WATER RESOURCES ON THE PUEBLOS OF JEMEZ, ZIA, AND SANTA ANA, SANDOVAL COUNTY, NEW MEXICO

By Steven D. Craigg

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CONTENTS

CONTENTS--Continued

CONTENTS--Continued

CONTENTS--Concluded

PLATES

[Plates are in pocket]

FIGURES

FIGURES--Continued

FIGURES--Concluded

TABLES

TABLES—Concluded

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
mile	1.609	kilometer
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
cubic foot per second	0.02832	cubic meter per second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

The Pueblos of Jemez, Zia, and Santa Ana are located in north-central New Mexico on semiarid lands characterized by mesas, buttes, mountains, and broad upland and valley areas. This investigation was an appraisal of the water resources of the pueblos. The major purpose was to better define the ground-water systems, surface-water systems, and water chemistry on pueblo lands.

The major potential aquifer available to the Pueblo of Jemez for development of public- and irrigation-water supplies is alluvium along the Jemez River. Properly constructed wells in these deposits will yield at least 500 gallons per minute of water that contains about 500 to 700 milligrams per liter dissolved solids. Alluvium along the southeastern part of the Jemez River valley offers some potential to the Pueblos of Zia and Santa Ana for developing public- and irrigation-water supplies, but well yields would be expected to be smaller than those on the Pueblo of Jemez and the water would contain about 900 to 1,350 milligrams per liter dissolved solids. The major potential aquifer available to the Pueblos of Zia and Santa Ana for the development of public- and irrigation-water supplies is the Santa Fe aquifer. This aquifer probably would yield as much as several hundred gallons per minute of water that contains about 350 to 550 milligrams per liter dissolved solids to properly constructed wells. Water of sufficient quantity and suitable quality for livestock can be obtained from any major or minor potential aquifer on pueblo lands. These aquifers include alluvium, terrace deposits, sand and gravel in the Santa Fe aquifer, volcanic rocks, sandstone beds in the Mancos Shale, Dakota Sandstone, sandstone beds in the Morrison Formation, Entrada Sandstone, sandstone beds in the Chinle Formation, sandstone beds in various Permian rocks, Madera Limestone, and crystalline rocks.

Aquifers are recharged directly by transmission loss of water from streams that cross outcrops and by precipitation that falls on outcrops. Aquifers also are recharged indirectly by subsurface leakage of water between geologic units.

Three distinct hydrogeologic provinces were identified: the San Juan Basin, Sierra Nacimiento, and Jemez Valley provinces. Ground-water movement in the San Juan Basin province is south and southeast toward the southwestern part of the Jemez Valley province. The quality of water in this province ranges from fresh (less than 1,000 milligrams per liter dissolved solids) near the Sierra Nacimiento front to very saline (10,000 to 35,000 milligrams per liter dissolved solids) near the mouth of the Rio Salado. Movement of ground water in the Sierra Nacimiento province generally is south, although some water discharges westward into the San Juan Basin province and eastward into the Jemez Valley province. Water quality in this province ranges from fresh to moderately saline (3,000 to 10,000 milligrams per liter dissolved solids) in the southern part. Ground-water movement in the Jemez Valley province generally is south in the Santa Fe aquifer and moves in the same direction as streamflow in the alluvium. The quality of water in this province ranges from fresh to slightly saline (1,000 to 3,000 milligrams per liter dissolved solids) and is more mineralized in the southern part of the Jemez Valley province. Much of the ground water beneath tribal lands moves through and does not discharge at the land surface in the study area.

Average annual discharge of the Jemez River at the Jemez River near Jemez streamflow-gaging station is 72 cubic feet per second. On the average, 70 percent of the flow occurs from March through May or June and originates as snowmelt from mountain areas. Base flow of the Jemez River is sustained year-round by ground-water discharge. Streamflow and water-quality data collected during two seepage investigations along the Jemez River indicate that in general, the river is a gaining stream during winter and a losing stream during summer. Quality of water from the Jemez River generally is fresh, but is more mineralized downstream from the Rio Salado confluence because of inflow of very saline water. The quality of water from the Rio Salado ranges from slightly saline in upstream reaches to very saline in downstream reaches probably because of discharge of very saline ground water from the San Juan Basin province.

INTRODUCTION

The Tribal Councils of the Pueblos of Jemez, Zia, and Santa Ana have formed the Jemez River Indian Water Authority (JRIWA) to organize efforts to study water availability in the parts of the Jemez River basin on tribal lands of the three pueblos. The pueblos are concerned about continued development of water resources in the Jemez River basin on lands adjacent to pueblo lands. As a result, the U.S. Geological Survey, in cooperation with the JRIWA, conducted an appraisal of water resources on the approximately 400 square miles of pueblo lands.

Purpose and Scope

This report describes the results of an investigation to define the ground-water systems, surface-water systems, and water chemistry on the Pueblos of Jemez, Zia, and Santa Ana. Specific objectives of the study were to:

1. Analyze the stratigraphic framework of the area and identify potential aquifers available for development.

2. Obtain data about geologic characteristics (texture, extent, thickness, and depth), hydrologic characteristics (well and spring yield, and aquifer coefficients), and water-quality characteristics of potential aquifers.

3. Assess the effects that geologic factors (structure, stratigraphy, and texture of units) have in controlling occurrence, movement, and quality of ground water.

4. Inventory wells and springs on tribal lands.

5. Investigate interactions between ground water and surface water along the Jemez River.

6. Identify areas of potential water-resource development for public supply, irrigation, and livestock use.

This investigation was limited to a 15-month period (September 1983 through November 1984), and available data were used where possible to meet the stated objectives; however, additional onsite data, including water levels, well yields, water quality, and streamflow, were collected to give an improved description of the hydrology of the study area. The hydrology of areas adjacent to the Jemez River valley was emphasized because the population is centered there and because unconsolidated and poorly consolidated deposits in the valley are the principal aquifers in the drainage basin. Although the study was principally a hydrogeologic investigation of ground-water systems, general characteristics of major surface-water systems also are discussed. When data about particular aquifers were sparse or unavailable from within the study area, data from adjacent areas were sometimes used.

Location and Geographic Setting

The Pueblos of Jemez, Zia, and Santa Ana are located in north-central New Mexico, in central Sandoval County (fig. 1). The study area consists of about 400 square miles of original Spanish land grants, land grants later acquired by Presidential Executive Order (reservation lands), and land purchased by the pueblos; in this report these lands will be referred to as pueblo lands. The study area is bounded by the Santa Fe National Forest (pl. 1) on the north, public land administered by the U.S. Bureau of Land Management on the west, privately owned land on the south, and the San Felipe and Santo Domingo Pueblo Grants (pl. 1) on the east. The lands of the study area lie in the southern part of the Jemez Mountains volcanic region.

The study area lies in the Southern Rocky Mountains physiographic province and in the Navajo and Datil sections of the Colorado Plateaus physiographic province (classification of Fenneman, 1931). These provinces are characterized by uplifted granitic mountains, high mesas, canyons, and abundant evidence of volcanic activity.

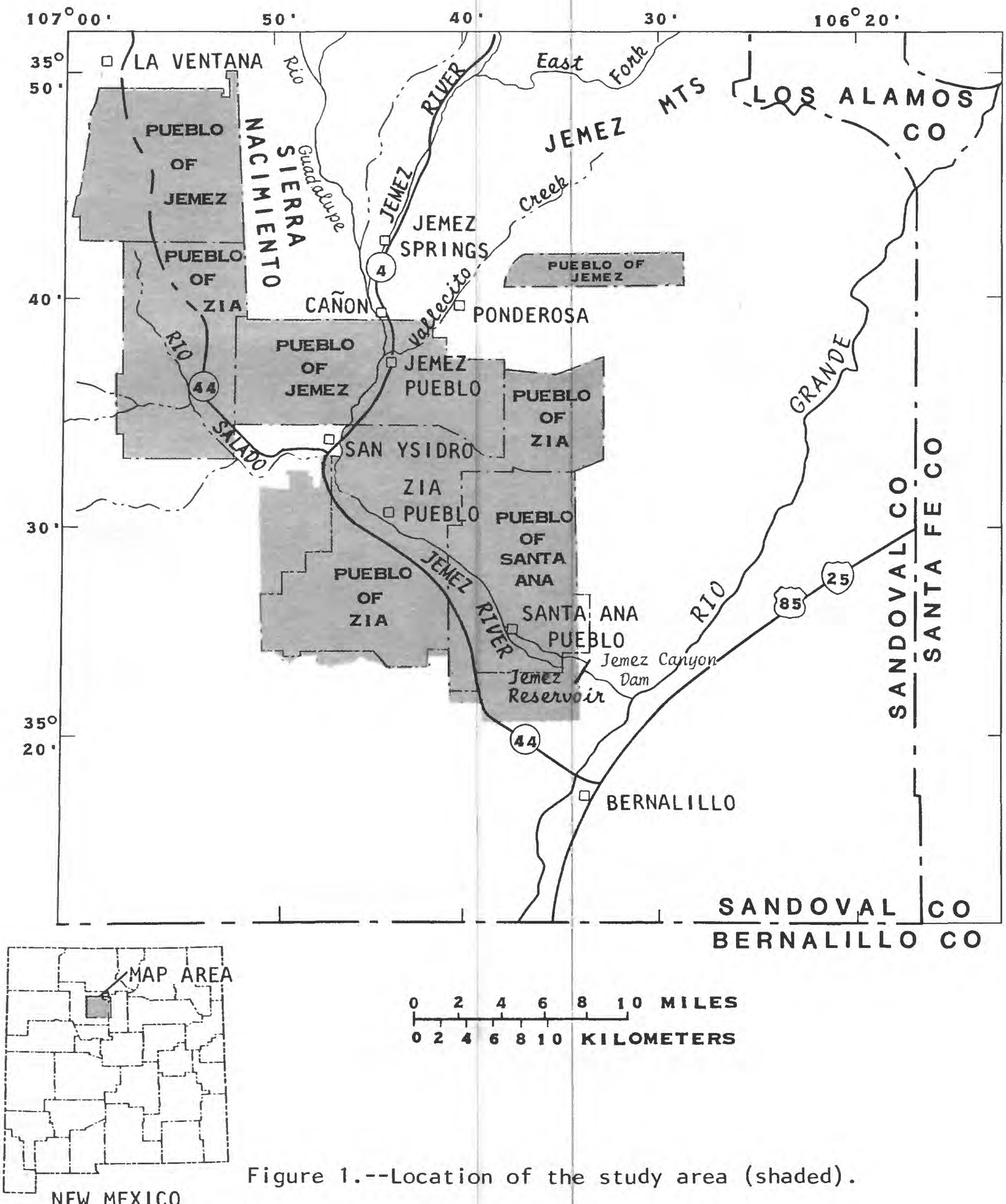


Figure 1.--Location of the study area (shaded).

Topography in the western part of the area (Ojo del Espiritu Santo Grant) generally consists of mesas and buttes, formed of soft shale capped by erosion-resistant sandstone, and intervening valleys. In the eastern part of this grant are steep, north-trending hogback ridges of tilted sedimentary rock and the granitic cliff faces and peaks of the Sierra Nacimiento. Altitudes in this area range from about 5,700 feet in mesa-butte-valley lands to 9,000 feet on Pajarito Peak (pl. 1).

The central part of the area lying between Arroyo Peñasco and Borrego Canyon (pl. 1) is a south-sloping block of upland mesas and buttes cut by deep canyons of which Cañon San Diego of the Jemez River is the largest. Altitudes in this region range from about 5,500 feet in Cañon San Diego to 7,500 feet on Borrego Mesa (pl. 1).

Topography in the southern part of the area consists of low, broad hills and wide valley flats formed on the Santa Fe Group, sloping south and north toward the Jemez River. Santa Ana Mesa (pl. 1) is an extensive upland at the eastern edge of the area, formed on the Santa Fe Group and capped by basalt. Altitudes in this region range from about 5,200 feet along the Jemez River to 6,300 feet on Santa Ana Mesa (pl. 1).

The Jemez River is the principal drainageway in the study area, flowing generally south through the Jemez Pueblo to San Ysidro and then generally southeast through the Zia and Santa Ana Pueblos (fig. 1). This stream is perennial, except in the reach from about San Ysidro to Jemez Reservoir during the summer. The largest tributary of the Jemez River is the Rio Salado, an intermittent stream that enters the Jemez River from the west. Arroyo Peñasco is a perennial stream, which is sustained by springflow, that enters the Rio Salado near State Highway 44 (pl. 1). Other streams are either ephemeral or intermittent and include Arroyo Semilla, Arroyo Ojito, Vallecito Creek, Tecolote Canyon, Borrego Canyon, Arroyo Piedra Parada, Arroyo Chamisa, and Arroyo Arenoso (pl. 1).

The climate of the area is semiarid. The average annual precipitation ranges from about 10 inches in the south to about 20 inches in the higher altitudes of the Sierra Nacimiento (U.S. Soil Conservation Service, 1972).

Methods of Investigation

The hydrogeology and water-resource potential of the area were determined through use of existing data and supplemented by onsite data collection, laboratory analyses, and review of pertinent literature. Onsite data collection was accomplished mainly during January through March and June through September 1984. Wells (pl. 1) and springs (pl. 2) were inventoried, and these data were presented in an earlier project data report (Craigg, 1984, tables 1 and 2). The inventory included identification of aquifers, measurement of well depths and static water levels, measurement or estimation of discharge of water from wells and springs, and collection of water-quality data (Craigg, 1984, tables 3-6).

Two sets of systematic streamflow measurements, known as seepage runs, were made along the Jemez River between the streamflow-gaging station north of the Jemez Pueblo and the Santa Ana Pueblo. These measurements were made during March and August 1984 to determine relations between ground water and surface water. Results are reported in Craigg (1984, tables 9 and 10), and also are discussed in this report. Streamflow measurements or estimates were made and water-quality data were collected at points along the Rio Salado and Arroyo Peñasco in an attempt to determine sources of salts in the area west of the Jemez River.

Available literature about the geology and hydrology of the area was examined. The information was used to supplement the onsite studies and laboratory analyses.

Previous Investigations

Several detailed studies have been done on various aspects of the geology of the Jemez Mountains-Sierra Nacimiento region. Few hydrologic studies have been conducted, most of which have been of a reconnaissance nature. No comprehensive study of the availability and quality of water in the southern Jemez Mountains and adjacent areas has been made.

Wood and Northrop (1946) published a reconnaissance geologic map of the Sierra Nacimiento region that included the western part of the study area. Spiegel (1961) discussed Cenozoic deposits of the southeastern part of the Jemez River valley area. Smith and others (1970) published a 1:125,000-scale map of the Jemez Mountains region, concentrating mainly on volcanic rocks. Woodward and Schumacher (1973a, b), Woodward and Martinez (1974), Woodward and others (1974), Woodward and Ruetschilling (1976), and Woodward and others (1977) conducted geologic studies and mapped the complex structure along the west flank of the Sierra Nacimiento. Kelley (1977) discussed the geologic structure and stratigraphy of the Albuquerque Basin area, and Kelley and Kudo (1978) published information on volcanoes and lava flows of the Albuquerque Basin. Manley (1978) mapped the Bernalillo NW 7.5-minute quadrangle. Numerous other papers concerning the geology of this area have been published; many of these are cited in the text of this report.

Few studies deal specifically with the hydrology of the region. Kelly and Anspach (1913) conducted a preliminary study of ground and surface waters in the Jemez Plateau area and discussed the mineral springs in the Rio Salado and Arroyo Peñasco area. Clark (1929) conducted further reconnaissance studies on the Rio Salado area salt springs and presented data about two flowing geothermal wells drilled in the Ojo del Espiritu Santo Grant. The first investigation to report on ground-water conditions in specific rock units of the area was conducted by the U.S. Geological Survey in western Sandoval County (Renick, 1931). Hodges (1938) published a large volume concerning the status of irrigation and water supply of pueblos near the Rio Grande. Maxwell (1960) published a report discussing potential irrigation-water supplies on the Zia Reservation. Bjorklund and Maxwell (1961) investigated the potential for ground-water supplies in the Albuquerque vicinity and discussed the general occurrence of ground water along the downstream reaches of the Jemez River valley. Spiegel (1962) investigated the potential for additional domestic-water supplies at Jemez Pueblo. Griggs (1964) discussed the geology and hydrology of the Los Alamos area, reporting on aquifer tests conducted in the Santa Fe Group. Trainer (1974) and Trainer and Lyford (1979) published papers about the ground water and geothermal hydrology of the Jemez Mountains and Rio Grande rift areas. Trainer (1978) published a report in which a large quantity of hydrologic data from the Jemez Mountains region was tabulated. A master's thesis by Craigg (1980) detailed the stratigraphy and ground-water hydrology in the vicinity of the Rio Puerco just west of the Ojo del Espiritu Santo Grant. Fischer and Borland (1983) estimated the natural streamflow in the Jemez River at the boundaries of the Pueblos of Jemez, Zia, and Santa Ana. Stone and others (1983) published a comprehensive report about the regional hydrogeology of the San Juan Basin. Data pertaining to ground water and surface water on the Pueblos of Jemez, Zia, and Santa Ana were tabulated in a report by Craigg (1984).

Acknowledgments

The full cooperation of pueblo residents and the Tribal Councils of the Pueblos of Jemez, Zia, and Santa Ana given the U.S. Geological Survey throughout this investigation is gratefully acknowledged. The U.S. Bureau of Indian Affairs, particularly personnel of the Albuquerque Area Office and Southern Pueblos Agency, provided some water-quality data and information about certain pueblo wells and springs.

Site-Identification Numbering System

The numbering system used in this report to locate a well or spring is that used by the New Mexico State Engineer and is based on the township, range, and section land grid. In this system, each well or spring has a unique location number consisting of four segments that are separated by periods, as shown in figure 2. The first segment indicates the township north or south of the New Mexico Base Line (all wells or springs in this report are north), and the second denotes the range east or west of the New Mexico Principal Meridian. The third segment indicates the section within which the well or spring is located. The fourth segment of the location number is determined by dividing the section into quarters numbered 1, 2, 3, and 4, which correspond to the northwest, northeast, southwest, and southeast quarters, respectively. Each quarter section is similarly divided into as many as three subdivisions, depending on how accurately the well or spring can be located. In unsurveyed areas, land lines were projected. All such numbered wells referred to in this report are given in the earlier project data report (Craigg 1984, table 1); all such numbered springs are given in table 2 of that report. The method used to locate a surface-water site is the grid system of latitude and longitude.

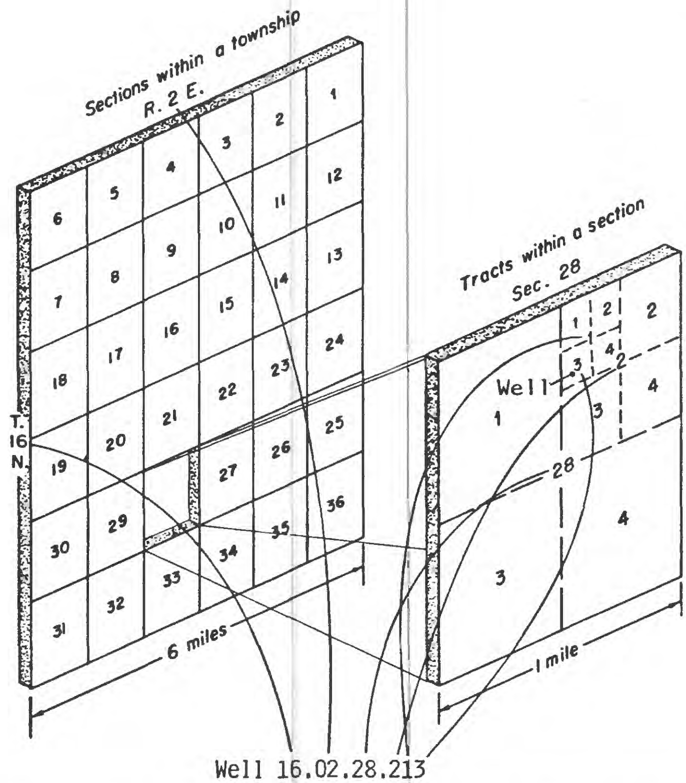


Figure 2.--Well- and spring-numbering system.

GEOLOGIC SETTING

Stratigraphic Framework

Geologic units that crop out in the study area range in age from Precambrian through Cenozoic. They include Precambrian metamorphic and igneous rocks; Paleozoic, Mesozoic, and Cenozoic sedimentary rocks; Cenozoic igneous rocks; and Quaternary deposits.

The Precambrian crystalline rocks consist of various plutonic intrusive rocks, such as granite, and metamorphic rocks, such as gneiss and schist. The Paleozoic rocks consist of limestone, sandstone, siltstone, and shale: Mississippian and Pennsylvanian strata mostly are of marine origin; Permian strata, however, were deposited in a continental setting. Mesozoic strata consist principally of sandstone and shale with some beds of gypsum and limestone: Triassic and Jurassic rocks were deposited in a continental setting; Cretaceous strata were deposited in a series of marine transgressions and regressions of a major inland sea. Cenozoic sediments, deposited in continental environments, consist of poorly cemented conglomerate, sandstone, and shale of Tertiary age, and also include deposits of unconsolidated gravel, sand, and clay in stream valleys, stream-terrace gravel and sand, landslide debris, and windblown sand of Quaternary age. Various volcanic rocks and mineral-spring deposits, called travertine, also are of Tertiary and Quaternary age.

The stratigraphic relations of these geologic units are shown in figure 3. Their areal distribution is shown on plate 3, and hydrogeologic sections are shown on plate 4.

ERATHEM	SYSTEM	ROCK STRATIGRAPHIC UNIT	
CENOZOIC	QUATERNARY	Valley-fill alluvium[1], eolian deposits, landslide and talus deposits, terrace-gravel deposits[2], travertine	
CENOZOIC	TERTIARY	Travertine and travertine-cemented terrace deposits	Volcanic rocks[2] associated with Jemez Mountains
CENOZOIC	TERTIARY	Santa Fe Group (or Formation), Zia Sand, and Cochiti Formation, undivided[1]	
MESOZOIC	CRETACEOUS	Mesaverde Group	Cliff House Sandstone
MESOZOIC	CRETACEOUS	Mesaverde Group	Menefee Formation
MESOZOIC	CRETACEOUS	Mesaverde Group	Point Lookout Sandstone
MESOZOIC	CRETACEOUS	Mancos Shale[2]	
MESOZOIC	CRETACEOUS	Dakota Sandstone[2]	
MESOZOIC	JURASSIC	Morrison Formation	Jackpile Sandstone Member[2]
MESOZOIC	JURASSIC	Morrison Formation	Brushy Basin Shale Member
MESOZOIC	JURASSIC	Morrison Formation	Westwater Canyon Sandstone Member[2]
MESOZOIC	JURASSIC	Morrison Formation	Recapture Shale Member
MESOZOIC	JURASSIC	Todilto Limestone Member of Wanakah Formation	
MESOZOIC	JURASSIC	Entrada Sandstone[2]	
MESOZOIC	TRIASSIC	Chinle Formation	Petrified Forest Member
MESOZOIC	TRIASSIC	Chinle Formation	Agua Zarca Sandstone Member[2]
PALEOZOIC	PERMIAN	Bernal Formation	
PALEOZOIC	PERMIAN	San Andres Limestone	
PALEOZOIC	PERMIAN	Glorieta Sandstone	
PALEOZOIC	PERMIAN	Yeso Formation[2]	
PALEOZOIC	PERMIAN	Abo Formation[2]	
PALEOZOIC	PENNSYLVANIAN	Madera Limestone[2]	
PALEOZOIC	PENNSYLVANIAN	Sandia Formation	
PALEOZOIC	MISSISSIPPIAN	Log Springs Formation	
PALEOZOIC	MISSISSIPPIAN	Arroyo Peñasco Group	
PRECAMBRIAN		Intrusive igneous (granitic) and metamorphic (gneiss and schist) complexes	

[1]Major aquifer
[2]Minor aquifer

Figure 3.--General relation of major rock- and time-stratigraphic units.

Structural Framework

The study area includes the southeastern part of the San Juan Basin, the southern part of the Nacimiento uplift, the southern part of the Jemez Mountains volcanic field, and the western part of the Rio Grande rift. The San Juan Basin was defined by Kelley (1950) as a northwest-trending structural depression mainly formed during the Laramide orogeny (Late Cretaceous-early Tertiary) at the eastern edge of the Colorado Plateau. The San Juan Basin is separated from the Sierra Nacimiento by the Pajarito fault, which is a steep-angle reverse fault (Woodward and Schumacher, 1973b); the steeply dipping, complexly faulted hogback ridges at the western foot of the Nacimiento uplift and the San Juan Basin range in altitude from about 5,500 to 7,000 feet in this area (Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976).

The Jemez Mountains volcanic field is a thick accumulation of Cenozoic extrusive rocks that rest on the western margin of the Rio Grande rift. The present land-surface altitudes in the Jemez Mountains are the result of the accumulation of volcanic rocks on a preexisting surface and not the result of structural uplift (Woodward, 1974). Volcanism in the Jemez Mountains region began after the Rio Grande rift started forming (late Tertiary and early Pleistocene) and continued throughout the rifting.

The Rio Grande rift is a downdropped structural feature consisting of a series of en echelon north-trending grabens; the Albuquerque Basin, the northwestern margin of which is part of the study area, is one of these grabens. The Albuquerque Basin is bounded on the west by the San Juan Basin and Sierra Nacimiento. Volcanic rocks of the Jemez Mountains cover the northern part of this basin. Toward the Nacimiento uplift, numerous normal faults are present, marking the western margin of the Albuquerque Basin and Rio Grande rift. Woodward (1974) reported a maximum stratigraphic separation of 2,250 feet at the western margin. Some of the principal faults are the Jemez, Doval, and Santa Ana faults, although many smaller ones exist (pl. 3).

GROUND-WATER PROVINCES

The study area can be divided into three ground-water provinces, each with distinct physiography, geologic structure, stratigraphy, different groups of potential aquifers, regional ground-water flow systems, and differences in water quality. The water-quality differences are especially apparent, even within the same geologic unit, from province to province.

The three ground-water provinces are the San Juan Basin, Sierra Nacimiento, and Jemez Valley shown in figure 4 and on plate 3. The separation of the area into these provinces provides a useful approach to discussion of potential aquifers and of various geologic controls affecting ground-water occurrence, movement, and quality.

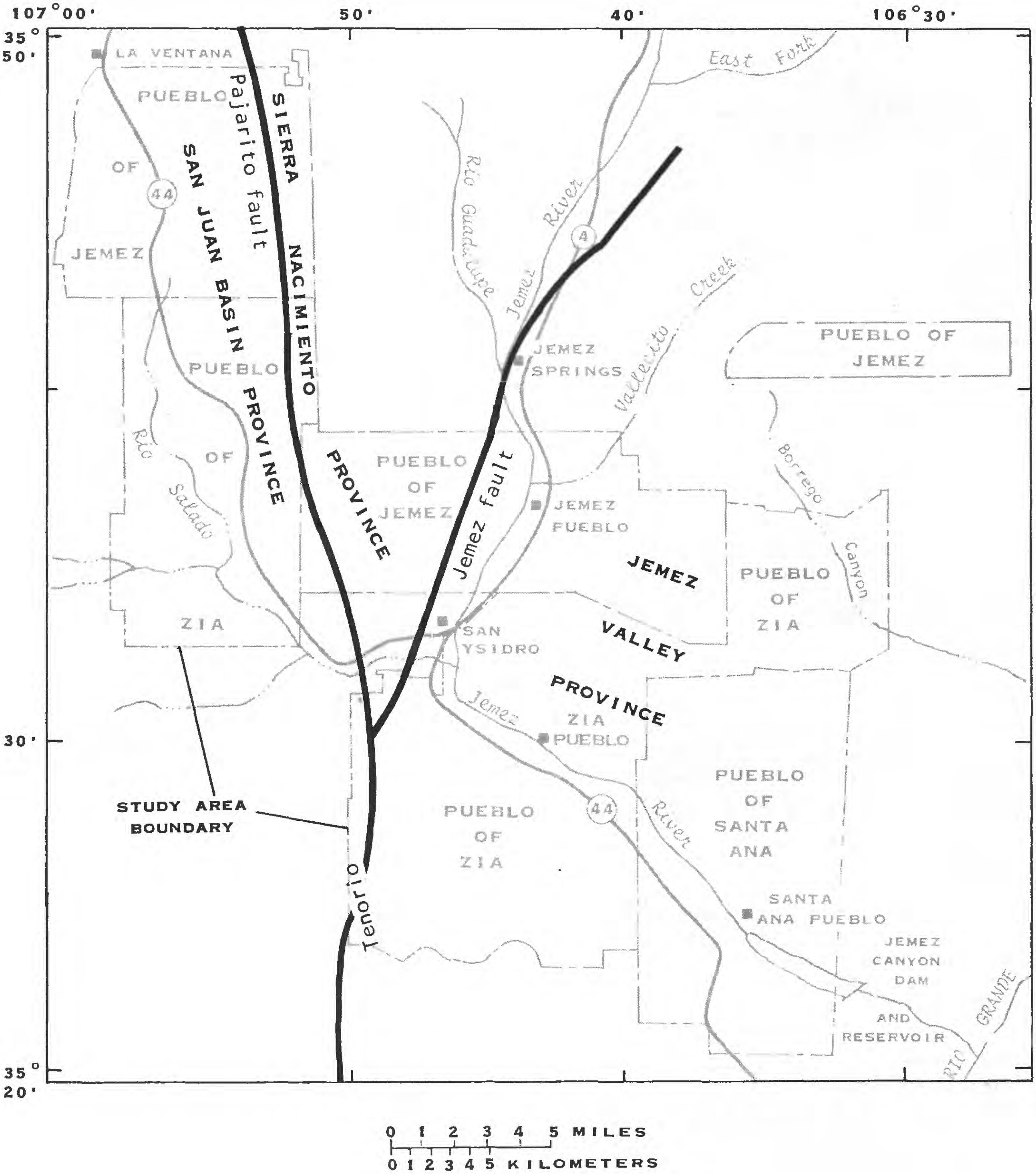


Figure 4.--Ground-water provinces. The faults shown on the map coincide with the boundaries of the provinces on the pueblo lands.

San Juan Basin Province

The San Juan Basin province corresponds with Pueblos of Jemez and Zia lands in the Ojo del Espiritu Santo Grant; regionally, the province is in the southeastern part of the San Juan Basin. The province is bounded on the east by the Pajarito fault (Nacimiento uplift) and Tenorio fault (Rio Grande rift) (fig. 4; pl. 3). Steeply dipping hogbacks of tilted sedimentary rock are near the western front of the Sierra Nacimiento. Farther west, dips of the strata decrease, and sandstone-capped mesas and cuestas predominate. Geologic units in this province range in age mainly from Pennsylvanian through Cretaceous, and there are Quaternary deposits in stream valleys and on terraces. Potential aquifers in the San Juan Basin province include alluvium and terrace deposits (Quaternary), sandstone beds in the Mancos Shale (Cretaceous), the Dakota Sandstone (Cretaceous), sandstone beds in the Morrison Formation and Entrada Sandstone (Jurassic), sandstone beds in the Chinle Formation (Triassic), and various sedimentary rocks (Permian).

Sierra Nacimiento Province

The Sierra Nacimiento province lies in the west-central part of the study area on Pueblos of Jemez and Zia lands. The province is bounded by the Pajarito fault on the west and by the Jemez fault on the east (fig. 4; pl. 3). The province is the southernmost extension of the Nacimiento uplift. Bedrock in the northern part mainly is Precambrian crystalline rocks overlain by Paleozoic limestone, sandstone, and shale; bedrock in the southern part mostly is Mesozoic sandstone, shale, and some gypsum. Potential aquifers in the Sierra Nacimiento province include alluvium (Quaternary) and sandstone beds in the Chinle Formation (Triassic) in the south, various sedimentary rocks (Permian) and the Madera Limestone (Pennsylvanian) in the central part of the province, and crystalline rocks (Precambrian) in the north.

Jemez Valley Province

The Jemez Valley province is located in the eastern one-half of the study area (fig. 4). It is dominated by gently dipping, poorly consolidated strata of the Santa Fe Group (Tertiary and Quaternary) and by alluvium (Quaternary) in stream channels eroded into the Santa Fe Group. In the easternmost part of the province, volcanic rocks of the Santa Ana and Borrego Mesas overlie the Santa Fe Group. This province, which is located within the western part of the Albuquerque Basin, is bounded on the west by the Jemez fault. Several north-trending faults also displace strata of the province (pl. 3). Potential aquifers in this province are alluvium and sand and gravel of the Santa Fe Group. Volcanic rocks in the eastern part of the province also may offer some potential for ground-water supplies if conditions for a perched water table are present.

MAJOR AQUIFERS

Major aquifers as discussed in this report are defined as those geologic units that are known to be capable of producing water in large enough quantities and of sufficient quality for use as public- or irrigation-water supplies. These include only two geologic units: the alluvium along the Jemez River and the Santa Fe Group. These aquifers also can be developed for stock-water supplies.

Alluvium (Quaternary)

Geologic Characteristics

Alluvium (or valley fill) occurs in all three provinces in the banks adjacent to and in the channels of streams (pl. 3). Several stages of alluviation probably are present at various topographic levels, but two ages are particularly important; these are the older deposits in valleys that are now incised by streams and more recent deposits of modern, active channels. Arroyos in some areas are incised into bedrock resulting in discontinuous alluvial deposits. For example, in the Ojo del Espiritu Santo Grant, arroyos commonly are incised into shaly strata of the Mancos Shale and the Morrison and Chinle Formations. Alluvium is not present in these areas. In the southern part of this grant, north and northeast of Cucho Mesa, the Rio Salado has incised a gorge into solid gypsum beds of the Todilto Limestone Member of the Wanakah Formation, leaving no alluvium.

Alluvium consists of unconsolidated sediments mainly deposited by streams. Geologic characteristics (texture, color) of alluvium commonly reflect the source-rock area from which the deposits were derived. Given the large variety of bedrock types in the study area, the alluvial deposits tend to vary in texture and color from place to place; in general, alluvium tends to be much coarser grained near the mountain slopes. Locally, areas of windblown sand deposits overlie the valley fill as on the Zia and Santa Ana Pueblos along the Jemez River.

Along the Rio Puerco and upstream reaches of the Rio Salado, alluvium consists mainly of light-brown, clayey silt with fine-grained sand derived from rocks of Cretaceous age. For example, the driller's log of well RWP-1 (18.02W.36.421) (pl. 1), a stock well on the Pueblo of Jemez that is completed in the alluvium of the Rio Puerco at a depth of 74 feet, reports the material to be composed of brown clay and yellow clay with thin layers of sand. In the Rio Salado valley, various downstream color changes in the alluvium are evident as that stream flows through older deposits of the variegated shale and sandstone of the Morrison Formation, the white gypsum of the Todilto Limestone Member of the Wanakah Formation, the yellow and red sandstone of the Entrada Sandstone, and the red shale and multicolored sandstone of the Chinle Formation. A general increase in average grain size in the alluvium also is apparent where the Rio Salado has incised into rocks containing a greater percentage of sandstone and conglomerate.

Alluvium in the Ojo del Borrego Grant, which was derived from the Cochiti Formation, mainly is sand and gravel with minor silt and clay. Well Borrego 3 (16.03E.24.421) (pl. 1), a stock well on the Pueblo of Zia, is completed in the alluvium of Borrego Canyon at a depth of 56 feet. The driller's log of the well mentions sand and gravel beds with beds of "sandy shale."

Along the Jemez River valley, alluvium consists mostly of sand of various grain sizes derived principally from the Santa Fe Group; gravel also may be present locally, derived from conglomerate in the Santa Fe. Drillers' logs of wells drilled in the reach of the river between the Zia and Santa Ana Pueblos indicate mainly thick beds of sand with gravel layers. Closer to the mouth of the Rio Salado, beds of finer sand and sandy clay may be present. Because of the lithologic similarity between alluvium in the downstream part of the Jemez River valley and geologic units in the Santa Fe Group, the exact location of contacts and, therefore, thicknesses are difficult to estimate from drillers' logs; data from a test well drilled at the site of the Jemez Canyon Dam before the dam was constructed indicate a maximum thickness for alluvium at that point of 65 feet.

