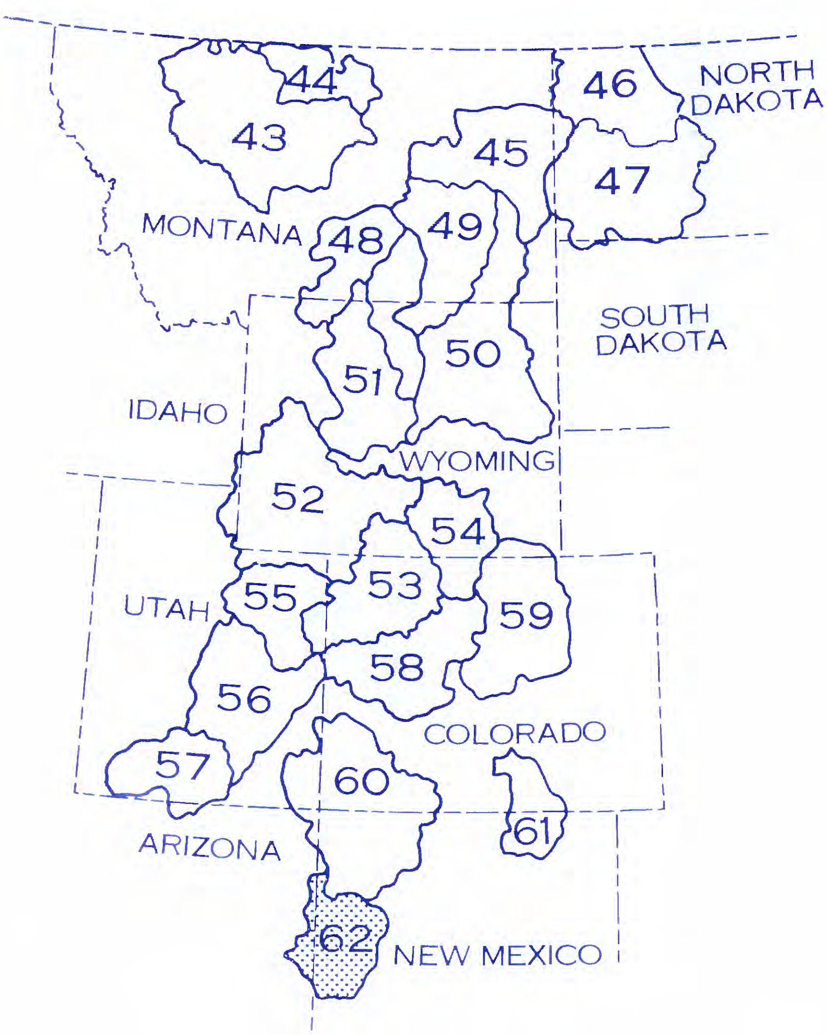
HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA



- PUERCO RIVER
- ZUNI RIVER
- LARGO CREEK
- CARRIZO WASH
- RIO SAN JOSE
- BLACK CREEK

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698

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WRI 83-698

HYDROLOGY OF AREA 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA

BY
F. E. ROYBAL, J. G. WELLS, R. L. GOLD, AND J. V. FLAGER

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS
OPEN-FILE REPORT 83-698

ALBUQUERQUE, NEW MEXICO
APRIL, 1984

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, *SECRETARY*

U.S. 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
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot per square mile (acre-ft/mi^2)	4.761	cubic meter per hectare (m^3/hectare)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
ton, short	0.9072	megagram (Mg)
	Temperature	

$$°C = 5/9\,(°F - 32)$$

$$°F = 9/5\,(°C) + 32$$

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 62, NORTHERN GREAT PLAINS AND ROCKY MOUNTAIN COAL PROVINCES, NEW MEXICO AND ARIZONA

BY
F.E. ROYBAL AND OTHERS

Abstract

This report summarizes available hydrologic data for Area 62 and will aid leasing decisions, and the preparation and appraisal of environmental impact studies and mine-permit applications. Area 62 is located at the southern end of the Rocky Mountain Coal Province in parts of New Mexico and Arizona and includes approximately 9,500 square miles. Surface mining alters, at least temporarily, the environment; if the areas are unreclaimed, there can be long-term environmental consequences.

The land-ownership pattern in Area 62 is complicated. The checkerboard pattern created by several types of ownership makes effective management of these lands difficult.

The climate generally is semiarid with average annual precipitation ranging from 10 to 20 inches. Piñons, junipers, and grasslands cover most of the area, and much of it is used for grazing by livestock. Soils vary with landscape, differing from flood plains and hillslopes to mountain slopes.

The major structural features of this area were largely developed during middle Tertiary time. The main structural features are the southern San Juan Basin and the Mogollon slope. Coal-bearing rocks are present in four Cretaceous rock units of the Mesaverde Group: the Gallup Sandstone, the Dilco Coal Member, and the Gibson Coal Member of the Crevasse Canyon Formation, and the Cleary Coal Member of the Menefee Formation.

Area 62 is drained by Black Creek, the Puerco River, the Zuni River, Carrizo Wash-Largo Creek, and the Rio San Jose. Only at the headwaters of the Zuni River is the flow perennial. The streamflow-gaging station network consists of 25 stations operated for a variety of needs. Streamflow changes throughout the year with variation related directly to rainfall and snowmelt. Base flow in Area 62 is zero indicating no significant ground-water discharge. Mountainous areas contribute the highest mean annual runoff of 1.0 inch. Very few water-quality data are available for the surface-water stations. Of the nine surface-water stations that have water-quality data, only one has chemical analyses from more than 10 samples. Therefore, sufficient data to characterize the area in detail are not available. Suspended sediment data are available only for a few surface-water stations in the area. Erosion rates generally are less than 1 acre-foot per square mile per year. Greater erosion rates are found within the badland areas.

Water levels are periodically measured at 21 selected wells in Area 62. These observation wells are located mostly along the Rio San Jose and northeast of Gallup, New Mexico. The recharge to ground-water aquifers generally coincide with areas of greater precipitation in the mountainous areas. Depth to water below land surface is generally less than 200 feet. Well yields of 100 gallons per minute are common in most of the area.

Ground-water quality is variable both within each aquifer and between aquifers. Water quality generally is best near recharge areas.

Historical and current data related to stream discharge, water quality, and suspended sediment are available from computer files in the U.S. Geological Survey's National Water Data Storage and Retrieval System (WATSTORE) and through the National Water Data Exchange (NAWDEX).

1.0 INTRODUCTION

1.1 Objective

Report Summarizes Available Hydrologic Data

Existing hydrologic conditions and sources of information are identified to aid leasing decisions, and the 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 62 in New Mexico and Arizona (fig. 1.1-1). This report is one of a series that describes coal provinces nationwide.

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

The hydrologic information presented herein or available through sources identified in this report will be useful in describing the hydrology of the "general area" of any proposed mine. This hydrologic information will be supplemented by the lease applicant's site-specific data as well as data from other sources. The purpose of the site-specific 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.

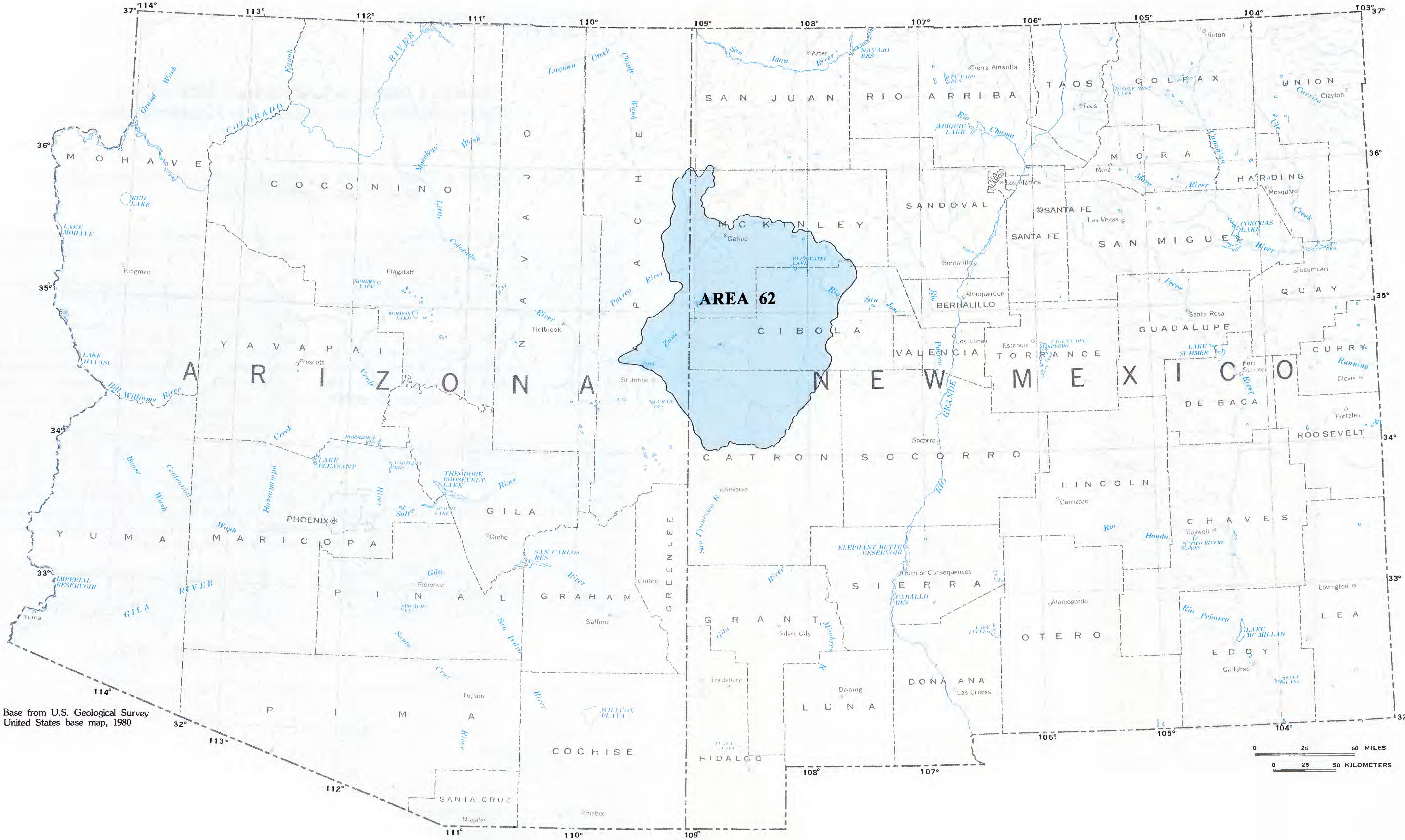


Figure 1.1-1 Location of Area 62 in Arizona and New Mexico.

Area 62 Comprises 9,500 Square Miles of the Little Colorado River and the Rio Grande Basins

The area is in the Colorado Plateau Physiographic Province and includes parts of the Navajo and Datil Sections.

The Northern Great Plains and the Rocky Mountain Coal Provinces are divided into 20 hydrologic reporting areas (see report cover). The division is based on hydrologic factors, location, size, and mining activity. Hydrologic drainage basins or parts of basins are combined to form Area 62 (fig. 1.2-1).

Area 62 is located at the southern end of the Rocky Mountain Coal Province, in northwestern New Mexico and northeastern Arizona. The area includes parts of McKinley, Cibola, Catron, and San Juan Counties, New Mexico; and part of Apache County, Arizona.

The Continental Divide separates two major river basins in the study area; there are 7,160 square miles of the Little Colorado River basin on the west and 2,360 square miles of the Rio Grande basin on the east (fig. 1.2-1). The area west of the divide is drained by Black Creek, Puerco River, Zuni River, Carrizo Wash-Largo Creek and other minor drainages. These streams eventually drain to the Little Colorado River in Arizona. Only at the headwaters of the Zuni River is the flow perennial. The study area east of the divide has two types of drainage. In the north, flow is to the Rio San Jose, which eventually drains into the Rio Grande in New Mexico. In the south, the area is a closed basin, streams are generally dry, and water courses are poorly defined.

Area 62 lies within the Colorado Plateau Physiographic Province, which has been subdivided into six sections (Fenneman, 1931). Two of these sections lie within the study area--the Navajo section and the Datil section (fig. 1.2-2). The primary basis of subdivision is altitude and extent of dissection of the land surface. The Navajo section is characterized by mesas, cuestas, rock terraces, escarpments, canyons, and arroyos. Altitudes generally range from about 6,000 to 7,500 feet above sea level. The Datil section is characterized by lava flows, remnants of flows, volcanic plugs, mesas, valleys, and cliffs. The most prominent feature of the Datil section is the Zuni uplift, which has a structural relief of at least 5,000 feet (U.S. Department of Agriculture, 1981a). Altitudes generally range from about 6,500 to 8,000 feet above sea level, but Mount Taylor, located approximately 14 miles northeast of Grants, New Mexico, reaches an altitude of 11,389 feet.

Area 62 is sparsely populated; most of the population is concentrated along the Puerco River and Rio San Jose. The population of selected towns or Census County Divisions is given in table 1.2-1.

Table 1.2-1 Population of selected towns or Census County Divisions.

New Mexico		Arizona	
Gallup	18,161	Window Rock	2,230
Grants	11,451		
Milan	3,747		
Quemado division*	1,028		
Zuni-Ramah Navajo divison*	1,369		

* Census County Division--Geographic areas which have been defined by the Census Bureau in cooperation with state and county officials for the purpose of presenting statistical data. Census County Divisions have been defined where there are no legally established boundaries, and/or where boundaries are not well known to the public.

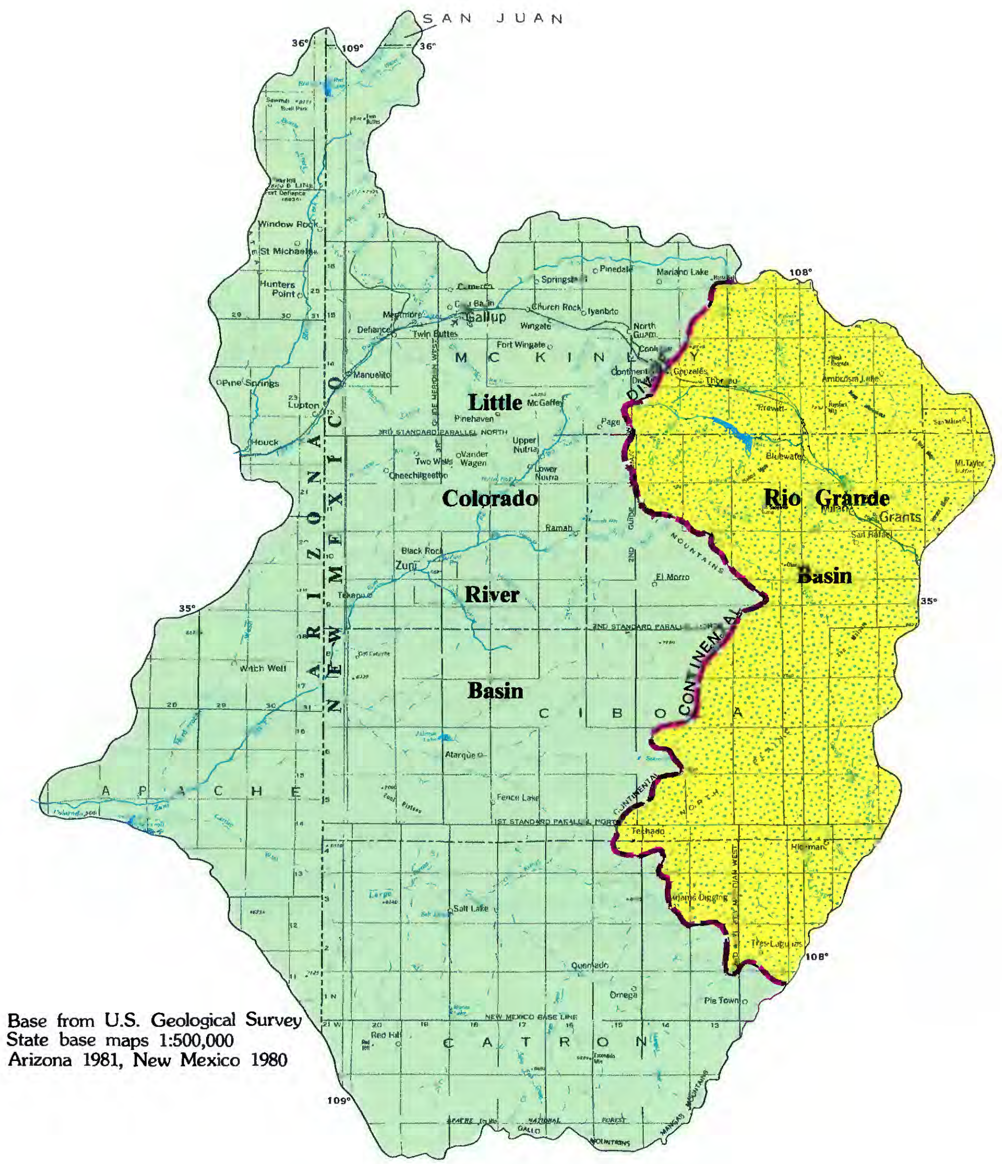
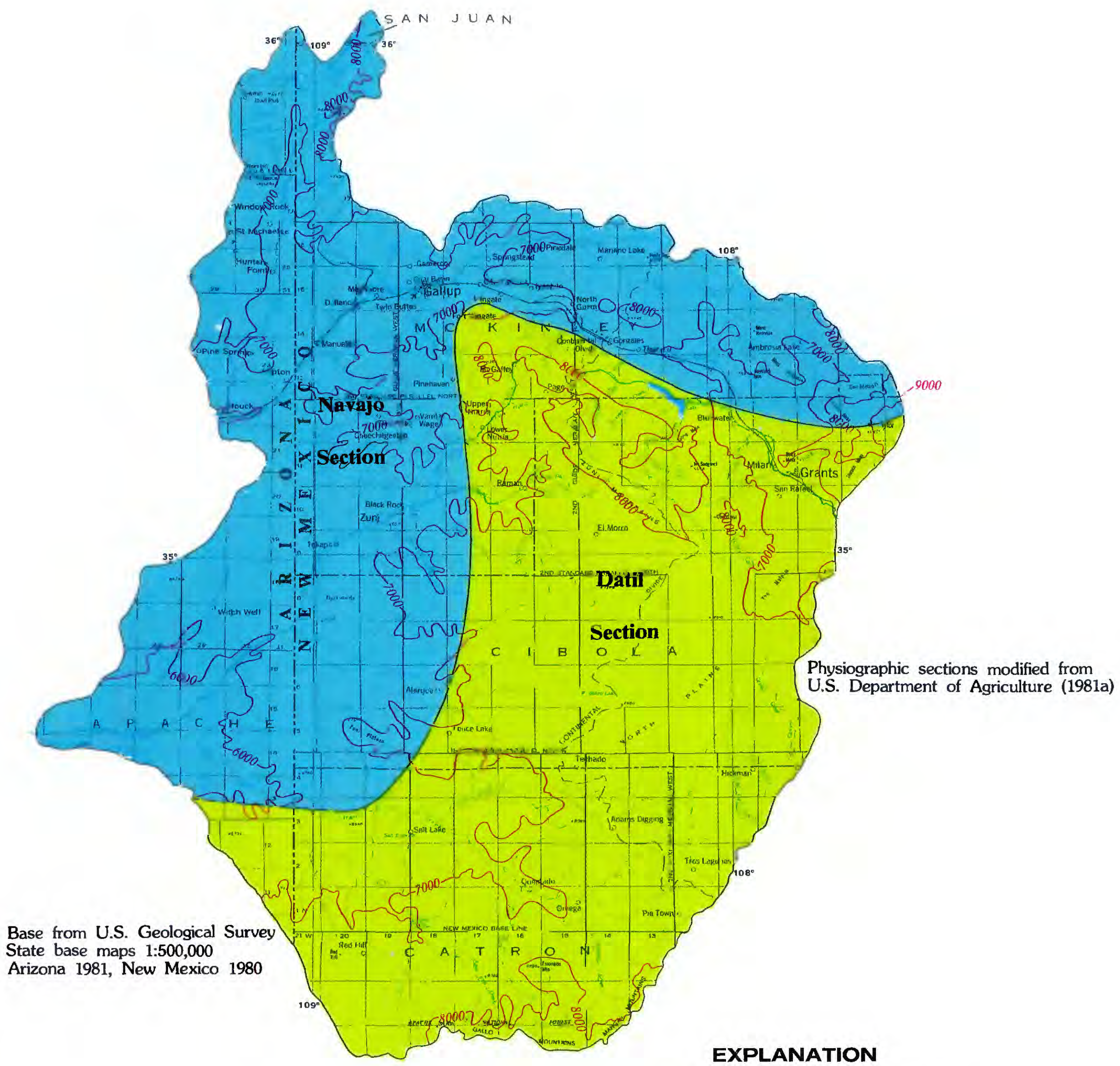


Figure 1.2-1 Drainage basins.

SCALE 1:1,500,000

0 15 30 MILES

0 15 30 KILOMETERS



EXPLANATION

PHYSIOGRAPHIC SECTIONS OF THE COLORADO PLATEAU PROVINCE

Navajo Section Mesas, cuestas, rock terraces, escarpments, canyons and arroyos.

Datil Section Lava flows, remnant flows, volcanic plugs, mesas, valleys, and cliffs.

8000 **TOPOGRAPHIC CONTOUR** Contour interval 1000 feet. Datum is sea level.

Figure 1.2-2 Physiographic sections in Area 62.

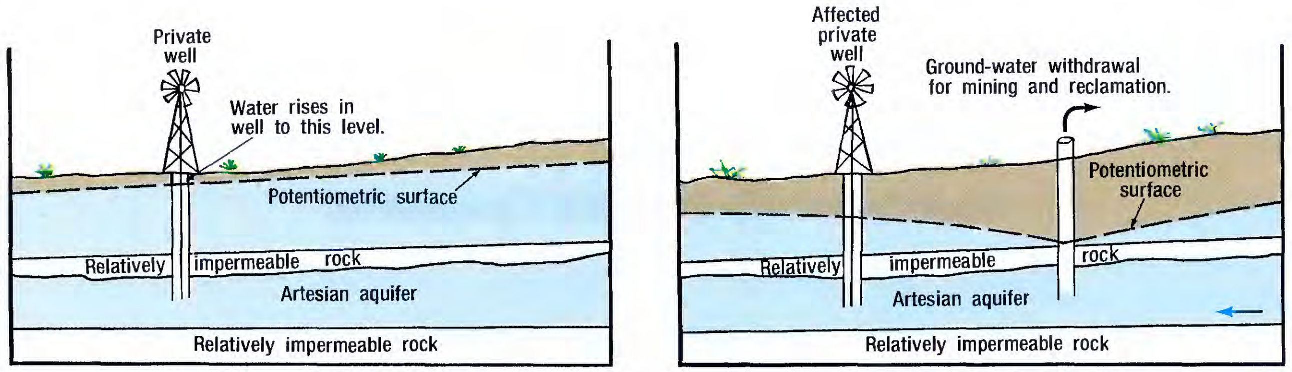
Hydrologic Environment can be Significantly Altered by Surface Coal Mining

Changes in ground-water levels, water quality, and drainage patterns may be the potential effects on hydrologic systems caused by surface coal mining.

Much of the future water supply for coal washing, dust suppression, human consumption, and irrigation of reclaimed land would be drawn from available surface-water or ground-water sources. Because streams in the area generally are ephemeral, that is flowing only in response to spring snowmelt and summer thunderstorms, surface water is not a reliable water supply for mining operations. Therefore, supplies will generally be obtained from ground-water sources.

Ground-water withdrawals for mining operations (fig. 1.3-4) may cause a lowering of the potentiometric surface in the area near the mines. As illustrated in figure 1.3-1, this could cause decreases in well yields and may increase well maintenance costs. The quality of ground water can be affected as shown in figure 1.3-2, although the effects may take much longer to impact points remote from mining activities because of the relatively slow movement of water in the subsurface. The modification of the natural topography in the mined areas could cause local changes in natural drainage patterns. As shown in figure 1.3-3, runoff originating above mines is routed around mines, creating new channels. More information concerning effects of mining on the hydrologic environment in the study area is available in a report by Dennis and Kelly (1981).

An increased population and industrial growth associated with coal development may exert additional demands on the water supplies. Depending on local conditions, additional supply could be difficult to obtain. Coal mining by itself is not a major user of either ground or surface water. With careful consideration to planning, engineering, and regulations, adverse impacts to the hydrologic environment may be minimized.



A. Undisturbed condition **B. Affected private well**

Figure 1.3-1 Possible changes in ground-water level caused by a mine well.

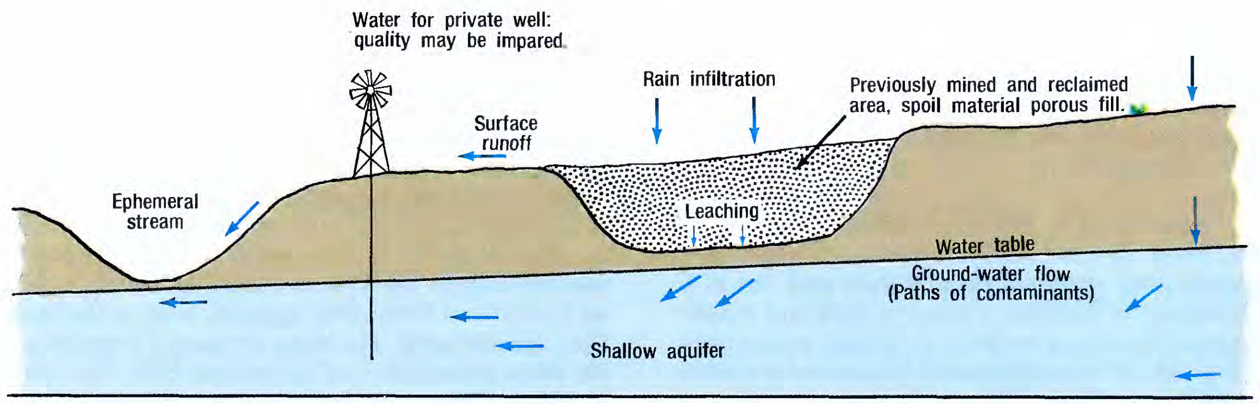
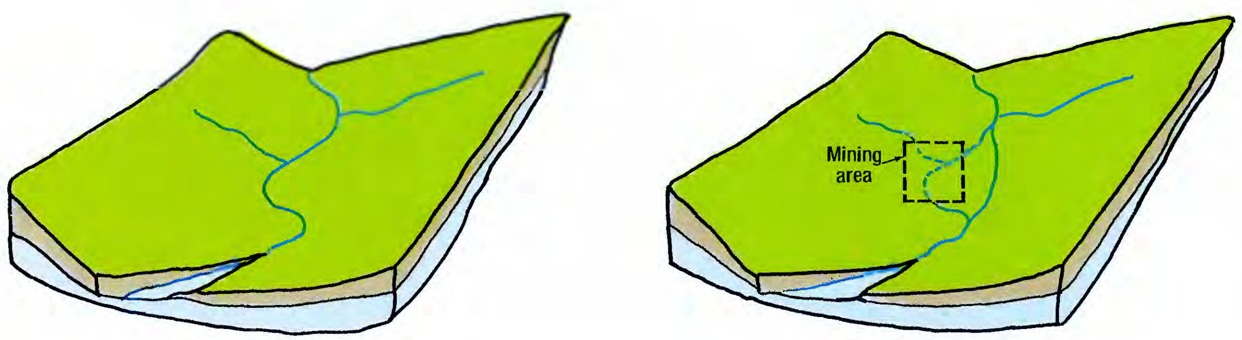


Figure 1.3-2 Dissolved substances leaching from spoil material.



A. Before mining **B. During mining**

Figure 1.3-3 Possible changes in natural drainage patterns caused by surface coal mining.

Figure 1.3-4 View of surface coal mining area northwest of Gallup, New Mexico.

