief caused by river entrenchment, which has either exposed the coal-bearing zone or decreased the thickness of the overburden.

A stratigraphic section (table 2.7-1) shows the relation of the coal-bearing and adjacent rock units to rock units that are considered to be water bearing.

Figure 2.7-2 Coal bed outcrop in Chaco River area.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

Coal field areas modified from U.S. Geological Survey (1964), Tabet and Frost (1978), and Kelso and others (1981).

EXPLANATION

APPROXIMATE AREA OF COAL REGION

COAL REGION BOUNDARY

ACTIVE MINE -- Number indicates coal field

SAN JUAN BASIN REGION

1 San Juan Basin field
2 Pagosa Springs field
3 Durango field

DAKOTA SANDSTONE REGION

4 Nucla-Naturita field
5 San Juan River field

Figure 2.7-1 Coal field areas.

Table 2.7-1 Generalized stratigraphic section of upper Jurassic, Cretaceous, and Tertiary age rocks.

Era	System	Series	Group	Formation	Aquifer	COAL-BEARING ROCK UNITS
CENOZOIC	TERTIARY	Pliocene		Volcanics and basalts undifferentiated		
		Miocene				
		Oligocene				
		Eocene		Telluride Conglomerate; Creede Formation		
				San Jose Formation	**	
		Paleocene		Animas Formation; Nacimiento Formation	**	
				Animas Formation; Ojo Alamo Sandstone	*	
MESOZOIC	CRETACEOUS	Upper		Kirtland Shale	*	
				Fruitland Shale	*	■
				Pictured Cliffs Sandstone	**	
			Mesaverde Group	Lewis Shale		■
				Cliff House Sandstone	**	■
				Menefee Formation		■
				Point Lookout Sandstone	*	■
				Crevasse Canyon Formation	*	■
				Dilco Member		■
				Gallup Sandstone	**	■
				Lower Mancos Shale		
		Lower		Dakota Sandstone	*	■
				Burro Canyon Formation		
	JURASSIC	Upper		Morrison Formation	**	
			San Rafael Group	Cow Springs (Bluff) Sandstone		
				Summerville Formation		
				Todilto Formation		
				Entrada Sandstone	**	

* Minor aquifer
** Major aquifer

Modified from C.M. Molenaar (1977), and R.W. Pearl and D.K. Murray (1974).

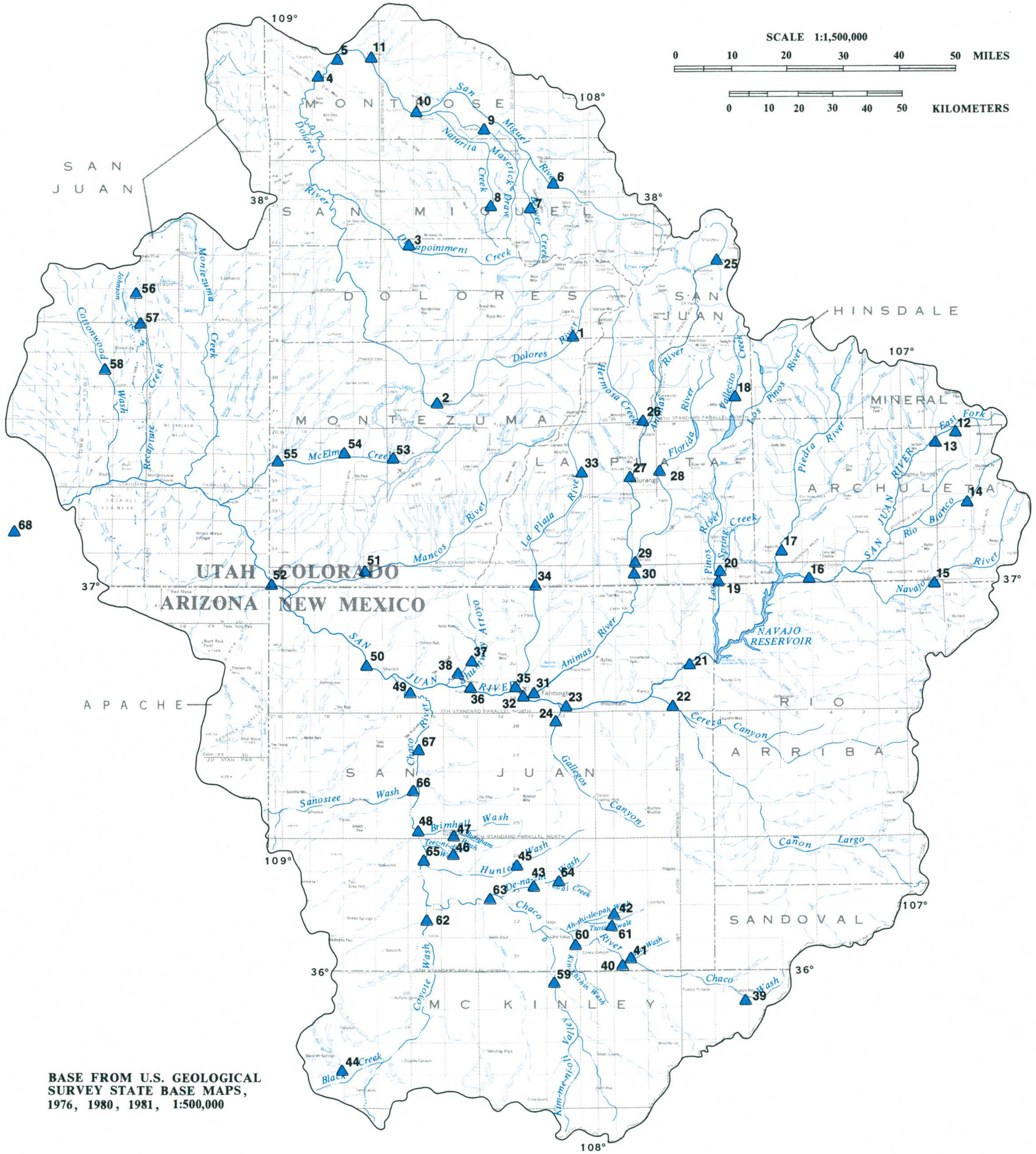
Data Collected from 68 Surface-Water Stations Were Used to Determine Streamflow Characteristics

Basin coverage, location on major rivers, length of streamflow records, and proximity of stations to coal-development areas were factors used to select the streamflow stations.

The analyses of streamflow characteristics in this report are based on the streamflow data collected at 68 surface-water stations. The locations of these stations are shown in figure 3.1-1; the map numbers can be used to identify the stations on the list in section 6.1. The stations are assigned 8-digit downstream numbers or 15-digit latitude-longitude identification numbers, which are used to identify the stations in the U.S. Geological Survey's National Water Data Storage and Retrieval system (WATSTORE).

Discharge measurements are available in WATSTORE for 317 other stations, but the streamflow data for most of these stations consist of fewer than four measurements that were collected in conjunction with the collection of miscellaneous water-quality data. The sparse streamflow data collected at these station were not used in the streamflow analysis. The locations of these miscellaneous stations are shown in figure 3.6-1.

Surface-water gaging stations for obtaining continuous streamflow records in Area 60 were established for various purposes, including long-term water-supply inventories, evaluation for water-resource-development projects (such as reservoir storage or diversion for irrigation), fulfilling data needs for the Colorado River Compact and other legal entities, and more recently for assessing impacts by energy-related mineral developments on the hydrologic environment.



SURFACE-WATER STATION AND NUMBER WITH CONTINUOUS STREAMFLOW RECORDS IN WATSTORE
Number refers to station identified in section 6.1

Figure 3.1-1 Location of surface-water stations selected for streamflow analyses.

Variations of Streamflow Result from Snowmelt and Seasonal Storms

The melting of winter snows in the mountains accounts for most of the streamflow in perennial streams; however, rainfall does have an effect, especially on ephemeral streams.

Surface runoff in Area 60 is mostly a result of the melting of winter snows in the mountain ranges. Streamflow records indicate that most melting occurs during April, May, and June. The great increase in streamflow during this period of the year is shown in the accompanying hydrographs (fig. 3.2-1) for streamflow-gaging stations on the La Plata, Dolores, and Animas Rivers. These hydrographs, based on data collected during the 1979 water year, are intended to show changes in flow from season to season.

In addition to snowmelt, rainfall--especially the localized intense storms that generally occur during the summer--may have a great effect on runoff. As shown in the figure, the Chaco River is ephemeral, only flowing in response to precipitation.

The hydrographs are for streams that are not affected by regulation; thus, the trends shown are naturally occurring. The San Juan River, which has significant regulation, was not included.

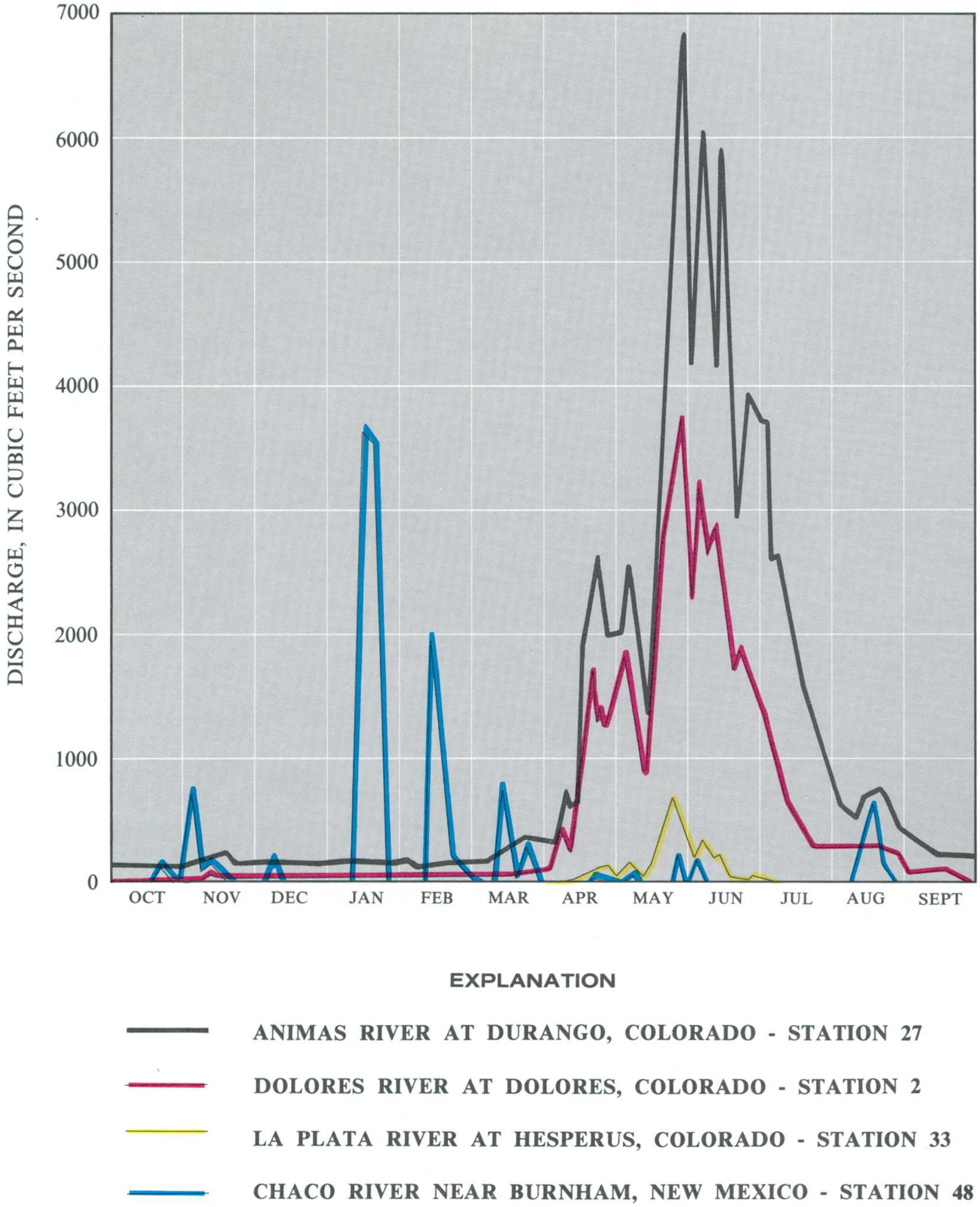


Figure 3.2-1 Seasonal pattern of streamflow for the La Plata, Dolores, Animas, and Chaco Rivers, 1979 water year.

Base Flow Severely Limited in Area 60

Streams in the southern areas tend to stop flowing during the summer, whereas most northern streams continue to flow.

The absence of substantial quantities of precipitation in most of Area 60 results in a correspondingly small quantity of water available for dry periods when streamflow is totally base flow. Base flow is defined as that part of streamflow wholly comprised of ground water discharged into the stream. Aquifers that are recharged in the mountain areas, which receive substantial precipitation, are generally too deeply buried in the valleys to provide discharge to streams in most river valleys.

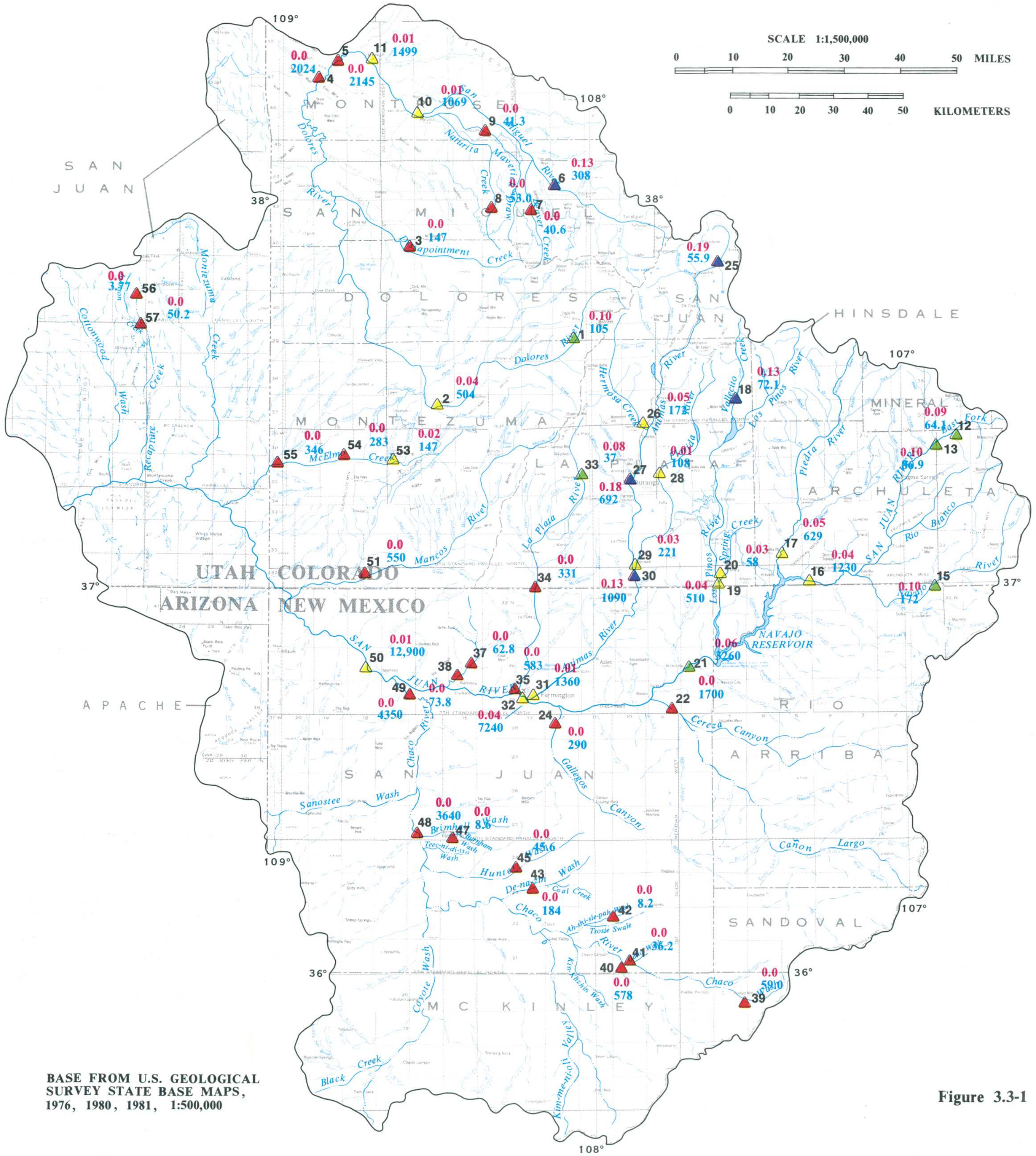
Unit base flows, reported as 7-day, 10-year recurrence-interval low flows divided by the corresponding drainage area are depicted in figure 3.3-1. The 7-day, 10-year recurrence-interval low flow is defined as the lowest average discharge that is expected to occur, on the long-term average, for 7 consecutive days once in 10 years. As can be seen in figure 3.3-1, unit flows are zero at many stream stations, notably in the south and west; at most of the other stations, the values range from 0.001 to 0.19 cubic foot per second per square mile.

Base flows in the areas drained by Cañon Largo and the Chaco River are zero. This area is dominated by desert topography, with streamflow occurring in direct response to infrequent precipitation.

Unlike the southern part of Area 60, base flows exist in the Dolores and San Miguel River basins. Base flows in this area are small, but the streamflow does have the ground-water contribution that is lacking in the south. It should be noted that some of the base-flow figures are affected by irrigation withdrawals and returns. The irrigation returns may tend to supplement the base flows.

The San Juan River, the largest river in the area, has small base flows along its course. Most of the streamflow is a result of snowmelt and direct storm runoff.

The aforementioned base-flow data will be of aid in water-resource planning. The suitability of a stream for water supply will be dependent on the amount of water available during periods of base flow. If streamflow tends to zero or is zero for long periods, alternate water supplies will need to be found for those periods. Base-flow figures can also be used for wastewater treatment plant design. The discharge from the plants into receiving streams will be limited by the amount of dilution afforded by the stream during base periods. If insufficient streamflow exists at most times, the degree of wastewater treatment may need to be upgraded.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

EXPLANATION

0.09 7-DAY, 10-YEAR RECURRENCE INTERVAL BASE FLOW IN CUBIC FEET PER SECOND PER SQUARE MILE

8.2 DRAINAGE AREA IN SQUARE MILES

RANGE OF BASE FLOW, IN CUBIC FEET PER SECOND PER SQUARE MILE

- Zero
- 0.01 to 0.05
- 0.06 to 0.10
- 0.11 to 0.20

3 SURFACE-WATER STATION NUMBER
See section 6.1 for description of stations.

Figure 3.3-1 Base-flow network.

Storm Runoff Less in Southern Part of Area 60

The area drained by the Chaco River has markedly less storm runoff than the Dolores, Mancos, Animas, and Piedra drainages.

The Chaco River, which drains much of the southern part of Area 60, has smaller storm-runoff volumes than the other major rivers in the area. The Chaco River basin is an area of high mesas and desert that receives small quantities of rainfall. Because of the small quantities of rainfall, flood volumes in the Chaco River basin are smaller than the volumes in other basins with the same drainage-area size.

Unit flood volumes of specific recurrence intervals for the 1-day flood are listed in table 3.4-1 for selected drainage basins. The unit volumes were calculated using streamflow records. As can be seen, unit values of flood volumes are variable from stream to stream and even in different reaches along the same stream (unit volumes decrease in the downstream direction). For equivalent drainage-area size, variability may be a result of differences in stream slope, land use, vegetation, soil type and precipitation.

Methods of determining flood magnitudes and frequencies at sites where no flood data have been collected have been developed, based on estimating equations. Thomas and Gold (1982) presented flood-estimating equations using basin characteristics developed from data collected in New Mexico. McCain and Jarrett (1976) presented estimating equations for Colorado streams based on basin characteristics.

The following summarizes the estimating equations available for Area 60 for the indicated return intervals. The equations developed by Thomas and Gold are:

Recurrence interval (years)	Estimating Equation	*Standard* error (percent)
10	$Q_{10} = 3.88 \times 10^4 A^{0.444} (Sa/1000)^{-2.78}$	+124 -55
50	$Q_{50} = 2.01 \times 10^5 A^{0.403} (Sa/1000)^{-3.18}$	+140 -58
100	$Q_{100} = 3.54 \times 10^5 A^{0.389} (Sa/1000)^{-3.52}$	+145 -59

where A is the contributing drainage area in square miles and Sa is site altitude in feet above sea level.

The equations developed by McCain and Jarret are:

Recurrence interval (years)	Estimating Equation	Standard error (percent)
10	$Q_{10} = 59.7\ A^{0.709}$	+58 -36
50	$Q_{50} = 89.1\ A^{0.709}$	+62 -38
100	$Q_{100} = 103\ A^{0.710}$	+66 -40

where A is total area of the basin contributing to flood discharges in square miles.

The equations presented by Thomas and Gold were developed by regression analysis which included data from neighboring Colorado streams. Therefore Thomas and Gold's estimating equations can be used for the San Juan River and it's tributaries. McCain and Jarrett's equations should be used in the Dolores and San Miguel river basins.

Table 3.4-1 Flood volumes for selected stations.

Map Number	Station Number	Station Name	Drainage Area (mi^2)	1-day flood volume [$(ft^3/s)/mi^2$] Recurrence interval (years) 2	10	50
1	09165000	Dolores River below Rico, Colo.	105	9.9	14.9	16.7
2	09166500	Dolores River at Dolores, Colo.	504	5.6	9.5	12.0
4	09169500	Dolores River at Bedrock, Colo.	2,024	1.5	3.9	6.9
16	09346400	San Juan River near Carracas, Colo.	1,230	2.3	4.6	6.7
17	09349800	Piedra River near Arboles, Colo.	629	2.9	6.8	11.4
21	09355500	San Juan River near Archuleta, N. Mex.	3,260	0.6	1.91	2.4
25	09357500	Animas River at Howardsville, Colo.	55.9	12.6	18.8	24.0
27	09361500	Animas River at Durango, Colo.	692	6.7	11.2	14.7
30	09363500	Animas River near Cedar Hill, N. Mex.	1,090	4.6	8.0	10.9
31	09364500	Animas River at Farmington, N. Mex.	1,360	3.7	6.7	9.2
32	09365000	San Juan River at Farmington, N. Mex.	7,240	0.8	1.5	2.3
49	09367950	Chaco River near Waterflow, N. Mex.	4,350	0.4	0.7	0.8
50	09368000	San Juan River at Shiprock, N. Mex.	12,900	0.5	0.9	1.4
51	09371000	Mancos River near Towaoc, Colo.	550	0.7	1.9	3.5

Flow Duration Varies Greatly Among Basins in Area 60

The tendency of a stream to sustain flows is graphically represented by duration curves.

The flow-duration curve is a cumulative-frequency curve that shows the percentage of time that specified discharges were equaled or exceeded during a specified time. The curve is a convenient way to represent the entire range of flow of a stream in a single diagram. The shape of such a curve is indicative of the tendency of a stream to sustain a particular flow magnitude. A curve with a steep slope represents a stream with little sustained base flow and indicates the stream is not well supplied with discharge from either surface-or ground-water storage. Flatter slopes indicate more available storage in the basin and thus a better sustained flow.

The flow-duration curves for the streamflow-gaging stations in Area 60 reveal differences between basins. For example, the curve for the station on the Animas River at Durango, Colorado (fig. 3.5-1), shows a flat slope in the upper and lower parts of the curve, indicating that surface-and ground-water storage in the Animas River basin is sufficient to provide a sustained flow.

The flow-duration curve for the station, La Plata River at Hesperus, Colorado, is typical of the shape of a stream sustained by snowmelt, having a relatively flat slope at the upper end and steep slope in the center part of the curve.

The curve for the Chaco River near Burnham, New Mexico, displays the characteristics of a stream that is usually dry and flows only as a direct result of precipitation. The curve has a steep slope at the high end indicating a large storm-runoff contribution as opposed to the flatter slope of a snowmelt condition.

