GEOHYDROLOGY OF THE AGUIRRE AND POZO HONDO AREAS, SOUTHERN PUERTO RICO

By Robert P. Graves

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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
	Area	
acre	0.4047	hectare
square mile	259.0	hectare
	Flow	
cubic foot per second	0.02832	cubic meter per second
	Hydraulic conductivity	
foot per day	0.3048	meter per day
	Transmissivity	
square foot per day	0.09290	square meter per day

Temperature: In this report air temperatures are given in degrees Fahrenheit (°F). Temperatures may be converted to degrees Celsius (°C) as follows:

$$°C = 5/9 \times (°F - 32)$$

Abbreviated water-quality units used in report:

microgram per liter	(µg/L)
milligram per liter	(mg/L)
microsiemen per centimeter at 25 °C	(µS/cm)

Acronyms used in report:

National Oceanic and Atmospheric Administration	(NOAA)
Puerto Rico Industrial Development Company	(PRIDCO)
U.S. Geological Survey	(USGS)

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ABSTRACT

The subsurface geology in the Aguirre and Pozo Hondo areas is primarily a fractured igneous volcanic rock (andesite) with three distinct divisions: regolith, transition zone, and bedrock. Alluvial deposits occur locally in each area. In the Aguirre area, weathered low-grade metamorphosed volcanic rock with a schistose texture and a vertical plane of foliation is found in association with the regolith.

A thin, water-table aquifer is defined in the Aguirre and Pozo Hondo areas, with ground water occurring primarily in the regolith and transition zone. The depth to the water table can range from land surface to 75 feet below land surface. Ground-water flow out of the Aguirre area is south into the southern coastal plain. Aquifer characteristics determined from 2 multiple-well aquifer tests and 21 single-well slug injection and removal tests in the Aguirre and Pozo Hondo areas indicated a range of transmissivities from 175 to 5,700 feet squared per day, hydraulic conductivities from 0.02 to 160 feet per day, and storage coefficients from 0.02 to 0.2.

The ground water in the Aguirre and Pozo Hondo areas is of the calcium-carbonate type. With the exception of dissolved solids which were as high as 1,110 milligrams per liter, concentrations of common constituents did not exceed U.S. Environmental Protection Agency's drinking water criteria.

INTRODUCTION

Since 1970, Puerto Rico has experienced significant industrial development dominated by pharmaceutical, chemical, and electronic industries. A consequence of this industrial growth has been an increase in the generation of hazardous waste materials. It is estimated that 350,000 tons of hazardous waste are generated annually (Felix Prieto, Puerto Rico Industrial Development Company, oral commun., 1986) of which 40 percent is shipped to the mainland United States (Migdalia Aponte, Autoridad para el Manejo de los Desperdicios Sólidos, written commun., 1986).

Because of Puerto Rico's limited area (3,400 square miles) and high population density (1,029 inhabitants per square mile), the management, proper storage, and disposal of hazardous wastes on the island is difficult. Future industrial growth in Puerto Rico could be significantly reduced, due to the lack of adequate facilities to properly handle hazardous wastes. For the Commonwealth of Puerto Rico to continue to encourage new industrial growth on the island, hazardous-waste sites that pose minimal ecological, hydrologic, or aesthetic threats to Puerto Rico, and that meet all governmental regulations, must be developed.

The Puerto Rico Industrial Development Company (PRIDCO) is the government agency in Puerto Rico responsible for encouraging and developing industrial growth. In the early 1980's, PRIDCO began a search for sites in Puerto Rico that could be developed into hazardous-waste facilities. To locate these potential sites, PRIDCO used the U.S. Geological Survey's (USGS) computerized data base and "geographic information system" to eliminate all areas that were not suitable for development of a hazardous-waste facility. Sites that were flood or landslide prone areas (figs. 1 and 2), protected lands of Puerto Rico (fig. 3), or overlying the principal aquifers of the island (fig. 4) were eliminated. This elimination of areas not suitable for hazardous-waste facilities was accomplished by merging the areas identified in figures 1 through 4 into one map (fig. 5), which shows that nearly all of the island is unsuitable for these facilities. Only small, isolated areas remained that might be considered suitable for development of hazardous-waste facilities. This site evaluation resulted in PRIDCO selecting two sites that they believed were adequate for development into a hazardous-waste facility.

