GROUND-WATER REPORT 4

Geology and Ground-Water Resources of Northeastern Socorro County, New Mexico

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GEOLOGY AND GROUND-WATER RESOURCES OF NORTHEASTERN SOCORRO COUNTY, NEW MEXICO

BY ZANE SPIEGEL

U. S. Geological Survey

Abstract

This report presents the results of an investigation of the ground-water conditions and resources in northeastern Socorro County made by the United States Geological Survey in cooperation with the New Mexico Bureau of Mines and Mineral Resources and the State Engineer of New Mexico.

Socorro County, in west-central New Mexico, is characterized by rugged mountains and broad mesas which separate alluvial basins lying at lower altitudes. Except for the Rio Grande, the master stream in the area investigated, there are no perennial streams for stock or irrigation use, although in some tributaries there are short stretches in which there is a perennial spring-fed stream flow. As the evaporation-precipitation ratio in the area is high, and extended droughts are common, surface-water tanks generally are not dependable as a source of stock water at lower altitudes.

The consolidated rocks in the high areas are principally Precambrian, Pennsylvanian, and Permian in age. The availability of water from these older rocks is dependent chiefly upon the topography and geologic structure, whereas the occurrence of water in the partly consolidated Tertiary rocks and the Quaternary alluvium of the basins is relatively more dependent upon the hydrologic character of the alluvium and associated rocks and upon the recharge by rainfall and stream-flow, although in both areas all these factors are important to some extent. Small amounts of water of fair to good chemical quality are available in weathered or jointed zones of the Precambrian rocks. Larger supplies of harder water are available in the limestones of Pennsylvanian age, but the depth to water in these rocks is probably greater than 300 feet except in the major valleys. The Bursum formation of Permian (?) age yields small amounts of soft water that is high in sodium and bicarbonate. Sandstone beds in the overlying Abo formation of Permian (?) age generally yield sufficient water for stock supplies, although these permeable beds are separated by thick shale beds of low permeability. South of Arroyo Abo, water from the Abo formation is high in sulfate and undesirable for domestic use. The sulfate is probably derived from ground water flowing in from overlying gypsiferous rocks.

The Yeso and San Andres formations contain gypsum and thin limestone beds which yield water too high in sulfate to be desirable for drinking. Locally large yields of water can be obtained from these formations, however. Sandstone beds may yield somewhat better water in small areas where there is no inflow from gypsiferous rocks. Generally, all these formations yield water suitable for stock, but water suitable for domestic use is not obtainable from the Yeso and San Andres formations in most localities.

Triassic and Cretaceous rocks, which occupy small areas in northeastern Socorro County, are poor aquifers because of their low permeability and the impedance to movement of ground water through these rocks by local faults. In faulted areas the ground waters are highly mineralized.

Natural discharge of the aquifers in Pennsylvanian and Permian rocks in most of the area investigated is by springs and underflow into Arroyos Abo, Agua Torres, Cibola, and Alamillo east of the Rio Grande, and into the Rio Salado west of the Rio Grande. The water that discharges from these aquifers and flows through the arroyos is of poor quality—high in sulfate east of the Rio Grande, high in chloride west of the Rio Grande—and locally contaminates the ground water in the Santa Fe and Popotosa formations of the Rio Grande trough in areas adjacent to these arroyos. Ground water in Permian rocks in T. 1 S., Rs. 3, 4, and 5 E., probably moves southward to discharge into the north end of the Jornada del Muerto. In this area ground water occurs in the Meseta Blanca sandstone member of the Yeso formation and in the Abo formation. Locally the Yeso formation is not saturated, the upper part of the Abo formation is nearly impermeable, and ground water can be obtained only at great depths in the Abo formation or in rocks of the Magdalena group.

The Baca formation, a sequence of cemented sandstone and conglomerate of Eocene (?) age, and the Datil formation, a sequence of volcanic rocks and interbedded sediments, crop out in small areas east of the Joyita Hills. The prospects for obtaining ground water from these rocks are not favorable because of their small extent and low permeability.

Monzonite dikes and sills intrude the Permian rocks east of the Los Pinos Mountains, but no evidence was found to indicate that they control the movement of ground water in the Permian rocks.

The Santa Fe formation of Tertiary age and alluvium of Quaternary age are probably the most important aquifers in the area. These aquifers occur principally in the Rio Grande fault trough. The Popotosa formation is distinctive because it is derived principally from volcanic rocks of the Datil formation. It yields only small quantities of water of poor quality, some of which is unfit even for stock. The Santa Fe formation generally is favorable for the development of wells yielding more than 100 gpm. Recharge to this unit is from precipitation on the broad mesas of the Rio Grande trough, by infiltration of storm runoff from bordering uplands, and by inflow of ground water from Permian rocks adjacent to the trough. Ground-water inflow from the Permian rocks is of poor quality, and therefore in the areas of the Rio Grande trough which are recharged by these waters (south of Arroyo Abo east of the Rio Grande, and in most of the Llanos del Rio Puerco in Socorro County) the ground water is high in sulfate or chloride.

Recharge to the Santa Fe formation east of the Rio Grande and north of Arroyo Abo is by infiltration of direct precipitation and surface runoff from the Manzano Mountains. Ground water in the Rio Grande trough in Valencia County (east of the river) is therefore of excellent chemical quality. Losses of the Rio Puerco computed from surface-water records suggest that at least 190 acre-feet of surface runoff per lineal mile is recharged to the Santa Fe formation in the lower 20 miles of the Rio Puerco. Most of this ground water moves generally eastward. Ground water in the area between the Rio Puerco and the Rio Grande is therefore of somewhat better quality than that west of the Rio Puerco.

The slope of the water table in the Rio Grande trough, as inferred from the altitude of water levels measured in wells, indicates that movement of ground water in the Santa Fe formation is from the borders of the trough generally toward the river, but downstream at an angle of about 45 degrees with the river, and at a gradient of 5 to 10 feet per mile. The sharply defined belts of varying quality of the ground water are good indications that ground-water bodies in the Santa Fe formation are recharged locally according to the geography and geology, and that ground water discharges to the river not far downvalley from the latitude of the recharge. If the ground-water gain to the valley (820 acre-feet per lineal mile per year) previously computed for the Belen area holds for this stretch, the average transmissibility of the Santa Fe formation is computed to be 50,000 to 100,000 gpd per foot of aquifer width under a unit hydraulic gradient. These values are within the range generally considered as favorable for moderate to large yields from wells.

Alluvium of Quaternary age is saturated with water in the valley floor of the Rio Grande and in the valleys of its major tributaries. However, the thickness and permeability of the alluvium are sufficiently great to provide large yields only in the Rio Grande valley. Although no large-yield wells were reported to have been put down in the alluvium as of 1950, quantities sufficient for irrigation should be obtainable nearly everywhere in the Rio Grande's inner valley. However, withdrawal and consumptive use of ground water from wells in the alluvium and Santa Fe formation will generally result in an eventual decrease in flow of the Rio Grande. The quality of water in the alluvium of the Rio Grande valley in this part of Socorro County is generally good enough for stock and irrigation but not for domestic use. Ground water in the Santa Fe formation below the valley alluvium should generally be similar in quality to that under the adjacent mesas.

Introduction

PURPOSE AND SCOPE OF INVESTIGATION

This report presents the results of an investigation of the ground-water conditions and resources in northeastern Socorro County made by the United States Geological Survey in cooperation with the New Mexico Bureau of Mines and Mineral Resources and the State Engineer of New Mexico as part of a continuing program of investigation of the ground-water resources of New Mexico. The areas discussed in this report and in previous reports prepared under this part of the cooperative program are shown in Figure 1.

Except for the Rio Grande, the master stream in the area investigated, there are no perennial streams for stock or irrigation use, although in some tributaries there are short stretches in which there is a perennial spring-fed stream flow. Water in surface ponds at the lower altitudes is not dependable because of the high evaporation rate and the low precipitation. For those reasons ground water is important in the area for ranch and community and irrigation use. The purpose of this investigation was to determine how and where ground water occurs in the area, and in what quantities and of what quality.

METHOD OF INVESTIGATION

Field work for this report was started by the author in July 1949 and was continued, with some interruptions, through August 1950. During this time more than 150 wells and springs were visited to determine their yield and the source of their water, and to determine the water-bearing characteristics of each geologic formation. Representative water samples were taken by the writer and analyzed in the laboratory of the U. S. Geological Survey at Albuquerque to determine the dissolved chemical constituents. Wherever possible the depth to water in wells was measured with a steel tape. The altitudes of the wells and springs were determined by interpolation from topographic maps or by aneroid barometer, and the water-table altitude was computed.

PREVIOUS INVESTIGATIONS

Early reconnaissance studies of the geology and ground-water resources of Socorro County were made by Bryan (1926) and by Black and Powell (1928). The water resources of the Rio Grande valley were studied by W. T. Lee (1907), and a more recent and detailed study of the geology and water resources of the inner valley of the Rio Grande was made for the National Resources Committee by Bryan (1938) and Theis (1938). Reconnaissance geologic maps of much of the area were

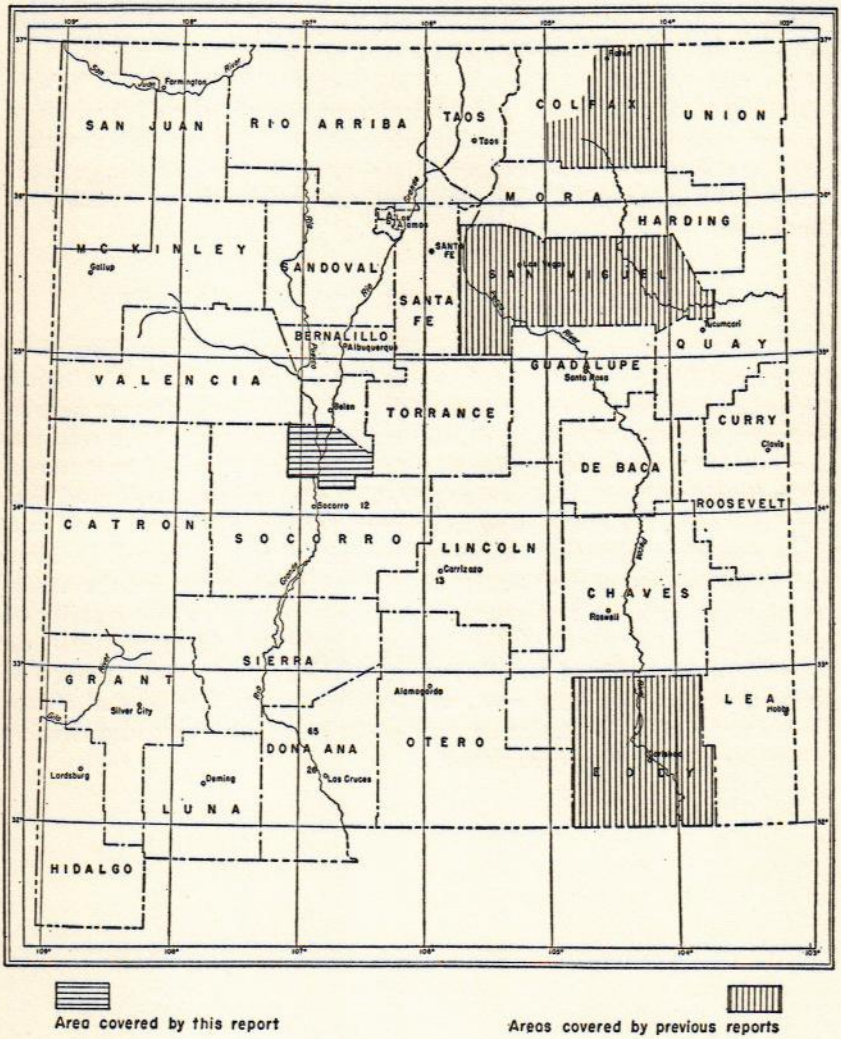

Figure 1

AREAS IN NEW MEXICO DISCUSSED IN GROUND-WATER REPORTS PUBLISHED BY THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES AS PART OF THE COUNTY PROGRAM IN COOPERATION WITH THE U. S. GEOLOGICAL SURVEY AND THE NEW MEXICO STATE ENGINEER.

made by Darton (1928-a and 1928-b). The geology of the northeastern part of the county has been studied by the United States Geological Survey (Wilpolt and others, 1946 and 1951; Kelley and Wood, 1946; Kelley, 1954), and the geology of parts of the area has been studied by Bryan and McCann (1937 and 1938), Denny (1940 and 1941), and Wright (1946). All the above work is drawn upon in the discussions of geology and ground water. Specific references are made to the literature listed at the end of the report, and the sources from which the geologic map (pl 1) was compiled, with modifications by the writer, are shown on that plate.

SUPERVISION AND ACKNOWLEDGMENTS

This investigation was made under the general supervision of A. N. Sayre, Chief of the Ground Water Branch of the U. S. Geological Survey, and under the direct supervision of C. V. Theis, former district geologist, and C. S. Conover, district engineer in charge of the cooperative ground-water investigations in New Mexico. Parts of manuscript maps furnished by C. B. Read and V. C. Kelley, of the Geological Survey, were useful in completing the report. Messrs. Theis and Read critically read the report and offered many helpful suggestions. J. D. Hem and L. S. Hughes, of the Quality of Water Branch, provided the analyses of water samples and read the sections concerning the quality of water. R. C. Lemoine, of the Service Cooperatif Interamericain de Production Agricole of the Republic of Haiti, made many pertinent suggestions and critically read parts of the report. The cordial aid in furnishing well information, extended by many residents and drillers of the area, is greatly appreciated.

Geography

LOCATION, AREA, AND ACCESS

Socorro County is in west-central New Mexico. It has an area of 6,300 square miles and is the third largest county in the State. It has a rather irregular shape, with a maximum east-west dimension of about 100 miles, and maximum north-south dimension of about 75 miles. Socorro County is bordered by Torrance and Valencia Counties on the north, Catron County on the west, Sierra County on the south, and Otero and Lincoln Counties on the east. This report covers the eastern part of the northern projection of the county, an area of about 750 square miles (shown shaded in fig 1).

The "Belen cutoff" of the Atchison, Topeka and Santa Fe Railway parallels the Socorro-Valencia county line and crosses the northeast corner of Socorro County through Abo Canyon. This line connects Belen and Mountainair, in Valencia and Torrance Counties respectively, and is an important rail link between Texas and Arizona. A branch of the same railway connects Socorro, the county seat, 20 miles south of the area, with Albuquerque 36 miles to the north of the area, and El Paso, Tex., 225 miles south of the area. A short railroad spur runs from Socorro to Magdalena, N. Mex., and connects with a cattle driveway from the Arizona border.

U. S. Highways 60 and 85 extend generally east-west and north-south respectively through the area and connect the same towns served by the railroads, except that Highway 60 continues west from Magdalena into Arizona. New Mexico Highway 6 connects Belen with Highway 60 near the mouth of Abo Canyon. There are several short improved State highways in northern Socorro County. Other than these, unimproved ranch roads and broad but sandy arroyos provide the only means of access to much of the area investigated, and they are usually impassable in wet weather.

DRAINAGE

The Rio Grande, the most important river in New Mexico, heads in the San Juan Mountains of Colorado. It flows generally south-southwest across New Mexico and through Socorro County. Its drainage area above the junction of the Rio Puerco at Bernardo is 19,230 square miles, including 2,949 square miles in a closed basin in the northern part of the San Luis Valley in Colorado. The drainage area of the Rio Grande at San Acacia is increased to 26,770 square miles, principally by the addition of the Rio Puerco and Rio Salado drainage areas (Surface Water Supply of the United States, 1946, pp 206, 207). The Rio Puerco, which enters the Rio Grande in the area studied, is one of the most important tributaries of the Rio Grande in New Mexico. Its headwaters are in the area west of San Pedro Mountain near Cuba, N. Mex., about 110 miles above the mouth. The headwaters drain Eocene rocks in part of the San Juan basin and Precambrian and Paleozoic rocks on the west slope of San Pedro Mountain east of Cuba, but the greater part of its drainage area is underlain by fine-grained Cretaceous sedimentary rocks, though some tributary drainage is on Triassic formations. In Socorro County and adjacent parts of Valencia County, however, the Rio Puerco flows entirely across unconsolidated late Cenozoic sediments.

Similarly, the Rio Salado drains areas underlain by Triassic, Jurassic, and Cretaceous rocks, with important tributary drainage from the Tertiary lavas and tuffs of the Gallina (T. 1 N., R. 7 W.) and Bear (T. 1 N., R. 4 W.) Mountains, but its lower course is across unconsolidated and relatively more permeable sediments of late Cenozoic age. Arroyos Abo, Agua Torres, Cibola, and Alamillo are lesser tributaries of the Rio Grande. The eastern tributaries all head in the gypsiferous Pennsylvanian and Permian rocks in the cuesta area east and south of the Los Pinos Mountains. The Quaternary channel alluvium in the upper reaches of all these arroyos, like that of the Rio Puerco and Rio Salado, is underlain by pre-Tertiary rocks which either contribute inflow to the alluvium or form the floor for perched underflow in the channel alluvium. The lower courses of all these arroyos and rivers are usually dry because of recharge to underlying sediments. Many other arroyos, all intermittent or ephemeral, contribute directly or indirectly to the Rio Grande. The Rio Grande is the only perennial stream in the area, except for perennial stretches sustained by spring flow in some of the arroyos.

PHYSIOGRAPHY

The area investigated and covered in this report is in the Mexican Highland and Sacramento sections of the Basin and Range province, as classified by Fenneman (1931). Most of the area is in the Mexican Highland section and consists of a series of gently sloping alluvium-filled basins separated by complexly faulted mountains. In the small portion of the Sacramento section east of the Los Pinos Mountains, erosion of gently eastward dipping sedimentary rocks has resulted in the formation of a series of cuestas. The drainage of the alluvial basins is integrated with the Rio Grande by means of a system of intermittent or ephemeral arroyos (pl 1).

The inner valley and flood plain of the Rio Grande trough has been divided into several parts (Bryan, 1938, pp 200, 201). The Belen division of the Middle Rio Grande Conservancy District extends from the constriction at San Acacia northward into Valencia County, and the Socorro division extends southward from San Acacia beyond the area considered here. The constriction at San Acacia is a narrow canyon 275 feet deep, cut into a remnant of an andesite flow interbedded with sediments of the Santa Fe formation of the Rio Grande depression. The inner valley of the river broadens to a flood plain 1 to 4 miles wide, both north and south of San Acacia. The altitude of the river at the constriction is 4,660 feet. Its altitude at Bosque, near the Valencia-Socorro county line 20 miles north, is 4,757 feet, indicating a river gradient of about 5 feet to the mile.

The Rio Grande trough broadens from about 12 miles in width above San Acacia to more than 35 miles at the Valencia-Socorro county line, but it remains rather narrow between San Acacia and Socorro. Extensive surfaces of Pleistocene (?) age eroded on the partly consolidated fill of the depression rise gently from low bluffs near the edges of the inner valley to the bordering highlands. The surface east of the river, the Llano de Sandia, rises uniformly to a maximum altitude of about 6,000 feet. At the eastern edge of the plain, north of the area drawn on Plate 1, the Manzano Mountains rise sharply to peaks, some of which are slightly more than 10,000 feet in altitude. The Los Pinos Mountains to the south rise even more abruptly in places, but only to about 7,700 feet. The summit of the southern Manzano Mountains is narrow, sharp, and rugged in comparison with the relatively flat summit of Los Pinos Mountains, which slope gently southeast parallel to the dip of the Pennsylvanian rocks there.

East of the Los Pinos Mountains the topography is distinctly different from that in the Rio Grande valley. Erosion of gently eastward dipping Pennsylvanian and Permian rocks by the westward-draining Arroyo Abo and its tributaries has formed a series of cuestas upheld by the more resistant beds. Outliers of Chupadera Mesa (the main part of which is in Torrance and Lincoln Counties) form prominent buttes in a portion of T. 1 N., R. 5 E. A few miles west of the buttes, in T. 1 N., R. 4 E., dikes have intruded the Permian rocks and form a series of narrow northeast-trending ridges 25 to 75 feet high.

The western boundary of the Rio Grande depression in the vicinity of the Valencia-Socorro county line is formed by the fault scarps and mesas of the Lucero uplift (see Kelley and Wood, 1946), northwest of the mapped area. The northern part of the west boundary of the area investigated is formed by these structural features. This boundary serves also to separate the Basin and Range province from the Colorado Plateau province. The Llanos del Rio Puerco, a series of pediments and partially pedimented surfaces, rise from the Rio Puerco to the foot of the escarpments bounding the Rio Grande depression on the west. Between the Rio Puerco and Rio Grande valleys is a flat-topped remnant of the oldest erosion surface formed in Tertiary time that is recognized in the area. This remnant is bounded on the west by an abrupt erosional escarpment termed the "Ceja del Rio Puerco," and on the east by the equally abrupt "Cejita Blanca." The surface of this low mesa, 300 feet above the Rio Grande, is the southernmost extension of the Llano de Albuquerque (Bryan and McCann, 1938; Wright, 1946.)

The Rio Grande depression in Ts. 2 and 3 N. is bounded on the west by the extremely rocky and rugged fault block of the Ladron Mountains, which have a maximum altitude of 9,214 feet. The Ladron Mountains are bordered on the north and northeast by extensions of the Llanos del Rio Puerco. Many intermittent tributaries to the Rio Puerco drain the Ladron Mountains and have incised broad arroyos into the bordering plains, leaving smooth inter stream remnants. However, the areas east and southeast of the Ladron Mountains have been minutely dissected into badlands which contrast strongly with the broad Llanos north and northeast of the Ladrons. South of the Rio Salado the badlands continue, in places somewhat modified by drifting sand. The major cause of the badland topography is differential erosion on tilted fault blocks of Tertiary rocks.

East of the Rio Grande, two small basins southwest of the Los Pinos Mountains, Valle del Ojo de la Panda (1'. 1 S., R. 2 E.) and a basin eroded by Arroyo Cibola, are separated from the Rio Grande trough by the Joyita Hills uplift just east of San Acacia, and by the Cerrillos del Coyote and their northern extensions. Valle del Ojo de la Parida is separated from the valley of Arroyo Cibola by a low divide veneered with alluvium, through which project island like remnants of Cretaceous and Tertiary rocks.

CLIMATE

The climate of northern Socorro County is generally semiarid. It has a wide range of temperature, rainfall, and evaporation rate because of local topographic irregularities. No permanent weather stations are maintained within the area covered by this report, but the data for all nearby stations are presented in Table 1. Stations at the Kelly ranch (west of the area shown on pl 1, near the Rio Salado), the Diamond-T ranch (sec. 34, T. 2 N., R. 3 E.), and Bernardo (Sabinal) were in operation for several years, but the data from these stations are incomplete and are not tabulated. The Belen, Socorro, and Los Lunas records represent approximately the climate of the Rio Grande valley, whereas the records for Magdalena and Mountainair represent the climate of the higher plains bordering the Rio Grande depression. There are no climatic data for the mountains, but it is believed that the mountain areas receive much greater precipitation and have lower temperatures and evaporation rates than do any of the stations listed. The tables show that about 40 percent of the annual precipitation at all stations occurs in the three months July through September. October is the fourth wettest month at the valley stations; but April, May, and June are slightly wetter than October at the higher stations. Most of the summer precipitation occurs in scattered heavy thundershowers. The amount of snow that falls in the winter increases considerably with the elevation, as does the total annual precipitation. Through most of the winter, the higher

TABLE 1. CLIMATOLOGICAL SUMMARY FOR STATIONS IN VICINITY OF NORTHEASTERN SOCORRO COUNTY, N. MEX.