Flow-duration values for selected stations are shown in table 3.5-1. These flow values can be used to draw flow-duration curves for the stations listed.

Flow-duration curves may serve various purposes in water-resources and geologic activities. Design of water-supply structures have been based on a particular stream discharge that occurs at a specific percent duration level. For example, the discharge that is listed at a 50 percent duration would be used as a design figure. Also the 90 percent duration discharge is sometimes used as an indicator of a base flow streamflow characteristic. Lastly, the geology of basins can be compared using flow-duration curves. Streams draining similar geologic formations will likely have similarly shaped duration curves.

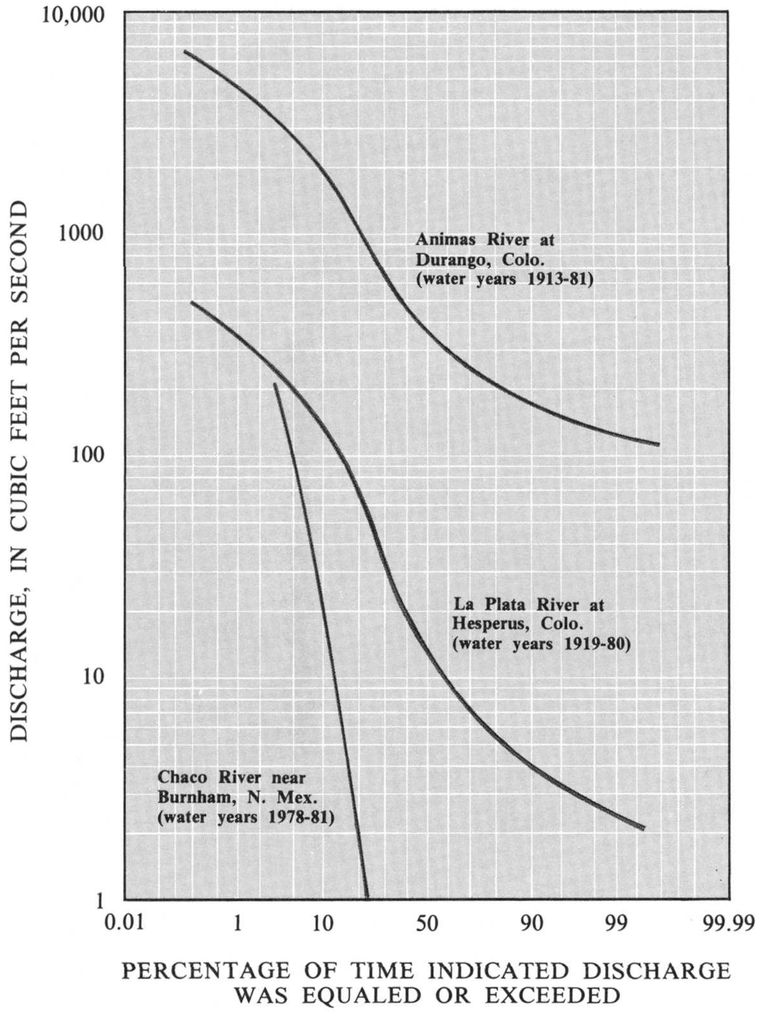


Figure 3.5-1 Flow-duration curves for the La Plata, Animas, and Chaco Rivers.

Table 3.5-1 Flow-duration values for selected stations in Area 60.

Map [1] Number	Station Name	Flow, in cubic feet per second, which was equaled or exceeded for the percentage of time indicated								
		99.5	95	90	75	50	25	10	5	1
2	Dolores River at Dolores, Colo.	20.0	34.0	39.0	56.0	110	390	1,400	2,060	3,280
9	Maverick Draw near Norwood, Colo.	0.1	0.2	0.4	1.2	2.1	3.7	7.9	12.0	19.0
11	San Miguel River at Uraven, Colo.	17.0	36.0	50.0	74.0	110	320	960	1,420	2,420
13	E. Fork San Juan River near Pagosa Springs, Colo.	7.8	11.0	13.0	18.0	33.0	110	370	560	940
15	Navajo River at Edith, Colo.	17.0	26.0	29.0	37.0	55.0	130	370	520	870
17	Piedra River nr Arboles, Colo.	30.0	41.0	49.0	65.0	110	370	1,000	1,700	2,990
19	Los Pinos River at La Boca, Colo.	25.0	40.0	48.0	66.0	110	190	480	940	1,780
20	Spring Creek at La Boca, Colo.	1.8	2.6	3.1	5.0	23.0	53.0	70.0	79.0	114
26	Hermosa Creek near Hermos, Colo.	8.7	14.0	16.0	22.0	39.0	70.0	400	635	1,190
28	Florida River below Florida Farmers Ditch near Durango, Colo.	1.1	3.0	4.1	6.0	9.4	18.0	75.0	220	530
51	Mancos River near Towaoc, Colo.	0.0	0.0	0.0	3.9	13.0	31.0	100	207	510
54	McElmo Creek below Cortez, Colo.	0.1	1.7	4.3	16.0	28.0	44.0	80.0	126	240

[1] See section 6.1 for description of stations.

Water-Quality Data are Available for 385 Surface-Water Stations

The water-quality data for 87 of these stations have 10 or more water-quality records.

Water-quality data for 385 surface-water stations in Area 60 are stored in WATSTORE's water-quality file. The WATSTORE system is described in section 5.3. The locations of these stations are shown in figure 3.6-1. These surface-water stations are located primarily on active stream channels; however, a few are located on small off-channel ponds and depressions.

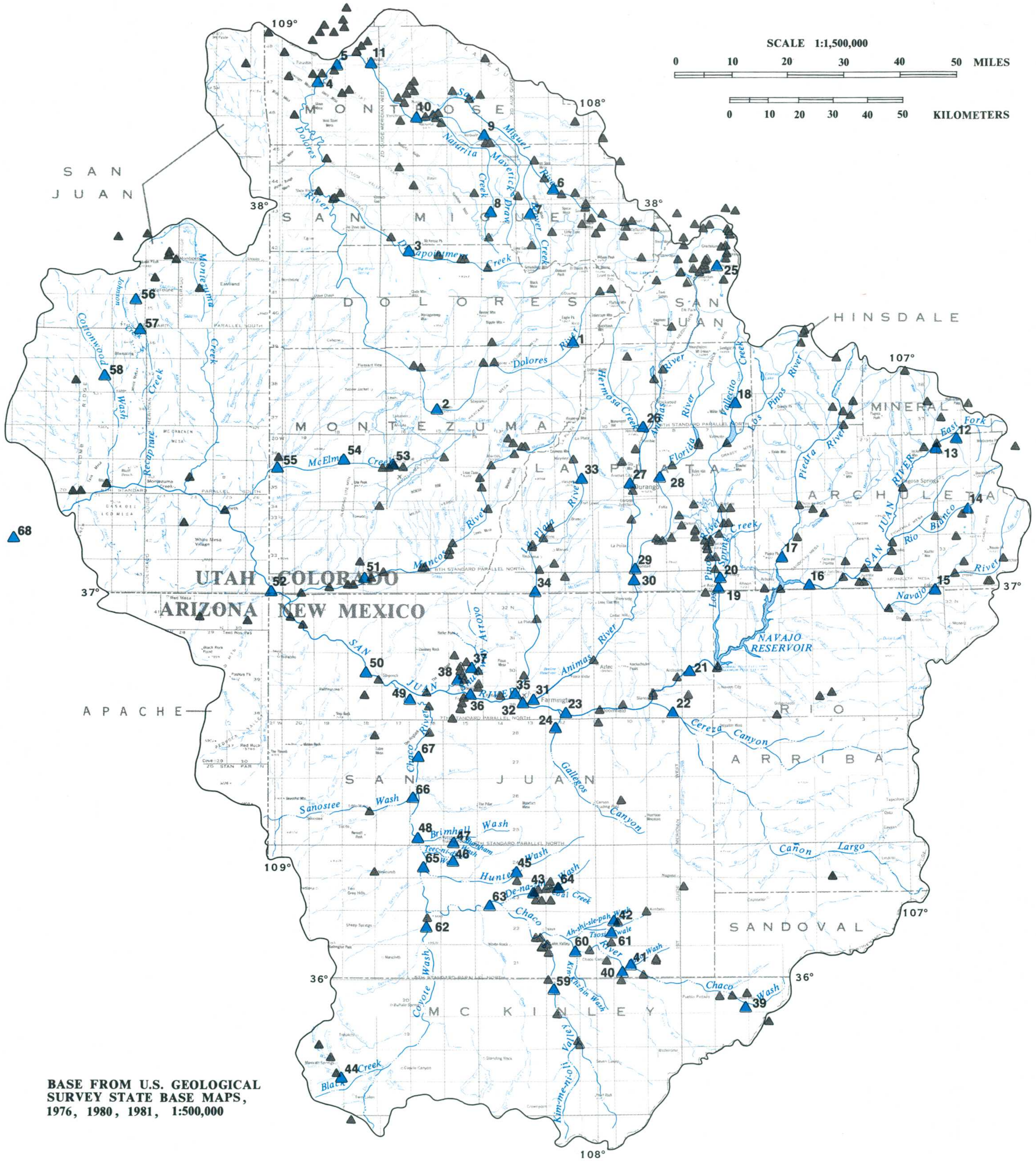
The water-quality data for 298 of these stations consist of fewer than ten water-quality records in the WATSTORE file. A water-quality record may be a single water-quality value such as a specific-conductance value or a record may consist of a set of ten or more values derived from a laboratory chemical analysis of a water sample. Each record applies to a specific sample. The stations with few records are referred to as miscellaneous stations, and data from these stations usually were collected as part of general hydrologic investigations.

The number of surface-water stations that have 10 or more water-quality records is 87, and only 17 stations have 100 or more records in the WATSTORE file. The stations with the greatest number of records usually are located at established streamflow-recording stations. The water-quality data at these stations were obtained under data collection programs of the U.S. Geological Survey, generally in cooperation with other Federal agencies or State governments. A large percentage of these data were collected under the U.S. Geological Survey's Collection of Basic Records (CBR) program, National Stream Quality Accounting Network (NASQAN) program, or National Coal Hydrology program. Systematic collection of water-quality data in the San Juan Basin began about 1940 as part of a technical assessment for water resources development in the Upper Colorado River Basin (Iorns, Hembree, and Oakland, 1965).

Not all of the surface-water stations with water-quality data were used to characterize water-quality in this coal area; rather, 67 surface-water stations were selected because these stations have at least 25 water-quality records in WATSTORE or are located in likely coal-mining areas such as the Chaco River drainage basin. The locations of these selected stations are shown on figure 3.6-1. Indentifying information including the period of record for types of water-quality data are listed in section 6.1 for the selected stations.

The water-quality data for these selected stations were summarized by examining the arithmetic average (mean) of the data and presenting them in ranges in the figures or tables. The arithmetic average is a statistical value and does not necessarily represent an actual physical condition.

Water-quality characteristics discussed in this report are salinity, sodium, pH, alkalinity, iron, manganese, suspended sediment, and the trace elements for which concentration limits have been set in the National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1976). Regulations of the U.S. Office of Surface Mining Reclamation and Enforcement (U.S. Department of the Interior Office of Surface Mining Reclamation and Enforcement, 1979a) have specified limits for mine-water effluents for most of these water-quality characteristics. Although aquatic-biological data may be used to indicate water-quality conditions, they are not discussed in this report because of the limited data available. In addition, aquatic organisms other than bacteria usually are not present in the stormflows of the many ephemeral channels in the central and southern parts of the area.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

EXPLANATION

▲ SURFACE-WATER STATION WITH WATER-QUALITY RECORDS IN WATSTORE

▲ SELECTED SURFACE-WATER STATION WITH MORE THAN 25 RECORDS IN WATSTORE. -- May be less than 25 if located in likely coal mining areas in which data collection began recently.

3 SURFACE-WATER STATION NUMBER
See section 6.1 for description of stations.

Figure 3.6-1 Location of surface-water stations with water-quality records in WATSTORE.

Average Dissolved-Solids Concentration is Less Than 500 Milligrams Per Liter at a Majority of the Selected Surface-Water Stations

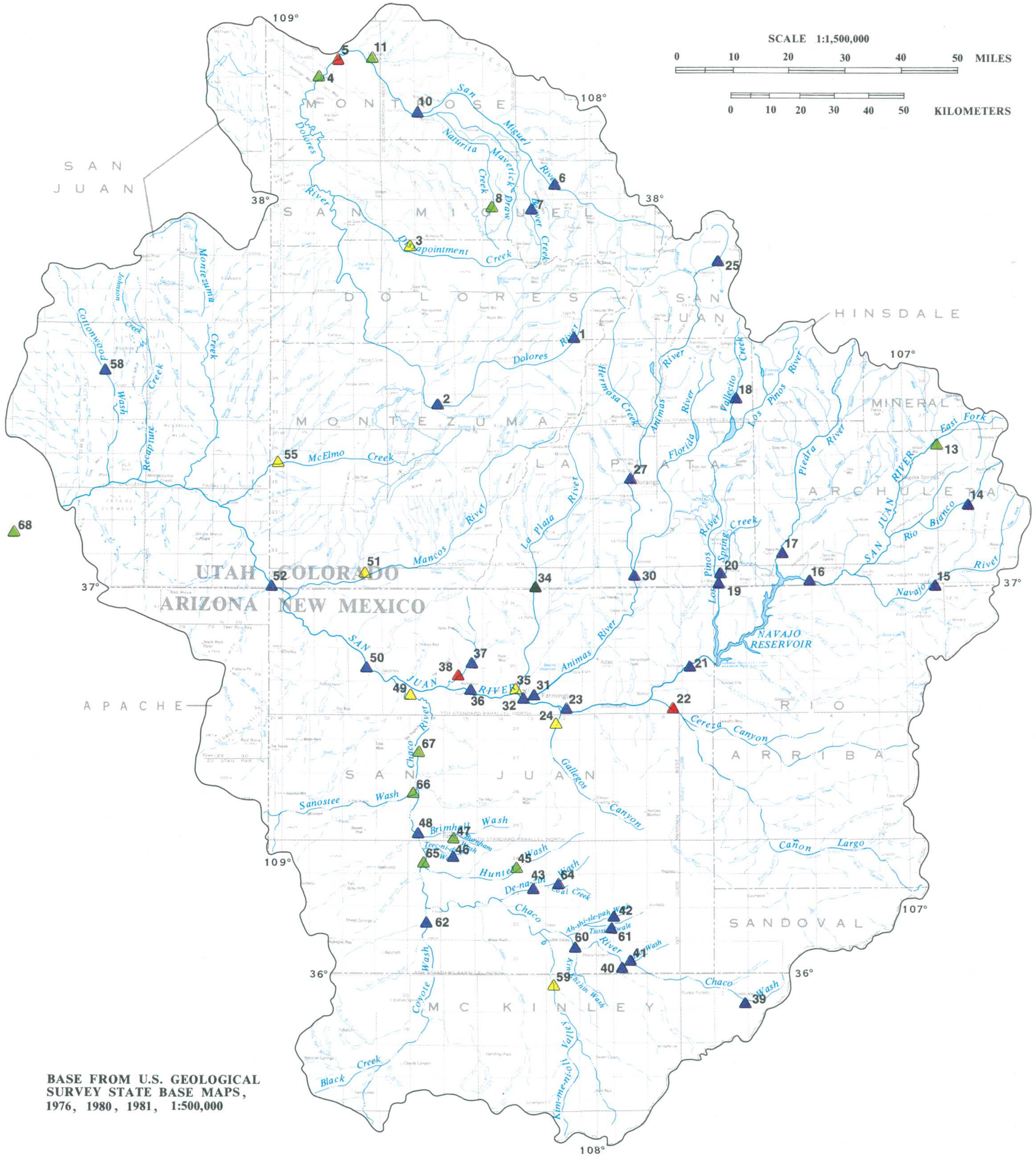
Larger concentrations of dissolved solids are present at stations on ephemeral channels and on the downstream reach of the San Juan River.

The average dissolved-solids concentrations determined from the sum of chemical constituents at 54 selected stations are shown in figure 3.7-1. The values range from 44 to 6,450 milligrams per liter; at 35 of the stations the concentration is less than 500 milligrams per liter. At stations on the San Juan River, the average dissolved-solids concentration exceeds 500 milligrams per liter only at the most downstream location, station 68, at Bluff, Utah.

The dissolved-solids concentration at a station can vary by more than 50 percent of its average value. Changes in concentration generally are caused by dilution from snowmelt runoff, increases in salt content from watershed flushing during the initial stages of thunderstorm runoff, concentration of solutes by evaporation during low-flow periods, mixing with ground-water seepage, and contamination from wastewater discharges.

Dissolved solids in water consist primarily of inorganic salts and small quantities of organic matter. The principal dissolved constituents are inorganic ions of sodium, potassium, calcium, magnesium, bicarbonate, chloride, and sulfate. These usually account for more than 95 percent of the weight of dissolved solids in natural waters.

Water with a dissolved-solids concentration greater than 1,000 milligrams per liter is considered saline. The degrees of salinity observed in Area 60 are shown in figure 3.7-1. The National Secondary Drinking Water Standards (U.S. Environmental Protection Agency, 1978) recommend a maximum dissolved-solids concentration of 500 milligrams per liter in drinking-water supplies , but water with a concentration as large as 1,000 milligrams per liter is considered acceptable in the absence of a less mineralized supply. Detrimental effects to crops may appear when using irrigation water with a dissolved-solids concentration greater than 500 milligrams per liter (National Technical Advisory Committee on Water-Quality to the Secretary of the Interior, 1968); however, concentrations as large as 5,000 milligrams per liter may be used for salt-tolerant crops on permeable soils. Many species of desert plants and grasses have this tolerance.



EXPLANATION

AVERAGE DISSOLVED SOLIDS CONCENTRATIONS, IN MILLIGRAMS PER LITER

- ▲ Less than 500 (very low salinity)
- ▲ 500 to 1000 (low salinity)
- ▲ 1000 to 3000 (slight salinity)
- ▲ 3000 to 10,000 (moderate salinity)

3 **SURFACE-WATER STATION NUMBER**
See section 6.1 for description of stations.

Figure 3.7-1 Average dissolved-solids concentrations at selected surface-water stations.

Concentrations of Dissolved Ions in Streamflow Varies Widely and May Be Affected by Irrigation and Industrial Activities

Water in perennial streams changes from a calcium carbonate to a sodium sulfate type, whereas water in ephemeral streams changes from a sodium bicarbonate to a sodium sulfate type in the downstream direction.

Piper (1944) devised a trilinear diagram that classifies water into water-quality types according to the percentages of ionic concentrations. The average ionic composition of water for 55 surface-water stations is shown on the Piper diagram in figure 3.8-1. (Several symbols with identical values are superimposed on the diagram) The water in upper reaches of perennial streams in Area 60 contains small concentrations of calcium and bicarbonate ions, whereas the water in the upper reaches of ephemeral channels usually contains small concentrations of sodium, bicarbonate, and to a lesser degree, sulfate ions.

The concentrations of ions, particularly sodium and sulfate, increase in the downstream direction. The more saline waters tend to be a sodium sulfate type with a few exceptions. The weathered shales and sandstones exposed on land surfaces are the primary sources of the major ions. Limestone or dolomite in the cementing materials of sandstone may be the source of the calcium, magnesium, and bicarbonate. The bicarbonate ion is formed as a product of the reaction between carbonate ions derived from dissolving limestone or dolomite and hydrogen ions. Some bicarbonate and hydrogen ions are produced when atmospheric carbon dioxide dissolves in water. The weathered clay minerals of exposed shale deposits especially in the Chaco River basin, are a major source of the sodium and sulfate ions.

The Dolores River near its mouth contains a sodium chloride type water that may originate from seepage of subsurface brine. The Mancos River and McElmo Creek contain calcium sulfate and magnesium sulfate type waters which have contacted surface deposits of dolomite or gypsum.

Irrigation and industrial activities may be changing the water-quality characteristics in streamflow. Water that is diverted for irrigation from the Navajo Reservoir on the San Juan River generally has smaller concentrations of sodium, bicarbonate, and sulfate than the irrigation return flow in Gallegos Canyon. The downstream reach of the Chaco River and the Shumway Arroyo may contain wastewater from coal mines and coal-fired powerplants. The predominant ions in these wastewaters usually are sodium and sulfate, generally in saline concentrations.

EXPLANATION

RIVER SYSTEM STATIONS

◇ Dolores River and San Miguel River

* Animas River and perennial tributaries of the upper San Juan River

△ La Plata River and Shumway Arroyo

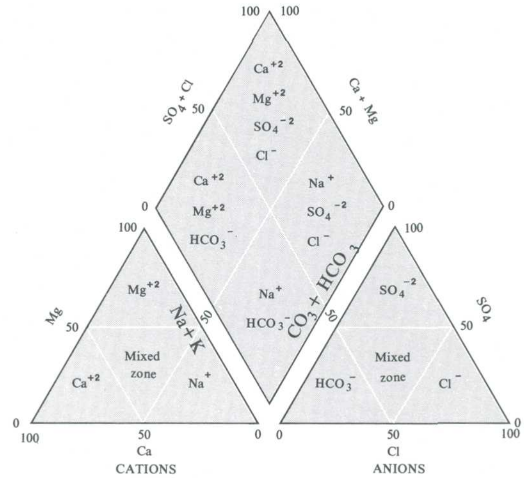
▽ Chaco River, Cañon Largo and Gallegos Canyon

○ Mancos River, McElmo Creek and Cottonwood Wash

□ San Juan River (mainstem)

AVERAGE DISSOLVED SOLIDS CONCENTRATIONS, IN MILLIGRAMS PER LITER

- Less than 500 (blue)
- 500 to less than 1000 (green)
- 1000 to less than 3000 (yellow)
- 3000 to less than 10,000 (red)



TRILINEAR DIAGRAM DOMINANT ION ZONES

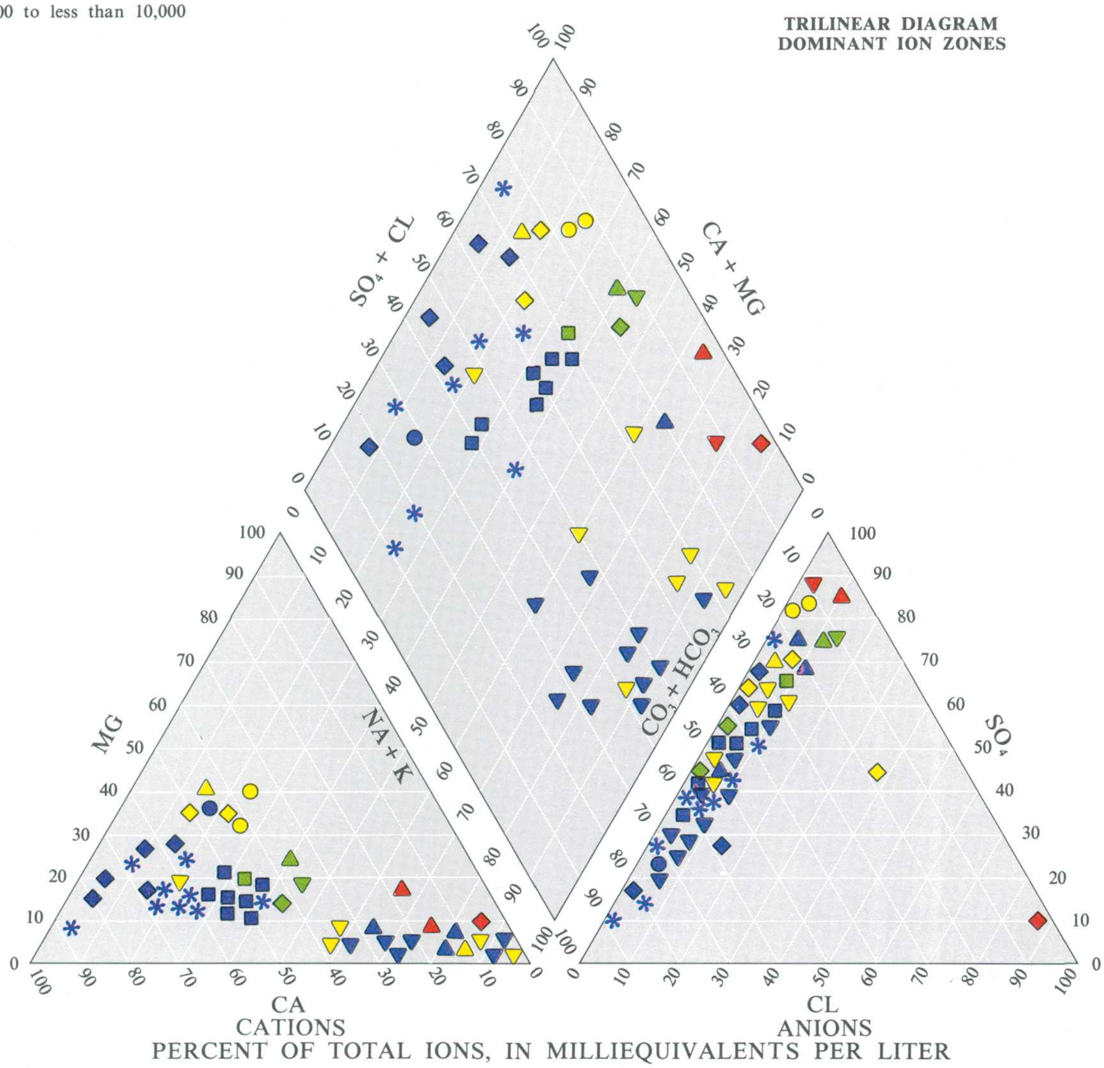


Figure 3.8-1 Trilinear (Piper) diagram for classifying surface-waters of Coal Area 60 into water-quality type by dominant ions.