The two sites selected by PRIDCO are located in the Aguirre and Pozo Hondo areas on the south coast of Puerto Rico (figs. 5 and 6). To gain a better understanding of the geohydrology of these areas, the USGS, in cooperation with PRIDCO initiated a detailed geohydrologic evaluation of the areas to provide PRIDCO the baseline data it needed to further evaluate the suitability of the areas as hazardous-waste sites.

Purpose and Scope

This report summarizes the results of a study started in 1986 to define the geohydrology of the Aguirre and Pozo Hondo areas on the south coast of Puerto Rico (fig. 6). The objectives of this study are to determine:

1. the geologic framework,

2. the occurrence and movement of the ground water and aquifer characteristics, and

3. the ground-water quality of the aquifer in each of the study areas.

Approach

The objectives of the investigation were addressed by first developing a two-phased test-hole drilling program. During phase one, 28 test holes were drilled at 13 sites in the Aguirre area and 5 test holes were drilled at 2 sites in the Pozo Hondo area using the USGS hollow-stem auger. Of the test holes drilled, 26 were completed as test wells in the Aguirre area and all were completed as test wells in the Pozo Hondo area. Depths of test holes drilled during phase one ranged from 9 to 95 feet below land surface. Continuous cores were collected in these test holes with a split spoon sampler to depths of up to 52 feet below land surface.