In more upstream reaches of the Jemez River, in the vicinity of the Jemez Pueblo, beds of gravel are more common. Two Bureau of Indian Affairs test wells, well PW-4 and well PW-3 (16.02E.16.334 and 16.02E.16.342) (pl. 1), were drilled into this alluvium. Lithologic logs of these wells indicate a predominance of coarse material (gravel and sand) with clayey fine sand and silt increasing both upwards and near the bottom; thickness of the alluvium in this area is reportedly about 85 feet (William White, U.S. Bureau of Indian Affairs, written commun., 1983).

Hydrologic Characteristics

Hydrologic characteristics of alluvium vary considerably with such factors as grain-size distribution and sorting, percentage of clay, thickness and lateral extent of the deposit, presence of layers and lenticular beds of varying lithology, and saturated thickness. In the Rio Puerco area, depths to water in alluvium generally are about 30 feet or less. The water level in the stock well on the Pueblo of Jemez, well RWP-1 (18.02W.36.421) (pl. 1), is 27 feet below land surface, and the water level in a test well drilled by the Bureau of Land Management in 1983 (sec. 7, T. 19 N., R. 1 W.) is 28 feet below land surface. Because of the fine-grained nature and layers of differing lithologies in the alluvium along the Rio Puerco and the upstream reaches of the Rio Salado, aquifer-transmissivity values and subsequent well yields would be expected to be small. For example, yield from well RWP-1 was measured at 15 gallons per minute after drilling, and that from the Bureau of Land Management test well at only 3 gallons per minute; the Bureau of Land Management well reportedly was pumped dry after only 30 minutes of testing.

Properly constructed wells in favorable locations, however, may yield larger volumes of water, according to Dames and Moore Consultants (1971) and Earth Environmental Consultants (1979). On the basis of aquifer tests performed on wells completed in the alluvium near La Ventana, Dames and Moore Consultants (1971) computed transmissivity values ranging from about 700 to

5,000 feet squared per day. Earth Environmental Consultants (1979) reported that a single well completed in the alluvium along the Rio Puerco is capable of producing a sustained yield of 150 gallons per minute and that five wells owned by Earth Resources Company near La Ventana have an average yield of 100 gallons per minute. These investigators also reported results of a 72-hour aquifer test conducted using wells completed in the alluvium along the Rio Puerco. While one well was pumped at a rate of 200 gallons per minute, drawdown and recovery were monitored in the pumped well and in four observation wells. Transmissivity was calculated to be about 2,000 feet squared per day. However, because the depositional environment of the alluvium along the Rio Puerco is nonhomogeneous, the transmissivity is variable. The permeable strata are lenticular and possibly isolated by almost impermeable clay layers. Therefore, hydrologic characteristics would be expected to be quite variable from place to place. However, transmissivity values greater than a few hundred feet squared per day probably are not representative of alluvium in the Rio Puerco valley.

In the Borrego Canyon area, depths to water in alluvium range from about 13 to 36 feet (Craigg, 1984, table 1). Only one well yield has been reported. The stock well on the Pueblo of Zia, Borrego 3 (16.03E.24.421) (pl. 1), yielded 3 gallons per minute.

Depth to water in the alluvium along the Jemez River ranges from about 3 to 55 feet, becoming deeper in the reach between the Zia and Santa Ana Pueblos. In the Jemez Pueblo area, depth to water ranges from about 3 to 15 feet. In the reach between the Zia and Santa Ana Pueblos, depth to water generally is less than 30 feet, but ranges from about 4 to 55 feet depending on distance from the streambed (Craigg, 1984, table 1).

Hydrologic characteristics of alluvium along the Jemez River vary with distance downstream probably as a function of median grain size. For example, transmissivity is greater and well yields are larger in the vicinity of Jemez Pueblo where the alluvium consists of a greater percentage of coarse sand and gravel; in the reach between the Zia and Santa Ana Pueblos, alluvium contains less gravel and larger quantities of clay and fine sand derived from the Rio Salado drainage basin.

In 1982, a 39-day aquifer test, using 2 discharging wells and 17 observation wells, was conducted in the alluvium along the Jemez River near the Jemez Pueblo; well PW-3 (16.02E.16.342) (pl. 1) was pumped at a rate of 350 gallons per minute, and well PW-4 (16.02E.16.334) (pl. 1) was pumped at a rate of 500 gallons per minute. This test was conducted by personnel from the U.S. Bureau of Indian Affairs; results of the test and calculation of aquifer coefficients were given in an informal report (William White, written commun., 1983). The major conclusions of this report are summarized below. Water in the alluvium in this area is under semiconfined conditions; thickness of the water-yielding zone is 45 feet and that of the semiconfining layer is 30 feet; width of the aquifer is 2,200 feet. The alluvial aquifer is hydraulically connected to the Jemez River, and the effect of pumping on the streamflow (streamflow depletion) during the test was 0.5 to 0.8 cubic foot per second. Values of transmissivity obtained ranged from about 4,000 to 5,500 feet squared per day, and the storage coefficient obtained was about 5 x 10^{-4}. The value computed for storage coefficient may be small because storage coefficients for unconfined aquifers commonly range from about 0.02 to 0.3 (Fetter, 1980, p. 97). The underlying Zia Sand has a higher hydraulic head and leaks water into the alluvium. Specific capacities of the two pumped wells, PW-3 and PW-4 (16.02E.16.342 and 16.02E.16.334), were 27 and 9 gallons per minute per foot of drawdown, respectively. Yields of several hundred gallons per minute and only a few feet of drawdown could be possible in this area with properly constructed wells.

Yields from wells completed in alluvium of the southeastern part of the Jemez River valley would be expected to be smaller because of smaller transmissivity values resulting from finer grained sediments and thinner saturated thickness. Well yields of as much as several tens of gallons per minute, however, might be possible. An irrigation test well near San Ysidro, Irr test-2 (15.02E.06.222b) (pl. 1), reportedly was pumped at a rate of 60 gallons per minute. An abandoned well on the Pueblo of Santa Ana, known as the Jemez Windmill (14.03E.06.423) (pl. 1), reportedly yielded 10 gallons per minute. A test well at Jemez Canyon (sec. 31, T. 14 N., R. 4 E.) was pumped at a rate of 25 gallons per minute with 11 feet of drawdown. Specific capacity of this well was 2.3 gallons per minute per foot. Presumably, no aquifer tests have been conducted in the alluvium in the southeastern part of the Jemez River valley, but, assuming a hydraulic conductivity of 13.4 feet per day (based on the values compiled in Davis and DeWiest, 1966) and a saturated thickness of 50 feet, a transmissivity of about 700 feet squared per day probably would be a reasonable estimate.

At least four springs apparently issue from alluvium in stream channels incised into the Aqua Zarca Sandstone Member of the Chinle Formation (Craigg, 1984, table 2). Vallecito Spring "2" (16.02E.11.232) (pl. 2) on the Pueblo of Jemez issues from alluvium in Vallecito Creek at the rate of 5 gallons per minute (Trainer, 1978). Three other springs on the Pueblo of Zia part of the Ojo del Espiritu Santo Grant apparently are associated with alluvium in Cuchilla Arroyo although the Chinle Formation also may contribute to flow; discharge of these springs is not known. Thompson Spring (18.01W.14.112) (pl. 2) on the Pueblo of Jemez part of the Ojo del Espiritu Santo Grant issues from alluvium in Arroyo Dedos Gordos at the rate of 1.25 gallons per minute. Cachana Spring (17.01W.36.243) (pl. 2) on the Pueblo of Zia in Cachana Arroyo was dry when visited in June 1984. Another spring (unnamed) associated with alluvium on the Pueblo of Jemez (16.02E.30.323) (pl. 2) issues just east of the Jemez fault. Discharge of water was estimated at less than 1 gallon per minute.

Water Quality

Water from alluvium in the study area generally ranges from fresh to moderately saline. (The salinity classification of Swenson and Baldwin, 1965, is used in this report; this classification defines water-quality terms on the basis of dissolved-solids concentration, in milligrams per liter, as follows: fresh = less than 1,000; slightly saline = 1,000-3,000; moderately saline = 3,000-10,000; very saline = 10,000-35,000; brine = greater than 35,000.) Although the water quality is variable and somewhat unpredictable, some generalizations can be made. Areal variations in water quality are apparent; these areal variations generally coincide with a particular stream valley and also may coincide with distance downstream in a stream valley. Areal variations also are related to lithologic composition of the alluvium and quality of the recharge water.

Water in the alluvium along the Rio Puerco is slightly saline. The specific conductance of water from the stock well on the Pueblo of Jemez, well RWP-1 (18.02W.36.421) (pl. 1), was 2,600 microsiemens (microsiemens per centimeter at 25 degrees Celsius). Water from wells completed in the alluvium along the Rio Puerco just north of the study area near La Ventana (T. 19 N., R. 1 W.) had a specific conductance of about 2,200 microsiemens (Earth Environmental Consultants, 1979), contained about 1,450 to 1,850 milligrams per liter dissolved solids, and was a sodium or calcium sulfate type. Water from a test well drilled by the U.S. Bureau of Land Management in alluvium near La Ventana had a specific conductance of 3,300 microsiemens, contained 2,160 milligrams per liter dissolved solids, and was of a mixed sodium calcium sulfate bicarbonate chloride type. Water from alluvium in the northern part of the Rio Salado valley could be expected to be similar in quality to that from the alluvium along the Rio Puerco because of similar lithology and quality of recharge water.

In the southern part of the Rio Salado valley, water in the alluvium is more mineralized than that in alluvium elsewhere in the study area. Water from an abandoned well on the Pueblo of Zia land south of the Rio Salado near the Jemez River confluence (15.01E.13.422) (pl. 1, fig. 5) reportedly had a specific conductance of 23,000 microsiemens and a sodium-adsorption ratio (SAR) of 56. Water from an abandoned test well on the Pueblo of Zia land in Arroyo Piedra Parada (15.02E.19.142) (pl. 1, fig. 5) had a specific conductance of 4,500 microsiemens. An irrigation test well was drilled on the Pueblo of Zia land in the San Ysidro Grant along the east bank of the Jemez River, Irr test-2 (15.02E.06.222b) (pl. 1, figs 5). Two conflicting values of specific conductance exist, one for a sample collected in March 1954 and the other for a sample collected in April 1954; a chemical analysis is available for this sample. The March 1954 data included a specific conductance of 1,290 microsiemens (Craigg, 1984, table 1). The April 1954 analysis included a specific conductance of 5,920 microsiemens, a dissolved-solids concentration of 3,680 milligrams per liter, and a SAR of 21; the water was of a sodium bicarbonate chloride type (Craigg, 1984, table 3). Upward leakage of more mineralized water from deeper bedrock units may account for the results of the later sample because this chemical analysis is almost identical to those for water from Indian Spring (16.02E.29.142) (pl. 2) and Salt Spring (16.02E.20.331) (pl. 2), which issue from the Madera Limestone (Pennsylvanian), and possibly the Abo and Yeso Formations (Permian) about 3 miles upstream.

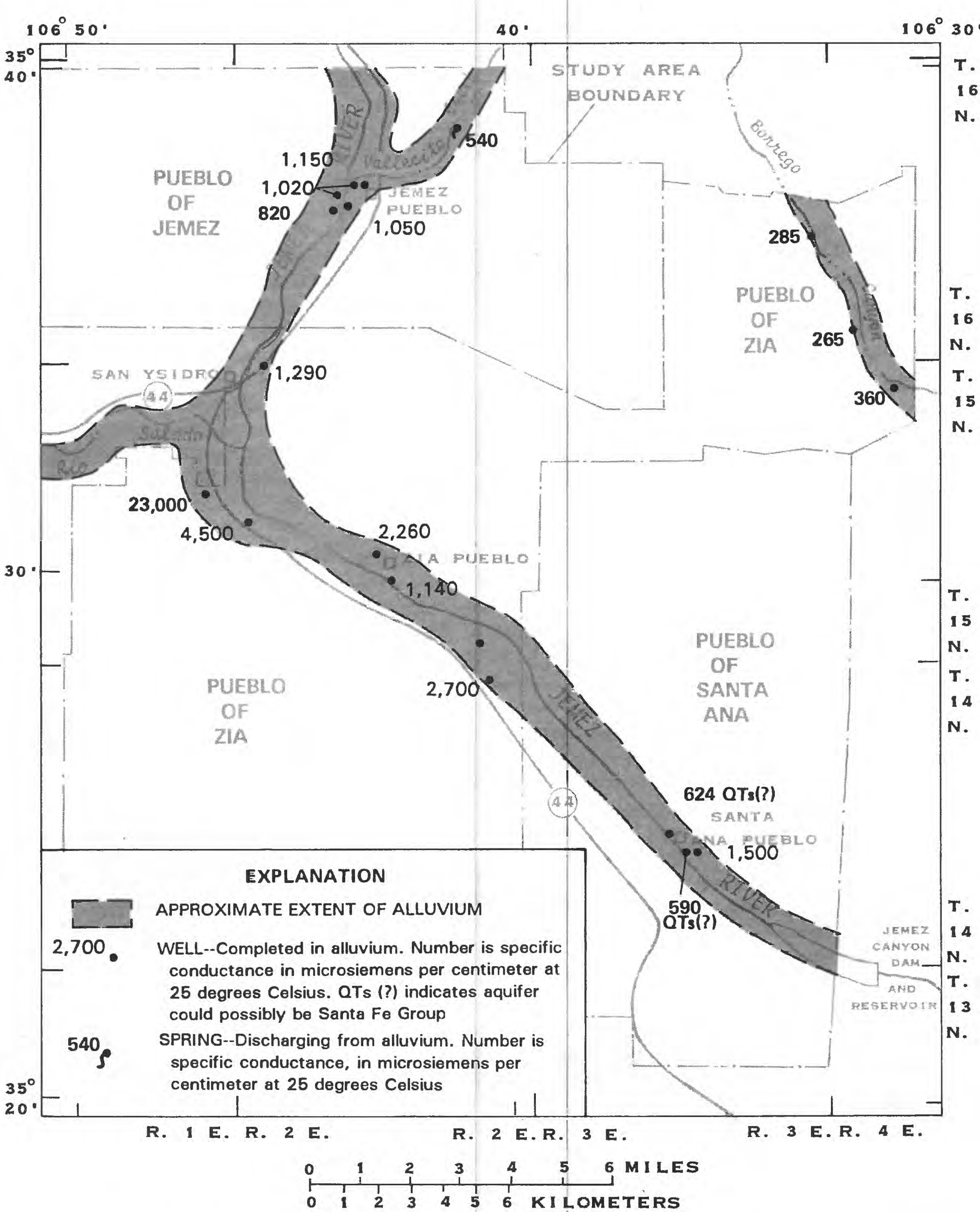


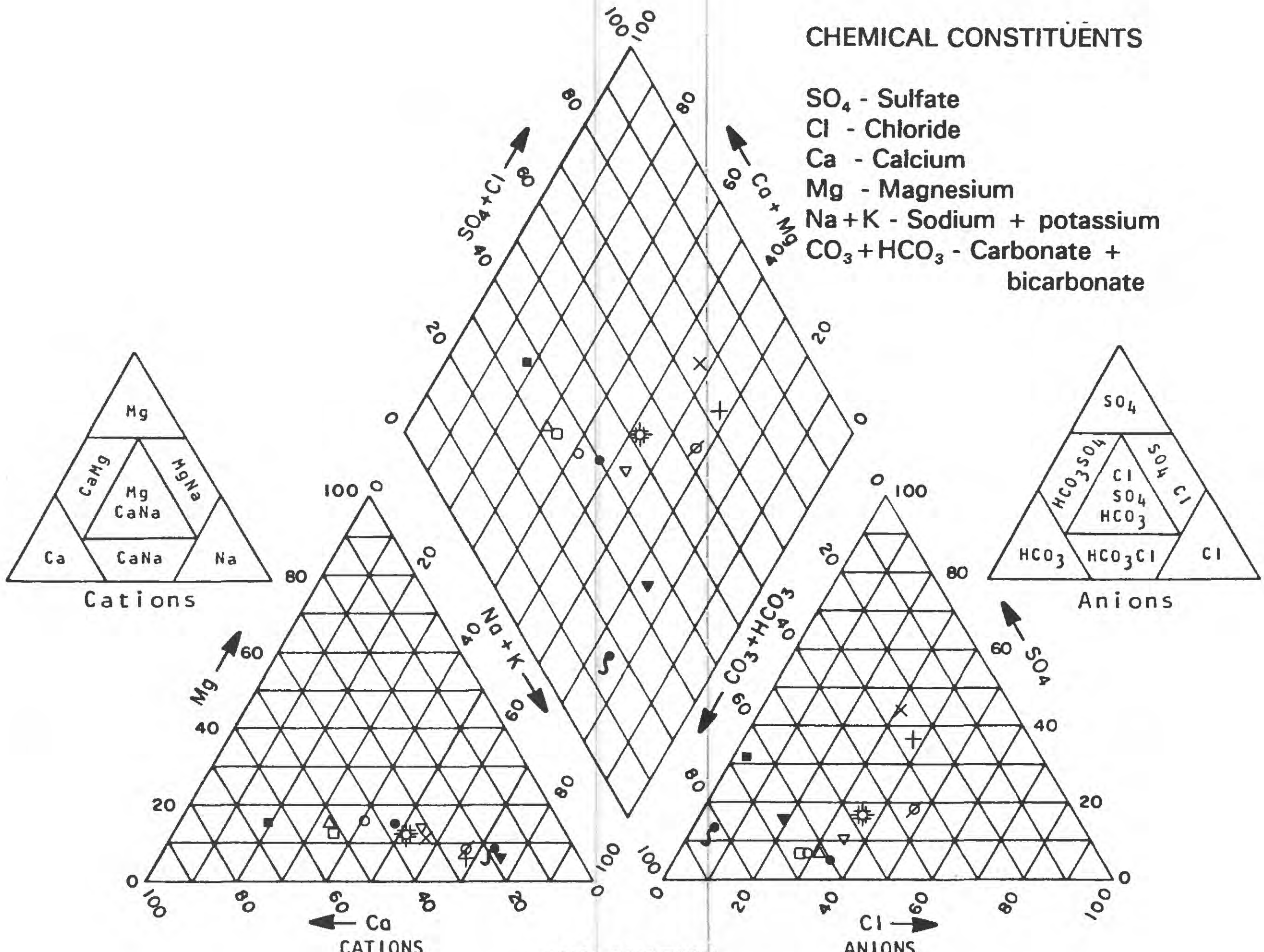
Figure 5.--Specific conductance of water from the alluvium along the Jemez River, Rio Salado, Vallecito Creek, and Borrego Canyon (see Craigg, 1984, tables 3 and 5 for chemical analyses).

Water from alluvium in the Ojo del Borrego Grant is fresh, as indicated by water from two Pueblo of Zia stock wells, Borrego 1 (15.04E.05.143) (pl. 1, fig. 5) and Borrego 3 (16.03E.24.421) (pl. 1, fig. 5). Values of specific conductance of water from these wells were 360 and 285 microsiemens, respectively.

Water in the alluvium along the Jemez River generally ranges from fresh to slightly saline. Although quality is variable, in general the specific conductance and dissolved-solids concentration tend to increase downvalley toward the southeast, especially in the reach downstream from the confluence with the Rio Salado (fig. 5). Water is less mineralized in the upstream areas. For example, in the Jemez Pueblo area, specific conductance ranged from 820 to 1,150 microsiemens, dissolved-solids concentrations ranged from 514 to 756 milligrams per liter, and the water was a sodium calcium bicarbonate type (fig. 6); the water also contained large concentrations of potassium, chloride, and silica (Craigg, 1984, table 3). SAR values were small, ranging from 2.1 to 3.6. In the downstream reaches in the Zia and Santa Ana Pueblo areas, specific conductance of water in alluvium was larger, ranging from 1,110 to possibly as large as 23,000 microsiemens near the Rio Salado confluence (fig. 5); dissolved-solids concentrations generally ranged from 914 to 1,350 milligrams per liter for water samples collected along the Zia-Santa Ana Pueblo reach. These water samples plot in the mixed sodium chloride bicarbonate field (fig. 6); SAR values of generally less than 10 are likely from water in alluvium between the Zia and Santa Ana Pueblos.

The effect of inflowing saline surface and ground water from the Rio Salado area on ground-water quality in alluvium of the southeastern part of the Jemez Valley can be seen in figures 5 and 6. The water-quality type shifts from the calcium sodium and bicarbonate fields toward the sodium and sulfate fields (fig. 6). The distribution of specific conductance (fig. 5), although no definite trend is apparent, shows that values consistently are larger downstream from the confluence of the Rio Salado. This is because of the combination of saline recharge water from the Rio Salado-Arroyo Peñasco drainages and discharge of southeast-flowing saline ground water from both the Rio Salado alluvium and deeper bedrock units in the San Juan Basin. Concentration of salts in the alluvium because of evapotranspiration by phreatophytes also may increase the salinity of ground water in this area.

Chemical analyses of trace metals in water from the alluvium are available only from the Jemez Pueblo area. Values for arsenic ranged from 9.9 to 24.1 micrograms per liter, those for barium ranged from 224 to 490 micrograms per liter, those for boron ranged from less than 50 to 1,240 micrograms per liter, those for iron ranged from 20 to 600 micrograms per liter, and those for manganese ranged from 270 to 750 micrograms per liter; other trace-metal concentrations in water from alluvium in this area are in Craigg (1984, table 4). Randall Willard (Environmental Engineer, U.S. Indian Health Service, written commun., 1984) reported that the arsenic concentration in water from well IHS-2 has increased to more than 50 micrograms per liter during the past 5 years since it was first drilled in 1979. The water-quality standard of 50 micrograms per liter set by the U.S. Environmental Protection Agency (1976, table 12) for public supplies is exceeded by the arsenic concentration in water from this well; this water presently is being mixed with water from well IHS-1 to decrease the arsenic concentrations to less than 50 micrograms per liter. The large arsenic concentration in ground water in this area could be caused by the combination of natural and pumping-induced upward leakage of water from deeper bedrock units of Permian and Pennsylvanian age.



EXPLANATION

WATER FROM:

PUEBLO OF JEMEZ

- • Well PW-3
- ○ Well PW-4
- □ Well IHS-1
- △ Well IHS-2
- ▽ BIA observation well lwt
- Vallecito Spring "2" (Chinle Formation also may be source)

PUEBLO OF ZIA

- ø School dug well
- + Galvan dug well
- × Well 14N.03E.22.323
- ■ Cuchilla Spring "3"
- ▼ Cachana Spring

Average of analyses, excluding Vallecito Spring "2", Cuchilla Spring "3", and Cachana Spring. The Chinle Formation also may contribute water to these springs

Figure 6.--Trilinear plot of major dissolved consituents in water from the alluvium. Small triangles at sides give key to classification (see Craigg, 1984, tables 3 and 5 for chemical analyses).

Chemical analyses of water from springs issuing from or associated with alluvium are available from Vallecito "2", Cachana, and Cuchilla "3" Springs (Craigg, 1984, table 5). Water from the Vallecito Spring "2" (16.02E.11.232) (pl. 2) had a specific conductance of 540 microsiemens, a dissolved-solids concentration of 324 milligrams per liter, and was a sodium bicarbonate type (fig. 6); a partial trace-metal analysis also is available for water from this spring (Craigg, 1984, table 6). Water from the Cachana Spring (17.01W.36.243) (pl. 2) was analyzed in 1946 (Craigg, 1984, table 5) and reportedly had a specific conductance of 1,130 microsiemens, contained 674 milligrams per liter dissolved solids, and was a sodium bicarbonate type (fig. 6). Water from the Cuchilla Spring "3" (16.01E.19.114) (pl. 2) reportedly contained 396 milligrams per liter dissolved solids, was a calcium bicarbonate type (fig. 6), and contained 300 micrograms per liter of iron (Craigg, 1984, table 6).

Water from an unnamed spring on the Pueblo of Jemez (16.02E.30.323) (pl. 2) had a specific conductance of 3,190 microsiemens, contained 2,350 milligrams per liter dissolved solids, and was a mixed sodium calcium sulfate chloride bicarbonate type. The large chloride concentration of 410 milligrams per liter and the similarity of this chemical analysis with that from the Blue Water Spring (16.01E.25.422) (pl. 2) indicate that the source of this spring also may be upward leakage of water from deeper units, possibly the Chinle Formation. A partial analysis of trace metals in water from this spring also is available (Craigg, 1984, table 6).

Sand and Gravel in the Santa Fe Group and Related Strata (Quaternary and Tertiary)

Geologic Characteristics

Because of similar depositional environments and lithologies, uncertain stratigraphic relations, probable hydraulic connection, and similar hydrologic properties, the Zia Sand, Santa Fe Group (or Formation), and Cochiti Formation are combined in this report. The units form a single aquifer herein referred to as the Santa Fe aquifer.

Basal strata comprising the Santa Fe aquifer unconformably overlie rocks of Permian through Cretaceous age in the study area (fig. 3, pl. 3). The Santa Fe Group is the principal geologic unit exposed in the Jemez Valley province from Jemez Pueblo toward the east, southeast, and south (pl. 3). The northwestern extent of the interval is represented by the Zia Sand, which crops out just west and north of Jemez Pueblo. West of the pueblo, the Zia Sand is downfaulted against rocks of Pennsylvanian through Triassic age by a major fault through San Diego Canyon known as the Jemez fault. The Zia Sand, which also subcrops beneath the Jemez River in the vicinity of the pueblo, is covered by alluvial deposits. The Santa Fe Group extends southward to the eastern base of White Mesa, eastward beneath Borrego Mesa, and southeastward beneath the basalt flows of Santa Ana Mesa (pl. 3). The whitish and buff-colored cliffs along State Highway 44 between the Zia and Santa Ana Pueblos are outcrops of typical Santa Fe Group strata. The Zia and Santa Ana Pueblos are built on Santa Fe Group outcrops.

Sediments comprising the Santa Fe aquifer were deposited in a variety of continental environments, including alluvial fans, rivers and flood plains, sand dunes, and lakes. Alluvial-fan and river deposits probably are the most common types of sediments.

Examination of drillers' logs from stock wells drilled into the Santa Fe aquifer in the study area (Craigg, 1984, table 1) gives an indication of the general nature of the unit. These logs mainly report thick layers of buff, gray, and red sand with thinner beds of red and gray clay, silt, gravel, and boulders.

Various detailed studies of the Santa Fe Group have been done, and nomenclature of the unit is continually being revised. The following lithologic descriptions have been summarized mainly from reports by Renick (1931), Maxwell (1960), Spiegel (1961), Griggs (1964), Smith and others (1970), and Manley (1978).

Renick (1931) commented on the variable lithologic character of Santa Fe Group beds in the area. He described the unit as mostly white sand near the Jemez Pueblo and reported at least 1,500 feet of alternating beds of sand, conglomerate, and sandy shale at Santa Ana Mesa (pl. 3). For the broad Jemez River valley east of San Ysidro, he reported alternating lenticular beds of conglomerate, sand, sandstone, and sandy shale, mostly light tan. Maxwell (1960) reported that in the Zia Pueblo area, the Santa Fe Group generally consists of about 1,000 feet of loosely consolidated brown to gray arkosic sand that locally contains beds of gravel, silt, and clay.

Spiegel (1961) described three unnamed subdivisions within Santa Fe Group strata, which he designated as the lower formation, upper formation, and uppermost gravel. The lower formation consists of a thick, light-tan, poorly cemented sandstone overlain by red mudstone, reddish-brown sandstone, and red silty conglomerate. This unit thickens between the Zia Pueblo and the Santa Ana Mesa. The upper formation consists of alluvial-fan sand and gravel containing red granite pebbles and basalt boulders. The uppermost gravel, about 30 feet thick, consists of coarse sand and gravel capping the high plains west of the Rio Grande. He reported that west of the Zia Pueblo area, Santa Fe Group sediments represent erosional debris from the Sierra Nacimiento-western Jemez Mountains area; toward the east, the sediments represent material eroded from rocks east of the Rio Grande.

Smith and others (1970) described formations that herein are included in the Santa Fe aquifer; in ascending order, these are the Zia Sand, Santa Fe Formation, and Cochiti Formation. They reported the Zia Sand to be as much as 1,000 feet thick and to consist of poorly consolidated, light-gray to yellow, greenish- and pinkish-gray arkosic sands that are locally crossbedded and that contain calcareous ledges and silica ash in the upper part. They described the Santa Fe Formation as consisting of as much as 5,000 feet or more of poorly consolidated, buff, red, or gray arkosic sand with silt, clay, or pebble beds. The Cochiti Formation was described as possibly as much as 1,500 feet of poorly consolidated gravel and sand composed of volcanic and granitic detritus.

In 1972, the Shell Oil Co. drilled an 11,000-foot-deep test hole about 6 miles south of the Jemez River near the southern boundary of the Pueblo of Santa Ana (sec. 18, T. 13 N., R. 3 E.). This test well, known as the Santa Fe Pacific No. 1, was spudded in the Santa Fe Formation. The well reportedly penetrated 2,800 feet of Santa Fe Formation and 170 feet of Zia Sand (Hiss and others, 1975).

Hydrologic Characteristics

The areal distribution of depth to the water table in the Santa Fe aquifer is shown in figure 7. The water-table surface slopes gradually south and southeast at less than 2 degrees. Depths to water, therefore, are dependent on topographic expression; for example, on Santa Ana Mesa and near Loma Creston in the Ojo del Borrego Grant, depths to the water table are as great as 1,100 feet (fig. 7). In canyon bottoms and stream valleys, depths to water are much less, ranging from 5 feet west of the Jemez Pueblo to about 100 feet northwest and southeast of the Zia Pueblo (fig. 7).

Reported yields of wells completed in the Santa Fe aquifer vary, ranging from 3 to 30 gallons per minute; most of these wells are stock wells, and the yields are those reported by the driller during short-term bailing tests. The two public-supply wells at the Zia Pueblo are completed in the Santa Fe aquifer. The main public-supply well (15.02E.22.414a) (pl. 1) is 320 feet deep, the producing interval is between the depths of 260 and 297 feet, and the static water level is 150 feet; the standby well (15.02E.22.414b) (pl. 1) is 323 feet deep, the producing interval is between the depths of 271 and 297 feet, and the static water level is 148 feet (Craigg, 1984, table 1). The yields of these wells are 34 and 18 gallons per minute, respectively (Randall Willard, written commun., 1983). A short-term aquifer test was conducted on the standby well in 1960. The well was pumped for 55 minutes at rates ranging between 27.5 and 55 gallons per minute, with 139 feet of water-level drawdown; pumping was continued for 4.25 hours at a rate of 28.2 gallons per minute, the drawdown stabilizing during the entire period at 139 feet below the static level. The water level reportedly recovered to static level in 16 minutes (Randall Willard, written commun., 1983).

Although hydraulic properties of the Santa Fe aquifer are not known within the study area proper, reasonable estimates can be made by using results of previous investigations in surrounding areas. In a study of the Los Alamos area, Griggs (1964) reported that the hydraulic conductivity for various units in the Santa Fe aquifer ranged from 0.7 to 13.4 feet per day. The transmissivity reportedly ranged from 350 to 2,100 feet squared per day; the specific capacity of wells ranged from 5 to 7 gallons per minute per foot of drawdown. Griggs (1964) also reported results of a 13-day aquifer test conducted in the Santa Fe aquifer. The pumping rate during this test was 525 gallons per minute, and the drawdown was 110 feet. The specific capacity was calculated to be 5 gallons per minute per foot of drawdown. Transmissivity calculations ranged from 1,000 to 3,300 feet squared per day, the average being 2,000 feet squared per day.

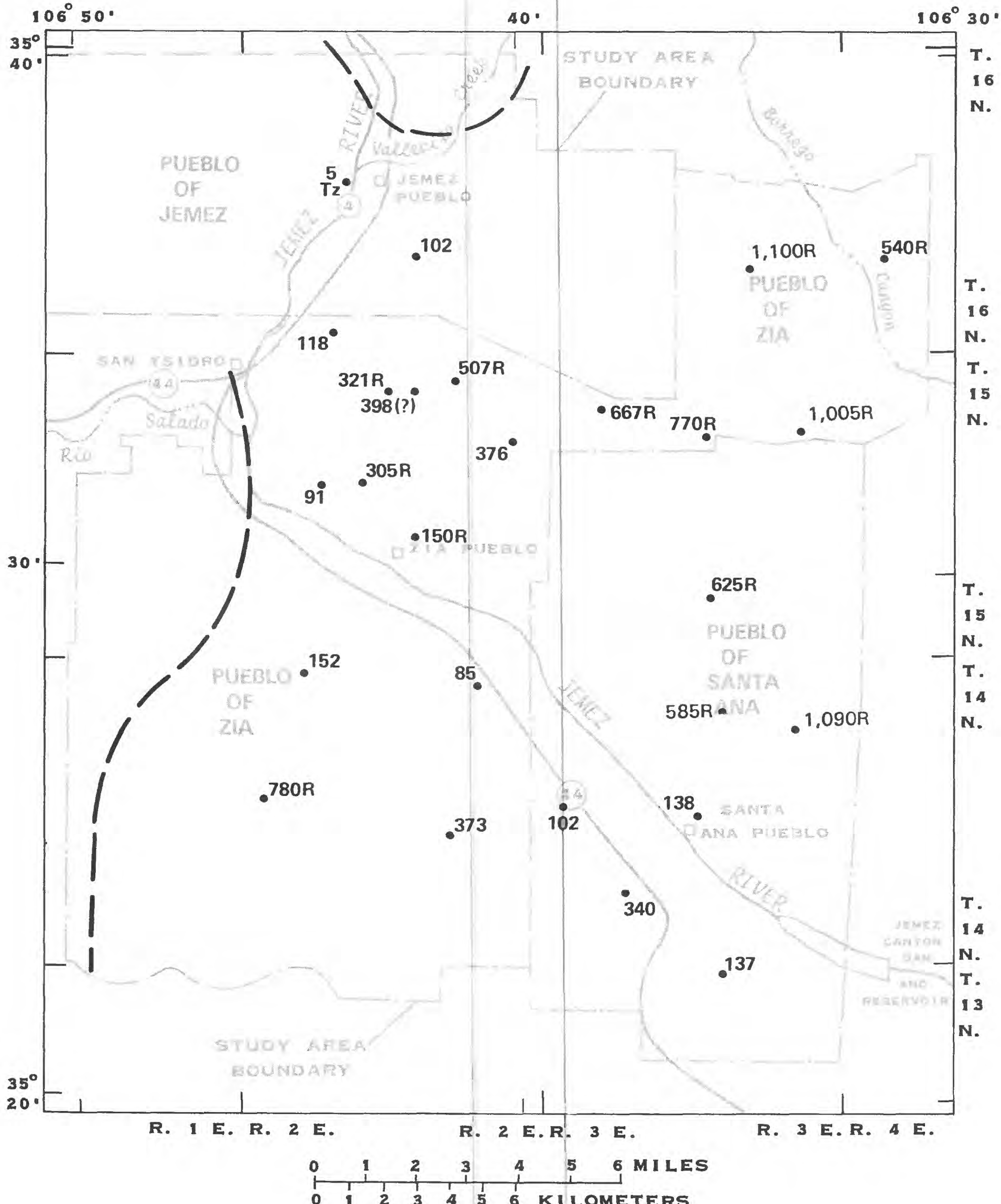


Figure 7.--Depth to water in the Santa Fe aquifer (data from Craigg, 1984, table 1).

The U.S. Geological Survey is conducting digital-model simulations on parts of the Santa Fe aquifer in the Albuquerque Basin. Assuming strata comprising the Santa Fe aquifer are lithologically similar in the study area, a hydraulic conductivity of 2 feet per day probably would be a reasonable minimum value and 10 feet per day a reasonable maximum value (J.M. Kernodle, U.S. Geological Survey, oral commun., 1984).

A possible range of specific-yield values for the Santa Fe aquifer in this area was estimated by using a technique devised by Johnson (1967). In this method, known specific yields for a particular sequence of deposits are listed along with drillers' general descriptions of those same deposits. By applying this matching technique to drillers' logs of sediments from the Santa Fe aquifer in the study area, a range for specific yield of about 5 to 20 percent is obtained.

The Santa Fe aquifer probably is nonhomogeneous and anisotropic in nature because of the various laterally extensive depositional systems in the aquifer. The strata vary greatly in thickness, extent, and lithologic character both laterally and vertically. Therefore, ground-water conditions in this aquifer would be expected to vary in different parts of the study area and at different stratigraphic positions.