Surface Waters Generally Exhibit Low to Medium Salinity and Sodium Hazards for Irrigation

The flows in perennial rivers generally are more suitable than the flows of ephemeral channels for irrigation and reclamation uses.

The salinity and sodium hazards to irrigation for water at 55 surface-water stations are plotted in figure 3.9-1. The sodium hazard or salinity hazard in irrigation waters may be determined from the diagram shown in figure 3.9-2. This diagram is modified from one that appears in the U.S. Salinity Laboratory manual (U.S. Salinity Laboratory Staff, 1954) on salinity and alkalinity in soils and water. Low sodium and low salinity hazards generally are found in the waters of the San Juan River and other perennial rivers in this area.

Larger sodium and salinity hazards generally are present in the ephemeral flows of arroyos in the southern part of the area, including the Chaco River basin, which drains a large area of strippable coal in the Fruitland Formation. Surface waters with low or medium salinity coupled with high sodium hazard are not present in Coal Area 60. The source in Kim-me-ni-olo wash of water with high salinity and high sodium hazards may be the effluent being discharged into the wash from dewatering a potential underground uranium mine; whereas, the source of water with these high hazards near the mouth of Dolores Creek is natural seepage of subsurface brines.

The specific-conductance and sodium-adsorption-ratio (SAR) values can be used to determine the suitability of waters for irrigation, but successful use of the water for irrigation also is related to the soil's mineral composition, particle-size distribution of the soil, surface-drainage patterns, the depth of permeable soils for downward leaching of salts, and the tolerance of young or mature plant species to high sodium and high salinity. Desert plants usually have greater tolerances to high sodium and high salinity than most fruit trees, vegetable crops, and forage crops.

The primary use of surface water in Coal Area 60 is for irrigation; a greater proportion of these surface-water supplies may be used for reclamation purposes as more coal is mined. Reclamation and revegetation of abandoned coal-mining areas are required under the Surface Mining Control and Reclamation Act (U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979a).

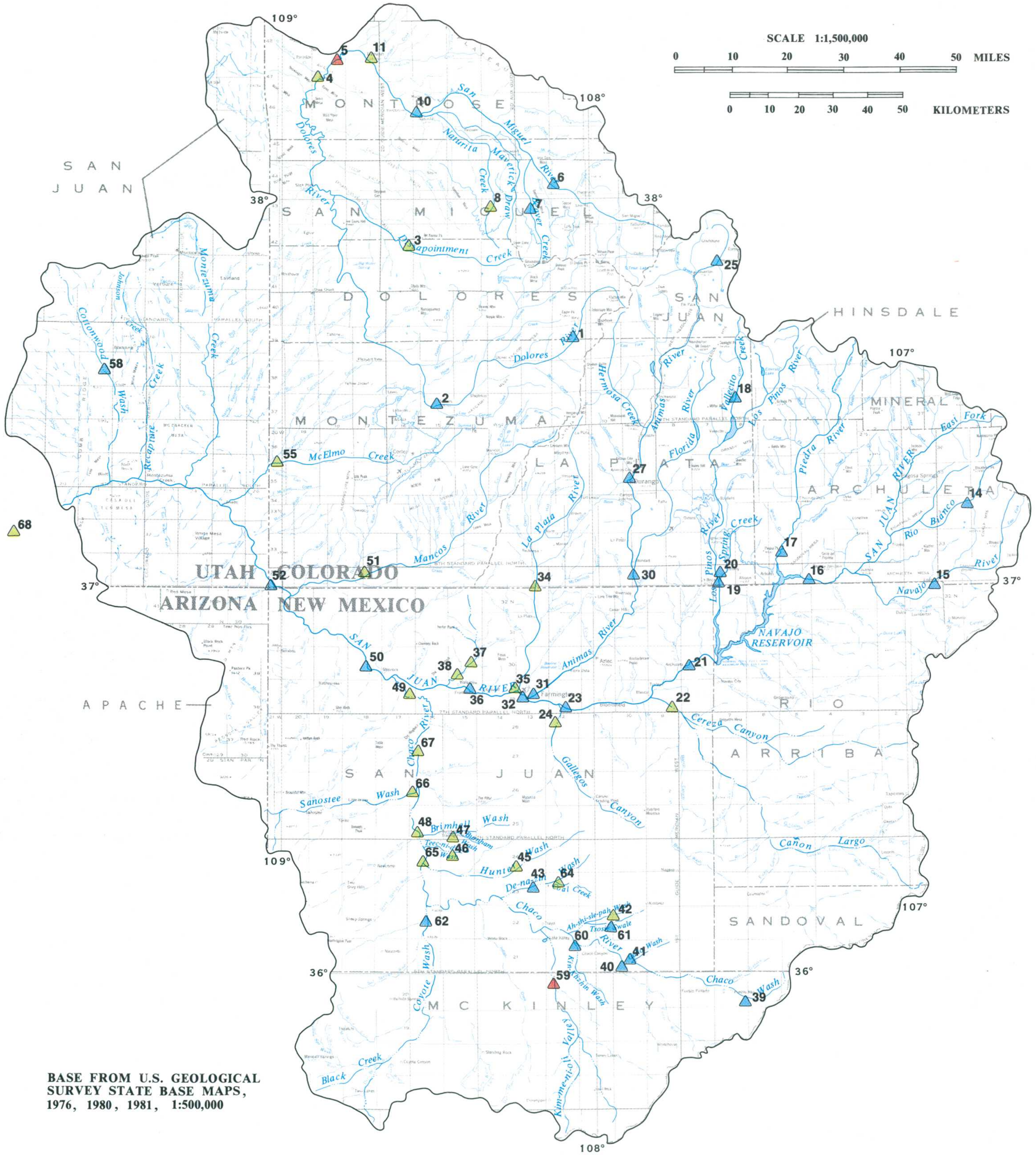


Figure 3.9-1 Average salinity hazard and average sodium hazard of water for irrigation at selected surface water stations.

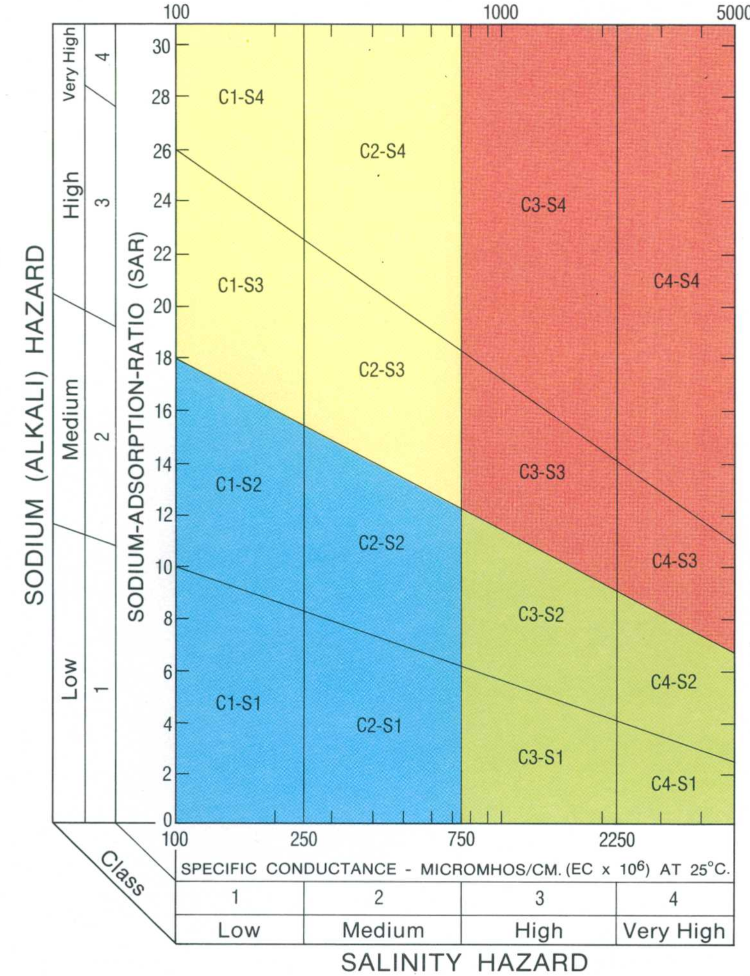
EXPLANATION

SALINITY HAZARD AND SODIUM HAZARD AT A STATION WERE DETERMINED FROM THE AVERAGE SPECIFIC-CONDUCTANCE VALUE AND AVERAGE SODIUM-ADSORPTION-RATIO (SAR) VALUE MEASURED IN WATER SAMPLES COLLECTED FROM THAT STATION (See Figure 3.9-2)

- Low to medium salinity hazard (conductivity 100 to 750 micromhos) and low to medium sodium hazard (SAR from 0 to 18)
- High to very high salinity hazard (conductivity from 750 to 5000 micromhos) and low to medium sodium hazard (SAR from 0 to 18)
- High to very high salinity hazard (conductivity from 750 to 5000 micromhos) and high to very high sodium hazard (SAR from 18 to 30)

Note: Low to medium salinity hazard (conductivity from 100 to 750 micromhos) and high to very high sodium hazard (SAR from 7 to 30 or over) shown as yellow in figure 3.9-2

3 **SURFACE-WATER STATION NUMBER**
See section 6.1 for description of stations



EXPLANATION

SALINITY HAZARD CLASS

Low (C1) Useable on most crops and most leachable soils; avoid very impermeable soils.

Medium (C2) Useable on crops with moderate salt tolerances; moderate leaching required.

High (C3) Useable on crops with good salt tolerances; significant leaching required.

Very high (C4) Useable on very salt-tolerant plants and very permeable soils; extra irrigation required for increase leaching.

SODIUM HAZARD CLASS

Low (S1) Useable on all soils; avoid crops sensitive to sodium at greater sodium-adsorption-ratios.

Medium (S2) Useable on coarse-textured soils with organic matter; moderate leaching required; avoid sodium-sensitive crops.

High (S3) Useable on very permeable soils; significant leaching required; recommend use of soil amendments containing calcium and organic matter.

Very high (S4) Generally unsatisfactory for irrigation purposes except at low (C1) or medium (C2) salinities applied on calcareous and organic rich soils; liberal application of calcium-organic soil amendments required.

Figure 3.9-2 Diagram for determining salinity hazards and sodium hazards of irrigation waters.

Adapted from the U.S. Salinity Laboratory manual on salinity and alkalinity (1954)

Natural Surface Waters of Area are Alkaline

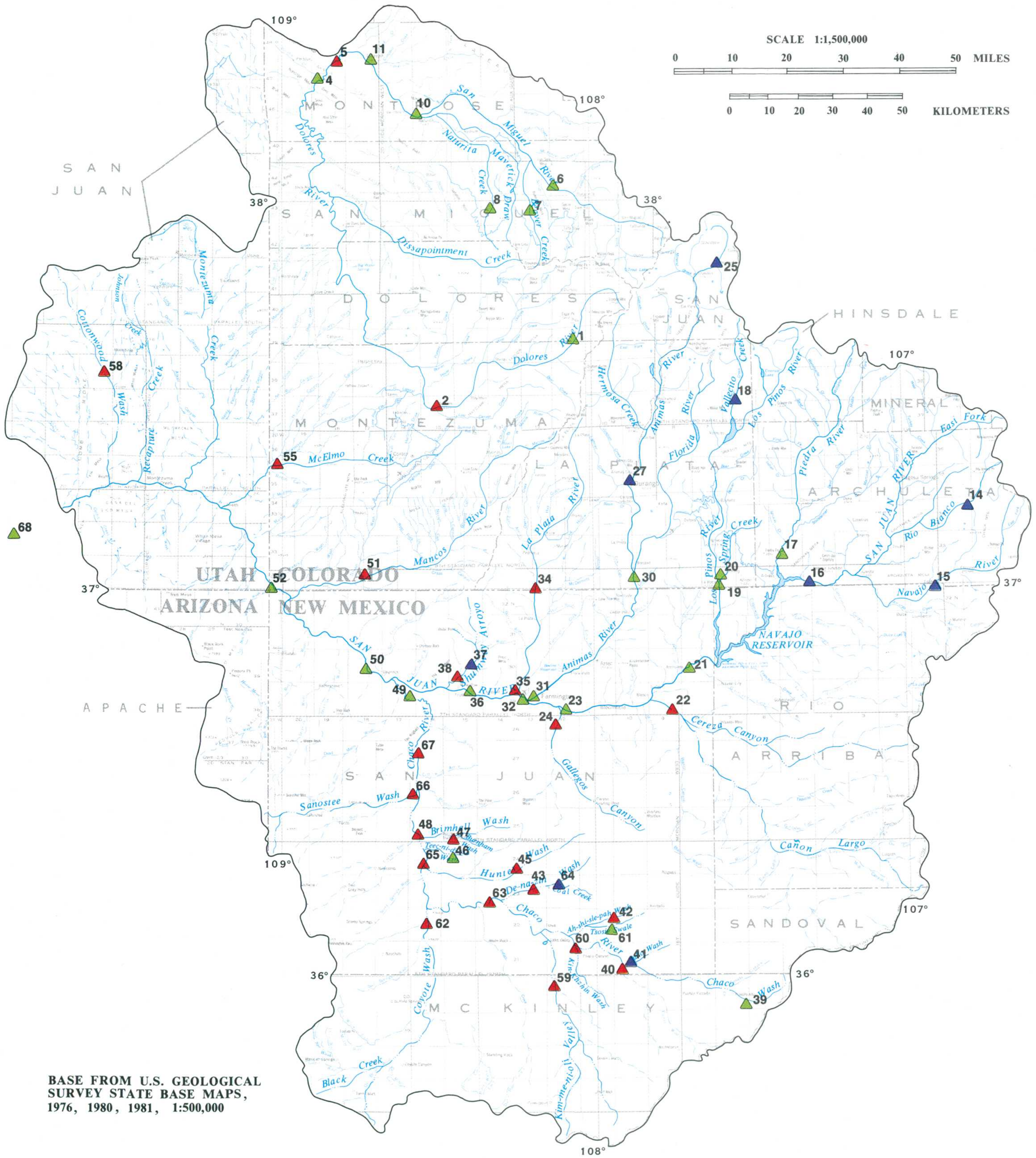
Large alkalinity concentrations, which are attributed to bicarbonate ions in solution are common in the Chaco River system.

Average alkalinity concentrations, expressed as milligrams per liter of calcium carbonate ($CaCO_3$), are shown for selected surface-water stations in figure 3.10-1. These values range from less than 80 milligrams per liter at many upstream stations on perennial rivers to more than 160 milligrams per liter at many downstream stations. Large average alkalinity concentrations are present throughout the Chaco River system along which extensive surface mining of coal is planned. Alkalinity is defined as the quantitative capacity of a water solution to neutralize acidic solutions to a pH of 4.5. Alkalinity in most natural water supplies is attributed principally to the presence of the bicarbonate ion. The bicarbonate concentrations, expressed as $CaCO_3$, found in most natural surface waters usually are less than 160 milligrams per liter (Hem, 1970). Other chemical constituents such as silica or phosphorous may contribute to alkalinity in water. The chemistry of alkalinity is complex and is related to such factors as dissolved carbon dioxide (CO_2) gas, carbonate mineral contact with water, and available mineral or biological sources of hydrogen ions (H^+) or hydroxyl ions (OH^-).

Significant alkalinity due to the presence of bicarbonate in water is characteristic in the arid to semiarid regions of the southwestern United States (U.S. Salinity Laboratory Staff, 1954) The bicarbonate in water is a buffering agent in that it reacts with alkalinity or acidity in a water solution while causing little change in pH.

Naturally occurring acidic surface waters have not been found in Coal Area 60. The pH of pure water is 7.0 which is neutral, whereas pH values more than 7 are alkaline. The lesser the pH reading the greater the hydrogen ion concentration or acidity. The Surface Mining Control and Reclamation Act (U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979) requires the pH of any coal mining effluent to be within the range of pH 6 to 9. Water with pH values of 2.5 have been measured occasionally on the Shumway Arroyo near Waterflow, station S38. This station is located downstream from coal mines and coal-fired powerplants, and waste waters from these operations may flow by this surface-water station.

Acidic waters draining from coal mines into streams are a chronic problem in certain coal-mining regions of the United States. The acidic waters may destroy aquatic life or create discolorations in the receiving streams.



EXPLANATION

AVERAGE ALKALINITY VALUES EXPRESSED AS MILLIGRAMS PER LITER OF $CaCO_3$. MOST NATURAL SURFACE WATERS HAVE ALKALINITIES LESS THAN 160 MILLIGRAMS PER LITER.

- ▲ Less than 80
- ▲ 80 to 160
- ▲ 160 or more

3 SURFACE-WATER STATION NUMBER
See section 6.1 for description of stations.

Figure 3.10-1 Average alkalinity values at selected surface-water stations.

Dissolved Iron Usually is Present in Trace Concentrations in Streams of the Area

Dissolved concentrations of iron, manganese, and other trace elements in surface waters generally are less than limits set in mining regulations or drinking-water standards.

Average concentrations of dissolved iron in water at selected surface-water stations are shown in figure 3.11-1. These average concentrations commonly are less than 100 micrograms per liter; however, concentrations at many stations in the Chaco River basin are larger. Generally, dissolved iron is present only in trace concentrations. Trace concentrations are regarded as those concentrations that are less than 1 milligram per liter and are reported in micrograms per liter. One milligram per liter equals 1,000 micrograms per liter.

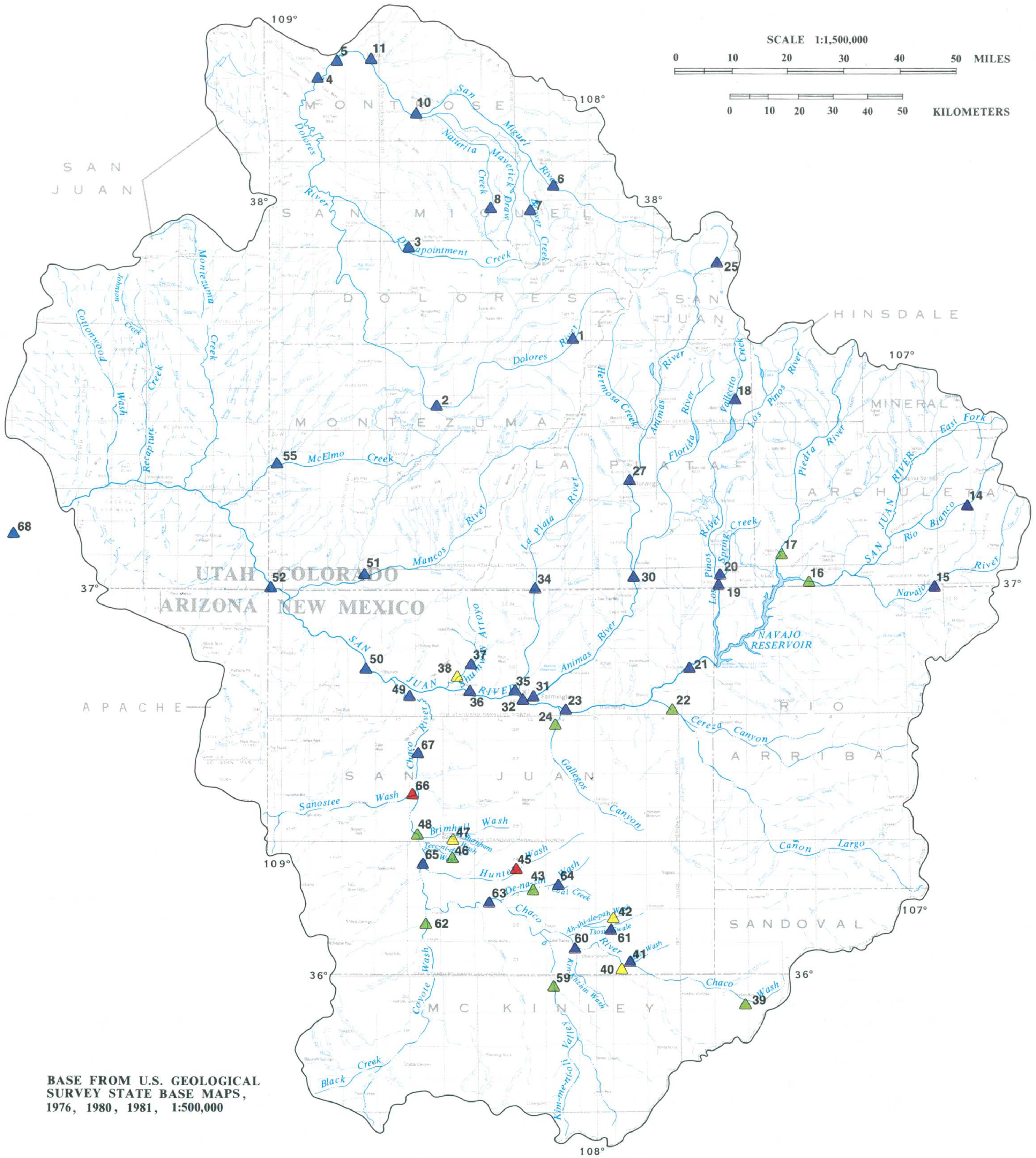
The surface environment of Coal Area 60 contains an abundance of iron as oxide coatings on sands, silts, and clays; as inorganic minerals or organic compounds in the soils, shales, and coal; and in plant and animal detritus. Iron oxides accumulate in the weathered outcrops of shales and coals in arid areas. Generally, iron is very soluble in acidic water but relatively insoluble in alkaline water; thus, the alkalinity of runoff in the area limits the quantity of iron that is dissolved. The greater dissolved iron found at certain surface-water stations in the Chaco River basin may be attributed to ultra-fine suspensions of particulate iron compounds, which are difficult to filter from water samples and are analyzed as dissolved iron. Flows in the Chaco River have very large suspended-sediment concentrations containing iron.

The chemistry of manganese is similar to iron; however, manganese is less abundant, and the chemistry of manganese allows for more dissolved chemical species. Dissolved manganese concentrations usually are present in surface-water samples at about the same, or smaller, concentrations as dissolved iron.