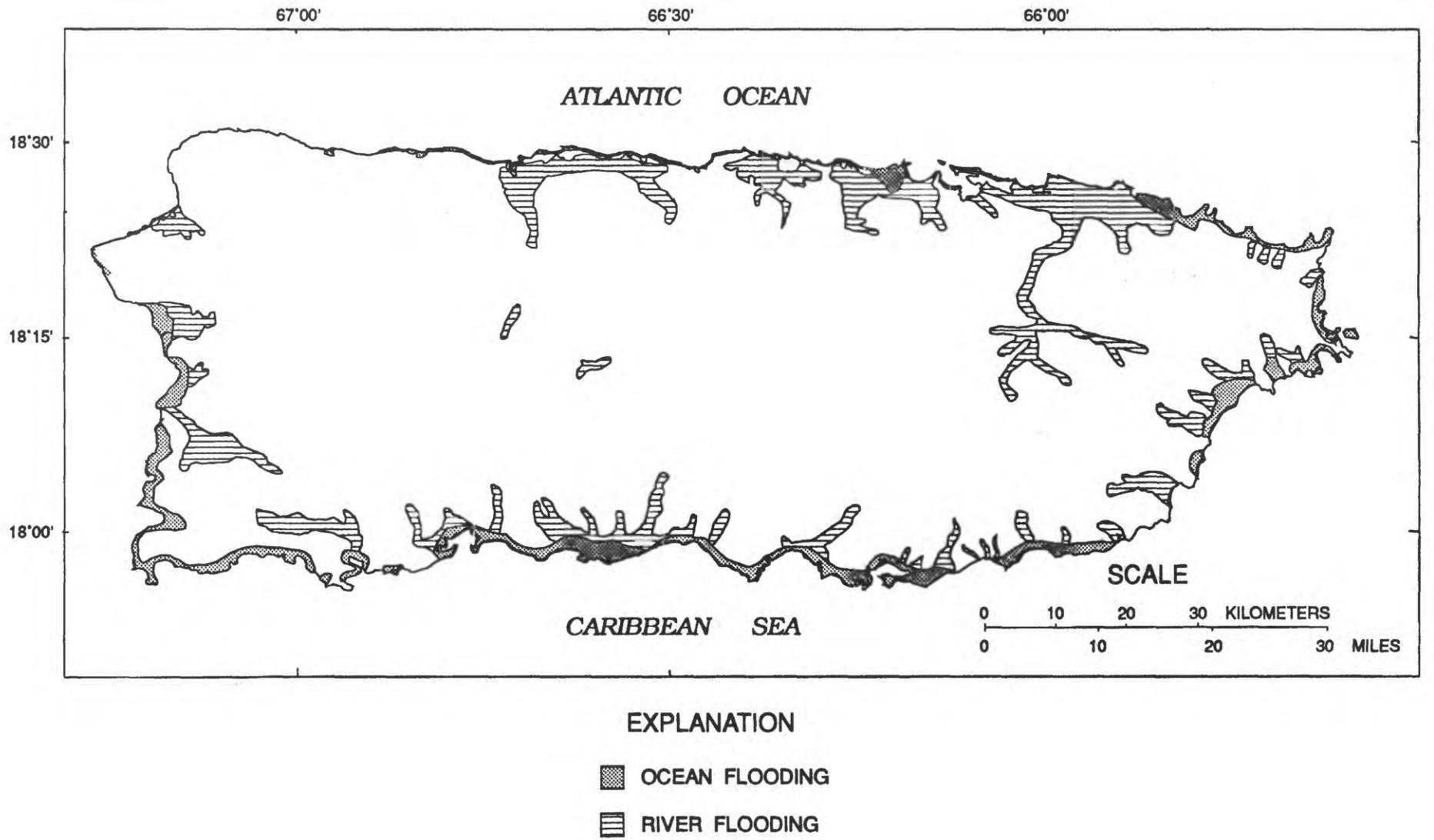


Figure 1.--Areas susceptible to river and ocean flooding in Puerto Rico.