At least four springs, all of which are on the Pueblo of Jemez lands, are known to issue from the Santa Fe aquifer (Craigg, 1984, table 2, pl. 2). Vallecito Spring "3" (16.02E.11.442) (pl. 2) issues from the Zia Sand south of Vallecito Creek at a rate of about 0.25 gallon per minute. Three other springs (pl. 2) issue from the Santa Fe Formation--an unnamed spring at 16.03E.20.412, an unnamed spring at 16.03E.29.342, and the Ojo Chamisa Spring (16.03E.29.344). Discharge of water from the Ojo Chamisa Spring was estimated at less than 1 gallon per minute (Trainer, 1978).

EXPLANATION

APPROXIMATE LIMIT OF SANTA FE GROUP AND RELATED STRATA

118 WELL--Completed in Santa Fe aquifer. Number is depth to water, in feet below land surface, rounded to the nearest foot. Tz indicates Zia Sand. R indicates a reported water level. (?) indicates a questionable water level

Water Quality

Water from the Santa Fe aquifer generally is fresh and probably is the best quality water available in the study area. Specific conductance of water from the Santa Fe aquifer generally is less than 800 microsiemens and commonly is less than 500 microsiemens (dissolved-solids concentrations of about 550 and 350 milligrams per liter, respectively). Specific conductance is least, less than 300 microsiemens, principally in the northeastern part of the Pueblo of Zia and in the northeastern one-third of the Pueblo of Santa Ana (fig. 8). Specific-conductance values tend to increase toward the Jemez River. Values are largest in a band approximately paralleling the Jemez River, ranging from about 600 to 2,250 microsiemens (fig. 8). The most mineralized water is from a stock well on the Pueblo of Santa Ana--well RWP-1 (14.03E.18.433) (pl. 1)--on the south side of the river; this water had a specific conductance of 2,250 microsiemens (dissolved-solids concentration of about 1,600 milligrams per liter). Southwest of this band along the river, specific conductance again decreases (fig. 8).

In the vicinity of the Zia Pueblo and extending southeastward for several miles, the band of most mineralized water generally is within the area where the depth to water in the Santa Fe aquifer is less than 100 feet (compare figs. 7 and 8). This band of most mineralized water may reflect some recharge of slightly saline water from the alluvium (compare figs. 5 and 8) if there is hydraulic connection between the alluvium and the Santa Fe aquifer.

EXPLANATION

SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS

>indicates value greater than that shown

200-300

300-600

600-800

>800

No data

APPROXIMATE LIMIT OF SANTA FE GROUP AND RELATED STRATA

520• WELL--Completed in Santa Fe aquifer. Number is specific conductance, in microsiemens per centimeter at 25 degrees Celsius. Tz indicates Zia Sand

495 SPRING--Discharging from Santa Fe aquifer. Number is specific conductance, in microsiemens per centimeter at 25 degrees Celsius

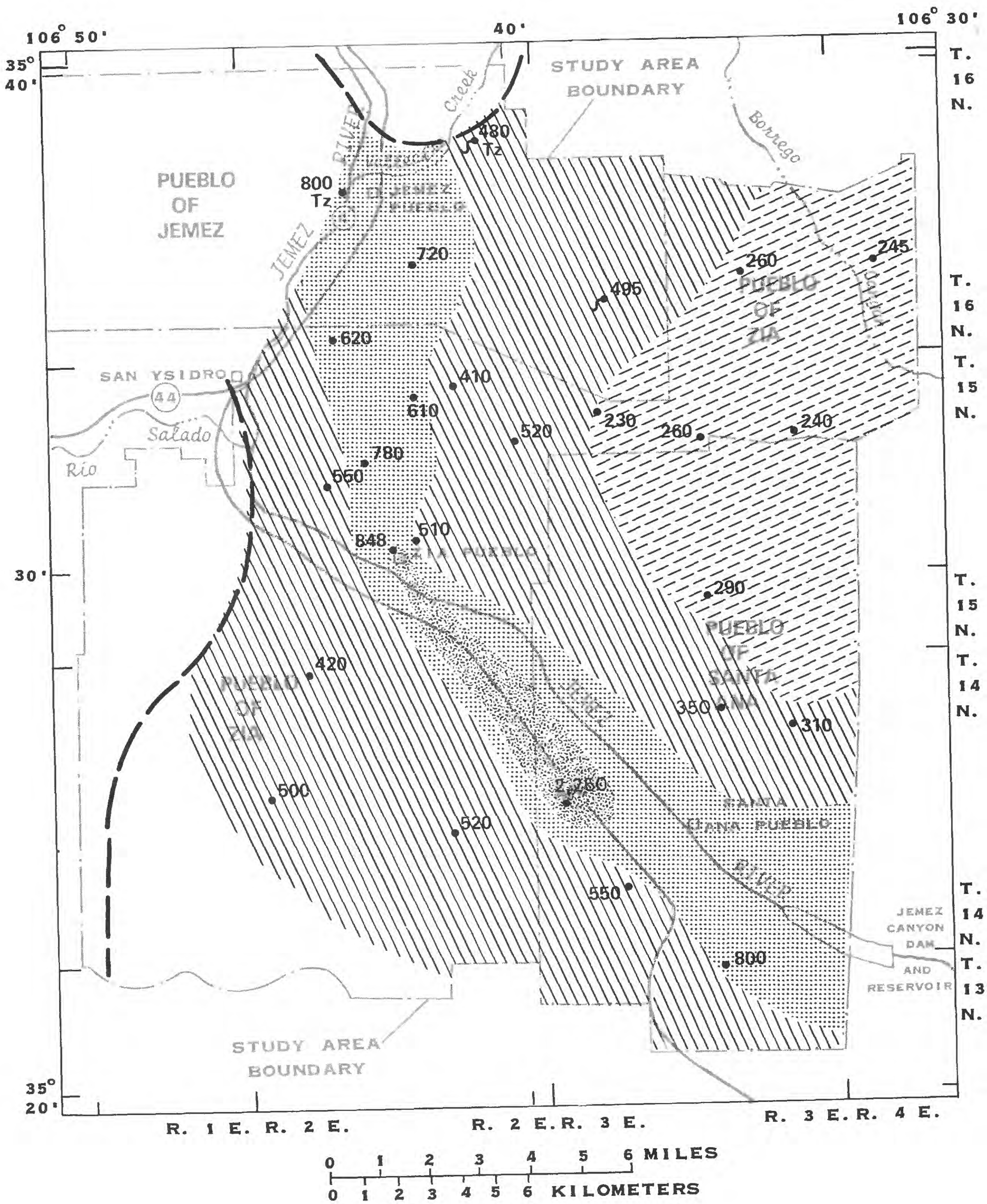


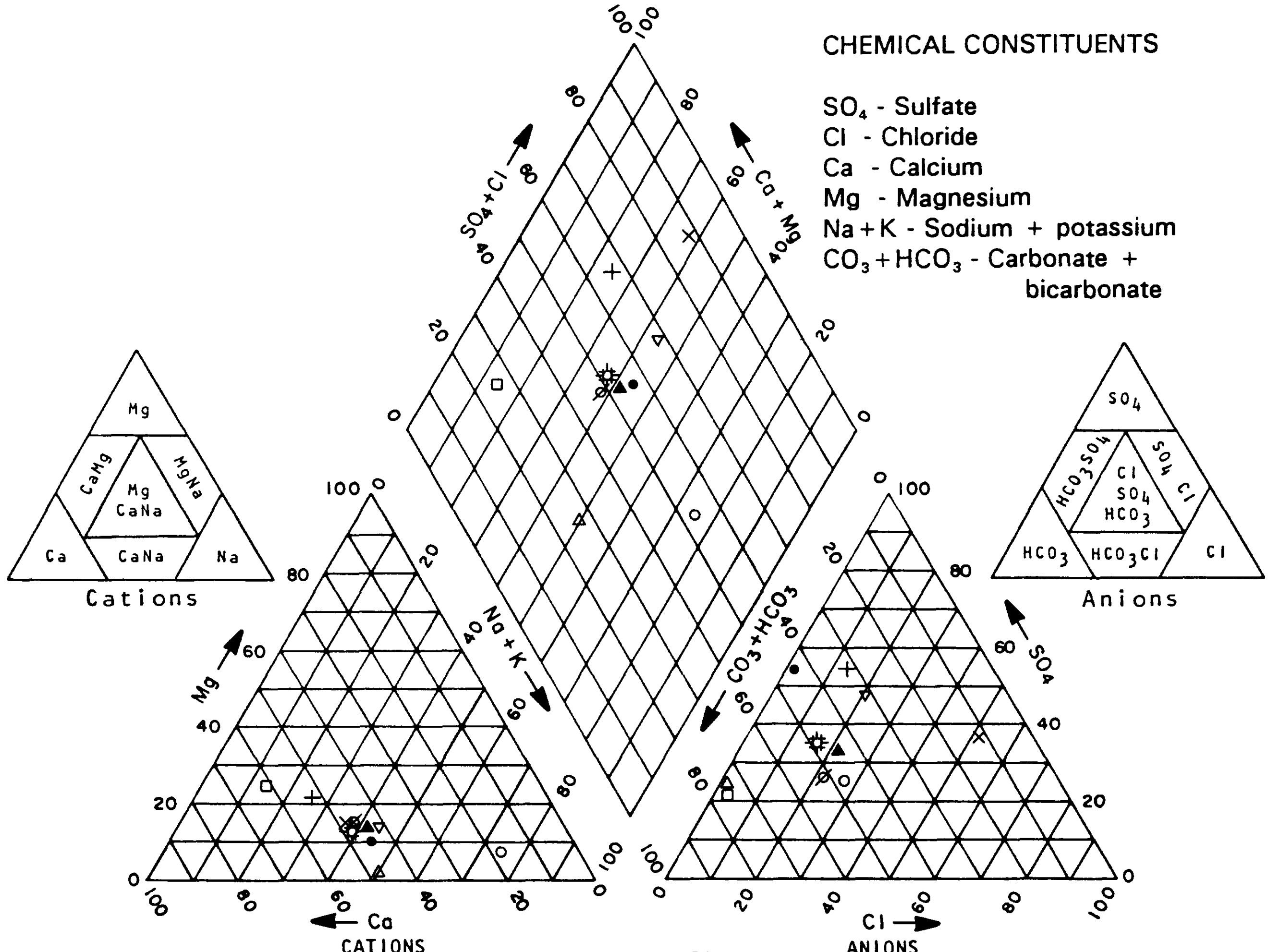
Figure 8.--Specific conductance of water from the Santa Fe aquifer (see Craigg, 1984, tables 3 and 5 for chemical analyses).

Water-quality types from the Santa Fe aquifer are mixed (fig. 9). The water from the Santa Fe aquifer generally is a calcium sodium bicarbonate sulfate type. However, water from stock well RWP-1 is a sodium calcium chloride sulfate type, and water from the Zia Sand (BIA observation well Iz; 16.02E.16.332b on pl. 1) is a sodium bicarbonate chloride sulfate type.

Values of SAR are small, ranging from 1.1 to 3.7. No areal distribution is apparent. The larger value is from stock well RWP-1.

Partial trace-metal analyses of water from the Santa Fe aquifer are available (Craigg, 1984, table 4). Reported concentrations generally do not exceed water-quality criteria set for various uses (tables 7, 8, 10, and 12, located at the end of the text). However, three analyses indicated iron concentrations of 1,700, 2,600, and 3,700 micrograms per liter, all of which exceed the recommended standard of 300 micrograms per liter set for iron in public-water supplies (U.S. Environmental Protection Agency, 1976). Whether or not these iron concentrations are representative of formation water is not known because dissolved iron also can be introduced by iron-oxidizing bacteria on well casings. Water from the standby well at the Zia Pueblo (15.02E.22.414b) (pl. 1) reportedly contained 910 micrograms per liter of boron and 60 micrograms per liter of manganese, both of which exceed water-quality criteria set for those ions (tables 7, 8, 10, and 12).

Regionally, water from the Santa Fe aquifer is less mineralized than that from all other potential aquifers in the study area. Whether or not dissolved-solids or specific-ion concentrations increase with depth is not known because most wells in the area generally penetrate less than 100 feet below the water table in the Santa Fe aquifer. Some increase in dissolved-solids concentrations with depth, however, would be expected. Hiss and others (1975) reported general water-quality data for water from the Santa Fe aquifer in the Shell Oil Co.'s test hole Santa Fe Pacific No. 1. Dissolved-solids concentrations gradually increased from 400 milligrams per liter near the top of the water table to 8,000 milligrams per liter near the bottom of the aquifer.



EXPLANATION

WATER FROM:

PUEBLO OF JEMEZ

- ● Stock well 1
- ○ BIA observation well Iz (completed in Zia Sand)

PUEBLO OF ZIA

- □ Well RWP-4
- △ Well RWP-3
- ▽ "Proposed" domestic well
- ▲ Main public-supply well
- ø Standby well

PUEBLO OF SANTA ANA

- + Perea well
- × Well RWP-1

☼ Average of analyses

Figure 9.--Trilinear plot of major dissolved constituents in water from the Santa Fe aquifer. Small triangles at sides give key to classification (see Craigg, 1984, table 3 for chemical analyses).

MINOR AQUIFERS

Minor aquifers as discussed in this report are defined as those geologic units that generally will not yield water in sufficient quantities or of suitable quality to be used for public- or irrigation-water supplies. The water-resource potential of these aquifers generally is limited to stock-water supplies.

Terrace Deposits (Quaternary and Late Tertiary)

Geologic Characteristics

Terrace deposits principally occur along the western margin of the Sierra Nacimiento in the San Juan Basin province (pl. 3). These deposits cap hills and ridgetops and sometimes form mesalike landforms in upland reaches of westward-flowing drainages such as the Arroyos Dedos Gordos, Veguita Blanca, and Lopez and the Rito Olguin. Extensive exposures of terrace deposits are located east of State Highway 44, on the Pueblo of Jemez, between Arroyo Semilla and the northern boundary of the study area (pl. 3).

These deposits consist of poorly sorted erosional debris including: bouldery gravel with clasts of Precambrian, Paleozoic, and Mesozoic rocks; stream-laid gravel and sand; and silt and clay. The average grain size probably decreases with distance from the mountain front.

These sediments were deposited on the beveled eroded surfaces of Precambrian, Paleozoic, and Mesozoic rocks. Although the deposits were once much more laterally extensive, erosion has dissected the terraces in most places to expose the older sedimentary, igneous, and metamorphic rocks below. Woodward and Schumacher (1973b) estimated that the thickness of the terrace deposits may be as much as 30 feet, and Anderholm (1979) reported that similar deposits on the northernmost margins of the Sierra Nacimiento are as much as 110 feet thick. Drill-hole data from a stock well on the Pueblo of Jemez, well RWP-7 (18.01W.14.111) (pl. 1), near Thompson Spring indicate a terrace-deposit thickness of 85 feet.

Hydrologic Characteristics

One stock well on the Pueblo of Jemez, well RWP-7 (18.01W.14.111) (pl. 1), is known to be completed in terrace deposits. This well, drilled in 1971, bottomed in the underlying Mancos Shale at a depth of 90 feet. It produces water from a 5-foot-thick interval between the depths of 80 and 85 feet. The well reportedly was tested at a rate of 6 gallons per minute for 3 hours; pumping yield was measured on December 6, 1983, at a rate of 1 gallon per minute.

Water Quality

The density of water-quality data from terrace deposits in this area is sparse, but in general water from this aquifer probably is fresh. The only water-quality data for this potential aquifer in the study area are from the stock well (well RWP-7, 18.01W.14.111 on pl. 1) near Thompson Spring. Water from this well had a specific conductance of 850 microsiemens (about 600 milligrams per liter dissolved solids) and a temperature of 11.0 degrees Celsius (Craigg, 1984, table 1). Anderholm (1979) reported chemical analyses of ground water from terrace deposits near Cuba, New Mexico, an area with a similar hydrogeologic setting about 15 miles north of the study area. Dissolved-solids concentrations of these waters ranged from 80 to 355 milligrams per liter; the major constituents were calcium and bicarbonate with lesser concentrations of sodium and sulfate.

Volcanic Rocks (Quaternary and Tertiary)

Geologic Characteristics

Volcanic rocks in the study area are mainly present in the Cañada de Cochiti and Ojo del Borrego Grant areas and on Santa Ana Mesa in the Jemez Valley province (pl. 3). These rocks consist of a complex pile of lava flows, ash-flow tuffs, and local intrusive bodies. Bailey and others (1969) and Smith and others (1970) divided these complex rocks into five major formations, which in ascending age order are the Canovas Canyon Rhyolite, Paliza Canyon Formation, Bearhead Rhyolite, basaltic lavas of Santa Ana Mesa, and Bandelier Tuff. Although none of these are important water resources, stock-water supplies probably could be obtained from some units where geologic controls exist.

The Canovas Canyon Rhyolite crops out in the central part of the Cañada de Cochiti Grant and in scattered areas in the western part of the Ojo del Borrego Grant. This formation generally consists of as much as 150 feet of rhyolite lava flows and bedded tuffs.

The Paliza Canyon Formation crops out in the east-central and western parts of the Cañada de Cochiti Grant, in the western part of the Ojo del Borrego Grant, and on Chamisa and Borrego Mesas. It mainly consists of andesite and basalt lava flows and may be as much as 200 feet thick in the study area.

The Bearhead Rhyolite crops out in the eastern part of the Cañada de Cochiti Grant in the La Jara and Peralta Canyon areas. It consists principally of bedded rhyolite tuffs and tuff breccias and thick lava flows. Smith and others (1970) reported a maximum thickness of about 2,000 feet for this formation, but thickness probably does not exceed 300 or 400 feet in the study area.

Basaltic lavas of Santa Ana Mesa consist of basalt lava flows and associated scoriaceous material. Thickness reportedly may reach a maximum of 1,000 feet (Smith and others, 1970), but probably is less than that in the study area.

The Bandelier Tuff crops out in the study area only as an eroded remnant in the eastern part of Cañada de Cochiti Grant, south of Peralta Canyon. It consists of nonwelded to densely welded rhyolite ash-flow deposits and pumice. Thickness reportedly reaches a maximum of about 1,000 feet outside of the Valles caldera (U.S. Department of Energy, 1979), but it is probably much thinner in the study area.

Hydrologic Characteristics

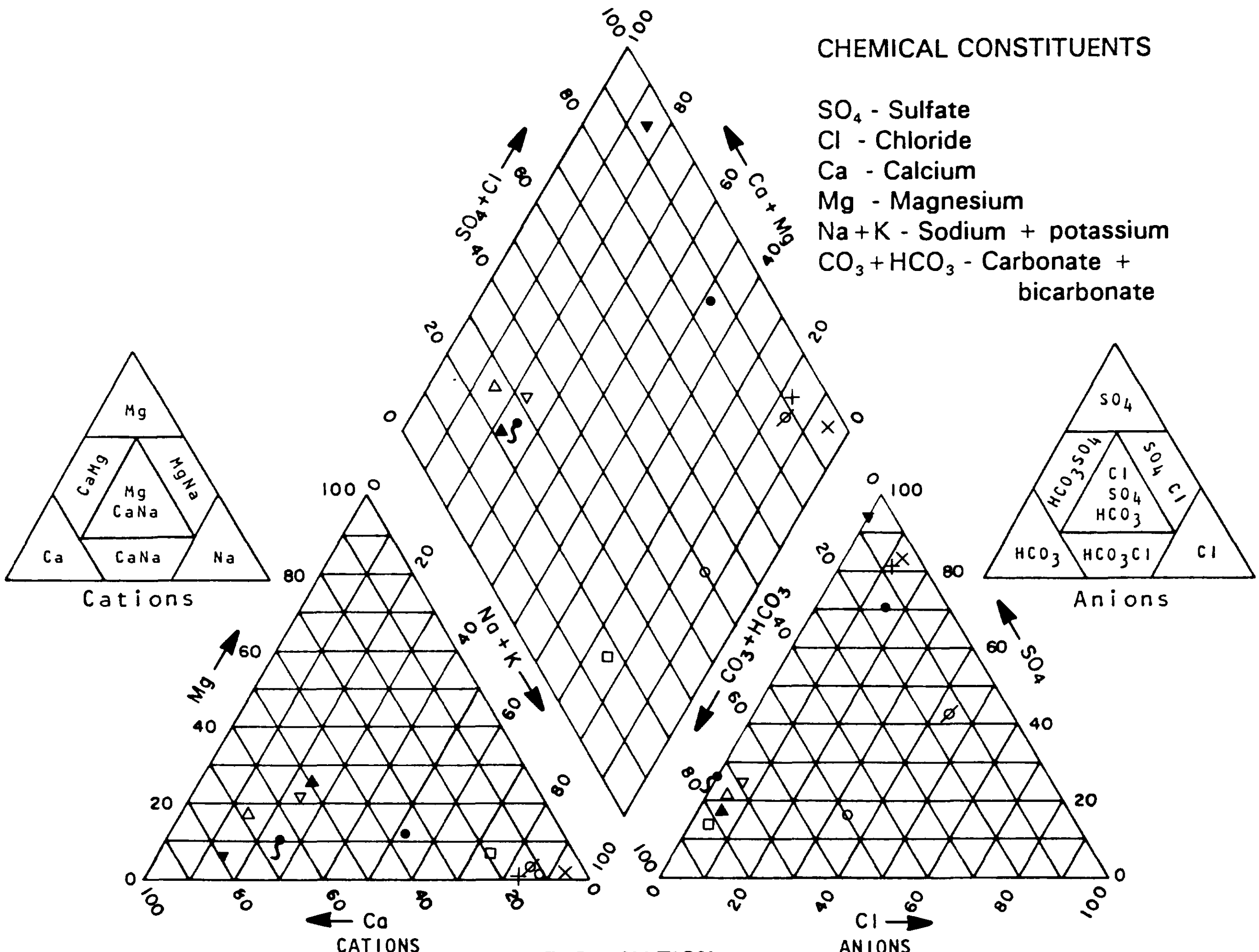
The only ground water known to be associated with volcanic rocks in the study area is from an unnamed spring (17.03E.25.113) (pl. 2) on the Pueblo of Jemez in the Cañada de Cochiti Grant (Craigg, 1984, pl. 2). This spring issues from the Paliza Canyon Formation in Hondo Canyon (Trainer, 1978; Craigg, 1984) and apparently is associated with a normal fault through Hondo Canyon. Discharge of water from this spring was measured at 2 gallons per minute (Trainer, 1978).

Other springs in the general region, however, also issue from volcanic rocks (Trainer, 1978). Discharge of water from these springs ranges from less than 1 to 100 gallons per minute; however, discharges in the range of 1 to about 10 gallons per minute are the most common.

Griggs (1964) briefly discussed hydrologic characteristics of similar volcanic rocks in the Los Alamos region northeast of the study area. He concluded that, in general, these volcanic rocks yield little water, but that they do contain bodies of "perched" ground water locally. Yields of wells completed in these units, however, should be sufficient for stock use.

Water Quality

Water from perched ground-water bodies in volcanic rocks should be fresh. Specific conductance of water from the unnamed spring in Hondo Canyon (17.03E.25.113) (pl. 2) was 180 microsiemens, the dissolved-solids concentration was 160 milligrams per liter, and the water was a mixed calcium magnesium sodium bicarbonate type (fig. 10; Craigg, 1984, table 5).



EXPLANATION

WATER FROM:

PUEBLO OF JEMEZ

- Holy Ghost Spring (Dakota Sandstone)
- ● Blue Water Spring (Chinle Formation)
- ○ Vallecito Spring "1" (Chinle Formation)
- □ Vallecito Spring "2" (Chinle Formation and alluvium?)
- △ Unnamed spring (16N.01E.03.441)(Abo Formation)
- ▽ Log Spring (Precambrian gneiss)

PUEBLO OF ZIA

- ▲ Unnamed spring (17N.03E.25.113)(volcanic rocks)
- ▼ Chamisa Vega Spring (Mancos Shale)
- × Ojito Spring (Mancos Shale)
- + Well 2-C-278 (15N.01E.23.444) (Morrison Formation)
- ⌀ Kaseman test well 1

Figure 10.--Trilinear plot of major dissolved constituents in water from volcanic rocks; the Mancos Shale; the Dakota Sandstone; the Morrison, Chinle, and Abo Formations; and the Precambrian gneiss. Small triangles at sides give key to classification (see Craigg, 1984, tables 3 and 5 for chemical analyses).

Trainer (1978) tabulated water-quality data for other springs in the general region that issue from volcanic rocks. Specific conductance of water from these springs ranged from 120 to 540 microsiemens; most values were between 150 and 200 microsiemens. Water from these springs most commonly was a calcium bicarbonate type.

Sandstone Beds in the Mancos Shale (Cretaceous)

Geologic Characteristics

The Mancos Shale conformably overlies the Dakota Sandstone and intertongues with the upper part of that unit. The Mancos commonly forms rounded hills and broad valleys in the Ojo del Espiritu Santo Grant, where it is the most extensive Cretaceous geologic unit (pl. 3). Typical westward-dipping exposures of the Mancos are east and west of State Highway 44, along the access road to Holy Ghost Spring, and along Sandoval County Road 279 in the San Juan Basin province (pl. 3).

The Mancos Shale was deposited in an offshore marine environment. In the study area, the Mancos mainly consists of dark-gray to black, dusky-yellow, and pale-green shale, and silty shale, and thin light-gray to buff, very fine to fine-grained sandstone interbeds; gray limestone beds and yellowish limy concretions also are present (Woodward and Martinez, 1974; Craigg, 1980). Stratigraphic sections constructed by Stone and others (1983) indicate the Mancos Shale probably has a maximum thickness of about 800 to 1,000 feet in the study area.

The Semilla Sandstone Member is the most significant unit of the Mancos Shale in the study area. The Semilla Sandstone Member is a stratigraphically persistent bed ranging from about 40 to 60 feet thick and is erosion resistant, forming ridges in the Semilla Canyon area (La Fon, 1980).

Hydrologic Characteristics

The Mancos Shale generally is considered to be a confining unit. However, in the Ojo del Espiritu Santo Grant and south of White Mesa, sandstone beds within the Mancos probably transmit water to wells in large enough quantities for stock-water supplies.

Two stock wells on the Pueblo of Jemez part of the Ojo del Espiritu Santo Grant (well RWP-8, 18.01W.19.241; and well 18.01W.30.214 on pl. 1) are completed in sandstone beds associated with the Mancos Shale. The first of these wells is 290 feet deep and produces water between the depths of 280 and 290 feet. The depth to water is 225 feet. The well reportedly was tested at a rate of 10 gallons per minute (Craigg, 1984, table 1). The second well is abandoned. The depth to water was measured at 293 feet; the well depth could not be measured accurately, but may be about 320 feet (Craigg, 1984, table 1).

Two abandoned wells (well C200-1, 14.01E.02.121; and well C200-2, 14.01E.02.314 on pl. 1) and one stock well (well ECW-1, 14.01E.03.414 on pl. 1) on the Pueblo of Zia also are completed in the Mancos. Water levels in the abandoned wells are 144 and 107 feet, respectively. The stock well is 132 feet deep and produces water from a sandstone between the depths of 116 and 130 feet. The depth to water is 83 feet. The well was reportedly tested at a rate of 7 gallons per minute (Craigg, 1984, table 1).

Ojito Spring (16.01W.29.232 on pl. 2) and Chamisa Vega Spring (17.01W.28.243 on pl. 2) on the Pueblo of Zia issue from sandstone beds in the Mancos. The discharge of water from Ojito Spring was measured at 2 gallons per minute, and the discharge of water from Chamisa Vega Spring was estimated at 1 gallon per minute (Craigg, 1984, table 2).

Water Quality

The quality of water from the Mancos Shale in the study area is variable, but generally ranges from slightly to moderately saline. Water from one of the stock wells on the Pueblo of Jemez, well RWP-8 (18.01W.19.241) (pl. 1), may have had a specific conductance as great as 7,000 microsiemens based on a sample collected from a storage tank (Craigg, 1984, table 1). Water from one of the abandoned wells on the Pueblo of Zia, well C200-2 (14.01E.02.414) (pl. 1), is considerably less saline; the specific conductance was 1,350 microsiemens (Craigg, 1984, table 1).

Water from Ojito Spring had a specific conductance of 10,100 microsiemens, a dissolved-solids concentration of 7,750 milligrams per liter, and plots in the sodium sulfate field in figure 10. Water from this spring also contained large concentrations of calcium (120 milligrams per liter) and chloride (580 milligrams per liter) (Craigg, 1984, table 5). The water from Chamisa Vega Spring is less saline than that from Ojito Spring. The water from Chamisa Vega Spring had a specific conductance of 2,450 microsiemens and a dissolved-solids concentration of 2,410 milligrams per liter, and plots in the calcium sulfate field in figure 10, illustrating the variability in water chemistry from the Mancos. Large concentrations of sodium (101 milligrams per liter) and bicarbonate (143 milligrams per liter) also were present in water from this spring (Craigg, 1984, table 5).

In a study of ground-water conditions in the Arroyo Chico-Rio Puerco area a few miles to the west, Craigg (1980) determined water-quality characteristics for the various members of the Mancos Shale. Specific conductance ranged from 560 to 4,000 microsiemens, and the water was a sodium bicarbonate or a sodium sulfate type. Bureau of Indian Affairs personnel collected a water sample from Soda Spring (sec. 32, T. 17 N., R. 1 W.). This spring is located at the contact of the Mancos Shale and the underlying Dakota Sandstone just across the western boundary of the study area and flows onto the Pueblo of Zia part of the Ojo del Espiritu Santo Grant. Water from this spring had a specific conductance of 1,780 microsiemens and a dissolved-solids concentration of 1,610 milligrams per liter, and was a calcium sulfate type.

Dakota Sandstone (Cretaceous)

Geologic Characteristics

The Dakota Sandstone unconformably overlies the Morrison Formation (fig. 3), and its outcrop area parallels that of the Morrison (pl. 3). The Dakota commonly caps mesas and forms erosion-resistant dip slopes in the San Juan Basin province. Typical exposures of the Dakota occur in the Ojo del Espiritu Santo Grant area of the Pueblos of Jemez and Zia, in hogbacks east of Holy Ghost Spring, and just west of the Rio Salado in T. 16 N., R. 1 W. (pl. 3).

The Dakota Sandstone was deposited in environments associated with a transgressing sea (streams, coastal swamps, and beaches). Geologic characteristics of the Dakota Sandstone in this area have been well documented (Landis and others, 1973; Owen, 1973; Woodward and Martinez, 1974; Craigg, 1980). It typically consists of three distinct lithologic members: a yellowish-brown, fine-grained, ledge-forming sandstone at the top; a shale and carbonaceous shale unit in the middle; and a light-gray, conglomeratic, ledge-forming sandstone at the base (Craigg, 1980). The thickness averages about 200 feet, although Stone and others (1983) reported a 355-foot thickness penetrated by an oil well drilled in the Ojo del Espiritu Santo Grant. Depth to the top of the Dakota in the study area reaches a maximum of about 3,000 feet because of regional northward and westward dips and topographic rise of the land surface (pl. 4) (Craigg and others, 1989, fig. 5).

Hydrologic Characteristics

Water in the Dakota Sandstone is under artesian conditions. Three stock wells on the Pueblo of Jemez in the San Juan Basin province (well RWP-4, 17.01W.02.214; well RWP-3, 17.01W.05.124; and well RWP-5, 18.01W.20.442 on pl. 1) probably are completed in the Dakota Sandstone (Craigg, 1984, pl. 1). The depth of these wells ranges from 550 to 950 feet, and the depth to water ranges from 95 to 212 feet. Well RWP-4 was bail-tested at a rate of 2 gallons per minute for 4 hours, and well RWP-3 was tested at 12 gallons per minute for 6 hours; no water-level drawdowns were reported (Craigg, 1984, table 1).

A flowing artesian well about 10 miles west of the study area (sec. 17, T. 16 N., R. 3 W.) is completed in the Dakota Sandstone at a depth of 1,840 feet (Craigg, 1980). Discharge of water from this well was measured at 13.5 gallons per minute.

Transmissivity of the Dakota Sandstone generally is less than 50 feet squared per day (Stone and others, 1983). The specific capacity of wells completed in the Dakota Sandstone also is small, estimated at 0.05 to 0.20 gallon per minute per foot of drawdown by Shomaker and Stone (1976).

Holy Ghost Spring (17.01W.10.241 on pl. 2) on the Pueblo of Jemez probably issues from the Dakota Sandstone that is covered by a veneer of alluvium. Discharge of water from this spring was measured at 9.5 gallons per minute and apparently is constant, regardless of season (Craigg, 1984, table 2).

Elk Spring, just across the northern boundary of the study area and Ojo del Espiritu Santo Grant in sec. 1, T. 18 N., R. 1 W., issues from the lower unit of the Dakota Sandstone where an arroyo has incised through a steep westward-dipping hogback. Discharge of water from this spring was measured at a rate of 1 gallon per minute.

Water Quality

Water from the Dakota Sandstone in this area ranges from fresh to moderately saline. Water from Holy Ghost Spring had a specific conductance of 580 microsiemens and a dissolved-solids concentration of 363 milligrams per liter, and plots in the calcium bicarbonate field in figure 10. Water from well RWP-3 had a specific conductance of 4,250 microsiemens (Craigg, 1984, tables 2 and 5). Water from the flowing well west of the study area had a specific conductance of 2,500 microsiemens and a dissolved-solids concentration of 1,885 milligrams per liter, and was a sodium sulfate type (Craigg, 1980). Specific conductance of water from Elk Spring was 1,500 microsiemens and the dissolved-solids concentration was 1,210 milligrams per liter, and the water was a calcium sulfate type.

Stone and others (1983) reported that, in general, specific conductance of water from the Dakota is greater than that of water from the underlying Morrison Formation. Quality of water from the Dakota in this area would be expected to become more mineralized downdip from the outcrop area toward the west and northwest because of longer residence time and dissolution of minerals. This is discussed further in the section "Generalized geologic controls of ground-water quality."

Sandstone Beds in the Morrison Formation (Jurassic)

Geologic Characteristics

The Morrison Formation crops out in the narrow, steeply dipping and faulted hogback zone along the western flank of the Sierra Nacimiento in the San Juan Basin province (pl. 3). Farther west from the mountain front, the Morrison is exposed as a broad, gently dipping, north-trending outcrop band as much as 3 miles wide along the Rio Salado and State Highway 44 in the Ojo del Espiritu Santo Grant. The Morrison Formation also is exposed southwest of San Ysidro and on the south end of White Mesa (pl. 3).

The Morrison Formation conformably overlies the Todilto Limestone Member of the Wanakah Formation (fig. 3) and in the study area ranges in thickness from about 650 to 800 feet (Woodward and Schumacher, 1973a). It consists of four members deposited by streams, flood plains, and lakes; these four members in ascending order are the Recapture Shale, Westwater Canyon Sandstone, Brushy Basin Shale, and Jackpile Sandstone Members.

The Recapture Shale Member was described by Woodward and Schumacher (1973a) as about 300 to 350 feet of reddish-brown mudstone, green mudstone, gray siltstone, and very fine to fine-grained sandstone. This member forms a slope or topographic saddle between the overlying Westwater Canyon Sandstone Member and underlying Todilto Limestone Member of the Wanakah Formation.

The Westwater Canyon Sandstone Member varies in thickness from about 100 to 200 feet, increasing northward. Woodward and Schumacher (1973a) described this unit principally as yellowish-tan to pink, fine- to very coarse grained and locally conglomeratic, thick-bedded arkosic sandstone. The Westwater Canyon Sandstone Member forms steep cliffs throughout the study area.

The Brushy Basin Shale Member ranges in thickness from 240 to 280 feet, increasing northward (Woodward and Schumacher, 1973a). Woodward and Schumacher (1973a) described the unit as brick-red and green mudstone and minor interbeds of sandstone and gray limestone. It commonly forms a topographic saddle or slope above the Westwater Canyon Sandstone Member. Woodward and Schumacher (1973a) also identified an informal upper member, which they included in the Brushy Basin Member. Recent work by Owen (1984) has formalized this unit as the Jackpile Sandstone Member. This member consists of about 80 to 180 feet of yellowish-tan to white, fine- to coarse-grained arkosic sandstone; thickness decreases northward. The Jackpile Sandstone Member crops out discontinuously and forms ledgy slopes or rounded cliffs.