In general, the concentrations of dissolved iron and dissolved manganese present in the area are not considered harmful to humans or aquatic life. Larger concentrations, if found, are not a serious problem; however, they are a nuisance because of the staining they cause and the disagreeable taste they may impart in drinking water. Large concentrations of iron or manganese, however, may indicate a potentially more serious acidic condition in which many trace elements are more soluble. Dissolved concentrations of other trace elements at toxic concentrations may appear under acidic conditions. The Surface Mining Control and Reclamation Act of 1977 (U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979) sets the allowable limits for iron and manganese in coal-mining effluents as follows:

Constituent	Allowable concentration, in micrograms per liter: Maximum	30-day average
Iron, as Fe in all dissolved chemical species	7,000	3,500
Manganese, as Mn in all dissolved chemical species	4,000	2,000

The ranges of the average concentrations for the chemical constituents listed in the National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1976) are presented in table 3.11-1. The ranges are average concentrations in water samples for the selected surface-water stations, which were grouped by river system to obtain a larger statistical sample for trace-element concentrations. In the past measurements of trace-element concentrations were not made frequently, because of the difficulty and expense involved. For many stations, no more than one or two values appear in the WATSTORE file. The boron values may be of interest because of boron's toxicity to certain plants at concentrations greater than 1,000 micrograms per liter and because of its common occurrence in arid regions (U.S. Salinity Laboratory Staff, 1954). The radioactivity values (gross alpha) may be of interest because of the proximity of uranium mining to coal-resource developments. The concentration ranges in table 3.11-1 generally are within the limits set for drinking-water standards, mining regulations, or irrigation criteria.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

Figure 3.11-1 Average dissolved-iron concentrations at selected surface-water stations.

EXPLANATION

AVERAGE DISSOLVED-IRON CONCENTRATION, IN MICROGRAMS PER LITER

- ▲ (blue) Less than 100
- ▲ (green) 100 to 500
- ▲ (yellow) 500 to 1000
- ▲ (red) 1000 or greater

3 **SURFACE-WATER STATION NUMBER**
See section 6.1 for description of stations.

Table 3.11-1 Range of average trace-element concentrations for major river systems.

[Values are in micrograms per liter (ug/L) or milligrams per liter (mg/L) as indicated. Gross - alpha radioactivities are from all dissolved sources including radium. Limits shown are those in the National Interim Drinking Water Standards, Surface Mining Control and Reclamation Act, or water-quality criteria for irrigation.

As, arsenic; Ba, barium; Cd, cadmium; Cr, chromium; Pb, lead; Hg, mercury; Se, selenium; Ag, silver; gross - alpha radioactivity as equivalent uranium; F, fluoride; NO as N, nitrate as nitrogen; B, boron; Fe, iron; Mn, manganese.]

River System	Range of Average Concentrations													
	As (ug/L)	Ba (ug/L)	Cd ug/L)	Cr (ug/L)	Pb (ug/L)	Hg (ug/L)	Se (ug/L)	Ag (ug/L)	Gross-Alpha as U (ug/L)	F (mg/L)	NO_3 as N (mg/L)	B (ug/L)	Fe (ug/L)	Mn ug/L)
Dolores and San Miguel	1.0 to 1.5	82 to 87	1.0 to 1.5	3.0 to 6.0	2.0 to 8.7	0.0 to 0.5	0.5 to 1.7	--	2.2 to 8.8	0.1 to 0.6	0.1 to 0.2	26 to 67	5.0 to 43	8.1 to 227
Upper San Juan River tributaries	0.8 to 55	14 to 100	0.8 to 17	0.8 to 13	6.1 to 37	0.0	0.5 to 16	0.0	1.0	0.1 to 0.6	0.1 to 0.2	13 to 45	23 to 204	10 to 21
Cañon Largo and Gallegos Canyon	2.3 to 3.3	75 to 149	0.8 to 1.0	13 to 14	1.7 to 3.0	0.2 to 0.3	1.8 to 3.3	--	39	1.0	0.4 to 1.1	153 to 230	110 to 159	430 to 1100
Animas River and tributaries	1.2 to 48	50 to 102	1.5 to 16	3.3 to 31	4.8 to 28	0.3	1.0 to 17	0.5	1.0 to 24	0.4 to 0.5	0.1 to 0.2	12 to 92	28 to 92	70 to 355
La Plata and Shumway	1.0 to 5.8	83 to 167	1.2 to 1.5	4.5 to 13	2.0 to 4.7	0.1 to 0.5	1.6 to 147	0.0	13 to 140	0.3 to 5.5	0.3 to 8.3	58 to 2060	20 to 690	32 to 484
Chaco River and tributaries	1.0 to 5.2	20 to 400	0.8 to 1.5	0.0 to 20	1.6 to 12	0.1 to 0.3	1.3 to 11	0.0	4.8 to 46	0.4 to 3.4	1.0 to 4.0	55 to 4350	30 to 600	4.8 to 234
Mancos, McElmo and Cottonwood	1.2 to 3.0	20 to 200	1.8	7.7	25	0.1 to 0.5	7.0	--	44	0.3	1.9	63 to 116	10 to 42	85 to 138
Mainstem of the San Juan River	1.1 to 55	73 to 147	1.0 to 6.3	0.0 to 5.0	1.1 to 6.6	0.1 to 0.3	1.0 to 3.3	0.3 to 0.4	2.7 to 10	0.2 to 0.4	0.1 to 0.8	39 to 116	25 to 45	6.0 to 103
Limits	60	1000	10	50	50	2.0	10	50	22	1.8	10	1000	7000	4000

Evidence of Extreme Natural Erosion is Present Throughout Area

Sediment yield is largest in badlands areas.

Erosion is defined as the general process or the group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another, by natural agencies, which include weathering, solution, corrosion, and transportation. The rugged and sculptured landscape in many parts of the area attest to very active erosional processes that are taking place. Dramatic erosional features can be seen in the Mesa Verde National Park, Colorado, the Chaco Canyon National Monument, and the Bisti Badlands, New Mexico. The erosion of shale around sandstone-capped pedestals in the Bisti Badlands (fig. 3.12-1) is an example of extreme erosion.

The primary agent in the erosional process usually is water. Wind also causes some erosion. The action of water on the landscape is obvious in the many deeply incised arroyos in the central and southern parts of the area. Active headcutting that deepens and lengthens a channel is present throughout this area.

The rates at which erosional processes occur are dependent on such variables as climate, surface geology, relief, vegetative cover, and land use. Most of the precipitation in the area usually falls during intense summer rainstorms, which readily erode particles from bare land surfaces. The land surface over most of this area consists of exposures of weathered shales and sandstones or deposits of loose sand or soil. The land-surface altitude of this area varies from about 4,300 feet above sea level along the downstream reach of the San Juan River to more than 14,000 feet above sea level in the northern part of the area. Slopes of 40 percent or greater are not uncommon in badland and canyon areas. These extremes in relief allow gravity to act forcefully in transporting sediment to lower altitudes. The higher altitudes in the northern part of the area and along the eastern and southern boundaries of the area are covered more densely with vegetation; hence, these areas are much less susceptible to erosion than areas that are sparsely covered with vegetation such as the badlands of the central and southern parts of the area. Much of the area is used to graze livestock; very intense grazing may decrease the density of vegetative cover, which increases the erosional potential of the grazed area.

The sediment yield from an area is a measure of the degree of erosion. Sediment yield can be defined as the volume of sediment that is removed from a drainage area by runoff. Sediment yield commonly is expressed as the volume of sediment yielded per unit area, such as acre-feet per square mile.

The Water Management Subcommittee of the Pacific Southwest-Interagency Committee (1968) evaluated nine erosional factors for estimating sediment yield from small areas (10 square miles or less) in the southwestern United States, within which Area 60 lies. The nine factors are surface geology, soils, climate, runoff, topography, vegetative ground cover, land use, upland erosional patterns, and geomorphology of channels. Numerical ratings were assigned to each of these factors. Table 3.12-1 presents an example of sediment-yield ranges derived by this method (U.S. Department of the Interior, Bureau of Land Management, 1977). The sediment-yield ranges are shown for a variety of landforms and conditions found in U.S. Bureau of Land Management coal-lease area near Bisti, New Mexico. This area was selected to represent a typical area along the strippable coal deposits of the Fruitland Formation.

Most of the nine erosional factors may be affected or altered by coal development activities; therefore, coal development may either add or subtract from the sediment yield of an area, depending on the effectiveness of mining and reclamation practices that are used to control erosion.

Figure 3.12-1 Erosion of shale around the base of sandstone-capped pedestals in the Bisti Badlands, New Mexico.

Table 3.12-1 Estimated annual source-area sediment yield for the Bisti West study area.

Erosion Rate	Land Form	Range of Slope (percent)	Range of bare soil (percent)	Annual Range of sediment yield (acre-feet per square mile)
Low	- Mesa top - Low to flat dunes - Alluvial plains with low dunes - Dry lake bed - Clinker hills	0 to 10	33 to 65	0 to 0.4
Moderate	- Low badland mounds - Scoured or gullied alluvial plains - Wide sandy channels	1 to 10	41 to 100	0.4 to 1.2
High	- Badlands or moderate to steep hills - Badlands escarpments	1 to 40	80 to 94	1.2 to 3.2

Data from U.S. Department of the Interior, Bureau of Land Management (1977).

Large Concentrations of Suspended Sediments are Transported in Streamflows in the Southern and Central Parts of Area 60

Ephemeral streams commonly have the largest concentrations of suspended sediments.

The average suspended-sediment concentrations at selected surface-water stations are shown in figure 3.13-1. Most of the water samples containing suspended sediments were collected during steady flow in perennial streams and during storm runoff in ephemeral streams. Steady flows generally have smaller suspended-sediment concentrations than storm flows; therefore, these average values may be biased: less than actual concentrations for perennial streams and more than actual concentations for ephemeral streams. The ephemeral streams in the central and southern parts of this coal area have suspended-sediment concentrations that usually are several orders of magnitude greater than those in the perennial streams in the northern part of the area. Generally, more than 70 percent (by weight) of suspended-sediment particles are smaller than 62.5 micrometers in diameter. Particle sizes smaller than 62.5 micrometers in diameter are considered to be clay and silt size.

Samples with large suspended-sediment concentrations are shown in figure 3.13-2. They were collected from Hunter Wash near Bisti, New Mexico, station 45. The suspended-sediment concentrations of these samples ranged from 11,000 to 39,000 milligrams per liter, with 98 percent or more of the sediment finer than 62.5 micrometers in diameter.

The surface deposits in much of this area, particularly in the central and southern parts, are composed of unconsolidated, fine-grained clays, silts, and sands, which are readily suspended and transported in overland runoff. Long reaches of many arroyos are eroded deeply into these unconsolidated deposits, and the arroyos' banks and beds are major sources of suspended sediments.

Suspended sediment in streams, whether caused naturally or culturally, is considered very undesirable for aquatic life, reservoir storage, public-water supplies, and esthetic reasons. Cultural activities may be regulated to decrease soil erosion or to limit the concentration of suspended sediments allowed to be discharged into streams. The Surface Mining Control and Reclamation Act (U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement, 1979a) sets a maximum allowable suspended-sediment concentration of 70 milligrams per liter, or a 30-day maximum average concentration of 35 milligrams per liter, for effluents from surface-mining operations.

A water-quality aspect of suspended sediment is that it is a vehicle for transporting chemical constituents in streamflow. A chemical constituent may be part of the mineral assemblage of the suspended sediments or it may be adsorbed on or form an oxide coating on the surfaces of particles. Silt and clay-size particles have a greater surface area than an equal weight of sand, so they have greater corresponding adsorption or coating capacities. The "total-recoverable" concentration of a chemical constituent includes the dissolved concentration plus the concentration recovered, or extracted, from the suspended sediments. In general, a much greater proportion of many trace elements in a water-sediment mixture is found in association with the sediments than in the dissolved phase. The exact relationships between the dissolved phase and the solid or suspended-sediment phase for a chemical constituent in a water-sediment mixture are complex and not understood completely.

The data in table 3.13-1 from samples collected from the Chaco River at Waterflow illustrate that trace elements are not uniformly distributed between the dissolved phase and the suspended-sediment phase. Suspended sediments may serve as a "sink" by adsorbing dissolved chemical constituents in a water-sediment mixture, or they may serve as a "source" for these same chemical constituents by desorbing from the suspended sediments.

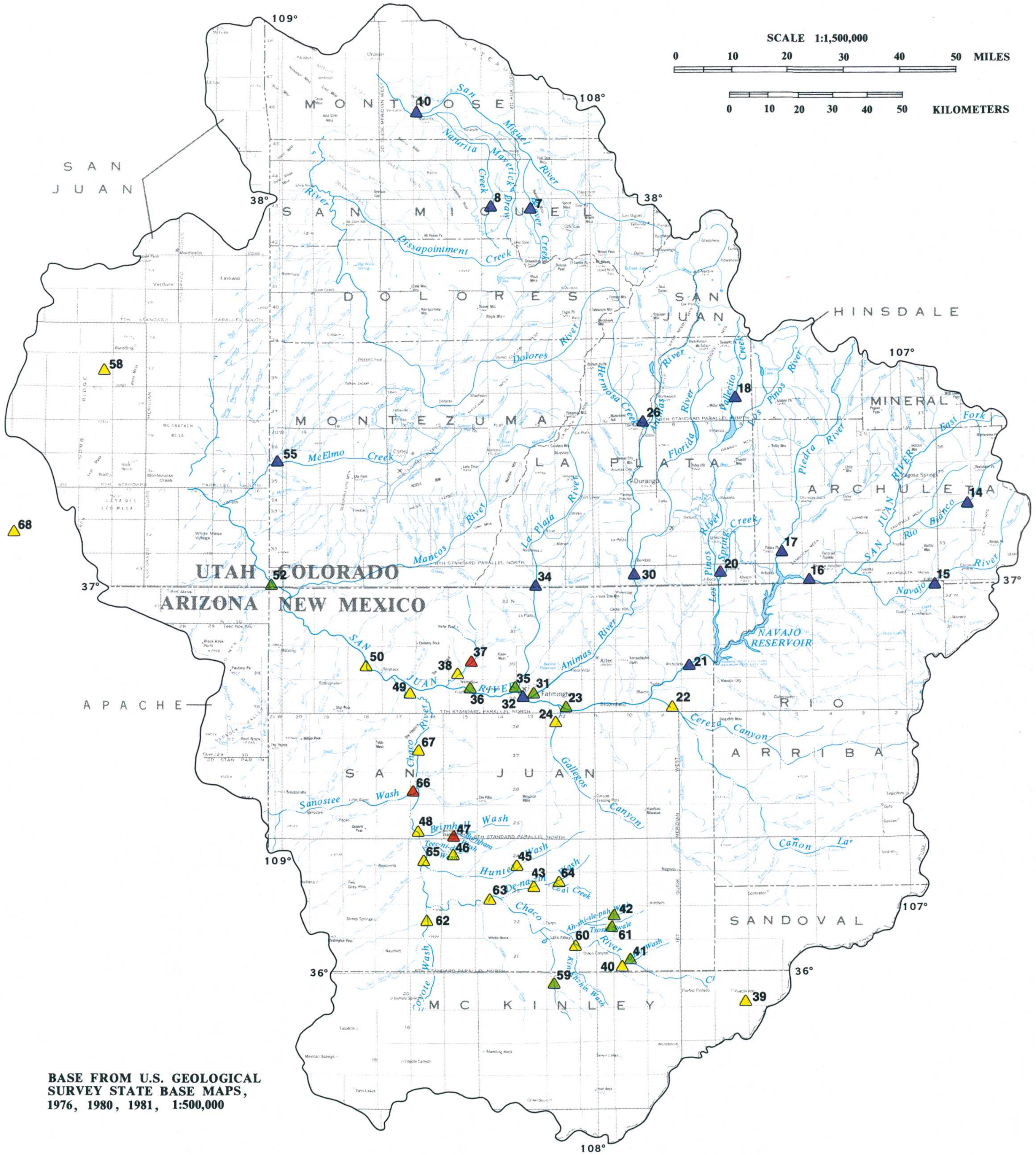


Figure 3.13-1 Average suspended-sediment concentrations at selected surface-water stations.

EXPLANATION

AVERAGE SUSPENDED-SEDIMENT CONCENTRATION, IN MILLIGRAMS PER LITER

- ▲ (blue) Less than 1000
- ▲ (green) 1000 to 10,000
- ▲ (yellow) 10,000 to 100,000
- ▲ (red) Greater than 100,000

7 SURFACE-WATER STATION NUMBER

See section 7.1 for description of stations.

Figure 3.13-2 Bottles (center of photograph) containing water-suspended sediment-mixture samples from Hunter Wash near Bisti, New Mexico.

Table 3.13-1 Samples collected from the Chaco River at Waterflow (station 49). [mg/L, milligrams per liter; ug/L, micrograms per liter]

Constituent	Concentration: November 28, 1979 sample, Dissolved	Concentration: November 28, 1979 sample, Total Recoverable	Concentration: April 29, 1980 sample, Dissolved	Concentration: April 29, 1980 sample, Total Recoverable
Suspended sediment, mg/L	--	148*	--	20,900*
Percent smaller than 62.5 micrometers in diameter	--	76*	--	92*
Arsenic (As), ug/L	20	20	4	38
Barium (Ba), ug/L	300	500	500	2,200
Cadmium (Cd), ug/L	1	1	0	2
Chromium (Cr), ug/L	10	10	0	120
Iron (Fe), ug/L	60	1,900	0	200,000
Lead (Pb), ug/L	4	8	2	240
Manganese (Mn), ug/L	80	90	10	5,500
Mercury (Hg), ug/L	0.0	0.0	0.1	0.6
Selenium (Se), ug/L	7	8	3	7

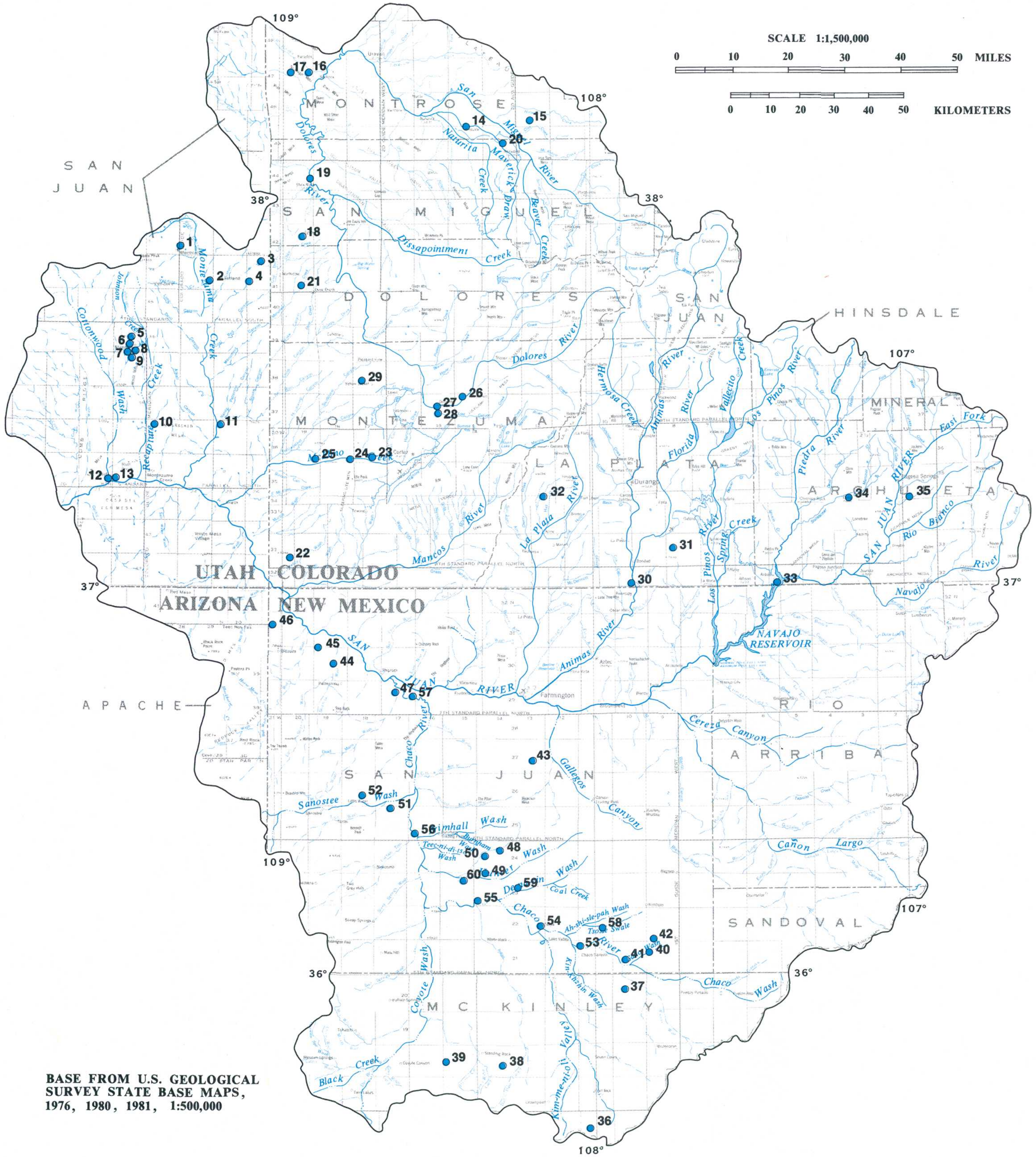
*Suspended-sediment concentrations and particle sizes are total concentration rather than total-recoverable concentrations.

Information is Available on Ground-Water Levels for Some Localities in Area 60

The U.S. Geological Survey ground-water monitoring network includes 60 wells in Area 60.

The ground-water monitoring network in Area 60 provides water-level information at 60 selected wells where water levels are measured periodically (fig. 4.1-1). The location of the network wells is shown in figure 4.1-2. Information including the local identifier, State, county, and period of record is given in table 4.1-1. Additional information about the well and type of data available for each well is given in section 6.2. The 15-digit well numbers shown in section 6.2 are unique identification numbers assigned to the well in WATSTORE. They are derived from the latitude and longitude location of the well. Data for these wells are available from: (1) The National Water Data Exchange (NAWDEX), (2) the National Water Data Storage and Retrieval System (WATSTORE), (3) the annual water-resources data reports of the U.S. Geological Survey, published as separate volumes for each State, and (4) reports on water availability for individual counties or areas published by the U.S. Geological Survey or cooperating agencies. Information also is available for numerous additional wells in this area that have only one measurement, or a series of measurements, but are not currently being monitored.

Figure 4.1-1 Ground-water observation well.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

●26 ACTIVE OBSERVATION WELL AND NUMBER

See section 6.2 for description of observation wells

Figure 4.1-2 Ground-water observation-well network.

Table 4.1-1 Observation wells.

