HYDROGEOLOGY OF THE SOCORRO AND LA JENCIA BASINS, SOCORRO COUNTY, NEW MEXICO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4342

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By Scott K. Anderholm

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CONTENTS

CONTENTS - Concluded

PLATES

[Plates are in pocket]

FIGURES

FIGURES - Concluded

TABLES

CONVERSION FACTORS

In this report figures for measurements are given in inch-pound units only. The following table contains factors for converting to metric units.

Multiply inch-pound units	By	To obtain metric units
inch	25.40	millimeter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
foot per mile	0.1894	meter per kilometer
mile	1.609	kilometer
acre	4047	square meter
gallon per minute	0.06309	liter per second
acre-foot	1233	cubic meter
acre-foot per day	0.001233	cubic hectometer per day
acre-foot per year	0.001233	cubic hectometer per year
acre-foot per acre per year	0.003048	cubic hectometer per hectare per year
cubic foot per second	0.02832	cubic meter per second

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ABSTRACT

The Socorro and La Jencia Basins are located in central Socorro County, New Mexico. The principal aquifer system in the Socorro and La Jencia Basins consists of, in descending order, the shallow aquifer, the Popotosa confining bed, and the Popotosa aquifer. The minor aquifer systems, which are dominant along the basin margins, are the Socorro volcanics aquifer system and the Mesozoic-Paleozoic aquifer system.

On the east side of the Socorro Basin, water enters the principal aquifer system from the Mesozoic-Paleozoic aquifer system. On the west side of the Socorro Basin, ground water flows from the principal aquifer system in La Jencia Basin eastward to the principal aquifer system in the Socorro Basin. The volume of this flow is limited by the permeability of the minor aquifer systems and the Popotosa confining bed. A water budget indicates that if no change in ground-water storage occurs in the Socorro Basin, ground-water inflow to the basin is about 53,000 acre-feet per year greater than ground-water outflow.

Dissolution of gypsum, calcite, and dolomite seems to control water quality in the Mesozoic-Paleozoic aquifer. Water with a chloride concentration of as much as 1,000 milligrams per liter and a specific conductance of as much as 6,700 microsiemens per centimeter at 25° Celsius is present in the northern and southern parts of the Socorro Basin. These large chloride concentrations may indicate upward movement of water from deeper in the basin in these areas. The water with the large chloride concentration in the southern part of the basin also may be caused by leakage of geothermal waters along the Capitan lineament. In the central part of the Socorro Basin, infiltration of excess irrigation water and inflow of ground water from the basin margins control water quality. In this area, specific conductance generally is less than 1,000 microsiemens per centimeter. Water in La Jencia Basin generally is of the calcium sodium bicarbonate type with specific conductance less than 500 microsiemens per centimeter.

INTRODUCTION

In 1978, Congress appropriated funds to begin a ground-water program called Regional Aquifer Systems Analysis (RASA). This program was designed to study large areas of the country that are underlain by a regional aquifer system. A regional aquifer system as defined in this program may consist of hydraulically connected aquifers or confining beds that underlie large regions, commonly parts of several States. Some regional studies contain many independent aquifers that have similar characteristics.

The Southwest Alluvial Basins (SWAB) regional aquifer study began in fiscal year 1978. The SWAB study area consists of the basins along the Rio Grande from its headwaters in southern Colorado to Presidio, Texas, and several closed basins in southwestern and central New Mexico (fig. 1). Twenty-two basins were identified in this study area. Because of the time frame of the project and the large number of basins, not all basins were studied in detail. This area is dependent on ground water and surface water for irrigation and municipal use. With the rapid increase in population and in agriculture in this area recently, the need has been recognized for a better understanding of the interaction of ground water and surface water and the effect of increased water use on the hydrologic system of the area. The principal objectives of the SWAB study are to: (1) Develop a computer-stored, hydrologic data base; (2) study the flow systems and water quality of the area; and (3) simulate the hydrologic system for selected basins (Wilkins and others, 1980, p. 10).

Purpose and Scope

The Socorro and La Jencia Basins were chosen to be studied in detail because of the opportunity to investigate the hydraulic connection between an open basin (Socorro) and a partly closed basin (La Jencia). The purpose of this study was to develop a data base that contained both well-completion and water-quality information, describe the hydrogeology of the area, and identify data needs for future studies.

Location

The study area is located in central Socorro County, New Mexico (fig. 2). The Socorro and La Jencia Basins for purposes of this paper consist of the area shown in figure 2. Population centers in the area are Socorro, Magdalena, San Antonio, Lemitar, and Polvadera. Socorro is the largest community, having a population of 7,173 in 1980. Agriculture and ranching are the major factors controlling the economy of the area. Federal and State agencies employ a significant part of the population.

The Socorro Basin is one of many basins in the Rio Grande Rift that have through-flowing drainage and is linked to other basins in the rift by the Rio Grande. The Socorro Basin is bounded by the Albuquerque-Belen Basin on the north and the San Marcial Basin on the south (fig. 1).

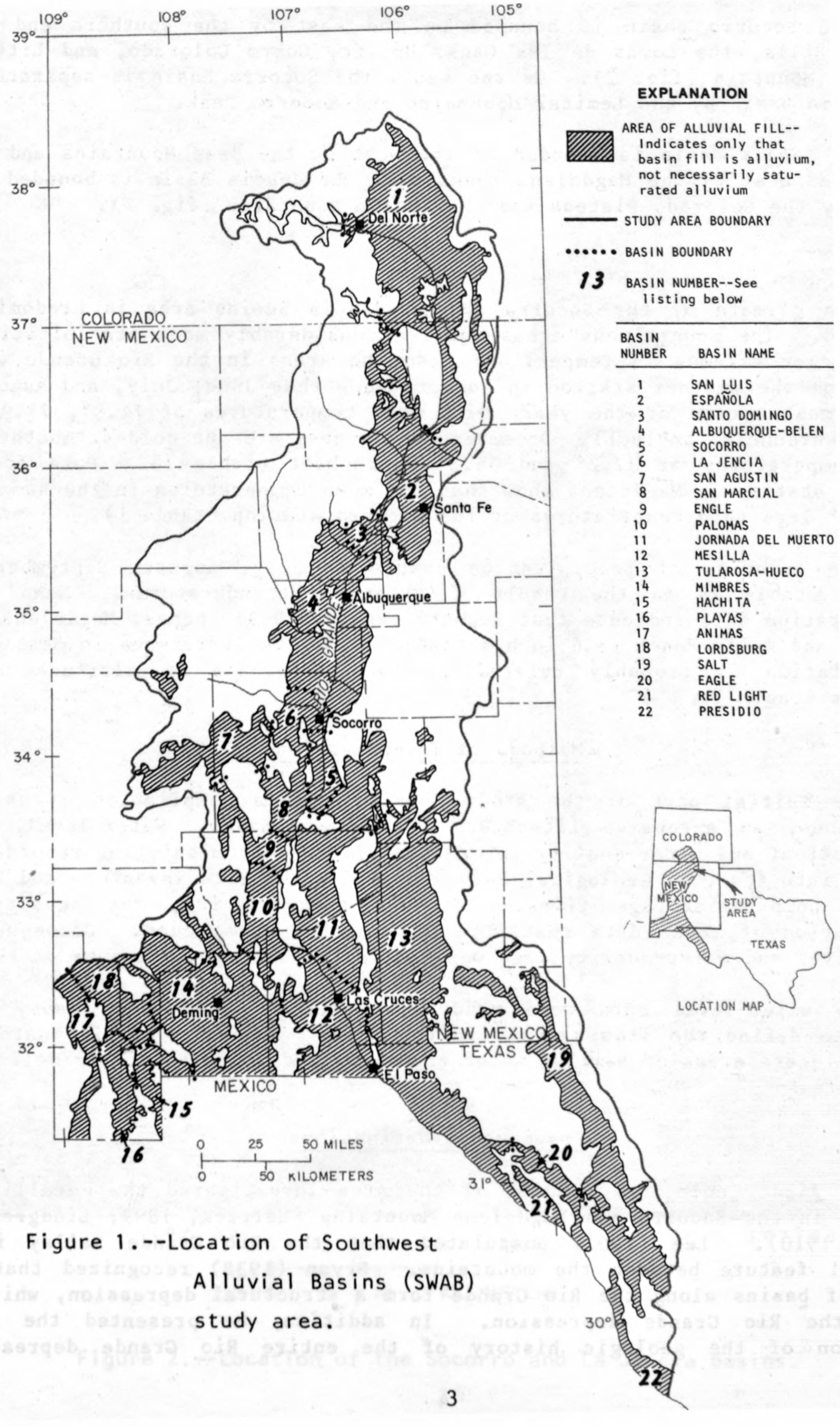


Figure 1.--Location of Southwest Alluvial Basins (SWAB) study area.

The Socorro Basin is bounded on the east by the southern end of the Joyita Hills, the Lomas de las Canas Uplift, Cerro Colorado, and Little San Pascual Mountain (fig. 2). On the west, the Socorro Basin is separated from La Jencia Basin by the Lemitar Mountains and Socorro Peak.

La Jencia Basin is bounded on the west by the Bear Mountains and on the south and west by the Magdalena Mountains. La Jencia Basin is bounded on the north by the Colorado Plateau and the Ladron Mountains (fig. 2).

Climate

The climate of the Socorro and La Jencia Basins area is predominantly semiarid. The mountainous areas receive considerably more precipitation and have larger extemes in temperature than the areas in the Rio Grande valley. Data from the weather station in Socorro show that June, July, and August are the warmest months of the year, with mean temperatures of 74.8°, 77.9°, and 75.0° Fahrenheit (table 1). December and January are the coldest months, with mean temperatures of 37.2° and 36.3° Fahrenheit (table 1). Data from the weather station in Magdalena show that the mean temperatures in the summer are about 6° less than temperatures at the Socorro station (table 1).

The majority of precipitation occurs in July, August, September, and October (table 1) as the result of afternoon thunderstorms. Mean annual precipitation data indicate that Socorro receives 9.35 inches, Magdalena 11.74 inches, and Kelly Ranch 13.6 inches (table 1). This difference in mean annual precipitation is probably related to the difference in altitude of the stations (table 1).

Methods of Investigation

The initial part of the study consisted of a compilation of existing data; thus, an extensive literature review was made. Water-level, well-construction, and water-quality information derived from existing records were entered into the U.S. Geological Survey Ground-Water Site Inventory and Water-Quality computer-storage files. It was apparent from the density and distribution of these data that more information was needed. Consequently, water-level and water-quality data were collected during the summer of 1980.

The water-level data were used to construct water-level maps, which helped to define the flow systems in the area. The water-quality data were used to locate areas of similar water chemistry and to help further define the flow systems.

Previous Investigations

The first geological studies of the area investigated the metallic ore deposits in the Socorro and Magdalena Mountains (Herrick, 1899; Lindgren and others, 1910). Lee (1907) postulated that the Rio Grande valley is an erosional feature between the mountains. Bryan (1938) recognized that the series of basins along the Rio Grande form a structural depression, which he called the Rio Grande depression. In addition, he presented the first discussion of the geologic history of the entire Rio Grande depression.

Figure 2.--Location of the Socorro and La Jencia Basins.

Table 1. Climatic data for three stations in and near the study area (from Gabin and Lesperance, 1977)

Station: Socorro
County: Socorro
Latitude: 34°05'
Longitude: 105°53'
Altitude: 4,585 feet

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Precipitation													
Years of record	82	83	83	84	84	83	84	82	82	84	84	84	76
Mean	.39	.40	.46	.52	.54	.54	1.06	1.50	1.37	1.06	.36	.60	9.35
Temperature													
Years of record	82	81	81	84	84	84	85	83	83	83	82	83	69
Mean	36.3	42.5	49.4	57.7	65.8	74.8	77.9	75.0	69.1	58.1	45.5	37.2	56.8

Station: Magdalena
County: Socorro
Latitude: 33°46'
Longitude: 106°54'
Altitude: 6,540 feet

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Precipitation													
Years of record	68	65	65	65	65	65	66	63	65	65	66	63	53
Mean	.46	.43	.51	.67	.51	.69	2.46	2.71	1.52	.86	.43	.59	11.74
Temperature													
Years of record	59	59	60	60	61	61	61	57	56	57	57	56	36
Mean	33.1	37.3	43.0	50.5	59.2	68.7	71.3	69.0	63.2	53.2	42.0	34.0	52.0

Station: Kelly Ranch
County: Socorro
Latitude: 34°02'
Longitude: 107°08'
Altitude: 6,700 feet

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Precipitation													
Years of record	30	30	30	30	30	30	30	30	30	30	30	31	28
Mean	.52	.59	.61	.43	.50	.80	2.98	3.19	1.79	1.27	.37	.71	13.60

Bryan (1938, p. 209) suggested that the center of the ancestral Socorro-Lemitar Basin is very near the east side of Socorro Peak-Lemitar Mountains, which were uplifted relatively recently. Bryan (1938) also characterized alluvial basins on the basis of ground- and surface-water flows into and out of the basin.

Denny (1940, 1941) described the Quaternary and Tertiary geology of the San Acacia area. Denny (1940) named the Popotosa Formation and expounded on the relationships between Popotosa and post-Popotosa sediments. Bruning (1973) studied the origin and distribution of the Popotosa Formation in the Socorro area.

Chapin and Seager (1975) discussed the evolution of the Rio Grande Rift from the pre-rift setting until present time. Chapin and others (1978a) described the hydraulic and geologic setting of the Socorro geothermal area.

In a geologic map of the San Acacia 7.5-minute quadrangle, Machette (1978a) named the Sierra Ladrones Formation and assigned it and the Popotosa Formation to the Santa Fe Group. This geologic map shows the relation between the Tertiary deposits of the area. Osburn (1978), Chamberlin (1980), and Eggleston (1982) mapped the geology of the Socorro and Chupadera Mountains.

There are many early studies of the surface-water and shallow ground-water interaction in the Socorro area (Yeo, 1928; Bloodgood, 1930; Debler, 1932). Mauger (1932) discussed the chemical quality of surface water near Socorro. Theis (1938) discussed the effect of the installation of drains and changes in river stage on ground-water levels as well as the occurrence and movement of ground water near the river.

Waldron (1956) studied the geology and ground-water resources in the Socorro Basin-Snake Ranch Flats area. Much of the data in the present report was obtained from Waldron's report. Hall (1963) studied the geochemistry of the springs in the Socorro area. He suggested, on the basis of chemical-equilibrium calculations, that the rhyolites in the area are sites of ion exchange, exchanging sodium for calcium in the ground water. Bushman (1963) studied the ground-water movement and quality along the Rio Grande near Socorro. He estimated that the ground-water flow parallel to the river in the Socorro area is about 27 acre-feet per day. Bushman also discussed the changes in ground-water quality as a function of depth, location, and withdrawals. Gross and Wilcox (1981) described the hydrogeology of the Socorro geothermal area and presented tritium data.

Well-Numbering System

The system of numbering wells in New Mexico is based on the common subdivision of public lands into sections. The well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land network. The number is divided by periods into four segments. The first segment denotes the township north or south of the New Mexico base line; the second denotes the range east or west of the New Mexico principal meridian; and the third denotes the section. The fourth segment of the number, which consists of three digits, denotes the 160-, 40-, and 10-acre tracts, respectively, in which the well is situated. For this purpose, the section is divided into four quarters, numbered 1, 2, 3, and 4 for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section, which is a tract of 160 acres. Similarly the 160-acre tract is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract.

If a well cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If a well cannot be located more closely than the section the fourth segment of the well number is omitted. An example of the well-numbering system in New Mexico is shown in figure 3.

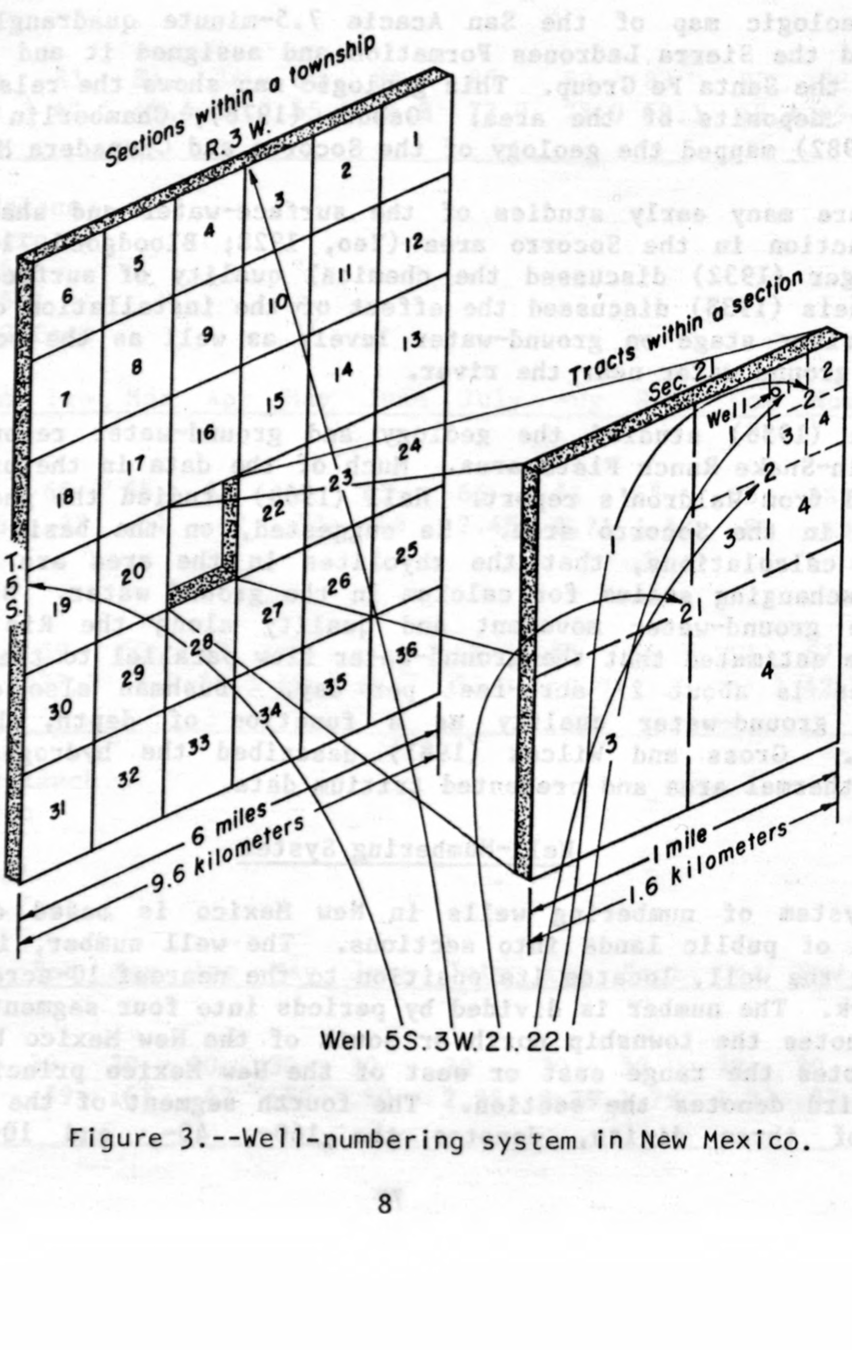


Figure 3.--Well-numbering system in New Mexico.

GEOLOGIC UNITS AND THEIR WATER-YIELDING CHARACTERISTICS

Many of the interpretations concerning ground-water movement and water quality are based on aspects of the geology of the area; therefore, the geology is discussed in detail. The depositional environment of a unit can be helpful in the understanding of the relative hydraulic conductivity, extent, and continuity of the unit. The depositional environment also can be helpful in understanding the interfingering relationships between units. The mineralogy of a unit many times affects the chemical nature of water moving through the unit. The structural geology is important in the interpretation of the flow system of an area. Faults that juxtapose relatively impermeable sediments against relatively permeable sediments can have significant effects on a flow system. Adjacent fault blocks that have large differences in thickness of permeable sediments also can affect flow systems.