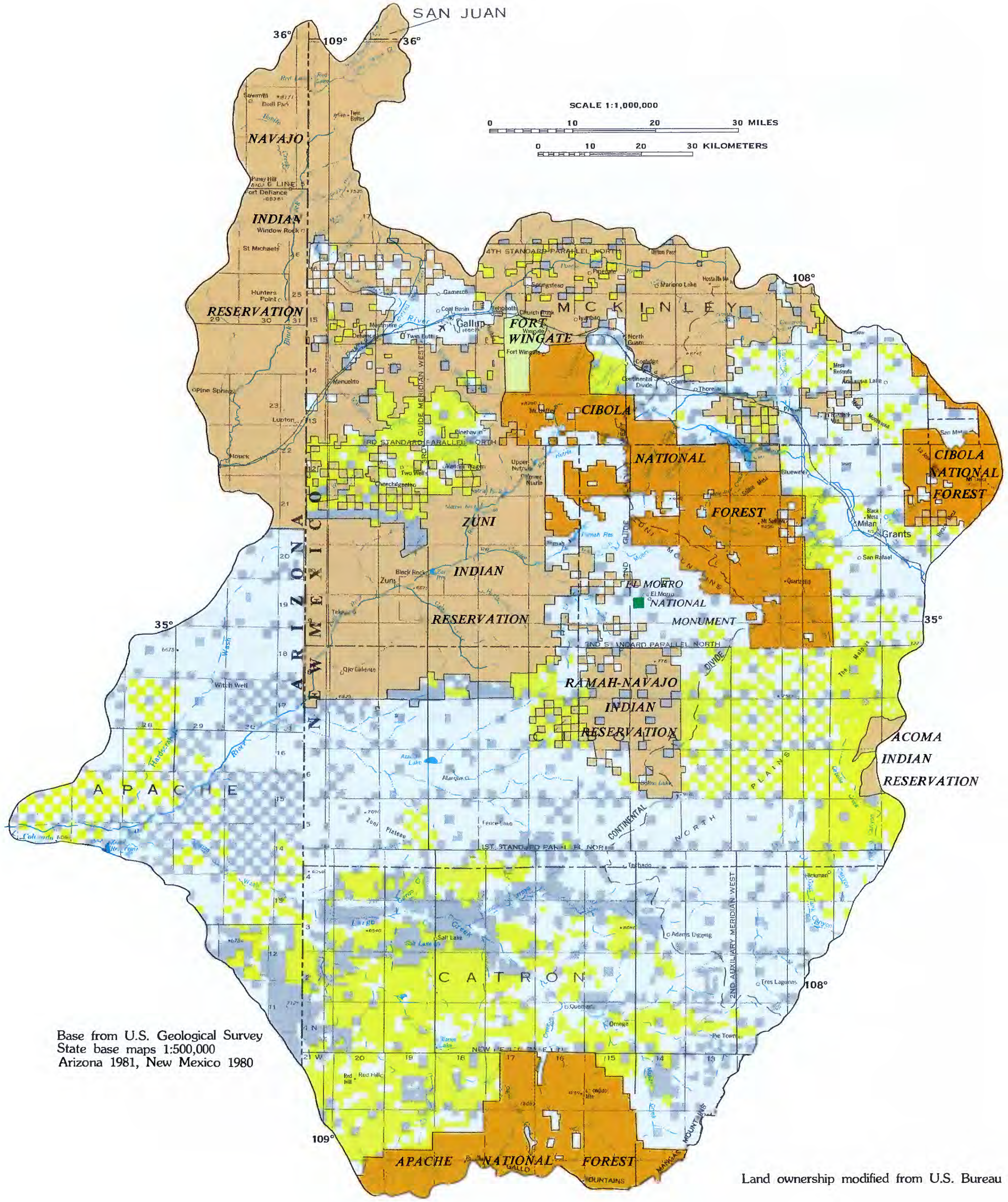
Land-Ownership Pattern is Complicated

Indian, Federal, and private ownership is represented.

As shown in figure 2.1-1, the land-ownership pattern in Area 62 is complicated. The checkerboard pattern created by several types of ownership makes it difficult to effectively manage these lands and consequently complicates the water rights. Indian ownership includes trust and deeded lands, but these categories are not identified on the map. Three Indian reservations are located entirely or partly within Area 62: the Navajo Reservation in New Mexico and Arizona, the Zuni and Acoma Reservations in New Mexico.

Federal land in Area 62 is administered by the U.S. Forest Service, the U.S. Bureau of Land Management, the National Park Service and the U.S. Department of Defense. Parts of Cibola and Apache National Forests are included in the New Mexico part of Area 62. El Morro National Monument is administered by the National Park Service, Fort Wingate Military Reservation, east of Gallup, New Mexico, is administered by the Department of Defense.

State and private lands are generally scattered in a checkerboard pattern. In the early 1850's, the Santa Fe Railroad received government grants for alternate sections of land in strips to build railroads in vacant and sparsely settled sections of the area. These grants created a checkerboard pattern of land ownership (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, Appendix VI, 1971, p. 56). Most of the privately owned lands are within Cibola County, New Mexico. In New Mexico, State lands are administered by the Commissioner of Public Lands with assistance from other agencies such as the State Park Commission, the State Forestry Commission, the State Department of Game and Fish, the State Engineer Office, and the State Department of Transportation.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

- INDIAN LANDS
- U.S. FOREST SERVICE
- U.S. BUREAU OF LAND MANAGEMENT
- NATIONAL PARK SERVICE
- U.S. DEPARTMENT OF DEFENSE
- STATE TRUST AND DEEDED
- PRIVATE

Land ownership modified from U.S. Bureau of Reclamation (1968) and U.S. Department of Agriculture (1981a).

Figure 2.1-1 Generalized land ownership.

Average Annual Precipitation is 10 to 12 Inches in the Valleys and Plateaus and 16 to 20 Inches in the Mountains

Temperatures generally are warmest in July and coolest in January.

The climate is semiarid (about 10 to 20 inches of annual rainfall), except for a few isolated areas that receive more than 20 inches of precipitation per year. The variation in precipitation and temperature is controlled by altitude. Areas at high altitude have greater precipitation and lower temperatures than areas at lower altitudes. The approximate areal distribution of average annual precipitation is shown in figure 2.2-1. Average annual precipitation from long-term records are available for three stations: 12.34 inches at El Morro, 11.33 inches at Zuni, and 9.24 inches at Quemado. The distribution of average monthly precipitation for these three stations is shown in figure 2.2-2. The wettest months generally are July and August and the dryest months are generally May and June. During the winter, snowfall is common; a total of about 50 inches was recorded at McGaffey, New Mexico, in December 1967.

In Area 62, winters are rather cold, summers are warm, and days are sunny. Daily temperatures vary by 30 to 40 degrees. Temperatures greater than 90 degrees are not common in most of the area, but at Gallup, the maximum recorded was 99 degrees; the minimum was 23 degrees below zero (Tuan and others, 1973, p. 193). The distribution of average monthly temperatures at selected stations is shown in figure 2.2-2. The average temperature for the warmest month (July) is about 70° Fahrenheit, and for the coolest month (January) is about 32° Fahrenheit.

Daily precipitation and temperature data are available in monthly issues of "Climatological Data for New Mexico" and "Climatological Data for Arizona." The data are published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

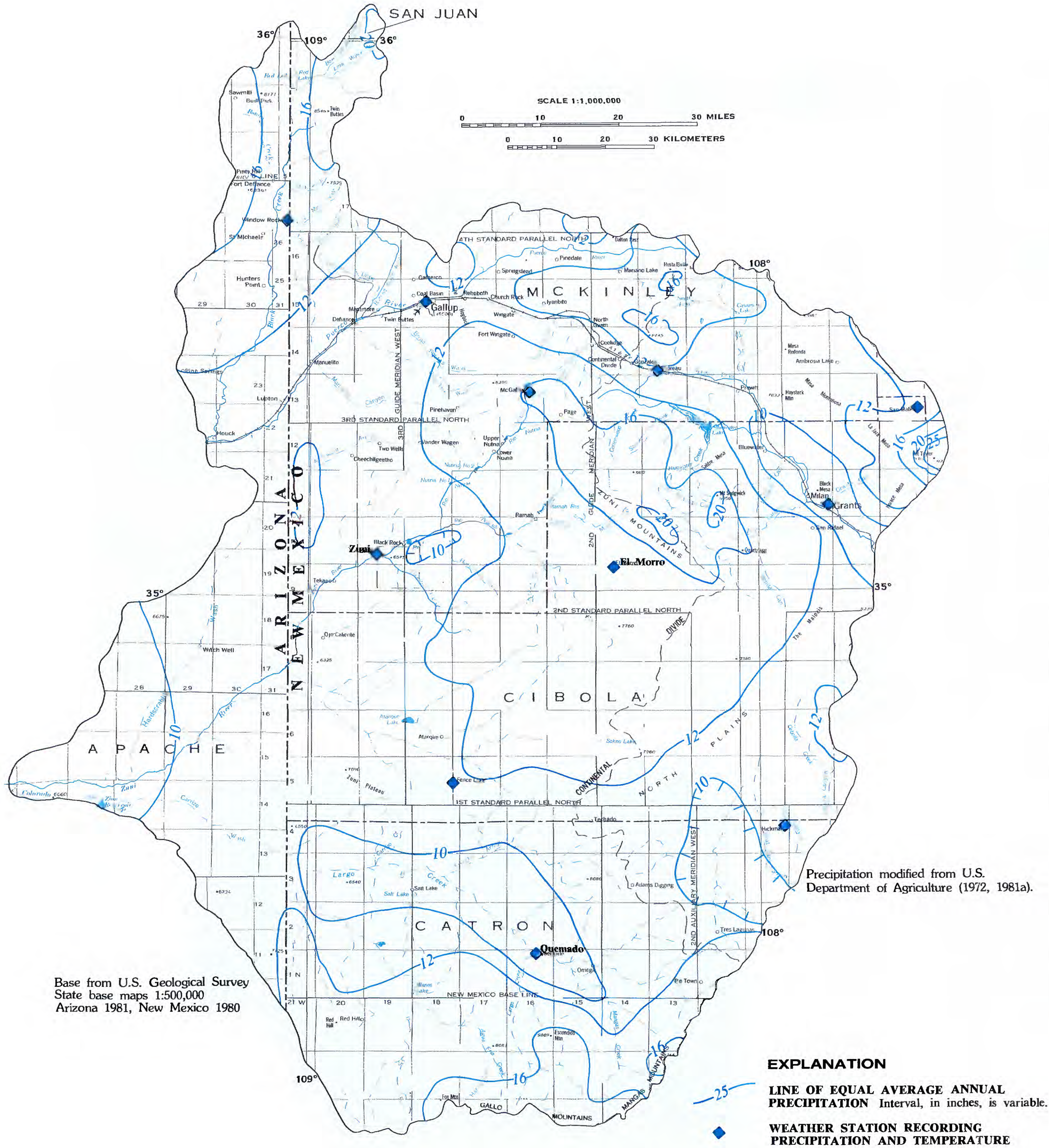


Figure 2.2-1 Average annual precipitation, 1931-60.

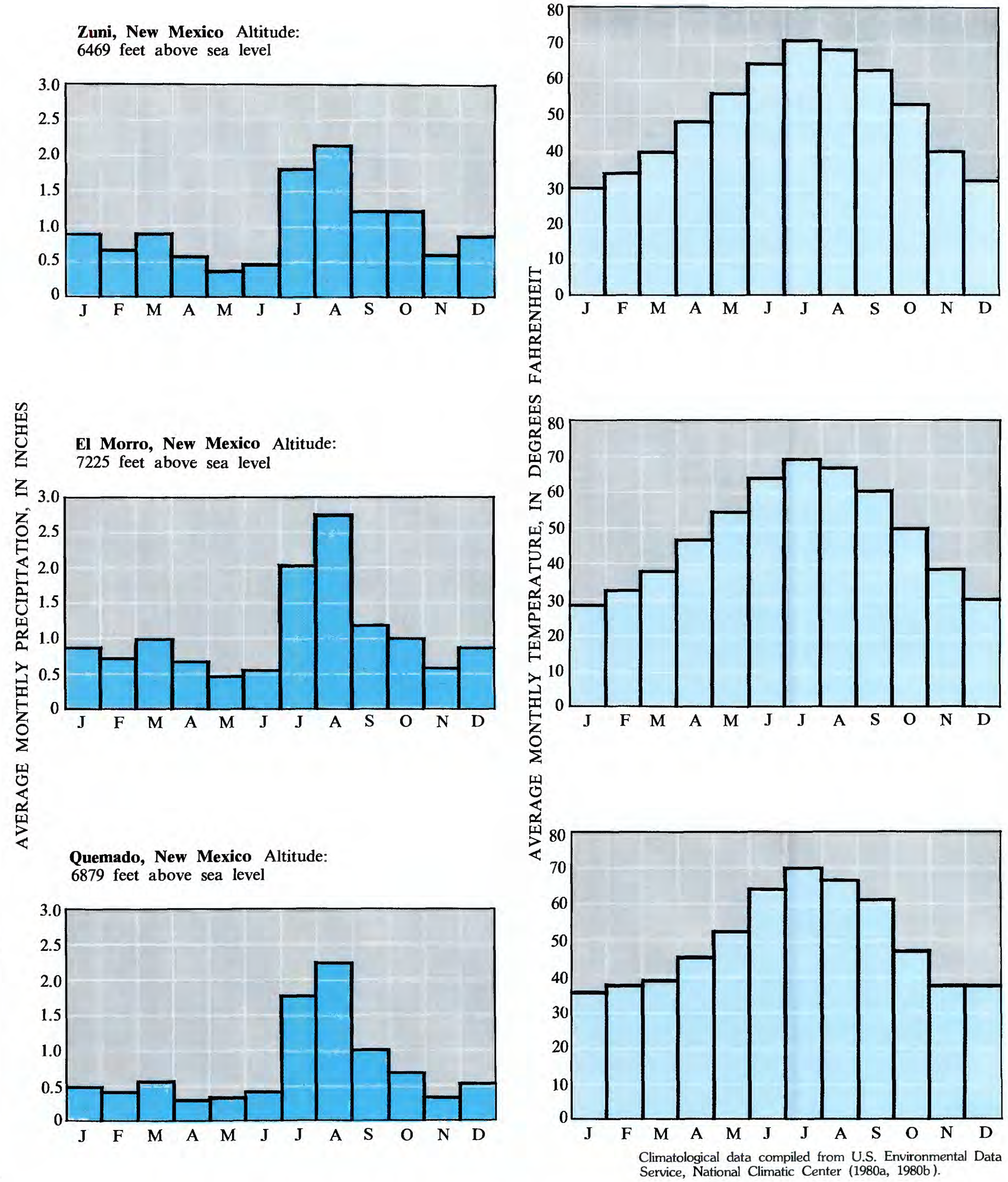


Figure 2.2-2 Average monthly precipitation and temperature at selected weather stations, 1941-70.

Piñon Pine, Junipers, and Grasslands Cover Most of Area

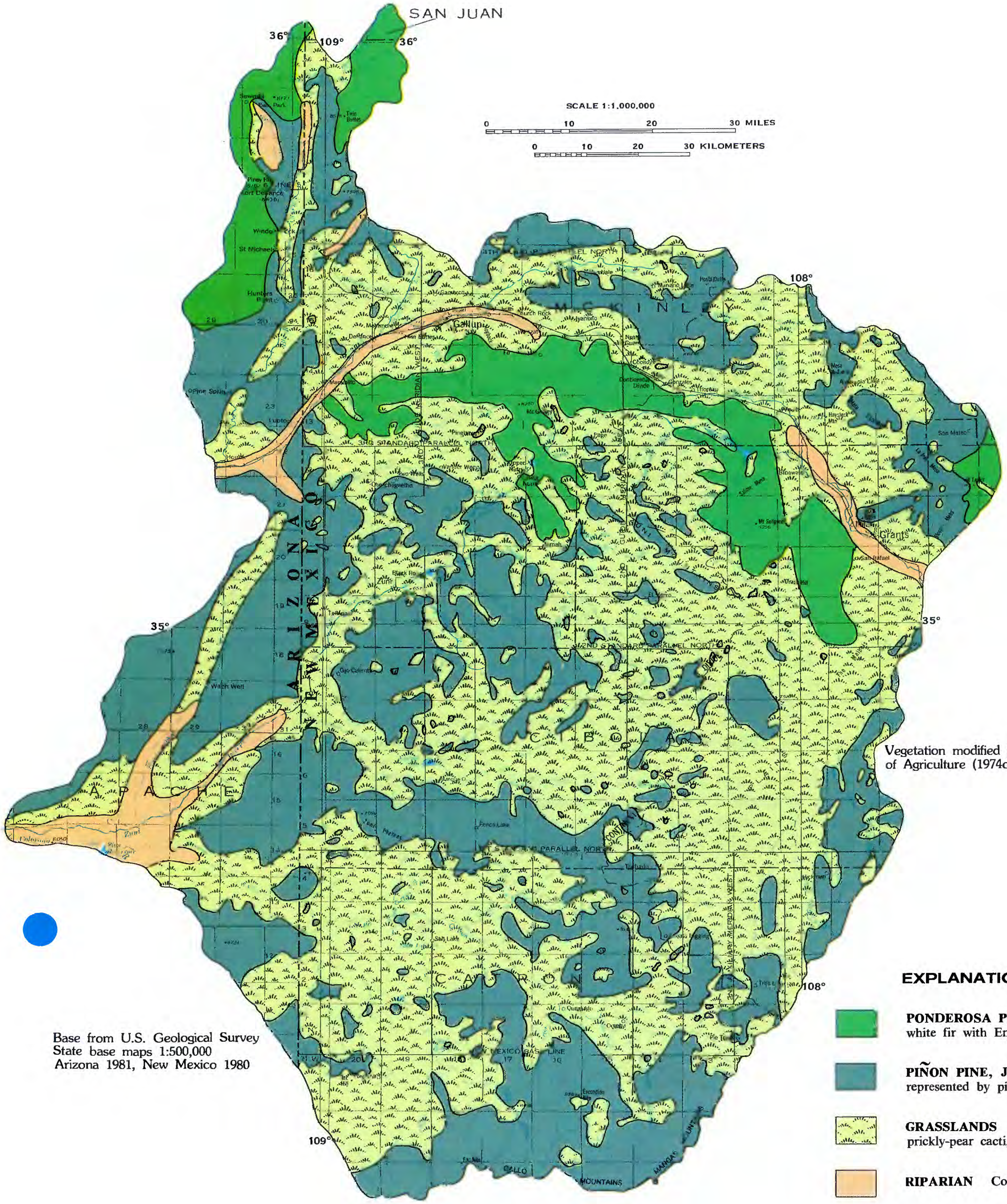
Major land use is for grazing.

Four general types of vegetative cover are delineated in figure 2.3-1. Each type merges gradually with the adjacent type, and the demarcation between these types is not distinct. Ponderosa pine and mixed conifer vegetation has an understory of grasses and some brush species. On north-facing slopes, firs and Englemann spruce are dominant above 8,000 feet; ponderosa pines generally are present below 8,000 feet and on south-facing slopes. Piñon pines, junipers, and grasslands are present throughout Area 62, but are most common at altitudes between 5,000 and 7,500 feet. Grama species are the main species in the grasslands. Riparian vegetation is present along stream banks.

Grazing on rangeland and woodland is the largest land-use category in Area 62 (fig. 2.3-2). The next most common is commercial timber, generally at high altitudes in the Zuni Mountains. Farmlands generally are located near streams and lakes. Most of the irrigated farmland is in the vicinity of Bluewater, Zuni, and Ramah, New Mexico. Alfalfa, corn, barley, wheat, sorghum, and chile are the principal irrigated crops produced. Dry farming areas are located south of Gallup, near EL Morro, and around Fence Lake, New Mexico. Corn and small grains are the principal crops produced by dry farming.

Recreation is an important land use in Area 62; the Zuni Mountains and Mt. Taylor are within the Cibola National Forest and camping and picnicking facilities are available. El Morro National Monument (fig. 2.3-3) and Bluewater Lake State Park are both in Cibola County, New Mexico. Fort Wingate Military Reservation, located east of Gallup, New Mexico, is the only land administered by the Department of Defense in the area. The land-use map (fig. 2.3-2) indicates the primary use, although most lands are used for more than one purpose.

Figure 2.3-3 El Morro National Monument at El Morro, New Mexico.



Vegetation modified from U.S. Department of Agriculture (1974c, 1981a).

Base from U.S. Geological Survey State base maps 1:500,000 Arizona 1981, New Mexico 1980

EXPLANATION

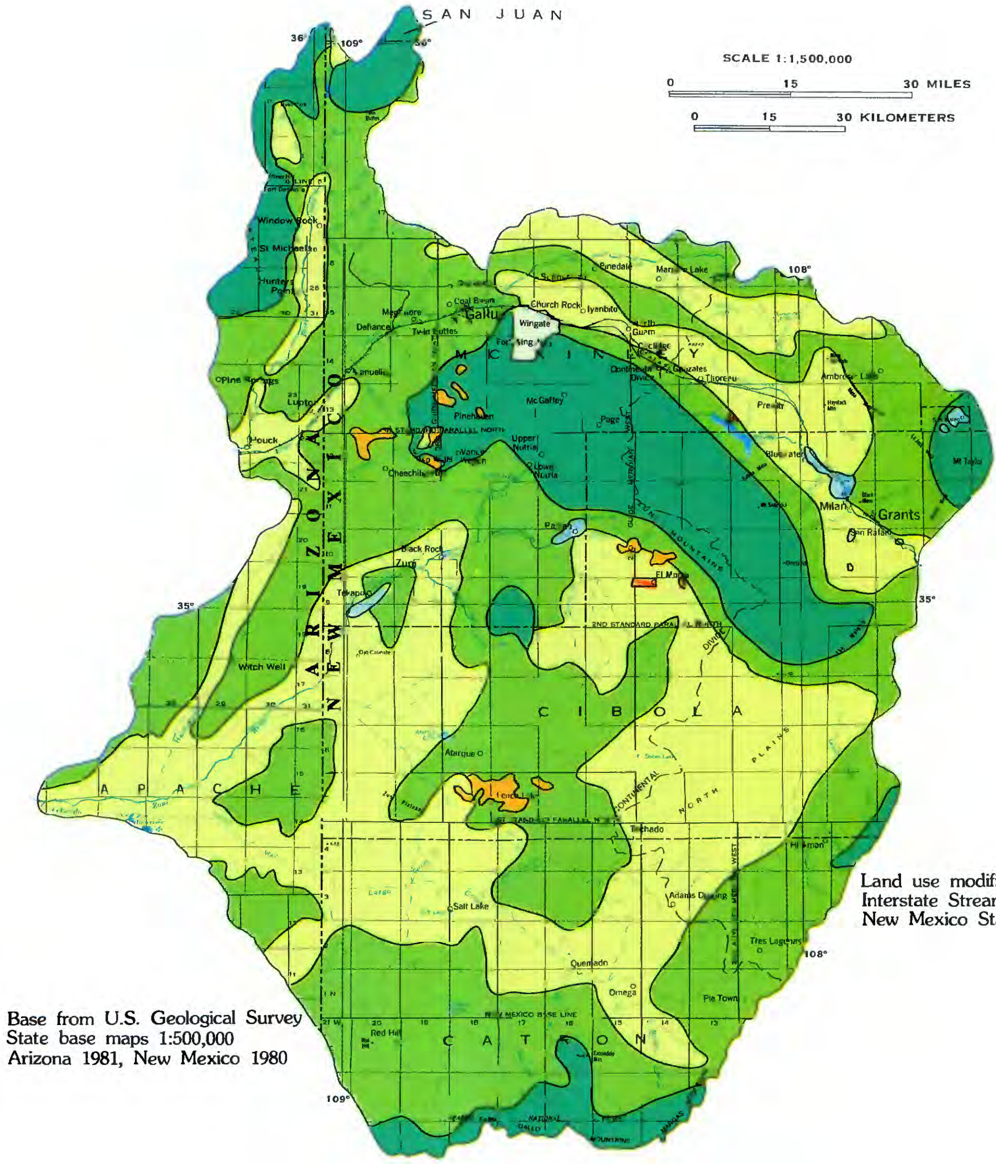
PONDEROSA PINE AND MIXED CONIFER Douglas fir and white fir with Englemann spruce and sub-alpine fir at higher altitudes.

PIÑON PINE, JUNIPER Altitude below the ponderosa pine represented by piñon pine-junipers, and sagebrush.

GRASSLANDS Blue grama, galleta, alkali sacaton, cholla, prickly-pear cacti, broom snakeweed, yucca, and forbs.

RIPARIAN Cottonwoods, willows, and salt cedar.

Figure 2.3-1 Vegetation.



Land use modified from New Mexico Interstate Stream Commission and the New Mexico State Engineer Office (1968).

Base from U.S. Geological Survey State base maps 1:500,000 Arizona 1981, New Mexico 1980

EXPLANATION

GRAZING	FARMLAND
Rangeland	Irrigated
Woodland	Dry farm
TIMBER	**RECREATION**
	MILITARY

Figure 2.3-2 Land use.

Light-Colored Low Humus Soils Predominant

Soils vary with landscape and are different on flood plains, hillslopes, and mountain slopes.

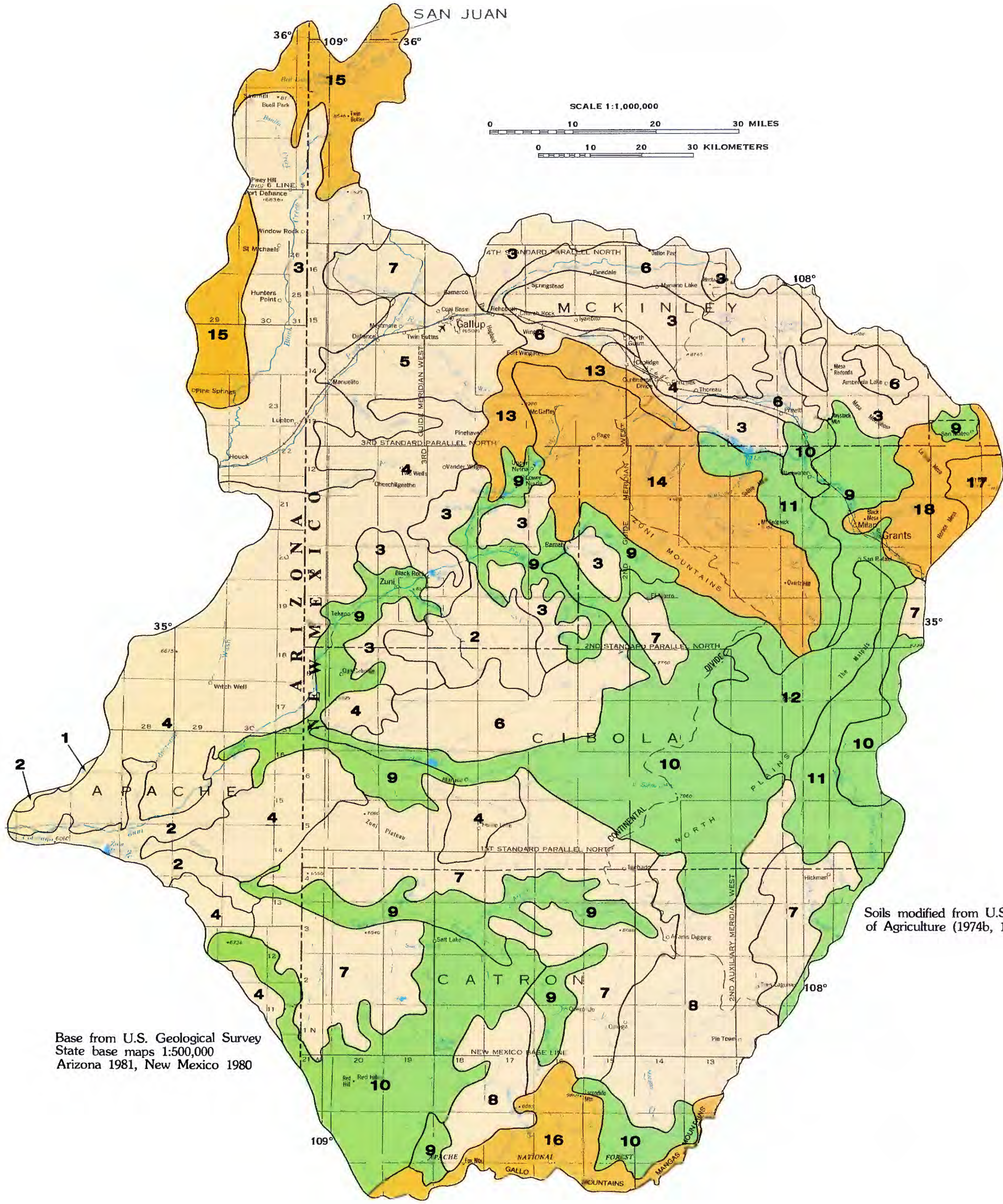
The soils of Area 62 are separated into 18 map units as described in figure 2.4-1. These map units have been grouped into three broad categories classified largely with respect to climate, to topographic setting, and to soil colors. The color of soil generally relates to the amount of humus present with dark-colored soils containing more humus than light-colored soils. The three categories are described below.