PRECIPITATION (INCHES)

STATION	LAST COMPLETE YEAR OF RECORD	YEARS OF RECORD	ALTITUDE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Belen[1]	1943	55	4,800	0.43	0.35	0.52	0.68	0.52	0.63	1.37	1.40	1.19	0.84	0.44	0.45	8.82
Near Los Lunas[2]	1940	40	4,800+	.39	.31	.48	.60	.56	.65	1.23	1.31	1.20	.76	.41	.41	8.31
Socorro[1]	1949	62	4,618	.41	.42	.54	.62	.67	.60	1.75	1.54	1.51	1.03	.42	.61	10.12
Magdalena[1]	1949	46	6,556	.60	.45	.66	.92	.62	.85	2.52	2.59	1.55	.82	.57	.65	12.80
Mountainair[1]	1948-49	42	6,500	.73	.92	.92	1.15	1.22	1.08	2.65	2.71	1.69	1.08	.99	1.18	16.32

AVERAGE EVAPORATION RATE (INCHES)

STATION	LAST COMPLETE YEAR OF RECORD	YEARS OF RECORD	ALTITUDE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Jornada Experimental Range, 1949 Dona Ana County[1]		—	—	2.52	4.19	7.28	10.22	13.06	14.43	12.67	10.68	8.56	9.11	3.67	2.32	95.73

TEMPERATURE

STATION	LAST COMPLETE YEAR OF RECORD	YEARS OF RECORD	ALTITUDE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	ANNUAL
Socorro[1]	1949	57	4,618	37.6	43.0	49.8	57.8	65.9	75.1	77.8	76.0	69.2	58.3	45.8	38.1	57.9
Magdalena[1]	1949	37	6,556	33.3	37.4	42.9	49.5	58.7	68.4	70.9	68.8	62.7	52.9	41.5	33.1	51.7
Mountainair[1]	Dec. 1948-1949	36	6,500	31.6	35.3	41.9	49.1	57.4	66.7	70.4	68.7	62.6	51.4	39.9	32.6	50.6

MISCELLANEOUS CLIMATIC DATA

STATION	AVERAGE ANNUAL TEMP.	YEARS OF RECORD	TEMPERATURE				YEARS OF RECORD	KILLING FROST		
			JANUARY AVERAGE	JULY AVERAGE	MAXIMUM	MINIMUM		LAST (AVERAGE)	FIRST (AVERAGE)	AVERAGE NUMBER FROST-FREE DAYS
Near Los Lunas[2]	—	40	31.6	77.4	106	−25	39	Apr. 20	Sept. 20	183
Socorro[2]	57.9	40	37.4	79.7	108	−16	40	Apr. 9	Sept. 22	196
Magdalena[2]	51.7	28	32.9	70.8	102	−21	30	Apr. 29	Sept. 19	173

[1] Compiled from Annual Climatic Summary (U. S. Weather Bureau) for years indicated.
[2] From Yearbook of Agriculture, 1941, Climate and Man (U. S. Weather Bureau), pp 1015, 1016.

parts of the Magdalena and Manzano Mountains retain snow, in contrast with the Rio Grande valley which in the winter receives some rain but only a few inches of snow which soon melts. The intermediate plains and the lower mountains receive less snow than the high mountains and usually retain it for only a few days at a time. The seasonal differences in precipitation are due to differences in the predominant movement of air masses at different seasons, whereas the regional differences within the county, even at equal altitudes, are due to the influence of topographic barriers on the movements of air masses.

The average annual, maximum, and minimum temperatures at some stations are shown in Table 1. The average annual temperature of an area is especially useful when it is compared to the temperatures of the ground water in the area, as the temperature of shallow ground water is generally about equal to the average annual air temperature of the area. The evaporation rate is an important factor to consider with respect to plant water use and the available water supply. Evaporation in turn is influenced greatly by temperature, wind velocity, and relative humidity. Wind velocity, relative humidity, and evaporation data for northern Socorro County are not available but may be interpolated from the data gathered at nearby points in the Rio Grande valley. Evaporation data from the Jornada Range Experiment Station (Dona Ana County, lat. 32° 37' N., long. 106° 44' W.), are given in Table 1. The evaporation rate in northeastern Socorro County is probably somewhat less than that at the Jornada station.

Unfortunately, the average figures given in the accompanying tables do not show the wide range of deviations from the average monthly and annual rates of precipitation and evaporation which is characteristic of the semiarid and arid Southwest, nor do they show the intensity pattern of the rainfall which is so important for estimating surface runoff, ground-water recharge, and soil-moisture retention. The annual precipitation may deviate 50 percent or more from the average annual amount, and the monthly precipitation may deviate as much as several hundred percent from the average. Nor do the data presented show the local fluctuations, some of which are quite important, caused by differences in radiation, sun exposure, cold-air drainage at night, or local surface wind currents. All these are particularly important with reference to night temperatures. For example, radiation and cold-air drainage at night cause temperature inversions in the valley bottoms, where frost may form during many nights even when temperatures on the higher slopes are well above freezing.

ECONOMY

NATURAL RESOURCES

Water derived from the Rio Grande for irrigation, and from the ground for the sustenance of stock and for irrigation and domestic use, is probably, at present, the most important natural resource of northeastern Socorro County. The Magdalena and Socorro mining districts southwest of the area support the only active metal mining in northern Socorro County at present, although small abandoned mines and prospects dot the county. Mines near Carthage southeast of Socorro produce a small amount of coal from the Mesaverde group, and small abandoned coal mines are reported southeast of La Joya. An undeveloped bentonite deposit exists in the southeast part of the area investigated. Gravel pits and a quartzite quarry provide road materials and railroad ballast respectively. Pition and juniper wood is collected by local wood gatherers for domestic use. Ponderosa pines in the Ladron, Los Pinos, and Manzano Mountains in Socorro County are, in general, scattered and inaccessible, but some timber is cut in the National Forest lands of the western part of Socorro County. Semidesert grassland suitable for grazing covers much of the area investigated.

AGRICULTURE

Agricultural census figures for the northeastern part of Socorro County alone are not available, but that part is considered to be nearly representative of the county as a whole. With the exception of the Rio Grande flood plain, and small areas along some streams or arroyos where dry farming is practiced, all the area investigated is utilized principally for grazing of cattle and sheep. Irrigated parts of the Rio Grande flood plain in northern Socorro County yield alfalfa, hay, cotton, and other crops. Water is diverted from the Rio Grande for irrigation, but in dry years this source is at times insufficient; however, no supplementary irrigation with ground water is known to have been practiced prior to 1952, although several irrigation wells were drilled in 1952 and 1953. Ground-water irrigation was attempted in the small basin along Arroyo Cibola in 1950, but the total irrigable acreage there is small.

Statistics compiled for the U. S. Census of Agriculture (1945)[1] show that there are 857 farms and ranches in Socorro County, having a total of 4,960,000 acres and averaging 2,034 acres per farm or ranch. Only 36,306 acres is actually cropland (mostly in the Rio Grande valley), the remainder being rangeland or woodland. The farms and ranches range in size from a few acres to thousands of acres. The number of mules, horses, and cattle in Socorro County in 1945 was 40,717, mostly cattle. Hogs, sheep, and goats totaled 37,332 for the county, most of this number being sheep. It is believed that the proportion of cattle to sheep in eastern Socorro County is greater than the ratio for the county as a whole.

POPULATION

Socorro and Magdalena are the only important towns in Socorro County. They have populations of 4,476 and 1,297 respectively, according to the 1950 census. The remaining 5,649 people in Socorro County

1 Statistics are for the county area prior to the transfer of a portion of southern Socorro County to Sierra County.

live on ranches or in small communities which are scattered throughout the county but are especially concentrated along the Rio Grande valley. The area investigated contains no large town, but in this area there are a number of small unincorporated communities along the Rio Grande. Except for these and Scholle, a tiny community on the Socorro-Torrance county line, the inhabitants of the area live on widely scattered ranches. The total population of the area in 1950 was about 1,350. The population density over much of this range country is probably less than 1 person for 10 square miles, but that of the area as a whole is about that of the county population density, or 15 persons for 10 square miles.

Geology and Ground Water

PRINCIPLES OF GROUND-WATER OCCURRENCE

BASIC CONCEPTS

As the climate of northern Socorro County is arid or semiarid, and most of the area is remote from perennial streams, ground water is necessary for the full development of other natural resources of the county. Some of the water under the ground flows out onto the surface as springs in favorable localities. These springs were important for existence in earlier days, and there are ruins of old stone houses or groups of houses in the vicinity of nearly every spring. Many of these springs are no longer flowing, although some are still marked by moistened areas and salt deposits.

The occurrence of water in the ground, its movement, and its appearance at the surface as springs are governed by definite geologic and physical principles. In order for water to occur in the ground, there must be spaces in the soil, alluvium, or rocks for it to occupy. In origin these spaces can be primary, secondary, or both. Primary interstices or pores, the more important type in this area, are the spaces between the particles of a sedimentary rock. These spaces exist because the particles usually are not fitted together perfectly or cemented by the geologic processes which formed the rocks. However, if the spaces between the larger particles are occupied by smaller ones, as in sandy gravel or silty sand, space for water is reduced.

A secondary type of interstice is joints or fractures in consolidated rocks caused by structural forces acting on the earth's crust or by cooling and contraction of igneous rocks. All types of interstices may be modified by geologic processes which act after the original deposition of rocks or the formation of interstices. Deposition of fine materials or precipitation of minerals from solution by ground water may reduce the size of the openings; solution and removal of material may enlarge the openings. Decomposition of the rock in place may develop either greater or less porosity; compression and compaction of the rock may decrease porosity. Probably the most important modification resulting in enlargement is the solution of limestone or gypsum, which generally begins along joint or bedding planes. By this process solution channels are developed in rocks that originally were nearly impermeable, and these rocks became in some places, such as the Roswell artesian area in southeast New Mexico, among the most permeable of aquifers or water-bearing beds. Different types of porosity are shown in Figure 2.

The relative volume of the interstices (that is, the porosity) determines how much water is contained in a given volume of rock or alluvium. Permeable, uncemented alluvium consisting of even-grained round particles theoretically may contain as much as 48 percent water.

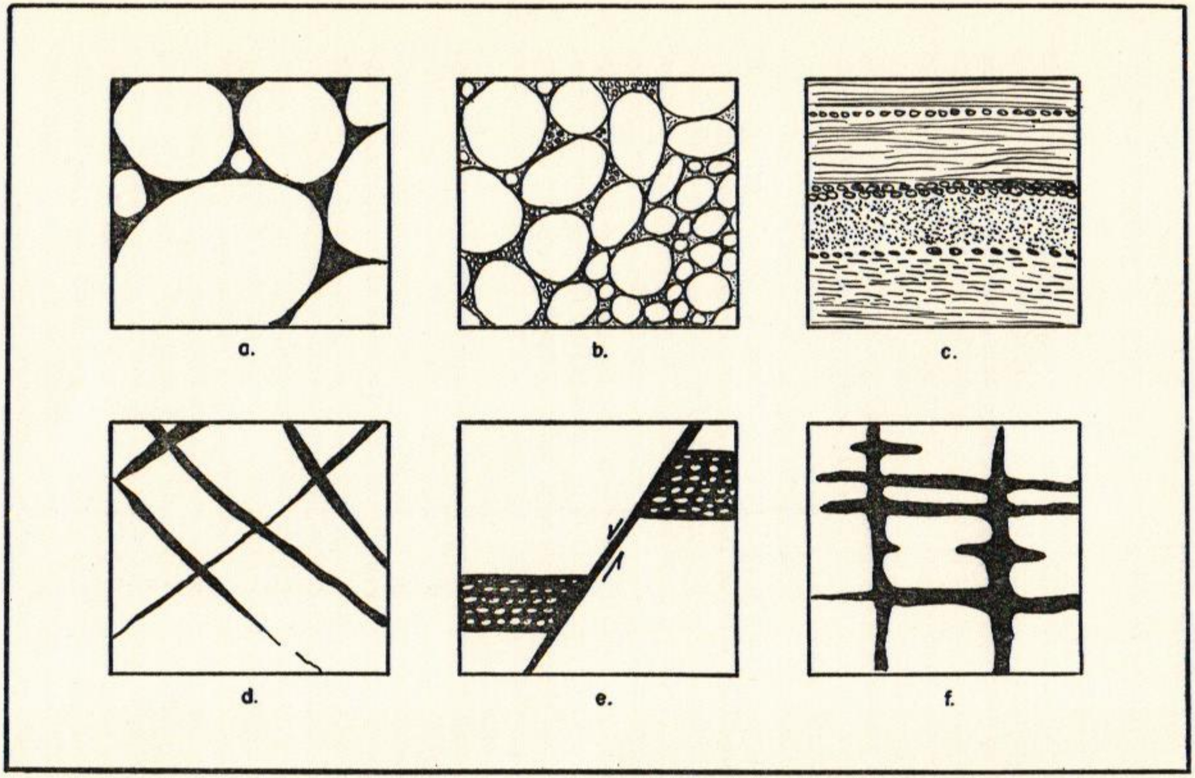

Figure 2. Types of interstices in rocks. (Modified from Meinzer, 1923)

a. Permeable (open-work) gravel.
b. Gravel rendered less permeable by finer-grained interstitial filling.
c. Fine-grained sediments, relatively impermeable.
d. Jointed crystalline rock.
e. Faulted rocks.
f. Solutionally enlarged joint and bedding planes in limestone or gypsum.

Clay, and coarser-grained sediments composed of irregularly shaped particles, may have even higher porosities; the porosity of most sediments, however, is 10 to 25 percent.

Nearly all ground water that is potentially useful to man is in motion. In order that water may move through the ground, not only must there be spaces in the rocks for it to occupy, but these spaces must interconnect; they must also be of a size sufficient to permit substantial motion of the ground water. The size of these interstices is one of the factors that determine the rate of movement of the water and the rate of flow of the water into wells that penetrate saturated rocks.

Not all the water contained in the pores is free to drain out by gravity. Some of it is retained in the smaller openings by capillary force, against the pull of gravity. That part is called the "specific retention." The part that will drain out by gravity is called the "specific yield." These two, expressed as percentages of the total volume of the material, add up to the porosity, also expressed as a percentage.

The permeability of a rock takes into account the relative size and degree of interconnection of the pores, and is thus a measure of the rate at which a rock will transmit water. Ground water flows through permeable rocks according to a simple law given by Darcy (1856), which states that the rate of flow is proportional to the hydraulic gradient, or the ratio of the vertical fall to the length of path followed by the water. The U. S. Geological Survey uses the term "coefficient of permeability," which is defined as the number of gallons of water that can pass in 1 day through a 1-square-foot cross-sectional area of the rock under a unit hydraulic gradient at 60°F. The "field coefficient of permeability" is the same unit except that it is measured at the prevailing temperature of the water. The "coefficient of transmissibility" is another useful concept; it is the measure of the ability of an entire aquifer, or water-bearing geologic unit, to transmit water, and is expressed as the number of gallons of water that will pass in **1** day through a 1-foot-wide vertical strip of the entire aquifer under a unit hydraulic gradient, at the prevailing temperature of the water. The transmissibility is thus equal to the weighted average field coefficient of permeability multiplied by the thickness of the aquifer or water-bearing saturated bed, in feet.

Ground water that does not move, or that moves very slowly, has had time to dissolve out parts of the containing rocks and to become more highly mineralized. The quality of ground water in a particular rock is determined not only by the length of time in contact (determined by the rate at which it moves) but also by the solubility of the rocks and soils through which the water passes, the temperature of the water, and its original chemical content at the time it entered the rock.

The level to which the ground is saturated with water is known as the ground-water table or simply the water table. Above this level the pores of soil or rocks are filled either with air or partly with air and partly with water, of which a part may be moving downward to the water table from the surface. The water above the water table is derived mostly from precipitation that falls directly upon the surface, or from seepage of runoff through stream beds. The form of the water table in a uniform aquifer not confined by impermeable beds is in equilibrium with the rates of recharge, storage, and discharge. Differences in permeability in the aquifer affect the movement, and thus change the form of the water table.

Pumping a well lowers the water level in the well and in the aquifer surrounding it, producing a cone of depression in the water table. The shape of the cone of depression and its rate of growth are determined by the coefficients of transmissibility and storage of the aquifer (Theis, 1940, p 278). The coefficient of storage indicates the volume of water released from storage in the aquifer as a result of a given lowering of water level in the aquifer. In a given aquifer, and for equal periods of pumping, the amount of drawdown in a well is approximately proportional to the rate of pumping. Therefore the specific capacity, or the yield in gallons pumped per minute divided by the drawdown in feet, is roughly constant for most pumping rates in a given aquifer, except where the conditions of flow are not uniform, as in cavernous limestone or gypsum. Accordingly, the specific capacity is generally used for comparing performances of wells.

Under natural conditions, during a period of generally uniform climate, the amount of water recharged to the ground and flowing underground is in dynamic equilibrium with the amount of water discharged from the aquifer. The slope of the water table is an expression of this equilibrium, the difference in altitude between the recharge and discharge areas, and the hydraulic characteristics of the aquifer. An increase in recharge must cause a rise in the water table, which in turn causes an increase in rate of movement under the increased head. Wells, either pumped or flowing, constitute artificial discharges that disturb the natural equilibrium by withdrawing water from storage. This lowers the water table in the vicinity of a well, and the rate of flow of water toward the well is increased. As the area over which the water table is lowered becomes larger, water is diverted from its natural course, eventually reducing natural discharge. Also, the recharge may be increased, but only if the water table in the recharge area is at the surface and some water is normally rejected by the aquifer (Theis, 1940, p 280). In many situations, particularly in arid areas, there is no rejected recharge, and recharge cannot be increased by lowering the water table. In these areas, either the pumpage must be compensated for by a decrease in natural discharge, or else all water withdrawn by wells must come from storage. The latter is the case in many large aquifers where the centers of artificial discharge are distant from the area of natural discharge.

In northern Socorro County, most of the aquifers are so limited in extent that any large new discharge imposed on the hydrologic system will probably reduce the natural discharge from the aquifer (spring flow, stream flow, or valley underflow) within a few decades. However, in most areas, small quantities of water can be safely withdrawn from storage without seriously affecting water levels. The places where some water can be utilized without affecting adversely, in the long run, the quantity of water available for use elsewhere are in areas where lowering the water table will reduce or stop the wasted discharge of ground water by evapotranspiration. Such areas are found in the Rio Grande flood plain and in some of the larger intermittent arroyos where salt cedars flourish. Even in such places, much of the water withdrawn will be from storage. Large quantities can be withdrawn from storage in extensive aquifers such as the Tertiary and Quaternary fill of the Rio Grande depression without causing immediate depletion of ground water elsewhere.

If a permeable layer at a relatively shallow depth is underlain by an impermeable or slightly permeable zone, a perched or semi-perched water table respectively may be developed. Several impermeable layers may separate permeable ones, and, depending upon the thickness of permeable strata and the amount of recharge into them, several perched water tables may result, or some confined zones may be completely saturated with ground water and artesian conditions may exist. That is, if the dip of the confining upper layer is steeper than the hydraulic gradient characteristic of the aquifer were it unconfined, the confined water is then placed under an additional hydrostatic head caused by the weight of the water that is higher than the water at that point. This head, which is equal to that height minus losses in head caused by friction as the water moves, will cause the water to rise, in a well piercing the confining layer, to a point where it is in equilibrium with the water table in the up dip portion of the aquifer. The surface determined by the elevations to which the water in an infinite number of wells in an aquifer would rise is the piezometric surface, and is analogous to the water table in non-artesian systems. If this piezometric surface is above the ground level at any point, a well piercing the confined aquifer at that point will flow. The storage capacity of an artesian aquifer is dependent on the compressibility of the aquifer and contained water, and is usually only a small fraction of the storage capacity of a water-table aquifer, which is essentially, though not exactly, equivalent to the specific yield. Some of the common types of occurrence of ground water, under perched and confined or artesian conditions, such as may be encountered locally east of the Manzano Mountains or west of the Ladron Mountains, are illustrated by Figure 3.

SPRINGS

Springs are natural discharges of artesian (confined), perched, or water-table (unconfined) bodies of ground water. Water moving upward under pressure through a slightly permeable confining layer capping an artesian aquifer is a common type of spring in artesian basins. Water perched on a slightly permeable stratum often moves down dip to emerge as springs where arroyo alluvium is thin or absent over shallow bedrock, where the alluvium is less permeable, or where erosion has dissected the aquifer below the perched-water surface. Similarly, springs occur where erosion intersects the main water table.

Springs may emerge from and near faults, because the faults cut across rocks in which the ground water is not otherwise able to discharge to the surface; because the faults provide a lower place for discharge; or because the rocks across the fault from the aquifer, or ground-up material (gouge) in the fault itself, are impermeable or nearly so. The source of fault-spring water is rainfall or arroyo runoff that seeps into the ground and rocks, percolates to the water table, and then moves in the direction of the slope of the water table to a place of discharge lower than the water level in the aquifer in the intake area. Springs that emerge from faults frequently are highly mineralized and have a temperature higher than the mean annual temperature in the area. This is usually because the water is carried deep below the ground surface and warmed to the higher temperature prevailing at depth and then brought to the surface along faults or other interstices more rapidly than it can readjust to the lower temperatures of the shallower rocks. Warm water can dissolve more minerals from rocks in the same time than can cold water. Heat and mineralization can also be contributed along with juvenile (magmatic) water from very deep in the earth.

In a simple case the temperature of the water from a fault spring depends on the depth to which the water descended. Its mineralization, however, depends on the strata providing the recharge and the time and length of passage from intake to discharge, as well as the temperature of the water. Both the temperature and mineralization can be altered greatly by mixture with water from other formations and depths, and from igneous sources.

WELL-NUMBERING SYSTEM

The system of numbering water wells used by the Geological Survey in New Mexico is based on the common subdivisions in sectionized land. The well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land net (fig 4). The number is divided into four segments by periods. 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. In a county such as Socorro County, where wells are situated both north and south of the base line, an N is added to the first segment of the well number if the well is north of the base line, but no letter is added if the well is south of the base line. Similarly, in Socorro County, where wells are located both east and west of the principal meridian, an E is added to the second segment of the well number of those wells east of the meridian.

The fourth segment of the number, which consists of three digits, denotes the particular 10-acre tract in which the well is situated. For this purpose, the section is divided into four quarters numbered 1, 2, 3, and 4, in the normal reading order, 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 quarter section 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 tracts. Thus, well 4N.3.24.131 in Socorro County is in the NW/SW/NW/ sec. 24, T. 4 N., R. 3 W. If a well cannot be located accurately to a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeroes are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth segment of the well number is omitted. Letters a, b, c, etc., are added to the last segment to designate the second, third, fourth, and succeeding wells observed in the same 10-acre tract.

In maps accompanying this report, the township and section lines within the land grants are projected from adjacent sectionized land; these lines are shown dotted on the maps. Springs are given location numbers by the same system, but are listed separately in Table 4. Location numbers of wells in Torrance and Valencia Counties are preceded by T and V respectively.

The following diagram shows the method of numbering the sections within a township and the tracts within a section.

GEOLOGIC UNITS

Post depositional events have deformed and otherwise modified most rocks from their original state and changed the properties that affect the movement and quality of ground water. Except that older rocks generally have been more deformed and changed internally and are better indurated than younger rocks, the age of the rocks has little direct influence on the occurrence of ground water. However, age is the generally accepted means of classification of rocks, and will be followed here, beginning with the oldest rocks. The method of deposition of the rocks, their present attitudes due to earth movement in the past, and the modifications that have occurred in them are important to the occurrence of ground water within them, and these aspects will be treated in the following sections. The water-bearing characteristics of each formation are described, and the intake and discharge areas of each formation are pointed out. A more complete discussion of local ground-water conditions and availability of ground water in particular areas is given in the descriptions, pages 47-77. The following table presents a summary of the geologic units and their water-bearing properties, in order from youngest to oldest. A history and description of the structural move-

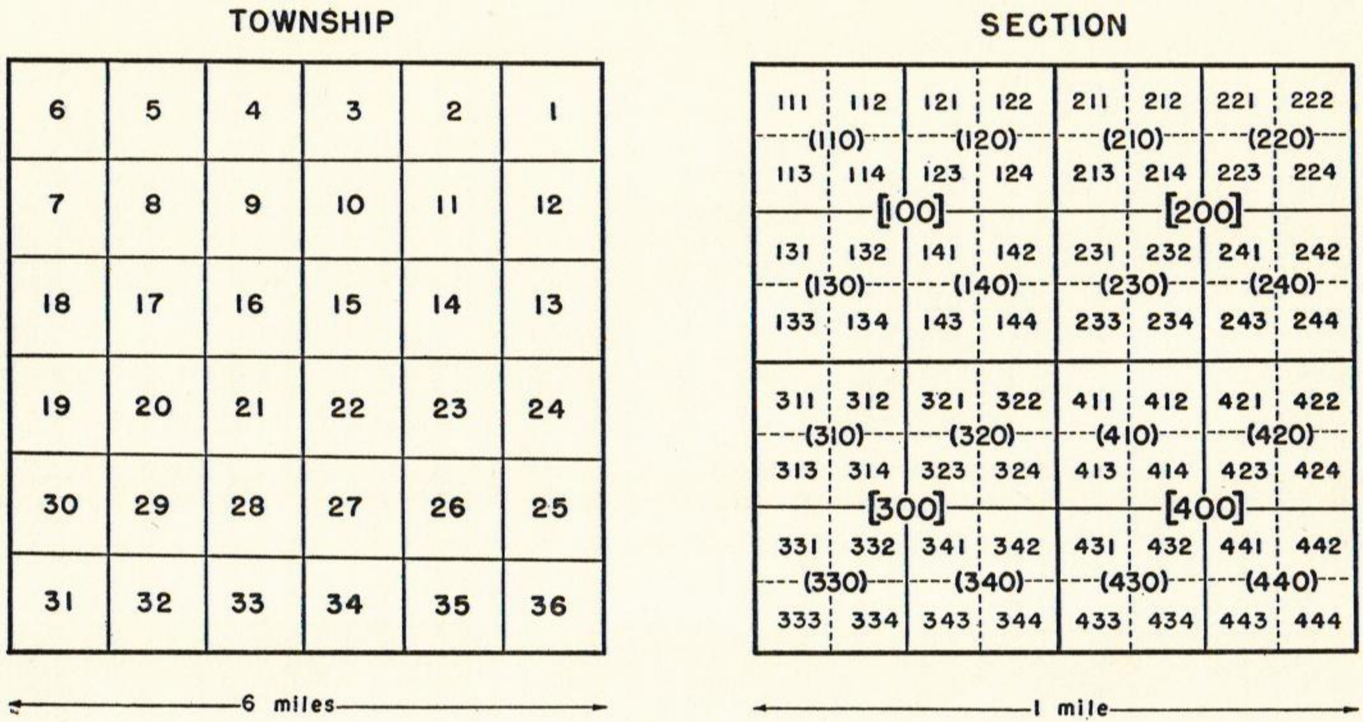

Figure 4

METHOD OF NUMBERING SECTIONS IN A TOWNSHIP AND TRACTS IN A SECTION.

ments that have occurred in geologic time, and their effects on ground-water occurrence, is given on pages 44-45. The general principles of ground-water occurrence are given on pages 15-20.