Depth to the top of the Morrison Formation ranges from zero to about 2,500 feet toward the north and west because of regional dip and topographic rise of the land surface (pl. 4). Stone and others (1983) and Dam and others (1990, fig. 6) included maps showing the generalized depth to the top of the Morrison Formation in the San Juan Basin.

Hydrologic Characteristics

The major water-yielding zones in the Morrison Formation are the Westwater Canyon Sandstone Member, sandstones in the Brushy Basin Shale Member, and the Jackpile Sandstone Member. Risser and others (1984) reported that transmissivity of the Jackpile Sandstone Member in the Laguna area ranges from 2 to 47 feet squared per day, that the storage coefficient ranges from 1.9×10^{-4} to 2.9×10^{-4}, and that well yields of at least 15 gallons per minute are possible.

Maps showing transmissivity zones in the Westwater Canyon Sandstone Member were presented by Lyford (1979) and by Stone and others (1983). These maps indicate that transmissivity of this unit in the Ojo del Espiritu Santo Grant area may be as much as 100 feet squared per day, but generally is 50 feet squared per day or less. Specific capacity may range from 0.2 to 0.4 gallon per minute per foot of drawdown. Well yields from the Westwater Canyon Sandstone Member probably are adequate for stock-water supplies.

On the Pueblo of Zia, one abandoned stock well (well RWP-6, 16.01W.14.11 on pl. 1) on the Ojo del Espiritu Santo Grant and one stock well (well 2-C-278, 15.01E.23.444 on pl. 1) south of White Mesa are completed in units of the Morrison Formation (Craigg, 1984, table 1). Well RWP-6 probably is completed in fine-grained rocks of the Brushy Basin Shale Member. This well was drilled to a depth of 225 feet in 1970, and the well was test pumped at a rate of 3 gallons per minute. The water level reportedly was 32 feet below land surface. Records from 1972, however, show that the well was abandoned and dry. Well 2-C-278 is 143 feet deep, and the water level is 102 feet below land surface. The driller's log indicates that the water-yielding zone is a "yellow and white" sandstone, which may be part of the Westwater Canyon Sandstone Member.

A well about 4 miles north of the Ojo del Espiritu Santo Grant boundary (sec. 14, T. 19 N., R. 1 W.) is completed in the Morrison Formation between the depths of 1,912 and 1,950 feet. A short-term aquifer test was conducted on this well in 1978; it was bailed at a rate of 0.3 gallon per minute for 2.5 hours with a drawdown of 3 feet (Stone and others, 1983).

Water Quality

Water from well 2-C-278 is moderately saline. The specific conductance of this water was 6,510 microsiemens and the dissolved-solids concentration was 5,320 milligrams per liter, and the chemical analysis plots in the sodium sulfate field (fig. 10). No water-quality data exist for water from the abandoned stock well.

Water from the Morrison Formation probably is slightly saline near outcrop areas along the western edge of the Sierra Nacimiento, as indicated by the well drilled about 4 miles north of the study area east of La Ventana (sec. 14, T. 19 N., R. 1 W.). Water from this well had a dissolved-solids concentration of 2,140 milligrams per liter, and chloride, calcium, and sodium were the major dissolved ions.

Quality of water from the Morrison Formation in the study area probably is more mineralized with depth and distance from outcrop. Large concentrations of dissolved solids are expected in water samples from the Morrison in the Rio Puerco and Rio Salado areas because more mineralized ground water flows southeast from the San Juan Basin and leaks upward from deeper units (Stone and others, 1983). Lyford (1979) showed dissolved-solids concentrations greater than 4,000 milligrams per liter in those areas.

Entrada Sandstone (Jurassic)

Geologic Characteristics

The Entrada Sandstone was deposited in a desert environment and much of it represents ancient sand dunes. The Entrada Sandstone has a similar areal distribution to that of the Morrison Formation, but is present in much narrower outcrop bands (pl. 3). The Entrada unconformably overlies the Chinle

Formation (fig. 3) and forms steep buff- to red-colored cliffs and slopes beneath the white gypsum beds of the Todilto Limestone Member of the Wanakah Formation. Typical exposures of the Entrada Sandstone occur along the north face of White Mesa south of the Rio Salado and along the west side of State Highway 44 in the Cuchilla Arroyo valley (pl. 3).

The Entrada Sandstone maintains a fairly constant thickness of about 100 to 120 feet in the study area (Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976). In 1978, the author measured a stratigraphic section through the Entrada Sandstone in the Ojo del Espiritu Santo Grant area of the Zia Reservation (NE$\frac{1}{4}$ sec. 24, T. 16 N., R. 1 W.; reported in Stone, 1979). At this locality, the Entrada consists of 115 feet of light- to reddish-brown, pale-yellow and white, fine- to medium-grained crossbedded sandstone and silty sandstone. This measured section probably is representative of the Entrada Sandstone in the study area. Depth to the top of the Entrada Sandstone increases toward the north and west to a maximum of about 4,000 feet because of regional dip and topographic rise of the land surface (pl. 4).

Hydrologic Characteristics

No wells in the study area or adjacent areas are known to be completed in the Entrada Sandstone and no springs are known to issue from this unit. Hydrologic characteristics of the Entrada are not well documented. Stone and others (1983) reported that transmissivity (as calculated from a few specific-capacity tests) is less than 50 feet squared per day near outcrop areas along the southern edge of the San Juan Basin. Risser and Lyford (1983) stated that transmissivity is minimal for the Entrada on the Laguna Reservation. Risser and Lyford (1983) also reported that well yields usually are less than 3 gallons per minute and that less than 10 gallons per minute would be the maximum sustained yield. They reported one specific-capacity value of 0.24 gallon per minute per foot. Similar hydrologic characteristics could be expected for the Entrada in the study area because these rocks in the study area are similar to those in areas studied by Risser and Lyford (1983).

Water Quality

The density of water-quality data for the Entrada Sandstone near the study area is sparse. Lyford (1979) reported dissolved-solids concentrations of 1,000 milligrams per liter or less in or near recharge areas in the southern part of the San Juan Basin.

Water obtained from the Entrada in the study area probably would be of suitable quality only for stock use because the calcareous nature of the sandstone and the presence of the overlying gypsiferous Todilto Limestone Member of the Wanakah Formation would result in large hardness values. Quality of water from the Entrada would be expected to become more mineralized with increasing depth because of longer residence time and dissolution of minerals. This is discussed further in the section "Generalized geologic controls of ground-water quality."

Sandstone Beds in the Chinle Formation (Triassic)

Geologic Characteristics

The Chinle Formation unconformably overlies rocks of Permian age (fig. 3). Major outcrop areas are in the Cuchilla Arroyo valley along State Highway 44, in the Rio Salado valley between State Highway 44 and the base of White Mesa, north of State Highway 44 in the Red Mesa and Arroyo Peñasco areas, and in the Vallecito Creek drainage (pl. 3). The Chinle also crops out as steeply dipping hogback ridges along the western flank of the Sierra Nacimiento.

The Chinle Formation in the study area is as much as 1,250 feet thick. It consists of two members deposited in stream and flood-plain environments. These members, in ascending order, are the Agua Zarca Sandstone and Petrified Forest Members.

The Agua Zarca Sandstone Member forms steep cliffs and resistant dip slopes. It consists of about 150 to 250 feet of white to buff or locally red to pink, thick-bedded, medium- to very coarse grained conglomeratic sandstone (Woodward and Martinez, 1974; Woodward and Ruetschilling, 1976).

The Petrified Forest Member may be as much as 1,000 feet thick. It consists of variegated reddish-brown, red, greenish-gray, and purple shale; silty shale with minor ledge-forming beds of gray sandstone; and brown limestone (Woodward and Martinez, 1974; O'Sullivan, 1977).

Depths to the Chinle Formation vary with the particular outcrop area. Depths may be as much as 4,000 feet in the northern and western parts of the Ojo del Espiritu Santo Grant. Depths probably become shallower, however, updip toward the Sierra Nacimiento. Depths to potential water-producing sandstones of the Chinle in the Vallecito Creek and Red Mesa areas are much shallower than depths in the Ojo del Espiritu Santo Grant.

Hydrologic Characteristics

Only the Agua Zarca Member of the Chinle Formation in this area has the potential to yield sufficient water for stock supplies. Two petroleum-test wells on the Pueblo of Zia that penetrated the Chinle, known as Kaseman 1 and 2 (16.01W.01.41 and 16.01W.01.421, respectively, on pl. 1), were drilled in 1926 in the Arroyo Cachana valley in the eroded Rio Salado anticline (Craigg, 1984, table 1). The Kaseman 1 well was plugged, and an unsuccessful attempt was made to plug the Kaseman 2 well. The Kaseman 2 well is a flowing artesian well along State Highway 44 now known as Warm Springs (pl. 1). These wells were visited during drilling in 1926 by Clark (1929), who presented drillers' logs and water-quality data. These wells also were visited during drilling in 1926 by Renick (1931).

The Kaseman 1 well, drilled to a depth of 550 feet, yielded hot (46 degrees Celsius) saline water from the Agua Zarca Member at a depth of 500 feet. This water flowed at the land surface at an estimated rate of 2,450 gallons per minute; the initial pressure at the well head reportedly was 225 pounds per square inch (Craigg, 1984, table 1).

The Kaseman 2 well (Warm Springs) was drilled to a depth of 2,008 feet about 0.2 mile northeast of the Kaseman 1 well (pl. 1). This deeper well penetrated the complete section of Triassic and Permian rocks and 120 feet of the Madera Limestone (Pennsylvanian). Flows of hot (42 degrees Celsius), saline water were first yielded when the well penetrated the Agua Zarca Member at a depth of 425 feet. Additional flows of hot (42 to 61 degrees Celsius), saline water were yielded as drilling progressed through the Yeso and Abo Formations, and into the Madera Limestone (Renick, 1931). The present flow from the well, therefore, probably represents a mixture of water from the Chinle, Yeso, and Abo Formations, and the Madera Limestone.

The hot, saline water from the Kaseman 1 and 2 wells may be associated with a geothermal anomaly (the water temperatures were much higher than those associated with a normal geothermal gradient--about 25 degrees Celsius per 3,300 feet of depth) and, therefore, is not representative of typical hydrologic conditions in the Chinle Formation. A stock well 1/2 mile south of the study area (sec. 34, T. 16 N., R. 1 E.) in the San Ysidro Grant that was drilled in 1978 produces water from a fractured zone in the Agua Zarca Member between the depths of 176 and 200 feet. The depth to water in this well is 131 feet below the land surface. The specific capacity of this well is reportedly 10 gallons per minute per foot of drawdown (Peter Frenzel, U.S. Geological Survey, written commun., 1978).

At least two springs on the Pueblo of Jemez issue from the Agua Zarca Member: these are Blue Water Spring (16.01E.25.422 on pl. 2) and Vallecito Spring "1" (16.02E.10.424 on pl. 2). The discharge of water from Blue Water Spring was measured at 2 gallons per minute in September 1973 (Trainer, 1978), but in May 1984, the discharge was estimated at 0.5 gallon per minute (Craigg, 1984). Discharge from Vallecito Spring "1" is 3 gallons per minute (Trainer, 1978).

Salt Spring on the Pueblo of Jemez (16.02E.20.331 on pl. 2) apparently issues from the Agua Zarca at the intersection of the Jemez fault and a fault transverse to it. Specific-conductance data (Craigg, 1984, table 2), however, indicate that the Madera Limestone may be the principal source of the water. Trainer (1978) reported another spring (Vallecito Spring "2", 16.02E.11.232 on pl. 2) issuing from the Chinle Formation at the rate of 5 gallons per minute.

A group of large moundlike or craterlike springs on the Ojo del Espiritu Santo Grant on the Pueblo of Zia, in the Arroyo Peñasco drainage, appears to issue from the Agua Zarca Member near the Pajarito fault. These springs were called the Phillips Springs by Renick (1931), but are referred to as the Peñasco springs in this report. Various investigators, on the basis of water-quality data, have suggested that the deeper Madera Limestone (Pennsylvanian) and possibly various Permian rocks are the actual source of the water (Renick, 1931; Trainer, 1978; Trainer and Lyford, 1979). These springs are discussed in the Madera Limestone section.

Water Quality

The quality of water from the Chinle Formation varies from ground-water province to ground-water province. Water from the Kaseman 1 well in the San Juan Basin province had dissolved-solids concentrations of 11,274 milligrams per liter (Clark, 1929) and 10,984 milligrams per liter (Renick, 1931). The chemical analysis plots in the sodium chloride sulfate field in figure 10; a large concentration of sulfate also is present (Craigg, 1984, table 3). Water from the Chinle Formation, above the depth of 940 feet, in the Kaseman 2 well (Warm Springs) contained 11,760 milligrams per liter dissolved solids, 5,450 milligrams per liter sodium, and 1,130 milligrams per liter carbonate (Renick, 1931). Water from these two wells probably is not representative of conditions in the Chinle Formation because a geothermal anomaly may exist in this vicinity; temperature at a depth of only 425 feet in the Kaseman 1 well was 42 degrees Celsius. Furthermore, because Renick (1931) reported water flow from the Chinle, Yeso, and Abo Formations and the Madera Limestone, the water samples from the Kaseman 2 well (Warm Springs) probably are a composite sample of water from the Chinle Formation, various Permian rocks, and the Madera Limestone.

Water from the stock well 1/2 mile south of the study area (sec. 34, T. 16 N., R. 1 E.) in the Sierra Nacimiento province may be more representative of the Agua Zarca Member because this water is more similar in chemical characteristics to water discharging from the Blue Water Spring and the Vallecito Spring "1", which issue from the Agua Zarca, than to water flowing from the Kaseman 2 well (Warm Springs). This water had a specific conductance of 1,700 microsiemens, contained 1,400 milligrams per liter dissolved solids, and was a calcium sulfate type water.

Water from Blue Water Spring in the Sierra Nacimiento province had a specific conductance of 2,500 microsiemens, a dissolved-solids concentration of 1,830 milligrams per liter, and a large iron concentration of 15 milligrams per liter, and plots in the sodium calcium sulfate field (fig. 10; Craigg, 1984, table 5). Water from Vallecito Spring "1" in the Jemez Valley province had a specific conductance of 2,800 microsiemens and a dissolved-solids concentration of 1,560 milligrams per liter, and plots as a sodium bicarbonate chloride type (fig. 10). Water from Salt Spring is highly mineralized and has a specific conductance of 8,200 microsiemens. This spring is discussed further in the Madera Limestone section.

Sandstone Beds in Permian Rocks

Geologic Characteristics

Rocks of Permian age crop out along the Jemez River in Cañon de San Diego, as caprocks on Mesa Cuchilla and Red Mesa, and as steeply dipping hogbacks along the western edge of the Sierra Nacimiento (pl. 3). These rocks consist of ancient stream, flood-plain, lake, and eolian deposits. These rocks range in thickness from about 700 to 1,500 feet in the study area. Permian rocks have been divided into three major formational units in this area (Woodward and Ruetschilling, 1976; Woodward and others, 1977). These are, in ascending order, the Abo Formation, Yeso Formation, and the undivided Glorieta Sandstone and Bernal Formation; the upper part of this interval may locally include the San Andres Limestone. The Abo Formation consists of about 300 to 850 feet of reddish-brown mudstone and minor beds of light-gray sandstone and nodular limestone.

The Yeso Formation consists of 300 to 525 feet of orange-buff, fine- to very fine grained, crossbedded sandstone. The distinctive reddish-orange sandstone bluffs along the Jemez River north of Jemez Pueblo are exposures of the Yeso Formation.

The undivided Glorieta Sandstone and Bernal Formation consists of 30 to 100 feet of white to tan, fine- to coarse-grained, thick-bedded, cliff-forming sandstone with local lenses of gypsum in the lower part (Glorieta Sandstone) and 15 to 80 feet of reddish-brown, very fine to medium-grained thin-bedded sandstone (Bernal Formation). Depth to Permian rocks increases southward from the outcrops north of Jemez Pueblo and westward from the Sierra Nacimiento.

Hydrologic Characteristics

No wells in the study area are known to produce water from Permian rocks. However, three wells a few miles north of the study area in Cañon de San Diego are completed in the Abo Formation at depths ranging from 128 to 295 feet (Trainer, 1978). No discharge data exist for these wells.

One unnamed spring on the Pueblo of Jemez (16.01E.03.441 on pl. 2) issues from the Abo Formation in the Mesa Cuchilla-Jack Rabbit Flats area, near the intersection of two faults (Craigg, 1984, table 2). Discharge of water from this spring was estimated at less than 1 gallon per minute (Trainer, 1978). One spring north of the study area also issues from the Abo Formation at a rate of less than 1 gallon per minute (Trainer, 1978). No springs in the study area and vicinity are known to issue from the other Permian formations.

Water Quality

Chemical analyses of water from two of the three wells that yield water from the Abo Formation a few miles north of the study area are given in Trainer (1978). The specific-conductance values were 3,200 and 3,500 microsiemens, and the water contained large concentrations of sodium, bicarbonate, and chloride. Water-quality data for Permian rocks in the study area are limited to the unnamed spring (16.01E.03.441 on pl. 2). Water from this spring had a specific conductance of 640 microsiemens and a dissolved-solids concentration of 418 milligrams per liter, and plots in the calcium bicarbonate field in figure 10. The specific conductance of water from the two springs that issue from the Abo Formation north of the study area was 700 and 1,000 microsiemens. Chemical analyses of water from these springs also are given in Trainer (1978).

Madera Limestone (Pennsylvanian)

Geologic Characteristics

Rocks of Pennsylvanian age unconformably overlie Precambrian crystalline rocks in the study area and locally overlie eroded remnants of Mississippian rocks. The most important Pennsylvanian rock is the Madera Limestone because of its regional extent and continuity throughout the three ground-water provinces.

The major outcrop area of the Madera Limestone is to the west and northwest of Jemez Pueblo, in the Tecolote Canyon-Coyote Flats area on the southeastern edge of the Sierra Nacimiento province (pl. 3). The Madera also is exposed in hogbacks along the western flank of the Sierra Nacimiento in the San Juan Basin province and is present in the subsurface of that province. In the Jemez Valley province, the Madera is present in the subsurface beneath the Jemez River where it has been downdropped by the Jemez fault (pl. 3).

The Madera in this area principally consists of gray, thick-bedded, fossiliferous marine limestone and minor beds of light-gray sandstone, coarse-grained arkosic sandstone, and reddish and gray shale (Woodward and Ruetschilling, 1976; Woodward and others, 1977). Thickness of the Madera in the study area may be as much as 760 feet.

Hydrologic Characteristics

Only one well in the study area, a flowing well known as Warm Springs or the Kaseman 2 well in the San Juan Basin province (16N.01W.01.421 on pl. 1), produces water from the Madera Limestone. This well, drilled in 1926 to a depth of 2,008 feet, penetrated the Madera at 1,890 feet. Flows of hot, saline water were penetrated at various depths, and none of these zones were successfully plugged off. In 1926, the composite flow was estimated at a rate of 2,050 gallons per minute (Renick, 1931), decreasing since then to 63 gallons per minute in May 1984 (Craigg, 1984, table 1). The hydrologic conditions of the Madera at this locality may not be representative of typical conditions because of a possible geothermal anomaly in the Arroyo Cachana valley.

Several springs issue from the Madera Limestone in the study area. These are controlled by geologic structure and can be separated into three groups according to ground-water provinces. These three groups are those springs east of the Jemez fault in the Jemez Valley province, those between the Jemez fault and the Pajarito fault in the Sierra Nacimiento province, and those west of the Sierra Nacimiento in the San Juan Basin province (the Peñasco springs).

Springs in the San Juan Basin province

These are a group of both active and extinct nonthermal (?) mineral springs in the Ojo del Espiritu Santo Grant, along the southwest edge of the Sierra Nacimiento, in the Arroyo Peñasco area. The springs are oriented in a north and northeast direction in line with the major Nacimiento faulting. They were described in an early report by Kelly and Anspach (1913) and later were described in greater detail by Clark (1929) and Renick (1931). These springs are referred to as the Peñasco springs in this report. Similar springs are on the north and south sides of the Rio Salado valley, west of San Ysidro outside the study area.

The Peñasco springs, large moundlike or volcanolike landforms, are features composed of layers of calcium carbonate deposits known as travertine (figs. 11 and 12). Associated with these mounds is an areally extensive travertine surface, which covers an area of more than 2 square miles in the Cuchilla Arroyo and Arroyo Peñasco valleys between State Highway 44 and the Sierra Nacimiento. This deposit consists of light-tan to white, thick-bedded travertine as much as about 50 feet thick; it grades upward from calcium carbonate cemented gravels at the base to pure travertine. Local deposition of travertine is still occurring in the vicinity of active springs.

The major active mound spring of this group is known as Swimming Pool Spring (fig. 13) (16.01E.20.412 on pl. 2). This spring issues directly from the Pajarito fault and has built up a travertine mound at least 50 feet high that has gently sloping sides and vertical crater walls inside. The crater itself is about 50 feet in diameter and is a near-perfect circle in plan view. Depth of the crater is not known, but according to Renick (1931) it is greater than 40 feet. The crater is filled to the top with water, which spills over the western crater rim at an estimated rate of 20 gallons per minute (Craigg, 1984).

There are several craters of mound springs along a nearly north trending line parallel to the mountain front north of Arroyo Peñasco. This line of extinct and nearly extinct mound springs extends northward for about 3 miles following the trend of the Pajarito fault. Some of these mounds are as much as 300 feet across at the base and as much as 100 feet high and have craters 50 to 80 feet in diameter (figs. 11 and 12). A few of the more spectacular of these were visited during this study. Some are completely dry because the water level in the craters fell below the crater bottoms. Some still contained water in the craters, the depths to the water surface ranging from about 15 to 60 feet. One of the more impressive mounds has a large phreatophyte growing from the crater bottom about 50 feet down.

Figure 11.--One of the Peñasco springs showing travertine mound and spring crater (top center of mound). Spring mound is about 30 feet high, 100 feet in diameter, and circular in plan view; crater is about 15 feet in diameter and about 40 feet deep. The spring is inactive. Western edge of Red Mesa at upper left. View south from NE$\frac{1}{4}$, SE$\frac{1}{4}$, sec. 18, T. 16 N., R. 1 E.

Figure 12.--One of the Peñasco springs showing crater rim and massive, thick-bedded travertine along crater wall. Crater is circular in plan view, about 50 feet in diameter, and about 60 feet deep. A small pool of water is on the crater floor, indicating an active spring. The spring mound, one of the largest in the area, is about 300 feet in diameter at the base and about 100 feet high. Mesa Chivato and Cabezon Peak in background. View west from NE¼, SE¼, sec. 18, T. 16 N., R. 1 E. (photograph by J.M. Kernodle, U.S. Geological Survey).

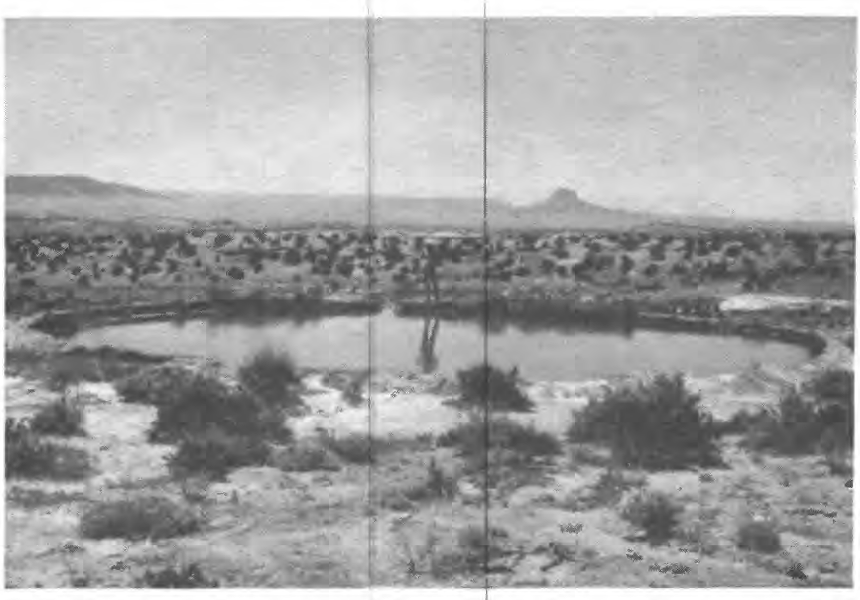
It is evident that these mound springs are in various stages of decreasing activity; some are completely extinct and some are on the verge of extinction. These are artesian springs, and it is obvious that the water was under greater artesian pressure at one time, as indicated by travertine deposits as much as 200 feet or more above the present active level; heights of the mounds of extinct springs also indicate this. Some of the mound springs are active only in the sense that the water in the craters is flowing by gravity through small fracture systems in the mound sides to issue at the surface near the mound bases. In these instances, travertine is being deposited in thin wavy layers. Swimming Pool Spring is a good example of how the other mounds must have appeared when their craters contained active springs.

The rocks that these spring mounds and travertine deposits overlie are mainly the Agua Zarca Sandstone Member of the Chinle Formation and minor outcrops of the Abo Formation east of the Pajarito fault. The principal source of the artesian spring water probably is the Madera Limestone, as suggested by various workers (Renick, 1931; Trainer, 1974; Trainer and Lyford, 1979). The Madera in this area is present at depths as much as 2,000 feet and contains highly mineralized water under artesian pressure. The Peñasco springs probably originated when ground water flowing through the Madera Limestone from the San Juan Basin southeast toward the Rio Grande rift became blocked by the Pajarito fault zone. This ground water then migrated vertically upward through fractures associated with the fault zone to eventually discharge at the land surface. Discharge of water to the land surface in the Arroyo Peñasco drainage is at a virtually constant rate of 0.3 cubic foot per second, as measured at State Highway 44 (table 5; Craigg, 1984, table 9).

Springs in the Sierra Nacimiento province

Two springs discharge from the structurally elevated block of Madera Limestone on the east side of the Sierra Nacimiento, west of the Jemez fault; these are Owl Spring (16.02E.07.423 on pl. 2) and Tunnel Spring (16.02E.18.214 on pl. 2). Both springs are associated with fracturing in the Madera. Owl Spring issues from solution-enlarged fractures in Tecolote Canyon. Discharge estimates have ranged from 15 gallons per minute (Trainer, 1978) to 25 gallons per minute (Spiegel, 1962) to 75 gallons per minute (Randall Willard, oral commun., 1984). Flow from the discharge pipe was measured at 72 gallons per minute by Craigg (1984). This spring has been developed for stock use and also is occasionally used as a backup public supply for the Pueblo of Jemez. Tunnel Spring issues from the Madera Limestone near a fault that intersects the Jemez fault. Flow estimates are less than 1 gallon per minute (Trainer, 1978; Craigg, 1984).

(A)



(B)

(C)

Figure 13.--Swimming Pool Spring (16.01E.20.412). This spring is one of the larger active mound springs in the Arroyo Peñasco area. The spring is located directly on the Pajarito fault, which brings the Chinle Formation (Triassic) on the west side into contact with the Abo Formation (Permian) on the east side (pl. 3).

(A) View southwest looking down at spring mound and crater. Mound is about 50 feet high and forms an arcuate travertine slope on the west side. Crater is circular in plan view and about 50 feet in diameter; depth in not known. Crater is filled to rim with moderately saline water that flows out through a notch over the west part of the rim. Note inactive springs in grassy area to left and large active spring mound at center of photograph in distance.

(B) View west across water surface at top of mound. Note notch where water flows from crater, just to the author's right (standing on crater rim.) Cabezon Peak and Mesa Chivato in background (photograph by J.M. Kernodle, U.S. Geological Survey).

(C) View east from base of mound showing the form of constructional travertine mound and discharge of water from notch in crater rim. Note recent travertine depostits (whitish areas on mound slope) (photograph by J.M. Kernodle, U.S. Geological Survey).

Springs in the Jemez Valley province

Springs east of the Jemez fault in the Jemez River valley are Salt Spring (16.02E.20.331 on pl. 2) and Indian Spring (16.02E.29.142 on pl. 2). Salt Spring issues near the intersection of the Jemez fault and a fault transverse to it near the West Side Lateral Canal (Craigg, 1984, table 2); Trainer (1978) estimated discharge to be less than 1 gallon per minute. Indian Spring, in the Jemez River channel, has discharge reported to be 2 gallons per minute (Trainer, 1978). Water-quality data indicate that, although the Madera Limestone is not the surface formation in this area, the Madera contributes water to these springs by upward leakage. This will be discussed in the section on water quality.

Water Quality

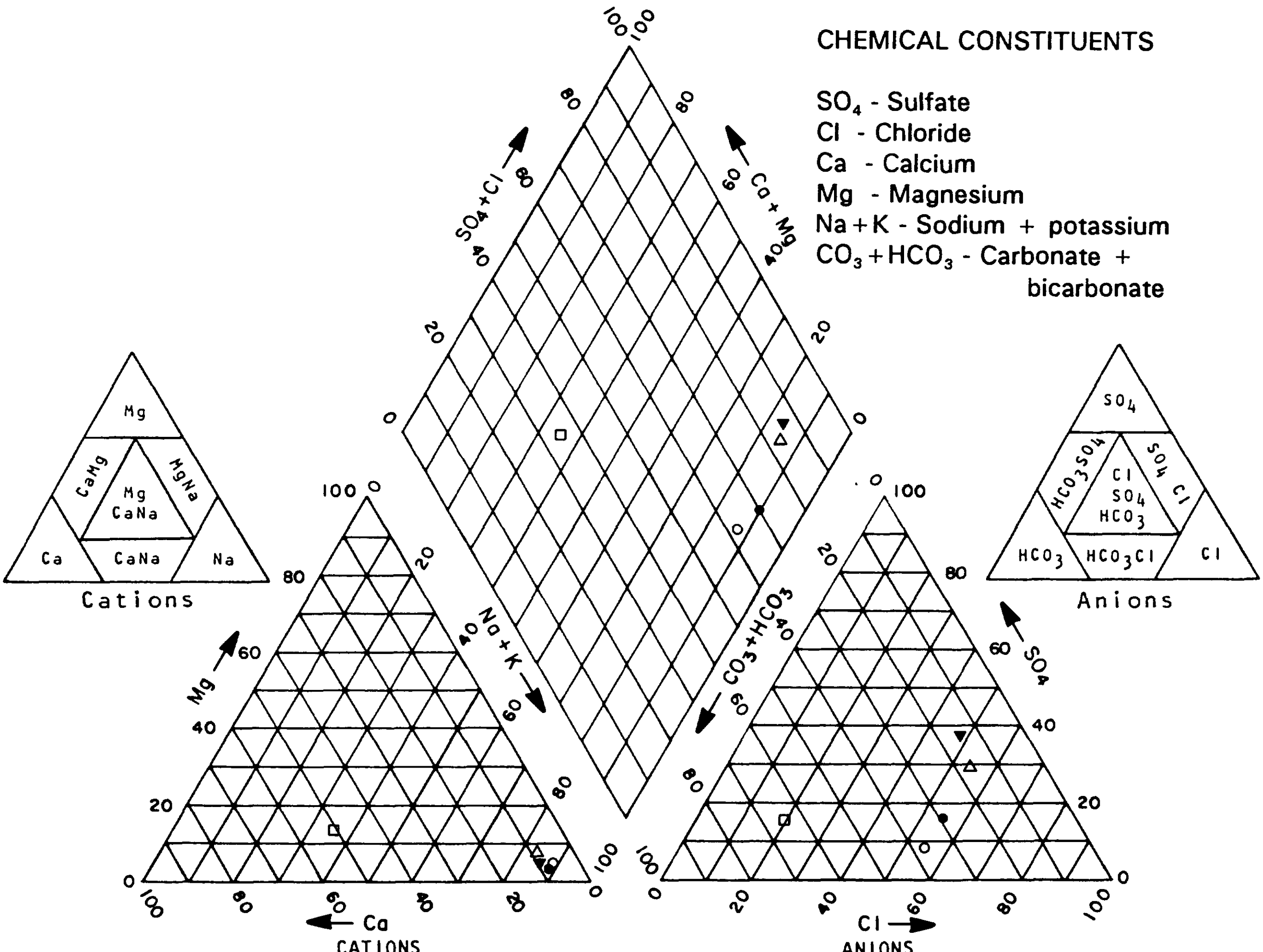
Quality of water from the Madera Limestone varies from fresh to very saline. This variation in water quality depends on the particular ground-water province.

San Juan Basin province

Quality of water in the Madera Limestone in the San Juan Basin province is moderately saline to very saline. For example, the numerous samples of water from Kaseman 2 well (Warm Springs) probably represent a composite of water from the Madera Limestone and from the overlying Abo, Yeso, and Chinle Formations. The specific conductance was 15,000 microsiemens and the dissolved-solids concentration was about 11,000 milligrams per liter (Craigg, 1984, table 3), and the analysis plots in the sodium chloride sulfate field (fig. 14). The water also contained large concentrations of certain trace elements; reported values ranged from 360 to 600 micrograms per liter arsenic, 4,800 to 7,900 micrograms per liter boron, and 1,400 to 2,100 micrograms per liter iron. One analysis reported 7,200 micrograms per liter of lithium (Craigg, 1984, table 4). Temperature of the water was 52 degrees Celsius.

Water from the Peñasco mound springs is moderately saline, but variable. For example, water from Swimming Pool Spring had a specific conductance of 10,500 microsiemens and a dissolved-solids concentration of 7,460 milligrams per liter (Craigg, 1984, table 5), and plots as a sodium chloride sulfate type (fig. 14). The specific conductance of water from other mound springs in the area ranged from 9,000 to 16,000 microsiemens. Temperatures ranged from 19 to 27 degrees Celsius.

A sample of water from one of the San Ysidro group of mound springs along State Highway 44 was collected by the author in 1982 (sec. 10, T. 15 N., R. 1 W.). The specific conductance of this water was 9,000 microsiemens and the dissolved-solids concentration was 6,080 milligrams per liter, and the water was a sodium chloride bicarbonate sulfate type. The water also contained large concentrations of arsenic (520 micrograms per liter), iron (1,100 micrograms per liter), and manganese (2,000 micrograms per liter). Although the Madera Limestone probably is the principal source of spring discharge in this area, samples may represent a composite from the Madera and the overlying Abo, Yeso, and Chinle Formations.



EXPLANATION

WATER FROM:

PUEBLO OF JEMEZ

- ● Salt Spring
- ○ Indian Spring
- □ Owl Spring
- △ Swimming Pool Spring

PUEBLO OF ZIA

▼ Kaseman 2 well (Warm Springs)
(water sample probably is a composite from the Madera Limestone, various Permian rocks, and the Chinle Formation)

Figure 14.--Trilinear plot of major dissolved constituents in water from the Madera Limestone. Small triangles at sides give key to classification (see Craigg, 1984, tables 3 and 5 for chemical analyses).

The Peñasco mound springs discharge into Arroyo Peñasco at a fairly constant cumulative rate of about 0.3 cubic foot per second, and the water has a virtually constant specific conductance of 12,000 microsiemens (Craigg, 1984, table 9). A chemical analysis of this water made in 1974 determined that the water contained 8,260 milligrams per liter dissolved solids and large concentrations of sodium, sulfate, and chloride. The water also contained 70 micrograms per liter arsenic, 7,400 micrograms per liter boron, and 6,100 micrograms per liter lithium (Craigg, 1984, table 8).

Sierra Nacimiento province

Quality of water from this structurally elevated block of Madera Limestone, on the south end of the Sierra Nacimiento, is fresh. The specific conductance of water from Owl Spring was 650 microsiemens and the dissolved-solids concentration was 482 milligrams per liter, and the analysis plots in the calcium sodium bicarbonate field (fig. 14). Water from Tunnel Spring had a specific conductance of 1,100 microsiemens and a dissolved-solids concentration of 674 milligrams per liter (Craigg, 1984, table 5).

Trace-metal concentrations also are much smaller in water from this ground-water province. For example, water from Owl and Tunnel Springs contained, respectively, 0 and 8 micrograms per liter arsenic, 170 and 320 micrograms per liter boron, and 0.2 and 0.6 microgram per liter bromide. Water from Owl Spring contained 110 micrograms per liter lithium and no manganese (Craigg, 1984, table 6).