The "light colored soils of the cool plateau region" (map units 1 to 8) (fig. 2.4-2) are dominated by Torriorthents and Haplargids groups. These soils are dry and (or) salty. The soils principally are derived from sandstone, shale, and limestone. Soils of this category mainly are present on gently sloping and undulating landscapes, but also on steeply sloping and rolling ridges. The texture of this soil category ranges from sandy loam to heavy clay loam.

The "moderately dark colored soils of the cool plateau region" (map units 9 to 12) are dominated by Argiustolls and Rockland groups. Soils are primarily derived from volcanic rock and limestone. Soils of this category are on steeply sloping mesa tops and steep to very steep slopes and escarpments. These soils generally have surface layers of stony loam, clay loam, and fine sandy loam.

The "moderately dark and dark colored soils of the cool to cold mountain region" (map units 13 to 18) are dominated by the Eutroboralfs group. Soils are weathered from sandstone, shale, limestone, and basalt. Generally, soils are deep on nearly level valley areas. Soils are shallow on steep to very steep mountain slopes. The soil texture ranges from loam to clay. The soils in this category are located within the zones of greatest precipitation and highest altitude of Area 62.

More detailed information on the soil types described in this report are available from reports by Maker and others (1972, 1974, 1978). For the soils scientist involved in planning for reclamation of mined land, the report by the U.S. Department of Agriculture (1979) might also be useful.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

Soils modified from U.S. Department of Agriculture (1974b, 1981a).

Figure 2.4-1 General soil map.

Figure 2.4-2 Light-colored soils (south of Gallup, New Mexico).

EXPLANATION

(>, greater than)

Map Symbol	Map unit	Topographic setting	Soil depth (inches)	Slope (percent)	Altitude above sea level (feet)
	LIGHT COLORED SOILS OF THE COOL PLATEAU REGION				
1	Badland-Torriorthents-Torrifluvents	Hillslopes, ridges, flood plain	0-60	0-60	5,500 to 6,000
2	Torrifluvents	Flood plain, alluvial fans	>60	0-2	5,500 to 7,000
3	Rock outcrop-Torriorthents-Haplargids	Canyon walls, hillslopes, plains	0-40	1-70	5,800 to 7,500
4	Haplargids-Torripsamments-Torrifluvents	Plains, stabilized dunes	>60	0-8	5,500 to 7,500
5	Torriorthents-Rock outcrop	Hillslopes, escarpments	0-20	3-60	6,200 to 6,800
6	Camborthids-Torriorthents	Plains, hillslopes	6-40	1-12	6,400 to 7,000
7	Haplargids-Torriorthents-Rock outcrop	Plains, hillslopes, canyon walls	0-40	1-60	6,200 to 7,000
8	Haplargids	Plains	15-60	1-20	6,400 to 7,900
	MODERATELY DARK COLORED SOILS OF THE COOL PLATEAU REGION				
9	Torrifluvents-Haplargids-Haplustolls	Flood plain, plains, valley floors	>60	0-3	6,200 to 7,400
10	Argiustolls-Haplustalfs-Rock outcrop	Plains, hillslopes, escarpments	0-40	0-30	7,100 to 7,800
11	Rockland-Torriorthents-Argiustolls	Hillslopes, escarpments	0-20	2-75	7,000 to 7,500
12	Lava rockland	Rock, broken land surface	--	2-10	7,000 to 7,500
	MODERATELY DARK AND DARK COLORED SOILS OF THE COOL TO COLD MOUNTAIN REGION				
13	Rock outcrop-Haplustolls-Argiustolls	Canyon walls, hillslopes	0-20	5-70	6,000 to 7,500
14	Eutroboralfs-Argiborolls	Mountain slopes	10-40	5-40	7,500 to 8,500
15	Eutroboralfs-Ustorthents	Mountain slopes	10-50	2-40	7,000 to 9,000
16	Argiborolls-Cryoborolls-Ustorthents	Mountain slopes	15-60	2-40	7,000 to 9,800
17	Cryoboralfs-Paleboralfs-Eutroboralfs	Mountain slopes	20-60	10-75	8,500 to 11,300
18	Argiustolls-Rockland	Basalt-capped mesas, lava flows, volcanic hills, escarpments	0-40	0-75	7,000 to 8,500

The Major Structural Features of the Coal Area were Largely Developed by Middle Tertiary Time

The major structural features in Area 62 are the southern San Juan Basin, its bounding structures, and the Mogollon slope.

Area 62 lies in the southeastern quarter of the Colorado Plateau, one of the major structural provinces of the United States. The Plateau is characterized by a thick sequence of sedimentary rocks that indicate a long tectonic history (Foster, 1971, p. 363 and Kelley, 1951, p. 124-129). The southern part of the San Juan Basin, its major bounding structures (Kelley, 1951), and the Mogollon slope are the major structural features in Area 62 (fig. 2.5-1).

During the nineteenth century the study of sedimentary rocks and the plant and animal fossils they contained led to the development of the geological time scale (fig. 2.5-2). The scale shows the immensity of time involved for formation of the structural features in Area 62.

The San Juan Basin, a structural embayment of the Colorado Plateau, began to form during a period of uplift as early as Late Paleozoic time (Kelley, 1951, p. 130). The Defiance and Zuni uplifts the major highland elements in the southern San Juan Basin were forming in Paleozoic and Mesozoic Time. Kelley states that the present structural elements of the San Juan Basin were probably developed by Middle Tertiary time.

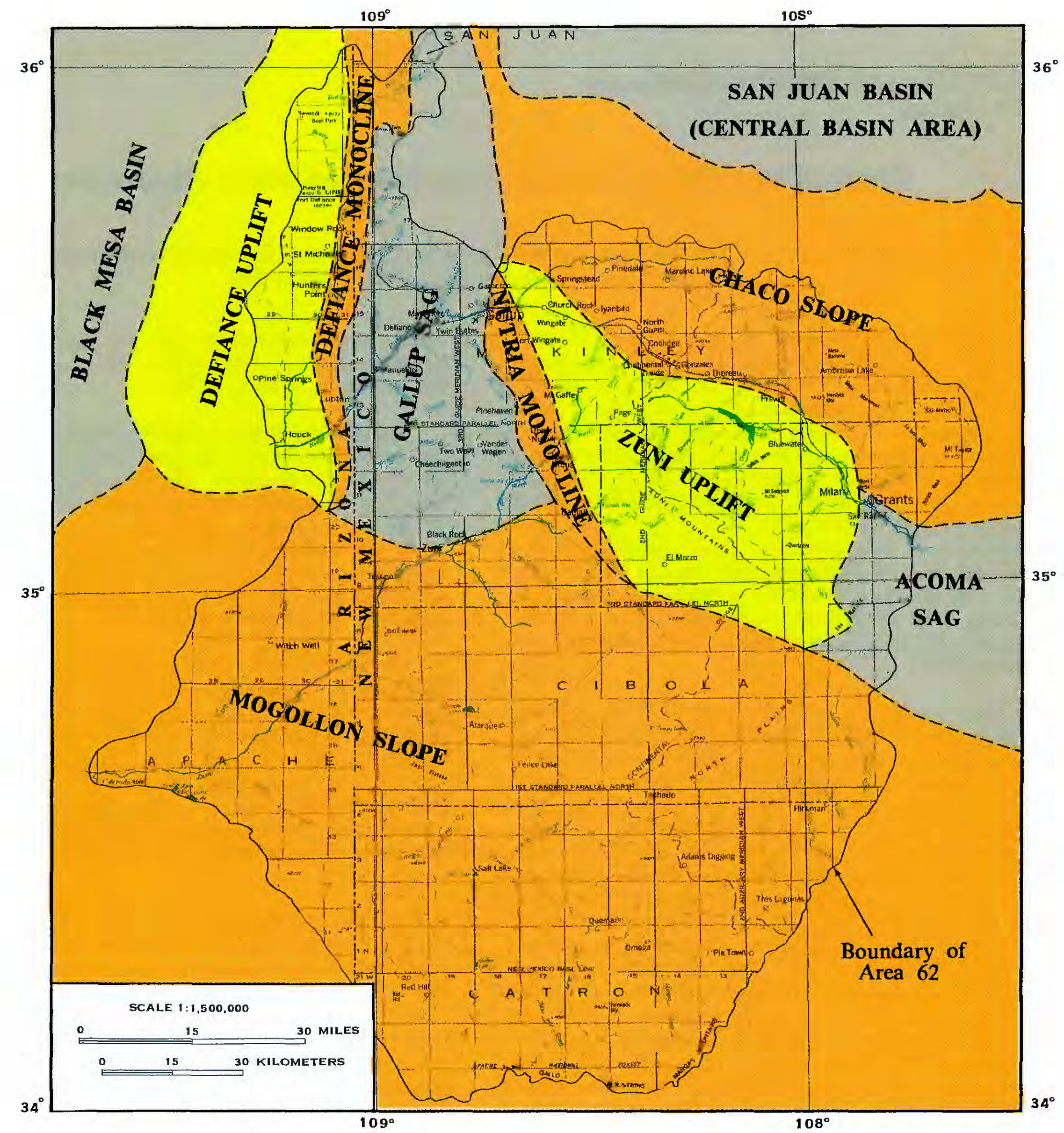
The Mogollon highland dominated the south side of the Colorado Plateau during Late Jurassic time. The south half of the highland (shown in fig. 2.5-1 as the Mogollon slope) was broken and tilted to the northeast during volcanic episodes at the end of the Jurassic Period (Saucier, 1976, p. 152). The Mogollon slope is the structural feature which represent the tectonic remnants of the Mogollon highland.

The Zuni and Defiance uplifts are located on the southern and western edges of the San Juan basin. The Zuni uplift trends northwestward, is 80 miles long by 35 miles wide, and has a structural relief of 5,500 feet (Kelley, 1951, p. 126). The steep limb of the uplift dips southwestward away from the basin. The Defiance uplift trends northward past the study area, is 100 miles long by 30 miles wide, and has a maximum structural relief of 7,500 feet (Kelley, 1967, p. 28). The steep limb dips east toward the San Juan basin (Kelley, 1951).

Two structural platforms (Kelley, 1951, p. 126) are located in the study area: The Acoma sag and the Gallup sag. The Acoma sag is a flat wide area bordering the Zuni uplift on the east. The Gallup sag extends from the San Juan basin southward between the Defiance and Zuni uplifts (Kelley, 1967, p. 29).

Two monoclines border the Gallup sag. The Nutria Monocline bounds the north two-thirds of the Zuni uplift on its west side (Kelley, 1967) and the Defiance monocline borders the Defiance uplift on its east side.

Kelley (1951, p. 126) describes the Chaco slope as the southern part of the San Juan Basin that lies between the Central Basin (fig. 2.5-1) and the Zuni uplift and Acoma sag. The Chaco slope resembles the platforms but differs from them because of "its more pronounced and continuous regional inclination toward the center of the basin and by the absence of a 'monocline' separating it from the Central Basin" (Kelley, 1951, p. 126).



Structural features modified from Kelley (1951, 1955)

EXPLANATION

- UPLIFTS
- BASINS AND PLATFORMS
- SLOPES AND MONOCLINES
- ---- BOUNDARY BETWEEN STRUCTURAL FEATURES

Figure 2.5-1 Major structural features.

ERA	APPROXIMATE AGE IN MILLIONS OF YEARS*	PERIOD (System)	EPOCH	TECTONIC FEATURES (Approximate time of formation)
CENOZOIC	.010	Quaternary	Holocene	
	2		Pleistocene	
	5	Tertiary	Pliocene	
	24		Miocene	
	38		Oligocene	OTHER UPLIFTS PLATFORMS MONOCLINES; MOGOLLON SLOPE; ZUNI AND DEFIANCE UPLIFTS; SAN JUAN BASIN; COLORADO PLATEAU
	55		Eocene	
			Paleocene	
	63			
MESOZOIC	138	Cretaceous		
	205	Jurassic		
		Triassic		
	~240			
PALEOZOIC	290	Permian		
	~330	Pennsylvanian		
	360	Mississippian		
	410	Devonian		
	435	Silurian		
	500	Ordovician		
		Cambrian		
	~570			
PRECAMBRIAN				
	4550			

*Ages shown are estimates based on isotopic and biostratigraphic age assignments.
Age of rocks represented by ~ are not supported as closely by existing data.

Figure 2.5-2 Geologic time.

Exposed Rocks Range in Age from Precambrian to Quaternary

Cretaceous rocks in the New Mexico part of the study area make up the most extensive outcrops of any of the rock units.

Exposed rocks in the area range in age from Precambrian (older than 570 million years ago) to Quaternary (about 10,000 years age to the present). The geologic map (fig. 2.6-1) shows the rocks exposed at the surface. Cross sections in section 4.5 provide information on stratigraphic relationships. Exposures of Precambrian gneissic granite are found southeast of Gallup in the Zuni Mountains (Hackman and Olson, 1977). Rocks of Cambrian through Mississippian age do not crop out in the study area. Pennsylvanian to Permian rocks of the Supai Formation are exposed along the Defiance uplift (fig. 2.5-1) in Apache County. The lithology of the Supai Formation consists of alternating beds of reddish-brown sandstone, siltstone, mudstone and white gypsum and gray limestone (Hackman and Olson, 1977).

A thick sequence of Permian rocks was deposited by alternating transgressions and regressions of the sea (McKee, 1967, p. 219). Extensive exposures of Permian rock are present along the Defiance uplift in Apache County, Arizona, and the Zuni uplift in Cibola and McKinley Counties, New Mexico. The Permian De Chelly Sandstone in Apache County is composed of orange, pink, and red fine-to-medium-grained sandstone (Hackman and Olson, 1977). The exposed Permian sequence of rocks in Cibola and McKinley Counties in ascending order consists of the Abo and Yeso Formations, the Glorieta Sandstone, and the San Andres Limestone. The Abo and Yeso Formations of Early Permian age are composed mostly of reddish sandstone and siltstone with several limestone and gypsum beds in the upper part of the Yeso Formation (Hackman and Olson, 1977). The Glorieta Sandstone, a white and buff-colored sandstone, is overlain by the San Andres Limestone, a gray and yellow thick-bedded dolomitic limestone (Hackman and Olson, 1977).

Triassic, Jurassic, and Cretaceous sediments were deposited in continental, near-shore, and marine environments. Frequent facies changes represent the fluctuations of the depositional environments and regional unconformities illustrate periods of erosion in Mesozoic time.

The Moenkopi Formation and Chinle Formation are the Triassic sedimentary rocks in Area 62. The Moenkopi Formation is composed mainly of red to brown gypsiferous sandstone, siltstone, and shale and is shown in figure 2.6-1 as part of the Triassic rocks cropping out in southern Apache County. The Chinle Formation, a variegated sequence of sandstone and siltstone (Repenning and others, 1969, p. B-2) is exposed near Window Rock, Arizona, along the Zuni River in Arizona, in southern and central McKinley and northern Cibola Counties, New Mexico (fig. 2.6-2).

Rocks in the Glen Canyon Group are probably both Jurassic and Triassic in age and are found in the northern part of the study area along the Arizona-New Mexico boundary, in southern and central McKinley County, and northern Cibola County. The Glen Canyon Group contains several formations that are composed mainly of sandstone and siltstone and that have cross-bedding (Cooley and others, 1969, p. A-14).

Middle and Upper Jurassic sedimentary rocks include the San Rafael Group, the Zuni Sandstone (fig. 2.6-2) and the Morrison Formation, which lie unconformably on the Glen Canyon Group. They are exposed in the northern part of the study area in Arizona, in southern and central McKinley County, and northern Cibola County. These formations consist of mostly sandstone with some silty sandstone and siltstone (Cooley and others, 1969, p. A-14 and Dane and Bachman, 1965).

Cretaceous rocks form the most extensive outcrops of rock units in the New Mexico part of the study area. The Dakota Sandstone and Mancos Shale exposures are scattered throughout the area. These formations are composed of mostly gray, yellow, and orange sandstone, shale, clay, and silt (Hackman and Olson, 1977). The Mesaverde Group overlies the Mancos Shale and major lithologies are characterized by transgressive and regressive wedges of sandstone with thick lenses of shale and coal (Silver, 1951, p. 111-113).

Tertiary formations include the Bidahochi and the Baca Formations which are mostly fluvial sediments and contain some sediments of volcanic origin (Orr, 1982, p. 30 and U.S. Department of Agriculture, 1981a, p. 1-14). These formations are present in the southern part of the study area. The Tertiary Chuska Sandstone contains wind-blown and fluvial sediments and is present along the extreme northern edge of the area (Cooley and others, 1969, p. A-17). Other sedimentary rocks are included in the Tertiary designation on figure 2.6-1 and consist of conglomerate, sandstone, siltstone, and limestone. They are found at the surface in the western and central parts of the study area.

A considerable amount of volcanic activity started in Tertiary time and continued through much of Quaternary time (Cooley and others, 1969, p. A-17). Outcrops of Tertiary and Quaternary lava flows and volcanic deposits (including volcanic breccia, tuff, basalt, and cinders) are present along the southeastern edge of the area at Pie Town, New Mexico, westward to the State line and into southern Apache County, Arizona, and in the northeast including the Mount Taylor volcanic field. Necks, volcanic buttes, and diatremes protrude locally and are composed mostly of intrusive igneous rocks (rhyolite, trachyte, and latite), basalt, and consolidated ash (tuff) (Callaghan, 1951, p. 120-122, and U.S. Department of Agriculture, 1981a, p. 1-14).

Quaternary and Tertiary alluvium and bolson deposits are found mostly along streams and valleys, and as landslide deposits throughout the study area. These sedimentary deposits are composed of sand, silt, and gravel.

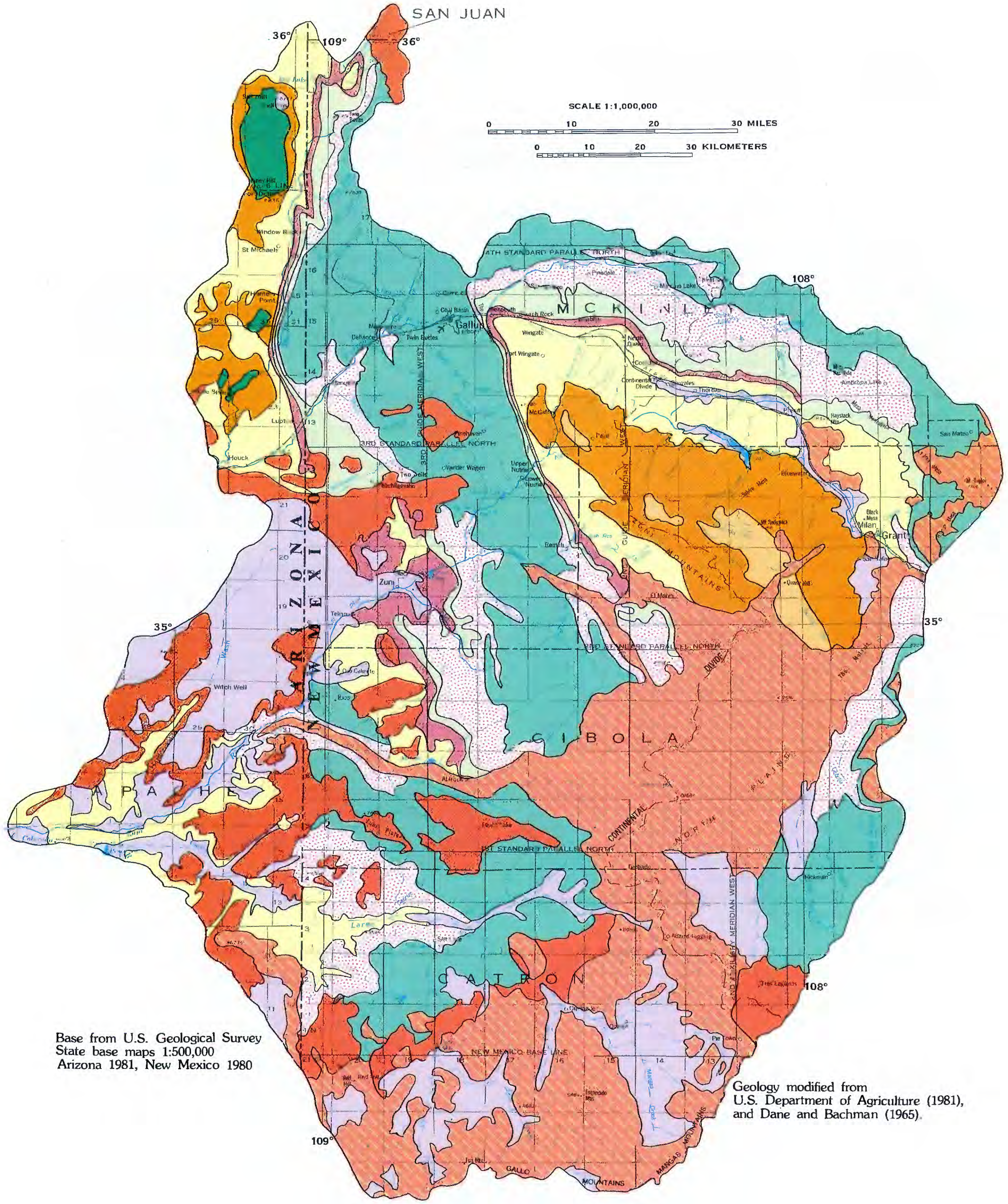
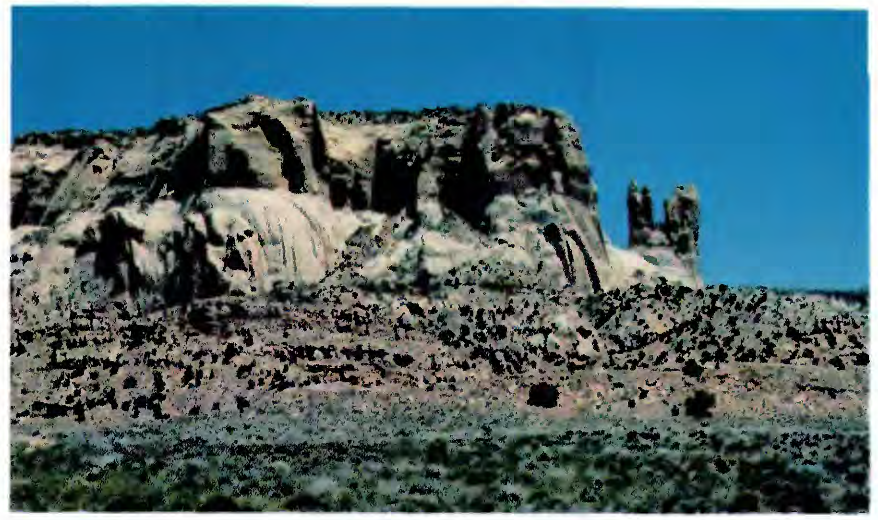


Figure 2.6-1 Generalized geologic map.



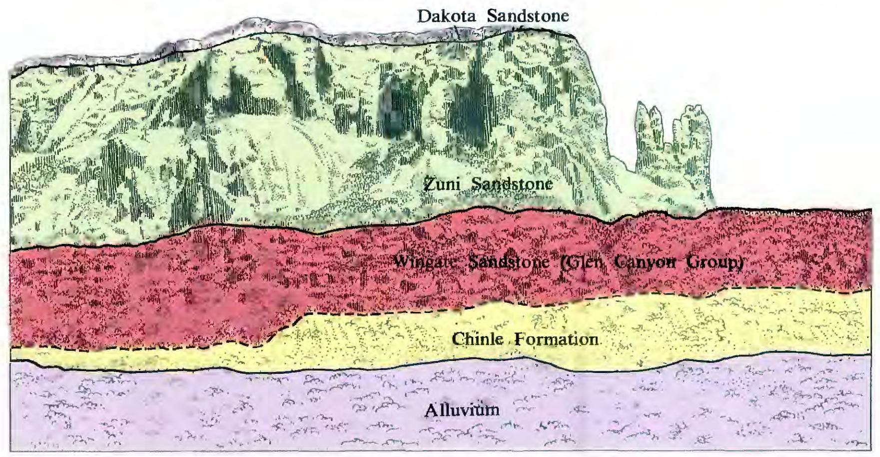


Figure 2.6-2 Dowa Yallane Mesa near Zuni, New Mexico, showing exposed formations (contact dashed where approximated).

EXPLANATION

QUATERNARY AND TERTIARY	ALLUVIUM AND BOLSON DEPOSITS
	IGNEOUS ROCKS, INCLUDES BASALT FLOWS, VOLCANIC BRECCIA, TUFF AND CINDERS, AND EXPOSED INTRUSIVE IGNEOUS ROCKS
TERTIARY	SEDIMENTARY ROCKS INCLUDING BIDAHOCHI FORMATION, CHUSKA SANDSTONE, AND BACA FORMATION
CRETACEOUS	MESAVERDE GROUP
	MANCOS SHALE AND DAKOTA SANDSTONE, UNDIVIDED
JURASSIC	MORRISON FORMATION, ZUNI SANDSTONE, AND SAN RAFAEL GROUP, UNDIVIDED
JURASSIC AND TRIASSIC	GLEN CANYON GROUP
TRIASSIC	CHINLE FORMATION; LOCALLY INCLUDES MOENKOPI FORMATION
PERMIAN	SAN ANDRES LIMESTONE AND GLORIETA SANDSTONE IN NEW MEXICO, DE CHELLY SANDSTONE IN ARIZONA, AND THE YESO AND ABO FORMATIONS IN NEW MEXICO
PERMIAN AND PENNSYLVANIAN	SUPAI FORMATION
PRECAMBRIAN	PRECAMBRIAN ROCKS, UNDIVIDED

Economic Coal-Bearing Rocks of Cretaceous Age Exist in Four Major Coal Fields

Surface mining has continued on a large scale since mid-1961.

Area 62 contains the following coal fields: Part of the San Juan Basin field along the northern edge of the area; the Gallup-Zuni field; the Salt Lake field; and part of the Datil Mountain field along the southeastern side of the area (fig. 2.7-1). All the coal fields contain surface-minable reserves (less than 250 feet of overburden) and deep reserves (greater than 250 feet of overburden). Only three strip mines are in operation presently (Martinez, 1981, p. 42-43) and they are located in the northern Gallup-Zuni field. Fourteen surface or underground mines, located in three of the four coal fields, are abandoned or inactive. Additional information about some of these mines is found in a report by Sears (1925).

The coal-bearing rock units with surface-minable coal include the Gallup Sandstone, the Dilco Coal Member and the Gibson Coal Member of the Crevasse Canyon Formation, and the Cleary Coal Member of the Menefee Formation, all of the Upper Cretaceous Mesaverde Group (table 2.7-2). The coal-bearing units are separated by three non-coal-bearing units of varying thicknesses--the Dalton Sandstone and Bartlett Barren Members of the Crevasse Canyon Formation, and the Point Lookout Sandstone. Current studies by Hook and others (1983, in press) have redefined and renamed some units in the Mesaverde Group, Mancos Shale, and Dakota Sandstone in the Salt Lake Field. "Deposition of marine rocks occurred earlier in the Salt Lake coal field than in the northern Zuni Basin apparently because of a faster southwesterly transgression rate" (Hook and others, 1980, p. 46).

Underground mining in the Gallup-Zuni field, which began in the 1880s, continued on a large scale until 1951. Surface mining became the predominant method of extraction by mid-1961 and has continued on a large scale to the present (1983) (Kottlowski and others, 1980, p. 549). The coal beds of the Dakota Sandstone were successfully mined underground. The beds have limited extent and surface-minable reserves do not exist.

In the northern part of the Gallup-Zuni field, surface-minable coal is within the Dilco Coal and Gibson Coal Members of the Crevasse Canyon Formation, each of which contains five commercial coal beds of bituminous rank. The remaining surface-minable coal in this field has been estimated to be 358 million tons (Martinez, 1981, p. 50).

Coal-bearing rocks in the southern part of the Gallup-Zuni field are mainly within the Gallup Sandstone with a few lenses in the Dilco Coal Member. The rocks extend for about 55 miles south of Zuni Pueblo but are covered by Cenozoic volcanic rocks in many areas. Considerable reserves of deep coal and coal seams lie beneath thick sandstones. Estimated surface-minable reserves for the southern part of the Gallup-Zuni field are about 6.2 million tons (Martinez, 1981, p. 50).