PRECAMBRIAN ROCKS

The Precambrian rocks in this area crop out in four major places: the Manzano Mountains, Los Pinos Mountains, Joyita Hills, and Ladron Mountains. In general they are exposed in the highest and most rugged areas, even though they lie at the base of the geologic column and form the basement upon which younger sedimentary rocks were deposited. Primarily, their position is due to faulting which has lifted these areas high relative to adjacent blocks. Secondarily, erosion has stripped the younger sediments off the high parts after the uplift. These rocks are considered to be Precambrian in age because of their lack of fossils, their deformed and metamorphosed character, their relation to the Carboniferous rocks which overlie them unconformably, and their similarity to rocks in other parts of New Mexico which are considered to be Precambrian. However, it is possible that some of the sedimentary rocks in this group may be of Cambrian age. The Precambrian rocks are of two general but intergrading types: (a) Metasedimentary rocks, most of which probably were once shale and sandstone but which have become metamorphosed to schist and quartzite respectively. Dikes, sills, and flow rocks are associated with the metamorphosed sediments and have been deformed and metamorphosed with the enclosing rocks. (b) Granite and gneiss, which in many places grade into the schist and quartzite (Stark and Dapples, 1946).

Water-bearing Properties

Although none of the crystalline Precambrian rocks have appreciable primary porosity or permeability, ground water may occur in the openings caused by secondary structural deformation of the rocks, or in decomposed zones near the surface and near faults. According to Ellis (1906, p 22), few wells intersect faults, because faults have a relatively small areal distribution, usually are not closely spaced, and usually are vertical or nearly so. Faults, however, are often important as conduits feeding springs. Most wells drilled in crystalline rocks obtain water from joints intersected at moderate depths. Ellis concluded that few of the wells in the crystalline rocks of Connecticut got water at depths greater than 400 feet, and most got water above 250 feet. This general principle appears to hold true for the few wells drilled in the crystalline rocks of northeastern Socorro County. However, most of the wells in these areas of Precambrian rocks are dug, shallow wells which penetrate only the decomposed rock near the surface. Except in faulted or jointed areas, drilling more than a few tens of feet in undecomposed crystalline Precambrian rocks usually is not advisable. The quality of water in Precambrian rocks is generally good, but some of the wells in this area

TABLE 2. SUMMARY OF GEOLOGIC UNITS IN A PART OF NORTHEASTERN SOCORRO COUNTY, N. MEX., AND THEIR WATER-BEARING PROPERTIES

SYSTEM	GEOLOGIC UNIT	DESCRIPTION	THICKNESS (ft)	GROUND-WATER OCCURRENCE
Quaternary	Windblown sand	Fine to medium well-sorted sand in both stabilized and unstabilized dunes.	0 to 50	Water not available. Serve as recharge areas for underlying water-bearing beds.
	Alluvial-fan deposits	Coarse granitic debris at mountain fronts, merging into pediment gravels.	0 to 50+	Coarsest near highlands. Supplies some springs and seeps; may yield water to shallow wells.
	Alluvium	Fine sand and silt and some coarse channel gravels.	0 to 100±	Contains fair to poor water in the form of "underflow" of Rio Grande and some tributaries. Small to large quantities. Wells should be constructed to keep out sand.
	Pediment gravel	Gravel and boulders in a silty or sandy matrix. Commonly has a subsurface caliche zone 1 to 10 ft thick.	0 to 20	Not saturated except locally at borders where the gravel overlaps impervious rocks.
Upper Tertiary	Santa Fe formation	Silt, clay, sand, and gravel beds having much horizontal and vertical variation.	500 to 5,000+ (est.)	Yields small to moderate supplies of good-quality water, except that poor-quality water is encountered locally. Wells should be constructed to keep out sand.
	Popotosa formation	Thick conglomeratic sandstone (upper part) and fine-grained sandstone, siltstone, and clay (lower part) containing much reworked volcanic debris.	4,000 to 5,000 (est.)	Highly mineralized water in sandstones and siltstones. No water available in clay.

TABLE 2 (continued). SUMMARY OF GEOLOGIC UNITS IN A PART OF NORTHEASTERN SOCORRO COUNTY, N. MEX., AND THEIR WATER-BEARING PROPERTIES

SYSTEM	GEOLOGIC UNIT	DESCRIPTION	THICKNESS (ft.)	GROUND-WATER OCCURRENCE
Lower (?) Tertiary	Datil formation	Thick flows of purple, red, and gray rhyolite and andesite with reworked tuffs and clays. Monzonite, syenite, and trachyte, that presumably are equivalent at least in part to the Datil formation, intrude Permian rocks east and southeast of the Los Pinos Mountains.	2,000± (est.)	Some springs yield good-quality water from faults and joint fissures. Wells may obtain some good-quality water from such sources. Intrusive rocks east and southeast of the Los Pinos Mountains are unimportant as water bearers.
Lower Tertiary	Baca formation	Sandstone and conglomerate, well-cemented.	80 to 104	Small outcrop area, but may yield some poor-quality water where buried by Quaternary alluvium.
Cretaceous	Mesaverde group	Buff sandstone and shale.	200±	Highly mineralized water in small quantities. Some unfit for stock.
	Mancos shale	Light-brown sandstone, siltstone, and shale.	700±	do.
	Dakota sandstone	Well-cemented medium-grained sandstone mottled brown and black; some sandy black shale.	100±	do.
Triassic	Dockum group	Maroon and green shale.	500±	No ground water available.
Permian	San Andres formation: Upper member	Siltstone and fine-grained sandstone having very small outcrops.	0 to 20	do.

TABLE 2 (continued). SUMMARY OF GEOLOGIC UNITS IN A PART OF NORTHEASTERN SOCORRO COUNTY, N. MEX., AND THEIR WATER-BEARING PROPERTIES

SYSTEM	GEOLOGIC UNIT	DESCRIPTION	THICKNESS (ft.)	GROUND-WATER OCCURRENCE
Permian (cont.)	Limestone member	Bedded limestone and gypsum with solutionally enlarged openings.	300±	Moderate to large quantities available where structure and recharge are favorable; small areas of these rocks in northern Socorro County.
	Glorieta sandstone member	Massive red-brown-weathering medium-grained sandstone.	100 to 200	Water of good to fair quality in moderate quantities where structure and local recharge are favorable.
	Yeso formation:			
	Joyita sandstone member	Mostly siltstone and fine-grained sandstone.	20 to 30	Small quantities of water, generally of poor quality.
	Cañas gypsum member	Gypsum, limestone, sandstone.	0 to 35	Small to moderate quantities of sulfate water available in most outcrop areas.
	Torres member	do.	400 to 650	do.
	Meseta Blanca sandstone member	Massive light red-brown fine- to medium-grained sandstone.	60 to 140	Moderate quantities of water of fair to poor quality; fit for stock.
Permian (?)	Abo formation	Thick red shale beds, partially cemented sandstone, and siltstone.	500 to 1,100	Perched and confined water in sandstones at moderate depths; water fair to poor in quality.

TABLE 2 (continued). SUMMARY OF GEOLOGIC UNITS IN A PART OF NORTHEASTERN SOCORRO COUNTY, N. MEX., AND THEIR WATER-BEARING PROPERTIES

SYSTEM		GEOLOGIC UNIT	DESCRIPTION	THICKNESS (ft.)	GROUND-WATER OCCURRENCE
Pennsylvanian	Magdalena group	Bursum formation	Purple and maroon shale, fine-grained sandstone, and thin limestone layers.	80 to 120	Soft water in small to moderate quantities in outcrop area only. Water probably highly mineralized in subsurface strata.
		Madera limestone:			
		Arkosic limestone member (east of Rio Grande); possible equivalent of	Gray limestone with gray-green shale and well-cemented sandstone, especially in lower half.	0 to 520	Water in fissures and solution openings; some perched on shale.
		Atrasado member (west of Rio Grande)	Red to gray shale, conglomeratic sandstone, and limestone.	550 to 800	do.
		Lower limestone member (east of Rio Grande), probably correlative with	Cherty gray limestone, shale, and well-cemented conglomeratic sandstone.	80 to 830	do.
		Gray Mesa member (west of Rio Grande)	Mostly cherty gray limestone.	850 to 900	do.
		Sandia formation:			
		Upper clastic member	Well-cemented conglomeratic sandstone, carbonaceous shale, and sandy limestone.	400±	Narrow outcrops of steeply dipping rocks; mostly buried by thick younger strata; ground water generally unavailable.
		Lower limestone member (absent east of Rio Grande)	Dark limestone and light-colored sandstone.	0 to 15±	do.

TABLE 2 (continued). SUMMARY OF GEOLOGIC UNITS IN A PART OF NORTHEASTERN SOCORRO COUNTY, N. MEX., AND THEIR WATER-BEARING PROPERTIES

SYSTEM	GEOLOGIC UNIT	DESCRIPTION	THICKNESS (ft.)	GROUND-WATER OCCURRENCE
Mississippian	Lake Valley limestone	Gray limestone with well-cemented clastics at base.	0 to 100	Buried by thick Pennsylvanian rocks except in one narrow outcrop area; probably contains poor-quality water at great depths.
Precambrian		Very hard schist, quartzite, rhyolite, and old intrusive granite.	4,000 to 5,000±	Small amounts of fair to good water available from dug wells in shallow decomposed zones or in drilled wells less than 250 feet deep.

produce hard water because of slow movement of ground water or inflow of water from areas of limestone and gypsum rocks, or because salts previously deposited near the surface in the soil or in arroyo alluvium re-dissolve in periods of heavy precipitation and pass into the underlying crystalline rocks.

MISSISSIPPIAN SYSTEM

The Lake Valley limestone crops out on the southwestern flank of the Ladron Mountains (Darton, 1928-b, pp 130, 131). It consists of gray limestone which grades downward into sandy, clastic limestone and land-derived sediments with a basal conglomerate which is unconformable on the Precambrian rocks. The Mississippian rocks dip westward under thick Pennsylvanian strata but apparently pinch out northward in the central portion of the Ladron Mountains. The thickness of the formation ranges from a knife-edge to about 100 feet (Lasky, 1932, pp 87, 88).

Water-bearing Properties

Although recharge to the Lake Valley limestone may occur locally in its outcrop area, the formation is too deeply buried by overlying sediments to be considered an aquifer in the area covered by this report. No wells are known to penetrate to the Lake Valley limestone there.

PENNSYLVANIAN SYSTEM

Pennsylvanian rocks crop out over a large area in the Los Pinos and Manzano Mountains and the Joyita Hills and on the west slope of the Ladron Mountains. They probably exist at great depth below all the areas covered by later Paleozoic rocks. The Pennsylvanian rocks in all these localities are generally similar. They are all included in the Magdalena group, which consists in ascending order of the Sandia formation and Madera limestone. West of the Rio Grande two members are recognized in the Sandia formation, and three members in the Madera limestone (Kelley and Wood, 1946). East of the Rio Grande, however, only one member is recognized in the Sandia formation, and two members in the Madera limestone (Wilpolt and others, 1946). The Magdalena group consists chiefly of gray limestone but contains much conglomerate, sandstone, and shale, especially in the Sandia formation.

The rocks of the Magdalena group were deposited in a fairly shallow sea adjacent to land areas of the same types of Precambrian rocks which now underlie the group or are exposed in the uplifted areas. As the thickness of the formations and members differs markedly from place to place, the area may have been structurally unstable during the Pennsylvanian period. Pennsylvanian rocks are thinnest in the Joyita Hills area, where two members in the Magdalena group are completely absent. It was probably a rising, or stable positive area during Pennsylvanian time and therefore received little or no sediment. The alternation and intergradation of sandstone, shale, and limestone are probably related to cyclic sedimentation recognized in other regions in the Pennsylvanian period, but complicated in this area by greater local structural instability.

Madera Limestone

The lower gray limestone member of the Madera limestone east of the Rio Grande conformably overlies the Sandia formation. It consists of massive to thin-bedded cherty medium- to dark-gray limestone and minor amounts of gray and green shale, well-cemented sandstone, and conglomerate. The member ranges in thickness from 80 feet in the Joyita Hills to 830 feet in the east-central Los Pinos Mountains and is probably correlative with the Gray Mesa member west of the Rio Grande, on the basis of similar lithology and position in the strati-graphic sequence. The thick Gray Mesa member of the Madera limestone is nearly all cherty gray to dark-gray limestone, 850 to 900 feet thick, and is overlain by the much less cherty limestone of the Atrasado member.

The arkosic limestone member is conformable on the lower gray limestone member east of the Rio Grande and consists of thin- to thick-bedded medium- and light-gray limestone which generally contains much less chert than the underlying member. Beds of gray, black, and red shale and of well-cemented green, brown, and gray feldspathic sandstone occur in the lower half of the member. This member is not present in the Joyita Hills, but has a thickness of 520 feet in the southern Los Pinos Mountains. It may be the equivalent, on the basis of lithology and stratigraphic position, of the Atrasado member of the Madera limestone west of the Rio Grande, which contains thick beds of gray to red shale and conglomeratic sandstone between somewhat cherty limestone beds. The Atrasado member is 550 to 800 feet thick.

Small and scattered patches of the Red Tanks member of the Madera limestone overlie the Atrasado member just west of the area investigated; the member is lithologically similar to strata placed in the Bursum formation east of the Rio Grande (*N.* Mex. Geol. Soc., 1952, p 50).

Sandia Formation

The lower limestone member of the Sandia formation is present on the west slope of the Ladron Mountains, where dark-gray to black limestone with a white to gray basal sandstone lies in unconformable contact with Precambrian granite, in secs. 23 and 24, T. 3 N., R. 3 W. This member may be of Mississippian age and possibly may correlate with limestone of Mississippian age exposed farther south in the Ladron Mountains (Kelley and Wood, 1946). The upper clastic member of the Sandia formation may be unconformable with the lower limestone member in this area. The upper clastic member consists of about 400 *feet* of sandy limestone, carbonaceous shales, and red to gray sandstone and conglomerate, poorly exposed in covered slopes beneath ledges and cliffs of the more resistant Madera limestone. Only the upper clastic member of the Sandia formation occurs east of the Rio Grande, where it consists of well-cemented gray and green sandstone; green, gray, and black carbonaceous shale; and dark-gray sandy limestone. It ranges in thickness from 100 feet in the Joyita Hills to 350 feet in the western part of the Los Pinos Mountains, but thins to 190 feet in the east part of those mountains.

Water-bearing Properties of Pennsylvanian Rocks

Recharge.—Erosion of Pennsylvanian strata of differing resistance has resulted in a hogback-and-cuesta topography cut by deep, steep-walled canyons, especially in the Manzano and Los Pinos Mountains. The shaly and sandy or arkosic Sandia formation and the softer clastic portions of the Madera limestone form moderate slopes beneath cliffs and ledges of the more resistant limestone beds of the Madera limestone. The shales, well-cemented sandstones, and dense limestones of the Magdalena group probably allow little or no movement of ground water among their individual particles. However, joints and openings along bedding planes probably allow rather free movement of ground water, especially where they are enlarged by solution of the limestone. The general structure of the long hogbacks east of the Manzano Mountains and west of the Ladron Mountains is favorable for ground-water recharge where arroyos that drain the Precambrian rocks of the mountains cross the upturned edges of the limestone strata in the hogback. Much of the geologic section seen in these canyons shows some solutional enlargement of the bedding and joint openings in the limestone, which should afford excellent intakes for the storm runoff in the arroyos. The arroyo floors are veneered with rather coarse and permeable granite debris, but most of the veneers are thin and show no underflow where the bedrock is exposed. Other arroyos have thick alluvial deposits, but no evidence of perennial perched ground water was seen in them. These sands are saturated temporarily after rains but the water is probably yielded quickly to the underlying limestone. Water that enters these rocks moves generally downward along openings in the rock to the main water table or to less permeable zones, then down gradient to points of discharge.

Discharge.—Springs discharge water in the lower courses of some of the canyons. Part of the perennial flow and underflow in Arroyo Abo may be fed by discharge from the Madera limestone into the alluvium of the arroyo. Farther north, some ground water may be discharged across the bedding of the Pennsylvanian rocks and into the alluvium of the Estancia Valley east of the Manzano Mountains just outside the area investigated. On the west slope of the Ladron Mountains the discharge of the limestone aquifers of Pennsylvanian age is into the Rio

Salado. All the perennial flow of the Rio Salado in T. 1 N., R. 2 W., is the result of discharge from springs in the limestone canyon walls and floor in sec. 7, T. 1 N., R. 2 W.

The depth to the water table in the inter-canyon areas is great, but some water may be perched at shallow depths there. However, the probability of encountering such perched water bodies is low. The nature of the fractures and their solutional enlargement in limestone strata make it difficult to predict the probabilities of obtaining ground water, for even if a well is drilled below the level of the water table in the limestone, no water will be obtained unless open fractures are intersected. However, sufficient water for stock and domestic use can be obtained economically in some places in the larger inter-stream areas from wells drilled into limestone strata far from deeply incised canyons. Larger quantities of water may be available in the shallow-water areas discussed on pages 54-56. It is usually impractical to drill to the Pennsylvanian limestone strata where they are overlain by the thick Abo formation. However, they lie at shallow depths beneath the outcrop belt of the thin Bursum formation near Dripping Springs.

Chemical quality.—The chemical quality of water in the Pennsylvanian rocks generally is only fair. The waters analyzed have high concentrations of sulfate, in addition to the high calcium and magnesium hardness to be expected in water from limestone. A noticeable sulfate taste in the waters makes them undesirable, although tolerable, for human consumption. The source of the sulfate in some localities may be the gypsum from the overlying Permian rocks. This is probably the origin of the sulfate in Dripping Springs, 2N.4E.I2.210 (see table 5), and other springs downstream in the same canyon, 2N.4E.1.430. In other localities the sulfate may be derived from the Pennsylvanian rocks, possibly dissolved from the shaly layers or from gypsum deposited with the limestone, although no gypsum was noted in outcrops.

PERMIAN (?) SYSTEM

Bursum Formation

The age of both the Bursum formation and the overlying Abo formation is in question, but apparently these formations represent a transition from the Pennsylvanian marine conditions to the Permian terrestrial conditions (New Mexico Geol. Soc., 1952, p 50). Lithologically the Bursum formation is similar to the Red Tanks member at the top of the Madera limestone west of the Rio Grande. The major outcrop of the Bursum formation in the area investigated for this report is a long, narrow belt extending north-northeast and southwest from Scholle, N. Mex., at the junction of Socorro, Valencia, and Torrance Counties. The width of the outcrop varies with the dip and degree of erosion of the formation. Thus the belt is widest in Valencia County, where the dip is low and the soft formation has been partially protected by Quaternary alluvium and pediment gravels, as well as by the thick Abo formation.

In Socorro County the outcrop belt narrows considerably near the Paloma fault, where the Bursum formation is tilted up very steeply along with the underlying Pennsylvanian rocks. The Bursum formation crops out also as narrow belts in the Joyita Hills. In general the dip there is steep and the outcrop belt is narrow. The Bursum formation in northern Socorro County consists of dark purplish-red and green shale in beds up to 40 feet thick, separated by thinner beds of arkose, arkosic conglomerate, and gray limestone. A thin rubbly, nodular purplish-gray limestone consisting of reworked limestone of the underlying arkosic limestone member of the Madera limestone occurs locally at the base. The limestone beds higher in the section carry marine invertebrate fossils (Wilpolt and others, 1946).

Water-bearing properties.—Water enters the Bursum formation in its outcrop area; also, slightly down dip from the outcrop area, water may possibly enter the formation by inflow from the overlying strata. Shale beds in the Bursum formation cause perched water-table springs and artesian conditions in the interbedded limestones and sandstones. Most wells in the Bursum formation are reported to have small yields. The water is generally soft, but is objectionably high in sodium and carbonate in some wells, such as wells 2N.5E.6.223 and V3N.5E.32.210. The source of this mineralization is probably within the formation itself, as ground water in formations both above and below is chemically quite different. It is possible, however, that calcium and magnesium of the water from overlying formations are exchanged for sodium in the shale beds of the Bursum formation.

Abo Formation

The Abo formation contains thick, easily eroded shales and hard, well-cemented sandstone and conglomerate beds of differing thickness. Erosion on these low-dipping beds of differing resistance has produced a characteristic cuesta topography. The outcrops of the formation are also distinctive because of the dark-red and maroon color of the shales, which contrasts with the duller green and purple shale of the underlying Bursum formation and with the yellow and orange-brown color of the overlying siltstone and shale of the Yeso formation. The sandstones and conglomerates in the Abo formation are usually dark red, but in places they are leached to a lighter color, probably by passage of ground water along bedding or joint planes, or in zones of more permeable sandstone. Similarly, some of the red-shale exposures show green streaks along joint and bedding planes. These are probably areas where ground water has reduced the ferric iron (red) to ferrous iron (green). The red color, mud cracks, current ripple marks, cross bedding, tracks of land vertebrates, and plant impressions, and the lenticular character of the sandstone beds show the continental origin of the Abo formation (Wilpolt and others, 1946). The thickness of the formation ranges from 300 feet in the Joyita Hills to 910 feet in Abo Canyon, the type locality.

Water-bearing properties.—The silty, fine-grained, well-cemented sandstones of the Abo formation have a low permeability, and the thick shales probably are nearly impermeable. Some of the sandstone beds are coarser, and in most localities sufficient water for stock and domestic uses can be obtained from the sandstone beds of the Abo. The interbedded shales locally cause perched-water springs. Artesian conditions may also be present, but no *evidence* for them was found. The water is likely to be hard and to have a high concentration of calcium and sulfate, as in wells 2N.4E.86.142 and 2N.5E.20.244. These chemical properties of the water in the Abo formation contrast strongly with the soft sodium carbonate water in the Bursum formation in adjacent areas. The high mineral content of water in the Abo formation is probably due to groundwater inflow from the overlying gypsiferous Yeso formation, but may be due in part to the slowness of ground-water movement in this area through beds containing soluble substances. The Abo formation in the Estancia Valley to the northeast yields water of good quality.

PERMIAN SYSTEM

Yeso Formation

Yeso, the Spanish word for gypsum, is an appropriate name for this gypsiferous Permian formation which crops out over a large area in northern Socorro County. The formation has been divided into four members, but the upper three members have been shown as one unit on the geologic map, Plate 1. The marine Meseta Blanca sandstone member of the Yeso formation overlies the land-deposited red strata of Permian (?) age. In northern Socorro County the member consists of uniformly bedded red-brown and variegated sandstone and sandy shale. The sandstone is composed of well-cemented fine to medium grains and ranges in thickness from 104 to 222 feet (Wilpolt and others, 1946). The major outcrop is in the eastern part of the area investigated, but the member crops out also in the Joyita Hills and east of the Valle del Ojo de la Panda, in the Cerrillos del Coyote.

The three upper members of the Yeso formation, which are mapped as a unit, are in ascending order the Torres member, the Callas gypsum member, and the Joyita sandstone member. The type sections of all three members are in northeastern Socorro County, and their names are taken from local geographic features. The type section of the Tones member is in sec. 13, T. 1 N., R. 2 E., although its largest outcrop is in T. 1 N., Rs. 4 and 5 E. It is the thickest member of the Yeso formation and consists of alternating beds of orange-red and buff sandstone and siltstone, thinner beds of gray limestone, and gypsum beds. The total thickness ranges from 350 to 600 feet. The Callas gypsum member contains some thin gypsiferous siltstone and limestone, but is chiefly white gypsum. It is as thick as 103 feet. The relatively thin Joyita sandstone member consists entirely of orange-red, buff, and yellow sandstone, silty sandstone, and siltstone ranging in thickness from 60 to 90 feet.

Water-bearing properties.—In parts of T. 1 N., R. 5 E., arroyos have deeply dissected the siltstones and gypsum of the Yeso formation, especially around the bases of the scattered outliers of Chupadera Mesa. Several small buttes of gypsum and gypsiferous siltstones, capped by a thin layer of gray limestone, lie in sec. 1, T. 1 S., R. 4 E. Solution furrows are abundant on the surfaces of both the limestone and the gypsum wherever they are exposed, showing that surface runoff must dissolve an appreciable amount of these rocks. That portion of the rainfall which percolates through the ground to the water table may be expected to be highly mineralized. In conformation, the wells, such as well 2N.5E.33.222, and springs in the Yeso formation furnish extremely gypsiferous water. However, solution channels in the gypsum and limestone beds may give moderately large yields to wells.