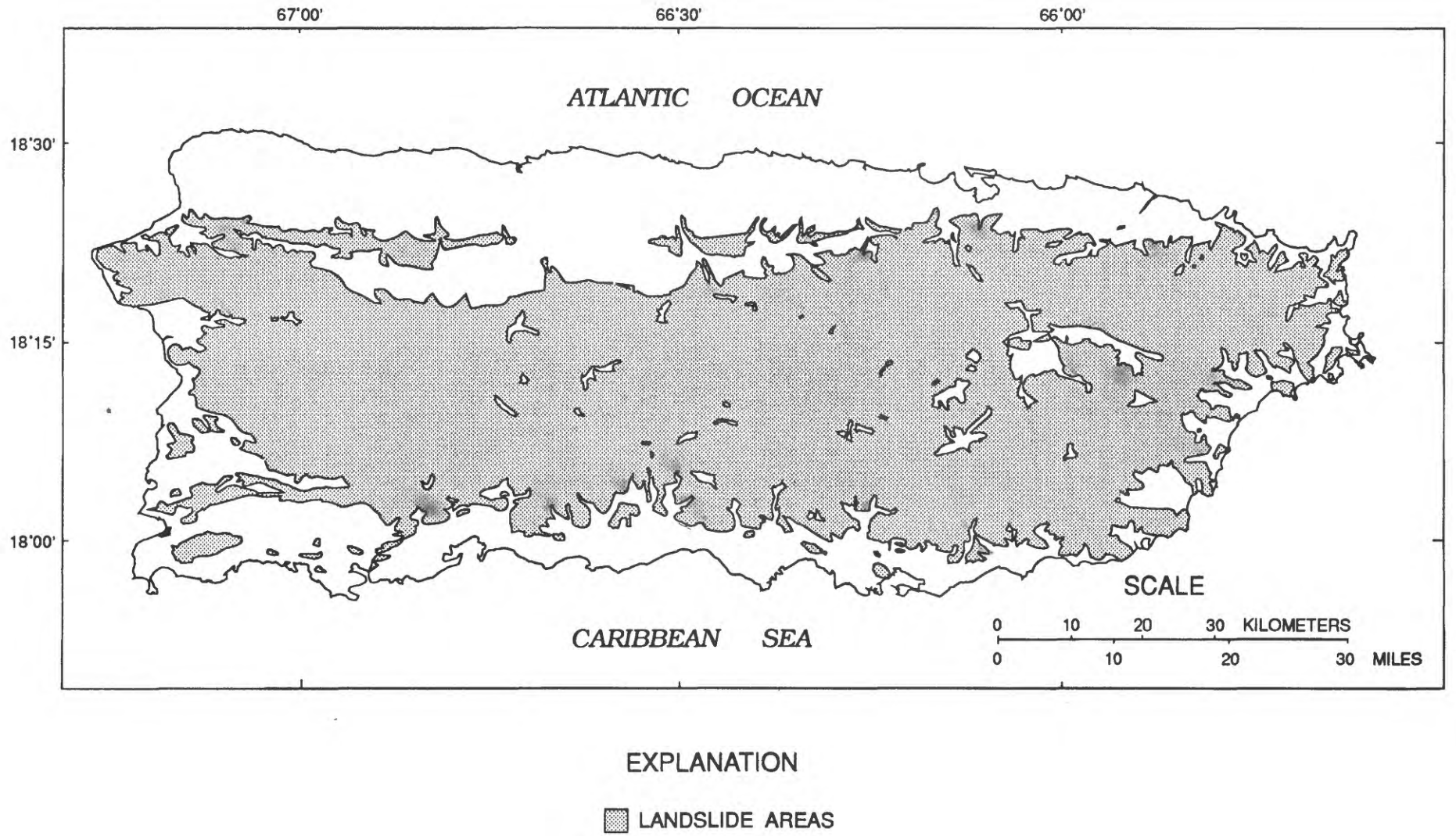


Figure 2.--Areas susceptible to landslides in Puerto Rico.