Map Number	Local Identifier	State	County	Period of Record	Aquifer: Alluvium Valley Fill	Aquifer: Bedrock
1	(D-33-24) 30 DAB-1	Utah	San Juan	55-	--	X
2	(D-34-24) 25 AAD-1	Utah	San Juan	46-51, 53-	--	X
3	(D-34-26) 4 DAD-1	Utah	San Juan	46-51, 53-	--	X
4	(D-34-26) 30 CCB-1	Utah	San Juan	60-	X	--
5	(D-36-22) 22 DAA-1	Utah	San Juan	60-	--	X
6	(D-36-22) 27 DDB-2	Utah	San Juan	48-	--	X
7	(D-36-22) 34 ABB-1	Utah	San Juan	52-	--	X
8	(D-36-22) 35 BBA-1	Utah	San Juan	52-	--	X
9	(D-36-22) 3 ADB-1	Utah	San Juan	51-	--	X
10	(D-39-23) 5 ACC-1	Utah	San Juan	62-	--	X
11	(D-39-25) 5 ACA-1	Utah	San Juan	54, 62, 64-	--	X
12	(D-40-21) 25 ACD-1	Utah	San Juan	62-	--	X
13	(D-40-22) 30 BBB-1	Utah	San Juan	65-71, 74-	--	X
14	NB04501409 AAA1	Colorado	Montrose	76-	X	--
15	NB04601233 ACC1	Colorado	Montrose	76-	--	X
16	NB04701913 DAA	Colorado	Montrose	76-	--	X
17	NB04701917 BBA	Colorado	Montrose	76-	X	--
18	NB04201914 BBB	Colorado	San Miguel	76-	--	X
19	NB04401935 ACC	Colorado	San Miguel	77-	X	--
20	NB04501314 CCD	Colorado	San Miguel	77-	--	X
21	NB04101935 BCA	Colorado	Dolores	76-	--	X
22	NB03302025 CDC	Colorado	Montezuma	76-	--	X
23	NB03601734 BAB	Colorado	Montezuma	79-	--	X
24	NB03601836 DAC1	Colorado	Montezuma	79-	--	X
25	NB03601936 DCC1	Colorado	Montezuma	79-	--	X
26	NB03701405 DAC	Colorado	Montezuma	76-	--	X
27	NB03701516 DAD	Colorado	Montezuma	76-	--	X
28	NB03701522 BBB	Colorado	Montezuma	77-	--	X
29	NB03801721 BBA	Colorado	Montezuma	76-	--	X
30	NB03200918 BBB	Colorado	La Plata	76-	--	X
31	NB03300817 BDD1	Colorado	La Plata	77-	--	X
32	NB03401222 BBD	Colorado	La Plata	76-	--	X
33	NB03200520 ABA1	Colorado	Archulata	73-	--	X
34	NB03400311 CCD	Colorado	Archulata	73-76, 80-	--	X
35	NB03500131 ADA	Colorado	Archulata	73-76, 80-	--	X
36	16.11.17.4322	New Mexico	McKinley	59-	--	X
37	20.10.16.4413	New Mexico	McKinley	59-	--	X
38	NR086-3.95X17.20	New Mexico	McKinley	69, 76-77, 81-	--	X
39	NR086-12.95X15.30	New Mexico	McKinley	37, 81-	--	X
40	21.09.07.3334	New Mexico	San Juan	60, 80-	--	X
41	21.10.21.3444	New Mexico	San Juan	72, 80-	--	X
42	22.09.29.3443	New Mexico	San Juan	68, 80-	--	X
43	27.13.26.3411	New Mexico	San Juan	75, 80-	--	X
44	18-5.5X14.0	New Mexico	San Juan	78, 80-	--	X
45	18-6.7X10.5	New Mexico	San Juan	57, 80-	--	X
46	19-2.00X8.00	New Mexico	San Juan	57, 80-	--	X
47	32-7.55X2.47	New Mexico	San Juan	78, 81-	--	X
48	NR048-2.35X11.35	New Mexico	San Juan	52, 81-	--	X
49	NR048-4.0X16.9	New Mexico	San Juan	73, 81-	--	X
50	NR048-4.29X13.19	New Mexico	San Juan	54, 81-	--	X
51	NR049-7.75X5.80	New Mexico	San Juan	35, 52, 80-	--	X
52	49-12.85X3.35	New Mexico	San Juan	78, 81-	--	X
53	21.11.07.242	New Mexico	San Juan	77-	X	--
54	22.13.24.3222A	New Mexico	San Juan	77-	X	--
55	NR066.0668X0380	New Mexico	San Juan	76-	X	--
56	NR049.0380X0891	New Mexico	San Juan	77-	X	--
57	NR032.0505X0180	New Mexico	San Juan	77-	X	--
58	22.11.26.432	New Mexico	San Juan	77-	X	--
59	22.13.17.334	New Mexico	San Juan	77-	X	--
60	NR048.0898X1715	New Mexico	San Juan	77-	X	--

55- indicates 1955 to 1982.

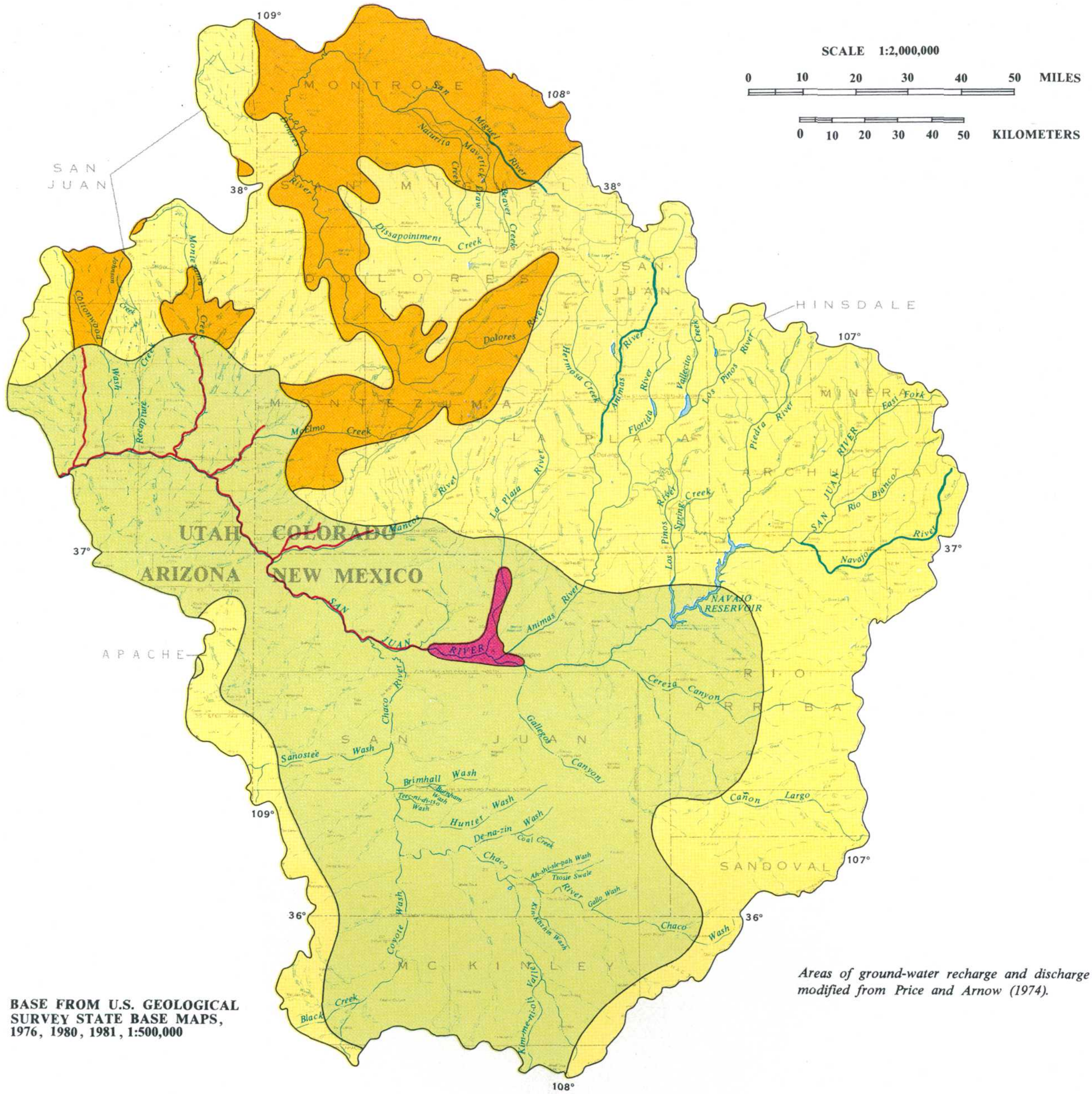
Greatest Recharge to Aquifers is in the Northern Part of Area

Recharge from precipitation is greatest in the high mountain country of Colorado, greatest discharge is in the San Juan Basin.

The source of virtually all ground water in transient storage in the area is the precipitation that falls within the region. Most of the rain and snow either is returned to the atmosphere at or near the place it falls by evapotranspiration and sublimation or becomes overland runoff. It has been estimated that only 4 percent of the precipitation becomes ground-water recharge (Upper Colorado Region State-Federal Inter-Agency Group, 1971c, p. i). This recharge includes precipitation percolation through the soil zone as well as seepage from streams and irrigation-return flow.

The principal areas of natural ground-water recharge are in the higher mountains and plateaus, which receive the largest volume of annual precipitation and produce the most runoff. The ground water moves from areas of recharge to areas of natural discharge, which include numerous widely scattered springs, gaining reaches of streams, and areas of phreatophyte growth (fig. 4.2-1). The principal areas of ground-water recharge and natural ground-water discharge are shown in figure 4.2-2.

Figure 4.2-1 Phreatophyte growth along arroyo.



EXPLANATION

PRINCIPAL AREAS OF NATURAL GROUND-WATER RECHARGE

Light blue depicts areas where average annual precipitation exceeds 12 inches and is assumed to be sufficient to contribute significantly to ground-water recharge; dark blue depicts outcrop areas of the more permeable geologic formations in the principal recharge areas.

PRINCIPAL AREAS OF NATURAL GROUND-WATER DISCHARGE

Blue lines are reaches of streams where gaging-station records indicate that at least 25 percent of the average annual streamflow is contributed by ground water. (See Iorns and others, 1965, p. 152, 259, 344.) There are assumed to be other significant gaining reaches of streams in ungaged areas of the region. Red lines are reaches of streams where large quantities of ground water are consumed by greasewood and saltcedar. In part after Iorns, others (1965, pls. 5, 7, 9).

AREA OF LITTLE OR NO NATURAL RECHARGE OR DISCHARGE

Local recharge occurs along reaches of some streams and in areas directly underlain by permeable rock; local discharge occurs mainly in widely scattered spring and seep areas.

MAJOR IRRIGATED AREA

Area where local ground-water recharge occurs from canals, ditches, and irrigated lands. Ground water levels generally are shallow, and ground water discharges by evapotranspiration and seepage to streams.

Figure 4.2-2 Areas of ground-water recharge and discharge.

Depth to Water Below Land Surface Varies Widely

Depth to water in most of the area ranges from 100 to 500 feet below land surface.

The depth to ground water ranges from only a few feet in some areas along the major streams and rivers to more than 1,000 feet in the western part of the San Juan Basin. Some wells in the western part of the San Juan Basin will flow under artesian pressure, but wells commonly must be drilled through several hundred feet of unsaturated rock before the artesian aquifers are reached (fig. 4.3-1). The depth to water also varies widely in wells drilled in the northern part of Area 60. In areas with relatively flat-lying aquifers, water levels may be at a relatively constant depth; however, in areas that are geologically complex or have significant topographic relief, the depth to water may vary widely in a relatively small area.

Ground water is present under both water-table (unconfined) and artesian (confined) conditions in Area 60. Water-table conditions commonly exist in shallow alluvial aquifers along the larger streams, in principal recharge areas, and in the relatively flat-lying rocks that are common in the Canyon Lands and Navajo sections of the region (see section 2.2). Artesian conditions are present locally throughout the region but are most prevalent in Cretaceous and older aquifers of the San Juan Basin. The depth to water shown in figure 4.3-2 is the depth below land surface at which water is first penetrated, and not the altitude to which the water will rise in a well.

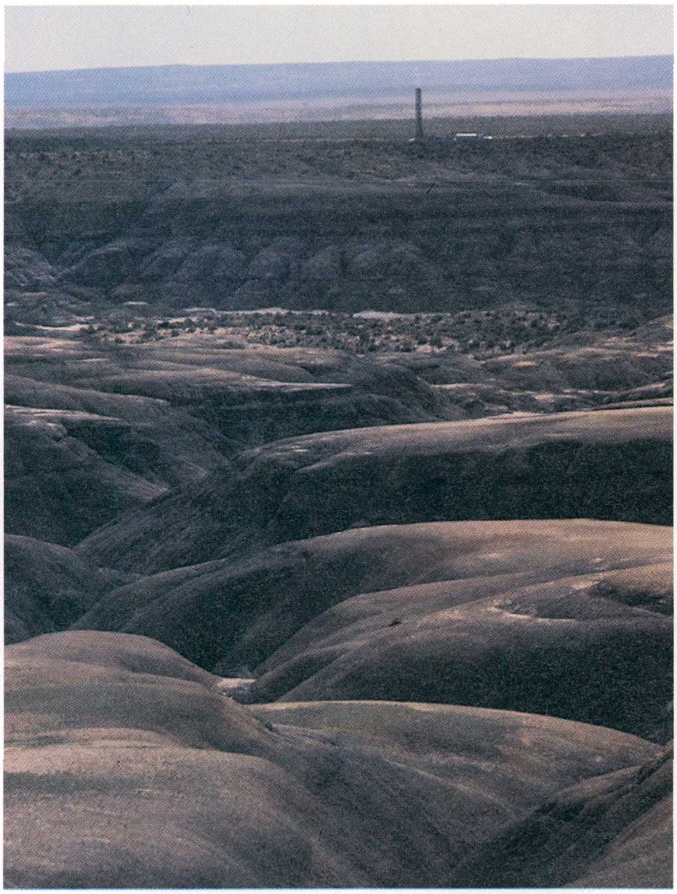
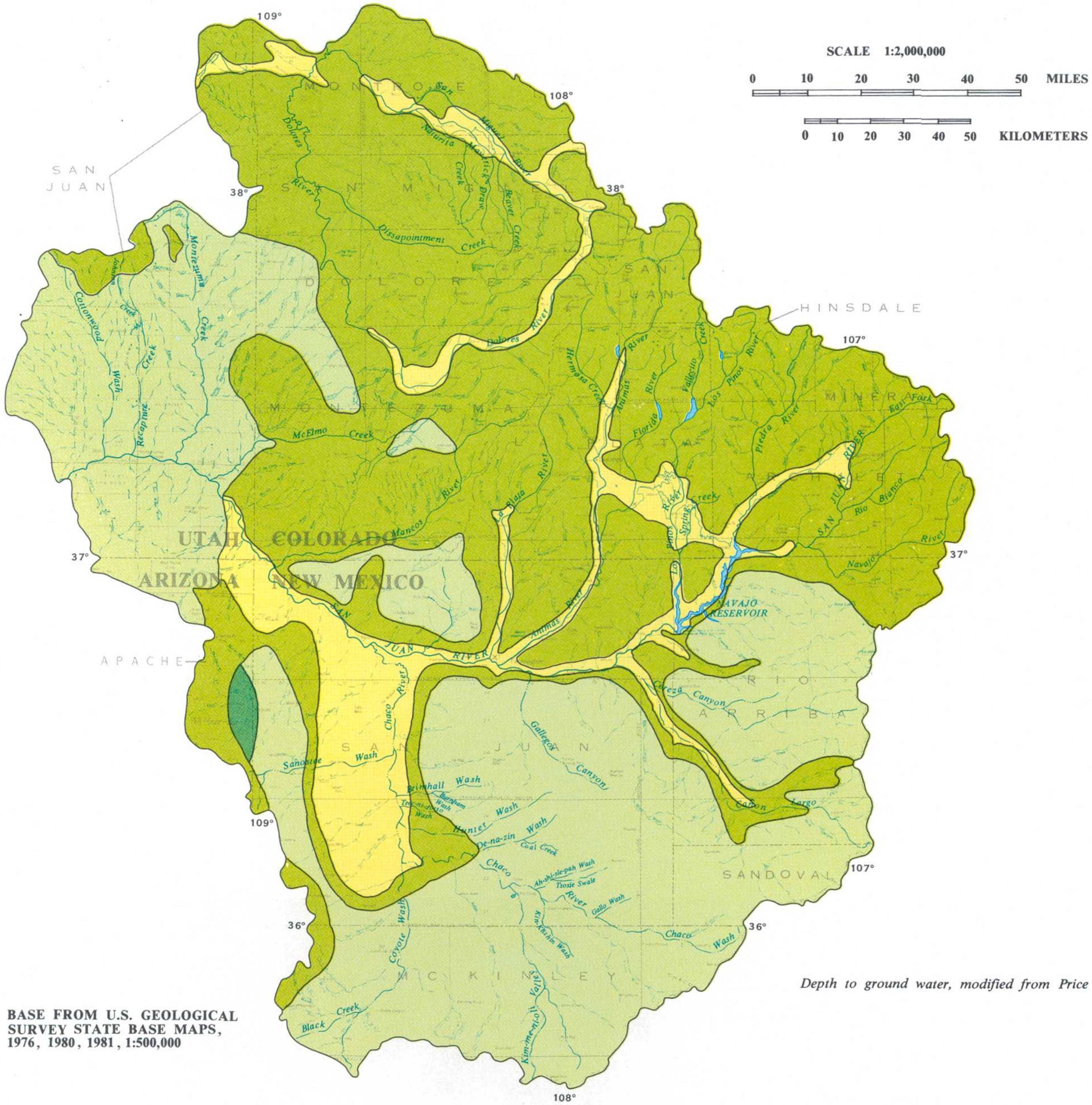


Figure 4.3-1 Water-well drilling rig in San Juan Basin.



Depth to ground water, modified from Price and Arnow (1974).

BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

DEPTH TO GROUND WATER, IN FEET BELOW LAND SURFACE

- **Less than 100** -- Less than 50 along perennial streams
- **100 to 500**
- **More than 500** -- More than 1000 locally
- **Unknown** -- Less than 50 along perennial streams to more than 500 beneath some plateaus

Figure 4.3-2 Depth to ground water.

Well Yields of 5 to 50 Gallons Per Minute Common in Most of the Area

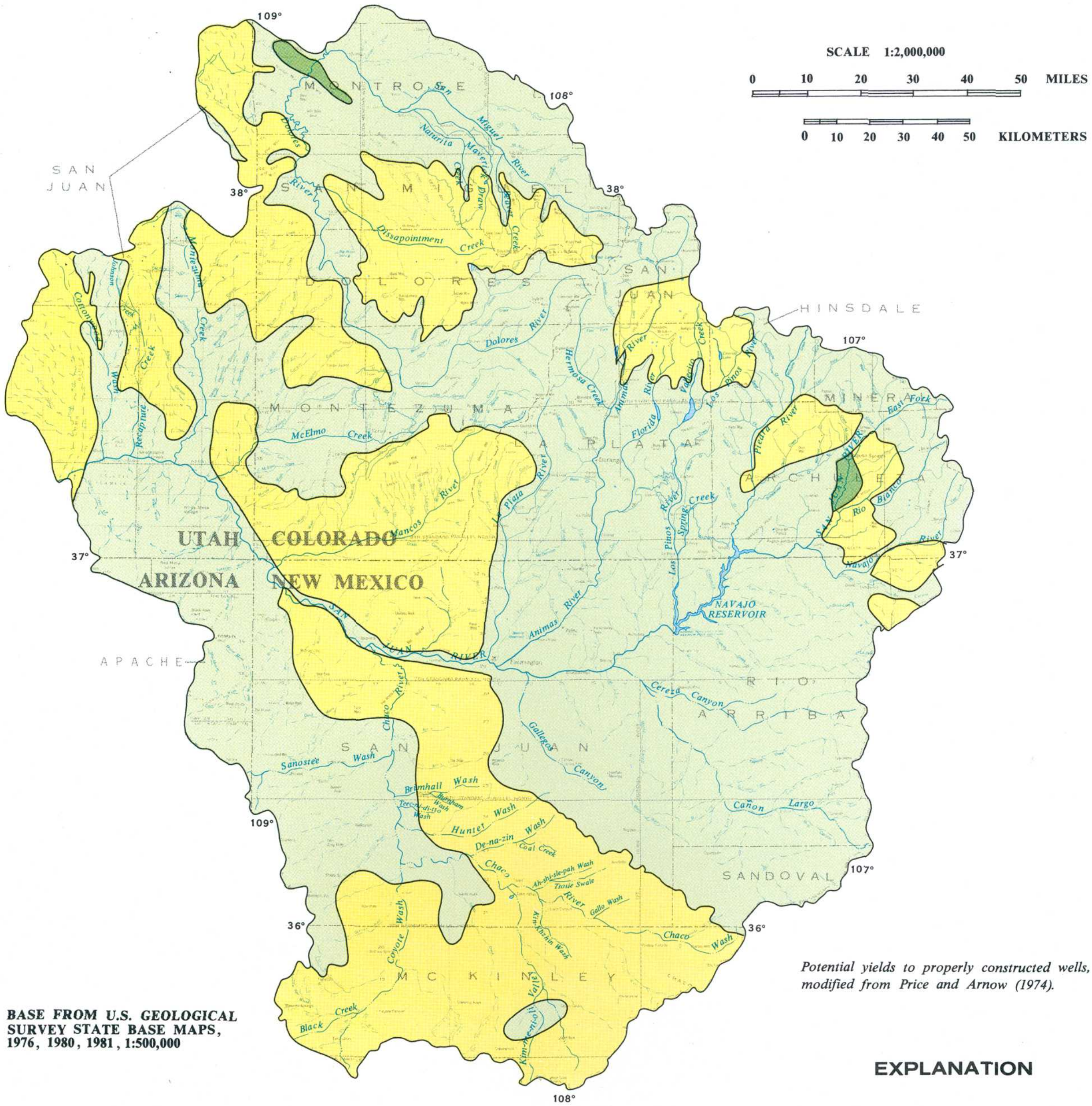
Rock permeability and saturated thickness determine potential yield.

Wells completed in aquifers containing fresh and slightly saline water may yield 5 to 50 gallons per minute throughout much of the area (fig. 4.4-1). The map showing well yields (fig. 4.4-2) indicates that this quantity is available in more than one-half the area. Although the volume of water in storage is great, the water cannot be recovered rapidly from wells. Most of the water in storage is present in sedimentary rocks that have relatively little permeability, and therefore yield water slowly

The principal aquifers in the New Mexico-Arizona part of the area are the Entrada Sandstone, Morrison Formation, sandstones in the Mesaverde Group, Picture Cliffs Sandstone, Nacimiento Formation, San Jose Formation, and alluvial deposits along some of the major rivers and streams. In the Colorado and Utah parts of the area, most of the aquifers mentioned above, where present, yield significant quantities of water to wells, as does the Dakota Sandstone. Permeable volcanics may yield large quantities of water to wells in some areas.

Well yields from all the aquifers mentioned may vary widely, depending on local depositional factors, which affect permeability, and saturated thickness of the rock, as well as the method of drilling and construction of the well. Some wells will yield considerably more or less water than indicated in figure 4.4-2 due to unique local conditions.

Figure 4.4-1 Wells in San Juan Basin.



EXPLANATION

POTENTIAL YIELD, IN GALLONS PER MINUTE

- 1 to 10
- 5 to 50
- 50 to 500

Figure 4.4-2 Potential yields to properly constructed wells

Quantity of Ground Water Available is Extremely Variable

The volume of recoverable ground water is estimated to range from 0 to as much as 9,600 acre-feet per square mile in the upper 100 feet of saturated rock.

The volume of recoverable ground water in storage in the upper 100 feet of saturated rocks has been estimated to range from slightly more than 0 to 9,600 acre-feet per square mile (Price and Arnow, 1974), as is shown in figure 4.5-1. Estimates of recoverable water in storage are based on the type of rock that comprises the aquifer. The total recoverable water in storage in the complete section of saturated rocks is many times the volume stored in the upper 100 feet. The volume of water recoverable from storage per square mile varies greatly from place to place and is dependent on the physical properties of the rock (fig. 4.5-2). The greatest recoverable volumes are in the Tertiary-age volcanics in San Juan County, Colorado, and the unconsolidated fluvial and glaciofluvial deposits of Quaternary age in western Montrose County, Colorado. Sandstones of wide areal extent and fluvial deposits along the major rivers and streams are the most significant source of water regionally.