Coal reserves in the southeastern end of the San Juan Basin field are found in the Gallup Sandstone and the Gibson and Dilco Coal Members. The beds are discontinuous and are commonly overlain by thick sandstone units. Although considerable reserves of deep coal may be present, drill-hole data provide estimates of only about 15 million tons (table 2.7-1) of surface-minable coal reserves (Kottlowski and others, 1980,p. 551).

Coal reserves from the Gallup Sandstone and Crevasse Canyon Formation in the Datil Mountain field are estimated at 1,320 million tons (Martinez, 1981, p. 49). Recent studies by Roybal and Campbell (1982, p. 18) estimate surface-minable reserves in the Salt Lake field to be 287.90 million tons (table 2.7-1). Only minor occurrences of coal are known in the Arizona part of the study area. Arizona's principal coal field, the Black Mesa field, is located about 50 miles northwest of Area 62.

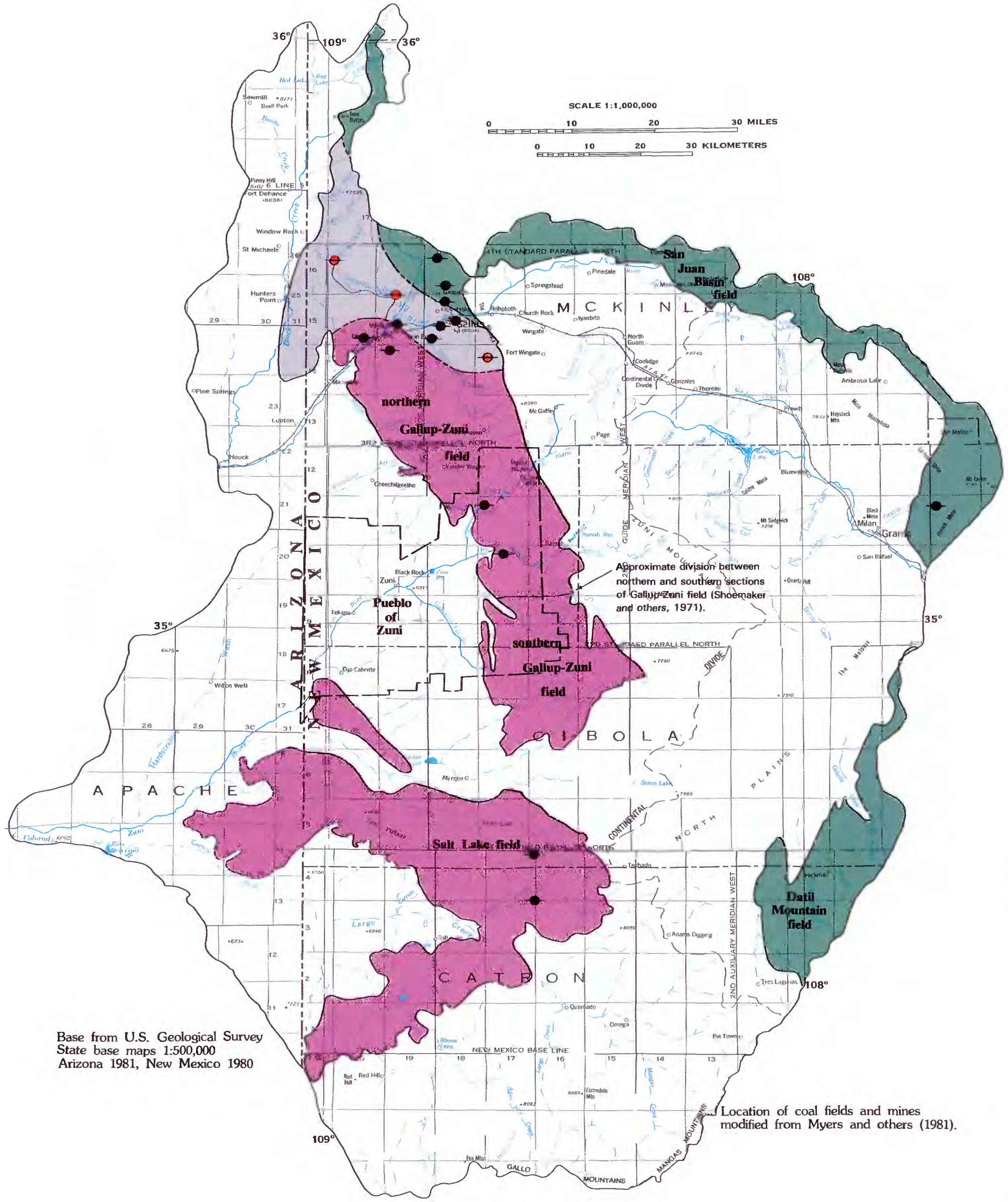
Table 2.7-1 Surface-minable coal reserves in Area 62, in millions of short tons.

Coal field	Overburden,[1] less than 150 feet	Overburden, 150 feet to 250 feet	Total
Northern Gallup-Zuni	270.0	88.0	358.0
Southern Gallup-Zuni	6.2		6.2
Southeastern San Juan Basin	15.0		15.0
Datil Mountain			1,320[2]
Salt Lake	227.08	60.82	287.90

[1] Overburden includes both measured and inferred amounts.

[2] Number refers to both surface-minable and deep resources in the entire Datil Mountain field. Only a part of the field is present in Area 62.

Data from Kottlowski, 1981; Martinez, 1981; and Roybal and Campbell, 1982.



Base from U.S. Geological Survey State base maps 1:500,000 Arizona 1981, New Mexico 1980

Location of coal fields and mines modified from Myers and others (1981).

Table 2.7-2 Age, nomenclature, and relationship of Cretaceous age and younger rock units in Coal Area 62.

Era	System	Series	Lithologic Unit		
CENOZOIC	Quaternary	Holocene and Pleistocene	[1]Valley-fill sediments. Includes alluvium loess, colluvium terrace gravels, and basalt flows.		
	Tertiary	Pliocene and Miocene	[1]Bidahochi Formation		
		Oligocene and Eocene (?)	[2]Chuska Sandstone		
		Eocene to Paleocene	[2]Baca Formation		
MESOZOIC	Cretaceous	Upper Cretaceous	[1,3]Mesaverde Group	Tohatchi Formation	
				[1]Cliff House Sandstone	
				[1]Menefee Formation	Allison Member
					[3]Cleary Coal Member
				[1]Point Lookout Sandstone	
				Crevasse Canyon Formation	[2,3]Gibson Coal Member
					Bartlett Barren Member
					[1]Dalton Sandstone Member
					[2,3]Dilco Coal Member
				[1,3]Gallup Sandstone	
			[2]Mancos Shale		
		Lower Cretaceous	[1]Dakota Sandstone		

[1]Major Aquifer
[2]Minor Aquifer
[3]Contains strippable coal deposits

Modified from Kelly (1981); Smith (1951); Lochman-Bach (1967); and Orr (1982)

EXPLANATION

RANK OF COAL

Bituminous coal A rank of coal between subbituminous and anthracite having a lower moisture content and higher carbon content than subbituminous coal and having experienced greater pressure at time of formation than subbituminous coal.

Subbituminous coal A rank of coal between lignite and bituminous having a lower moisture content and higher carbon content than lignite and having experienced greater pressure at time of formation than lignite.

Bituminous and subbituminous coal Coal deposits of both ranks may occur together in vertical and lateral stratigraphic sequences.

BOUNDARIES

Field boundary Dashed where coal-bearing rocks are inferred.

Rank boundary

Boundary of Zuni Pueblo

COAL MINES

Active surface mine

Abandoned or inactive surface or underground mine

Figure 2.7-1 Major coal-bearing regions (fields) and coal mines in Cretaceous rocks.

Streamflow-Gaging Network Consists of 25 Stations

Streamflow data have been collected for a variety of needs.

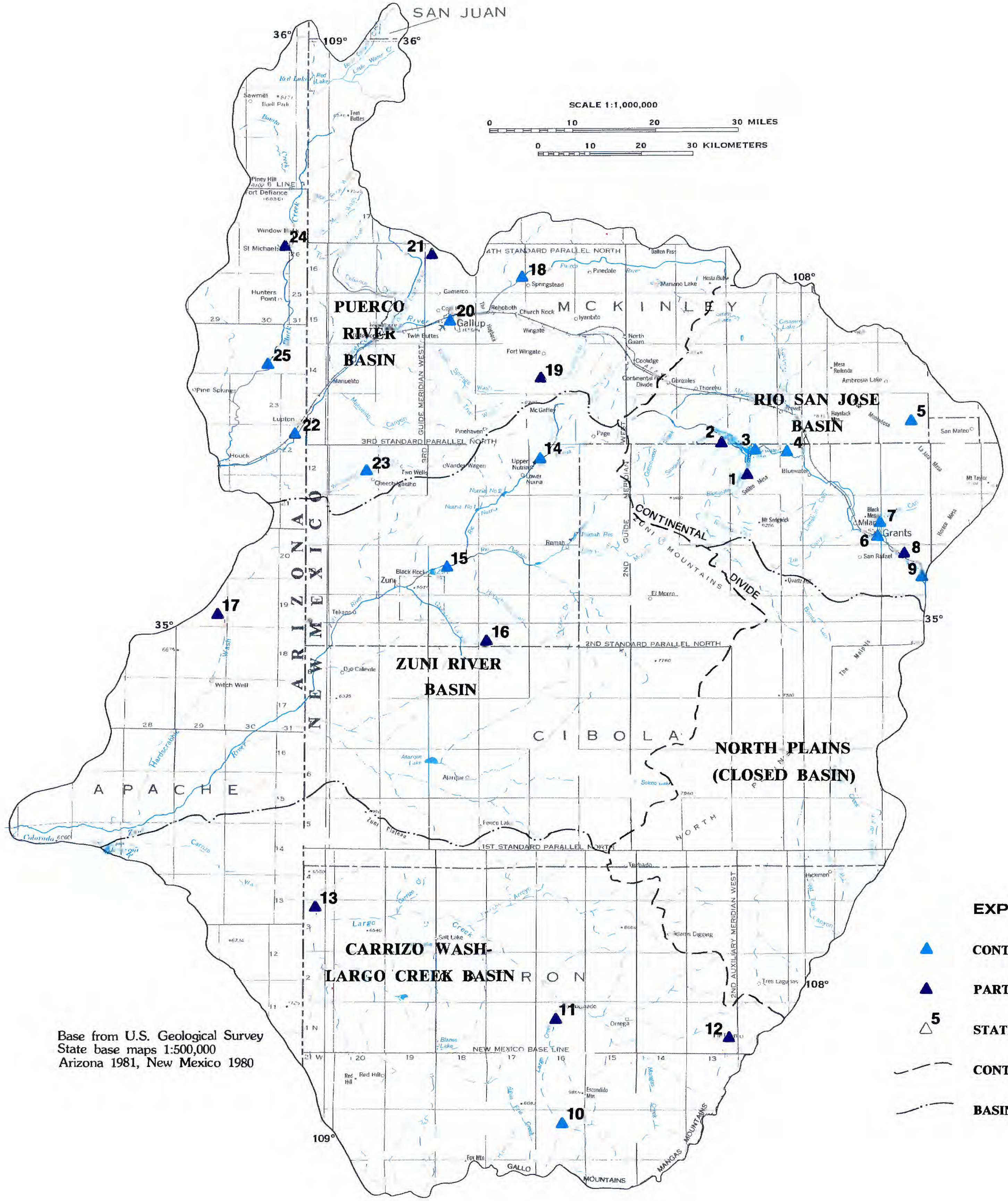
Data have been collected at three types of streamflow gaging stations in Area 62. These stations, classified as continuous, partial-record, and miscellaneous, have been established in response to various needs and provide differing types of streamflow information. For example, daily mean discharges, peak flows, base flows, and instantaneous measurements for the complete year are available for continuous-record stations. The daily mean discharges are computed from records of continuous stage readings collected at the stations. Data concerning peak flows, low-flows and some instantaneous measurements are available at partial-record stations. Instantaneous measurements of streamflow are made at miscellaneous stations. The gaging stations were established for various purposes, including long term hydrologic assessment, data collection for short-term projects established to study specific problems, or in response to data needs caused by legal decisions or compacts.

The Continental Divide, shown in figure 3.1-1, crosses the study area. Streams to the east of the Divide are within the Rio Grande basin. The Rio San Jose (fig. 3.1-2) is included in this area. Streams to the west of the Divide, which include the Zuni River, Black Creek, Puerco River, and Carrizo Wash-Largo Creek are part of the Little Colorado River basin. The major river basins in the study area are delineated in figure 3.1-1.

The locations of the stations for which streamflow data were analyzed in this report are shown in figure 3.1-1. Periods of record, drainage areas and other information about the streamflow stations are tabulated in section 6.1. As noted in section 6.1 some of the stations shown have been discontinued or changed from partial record to continuous record. Fifteen of the 25 stations are currently being operated. Miscellaneous discharge measurements have not been included in analysis of surface-water data performed in the following sections.

Data from miscellaneous stations are available from the Geological Survey offices in Tucson, Arizona and Albuquerque, New Mexico.

Additional details about the period of record and type of data collected as well as the actual data, are available from computer storage through the National Water Data Exchange (NAWDEX) (section 5.2) and WATSTORE (section 5.3).



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

- CONTINUOUS-RECORD GAGING STATION
- PARTIAL-RECORD GAGING STATION
- △5 STATION AND NUMBER
- CONTINENTAL DIVIDE
- BASIN DIVIDE

Figure 3.1-1 Location of surface-water gaging stations.

Figure 3.1-2 Streamflow-gaging station (9), Rio San Jose near Grants, New Mexico.

Streamflows Exhibit Marked Changes Throughout the Year

Variation in streamflow is directly related to rainfall and snowmelt.

Most streams draining Area 62 are typical of streams in arid or semiarid lands. For such streams, there is no flow during most of the year. Most of the streamflow results from infrequent intense storms and from snowmelt causing a great deal of variability within a year.

To illustrate the variability of streamflow that exists within a particular year, streamflow hydrographs for the 1980 water year for the Zuni River (subject to regulation from upstream reservoirs) and Rio San Jose (regulated by Bluewater Lake) are presented in figure 3.2-1. As can be seen, there is little flow for much of the year. The periods of no flow can be contrasted against the peaks resulting from surface runoff from snowmelt and storms. Storm activity results in "flashy" peaks; that is, the storms result in a rapid rise in streamflow to the peak, followed by a rapid decrease in flow.

The monthly mean, maximum, and minimum for flows on the Rio San Jose and Zuni River for the period of record are summarized in figure 3.2-2. A majority of the annual discharge occurs from March through August in response to snowmelt and storms. Differences between the maximum and minimum flows are variable from month to month. Maximum discharges vary greatly between months, while the minimum discharges are zero for most months. For contrast, the maximum and minimum flows are summarized below for the Zuni River and Rio San Jose.

Map No.	Station Name	Maximum average flow		Minimum average flow		
		Flow	Water year	Flow	Water year	Average flow
15	Zuni River above Black Rock Reservoir, N. Mex.	46.9	1973	1.39	1972	13.0
6	Rio San Jose at Grants, N. Mex.	28.7	1916	0.01	1961	3.22

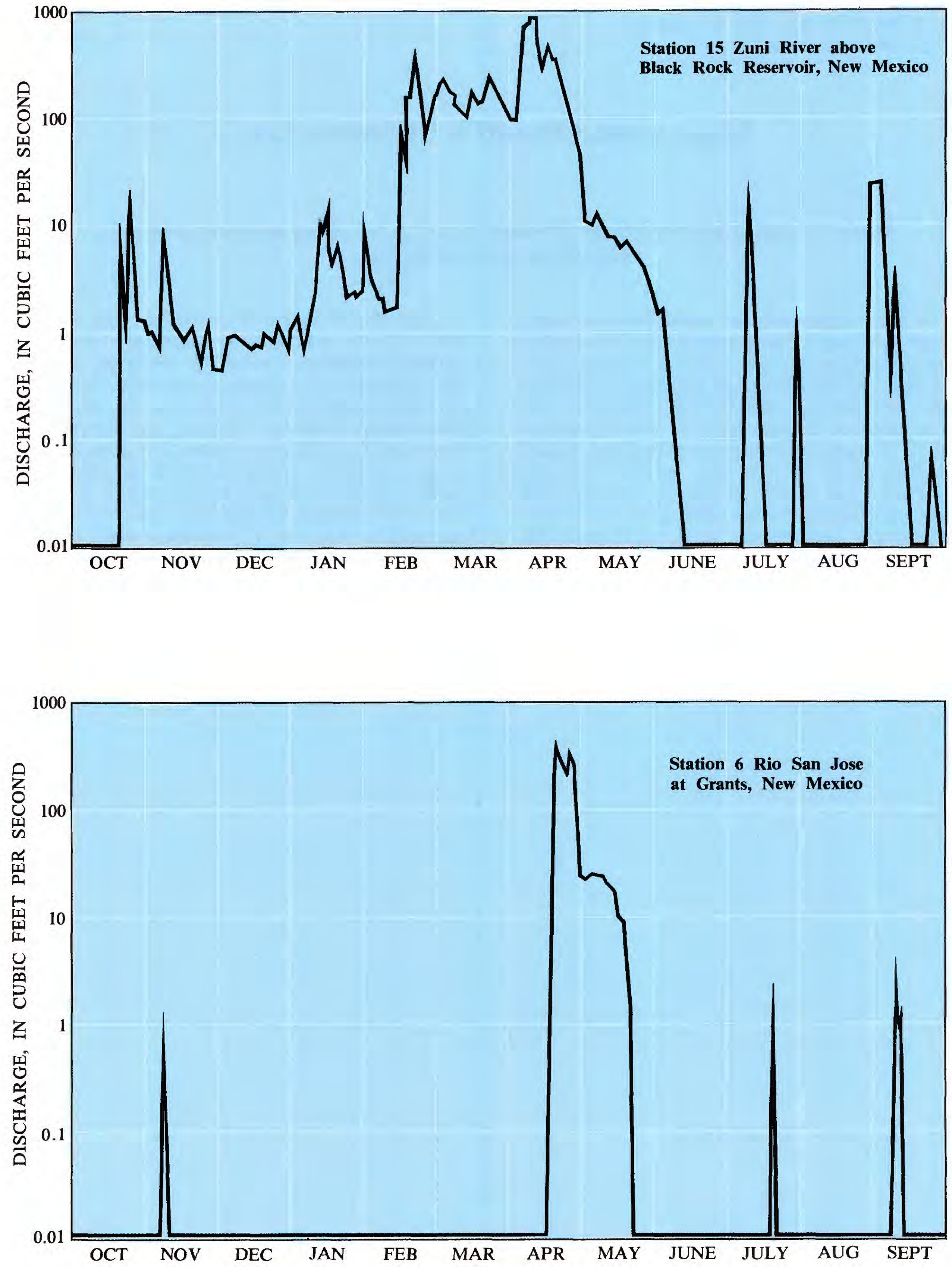


Figure 3.2-1 Daily mean discharge hydrographs (1980 water year) for Zuni River and Rio San Jose.

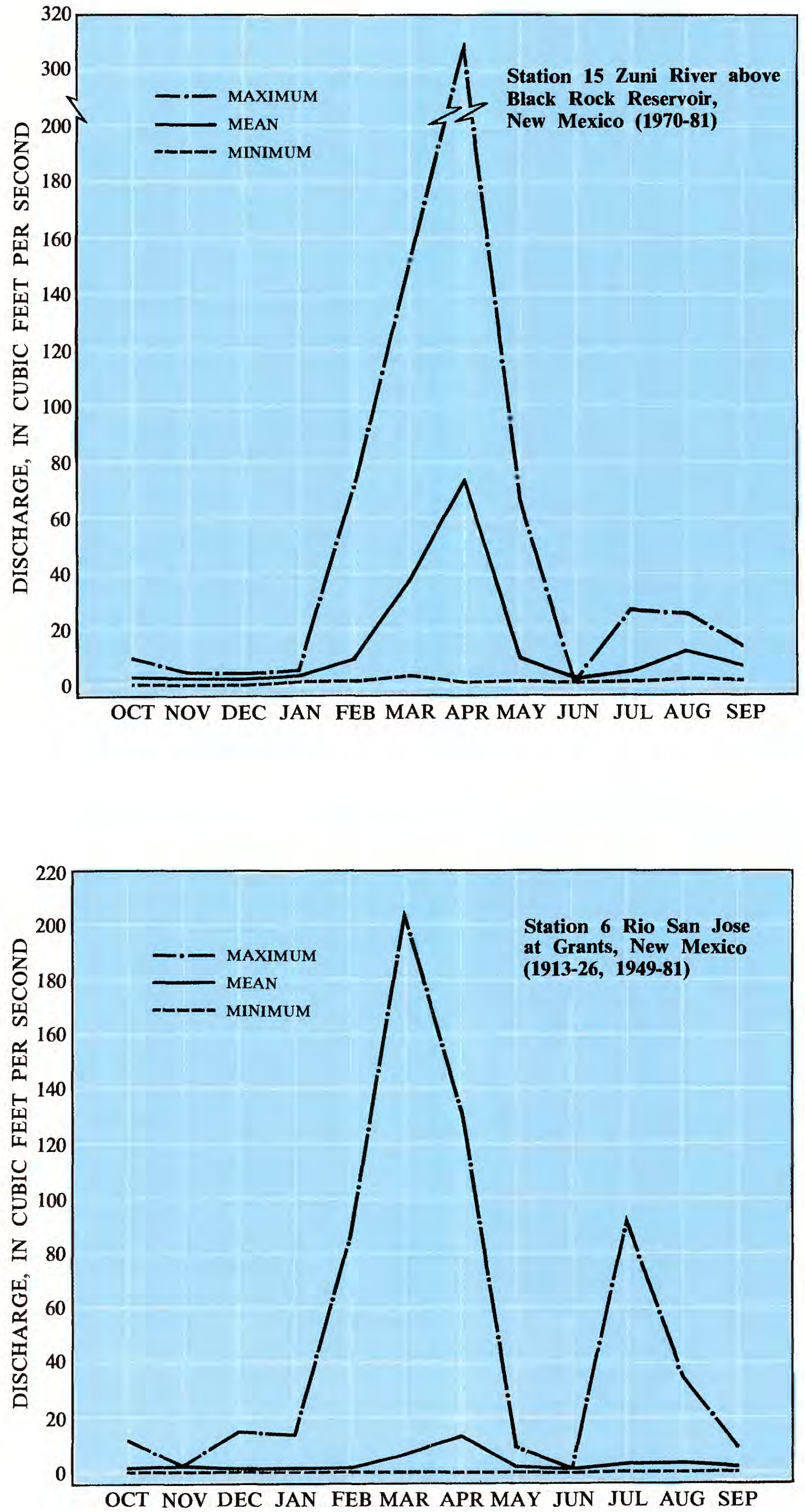


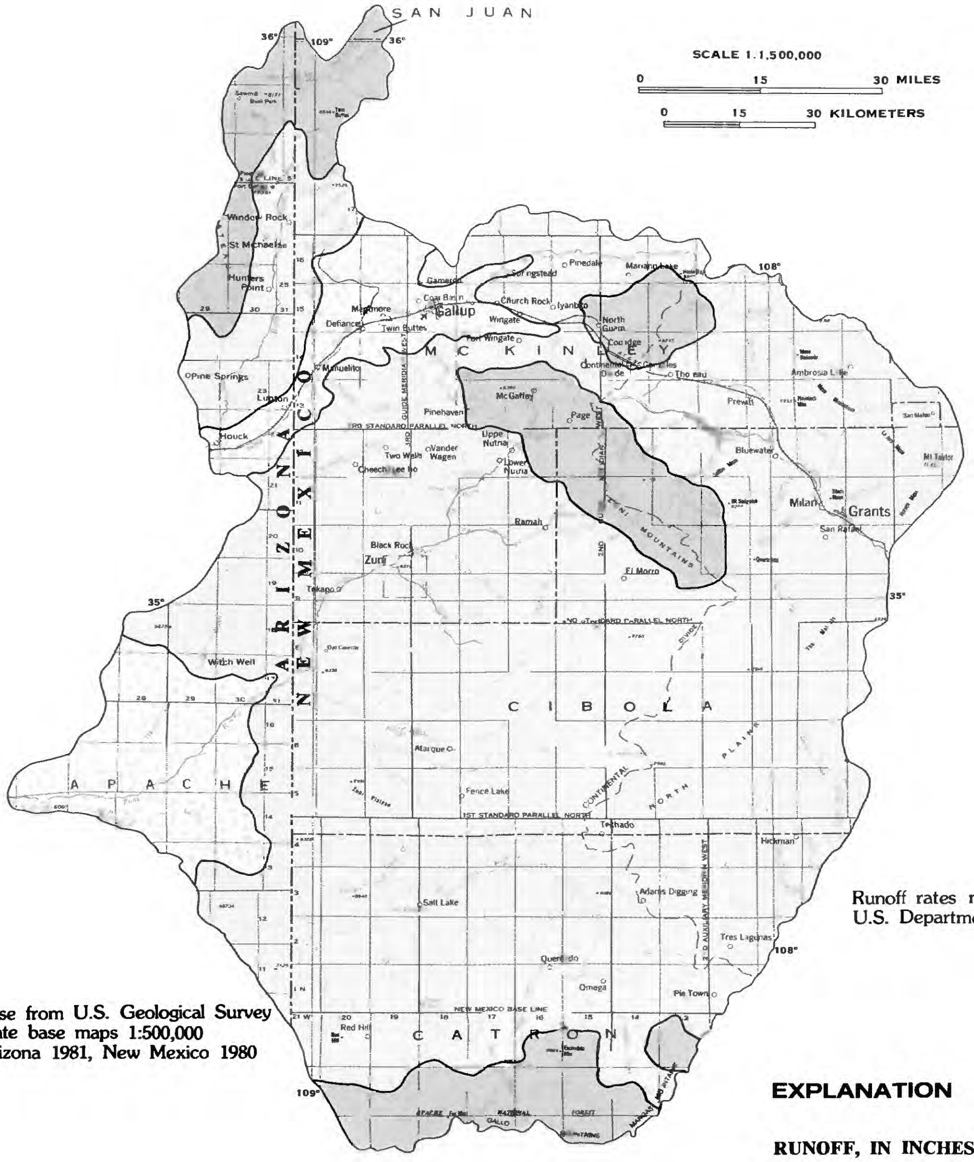
Figure 3.2-2 Maximum, mean, and minimum monthly mean discharges for the Zuni River and Rio San Jose.

Mean Annual Runoff is 1.0 Inch or Less

Mountainous areas contribute the most runoff; base flows are indicative of no ground-water contribution.

A map delineating the distribution of mean annual unit runoff (mean annual runoff divided by drainage area) in Area 62 is shown in figure 3.3-1. The map, modified from one published by the U.S. Department of Agriculture (1981b), represents runoff in terms of average depth of yearly runoff in inches. Mountainous areas contribute the highest runoff value of 1.0 inch with the lower altitudes contributing less runoff. As pointed out in the U.S. Department of Agriculture publication, for streams draining the mountainous areas, unit runoff decreases downstream.

Base flow is defined as streamflow that is comprised of only ground-water discharge. Most unregulated streams in Area 62 are ephemeral, flowing only in response to storms and snowmelt. Base flow for these streams is zero indicating no significant ground-water discharge. Streams that continue to flow when the ephemeral streams have gone dry, do so as a result of spring discharge or man-made discharge, such as from treatment plants or reservoirs. For example, the Rio San Jose near Grants continues to flow due to discharges from Horace Springs and the Grants sewage treatment plant.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

Runoff rates modified from
U.S. Department of Agriculture (1981b)

EXPLANATION

RUNOFF, IN INCHES

Less than 0.1

0.1-0.5

0.5-1.0

Figure 3.3-1 Mean annual unit runoff.