Jemez Valley province

Quality of water from the Madera Limestone in the Jemez Valley province is moderately saline. For example, water from Salt Spring had a specific conductance of 8,200 microsiemens and contained 4,150 milligrams per liter dissolved solids (Craigg, 1984, table 5), and plots in the sodium chloride bicarbonate field (fig. 14). Water from Indian Spring, which discharges into the Jemez River, had a specific conductance of 7,000 microsiemens and a dissolved-solids concentration of 3,770 milligrams per liter (Craigg, 1984, table 5), and also plots in the sodium chloride bicarbonate field of figure 14. Chloride concentrations in water from Salt and Indian Springs are large, being 1,400 and 1,200 milligrams per liter when sampled, respectively (Craigg, 1984, table 5).

Concentrations of certain trace metals in ground water also are large in this ground-water province. For example, water from Salt Spring contained 86 micrograms per liter arsenic, 5,800 micrograms per liter boron, 5.0 micrograms per liter bromide, about 2,800 micrograms per liter lithium, and 340 micrograms per liter manganese. Water from Indian Spring contained 69 micrograms per liter arsenic, 8,200 micrograms per liter boron, 5.0 micrograms per liter bromide, 6,700 micrograms per liter lithium, and 300 micrograms per liter manganese (Craigg, 1984, table 6).

Precambrian Rocks

Geologic Characteristics

Precambrian rocks in the study area are exposed only in the Sierra Nacimiento province at the eastern boundary of the Ojo del Espiritu Santo Grant (pl. 3). These rocks generally consist of various intrusive igneous and metamorphic rock types, such as coarsely crystalline, pinkish granite; and grayish-pink schist and gneiss. These rocks are unconformably overlain by and in fault contact with much younger rocks of Paleozoic age. The specific rock types present and their relations have been discussed in detail by Woodward and others (1974). The Precambrian rocks are locally fractured, intensely jointed and foliated, and faulted.

Hydrologic Characteristics

No wells in the study area are known to be completed in Precambrian rocks. Three springs in the study area, all on the Pueblo of Jemez, issue from Precambrian rocks in the Sierra Nacimiento province (Craigg, 1984, table 2, pl. 2). Log Spring (16.01E.05.244 on pl. 2) issues from gneiss in a tributary of Arroyo Peñasco in the Jack Rabbit Flats area. Discharge of water from Log Spring is 9 gallons per minute. Bear Spring (18.01E.17.324 on pl. 2) issues from granite in the headwaters of Rito Olguin, reportedly at a rate of 1 gallon per minute. An unnamed spring (18.01E.07.424 on pl. 2) also issues from granite about 1 mile north of Bear Springs; no discharge or other data are available for this spring, but the yield probably is small. It is not known if discharge from these springs fluctuates seasonally. Numerous small seeps issuing from Precambrian rocks probably are present throughout this part of the Pueblo of Jemez. Several other springs that issue from Precambrian crystalline rocks also occur outside the study area boundary in the Sierra Nacimiento (Trainer, 1978).

Water Quality

Quality of water from springs issuing from Precambrian rocks in the study area probably is fresh because of close proximity to the local recharge areas. Water from Log Spring had a specific conductance of 450 microsiemens and a dissolved-solids concentration of 310 milligrams per liter (Craigg, 1984, table 5), and plots in the calcium magnesium sodium bicarbonate field in figure 10.

A chemical analysis exists for water from Crow Spring about 2 miles east of Pajarito Peak (sec. 23, T. 17 N., R. 1 E.). The specific conductance of the water was 550 microsiemens and the dissolved-solids concentration was 335 milligrams per liter, and the water type was calcium bicarbonate.

HYDROGEOLOGY

Hydrogeology is the study of geologic controls of the occurrence, movement, and quality of ground water. Once geologic and hydrologic characteristics of an area have been determined, their relation may be assessed. Although geologic controls can be generalized for many hydrologic systems, each area has its local, generally complex, geologic conditions. Based on the geologic and hydrologic information presented in the previous sections, some interpretations of the hydrogeology of the study area can be made.

Generalized Geologic Controls of Ground-Water Occurrence

Ground water in all three provinces of the study area (fig. 4) mainly is present in the intergranular pore spaces of sandstone and alluvium and in fractures and solution cavities of limestone. In the San Juan Basin province, some ground water also may be in solution cavities of gypsum. In the Sierra Nacimiento province, ground water also is in fractures in crystalline rocks. In the Jemez Valley province, some ground water may be in fractures in basalt flows.

The occurrence of ground water in sandstone beds primarily is controlled by the porosity, permeability, and geometry of the sandstone beds. These factors are in turn controlled by the depositional and postdepositional history of the sandstone beds.

Generalized Geologic Controls of Ground-Water Movement

Ground-water movement consists of three major parts: (1) recharge, the process by which ground water is replenished; (2) flow, the process by which ground water is moved from areas of recharge to areas of discharge; and (3) discharge, the process by which ground water is released from the aquifer.

Recharge

Recharge is enhanced where aquifers are at or near the land surface, thus intercepting precipitation and runoff. Uplift, folding, faulting, and erosion have placed aquifers at the land surface both in and adjacent to the study area. Alluvium and the Santa Fe aquifer were placed at the land surface by the processes of erosion and deposition. Recharge in the study area is both direct (from the land surface) and indirect (from the land surface by means of other geologic units). The primary means of recharge to aquifers in the study area probably is by transmission loss of flow in streams crossing outcrops. An unknown quantity of recharge also results from infiltration of precipitation falling directly on outcrops and by subsurface leakage between geologic units containing water under different hydraulic heads.

Flow

Movement of water in an aquifer or aquifers can be divided into flow systems. The directions of ground-water flow may be controlled by the orientation of permeable zones or by regional topography because it affects the location and altitude of recharge and discharge areas. In these systems, flow commonly is through interconnected pore spaces. Water in confined (artesian) bedrock aquifers flows from areas of higher hydraulic head to areas of lower hydraulic head. In unconfined (water-table) aquifers, water moves from areas of higher altitude of the water table to areas of lower altitude in response to gravity. Flow in alluvium is generally downslope in virtually the same direction as the associated streamflow.

Discharge

Geologic controls of discharge are much like those of recharge. Ground water in confined aquifers, like water in most bedrock units in the study area, discharges wherever the potentiometric surface representative of the hydraulic heads is at or above the land surface and the water can move easily to the land surface either because the unit is exposed at the land surface or because the overlying units are fractured. Water in unconfined aquifers, such as alluvium, discharges wherever the water table intersects the land surface or wherever the roots of plants that consume ground water (phreatophytes) reach the water table.

Ground-water discharge in the study area is both natural and induced. Natural discharge consists of springflow, especially along the Pajarito fault zone on the west flank of the Sierra Nacimiento and along the Jemez fault zone west of the Jemez River. Natural discharge also is caused by evapotranspiration, principally by phreatophytes (cottonwood, salt cedar, and Russian olive) along the Jemez River. Induced discharge is caused by pumping wells and by discharge from flowing wells.

Generalized Geologic Controls of Ground-Water Quality

A commonly used measure of water quality is dissolved-solids concentration. Dissolved ions in water in aquifers in the study area originate from dissolution of minerals in rocks or sediments through which the water flows and from mixing with water that has leaked from adjacent geologic units.

Other factors that affect water quality in a particular aquifer are the quality of the initial recharge water, chemical reactions between the water and minerals in the aquifer, and the distance traveled and length of time the water has remained in the aquifer (residence time).

Hydrogeology of the Ground-Water Provinces

The three regions described under "Ground-water provinces" (fig. 4) are hydrogeologically distinct. Each province can be considered to contain separate regional ground-water flow systems. At province boundaries, however, these flow systems converge, and as a result, ground waters of differing quality mix. For example, the crystalline-rock terrain of the northern one-half of the Sierra Nacimiento province contributes fresh water locally to the San Juan Basin province on the west and to the Jemez Valley province on the east via fractures. Near the mouth of the Rio Salado, ground water flowing from the three provinces mixes and flows generally southeast toward the Rio Grande valley. This mixing adversely affects the quality of water from alluvium and the Santa Fe aquifer downgradient from the area of convergence (figs. 5 and 8).

Division of the study area into three hydrogeologically distinct provinces provides a useful basis for discussion of geologic controls of ground-water occurrence, movement, and quality. Although controls of ground-water occurrence and movement may be similar for aquifers in a given province, these controls differ between provinces. Controls of ground-water quality are more specific to each province.

San Juan Basin Province

Occurrence of ground water

Potential aquifers in the San Juan Basin province include the alluvium, terrace deposits (near the mountain front), sandstone beds in the Mancos Shale, the Dakota Sandstone, sandstone beds in the Brushy Basin Shale Member of the Morrison Formation, the Westwater Canyon Sandstone Member of the Morrison Formation, the Jackpile Sandstone Member of the Morrison Formation, the Entrada Sandstone, the Agua Zarca Sandstone Member of the Chinle Formation, and sandstone beds in various Permian rocks. Because of regional westerly dip of the strata, aquifers are deeper toward the west and ground water probably becomes more mineralized.

Most bedrock aquifers basically have a sheetlike geometry. Depths to a particular unit at a given locality, therefore, can be predicted with confidence. Sandstone beds in the Mancos Shale, however, probably are lenticular in nature, and exploration for ground water in this unit may be more difficult.

The location of a group of large mound springs in the Arroyo Peñasco area is controlled by the north- and northeast-trending Pajarito fault; some of these springs occur directly on the Pajarito fault. The Pajarito fault probably has created a conduit for deep ground water flowing southeastward in the San Juan Basin province to move upward and discharge at the land surface. Springs issuing from Cretaceous rocks to the northwest likely are controlled by local fracturing or are located where saturated sandstone overlies almost impermeable shale. Springs in alluvium occur where the local water table intersects the land surface.

Movement of ground water

Aquifers in the San Juan Basin province are recharged along the western flank of the Sierra Nacimiento directly by infiltration of precipitation on outcrops and by infiltration of runoff in streams originating in the Sierra Nacimiento province. Farther west, as the aquifers dip deeper into the subsurface, water may be contributed by leakage of water from adjacent geologic units. Aquifers also are recharged north of the study area along the Sierra Nacimiento front and to the southwest along the flanks of Mount Taylor (outside the study area) where streams cross the outcrops.

Movement of water in Cretaceous rocks in the province is southwest (fig. 15). Farther south, in the Rio Salado area, flow moves southeast in younger rocks and merges with regional ground-water flow from the central part of the San Juan Basin, as shown by Lyford (1979) and Craigg (1980). This ground water flows into the southeastern part of the Jemez Valley and Rio Grande rift (Albuquerque Basin); some of the water moves upward and discharges along faults and fractures as saline springs in the Arroyo Peñasco and Rio Salado areas (pl. 4).

Quality of ground water

Ground water in this province is fresh near the mountain front. Farther west and in the Rio Salado area, it ranges from slightly to very saline because of upward leakage of saline ground water flowing southeast from the San Juan Basin (Craigg, 1984, tables 2 and 5, pl. 2). Controls of ground-water quality include mineralogic composition of aquifers and residence time of the water in aquifers and adjacent units.

Sierra Nacimiento Province

Occurrence of ground water

Ground water in the Sierra Nacimiento province is present in the alluvium and the Agua Zarca Sandstone Member of the Chinle Formation in the south; in sandstone beds of various Permian rocks, in the Madera Limestone, and in fractured Precambrian crystalline rocks in the north. Several springs issue from Permian sandstones and Precambrian rocks in the northern part of the province (Craigg, 1984, table 2, pl. 2). The springs issuing from Permian rocks are located where saturated sandstone overlies almost impermeable shale. The springs issuing from Precambrian rocks are controlled by local permeable zones associated with fracturing and jointing. At the eastern edge of the province along the Jemez fault, a group of springs issues from the Chinle Formation, Abo Formation, and Madera Limestone (Craigg, 1984, table 2, pl. 2).

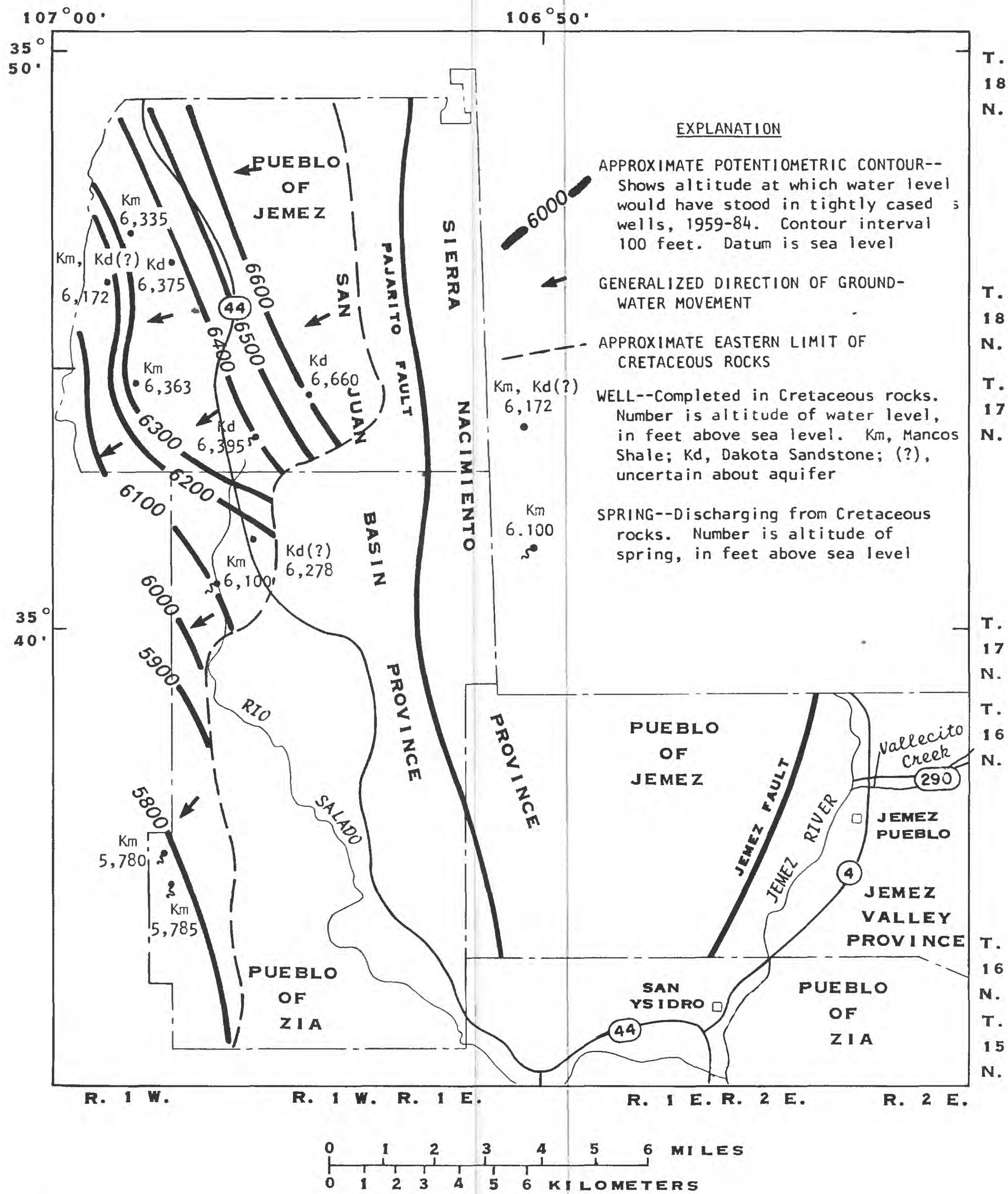


Figure 15.--Water-level altitudes, generalized potentiometric surface, and generalized direction of water movement in Cretaceous rocks in the San Juan Basin province (data from Craigg, 1984, tables 1 and 2).

Movement of ground water

The Sierra Nacimiento province is a structurally elevated block lying between the San Juan Basin province on the west and the Jemez Valley province on the east. Aquifers are recharged directly by infiltration of snowmelt and storm runoff from streams crossing the outcrops. Much of the recharge may occur north of the study area along perennial mountain streams. Regional flow is from higher altitudes of the recharge areas south toward the Rio Salado, southwest toward the San Juan Basin, and southeast toward the Jemez Valley province.

Discharge is by springs along the Sierra Nacimiento front at fracture zones and by ground-water base flow to perennial streams. The altitudes of these springs are shown in figure 16. Discharge of water from the Sierra Nacimiento province contributes to recharge of aquifers in the San Juan Basin and Jemez Valley provinces.

Quality of ground water

Ground water in the northern part of the province is fresh because of local recharge from snowmelt and storm runoff. Water samples from fractured Precambrian crystalline rocks have specific-conductance values of about 500 microsiemens. Water samples from Paleozoic rocks have specific-conductance values of generally less than 1,000 microsiemens. Farther south, water becomes more mineralized, and specific-conductance values are about 2,500 microsiemens in the samples from the Chinle Formation (Craigg, 1984, tables 2 and 5, pl. 2). This probably is because of longer residence time of the water and possible mixing with more mineralized ground water from the other provinces.

Jemez Valley Province

Occurrence of ground water

Ground water in the Jemez Valley province is under unconfined (water-table) conditions principally in alluvium and poorly consolidated sediments of the Santa Fe aquifer (pl. 4). These are the two most important aquifers in the study area. Water also is present in the Agua Zarca Sandstone Member of the Chinle Formation and probably in local fractured zones in volcanic rocks of the Borrego and Santa Ana Mesa areas. Water also is present in deeper Paleozoic limestone and sandstone.

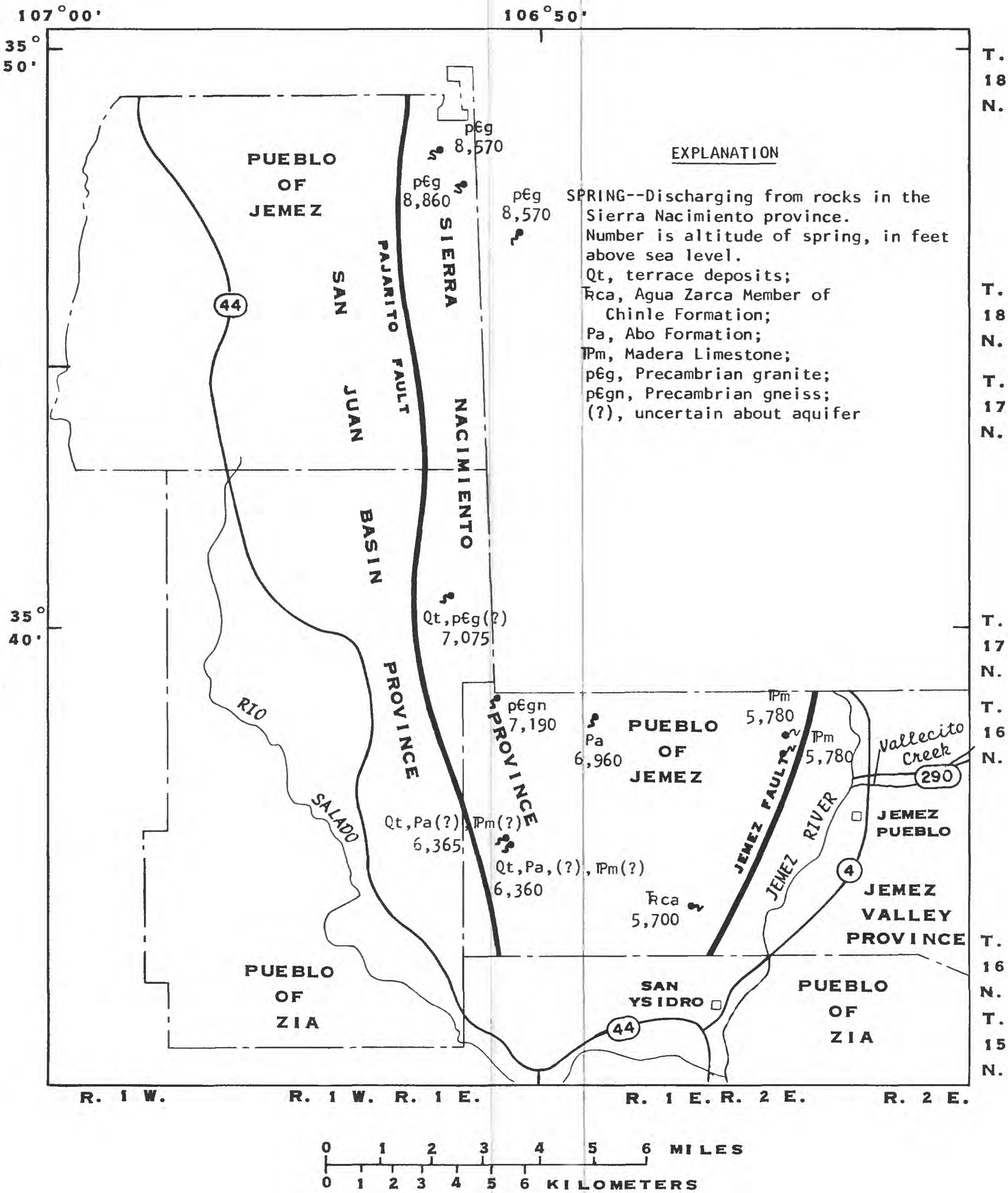


Figure 16.--Altitudes of springs in the Sierra Nacimiento province (data from Craigg, 1984, table 2).

Movement of ground water

Water in alluvium in the Jemez Valley province is recharged directly by infiltration of runoff in stream channels and by the leakage of more mineralized water from bedrock units. The Santa Fe aquifer mainly is recharged by infiltration of runoff where arroyos cross the extensive, gently dipping outcrops; the aquifer also is recharged by infiltration of precipitation on the extensive outcrop of the aquifer. Recharge areas are in and north of the study area. The Jemez River provides a dependable source of recharge to the alluvium and the Santa Fe aquifer. North-trending normal faults between the Zia and Santa Ana Pueblos probably enhance recharge to the Santa Fe aquifer, especially where these faults intersect the Jemez River, allowing for infiltration of streamflow. The Santa Fe aquifer probably also is recharged locally on Borrego and Santa Ana Mesas through fractures in volcanic rocks (pl. 3). Triassic, Permian, and Pennsylvanian rocks are recharged north of the area where the Jemez River and other streams cross the extensive outcrops of these rocks.

Flow of water in the alluvium of the Jemez River valley is downgradient generally in the same direction as streamflow (fig. 17). Slope of the water table in the alluvium is about 17 feet per mile. Flow of water in the Santa Fe aquifer generally is from higher altitudes in the north toward the Jemez River in the south (fig. 18). In the vicinity of the Jemez River, flow lines bend southeast toward the Rio Grande. There probably is a deeper component of water flow in the Santa Fe beneath the Jemez River that trends south. Slope of the water table in the Santa Fe aquifer ranges from about 17 feet per mile between the Zia and Santa Ana Pueblos to 300 feet per mile beneath Borrego Mesa (fig. 17). A hydraulic gradient probably exists from the sides of the valley toward the Jemez River, especially when the stream is gaining.

In the Jemez Pueblo area, the Santa Fe aquifer and deeper aquifers may discharge water upward into the alluvium, as indicated by differences in hydraulic head (pl. 4, figs. 17 and 18; Craigg, 1984, table 1). An increase in chloride concentration downgradient also indicates upward leakage of ground water. This was reported in Trainer (1978), Craigg (1984, table 7), and is discussed further in the section "Relation of surface water and ground water." In the southeastern part of the Jemez River valley, more mineralized water in alluvium leaks downward into the Santa Fe aquifer.

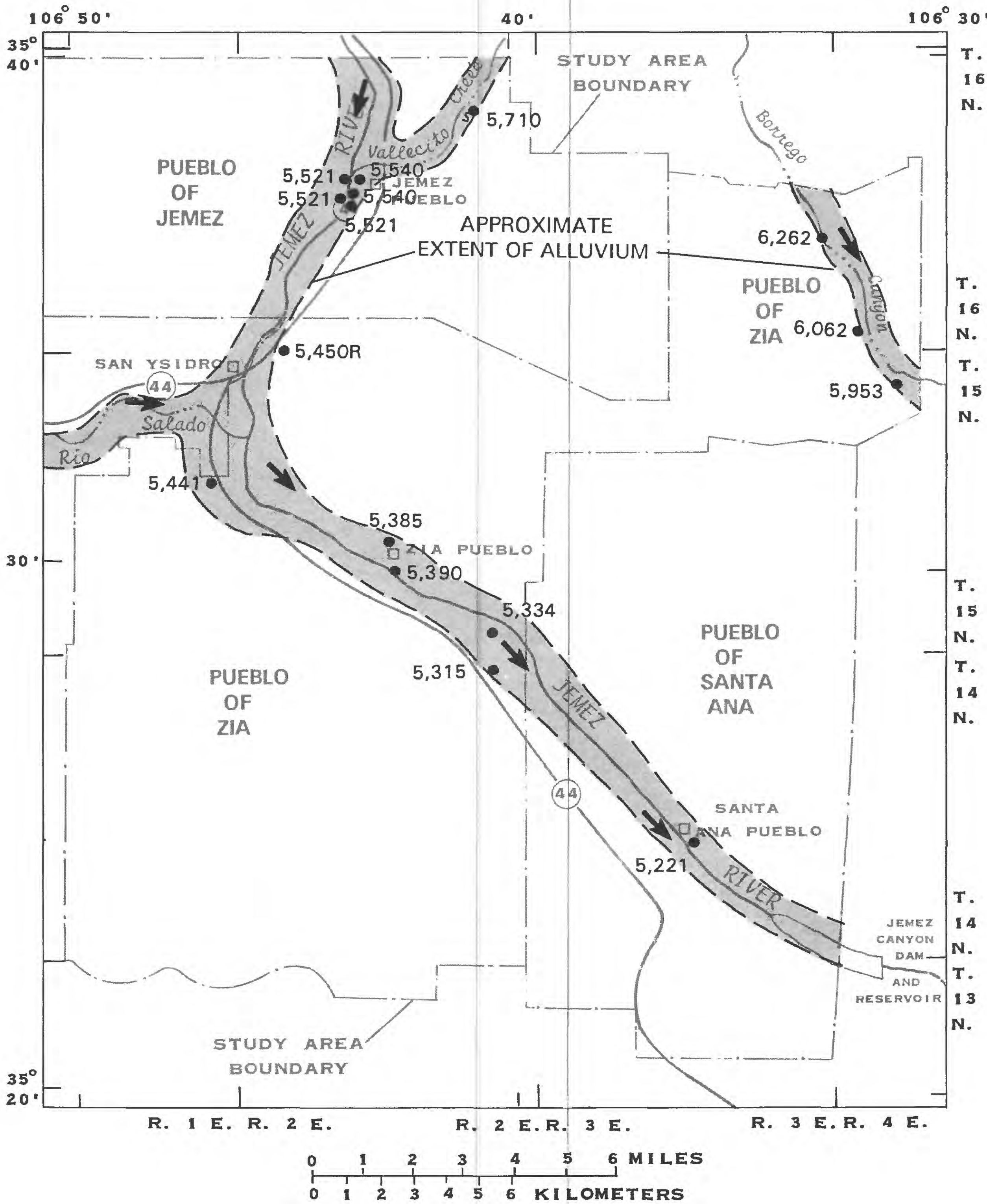


Figure 17.--Water-level altitudes and generalized direction of water movement in the alluvium in the Jemez Valley province (data from Craigg, 1984, tables 1 and 2).

Water in the alluvium is discharged naturally along the major stream valleys as evapotranspiration, particularly along the Jemez River. Induced discharge is by pumping of wells completed in alluvium, particularly the municipal-supply wells at Jemez Pueblo. Water in the Santa Fe aquifer is discharged naturally as evapotranspiration and induced discharge is by pumping of numerous wells (Craigg, 1984, table 1, pl. 1). Several springs on the south end of Borrego Mesa discharge water from the Santa Fe aquifer along north-trending normal faults (pl. 3; Craigg, 1984, pl. 2) and also discharge water by leakage in the alluvium. The Chinle Formation discharges water at springs along Vallecito Creek (Craigg, 1984, table 2, pl. 2). The Chinle probably also discharges water by upward leakage of water to shallower units. Discharge of water from the Madera Limestone is by upward leakage of water into shallower aquifers including the Santa Fe aquifer and alluvium. The Madera Limestone on the east side of the Jemez fault probably is hydraulically connected to the Jemez geothermal area, and ground water discharged to shallower units in the Jemez River valley is believed to be associated with the geothermal water of the Jemez caldera (F.P. Trainer, U.S. Geological Survey, retired, oral commun., 1985).

Quality of ground water

Water from the alluvium in the Jemez Valley province generally is fresh upstream from the confluence of the Rio Salado and the Jemez River, and is slightly saline downstream from that confluence because of inflowing saline ground water from the San Juan Basin province and because of recharge from very saline surface water in the Rio Salado. Water from the Santa Fe aquifer is fresh except adjacent to the alluvium in the southeastern part of the Jemez River valley because of downward leakage of water from the alluvium and inflowing saline ground water from the San Juan Basin province (figs. 15, 17-19). Controls of ground-water quality include lithologic composition of aquifers, residence time of ground water, and faulting, which may enhance upward leakage of more mineralized water from deeper units.

EXPLANATION

→ GENERALIZED DIRECTION OF GROUND-WATER MOVEMENT

5,521 ● WELL--Completed in alluvium. Number is altitude of water level, in feet above sea level. R, reported water level

5,710 SPRING--Discharging from alluvium. Number is altitude of spring, in feet above sea level

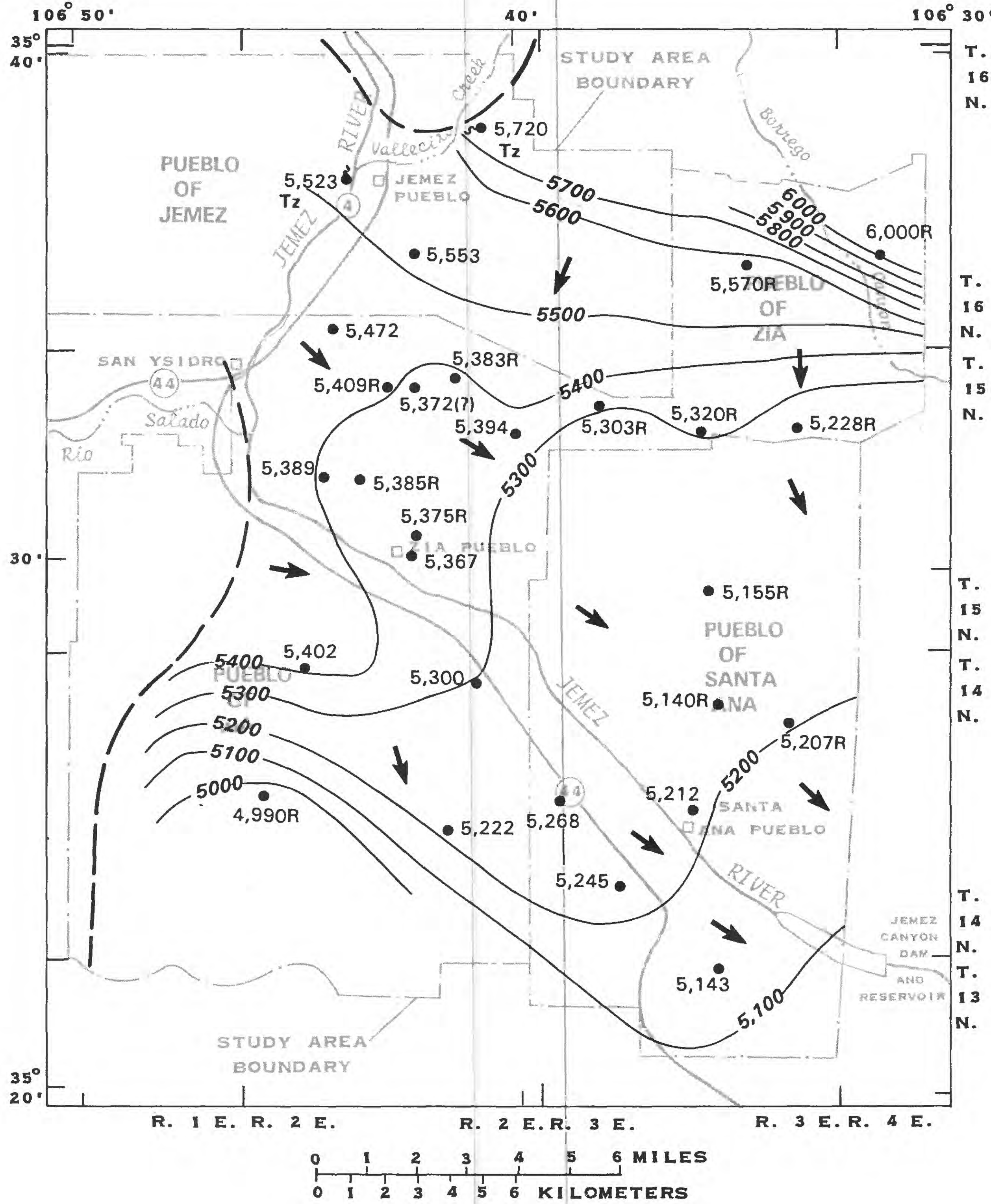


Figure 18.--Water-level altitudes, generalized potentiometric surface, and generalized direction of water movement in the Santa Fe aquifer in the Jemez Valley province (see Craigg, 1984, tables 1 and 2).

REGIONAL SURFACE-WATER HYDROLOGY

The Jemez River is the major perennial stream on the Pueblos of Jemez, Zia, and Santa Ana. The river drains an area of about 1,050 square miles of mountain and semidesert terrain before joining the Rio Grande. The drainage basin is approximately elliptical and elongated in a northerly direction (fig. 20). Principal tributaries within the study area are the Rio Salado, Vallecito Creek, Tecolote Canyon, Arroyo Chamisa, Arroyo Arenoso, Arroyo Piedra Parada, and Arroyo Ojito (pl. 1). Most tributaries are ephemeral; however, the Rio Salado and Vallecito Creek are intermittent through certain reaches.

Few studies have been conducted on the Jemez River, especially along the reach between the Jemez and Santa Ana Pueblos. Most of the data collection and interpretation have been done by the U.S. Geological Survey. Trainer (1978) collected data on streamflow and water quality in the reach upstream from San Ysidro. Fischer and Borland (1983) estimated natural streamflow at the boundaries of the Pueblos of Jemez, Zia, and Santa Ana. Craigg (1984) tabulated miscellaneous streamflow and water-quality data and reported results of a seepage run conducted between the Jemez and Santa Ana Pueblos.

A quantitative surface-water investigation is beyond the scope of this study. Some observations, generalizations, and interpretations can be made, however, about streamflow, surface-water quality, and interactions between surface water and ground water.

Streamflow

Discharge has been measured for various periods at several streamflow-gaging stations in the Jemez River basin (fig. 20, table 1). Discharge of the Jemez River has been measured at the U.S. Geological Survey's streamflow-gaging station (Jemez River near Jemez) about 3 miles upstream from Jemez Pueblo from June 1936 to May 1941, August 1949 to October 1950, May 1951 to September 1952 (irrigation seasons only), and March 1953 to the current year (table 1). The area drained by the river upstream from this gage is 470 square miles and mainly consists of mountainous terrain composed of Precambrian crystalline rocks, Paleozoic sandstone, shale, and limestone, and Tertiary and Quaternary volcanic rocks.