Precambrian rocks crop out along the margins of the Socorro and La Jencia Basins. On the east side of the Socorro Basin, Mississippian, Pennsylvanian, Permian, Triassic, Cretaceous, and Tertiary rocks are exposed. In the Socorro Peak-Lemitar Mountains, Magdalena Mountains, and Chupadera Mountains, Tertiary volcanic rocks overlie the Precambrian, Mississippian, and Pennsylvanian rocks. In the Socorro and La Jencia Basins, a considerable thickness of alluvial-basin deposits overlies the Tertiary volcanic rocks.

Rocks ranging in age from Precambrian to middle Oligocene are minor water-yielding units in the study area and are discussed only briefly. Rocks ranging in age from middle Oligocene to Holocene consist mainly of alluvial-basin deposits and are the major water-yielding units in the area; therefore, these rocks are discussed in more detail.

Many of the rock units are combined on the geologic map (pl. 1) because of the complex nature of the area and the nature of the previously published geologic maps. Much of the following discussion of the Precambrian, Paleozoic, Mesozoic, and early Tertiary rocks was condensed from Wilpolt and Wanek (1951). A simplified correlation chart and geologic map show the distribution of rocks in the area (pl. 1).

Precambrian Rocks

The Precambrian rocks consist of igneous and metamorphic rocks that are exposed on Socorro Peak, on the northeast side of the Socorro Basin, and in the Magdalena and Chupadera Mountains. The Precambrian rocks are not considered water-yielding units but may transmit water in densely fractured or weathered zones.

Mississippian Rocks

The Kelly Limestone and its Calosa Member consist of limestones and dolomitic limestones although the Calosa contains a conglomerate and sandstone near the contact with the underlying Precambrian rocks. The Mississippian rocks are not significant sources of water in the area.

Pennsylvanian Rocks

The Sandia Formation consists of a basal limestone and an upper clastic member that is composed of gray to green sandstone, conglomerate, limestone, and shale. The Madera Limestone overlies the Sandia Formation and consists of a lower, thin to massively bedded, cherty, gray limestone and an upper, thin- to thick-bedded, arkosic limestone that contains some gray, black, and red shale. The Pennsylvanian rocks yield water in the Magdalena Mountains and east of the Socorro Basin. No well data exist documenting the yield of these rocks. Springs issuing from these rocks usually are associated with faults and fracture zones, which indicates that secondary permeability is important in these rocks.

Permian Rocks

The Bursum Formation consists of dark-purplish-red to green shale and interbedded thin beds of arkosic conglomerate and gray limestone. The Abo Formation consists of thick shales and well-cemented sandstone and conglomerates.

The Yeso Formation is composed of four members, described as follows in ascending order. The Meseta Blanca Sandstone Member consists of red to brown sandstone and sandy shale. The Torres Member, which comprises the main part of the Yeso Formation, consists of orange-red to buff sandstone and siltstone with some interbedded limestone and gypsum. The Canas Gypsum Member consists almost entirely of white gypsum. The Joyita Sandstone Member is composed of orange-red, buff, and yellow sandstone, silty sandstone, and siltstone.

The Glorieta Sandstone is white to light-yellow to light-gray, medium- to coarse-grained, crossbedded sandstone. The San Andres Formation has been divided into two members. The lower limestone member is light- to dark-gray, thin- to medium-bedded limestone with interbedded gypsum. The upper member is composed of orange to red sandstone with thin interbeds of dark-gray limestone.

The Permian sandstones and silty sandstones yield and transmit water. The limestones, where fractured, also yield and transmit water. Weir (1965, p. 20) reported that a well (10S.1W.25.341) completed in the San Andres Limestone yields about 900 gallons per minute, but generally the yields from Permian rocks are less than 30 gallons per minute. The shales and unfractured limestones are barriers to ground-water flow.

Triassic Rocks

The Chinle Formation consists of red to light-gray sandstone, siltstone, and shale. Weir (1965, p. 21) reported that two wells in section 23, T. 4 S., R. 2 E. yield small quantities of water. The sandstones in the Chinle Formation transmit only minor quantities of water and are not major aquifers in the study area.

Cretaceous Rocks

The Dakota Sandstone consists of medium- to coarse-grained sandstone with interbeds of carbonaceous shale. The Mancos Shale consists of a basal gray to green, calcareous shale, a middle medium- to fine-grained buff sandstone, and an upper gray to green shale that contains septarian concretions. The Mesaverde Formation consists of interbedded buff sandstone, siltstone, and carbonaceous shale. Several coal beds also are present in the Mesaverde Formation.

Sandstones in the Dakota Sandstone and Mesaverde Formation transmit water, but the yields from these sandstones are small. The Mancos Shale and shales in the Mesaverde Formation and Dakota Sandstone are confining beds.

Tertiary Rocks

Baca Formation and Datil Group of Osburn and Chapin (1983)

The Baca Formation consists of conglomerate, red and white sandstones, and shales. Gardner (1910, p. 454) reported the Baca Formation to be at least 1,023 feet thick in the San Antonio area. The Datil Group (Osburn and Chapin, 1983) is composed of as much as 2,000 feet of rhyolitic to andesitic ash-flow tuffs and volcaniclastic conglomerates and sandstones.

In the southeastern part of the study area, several wells obtain water from the Baca Formation. Weir (1965, p. 23) estimated that well 6S.2E.1.144 yields 50 gallons per minute from the Baca Formation. Sandstones and conglomerates in the Datil Group yield water; however, Weir (1965, p. 24) reported that the Datil Group seems to be less permeable than the Baca Formation.

Socorro Volcanics

The Socorro volcanics consist of ash-flow tuffs with some andesite to basaltic-andesite lavas, landslide deposits, rhyolite lavas, and rhyolite domes. These volcanics have been estimated to be 20 to 33 million years old (Chapin and others, 1978a, p. 117). They are the result of volcanic activity from at least seven overlapping cauldrons. The vertical and areal distribution of volcanics is variable. Near the volcanic centers and cauldron margins, which overlap, there may be more than 10,000 feet of volcanic rocks. In areas outside of the cauldrons or in areas that were structurally high during volcanic activity, the volcanic rocks may be quite thin. The majority of these volcanic rocks are well jointed and probably have considerable fracture permeability (Chapin and others, 1978a, p. 121). This fracture permeability probably is greatest in areas adjacent to cauldron margins or areas adjacent to faults or lineaments.

Chapin and others (1978a, p. 124) suggested the presence of an ancient geothermal system in the Socorro area. Anomalously large potassium content in volcanic rocks and altered plagioclase feldspars in the area seem to support this thesis. The volcanic rocks of the area have been postulated by Chapin and others (1978a) to be the reservoir for this system. If this is the case, the volcanic rocks of the area may presently transmit large quantities of water. On the western side of the Socorro Basin, alluvial-basin deposits are in fault contact with these volcanics. In this area the volcanics may provide a hydraulic connection between the Socorro and La Jencia Basins.

Popotosa Formation

Denny (1940) originally described the Popotosa Formation of the Santa Fe Group in an area between San Lorenzo Arroyo and the Ladron Mountains. Bruning (1973, p. 25) designated the type-section area of the Popotosa to be along the drainage system of Cañada de la Tortola in T. 1 N., R. 1 W., which is just north of the Socorro Basin. The Popotosa was deposited during latest Oligocene and nearly all of Miocene time (Chamberlin, 1980, p. 227) in an arid to semiarid climate as a bolson sequence in a basin, which hereafter is referred to as the Popotosa Basin. This basin was bounded by the Magdalena Mountains and Chupadera Mountains on the south and southwest, the San Mateo and Bear Mountains on the west, and the Ladron Mountains on the north (Chapin and others, 1978a, p. 118). The exact nature of the eastern boundary of the Popotosa Basin is not completely understood although it probably consisted of some type of highland east of the present Rio Grande. The northeast and southeast boundaries of the Popotosa Basin have not been determined. Bryan (1926, p. 84) suggested that the axis of the Popotosa Basin was near the eastern front of the Lemitar Mountains and that the uplift of this range disrupted the basin. Bruning (1973) and Chamberlin (1980) documented the geometry and structural history of the Popotosa Basin.

Much of the following discussion of the Popotosa Formation was obtained from Bruning (1973) and Chamberlin (1980). The Popotosa Formation consists of two main lithofacies: a lower fanglomerate facies and an upper playa facies. Bruning (1973, p. 38) estimated the combined thickness at the type section to be 5,500 feet. Bruning (1973, p. 38-39) reported that the fanglomerate facies ranges in thickness from 2,700 to 6,200 feet and the playa facies ranges in thickness from 800 to 3,500 feet. The great variation in thickness is due to several factors: (1) The large relief of the Popotosa Basin floor at the initial stage of Popotosa deposition; (2) the differential movement of fault blocks in the Popotosa Basin during deposition of the Popotosa; (3) volcanic activity in and adjacent to the Popotosa Basin during Popotosa deposition; and (4) the erosion of the Popotosa Formation prior to deposition of the Sierra Ladrones Formation.

The fanglomerate and playa facies intertongue extensively due to changes in source areas and climatic conditions. Near the margins of the Popotosa Basin, the playa facies intertongues with fanglomerates derived from the neighboring highlands.

The fanglomerate facies near the Socorro Peak-Lemitar Mountains was deposited mainly as mudflows. The facies consists of 50 percent or more reddish-brown conglomerate; the remainder of the deposit is sandstone. The clasts in the conglomerates vary in size and lithology depending on source area and proximity to source areas. The fanglomerates near the Ladron Mountains contain a large percentage of Paleozoic and Precambrian clasts, whereas the fanglomerates near the Socorro Peak-Lemitar Mountains contain 60 to 80 percent volcanic clasts. The matrix consists of 40 to 70 percent lithic fragments, 15 to 25 percent crystal fragments, and red clay. Hematite, silica, calcite, and clay are common cements (Bruning, 1973, p. 47-49).

The sandstones in the fanglomerate facies throughout the Socorro area are volcanic wackes that contain about 35 percent feldspar, 15 to 20 percent quartz, 35 to 45 percent volcanic lithic fragments, and 15 to 30 percent calcite and silica cement (Bruning, 1973, p. 48). Chamberlin (1980, p. 242) suggested that the reddish, well-indurated nature of the fanglomerate facies may be the result of widespread hot-spring activity. This facies seems to thin from north to south (Chamberlin, 1980, p. 238). The hydraulic conductivity of the fanglomerate facies varies considerably depending on the degree of cementation, degree of alteration of the volcanic material, degree of sorting, and the distribution of grain size of the deposit.

The playa facies consists of moderately to poorly indurated claystone, mudstone, siltstone, and sandstone derived from highlands to the west and east. The color of the playa facies generally ranges from brown and reddish brown to buff and locally may include shades of bluish green, green, or yellow (Bruning, 1973, p. 50). Gypsum beds and vein fillings are very common in this facies (Chamberlin, 1980, p. 262). Bedding is well developed and beds range in thickness from less than 1 inch to 1 foot (Bruning, 1973, p. 50). The playa facies probably has minimal hydraulic conductivity because of the fine-grained nature of the deposit.

Tertiary and Quaternary Rocks

Machette (1978a) assigned the name Sierra Ladrones Formation, of early Pliocene to middle Pleistocene age, to the deposits that make up the low foothills of the Ladron Mountains. The Sierra Ladrones Formation of the Santa Fe Group is broadly equivalent to the Camp Rice Formation of Strain (1966) in southern New Mexico and to the upper buff member and part of the middle red member of the Santa Fe Formation of Bryan and McCann (1937) in northern New Mexico (Machette, 1978a).

The Sierra Ladrones Formation consists mainly of flood-plain and axial-stream deposits with some piedmont-slope deposits, alluvial-fan deposits, alluvial-flat deposits, and local basalts. The axial-stream deposits consist of light-gray to tan, moderately well to poorly sorted, fine- to coarse-grained sandstones and pebble conglomerates. The coarse deposits generally are well indurated with calcite cement (Chamberlin, 1980, p. 349). These deposits interfinger with over-bank or flood-plain deposits that consist of poorly indurated beds of mud, silt, and sand. The main body of the axial-stream deposits was deposited by a generally south-flowing river (Machette, 1978a; Chamberlin, 1980, p. 351). Chamberlin (1980, p. 348) described deposits of a tributary stream that are exposed west of the common line between sections 28 and 29, T. 2 S., R. 1 W. (pl. 1). Paleocurrent directions indicate a generally southeasterly transport direction (Chamberlin, 1980, p. 351).

The alluvial-fan, piedmont-slope, and alluvial-flat deposits consist of pale-red, light-brown, or pinkish-orange, poorly sorted conglomerates and sandstones that contain clasts derived from local highlands (DeBrine and others, 1963, p. 126; Chamberlin, 1980, p. 355). These deposits generally are wedge shaped and intertongue with the fluvial deposits. Near present highlands, these deposits may be quite thick.

The basalts in the Sierra Ladrones Formation are dark-gray, fine-grained aphanitic rocks, which contain small phenocrysts of yellowish-brown olivine (Chamberlin, 1980, p. 359). These basalts are quite local and generally are quite thin except near vents. The vent areas are located near San Acacia and in the Sedillo Hill area (Chamberlin, 1980, p. 358).

The thickness and extent of the Sierra Ladrones Formation are controlled by the degree of erosion across tilted fault blocks (Chamberlin, 1980, p. 342). The presence of outcrops of the axial-stream facies northeast, southeast, and southwest of the flanks of Socorro Peak seems to indicate that the area of the present Socorro Peak and Lemitar Mountains had little relief during early Pliocene time. Chamberlin (1980, p. 343) suggested that the Socorro Peak and Lemitar Mountains developed slowly, and piedmont slopes derived from the uplift caused the ancestral Rio Grande to move eastward. The early Pliocene fluvial or axial-stream deposits were then buried by piedmont gravels. A geothermal test well (3S.1W.9.220) penetrated 230 feet of piedmont-slope gravels above 270 feet of fluvial deposits (Chamberlin, 1980, p. 352). Chamberlin (1980, p. 352) estimated there may be as much as 1,000 feet of fluvial deposits north of Socorro Canyon and east of the Socorro Peak range-bounding fault.

Quaternary Deposits

The Quaternary deposits consist of alluvial-fan, piedmont-slope, terrace, colluvium, playa, landslide, and fluvial material. These deposits are very similar to the Sierra Ladrones Formation in lithology (Chamberlin, 1980, p. 364).

The alluvial-fan deposits are wedge shaped and range in size from silt and fine sand to boulder gravel. Near the mountain fronts, the deposits may be quite thick and probably have relatively large values of hydraulic conductivity.

The piedmont-slope, terrace, and colluvium deposits generally are less than 20 feet thick. In many places resistant beds in the underlying Popotosa and Sierra Ladrones Formations crop out through the thin Quaternary deposits (Chamberlin, 1980, p. 364). Four terrace levels have been recognized in the Socorro area. These terrace surfaces are located 230 to 246 feet, 121 to 141 feet, 59 to 79 feet, and 20 feet above the present arroyos (Chamberlin, 1980, p. 364).

The playa deposits were deposited in La Jencia Basin after the continued uplift of Socorro Peak and the Lemitar and Chupadera Mountains isolated the basin from the Socorro Basin. These deposits consist of interbedded clays and silts. Gross and Wilcox (1981) suggested that these deposits are confined to a small area near the center of the basin.

The landslide deposits generally consist of lava blocks that range from 98 to 2,000 feet in length and 20 to 600 feet in thickness (Chamberlin, 1980, p. 366). The surface on which these blocks slide is the playa facies of the Popotosa Formation (Chamberlin, 1980, p. 366).

The lithology of the fluvial deposits is very similar to the underlying fluvial facies of the Sierra Ladrones Formation; thus, contacts between these units are difficult to determine on drillers' and geophysical logs. Bjorklund and Maxwell (1961, p. 22) estimated the Holocene alluvium to be 80 to 120 feet thick in the Albuquerque area, north of the study area. The thickness of these deposits in the Socorro Basin probably is similar. The hydraulic conductivity of the fluvial deposits probably is very similar to the hydraulic conductivity of the fluvial facies of the Sierra Ladrones Formation because of the similar lithology of each unit.

STRUCTURAL HISTORY

The Morenci lineament, Capitan lineament, Socorro Peak-Lemitar Mountains horst, Chupadera Mountains, Socorro Basin, and La Jencia Basin are the major structural features in the Socorro area (fig. 2).

The structural history of the Socorro area before rifting is not well known because of the large areas covered with thick sequences of Oligocene volcanics. The Socorro area was deformed during late Paleozoic and again during Late Cretaceous to middle Eocene time (Chapin and Seager, 1975, p. 299). During Eocene time, the Baca Formation was deposited over much of west-central New Mexico. The Datil-Mogollon volcanic field was active during early Oligocene time; erosion of these extensive volcanics produced thick sequences of conglomerate, sandstone, and mudflow deposits (Datil Group) (Chamberlin, 1980, p. 429).

About 32 million years ago, crustal extension (rifting) began in the Socorro area (Chamberlin, 1980, p. 429). Early crustal extension was associated with the formation of at least seven overlapping cauldrons near Socorro. These cauldrons are located along the Morenci lineament. The Socorro cauldron formed about 27 million years ago and is one of the youngest cauldrons in the area (Chapin and others, 1978a, p. 118).

The Socorro cauldron has been interpreted to be a combination trapdoor and resurgent caldera (Chamberlin, 1980, p. 386). Collapse of the roof of a magma body probably was hosted along ring fractures or faults along the margins of the circular caldera. After collapse, resurgent doming may have occurred inside the caldera due to upward magma pressure. A moat probably formed between the resurgent dome and topographic walls of the caldera. This moat filled with lava flows, lava domes, and sedimentary material shed from the caldera walls and domes. After deposition of the moat deposits, the Socorro caldera was buried by alluvial-fan and mudflow deposits shed from the neighboring highlands. During burial of the Socorro caldera, the broad, sedimentary Popotosa Basin formed (Chapin and others, 1978a, p. 118). During the early formation of this basin, large alluvial fans formed along the margins. As the basin filled and continued to subside, a playa lake formed near the basin center. Chapin and others (1978a, p. 118) suggested that as much as 2,500 feet of gypsiferous clays may have been deposited in the playa.

Between 7 and 4 million years ago, the Popotosa Basin was broken into a combination of uplifted, tilted fault blocks and horst and graben structures with low topographic relief (Chapin and others, 1978a, p. 118). Socorro Peak and the Lemitar and Chupadera Mountains represent uplifted blocks that disrupted the Popotosa Basin. During breakup of the basin, the area was breached by a through-flowing stream (ancestral Rio Grande) that deposited fluvial sediments (Sierra Ladrones Formation) on the tilted blocks of the Popotosa Formation. The presence of the Sierra Ladrones Formation in Socorro Canyon (pl. 1) indicates that the Socorro Peak-Lemitar Mountains were topographically low during this time. As the Sororro Peak-Lemitar-Chupadera Mountains continued to rise, La Jencia Basin was isolated from the Socorro Basin. La Jencia Basin then became a closed drainage basin with a playa lake in the center.

A drop in base level of the ancestral Rio Grande in middle Pleistocene time caused the river to downcut through the earlier deposits (Chapin and others, 1978a, p. 118). Several cycles of downcutting and partial backfilling have occurred since Pleistocene time.

SURFACE WATER

The Rio Grande, the major through-flowing river in the Socorro area, enters the Socorro Basin near San Acacia and leaves the basin at San Marcial (pl. 2). A diversion dam at San Acacia diverts water from the Rio Grande Floodway into a conveyance channel and the Socorro Main Canal. Except during spring runoff or large storm runoff, the majority of the water in the Rio Grande Floodway is diverted into the conveyance channel at San Acacia. Diverting the water from the Rio Grande Floodway into the conveyance channel results in a significant decrease in evaporation because of the decrease in water-surface area. Water diverted into the Socorro Main Canal supplies a large part of the surface water used for irrigation in the Socorro Basin. The irrigation system is an important part of the surface-water system in the Socorro Basin.