Flood Magnitude and Frequency Values Computed for Selected Streams

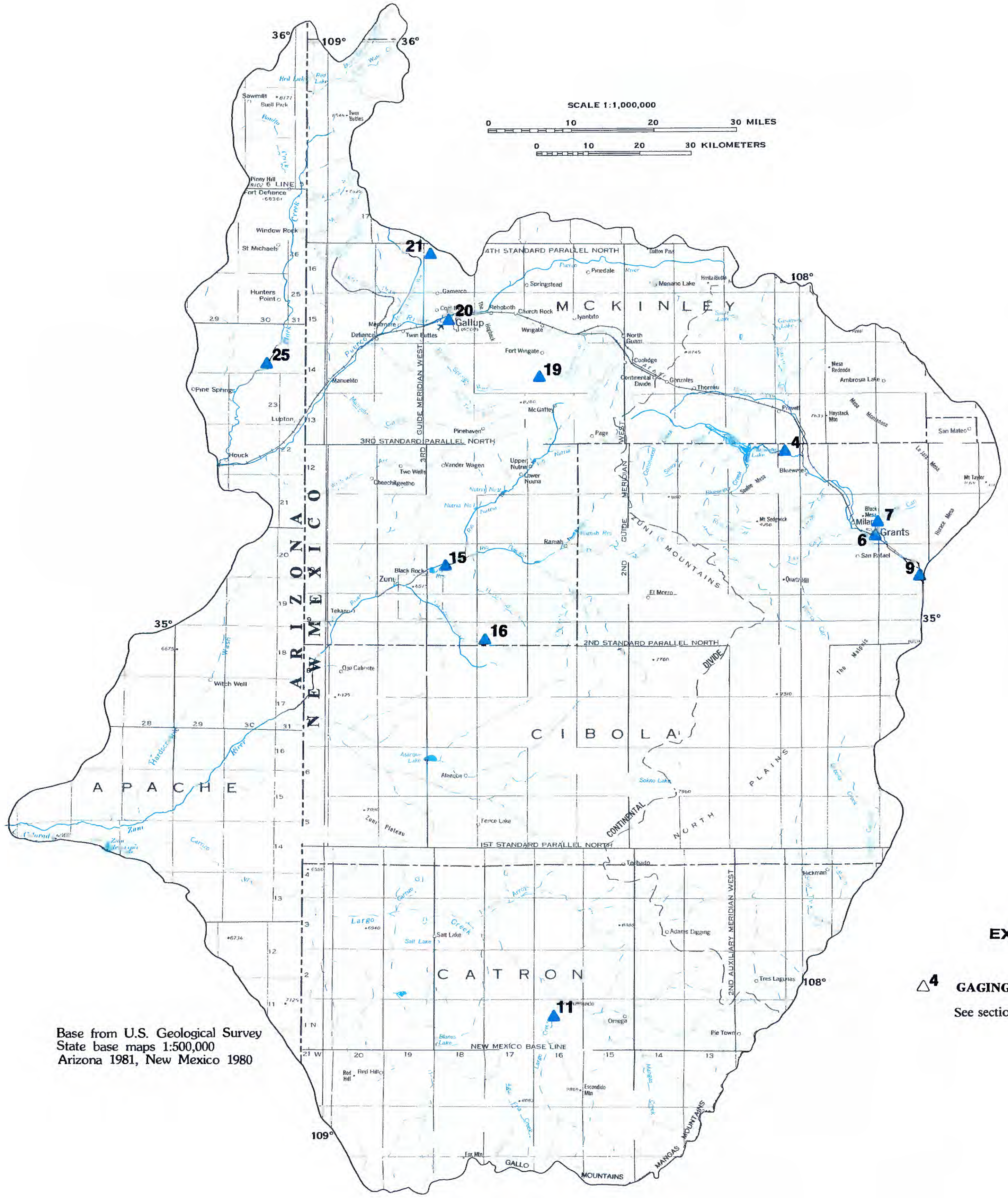
Technique available to estimate peak flood flows for ungaged streams.

Flood magnitude and frequency data for gaged streams having more than 10 years of peak-discharge record are listed in table 3.4-1. The flood values were computed using the station record according to guidelines outlined by the U.S. Water Resources Council (1981).

A multiple regression model was used by Thomas and Gold (1982) to develop flood-estimating equations for ungaged streams in New Mexico. The equations were developed using data from stations throughout New Mexico, as well as in Arizona bordering New Mexico; thus, the equations are applicable to all parts of Area 62. Basin characteristics, such as station altitude, rainfall, and drainage area were used as the independent variables, with flood flows at each gaged station used as the dependent variables. A complete description of the development of the equations can be found in Thomas and Gold (1982). The equations for estimating peak flood magnitudes for return intervals of 10 years (Q_{10}), 50 years (Q_{50}), and 100 years (Q_{100}) are presented below.

Estimating equation	Interval covered by standard error of estimate (percent)
$Q_{10} = 3.88 \times 10^{4} A^{0.444} (Sa/1,000)^{-2.78}$	+124 -55
$Q_{50} = 2.01 \times 10^{5} A^{0.403} (Sa/1,000)^{-3.18}$	+140 -58
$Q_{100} = 3.54 \times 10^{5} A^{0.389} (Sa/1,000)^{-3.32}$	+145 -59

In the equations, A is the contributing drainage area in square miles and Sa is site altitude in feet above sea level. For example, the 100-year recurrence flood at a site having an altitude of 6,300 feet and a drainage area of 6.76 square miles would be estimated by the following calculations: $(3.54 \times 10^5)(6.76)^{0.389}(6,300/1,000)^{-3.32} = 1,700$ cubic feet per second. This value is subject to the large interval of standard error listed with the estimating equations.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

Figure 3.4-1 Locations of stations where flood magnitude and frequency have been computed.

Table 3.4-1 Flood magnitude and frequency at selected stations.

Station number	Station name	Discharge, in cubic feet per second, for the indicated recurrence interval in years		
		10	50	100
4[1]	Bluewater Creek near Bluewater, N. Mex.	3,640	8,430	11,300
6[2]	Rio San Jose at Grants, N. Mex.	662	1,800	2,500
7	Grants Canyon at Grants, N. Mex.	1,040	2,290	3,020
9[2]	Rio San Jose near Grants, N. Mex.	766	1,440	1,770
11	Largo Creek near Quemado, N. Mex.	788	1,400	1,710
15[3]	Zuni River above Black Rock Reservoir, N. Mex.	3,930	7,540	9,450
16	Galestena Canyon Tributary near Black Rock, N. Mex.	435	855	1.080
19	Milk Ranch Canyon near Fort Wingate, N. Mex.	336	938	1,350
20	Puerco River at Gallup, N. Mex.	7,630	12,900	15,500
21	Wagon Trail Wash near Gomerco, N. Mex.	287	670	902
25	Black Creek near Lupton, Ariz.	5,370	8,060	9,300

[1] Flow regulated by Bluewater Dam
[2] Some withdrawals, diversions, and regulation upstream from station
[3] Some regulation from upstream reservoirs

EXPLANATION

△4 **GAGING STATION AND NUMBER**

See section 6.1 for detailed site description

Streamflow is Poorly Sustained

Duration curves indicate little, if any, contribution from ground-water sources.

The flow duration curve is a cumulative frequency curve of daily discharges showing the percent of time that specified discharges were equaled or exceeded during a given period.

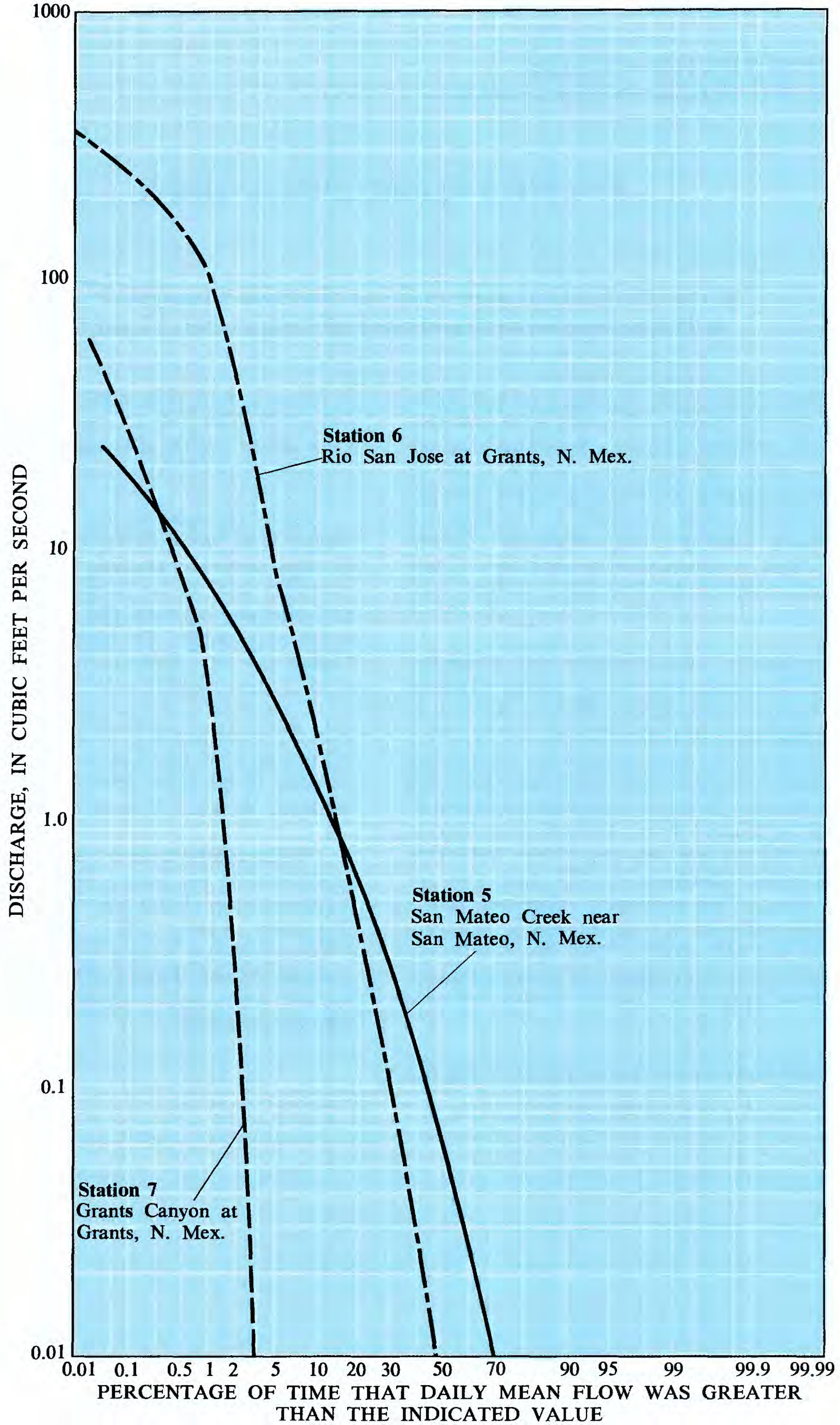
The data presented in the duration curves (fig. 3.5-1) for 6 stations in Area 62 were computed using a Geological Survey computer program (Hutchison, 1975). The curves may be interpreted using the following guidelines. A steep slope indicates poorly sustained flow. For example, a steep slope at the lower end indicates that streamflow is not sustained by ground-water discharge and tends rapidly toward zero during periods of low precipitation. Gentler slopes indicate a more sustained streamflow such as would occur if ground-water or other stored water were discharged to the stream.

The duration curves for several representative stations presented in figure 3.5-1, have, with one exception, steep slopes throughout the lengths of those curves. The only exception, Rio Nutria, displays a moderate slope, and therefore a well sustained condition for flows less than 0.1 cubic foot per second. Streamflows recorded at the stations on the Rio San Jose, San Mateo Creek, Puerco River, and the Zuni River are subject to regulation which will cause the shape of their duration curves to differ from curves representing natural flow. Duration of flow figures for other streamflow stations are contained in table 3.5-1. The tabulated data can be used to draw duration curves for those stations.

Table 3.5-1 Flow-duration data at selected stations.

Station number	Station name	Flow, in cubic feet per second, which was equaled or exceeded for percentage of time indicated								
		99.5	95	90	75	50	25	10	5	1
3[1]	Bluewater Creek below Bluewater Dam, N. Mex.	0.21	0.27	0.29	0.38	0.42	3.8	20	25	31
4[1]	Bluewater Creek near Bluewater, N. Mex.	0.38	0.62	0.76	1.1	1.2	3.2	18.6	24	33
9[2]	Rio San Jose near Grants, N. Mex.	3.5	4.2	4.4	4.7	5.3	6.0	7.6	9.3	32
10	Largo Creek near Mangas, N. Mex.	0.04	0.09	0.09	0.1	0.21	0.38	0.62	1.5	20
25	Black Creek near Lupton, Ariz.	0.0	0.0	0.03	0.07	0.19	1.9	10.7	31	130

[1] Flow regulated by Bluewater Dam
[2] Affected by diversions and discharges from city of Grants



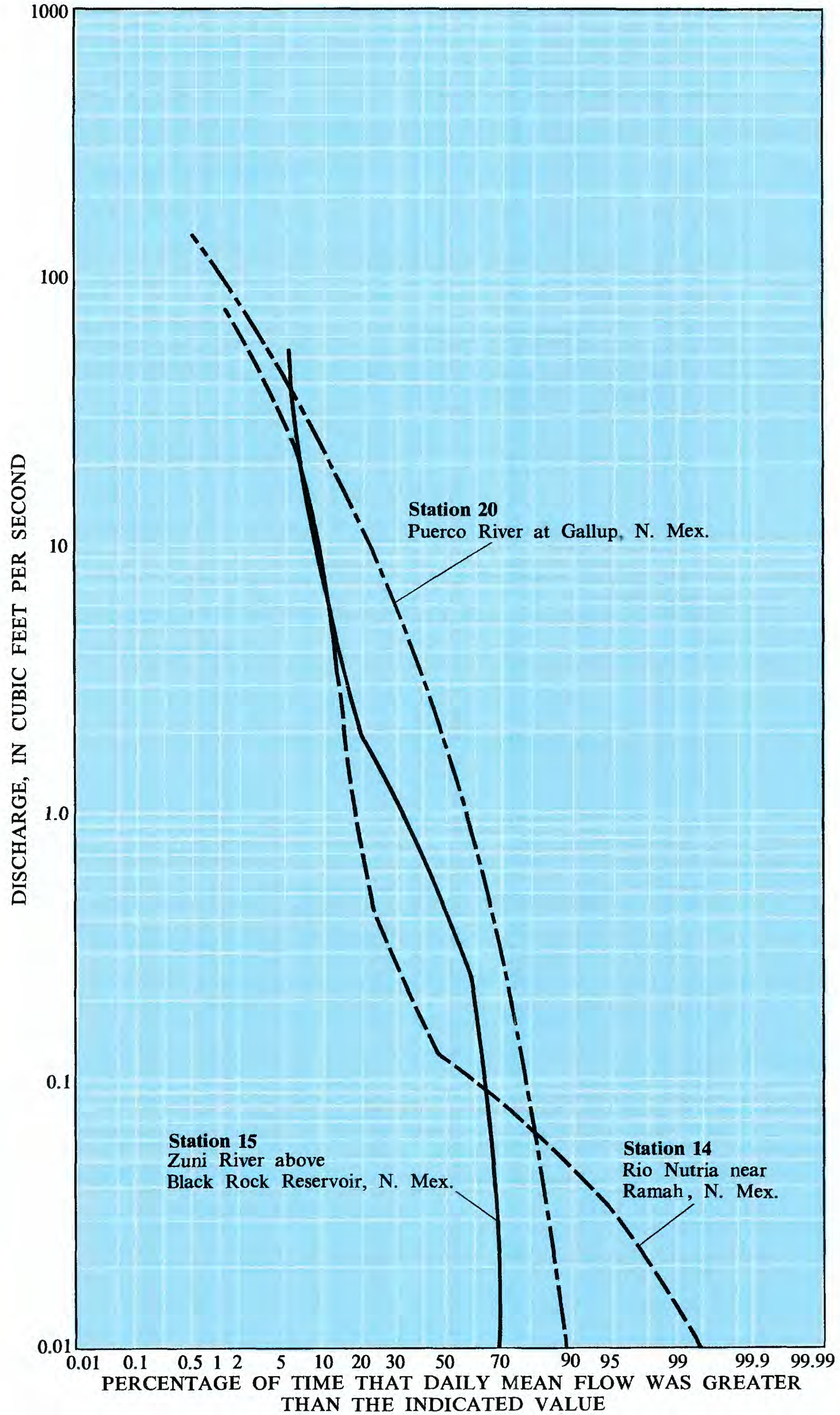


Figure 3.5-1 Flow-duration curves for selected stations.

Few Water-Quality Data Available

Of the nine surface-water stations that have water-quality data, only one has chemical analyses from more than 10 samples.

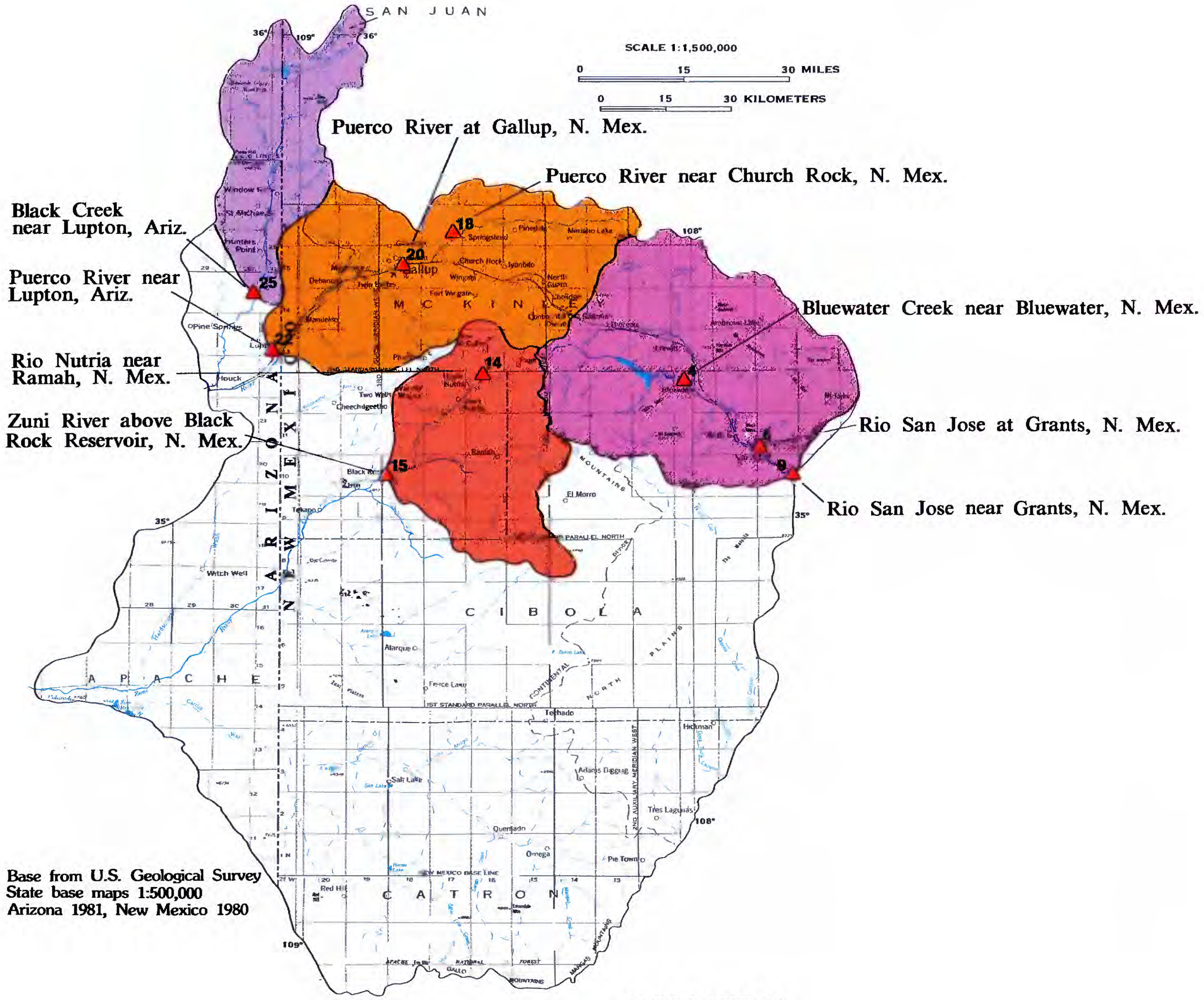
The nine surface-water stations shown in figure 3.6-1 are the only stations at which water has been collected for chemical analysis. As indicated in the figure, the areas that contribute surface runoff to these stations comprise less than one-half of Area 62. The water-quality data available in the National Water Data Storage and Retrieval System (WATSTORE) are summarized in table 3.6-1. These data are not sufficient to characterize surface-water quality.

The minimum concentrations for Bluewater Creek near Bluewater were from a sample collected in April 1980, when large quantities of water were being released from an upstream reservoir to relieve pressure on the dam. Both samples for the Rio San Jose at Grants were also from April 1980; the small concentrations of constituents may not be typical of the normal, ephemeral flows. The minimum concentrations for the Rio San Jose near Grants were from the same period (discharge of 333 cubic feet per second). Most of the maximum values are from a 1982 sample collected at a much smaller discharge (6.10 cubic feet per second). Since about 1978, the flow at this station has consisted of spring discharge and outflow from the Grants sewage-treatment plant.

The maximum concentrations shown for the Rio Nutria station are from a sample collected at very low flow (0.09 cubic foot per second). Samples from the Zuni River station also generally indicate larger concentrations with smaller streamflows.

All of the analyses for the Puerco River near Church Rock and at Gallup are from samples collected after upstream uranium-mine dewatering began providing most of the streamflow; thus, these analyses generally represent the chemical quality of the treated mine water. The maximum concentrations at Gallup and the values for the Puerco near Church Rock are from samples collected during a dam failure at an upstream uranium-milling operation. In contrast to the samples in New Mexico, the samples from the Puerco River near Lupton, Arizona, were collected prior to the mine dewatering and represent the quality of the naturally occurring ephemeral flows.

Water-quality criteria for various uses have been established by the Federal Water Pollution Control Administration (1968) and the U.S. Environmental Protection Agency (1973, 1976, and 1978). The Office of Surface Mining Reclamation and Enforcement of the U.S. Department of the Interior (1979) has set water-quality standards for effluent from mining operations.



EXPLANATION

- ▲ SURFACE-WATER STATION AND NUMBER WITH WATER-QUALITY DATA IN WATSTORE
- DRAINAGE BASIN UPSTREAM FROM STATION 9
- DRAINAGE BASIN UPSTREAM FROM STATION 15
- DRAINAGE BASIN UPSTREAM FROM STATION 22
- DRAINAGE BASIN UPSTREAM FROM STATION 25

See section 6.1 for detailed site description

Figure 3.6-1 Location of surface-water stations with water-quality data.

Table 3.6-1 Summary of chemical analyses of samples collected at surface-water stations.

Concentrations of dissolved constituents reported in milligrams per liter, except for boron and iron, which are reported in micrograms per liter. Analyses by U.S. Geological Survey. Median is not shown if fewer than three analyses are available; < , less than.

Surface-water station and number in figure 3.6-1	Bluewater Creek near Bluewater, N. Mex. 4	Rio San Jose at Grants, N. Mex. 6	Rio San Jose near Grants, N. Mex. 9	Rio Nutria near Ramah, N. Mex. 14	Zuni River above Black Rock Res., N. Mex. 15	Puerco River near Church Rock, N. Mex. 18	Puerco River at Gallup, N. Mex. 20	Puerco River near Lupton, Ariz. 22	Black Creek near Lupton, Ariz. 25
Number of analyses	2	2	5	2	10	1	49	6	3
Constituent or property	Concentration								
Boron (B)									
Range	30-190	50-80	80-400	40	110	160	80-510	10-190	120-150
Median	--	--	310	--	--	--	130	120	120
Calcium (Ca)									
Range	47-110	39-75	46-93	29-86	31-72	560	12-220	33-71	32-58
Median	--	--	86	--	52	--	34	42	45
Chloride (Cl)									
Range	2.2-5.3	2.7-12	12-150	3.1-6.5	6.5-38	38	11-160	11-38	16-28
Median	--	--	110	--	16	--	22	14	26
Fluoride (F)									
Range	0.3	0.3-0.4	0.2-0.8	0.3-0.4	0.2-0.4	0.8	0.1-1.0	0.7-1.4	0.4-0.6
Median	--	--	0.7	--	0.3	--	0.7	0.8	0.4
Hardness ($CaCO_3$)									
Range	160-380	130-250	160-400	110-310	120-310	1,700	45-2,800	110-230	110-200
Median	--	--	370	--	210	--	120	130	150
Iron (Fe)									
Range	< 10	--	9-40	40	10-560	51,000	9-580,000	10-120	20
Median	--	--	10	--	20	--	20	30	20
Magnesium (Mg)									
Range	4	8.4-16	12-42	7.9-23	8.1-31	75	2.5-540	5.7-12	7.4-13
Median	--	--	38	--	22	--	7.3	7.0	8.2
Potassium (K)									
Range	1.6-1.7	2.4-11	4.1-7.5	1.0-1.1	3.2-10	13	1.8-22	3.1-6.2	3.5-5.0
Median	--	--	7.1	--	3.7	--	4.0	4.5	4.5
Sodium (Na)									
Range	5.5-11	5.9-13	20-170	4.3-29	17-100	260	77-370	69-130	37-79
Median	--	--	140	--	69	--	160	89	61
Sulfate (SO_4)									
Range	50-240	49-130	82-340	16-62	29-180	2,300	100-6,600	150-210	81-140
Median	--	--	290	--	110	--	200	170	94
pH (units)									
Range	7.8-8.4	7.6-7.8	7.7-8.1	7.7-8.0	7.7-8.4	3.6	3.4-8.9	7.2-7.8	7.4-7.8
Median	--	--	7.8	--	8.1	--	8.1	7.4	7.5
Dissolved solids									
Range	187-526	206-341	254-969	128-329	178-626	3,350	286-8,710	333-544	281-455
Median	--	--	829	--	414	--	600	420	308

Annual Erosion Rates Generally Less Than 1 Acre-Foot per Square Mile

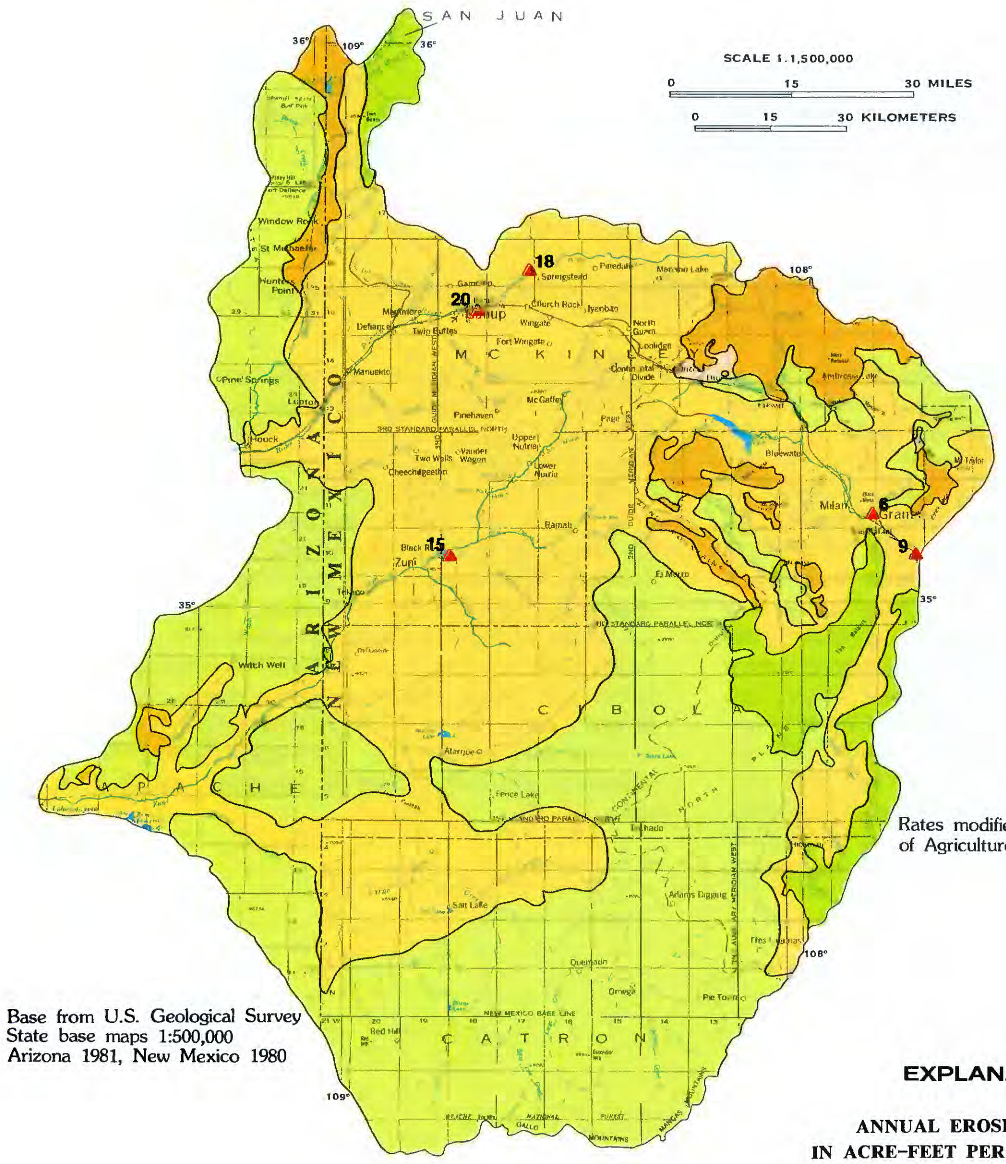
Sediment yield is dependent on topographic setting, soil type, climatic factors, and land uses.