The Yeso formation in the cuesta outcrop area yields calcium sulfate water to wells drilled less than 200 feet deep, except under buttes and mesas, where the water table lies at greater depths below the land surface. One well, 1N.4E.11.244, yields relatively soft water from the Meseta Blanca sandstone member. Local recharge of only slightly mineralized water may account for the good quality there. There is no ground-water information on the Yeso formation along Agua Torres Arroyo, in the Joyita Hills, and in the Cerrillos del Coyote. Conditions in these complex areas are favorable to shallow ground water along the main drainage ways, but the water is likely to be of poor quality. The water-bearing zones in the Torres member and the Callas gypsum member are probably solution channels in gypsum beds, which may yield sufficient, although gypsiferous, water for small-scale irrigation. Some of the coarser and less silty sandstone beds may contain some less mineralized water. In the Joyita Hills and the Cerrillos del Coyote, these members and the coarser beds of the Joyita and Meseta Blanca sandstone members may yield water, but farther east they are not likely to do so because of their high structural and topographic position.

San Andres formation

The San Andres formation has been divided into three members in northern Socorro County, the Glorieta sandstone member at the base, a limestone member, and a thin upper member. The Glorieta sandstone member consists of white, light-yellow, and light-gray medium- to coarse-grained cross-bedded sandstone, weathering red brown, and ranges in thickness from 140 to 170 feet. The limestone member is principally light- to dark-gray thin- and medium-bedded limestone interbedded with considerable thin-bedded and massive white gypsum and minor amounts of lenticular sandstone. It ranges in thickness from 270 to 280 feet southwest of the Los Pinos Mountains (Wilpolt and others, 1946).

The limestone member thickens to the southeast and is the principal aquifer of the Roswell artesian basin, where it provides large quantities of water under artesian pressure to irrigation wells. The water there is encountered in cavernous limestone beds in the upper and middle parts of the formation. The formation there is described by Morgan and Sayre (1942, p 29) as follows:

> The San Andres formation is 1,000 to 1,200 feet thick and is made up of limestone in the Sacramento Mountains and the Roswell basin, and anhydrite, anhydritic limestone, and limestone in the area to the north. The basal beds of the formation consist of sandstone, called the Hondo sandstone in the Sacramento Mountains and the Glorieta sandstone in the northern part of the basin. The sandstone ranges from 12 to 90 feet in the Sacramento Mountains and the Roswell basin to about 300 feet in Glorieta Mesa. The sandstone thickens to the north at the expense of the overlying limestone and anhydrite and in this paper it is considered as a facies of the San Andres formation. . . .
>
> . . . . Underground drainage through the cavernous zones in the San Andres formation, developed in both the limestone and gypsum units, provides for a large part of the drainage throughout the extensive outcrop area of the formation in the western part of the Pecos Basin. This is particularly true of the high upland section between the Capitan Mountains and Vaughn, where there is no through surface drainage across the outcrop area of the San Andres formation between Gallo Arroyo and Pintada Canyon. This section, covering an area of approximately 2,000 square miles, is drained entirely underground principally through cavernous limestone and gypsum beds of the San Andres formation.

The upper member of the San Andres formation in northern Socorro County is orange-red silty sandstone and local thin beds of dark-gray limestone. It ranges in thickness from 5 to 18 feet in its small and scattered outcrops between Arroyo Agua Tones and Arroyo Cibola in T. 1 N., R. 2 E., and is of little importance as an aquifer. It is a thin and nonresistant bed and has been eroded away completely except in narrow outcrops, where it dips steeply and has been protected by overlying beds.

Water-bearing properties.—All three members of the San Andres formation are found in the faulted area southwest of the Los Pinos Mountains. The limestone member, where saturated, gives large yields, but the total supply available depends on the extent of the aquifer. Both the limestone and sandstone members of the formation contain water at shallow depths where the structure and recharge are favorable, such as along Arroyo Cibola in sec. 34, T. 1 N., R. 2 E. Local conditions here are discussed in the section on the Valle del Ojo de la Panda, pages 69-71. The San Andres formation caps the small buttes in the southern part of the cuesta area in northern Socorro County, and, like the Yeso formation there, is not likely to yield any water.

TRIASSIC SYSTEM

Dockum Group

The Dockum group, of Late Triassic age, consists of correlatives of the Santa Rosa sandstone and the Chinle formation which total about 500 feet in thickness in this area (Wilpolt and others, 1946) and are slightly unconformable on the San Andres formation. The group consists of maroon shale and sandstone and a lesser amount of gray and green shale and sandstone. The Dockum group is mapped together with Cretaceous rocks on Plate 1. South-dipping beds of the Dockum group form part of the dissected north border of the basin of Arroyo Cibola, and the group probably underlies at least the northeastern part of the alluvial veneer in that basin. The Dockum group also crops out in small patches along Arroyos Agua Torres and Cibola and along the eastern border of the basin.

Water-bearing properties.—Elsewhere in New Mexico sandstones in the Dockum group supply small quantities of water to stock wells. However, the small outcrop area here, the large proportion of shale, and the fine-grained nature of the sandstones are unfavorable to the accumulation of usable ground water in the group in this area. The outcropping beds are in a depressed, faulted block or graben separated from the Rio Grande depression proper by the uplifted Joyita Hills block or horst. This horst, whose core is Precambrian crystalline rock, is relatively impermeable and probably blocks ground-water flow toward the Rio Grande except through alluvium in Arroyos Alamillo and Cibola. One well, 1N.2E.21.120, may obtain some water from rocks of the Dockum group, but the quality and quantity of water are unknown.

CRETACEOUS SYSTEM

Cretaceous rocks crop out in small areas in Valle del Ojo de la Parida and in the small basin north of it. The alluvial veneer of these basins is probably underlain by Cretaceous rocks, small exposures of which still project above the alluvium. The Dakota sandstone at the base of the Cretaceous section rests unconformably on the Dockum group. The Dakota consists of grayish-black shale overlain by well-cemented medium- to coarse-grained white and gray sandstone. The sandstone is mottled black in outcrops and well diggings in sec. 36, T. 1 S., R. 1 E., and vicinity. It is slightly more than 100 feet thick and is overlain conformably by about 700 feet of shale and fine-grained sandstone of the Mancos shale. Two hundred feet of buff sandstone and shale of the Mesa Verde group conformably overlie the Mancos shale.

Water-bearing Properties

There is probably very little movement of ground water in the Cretaceous rocks of these basins because of their graben structure. Wells that penetrate the Cretaceous rocks yield water of poor quality. In addition, the water may be contaminated by the highly mineralized water in the alluvial veneer of Valle del Ojo de la Parida.

TERTIARY SYSTEM

Five main units of Tertiary age are recognized in northern Socorro County. In upward succession these are the Baca and Datil formations, intrusive rocks, and the Popotosa and Santa Fe formations.

Baca Formation

The Baca formation, as defined by Wilpolt and others (1946) from correlative strata in Baca Canyon (secs. 4, 5, 8, T. 1 N., R. 4 W.) in the Bear Mountains, southwest of the area shown on the map, is composed of 80 to 140 feet of coarse indurated conglomerate, red and white sandstone, and red day beds. These beds were previously included in the Datil formation (Winchester, 1920). The Baca formation is considered by Wilpolt and others (1946) to be probable equivalents of other units of early Tertiary age in central New Mexico. Exposures in this area are limited to scattered small outcrops near the Joyita Hills, *where* the Baca formation is unconformable on Triassic and Cretaceous rocks. It is, however, probably present in places under the alluvium east of the Joyita Hills, and at one time probably was much more extensive. The Baca formation is mapped together with the Datil formation in this report.

Water-bearing properties.—Ground water in the Baca formation east of the Joyita Hills is likely to be highly mineralized because of inflow of water of poor quality from aquifers to the east and from the overlying alluvium.

Datil Formation

The Datil formation was originally named by Winchester (1920) for extensive lava flows and interbedded sediments in the Datil and Bear Mountains in northwestern Socorro County. The name was extended by Wilpolt and others (1946) to exposures in large, isolated fault blocks in the Joyita Hills area. The unit here overlies the Baca formation and consists principally of flows of purple, red, and gray latite, rhyolite, and andesite, and of welded tuff. Rocks similar to these and also presumably equivalent to the type Datil formation are exposed in the hills west of Alamillo. At the north margin of the Ladron Mountains, dark-red and purple conglomerates derived from volcanic rocks similar to the Datil formation were mapped by Kelley and Wood (1946) as Tertiary agglomerate. These conglomerates are here questionably included in the Datil formation.

Water-bearing properties.—Arroyos Alamillo (T. 1 S., R. 1 E.) and Cibola have cut deep canyons across the Datil formation, but neither canyon contains perennial surface flow. Up-faulting and erosion of the Datil formation has resulted in rocky, rugged terrain unsuited for any purpose except grazing. Some of the interbedded sandstones or conglomerates at depth might bear some water, but most of them are silty or tuffaceous and probably of low permeability. Although most of the lava beds are vesicular, most of the pores are filled with secondary minerals and are unconnected. Therefore, the thick lava beds of the Datil formation present poor ground-water prospects, although wells may encounter water in joints in the hard flow layers, as in the older crystalline rocks.

Intrusive Rocks

Dikes and sills of monzonite, syenite, and trachyte intrude Permian rocks east and southeast of the Los Pinos Mountains. These intrusives are probably related to other intrusive rocks to the east such as in the Gallinas Mountains in Lincoln County, and are probably of early Tertiary age.

The age of these intrusives relative to the Baca and Datil formations is not known, but they are presumed to be approximately equivalent to at least part of the Datil formation.

The intrusive rocks probably have a low permeability, but may yield very small supplies of water to wells. The dikes may impede ground-water flow in the intruded Permian rocks to some extent, but information on ground-water conditions was insufficient to detect such effects.

Popotosa Formation

The Popotosa formation, as described by Denny (1940, pp 73-106), was named from exposures of pre-Santa Fe Tertiary rocks along Arroyo Popotosa, a small tributary of the Rio Salado. Excellent exposures of the resistant upper part of the formation can be seen in the walls of the box canyon of the Rio Salado in T. 1 N., R. 2 W., and of the lower part of the formation in the badland areas of the western half of T. 2 N., R. 1 W. The lower part of the Popotosa formation is a thick series of very fine-grained sandstone, siltstone, and clay which vary in color from reddish brown to tan. The clay beds contain thin layers or lenses of gypsum and many gypsum-filled cracks. One bed of dull gray-green bentonite about 15 feet thick crops out in the badlands of T. 1 N., R. 2 W., and contrasts strongly with the reddish-brown color of the sandstones and siltstones there. The Popotosa formation is shown by Denny (1940, fig 2) to overlie volcanic rocks probably equivalent to the Datil formation.

The upper part of the Popotosa formation consists of massive beds of well-cemented conglomerate with a matrix of coarse light-brown sandstone. The cobbles and boulders exposed in the formation near the Rio Salado are sub angular to well-rounded fragments of red-brown and purple volcanic rocks, with a few fragments of assorted Precambrian rocks. Exposures northwest of the Ladron Mountains show rocks of similar appearance and induration, but with little or no volcanic debris. The rocks are probably correlative in time and are here included with the Popotosa formation. They may have been deposited farther from the main source of volcanic materials in the Rio Salado valley, or by different streams, or after the volcanic rocks were eroded away.

Inferred geologic history.—The Popotosa formation supplies a record of the initial phase of deformation and erosion of a varied geologic terrain covered extensively by volcanic rocks of early Tertiary age (the Datil formation). The coarse character of much of the Popotosa formation, and the large proportion of volcanic-rock fragments, suggest that the pre-Popotosa lava-covered area was faulted, presumably by horstand-graben deformation associated with the Rio Grande trough and other Basin and Range structures. As the volcanic rocks were eroded off the uplifts and deposited in the grabens (becoming the thick sequence of rocks termed in this area the Popotosa formation), successively older units were exposed to erosion. Down faulting of the grabens was renewed or continued, and basin-filling sediments having different appearances were deposited on the Popotosa formation, with local and possibly more extensive unconformity.

The Popotosa formation is thus inferred to be equivalent in age and origin to the Abiquiu tuff of Smith (1938), the Picuris tuff of Cabot (1938), and the Abiquiu formation of Stearns (1953).

Water-bearing properties.—Wells in the Popotosa formation have encountered either no water or very highly mineralized water.

Santa Fe Formation

The Santa Fe formation is the most important and most extensive Tertiary deposit in the Rio Grande depression in northern Socorro County. It unconformably overlies earlier formations in the Rio Grande depression and along its borders, but it has been removed by erosion from areas which have been severely deformed during or since the deposition of its sediments. It varies abruptly both laterally and vertically from coarse conglomerate and gravel to sand, silt, and clay. The gravel and sand strata are usually gray to tan in color and commonly contain much interstitial silt or calcite cement. The silt and clay beds are usually buff or light brown to pink and reddish brown in color. The thickness of the formation is probably very great, although its only exposures are short sections in arroyo walls and terrace escarpments along the Rio Grande and its tributaries. The Gabaldon Hills in Valencia County are reported to show a section of at least 4,800 feet (Wright, 1946, pp 383456) of the Santa Fe formation.

The Santa Fe formation has been deformed by faulting and broad warping. Quaternary pediment gravels and alluvium unconformably overlie the various units of the Santa Fe and obscure much of the deformation, as well as the stratigraphy, but structural control of the topography is very marked in some places. Exhumed interbedded flows of andesite and basalt interrupt the generally smooth pediments in some places. Where erosion has been accelerated along the major drainage lines, the pediment gravels are stripped off in some places, and wind has reworked the sandier phases of the Santa Fe where these pediment gravels have been removed, or where the so-called gravels are largely sand. The general pattern of the outcrops of the Santa Fe formation around the Joyita Hills and adjacent basins indicates that it may once have covered the entire area. Certainly the area was covered by pediment materials, remnants of which are still present as caps on hills and ridges in the area.

The veneers of residual materials which rest upon the pediments are included in the Santa Fe formation in this report, because, where exposures are poor, it is not always possible to differentiate the sediments from the surfaces or from older sediments of the Santa Fe. These features, however, genetically are a part of the formation in that they represent relatively quiescent stages following the sequence of deformation and sedimentation characteristic of the Santa Fe formation.

These pediment materials veneer a large part of the older portions of the Santa Fe formation, overlap onto older rocks, and grade into or are overlapped by alluvial fans along the mountain borders. A caliche zone is common near the surface of the pediment gravel or on pedimented older units. The caliche is particularly thick on the older, higher pediment surfaces. Caliche may be interpreted as a soil zone in which calcium carbonate is deposited in an arid or semiarid climate. Precipitation absorbed by the alluvium moves downward toward the zone of saturation, but high temperatures and evaporation rates cause rapid evaporation of the near-surface water, and consequent upward movement by capillarity. In semiarid or arid regions the net amount of water which seeps downward below the zone of capillarity is negligible, except during infrequent periods of very heavy rainfall. At such infrequent intervals, as has been noted in other areas, ground-water levels rise markedly, indicating recharge by downward seepage, at least under arroyo channels. All lighter precipitation is evaporated or transpired by plants before it can move below the zone of capillarity, and minerals dissolved from the surface during slope runoff and infiltration are then deposited in the caliche zone. The thickness of the caliche appears to be a function of the climate, the length of time during which the material has formed, and the calcium carbonate content of the surface material through which the surface runoff has passed, as well as of the rocks in which the caliche is developed. The caliche zone in the pediment gravels consists of 2 to 10 feet of calcite-cemented sand and gravel, the top of which is 6 inches to several feet below the land surface. Later erosion or deposition has in places caused it to be exposed, or buried more deeply.

Water-bearing properties.—The depth to water was measured in most of the wells in the Santa Fe formation in northeastern Socorro County. The altitudes of the wells were determined by aneroid barometer or from topographic maps by interpolation. The altitudes of the water table at these points were then computed and plotted, and contours of the water table drawn by interpolating between observed points. These contours (pl 2) indicate that recharge takes place from rainfall on the mesas and the bordering highlands, and the ground water in the Santa Fe then moves toward the Rio Grande at an angle of about 45° with the river. Calculations by Theis and Taylor (1938, pp 269-270) indicate that this water is discharged into the Quaternary alluvium of the Belen valley from the adjacent mesas at the rate of about 820 acre-feet per mile per year. This figure was obtained by measuring the difference in the totals of river and canal flow at sections 17 miles apart. Assuming this figure and the water-table gradient of about 10 feet per mile (pl 2), the average transmissibility of the combined alluvium and Santa Fe formation is computed to be from 50,000 to 100,000 gpd per foot of aquifer width under a unit hydraulic gradient.

Modifications in the form of the water table and movement of the ground water under the mesas are probably caused locally by faults, differences in permeability, or local recharge, but the principal deflection in contours is that caused by the Rio Puerco. The contours there indicate that ground water moves from the alluvium of the Rio Puerco toward the alluvium of the Rio Grande valley through the Santa Fe formation.

Water of fair to good quality can usually be obtained by drilling 200 to 500 feet below the surface of the mesas of the Rio Grande depression in northeastern Socorro County. Good water can also be obtained in the inner valley of the Rio Grande, but usually only by drilling to 200 to 400 feet and casing off the poorer water in the Quaternary alluvium and uppermost part of the Santa Fe formation above 200 feet. The poor quality of the shallow water in the Rio Grande valley is probably caused by concentration of dissolved solids in the valley alluvium from past evapotranspiration and by infiltration of irrigation water, whereas the better water at depth is from the neighboring mesas. From the vicinity of Arroyo Abo southward, however, the quality of water under the mesas is also poor, probably because of recharge of water of high sulfate content by Arroyos Abo, Agua Torres, and Cibola and recharge by the saline springs of the Rio Salado. The Santa Fe formation in parts of northeastern Socorro County may also contain soluble matter derived from erosion of the gypsiferous rocks in the neighboring highlands.

QUATERNARY SYSTEM

Alluvium

The most important deposits of the Quaternary system in northeastern Socorro County are the alluvial deposits in the valleys of the Rio Grande (fig 7), Rio Puerco (fig 8), and Rio Salado. The present inner valley of the Rio Grande is underlain by Quaternary alluvium estimated to be less than 100 feet thick. It is not easily distinguishable from the Santa Fe formation, especially in well logs. The depth to ground water in the inner-valley alluvium ranges from zero to 8 feet or more below the surface, depending upon the distance from the river, canals, ditches, and irrigated fields, as well as upon local topography, stratigraphy, and plant usage (Theis, 1938, pp 270, 271). In the Rio Puerco and Rio Salado valleys, as well as in many smaller arroyos, Quaternary alluvium has been deposited in at least two stages. The older alluvium is a silty red-brown sand and gravel fill in relatively broad, deep, but smoothly rounded valleys cut into the Santa Fe formation. The younger alluvium is the channel veneer of coarse sand and gravel that mantles the floor of the recently deeply incised channels of all the arroyos. The present channel of the Rio Puerco has been incised 20 to 40 feet into the older silty alluvium. Similarly, the Rio Salado is incised 10 to 20 feet into its old flood-plain deposits. These incisions, along with present valley broadening and gullying, are the cause of much of the siltation of the Rio Grande, its reservoirs, and its agricultural lands.

The writer believes that the red-brown, silty alluvium in these broad river and arroyo valleys, in some places as much as 2 miles wide and 50 feet deep, was not deposited during the cutting of the broad valley. The thick fill must have been deposited by an aggrading stream after the broad, deep valley was cut into the Santa Fe formation or older rocks. The large proportion of silt in the thick fill also indicates that the fill was deposited by a stream carrying a high load. The third of the following three possible explanations for the aggradation of intermittent stream channels is preferred by the writer:

1. a gradual rise in the base level of the Rio Grande (but this would necessitate a fall in base level to account for present incision).
2. a progressive increase in the amount of fine-grained material made available by erosion on uplands, thus overloading the stream and necessitating deposition in stream channels.
3. a decrease in rainfall or more sporadic distribution of rainfall, following a more humid cycle in which fine-grained red soils developed. Thus, the red silty fill represents reworked soil originally developed in a more humid climate, then rapidly removed when rainfall became too low to support retaining vegetation.

The recent incision of the thick alluvial fill of the Rio Grande tributaries is not correlative to any known incision of the Rio Grande itself; on the contrary, the Rio Grande is aggrading its channel at present, probably as a result of the existence of a higher base level formed by Elephant Butte reservoir and of the contribution of sediment eroded from tributary channels. It may be that a decrease in vegetative cover caused by overgrazing or by climatic changes induced greater storm runoff, which became concentrated into rills and streams. Large volumes of water that are concentrated into narrow courses must have load-carrying capacities larger than the loads supplied, in order to incise their channels. Once the arroyo flood plains were trenched, the water table where high was lowered to equilibrium with the new canyon bottoms; this must have led to further reduction in vegetative cover and thus to even more rapid erosion.

Alluvial fan deposits are mapped with Quaternary alluvium in the

Rio Grande inner valley, and with the Santa Fe formation in other parts of the map. Although no appreciable amounts of ground water are available from them, these deposits probably absorb much surface runoff.

Windblown sand

Sand, worked by the wind to some degree, mantles much of the Santa Fe formation, especially where the coarser Quaternary pediment gravels are absent from underlying sandy zones of the Santa Fe formation, or where a large amount of sandy Quaternary alluvium is exposed to strong winds. North of the lower Rio Salado several square miles of active or poorly stabilized dunes are present. The source of most of the sand in these dunes is the very broad, sandy bed of the Rio Salado itself, which is frequently swept by the hot, dry southwest winds characteristic of New Mexico in late winter and early spring. Sand is also blown by the wind to some extent from the smaller arroyos in much of northern Socorro County, as well as from sandy portions of the Santa Fe formation in inter stream areas. Sandy areas have poorly integrated surface drainage and probably absorb most of the runoff rather quickly. However, no saturated zones are known in the windblown sands, although small, thin lenses of ground water may be perched in the larger dune areas. As the dunes probably overlie permeable materials, most of the water that enters these materials probably moves downward into them. The quality of the ground water in the underlying Santa Fe formation in the dune areas may be somewhat better than average because of the relatively large local infiltration. Windblown sand is not differentiated on the geologic map, but the larger outcrops are included with alluvium.

STRUCTURE

Although the high mountain blocks in and near northern Socorro County are externally the most conspicuous structural and topographic features of the area, probably the most important structural feature is the Rio Grande trough. This complex fault trough extends the entire length of New Mexico and is bordered and accentuated by uplifted mountains and mesas. (See Kelley and Silver, 1952, for description of regional tectonics.) It is not a simple graben (fault trough) but a complex zone of horsts and grabens. The overall trend of the faults zone is north-south, but the individual faults are arranged en echelon and most of them are oriented generally northeast and northwest. A few faults in the Joyita Hills and Ladron Mountains areas trend nearly east-west.

The linear depression probably originated in middle Tertiary time, although isolated basins of structural depression and sedimentation existed in earlier Tertiary time. The earlier basins, however, apparently were neither linear nor fault bounded, but they were transected by faults at or before the beginning of Santa Fe time. Santa Fe time is marked by a distinctive type of sedimentation which has been interpreted as related to the faulting that accompanied the formation of the Rio Grande trough (Bryan, 1938). The Santa Fe formation originated because of this deformation. It is more than 5,000 feet thick and contains interbedded lava flows. Faulting and volcanic activity doubtless continued throughout Santa Fe time. The Santa Fe probably represents coalescing alluvial fans filling the Rio Grande depression that overlapped the earliest faults. Depression relative to stream base levels apparently did not accompany the latest deformation, and extensive basin filling is not apparent at the present time.

The central portion of the Rio Grande depression is filled with the deformed earlier units of the Santa Fe formation and covered with extensive younger units of that formation and later sediments which mask the structure of the underlying rocks. Therefore many more faults may exist than have been mapped. Some faults under the pediment and alluvial cover have been inferred by projecting faults observed in the dissected borders of the Rio Grande depression, and by correlation with anomalies in the contours on the ground-water levels (pl 2).

Rocks on the east slopes of the Manzano and Los Pinos Mountains dip gently southeast under Chupadera Mesa and the north end of the Jornada del Muerto, but locally near the mountains they dip steeply or are overturned. Similar rocks dip westward on the west side of the Ladron Mountains. Details of the structure in these areas are shown on maps by Wilpolt and others (1946), Kelley and Wood (1946), Stark and Dapples (1946), and Wilpolt and others (1951).

GEOMORPHOLOGY

Socorro County is in the Mexican Highland and Sacramento sections of the Basin and Range province and the Datil section of the Colorado Plateau province, but the area considered in this report is wholly within the Basin and Range province. The boundary between these provinces is not a clearly defined line but is generally along the east edge of the Lucero uplift (the northwest limit of the geologic map, pl 1), and extends southward toward the Magdalena Mountains, which are west of Socorro and south of Magdalena. The Basin and Range province has faulted blocks that rise from generally smooth alluvial basins now more or less integrated by intermittent drainage. All the major physiographic features in northern Socorro County are the result of Tertiary faulting and subsequent cycles of erosion from the highlands and deposition on the down faulted blocks. Lesser features, such as the pediment terraces in the Rio Grande valley, have other causes, as discussed in a later paragraph.