EXPLANATION

6000 — APPROXIMATE POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells, 1940-84. Contour interval 100 feet. Datum is sea level

GENERALIZED DIRECTION OF GROUND-WATER MOVEMENT

APPROXIMATE LIMIT OF SANTA FE GROUP AND RELATED STRATA

5,570R ● WELL--Completed in Santa Fe aquifer. Number is altitude of water level, in feet above sea level. R, reported water level. (?), questionable water level

5,720 Tz SPRING--Discharging from Santa Fe aquifer. Number is altitude of spring, in feet above sea level. R, reported water level. Tz, Zia Sand

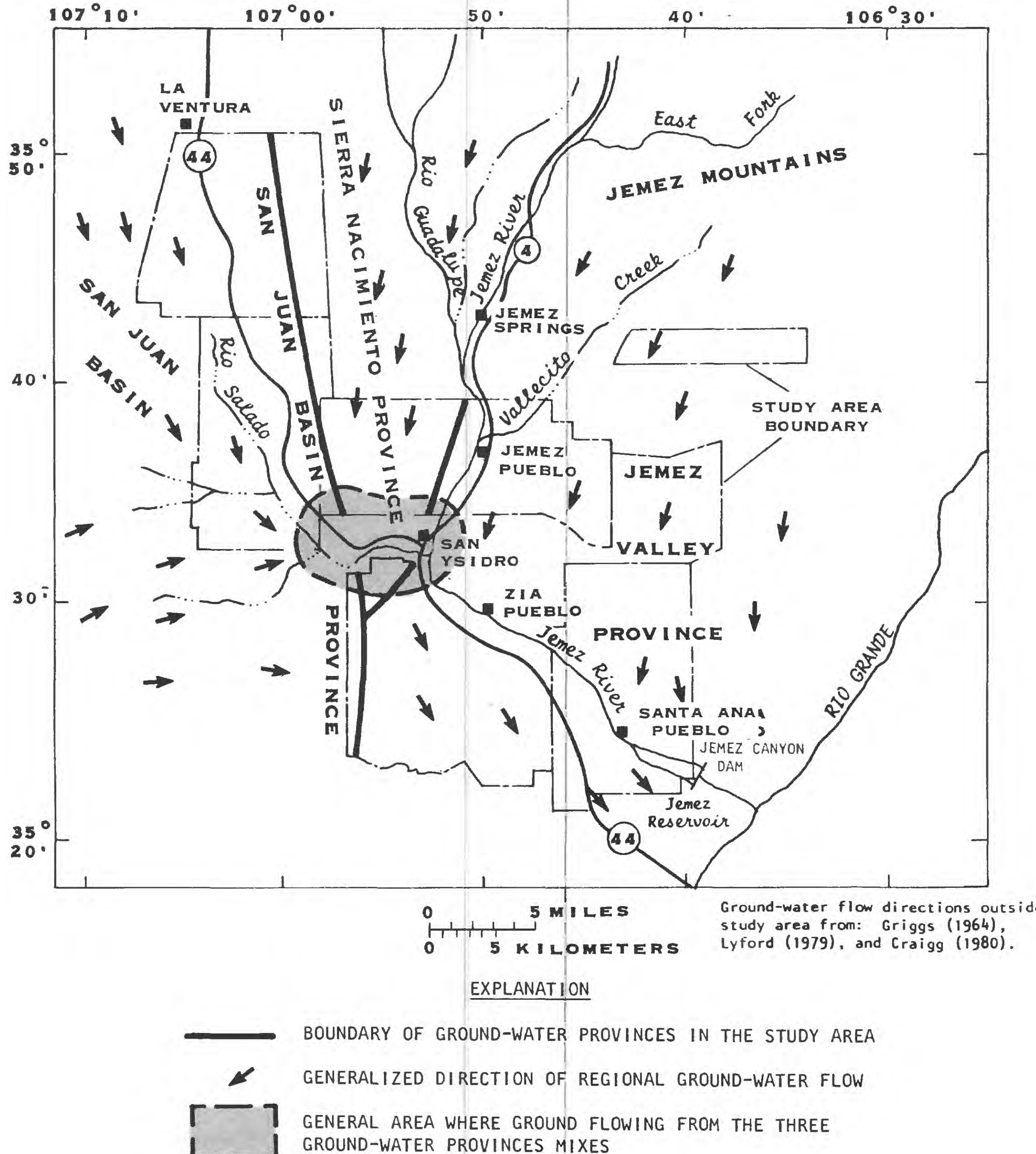


Figure 19.--Relation of ground-water flow systems in ground-water provinces of the study area to the major regional ground-water flow systems of the San Juan Basin and the Jemez Mountains (see figs. 12, 13, and 15).

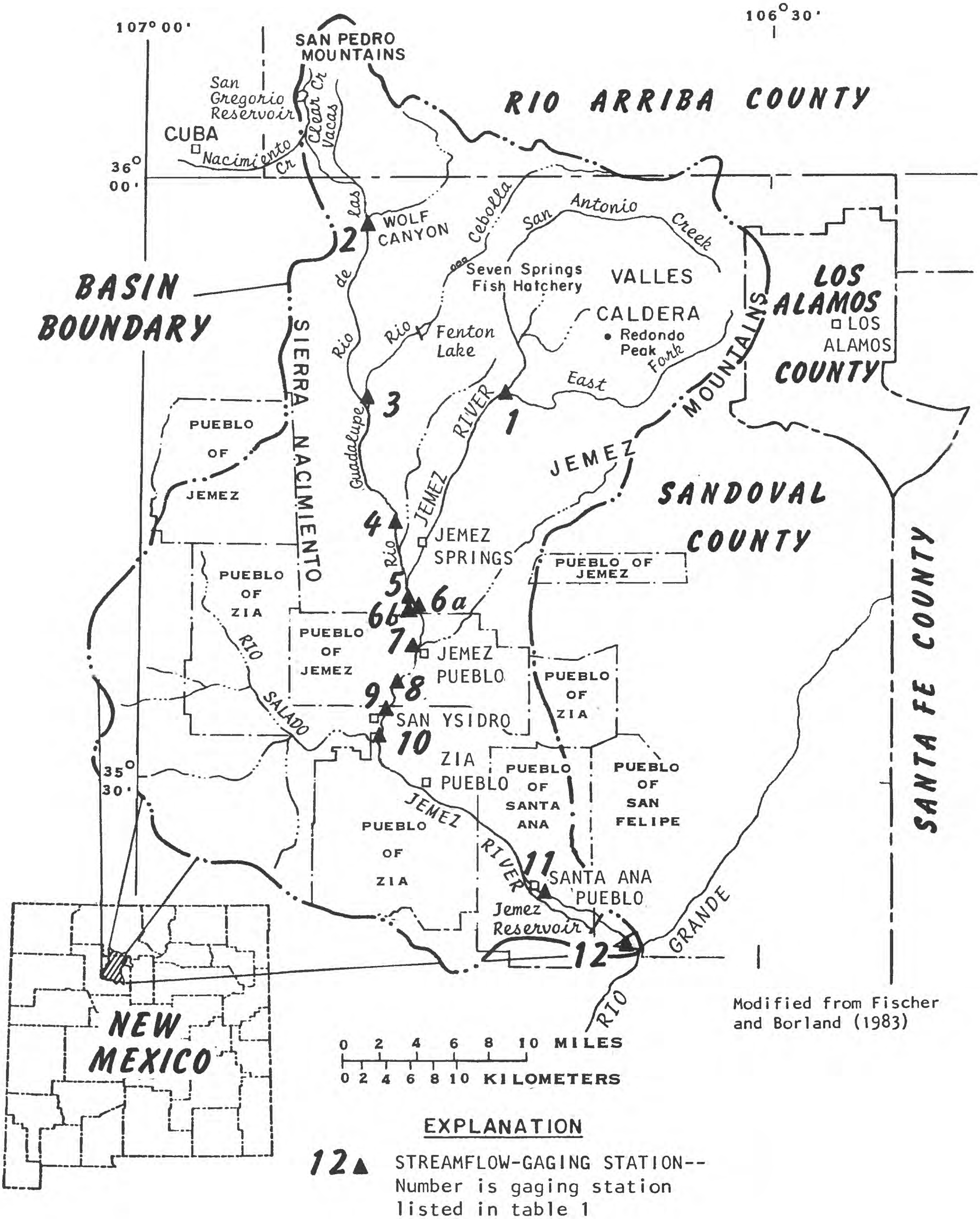


Figure 20.--Location of streamflow-gaging stations in the Jemez River basin.

Seasonal Variations

Average annual discharge past the Jemez River near Jemez streamflow gage for the period of record is about 72 cubic feet per second; the minimum average annual discharge was about 29 cubic feet per second during water year 1977, and the maximum was 189 cubic feet per second during water year 1973. The relation between average annual discharge and the period-of-record average discharge is shown in figure 21. Examination of this hydrograph indicates that average annual flow varies substantially from the period-of-record average.

Runoff past this streamflow gage is continuous throughout each year, but quantities vary seasonally. This seasonal variation of streamflow is shown graphically in figure 22, a hydrograph of mean monthly discharge for the period of record; the mean monthly discharge for each year of record is listed in table 2. Streamflow peaks occur during March through May or June, a period that represents snowmelt from the Sierra Nacimiento and Jemez Mountains (table 2). During March through May, an average of 63 percent of the annual streamflow is recorded at the gage (fig. 22); during March through June, an average of 70 percent of the annual streamflow is recorded (fig. 22). During the summer rainy season, commonly from July through September, an average of 12 percent of the annual streamflow is recorded (fig. 22). October through February commonly is a period of low flow, when an average of 18 percent of the annual streamflow is recorded (fig. 22). This period probably represents base-flow conditions when streamflow is sustained principally by ground-water discharge.

More than one-half of the annual flow in the Jemez River at the Jemez River near Jemez streamflow-gaging station originates as snowmelt. Different characteristics would be expected for the Rio Salado, however, which drains a semiarid area west of the Sierra Nacimiento. Although no streamflow records are available for the Rio Salado, Craigg (1980) reported that streams in semiarid drainage basins in this general area are ephemeral, and that as much as 99 percent of the annual discharge may occur during the summer rainy season.

Flow Duration

The tendency of the Jemez River at the Jemez River near Jemez streamflow-gaging station to sustain flows is shown graphically on the flow-duration curve (fig. 23). This curve shows the percentage of time that specific discharges were equaled or exceeded during the period of record. The entire range of flow is represented in figure 23. The shape of the flow-duration curve indicates the tendency of the river to sustain flows of particular magnitude. For example, only 1 percent of the time did flow equal or exceed about 700 cubic feet per second; 10 percent of the time flow equaled or exceeded about 150 cubic feet per second; 50 percent of the time flow equaled or exceeded about 30 cubic feet per second; 90 percent of the time flow equaled or exceeded 17 cubic feet per second; and 99 percent of the time flow equaled or exceeded about 12 cubic feet per second.

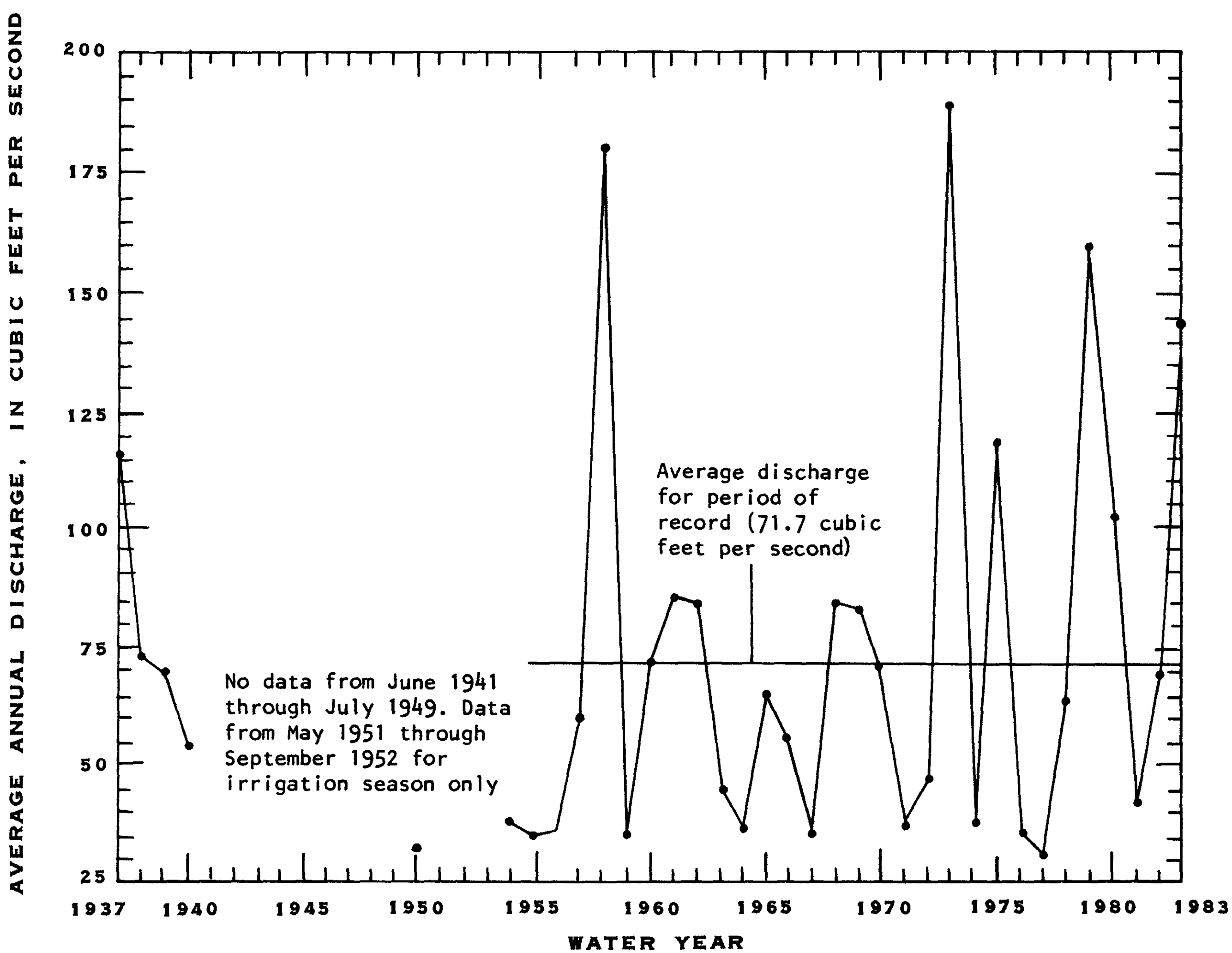


Figure 21.--Average annual discharge of the Jemez River at the Jemez River near Jemez streamflow-gaging station, and relation to average discharge for water years 1937-83.

WATER YEAR	AVERAGE ANNUAL DISCHARGE (CUBIC FEET PER SECOND)
1937	116.0
1938	73.5
1939	70.6
1940	53.8
1941	*
1950	31.7
1953	*
1954	37.7
1955	34.5
1956	35.5
1957	60.2
1958	180.0
1959	35.4
1960	72.7
1961	25.6
1962	83.6
1963	43.6
1964	35.6
1965	64.9
1966	54.6
1967	35.1
1968	84.1
1969	32.6
1970	70.3
1971	36.9
1972	45.5
1973	189.0
1974	37.2
1975	116.0
1976	35.3
1977	29.3
1978	62.5
1979	159.0
1980	102.0
1981	42.4
1982	68.2
1983	144.0

Average 71.7

* indicates data collected only during part of year

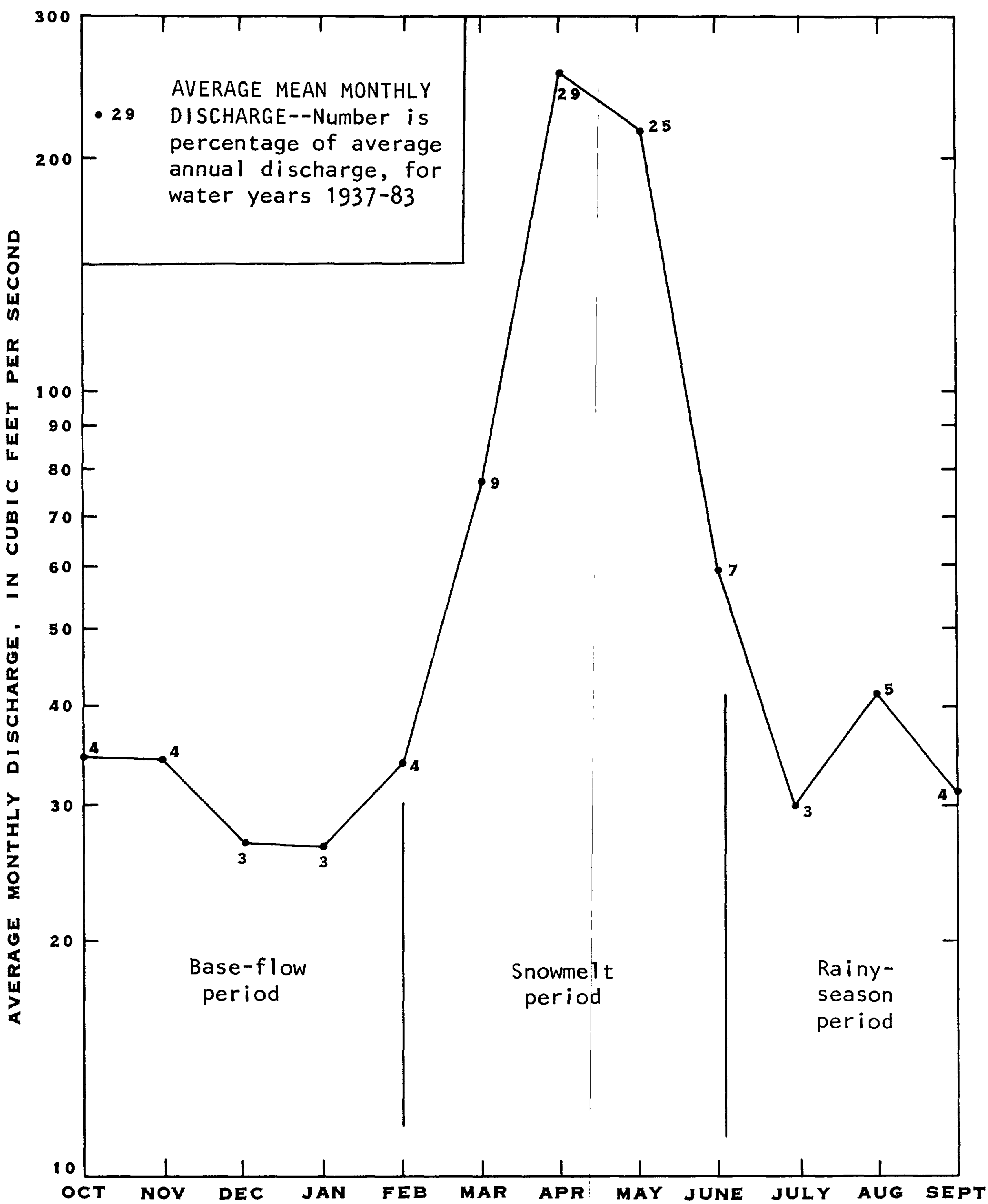
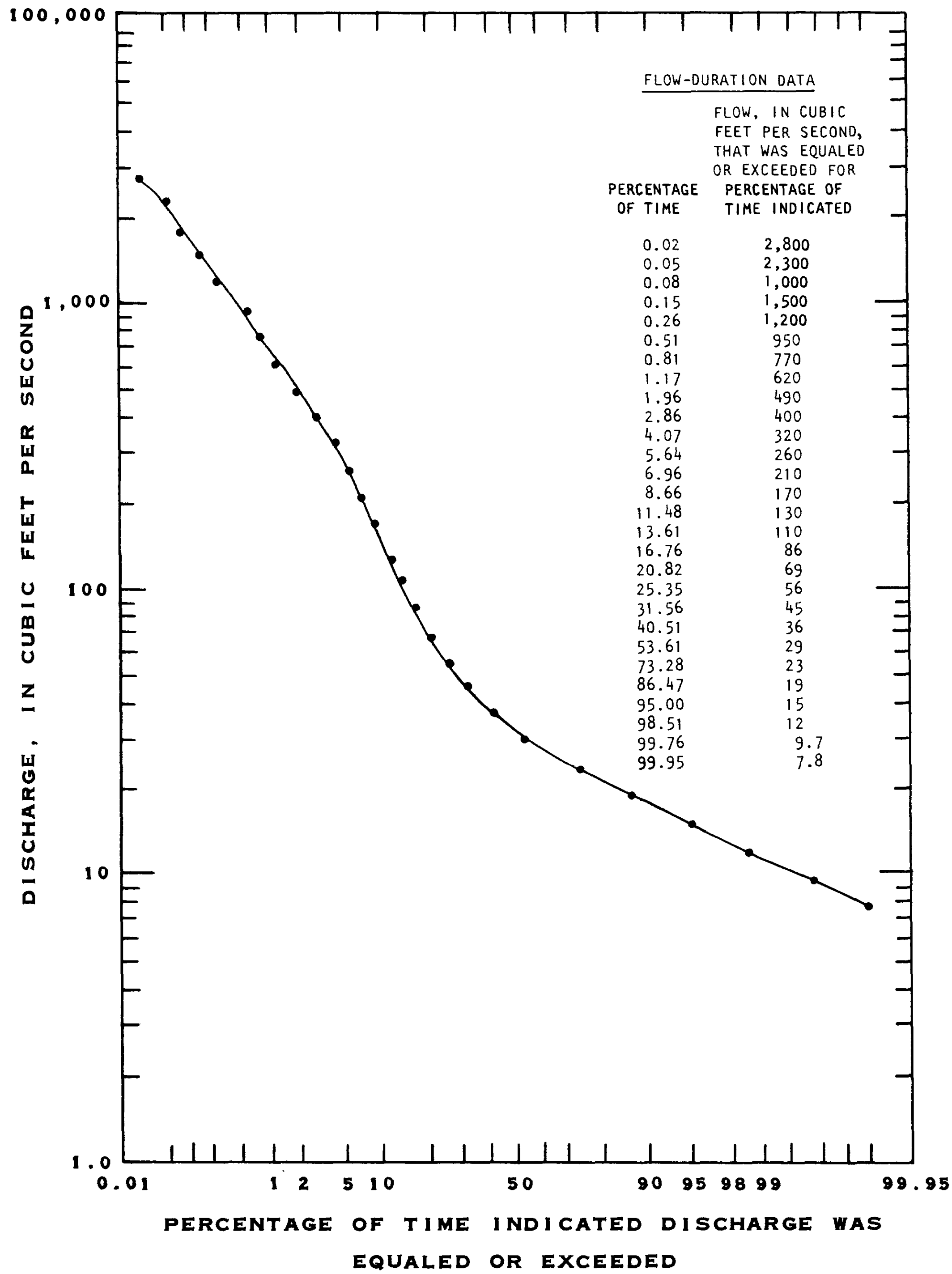


Figure 22.--Mean monthly discharge of the Jemez River at the Jemez River near Jemez streamflow-gaging station for water years 1937-83 (data from table 2).



PERCENTAGE OF TIME	FLOW, IN CUBIC FEET PER SECOND, THAT WAS EQUALED OR EXCEEDED FOR PERCENTAGE OF TIME INDICATED
0.02	2,800
0.05	2,300
0.08	1,000
0.15	1,500
0.26	1,200
0.51	950
0.81	770
1.17	620
1.96	490
2.86	400
4.07	320
5.64	260
6.96	210
8.66	170
11.48	130
13.61	110
16.76	86
20.82	69
25.35	56
31.56	45
40.51	36
53.61	29
73.28	23
86.47	19
95.00	15
98.51	12
99.76	9.7
99.95	7.8

Figure 23.--Flow-duration curve for the Jemez River at the Jemez River near Jemez streamflow-gaging station, water years 1937-83.

The gentler slope toward the upper end and the steep slope in the center part of the flow-duration curve (fig. 23) indicate that larger flows are derived mainly from snowmelt. The slope of the lower end of the curve shows the characteristics of perennial storage in the drainage basin (Searcy, 1959). The gentle slope at the lower end of figure 23 indicates the presence of ground-water storage and shows that low flows are sustained by ground-water discharge.

Seepage Investigations on the Jemez River

A seepage investigation, or seepage run, is a set of streamflow measurements made at several locations along a river. The measurements are compared and a determination is made of the quantity of water lost or gained by the stream between each point. An important condition that needs to be met for a seepage investigation to be meaningful is that steady-flow conditions exist while streamflow measurements are being made. If this condition is met, areas of ground-water recharge and discharge can be determined. Fischer and Borland (1983) presented results of two seepage investigations conducted on the Jemez River in February 1981; their results, however, were inconclusive because of unsteady streamflow conditions.

During this study, two seepage investigations were conducted along the Jemez River, one in March 1984 and the other in August 1984, to determine possible seasonal variations in streamflow (figs. 24 and 25). Streamflow and miscellaneous water-quality measurements were made at sites along the river where geologic conditions were thought to cause streamflow variations. These measurements were made beginning at the Jemez River near Jemez streamflow gage and ending at the Santa Ana Pueblo, a distance of about 24 river miles (tables 3 and 4; figs. 24 and 25). During these two seepage investigations, inflow from tributaries was negligible. These seepage investigations, therefore, located areas of streamflow accretion (ground-water discharge) and streamflow losses (ground-water recharge).

The two seepage investigations gave different results for the different seasons. The March measurements represent base-flow conditions of winter when there is little or no evapotranspiration. This seepage investigation showed that the Jemez River is, in general, a gaining stream throughout the reach measured. Principal areas of streamflow gain, or where streamflow is sustained by ground-water discharge, were between Jemez Pueblo (site 4 in fig. 24) and Zia Reservoir (site 8 in fig. 24), where a net gain of about 18 cubic feet per second (or about 2 cubic feet per second per river mile) was measured, and between Zia and Santa Ana Pueblos (sites 9 and 10 in fig. 24), where a net gain of about 8 cubic feet per second (or about 1 cubic foot per second per river mile) was measured. Water-quality data also indicate that the reach downstream from Jemez Pueblo is gaining. The specific conductance increased from 460 microsiemens at Jemez Pueblo to 600 microsiemens just upstream from the mouth of the Rio Salado, and the chloride concentration increased from 48 milligrams per liter at Jemez Pueblo to 100 milligrams per liter just upstream from the mouth of the Rio Salado, indicating discharge of ground water (table 3). Downstream from the mouth of the Rio Salado, chloride concentration and specific conductance were masked by very saline water in that stream. Water-quality data collected during the two seepage investigations are discussed later in greater detail under "Ground-water use and supply."

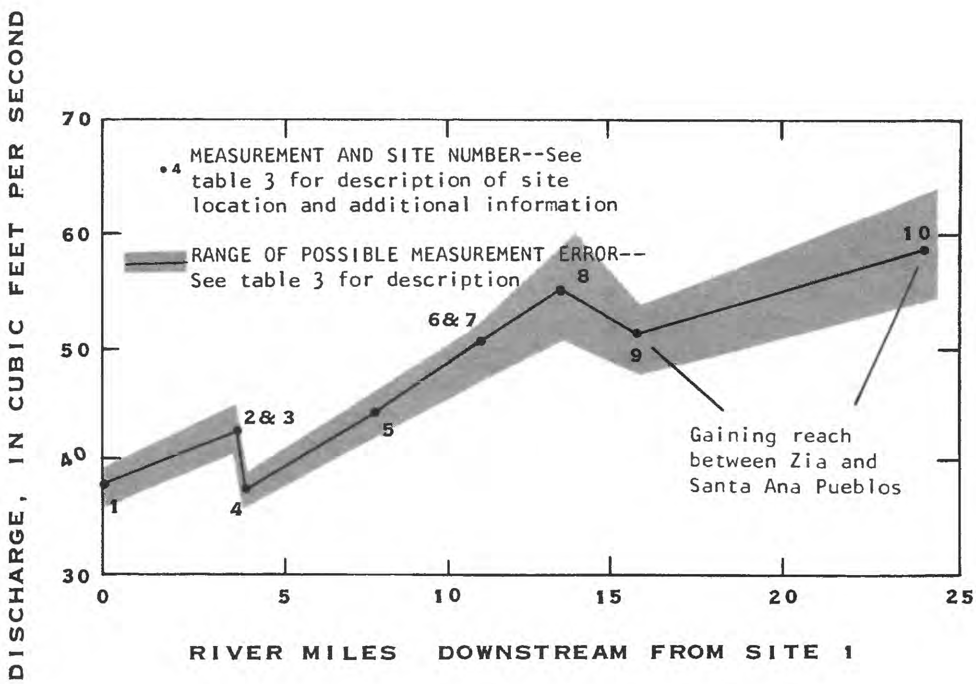


Figure 24.--Discharge of the Jemez River on March 1, 1984.

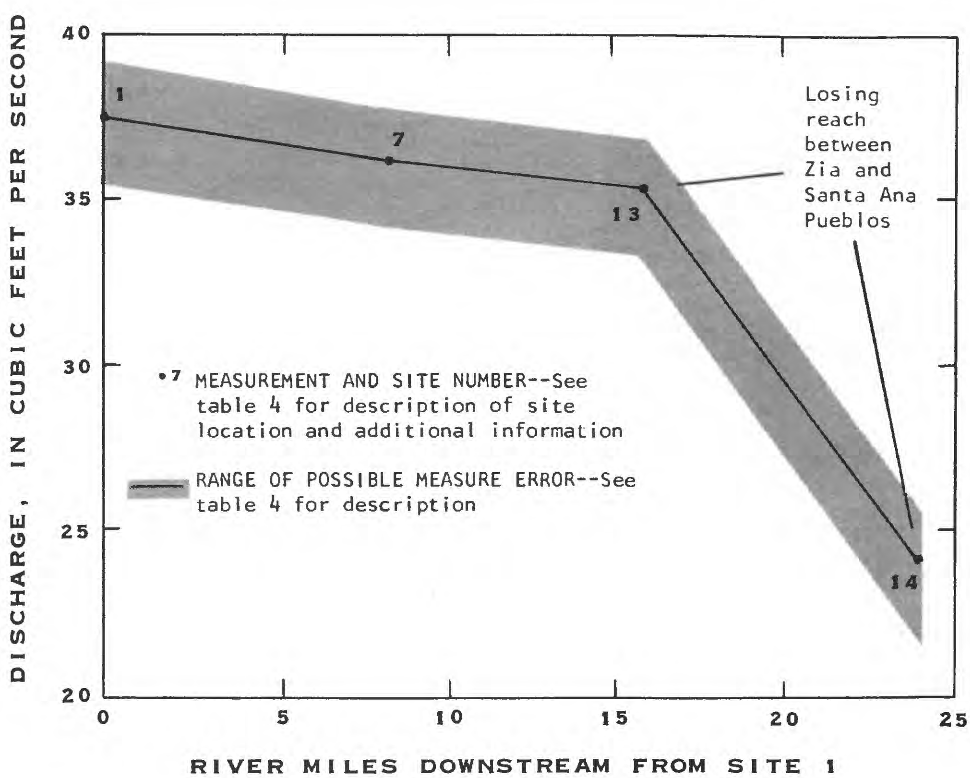


Figure 25.--Discharge of the Jemez River on August 28, 1984.

In the reach between Vallecito Creek (sites 2 and 3 in fig. 24) and Jemez Pueblo (site 4 in fig. 24), a distance of 0.6 river mile, a net streamflow loss of about 5.6 cubic feet per second was measured, and in the reach between Zia Reservoir (site 8 in fig. 24) and Zia Pueblo (site 9 in fig. 24), a distance of 2.2 river miles, a net streamflow loss of 4.5 cubic feet per second also was measured (table 3, fig. 24).

The August 1984 seepage investigation gave different results (table 4, fig. 25). These measurements showed that during summer when evapotranspiration is occurring, the Jemez River is a losing stream between the Zia and Santa Ana Pueblos (sites 13 and 14 in fig. 25). In this reach of 8.3 river miles, a net streamflow loss of about 11 cubic feet per second or about 1.3 cubic feet per second per mile of channel was measured. This loss probably was due to evapotranspiration of shallow ground water by phreatophytes along the channel. This evapotranspiration causes a lowering of the water table in the alluvium, thus allowing surface water to seep into unsaturated zones.

Streamflow did not change in the reach between the Jemez River near Jemez streamflow gage (site 1 in fig. 25) and the Zia Pueblo (site 13 in fig. 25). Although a small quantity of streamflow loss may have occurred in this reach, it was not measurable because of the possible measurement error (table 4, fig. 25).

Water Quality

The only systematically collected water-quality data available near the study area boundary are for the U.S. Geological Survey streamflow-gaging station Jemez River near Jemez (fig. 20). Water-quality samples also have been collected infrequently from the river at the Jemez Pueblo and at the State Highway 44 bridge (Craigg, 1984, tables 8 and 9). Chemical analyses also are available for water from various tributaries to the Jemez River (Vallecito Creek, Rio Salado, Arroyo Peñasco, Cuchilla Arroyo), but sampling has been infrequent and streamflow measurements rarely have been made when samples were collected (tables 5 and 6; Craigg, 1984, tables 8 and 9). No data are available for ephemeral streams crossing the Santa Fe aquifer.

Jemez River

Chemical quality of water from the Jemez River generally is fresh. Specific-conductance measurements ranged from 500 microsiemens at the Jemez River near Jemez streamflow gage to 1,400 microsiemens at Santa Ana Pueblo (table 5; Craigg, 1984, tables 8 and 9). Water in the Jemez River is less mineralized upstream from the confluence with the Rio Salado.

Upstream from confluence with the Rio Salado

The relation of specific conductance and, therefore, dissolved-solids concentration to discharge at the Jemez River near Jemez streamflow gage is shown in figure 26. Specific conductance is dependent on discharge (discharge is in turn dependent on season). For discharges of less than 100 cubic feet per second, specific conductance ranges from about 300 to 700 microsiemens, the larger values occurring with smaller streamflows. For discharges greater than 100 cubic feet per second, a dilution effect is apparent because specific conductance of the water generally is less than 300 microsiemens and commonly is less than 200 microsiemens for flows greater than 300 cubic feet per second. Specific conductance of water flowing past this gage also is dependent on season, as indicated by the larger values of discharge and the smaller values of specific conductance shown in figure 26 representing spring snowmelt. The smaller values of discharge and the larger values of specific conductance represent base-flow conditions of summer and autumn.

Seasonal control of water-quality type is shown in figure 27. Two distinct seasonal variations are apparent. During periods of larger discharge in the spring (snowmelt period), the water type is calcium bicarbonate. During periods of smaller discharge in the autumn (base flow contributed by ground water), the water types trend more toward sodium and chloride because dilution from fresher water is not as substantial; the shift in chemical quality reflects the more saline character of the ground water sustaining base flow of the stream.

For a given streamflow in the Jemez River, at least upstream from the Rio Salado confluence, an increase in chloride concentration downstream is apparent (Trainer, 1978; Craigg, 1984, tables 7, 8, and 9). This probably is due to ground-water discharge from deeper bedrock units. Downstream from the Rio Salado confluence, chloride concentrations are masked by the very saline water of the Rio Salado.

Downstream from confluence with the Rio Salado

Downstream from the Rio Salado confluence, water from the Jemez River contains a larger concentration of dissolved solids, as indicated by specific-conductance measurements (tables 2-4; Craigg, 1984, tables 7 and 9). The Rio Salado and its principal tributaries, Arroyo Peñasco and Cuchilla Arroyo, contribute saline water to the Jemez River. Water from the Rio Salado has had specific-conductance values as large as 18,500 microsiemens, and ground water from alluvium along the Rio Salado has had specific-conductance values as large as 23,000 microsiemens (Craigg, 1984, tables 1 and 9).

During the seepage investigation on March 1, 1984, specific conductance increased from 600 microsiemens upstream from the Rio Salado confluence to 1,050 microsiemens at the Santa Ana Pueblo (fig. 28, table 3; Craigg, 1984, fig. 3, table 7). Miscellaneous water-quality measurements made on August 1 and August 6, 1984, also show this trend (table 5). During the seepage investigation on August 28, 1984, specific conductance increased from 550 microsiemens upstream from the Rio Salado confluence to 950 microsiemens at the Santa Ana Pueblo. A larger increase would be expected in this reach but return flow from the Zia Pueblo irrigation diversion canals (which divert Jemez River water upstream from the mouth of the Rio Salado) provided a dilution effect between Zia and Santa Ana Pueblos (fig. 29, table 4).