Erosion potential and the resulting sediment yield are of great interest in Area 62. The effects of erosion may include degradation of water quality, deposition of sediments in streambeds and reservoirs, decreased reservoir capacity, and removal of soils and nutrients. All aspects of erosion may result in an economic loss to the inhabitants of the area who use streams as water supplies, use the land for stock grazing or farming, or build structures. Area 62 is marked by areas where extreme erosion has occurred in the past and is continuing. The effects of erosion (fig. 3.7-2) can be observed in the alluvial valleys of the Puerco and Zuni Rivers and in numerous washes throughout the area.

The extent of erosion of the land by wind and water varies greatly within the area, mostly in response to a combination of factors. Specifically, surface geology, soil types, climate, runoff, topography, vegetative cover, land use, and upland drainage pattern all affect erosion rates. Erosion rates can be increased by some uses of the land, such as unimproved roads, construction sites, and by livestock grazing. High rates are also a result of geologic conditions within the area. Specifically, badland areas, sites of substantial erosion, are a result of the significant erosion potential of the relatively unconsolidated shales, mudstones, and claystones cropping out in those areas. Low erosion rates occur in areas having good grass cover and in forested areas.

Estimated erosion rates for Area 62 are shown in figure 3.7-1. Summaries of suspended-sediment data collected at gaging stations are given in table 3.7-1. The location of the gaging stations is shown in figure 3.7-1.

The suspended particles may contain certain chemical constituents in quantities greater than that found in the water surrounding those particles. The samples for the two Rio San Jose stations were collected when large quantities of water were released to relieve pressure on an upstream dam. The samples for the stations Puerco River near Church Rock (18) and Puerco River at Gallup (20), resulting in the maximum values, were collected after a dam failure at an upstream uranium-milling operation.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

Rates modified from U.S. Department of Agriculture (1974a, 1981c).

EXPLANATION

ANNUAL EROSION RATE, IN ACRE-FEET PER SQUARE MILE

- Less than 0.2
- 0.2-0.5
- 0.5-1.0
- 1.0-3.0
- Greater than 3.0
- ▲9 STATION AND NUMBER

Figure 3.7-1 Soil erosion rates.

Figure 3.7-2 Effects of erosion in the alluvial valley (east of Gallup, New Mexico).

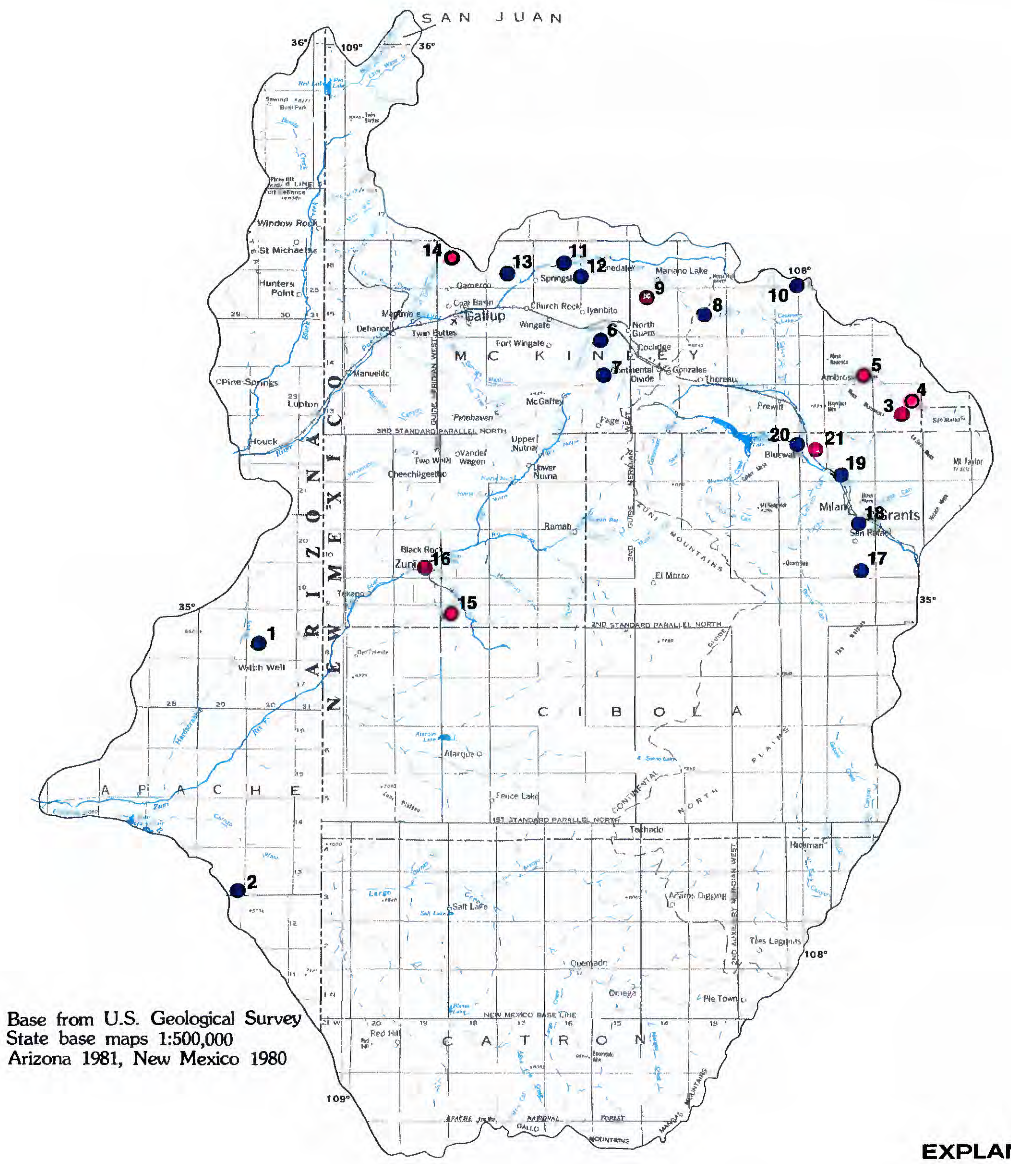
Table 3.7-1 Suspended sediment at gaging stations.

Station number	Station name	Number of samples taken	Suspended sediment concentration (mg/L) Mean	Minimum	Maximum
6	Rio San Jose at Grants, N. Mex.	4	3,540	523	8,300
9	Rio San Jose near Grants, N. Mex.	4	315	19.0	672
15	Zuni River above Black Rock Res., N. Mex.	35	345	18.0	2,090
18	Puerco River near Church Rock, N. Mex.	2		17,100	18,000
20	Puerco River at Gallup, N. Mex.	6	24,440	3,360	70,100

Information on Ground-Water Levels in Currently Monitored Wells is Available for Only a Few Localities

Hydrologic information is available for 1,358 wells and springs.

Water-level information is obtained from 21 observation wells in Area 62. Static water levels are periodically measured in all of the wells shown in figure 4.1-1 to monitor changes in ground-water storage (U.S. Geological Survey, 1982, p. 2). Information about the observation wells, including site name, state and county, geologic unit, water-level and water-quality record, is provided in section 6.2. The ground-water sites are assigned map numbers as cross references for this publication. Some of the wells are labled with 15-digit identification numbers (section 6.2) for the sites in the National Water Data Storage and Retrieval System (WATSTORE) (see section 5.3). These numbers are derived from the latitude and longitude locations of the well site. Access to additional data not in section 6.2 for these sites is available from: (1) The National Water Data Exchange--NAWDEX (see section 5.2); (2) WATSTORE; (3) the annual water-resources data reports of the U.S. Geological Survey for Arizona and New Mexico; (4) reports on water availability for individual counties or areas published by the U.S. Geological Survey and cooperating agencies; and (5) data on file at the U.S. Geological Survey, Water Resources Division offices in Albuquerque, New Mexico, and Tucson, Arizona. Information is available for numerous additional wells and springs shown in figure 4.1-2 that are not included in section 6.2. Ground-water quality is discussed in detail in sections 4.5-1, 4.5-2, and 4.5-3. Discharge from major springs is discussed in section 4.2. Additional information may be obtained from the U.S. Geological Survey, Water Resources Division offices in Albuquerque and Tucson.



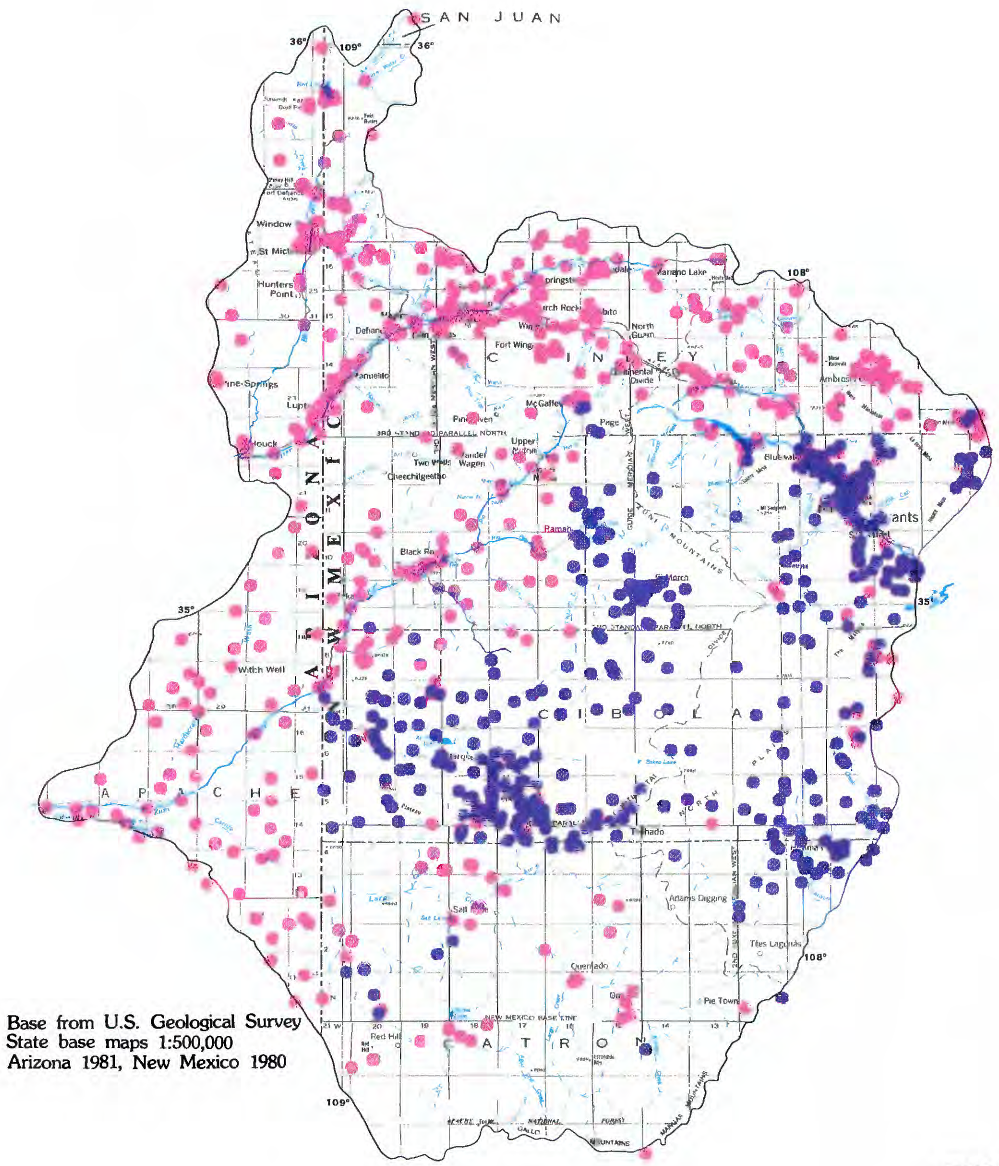
Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

- OBSERVATION WELL IDENTIFIED IN WATSTORE
- OBSERVATION WELL NOT IDENTIFIED IN WATSTORE
- o9 SITE AND NUMBER

See section 6.2 for detailed site description.

Figure 4.1-1 Selected ground-water observation wells.



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

- LOCATION OF A WELL OR A SPRING WITH SOME WATER-QUALITY DATA (888 SITES)-- May not indicate complete chemical analysis.
- LOCATION OF A WELL OR A SPRING WITH SOME WELL INFORMATION (470 SITES)-- Water-level data generally available. Well depth or completion information may be available.

Figure 4.1-2 Locations of wells and springs from WATSTORE files.

Ground-Water Recharge Occurs Primarily Above 6,000 Feet and Where Geology and Topography are Conducive to Infiltration

Major spring discharge occurs in the northwest and central parts of the study area.

Recharge to ground-water aquifers occurs primarily from infiltration of runoff from precipitation in the mountainous areas and on the flanks of structural basins (U.S. Department of Agriculture, 1981a, p. 5-22) (fig. 4.2-1). These highland areas, which account for as much as 80 percent of the ground-water recharge, are generally at an altitude greater than 6,000 feet above sea level and receive more than 15 inches of precipitation annually (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-21). Recharge probably occurs also on Mt. Taylor, along the Continental Divide, and in the Gallo and Mangas Mountains although it has not been mapped in these areas. Minor recharge also occurs from infiltration of excess irrigation water and canal seepage from surface-water sources and from infiltration of precipitation in the center of the basins. Infiltration in the center of the basin is generally negligible as a result of the arid to semiarid climate but may be affected by both topography and geology.

Ground water is discharged by four natural processes: (1) Evaporation in areas where the water table is near to the land surface; (2) transpiration by vegetation; (3) seepage into stream channels in places where the streambed (or channel) intersects the water table; and, (4) spring discharge (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-22).

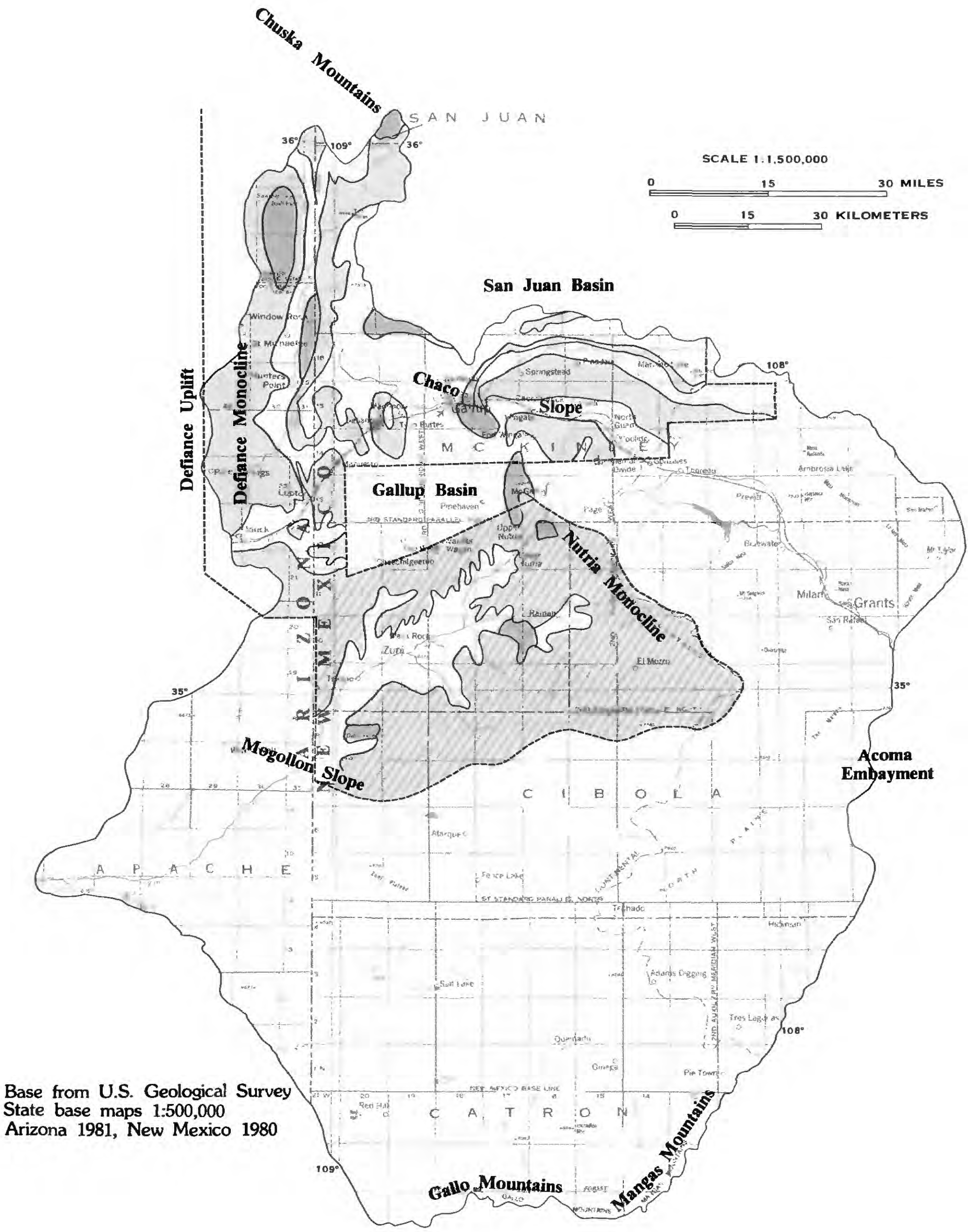
Only small amounts of ground water are discharged by evaporation in areas where the water table is near the surface (as the depth to the water table reaches 10 feet, discharge by evaporation becomes negligible). Large amounts of ground water are transpired from ground-water aquifers by vegetation.

Spring discharge occurs where the water table intersects the land surface or where water from artesian aquifers flows through fractures or fault zones in the rock (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1971, p. V-22). Major areas for spring discharge are in the vicinity of Ojo Caliente and Ramah. The combined discharge for springs near Ojo Caliente is about 1 cubic foot per second and for springs near Ramah combined discharge is about 1.1 cubic feet per second (Orr, 1982, p. 46, 90). Studies by Risser (1982) describe a spring called Ojo del Gallo located southwest of Grants, New Mexico. Ojo del Gallo yielded as much as 5 to 7 cubic feet per second in the 1930's, ceased flowing in the 1950's (Risser, 1982, p. 29), but has begun to flow again (J.A. Baldwin, oral communication, 1983). Springs on the southwest side of the San Juan Basin, around Window Rock, and in the Chuska Mountains usually do not yield any more than .02 cubic foot per second (Cooley and others, 1969, p. A-44). Other springs discharge near Black Rock Village, along outcrops of the Glorieta Sandstone and San Andres Limestone in the Zuni Mountains (Orr, 1982), and along the Zuni River in McKinley and Cibola Counties (Summers, 1972, p. 83).

Induced ground-water discharge takes place as ground-water pumpage from wells. Pumpage removes water from the flow system and thus diverts ground water from some of its natural points of discharge. This type of discharge will be discussed in more detail in Section 4.4.

The areas of ground-water recharge which have been mapped, and locally, areas of spring discharge are shown in figure 4.2-1. Several publications discuss ground-water recharge and discharge in specific aquifers but do not include maps. These publications include studies about the San Juan Basin (Lyford, 1979), Apache County (Akers, 1964), the Rio San Jose (Risser, 1982),and McKinley and Cibola Counties (Orr, 1982). Other information from some of these references describes gaining and losing reaches along some of the intermittent streams. In general ground water may be discharged to the stream (the stream gains) or the stream water may be recharged to the adjacent aquifer (the stream loses).

Ground-water movement in Area 62 is generally from recharge areas in the highlands to the central parts of the basins. Movement of ground water in central Apache County, Arizona, mainly is southward toward the Little Colorado River (Lower Colorado Region State-Federal Interagency Group for the Pacific Southwest Interagency Committee, 1970, p. V-21). Ground-water movement in New Mexico is toward the Puerco River in aquifers near Gallup (Lyford, 1979) and near Zuni; in Cibola County ground-water movement in the Glorieta-San Andres aquifer, the Chinle Formation, the Zuni-Dakota aquifer, and Bidahochi Formation is generally to the west (Orr, 1982). Locally, along the Nutria monocline, ground water in the Gallup Sandstone and Crevasse Canyon Formation moves toward the Rio Nutria and Rio Pescado, but ground water in more deeply buried Gallup and Crevasse Canyon rocks probably moves northward to join the flow system near Gallup (Orr, 1982, p. 77, 114).



Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

RECHARGE AREA, *Modified from area mapped by Cooley and others (1969).*

RECHARGE AREA, *Modified from area mapped by Summers (1972).*

AREA OF PROBABLE GROUND-WATER DISCHARGE FROM SPRINGS

AREA MAPPED FOR GROUND WATER RECHARGE
Note: Recharge areas in other parts of Area 62 have not been mapped.

Figure 4.2-1 Location of recharge areas and spring discharge areas.

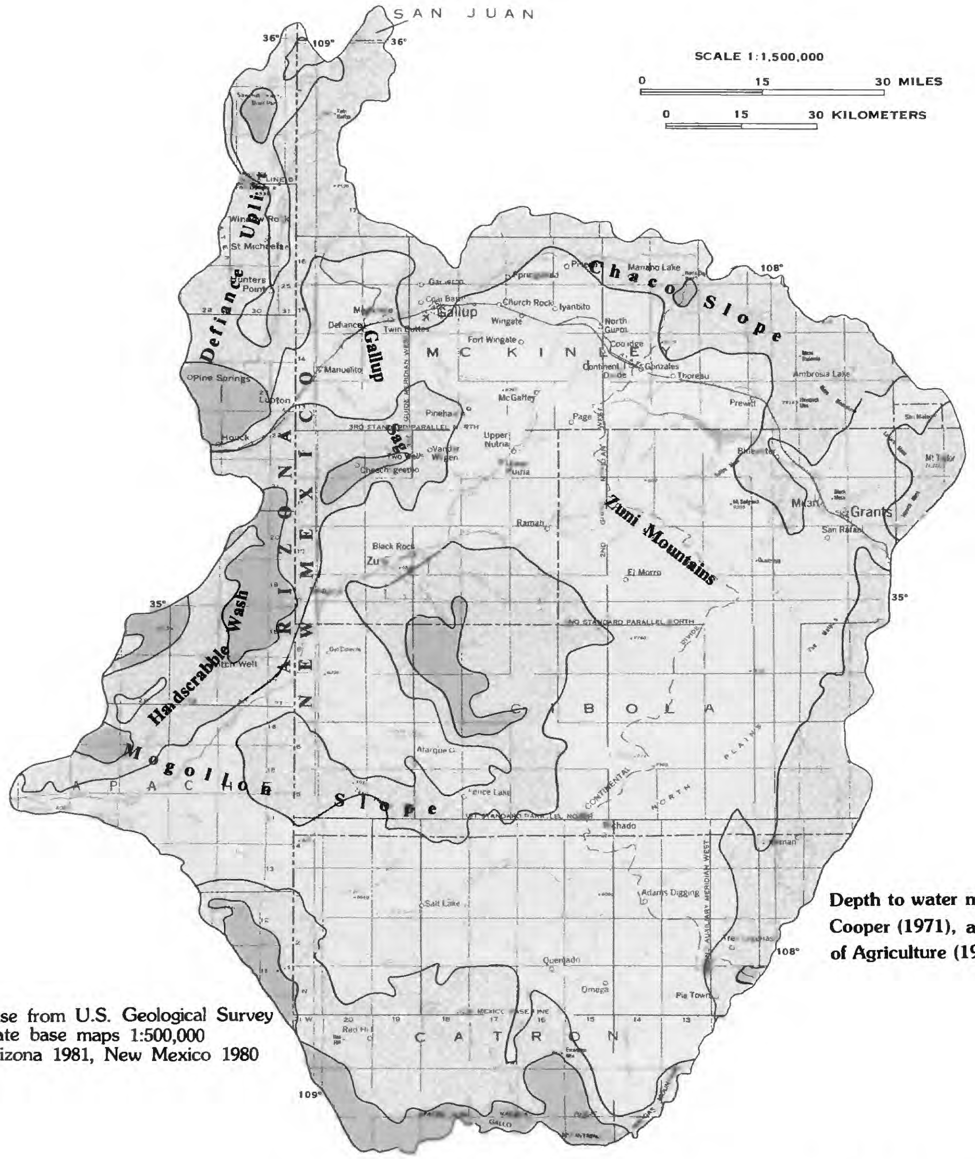
Depth to Water Below Land Surface Generally Less than 200 Feet

Depth to water varies because of complex geology and large topographic relief.

Depth to water ranges from only a few feet, especially along the major streams and rivers to about 500 feet along parts of the Defiance uplift, near Hardscrabble Wash south of the Defiance uplift, in the Gallup sag, and along the Mogollon slope on the southern boundary of the study area. Depths to water of less than 100 feet commonly occur in alluvial channels and in a few areas in Precambrian granite exposed southeast of Gallup, New Mexico, in the Zuni Mountains (fig. 2.6-1). Depth to water varies throughout the area because of the structural complexity of the geology and the substantial topographic relief. Generally, areas with similar depths to water roughly follow the physiographic and structural features of the area (Cooley and others, 1969, p. A-22).

Both artesian (confined) and water-table (unconfined) conditions occur in Area 62. Artesian conditions occur throughout the area and artesian springs and wells have been utilized in many areas (refer to figure 4.2-1 for the locations of major springs). Water-table conditions are present in the principal recharge areas (fig. 4.2-1), in the flat-lying rocks between major uplifts, and in the shallow alluvial aquifers along the major streams and rivers.

A generalized map of the depth to water in Area 62 is shown in figure 4.3-1. In specific areas, depth to water may differ considerably from the ranges indicated in this generalized map. The depth to water shown in figure 4.3-1 is the depth in feet below land surface, at which water is first penetrated, regardless of the quality, and is not the altitude to which the water will rise in a well. Data for figure 4.3-1 are from wells completed in the major aquifers (see section 4.5) and include data through 1980 for Apache County, Arizona (U.S. Department of Agriculture, 1981b), and through 1971 (Cooper, 1971) for counties in the New Mexico portion of Area 62.



Depth to water modified from:
Cooper (1971), and U.S. Department
of Agriculture (1981b).

Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

DEPTH TO WATER, IN FEET BELOW LAND SURFACE

- Less than 200
- 200 to 500
- More than 500

Figure 4.3-1 General depth to ground water.

Well Yields Commonly as Much as 100 Gallons per Minute in Most of the Area

Consolidated sedimentary rocks store most of the ground water; permeability and depth to water affect the availability of ground water.