Most of the area investigated is in the Mexican Highland section of the Basin and Range province, but the cuesta area east of the Los Pinos Mountains is in the Sacramento section, a transition zone between the

Basin and Range province and the High Plains province to the east (Fenneman, 1931, pp 393, 394). The Sacramento section is underlain by gently dipping Permian, Permian (?), and Pennsylvanian rocks upon which a gentle cuesta topography has developed. That part in northeastern Socorro County forms the southwest border of the Estancia Valley. The Manzano and Los Pinos Mountains, and the basins, hills, and mountains west of them, are in the Mexican Highland section of the Basin and Range province. The high areas consist generally of Precambrian cores flanked by Pennsylvanian and Permian rocks, but these rocks are overlapped by Tertiary and Quaternary alluvial-basin deposits. These deposits were worn from the highlands and deposited under variable climatic conditions. A complete analysis of these conditions and their criteria is not possible here. The Los Pinos Mountains have a generally flat summit level which probably represents the exhumed surface upon which Pennsylvanian sediments were deposited. The Joyita Hills area has several flat gravel-veneered upland surfaces, but these are the result of pedimentation in late Tertiary or Quaternary time.

The Rio Grande trough was filled with silt, sand, and gravel during the major period of faulting which caused the depression. Faults occurred contemporaneously with deposition, but another period of more intense faulting occurred in late Santa Fe time. The sequence of events in late Tertiary (late Santa Fe) through early Pleistocene time is not known in this area at present. Apparently conditions of deposition changed markedly at the end of the Pliocene, and an erosion surface of broad extent developed across the deformed but relatively easily eroded Santa Fe formation. This surface also extended across pre-Tertiary rocks, but the harder rocks were not planed off as easily nor as extensively. This highest surface (Ortiz surface of Bryan and Denny) was graded to a level of the Rio Grande 400 to 500 feet above its present level.

Extensive gravel-veneered pediment remnants at high levels may be partially the result of temporary slowdowns in the down cutting of the base level of the Rio Grande farther downstream. As obstructions such as interbedded lava flows were encountered, the rate of incision by the Rio Grande was slowed down, and pediments were graded to the temporary, local base level. Renewed down cutting to a lower base level after the obstruction was breached caused development at lower levels of younger and less extensive pediments which have not cut the older surfaces completely away. Climatic changes may have resulted in additional changes in the formation of these pediment flights, and more certainly they have been responsible for the lowest cut-and-fill structures of the intermittent and ephemeral arroyos. The rate of expansion and integration of the major tributary drainage systems may also have controlled some of the higher pediment surfaces and gravel deposits. Pleistocene climatic changes may be responsible indirectly for varying rates of integration.

Ground-Water Areas

The discussion of the water resources of northern Socorro County in the following pages is divided into a number of sections and subsections, each covering an area in which the physiography, surface drainage, ground-water movement, and geology can be discussed as units having characteristics generally different from those of adjoining units. Areas classed by quality and quantity of ground water, and the depth to water, are shown on Plate 2 and described in the summary of availability of water, pages 76-77. The following areas conform generally to the pattern of the availability areas, but are somewhat different in detail.

LOS PINOS AND MANZANO MOUNTAINS RECHARGE AND MOVEMENT

The Los Pinos and southern Manzano Mountains as discussed in this section are essentially the eastern tract of Area 1, Plate 2. The mountains receive more rainfall than the surrounding areas. The higher parts of the Manzano Mountains receive more than 25 inches of rain annually and the lower parts somewhat less. At the higher altitudes the evaporation rate is decreased and therefore the effectiveness of the rainfall is considerably increased. Except for the very highest parts of the Los Pinos Mountains, only juniper and pifion grow there. Ponderosa pines grow on the summits of the Los Pinos Mountains and cover much of the Manzano Mountains, especially on the east slopes. Spruce and aspen also are found on the upper slopes of the Manzano Mountains. Except on these upper slopes, the vegetation and soil of the mountains are probably thin enough to allow the rainfall to run off rather rapidly, but undoubtedly some is absorbed into the joint-plane interstices of the crystalline rocks. The canyon bottoms receive and are likely to retain a considerable amount of the runoff in the arroyo alluvium during and after storms. Probably the degree and depth of weathering of the bedrock are greatest in the canyon bottoms because of the presence of this water. Some arroyo gravels may retain sufficient water to form a permanent ground-water body perched on the underlying bedrock, but most seem to lose it by evapotranspiration or outflow downstream.

The movement of the ground water in the permeable zones of the crystalline rocks of the mountains undoubtedly is governed largely by the local topography and fracture pattern. The water probably moves in a downslope and down-canyon direction, with irregularities caused by variations in permeability and in the location of fissures. The natural discharge of the west slope of the mountains then must be to springs in the canyon bottoms that intersect the water table, to springs that appear at the edges of alluvial fans; and to the Tertiary alluvium filling the Rio Grande depression. The surface flow of the mountain arroyos which reaches the edges of the pediment spreads out onto the pediment, where a part probably adds to the recharge of the Santa Fe formation underlying the pediment gravels, a part continues to the larger streams as runoff, and a part evaporates.

DISCHARGE

No springs were observed in the canyons cut into the Precambrian rocks of the Los Pinos and southern Manzano Mountains, but two were noted in sec. 14, T. 3 N., R. 4 E., at the lower edges of convex alluvial fans which overlie the pediment and overlap on foothill spurs of Precambrian quartzite. Spring V3N.4E.14.140 flowed a total of 2 1/2 gallons per minute on September 2, 1949, but on March 27, 1950, neither spring flowed more than an estimated 1/2 pint per minute. The water from these springs is of good quality and is stored in large steel tanks and piped to troughs which provide stock water over a large part of the adjacent pediment. Both springs are conspicuously marked by small groves of large cottonwood trees. Some of the water of these springs may be derived from inflow from the weathered and fissured Precambrian granite east of the quartzite hills into the alluvial fan. However, the coarse sands of the fan may hold enough water in storage to be the main supply of these springs.

SEPULTURA CANYON AND VICINITY

Sepultura Canyon follows a large fault in some places, but in its upper and lower courses it is superimposed across fractured, blocky schist and massive, coarse-grained granite (and gradational granitized schist). Considerable recharge into the fault zone and the fractured schist itself is probably afforded along the arroyo during storm runoff. The fault is well exposed on the south side of the arroyo just upstream from the road crossing. Precambrian schist is faulted up against shales near the base of the Sandia formation, which dips gently southward and away from the fault. The schist is much decomposed for several feet away from the fault. However, just below the road crossing, the arroyo turns sharply off the fault, traverses a narrow rock-floored canyon cut through massive granite, and emerges onto the pediment in a broad embayment in the mountain front.

Two wells were drilled along Sepultura Canyon in the Los Pinos Mountains in order to test the possibilities of irrigating parts of the Llano de Sandia with ground water. The better of the two drilled wells (1N.3E.15.340a) is just across the arroyo from an exposure of the fault and is situated on a gravel-veneered bench cut on schist (fig 5). The driller's log indicates that water was encountered at 72, 85, and 103 feet —probably in joints. From further information supplied by the driller,

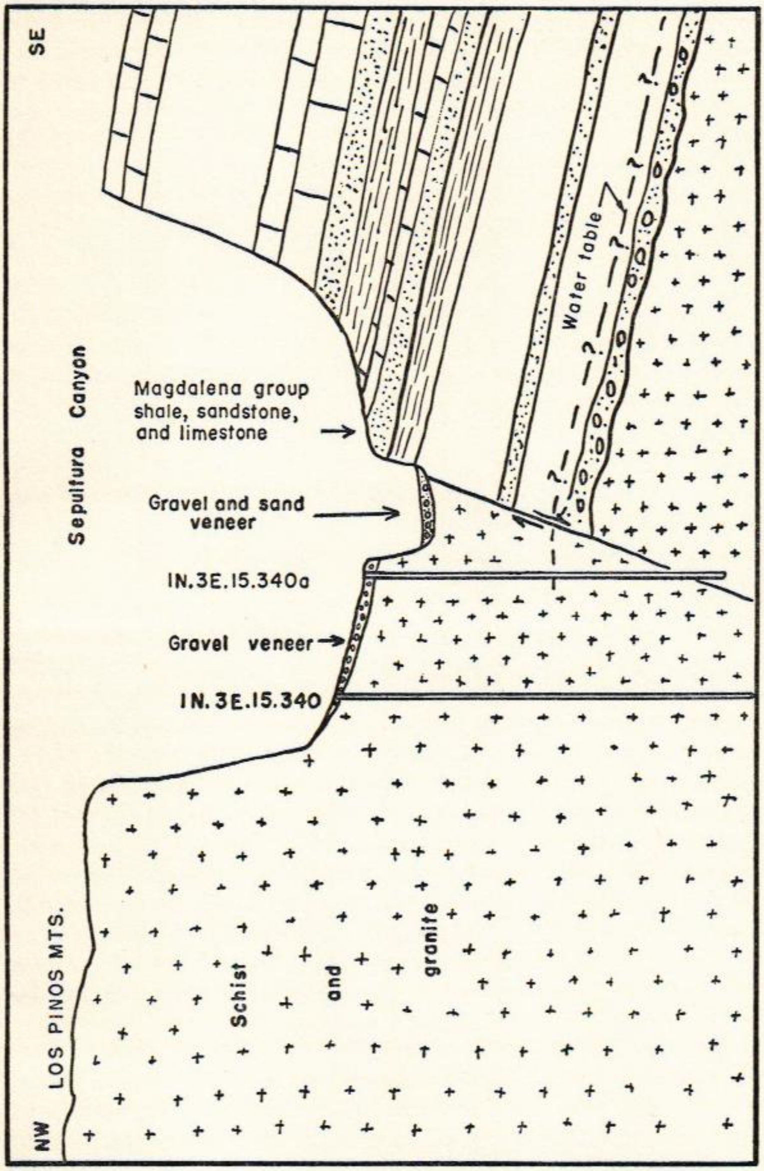

Figure 5
GENERALIZED SECTION ACROSS SEPULTURA CANYON.

the hole seemed to intersect the adjacent fault at about 195 feet, at which point more water was encountered. The hole was continued to 265 feet and tested with a turbine pump with the intake set at 120 feet. The static water level was about 55 feet below the land surface. It is reported that when the well was pumped at 450 gpm, the water did not draw down to the intake (the performance of the well under long pumping is not known), but that, at 1,000 gpm, the water level was drawn down to the intake in 45 seconds, indicating that the capacity of the well is much nearer 450 gpm than 1,000. Assuming that the well does yield 450 gpm with about 65 feet of drawdown, the specific capacity of the well must be about 7 gpm per foot of drawdown. This amount, although small for an irrigation well, is exceptionally large for a well in crystalline rocks, but may be accounted for by the proximity of the well to the fault. The quality of the water from this well is unknown. There may be some solution-channeled limestone near the base of the Sandia formation that is yielding water to the fault or drill hole, but the possibility is thought to be slight because rocks of the Sandia formation dip away from the fault on its downthrown side, and because the base of the formation is probably at a very shallow depth across the arroyo from the well site. Precambrian granite is exposed at the base of the Sandia formation, on the downthrown block, 200 yards southeast of and about 75 feet higher than the well site.

The other well (1N.3E.15.340) is about 120 feet farther from the arroyo and the fault in Sepultura Canyon. It is near the base of the north canyon wall where well-fractured, blocky schist is exposed. The well is reported to yield 12 gpm, with an unknown drawdown. The drill cuttings show that green chlorite schist was penetrated from the surface down to 75 feet, granitized schist or granite and schist from 75 feet to 180 feet, and granite to 885 feet. Water was reported at about 80 feet, and more at several greater depths, but none was reported beyond 180 feet. Apparently this well is at such a distance from the fault that the fault does not influence the occurrence of water, and at a relatively moderate depth the water was encountered in joints where water generally occurs in crystalline rocks. The low yield of the well indicates also that the zone that will yield water in reasonably large quantities is rather narrow. The water from the stock well is gypsiferous and hard, but the source of the mineralization is unknown.

Wells drilled into the parts of Sepultura Canyon that do not follow the fault probably will yield little or no water, whereas wells drilled into *the* fault itself may yield moderate amounts. Even the most favorable locations cannot be expected to produce any more water over a period of time than that produced by the better of the two wells already described. Large-scale pumping probably would cause a rapid decline of water levels in and near wells drilled along the fault. Because of the depth to the water table there can be no rejected recharge, and therefore pumping from one or more wells along the fault will not increase recharge to the rock. If the zone is assumed to be 50 feet wide and 1 mile long, it will have an area of less than 7 acres. A specific yield of as much as 20 percent would furnish only 1.4 acre-feet of water per foot of draw-down over the entire zone. The annual recharge might be increased somewhat, though at great expense, by storing storm runoff in a reservoir in the granite canyon half a mile upstream, and releasing the water slowly to percolate into the stream bed.

EAST SLOPES OF MOUNTAINS

Ground *water* on the east slopes of the Los Pinos Mountains and the southern Manzano Mountains presumably moves to the east, but the natural discharge is not apparent there; some may move into the Paloma thrust-fault zone which bounds the Precambrian rocks on the east. This thrust, which pushed Pennsylvanian rocks upward and in places overturned them, has formed a limestone hogback bordering the fault. Many drainage courses, however, are in deep canyons superimposed across the hogback. Arroyo Abo, the largest of these, drains westward, but many of its tributaries rise in the mountains and drain eastward across the hogback before joining it. No springs are known along the Paloma fault in the southern Manzano or the Los Pinos Mountains. However, just west of the Paloma fault in the northern Los Pinos Mountains there are several shallow wells in Precambrian schist. Dug wells 2N.4E.28.432 and 2N.4E.28.432a are used for stock and domestic supply respectively. These and three others, now caved in, are reported to have been dug through several feet of soil and gravel into decomposed schist, which is well exposed in nearby arroyos. The water is reported to be soft, but the quantity available is rather small. When the windmill well 2N.4E.28.432 pumps continuously at 2 gpm, the water level is drawn down more than 4 feet to *the* intake and nearly to the bottom of the well. The water level is reported to have dropped since 1944, and the well to have been deepened each year since then from the original depth of 17 feet to 23.7 feet in 1949. The arroyo near these wells has a thin veneer of sand and gravel, but no underflow crosses the limestone notch immediately to the east. As the water table in the schist is too deep for ground water to discharge into the alluvium or evaporate into the air, and as no ground-water plants grow there, the ground water in the schist must move into the Paloma fault zone, or move northward in the direction of the northeast slope of the Los Pinos Mountains.

Wells 2N.4E.19.200, 2N.4E.16.420, and 2N.4E.16.420a are shallow dug wells which receive water from decomposed schist in arroyo bottoms in the Los Pinos Mountains. Wells 2N.4E.16.420 and 2N.4E.16.420a are called the Goat Spring wells, and their location may have been determined originally by a natural flow or seep. When visited, however, the static water level in them was 13 feet below the ground surface. The water is unusually hard for water from Precambrian rocks. It contains 953 ppm of dissolved solids, of which 335 is sulfate and 130 is chloride. The source of the mineralization is unknown.

Small amounts of fair to good water are to be expected at shallow depths along the larger arroyos in this area, especially immediately upstream from bedrock constrictions or faults. Additional favorable factors are a thick cover of alluvium and the presence of fractured and decomposed rock. All the wells and springs in the Precambrian rocks of this area are in schist, which may indicate that it is a better aquifer than the quartzite and rhyolite in the higher parts of the mountains, or merely that the schist crops out in the more habitable areas of the mountains. There is no apparent reason why the other crystalline rocks should not produce water in favorable localities. As the permeability and porosity of all crystalline rocks are low, wells should be dug or drilled large and deep enough to provide storage capacity for an adequate supply. If nearby rock outcrops show considerable jointing or faulting it might be practical to drill as deep as 200 feet to secure a small domestic or stock supply.

LIMESTONE HIGHLANDS

RECHARGE AND MOVEMENT

The limestone highlands discussed in this section are essentially the same as the eastern tract of Area 2, Plate 2. Sand Canyon and its tributary arroyos drain a large part of the southern Manzano Mountains. When these arroyos carry storm runoff they probably add some recharge to the ground water in the Pennsylvanian rocks which they cross. All the canyons incised across the hogback east of the Manzano Mountains and north of sec. 7, T. 3 N., R. 5 E., have much coarse granite debris in their channels, but except at one small seep in sec. 30, T. 4 N., R. 5 E., underflow that might occur in the arroyos does not appear at the surface. South of sec. 7, T. 3 N., R. 5 E., the arroyos expose bedrock but have no perennial flow. The channel sands and gravels in the larger arroyos are continuous with the dissected sand and gravel fans east of the Manzano Mountains and may feed underflow, if any, into them and thence into the Madera and Bursum formations, upon which the fans were deposited. Pine Shadow Spring (T4N.5E.16.332) in adjacent Torrance County discharges 3 gpm (measured March 28, 1950) from strata of the Madera limestone at the head of Sand Canyon. The water then seeps into the coarse alluvial fill of upper Sand Canyon and reappears but once in a small seep 0.2 mile downstream. A shallow dug well (V3N.5E.9.424a), on an alluvial bench of Sand Canyon, extends to a perched water body in the arroyo alluvium. Part of the recharge here is probably by runoff seepage, but a large part may be contributed by seep*age* from the limestone strata in the Manzano Mountains, as at Pine Shadow Spring. The water in the dug well is thought to be perched on the underlying Bursum formation because the water level in deeper well V3N.5E.9.424, just across the arroyo, is more than 80 feet below the surface. As no natural surface discharge from the alluvium is known here or from the fans to the southwest, the water in the alluvium must move into the Madera limestone farther down the canyon.

DISCHARGE

Only one visible point of discharge from the limestone highland area is known. A spring (V3N.5E.30.100) flows about 1/2 gpm of hard water from a solutionally enlarged joint exposed in an arroyo floor. The water is piped downstream a short distance to a small stock tank. The overflow seeps into granite debris covering the arroyo floor and does not reappear. The spring does not discharge sufficient water to drain the entire hogback area, and additional water is discharged into Arroyo Abo downstream. Arroyo Abo has a small perennial underflow above the outcrop of the limestone of Pennsylvanian age. The flow alternately reappears and disappears in the outcrop belt of the Pennsylvanian rocks in adjustment with the character of the bedrock floor and the transmissibility of the alluvium. The low-water flow apparently increases somewhat downstream, but as the amount of alluvial fill also increases downstream, the total flow and underflow cannot be estimated. Many salt cedars grow in Arroyo Abo, especially in the areas of deep alluvium, which indicates that there is shallow ground water and loss of water by evapotranspiration. Although dry bedrock is exposed in the channel of the arroyo where it crosses the Precambrian rocks of the Los Pinos Manzano masses, north of the present channel there is deep alluvial fill in the canyon, which may conduct an appreciable amount of water across the bedrock. No salt cedars grow in the arroyo below the exposures of Precambrian rock; therefore, the underflow probably infiltrates into deeper unconsolidated materials of the Santa Fe formation which underlie the Quaternary alluvium of Arroyo Abo in its lower course.

AVAILABILITY OF GROUND WATER

Although the recharge potentialities of the limestones bordering the Paloma thrust fault east of the mountains are excellent, ground water is not easily obtained, owing in part to discharge to canyons deeply incised into the limestone. Springs that emerge in Abo Canyon discharge the water stored in the limestone, but because of the low-level discharge and the high relief, the water table is very deep below the limestone uplands. However, wells in Abo Canyon or in the lower portions of tributary canyons should obtain water at shallow depths. A well in the limestone of the lower part of Abo Canyon, just east of Paloma fault, might yield sufficient water for small-scale irrigation of land to the west. On the high areas it may be possible to get water in wells which intersect small ground-water bodies perched above impermeable elastic strata in the Madera limestone, but such perched bodies can be found only by chance. The sporadic nature of the fissures in limestone makes it difficult

to obtain water supplies in some localities, even in shallow-water areas. Some of the larger bodies of Quaternary alluvium might yield water to shallow wells but, more probably, water absorbed by it moves directly into the limestone below.

Wells in the Bursum formation in this vicinity produce soft water at shallow depths. However, the water of artesian well V3N.5E.32.210 is soft but comparatively high in sodium, bicarbonate, and chloride. This well produces a small amount of water from a confined zone 25 feet below the surface and is reported to flow if the well is not pumped for 7 to 10 days. The source of this water is probably the slightly permeable beds of the Bursum formation exposed up dip to the west and northwest.

Pennsylvanian strata dipping gently southward cover the south end of the Los Pinos Mountains. Erosion has carved this thick sequence of beds of differing resistance into a series of cuestas and some fairly deep canyons. Ground water at a moderate depth probably will be found only along the eastern and southern portions far from the high escarpments and deep canyons. Local conditions such as in the south limb of the gentle syncline across secs. 13 and 23, T. 1 N., R. 2 E., the pitching syncline of Sierra Montosa, the faults in sec. 24, T. 1 N., R. 2 E., and the Montosa fault may dam ground water and cause it to exist at a moderate depth locally. No natural surface discharge of ground water from these rocks is known, and the only outcrop areas down dip are small, complexly tilted and folded blocks 14 miles to the south. Ground water in some of the above localities may move into the Montosa or other faults and be discharged underground into other formations. Only one well (1.3E.2.310) has been completed successfully in the Pennsylvanian rocks of this area. The depth to water is about 67 feet, and the well is reported to have a good yield. A shallow water body probably exists here because the site is in a valley, the nearby Montosa fault is possibly a groundwater dam, and possibly the ground water is partially dammed by dikes supplying the basalt flows immediately to the south and down dip.

CUESTA AREA

RECHARGE AND MOVEMENT

The cuesta area is essentially the same as Area 3, Plate 2. Southeast of the Los Pinos and the southern Manzano Mountains, in an area of several consecutive low cuestas, the Bursum, Abo, and Yeso formations yield water of relatively poor quality in small quantities sufficient only for stock and domestic use. Recharge is from local rainfall on the rock outcrops and seepage from arroyos in flood. In the northern part of the cuesta area the regional structure is unfavorable for rapid ground-water movement, as the dip of the strata is to the southeast, and water levels indicate movement toward Abo Canyon (pl 2).

The profile in Figure 6 shows a topographic divide across T. 1 N., Rs. 4 and 5 E. The water levels in wells at the south end of the profile indicate a ground-water divide in this vicinity also. Therefore, ground water north of the divide moves northward across the dip of the beds. The regional slope of the water levels south of the divide is in the same general direction as the topography and structure there (southward to the north end of the Jornada del Muerto in eastern Socorro County). Ground water south of the topographic divide may be impeded somewhat by the transverse dikes in that area. These inferences are borne out by water-level contours and well data in adjacent Torrance County.[1]

Ground-water movement in T. 2 N. of the cuesta area must then be toward the northwest, in the direction of the general surface slope, and by overflow from one water-bearing zone to the next. Probably some of the movement is across slightly permeable beds, but overflow from higher aquifers to lower ones occurs at several weak springs and seeps in the Abo formation and possibly by some weak underflow in alluvium of arroyos crossing several formations. Wells in the area show great variation in the quality of the water. Some chemical variations may be due to horizontal stratigraphic variations, some to local inflow of water from other formations, and some to local recharge and dilution by rainfall and arroyo-runoff seepage.

Deep wells drilled by the Atchison, Topeka and Santa Fe Railway at Abo in southwestern Torrance County encountered salty water in the Abo formation. The total concentration of dissolved solids ranged from about 14,000 ppm at 354 feet to more than 29,000 ppm at 1,074 feet. Analyses of water at depths of 50 to 160 feet in the Abo formation at nearby Scholle showed concentrations of 2,100 to 2,220 ppm of dissolved solids, which is comparable to the mineralization of the water of the stock wells in the Scholle area.

DISCHARGE

Dripping Springs (2N.4E.12.210) discharges 3 gpm from fissures in a calcareous shale and from solution openings in immediately overlying limestone of the upper arkosic member of the Madera limestone. The springs are at the head of a small canyon eroded in the Madera limestone, just below the contact with shale of the overlying Bursum formation. Many more small springs discharge a total of about 10 gpm into Cafiada Montosa in sec. 1, T. 2 N., R. 4 E. An analysis of water from Dripping Springs (table 5) shows a sulfate content of 612 ppm. Comparison with analyses of water from the Abo formation shows many similarities; hence the water probably is derived at least in part from inflow from the Abo and Yeso formations, but it may include water recharged directly to the limestone in the hogback east of the northern Los Pinos Mountains, in the center of T. 2 N., R. 4 E. The profile on

1 Smith, R. E., U. S. Geol. Survey, personal communication, 1954.

Figure 6 shows the general situation in the area. As there is no discharge to the southeast, ground water cannot move downdip and must overflow from one permeable bed to the next in a direction determined by the topography and stratigraphy. Altitudes of the water table in the area are lower to the northwest, which indicates movement of the water in that direction. Discharge is at Dripping Springs, into Canada Montosa, and into Arroyo Abo. Spring 2N.5E.4.110 in the bottom of Arroyo Abo supplies about 15 to 20 gpm of calcium sulfate water. This flow increases to about 50 gpm where the full flow crosses the bedrock floor in sec. 32, T. 3 N., R. 5 E. A well in alluvium near the Arroyo Abo channel probably would yield a similar amount of water for small-scale irrigation, but continued pumping would lessen the present flow of Arroyo Abo.