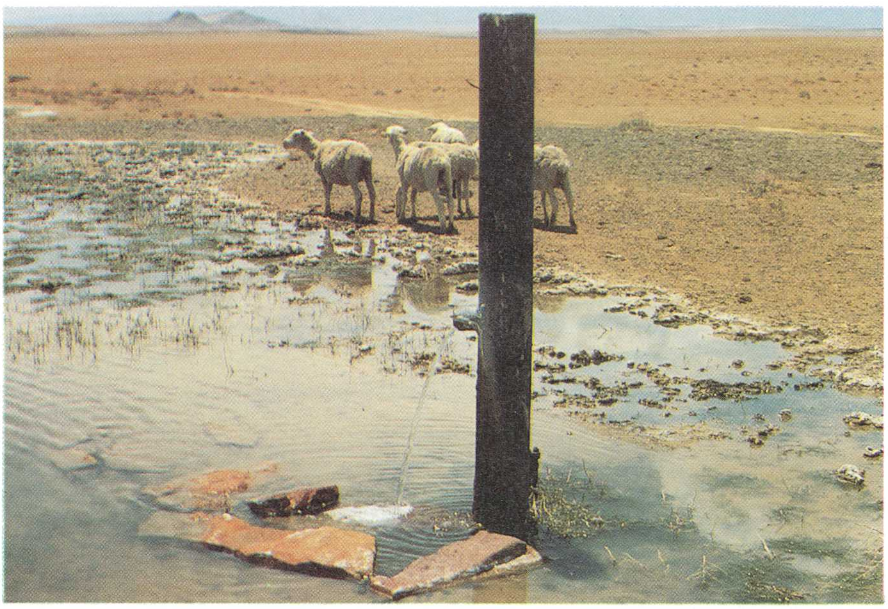
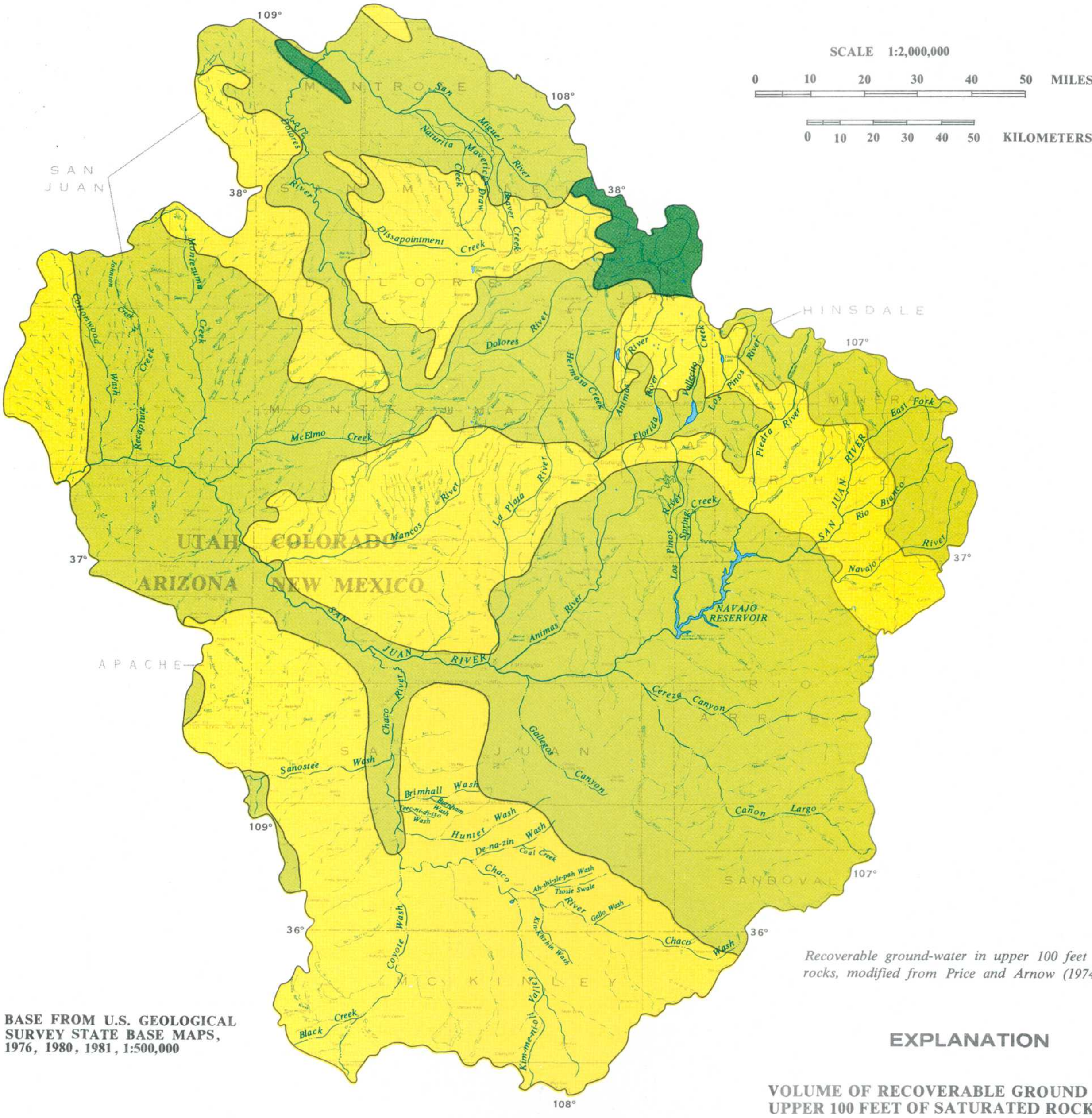


Figure 4.5-2 Artesian well in San Juan Basin.



BASE FROM U.S. GEOLOGICAL SURVEY STATE BASE MAPS, 1976, 1980, 1981, 1:500,000

Recoverable ground-water in upper 100 feet of saturated rocks, modified from Price and Arnow (1974).

EXPLANATION

VOLUME OF RECOVERABLE GROUND WATER IN UPPER 100 FEET OF SATURATED ROCKS, IN THOUSANDS OF ACRE-FEET PER SQUARE MILE.

- 0 to 0.6
- 0.6 to 1.3
- 1.3-9.6

Figure 4.5-1 Recoverable ground water in upper 100 feet of saturated rocks.

Water-Quality Data are Available in the WATSTORE for More Than 1,200 Wells and Springs

The water-quality characterization of ground waters in Area 60 is based on the WATSTORE records of 49 wells for which complete chemical analyses are available.

Water-quality data for more than 1,200 wells and springs are stored in WATSTORE's water-quality file. The locations of these wells and springs, which are mostly along river valleys in the northern part of the area and are widely scattered in the southern part, are shown in figure 4.6-1. The wells are mostly shallow windmill wells that were drilled either to augment the surface-water supplies of the rivers or to serve as the sole water-supply source. The wells include domestic wells, stock wells, and small community wells. A few of these wells, especially the deep wells, are oil, gas, uranium, or coal exploration holes that were converted into water-supply wells or ground-water observation wells.

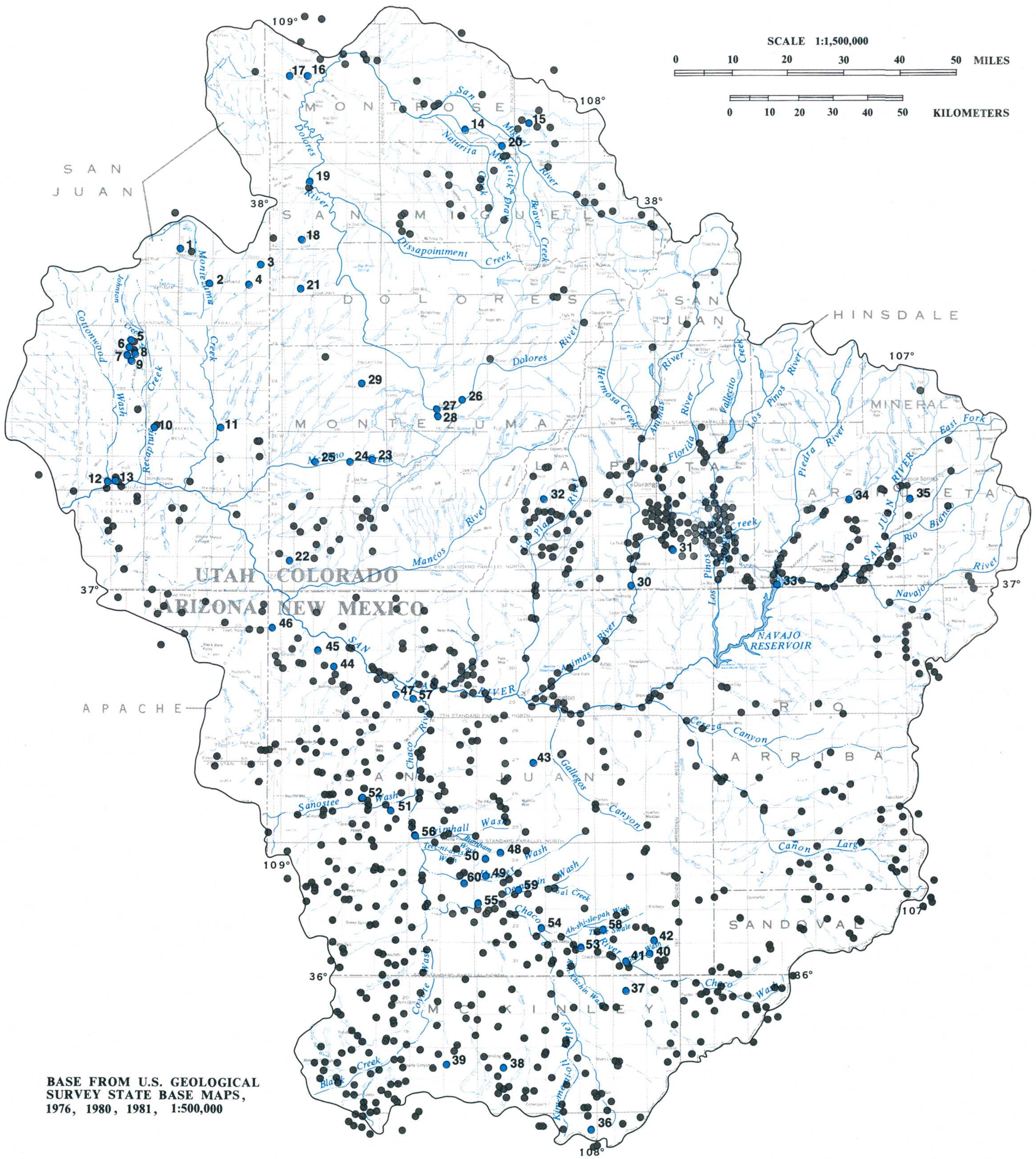
Water-quality data were collected as part of areal ground-water investigations conducted by the U.S. Geological Survey in cooperation with other Federal agencies and State governments. The U.S. Bureau of Reclamation, the U.S. Bureau of Indian Affairs, the U.S. Bureau of Land Management, and the State water-resources or mineral agencies of New Mexico, Colorado, Utah, and Arizona have been among the major cooperators.

Beginning in 1975 as part of the U.S. Geological Survey's Coal-hydrology program, additional wells were drilled principally within the Chaco River Basin and along the strippable-coal-resource areas of the Fruitland Formation for the purpose of obtaining additional hydrologic information. The U.S. Geological Survey also tested and monitored wells as part of site-specific hydrologic investigations for the Energy Mineral Rehabilitation Inventory and Analyses (EMRIA) program (U.S. Department of the Interior, Bureau of Land Management, 1977) for the Bisti and Kimbeto areas.

Most of the 1,200 wells and springs have few data in WATSTORE and were not used in the water-quality characterization. The following discussion of ground-water quality in Coal Area 60 is based on the data for 49 wells, which have more complete records. These wells were selected based on their location in relationship to existing or planned coal developments, the geologic formations from which water is obtained, and the completeness of the chemical analyses in their WATSTORE records. Indentifying information for these wells is given in section 6.2 along with the map numbers used for identification in this report. Also listed in section 6.2 are wells in the ground-water network described in section 4.1 that have not yet been entered in the WATSTORE file.

The water quality in a well remains relatively constant with time in comparison to the quality at a surface-water station; hence, fewer samples are needed to characterize the water in a well. The chemical quality of water may differ significantly within the same geologic formation because of distance from recharge areas and temperature and pressure differences within the formation.

The water quality in a well may be changed by the presence of drilling fluids or well-construction materials, by mixing of waters within the well, by leakage from one water-bearing zone to another water-bearing zone, or by drainage of surface water into the well. Conditions within a well are not always known and water samples from a few wells may not always accurately represent the water in the formation.



EXPLANATION

• GROUND-WATER STATION WITH LIMITED WATER-QUALITY RECORDS IN WATSTORE.

• SELECTED GROUND-WATER STATION WITH WATER-QUALITY RECORDS IN WATSTORE CONSISTING OF COMPLETE CHEMICAL ANALYSIS.

26 GROUND-WATER STATION NUMBER

See section 6.2 for description of observation wells

Figure 4.6-1 Location of wells and springs with water-quality records in the WATSTORE file.

Calcium and Bicarbonate Ions Are Predominant in Ground Waters with Small Dissolved-Solids Concentrations

The more saline ground waters contain larger concentrations of sodium ions with various mixtures of anions.

Constituents in ground water are derived principally from soluble minerals that the water contacts during its movement into and through the ground. A smaller proportion of constituents, including gases, is derived from the infiltrating rainfall, snowmelt, or streamflow. The dominant ions present in the water from various aquifers, grouped by geologic age, are shown in the trilinear diagram (Piper, 1944) of figure 4.7-1. Calcium and bicarbonate ions are the dominant ions in water with small dissolved-solids concentrations, such as the water in alluvial deposits and shallow sandstones. The source of the calcium and the bicarbonate may be the cementing material in sandstones. Saline ground water tends to have a greater sodium concentration with different mixtures of anions. Most sodium ions and sulfate ions probably originate from the shale deposits. Large concentrations of chloride may indicate the mixing of water in formations of marine origin that are incompletely leached and contain residuals of connate brine. Water in coal and some shale deposits tends to be saline but contains little sulfate, indicating a chemically-reducing environment caused by the carbon in coal or carbonaceous materials embedded within the shale. Oxidized sulfur species such as sulfate react in chemically-reducing environments to produce insoluble sulfide minerals.

The deeper aquifers of this area are confined layers of sandstone and are recharged where the sandstone formations crop out at higher altitudes (Lyford, 1979). The confining layers are shale with little hydraulic conductivity, which contain water that usually has greater salinity than the water in the confined sandstone layer. The water moves through shale formations very slowly in comparison to the movement of water within the sandstone. The salinity within a water-bearing formation generally increases with increasing distance down the hydraulic gradient from the recharge area.

There are several factors that may contribute to increases in salinity of ground water. The dissolved solids in the surface waters may be concentrated by evaporation or by contact with soluble salts before entering the ground. Evaporite salts buried within the geologic formations may be dissolved during contact with the moving water. The slow movement and direct contact of water with fine-grained mineral particles may allow for greater dissolution of the minerals. Leakage of saline water from adjacent geologic formations may increase the salinity in a formation. The greater temperatures underground increase the solubility of most minerals. The solubility of minerals increases with increased salinity or "ionic strength" of the water solution.

Water is required for many phases of coal development, and ground water could supply these needs; however, the factor that may limit the suitability of ground water for many uses in Coal Area 60 is its salinity.

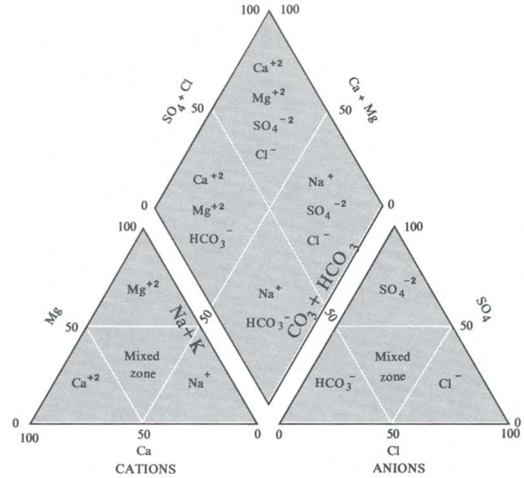
EXPLANATION

GROUND-WATER SOURCE

- ○ Quaternary alluvium
- □ Tertiary sandstone
- △ Cretaceous sandstone
- ◇ Cretaceous shales
- ✡ Cretaceous coals
- ▽ Jurassic sandstone
- * Triassic sandstone

DISSOLVED-SOLIDS RANGE, IN MILLIGRAMS PER LITER

- Less than 500 (blue)
- 500 to 1000 (green)
- 1000 to 3000 (yellow)
- 3000 or greater (red)



TRILINEAR DIAGRAM DOMINANT ION ZONES

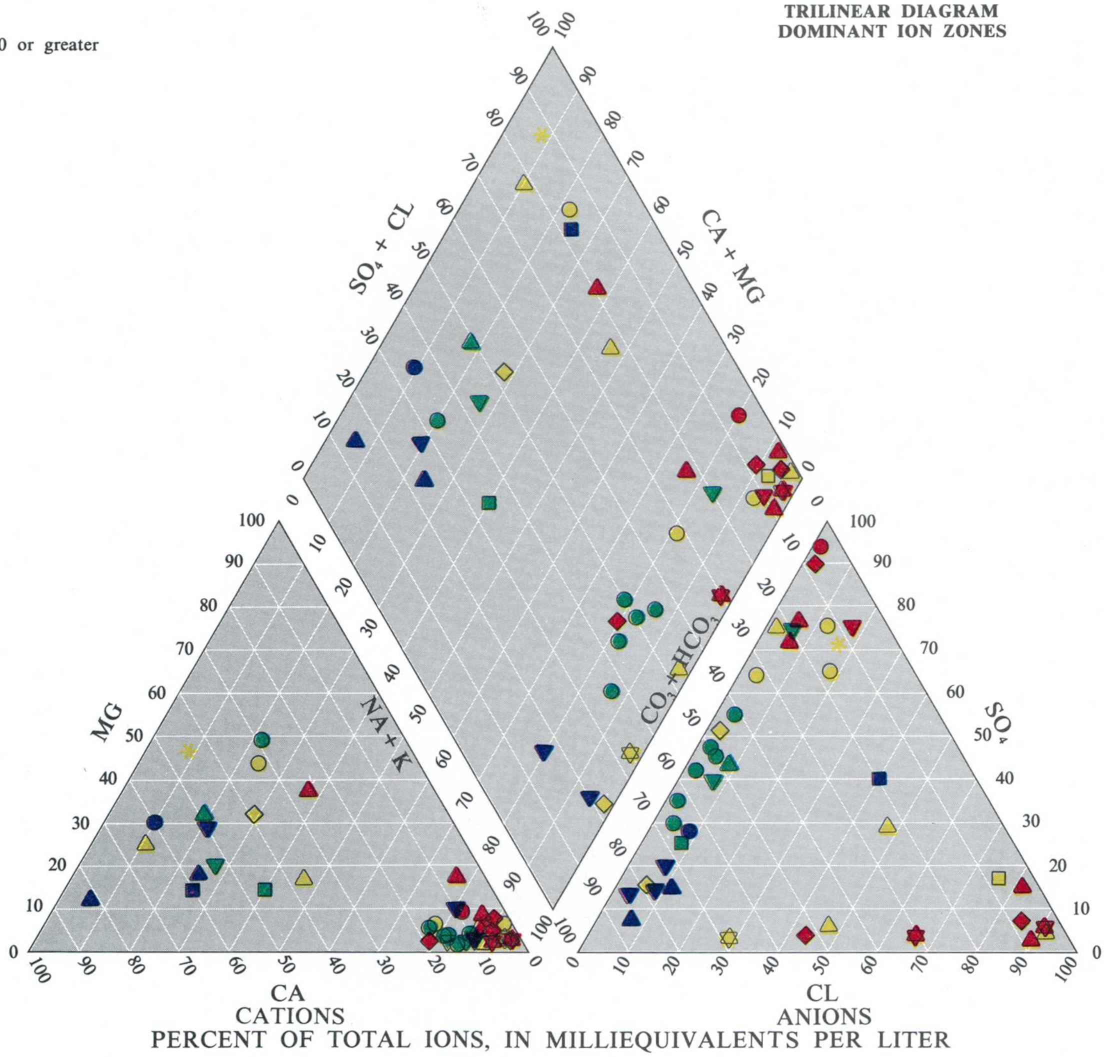


Figure 4.7-1 Trilinear (Piper) diagram for classifying ground waters of Coal Area 60 into water-quality types according to dominant ions.

Wide Ranges in the Average Values of Water-Quality Characteristics are Found in the Ground Waters of Area 60

Chemical constituents of concern in drinking-water supplies generally are present in concentrations less than the maximum contaminant levels specified in the National Interim Drinking Water Regulations.

The ranges of average values for selected water-quality characteristics in ground waters of Area 60 are presented in table 4.8-1 and 4.8-2. Arithmetic averages were calculated for water-quality data retrieved from the WATSTORE system for selected wells and springs. The wells and springs are grouped by the geologic age and the lithology of the water-bearing formations.

Wide ranges in average values for water-quality data are found for all the water-bearing formations. Generally, most of the values increase with distance away from the areas of ground-water recharge. The wide ranges also may indicate that soluble minerals from which the chemical constituents are derived are not uniformly distributed in these geologic formations. In addition, differences in pressure, temperature, salinity, the rate of water movement through the formations cause differences in solubilities of the chemical constituents.

Large average values for the water-quality characteristics in table 4.8-1 are present for all water-bearing units. Water in the Cretaceous-age shales generally has the greatest average values. Smaller averages generally are present in the water from sandstone deposits of all geologic ages. Ground waters in Coal Area 60 have pH values in the alkaline range and large bicarbonate concentrations. Dissolved iron and manganese concentrations appear to be larger in the water from alluvial deposits and Cretaceous sandstones than in the water from other geologic formations.

Ranges of average values are presented in table 4.8-2 for chemical constituents for which limits or maximum contaminant levels have been set for drinking-water supplies (U.S. Environmental Protection Agency, 1976). These limits are shown in table 4.8-2. Many of the averages indicate that these constituents are either absent in the ground water or are less than the maximum contaminant levels. Exceptions are the large average values for barium in water from Cretaceous shales, lead in water from all Cretaceous deposits, nitrate in water from Tertiary and Cretaceous sandstones, and fluoride in water from all deposits. Unusually large averages for selenium are present in water from Tertiary sandstones. Hutchison and Brogden (1976) reported these selenium concentrations in their water-quality report for the Southern Ute Indian Reservation.

The averages in these tables provide a brief summary of water-quality characteristics in ground-water supplies of the area. The variations of the average values indicate a need for detailed water-quality investigations of any local ground-water supply that is planned for use in, or that may be impacted by, development of the coal resources.

Table 4.8-1 Range of average chemical-quality values for selected ground-water stations grouped by geologic period and lithology.

[DS = dissolved solids, Na = sodium, SAR = sodium absorption ratio, SPC = specific conductance, B = boron, pH = standard unit, HCO_3 = bicarbonate, Fe = dissolved iron, Mn = dissolved manganese, mg/L = milligrams per liter, μg L = micrograms per liter, μmhos = micromhos per centimeter at 25 C°, gross alpha alpha radioactivity as natural uranium (U) from all dissolved sources]

Geologic Period	Lithology	DS (mg/L)	Na (mg/L)	SAR	SPC (μmhos)	B (μg/L)	pH	HCO_3 (mg/L)	Fe (μg/L)	Mn (μg/L)	Gross Alpha as U (μg/L)
		Range of Average Chemical-quality Values									
Quaternary	alluvium	465 to 10,100	18 to 2,700	0.7 to 33	720 to 11,100	46 to 2,300	7.5 to 8.2	234 to 527	10 to 8,060	10 to 1,760	8.8 to 159
Tertiary	sandstone	756 to 1,630	111 to 550	2.0 to 27	1,080 to 2,890	80 to 325	7.3 to 8.2	94 to 448	15 to 50	10 to 30	--
Cretaceous	sandstone	280 to 9,530	7.3 to 3,300	0.2 to 114	468 to 15,300	20 to 605	7.0 to 9.0	179 to 1,030	10 to 7,700	10 to 790	9.4 to 500
Cretaceous	shale	1,250 to 11,600	130 to 3,470	2.2 to 95	1,640 to 18,700	4.0 to 625	6.9 to 12.3	176 to 1,650	20 to 80	12 to 80	120 to 235
Cretaceous	coal	2,440 to 4,850	987 to 1,900	73 to 114	4,230 to 8,450	225 to 1,150	8.0 to 11.8	105 to 1,830	30 to 65	10 to 40	29 to 72
Jurassic	sandstone	297 to 8,320	18 to 2,800	0.5 to 84	500 to 10,000	30 to 1,900	7.5 to 8.5	166 to 570	0 to 350	8.0 to 130	7.2 to 780
Triassic	sandstone	1,800 to --	44 to --	0.5 to --	2,420 to --	370 to --	7.5 to --	228 to --	130 to --	10 to --	--

Table 4.8-2 Range of average trace element concentrations found at selected ground-water stations grouped by geologic period and lithology.