All irrigation in the Socorro Basin occurs in the Rio Grande valley. In the study area, the Rio Grande valley extends from San Acacia to San Marcial, about 50 miles. The valley width varies from less than 1 mile near San Acacia to about 3 miles near the Bosque del Apache National Wildlife Refuge. Most of the irrigable land is on the west side of the Rio Grande (pl. 2).

Irrigation has been practiced in the Socorro area since before the 1600's (Yeo, 1928, p. 8). The capacity of the irrigation ditches in 1896 was 294 cubic feet per second and the area irrigated was 5,700 acres (Yeo, 1928, p. 9). In 1928, the capacity of the ditches was 331 cubic feet per second and the total irrigated acreage was 10,060 acres (Yeo, 1928, p. 9). The ditches were numerous and no drains existed. Diversion structures consisted of temporary wing dams made of brush, rocks, posts, and mud that generally were destroyed by high water each spring. The ditches contained no sluice gates and very few regulating gates (Yeo, 1928, p. 10). The ditches and diversion structures were maintained by each landowner who obtained water from a particular ditch. By the early 1900's, much of the irrigable land had become waterlogged as a result of the infiltration of excess irrigation water and the resulting rise in the water table. The rising water levels also resulted in the concentration of salts near the ground surface.

It was estimated that 40,000 acres needed drainage to become suitable for agriculture (Bloodgood, 1930, p. 48-52). The Middle Rio Grande Conservancy District was organized in 1925 by landowners in the area. In 1928, a plan for the construction of diversion dams, canals, acequias (irrigation canals), ditches, laterals, and drains was presented by Burkholder (1928). Construction was completed by 1936.

The irrigation system in the Socorro Basin consists of the Socorro Main Canal, acequias, ditches, laterals, and drains. In general, acequias, ditches, and laterals divert water from the Socorro Main Canal and distribute the water to individual farms or fields. The drains are constructed at a depth sufficiently below land surface and the acequias, ditches, and laterals so that water infiltrating from the surface-water distribution system or infiltration of excess applied irrigation water does not cause large rises in water levels.

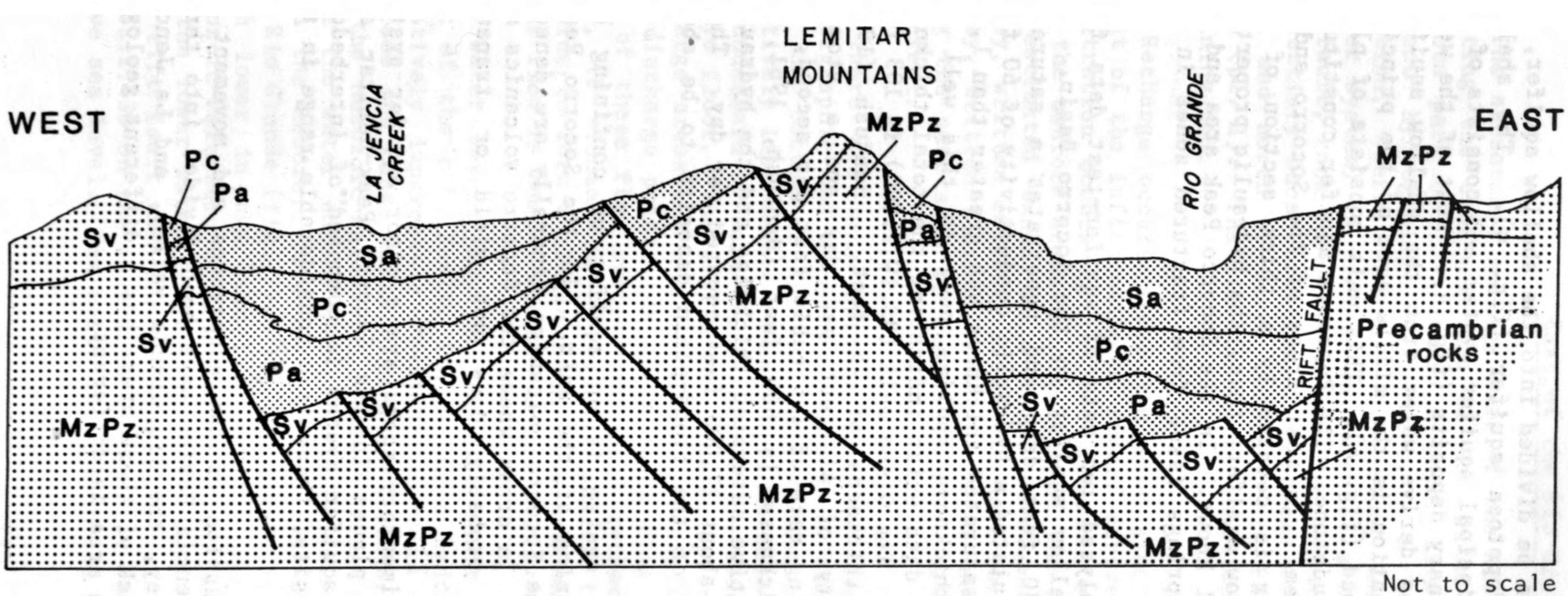
GROUND-WATER FLOW

The principal aquifer system in the Socorro and La Jencia Basins is composed of the Quaternary and Tertiary Santa Fe Group (Popotosa and Sierra Ladrones Formations) and Quaternary deposits. Minor aquifer systems are in Socorro volcanics of Tertiary age and the Mesozoic and Paleozoic sedimentary rocks. A weathered zone of Precambrian rocks near the contact with younger rocks may transmit water, but the thickness of this zone probably is small. This zone has been included in the Mesozoic-Paleozoic aquifer system. The Socorro aquifer system and Mesozoic-Paleozoic aquifer system correspond to geologic units or groups of units (fig. 4).

A generalized west-east hydrogeologic section through La Jencia and Socorro Basins displays the relationship between the subdivisions in the principal aquifer system and the relationship between the minor aquifer systems and the principal aquifer system (fig. 5). In many areas of the Socorro and La Jencia Basins, few data exist that document the relationship between the minor aquifer systems and the principal aquifer system.

	GEOLOGIC UNITS	HYDROLOGIC UNITS	AQUIFER SYSTEMS
Santa Fe Group	Quaternary deposits and Sierra Ladrones Formation	Shallow aquifer	Principal aquifer system
Santa Fe Group	Upper part of the Popotosa Formation	Popotosa confining bed	Principal aquifer system
Santa Fe Group	Lower part of the Popotosa Formation	Popotosa aquifer	Principal aquifer system
	Socorro volcanics	Socorro volcanics aquifer system	Minor aquifer system
	Datil Group (Osburn and Chapin, 1983) Baca Formation Mesozoic rocks Paleozoic rocks	Mesozoic-Paleozoic aquifer system	Minor aquifer system

Figure 4.--Relation between geologic units, hydrologic units, and aquifer systems.



EXPLANATION

PRINCIPAL AQUIFER SYSTEM

MINOR AQUIFER SYSTEM

Sa SHALLOW AQUIFER

Pc POPOTOSA CONFINING BED

Pa POPOTOSA AQUIFER

Sv SOCORRO VOLCANICS AQUIFER SYSTEM

MzPz MESOZOIC-PALEOZOIC AQUIFER SYSTEM

FAULT

CONTACT BETWEEN HYDROLOGIC UNITS

Figure 5.--Generalized hydrogeologic section through La Jencia and Socorro Basins (modified from Chapin and others, 1978b, p. 126).

The principal aquifer system can be divided into the shallow aquifer, the Popotosa confining bed, and the Popotosa aquifer (fig. 4). The shallow aquifer is the upper part of the principal aquifer system and consists of the Sierra Ladrones Formation and Quaternary deposits (fig. 4). Most of the wells in the Socorro and La Jencia Basins derive water from the shallow aquifer. The upper part of the Popotosa Formation is the middle part of the principal aquifer system and is a confining bed (fig. 4). This unit consists of playa deposits and contains considerable mudstone. The Popotosa aquifer constitutes the lower part of the aquifer system. In most areas of the Socorro and La Jencia Basins, the Popotosa aquifer is covered by a thick section of the Popotosa confining bed and the shallow aquifer; thus, the hydraulic properties of the Popotosa aquifer are not well known. In the Socorro Peak area and the San Lorenzo Arroyo area, several springs issue from fractured zones in the Popotosa aquifer.

Hantush (1961, p. 188-193) analyzed two sets of aquifer-test data from wells partially penetrating the shallow aquifer in the Socorro Basin. The Faulkner well (1S.1W.35.142) is 130 feet deep and penetrates a saturated thickness of 116 feet. Hantush calculated a hydraulic conductivity of 60 feet per day. The calculated effective saturated thickness was greater than 1,023 feet. This effective saturated thickness applies only to this well and pumping rate used for the test. No data exist indicating the total thickness of the shallow aquifer in this area. The Olsen well (3S.1W.2.000) is 103 feet deep and penetrates a saturated thickness of 75 feet. Hantush (1961) calculated a hydraulic conductivity of 41 feet per day and a storage coefficient of 0.23. For the pumping rate of 1.6 cubic feet per second, the calculated effective saturated thickness is 660 feet (Hantush, 1961, p. 190). Based on the calculated effective saturated thickness and the hydraulic conductivity, the transmissivity is about 27,000 feet squared per day. Theis (1938) estimated the transmissivity of the flood-plain deposits to be about 6,700 feet squared per day.

The Socorro volcanics aquifer system is an aquifer or confining bed depending on the density of fracturing of the unit. In the Socorro Peak-Lemitar and Magdalena Mountains, the Socorro volcanics generally are densely fractured and thus are an aquifer. In areas where the Socorro volcanics are not densely fractured, the unit probably does not yield or transmit significant quantities of water.

The Mesozoic and Paleozoic sedimentary rocks are a minor aquifer system east of the river valley and in places in the Socorro Peak-Lemitar and Magdalena Mountains. Because this aquifer system is composed of interbedded shale, sandstone, and evaporite deposits, there is a considerable range in the hydraulic properties.

To aid in the following discussion of the occurrence and movement of ground water, the Socorro and La Jencia Basins have been divided into three areas: east of the Rio Grande valley, the Rio Grande valley, and La Jencia Basin-Socorro Peak area (pl. 3). Each of these areas has a different geologic setting; thus, the hydrology of each area is different.

East of the Rio Grande Valley

The structural geology east of the Rio Grande valley is the major factor affecting the configuration of the water levels (pls. 1 and 3). In the northern part of this area, a major rift fault divides the area into two distinct hydrogeologic provinces. A very thick sequence of Popotosa Formation, Sierra Ladrones Formation, and Quaternary deposits (principal aquifer system) is present on the west side of the rift fault. East of the rift fault, rock types range from Precambrian igneous and metamorphic rocks to the Tertiary Baca Formation. The rocks most commonly found east of the rift fault and north of Cerro Colorado are Paleozoic limestone, sandstone, and shale (pl. 1). The limestones and sandstones are aquifers and the shale is a confining bed.

Recharge occurs along the east side of the Rio Grande valley as the result of the infiltration of runoff derived from precipitation. Most of the infiltration occurs in the bed material of arroyos where the arroyos cross from the bedrock areas to the area of the principal aquifer system. Recharge was estimated based on a model developed by Jack Dewey (U.S. Geological Survey, written commun., 1982) and described by Glenn Hearne (U.S. Geological Survey, written commun., 1984). Total annual recharge to the Socorro Basin along the east side of the Rio Grande valley was estimated to be about 1,600 acre-feet.

There are many springs east of the rift fault due to the complex stratigraphic and structural nature of the area. Most of the springs occur near the bottom of arroyos where permeable rocks are in fault contact with relatively impermeable rocks. Springs also occur where dipping permeable beds are underlain by relatively impermeable beds and the contact is exposed in the arroyo floor. The discharge of these springs is quite small due to the small recharge areas and minimal annual precipitation. In general, these springs are discharge points for small local flow systems. The discharge points for one of these flow systems may be a recharge point for another flow system; thus, if studied on a regional scale, the many small local flow systems combine to form a single large flow system. The general direction of ground-water flow is toward the Rio Grande valley in this regional flow system.

Water levels east of the rift fault are much higher than water levels west of the rift fault, indicating a hydraulic discontinuity (fig. 6). The relatively impermeable Precambrian rocks and Paleozoic shale are near the surface and cause these high water levels. In general, water flows westward in the Mesozoic-Paleozoic aquifer system until it reaches the rift fault. Here the water enters the principal aquifer system, which is more permeable than the Mesozoic-Paleozoic aquifer system and is hydraulically connected to the Rio Grande (fig. 7). The Rio Grande is a drain and maintains water levels much lower in the principal aquifer system than the water levels in the Mesozoic-Paleozoic aquifer system; thus, water would be expected to flow down to the lower water level (fig. 6). Well 1S.1E.9.410 is on the west side of the rift fault and has a water level of 4,689 feet above sea level. Well 1S.1E.1.430 on the east side of the rift fault has a water level of 5,018 feet above sea level. The wells are 3.25 miles apart.

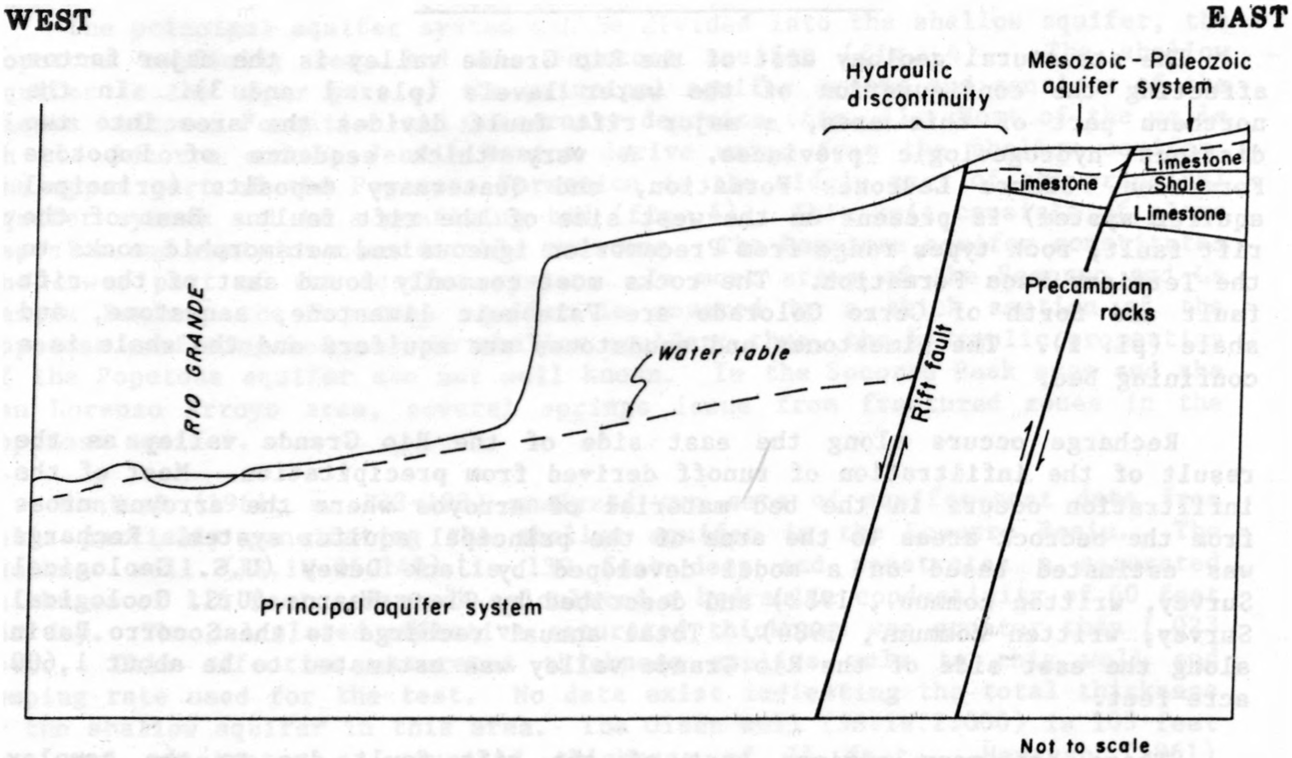


Figure 6.--Generalized hydrogeologic section of hydraulic discontinuity on the east side of the Rio Grande valley in the Socorro Basin.

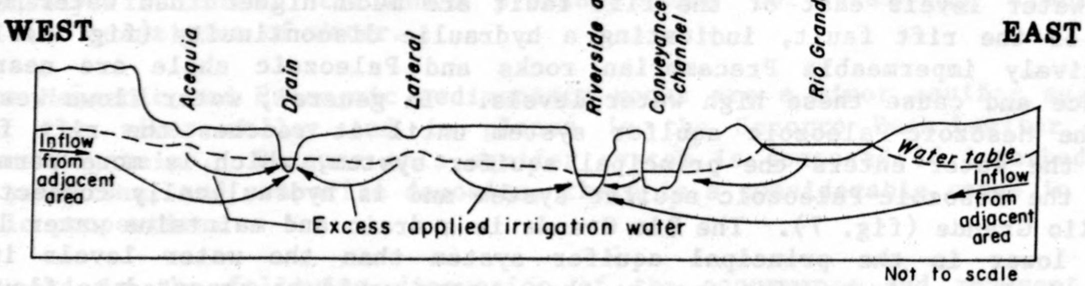


Figure 7.--Generalized hydrologic section of an irrigated part of the Rio Grande valley in the Socorro Basin.

Wells in sections 1, 2, and 12, T. 4 S., R. 1 E. are west of the rift fault but have water levels 300 to 350 feet above river level. In this area, the ground water seems to be perched much like in the area east of the rift fault. It is possible that a fault or transverse horst has brought finer grained sediments (Popotosa confining bed ?) close to the surface, thus causing these anomalously high water levels.

Near Cerro Colorado and south, the Tertiary and Quaternary rocks (Baca Formation, Datil Group, Santa Fe Group, and Quaternary deposits) are the water-yielding units (pl. 1). In this area, the Baca Formation, Datil Group, Santa Fe Group, and Quaternary deposits are a single hydrologic unit. The water-level map shows a ground-water mound, probably due to recharge in the Cerro Colorado area (pl. 3). South of Cerro Colorado, the water-level map shows low, southwest-trending gradients, indicating ground-water flow from the Jornada del Muerto to the southern Socorro Basin and northern San Marcial Basin (pl. 3).

Little San Pascual Mountain, east of San Marcial, consists of an uplifted block of Pennsylvanian and Permian rocks. No data exist that document the effect this mountain has on the regional ground-water flow, but it probably is a ground-water barrier because of the degree of cementation and fine-grained nature of the Paleozoic rocks in comparison to the Tertiary rocks. Ground-water flow probably is diverted around this relatively minimally transmissive block of rocks (pl. 3).

Rio Grande Valley

The first major study of the ground water of the middle Rio Grande valley was begun in 1917 because of the large acreage that had become very saline and waterlogged, and thus, unfarmable. Lines of observation wells perpendicular to the Rio Grande were installed in the river valley by 1920, and water levels were measured semimonthly (Bloodgood, 1930). Data obtained from these wells show the average depth to water was 2.37 feet (Bloodgood, 1930, p. 48-52). After completion of the drains and canals in 1936, Theis conducted a study that indicated the water levels had been lowered about 3 feet throughout the Rio Grande valley in the Socorro Basin (Theis, 1938, p. 273). The water-level contours on plate 2 are from Theis (1938). In general, these contours are the same as those determined in this study (pl. 3). There has been some minor variation caused by local withdrawals and changes in location of drains or laterals, but in general plate 2 reflects present conditions. Ground water flows from north to south in the irrigated part of the Rio Grande valley (pls. 2 and 3).

Ground-water flow in the Rio Grande valley is controlled by the river, conveyance channel, acequias, ditches, laterals, drains, and ground-water inflow from adjacent areas. A generalized hydrologic section through the Rio Grande valley is shown in figure 7. In general, fields are sloped such that surface water diverted from an acequia, ditch, or lateral will flow across the field. Water that is not used by the plants infiltrates and recharges the shallow aquifer (excess applied irrigation water) (fig. 7). The drains were constructed to discharge the excess water and to prevent waterlogging of the soils, which also helps keep the soils flushed of the salts that are concentrated by evapotranspiration. Regional ground-water inflow also is intercepted by the drains (fig. 7). The conveyance channel and riverside drains are constructed to be below river level, which causes water in the river to infiltrate and flow into the conveyance channel or riverside drains (fig. 7).