RIO GRANDE TROUGH

The character and origin of the Rio Grande trough are discussed on pages 39-45. In the following sections the Rio Grande trough has been divided into 17 units for ease of discussion of ground-water occurrence. The Rio Grande valley is a linear low area toward which the surface and ground water in the entire depression moves, to discharge into the Rio Grande, or to move downstream as "underflow" in the Quaternary alluvium in the valley. The Rio Grande trough as discussed in following sections includes Areas 4, 5, 6, 7, and the western tracts of Areas 1 and 2, Plate 2. The llanos or mesas are generally smooth, gently sloping erosion surfaces cut on the Santa Fe formation and other rocks of the depression and veneered with pediment gravels, here included in the Santa Fe formation, and with Quaternary alluvium. The llanos are interrupted at the south end by fault blocks which possibly were originally faulted up in pre-Santa Fe time, partially buried by the Santa Fe formation, faulted up again, then pedimented in early Quaternary time, and exhumed by erosion to lower levels in later Quaternary time. The exhumed fault blocks are discussed in the last three subsections.

RIO GRANDE VALLEY

The Rio Grande valley in northeastern Socorro County ranges in width from 1 to 4 miles. The relief of the valley floor is very low, and its general slope is southward parallel to the river at about 5 feet per mile. The fill in the valley is of Quaternary age but is difficult to distinguish from the underlying sandy Santa Fe formation, especially in well samples or logs. It was not possible to determine the thickness or subsurface topography of the valley alluvium. Recent aggradation of the river by the silt contributions of intermittent tributaries, especially the Rio Puerco, has caused some waterlogging of agricultural lands, the formation of natural levees, and frequent channel changes. The aggradation may be due, in part, to the presence of Elephant Butte reservoir, which has decreased the gradient of the Rio Grande in the

stretch upstream. Much of the broad valley is irrigated with surface water diverted from the Rio Grande, but in dry years this source is not sufficient for all needs. Ground-water irrigation in this area is generally feasible for utilization of land higher than the ditches, for supplemental irrigation when there is a shortage of river water, or for dewatering waterlogged areas. Consumptive use of ground water in the valley, however, ultimately will result in a decrease in flow of the Rio Grande, to the extent that it is not compensated for by a reduction in evapotranspiration.

A report of the Rio Grande Joint Investigation describes the geology and ground-water resources of the inner valley of the Rio Grande, and includes contour maps of the water table in the river valley as of October 1937 (Bryan, 1938; Theis, 1938). Where ground-water movement had not been disturbed by irrigation ditches and drainage canals, such as in the Bosque del Apache Wild Life Preserve, and in the Albuquerque valley in 1918-22 (Theis, 1938), the water table under the flood plain sloped downstream essentially parallel to the river. The water-table contours in the irrigated parts of the flood plain now show a modification of this simple pattern, owing to irrigation, canals, and drains. The water-table contours in the Rio Grande valley, mapped for the Rio Grande Joint Investigation of 1938, indicate that the ground water in the Quaternary alluvium of the inner valley moves from the irrigation canals, the irrigated fields, and the river toward the drainage ditches and has a marked downstream component. The water levels are also strongly influenced by plant transpiration, which causes both diurnal and seasonal fluctuations.

Inasmuch as the river is higher than adjacent flood plains in much of the Rio Grande valley, and some surface sediments have a low permeability, ordinary ditches are not everywhere completely satisfactory for drainage. In some areas, closely spaced drain ditches equipped with pumping stations at intervals to discharge the water to the river may be a solution. One method of reclaiming waterlogged areas that has received little attention in the past is by lowering of water levels in an area by pumping wells. Such a program would require test drilling and test pumping to determine the hydrologic properties of the river alluvium and underlying Santa Fe formation in order to guide the construction and spacing of well systems, and for success the water should be disposed of by lined ditches, or by piping to adjacent higher lands for irrigation or other use.

Reduction of non-beneficial use of water by lush vegetation on the valley floor of the Rio Grande is the only means of increasing the total supply of water available perennially within the drainage basin.

The water-table contours on the maps of the Rio Grande Joint Investigation report show that the river, canals, and drains affect the ground-water motion in the alluvium of the inner valley, but they do not show fully the relative movement of water in the valley alluvium and under the adjacent mesas. The depth to water in the river valley ranges from zero to more than 8 feet below the surface and is in adjustment with the many factors outlined above. The gradients and direction of movement of the ground water in any given location are also in adjustment with these factors, but the overall ground-water movement is generally downstream with a gradient of 5 feet per mile. Existing wells in the area investigated for this report are too scattered to permit analysis of the detailed shape of water-level contours or of the behavior of ground water at the margins of the inner valley.

Measurements of the flow of the Rio. Grande in various channels, canals, and drains during the winter, when evapotranspiration is low, indicate that ground water is moving into the Rio Grande valley from the adjacent mesas at the rate of 820 acre-feet per mile of valley (Theis and Taylor, 1939, p 270). Annual evapotranspiration by native and cultivated vegetation and evaporation from waterlogged lands, however, is greater than the annual increment to the valley by ground-water inflow, and the river itself is therefore losing water by natural infiltration (the river is generally confined by natural and artificial levees but in many stretches is higher than adjacent flood plains) and by diversion for irrigation.

The ground water contributed by the east mesa, or Llano de Sandia, originates from rainfall infiltration directly upon the mesa and by infiltration of storm runoff from the Manzano Mountains. That part contributed from west of the Rio Grande originates from direct rainfall infiltration, runoff from the Lucero uplift and the Ladron Mountains, and probably in large part from infiltration of the Rio Puerco's storm flow. As the shallow ground water in the valley is highly mineralized from repeated irrigation, it is unsuited for domestic use. In many places, however, water of good quality can be obtained from deeper wells which intercept ground-water inflow from the mesas, provided the more highly mineralized upper water is cased off.

The quality of ground water contributed from the side slopes of some parts of the Rio Grande trough in northeastern Socorro County is also relatively poor, and in the valley floor adjacent to Area 4e (east side of the valley) and the southern part of Area 4c (west side of valley near the mouth of Rio Puerco) the ground water in the Santa Fe formation may be undesirable for drinking, and possibly undesirable for irrigation.

Large yields may be obtained from Quaternary alluvium in much of the valley floor, and moderate to large yields sufficient for irrigation may be obtained from the Santa Fe formation in areas near the Rio Grande or Rio Puerco.

LLANO DE SANDIA

The Llano de Sandia is a broad, smooth plain that descends from the Los Pinos and the southern Manzano Mountains to the bluffs at the east edge of the Rio Grande flood plain. The smooth slope of the plain is broken by the channels of Arroyo Abo and Arroyo Agua Torres, which have cut deeply into the Santa Fe formation underlying the pediment-gravel cover of the plains. These arroyos contain a broad fill of reddish-brown silty alluvium which obscures the underlying Santa Fe. The alluvium fills a very broad, deep channel in the Santa Fe formation but is in turn incised by the present channel, which is veneered with more permeable coarse sand and gravel. More permeable zones may exist in the older fill also, but none is exposed. There is no indication of perennially perched water in the alluvium of Arroyo Abo or any of the smaller arroyos on the Llano de Sandia in the area of this report. Lack of adequate data on water levels under these plains prevents an analysis of the effect of the large arroyos on the recharge to the Santa Fe formation, but it seems likely that recharge is greater under the arroyos than under most of the plains, except on the bordering alluvial fans. Storm runoff from the mountains spreads out over the fans and probably is largely absorbed by the fans and pediment gravels, as the drainage lines are more and more indistinct with distance from the mountain front. Other than Arroyo Abo and Arroyo Agua Torres, none of the drainage lines is continuous across the plain. However, short arroyos working head ward from the Rio Grande are dissecting the Santa Fe formation there. Two small but prominent hills, formed by interbedded basalt and alluvium, modify the pediment surface somewhat, but probably do not alter the ground-water movement much. The conduits along which the basalt rose, or hidden faults associated with them, may have local influence on the ground water, but this cannot be determined from the sparse data on the water table in the area.

Generally the water table under the Llano de Sandia slopes from the mountains toward the Rio Grande with a component down the valley of the Rio Grande, as shown by the water-table contours on Plate 2, but not so steeply as the land surface. Inasmuch as the land surface rises more than a thousand feet in 12 miles from the valley, the water table is deep under most of the plains. However, two wells close to the mountain front have relatively shallow water levels, probably because the water is semi perched on less permeable Precambrian rocks underlying the Santa Fe formation there. The 30-foot depth to weathered granite at well 1N.3E.16.430 is undoubtedly the result of thin overlap by the Santa Fe on the eroded edge of the Los Pinos horst. This well once yielded water but has been dry in recent drought years. The water levels in wells 2N.2E.36.330 and 2N.3E.18.240 are about 800 and 700 feet lower respectively than the water levels in wells 1N.3E.16. 430 and 2N.3E.34.330, 41/2 miles southeast, indicating that a high ground-water cascade exists between these pairs of wells—probably because a saturated zone at the base of the Santa Fe is upheld by a bench of slightly permeable crystalline Precambrian rocks at the more eastern wells, whereas the more western wells tap the main water body in the thicker part of the Santa Fe formation which is present there. The Los Pinos fault, which bounds this subsurface bench on the west, is inferred to extend north from its outcrop, as mapped on Plate 1. The location of the fault on the map is aided by dry hole 2N.3E.23.120, which is reported to have hit granite at 150 feet. Figure 7 shows the inferred geologic and ground-water conditions under the Llano de Sandia and illustrates the effect of the fault on ground-water levels and movement. Between the projected Los Pinos fault and the east edge of the alluvial fans, the Precambrian rocks are likely to lie at shallow depth, and as a consequence ground water may be found in a few localities also at shallow depth.

The existence and thickness of the saturated zone depends on the subsurface configuration of the Precambrian rocks and on the recharge and rate of movement of the water that is semi perched on their surface. The thickness of Tertiary and Quaternary sediments above the Precambrian surface, the relief of that surface, and the thickness of the saturated zone could be determined by test drilling or by geophysical exploration by seismic methods or possibly, in favorable locations, by electric resistivity. Similar conditions exist west of the southern Manzano Mountains, where springs emerge from the alluvial fans at the edge of the pediment. The altitude of the springs is about 5,900 feet, but the water table in deep wells only 6 miles west is at about 4,800 feet, or 1,100 feet lower. Water levels in wells farther west indicate gradients of only 2 to 10 feet per mile toward the Rio Grande.

The yield of wells in the area is unknown except for those drilled by the Atchison, Topeka and Santa Fe Railway at Becker station, Valencia County. Well V3N.3E.10.430a, 420 feet deep, was tested at 50 gpm, and the drawdown was 36 feet, which indicates a specific capacity of 1.3 gpm per foot of drawdown. The static water level was reported at 364 feet in 1905. The static water level in well V3N.3E.10.430, 150 feet east, was measured at 367 feet below the land surface in August 1949. The quality of water in these wells is only fair. Dissolved solids range from 749 to 948 ppm, and the sulfate content is high. The quality of water from other wells in the Santa Fe formation underlying the Llano de Sandia ranges from poor to good. The water from well V3N.3E.5.320 is salty and bitter; the other waters contain mostly calcium and sulfate. Wells V4N.2E.I5.440 and V4N.3E.23.430 have excellent water containing 250 ppm and 168 ppm of dissolved solids respectively, but wells near Arroyo Abo and south of it yield water that contains appreciable sulfate. From Arroyo Abo south, much of the recharge to the Santa Fe formation under the Llano de Sandia is from surface and ground-water inflow from the gypsiferous Permian rocks east of the Los Pinos Mountains, especially from Arroyos Abo, Cibola, Agua Torres, and Alamillo.

LLANOS DEL RIO PUERCO

The Llanos del Rio Puerco slope gently to the east from the Lucero uplift (to the west of the mapped area) and northeast from the Ladron

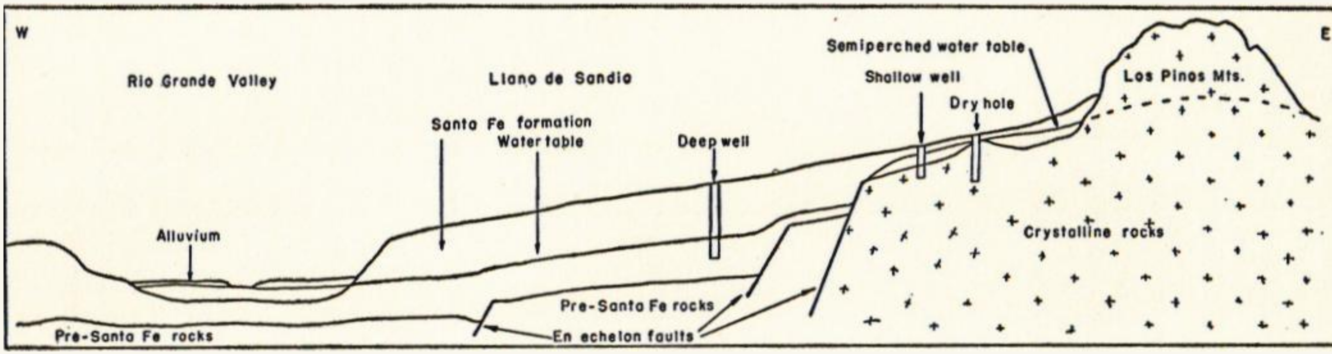

Figure 7

GENERALIZED SECTION ACROSS THE LLANO DE SANDIA THROUGH T. 2 N., SHOWING EFFECT OF BEDROCK FAULTS ON WATER TABLE. FAULTS NOT SHOWN) CUTTING SANTA FE FORMATION MAY INTRODUCE ADDITIONAL COMPLICATIONS

Mountains. These plains are underlain principally by the Santa Fe formation; but near the highlands faulting has brought what are probably pre-Santa Fe Tertiary rocks near the surface. Pediment gravels at several levels cover most of the Llanos del Rio Puerco in Socorro County and conceal the structure and stratigraphy of older units, but exposures in Red Tanks Arroyo show light-brown well-cemented conglomeratic sandstone, which may be the Popotosa formation, dipping west-southwest at about 8 degrees. Farther east are widely scattered exposures of flat-lying silty and somewhat cemented and conglomeratic sandstone beds, and excellent exposures on both sides of the extension of the Llano *de* Albuquerque in northern Socorro County show horizontal, unconsolidated clay, silt, and sandstone beds which are presumably younger than the Popotosa formation.

At times large amounts of water fill many broad, sandy arroyos which drain the bordering highlands, cross the Llanos del Rio Puerco, and join the Rio Puerco. Although water levels in scattered wells indicate that ground water moves from the highlands toward the Rio Puerco, the effect of recharge from individual arroyos cannot be determined in detail. In parts of the Llanos near the Ladron Mountains, water levels in neighboring wells differ by as much as 200 feet in a mile. Although the high levels may represent perched water zones in the Santa Fe formation, they are probably semi perched on concealed, up-faulted pre-Tertiary blocks similar to those inferred beneath the Llano de Sandia (pp 58-6o). The water-table gradients, as indicated by sparse data in the remainder of the area, range from 2 to 10 feet per mile, as shown on Plate 2.

The ground-water movement in secs. 14 and 22, T. 3 N., R. 2 W., is to the northeast. All the wells from which data were collected are along a drainage line cut into the Santa *Fe* formation and refilled to an unknown depth with Quaternary alluvium. The water obtained by the wells is probably perched or semi perched in the alluvium.

The east side of the Lucero uplift, just west of the northern part of the area investigated, is drained by arroyos that cross gypsiferous Permian rocks. Springs emerging from faults in Pennsylvanian and Permian rocks at the east edge of the Lucero uplift discharge highly saline water into these arroyos, which then cross the Llanos del Rio Puerco. The salty springs maintain perennial flow in some arroyos for 1 or 2 miles, and that water which is not utilized by plants or evaporated is absorbed by the arroyo alluvium and recharged to the underlying Tertiary rocks. The water under most of the Llanos del Rio Puerco in Socorro County is poor in quality, probably because of contamination by the highly mineralized water of these springs. Only near the Ladron Mountains, *where* recharge to the Santa Fe formation is by infiltration of storm runoff from a Precambrian mass into alluvial fans and into the broad, sandy arroyos that cross the Llanos, is the ground water of good quality.

In the small part of the Llano de Albuquerque that extends down into Socorro County between the Rio Puerco and Rio Grande, water moves under the Llano from the Llanos del Rio Puerco and from the Rio Puerco itself.

RIO PUERCO VALLEY AND LLANO DE ALBUQUERQUE

The Rio Puerco occupies a valley eroded in the Santa Fe formation. In this broad valley (see fig 8) the alluvial fill consists of red-brown silt and silty sand and gravel; but coarser sand and gravel containing less silt may exist at greater depths in the earlier fill. The silty valley fill is incised by the present channel of the river to a depth of 20 to 40 feet, and the channel floor is veneered to an unknown depth with silt and sand. No wells are known in either the earlier fill or in the more recent channel sands, nor is the depth of these fills known. The water table in the Rio Puerco channel is probably at or near the surface during most of the summer, when precipitation is heavy and there are occasional flood flows. During the winter and spring, when the channel is dry, the depth to water is probably greater. However, luxuriant salt cedar groves line the entire Rio Puerco channel in Socorro County, which indicates that ground water is at relatively shallow depths there.

The records of surface-water flow from 1940 to 1947 at the Rio Puerco and Bernardo gaging stations on the Rio Puerco indicate that an average of at least 5,800 acre-feet per year is lost by seepage or evaporation in the 30 miles of channel between these two stations. This loss was obtained by subtracting the discharge at the Bernardo station near the mouth of the Rio Puerco from that at the Rio Puerco station (at the crossing of the Atchison, Topeka and Santa Fe Railway west of Los Lunas) in those months or days during which there is no apparent increment from local storms.

The figures obtained in this way are much lower than actual, but they do show the minimum amounts lost. As detailed climatic data for the area are not available, the seepage loss of runoff that is contributed to the river between the stations is not included in the figures. Seepage loss-discharge ratios on a daily and monthly basis, taken from records of the Bernardo and Rio Puerco stations, show that the alluvium of the Rio Puerco and the underlying Santa Fe formation are capable of absorbing much larger amounts of the flow of the Rio Puerco than has ever been recorded. The ratio of losses to low discharges at the Rio Puerco station indicate that the lower rates of discharge (less than 100 acre-feet daily, or less than 600 acre-feet monthly) are insufficient to saturate the alluvium of the Rio Puerco continuously. Even at much higher daily-discharge rates, the loss-discharge ratios do not depart greatly from a proportional relationship, so that the upper limit of daily seepage loss cannot be determined. As the upper limit of loss is approached, much larger rates of discharge in the Rio Puerco should result in only slightly increased losses.

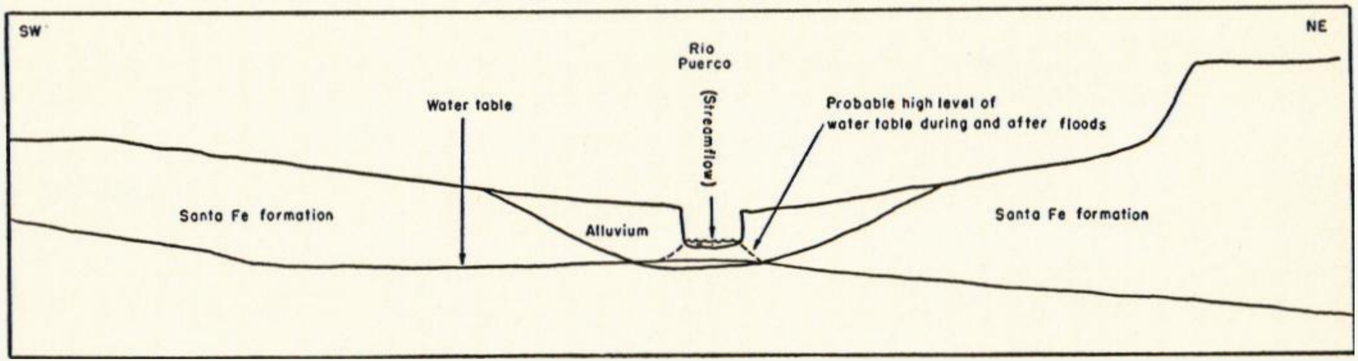

Figure 8. GENERALIZED SECTION OF RIO PUERCO VALLEY WEST OF BERNARDO.

The mound in the ground-water contours mapped on Plate 2 indicates that part of the seepage loss of the Rio Puerco is contributed to the Santa Fe formation underlying the Quaternary channel fills, and that this underflow moves toward the Rio Grande valley in the Santa Fe formation and is probably discharged there to the Quaternary fill, the river, or the drains. The contours indicate also that some water moves south from the Rio Puerco toward a trough in the water table, then down the axis of the trough toward the Rio Grande. The groundwater trough may be due to the presence of a more permeable zone, and possibly to confluence of two sources of ground water, infiltration from the Rio Puerco and runoff from the Ladron Mountains. Additional ground water may move downstream as underflow of the Rio Puerco in the Quaternary alluvium of its channel. Part of this underflow also is discharged to the Rio Grande and part is lost by transpiration by salt cedars.

LADRON MOUNTAINS AND VICINITY

The main mass of the Ladron Mountains is an uplifted block or horst of Precambrian granite, schist, and quartzite, faulted up on all sides against younger rocks. A large west-tilted block of Mississippian and Pennsylvanian limestones, lying non-conformably on Precambrian rocks, is adjacent to the Ladron Mountains horst on the west. Elsewhere the horst is bounded by complexly faulted Tertiary rocks and fault slivers of pre-Tertiary rocks. Thick gravels included in the Santa Fe formation overlap the horst on the north and northeast sides, and in places they conceal probable faults.

The Ladron Mountains are high enough to receive appreciably more rainfall than the adjacent plains, but their rugged, rocky character renders them unfit for any agricultural use with the possible exception of goat grazing. Joints in these crystalline Precambrian rocks store ground water which is discharged as springs in some canyons, especially on the west slope of the mountains. Inasmuch as alluvium and decomposed rocks in the canyon bottoms absorb this discharge in a very short distance, some ground water probably exists as underflow in some of these canyon-floor veneers and flows underground across the faults bounding the mountain block to recharge adjacent aquifers in Pennsylvanian and Tertiary rocks. Storm runoff from these relatively barren mountains is high, but probably only small amounts are stored in the alluvium of the upper portions of the drainage courses. In the broad lower courses of the arroyos the water absorbed by the sandy Quaternary alluvium is probably lost largely to the underlying Santa Fe formation, and perched water in the Quaternary alluvium is unlikely to be found there. Well 2N.2.3.340 yields a small amount of water from weathered granite or granite debris at the base of Quaternary alluvium in a canyon heading in the Ladron Mountains. This type of source is probably the most likely prospect for small water supplies in the area.

The Popotosa formation and pre-Santa Fe rocks are exposed in the faulted west-tilted blocks east of the Ladron Mountains. These blocks generally yield water of very poor quality, if any. These rocks have a low permeability, and they dip westward toward the mountains, where they have no apparent discharge. Near the mountains some weak springs are known that emerge from very slightly permeable zones perched and confined between impermeable layers. Here complex faulting has in places brought fault blocks of cemented sandstones near the surface. These rocks may contain water suitable for stock.

Projected faults and water-level contours under the plains north and east of the Ladron Mountains (see pl 1) indicate that, where faults have raised the impermeable underlying rocks, water is semi-perched or perched in the overlying Tertiary and Quaternary beds northeast of the mountains. This zone of saturation is probably thin because of the high water-table gradients that exist. East of the mountains a block of nearly impermeable beds of the Popotosa formation probably restricts ground-water movement to the east. Movement is most likely southward, where water may discharge into the Quaternary alluvial fill of the Rio Salado.

The structure, topography, and ground-water characteristics of the west slope of the Ladron Mountains are similar to those of the east slope of the southern Manzano Mountains. Runoff from the Precambrian rocks flows across hogbacks of Pennsylvanian-age limestone and affords excellent recharge to the solution channels in the limestones. However, springs in the Rio Salado canyon at much lower altitudes probably discharge this ground water, which is then absorbed by the arroyo alluvium in the lower course of the Rio Salado. Because of the low-level discharge of the limestone hogback, ground water is likely to be deep beneath the surface. In well 2N.3.23.000 the water level is more than 268 feet beneath the surface, and this is the only well known in the area near the mountains.

RIO SALADO VALLEY

The lower 10 miles of the Rio Salado valley is 11/2 to 2 miles wide and is filled with sandy Quaternary alluvium to an unknown depth. The broad sandy bed of the river here is dry throughout the fall, winter, and spring, but some flow past the gaging station, in sec. 24, T. 1 N., R. 1 W., is maintained through most of July and August by sporadic but heavy rains in the Rio Salado drainage area. The width and gradient of the Rio Salado reflect the character of the formations across which it flows. Where the Rio Salado crosses a narrow tongue of the Madera limestone, in sec. 7, T. 1 N., R. 2 W., it has cut a narrow, deep canyon having a very steep gradient. The river bed broadens where softer Tertiary and Quaternary formations are crossed, but narrows again in a box canyon where the well-consolidated upper conglomerate beds of the Popotosa formation, as described by Denny (1940), are crossed. In the lower stretches of the Rio Salado, a broad valley is formed in the soft silty and sandy strata of the lower part of the Popotosa formation and in the undifferentiated sediments of the Santa Fe formation. The gradient of the broader part of the river is 25 to 30 feet per mile, which is rather steep compared with the Rio Puerco (10 to 12 feet per mile) and the Rio Grande (5 feet per mile). Scattered wells in the Quaternary alluvium indicate that the water-table gradients near each of these rivers are about the same as the surface gradients in the river channels.