Values are in micrograms per liter (ug/L) or milligrams per liter (mg/L) as indicated. Limits shown are those in the National Interim Drinking Water Standards of 1977.

Geologic Period	Lithology	As (μg/L)	Ba (μg/L)	Cd (μg/L)	Cr (μg/L)	Pb (μg/L)	Hg (μg/L)	Se (μg/L)	Ag (μg/L)	F (mg/L)	NO_3 as N (mg/L)
		Range of Average Concentrations									
LIMITS		50	1000	10	50	50	2.0	10	50	1.8	10
Quaternary	alluvium	1.0 to 3.9	56 to 118	1.1 to 2.0	2.5 to 14	2.9 to 4.7	0.1 to --	0.6 to 4.8	0.0 to --	0.2 to 2.0	0.0 to 3.0
Tertiary	sandstone	1.0 to --	--	--	--	--	--	32 to 13,000	--	0.4 to 3.2	10 to 70
Cretaceous	sandstone	0.0 to 0.7	200 to 800	1.7 to 4.0	0.0 to 15	5.0 to 134	0.0 to 0.3	0.0 to 1.0	0.0 to --	0.3 to 7.0	0.0 to 20
Cretaceous	shale	0.5 to 1.5	300 to 3,000	0.0 to 2.0	10 to 15	1.7 to 45	0.0 to 0.4	1.0 to 12.0	0.0 to --	0.3 to 2.3	0.0 to 8.5
Cretaceous	coal	0.5 to 2.5	150 to 200	0.0 to 1.3	5.0 to 15	3.0 to 32	0.1 to 0.2	0.5 to 1.0	--	1.2 to 2.6	0.0 to 0.6
Jurrassic	sandstone	1.0 to 1.5	70 to 100	0.0 to 1.0	0.0 to --	3.0 to 4.0	0.1 to --	0.0 to 1.0	0.0 to --	0.2 to 5.3	0.0 to 0.1
Triassic	sandstone	--	--	--	--	--	--	--	--	0.6 to --	-- to 0.2

NAWDEX, WATSTORE, and OWDC Have Water Data Information

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

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

(1) The National Water Data Exchange (NAWDEX), which 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 is available.

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

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

A more detailed explanation of these three activities are given in sections 5.2, 5.3, and 5.4.

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 (fig. 5.2-1). 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 requester to the organization that retains the data required. To accomplish this service, NAWDEX maintains a computerized Master Water Data Index (fig. 5.2-2), 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. 5.2-3) 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)
U.S. Geological Survey
421 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
Telephone: (703) 860-6031
FTS 928-6031
Hours: 7:45 - 4:15 Eastern Time

NEW MEXICO
Western Bank Building
505 Marquette NW, Room 720
Albuquerque, NM 87102

COLORADO
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

UTAH
1016 Administration Building
1745 West, 1700 South
Salt Lake City, UT 84104

ARIZONA
Federal Building
301 W. Congress. FB-44
Tucson, AZ 85701

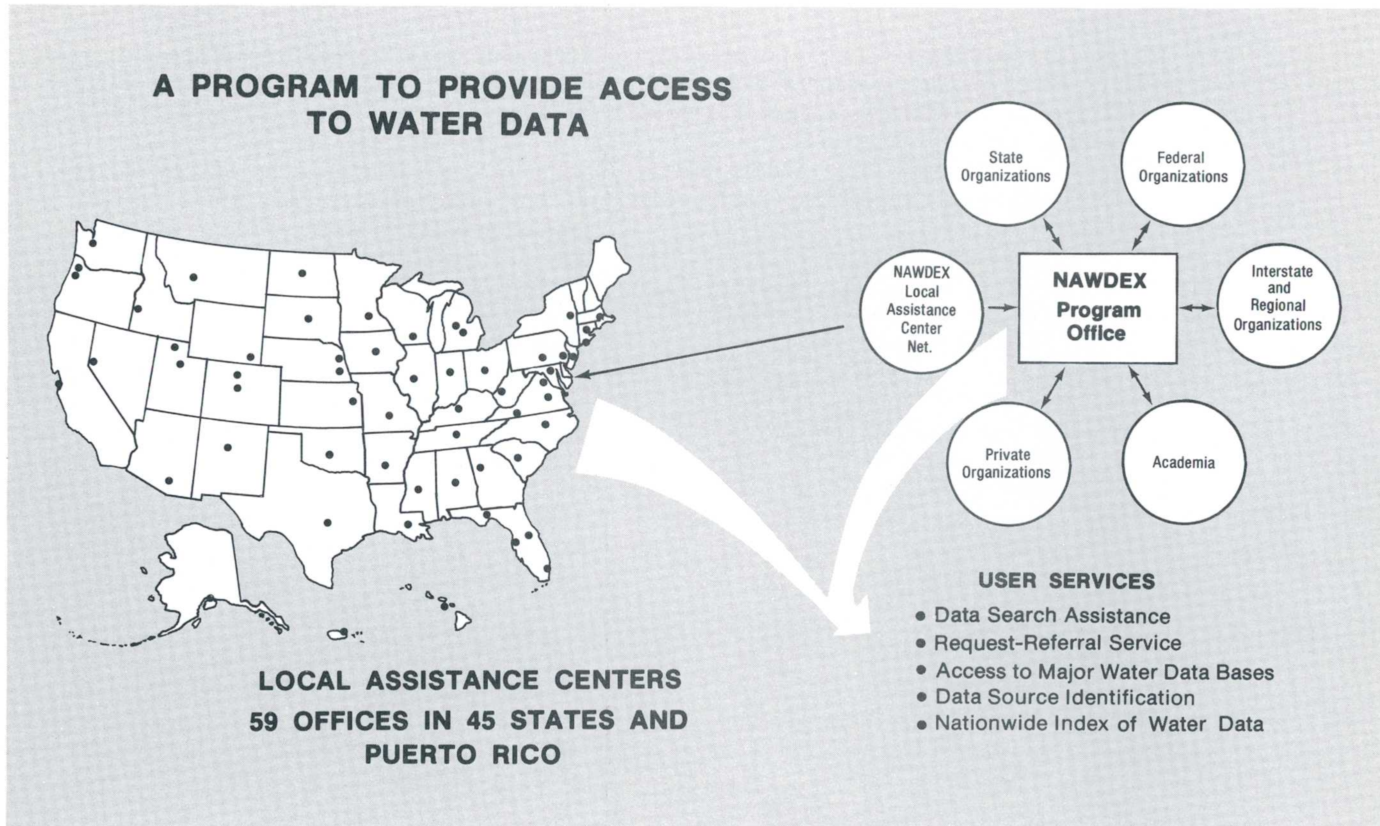


Figure 5.2-1 Access to water data.

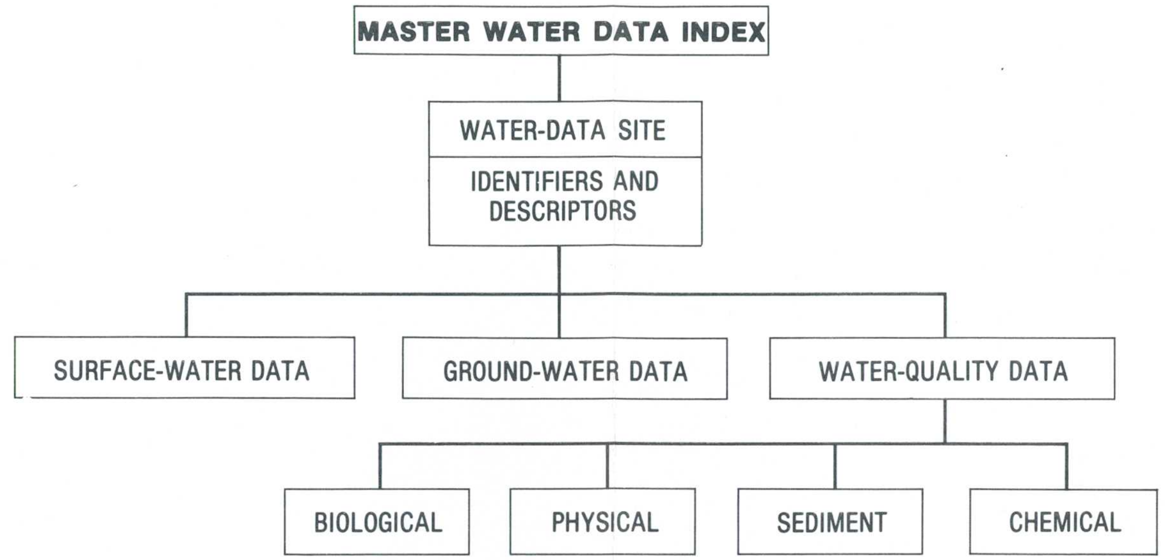


Figure 5.2-2 Master water-data index.

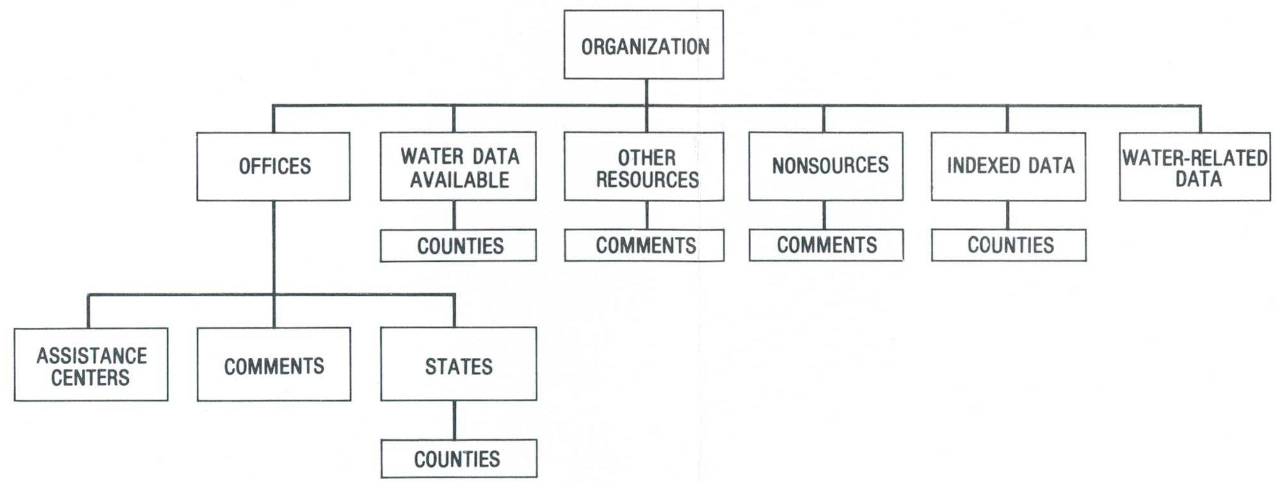


Figure 5.2-3 Water-data sources directory.

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:

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

NEW MEXICO
Western Bank Building
505 Marquette NW, Room 720
Albuquerque, NM 87102

COLORADO
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

UTAH
1016 Administration Building
1745 West, 1700 South
Salt Lake City, UT 84104

ARIZONA
Federal Building
301 W. Congress. FB-44
Tucson, AZ 85701

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

The WATSTORE system consists of several files in which data are grouped and stored by common characteristics and data-collection frequencies. The system is also designed to allow for the inclusion of additional data files as needed. Currently, files are maintained for the storage of: (1) surface-water, quality-of-water, and ground-water data measured on a daily or continuous basis; (2) annual peak values for streamflow stations; (3) chemical analyses for surface- and ground-water sites; (4) water parameters measured more frequently than daily; and (5) geologic and inventory data for ground-water sites. In addition, an index file of sites for which data are stored in the system is also maintained (fig. 5.3-1). A brief description of each file is as follows:

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

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

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

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

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

Ground-Water Site-Inventory File: This file is discussed above, but it is cross-referenced to the Water-Quality File and the Daily Values File. It contains inventory data about wells, springs, and other sources of ground water. The data included are site location and identification, geohydrologic characteristics, well-construction history, and one-time field measurements such as water temperature. The file is designed to accommodate 255 data elements and currently contains data for more than 800,000 sites.

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

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

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

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

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

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

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

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

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

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

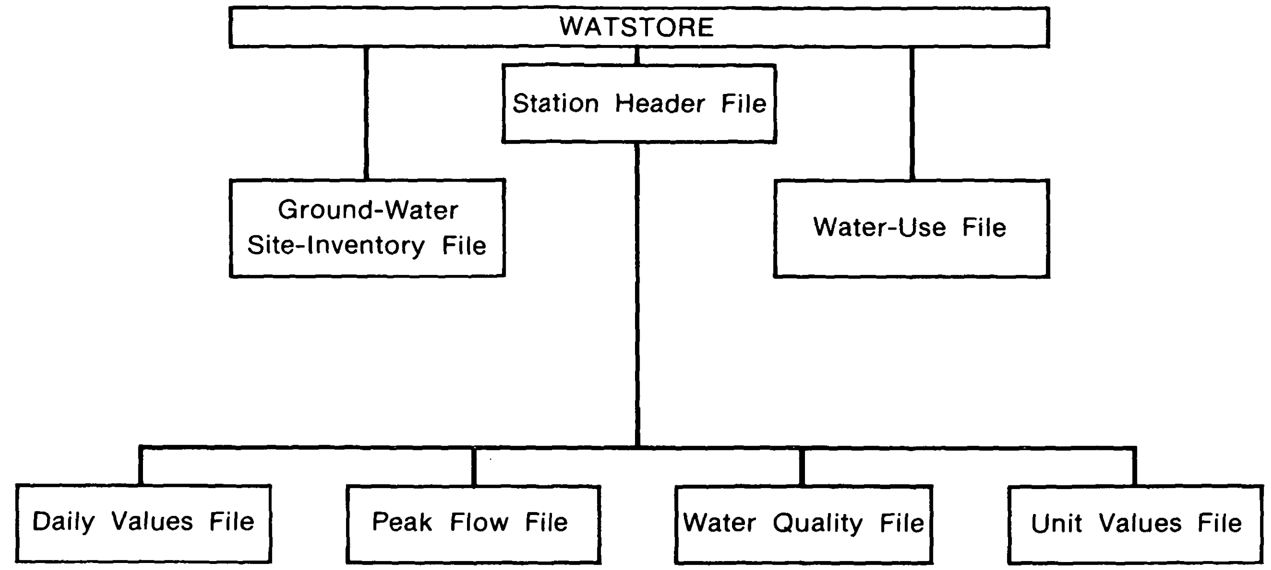


Figure 5.3-1 Index-file stored data.

District Chief - USGS, WRD
New Mexico District
Western Bank Building
505 Marquette NW, Room 720
Albuquerque, NM 87102

District Chief - USGS, WRD
Colorado District, MS 415
Box 25046, Denver Federal Center
Denver, Colorado 80225

District Chief - USGS, WRD
Utah District
1016 Administration Building
1745 West, 1700 South
Salt Lake City, Utah 84104

District Chief - USGS, WRD
Arizona District
Federal Building
301 W. Congress, FB-44
Tucson, Arizona 85701

U.S. Geological Survey District Offices in New Mexico, Colorado, Utah and Arizona.

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. 5.4-1): volume I, Eastern Coal province; volume II, Interior Coal province; volume III, Northern Great Plains and Rocky Mountain Coal provinces; volume IV, Gulf Coast Coal province; and volume V, Pacific Coast and Alaska Coal provinces. The information presented will aid the user in obtaining data for evaluating the effects of coal mining on water resources and in developing plans for meeting additional water-data needs. The report does not contain the actual data; rather, it provides information that will enable the user to determine if needed data are available.

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

Those who need additional information from the Catalog file or who need assistance in obtaining water data should contact the National Water Data Exchange (NAWDEX) (see section 5.2).

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

NEW MEXICO
Western Bank Building
505 Marquette NW, Room 720
Albuquerque, NM 87102

or

COLORADO
MS 415 Box 25046 Denver Federal Center
Lakewood, CO 80225

or

UTAH
1016 Administration Building
1745 West, 1700 South
Salt Lake City, UT 84104

or

ARIZONA
Federal Building
301 W. Congress. FB-44
Tucson, AZ 85701

or

Office of Surface Mining
U.S. Department of the Interior
219 Central Avenue NW
Albuquerque, NM 87102

Telephone: (505) 766-1486
FTS 474-1486

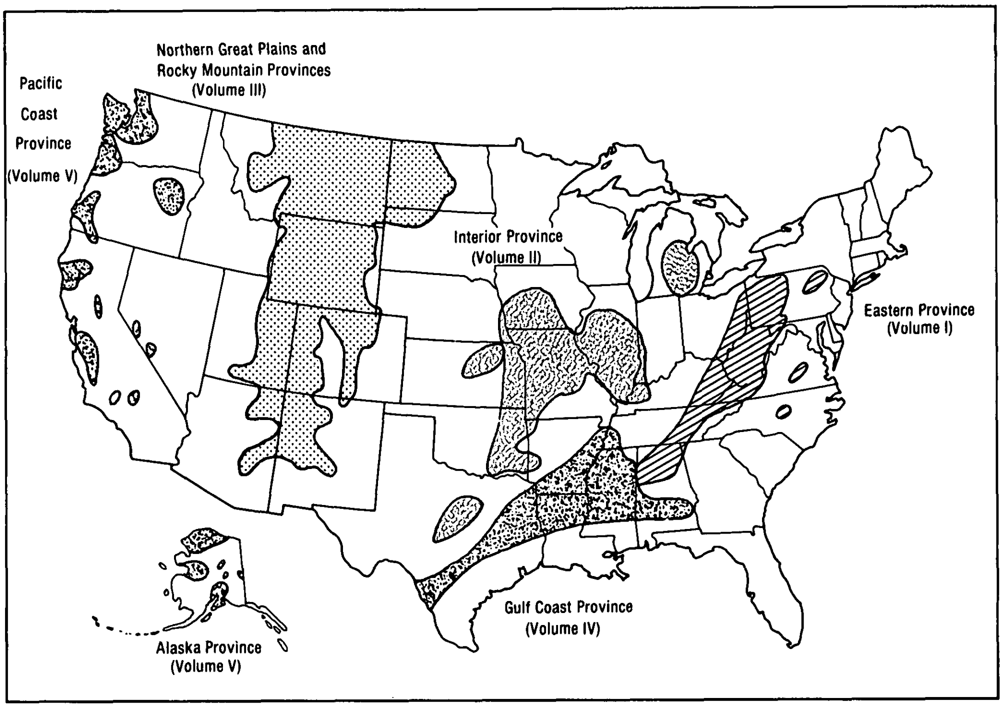


Figure 5.4-1 Index volumes and related provinces.

6.0 SUPPLEMENTAL INFORMATION FOR AREA 60

6.1 Index of Selected Surface-Water Stations

Table 6.1-1 Index of selected surface-water stations.

MAP NUMBER	STATION NUMBER	STATION NAME	LATITUDE ° ' "	LONGITUDE ° ' "	DRAINAGE AREA (square miles)
1	09165000	Dolores River below Rico, CO	37 38 20	108 03 35	105
2	09166500	Dolores River at Dolores, CO	37 28 16	108 30 15	504
3	09168100	Disappointment Creek near Dove Creek, CO	37 52 36	108 34 57	147
4	09169500	Dolores River at Bedrock, CO	38 18 37	108 53 05	2024
5	09171100	Dolores River near Bedrock, CO	38 21 29	108 49 54	2145
6	09172500	San Miguel River near Placerville, CO	38 02 05	108 07 15	308
7	09173000	Beaver Creek near Norwood, CO	37 58 12	108 11 42	40.6
8	09175000	West Naturita Creek near Norwood, CO	37 58 33	108 19 38	53.0
9	09175400	Maverick Draw near Norwood, CO	38 10 32	108 19 52	41.3
10	09175500	San Miguel River at Naturita, CO	38 13 04	108 33 57	1069
11	09177000	San Miguel River at Uravan, CO	38 21 26	108 42 44	1499
12	09339900	EF San Juan R AB Sand Creek, nr Pagosa Sprs, CO	37 23 23	106 50 26	64.1
13	09340000	East Fork San Juan River nr Pagosa Springs, CO	37 22 10	106 53 30	86.9
14	09343000	Rio Blanco near Pagosa Springs, CO	37 12 46	106 47 38	58.0
15	09346000	Navajo River at Edith, CO	37 00 10	106 54 25	172
16	09346400	San Juan River near Carracas, CO	37 00 49	107 18 42	1230
17	09349800	Piedra River near Arboles, CO	37 05 18	107 23 50	629
18	09352900	Vallecito Creek near Bayfield, CO	37 28 39	107 32 35	72.1
19	09354500	Los Pinos River at La Boca, CO	37 00 34	107 35 56	510
20	09355000	Spring Creek at La Boca, CO	37 00 40	107 35 47	58.0
21	09355500	San Juan River near Archuleta, NM	36 48 05	107 41 51	3260
22	09356565	Cañon Largo nr Blanco, NM	36 41 24	107 45 21	--
23	09357100	San Juan River at Hammond Br nr Bloomfield, NM	36 41 22	108 05 42	--
24	09357250	Gallegos Canyon nr Farmington, NM	36 38 52	108 07 30	--
25	09357500	Animas River at Howardsville, CO	37 49 59	107 35 56	55.9
26	09361000	Hermosa Creek near Hermosa, Co	37 25 19	107 50 40	172
27	09361500	Animas River at Durango, CO	37 16 45	107 52 47	692
28	09363050	Florida R Bl Flor farmer's ditch, nr Durango, CO	37 17 42	107 47 28	108
29	09363200	Florida River at Bondad, CO	37 03 24	107 52 09	221
30	09363500	Animas River near Cedar Hill, NM	37 02 17	107 52 25	1090
31	09364500	Animas River at Farmington, NM	36 43 12	108 12 08	1360
32	09365000	San Juan River at Farmington, NM	36 43 22	108 13 30	7240
33	09365500	La Plata River at Hesperus, CO	37 17 23	108 02 24	37.0
34	09366500	La Plata River at Colorado-New Mexico State Line	36 59 59	108 11 17	331
35	09367500	La Plata River near Farmington, NM	36 44 23	108 14 51	583
36	09367540	San Juan R nr Fruitland, NM	36 44 25	108 24 09	--
37	09367555	Shumway Arroyo near Fruitland, NM	36 48 23	108 23 42	62.8
38	09367561	Shumway Arroyo near Waterflow, NM	36 46 24	108 26 26	73.8
39	09367660	Chaco Wash nr Starlake Trading Post, NM	35 56 07	107 31 39	--
40	09367680	Chaco Wash at Chaco Canyon National Monument, NM	36 01 43	107 55 04	578
41	09367682	Gallo Wash at Chaco National Monument, NM	36 02 06	107 53 25	--
42	09367685	Ah-Shi-Sle-Pah Wash near Kimbeto, NM	36 09 18	107 56 47	8.21
43	09367710	De-Na-Zin-Wash nr Bisti Trading Post, NM	36 13 51	108 11 57	183
44	09367900	Black Springs Wash nr Mexican Springs, NM	35 45 40	108 49 00	77.05
45	09367930	Hunter Wash at Bisti Trading Post, NM	36 16 37	108 15 12	45.6
46	09367934	Teec-Ni-Di-Tso Wash nr Burnham, NM	36 18 26	108 27 22	--
47	09367936	Burnham Wash nr Burnham, NM	36 21 11	108 27 16	--
48	09367938	Chaco River nr Burnham, NM	36 21 57	108 33 57	--
49	09367950	Chaco River near Waterflow, NM	36 43 28	108 35 57	4350
50	09368000	San Juan River at Shiprock, NM	36 47 32	108 43 54	12,900
51	09371000	Mancos River near Towaoc, CO	37 01 39	108 44 27	550
52	09371010	San Juan R at Four Corners, Co	37 00 20	108 02 00	--
53	09371420	McElmo Creek above Alkali Canyon, nr Cortez, CO	37 19 38	108 38 55	147
54	09371700	McElmo Creek below Cortez, Co	37 20 26	108 48 19	283
55	09372000	McElmo Creek near Colorado-Utah State Line	37 19 27	109 00 54	346
56	09378630	Recapture Creek nr Blanding, UT	37 45 20	109 28 33	3.77
57	09378650	Recapture Cr Bl Johnson Cr nr Blanding, UT	37 40 51	109 27 43	50.2
58	09378700	Cottonwood Wash nr Blanding, UT	37 33 38	109 34 41	205
59	355841108081810	20N.12W.08.323 KNMO Wash 9 mi S Lk V School, NM	35 58 41	108 08 18	--
60	360439108041010	21N.12W.01.3412 Kin Klizhin Wash nr Chaco, NM	36 04 39	108 04 10	--
61	360743107571410	22N.11W.24.214 Tsosie Swale nr Kimbeto, NM	36 07 43	107 57 14	--
62	360809108323410	NR067.0225X0788 Coyote Wash nr Naschitti, NM	36 08 09	108 32 34	--
63	361137108202110	NR066.0500X0388 Chaco R Bl Denazin W nr Bisti, NM	36 11 37	108 20 21	--
64	361404108074710	Coal Creek above Tanner Lake near Bisti Tp, NM	36 14 07	108 07 47	47.5
65	361751108325210	NR049.0268X1397 Chaco R Bl Hunter Wa nr Burn., NM	36 17 51	108 32 52	--
66	362813108344110	NR049.0433X0206 Sanostee Wash nr Sanotee Tp, NM	36 28 13	108 34 41	--
67	363417108334910	NR032.0352X1230 Chaco R ab 4CPP nr Fruitland, NM	36 34 17	108 33 49	--
68	09379500	San Juan R nr Bluff, UT	37 08 49	109 51 51	23,000

Table 6.1-1 Index of selected surface-water stations.