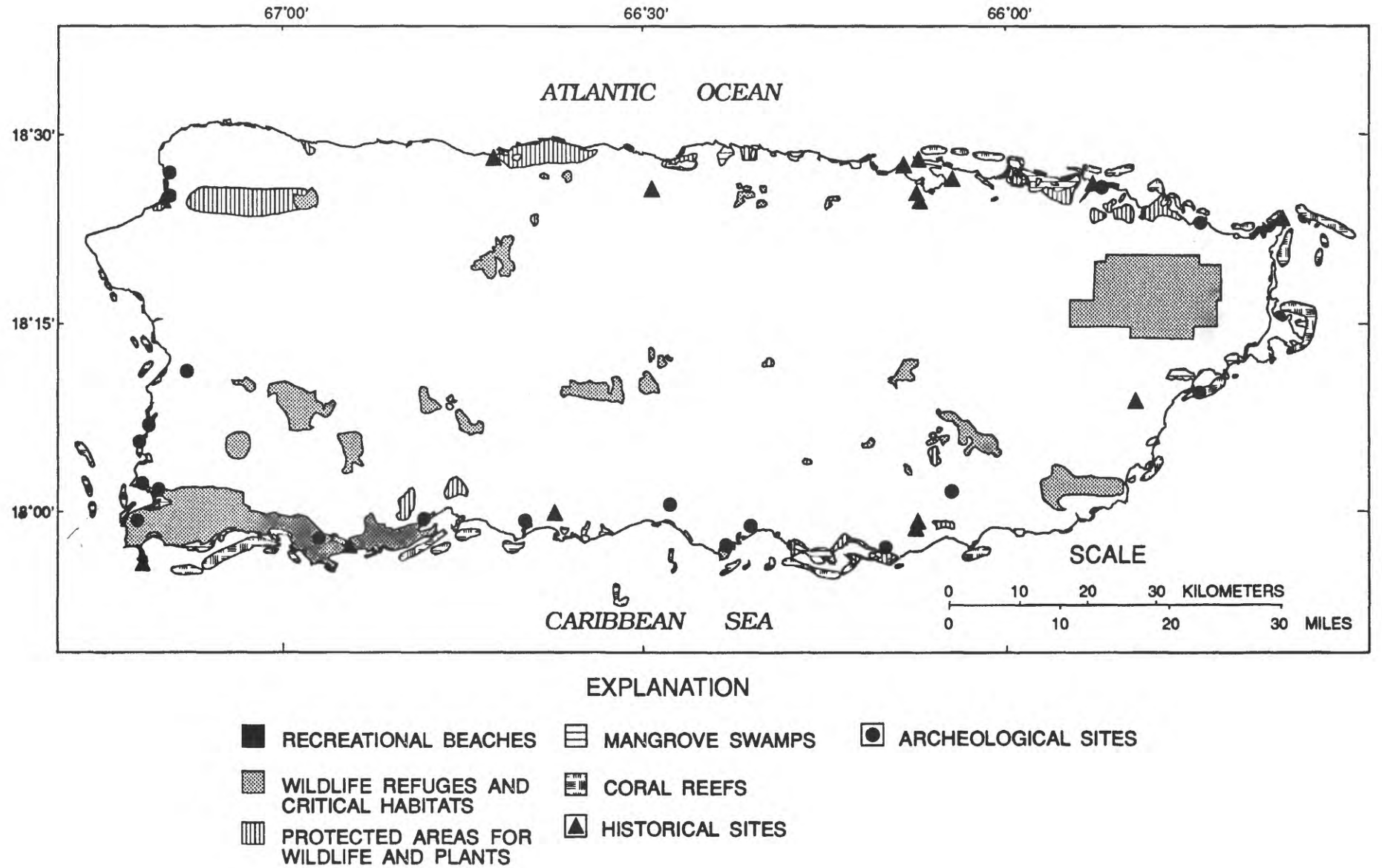
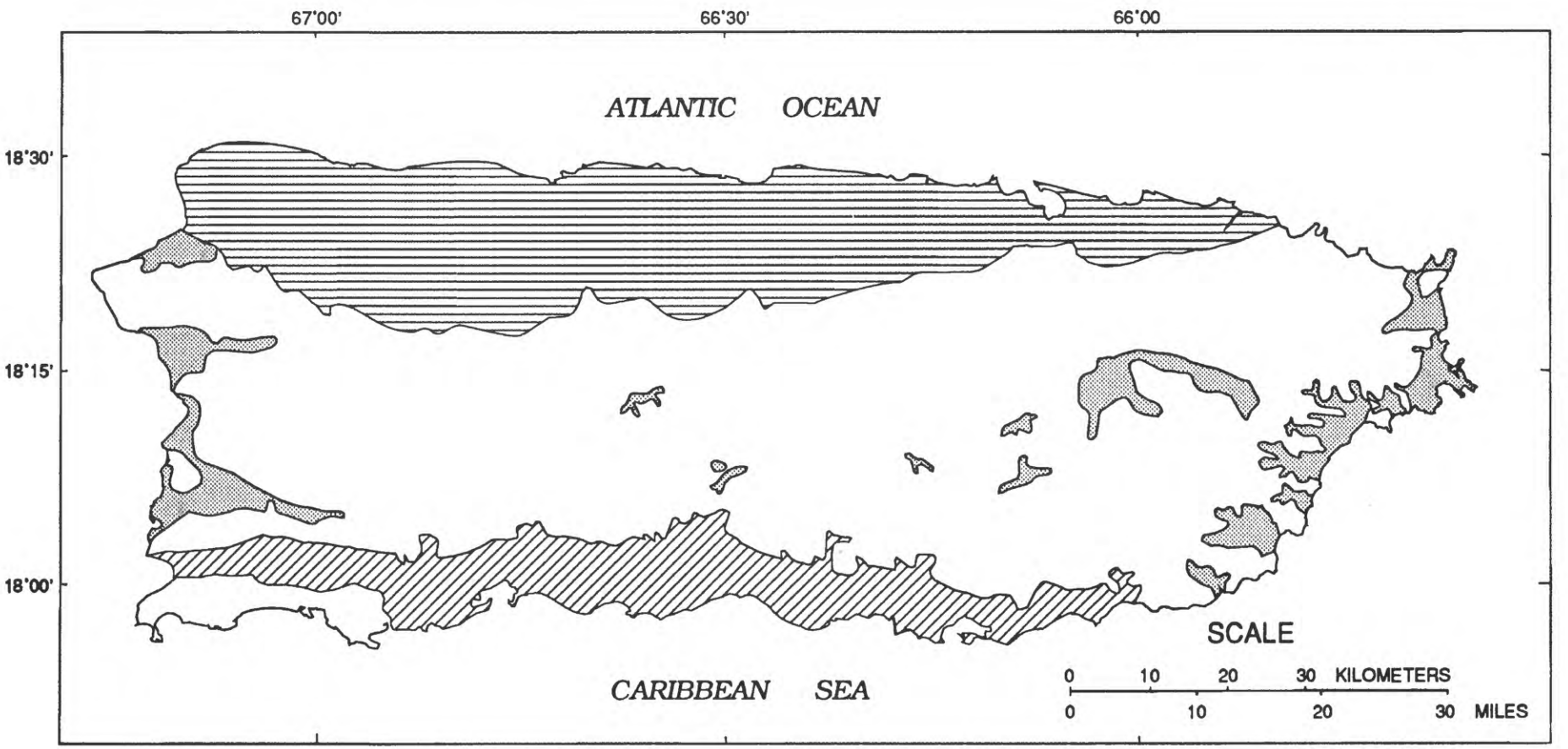


Figure 3.--Protected lands in Puerto Rico (modified from the Puerto Rico Electric and Power Authority, 1980).