Perennial saline springs emerge from the Madera limestone, in sec. 7, T. 1 N., R. 2 W., and flow an estimated 500 gpm into the Rio Salado at that point. This flow is absorbed by the sandy river bed within the next 10 miles. Shallow wells in the alluvium of the Rio Salado yield water similar in composition to that of the springs and the low-water flow in the river. Decreasing mineral content of the water with distance downstream (see analyses, table 6) may be due in part to dilution by ground-water inflow downstream from the source springs, which is only partly balanced by concentration of dissolved solids by evapotranspiration. All samples were taken during dry periods.

There is a striking chemical similarity between spring waters in the Rio Salado and the Red Tanks Arroyo, 14 miles to the north. The source of both these saline springs is the Rio Puerco fault zone, or its southward extension. Many saline springs emerge from this fault zone in Valencia County, and the waters from some of these springs contain as much as 34,000 parts per million of dissolved solids, as reported by Wright (1946). Analyses for the springs in Socorro County are given in Table 6. Extensive travertine deposits related to earlier Quaternary and present spring activity are mapped along the Rio Puerco fault zone (Kelley and Wood, 1946). Similarly, a small travertine deposit caps a bench along the Rio Salado in sec. 7, T. 1 N., R. 2. W., and is probably the result of earlier Quaternary spring activity. A general discussion of fault springs is given on pages 19-20.

Three test wells drilled in the lower part of the Popotosa formation north of the Rio Salado yield very highly mineralized water. Stock well 2N.1.30.330, which has the best water of the three, is in a small arroyo veneered with Quaternary alluvium and cut into west-dipping fine-grained clays and siltstones. A pit dug 5 feet into the sandy alluvium probably once yielded water but was dry when visited in the late summer of 1949. Several salt cedars growing in and near the pit indicate that shallow water exists there. Some water seeps slowly from gypsum-filled cracks in the clays and silts of the Popotosa formation in the east bank of the arroyo just downstream from the well. Some or all of the salty water in the alluvium is probably derived from such seepage, although it may receive additions from storm runoff perched on the less pervious Popotosa formation. Some less mineralized ground water may be available, perched in the alluvium of a larger arroyo to the west, where several cottonwood trees grow.

Drill hole 2N.2.36.440 yields very salty water from a depth of 255 to 320 feet in the fine-grained lower part of the Popotosa formation. The analyses in Table 5 show a minimum of 26,500 ppm of dissolved solids, largely sulfate, sodium, and chloride. The water flows weakly at the surface but can be drawn down quickly by bailing with a tin cup. A recovery of 2 inches in 10 minutes in the 8-inch drill hole indicates a yield of about 0.04 gpm. The water level declined 41/2 feet from August 1949 to December 1949. A bed of bentonite that crops out east-northeast of the well and dips toward it may be the confining bed of the artesian water. However, other fine-grained beds in the Popotosa formation are probably sufficiently impermeable to cause the artesian conditions. As the piezometric surface here in the Popotosa formation is more than 150 feet above the semi-perched water table in the alluvium of the Rio Salado which cuts across it, there is probably some inflow of highly mineralized water to alluvium in the Rio Salado, but in small quantities because of the low permeability of the Popotosa formation.

ALAMILLO AREA

Alamillo is a small community of 15 to 20 families just west of San Acacia and San Acacia dam. Most of the houses are built on a low terrace cut on uncemented sand of the Santa Fe formation at the edge of a Rio Grande meander scar which is now used for pasture and farming. The Quaternary alluvium and the sediments of the Santa Fe formation between the town and the Rio Salado to the north are extremely sandy and unconsolidated. The thick sandy beds of the Santa Fe are cut by a faulted anticline which trends generally north-northwest from sec. 33, T. 1 N., R. 1 W., to the Rio Salado. In the immediate vicinity of the fault these sandy beds are well cemented, but loose, wind-worked sand covers the surrounding area, and large dunes obscure or modify the topographic expression of the structure. There is little or no surface runoff in these sandy areas. West of this fault, a larger fault has brought up pink and purple conglomerate beds of probable Popotosa age, which grade into pink and green silty beds in places. Farther west the Datil formation is faulted up in the San Lorenzo Hills, which are just outside the area mapped. Many minor faults in the Datil and Popotosa formations are well exposed in the badlands in the west half of T. 1 N., R. 1 W.

Three drilled wells are reported in Alamillo. All are about 100 feet deep, and all yield salty, hard water unfit for domestic use but suitable for stock. Water from a shallow dug well at the edge of the meander scar on the flood plain of the Rio Grande is reported unfit even for stock. At present the residents of Alamillo haul water from the San Acacia school well 2 miles east. An analysis of water from well 1.1.2.120, owned by E. Chavez, of Alamillo, is in Table 5. This well was reported to be filling with sand and declining in yield. Well IN.1.34.330, 11/2 miles northwest of Alamillo, yields salty, hard water similar to that of the Chavez well, but it is relatively lower in chloride. It supplies, however, an adequate amount of water, possibly because the well was gravel packed. A spring in section 34 is reported to have good water, which is probably derived from local recharge from the west.

The poor quality of the water in the Alamillo area is the result of several factors. Four miles north of Alamillo the broad sandy bed of the Rio Salado absorbs a great deal of storm runoff. However, the highly saline winter flow of the Rio Salado contributes more than enough water high in chloride and sulfate to contaminate shallow wells to the south, as the water table at Alamillo is about 150 feet lower than that at the Rio Salado. The underflow of the Rio Salado is somewhat similar to the water in wells 1N.1.34.330 and 1.1.2.120, except that the wells near Alamillo have a much higher calcium and sulfate content.

Potable water probably is not present in the vicinity of Alamillo at any depth. The nearest known source of potable water is the reported spring west of the village.

JOYITA HILLS

The Joyita Hills, a complexly faulted and tilted horst, bounds the Valle del Ojo de la Parida on the west. Precambrian rocks are exposed on the east side of the hills, and westward-tilted Pennsylvanian and Permian rocks on the west side. These small west-dipping blocks offer some possibilities for ground-water supplies in small quantities only, for their small size and rugged topography are unfavorable factors. No ground-water information is available for the Joyita Hills, except that a mine shaft reported to be 300 feet deep in sec. 27, T. 1 N., R. 1 E., is reported dry. Formations that are water bearing may discharge underground to the Popotosa and Santa Fe formations or to Quaternary alluvium, as there is no known surface indication of natural discharge. The name "Arroyo del Ojo del Padre" in this area (sec. 22, T. 1 N., R. 1 E.) suggests that a spring existed here at one time, but no spring was found. Interbedded sandstones and limestones in nearly all the Pennsylvanian and Permian formations in the area may yield water suitable for stock, but in very small quantities.

VALLE DEL OJO DE LA PARIDA AND VICINITY

Valle del Ojo de la Parida and Valle Cibola, in T. 1 S., Rs. 1 and 2 E., and in T. 1 N., R. 2 E., are two smooth topographic basins separated by a low divide. These basins were eroded on the relatively soft Cretaceous sandstones and shales of a complex, structurally depressed block or graben. Hills of the Datil formation bound the topographic basins on the west and southwest, but the Precambrian core in the uplifted block or horst of the Joyita Hills bounds the structural basin on the west. North-northeast-striking fault blocks of Paleozoic rocks bound the basins on the east and southeast. The north side of the basins is bounded by a southwest-dipping block of Paleozoic and Triassic rocks. A veneer of alluvium conceals the rocks underlying these basins, but low isolated hills project above the alluvium to give scattered indications of the complex structure of the basin, as do several small outcrops along Arroyo Cibola. The log of well 1.1E.36.140 indicates that there is at least 167 feet of alluvial fill in the Valle del Ojo de la Parida, although the alluvium is absent near the projecting hills. Some of the material between depths of 40 and 167 *feet* in the well is a conglomerate composed largely of red and purple rhyolite and andesite, which may be equivalent to parts of the Popotosa formation or of the Datil formation. Alluvial fans border the larger hills in and around the basins. Parts of the large outcrop of the Mancos shale in Valle Cibola are covered by a pediment-gravel remnant which may correlate with pediment-gravel remnants on parts of the bordering hills. Arroyos Alamillo and Cibola were probably superimposed on the pediment gravels which cover the high erosion surface.

Shallow ground water is indicated in the eastern half of Valle del Ojo de la Panda by several small springs and by thick stands of alkali sacaton. In addition, seeps and thick salt crusts cover several acres of ground in sec. 30, T. 1 S., R. 2 E. These indicate a shallow water table and considerable direct evaporation of ground water. Some of this water must come from the small alluvial fan at the exit of drainage from Mesa del Yeso, as one of the seeps there is at the highest part of the convex fan, well above the surface of the saturated alluvium in the vicinity. Gypsiferous Permian rocks also may contribute some ground water here. The other alluvial fans of the basins do not show any seeps, but nevertheless they are probably a source of recharge to the alluvium of the basins. Recent erosion in the arroyo half a mile east of the springs and seeps has cut 6 to 8 feet below the ground surface and has intersected the water table. Immediately above the head of the recent gully, a shallow dug well (1.2E.29.340) contains water 5 feet below the ground surface. A large growth of salt cedars and alkali sacaton marks a seepage area in the NE $1/_4$ sec. 31, T. 1 S., R. 2 E., at the east edge of a small hill composed of the Mancos (?) shale. The shallow water in these areas is probably perched on impermeable or slightly permeable bedrock or older alluvium between adjacent hills of pre-Tertiary rock. The poor quality of the water in Valle del Ojo de la Panda is probably caused in large part by evapotranspiration in these shallow-water areas.

Well 1.2E.31.114 is reported to be dug to 110 feet, but it produced water of poor quality and was abandoned. Fragments of gray- and black-mottled white sandstone piled around the caved-in well indicate that the Dakota sandstone was probably encountered. A 130-foot well reportedly drilled nearby was not found. Wells 1.1E.36.140 and 1.1E.36. 140a penetrated Quaternary alluvium to 40 and 59 feet respectively, but were bottomed in Tertiary or early Quaternary alluvium derived largely from the Tertiary Datil formation. The silty gravels in the Quaternary alluvium were derived principally from Permian formations. Water of poor quality was found at the base of the Quaternary alluvium in well 1.1E.36.140, and water of poor quality was also encountered at 95 feet and 69 feet in wells 1.1E.36.140 and 1.1E.36.140a respectively. Depths to water in wells 1.1E.1.430 and 1.2E.19.220 on the north side of Valle del Ojo de la Panda are greater than 100 feet, and the wells yield water of very poor quality. The poor quality of the water in these wells may be due to solution of gypsiferous constituents of the alluvium or of the fine-grained Cretaceous and Tertiary rocks underlying the basin.

Arroyo Alamillo has cut a deep canyon across a thick block of the Datil formation at the west edge of the Valle. Some of the older fill of the Valle has been eroded and refilled with fine red-brown silt and silty gravel. Recent erosion has cut gullies 6 to 12 feet deep in the fill both above and below the canyon. A few salt cedars growing in these gullies possibly indicate some perched ground water. The canyon of Arroyo Alamillo is rather broad and may contain a deep fill carrying some ground-water underflow out of the Valle. Inasmuch as water in the wells and springs of the Valle is of poor quality, this underflow also is probably of poor quality. Water of better quality may be found by drilling in the large alluvial fans that border the Valle on the south side or in the eastern edge of the basin, secs. 28 and 33, T. 1 S., R. 2 E. These areas are farther from and higher than the areas of evapotranspiration, where concentration of minerals in the ground water takes place. In addition, the fans on the south side are derived mostly from the Datil formation in that area and probably do not contain soluble limestone and gypsum rocks as do the fans descending from Mesa del Yeso to the northeast, in sec. 30, T. 1 S., R. 2 E. The only potable water known at present in this basin is that in a spring and well in sec. 21, T. I S., R. 2 E. Here soft water is perched in a syncline of red-brown medium-grained sandstone of the Meseta Blanca (?) member underlain by red shale of the Abo formation. The recharge is local, and the flow of water from the spring is partly due to the synclinal structure in the sandstone as well as to the impermeable underlying shale. The Meseta Blanca sandstone member of the Yeso formation also contains shallow ground water in sec. 34, T. 1 N., R. 2 E.

VALLEY OF ARROYO CIBOLA

A smaller basin north of Valle del Ojo de la Parida is drained by Arroyo Cibola. The arroyo has a drainage area of 40.5 square miles east of the road crossing the basin at its east end. The alluvial basin west of the road has an area of 16 square miles, only a part of which is relatively un dissected. Faulting along the east *edge* of the basin has tilted a long, narrow block of the San Andres formation to the west. Outcrops in Arroyo Cibola, sec. 34, T. 1 N., R. 2 E., show the massive limestone and cavernous gypsum beds of the San Andres formation dipping west into a fault contact with relatively impervious shales of the Dockum group. The runoff from upper Arroyo Cibola crosses a block of the San

Andres formation in about half a mile of broad arroyo channel floored with coarse sand and gravel, which veneers an older fill of red-brown silt. Considerable recharge into the San Andres formation may occur in this channel, if the older silty fill is more permeable at its base than it is where exposed. Additional recharge by rainfall may be absorbed directly by the San Andres formation, as it is covered by little or no soil in most of the area outside the arroyos. The water level south of Arroyo Cibola and east of the fault is 24 feet deep in stock well 1N.2E.34.130, and 32 feet deep in irrigation well 1N.2E.34.130a, located 150 feet southeast and 10 feet higher. The irrigation well is reported to have encountered water in limestone and cavernous gypsum, and to have been tested at 1,250 gpm with a drawdown of 28 feet. A drill hole 600 feet south-southwest is reported to yield little water, and an untested well (1N.2E.34.310) drilled 1,200 feet south-southwest of the stock and irrigation wells showed at least 18 feet of drawdown, owing to pumping well 1N.2E.34.130a at 500 to 600 gpm intermittently for more than a month. The untested well is reported to have penetrated limestone from 107 to 193 feet.

Downstream from the wells in section 34, Arroyo Cibola is incised into a broad expanse of silty Quaternary channel fill, but it cuts across basalt dikes and Cretaceous and Tertiary rocks which crop out at intervals across the basin in areas too small to be mapped. Scattered salt cedars grow upstream from each of these exposures, but no flow across the consolidated rock was noted. Because of the chemical similarity of the gypsiferous spring water downstream to that of wells 1N.2E.34.130 and 1N.2E.34.130a, it is believed that the present channel does not occupy the deepest part of an older channel, which is now filled with older Quaternary alluvium and may conduct underflow that does not appear at the constrictions. Farther downstream, in secs. 19, 20, and 29, T. 1 N., R. 2 E., many salt cedars grow in the arroyo. In the winter of 1949 a flow of about 10 gpm emerged from the alluvium in section 19, disappeared, and reemerged in section 13, where the flow was 25 gpm across consolidated conglomerate of Tertiary age. Coarse Quaternary alluvium again absorbed the flow a short distance downstream from the springs. The surface flows ceased in March 1950, at least partly because of renewed transpiration by the salt cedars. In addition to the water discharged by these springs, there may be some underflow in unconsolidated alluvium to the south.

The water level in the block of the San Andres formation east of Valle Cibola is probably maintained at its shallow depth by a ground-water dam at the fault contact with fine-grained Triassic and Cretaceous rocks. Ground water probably flows over the fault dam through the alluvium, which overlies both the Cretaceous and Permian rocks at the fault and over most of this broad valley of Arroyo Cibola. The present and possible buried Pleistocene channels of Arroyo Cibola probably conduct a large part or all of this subsurface overflow discharged from the San Andres formation. Heavy pumping of wells in the block of the San Andres will draw down the water level in the block and prevent underground discharge from the San Andres formation through the overlying alluvium. Direct recharge and part or all of the arroyo-underflow recharge to the San Andres formation that is probably now being discharged underground will be diverted to the pumped wells instead of moving down in the alluvium of Arroyo Cibola and feeding the springs and salt cedars downstream. Therefore, the total amount of water that can be withdrawn from the San Andres formation annually in this area without excessive withdrawal from storage is equal to the amount of annual underground discharge from the San Andres formation to the alluvium of Arroyo Cibola. Considering the size of the block of San Andres rocks here, only a moderate quantity of water can be safely withdrawn without drawing down the water levels excessively in most of the small block.

Conditions in this area are typical of those to be expected all along this belt of complexly faulted rocks, overlapped by the Popotosa and Santa Fe formations and the Quaternary alluvium, which extends south to the vicinity of Carthage, N. Mex., and north to Arroyo Agua Tones. Sufficient water for small-scale irrigation may be available from small blocks of permeable rocks in many localities such as the one described above; large-scale irrigation seems impracticable.

Water-Level Contours

Water-level contour lines connect points on the water table or piezometric surface that are at the same altitude. The data upon which the contours are based are best obtained by measuring the depth to water below the land surface or below a measuring point at a well. The measured depth to water is then subtracted from the altitude of the reference point to give the altitude of the water level. The water-level altitudes were plotted on a map, and contour lines drawn between the plotted points. (See pl 2.) In the present investigation only measured depths to water were used for control in drawing the contours, but the altitudes were determined by an aneroid barometer, except at those wells at which U. S. Geological Survey bench marks were located. The elevations determined by aneroid survey are believed to be accurate within ±15 feet, the accuracy depending on the distance from the nearest benchmark.

As ground water moves at right angles to the water-level contours, the general direction of movement and the gradient of the water table or piezometric surface at any point can be determined from the contours on Plate 2. Ground water moves toward water-table depressions and away from water-table mounds. Because of minor deflections caused by local differences in the permeability of the rocks, evapotranspiration, and local recharge from irrigation water and arroyo runoff, only the general direction of movement can be determined. All these factors may cause deflections on a scale smaller than the contour interval, or smaller than can be detected by widely spaced water-level measurements. The general pattern of water-table contours in the vicinity of a stream may indicate whether the stream is receiving water or losing water to adjacent rocks. Water-table contours that are deflected upstream in the vicinity of a stream valley indicate an effluent stream—one that gains water from the rocks across which it flows. Contours deflected downstream indicate that a ground-water mound is built up by a stream which loses water by inflow to the adjacent rocks.

The general pattern of the water-table contours in the Santa Fe formation of the Rio Grande valley (see pl 2) indicates that ground water is contributed from the mesas to the river. Where the contours cross the Rio Puerco valley, a slight deflection of the contours downstream indicates that the Rio Puerco loses water by seepage to the Santa Fe formation. Surface-water data (Surface water supply of western Gulf of Mexico basins, 1939-47) also show that the Rio Puerco loses an average of at least 5,800 acre-feet per year between the Rio Puerco and Bernardo gaging stations, or an average of more than 190 acre-feet per mile annually. This recharge to the Santa Fe formation is part of the 820 acre-feet per mile that moves toward the Rio Grande in the Belen valley (Theis and Taylor, 1939, pp 269-270). It must be emphasized that the methods used to calculate the seepage losses of the Rio Puerco are such as to yield a minimum estimate, and that the total annual contribution by that stream may be far greater than these estimates.

Availability of Water In Northeastern Socorro County

On Plate 2, that part of northeastern Socorro County and Valencia County investigated is divided into areas and subareas based upon the quality and quantity of the water, and the depth to water. The boundaries of the areas are located approximately by reference to the geology and well data. The numbers of the areas, given below, correspond to those on Plate 2. More detailed discussions of hydrology and geology are found in the sections on ground-water areas in the text, pages 47-73.

1. Mountains: The Manzano, Los Pinos, and Ladron Mountains are composed of crystalline Precambrian rocks, which may yield water to shallow dug wells in the decomposed rock of the larger canyons, to springs emerging from joints or small faults, or to drilled wells as much as a few hundred feet deep intersecting water-bearing joints or faults. The quality is fair to good, but the quantity is likely to be very small. Locally, small water supplies may be found perched in Quaternary alluvial veneers of arroyos, or may be developed from springs emerging from joints and faults.

2. Limestone highlands: These areas bordering the mountains are incised by deep canyons. Although the recharge is probably large, water under the high inter stream areas is at great depths, except for possible local perched-water bodies. Water can be found at moderate depths in some canyons or un dissected areas, or where the rocks dip toward faults. Small-scale irrigation may be possible in such places, such as near the Montosa and Paloma faults east of the Los Pinos Mountains.

3. Cuesta area: Perched water bodies provide water of varying quality which is mostly high in sulfate. Generally, water suitable only for stock is available at less than 150 feet, except in very high areas. The quality of water may be better where local recharge occurs into the Abo formation and the Meseta Blanca sandstone member at the base of the Yeso formation.

4. Rio Grande depression: The alluvium-filled valleys of the Rio Grande, Rio Puerco, and Rio Salado comprise Area 4a and contain shallow underflow of poor quality at depths less than 50 feet. In the Rio Grande valley better water generally may be obtained, however, in the Santa Fe formation at greater depths. The quantity available is generally moderate, but in favorable localities large quantities may be available for supplemental irrigation. At present such areas cannot be determined without test drilling. Good water may be obtained at 50

to 450 feet in Area 4b, except at the south end, where water of poor quality probably will be encountered. Water of fair to poor quality at depths of 100 to 450 feet is to be expected in Area 4c. Wells in Area 4d produce the softest water in the entire area investigated. The depth to water ranges from 50 to about 450 feet. The quantity is unknown. Area 4e yields water high in sulfate at depths similar to those in 4d.

5. Alluvial fans: Good water in the Santa Fe formation and Quaternary alluvium may be encountered here in places at shallow depths semi perched on crystalline rocks. These perched-water bodies are likely to be too thin to support heavy pumping but may supply adequate domestic and stock supplies.

6. Areas of pre-Santa Fe Tertiary rocks: In the badlands of Area 6a faulted clay and siltstone strata yield either very highly mineralized water or none at all. Some water fit for stock may be obtained from coarse, well-cemented sandstones in the western part of the area, in arroyo alluvium, in the thick pediment gravels, and in weathered Precambrian rocks near the Ladron Mountains. Area 6b at depths of 250 to 400 feet probably will yield water of poor quality fit only for stock.

7. Joyita area: Area 7a offers poor prospects for potable ground water because evapotranspiration has concentrated dissolved solids in the shallow ground water. The most likely source of good water is in the fans bordering the basin, especially those fans that receive drainage from large areas of the surrounding hills. Area 7b is not likely to yield good water, but small quantities fit for stock may be available from alluvium, decomposed crystalline rocks, or deformed sedimentary rocks. Sandstone, limestone, and gypsum in all the sedimentary formations on the west side of the Joyita uplift are potential aquifers in this area, but their occurrence is on a small scale and impossible to describe in detail. Area 7c contains outcrops of limestone and gypsum of the San Andres formation, which locally yield water of fair quality at shallow depth because of damming by contact with impermeable rocks, and Permian sandstones that locally yield good water perched above shale.

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TABLE 3. RECORDS OF WELLS IN NORTHEASTERN SOCORRO COUNTY AND ADJACENT AREAS, N. MEX.

EXPLANATION OF WELL TABLE

LOCATION NUMBER: The location is described by means of location numbers, as explained on pages 20-23. An asterisk after the well-location number indicates that a chemical analysis of a water sample from the well is given in Table 5. The symbols V and T indicate wells in Valencia or Torrance County respectively. All other wells are in Socorro County.

AQUIFERS: Symbols are the same as used on the geologic map, Plate 1. Tsf generally refers to the undifferentiated Santa Fe formation.

ALTITUDE OF LAND SURFACE: Determined by aneroid-barometer traverse to nearest benchmark. Accuracy variable with distance to benchmark and local weather conditions, but generally within ±15 feet. Benchmark at well indicated in remarks column.

WATER LEVEL: Measured levels given to nearest 0.1 foot; reported levels given to nearest foot.

USE:

S = Stock
D = Domestic
A = Abandoned
I = Irrigation
T = Test hole
RR = Railroad
Sch = School

REMARKS: Temperatures given in degrees Fahrenheit. All wells pumped by lift pumps, windmill operated, unless otherwise noted in remarks column. All wells drilled unless noted otherwise in remarks column. Specific capacity in units of gpm per foot of drawdown.