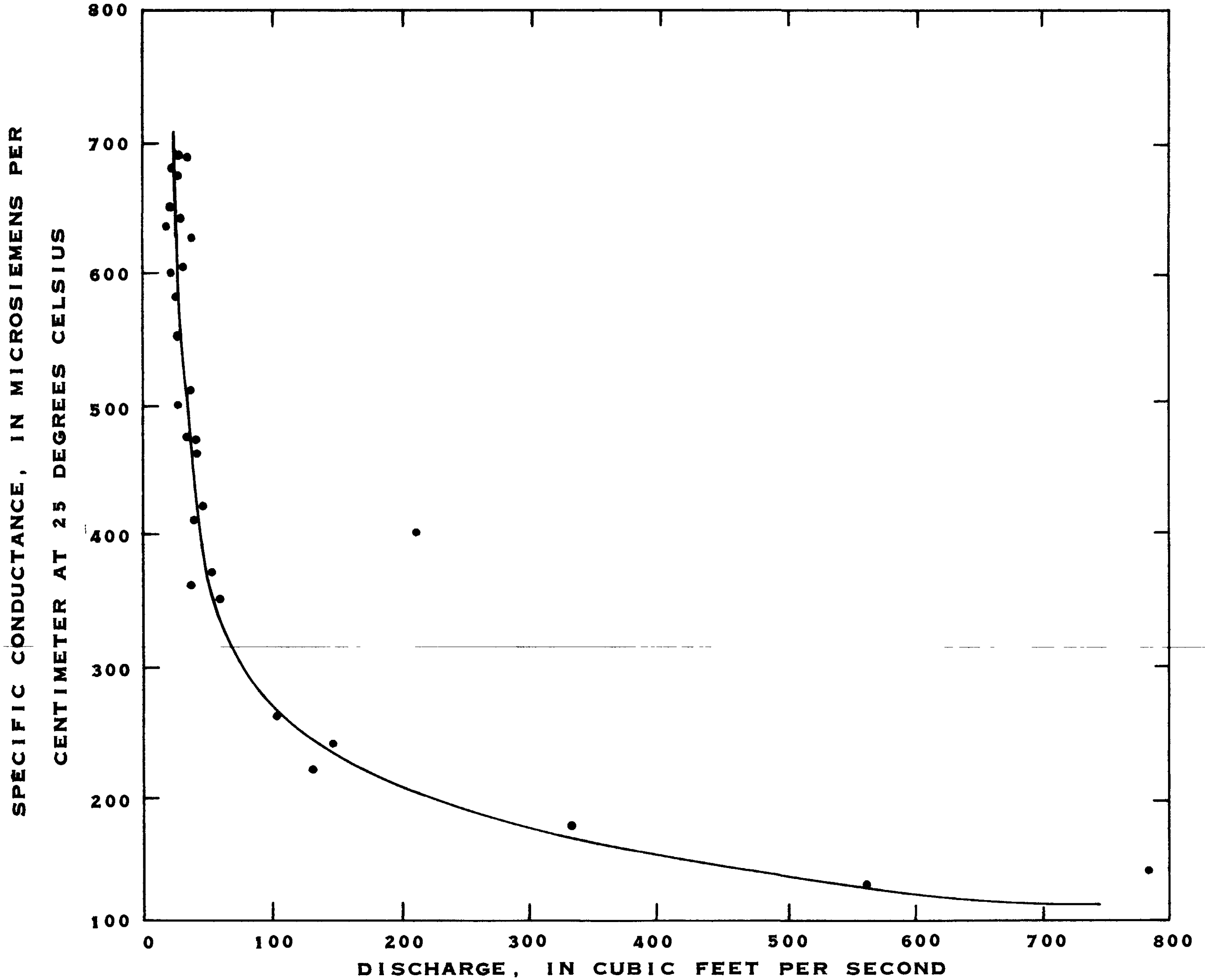
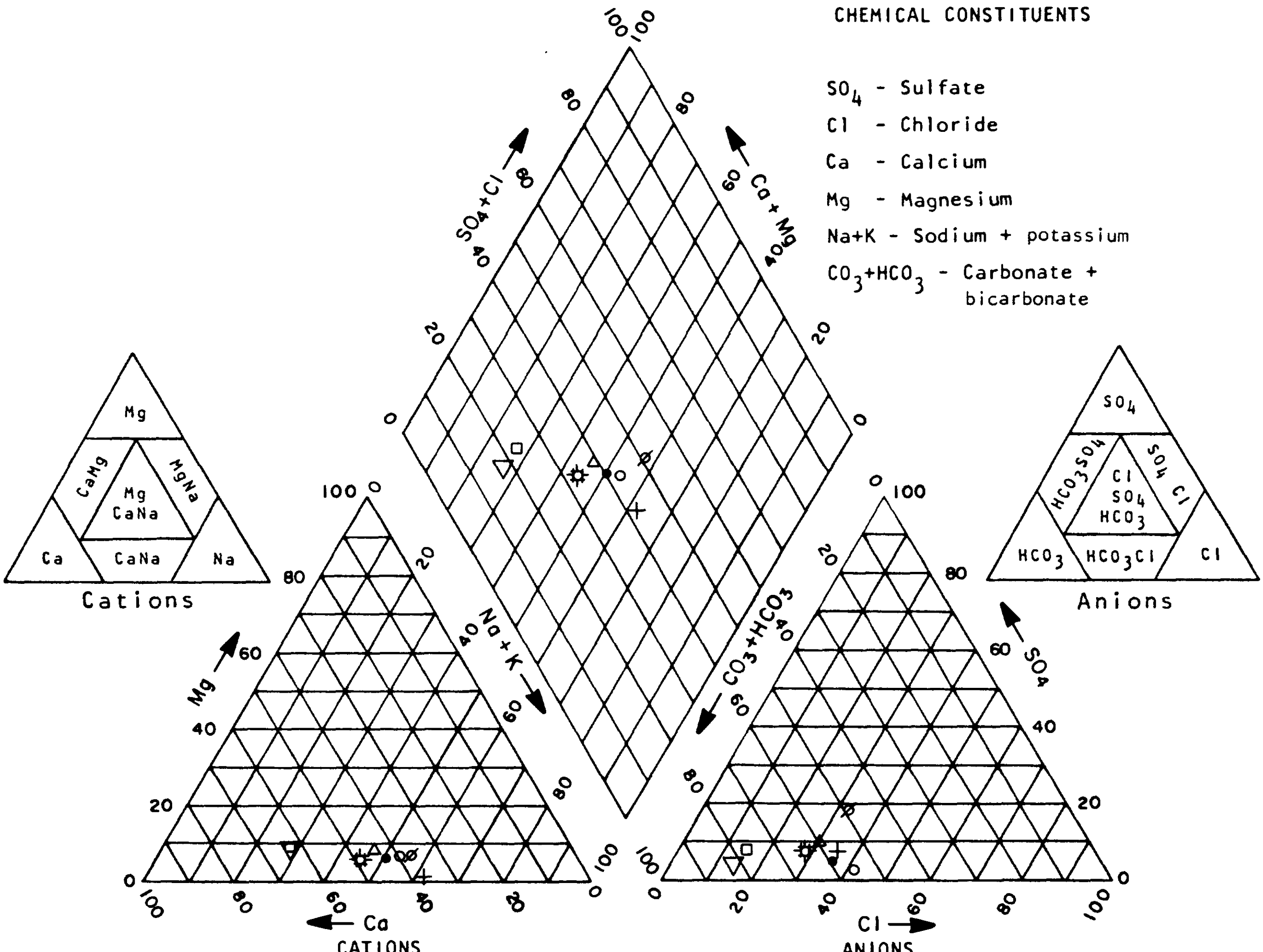


Figure 26.--Relations between specific conductance of water and discharge of the Jemez River at the Jemez River near Jemez streamflow-gaging station (data from Cragg, 1984, tables 8 and 9).



EXPLANATION

WATER FROM JEMEZ RIVER

Symbol	Sample location	Date	Streamflow, in cubic feet per second	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
●	Near Jemez (gaging station)	11–14–74	31	584
○	Near Jemez (gaging station)	11–04–81	24	675
□	Near Jemez (gaging station)	04–15–82	331	175
△	Near Jemez (gaging station)	11–10–82	59	350
▽	Near Jemez (gaging station)	05–26–83	561	130
ø	At Jemez Pueblo	08–17–82	–	633
+	At State Highway 4	01–12–74	23	900

☼ Average of analyses

Figure 27.--Trilinear plot of major dissolved constituents in water from the Jemez River. Small triangles at sides give key to classification (see Craigg, 1984, table 8 for chemical analyses).

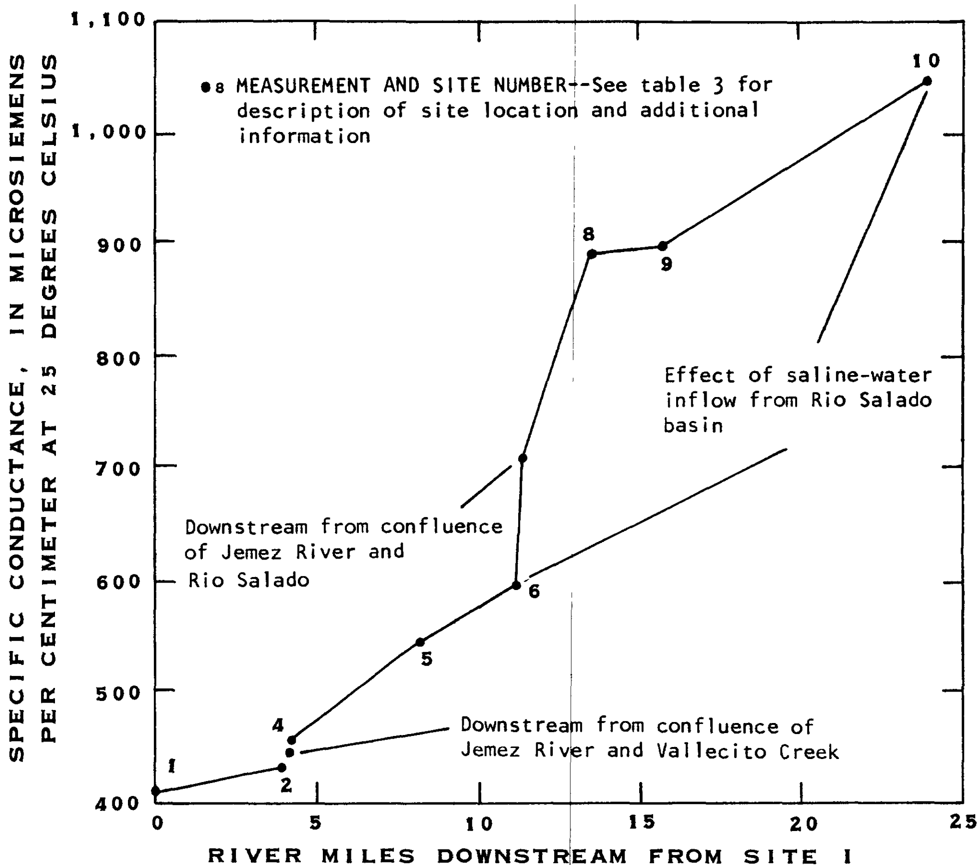


Figure 28.--Specific conductance of water in the Jemez River, March 1, 1984.

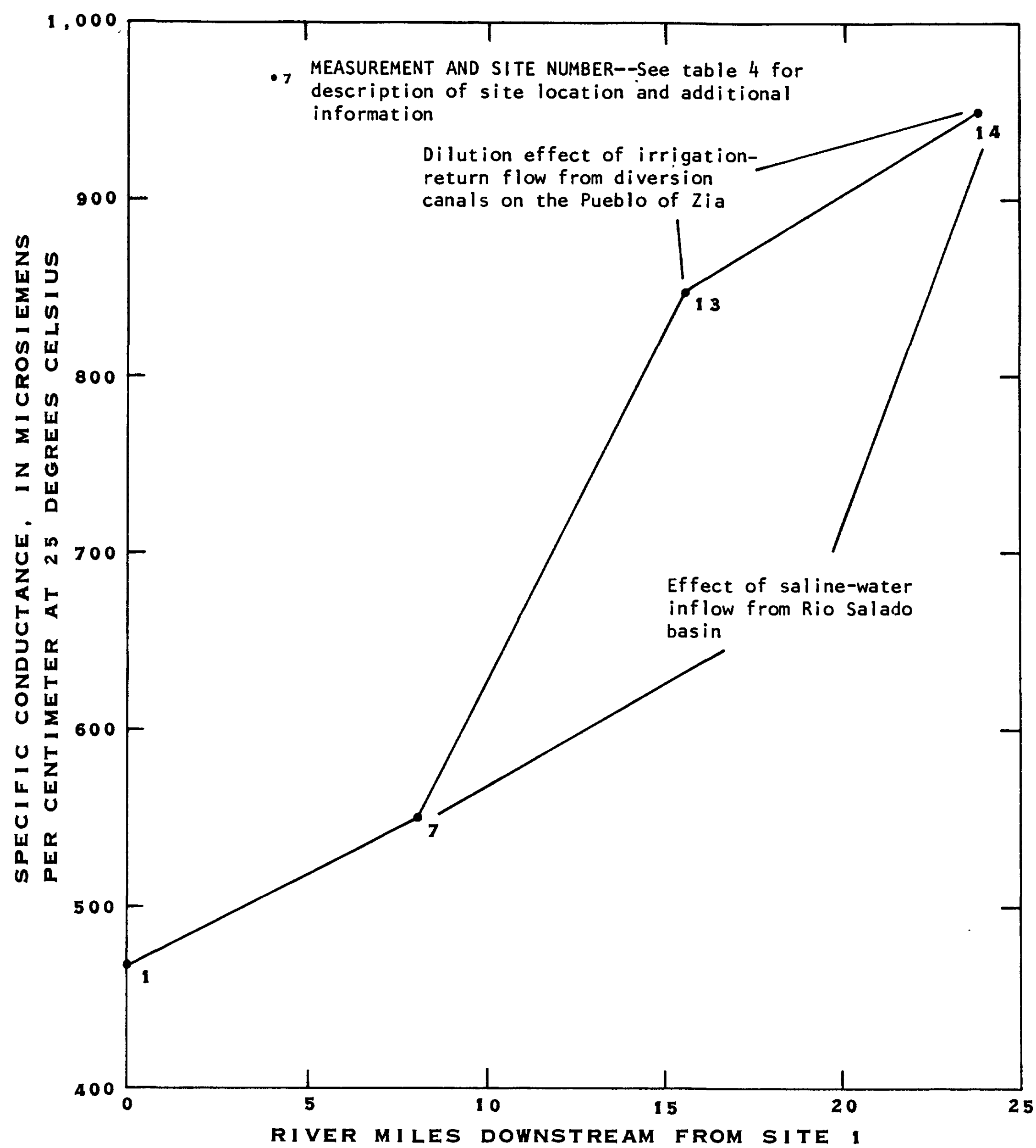


Figure 29.--Specific conductance of water in the Jemez River, August 28, 1984.

Rio Salado

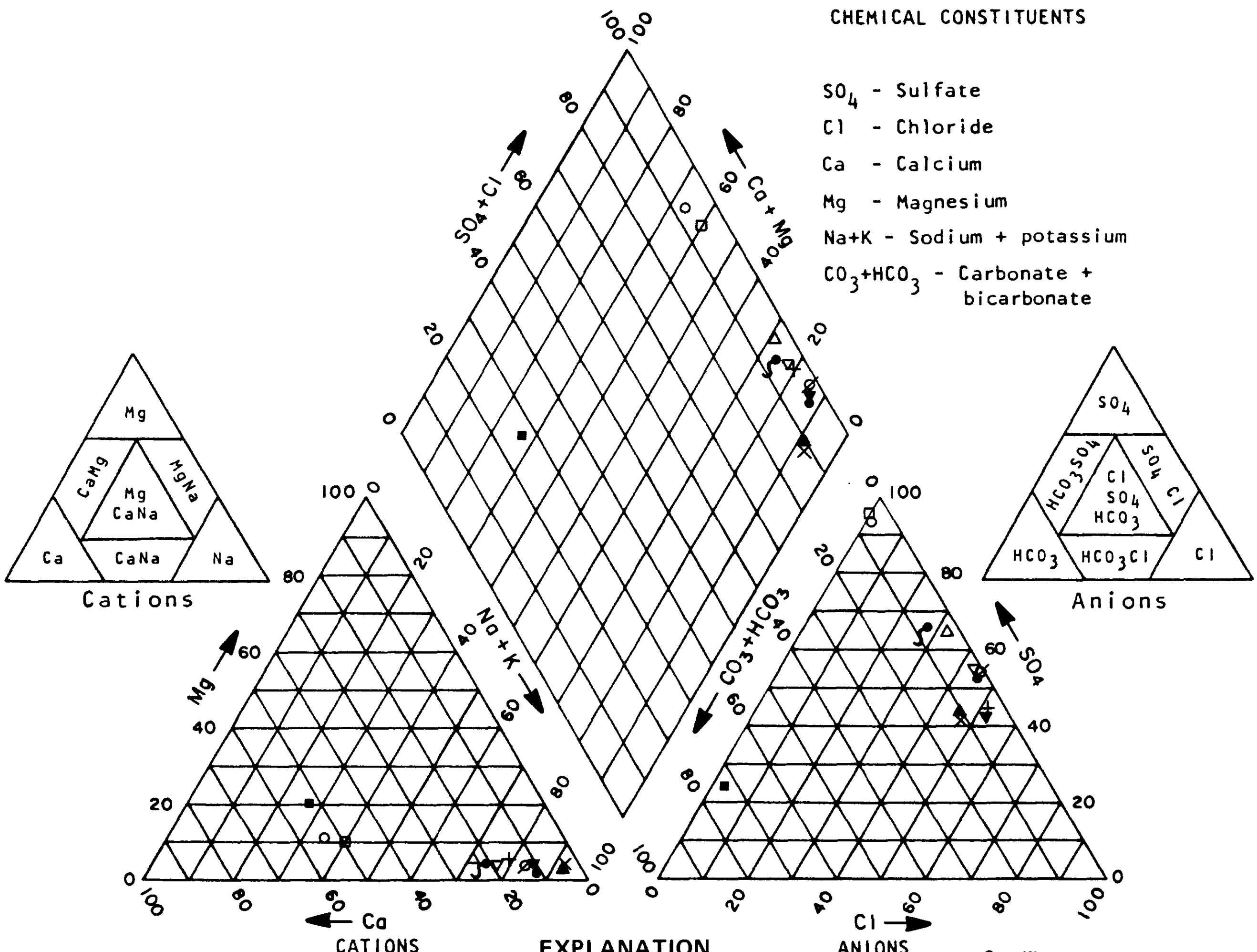
Water in the Rio Salado varies from slightly saline in the upstream reaches to very saline at the confluence with the Jemez River. This variability in water quality in different stream reaches was first reported by Clark (1929). Miscellaneous water-quality measurements and some water samples were collected along the Rio Salado in June 1984 (tables 5 and 6). Specific conductance increased downstream from 1,950 microsiemens where the stream flows over Cretaceous rocks to 4,300 microsiemens where it flows over the Todilto Limestone Member of the Wanakah Formation (Jurassic) and then to 18,500 microsiemens where it crosses Jurassic and Triassic rocks about 1/8 mile upstream from the Arroyo Peñasco confluence (pl. 3). Chemical analyses of water samples collected during this time show large concentrations of calcium, sodium, sulfate, and chloride; these analyses also show increased concentrations downstream (table 6). The water type also changed downstream from predominantly calcium sulfate to sodium sulfate chloride (fig. 30). Discharge of the Rio Salado during this sampling was intermittent and small, varying between a barely perceptible surface flow to about 0.3 cubic foot per second. Downstream from the Arroyo Peñasco confluence, discharge increased to about 0.5 cubic foot per second because of contributions from perennial springs (see sections "Madera Limestone (Pennsylvanian)" and "Hydrogeology"). The specific conductance of water in the Rio Salado decreased downstream from this confluence from 18,500 microsiemens to 13,000 microsiemens because of dilution from Arroyo Peñasco.

The specific conductance of base flow in Arroyo Peñasco is fairly constant at about 12,000 microsiemens (table 5), and the water contains large concentrations of sodium, bicarbonate, sulfate, and chloride (table 5; Craigg, 1984, table 8). The water is a sodium chloride sulfate type (fig. 30).

A water sample collected from Cuchilla Arroyo (pl. 1) had a specific conductance of 24,600 microsiemens and a dissolved-solids concentration of 12,800 milligrams per liter (Craigg, 1984, table 8). The water was a sodium chloride sulfate type.

The saline water of the Rio Salado drainage basin may result from the combination of three principal causes: (1) streams flowing across outcrops of shale, sandstone, and gypsum; (2) re-dissolution of salts that formed by evaporation of shallow ground water and stagnant pools left by previous flows; and (3) discharge of deep, very saline ground water from the San Juan Basin along the Pajarito fault (see sections "Madera Limestone (Pennsylvanian)" and "Hydrogeology").

During storm runoff, the quality of water in the Rio Salado improves for a short period because of dilution. This was first reported by Clark (1929). During the two seepage investigations on March 1 and August 28, 1984 (tables 3 and 4; Craigg, 1984, table 7), specific conductance of water in the Rio Salado during flows representative of base-flow conditions was 15,000 microsiemens. The dilution effect of a slightly higher flow is shown by miscellaneous measurements made on August 6, 1984. During a flood recession, specific conductance of the water was 7,500 microsiemens, and the discharge was estimated to be 2 to 3 cubic feet per second (table 5).



EXPLANATION

Water from:	Symbol	Sample location	Date	Estimated streamflow, in cubic feet per second	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
Rio Salado	●	At State Highway 44	01–29–74	–	–
Rio Salado	○	1	06–19–84	<0.10	2,350
Rio Salado	□	2	06–19–84	0.25	3,600
Rio Salado	△	3	06–19–84	<0.01	9,300
Rio Salado	▽	4	06–20–84	0.30	14,000
Rio Salado	ø	5	06–20–84	0.30	18,500
Rio Salado	+	Underflow	06–22–84	–	16,700
Arroyo Peñasco	×	At State Highway 44	06–29–74	–	–
Arroyo Peñasco	▲	At State Highway 44	06–19–84	0.5	–
Cuchilla Arroyo	▼	At State Highway 44	06–29–74	–	–
Vallecito Creek	■	At State Highway 4	09–01–83	0.04	–
Alabaster Cave	ʃ●	(16N.01E.32.343)	06–18–84	–	–

Figure 30.--Trilinear plot of major dissolved constituents in water from the Rio Salado, Arroyo Peñasco, Cuchilla Arroyo, and Vallecito Creek. Small triangles at sides give key to classification (see Craigg, 1984, table 8 for chemical analyses).

Vallecito Creek

Vallecito Creek drains terrain consisting of Triassic sandstone and shale, the Santa Fe Group and related strata (Tertiary and Quaternary), and Tertiary volcanic rocks (pl. 1). The water is fresh; specific-conductance values ranged from about 100 to 700 microsiemens (tables 5 and 6). One water sample collected after a short rain indicates that the water was a mixed calcium sodium magnesium bicarbonate type (fig. 30).

GROUND-WATER USE AND SUPPLY

Public Supplies

Community-water systems installed by the U.S. Indian Health Service supply the water needs of residents of the Jemez and Zia Pueblos. Domestic-water supplies for part-time residents of the Santa Ana Pueblo are provided by a single well. Hydrologic and water-quality data for pueblo public-supply wells were given in Craigg (1984, tables 1, 3, and 4). Water-quality standards for public-supply use are listed in tables 7 and 8.

Two wells (IHS-1 and IHS-2) supply the needs of the Jemez Pueblo residents. These wells are located west of the pueblo, along the east flood plain of the Jemez River, and are completed in the alluvial aquifer. The water is fresh. Dissolved-solids concentrations are about 620 milligrams per liter in water from well IHS-1 and about 700 milligrams per liter in water from well IHS-2 (Craigg, 1984, table 3). Arsenic concentrations are large, reportedly 17 micrograms per liter in water from well IHS-1 (Craigg, 1984, table 4) and greater than 50 micrograms per liter in water from well IHS-2 (Randall Willard, U.S. Indian Health Service, written commun., 1984). These concentrations of arsenic probably result from upward leakage of water from deeper bedrock units associated with the Jemez Mountains geothermal system.

Should additional public supplies be required for Jemez Pueblo, the alluvium along the Jemez River offers the best potential in terms of quantity. In terms of quality, however, the Santa Fe aquifer offers the best potential. Re-development of Owl Spring, which issues from the Madera Limestone and discharges freshwater, also offers potential for public supply (Craigg, 1984, table 5).

The Zia Pueblo obtains public-supply water from two wells (Main public supply well and Standby well) completed in the Santa Fe aquifer. These are located north of the pueblo on an outcrop of the Santa Fe Group. Water from these wells is fresh. Dissolved-solids concentrations are about 350 milligrams per liter and 300 milligrams per liter, respectively, for water from the Main and Standby wells (Craigg, 1984, table 3). Concentrations of trace elements (Craigg, 1984, table 4) do not exceed U.S. Environmental Protection Agency (1976) water-quality standards for public supplies (tables 7 and 8).

The Santa Fe aquifer offers the best potential for development of additional public-water supplies for the Zia Pueblo. Water quality from the Santa Fe aquifer is less mineralized than that in the alluvium at the Zia Pueblo (figs. 5 and 8; Craigg, 1984, tables 1 and 3).

Domestic-water supplies at the Santa Ana Pueblo are obtained from a single well (well RWP-2A) equipped with windmill, storage tank, and gravity-fed pipeline system. This well is located just northeast of the pueblo on an outcrop of the Santa Fe Group. There are no water-quality data for this well, but specific conductance of water from the Santa Fe aquifer in this area is probably about 600 to 800 microsiemens (fig. 8). Should additional domestic-water supplies be needed at the Santa Ana Pueblo, the Santa Fe aquifer offers the best potential for development (figs. 5 and 8; Craigg 1984, tables 1 and 3).

Irrigation Supplies

Only the Jemez and Zia Pueblos irrigate crops along the Jemez River flood plain; both pueblos use water from the Jemez River. Diversions for the Jemez Pueblo are located just downstream from the Jemez River near Jemez streamflow-gaging station. The diversion for the Zia Pueblo is located near San Ysidro upstream from the Rio Salado confluence. Values of sodium-adsorption ratio (SAR) for water in the Jemez River at the Jemez Pueblo diversions ranged from 0.5 to 2.9; the larger values were for lower flows (table 9). Values of SAR downstream near the Zia Pueblo diversion ranged from 3.8 to 6.4 (table 9). These waters meet water-quality standards set for irrigation use (table 10).

Should additional irrigation supplies from ground-water sources be needed by the Jemez Pueblo, the alluvium along the Jemez River offers the best potential. Values of SAR for water from the alluvium in this area ranged from 2.1 to 3.6 (table 11). Yields of water from wells probably are sufficient, as indicated by recent aquifer tests conducted by the U.S. Bureau of Indian Affairs (see section on hydrologic characteristics of alluvium).

Additional irrigation-water supplies for the Zia Pueblo also could be obtained from ground-water sources. Both the alluvial aquifer along the Jemez River and the Santa Fe aquifer could be developed. Values of SAR for water from the alluvium near the Zia Pueblo ranged from 7.8 to 21 (table 11). The Santa Fe aquifer offers the best potential for additional irrigation supplies because SAR values ranged from only 0.5 to 2.4 (table 11). Yields of several hundred gallons per minute may be possible from wells completed in the Santa Fe aquifer (see section on hydrologic characteristics of the Santa Fe Group).

The Santa Fe aquifer also offers the best potential for development of irrigation supplies from ground water in the Santa Ana Pueblo area. Values of SAR are less than 5.0 and are smaller than those for water from the alluvium (table 11).

Livestock Supplies

Ground water for livestock use mainly is obtained from wells equipped with windmills and from both developed and undeveloped springs (Craigg, 1984, tables 1 and 2, pls. 1 and 2). Additional supplies of sufficient quantity and adequate quality for livestock use could be obtained from wells completed in any of the major or minor potential aquifers previously discussed (table 12; Craigg, 1984, tables 5 and 6). Water yields from several undeveloped springs also could be enhanced by various development techniques (U.S. Bureau of Land Management, 1964).

SUMMARY AND CONCLUSIONS

1. Hydrologically, the most suitable aquifer available for development of public- and irrigation-water supplies for the Jemez Pueblo is the alluvium in the Jemez River valley. The Santa Fe aquifer also offers potential for public-water supplies, as does the Madera Limestone on the west side of the Jemez fault.

2. Hydrologically, the most suitable aquifer available for development of public- and irrigation-water supplies for the Zia and Santa Ana Pueblos is the Santa Fe aquifer. Alluvium in the southeastern part of the Jemez River valley also offers some potential for development, but the water is more mineralized than that from the Santa Fe aquifer.

3. Stock-water supplies can be obtained from any major or minor aquifer in the study area. These include the alluvium, terrace deposits, sand and gravel in the Santa Fe aquifer, volcanic rocks, sandstone beds in the Mancos Shale, the Dakota Sandstone, sandstone beds in the Morrison Formation, the Entrada Sandstone, sandstone beds in the Chinle Formation, sandstone beds in various Permian rocks, the Madera Limestone, and crystalline rocks.

4. Water in the alluvium, terrace deposits, sand and gravel in the Santa Fe aquifer, volcanic rocks, and crystalline rocks generally is under unconfined, or water-table, conditions.

5. Water in other bedrock aquifers generally is under confined, or artesian, conditions.

6. Wells completed in the alluvium of the Jemez River and in the sand and gravel of the Santa Fe aquifer probably are capable of yielding as much as several hundred gallons of water per minute. Well yields from all the bedrock aquifers will be much less, but sufficient for stock-water supplies.

7. The study area can be divided into three distinct ground-water provinces on the basis of both hydrogeology and physiography. These are the San Juan Basin, Sierra Nacimiento, and Jemez Valley provinces.

8. Aquifers are recharged directly by infiltration of precipitation on outcrops and by infiltration of runoff from streams crossing outcrops. Aquifers also are recharged by subsurface leakage of water from adjacent geologic units that have a higher hydraulic head than that in the aquifers.

9. Ground-water movement in the San Juan Basin province generally is south to southeast toward the southwestern part of the Jemez Valley province. Ground water in the San Juan Basin province varies from fresh (less than 1,000 milligrams per liter dissolved solids) near the Sierra Nacimiento front to very saline (10,000 to 35,000 milligrams per liter dissolved solids) near the mouth of the Rio Salado.

10. Ground-water movement in the Sierra Nacimiento province generally is south. Some water moves southwest into the San Juan Basin province and southeast into the Jemez Valley province. Ground water in the Sierra Nacimiento province varies from fresh to moderately saline (3,000 to 10,000 milligrams per liter dissolved solids).

11. Ground-water movement in the Jemez Valley province generally is south in the Santa Fe aquifer and in the same directions as streamflow in the alluvium. Ground water in this province varies from fresh to slightly saline (1,000 to 3,000 milligrams per liter dissolved solids). In the southern part of the Jemez Valley province, ground water is more mineralized than that in the northern part because of inflow of very saline surface and ground water from the San Juan Basin province, and because of concentration of salts by evapotranspiration.

12. The location of several large moundlike springs in the Arroyo Peñasco valley is controlled by the north-trending Pajarito fault. Southeast-flowing, confined ground water from the San Juan Basin province is blocked by this fault zone causing moderately to very saline water to be discharged at the land surface.

13. A considerable range of flow conditions has been recorded at the U.S. Geological Survey Jemez River near Jemez streamflow gage. The average annual flow for water years 1937-83 at this gage is 72 cubic feet per second.

14. The variability of flow in the Jemez River at the Jemez River near Jemez gage results from seasonal variations in precipitation. An average of 70 percent of the annual streamflow passes this gage during the snowmelt season--from March through May or June. Streamflow mainly is sustained by ground-water discharge from October through February.

15. The Rio Salado derives most of its flow from local summer thunderstorms during July, August, and September.

16. Data obtained from two seepage investigations on the Jemez River indicate that during winter the river generally is a gaining stream, and that during summer it generally is a losing stream.

17. Water in the Jemez River generally is fresh. Downstream from the confluence with the Rio Salado, the water is more mineralized than that upstream from the confluence because of inflow of very saline ground and surface water.

18. Water in the Rio Salado is saline. Near the headwaters, the stream contains slightly saline water; near the mouth, the water is very saline because of ground-water discharge from the San Juan Basin.

19. The quality of water in the alluvium generally is similar to the quality of the water recharged locally from streams.

20. Water in the Santa Fe aquifer is less mineralized than that in either the alluvium or the Jemez River.

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Table 1.--Partial list of streamflow-gaging stations in the Jemez River basin

[--, no data]

Number in figure 20	Station number	Station name	Drainage area (square miles)	Period of record (water years)
1	08321500	Jemez River below East Fork, near Jemez Springs	173	[1]1951-57, 1958-76
2	08322000	Rio Las Vacas [Rio de las Vacas] near Cuba	--	1939-41
3	08322500	Rio Cebolla near Jemez Springs	--	1939
4	08323000	Rio Guadalupe at Box Canyon, near Jemez	235	1951-76
5	08324000	Jemez River [Jemez Creek] near Jemez	470	1936-41, 1949-50, [1]1951-52, 1953-current year
6a	08324500	Jemez east side ditch near Jemez	--	1936-41
6b	08325000	Jemez west side ditch near Jemez	--	1936-41
7	08325500	Antonio Pecos ditch near Jemez	--	1936-41
8	08326000	San Ysidro ditch near San Ysidro	--	1936-41
9	08326500	Jemez Creek [River] at San Ysidro	854	1937-41
10	08327000	Zia ditch near San Ysidro	--	1936-41
11	08328000	Jemez River above Jemez Canyon Dam	961	1953-58
12	08329000	Jemez River below Jemez Canyon Dam [Jemez Creek near Bernalillo]	1,038	1936-38, 1943-current year

[1]Irrigation seasons only.

From Fischer and Borland (1983)

Table 2.—Monthly mean discharges, in cubic feet per second, for period of record at the Jemez River near Jemez streamflow-gaging station

[—, missing record]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1937	64.90	57.60	41.70	21.20	52.00	118.00	572.00	259.00	89.80	58.80	31.50	29.80
1938	36.40	28.30	27.20	28.20	34.40	99.60	181.00	226.00	50.40	36.40	21.90	110.00
1939	61.30	32.80	26.20	28.60	32.70	208.00	255.00	96.90	20.30	26.00	28.40	28.60
1940	30.70	26.40	26.90	27.50	30.10	129.00	155.00	93.70	28.70	30.70	37.60	27.80
1941	28.60	31.60	33.40	37.20	53.40	126.00	632.00	—	—	—	—	—
1950	26.30	24.90	23.50	24.60	34.90	56.40	85.40	32.10	15.30	19.60	15.20	23.40
1953	—	—	—	—	—	44.30	63.30	52.80	19.20	24.20	22.90	13.00
1954	18.10	22.30	20.50	22.60	36.00	74.50	110.00	68.00	17.10	25.50	20.50	18.40
1955	22.10	18.50	19.40	19.80	19.90	46.90	43.30	57.40	11.90	26.80	101.00	24.30
1956	17.00	21.10	20.30	21.90	24.80	110.00	103.00	53.80	12.30	15.00	15.80	11.10
1957	14.50	18.40	17.00	23.20	41.10	44.70	94.70	194.00	93.70	28.60	121.00	29.50
1958	91.10	103.00	51.20	36.90	46.90	73.60	961.00	626.00	73.40	21.80	35.50	40.80
1959	29.70	27.00	26.20	24.00	27.30	50.40	76.10	63.90	20.60	15.80	43.80	18.80
1960	27.80	29.20	21.90	24.20	27.10	153.00	345.00	139.00	40.10	23.70	25.60	17.60
1961	38.20	31.10	28.40	21.70	31.40	81.40	393.00	239.00	43.30	30.00	57.40	32.70
1962	33.00	50.50	33.10	31.30	50.10	55.40	475.00	175.00	32.50	29.70	21.10	21.80
1963	29.00	30.20	25.40	21.90	50.60	113.00	121.00	40.50	12.90	17.10	38.50	24.90
1964	21.10	26.90	21.20	19.90	22.20	39.60	105.00	74.10	19.00	25.50	34.00	18.30
1965	17.30	21.30	19.90	24.60	24.90	31.90	230.00	248.00	76.10	30.50	29.20	25.10
1966	25.00	32.40	37.90	27.80	29.00	127.00	171.00	95.70	33.80	25.20	28.30	20.20

Table 2.—Monthly mean discharges, in cubic feet per second, for period of record at the Jemez River near Jemez streamflow-gaging station—Concluded

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1967	17.50	20.80	24.30	17.70	25.30	41.30	46.10	22.50	18.00	27.00	111.00	48.20
1968	25.40	23.50	17.40	21.60	26.70	48.80	276.00	368.00	72.50	37.00	67.60	22.80
1969	21.90	30.10	23.10	24.40	24.10	41.00	336.00	278.00	63.60	34.10	53.20	60.50
1970	79.00	56.00	36.50	28.10	31.40	39.30	155.00	180.00	67.40	49.20	66.60	52.50
1971	37.40	31.00	25.20	29.90	31.40	50.60	69.80	42.90	14.90	29.80	47.10	32.10
1972	82.10	57.60	34.30	33.70	56.80	102.00	45.50	24.20	23.50	14.50	24.30	48.20
1973	72.10	63.40	40.10	32.40	37.20	71.20	489.00	1118.0	212.00	48.50	36.60	31.00
1974	28.60	28.10	22.20	24.60	26.50	75.10	97.00	66.60	16.30	20.10	26.00	15.00
1975	34.40	33.50	22.80	25.70	29.80	62.80	454.00	514.00	116.00	43.80	30.80	41.40
1976	22.00	25.80	22.20	23.50	35.50	49.80	77.70	75.20	21.40	23.00	26.20	21.30
1977	22.10	21.40	18.40	16.60	20.20	32.10	68.20	45.50	12.80	27.40	43.60	22.70
1978	19.10	24.70	19.80	24.20	29.00	91.10	213.00	208.00	60.10	19.40	22.60	17.30
1979	22.40	69.70	35.00	42.20	46.70	105.00	607.00	590.00	274.00	54.40	42.30	23.60
1980	20.90	26.90	23.40	25.80	33.80	54.10	360.00	475.00	127.00	24.00	27.70	23.00
1981	25.00	26.20	28.00	26.00	25.40	31.60	125.00	87.30	39.50	26.20	24.60	44.60
1982	34.60	22.90	22.40	22.80	25.60	54.30	229.00	235.00	61.30	24.30	42.40	42.70
1983	28.40	36.90	32.60	33.40	38.10	101.00	503.00	582.00	221.00	45.20	74.30	33.90
Mean	34.00	34.20	26.90	26.10	33.70	76.60	252.00	215.00	59.20	29.40	41.50	31.00

Table 3.--Streamflow and miscellaneous water-quality measurements along the Jemez River, March 1, 1984

[--, no data]

EXPLANATION

Station name and number: Stations are numbered sequentially, in downstream order; names correspond to some nearby geographic landmark or political boundary.