The drains are the major factor controlling water levels in the Rio Grande valley. An increase in excess applied irrigation water causes increases in drain flow and small increases in water levels. Ground water withdrawn for irrigation or domestic use in the Rio Grande valley is quickly replaced with excess applied irrigation water, regional ground-water inflow, or infiltration of surface water from acequias, ditches, laterals, the river, riverside drains, conveyance channel, or drains.

If the configuration and altitude of the drains are not changed, large changes in water levels in the river valley can only occur because of large withdrawals of ground water. Changes in water levels will occur if the rate of ground-water withdrawal is greater than the rate of infiltration of excess applied irrigation water, infiltration of surface water, and inflow of regional ground water.

La Jencia Basin-Socorro Peak Area

The Socorro Peak-Lemitar Mountains are a structurally complex intergraben horst composed of Precambrian, Paleozoic, and Tertiary rocks (pl. 1 and fig. 5) that restrict ground-water flow between the principal aquifer system in La Jencia Basin and the principal aquifer system in the Socorro Basin. Recharge in the Socorro and La Jencia Basins occurs as infiltration of mountain-front runoff from the Socorro Peak-Lemitar Mountains, Chupadera Mountains, Magdalena Mountains, and Bear Mountains. Recharge due to the infiltration of mountain-front runoff was estimated by Jack Dewey (written commun., 1982). The recharge due to the infiltration of mountain-front runoff from the Socorro Peak-Lemitar Mountains was estimated to be about 420 acre-feet per year. The recharge from the Chupadera Mountains was estimated to be about 370 acre-feet per year and the recharge to La Jencia Basin from the Magdalena Mountains was estimated to be about 4,150 acre-feet per year. Some direct recharge may occur in La Jencia Basin, but this probably is small. La Jencia Basin contains clays or playa deposits near the center. This minimal-permeability material impedes the downward movement of ground water, which allows more evapotranspiration to occur near the basin center; thus, most recharge probably occurs near the margins of the basin.

In La Jencia Basin, water levels are much higher near the basin margins than near the basin center (pl. 3). These areas of relatively high water levels probably are underlain by benches of relatively impermeable rocks that are covered with a thin veneer of basin-fill sediments (shallow aquifer). Hydraulic discontinuities probably exist along the faults that separate these benches of relatively impermeable rocks and the principal aquifer system in La Jencia Basin (pl. 3). The ground-water levels near the basin center are nearly the same, which indicates slight ground-water gradients (pl. 3).

In the northern part of the basin, ground water flows to La Jencia Creek (pl. 3). In the Nogal Canyon-Snake Ranch Flats area, the water levels indicate that water flows eastward out of La Jencia Basin and into the Socorro Basin. Waldron (1956, p. 127) mentioned a dry hole in 2S.2W.28.244 that was completed at a depth about 60 feet below the projected water level derived from other water levels in the area. This dry hole indicates that the fault in Nogal Canyon (pl. 1) juxtaposes relatively impermeable sediments (Popotosa confining bed) against permeable sediments (shallow aquifer) south of the fault. These relatively impermeable sediments (Popotosa confining bed) probably cause ground water flowing eastward to be diverted southward toward Nogal Canyon. The volume of flow entering the Socorro Basin in the Nogal Canyon area probably is not very large because of the small thickness and width of permeable sediments in the area. The springs in Nogal Canyon are found near faults or in areas where the canyon narrows. In both cases, ground water probably is forced to the surface either by a change in permeability across a fault or by a change in the cross-sectional area of permeable sediments in the narrow canyon.

The water-level map indicates there is ground-water flow from La Jencia Basin to the Socorro Basin in the Socorro Canyon area (pl. 3). The Popotosa confining bed is exposed along most of Socorro Canyon and probably restricts ground-water flow in the area. Most wells in Socorro Canyon are near arroyos and may obtain water from the Holocene alluvium (shallow aquifer) that is perched above the Popotosa confining bed. There is a large hydraulic discontinuity between wells 3S.1W.33.130 and 3S.1W.27.332 (pl. 3). The difference in water-level altitude between these two wells is about 470 feet, and the distance between them is less than 1.5 miles. The upper part of the Popotosa (Popotosa confining bed) crops out on both sides of Socorro Canyon near well 3S.1W.33.130 and probably is continuous under Socorro Canyon (pl. 1). Thus, the water level in this well may reflect water that is perched above the Popotosa confining bed. East of this well, the Popotosa confining bed is downthrown by two large north-trending faults, forming a thick section of the permeable shallow aquifer that is hydraulically connected to the Rio Grande. This is the only area where this hydraulic discontinuity can be documented by water levels west of the Rio Grande valley. Hydraulic discontinuities probably are present along much of the east side of the Chupadera and Socorro Peak-Lemitar Mountains because of the large difference in permeability between the rocks that comprise these mountains and the shallow aquifer (pl. 3).

Based on tritium data, Gross and Wilcox (1981) suggested a 9:1 mixing ratio of regional ground water from La Jencia Basin versus local recharge from precipitation that infiltrates in the Socorro Peak area for Socorro Springs. Gross and Wilcox (1981) indicated that there is ground-water flow from the principal aquifer system in La Jencia Basin through the Socorro Peak area. The Socorro volcanics and Mesozoic-Paleozoic aquifer systems are expected to be densely fractured near Socorro Peak; thus, ground-water flow between basins may be larger in this area than in other areas in the Socorro Peak-Lemitar Mountains. If the 9:1 ratio is similar for all ground water entering the Socorro Basin from La Jencia Basin through the Socorro Peak-Lemitar Mountains, the total ground-water flow between basins probably is small because the local or direct recharge in the Socorro Peak-Lemitar Mountains is small due to the relatively impermeable sediments in the area.

Many of the other springs along the west side of the Socorro Basin have characteristics that are different from Socorro Springs. The springs in San Lorenzo Arroyo, Cañoncito de las Cabras, Nogal Arroyo, and in an arroyo northeast of Strawberry Peak occur near faults or in narrow canyons. The discharges of these springs are quite small and vary considerably compared to the relatively constant discharge of about 315 gallons per minute of Socorro Springs. These differences indicate that the local recharge component of flow of the small springs is much greater than that of Socorro Springs.

There may be some ground-water flow from La Jencia Basin to the Socorro Basin under the Popotosa confining bed in the Socorro-Sixmile Canyon area. The Capitan and Morenci lineaments intersect in the Socorro Peak-Socorro Canyon area. In this area, the Socorro volcanics aquifer system probably is densely fractured due to these lineaments. The Socorro volcanics aquifer system may be a conduit for deep ground-water flow between La Jencia and Socorro Basins.

GROUND-WATER QUALITY

The study area was divided into three areas for the following discussion of water quality: east of the Rio Grande valley, the Rio Grande valley, and La Jencia Basin-Socorro Peak area (pl. 4). The divisions were made because in each area the water quality is affected by similar processes.

Piper diagrams are useful to graphically show the distribution of ions dissolved in water (Piper, 1953). Piper diagrams utilize two triangles, one for anions and one for cations, and a diamond-shaped field used to represent the composition of the water with respect to both cations and anions. Values in the cation triangle are expressed as milliequivalent percentage of a particular cation with respect to total milliequivalents per liter of cations. Values in the anion triangle are plotted by the same method. Any reference in the discussion of water quality to percentage of a particular ion will be in conjunction with a Piper diagram; thus, the percentage will be a percentage of milliequivalents of a particular ion with respect to total cation or anion milliequivalents.

East of the Rio Grande Valley

The water quality east of the Rio Grande valley is much different than the water quality elsewhere in the study area. The water quality probably is affected most by the rock type the water travels through and the residence time of the water in a specific rock type or flow system.

The specific conductance ranges from about 560 to 6,500 microsiemens per centimeter at 25° Celsius for ground water derived from Paleozoic limestone, sandstone, and shale (table 2). A Piper diagram shows that the magnesium ions generally account for more than 25 percent of the cations for this water (fig. 8). This water was found to be supersaturated with respect to dolomite and calcite in most cases (table 3). Water with a specific conductance greater than 2,000 microsiemens also was supersaturated with respect to gypsum (table 3). The dissolution of these minerals probably is one of the major factors controlling the water chemistry in this region. The concentration of sodium in this water generally is less than 200 milligrams per liter, which indicates that cation exchange may not be a dominant process in the chemical evolution of this water.

Spring 2S.2E.30.234 discharges water with a specific conductance of 561 microsiemens, which is small for water in this area. This water also is undersaturated with respect to gypsum (table 3), which may indicate that the water has not come in contact with gypsum-bearing rocks. Bicarbonate accounts for about 90 percent of the anions in this water, which may indicate that the dissolutions of calcite and dolomite are dominant chemical processes. This water probably is representative of recharge water (short residence time) that has not come into contact with gypsum-bearing rocks.

Table 2. Chemical analyses of water samples from selected wells and springs east of the Rio Grande valley in the Socorro Basin

[Well depth in feet: *indicates water level in feet below land surface; SP, spring; Geologic unit: Tb, Baca Formation; Td, Datil Group of Osburn and Chapin (1983); M, Mesozoic rocks; P, Paleozoic rocks; °C, degrees Celsius; mg/L, milligrams per liter]

Location	Date sampled	Well depth	Geo-logic unit	Tem-pera-ture (°C)	Specific conductance (microsiemens per centimeter at 25 °C)	pH	Cal-cium (mg/L)	Mag-nesium (mg/L)	Sodium (mg/L)	Sodium plus potas-sium (mg/L)	Potas-sium (mg/L)	Bicar-bonate (mg/L)	Car-bonate (mg/L)	Sul-fate (mg/L)	Chlo-ride (mg/L)	Fluo-ride (mg/L)	Silica (mg/L)	Dis-solved solids (mg/L)
7S.1E.27.214	61-06-26	-	-	-	3,180	7.4	-	-	-	330.0	-	180	-	1,700	60	2.0	15	-
7S.1E.2.334	56-09-26	178*	Tb	21.5	3,150	7.3	-	-	-	480.0	-	200	-	1,500	81	-	-	-
6S.1E.36.233	55-02-08	-	-	21.0	3,490	-	-	-	-	-	-	200	-	1,800	130	-	-	3,020
6S.2E.1.444	56-04-18	600	Tb	24.5	3,080	7.4	390	180.0	-	270.0	-	58	-	2,100	44	1.0	37	-
6S.2E.28.400	55-02-08	300	Tb	24.5	1,970	-	200	66.0	-	-	-	84	-	870	85	-	-	1,560
6S.3E.17.200	53-06-29	-	Td	-	3,450	7.7	430	160.0	-	280.0	-	73	-	2,100	47	-	-	-
6S.2E.10.141	56-05-21	454	Td	25.5	2,010	7.8	-	-	-	-	-	64	-	900	39	-	-	-
6S.2E.4.144	56-08-22	700	Td	28.5	771	7.6	33	8.8	-	130.0	-	140	-	220	24	1.6	-	-
6S.3E.5.232	60-08-01	752	Tb	26.5	3,430	7.6	410	170.0	-	290.0	-	51	-	2,200	42	.9	32	3,380
5S.3E.28.400	55-02-01	169*	Tb	19.5	3,770	-	500	110.0	-	-	-	32	-	2,300	62	-	-	3,580
5S.2E.16.323	55-02-07	280	M	19.0	1,290	7.9	37	28.0	-	210.0	-	240	-	400	33	1.5	25	866
5S.3E.17.111	55-02-10	-	Tb	21.5	1,680	-	-	-	-	-	-	43	-	750	44	-	-	1,210
5S.2E.10.220	55-02-10	-	M	19.0	2,460	-	-	-	-	-	-	320	-	1,200	32	-	-	2,100
4S.2E.23.344	55-02-10	-	M	-	1,440	8.0	100	57.0	-	150.0	-	320	1	490	18	.1	22	1,060
4S.4E.7.143	55-05-28	SP	P	-	3,050	-	586	167.0	-	34.0	-	132	-	1,960	50	1.0	18	-
3S.2E.19.314	80-06-19	SP	P	24.0	3,070	8.3	530	160.0	63	-	6.0	210	-	1,800	77	.7	19	3,100
3S.3E.5.213	80-06-03	315	M	19.0	2,420	7.7	410	110.0	90	-	3.4	180	-	1,500	21	1.1	12	2,410
2S.1E.27.243	80-06-09	SP	P	25.0	1,500	8.9	60	78.0	150	-	5.6	160	-	610	39	.9	13	1,150
2S.2E.30.234	80-06-09	SP	P	24.0	561	8.5	43	41.0	22	-	4.1	350	-	33	4	.5	13	345
2S.1E.23.331	80-09-17	SP	P/Tb	16.5	6,500	8.7	390	530.0	760	-	.8	510	-	3,900	260	2.3	19	7,180
2S.1E.14.221	60-09-17	-	M	-	2,260	7.5	-	-	-	66.0	-	210	-	1,310	17	.8	42	-
2S.2E.5.223	79-07-10	-	P	30.0	4,000	8.3	560	280.0	190	-	12.	220	-	2,600	68	.8	20	4,220

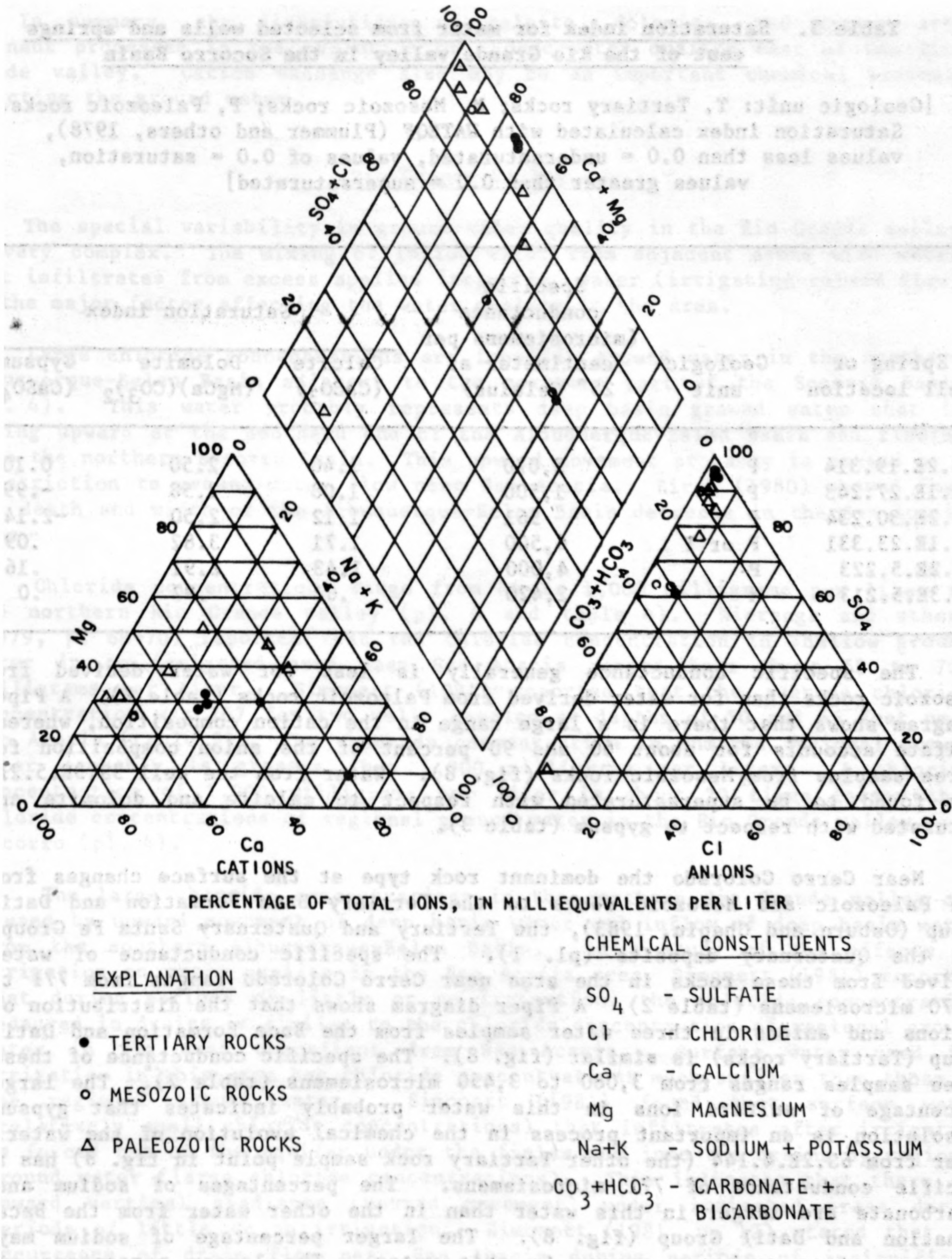


Figure 8.--Piper diagram of chemical analyses of water samples from east of the Rio Grande valley in the Socorro Basin.

Table 3. Saturation index for water from selected wells and springs east of the Rio Grande valley in the Socorro Basin

[Geologic unit: T, Tertiary rocks; M, Mesozoic rocks; P, Paleozoic rocks. Saturation index calculated with WATEQF (Plummer and others, 1978), values less than 0.0 = undersaturated, values of 0.0 = saturation, values greater than 0.0 = supersaturated]

Spring or well location	Geologic unit	Specific conductance (microsiemens per centimeter at 25° Celsius)	Saturation index		
			Calcite ($CaCO_3$)	Dolomite $(MgCa)(CO_3)_2$	Gypsum ($CaSO_4$)
3S.2E.19.314	P	3,070	1.40	2.50	0.10
2S.1E.27.243	P	1,500	1.08	2.58	-.99
2S.2E.30.234	P	561	1.12	2.50	-2.14
2S.1E.23.331	P or T	6,500	1.71	3.82	.09
2S.2E.5.223	P	4,000	1.43	2.91	.16
3S.3E.5.213	M	2,420	.64	.97	.0

The specific conductance generally is less for water derived from Mesozoic rocks than for water derived from Paleozoic rocks (table 2). A Piper diagram shows that there is a large range in the cation composition, whereas sulfate accounts for about 60 and 90 percent of the anion composition for three samples from Mesozoic rocks (fig. 8). Water from the well 3S.3E.5.213 was found to be supersaturated with respect to calcite and dolomite and saturated with respect to gypsum (table 3).

Near Cerro Colorado the dominant rock type at the surface changes from the Paleozoic and Mesozoic rocks to the Tertiary Baca Formation and Datil Group (Osburn and Chapin, 1983), the Tertiary and Quaternary Santa Fe Group, and the Quaternary deposits (pl. 1). The specific conductance of water derived from these rocks in the area near Cerro Colorado ranges from 771 to 3,770 microsiemens (table 2). A Piper diagram shows that the distribution of cations and anions in three water samples from the Baca Formation and Datil Group (Tertiary rocks) is similar (fig. 8). The specific conductance of these three samples ranges from 3,080 to 3,450 microsiemens (table 2). The large percentage of sulfate ions in this water probably indicates that gypsum dissolution is an important process in the chemical evolution of the water. Water from 6S.2E.4.144 (the other Tertiary rock sample point in fig. 8) has a specific conductance of 771 microsiemens. The percentages of sodium and bicarbonate are larger in this water than in the other water from the Baca Formation and Datil Group (fig. 8). The larger percentage of sodium may indicate cation exchange occurs in this water. The larger percentage of bicarbonate may indicate that gypsum dissolution has not been the dominant process in the chemical evolution of the water, as compared to the other three samples from Tertiary rocks shown in the Piper diagram.

In summary, the dissolutions of calcite, dolomite, and gypsum are dominant processes in the evolution of ground-water quality east of the Rio Grande valley. Cation exchange also may be an important chemical process affecting the ground water.