See tables that follow:

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUI-FERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
1N.1E.2.130*	Campbell Farming Corp.	Tsf	—	4,838	116.1	5-16-50	S	Drawdown 8 ft at 4 gpm. Sulfate taste. Temperature 67°F.
1N.2E.15.220*	do.	Py (?)	—	—	—	—	S	Sulfate taste. Temperature 64°F.
21.120	do.	—	—	7,100	61.2	1-24-50	S	Mine shaft cased and backfilled.
34.130*	do.	Psl	33	5,200	25.0	do.	SD	Sulfate taste. Temperature 65°F.
34.130a	do.	do.	120	5,210	31.6	1-27-50	I	Gasoline powered turbine pump. Reported drawdown 28 ft at 1,250 gpm. Sulfate taste.
34.310	do.	do.	193	5,239	65 82.7	4-50 5-18-50	I	Well 1N.2E.34.310a, 1,200 ft north, pumping 5-18-50.
1N.3E.15.340	do.	p€	385	—	—	—	S	Slight sulfate taste. Reported yield 12 gpm from schist.
15.340a	do.	do.	265	—	54.2	11-29-49	T	Water reported at 72, 85, 103, and 195 ft.
16.430	do.	Qal	30	5,715	—	—	SA	Reported once adequate, now dried up and filled in.
1N.4E.3.444	A. Sanchez	Pa	145	6,319	137.1	8-22-49	S	—
10.120*	E. Bryan	do.	169	6,353	146.0	do.	SD	Slight sulfate taste.
11.244*	W. G. Broome	Pym	163	—	118	1921	SD	—
14.113*	E. Bryan	Pa	—	6,287	163	8-31-49	S	Water-level measurement approximate only.
26.424	R. Sais	Py	—	6,144	141.9	11-16-49	SD	—
29.413*	E. Bryan	Pa	180+	—	154.5	8-31-49	S	Cased to 20 ft. Slight sulfate taste.
35.434	R. Sais	Py	160+	—	100	8-2-49	S	Water-level measurement approximate only.
1N.5E.7.311*	E. Bryan	Pym	162	6,225	140.2	11-16-49	S	—
2N.1E.3.330	D. B. Salas	Qal (?)	40	—	13.6	8-16-49	DA	Dug well backfilled around 2-inch casing.

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUIFERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
2N.1E.3.330a	D. B. Salas	Qal (?)	80	—	—	—	D	Equipped with 2-hp electric pump. Temperature 66°F. East of well 2N.1E.3.330.
4.444*	do.	Tsf	285	—	23.6	8-5-49	D	Electric jet pump.
2N.1E.23.330*	Contreras School	Qal	—	4,753	27.4	1-25-50	Sch	—
31.440*	Campbell Farming Corp.	do.	150	—	—	—	D	Very salty, bitter water.
2N.2E.6.110	N. Mex. Boys' Ranch	Tsf	170	4,763	37	2-49	S	Casing perforated 150 to 170 ft. Reported drawdown 5 ft at 30 gpm.
9.330*	Campbell Farming Corp.	do.	—	4,993	255.0	12-7-49	S	—
31.110*	do.	do.	—	5,016	270.2	5-16-50	S	4-ft drawdown at 2 gpm. Temperature 69°F. Slight sulfate taste.
36.330	do.	do.	715	5,248	369.7	12-7-49	S	Gasoline powered.
2N.3E.10.410	West-Pyle Cattle Co.	do.	420	5,217	380+	9-2-49	S	—
18.240	Campbell Farming Corp.	do.	—	5,116	328.4	12-7-49	S	Equipped with 2-hp gasoline engine.
23.120	do.	—	180	—	Dry	7-26-49	T	Granite reported at 150 ft.
34.330	do.	Tsf	196	5,505	116.2	7-26-49	SD	—
2N.4E.3.340	M. Miranda	p€	25	5,728	22.5	9-2-49	SD	Small yield, dug well, in schist.
12.223	R. E. Miller	Pb	32	5,810	30.2	8-4-49	D	Small yield. Water level not static. Dug well.

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUI-FERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
2N.4E.14.224	R. B. Laing	Cml	59	5,833	55.8	do.	SD	1-hp gasoline pump and windmill. Reported bailed at 30 gpm when drilled.
14.232	do.	—	—	5,840	48.7	11-17-49	A	—
16.420*	Campbell Farming Corp.	p€	—	5,995	23.1	12-8-49	S	Small yield. Dug well in schist. Temperature 56°F.
16.420a	do.	do.	—	5,994	16.1	do.	SA	Dug well in schist.
19.200	do.	do.	18	—	15.3	7-26-49	S	Very small yield. Dug well in schist.
23.223	F. Barelas	Qal	12+	5,891	9.8	8-4-49	SD	Temperature 64°F. Dug well.
28.432	R. P. Parker	p€	26	6,314	25.1	7-28-49	S	Dug well in schist.
28.432a	do.	p€	47	6,340	35.2	7-28-49	D	Necessary to deepen well annually since 1944. Dug well in schist.
36.142*	A. Sanchez	Pa (?)	—	5,995	21.3	8-22-49	SD	Sulfate taste. Dug well.
2N.5E.6.223*	T. Pineda	Pb	100	5,769	41.0	8-29-49	SD	Temperature 58°F.
7.140	R. B. Laing	do.	175	5,884	127.9	8-4-49	S	Small yield. Temperature 65°F. Water level drawn down by pumping.
8.430	do.	Pa	125	5,943	124.2	do.	S	Slight sulfate taste. Maximum yield 3 gpm. Temperature 63°F.
9.130	J. J. Contreras	do.	55+	—	—	—	—	—
20.244*	do.	do.	58	6,026	39.8	7-28-49	S	Sulfate taste. Temperature 57°F.
29.240	J. J. Brazil	Py	125	6,153	—	—	SD	Sulfate taste.
33.222*	E. Bryan	do.	200	6,215	45.9	11-16-49	S	Sulfate taste. Temperature 57°F.
3N.1E.14.210	Sabinal School	Tsf	—	4,774	33.7	8-24-49	Sch	—
15.440	Mr. Abeytas	do.	137	4,807	83	do.	S	—

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUIFERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
3N.1E.16.140	Campbell Farming Corp.	Tsf	585	5,074	334	1939	TS	Oil test well.
34.430*	J. Averitt	do.	155	4,739	—	—	D	Equipped with electric jet pump.
34.430a*	do.	Tsf (?)	35	4,745	20	6-48	D	Driven well.
3N.2E.15.240	J. E. Bryan	Tsf	200+	4,981	—	9-1-49	S	Strong sulfate taste.
26.330	do.	do.	250+	5,005	244.8	12-7-49	S	Sulfate taste. Equipped with windmill and gasoline engine.
30.230	C. Romero	Qal	—	4,760	23.5	9-1-49	SD	—
3N.3E.16.440*	West-Pyle Cattle Co.	Tsf	400	5,175	—	—	SD	Temperature 66°F.
20.130*	do.	do.	380	—	—	—	S	—
32.240*	do.	do.	388	—	—	—	S	—
4N.1E.27.320	Campbell Farming Corp.	do.	500±	—	—	—	—	Reported yield 12 gpm.
1N.1.3.410	do.	Tsf	250+	4,975±	—	—	S	—
17.210	do.	Qal	—	—	17.2	1-14-50	S	Salty taste. Water level not static.
22.220*	do.	do.	—	4,816	12.0	do.	SD	Salty taste. Small yield. Water level not static.
34.330*	do.	Tsf	—	4,801	118.5	1-15-50	S	Reported gravel packed. Salty taste. Drilled by owner.
1N.2.1.330*	do.	Qal	44	4,984±	10.9	11-30-49	S	Small-yield well. Salty taste. Drilled by owner.
2N.1.9.220	do.	Tsf	400	5,065±	295+	7-14-49	S	Reported yield 8 gpm. Temperature 67°F.
13.220	do.	do.	140 (?)	4,861±	134.5	7-15-49	S	—

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUIFERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
2N.1.19.110	Campbell Farming Corp.	Tp	360	5,345±	Dry	8-5-49	TA	Drilled by owner.
22.440	do.	Tsf	450	5,020±	280	5-49	TA	—
30.330*	do.	Tp	90	5,150	7.0	11-30-49	S	Salty taste.
2N.2.3.340	Mr. Jeter	p€	285	—	—	—	SD	Small yield reported.
14.420	Campbell Farming Corp.	Tp (?)	195	5,526	40	8-49	TA	Yield reported small.
24.220	do.	Tp	90	5,368	84.5	7-21-49	TA	Very small yield reported.
36.440*	do.	do.	320	5,090	0.0	do.	TA	Extremely salty. Very weak flow.
2N.3.23.000	—	Cml	268+	—	268+	1-4-50	S	—
3N.1.15.222	Bryan and Mumford	Tsf	135	4,890	116.9	11-21-49	SD	—
21.310	—	do.	—	5,122	191.3	12-21-49	S	—
25.444	Bryan and Mumford	do.	85	4,783	36.2	11-21-49	S	Specific capacity 1±. Sulfate taste. Temperature 62°F.
31.440	J. M. Smith	Tsf (?)	20	5,346	18.6	12-21-49	S	Windmill pumping 2-3 gpm, 12/21/49. Possibly in pediment gravel or fan.
35.430	do.	Tsf	190	4,939	175.6	11-21-49	SD	Reported yield 8 gpm, when drilled. Specific capacity less than ½.
3N.2.14.323	M. Baca	Qal	—	5,394	25.8	1-6-50	SA	—
14.331	E. Lopez	do.	—	5,406	27.1	do.	SD	—
14.332	do.	do.	—	5,403	27.7	do.	SD	—
22.214a	do.	do.	—	5,472	33.9	do.	SDA	Dug well backfilled around casing.
22.234*	do.	Tp (?)	40	5,578	18.4	do.	SD	—
22.411	do.	p€	30	—	20.4	do.	SDA	Quartzite.

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUIFERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
3N.2.32.223	—	Tsf (?)	45	—	Dry	1-50	A	Possibly in pediment gravel.
4N.1.14.111*	F. D. Huning	Tsf	232±	5,036	226.8	12-26-49	S	Benchmark near well.
28.440	do.	do.	—	5,007	208.3	do.	S	—
36.140	Jim Storey	do.	—	4,849	55.2	11-21-49	S	Benchmark at well. Bitter taste. Small yield.
4N.3.24.131	F. D. Huning	Tp	—	—	241.4	5-25-50	S	Salty water.
1.1E.1.430	Campbell Farming Corp.	—	—	5,120	123.7	1-26-50	S	Benchmark at well. Salty and bitter.
9.410	do.	Tsf	—	5,012	352	2-22-50	S	Benchmark at well. Salty water. Measurement of water level approximate.
36.140	Bland and McDonald	Qal (?)	145	—	36	5-18-50	S	Salty and bitter. Poorer water at 40 ft cased off.
1.2E.19.220*	Campbell Farming Corp.	—	—	—	103.3	1-26-50	S	Very salty and bitter.
20.240	do.	Py (?)	9+	—	7.3	2-23-50	S	—
29.340*	Bland and McDonald	Qal (?)	13	—	4.7	1-27-50	SA	—
31.114	do.	Kd (?)	110	—	—	—	S	Dug well, caved. Reported not potable.
1.3E.2.310	J. W. Conant	Cma	92	5,829	73.9	8-12-49	S	Benchmark at well. Reported large yield. Agua Torres well.
6.130*	T. D. Campbell	Qal	35+	5,519	12.20	12-28-50	S	Sulfate taste. Specific capacity 1±. Temperature 61°F.
12.211	J. W. Conant	Pa	60	—	40.11	8-12-50	SA	Reported small yield.
16.240	do.	Py (?)	90	—	54.21	do.	S	Cibola well. Slight sulfate taste.

See explanation at beginning of table.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUIFERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Socorro County				
1.3E.30.110	J. W. Conant	Qal or Pym	29	—	13.7	8-12-49	S	Rancho Grande well. Sulfate taste.
34.210	do.	Pym or Pa	397	—	357	8-50	S	Water level reported by owner. Ponciana well. Sulfate taste.
1.4E.6.444	do.	Pa	185	—	140.00	8-12-50	SD	—
1.1.2.120*	E. Chavez	Tsf	98	4,672	29.00	1-15-50	SD	Salty, bitter water; yield reduced by sand.
				Valencia County†				
V3N.3E.5.320	West-Pyle Cattle Co.	do.	330+	—	—	—	S	Salty, bitter taste.
10.430*	A. T. & S. F. Railway	do.	420	5,175	367.70	8-26-50	RR	Benchmark near well.
10.430a	do.	do.	420	5,175	364	1905	RR	Drawdown 36 ft at 50 gpm. 150 ft west of well V3N.3E.10.430.
V3N.5E.9.424	Mr. Padilla	Pb	82+	—	82.0+	3-27-50	SD	—
9.424a	do.	Qal	—	—	22.20	3-28-50	SDA	—
16.410	M. M. McKinley	Pa	—	—	40+	3-29-50	SD	—
28.444*	C. Pohl	do.	21	5,835	11.90	8-29-50	SD	—
32.210	M. A. Pohl	do.	25	5,800	20.69	do.	SD	Reported flow 0.1 gpm. Measured water level while pumping 1 gpm.
V4N.2E.15.440*	Campbell Farming Corp.	Tsf	160	—	—	—	—	—

See explanation at beginning of table.
† Only those shown on Plate 2.

TABLE 3 (continued).

LOCATION NUMBER	OWNER	AQUI-FERS	DEPTH (ft)	ALTITUDE (ft)	WATER LEVEL BELOW LAND SURFACE (ft)	DATE MEASURED	USE	REMARKS
				Valencia County†				
V4N.2E.20.220	A. Baldonado	Tsf (?)	32	4,790	16.32	5-16-50	D	Driven well, hand pump.
35.220*	Campbell Farming Corp.	Tsf	187	4,957	170.09	do.	S	Small yield. Temperature 73°F.
V4N.3E.20.130	West-Pyle Cattle Co.	do.	—	—	—	—	S	—
23.430*	West-Pyle Cattle Co.	Tsf	370	—	—	—	S	Temperature 72°F.
V4N.1.12.343	F. Padilla	do.	60+	4,867	57.84	12-27-49	S	—
V4N.2.11.211	F. D. Huning	do.	—	5,243	401.23	do.	SDA	—
V5N.1.32.444	do.	do.	—	5,189	398.7±	do.	S	—
				Torrance County†				
T2N.5E.3.310	C. Pohl	—	50	5,855	45.98	8-29-49	SD	Sulfate taste. Low yield.
10.332	R. B. Laing	—	—	5,931	34.41	11-17-49	S	—

See explanation at beginning of table.
† Only those shown on Plate 2.

TABLE 4. RECORDS OF SPRINGS IN NORTHEASTERN SOCORRO COUNTY AND ADJACENT AREAS, N. MEX.

EXPLANATION OF SPRING TABLE

LOCATION: The location is described by means of location numbers as explained on pages 20-23. An asterisk after the number indicates that a chemical analysis of the water is given in Table 5. The symbols V and T indicate springs in Valencia or Torrance County respectively. All other springs arc in Socorro County.

YIELD: All yields estimated, unless marked M for measured.

REMARKS: First number is altitude, determined by aneroid-barometer traverse to nearest benchmark; accuracy variable with distance to benchmark and local barometric conditions, but generally ± 15 feet. All used for stock unless otherwise indicated.

TABLE 4 (continued).

LOCATION NUMBER	OWNER	TOPOGRAPHIC SITUATION	YIELD (gpm)	DATE	WATER-BEARING UNIT (SOURCE AND OUTLET BEDS)	REMARKS
			Socorro County			
1N.2E.19.140*	Campbell Farming Corp.	Arroyo floor	10 Dry	1-27-50 5-50	Quaternary alluvium	Sulfate taste. Sample taken in sec. 3, T. 1 N., R. 2 E.
2N.4E.1.430	West-Pyle Cattle Co.	Arroyo wall	5	8-30-49	Madera limestone formation	Large water use by salt cedars.
12.210*	R. E. Miller	Head of canyon	¾ M	8-26-49	do.	Dripping Springs, 5,773. Reported small flow since 1945. Domestic supply.
2N.5E.4.110	—	Floor of Arroyo Abo	10-15	1-50	Abo formation (source), Quaternary alluvium	Sulfate taste.
9.440	R. B. Laing	Narrow arroyo bottom	—	—	Abo formation	Vega Spring, 5,897. Spring flow is reabsorbed by alluvium.
3N.4E.33.440	West-Pyle Cattle Co.	Small arroyo in mountain front	—	8-22-49	Precambrian schist	Blue Springs.
1N.2.1.330	Campbell Farming Corp.	Broad arroyo terrace of Rio Salado	—	—	Quaternary alluvium	Salty water.
1N.2.7.100*	do.	Canyon walls	500	11-30-49	Madera limestone	Salty water. Source of perennial flow of Rio Salado. Temp. 70°F.
2N.2.2.430	—	Arroyo bottom	Dry	8-10-49	Popotosa formation	—

See explanation at beginning of table.

TABLE 4 (continued).

LOCATION NUMBER	OWNER	TOPOGRAPHIC SITUATION	YIELD (gpm)	DATE	WATER-BEARING UNIT (SOURCE AND OUTLET BEDS)	REMARKS
			Socorro County			
2N.2.12.110	Campbell Farming Corp.	Arroyo	1	8-10-49	Popotosa formation	Yeso Springs.
3N.2.14.420	Lopez	Shallow arroyo bottom	—	5-49	Quaternary alluvium	5,244.
4N.3.25.334*	—	Arroyo floor	100	1-5-50	Arroyo underflow; source is in NE¼ sec. 4, T. 3 N., R. 3 W.	Salty water. Flow absorbed by alluvium one-quarter mile downstream.
1.2E.20.240*	Campbell Farming Corp.	Hillside	3	2-23-50	Abo (?) formation	—
29.330	do.	Broad valley	—	—	Quaternary alluvium	Salty, alkali water.
30.340	do.	Foot of alluvial fan	¼	2-23-50	Quaternary (?) alluvium	do.
			Valencia County			
V3N.4E.14.140	West-Pyle Cattle Co.	Base of alluvial fan	2½ M 0.1 M	9-2-49 3-27-50	Quaternary alluvial fan	5,897.
V3N.5E.30.100	—	North wall of canyon	¼-½	12-2-49	Madera limestone formation	Slight sulfate taste.
			Torrance County			
T4N.5E.16.332	U. S. Forest Service	Hillside	3	3-28-50	do.	Pine Shadow Spring.

See explanation at beginning of table.

TABLE 5. CHEMICAL ANALYSES OF WATER FROM WELLS IN NORTHEASTERN SOCORRO AND SOUTHEASTERN VALENCIA COUNTIES, N. MEX.

(Numbers correspond to numbers in Table 3.)

Analyses by Geological Survey (parts per million, except percent sodium and specific conductance)

LOCATION NUMBER	DATE OF COLLECTION	SPECIFIC CONDUCTANCE (micromhos at 25°C)	SILICA (SiO_2)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM AND POTASSIUM (Na + K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	DISSOLVED SOLIDS	HARDNESS AS $CaCO_3$	PERCENT SODIUM
						Socorro County								
1N.1E.2.130	1-25-50	677	28	90	18	27	128	195	23	0.3	20	464	298	17
1N.2E.15.220	1-24-50	1,360	24	184	49	53	135	521	24	.5	108	1,030	660	15
34.130	do.	2,760	21	562	130	21	142	1,770	10	.6	10	2,590	1,940	2
34.130a	2-3-50	2,850	18	586	144	15	130	1,880	13	.7	4.3	2,720	2,050	2
1N.4E.10.120	12-19-49	956	12	16	6.6	187	259	203	32	1.3	.8	586	67	86
11.244	do.	830	23	68	40	55	280	171	25	1.1	4.2	525	329	27
14.113	8-31-49	2,860	25	408	114	241	212	1,710	36	.8	4.1	2,640	1,490	26
29.413	12-19-49	774	19	38	25	96	302	73	57	.6	.8	458	198	51
1N.5E.7.311	do.	2,420	23	466	135	10	130	1,500	14	.7	24	2,230	1,720	0
2N.1E.4.444	8-23-49	820	34	14	3.1	161	122	242	28	1.1	3.2	546	48	88
23.330	1-25-50	1,070	27	88	35	84	99	314	94	1.0	4.4	696	364	33
31.440	2-15-50	3,910	26	145	75	639	262	896	645	.6	2.0	2,560	670	67
2N.2E.9.330	12-1-49	1,040	—	105	38	74	128	384	48	—	8.0	720	418	28
31.110	1-25-50	1,130	24	77	32	115	122	389	42	2.0	4.9	746	324	44
2N.4E.16.420	12-8-49	1,470	—	126	56	119	287	335	130	—	46	953	545	32
36.142	8-22-49	1,710	26	244	94	50	286	794	19	.9	16	1,380	996	10
2N.5E.6.223	12-8-49	2,060	—	6.8	7.0	472	556	505	64	—	.7	1,330	46	96
20.244	12-19-49	3,010	—	468	184	98	175	1,830	48	—	26	2,740	1,920	10
33.222	do.	3,190	—	538	214	66	179	2,090	29	—	2.4	3,030	2,220	6
3N.1E.34.430	8-24-49	850	—	26	9.6	143	152	225	39	—	1.2	519	104	—
34.430a	do.	3,460	—	260	114	377	179	1,060	485	—	2.7	2,390	1,120	42

TABLE 5 (continued).

LOCATION NUMBER	DATE OF COLLECTION	SPECIFIC CONDUCTANCE (micromhos at 25°C)	SILICA (SiO_2)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM AND POTASSIUM (Na + K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	DISSOLVED SOLIDS	HARDNESS AS $CaCO_3$	PER CENT SODIUM
						Socorro County								
3N.3E.16.440	12-1-49	834	—	94	33	42	173	276	19	—	6.2	555	370	20
20.130	do.	1,100	—	134	45	52	161	437	28	—	6.2	782	520	18
32.240	8-26-49	1,030	—	114	42	54	160	403	16	—	1.9	710	457	20
1N.1.22.220	1-14-50	2,850	28	160	49	413	193	683	440	.5	8.8	1,880	600	60
34.330	1-18-50	3,950	54	236	64	598	197	1,050	635	.7	.7	2,740	852	60
1N.2.1.330	8-23-49	4,830	18	154	68	861	303	838	1,000	1.0	1.5	3,090	664	74
2N.1.30.330†	11-30-49	9,970	—	462	91	2,240	147	5,820	156	—	1.9	8,840	1,530	76
2N.2.36.440	8-23-49	29,400	18	480	141	8,350	271	13,100	4,310	—	—	26,500	1,780	91
3N.1.25.444	5-44	3,520	—	110	50	622	279	711	610	—	3.8	2,240	480	—
3N.2.22.234	1-6-50	710	33	72	28	40	303	76	30	1.4	9.2	439	294	23
4N.1.14.111	1-9-50	3,270	24	280	101	342	204	1,060	410	.1	12	2,330	1,110	40
1.2E.19.220	2-23-50	4,200	12	330	121	613	132	2,360	60	1.0	2.6	3,560	1,320	50
29.340	2-22-50	7,640	28	458	779	765	530	5,150	151	.2	.7	7,590	4,350	28
1.3E.6.130	12-28-49	818	25	85	38	29	246	125	34	.3	63	520	368	15
1.1.2.120	1-18-50	4,700	24	318	121	539	179	869	1,000	.2	1.6	2,960	1,290	48
						Valencia County								
3N.3E.10.320‡	8-12-03	—	—	88	42	68	68	449	37	—	—	945	—	—
10.430‡	10-3-06	—	—	132	38	85	—	455	33	—	—	834	—	—
3N.5E.28.444	8-29-49	611	16	32	25	66	272	55	27	1.0	7.6	364	183	44
32.210	do.	1,140	13	4.0	2.2	264	422	70	120	1.8	.1	683	19	97
4N.2E.15.440†	3-27-50	357	49	40	9.7	21	143	40	17	.4	2.4	250	140	25
35.220	2-24-50	310	32	24	6.3	34	115	49	9	.8	1.6	214	86	47
4N.3E.23.430	3-29-50	263	17	20	6.0	28	98	40	7	.6	1.6	168	74	45

† Collected from stock tank.
‡ Converted from grains per U. S. gallon. Analysis reported by Atchison, Topeka and Santa Fe Railway.

TABLE 6. CHEMICAL ANALYSES OF WATER FROM SPRINGS AND STREAMS IN NORTHEASTERN SOCORRO AND SOUTHWESTERN TORRANCE COUNTIES, N. MEX.

(Numbers correspond to numbers in Table 4.)

Analyses by Geological Survey (parts per million, except percent sodium and specific conductance)

LOCATION NUMBER	DATE OF COLLECTION	SPECIFIC CONDUCTANCE (micromhos at 25°C)	SILICA (SiO_2)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM AND POTASSIUM (Na + K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	DISSOLVED SOLIDS	HARDNESS AS $CaCO_3$	PERCENT SODIUM
						Socorro County								
1N.1E.13. †	1-27-50	2,980	25	576	110	82	176	1,830	12	0.6	0.4	2,720	1,890	9
2N.4E.12.210	8-22-49	1,440	25	178	58	86	236	612	20	1.5	10	1,110	682	22
1N.2.2.330‡	8-23-49	4,440	22	176	64	727	248	647	995	.7	2.2	2,760	702	69
7.	11-20-49	5,810	—	250	85	965	446	795	1,330	—	3.6	3,650	974	68
7.100§	11-30-49	5,020	—	189	59	877	420	611	1,160	—	4.9	3,110	714	73
4N.3.25.334	1-5-50	5,200	24	138	67	887	354	471	1,250	.8	4.3	3,020	620	76
1.2E.20.240	2-23-50	562	14	22	47	38	293	71	12	.4	.3	349	248	25
						Torrance County								
4N.5E.16.332	3-28-50	416	13	76	7.9	3.7	254	17	3	.2	.3	246	222	3

† Arroyo Cibola, low-water stage.
‡ Rio Salado, low-water stage.
§ Rio Salado, low-water stage below source.

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Numbers in *italics* indicate figures and plates; **boldface** indicates main references.