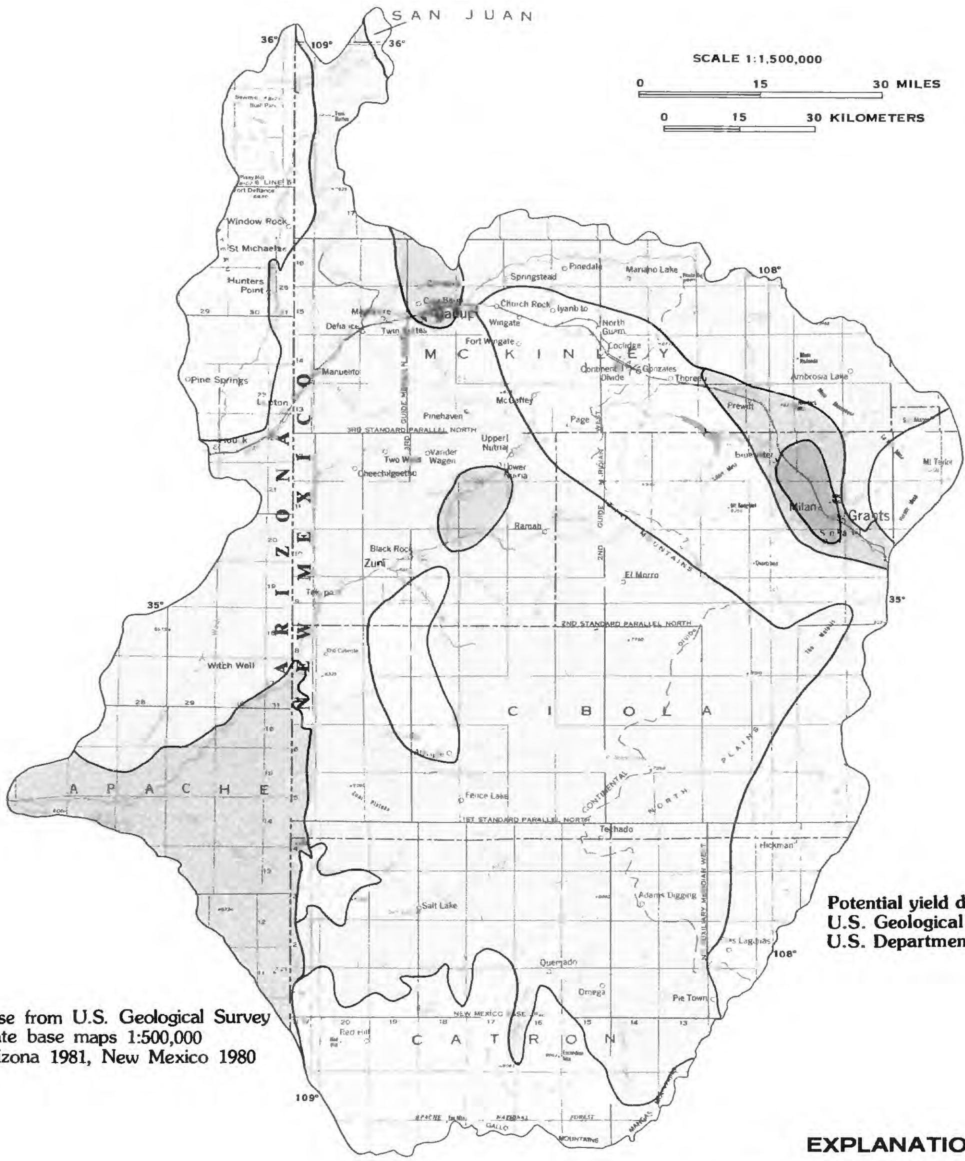
Wells completed in aquifers containing fresh to slightly saline water (dissolved solids concentration of less than 3,000 milligrams per liter) commonly yield as much as 100 gallons per minute. Yields of this magnitude can be obtained in more than one-half of the area (fig. 4.4-1). Water is obtained primarily from both consolidated sedimentary rocks and from unconsolidated stream-valley sediments and alluvium. Only a small amount of unconsolidated rocks are present in the area; therefore, the consolidated rocks store most of the ground water. Well yields in the unconsolidated rocks generally range from 100 to 500 gallons per minute. Yields in the consolidated rocks vary greatly because of differences in rock permeability. Most of the consolidated rocks yield from 25 to 100 gallons per minute. The use of ground water is affected economically by the depth from which it must be pumped.

Principal aquifers in the study area include the Permian Kaibab Limestone and Coconino Sandstone in Arizona, which grade laterally eastward to the San Andres Limestone and Glorieta Sandstone; the Triassic Chinle Formation; the Zuni Sandstone, members of the Morrison Formation, and the Entrada Sandstone and Summerville Formation of the San Rafael Group, all of Jurassic age; the Cretaceous Dakota Sandstone, Mancos Shale, Gallup Sandstone and formations in the Mesaverde Group; the Tertiary sediments of the Bidahochi Formation; and the stream-valley sediments of Tertiary to Quaternary age (table 2.7-1). Permeable volcanic rocks of Tertiary to Quaternary age yield water to wells locally.

The estimated potential yield for wells in Catron County is generally as much as 100 gallons per minute. Yields in Cibola and McKinley Counties are similar. Greater yields of as much as 500 gallons per minute are found around Gallup, north of Black Rock, and along the western edges of Cibola and Catron Counties. Well yields may exceed 500 gallons per minute around Bluewater in Cibola County. Studies by Mercer and Cooper (1970), Hiss and Marshall (1975), and McLean (1980) provide more detailed evaluations concerning the availability of ground water and potential yields in the Gallup area. Estimated potential yields in Apache County range widely from about 25 gallons per minute in the north to about 500 gallons per minute in the south.

Estimates for the volume of recoverable ground water are not available for the entire study area. The general location and estimated potential yields of ground water are shown in figure 4.4-1. Detailed investigations locally provide some information, but more data are needed to realize actual development of ground-water supplies (U.S. Department of Agriculture, 1981b).

Although the major water supply for rural-domestic, municipal, and industrial uses is ground water, water supply for livestock use is from both surface water and ground water (U.S. Department of Agriculture, 1981b, p.3-2). The U.S. Department of Agriculture (1981b, p. 3-14--3-20) estimated that future livestock water requirements will be increasing and that development of ground water is the best future source of water supply. Irrigation needs are served mostly by surface-water sources. In New Mexico and Arizona some of the wells for municipal, industrial, irrigation, rural domestic, and livestock use are completed in alluvial aquifers. Because these aquifers are generally thin and of limited saturated thickness, aquifers of Cretaceous age and older have been developed (refer to section 4.5 for major aquifers).



Potential yield data from:
U.S. Geological Survey (1972), and
U.S. Department of Agriculture (1981b).

Base from U.S. Geological Survey
State base maps 1:500,000
Arizona 1981, New Mexico 1980

EXPLANATION

MAXIMUM POTENTIAL YIELDS OF PROPERLY CONSTRUCTED WELLS, IN GALLONS PER MINUTE

- Less than 25
- 25 to 100
- 100 to 500
- More than 500

Figure 4.4-1 Estimated potential yield of water wells.

Water Quality in Quaternary Aquifers More Variable than in Tertiary Aquifers

The median dissolved-solids concentration in samples from the Tertiary aquifers is smaller than that from other aquifers in Area 62.

Quaternary and Tertiary rocks overlie the coal-bearing Cretaceous rocks in some parts of Area 62. However, in the western part, they overlie the Triassic Chinle Formation (fig. 4.5.1-1).

Chemical analyses are available in the National Water Data Storage and Retrieval System (WATSTORE) for 60 sites (wells or springs) at which water samples have been collected from Quaternary aquifers. Fifty-four of the sites derive water from alluvium along stream channels, the other six from basalt. Of the 30 sampling sites for Tertiary aquifers listed in WATSTORE, 28 produce water from the Bidahochi Formation and 2 from the Baca Formation. The sites and outcrop areas are shown in figure 4.5.1-2. Because of the map scale, one sampling site may represent several closely spaced wells or springs. All areas with thin alluvial deposits are not delineated in the figure; thus, some sites appear to be isolated from Quaternary deposits.

The chemical analyses of samples from the sites are summarized in table 4.5.1-1. The median concentration and the range of concentrations for each constituent listed (except manganese) are greater in the Quaternary alluvium and basalt than in the Tertiary Bidahochi and Baca Formations. Both the Quaternary and the Tertiary aquifers have small median dissolved-solids concentrations compared to the other aquifers in Area 62; in fact, the Tertiary aquifers have the smallest. The median concentrations of hardness (expressed as calcium carbonate) and bicarbonate in both aquifers are rather large given the small dissolved-solids concentrations.

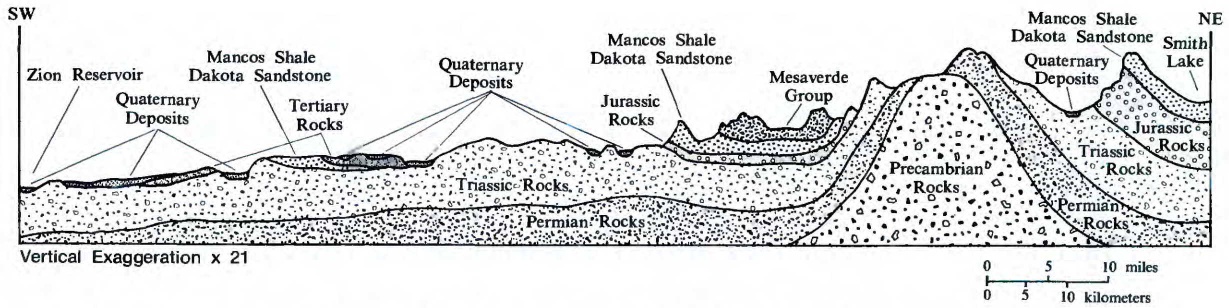


Figure 4.5.1-1 Schematic diagram showing stratigraphic relationship of Quaternary and Tertiary rocks to underlying rocks between Zion Reservoir and Smith Lake.

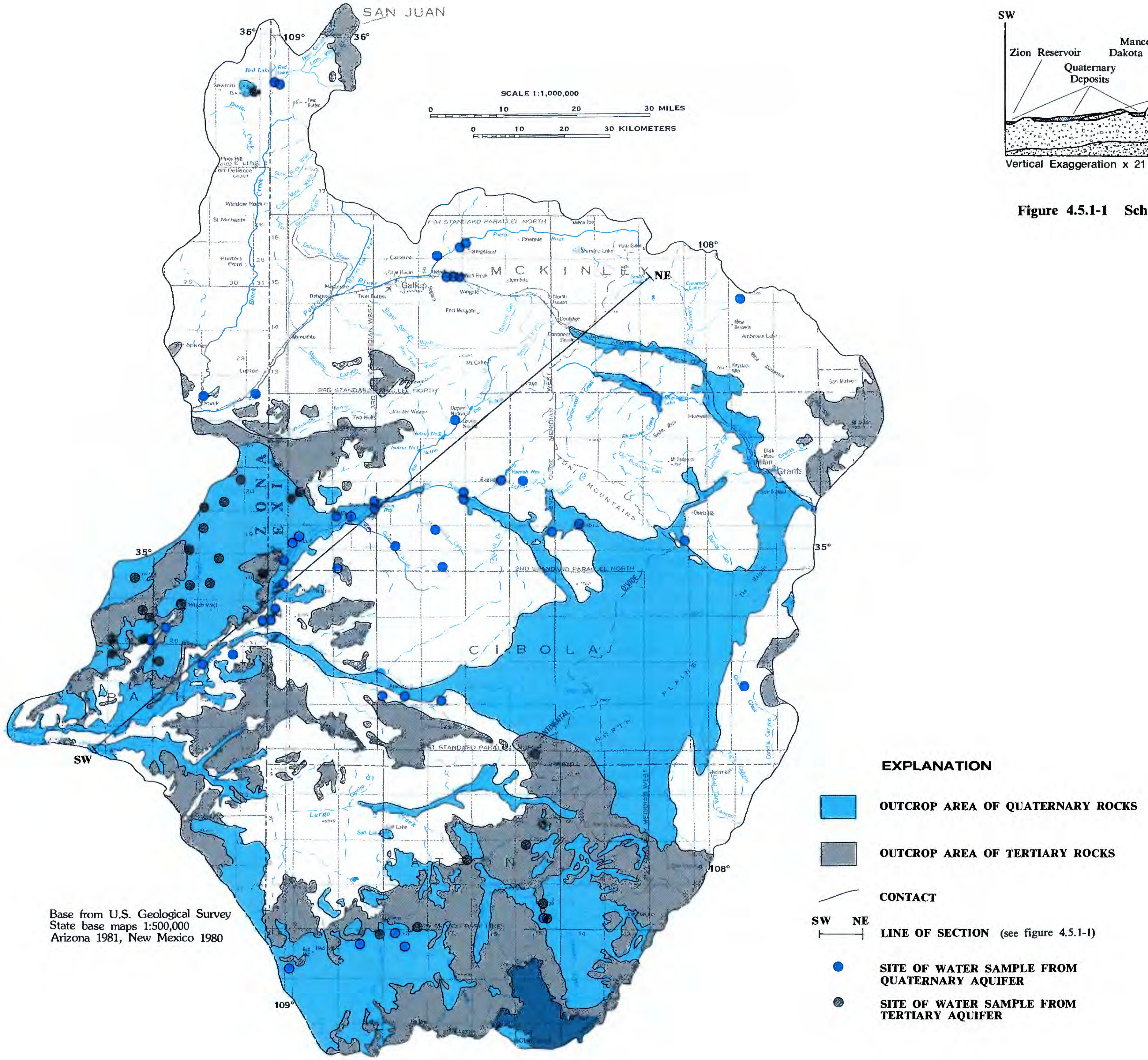


Figure 4.5.1-2 Sites of water samples from Quaternary and Tertiary aquifers.

Table 4.5.1-1 Summary of chemical analyses of water samples from Quaternary and Tertiary aquifers.

Concentrations of dissolved constituents reported in milligrams per liter, except as indicated. Micromhos, micromhos per centimeter at 25° Celsius. <, less than.

Quaternary Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	308-5,080	835	60
pH (units)	6.8-9.5	7.8	57
Bicarbonate (HCO_3)	140-670	320	41
Hardness ($CaCO_3$)	7-2,700	180	60
Calcium (Ca)	2.4-530	54	60
Sodium (Na)	8.5-1,000	120	50
Chloride (Cl)	2.9-1,100	26	60
Sulfate (SO_4)	0.8-2,600	84	60
Iron (Fe)	0-3.2	.024	50
Manganese (Mn)	<1-1.0	.003	16
Dissolved solids	178-3,600	479	59

Tertiary Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	270-1,000	420	29
pH (units)	7.1-10.0	8.0	25
Bicarbonate (HCO_3)	82-330	153	19
Hardness ($CaCO_3$)	82-262	150	23
Calcium (Ca)	2.8-69	34	30
Sodium (Na)	8.0-230	40	30
Chloride (Cl)	4.2-130	14	30
Sulfate (SO_4)	4.8-95	14	30
Iron (Fe)	0-0.530	.020	29
Manganese (Mn)	0-0.120	.006	11
Dissolved solids	153-625	262	30

Water in Gallup Sandstone Generally More Mineralized than Water in Other Cretaceous Aquifers

Nearly all the chemical analyses in WATSTORE are from sampling sites on Cretaceous outcrops.

Cretaceous rocks in Area 62 are divided into the Mesaverde Group, the Mancos Shale, and the Dakota Sandstone. All coal-bearing rocks are included in the Mesaverde Group (see section 2.7). The stratigraphic relationship of the Mesaverde Group to other rock units is illustrated in figure 4.5.2-1. Outcrop areas and sampling sites are shown in figure 4.5.2-2; because of the map scale, one sampling site may represent several closely spaced wells or springs. Of the aquifers in the Mesaverde Group, only the Gallup Sandstone has an appreciable number of chemical analyses in the National Water Data Storage and Retrieval System (WATSTORE); therefore, it is distinguished from the Mesaverde Group aquifers (undifferentiated) in table 4.5.2-1.

The 63 chemical analyses for the Mesaverde Group aquifers (undifferentiated) summarized in table 4.5.2-1 include 19 from the Crevasse Canyon Formation, 3 from the Menefee Formation, and 1 from the Point Lookout Sandstone. The median concentrations of hardness, sodium, and sulfate for these 23 samples are significantly larger than those given in table 4.5.2-1. However, ten of these analyses are for Crevasse Canyon samples from an outcrop area in the southeastern part of Area 62 and may reflect localized water quality. The aquifer for the remaining 40 samples in WATSTORE is listed as the Mesaverde Group. It is not possible to distinguish if the water is from the previously mentioned units or the Gallup Sandstone.

The Gallup Sandstone is the lowermost aquifer in the Mesaverde Group. It has been most extensively developed in the vicinity of Gallup, New Mexico. The median concentrations of dissolved solids and sulfate are much larger in samples from the Gallup Sandstone than those from the Mesaverde Group aquifers (undifferentiated), whereas the median concentrations of bicarbonate, hardness, and calcium are somewhat smaller.

The Mancos Shale separates the Dakota Sandstone from the overlying Mesaverde Group in most of Area 62. Because some sandstones in the Mancos may be water bearing, it has been combined with the Dakota Sandstone as a single aquifer system in figure 4.5.2-2 and table 4.5.2-1.

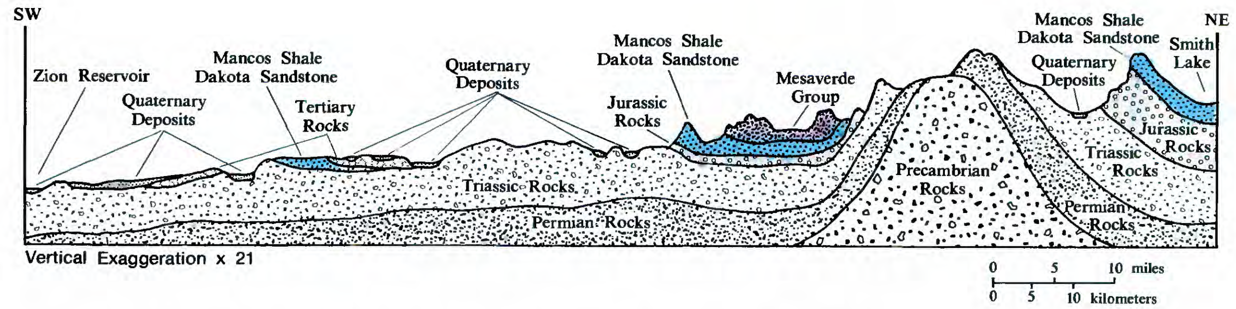
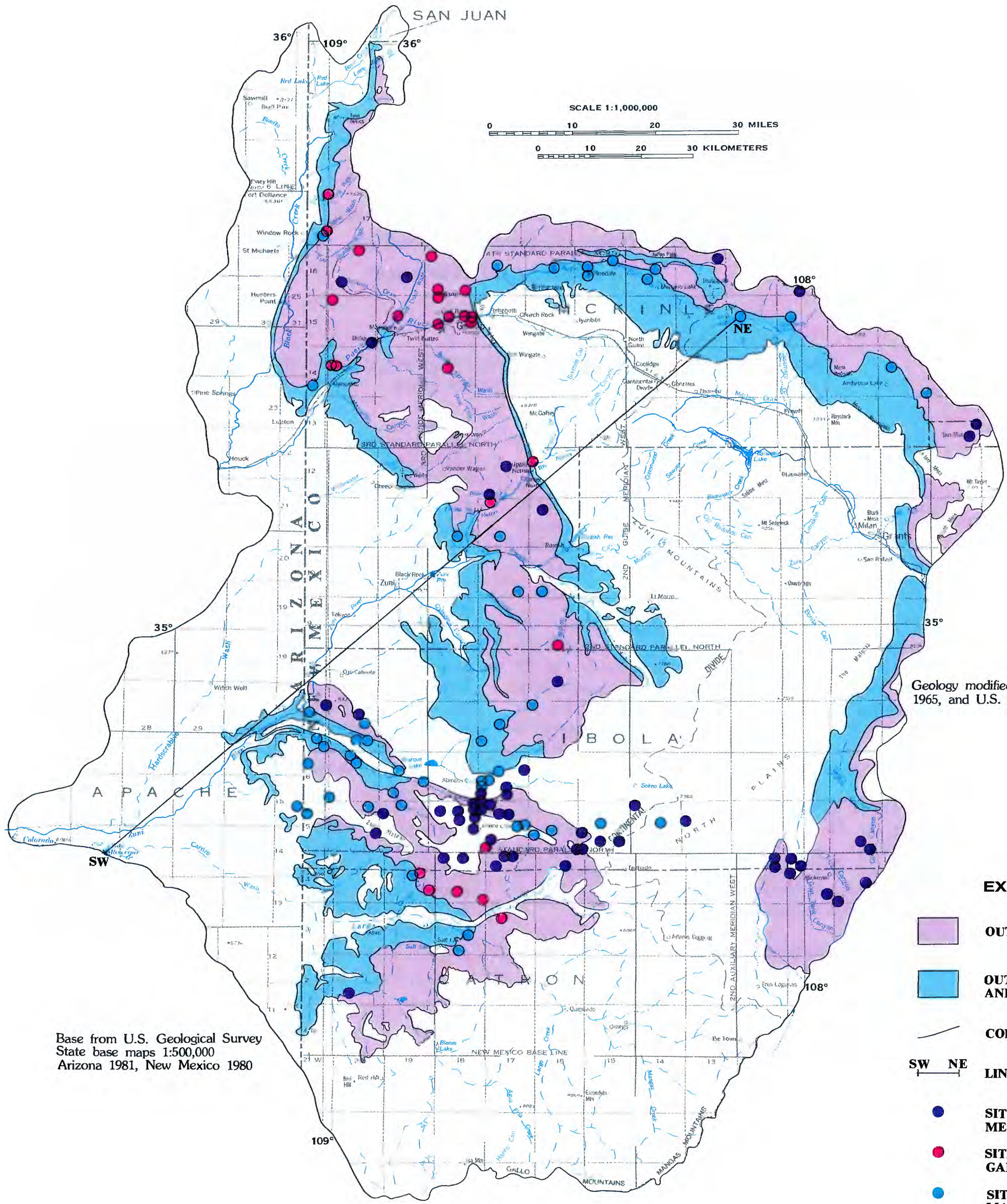


Figure 4.5.2-1 Schematic diagram showing stratigraphic relationship of Cretaceous rocks to other rocks between Zion Reservoir and Smith Lake.



Geology modified from Dane and Bachman, 1965, and U.S. Department of Agriculture, 1981.

Base from U.S. Geological Survey State base maps 1:500,000 Arizona 1981, New Mexico 1980

EXPLANATION

OUTCROP AREA OF MESAVERDE GROUP

OUTCROP AREA OF MANCOS SHALE AND DAKOTA SANDSTONE

CONTACT

SW NE LINE OF SECTION (See figure 4.5.2-1)

SITE OF WATER SAMPLE FROM UNDIFFERENTIATED MESAVERDE GROUP AQUIFERS

SITE OF WATER SAMPLE FROM GALLUP SANDSTONE

SITE OF WATER SAMPLE FROM MANCOS-DAKOTA AQUIFER

Figure 4.5.2-2 Sites of water samples from Cretaceous aquifers.

Table 4.5.2-1 Summary of chemical analyses of water samples from Cretaceous aquifers.

Concentrations of dissolved constituents reported in milligrams per liter, except as indicated. Micromhos, micromhos per centimeter at 25° Celsius. <, less than.

Undifferentiated Mesaverde Group Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	327-3,590	750	62
pH (units)	7.0-9.6	8.0	62
Bicarbonate (HCO_3)	31-710	320	12
Hardness ($CaCO_3$)	4-2,500	140	63
Calcium (Ca)	1.0-620	41	63
Sodium (Na)	7.9-380	110	62
Chloride (Cl)	2.9-120	14	63
Sulfate (SO_4)	2.9-2,000	73	62
Iron (Fe)	<0.010-3.2	0.050	61
Manganese (Mn)	<0.001-0.590	0.010	50
Dissolved solids	199-3,400	446	63

Gallup Sandstone

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	450-5,350	1,200	38
pH (units)	7.1-11.7	8.0	36
Bicarbonate (HCO_3)	190-610	280	33
Hardness ($CaCO_3$)	2-1,500	130	41
Calcium (Ca)	1.0-320	31	40
Sodium (Na)	11-1,000	180	26
Chloride (Cl)	2.0-1,300	20	41
Sulfate (SO_4)	22-2,100	280	40
Iron (Fe)	0-1.6	0.040	39
Manganese (Mn)	<0.001-0.330	0.040	10
Dissolved solids	256-3,390	788	39

Mancos-Dakota Aquifer

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	290-4,490	990	56
pH (units)	6.9-9.3	8.2	55
Bicarbonate (HCO_3)	210-510	310	19
Hardness ($CaCO_3$)	3-1,300	140	57
Calcium (Ca)	0.1-370	36	56
Sodium (Na)	18-900	150	55
Chloride (Cl)	2.5-170	12	57
Sulfate (SO_4)	1.7-1,900	150	57
Iron (Fe)	0-5.1	0.060	52
Manganese (Mn)	<0.001-0.8	0.020	39
Dissolved solids	218-3,050	616	56

Water in Permian Aquifers has the Largest Median Concentrations of Dissolved Solids, Calcium, Sulfate, and Hardness

Water-quality data are summarized for 38 Jurassic sites, 68 Triassic sites, and 69 Permian sites.

Throughout much of Area 62, Jurassic through Permian aquifers underlie the coal-bearing rocks (fig. 4.5.3-1). The location of sampling sites for these aquifers is shown in figure 4.5.3-2; because of the map scale, one sampling site may represent several closely spaced wells or springs. A summary of the chemical analyses for samples is given in table 4.5.3-1.

The National Water Data Storage and Retrieval System (WATSTORE) lists 38 sites at which samples have been collected from Jurassic aquifers: 25 for the Morrison Formation, 8 for the combined Zuni Sandstone-Cow Springs Sandstone, and 5 for the Entrada Sandstone. Compared to other aquifers in Area 62, Jurassic aquifers exhibit small median concentrations of hardness and chloride.

Of the 68 Triassic sampling sites, 61 derive water from the Chinle Formation, 5 from the Wingate Sandstone, and 2 from the Moenkopi Formation. The water typically is enriched with bicarbonate and sodium but has small median concentrations of calcium and calcium carbonate hardness.

The summary of chemical analyses for Permian aquifers in table 4.5.3-1 is based on samples from two aquifer systems: the undifferentiated San Andres Limestone-Glorieta Sandstone in New Mexico (51 sites) and the undifferentiated Kaibab Limestone-Coconino Sandstone in Arizona (18 sites). As a group, the Permian aquifers have the most mineralized water in Area 62, with the largest median concentrations of hardness, calcium, sulfate, and dissolved solids; however, the sodium and chloride concentrations are rather small. Although the San Andres-Glorieta and Kaibab-Coconino are stratigraphically lateral equivalents, the available data indicate that water quality is markedly different in the units. Median concentrations of all constituents in the San Andres-Glorieta are much smaller than in the Kaibab-Coconino; especially notable are the concentrations of sodium (60 versus 360 milligrams per liter), chloride (22 versus 430 milligrams per liter), and dissolved solids (740 versus 1,750 milligrams per liter). These differences may be an aberration caused by the few samples available or the location of the sampling sites. However, the water-quality differences could be caused by differences in composition of the rocks or the chemical composition of the recharge to the aquifers.

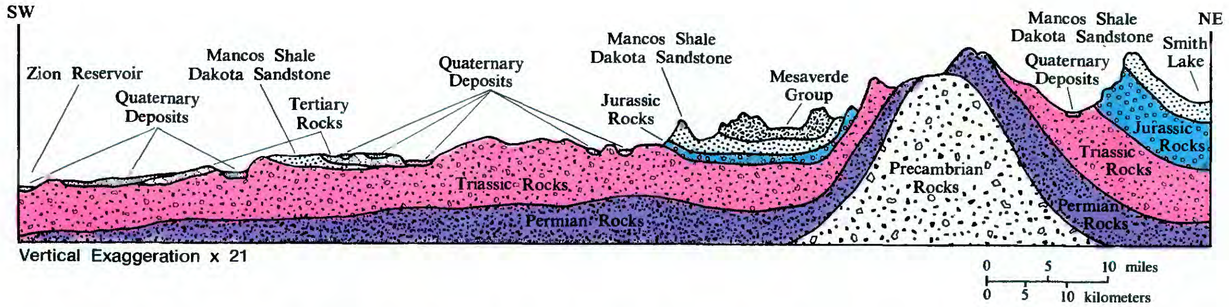


Figure 4.5.3-1 Schematic diagram showing stratigraphic relationship of Jurassic, Triassic, and Permian rocks between Zion Reservoir and Smith Lake.