Rio Grande Valley

The spacial variability in ground-water quality in the Rio Grande valley is very complex. The mixing of inflow water from adjacent areas with water that infiltrates from excess applied irrigation water (irrigation-return flow) is the major factor affecting the water quality in the area.

Large chloride concentrations are found in ground water in the southern Albuquerque-Belen Basin adjacent to the northern part of the Socorro Basin (pl. 4). This water probably represents deep basin ground water that is moving upward at the southern end of the Albuquerque-Belen Basin and flowing into the northern Socorro Basin. This upward movement probably is caused by a constriction to ground-water flow near San Acacia. Birch (1980) showed that the depth and width of the Albuquerque-Belen Basin decrease in the San Acacia area.

Chloride concentrations range from 44 to 1,000 milligrams per liter in the northern Rio Grande valley (pl. 4 and table 4). Wierenga and others (1979, p. 68-70) reported that the chloride concentration in shallow ground water in an irrigated area near San Acacia ranged from about 50 to 700 milligrams per liter. Simonett (1981) reported that the average chloride concentration was 767 for two wells sampled at depths of 50 and 65 feet near San Acacia (table 5). The chloride concentration in unmixed regional ground water probably is greater than 1,000 milligrams per liter. A chloride concentration of 1,000 milligrams per liter is about 20 times larger than chloride concentrations of regional ground water in the Rio Grande valley near Socorro (pl. 4).

The large chloride concentrations in the northern Rio Grande valley are caused by upward movement of deep basin water and inflow of deep basin water from the southern Albuquerque-Belen Basin. In a study of the effects of irrigation on water quality in the San Acacia area, Simonett (1981) reported that during periods of little or no irrigation, the chloride concentration measured in drains is similar to the chloride concentration of regional ground water in the area upgradient from San Acacia. Surface water used for irrigation in this area has chloride concentrations much smaller than those of the regional ground water. Simonett (1981) found that surface water (relatively small chloride concentrations) that infiltrates after irrigation is forced out of the aquifer under the fields and into the drains by regional ground water (large chloride concentrations). This indicates that there are upward vertical gradients (upward movement) under irrigated areas during periods of little or no irrigation. Simonett (1981, p. 12) stated that the occurrence of drain flow near San Acacia during periods of insignificant surface recharge implies regional ground-water inflow.

Table 4. Chemical analyses of water samples from selected wells and springs in the Rio Grande valley in the Socorro Basin

[Well depth in feet: *indicates water level in feet below land surface; SP, spring; E, estimated; °C, degrees Celsius; mg/L, milligrams per liter]

Location	Date sampled	Well depth	Temperature (°C)	Specific conductance (microsiemens per centimeter at 25 °C)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sodium plus potassium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Dissolved solids (mg/L)
7S.1W.18.140	80-07-18	140	22.0	825	7.8	31	4.1	130	-	3.0	220	-	110	70	0.9	33	-
7S.1W.18.200	52-10-02	113	21.0	1,480	-	85	11	-	200	-	130	-	180	290	.7	32	-
6S.1E.17.133	58-02-13	-	-	1,480	8.0	-	-	-	-	-	260	-	340	160	-	-	-
6S.1W.12.431	58-02-06	-	15.5	980	7.9	37	5.2	-	200	-	360	-	110	98	2.8	42	614
6S.1E.7.213	80-07-02	100	33.0	4,600	7.4	120	41	810	-	31	410	-	560	980	1.0	24	-
6S.1E.9.111	63-11-15	200	15.5	1,060	8.1	6	1.5	230	-	8.0	230	-	240	56	1.4	35	-
6S.1E.5.233	80-07-02	170	16.0	1,200	7.8	73	17	140	-	8.4	230	-	230	93	.4	33	-
6S.1W.15.100	58-02-06	130	-	484	8.2	12	7.6	-	86	-	150	-	85	22	.6	26	301
5S.1E.36.442	62-11-05		26.5	6,740	7.0	-	-	-	-	-	260	-	2,200	1,100	-	-	-
5S.1W.36.200	58-02-05	-	16.5	3,430	7.5	-	-	-	-	-	150	-	370	880	-	-	-
5S.1E.29.310	63-06-14	142	-	1,300	-	-	-	-	-	-	-	-	290	120	-	-	-
5S.1E.30.133	80-07-02	65	22.5	1,000	8.0	52	12	120	-	5.0	140	-	120	150	.5	46	-
5S.1E.30.241	80-07-02	142	17.0	1,400	7.7	120	28	140	-	8.3	400	-	270	100	.5	40	-
5S.1E.17.344	80-07-02	125	17.0	1,800	7.7	180	32	160	-	8.4	310	-	330	260	.2	32	-
5S.1E.18.300	58-02-05	125	-	1,030	7.8	66	13	-	150	-	230	-	230	81	.8	39	684
5S.1E.18.431	58-02-05	25*	18.5	583	8.0	-	-	-	-	-	220	-	91	33	-	-	-
5S.1E.15.130	62-11-05	19*	19.0	5,680	7.8	-	-	-	-	-	230	-	1,400	1,100	-	-	-
5S.1W.11.132	80-09-02	550	19.0	382	8.4	19	1.2	66	-	3.1	-	-	54	13	.6	45	304
4S.1E.33.400	62-03-16	102	-	4,750	7.8	-	-	-	910	-	340	-	1,300	670	1.7	66	-
4S.1E.32.311	65-05-06	90	-	1,150	8.5	106	22	127	-	-	300	13	261	66	.4	33	765
4S.1E.30.400	61-07-11	154	-	621	8.0	-	-	32	-	4.0	200	-	83	52	.2	32	-
4S.1E.29.424	80-10-20	-	20.0	3,050	8.1	84	19	730	-	21	-	-	750	470	1.0	41	2,400
4S.1E.20.430	51-09-12	89	-	4,000	-	98	36	-	740	-	290	-	640	780	.5	46	-
4S.1E.19.242	80-07-03	47	22.0	700	8.2	46	6.7	80	-	4.8	210	1	76	46	1.0	35	-
4S.1E.21.241	80-09-18	125	21.0	1,550	8.6	33	14	330	-	7.7	-	-	240	340	.8	37	961
4S.1W.23.100	55-06-24	560	-	800	7.6	72	18	-	58	-	140	-	87	120	1.2	42	-
4S.1E.17.200	61-07-21	125	-	4,530	7.7	78	23	940	-	22	500	-	600	920	.6	56	-
4S.1E.6.100	55-09-01	37	-	1,210	8.1	57	11	-	200	-	240	1	230	120	-	44	-

Table 4. Chemical analyses of water samples from selected wells and springs in the Rio Grande valley in the Socorro Basin - Concluded

Location	Date sampled	Well depth	Temperature (Celsius)	Specific conductance (microsiemens per centimeter at 25 °C)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sodium plus potassium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Dissolved solids (mg/L)
3S.1E.30.400	59-03-12	25	-	292	7.7	-	-	22	-	2.0	120	-	29	14	.6	26	-
3S.1E.30.100	59-03-12	90	12.5	772	-	-	-	65	-	4.3	209	-	172	43	.6	30	-
3S.1W.24.400	59-03-12	113	15.5	1,300	7.5	-	-	100	-	6.0	320	-	330	88	.6	30	-
3S.1E.20.400	57-04-18	150	18.0	582	8.5	56	17	-	42	-	140	6	120	32	.8	30	-
3S.1W.23.424	53-04-17	135*	18.0	705	-	-	-	-	80	-	270	-	83	36	.6	32	-
3S.1W.24.200	59-03-12	E90	-	1,640	7.4	-	-	210	-	7.0	350	-	470	100	.5	36	-
3S.1W.13.400	56-04-07	85	-	780	7.6	-	-	-	39	-	200	-	180	41	.4	29	-
3S.1W.13.300	61-06-26	100	-	1,280	7.7	-	-	-	130	-	120	-	350	110	.3	34	-
3S.1W.21.000	62-06-26	130	23.0	616	7.5	78	9.1	-	39	-	180	-	100	39	.5	33	-
3S.1W.11.314	62-11-08	115	18.0	1,390	7.6	160	19	-	130	-	290	-	370	92	.7	31	-
3S.1W.12.324	65-05-07	200	-	395	8.3	40	4.1	40	-	-	146	2	54	16	.5	27	262
3S.1W.2.414	51-00-00	63	18.0	-	7.4	51	8	-	24	-	200	-	40	8	-	-	286
3S.1E.6.000	57-04-18	50	18.5	599	7.5	64	15	-	43	-	190	-	110	27	.4	28	-
2S.1W.36.433	51-00-00	63	19.0	-	7.6	43	14	-	41	-	180	-	72	24	-	-	288
2S.1W.36.143	80-10-30	-	14.5	430	8.3	39	7.8	37	-	2.9	-	-	67	17	.5	28	272
2S.1W.25.300	59-03-17	40	-	904	7.5	-	-	79	-	4.0	170	-	200	86	.8	32	-
2S.1W.25.200	59-09-00	137	-	823	7.8	-	-	41	-	4.0	190	-	200	53	.9	38	-
2S.1W.24.423	51-00-00	33	18.0	-	7.4	110	21	-	72	-	270	-	220	44	-	-	590
2S.1W.22.141	51-00-00	254	23.0	-	7.5	67	24	-	96	-	220	-	240	28	-	-	542
2S.1W.13.311	51-00-00	40	17.0	-	7.6	150	39	-	180	-	350	-	390	170	-	-	1,020
2S.1W.13.113	52-07-29	104	15.5	2,240	-	240	41	-	250	-	480	-	730	120	.3	33	-
2S.1W.11.114	51-00-00	140	21.0	-	7.7	120	26	-	85	-	310	-	240	64	-	-	640
2S.1W.2.434	65-05-07	60	-	1,590	7.9	137	29	193	-	-	356	-	438	93	.3	28	1,080
1S.1W.34.422	51-00-00	160	20.0	-	7.8	80	15	-	58	-	190	-	150	52	-	-	464
1S.1W.35.142	51-00-00	130	19.0	-	7.8	72	26	-	120	-	260	-	250	44	-	-	-
1S.1W.27.434	51-00-00	80	18.0	-	7.6	150	31	-	140	-	290	-	420	92	-	-	1,000
1S.1W.27.242	51-00-00	35	17.0	-	7.7	140	44	-	360	-	390	-	590	270	-	-	1,640
1S.1W.26.200	57-03-25	80	-	1,930	7.6	150	43	-	200	-	250	-	320	330	4.0	53	-
1S.1W.25.100	57-03-25	72	-	825	7.4	75	10	-	93	-	210	-	180	49	.4	28	-
1S.1W.22.442	65-05-13	88	-	4,020	7.3	278	94	496	-	-	264	-	788	760	.4	9	2,800
1S.1W.22.324	51-00-00	177	21.0	-	7.5	170	49	-	260	-	360	-	500	280	-	-	1,540
1S.1W.23.122	51-00-00	38	20.0	-	7.5	190	60	-	650	-	340	-	870	680	-	-	2,660
1S.1W.2.123	50-01-18	98	-	4,700	-	320	120	-	540	-	180	-	870	1,000	.2	24	-
1N.1W.35.334	50-01-18	-	-	3,950	9.4	240	64	-	600	-	170	14	1,000	640	.7	54	-

Table 5. Average quality of irrigation water, irrigation-return flow, and ground water sampled at depths of 50 and 65 feet in the San Acacia area (modified from Simonett, 1981, p. 14)

Constituent	Irrigation water: Millimoles per liter	Irrigation water: Milligrams per liter	Average irrigation-return flow (irrigation water X 2): Millimoles per liter	Average irrigation-return flow (irrigation water X 2): Milligrams per liter	Ground water: Millimoles per liter	Ground water: Milligrams per liter
Chloride	1.5	52	3.0	104	21.6	767
Sulfate	1.55	149	3.1	298	8.08	776
Calcium	1.55	62	3.1	124	5.65	226
Sodium	3.6	82	7.2	164	24.2	558
Magnesium	.5	12	1.0	24	2.47	60
Bicarbonate	3.0	186	6.0	372	3.4	205
Dissolved solids	—	543	—	—	—	2,592

The large range in chloride concentrations in the northern Rio Grande valley is caused by the mixing of irrigation-return flow and regional ground water, which has large chloride concentrations. Average irrigation-return flow has a chloride concentration of about 100 milligrams per liter (table 5) and the regional ground water probably has a chloride concentration of 1,000 milligrams per liter or greater. The concentration of chloride in a particular water sample is dependent on the mixing ratio of these two waters. Changes in the vertical direction of ground-water flow because of the infiltration of excess irrigation water and local pumping cause the mixing ratio of irrigation-return flow and regional water in any area to change throughout the year. This results in a large range of chloride concentrations and changes in the spacial distribution of chloride concentrations during the year.

A plot of the ratio of milliequivalents of chloride/total milliequivalents of anions, milliequivalents of bicarbonate/total milliequivalents of anions, and milliequivalents of calcium/total milliequivalents of cations versus distance south of San Acacia shows that the chloride ratio decreases southward and bicarbonate and calcium ratios increase southward (fig. 9). A plot of total milliequivalents of cations versus distance south from San Acacia shows a decrease of total milliequivalents of cations southward (fig. 9). This indicates that the mixing ratio (irrigation-return flow with small chloride concentrations/regional ground water with large chloride concentrations) increases southward. This probably indicates that the upward movement of regional ground water with large chloride concentrations is greatest near San Acacia and decreases southward.

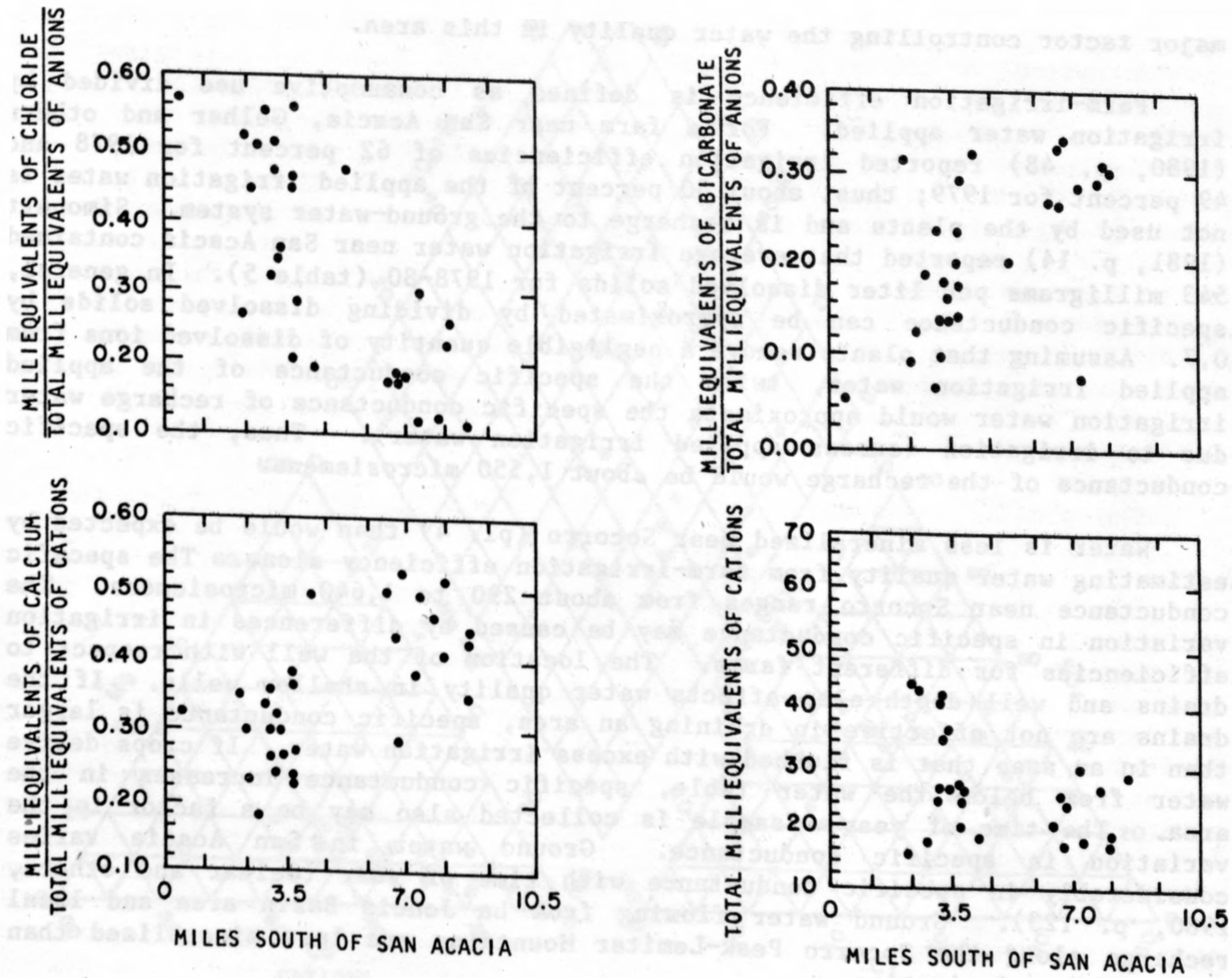


Figure 9.--Ground-water quality versus distance south of San Acacia.

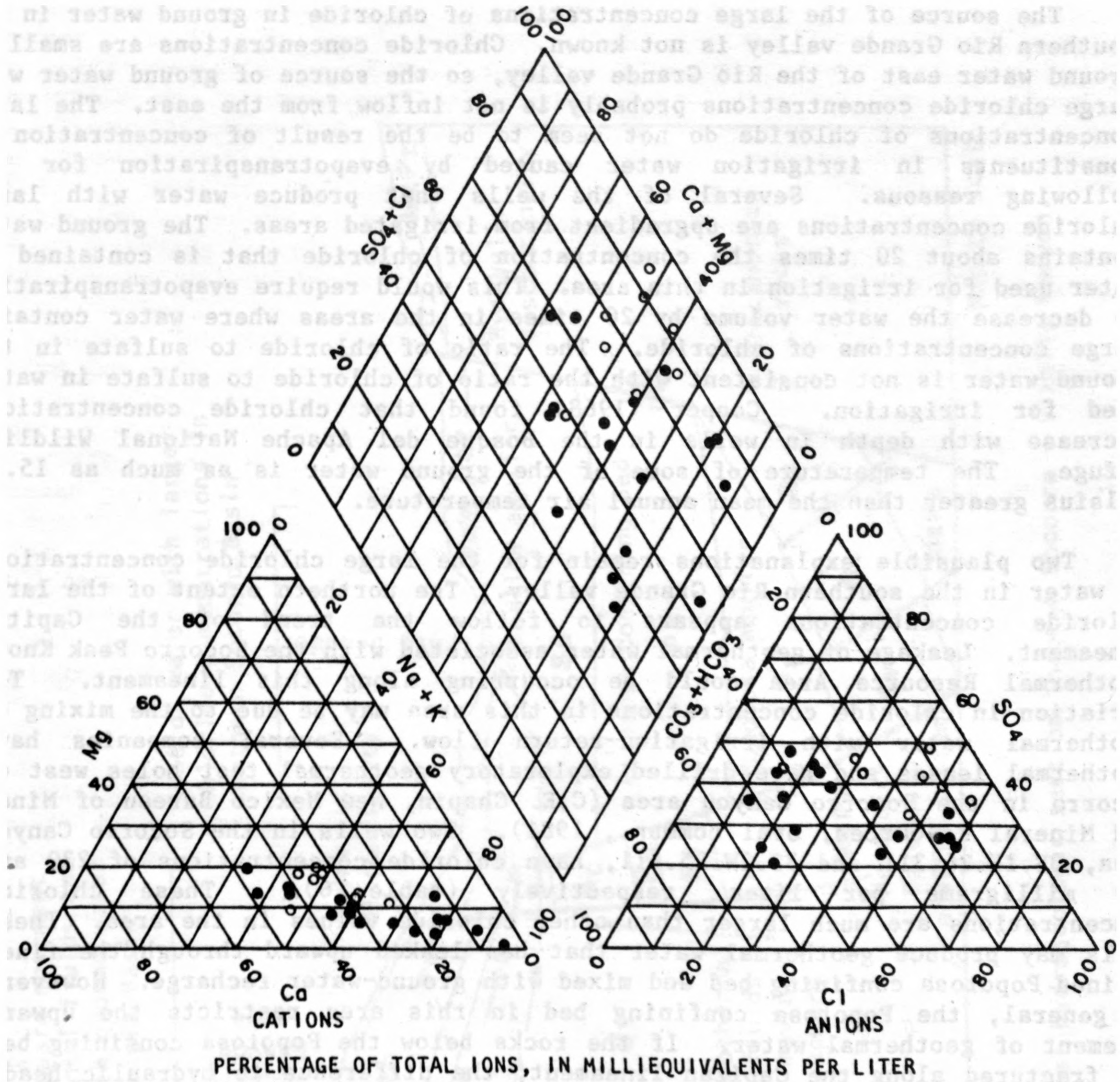
The water quality in the Rio Grande valley near Socorro does not seem to be affected significantly by the water with large chloride concentrations found in the northern area of the river valley. The mixing of irrigation-return flow, inflow from adjacent areas, and regional ground water is the major factor controlling the water quality in this area.