MAP NUMBER	FLOW perennial (P) or ephemeral (E)	HYDROLOGIC DATA PERIOD OF RECORD (BEGIN YEAR-END YEAR)			
		STREAMFLOW	MAJOR CHEMICAL CONSTITUENTS	TRACE ELEMENTS	SUSPENDED SEDIMENT
1	P	1951-	1971-	1971-78	----
2	P	1957-	1976-	1978	----
3	E	1971-	1976-	1980	----
4	P	1971-	1970-	1978	----
5	P	1895-1903, 1912-	1972-	1978	----
6	P	1909-12, 1930-34, 1942-	1976-	1978	----
7	P	1941-67, 1975-	1976-	1977-	1977-
8	P	1940-52, 1975-	1976-	1977-	1977-
9	P	1975-	1976-80	----	----
10	P	1917-29, 1940-	1976-	1977-	1977-
11	P	1954-62, 1973-	1947-	1972-78	----
12	P	1956-	1958-	----	----
13	P	1935-	1956-	1973-74	----
14	P	1935-62	1958-74	1970-74	1962-74
15	P	1912-	1969-	1969-73	1970-74
16	P	1961-	1969-	1969-73	1970-73
17	P	1962-	1969-	1969-73	1970-73
18	P	1962-	1958-	1970-	1963-
19	P	1950-	1969-	1969-74	1970-73
20	P	1950-	1958-	1973-74	----
21	P	1954-	1954-	1954-	1955-
22	E	1978-	1958, 1977-	1958, 1977-	1977-
23	P	1978-	1977-	1977-	1977-
24	E	1978-	1978-	1978-	1978-
25	P	1935-	1958-75	1959-75	1972-75
26	P	1911-14, 1919-28, 1939-	1958-80	----	----
27	P	1911-	1958-	1975	----
28	P	1967-	1976-	----	----
29	P	1956-63, 1967-	1958-	----	----
30	P	1933-	1969-73	1969-73	1970-73
31	P	1904-	1941-	1955-	1950-
32	P	1913-	1962-	1969-	1977-
33	P	1904-06, 1910, 1917-	----	----	----
34	E	1920-	1958-	1977-	1977-
35	E	1938-	1958-59, 1973-	1973-	1977-
36	P	1978-80	1977-	1977-	1977-80
37	E	1975-	1976-	1976-	1976-
38	P	1974-	1974-	1974-	1974-
39	E	1978-	1977-	1978-	1977-
40	E	1980-	1976-	1976-	1976-
41	E	1976-	1979	1979	1979
42	E	1977-	1977-	1978-	1977-
43	E	1976-	1976-	1974-	1974-
44	E	1979-	1981-	----	----
45	E	1975-	1974-	1976-	1974-
46	E	1978-	1979-	1979-80	1978-80
47	E	1978-	1977-	1978-80	1977-80
48	E	1978-	1977-	1978-	1977-
49	P	1978-	1969-	1975-	1975-
50	P	1911, 1927-	1941-45, 1957-	1958-	1950-
51	E	1920-43, 1951-	1969-	1973-75	----
52	P	1977-	1977-	1977-	1977-
53	P	1972-	1976-	----	----
54	P	1972-	1976-	----	----
55	P	1951-	1961-	1977-	1977-
56	E	1965-	1971-	----	----
57	E	1975-	1978-	----	----
58	E	1959-	1969-	----	1968-71
59	E	1978-	1978-	1978-	1978-
60	E	1976-	1976-78	1976	1976
61	E	1978-79	1978-80	1978-80	1978-79
62	E	1976-78	1976-78	1976-77	1977-78
63	E	1976-79	1976-79	1977	1976-79
64	E	1975	1975	1975	1975-77
65	E	1976-78	1976-78	1976-78	1976-78
66	E	1976-79	1976-79	1976	1976-79
67	E	1976-79	1976-79	1976	1976-79
68	P	1914-	1929-	1970-	1929-

Table 6.2-1 Index of selected ground-water stations.

EXPLANATION

State: CO., COLORADO; NM, NEW MEXICO; UT, UTAH;
Geologic Unit: 110 ALVM, QUATERNARY ALLUVIUM; 110 AVMB, QUATERNARY ALLUVIUM and BOLSON; 111 VLFL, QUATERNARY VALLEY-FILL; 124 SNJS, QUATERNARY SAN JOSE FORMATION; 125 ANMS, QUATERNARY, ANIMAS FORMATION; 210 DKOT, CRETACEOUS; 211 CLFH, CRETACEOUS CLIFF HOUSE SANDSTONE; 211 MNCS, CRETACEOUS MANCOS SHALE; 211 GLLP, CRETACEOUS GALLUP SANDSTONE; 211 FRLD, CRETACEOUS FRUITLAND FORMATION; 211 PCCF, CRETACEOUS PICTURED CLIFF SANDSTONE; 217 BRCN, CRETACEOUS BURRO CANYON FORMATION; 220 JRSC, JURASSIC SYSTEM; 211 BLFF, JURASSIC BLUFF SANDSTONE; SALTWASH SANDSTONE; 211 MRSN, JURASSIC MORRISON FORMATION; 221 WSRC, JURASSIC WESTWATER SANDSTONE; 221 ENRD, JURASSIC ENTRADA SANDSTONE; 231 SHNL, UPPER TRIASSIC CHINLE FORMATION.

MAP NUMBER	STATION NUMBER	INDEX OF SELECTED GROUND-WATER STATIONS IN WATSTORE	STATE	COUNTY	GEOLOGIC UNIT	HYDROLOGIC DATA PERIOD OF RECORD	
		STATION LOCATION				WATER LEVEL	CHEMICAL QUALITY
4	374720109070001	(D-34-26)30CCB-1	UT	San Juan	110ALVM	----	1957-61
5	373830109283201	(D-36-22)22DAA-1	UT	San Juan	110ALVM	----	----
6	373725109284101	(D-36-22)27DDB-2	UT	San Juan	110ALVM	----	----
10	372548109242501	(D-39-23) 5ACC-1	UT	San Juan	221BLFF	----	----
11	372540109113401	(D-39-25) 5ACA-1	UT	San Juan	221BLFF	----	1952-54
12	371657109331901	(D-40-21)25ACD-1	UT	San Juan	220JRSC	----	----
13	371716109325501	(D-40-22)30BBB-1	UT	San Juan	220JRSC	1977	1961-81
14	381028108243001	NB04501409AAA1	CO	Montrose	111VLFL	----	1974
15	381203108103301	NB04601233ACC1	CO	Montrose	217BRCN	----	1974
16	381932108542801	NB04701913DAA	CO	Montrose	231CHNL	----	1974
17	382025108530401	NB04701917BBA	CO	Montrose	111VLFL	----	1974
18	375433108561900	NB04201914BBB	CO	San Miguel	210DKOT	----	1973
19	380258108544400	NB04401925ACC	CO	San Miguel	111VLFL	----	1974
21	374642108561800	NB04101935BCA	CO	Dolores	210DKOT	----	1973
22	370410108583701	NB03302025CDC	CO	Montezuma	210DKOT	----	1959
26	372930108244800	NB03701405DAC	CO	Montezuma	221SLWS	----	1973
28	372700108295600	NB03701522BBB	CO	Montezuma	221MRSN	----	1973
29	373235108440400	NB03801721BBA	CO	Montezuma	210DKOT	----	1973
30	370118107522700	NB03200918BBB	CO	La Plata	125ANMS	----	1973, 1975
31	370620107442700	NB03300817BDD1	CO	La Plata	124SNJS	----	1974, 1975
32	371052108083200	NB03401222BBD	CO	La Plata	211CLFH	----	1973
33	370033107244300	NB03200520ABA1	CO	Butte	124SNJS	----	1973, 1975
34	371327107105400	NB03400311CCD	CO	Butte	211MNCS	----	1973, 1975
35	371346106590200	NB03500131ADA	CO	Butte	211MNCS	----	1973
36	353644108011401	16N.11W.17.4322	NM	McKinley	211GLLP	1959	1959, 1973
37	355811107534701	20N.10W.16.4431 Jm Obs S of Chaco Canyon, NM	NM	McKinley	221MRSN	----	1979
38	354514108190601	NR086.0395X1720 18N.14W.34.121	NM	McKinley	211GLLP	----	1976
39	354643108285201	NR086.1295X1530	NM	McKinley	211PNLK	----	1950, 1955
40	360336107501801	21N.09W.07.333 CCR9 Well 3 mi NE Chaco, NM	NM	San Juan	211CLFH	----	1978
42	360612107484901	22N.09W.29.3443	NM	San Juan	211CLFH	----	1967
48	362009108173201	NR048.0235X1135	NM	San Juan	211CLFH	----	1952
49	361528108192201	NR048.040 X169 23N14W.03.130	NM	San Juan	221WSRC	1973	1973
50	361833108193801	NR048.0429X1319	NM	San Juan	211CLFH	1953	1953
51	362458108382201	NR049.0775X0580	NM	San Juan	211CLFH	----	1954
53	360415108022201	21N.11W.07.242 Chaco R Well B1 Chaco Mon, NM	NM	San Juan	110AVMB	1977-78	1977-81
54	360733108103201	22N.13W.24.3222A Chaco R Well nr Lk Valley, NM	NM	San Juan	110AVMB	----	1977-81
55	361142108220401	NR066.0668X0380 Chaco R Well Bl Denazin nr Bisti	NM	San Juan	110AVMB	1977	1977-81
56	362213108340501	NR049.0380X0891 Burnham Recorder Well nr Bnhm,NM	NM	San Juan	110AVMB	1977-1978	1977-81
57	364325108353001	NR032.0505X0180 Chaco R Well nr Waterflow, NM	NM	San Juan	110AVMB	1977-1978	1977-81
58	360621107582301	22N.11W.26.432 Escavado Wash Well nr Chaco Tp,NM	NM	San Juan	110AVMB	1977-1978	1977-80
59	361318108151401	23N.13W.17.334 DE-NA-ZIN Wash Well nr Bisti, NM	NM	San Juan	110AVMB	1977-1978	1977-81
60	361503108243801	NR048.0898X1715 Hunter Wash Well nr Burnham, NM	NM	San Juan	110AVMB	1977, 1980	1977-81
61	360857107531001	22N.10W.10.341DH8K Kimbeto Ob Well nr Kimbeto,NM	NM	San Juan	211FRLD	1977	1977-80
62	360849107561801	22N.10W.18.211DH2K Kimbeto Coalwell nr Kimbeto	NM	San Juan	211FRLD	1977, 1978	1977-80
63	360916107543901	22N.10W.08.244DH5K Kimbeto Pc Well nr Kimbeto	NM	San Juan	211PCCF	----	1977-80
64	361446108083701	23N.12W.08.114 TLS-1 Ob Well 7 Mise Bistii Tp,NM	NM	San Juan	211FRLD	1976, 1980	1976-80
65	361513108090701	23N.12W.06.4411 AMW6-1 Coal Well 7 mi SE Bisti	NM	San Juan	211FRLD	1980	1980
66	361457108081901	23N.12W.08.2111 Bisti DH7 Well nr Bisti Tp, NM	NM	San Juan	211PCCF	1975-1980	1975-80
67	364750108214701	30N.15W.24.423 SJ24-4 CD Ob Well nr Fruitland,NM	NM	San Juan	211FRLD	1978-1980	1978-80
68	364845108214201	30N.15W.13.414 SJ13-2 Coal well nr Fruitland, NM	NM	San Juan	211FRLD	1978-1980	1978-80
69	364744108225001	30N.15W.23.441 SJ23-4 CD PC well nr Fruitland,NM	NM	San Juan	211PCCF	1977-1980	1978-80
70	360344107515601	21N.10W.11.431 Dome Oil Well nr Chaco, NM	NM	San Juan	221ENRD	----	1978
71	354143108083801	17N.12W.20.1111	NM	McKinley	221WSRC	----	1981
		STATIONS NOT IN WATSTORE FILE:					
1	3758021091913	(D-33-24)30DAB-1	UT	San Juan	----	1955-	----
2	3747521091337	(D-34-24)25AAD-1	UT	San Juan	----	1946-51,1953	----
3	3750501090348	(D-34-26) 4DAD-1	UT	San Juan	----	1946-51,1953	----
7	3737091092904	(D-36-22)34ABB-1	UT	San Juan	----	1952-	----
8	3737121092817	(D-36-22)25BBA-1	UT	San Juan	----	1952-	----
20	3810001082000	NB04501314CCD	CO	San Miguel	----	1977-	----
23	3720001084000	NB03601734BAB	CO	Montezuma	----	1979-	----
24	3720001084200	NB036018360AC1	CO	Montezuma	----	1979-	----
25	3720001084400	NB03601936DCC1	CO	Montezuma	----	1979-	----
27	3730001083200	NB03701516DAD	CO	Montezuma	----	1976-	----
41	3602151075400	21.10.21.3444	NM	San Juan	----	1972, 1980-	----
43	3632451081130	27.13.26.3411	NM	San Juan	----	1975, 1980-	----
44	3648001084900	18-5.5X14.0	NM	San Juan	----	1978, 1980-	----
45	3650451085100	18-6.7X10.5	NM	San Juan	----	1957, 1980-	----
46	3654001085945	19-2.00X8.00	NM	San Juan	----	1957, 1980	----
47	3643451083715	32-7.55X2.47	NM	San Juan	----	1978, 1981	----
52	3627451084400	49-12.85X3.35	NM	San Juan	----	1978, 1981	----

Glossary of Terms

Technical terms that appear in this report are defined.

Acidity is the capacity of a water solution to neutralize basic or alkaline solutions. The conventional neutralization endpoint for water solutions is near pH 8.3. Acidity in water is due to the presence of excess hydrogen ions. This condition sometimes is present in waters associated with thermal springs, mines, and industrial activities.

Alkalinity is the capacity of a water solution to neutralize acid solutions. The conventional neutralization endpoint for water solutions is near pH 4.5. This property in natural waters is attributed largely to the presence of the bicarbonate ion (HCO_3^-) in solution; other ions such as carbonate (CO_3^{-2}) and hydroxyl (OH^-), may contribute to this property. Commonly, natural waters are alkaline.

Average value is the arithmetic average of a set of values obtained by dividing the sum of the values by the number of values. Also known as the mean value.

Bed material is the unconsolidated material of which a streambed, lake, pond, reservoir, or estuary bottom is composed.

Buffering agent is a chemical substance that reacts with acidity or alkalinity in a water solution while causing little change in the pH of the solution. In most natural waters the principal buffering agent is the bicarbonate ion (HCO_3^-).

Cubic foot per second (ft^3/s) is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second and is approximately equivalent to 7.48 gallons per second or 0.02832 cubic meters per second.

Degrees Celsius (°C) is the proper name for expressing temperature on the International System of Units (SI) scale. The temperature scale is such that the freezing point of water is nearly 0°C and the boiling point of water is nearly 100°C at sea level. This scale formerly was known as the centigrade temperature scale.

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

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

Dissolved concentration is the concentration of a given constituent in the dissolved phase of a representative water-suspended sediment mixture. The "dissolved" phase, by U.S. Geological Survey convention, is regarded as the part of a water-suspended sediment sample that passes through a 0.45-micron pore-size membrane filter, although the filtered sample may contain colloidal particles.

Dissolved solids are solutes derived from minerals and, to a lesser degree, from organic materials. The concentration of dissolved solids is determined either by evaporation of a measured volume of filtered water and the residue weighed, or by summation of the individual chemical-constituent concentrations. Any material that passes through a 0.45-micron pore-size membrane filter is treated as being dissolved. Ultra-fine colloidal particles will pass through this size filter. The expressions "total dissolved solids", and "dissolved solids" often were used interchangeably.

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the river above the specified point. Figures of drainage area given herein include all closed basins, or noncontribution 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 flow is streamflow in a normally dry channel resulting directly from precipitation.

Erosion is the general process or the group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another, by natural agencies, which include weathering, solution, corrasion, and transportation.

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

Fecal bacteria are microscopic unicellular organism that are present in the intestinal tracts or feces of warm-blooded animals. Their presence in water indicates fecal pollution. The specific groups of bacteria usually analyzed for in water samples are the *coliform* group and the *streptococcal* group. Their concentrations are expressed as the number of colonies per 100 milliliters of sample.

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

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

Gram-mole is the molecular weight of a chemical substance expressed in grams divided by its valence.

Hydraulic conductivity is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

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 8-digit number.

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

Ion is an electrically charged atom or molecule in a water solution that is derived from dissociation of a mineral or organic molecule dissolved in the water. A positively charged (+) ion is called a cation, and a negatively (-) charged ion is called an anion.

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

Micrograms per liter (μg/L) is a unit expressing the concentration of a given substance, usually a chemical constituent or suspended sediment, in a water-sediment mixture as mass in micrograms of the given substance per unit volume as liter of the water-sediment mixture. A microgram is one-millionth of a gram and is approximately equivalent to one part per billion for dilute solutions.

Micron (μm) a unit of length that is equal to one-millionth of a meter. It is also known as a micrometer.

Milligrams per liter (mg/L) is a unit expressing the concentration of a given substance, usually a chemical constituent or suspended sediment, in a water-sediment mixture as mass in milligrams of the given substance per unit volume as liter of the water-sediemtn mixture. A milligram is one-thousandth of a gram and is approximately equivalent to one part per million for dilute solutions.

Particle-size is the dimension of a sediment particle based on the premise that the particle is a sphere. The size is determined by sieve or settling-velocity methods. The classification of particle-size as recommended by the American Geophysical Union Subcommittee on Sediment terminology is as follows:

Classification	Size, in millimeters
Clay	0.00024 to 0.0040
Silt	0.0040 to 0.0625
Sand	0.0625 to 2.0
Gravel	2.0 to 64.0

Perennial flow is continuous streamflow in a channel throughout the year except during periods of extreme drought.

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

pH is a standard unit for expressing the hydrogen ion concentration. It is defined as the negative logarithm to the base 10 of the hydrogen-ion concentration in gram-moles per liter. A pH of 7 is neutral, whereas values below 7 are acidic and values above 7 to the theoretical maximum of 14 are alkaline. More precisely, chemical activity rather than concentration of the hydrogen-ions are measured with pH meters; however, activity is equal to or nearly equal to concentration in dilute solutions.

Phreatophyte is a plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe.

Phytoplankton is the microscopic plant community of suspended, floating, or weakly swimming organisms whose movements are subject to the water currents. Phytoplankton growth in water is dependent on sunlight and chemical nutrients such as phosphorous and nitrogen compounds. Phytoplankton is commonly known as algae.

Representative sample is a sample that is collected by prescribed techniques to assure that the sample accurately represents the streamflow or the ground-water system at the time of collection.

Runoff is the part of the precipitation that appears in surface streams that are not regulated by dams or diversions.

Salinity is a term describing water solutions containing dissolved mineral solids. The U.S. Geological Survey has assigned terms for degrees of salinity for waters with the following dissolved-solids concentration ranges:
slight = 1,000 to 3,000 mg/L
moderate = 3,000 to 10,000 mg/L
very = 10,000 to 35,000 mg/L
briny = over 35,000 mg/L

Sediment is solid particulate material that originates mostly from disintegrated rocks and is transported by, suspended in, or deposited from water. The solid material includes inorganic mineral particles and decomposed organic fragments.

Sediment yield is the volume of sediment that is removed from a drainage area by runoff. Sediment yield usually is expressed in acre-feet per square mile.

Sodium adsorption ratio (SAR) is the expression of relative activity of sodium ions in exchange reactions with soils and is an index of sodium hazard to the soil. This ratio is useful for classifying the suitability of water for irrigation or reclamation.

Solute is a chemical substance that is dissolved in water and is derived principally from minerals such as salt and rocks in the hydrologic enviroment. The solute will dissociate into ions and move towards a uniform distribution in the water. Trace amounts of organic substances also occur as solutes in natural water systems.

Solution is the homogeneous liquid phase of a mixture of solutes and solvents. In a hydrologic system, the solutes mostly are dissolved minerals in solution as ions and the solvent is water.

Solvent is that part of a solution that is present in the larges amount, or the part that is normally liquid in its pure state. In a hydrologic system water is that solvent.

Specific conductance is a measure of the ability of a water to conduct an electrical current. It is the reciprocal of the electrical resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specific temperature. The standard measurement is expressed in micromhos (μmhos) per centimeter (cm) at 25 degrees Celsius (°C). Specific conductance is related to the type and concentration of ions in solution and can be used to approximate the dissolved-solids concentration in water. Estimates of the dissolved-solids concentration in milligrams per liter (mg/L) range from 60 percent to 85 percent of the specific-conductance value in μmhos per cm at 25°C.

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

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.

Sublimation is the loss of water in the form of ice and snow through direct evaporation.

Suspended, recoverable concentration is the concentration of a given constituent that is put in solution from the suspended-sediment part of a representative water-suspended sediment sample. The suspended sediments are digested partially, and not usually completely, by a prescribed chemical acid-heat treatment in the laboratory.

Suspended sediment is the sediment that is maintained in suspension in streamflow by the upward components of turbulent currents or that stays suspended in the water-sediment mixture as ultra-fine particles such as colloids.

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

Total, recoverable concentration is the total concentration of a given constituent in a representative water-suspended sediment mixture. The total concentration is the sum of the dissolved concentration and the concentration recovered from the suspended sediment by a prescribed partial, but not complete, chemical digestion of the suspended sediment.

Trace concentration is a concentration of a solute in water that is 1.0 milligrams per liter or less. Trace concentrations are expressed in micrograms per liter (μg/L). One milligram per liter equals 1,000 micrograms per liter.

WATSTORE is the acronym for the computerized **WAT**er data **STO**rage and **RE**trieval system of the Water Resources Division of the U.S. Geological Survey.

WATSTORE record is a data set that is uniquely identified in the WATSTORE file by a station identification number, time, designation of the data set, and the data itself, which may be one measurement or a suite of hydrologic measurements.

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