Streamflow: The streamflow as measured at a station is the volume of water that flowed past the particular station at the time of measurement, reported in cubic feet per second. Streamflow per square mile of area drained is the measured value at a particular station in cubic feet per second divided by the drainage area of the stream at that station.

Time of measurement: The time of day the streamflow measurement was begun.

Possible measurement error: Reported as a percentage (plus or minus) of the discharge measured at a station; based on various channel and flow conditions.

Specific conductance: Specific conductance was measured onsite during the streamflow measurement at midflow depth and midstream width.

Chloride concentration: Reported in milligrams per liter; samples collected at stations 1 through 6 at midflow depth and midstream width; analyses by U.S. Geological Survey.

River miles: Distance of a particular station, in miles upstream from mouth of Jemez River.

Table 3.—Streamflow and miscellaneous water-quality measurements along the Jemez River, March 1, 1984—Concluded

Station name and number in figures 24 and 28	Latitude and longitude (degrees, minutes, and seconds)	Streamflow: Measured (cubic feet per second)	Streamflow: Per square mile of area drained (cubic feet per second per square mile)	Time of measurement	Possible measurement error (percent)
1. Jemez River near Jemez (U.S. Geological Survey streamflow-gaging station)	353942 1064434	37.8	0.08	0950	±5
		—	—	1330	—
2. Jemez River upstream from Vallecito Creek	353730 1064348	41.3	.08	0955	±5
3. Vallecito Creek at mouth	353727 1064345	1.51	—	1025	±5
4. Jemez River at Jemez Pueblo	353637 1064403	37.2	.06	1110	±5
5. Jemez River at State Highway 4	353430 1064527	44.2	.07	1110	±5
		—	—	1400	-
6. Jemez River upstream from Rio Salado	353227 1064618	50.2	.07	1250	±5
7. Rio Salado at mouth	353222 1064620	.13	—	1235	±5
8. Jemez River near Zia Reservoir	353120 1064513	55.1	.06	1230	±5 to ±8
9. Jemez River at Zia Pueblo	353013 1064327	50.6	.06	1330	±5
10. Jemez River at Santa Ana Pueblo	352544 1063715	58.7	.06	1430	±8

Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Chloride concentration (milligrams per liter)	River miles	General appearance of water	Remarks
410	3.0	46	29.9	Clear	Outside gage height = 3.61 feet.
440	9.0	48	—	Clear	Outside gage height = 3.59 feet.
435	3.5	49	26.3	Slightly reddish brown	Channel material consists of cobbles, gravel, and sand.
550	3.0	21	—	Muddy, reddish brown	Channel material consists of gravel and sand.
460	5.0	48	25.7	Slightly reddish brown	Channel material consists of cobbles, gravel, and sand.
550 580	7.5 11.0	74 —	21.8 —	Slightly reddish brown	Channel material consists mostly of sand with some gravel.
600	9.5	100	18.7	Slightly reddish brown	Channel material is sand; 4 feet of quicksand in places; silt and sand being transported in suspension.
15,000	14.5	—	—	Clear	Extensive surface deposits of white salts along flood plain.
895	10.5	—	16.5	Slightly brown	Channel material is sand and silt; flood plain is a broad alluvial valley; silt being transported in suspension.
900	14.5	—	14.3	Slightly brown	Channel material is sand and silt; flood plain is a broad alluvial valley; silt being transported in suspension.
1,050	13.0	—	6.0	Brown	Channel material is sand and silt; flood plain is a broad alluvial valley; silt being transported in suspension; water flowing in two broad distributary channels.

Table 4.—Streamflow and miscellaneous water-quality measurements along the Jemez River, August 28, 1984

[—, no data. See explanation for table 3]

Station name and number in figures 25 and 29	Latitude and longitude (degrees, minutes, and seconds)	Streamflow: Measured (cubic feet per second)	Streamflow: Per square mile of area drained (cubic feet per second)	Time of measurement	Possible measurement error (percent)
1. Jemez River near Jemez (U.S. Geological Survey streamflow-gaging station)	353942 1064434	37.40	0.08	1000	±5
2. Right-bank diversion for Jemez Pueblo (Westside Canal)	353941 1064427	4.25	—	1000	±5
3. Left-bank diversion for Jemez Pueblo (Eastside Canal)	353941 1064426	7.04	—	1030	±5
4. Return flow from Eastside Canal	353940 1064425	.57	—	1030	±5
5. Vallecito Creek at State Highway 4	353730 1064322	Estimated at much less than 0.10 (see remarks)	—	1100	—
6. Eastside Canal return flow at State Highway 4	353507 1064435	1.62	—	1145	±5
7. Jemez River at State Highway 4	353430 1064527	36.20	.06	1215	±5
8. Rio Salado at State Highway 44	353243 1064653	No flow (see remarks)	—	1215	—
9. Zia Pueblo diversion on left bank, upstream from Rio Salado	353315 1064603	14.10	—	1240	±5

Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	River miles	General appearance of water	Remarks
470	17.0	29.9	Light reddish brown	Outside gage height = 3.60 feet.
470	17.0	—	Light reddish brown	Approximately 700 feet downstream from gage.
470	17.0	—	Light reddish brown	Approximately 700 feet downstream from gage.
470	17.0	—	Clear	Approximately 300 feet downstream from diversion; from seepage through gate.
650	25.0	—	Clear to light reddish brown	Discharge represents recession of flow from storm during late evening on 8/27/84; flow was too low and shallow to measure, and was spread out in several braided channels.
460	21.0	—	Clear to light reddish brown	Canal crosses State Highway 4 about 2 miles south of Jemez Pueblo; canals probably are free flowing.
550	22.5	21.8	Very light reddish brown	Measurement at bridge upstream from diversion for Zia Pueblo.
15,000	31.5	—	Clear	No apparent flow, but had flowed overnight because channel was wet across bed and recession pools were elongated; no return flow from canals that empty near left bank.
550	23.0	—	Clear to very light reddish brown	Concrete canal approximately 4,000 feet downstream from diversion. Canal is free flowing. Diversion is upstream from Rio Salado.

Table 4.—Streamflow and miscellaneous water-quality measurements along the Jemez River, August 28, 1984—Concluded

Station name and number in figures 25 and 29	Latitude and longitude (degrees, minutes, and seconds)	Streamflow: Measured (cubic feet per second)	Streamflow: Per square mile of area drained (cubic feet per second)	Time of measurement	Possible measurement error (percent)
10. Zia Pueblo Northside Canal return flow	353017 1064330	7.67	—	1300	±5
11. Jemez River at Zia Pueblo, upstream from return flows	353018 1064333	22.9	—	1320	±5
12. Zia Pueblo Southside Canal return flow	353013 1064326	4.77	—	1340	±5
13. Jemez River at Zia Pueblo, downstream from return flows	353008 1064321	35.34	0.04	1340	—
14. Jemez River at Santa Ana Pueblo	352544 1063715	24.2	.03	1430	±8

Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temper-ature (degrees Celsius)	River miles	General appearance of water	Remarks
550	23.0	—	Clear to light reddish brown	Return flow to river approximately 1,000 feet upstream from Zia Pueblo bridge.
850	29.5	14.3	Light reddish brown	Measured upstream from return flows from Northside and Southside Canals; measured specific conductance at six points—four measurements were 850 microsiemens and two measurements were 900 microsiemens; water temperature was constant.
550	24.5	—	Clear to reddish brown	Return flow to river approximately 100 feet upstream from Zia Pueblo bridge.
850	30.5	14.2	Light reddish brown	Calculated discharge as sum of stations 10, 11, and 12. Both specific conductance and temperature were constant; measured approximately 400 feet downstream from Zia Pueblo bridge. Canals probably are free flowing.
950	33.0	6.0	Light to medium brown	Specific conductance and temperature constant across channel. Measured flow across two main braided channels.

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco

[Also see tables 3, 4, and 6; and Craigg, 1984, table 9. —, no data]

EXPLANATION

Site name or location: Name of stream and its proximity to some nearby geographic landmark or political boundary.

Streamflow: The volume of water that flowed past the particular site at the time of measurement, reported in cubic feet per second. Values followed by E were estimated; < preceding value indicates streamflow was less than that shown.

Specific conductance and temperature: These water-quality measurements were made at midflow depth and midstream width.

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temper-ature (degrees Celsius)	Remarks
Part 1. Jemez River							
Jemez River near Jemez (U.S. Geological Survey streamflow-gaging station)	353942 1064434	8-01-84	1015	27.5	500	18.0	Outside gage height = 3.5 feet. Appearance of water was translucent reddish brown. Station 1 of March 1 and August 28, 1984, seepage investigations.
Jemez River at Jemez Pueblo	353637 1064403	8-01-84	1000	—	550	21.0	Streamflow noticeably less than downstream at State Highway 4 because of irrigation diversions of Jemez Pueblo. Appearance of water was light reddish brown to almost clear. Station 4 of March 1, 1984, seepage investigation.

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temper-ature (degrees Celsius)	Remarks
Part 1. Jemez River - Continued							
Jemez River at State Highway 4	353430 1064527	8-01-84 8-06-84	0930 1000	30 E 25 E	820 550	19.5 20.0	Appearance of water was reddish brown, probably due to storm runoff over Permian and Triassic red beds upstream. Station 5 of March 1, 1984, seepage investigation and station 7 of August 28, 1984, seepage investigation.
Jemez River downstream from Rio Salado	353211 1064613	8-06-84	1030	30-35 E	600	21.0	Appearance of water was reddish brown; flow may not have been completely mixed with flow from Rio Salado.
Jemez River at Zia Pueblo, upstream from irrigation-return flow in ditches	353018 1064333	8-06-84	1215	20 E	1,250	26.5	Appearance of water was chocolate brown; water was more mineralized than that downstream from ditch return because less mineralized water from ditches diluted flow. Station 11 of August 28, 1984, seepage investigation.
Jemez River at Zia Pueblo, downstream from irrigation-return flow in ditches	353008 1064321	8-01-84 8-01-84 8-06-84	0840 1245 1045	-- — 25 E	— 27.0 22.0	— 1,150 700	Streamflow of several cubic feet per second concentrated against left bank. Appearance of water was moderate reddish brown. Station 13 of August 28, 1984, seepage investigation.

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Remarks
Part 1. Jemez River - Concluded							
Jemez River at Santa Ana Pueblo	352544 1063715	8-01-84 8-06-84	1300 1400	No flow 15-20 E	— 1,400	— 28.0	Appearance of water was light brown; much organic debris in flow. Flow visibly less than that at Zia Pueblo. Evidence of greater flow because entire active channel width was wet. Station 10 of March 1, 1984, seepage investigation and station 14 of August 28, 1984, seepage investigation.
Part 2. Vallecito Creek							
Vallecito Creek at mouth	353727 1064345	2-28-84 8-01-84	— 1010	0.5 E No flow	500 —	7.5 —	Channel wide (400-500 feet) and sandy. Appeared to be losing flow between this site and State Highway 4. Station 3 of March 1, 1984, seepage investigation.
Part 3. Rio Salado							
Rio Salado near beginning of intermittent reach, downstream from old railroad grade	353925 1065635	6-19-84	—	0.1 E	1,950	31.0	All measurements on June 19 and 20, 1984, were made with the assistance of William White (Hydrologist, U.S. Bureau of Indian Affairs). Measurements are in downstream direction and represent base-flow conditions in intermittent reaches of the Rio Salado.
Rio Salado 0.25 mile downstream from the site mentioned above	353914 1065636	6-19-84	—	.15 E	2,050	22.0	Rising stream in salt grass-covered channel eroded into Brushy Basin Shale Member of Morrison Formation.

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Remarks
Part 3. Rio Salado - Continued							
Rio Salado at fence line downstream from old railroad grade	353851 1065624	6-19-84	—	0.25 E	2,250	29.5	Alluvium consists mainly of Mancos Shale detritus; stream eroded into Westwater Canyon Sandstone Member of Morrison Formation. Minnows as much as 4 inches long in stream.
Rio Salado at base of cliff below old railroad grade	353834 1065556	6-19-84	—	<.1 E	2,350	29.5	Alluvium consists of Morrison Formation detritus on right bank, Mancos Shale detritus on left bank. Possible ground-water discharge from Morrison Formation in this reach. Rio Salado water-quality sampling site 1 (see table 6).
Rio Salado upstream from where stream crosses Todilto Limestone Member of Wanakah Formation	353813 1065535	6-19-84	—	.2 E	3,100	28.5	Ground water at 1 foot below land surface; specific conductance of ground water was 3,150 microsiemens; air temperature was 19.0 degrees Celsius. Alluvium consists of Mancos Shale detritus and gypsum fragments from Todilto Limestone Member of Wanakah Formation. Channel eroded into Recapture Shale Member of Morrison Formation.
Rio Salado just downstream from where stream crosses Todilto Limestone Member of Wanakah Formation	353813 1065527	6-19-84	—	.2 E	3,200	23.5	Alluvium consists of a layer of Mancos Shale deritus overlain by a layer of detritus from Todilto Limestone Member of Wanakah Formation.

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Remarks
Part 3. Rio Salado - Continued							
Rio Salado 0.25 mile downstream from the site mentioned above	353803 1065518	6-19-84	—	0.25 E	3,600	28.5	Rio Salado water-quality sampling site 2 (see table 6). Intermittent stream. Alluvium consists of detritus from Mancos Shale and Todilto Limestone Member of Wanakah Formation. Ground water at 1 foot below land surface; specific conductance of ground water was 4,200 microsiemens and air temperature was 21.0 degrees Celsius.
Rio Salado at altitude of 5,846 feet, downstream from old railroad grade	353706 1065445	6-19-84	—	<.01 E	4,300	30.0	Ground water at 1 foot below land surface; specific conductance of ground water was 4,200 microsiemens and air temperature was 24.0 degrees Celsius. Channel is eroded into solid gypsum outcrops of the Todilto Limestone Member of Wanakah Formation. Alluvium consists of detritus from Todilto Limestone Member of Wanakah Formation on left bank and detritus from Morrison Formation on right bank.
Rio Salado at jeep trail crossing, downstream from Arroyo Ojito	353441 1065412	6-20-84	—	.3 E	9,300	27.5	Rio Salado water-quality sampling site 3 (see table 6). Channel becomes broad and sandy near site. Intermittent flow from ground-water discharge (deep San Juan brines plus shallower alluvial ground water).

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Remarks
Part 3. Rio Salado - Concluded							
Rio Salado at old railroad grade, at base of Todilto Limestone Member of Wanakah Formation	353441 1065343	6-20-84	—	0.3 E	14,000	30.0	Rio Salado water-quality sampling site 4 (see table 6). Combination of ground-water discharge and warmer water re-dissolving salts on channel results in greater dissolved-solids concentration.
Rio Salado 0.2 mile upstream from Arroyo Peñasco	353333 1065202	6-20-84	—	.2 E	18,500	31.5	Rio Salado water-quality sampling site 5 (see table 6). Flow visibly less than at Rio Salado water-quality site 4. Much salt deposition and salt re-dissolution occurring along channel.
Rio Salado 0.1 mile downstream from Arroyo Peñasco	353333 1065145	6-20-84	—	.5 E	13,000	30.0	Increased flow and decreased specific conductance result from mixing with water from Arroyo Peñasco (see table 6).
Rio Salado at State Highway 44	353243 1064653	8-01-84	1230	No flow	—	—	—
		8-06-84	0900	203 E	7,500	20.0	Appearance of water was light brown and represented a flood recession from a recent storm. Decreased specific conductance resulted from dilution by larger volume flow.
Part 4. Arroyo Peñasco							
Arroyo Peñasco where it crosses the Pajarito fault	353610 1065120	5-08-84	—	.2 E	3,200	23.0	Appearance of water was clear. Source of flow was mound springs upstream (see Craigg, 1984, table 2, pl. 2).

Table 5.—Miscellaneous water-quality measurements along the Jemez River, Vallecito Creek, Rio Salado, and Arroyo Peñasco—Concluded

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date	Time	Stream-flow	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Water temperature (degrees Celsius)	Remarks
Part 4. Arroyo Peñasco - Concluded							
Arroyo Peñasco downstream from Swimming Pool Spring	353542 1065140	3-10-84	—	0.3	13,800	13.0	Data from U.S. Bureau of Indian Affairs, Albuquerque, New Mexico.
		5-08-84	—	.4 E	7,000	20.0	Streamflow had doubled from that at above site because of downcutting through saturated travertine and alluvium. Flow from Swimming Pool Spring does not reach Arroyo Peñasco as surface flow.
Arroyo Peñasco at State Highway 44	353407 1065137	5-08-84 6-12-84	— 1100	.5 E .5 E	12,000 12,000	17.0 17.5	Appearance of water was clear. Flow was perennial and represents base flow sustained by mound springs (see Craigg, 1984, table 2, pl. 2).
		6-19-84	—	.5 E	12,000	27.5	See chemical analysis of water, table 6.
		8-06-84	1110	1 E	12,500	18.5	Appearance of water was light brown and represented a flood recession, of which the peak was 1.5 feet higher in stage than that of base flow.

Table 6.--Chemical analyses of water from the Rio Salado, Arroyo Peñasco, and Vallecito Creek

[See tables 7 and 8; and Craigg, 1984, table 8]

EXPLANATION

Site name or location: Name of stream and sample number or its proximity to some nearby geographic landmark or political boundary.

Laboratory: USGS, U.S. Geological Survey; BIA, U.S. Bureau of Indian Affairs.

Streamflow: The volume of water that flowed past the particular site at the time of sample collection, reported in cubic feet per second. Values followed by E were estimated; < preceding value indicates streamflow was less than that shown.

Sodium-adsorption ratio: An alkali-hazard index computed using sodium, calcium, and magnesium concentrations. This ratio predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil (see table 10).

Note: All constituents are dissolved; concentrations of major ions, hardness, and dissolved solids are reported in milligrams per liter; concentrations of minor constituents are reported in micrograms per liter. < indicates concentration is known to be less than value given; -- indicates value was not reported. Precision as reported by laboratory.

Table 6.—Chemical analyses of water from the Rio Salado, Arroyo Peñasco, and Vallecito Creek—Continued

Site name or location	Latitude and longitude (degrees, minutes, and seconds)	Date of collection	Laboratory	Streamflow	Major ions											Hardness	
					Calcium	Magnesium	Sodium	Potassium	Bicarbonate (as HCO_3)	Carbonate (as CO_3)	Sulfate	Chloride	Fluoride	Silica	Nitrite plus nitrate (as N)	Calcium-magnesium (as $CaCO_3$)	Noncarbonate
Part 1																	
Rio Salado at State Highway 44	353243 1064653	1-29-74	USGS	—	390	55	3,800	3.1	483	0	4,700	3,100	1.7	12	0.18	1,200	850
Rio Salado 1	353834 1065556	6-19-84	BIA	0.1 E	505	60.8	372	8.21	150	8.10	2,195	18.4	1.13	—	—	1,510	—
Rio Salado 2	353803 1065518	6-19-84	BIA	<.25 E	396	46.2	356	8.60	109	6.60	2,279	.35	1.14	—	—	1,180	—
Rio Salado 3	353441 1065412	6-20-84	BIA	.3 E	521	72.9	1,862	50.8	204	6.30	3,754	1,432	1.72	—	—	1,600	—
Rio Salado 4	353441 1065343	6-20-84	BIA	.3 E	545	72.9	2,851	62.6	305	14.7	4,302	2,534	1.79	—	—	1,660	—
Rio Salado 5	353333 1065202	6-20-84	BIA	.2 E	565	102	3,954	78.2	201	9.9	6,023	3,653	1.86	—	—	1,830	—
Rio Salado underflow	353243 1064653	6-22-84	BIA	—	629	104	3,357	78.2	288	12.9	3,763	3,026	1.57	—	—	2,000	—
Alabaster Cave	353402 1065137	6-19-84	BIA	—	452	53.5	1,821	75.1	278	10.8	3,505	1,238	2.45	—	—	1,350	—
Arroyo Peñasco at State Highway 44	353407 1065137	6-20-84	BIA	.5 E	118	80.2	2,713	93.8	889	21.9	2,840	2,372	3.42	—	—	625	—
Vallecito Creek at State Highway 4	354706 1063210	9-01-83	USGS	.04	9.3	2.2	3.8	3.4	50	0	14	.9	<.1	39	<.1	34	0

Table 6.—Chemical analyses of water from the Rio Salado, Arroyo Peñasco, and Vallecito Creek—Concluded

Site name or location	Specific conductance (microsiemens per centimeter at 25 degrees Celsius) On-site	Laboratory	pH (units) On-site	Laboratory	Temperature (degrees Celsius)	Dissolved solids Sum of constituents	Residue at 180 degrees Celsius	Sodium-adsorption ratio	Selected minor constituents (micrograms per liter)	Remarks
Part 2										
Rio Salado at State Highway 44	—	16,600	7.6	—	2.0	12,300	—	48	Arsenic = 0, boron = 8,000, iron = 20, lithium= 8,300, manganese = 150	See Trainer (1978).
Rio Salado 1	2,350	3,510	—	8.00	29.5	—	3,204	4.2	Arsenic = 1.00, barium = 1,450, boron = 1,060, silver = 0.20	Stream in valley eroded into Morrison Formation; possible ground-water discharge in this reach.
Rio Salado 2	3,600	4,000	—	8.15	28.5	—	3,943	4.5	Arsenic = 1.60, barium = 1,695, boron = 1,060, selenium = 13.1, silver = 0.30	Intermittent stream; alluvium consists of erosional debris from Mancos Shale and Todilto Limestone Member of Wanakah Formation.
Rio Salado 3	9,300	10,300	—	8.05	27.5	—	7,915	20	Arsenic = 9.00, barium = 1,490, boron = 3,730, lead = 12.5, selenium = 3.00, silver = 0.30	Intermittent stream resulting from ground-water discharge (from San Juan Basin?). Channel broad and sandy.
Rio Salado 4	14,000	14,500	—	8.15	30.0	—	10,848	30	Arsenic = 68.9, barium = 1,450, boron = 5,100, selenium = 3.80, silver = 0.30	Stream eroded into base of Todilto Limestone Member of Wanakah Formation. Greater streamflow and specific conductance resulted from increased ground-water discharge and re-dissolution of salts on channel.
Rio Salado 5	18,500	19,100	—	8.40	31.5	—	14,497	40	Arsenic = 8.90, barium = 1,515, boron = 7,710, cadmium = 2.30, lead = 9.70, silver = 0.60	About 0.2 mile upstream from Arroyo Peñasco confluence.
Rio Salado underflow	—	16,700	—	7.70	-	—	12,751	33	Arsenic = 17.5, barium = 2,235, boron = 5,950, cadmium = 0.10, chromium = 4.00, selenium = 3.30, silver = 0.60	Sample from shallow hole dug into Rio Salado alluvium at State Highway 44.
Alabaster Cave	9,000	9,770	—	7.95	9.5	—	7,521	22	Arsenic = 9.80, barium = 1,335, boron = 5,250, chromium = 1.10, silver = 0.50	Pool inside cave in Todilto Limestone Member of Wanakah Formation, along right bank of Arroyo Peñasco.
Arroyo Peñasco at State Highway 44	12,000	12,900	—	8.10	27.5	—	8,800	47	Arsenic = 49.8, barium = 444, boron = 6,570, lead = 11.2, selenium = 2.30, silver = 0.50	Base flow of stream, derived from Arroyo Peñasco mound springs.
Vallecito Creek at State Highway 4	88	91	6.9	6.9	13.0	97	—	0.3	Arsenic = 1.0, boron = 10, manganese = 9.0, mercury = 0.1, vanadium = 2.3	Sample collected during a short rain shower.

Table 7.--Selected primary standards for public-water supplies

[Established by U.S. Environmental Protection Agency (1977). Standards based on health considerations]

Constituent	Maximum concentration (milligrams per liter)
Arsenic	0.05
Barium	1.00
Cadmium	.01
Chromium	.05
Lead	.05
Mercury	.002
Nitrate (as N)	10.0
Selenium	.01
Silver	.05

Table 8.--Selected secondary standards for public-water supplies

[Established by U.S. Environmental Protection Agency (1979). Standards based on esthetic considerations]

Constituent or property	Maximum concentration (milligrams per liter)[1]
Chloride	250
Copper	1
Iron	0.3
Manganese	.05
pH	6.5-8.5
Sulfate	250
Zinc	5

[1]Except pH, in standard units.

Table 9.--Irrigation-water-quality characteristics of water from streams

[See table 10. --, no data]

EXPLANATION

Name and location: Stream name and proximity to some nearby geographic landmark or political boundary.

Laboratory: USGS, U.S. Geological Survey; BIA, U.S. Bureau of Indian Affairs.

Streamflow: The volume of water that flowed past the particular site at the time of measurement, reported in cubic feet per second.

Specific conductance: In the table, specific-conductance values followed by L were measured in a laboratory and chemical analyses are available (see Craigg, 1984, tables 8 and 9); values followed by C were calculated by dividing the dissolved-solids concentration by 0.65; all other values were measured onsite.

Sodium-adsorption ratio: An alkali-hazard index computed using sodium, calcium, and magnesium concentrations. This ratio predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil (see table 10).

Irrigation class: Determined by plotting sodium-adsorption ratio against specific conductance on a diagram devised by the U.S. Soil Conservation Service. The larger the class numbers, the greater the irrigation hazard.

Table 9.—Irrigation-water-quality characteristics of water from streams—Concluded

Name and location	Latitude and longitude (degrees, minutes, and seconds)	Stream-flow	Date of collection	Labo-ratory	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Sodium-adsorption ratio	Irrigation class	Irrigation hazard
Jemez River	353942	—	9-25-24	USGS	750 C	2.8	C2S1	Low sodium/medium salinity
near Jemez (U.S.	1064434	—	11-14-74	USGS	584	2.2	C2S1	Low sodium/medium salinity
Geological Survey		19	2-12-81	USGS	650	2.5	C2S1	Low sodium/medium salinity
streamflow-gaging		131	5-6-81	USGS	220	0.9	C1S1	Low sodium/low salinity
station		19	8-5-81	USGS	680	2.9	C2S1	Low sodium/medium salinity
		24	11-4-81	USGS	675	2.5	C2S1	Low sodium/medium salinity
		331	4-15-82	USGS	175	.5	C1S1	Low sodium/low salinity
		38	9-2-82	USGS	360	1.9	C2S1	Low sodium/medium salinity
		59	11-10-82	USGS	350	1.6	C2S1	Low sodium/medium salinity
		52	3-3-83	USGS	370	1.5	C2S1	Low sodium/medium salinity
		561	5-26-83	USGS	130	.5	C1S1	Low sodium/low salinity
		42	7-19-83	USGS	420	1.7	C2S1	Low sodium/medium salinity
Jemez River at Jemez Pueblo	353637 1064403	—	8-17-82	BIA	633 L	2.6	C2S1	Low sodium/medium salinity
Jemez River at	353430	—	9-7-73	USGS	1,400	6.4	C3S2	Medium sodium/high salinity
State Highway 4	1064527	23.2	1-29-74	USGS	900	3.8	C3S1	Low sodium/high salinity
Arroyo Peñasco	353407 1065137	—	6-29-74	USGS	14,400	50	—	Water is not usable
Rio Salado at	353243	—	9-15-24	USGS	17,000 C,L	34	—	Water is not usable
State Highway 44	1064653	1-2	8-8-57	USGS	10,300 L	23	—	Water is not usable
		—	1-29-74	USGS	16,600 L	48	—	Water is not usable
Cuchilla Arroyo at State Highway 44	353525 1065313	—	6-29-74	USGS	24,600	48	—	Water is not usable

Table 10.--Selected water-quality standards for irrigation-water supplies

[Established by Federal Water Pollution Control Administration (1968); values with asterisks recommended by U.S. Environmental Protection Agency (1978)]

Constituent	Maximum recommended concentration (milligrams per liter)
Dissolved solids	1,000 or less suitable for many crops. 2,000 or greater not suitable for most crops. 2,000-5,000 useful only for salt-tolerant plants on permeable soils with careful management.
Chloride (dissolved-solids concentrations usually deter plant growth before chloride reaches detrimental levels)	700 or less suitable for many crops. 100 harmful to certain fruit plants.
Sulfate	600 or less acceptable for most crops. 1,000 or greater unsuitable for most crops.
Arsenic	0.10*
Beryllium	
(continuous irrigation on all soils)	.10*
(neutral to alkaline soils)	
Boron	
(continuous irrigation of sensitive crops)	.75*
(semitolerant crops)	1.0-2.0
(tolerant crops)	2.0-4.0

Sodium-adsorption ratio (SAR)

SAR values greater than 4 can be detrimental to sodium-sensitive crops.

SAR values of 8-18 generally are acceptable for most crops.

Table 11.--Irrigation-water-quality characteristics of water from wells completed in the alluvium and the Santa Fe aquifer

[See table 10. --, no data]

EXPLANATION

Location number: See text for explanation. Location numbers followed by P were projected by extending township, range, and section lines.

Laboratory: USGS, U.S. Geological Survey; BIA, U.S. Bureau of Indian Affairs; PHS, U.S. Public Health Service.

Principal water-yielding unit: The geologic unit from which the well obtains water. Questionable units are followed by (?). The abbreviations for water-yielding units are: Qal-alluvium, QTs-Santa Fe aquifer, Tz-Zia Sand.

Specific conductance: In the table, specific-conductance values followed by L were measured in a laboratory and chemical analyses are available (see Craigg, 1984, tables 3 and 4); values followed by C were calculated by dividing the dissolved-solids concentration of the water by 0.65; all other values were measured onsite.

Sodium-adsorption ratio: An alkali-hazard index computed using sodium, calcium, and magnesium concentrations. This ratio predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil (see table 10).

Irrigation class: Determined by plotting sodium-adsorption ratio against specific conductance on a diagram devised by the U.S. Soil Conservation Service. The larger the class number, the greater the irrigation hazard.

Table 11.—Irrigation-water-quality characteristics of water from wells completed in the alluvium and the Santa Fe aquifer—Continued

Location number on plate 1 and local name or number if known	Date of collection	Labo-ratory	Principal water-yielding unit	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Sodium-adsorption ratio	Irrigation class	Irrigation hazard
Part 1. Jemez Pueblo							
16.02E.16.334	7-26-82	BIA	Qal	820	2.1	C3S1	Low sodium/high salinity
Irrigation test PW-4	7-26-82	BIA	--	1,149 L	3.0	C3S1	
16.02E.16.411 IHS Well 1	8-30-73	USGS	Qal	1,020	3.5	C3S1	Low sodium/high salinity
16.02E.16.412 IHS Well 2	11- -81	PHS	Qal	1,151 L	3.3	C3S1	Low sodium/high salinity
16.02E.16.332a Observation Well Iwt	12-8-81	BIA	Qal	1,020 L	3.6	C3S1	Low sodium/high salinity
16.02E.16.332b Observation Well Iz	12-8-81	BIA	Tz	800 L	6.1	C3S2/C3S1	Low to medium sodium/high salinity
16.02E.27.213 Stock well 1	4-4-74	USGS	QTs	670	2.2	C2S1	Low sodium/medium salinity

Table 11.—Irrigation-water-quality characteristics of water from wells completed in the alluvium and the Santa Fe aquifer—Continued

Location number on plate 1 and local name or number if known	Date of collection	Labo- ratory	Principal water- yielding unit	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Sodium- adsorption ratio	Irrigation class	Irrigation hazard
Part 2. Zia Pueblo							
14.02E.05.323P RWP-4	4-18-57	USGS	QTs	399 L	0.5	C2S1	Low sodium/medium salinity
15.02E.06.222b Irrigation test 2	4-4-54	USGS	Qal	5,290 L	21	C4S4	Very high sodium/ very high salinity
15.02E.12.432 RWP-3	4-4-74	USGS	QTs	490 L	2.2	C2S1	Low sodium/medium salinity
15.02E.22.34 "Proposed" domestic well	5-19-52	USGS	QTs	848 L	2.4	C3S1	Low sodium/high salinity
15.02E.22.343 School dug well	12-18-51	USGS	Qal	2,260 L	7.8	C4S2	Medium sodium/very high salinity
15.02E.22.414A Main public-supply well	4-11-83	BIA	QTs	563 L	1.8	C2S1	Low sodium/medium salinity

Table 11.—Irrigation-water-quality characteristics of water from wells completed in the alluvium and the Santa Fe aquifer—Concluded

Location number on plate 1 and local name or number if known	Date of collection	Labo-ratory	Principal water-yielding unit	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Sodium-adsorption ratio	Irrigation class	Irrigation hazard
Part 2. Zia Pueblo - Concluded							
15.02E.22.414b Public-supply standby well	1-20-60	USGS	QTs	458 L	1.7	C2S1	Low sodium/medium salinity
Part 3. Santa Ana Pueblo							
13.03E.03.223 Perea	4-18-57	USGS	QTs	736 L	1.1	C2S1	Low sodium/medium salinity
14.03E.18.433 RWP-1	4-18-57	USGS	QTs, Qal(?)	2,570 L	3.7	C4S1	Low sodium/very high salinity
14.03E.22.323	9-27-24	USGS	Qal	1,500 L	5.0	C3S1/C3S2	Low to medium sodium/ high salinity

Table 12.--Selected water-quality standards for livestock and wildlife use

[Established by Federal Water Pollution Control Administration (1968)]

Constituent	Maximum recommended concentration (milligrams per liter)
Chloride	1,500 or less suitable for all livestock and poultry.
Nitrate plus nitrite	100 or less suitable for most livestock and poultry.
Sulfate	1,000 or less suitable for most livestock; 2,000 and greater can be detrimental to cattle.
Dissolved solids	3,000 and less very satisfactory for all livestock and poultry.
	5,000 to 7,000 suitable for cattle, sheep, swine, and horses, but not for lactating animals or poultry.
Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Maximum recommended value
Poultry	4,000
Swine	6,000
Horses	9,000
Dairy cattle	10,000
Beef cattle	14,000
Sheep	17,000