Farm-irrigation efficiency is defined as consumptive use divided by irrigation water applied. For a farm near San Acacia, Gelhar and others (1980, p. 48) reported irrigation efficiencies of 62 percent for 1978 and 49 percent for 1979; thus, about 50 percent of the applied irrigation water is not used by the plants and is recharge to the ground-water system. Simonett (1981, p. 14) reported that average irrigation water near San Acacia contained 543 milligrams per liter dissolved solids for 1978-80 (table 5). In general, specific conductance can be approximated by dividing dissolved solids by 0.7. Assuming that plants remove a negligible quantity of dissolved ions from applied irrigation water, twice the specific conductance of the applied irrigation water would approximate the specific conductance of recharge water due to irrigation (excess applied irrigation water). Thus, the specific conductance of the recharge would be about 1,550 microsiemens.

Water is less mineralized near Socorro (pl. 4) than would be expected by estimating water quality from farm-irrigation efficiency alone. The specific conductance near Socorro ranges from about 290 to 1,640 microsiemens. The variation in specific conductance may be caused by differences in irrigation efficiencies for different farms. The location of the well with respect to drains and well depth also affects water quality in shallow wells. If the drains are not effective in draining an area, specific conductance is larger than in an area that is flushed with excess irrigation water. If crops derive water from below the water table, specific conductance increases in the area. The time of year a sample is collected also may be a factor in the variation in specific conductance. Ground water in San Acacia varies considerably in specific conductance with time of year (Gelhar and others, 1980, p. 123). Ground water flowing from La Jencia Basin area and local recharge along the Socorro Peak-Lemitar Mountains are less mineralized than recharge from irrigation.

Ground water with chloride concentrations as large as 1,100 milligrams per liter is found in the southern part of the Rio Grande valley, from about La Borcita to San Marcial (pl. 4). The specific conductance of this water ranges from 500 to 6,750 microsiemens (pl. 4). The large range of chloride concentration and specific conductance is caused by the mixing of ground water having large chloride concentrations with irrigation-return flow having small chloride concentrations.

Although the ground water in the southern Rio Grande valley has large concentrations of chloride like the extreme northern part, the percentage of constituents is much different (fig. 10). The ground water in the southern part of the Rio Grande valley generally has a larger percentage of sodium and a smaller percentage of sulfate than ground water in the northern part of the Rio Grande valley (fig. 10).



EXPLANATION

o NORTHERN SOCORRO BASIN

● SOUTHERN SOCORRO BASIN

CHEMICAL CONSTITUENTS

SO_4 - SULFATE

Cl - CHLORIDE

Ca - CALCIUM

Mg - MAGNESIUM

Na+K - SODIUM + POTASSIUM

CO_3+HCO_3 - CARBONATE + BICARBONATE

Figure 10.--Piper diagram of chemical analyses of water samples from northern and southern Socorro Basin.

The source of the large concentrations of chloride in ground water in the southern Rio Grande valley is not known. Chloride concentrations are small in ground water east of the Rio Grande valley, so the source of ground water with large chloride concentrations probably is not inflow from the east. The large concentrations of chloride do not seem to be the result of concentration of constituents in irrigation water caused by evapotranspiration for the following reasons. Several of the wells that produce water with large chloride concentrations are upgradient from irrigated areas. The ground water contains about 20 times the concentration of chloride that is contained in water used for irrigation in this area. This would require evapotranspiration to decrease the water volume by 20 times in the areas where water contains large concentrations of chloride. The ratio of chloride to sulfate in the ground water is not consistent with the ratio of chloride to sulfate in water used for irrigation. Cooper (1968) found that chloride concentrations increase with depth in wells in the Bosque del Apache National Wildlife Refuge. The temperature of some of the ground water is as much as 15.0° Celsius greater than the mean annual air temperature.

Two plausible explanations remain for the large chloride concentrations in water in the southern Rio Grande valley. The northern extent of the large chloride concentrations appears to follow the trend of the Capitan lineament. Leakage of geothermal water associated with the Socorro Peak Known Geothermal Resource Area could be occurring along this lineament. The variation in chloride concentrations in this area may be due to the mixing of geothermal water with irrigation-return flow. Several companies have geothermal leases and have drilled exploratory geothermal test holes west of Socorro in the Socorro Canyon area (C.E. Chapin, New Mexico Bureau of Mines and Mineral Resources, oral commun., 1981). Two wells in the Socorro Canyon area, 3S.1W.26.311 and 3S.2W.25.111, have chloride concentrations of 230 and 210 milligrams per liter, respectively (table 6). These chloride concentrations are much larger than other chloride values in the area. These wells may produce geothermal water that has leaked upward through the fine-grained Popotosa confining bed and mixed with ground-water recharge. However, in general, the Popotosa confining bed in this area restricts the upward movement of geothermal water. If the rocks below the Popotosa confining bed are fractured along the Capitan lineament, the difference in hydraulic heads between the Socorro and La Jencia Basins (pl. 3) of about 1,000 feet may be forcing upward-moving geothermal water and water from La Jencia Basin laterally along the lineament into the Socorro Basin south and east of Socorro (fig. 11). Very few water-quality data exist in the area along the Capitan lineament between Socorro Canyon and north of San Antonio, making it difficult to prove or disprove this hypothesis. The fact that most of the water samples with large chloride concentrations in the southern Rio Grande valley do not have anomalously high temperatures may be due to conductive cooling of the water as it moves through the area associated with the Capitan lineament or cooling due to mixing with local ground water.

The other plausible explanation for the water with large chloride concentrations in the San Antonio area may be that there is upward movement of deep basin water, similar to what may be happening in the northern Rio Grande valley. The floor of the rift basin near the Capitan lineament may have

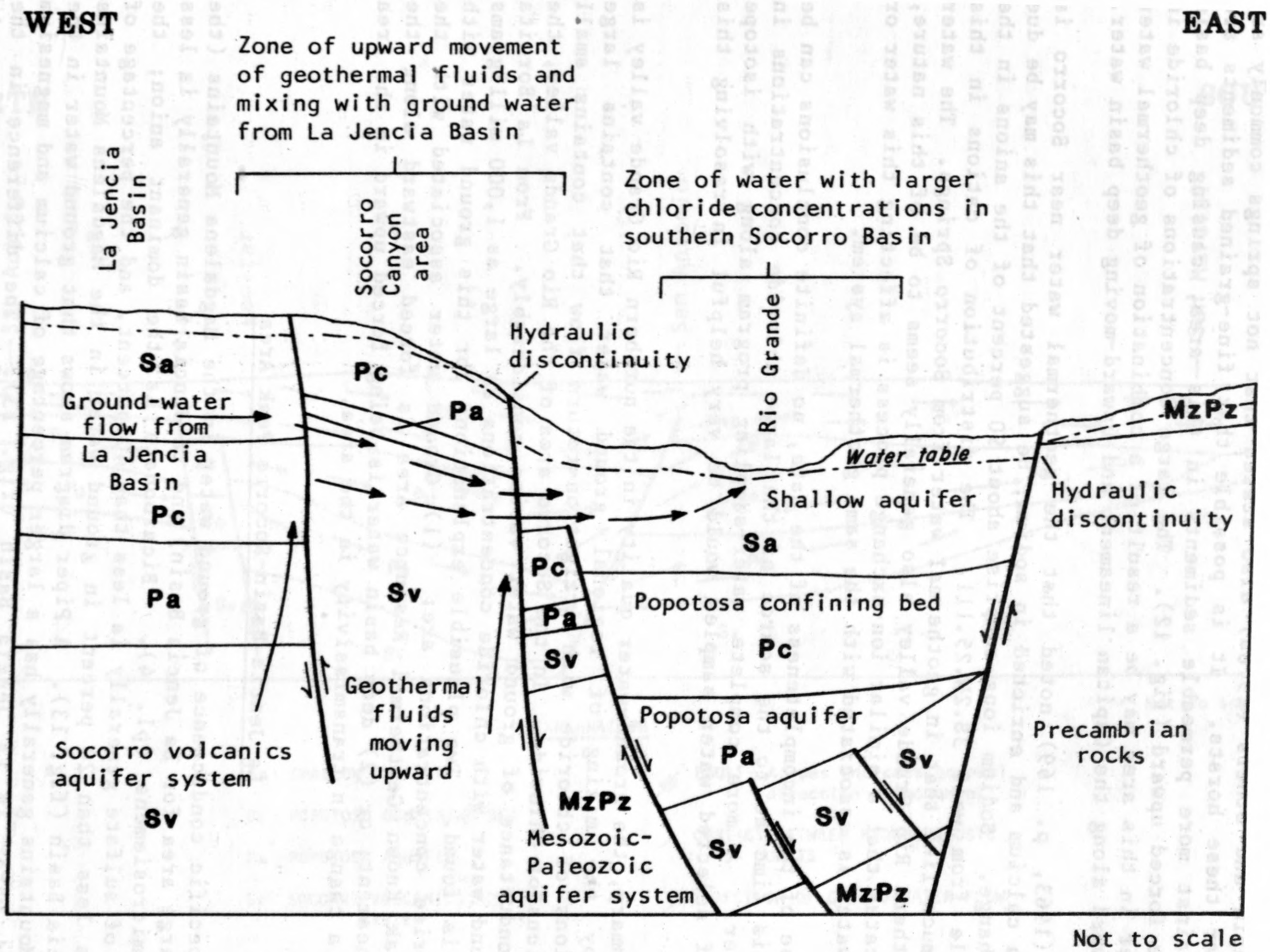


Figure 11.--Conceptual hydrogeologic section through Socorro - Sixmile Canyon.

significant relief. The presence of anomalous water levels south of San Antonio, as mentioned earlier, indicates that there may be a transverse structure in this area of the rift. Chapin and others (1978a) explained that transverse horsts are often associated with lineaments in the Rio Grande Rift. Chapin and others (1978a) also stated that hot springs commonly are present near these horsts. It is possible that fine-grained sediments are faulted against more permeable sediments in this area, causing deep basin water to be forced upward (fig. 12). The large concentrations of chloride in ground water in this area may be a result of a combination of geothermal water leaking upward along the Capitan lineament and upward-moving deep basin water.

Hall (1963, p. 169) noted that the geothermal water near Socorro is depleted in calcium and enriched in sodium; he suggested that this may be due to ion exchange. Sodium ions comprise about 90 percent of the anions in the water sample from well 3S.2W.25.111. The distribution of cations in this sample is much like that in geothermal water from Socorro Springs. The water in the southern Rio Grande valley also generally seems to be of this nature, which indicates that a similar ion-exchange process is affecting this water or that this water is associated with the same geothermal system.

Because of the incompleteness of the data, no definite conclusions can be made at this time as to the source of the large chloride concentrations in ground water. A more complete water-sampling program along with isotope analyses of selected water samples would be very helpful in resolving this problem.

In summary, the ground-water quality in the northern Rio Grande valley is affected by the mixing of regional ground water that contains large concentrations of chloride with irrigation-return flow that contains small concentrations of chloride. In the Socorro area of the Rio Grande valley, the specific conductance of ground water varies considerably. From La Borcita south, ground water with chloride concentrations as large as 1,000 milligrams per liter is found. Two plausible explanations for this ground water with large chloride concentrations are: (1) Ground water associated with the Socorro Peak Known Geothermal Resource Area is forced eastward along the Capitan lineament; or (2) deep basin water is being forced upward in the area because of a change in transmissivity in the area.

La Jencia Basin-Socorro Peak Area

The specific conductance of ground water in the Magdalena Mountains (the major recharge area for La Jencia Basin) and La Jencia Basin generally is less than 500 microsiemens (pl. 4). Bicarbonate is the dominant anion; the percentage of sulfate generally is less than 40 percent, and the percentage of chloride is less than 20 percent in ground water in the Magdalena Mountains and La Jencia Basin (fig. 13). A Piper diagram shows that ground water in the Magdalena Mountains generally has a larger percentage of calcium and magnesium than ground water in La Jencia Basin (fig. 13). The difference in the distribution of cations in the Magdalena Mountains and La Jencia Basin

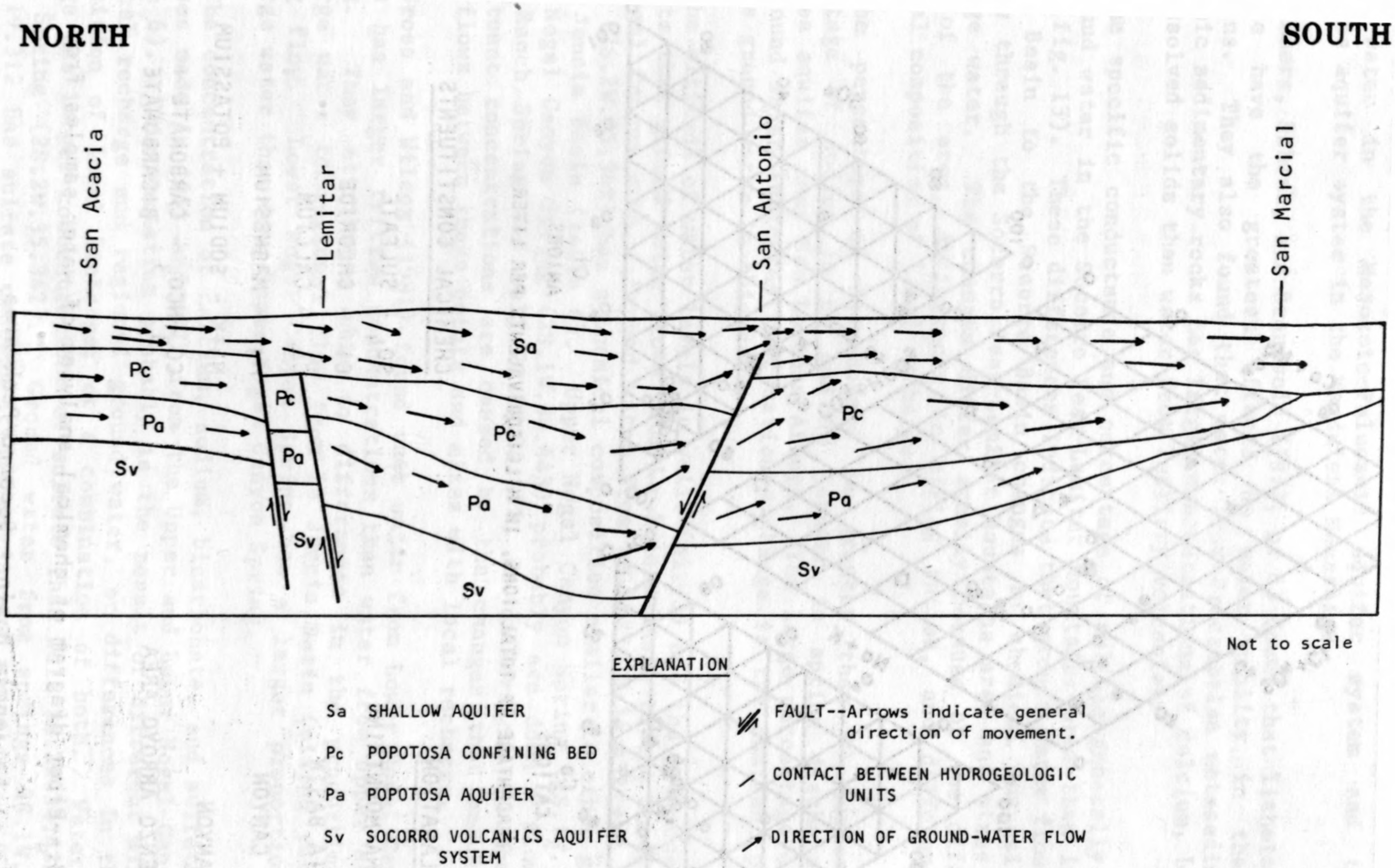


Figure 12.--Conceptual hydrogeologic section through Socorro Basin.

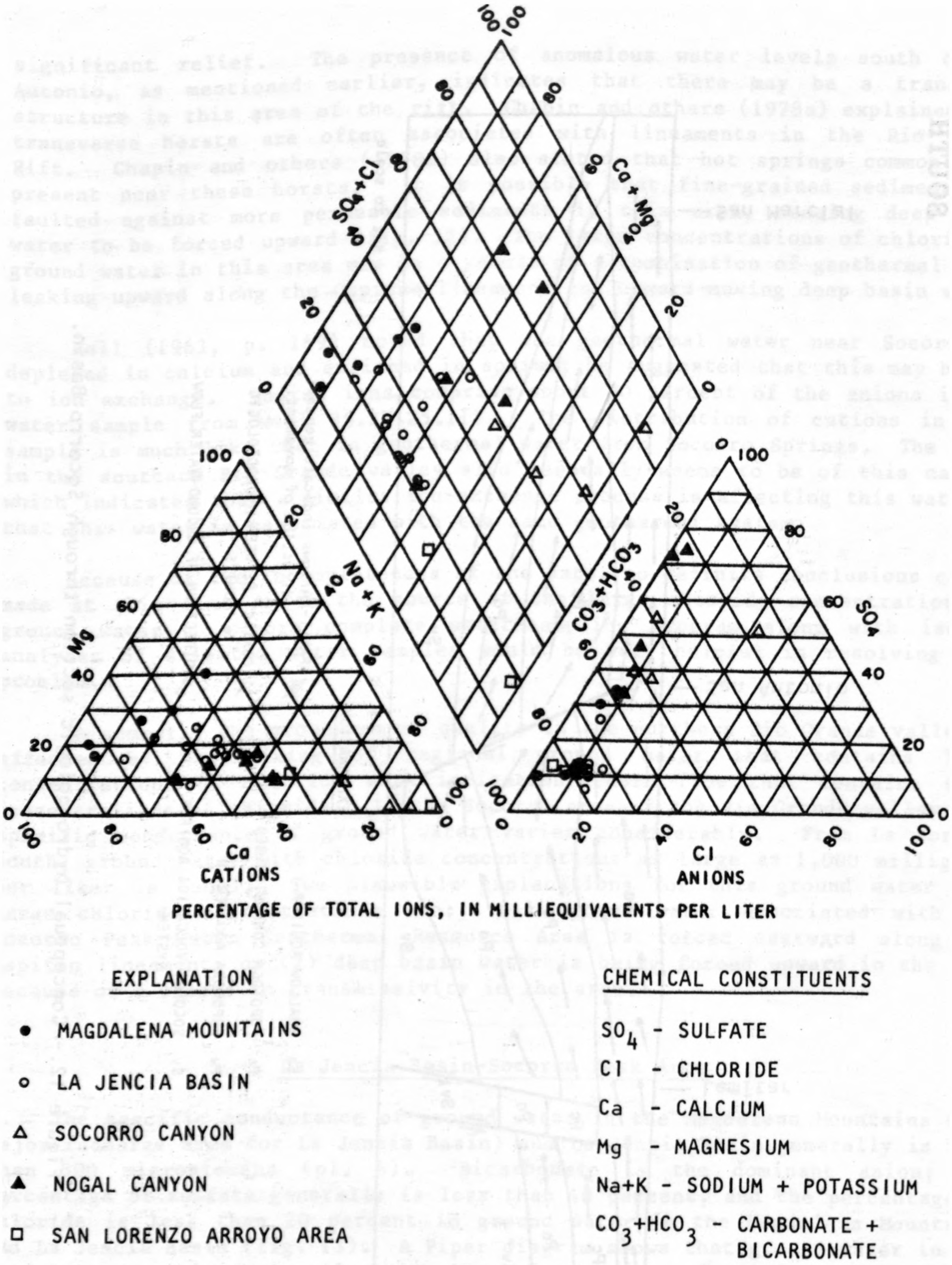


Figure 13.--Piper diagram of chemical analyses of water samples from La Jencia Basin - Socorro Peak area.

probably is caused by calcium and magnesium for sodium cation exchange. Ground water in the principal aquifer system in La Jencia Basin probably comes into contact with more clay minerals that have ion-exchange sites than does ground water in the Mesozoic-Paleozoic aquifer system and the Socorro volcanics aquifer system in the Magdalena Mountains.