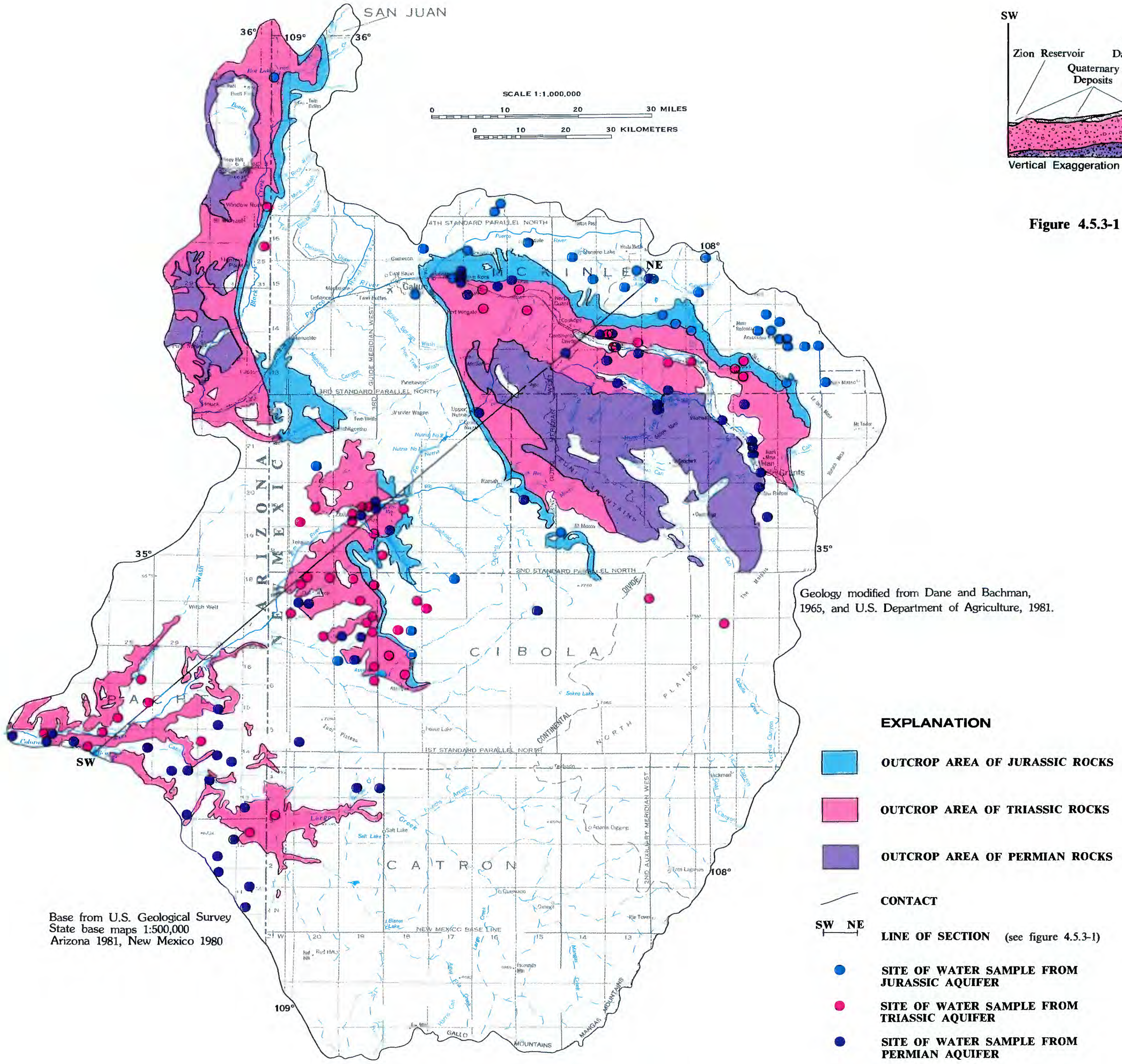


Figure 4.5.3-2 Sites of water samples from Jurassic, Triassic, and Permian aquifers.

Table 4.5.3-1 Summary of chemical analyses of water samples from Jurassic, Triassic, and Permian aquifers.

Concentrations of dissolved constituents reported in milligrams per liter, except as indicated. Micromhos, micromhos per centimeter at 25° Celsius. < , less than.

Jurassic Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	304-3,400	808	38
pH (units)	7.3-9.5	8.1	37
Bicarbonate (HCO_3)	170-710	240	32
Hardness ($CaCO_3$)	4-2,000	98	38
Calcium (Ca)	1.2-560	27	38
Sodium (Na)	24-700	140	35
Chloride (Cl)	2.5-97	10	38
Sulfate (SO_4)	11-2,000	150	38
Iron (Fe)	0-2.1	0.040	35
Manganese (Mn)	0-0.090	<0.010	17
Dissolved solids	189-3,400	500	38

Triassic Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	160-33,800	995	68
pH (units)	6.8-10.7	8.3	62
Bicarbonate (HCO_3)	46-821	320	45
Hardness ($CaCO_3$)	3-3,200	75	67
Calcium (Ca)	0.4-1,100	24	67
Sodium (Na)	6.9-7,100	200	66
Chloride (Cl)	0.8-13,000	33	68
Sulfate (SO_4)	8.5-1,700	180	67
Iron (Fe)	0-0.990	0.050	59
Manganese (Mn)	<0.001-0.130	0.010	23
Dissolved solids	130-23,000	675	66

Permian Aquifers

Constituent or property	Range	Median	Number of samples
Specific conductance (micromhos)	476-4,500	1,240	67
pH (units)	6.0-9.3	7.4	57
Bicarbonate (HCO_3)	180-692	290	57
Hardness ($CaCO_3$)	4-1,300	500	69
Calcium (Ca)	1.6-350	140	69
Sodium (Na)	8.0-550	100	57
Chloride (Cl)	1.1-770	34	69
Sulfate (SO_4)	33-820	300	69
Iron (Fe)	0-8.1	0.020	64
Manganese (Mn)	<0.010-0.340	0.060	20
Dissolved solids	180-2,850	889	69

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 aquiring 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

NAWDEX ASSISTANCE CENTER
NEW MEXICO
U.S. Geological Survey
Water Resources Division
Pinetree Office Park
4501 Indian School Road NE
Suite 200
Albuquerque, NM 87110

ARIZONA
U.S. Geological Survey
Water Resources Division
Federal Building
301 W. Congress, FB-44
Tucson, AZ 85701

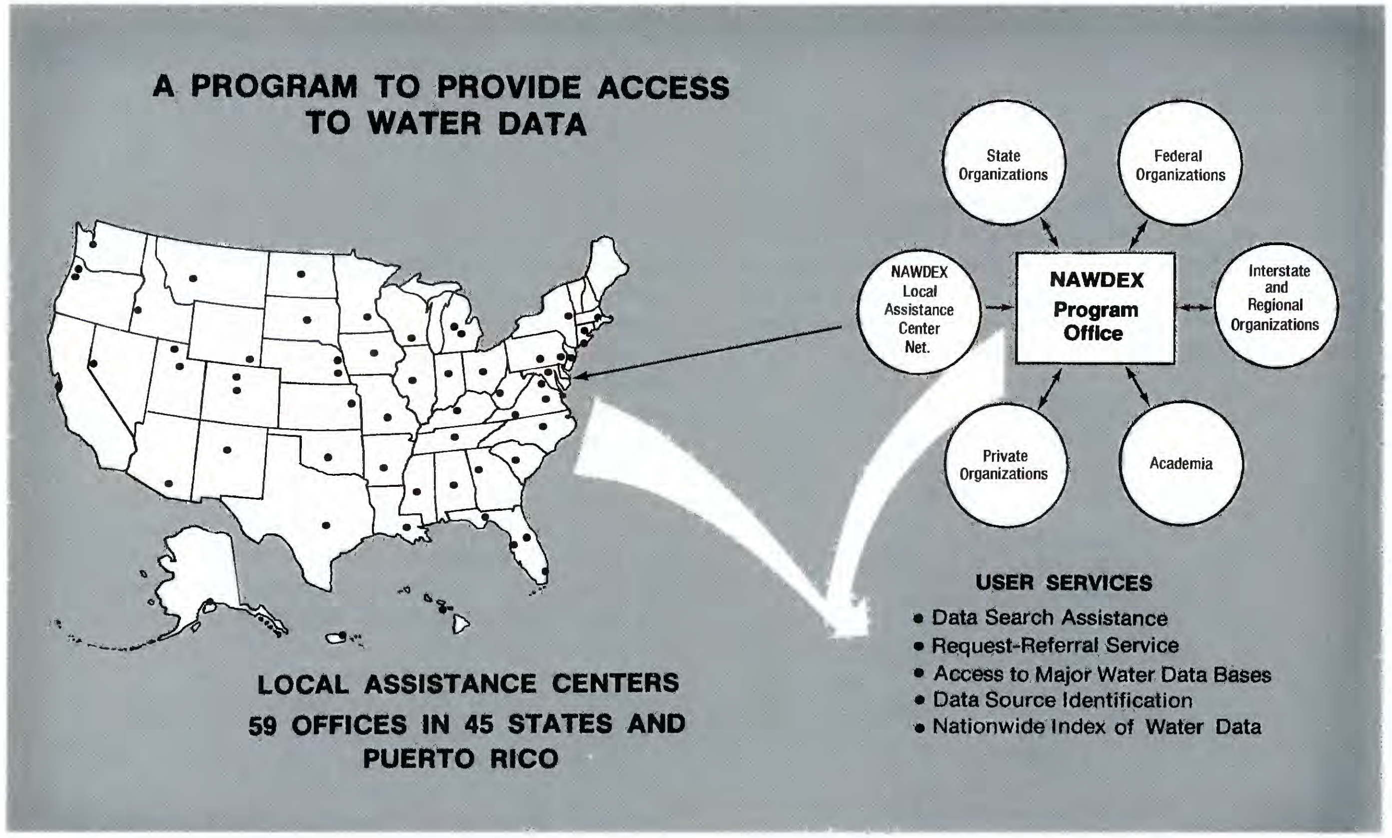


Figure 5.2-1 Access to water data.

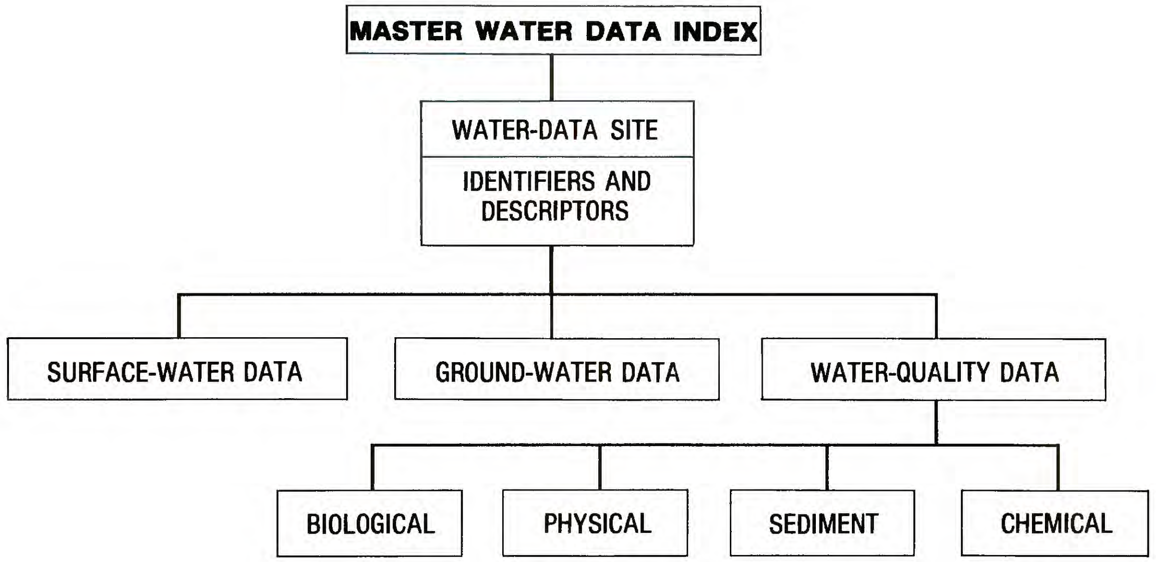


Figure 5.2-2 Master Water-Data Index.

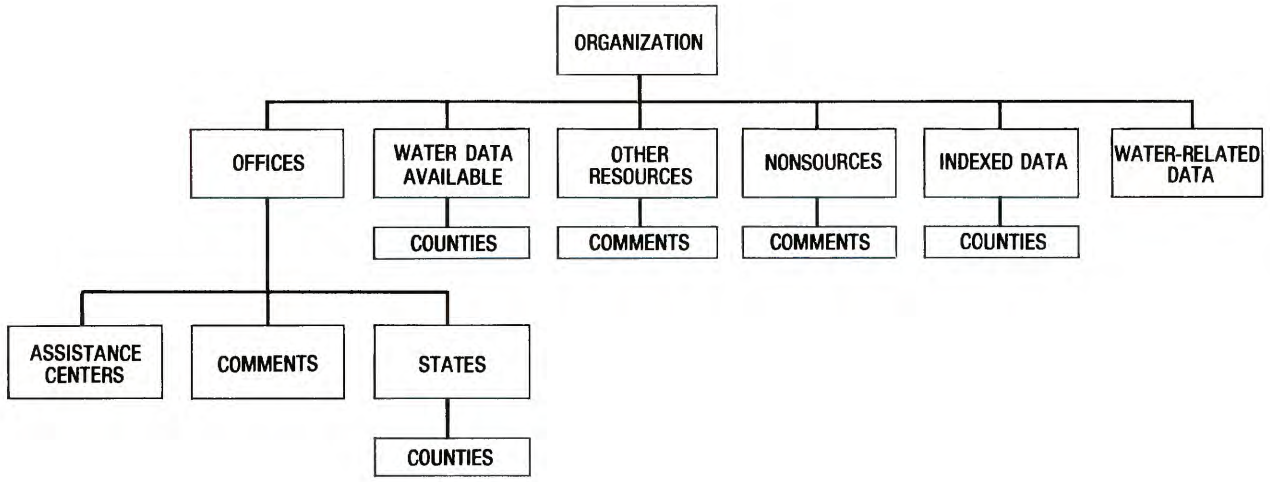


Figure 5.2-3 Water-Data Sources Directory.

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
U.S. Geological Survey
Water Resources Division
Pinetree Office Park
4501 Indian School Road NE
Suite 200
Albuquerque, NM 87110

ARIZONA
U.S. Geological Survey
Water Resources Division
Federal Building
301 W. Congress, FB-44
Tucson, AZ 85701

The Geological Survey currently (1983) 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 500 data relay stations are being operated currently (1983).

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.

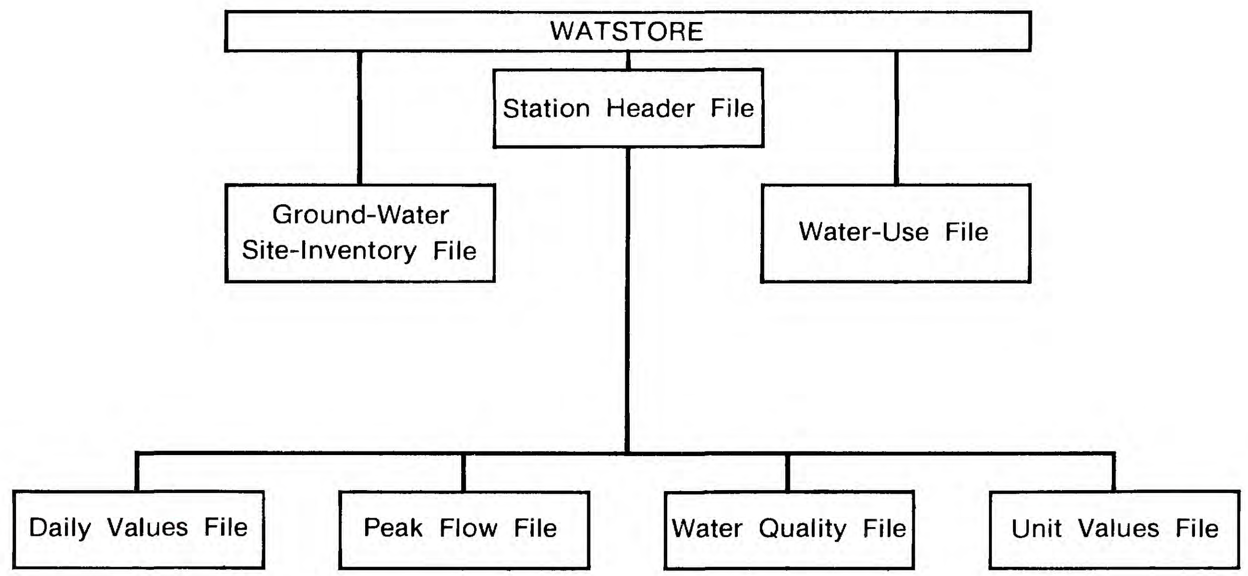


Figure 5.3-1 Index file stored data.

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) or NAWDEX Assistance Centers (see section 5.2).

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

Office of Surface Mining
U.S. Department of the Interior
219 Central Avenue NW
Albuquerque, NM 87102
Telephone: (505) 766-1486
FTS 474-1486

NEW MEXICO
U.S. Geological Survey
Water Resources Division
Pinetree Office Park
4501 Indian School Road NE
Suite 200
Albuquerque, NM 87110

ARIZONA
U.S. Geological Survey
Water Resources Division
Federal Building
301 W. Congress, FB-44
Tucson, AZ 85701

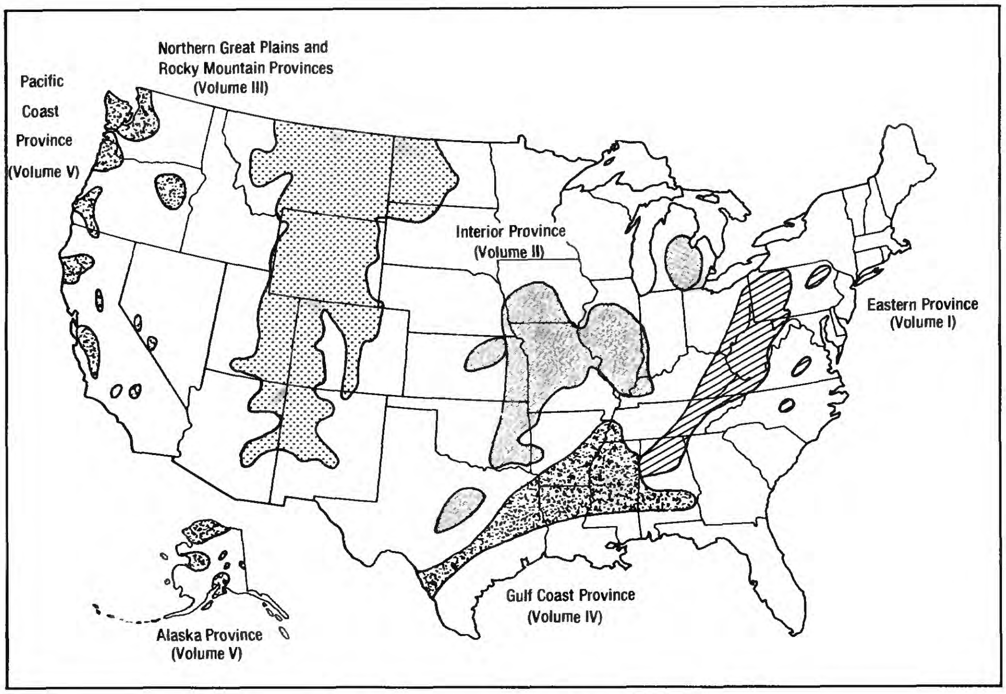


Figure 5.4-1 Index volumes and related provinces.

6.0 SUPPLEMENTAL INFORMATION FOR AREA 62

6.1 Index of Selected Surface-Water Stations

Map number	Station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Period of record (calendar years): Streamflow	Period of record (calendar years): Water quality
1	08341300	BLUEWATER CREEK ABOVE BLUEWATER DAM NEAR BLUEWATER, N.MEX.	35 15 35	108 07 05	75.0	1953-77	
2	08341370	PINE CANYON NEAR THOREAU, N.MEX.	35 18 35	108 10 14	6.09	1969-	
3	08341500	BLUEWATER CREEK BELOW BLUEWATER DAM, N.MEX.	35 17 35	108 06 35	201	1960-63	
4	08342000	BLUEWATER CREEK NEAR BLUEWATER, N.MEX.	35 17 40	108 01 40	209	1960-73	1980
5	08342600	SAN MATEO CREEK NEAR SAN MATEO, N.MEX.	35 20 46	107 46 31	75.6	1977-	
6	08343000	RIO SAN JOSE AT GRANTS, N.MEX.	35 09 16	107 52 11	1020	1912-66(MANY MISSING MONTHS) 1968-	1973-
7	08343100	GRANTS CANYON AT GRANTS, N.MEX.	35 09 39	107 50 15	13.0	1961-	
8	08343300	RIO SAN JOSE TRIBUTARY NEAR GRANTS, N.MEX.	35 06 55	107 47 05	.03	1952-59	
9	08343500	RIO SAN JOSE NEAR GRANTS, N.MEX.	35 04 27	107 45 01	2300	1936-	1972-
10	09386050	LARGO CREEK NEAR MANGAS, N.MEX.	34 08 30	108 30 05	63.0	1960-66	
11	09386100	LARGO CREEK NEAR QUEMADO, N.MEX.	34 19 25	108 31 40	151	1954-	
12	09386150	MANGAS CREEK TRIBUTARY NEAR PIETOWN, N.MEX.	34 18 11	108 08 30	.08	1952-	
13	09386200	CARRIZO CREEK NEAR SALT LAKE, N.MEX.	34 30 39	109 01 35	560	1957-	
14	09386900	RIO NUTRIA NEAR RAMAH, N.MEX.	35 16 57	108 33 10	71.4	1969-	1976, 1980-
15	09386950	ZUNI RIVER ABOVE BLACK ROCK RESERVOIR, N.MEX.	35 06 03	108 45 03	810	1969-	1976-
16	09387050	GALESTENA CANYON TRIBUTARY NEAR BLACK ROCK, N.MEX.	34 58 45	108 40 00	19.0	1957-	
17	09387600	BEACON DRAW NEAR SANDERS, ARIZ.	35 00 45	109 14 05	.85	1963-71	
18	09395350	PUERCO RIVER NEAR CHURCH ROCK, N.MEX.	35 36 41	108 33 11	193	1977-	1979
19	09395400	MILK RANCH CANYON NEAR FORT WINGATE, N.MEX.	35 25 55	108 33 30	14.0	1949,1953-	
20	09395500	PUERCO RIVER AT GALLUP, N.MEX.	35 31 45	108 44 41	558	1940-46, 1957-77 (ANN MAXIMUM), 1977-	1975-
21	09395600	WAGON TRAIL WASH NEAR GAMERCO, N.MEX.	35 39 00	108 47 40	.38	1951-74	
22	09395650	PUERCO RIVER NEAR LUPTON, ARIZ.	35 19 40	109 04 10	1050	1971-72	1971-
23	09395700	WHITEWATER ARROYO NEAR CHEECHILGEETHO, N.MEX.	35 15 35	108 55 15	78.5	1964-67	
24	09395850	BLACK CREEK TRIBUTARY NEAR WINDOW ROCK, ARIZ.	35 39 15	109 05 20	.28	1964-67	
25	09395900	BLACK CREEK NEAR LUPTON, ARIZ.	35 27 09	109 07 33	500	1964-72, 1974-	1971, 1976-

EXPLANATION

MAP NUMBER: Number corresponding to ground-water site in figure 4.1-1.
SITE NAME: Name of site using Arizona or New Mexico convention for identification by Township, Range, and Section.
STATE: NM, New Mexico; AZ, Arizona
GEOLOGIC UNIT: 110 ALVM, Quaternary alluvium; 121 BDHC, Tertiary Bidahochi Formation; 211 GLLP, Upper Cretaceous Gallup Sandstone; 211 DKOT, Upper and Lower Cretaceous Dakota Sandstone; 221 WSRC, Upper Jurassic Westwater Canyon Member of Morrison Formation; 221 CSPG, Jurassic Cow Springs Sandstone; 221 SMVL, Jurassic Summerville Formation of the San Rafael Group; 221 ENRD, Lower Jurassic Entrada Sandstone of the San Rafael Group,231 SRMP, Shinarump Member of the Upper Triassic Chinle Formation; 310 GLRT, Permian Glorieta Sandstone; 310 KIBB, Permian Kaibab Formation; 310 YESO, Permian Yeso Formation; 313 SADR, Permian San Andres Formation.

Data sites in WATSTORE file

Map number	Identification number		Site name	State	County	Geologic unit	Period of record	
	latitude	longitude					water level	water quality
1	342946	109133501	A-13-29 35aaa	AZ	Apache	310 KIBB	57, 75-	-
2	345620	109104001	A-18-30 20cdd	AZ	Apache	121 BDHC	69, 71-	-
6	352838	108261601	14N.15W.04.1134	NM	McKinley	231 SRMP 310 GLRT	69, 79-	69
7	352454	108260101	14N.15W.28.1434	NM	McKinley	310 GLRT 313 SADR	68, 79-	50
8	353125	108123601	15N.13W.22.111	NM	McKinley	221 SMVL 221 CSPG	64, 77, 80-	63, 64, 70, 74
10	353406	108005301	16N.11W.33.322	NM	McKinley	221 WSRC	72, 77, 80-	72, 81
11	353649	108305801	16N.16W.15.4322	NM	McKinley	211 DKOT 221 WSRC	59, 76	74
12	353519	108285001	16N.16W.25.2344	NM	McKinley	221 ENRD	65, 80-	74
13	353548	108383801	16N.17W.21.3442	NM	McKinley	221 WSRC	65, 78, 81-	74
17	350400	107510501	10N.10W.26.331	NM	Cibola	310 GLRT	52- 63, 65-	-
18	350925	107523001	11N.10W.27.241	NM	Cibola	313 SADR	53-	-
19	351400	107524201	12N.10W.29.434	NM	Cibola	313 SADR	44, 46- 65, 67-	-
20	351650	107535001	12N.11W.9.424	NM	Cibola	313 SADR 310 YESO	46-	-
			Data sites not in WATSTORE file					
3	352021	1074730	13N.09W.21.4123	NM	McKinley	221 WSRC	55-	-
4	352050	1074658	13N.09W.22.112	NM	McKinley	221 WSRC	58-	-
5	352418	1075134	14N.10W.35.221	NM	McKinley	221 WSRC	57, 80-	-
9	353248	1083438	15N.14W.09.2333	NM	McKinley	221 SMVL	76, 80-	-
14	353715	108460101	16N.18W.17.122a	NM	McKinley	211 GLLP 211 DKOT	69, 79	69
15	-	-	9N.18W.5.324	NM	McKinley	310 GLRT	63, 72, 78	64
16	-	-	10N.19W.27.112	NM	McKinley	310 GLRT	73, 78	73
21	351610	107514501	12N.11W.14.213	NM	Cibola	110 ALVM	49-	-

Glossary of Terms

Technical terms that appear in this report are defined.

Aquifer is a permeable formation or group of formations that contain enough saturated material to yield economically significant quantities of water to wells or springs.

Artesian is an adjective referring to ground water confined under hydrostatic pressure.

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.

Bolson is a basin or depression in the desert regions of the southwestern United States which has received great thicknesses of sediments washed from the surrounding mountains.

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. With respect to underground water, the movement of water out of the aquifer. Discharge may be natural including spring discharge, seepage, or evapotranspiration, or it may be artificial from constructed drains or wells. Pumping discharge as from wells is usually expressed in gallons per minute.

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 ultra-fine 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.

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.

Epoch refers to a unit of geologic time shorter than a Period during which rocks were formed.

Era refers to a large division of geologic time during which rocks were formed. The main eras include the Precambrian Era, the Paleozoic Era, the Mesozoic Era, and the Cenozoic Era.

Erosion is defined as the general process or processes where by the material of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another, by natural agents, which include weathering, solution, corrasion, and transportation.

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

Extrusive is said of igneous rock that has been erupted onto the surface of the Earth. A synonym is intrusive and pertains to igneous rocks formed beneath the Earth's surface.

Facies change is a vertical or lateral change in the lithology or paleontology of contemporaneous sedimentary rocks or unconsolidated deposits. A change in the deposition environment causes the facies change.

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

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.

Intermittent flow is temporary or seasonal streamflow in a channel when it receives water from a spring or another surface source.

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, generally a chemical constituent or suspended sediment, in a water-sediment mixture as mass (in micrograms) of the given substance per unit volume (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.

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

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.

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 per centimeter at 25 degrees Celsius. 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 micromhos per centimeter at 25°C.

Spoil material refers to overburden, nonore, or other waste material removed in mining.

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.

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 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).

Syncline is a fold in rocks in which the strata dip inward from both sides toward the axis.

System refers to a division of geologic time commonly considered synonymous with Period, based upon time and stratigraphy. In the United States the systems include: (in order of increasing age) Quaternary, Tertiary, Cretaceous, Jurassic, Triassic, Permian, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian. Internationally, opinions differ with respect to classification, nomenclature, and boundaries in almost all of the systems.

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 milligram per liter or less. Trace concentrations are expressed in micrograms per liter ($\mu g/L$). One milligram per liter equals 1,000 micrograms per liter.

Water table refers to the upper surface of the saturated zone at which the pressure is equal to the atmospheric pressure.

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