Summers, Schwab, and Brandvold (1972, p. 8) found that lithology and flow distance have the greatest effects on water quality in the Magdalena Mountains. They also found that water from Precambrian metasedimentary and Paleozoic sedimentary rocks has larger concentrations of calcium, bicarbonate, and dissolved solids than water from Tertiary volcanics.

The specific conductance and percentage of sulfate generally are larger in ground water in the Socorro Peak-Lemitar Mountains area than in La Jencia Basin (fig. 13). These differences indicate that ground water flowing from La Jencia Basin to the Socorro Basin changes in chemical composition as it travels through the Socorro Peak-Lemitar Mountains area and mixes with local recharge water. The changes differ areally because of the different rock types of the area, differences in mixing ratios, and differences in the chemical composition of local recharge.

The percentage of bicarbonate is greater than 80 percent and the percentage of sodium is 60 and 98 percent in spring discharge from the Popotosa aquifer near San Lorenzo Arroyo. The large percentage of sodium in the ground water indicates that cation exchange is the dominant process that affects ground water in this area.

The altitude of water levels in wells (pl. 3) and the presence of springs indicate that ground water flows from La Jencia Basin to the Socorro Basin in the Nogal Canyon area. Ground water from well 2S.2W.34.432 and Snake Ranch Spring (2S.2W.35.342) has a chemical composition similar to other ground water in La Jencia Basin (table 6). Upper Nogal Canyon Spring (2S.1W.31.314) and Lower Nogal Canyon Spring (2S.1W.30.443) probably are down a flow line from Snake Ranch Spring and well 2S.2W.34.432, so differences in the chemical-constituent concentrations are caused by the changes that occur as ground water flows between these points and mixes with local recharge.

Gross and Wilcox (1981) found that water from Lower Nogal Canyon Spring always has larger tritium concentrations than water from Upper Nogal Canyon Spring. They attributed this to differences in the proportion of local recharge water to regional flow from La Jencia Basin (mixing ratio) in the spring flow. Lower Nogal Canyon Spring has a larger proportion of local recharge water than does Upper Nogal Canyon Spring.

The concentration of calcium, sodium, bicarbonate, and sulfate varied in analyses made in 1951 and 1977 from the Upper and Lower Nogal Canyon Springs (table 6). This variation probably is the result of different mixing ratios of local recharge and regional ground water, or differences in the chemical composition of local recharge, or a combination of both. Water from both springs has larger concentrations of sulfate than well 2S.2W.34.432 and Snake Ranch Spring (2S.2W.35.342). Ground water from springs 2S.1W.19.414 and 2S.1W.19.312 has sulfate concentrations of 38 and 180 milligrams per liter,

Table 6. Chemical analyses of water samples from selected wells and springs in La Jencia Basin-Socorro Peak area

[Well depth in feet: *indicates water level in feet below land surface; SP, spring; Temperature, in degrees Celsius; Specific conductance in microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

Location	Date sampled	Well depth	Temperature (Celsius)	Specific conductance (microsiemens per centimeter at 25 °C)	pH	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sodium plus potassium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Dissolved solids (mg/L)
4S.2W.12.112	52-00-00	300	19.0	–	7.6	120	35	180	–	–	230	–	610	24	–	–	792
4S.2W.7.211	63-02-08	–	8.0	219	7.8	30	5	3	–	–	100	–	10	6	–	–	–
4S.2W.3.321	52-00-00	115	21.0	–	7.5	58	16	17	–	–	230	–	24	24	–	–	316
4S.1W.5.211	62-05-17	SP	16.5	1,870	8.3	39	3.0	370	–	–	440	–	480	42	–	–	–
3S.1W.27.300	63-04-23	565	–	861	7.9	64	11	–	120	–	280	–	170	30	0.4	81	–
3S.1W.26.311	60-10-06	440	–	1,220	7.6	–	–	–	190	–	160	–	110	230	.5	43	–
3S.1W.22.112	58-03-20	SP	31.5	362	8.4	–	–	–	57	–	160	5	33	16	.7	39	–
3S.2W.36.212	77-05-13	–	–	620	8.4	22	6.2	90	–	10.	160	2	100	28	–	–	–
3S.3W.27.441	66-04-16	SP	9.0	439	8.2	70	9.5	10	–	1.4	260	–	23	3	.2	22	–
3S.3W.25.111	77-03-04	–	–	300	8.1	33	12	15	–	1.2	140	–	53	8	–	–	–
3S.2W.25.111	62-06-16	100	–	1,880	8.0	27	3.0	–	380	–	180	–	450	210	.6	17	–
3S.1W.16.323	56-07-24	SP	30.0	380	–	–	–	–	–	–	140	8	37	14	.6	26	–
3S.2W.8.423	77-03-04	–	–	300	7.9	35	6.4	12	–	1.7	150	–	–	12	–	–	–
3S.3W.10.311	77-05-16	–	–	420	8.0	31	20	21	–	1.4	150	–	70	12	–	–	–
3S.2W.1.323	60-06-25	–	–	371	7.2	–	–	–	21	–	196	–	20	8	.4	29	–
2S.2W.35.333	60-06-25	–	–	578	7.5	–	–	–	–	–	–	–	23	–	–	–	–
2S.2W.34.432	51-00-00	134	18.0	–	7.8	68	10	19	–	–	240	–	16	26	–	–	290
2S.1W.31.314	77-03-04	SP	–	460	7.8	45	8.3	38	–	3.0	180	–	85	16	–	–	–
2S.1W.31.314	62-05-03	SP	16.1	505	7.9	62	9.0	–	32	–	240	–	40	16	–	–	–
2S.2W.35.342	60-06-25	SP	–	353	7.4	–	–	–	23	–	201	–	12	15	.4	31	–
2S.1W.30.443	77-03-04	SP	–	770	8.0	120	12	73	–	4.9	160	–	350	4	–	–	–
2S.1W.30.443	62-05-03	SP	19.0	727	7.0	89	11	–	62	–	270	–	140	20	–	–	–
2S.3W.25.133	51-00-00	280	19.0	–	7.7	34	11	25	–	–	170	–	20	16	–	–	188
2S.3W.27.223	51-00-00	420	22.0	–	7.8	44	10	18	–	–	170	–	22	22	–	–	206
2S.1W.19.414	51-00-00	SP	–	–	–	50	12	–	67	–	310	–	38	20	–	–	–
2S.2W.20.311	77-05-16	–	–	260	8.0	21	5.5	24	–	3.0	74	–	45	8	–	–	–
2S.3W.24.411	51-00-00	160	–	–	8.3	35	9.0	35	–	–	190	–	20	14	–	–	196
2S.1W.19.312	51-00-00	–	–	–	–	56	10	–	100	–	230	–	180	21	–	–	–
2S.3W.22.114	51-00-00	315	21.0	–	7.8	41	4.0	30	–	–	170	–	24	16	–	–	204
2S.2W.18.112	51-00-00	150	19.0	–	7.8	34	8.0	32	–	–	180	–	20	12	–	–	168
2S.3W.11.333	51-00-00	244*	19.0	–	7.9	30	7.0	32	–	–	160	–	22	12	–	–	168
2S.3W.7.433	51-00-00	325	20.0	–	7.6	67	15	–	–	–	230	–	28	20	–	–	302
2S.3W.1.322	60-06-30	160	22.0	–	7.9	26	7.0	35	–	–	160	–	18	14	–	–	150
1S.3W.31.433	51-00-00	390	19.0	–	7.7	34	8.0	23	–	–	160	–	18	14	–	–	190
1S.3W.30.213	80-07-15	–	25.0	503	7.7	43	13	40	–	2.3	180	–	80	16	.6	31	–
1S.2W.30.121	51-00-00	280	18.0	–	7.9	22	6.0	33	–	–	140	–	18	12	–	–	168
1S.3W.14.241	60-06-24		–	360	7.8	35	6.9	–	30	–	136	–	41	10	.5	28	245
1S.2W.11.422	50-01-18	SP	–	633	–	42	9.6	–	97	–	359	–	42	11	.6	25	–
1S.2W.11.130	63-04-08	SP	16.0	586	9.3	1	.1	–	133	–	222	31	30	16	1.2	21	–

respectively. These sulfate concentrations also are larger than most sulfate concentrations found in ground water in La Jencia Basin. This may indicate that ground water flowing through the Socorro Peak-Lemitar Mountains area dissolves gypsum or that the local recharge component of spring flow contains large concentrations of sulfate.

In summary, bicarbonate is the dominant anion and specific conductance generally is less than 500 microsiemens in ground water in the Magdalena Mountains and La Jencia Basin. Ground water in the Magdalena Mountains has larger percentages of calcium and magnesium than ground water in La Jencia Basin. Ground water flowing from La Jencia Basin to the Socorro Basin dissolves gypsum. This is indicated by the increases of sulfate concentrations in ground water in the Socorro Peak-Lemitar Mountains area.

WATER BUDGET FOR SOCORRO BASIN

A water budget is a useful means of developing a better understanding of the interaction of ground water and surface water in a given area. A water budget can have many forms but generally is based on the principle of inflow minus outflow equals a change in storage.

In the present study, a water budget was made for the Socorro Basin. A conceptual model of the water system for the Socorro Basin is shown in figure 14. Changes in storage are assumed to be zero for reasons discussed in the section "Changes in Ground-Water Storage." Not all of the variables in the water budget can be or have been measured, so some variables in the budget are estimated. In some cases, a reliable estimate of a variable is not possible but a range of values can be estimated. If the number of these variables is small enough, the calculation of the water budget can be helpful in understanding the possible magnitudes of these variables.

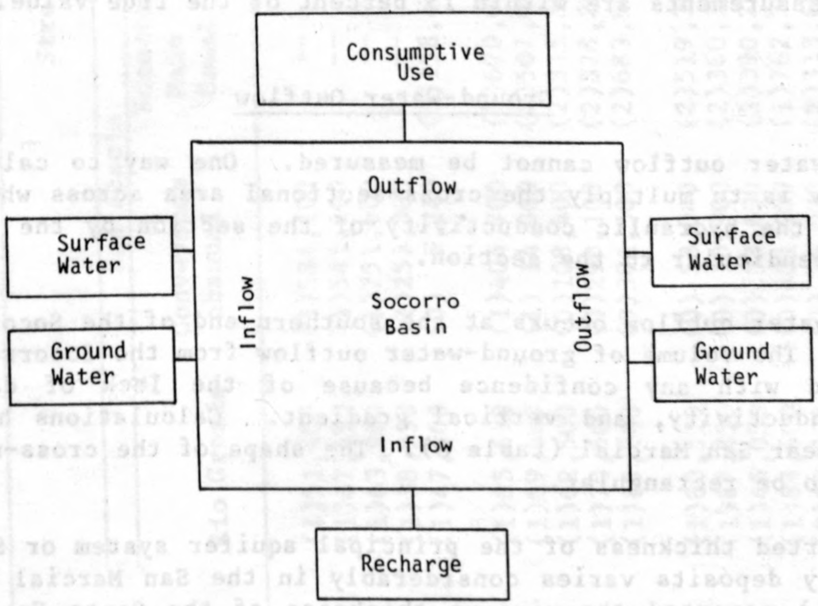


Figure 14.--Conceptual model of the Socorro Basin.

The variables in the water budget for the Socorro Basin and the reliabilities of these variables are discussed in the following sections. This is followed by the calculation of several water budgets for the Socorro Basin and a short discussion of the meaning of the results of these calculations.

Streamflow Depletion

Streamflow depletion is the difference between streamflow at the upstream and downstream points in a specific reach. The U.S. Geological Survey maintains streamflow-measurement stations at San Acacia and San Marcial. As mentioned in the surface-water section of this report, a diversion dam at San Acacia diverts water from the Rio Grande into a conveyance channel and the Socorro Main Canal. Streamflow is measured on the Socorro Main Canal, the Rio Grande conveyance channel at San Acacia and on the Rio Grande and conveyance channel at San Marcial. The Socorro Main Canal flows into the conveyance channel upstream of San Marcial. Examination of the streamflow measurements for the Rio Grande indicates that there is a net loss in streamflow between San Acacia and San Marcial (table 7). There is a net gain in streamflow in the conveyance channel between San Acacia and San Marcial (table 7). This gain in streamflow in the conveyance channel indicates that the conveyance channel may be a drain for the Rio Grande. The altitude of the conveyance channel is lower than the altitude of the channel of the Rio Grande, so surface water in the Rio Grande probably infiltrates through the bed material of the Rio Grande and flows into the conveyance channel. Examination of the total streamflow at San Acacia and San Marcial indicates that the average annual streamflow depletion was 70,632 acre-feet for the period of record, 1960-78 (table 7). In general, the degree of accuracy in the streamflow measurements is fair (table 7). This means that about 95 percent of the daily streamflow measurements are within 15 percent of the true value.

Ground-Water Outflow

Ground-water outflow cannot be measured. One way to calculate ground-water outflow is to multiply the cross-sectional area across which outflow is occurring by the hydraulic conductivity of the section by the potentiometric gradient perpendicular to the section.

Ground-water outflow occurs at the southern end of the Socorro Basin near San Marcial. The volume of ground-water outflow from the Socorro Basin cannot be calculated with any confidence because of the lack of data on depth, hydraulic conductivity, and vertical gradient. Calculations have been made for an area near San Marcial (table 8). The shape of the cross-sectional area was assumed to be rectangular.

The reported thickness of the principal aquifer system or Santa Fe Group and Quaternary deposits varies considerably in the San Marcial area. Geddes (1963, p. 201) reported the minimum thickness of the Santa Fe Group west of Little San Pascual Mountain to be 7,500 feet. A driller's log from a test well in 6S.1W.13.220 indicated a considerable thickness of anhydrite and salt

Table 7. Streamflow in the Rio Grande and differences in flow between San Acacia and San Marcial, 1960-78

[Numbers in parentheses indicate accuracy of streamflow records: (0) poor, (1) fair, (2) good, (3) excellent. Excellent means that about 95 percent are within 5 percent of the true value; good within 10 percent; fair within 15 percent; poor less than fair accuracy]

	Streamflow (acre-feet)							
	San Acacia				San Marcial			
Year	Rio Grande	Conveyance channel	Socorro Main Canal	Total	Rio Grande	Conveyance channel	Total	Depletion in streamflow (acre-feet)
1960	(1)51,400	(1)584,100	--	635,500	(1)551,600	--	551,600	83,900
1961	(1)67,450	(1)541,200	--	609,150	(1)544,500	--	544,500	64,650
1962	(1)63,960	(1)751,600	--	815,560	(1)745,900	--	745,900	69,660
1963	(1)38,930	(2)253,300	--	292,230	(1)267,000	--	267,000	25,230
1964	(1)47,460	(0) 5,240	(3)158,400	211,100	(1) 2,440	(1)166,600	169,040	42,060
1965	(1)85,410	(1)404,700	(3)670,000	1,160,110	(1)296,200	(2)740,100	1,036,300	123,810
1966	(1)69,660	(1) 14,960	(2)507,000	591,620	(1) 3,310	(2)565,500	568,810	22,810
1967	(1)62,500	(0)108,400	(2)315,500	486,400	(1) 63,010	(1)339,900	402,910	83,490
1968	(1)70,860	(0)290,100	(2)378,200	739,160	(1)206,500	(1)440,600	647,100	92,060
1969	(1)85,240	(0)301,500	(2)683,900	1,070,640	(1)198,200	(1)796,300	994,500	76,140
1970	(1)80,510	(0) 58,040	(2)519,200	657,750	(1) 30,640	(1)585,800	616,440	41,310
1971	(1)67,850	(0) 10,900	(2)360,100	438,850	(1) 2,120	(1)395,800	397,920	40,930
1972	(1)45,050	(0) 53,630	(2)390,200	488,880	(1) 31,880	(1)428,000	459,880	29,000
1973	(1)84,600	(0)601,000	(1)762,300	1,447,900	(1)471,900	(0)831,500	1,303,400	144,500
1974	(0)68,920	(0) 16,020	(2)313,600	398,540	(0)100,200	(0)253,200	353,400	45,140
1975	(0)75,710	(0)608,000	(1)448,400	1,132,110	(1)597,300	(1)398,600	995,900	136,210
1976	(0)95,120	(0)142,600	(1)307,800	545,520	(1)457,900	(1) 420	458,320	87,200
1977	(0)64,150	(0) 26,860	(1)182,800	273,810	(2)224,400	(2) 0	224,400	49,410
1978	(0)82,370	(0) 56,830	(1)363,000	502,200	(1)412,000	(2) 5,700	417,700	84,500

beginning at 1,955 feet below land surface. The top of this anhydrite probably represents the bottom of the principal aquifer system. The width of the area probably ranges between 4 and 7 miles.

Hantush (1961, p. 188-193) reported hydraulic conductivities in the Socorro-Lemitar area of 40 and 60 feet per day. These hydraulic conductivities are representative of the shallow aquifer and probably are the largest hydraulic conductivities in the Socorro Basin; therefore, 40 feet per day was used in the estimates. This value may be too large for the complete thickness of the principal aquifer system because of the decrease of hydraulic conductivity with depth due to compaction.

The gradient between wells 6S.1W.36.412 and 7S.1W.18.200 is about 8 feet per mile. This is the gradient used in the estimates; however, the gradient may change with depth. This would be especially true if there were significant vertical gradients in the area.

Bushman (1963, p. 157) calculated the ground-water flow through the Socorro Basin to be about 9,850 acre-feet per year. Values given in table 8 range from 6,440 to 141,200 acre-feet per year. As can be seen from table 8, a large range of values for ground-water flow can be calculated by changing only the cross-sectional area of flow. The gradient and hydraulic conductivity also probably vary in this area; thus, it is difficult (with the presently available data) to calculate a unique value for ground-water flow through the Socorro Basin.

Table 8. Estimates of ground-water flow through selected cross-sectional areas of the principal aquifer system at San Marcial

[Q = CKIA; where Q = volume of flow through cross section, in acre-feet per year; C = constant of 8.38×10^{-3}; K = hydraulic conductivity of 40 feet per day; I = gradient of 8 feet per mile; and A = cross-sectional area, in miles times feet]

Width (miles)	Ground-water flow (acre-feet per year) for indicated thickness (feet)				
	600	1,000	2,000	4,000	7,500
4	6,440	10,700	21,500	42,900	80,500
5	8,040	13,400	26,800	53,600	100,600
6	9,650	16,100	32,200	64,400	120,700
7	11,300	18,800	37,500	75,000	141,200

Ground-Water Inflow

Ground-water inflow cannot be measured, although ground-water inflow can be calculated by the same methods used to calculate ground-water outflow. Ground-water inflow occurs as inflow from the Albuquerque-Belen Basin in the northern part of the Socorro Basin near San Acacia, from La Jencia Basin along the west margin of the Socorro Basin, and from the Jornada del Muerto along the southeast margin of the Socorro Basin. The calculation of ground-water inflow was not done for the Socorro Basin because of the large number of unknown variables that are needed to make calculations for these three areas of ground-water inflow. Ground-water inflow can be examined as the residual in the water-budget calculation.

Recharge

Recharge to the ground-water system occurs as direct infiltration of precipitation, as infiltration of excess applied irrigation water, and as infiltration of mountain-front runoff in arroyos. Recharge has not been measured in the Socorro Basin but estimates of recharge have been made.

For the water-budget calculation, direct infiltration of precipitation was assumed to be negligible. This was based on the assumption that the volume of precipitation that did infiltrate would not be great enough to cause soil below the upper soil zone to reach field capacity; thus, the water would be held in the upper soil zone and used by vegetation. Annual precipitation is also significantly less than the potential evapotranspiration in the area (Gabin and Lesperance, 1977).

The recharge due to the infiltration of excess applied irrigation water was not calculated because this recharge was assumed to be part of the streamflow depletion. The streamflow depletion was measured, so streamflow depletion was used in the water-budget calculation.

Recharge due to the infiltration of mountain-front runoff in arroyos was calculated using a method developed by Jack Dewey (written commun., 1982). The method calculates the quantity of runoff due to precipitation from bedrock areas adjacent to the permeable alluvial-basin deposits. The runoff is then assumed to infiltrate through the bed material of arroyos in the basin or arroyos located on alluvial-basin material. Mountain-front recharge calculated for the east side of the Socorro Basin was 1,600 acre-feet per year (fig. 15). Mountain-front recharge calculated for the Socorro Peak-Lemitar Mountains was 420 acre-feet per year (fig. 15). For the water-budget calculation, one-half of this was assumed to recharge the Socorro Basin, and the other one-half was assumed to recharge La Jencia Basin. Mountain-front recharge from the Chupadera Mountains was calculated to be 370 acre-feet per year (fig. 15). One-half of this value was assumed to recharge the Socorro Basin; the other one-half probably recharged the area between the Magdalena and Chupadera Mountains. The total recharge to the Socorro Basin used in the water-budget calculation was 2,000 acre-feet per year. Significant error in this value would not significantly affect the water-budget calculation because of the large magnitude of the other numbers in the water-budget calculation.

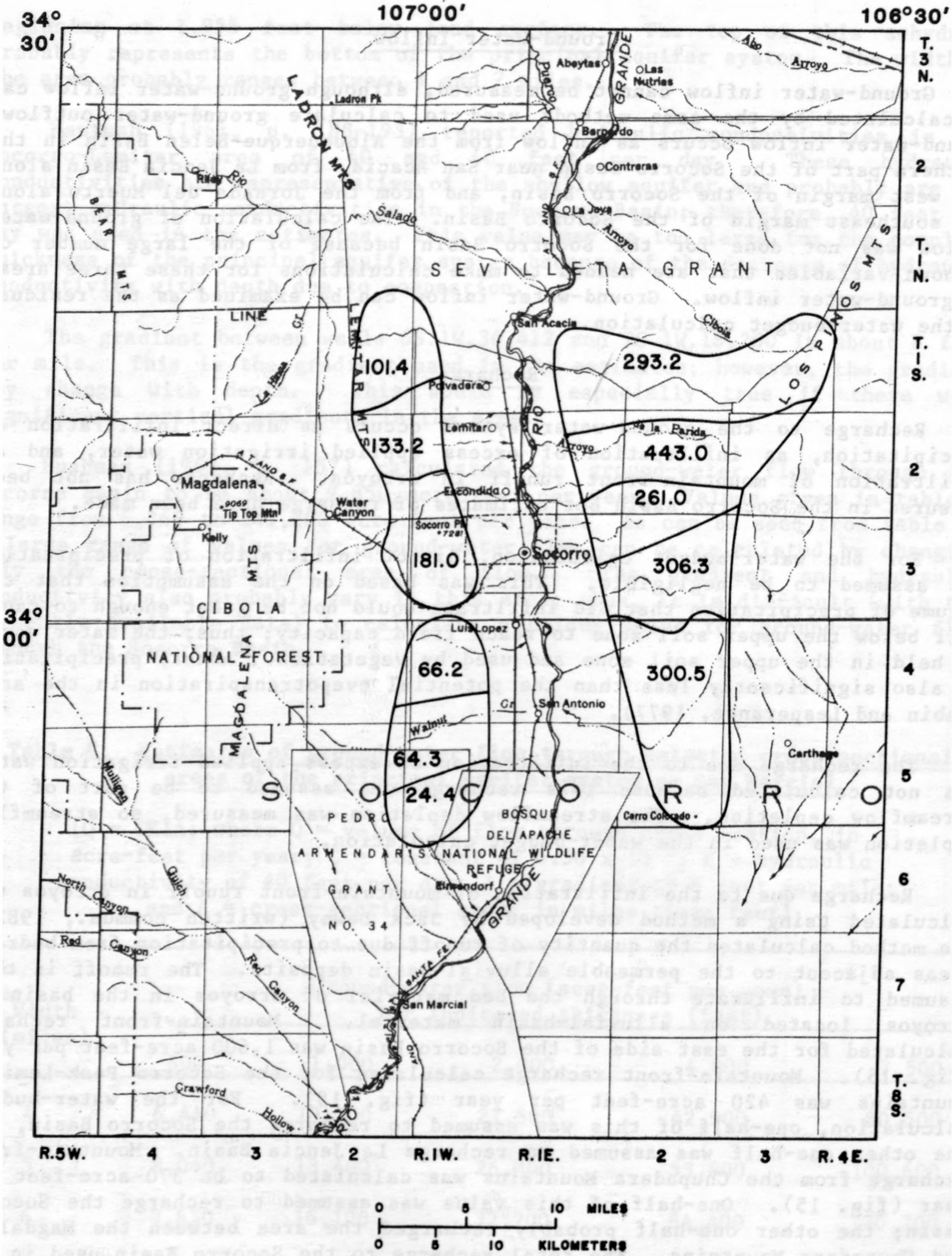


Figure 15.--Recharge to the Socorro Basin from adjacent areas. (Values reported in acre feet per year that would infiltrate in the major drainage channels in each subarea.)

Consumptive Use

Consumptive use in the Socorro Basin includes consumptive use by vegetation (both natural and agricultural), consumptive use by evaporation from open water, consumptive use by rural homesites, and consumptive use by municipalities. The Rio Grande valley in the Socorro Basin was divided into four subareas to estimate consumptive use by vegetation, by evaporation from open water, and by rural homesites. These areas are: the Rio Grande Floodway; the area east of the Rio Grande Floodway; the area west of the Rio Grande Floodway; and the bosque (pl. 2). Consumptive use from the ground-water system outside of the Rio Grande valley, with the exception of consumptive use by municipalities, was assumed to be insignificant because of the large depth to water, sparse density of phreatophytes, and sparse density of rural homesites outside of the river valley. Socorro is the only major population center in the Socorro Basin outside of the Rio Grande valley and consumptive use by municipalities was considered for Socorro.

Total consumptive use in the Socorro Basin was estimated based on a minimum, maximum, and most probable consumptive use for each subarea (table 9). These estimates were determined using visual estimates of vegetation type and density. Depth to water, soil type, water quality, and other factors that affect consumptive use were not examined. These factors probably affect vegetation type and density, so indirectly these factors have been used in the estimation of the minimum, maximum, and most probable consumptive use. The area of each subarea was measured using 15-minute quadrangle maps and a planimeter.

The Rio Grande Floodway is bounded on the west side by the conveyance channel or riverside drain and on the east side by the approximate eastern edge of the active river channel (pl. 2). The area of the floodway was determined to be 8,105 acres. A most probable consumptive use for the floodway is difficult to determine because of the large variations in the volume of water in the active river channel and in the type of vegetation. During the summer months when water is diverted into the conveyance channel, the active river channel is dry and supports very little vegetation. Much of the inactive river channel contains groves of saltcedars and cottonwoods. The consumptive use for native grass is about 2.0 acre-feet per acre per year (Blaney and Hanson, 1965, p. 47). The consumptive use for high densities of saltcedars is about 5.0 acre-feet per acre per year based on the rates computed by Blaney and Hanson (1965, p. 47). The most probable consumptive use was estimated to be 2.0 acre-feet per acre per year because of the large area with little or no vegetation during the summer months when the active river channel is dry.

The area east of the Rio Grande Floodway is bounded on the east by the edge of the river valley and on the west by the east edge of the active river channel (pl. 2). The area was determined to be 7,773 acres. The majority of land consists of bosque that has various densities of saltcedar, cottonwood, and native grass. The most probable consumptive use was estimated to be 3.0 acre-feet per acre per year. This rate is an intermediate value between the consumptive use for cottonwoods and saltcedars and for native grass (Blaney and Hanson, 1965, p. 47).

Table 9. Consumptive use, total acres, and total consumptive use by area in the Socorro Basin

Subarea	Consumptive-use rate (acre-feet per acre per year)			Area (acres)	Consumptive use (acre-feet)		
	Maximum	Minimum	Most probable		Maximum	Minimum	Most probable
Rio Grande Floodway	5.0	0	2.0	8,105	40,525	0	16,210
Area east of Rio Grande Floodway	5.0	2.0	3.0	7,773	38,865	15,546	23,319
Area west of Rio Grande Floodway:							
Irrigated land	3.0	1.0	2.5	14,587	43,761	14,587	36,468
Other land	3.0	0.5	1.0	11,566	34,698	5,783	11,566
Bosque	6.0	2.0	5.0	7,535	45,210	15,070	37,675
Total					203,059	50,986	125,238

The area west of the Rio Grande Floodway is bounded on the west by the westernmost lateral or irrigation ditch and on the east by the riverside drain or conveyance channel (pl. 2). The area was determined to be 26,153 acres. The land consists of irrigated cropland, roads, bosque, and homesites. In 1978, there were 14,587 acres of irrigated cropland in the Socorro Basin (New Mexico State Engineer Office, 1980). Alfalfa is the major crop in the Socorro Basin. Blaney and Hanson (1965) reported an average seasonal consumptive use of water, minus effective precipitation, for alfalfa grown in the Socorro Basin of 2.4 acre-feet per acre per year. A most probable consumptive use of 2.5 acre-feet per acre per year was estimated for the irrigated cropland. The area of unirrigated land in this area was determined to be 11,566 acres. The most likely consumptive use for the unirrigated land was estimated to be 1.0 acre-foot per acre per year. This estimate is based on the assumption that the majority of ground water pumped for domestic use is not consumed.

The Bosque del Apache National Wildlife Refuge is located near San Marcial (pl. 2). In the southern part of the refuge, the entire river valley is vegetated with saltcedar, cottonwood, tules, and Russian olive. The area of this southern part of the refuge (Bosque area) was determined to be 7,535 acres. The consumptive use of saltcedars and cottonwoods can be as much as 6.0 acre-feet per acre per year (Blaney and Hanson, 1965, p. 47). The most probable consumptive use was estimated to be 5.0 acre-feet per acre per year because of the density of vegetation.

The consumptive use by municipalities, with the exception of Socorro, was included in the calculation of consumptive use for the unirrigated land west of the Rio Grande Floodway because the majority of the homesites are in that area. The volume of water withdrawn by the city of Socorro in 1972 was reported to be 741 acre-feet (Randall and Dewbre, 1972, p. 40). In Albuquerque, about 50 percent of the ground water withdrawn for use is returned to the sewage-treatment plant and thus returned to the flow system (Hydrologic Engineering Center, 1979, p. 2-50). If this same percentage is assumed for Socorro, about 370 acre-feet of water is consumed within the city of Socorro. This volume of water is negligible compared to the other volumes of water in the water budget.

Changes in Ground-Water Storage

Changes in ground-water storage are indicated by changes in water levels in wells. As mentioned in the discussion of ground-water flow in the Rio Grande valley, the available data indicate that there have not been significant changes in water levels in the Rio Grande valley since the installation of the drains in the 1930's. Outside of the Rio Grande valley changes in water levels could be caused by large ground-water withdrawals or large changes in the distribution or volume of ground-water recharge. Ground-water withdrawals by the city of Socorro totaled 741 acre-feet in 1972, so there probably are some small changes in ground-water storage in the Socorro Basin. No changes in the distribution or volume of ground-water recharge in the Socorro Basin are known. Changes in ground-water storage are, therefore, assumed to be small enough to be neglected in the water-budget calculation.

Calculation of Water Budget

The water budget can be represented by the following equation:

$$\Delta S = (Qsi - Qso) + (Qgi - Qgo) - Qcu + Qr \qquad (1)$$

where

ΔS = change in ground-water storage, in acre-feet per year;
Qsi = surface-water inflow, in acre-feet per year;
Qso = surface-water outflow, in acre-feet per year;
Qgi = ground-water inflow, in acre-feet per year;
Qgo = ground-water outflow, in acre-feet per year;
Qcu = consumptive use, in acre-feet per year; and
Qr = recharge, in acre-feet per year.

Assuming there is no change in storage ($\Delta S = 0$), equation 1 can be rearranged so that the ground-water inflow and outflow terms are isolated.

$$(Qgi - Qgo) = Qcu - (Qsi - Qso) - Qr \qquad (2)$$

Three calculations using equation 2 and the previously presented total consumptive uses are presented in table 10. When the most probable consumptive use is used, the equation indicates a net ground-water inflow of 52,606 acre-feet per year greater than the net ground-water outflow. This indicates that if there is no change in storage in the Socorro Basin, there has to be 52,606 acre-feet per year more ground-water inflow to the basin than ground-water outflow. For example, if ground-water outflow is assumed to be 50,000 acre-feet per year, the ground-water inflow would be 50,000 acre-feet plus 52,606 acre-feet or 102,606 acre-feet per year.

The values in table 10 need to be used with caution because of the uncertainties that are inherent in the values used for consumptive use. As shown in table 10, if the minimum consumptive-use values are used, ground-water outflow is 21,646 acre-feet per year greater than ground-water inflow. If the maximum consumptive-use values are used, ground-water inflow is 130,427 acre-feet per year greater than ground-water outflow. The minimum and maximum values probably are not reasonable but were calculated to show the effect of consumptive use on the water budget in the Socorro Basin. The margin of error in the surface-water flows for the length of record used in the calculation is plus or minus 15 percent. The entire water budget may be changed just by the error margins of the surface-water records. The water budget gives ranges or orders of magnitude of the quantities of water lost or moving through the Socorro Basin.

Table 10. Calculation of water budget

[Qgi is ground-water inflow, Qgo is ground-water outflow, Qsi is surface-water inflow, Qso is surface-water outflow, Qcu is total consumptive use for the Socorro Basin, Qr is total recharge to the Socorro Basin. All values in acre-feet per year]

(Qgi - Qgo)	=	Qcu	-	(Qsi - Qso)	-	Qr
130,427 (maximum)		203,059		-70,632		-2,000
-21,646 (minimum)		50,986		-70,632		-2,000
52,606 (most probable)		125,238		-70,632		-2,000

CONCLUSIONS

The principal aquifer system in the Socorro and La Jencia Basins consists of the Popotosa aquifer, the Popotosa confining bed, and the shallow aquifer. Most wells in the Socorro and La Jencia Basins derive water from the shallow aquifer, which is composed of the Quaternary deposits and Sierra Ladrones Formation. The minor aquifer systems consist of the Socorro volcanics aquifer system and the Mesozoic-Paleozoic aquifer system. These aquifer systems are dominant along the basin margins. Recharge occurs along the margins of the basins as infiltration of runoff.

On the east side of the Rio Grande valley in the Socorro Basin, water moves westward toward the river in the Mesozoic-Paleozoic aquifer system. North of San Antonio, the quantity of water that enters the principal aquifer system from the east probably is quite small because of the small quantity of recharge in the area. South of San Antonio, ground water enters the Socorro Basin and the northern end of the San Marcial Basin from the Jornada del Muerto.

In the Rio Grande valley, drains, laterals, and the Rio Grande control the ground-water levels. Ground-water levels in the river valley indicate that ground water generally flows parallel to the river except along the basin margins where ground water is entering from adjacent areas. In many areas along the Socorro Basin margins, water levels in wells completed in the minor aquifer systems are much higher than in the principal aquifer system, indicating hydraulic discontinuities are common in these areas.

Ground water flows from the southeastern part of La Jencia Basin into the Socorro Basin through the Socorro Peak-Lemitar Mountains area. The volume of ground-water flow between basins is limited by the hydraulic conductivity of the rocks in the Socorro Peak-Lemitar Mountains area. Ground water in the northwestern part of La Jencia Basin flows northward parallel to La Jencia Creek.

Ground-water quality east of the Rio Grande valley in the Mesozoic-Paleozoic aquifer system is controlled by the mineralogy of these sediments. The dissolution of calcite, gypsum, and dolomite seems to be the major factor controlling the water chemistry. In general, ground water east of the Rio Grande valley contains large percentages of calcium, magnesium, and sulfate.

There are three zones of differing water quality in the Rio Grande valley in the Socorro Basin. In the northern area of the basin, water with large chloride concentrations is present. The water probably is deep basin water that is moving upward due to a constriction to ground-water flow near San Acacia. Near Socorro, irrigation-return flow and inflow from the basin margins are the flow components controlling water quality. In this area, specific conductances range from about 300 to 1,640 microsiemens. From approximately La Borcita south, water with large chloride concentrations is present. This water could be deep basin water that is moving upward due to a constriction to ground-water flow much like that at the northern part of the basin. This water also may represent geothermal water that is leaking upward along the Capitan lineament. It is also possible that this water is the result of both mechanisms.

Water in the principal recharge area for La Jencia Basin (Magdalena Mountains) contains large percentages of calcium and bicarbonate. Water in the principal aquifer system in La Jencia Basin contains large percentages of calcium, sodium, and bicarbonate. This change in water composition probably is the result of the exchange of calcium or magnesium for sodium on clays of the principal aquifer system. In general, water in La Jencia Basin has a specific conductance of less than 500 microsiemens.

Total consumptive use for the Socorro Basin is about 125,000 acre-feet per year, recharge is about 2,000 acre-feet per year, and surface-water loss between the northern and southern ends of the basin is about 70,600 acre-feet per year. If there is no change in storage in the basin, ground-water inflow to the basin is about 53,000 acre-feet per year greater than ground-water outflow.

The results of the present study have left four major unresolved problems in the Socorro and La Jencia Basins: (1) The distribution, thickness, and hydraulic properties of the principal and minor aquifer systems; (2) the quantity of ground-water inflow to and outflow from the Socorro Basin; (3) the source of the water with large chloride concentrations in the San Acacia area; and (4) the source of the water with large chloride concentrations in the San Antonio area.

To answer the first problem, geophysical work, test drilling, and aquifer tests are necessary. Test holes near San Acacia and San Antonio also would be helpful in resolving several of the other problems. Vertical gradients need to be measured in any test holes drilled. A ground-water model and testing of aquifer characteristics in the basins would be useful in determining the quantities of ground-water inflow and outflow in the Socorro Basin. A well-inventory and water-sampling program would also be beneficial in the understanding of the flow systems near the basin margins.

Further study of the southern end of the Albuquerque-Belen Basin and the northern end of the Socorro Basin in conjunction with measurement of vertical gradients in selected wells would be useful in determining the origin of the water with large chloride concentrations in the San Acacia area.

Further study of the area between San Antonio and Sixmile Canyon-Socorro Canyon in conjunction with test drilling, vertical-gradient measurement, and water-quality sampling (including stable and unstable isotopes) would be useful in developing a better understanding of the water with large chloride concentrations in the La Borcita area. This study would also be helpful in defining the nature of the hydraulic connection between the Socorro and La Jencia Basins in this area.

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WATER-RESOURCES INVESTIGATIONS REPORT 84-4342

PLATE 1

106°30'

EXPLANATION

Qal ALLUVIAL MATERIAL--Consists of tan to red sand and gravel.

Qc COLLUVIUM, PEDIMENT GRAVEL, AND TERRACE GRAVEL--Consists of sand and gravel.

...LADRONES FORMATION--Includes pediment-slope, ...fan, and axial-stream deposits consisting ... to reddish-brown clay, silt, sand, ...lenses.

...udes the upper and lower ...ion consisting of clay, ...e interbedded vol-

... deposits ...d with

T. 3 N.

T. 2 N.

POCKET CONTAINS
4 ITEMS