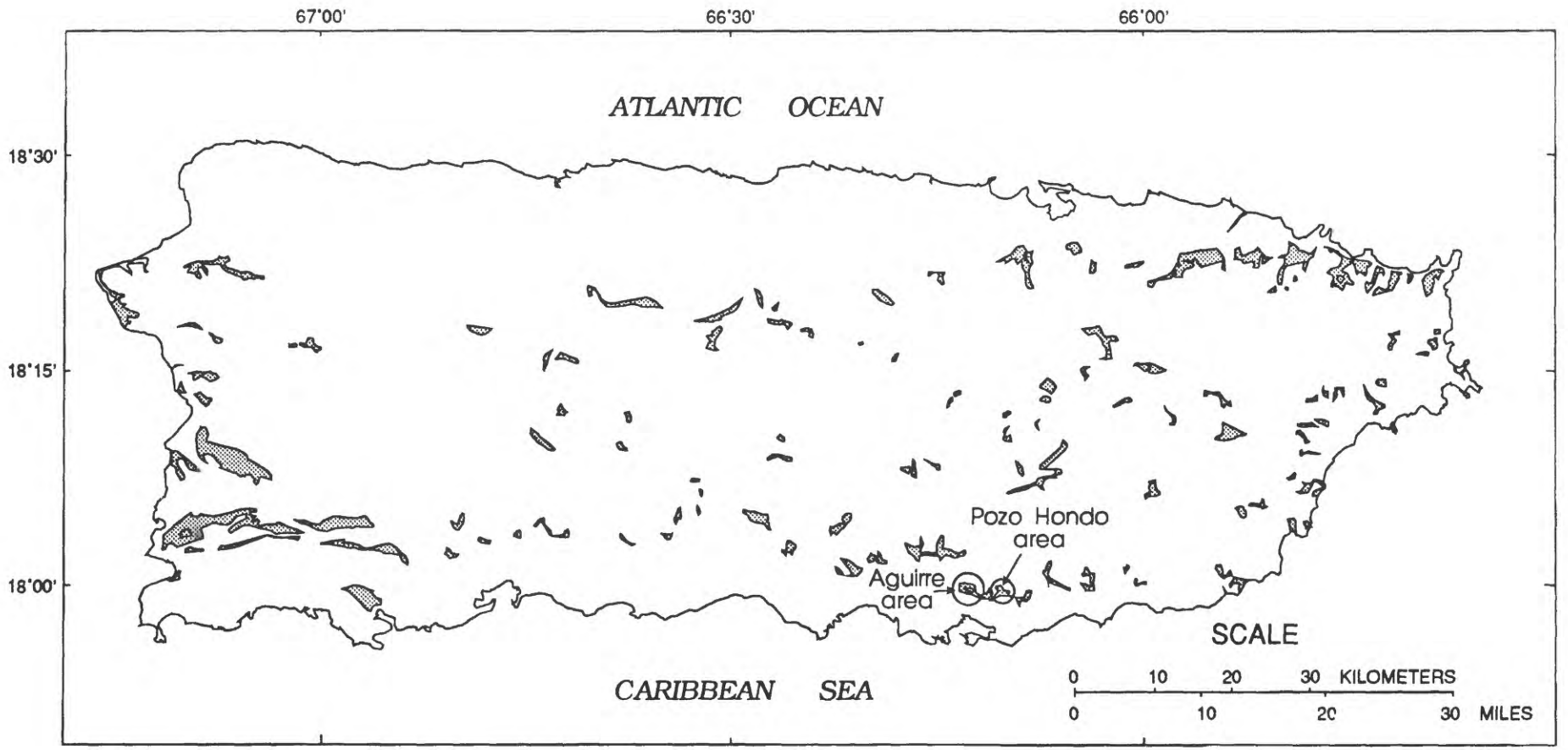
EXPLANATION

NORTH COAST LIMESTONE AQUIFER

EAST COAST, WEST COAST, AND INNER ISLAND ALLUVIAL AQUIFERS

SOUTH COAST AQUIFER

Figure 4.--Principal aquifers in Puerto Rico.

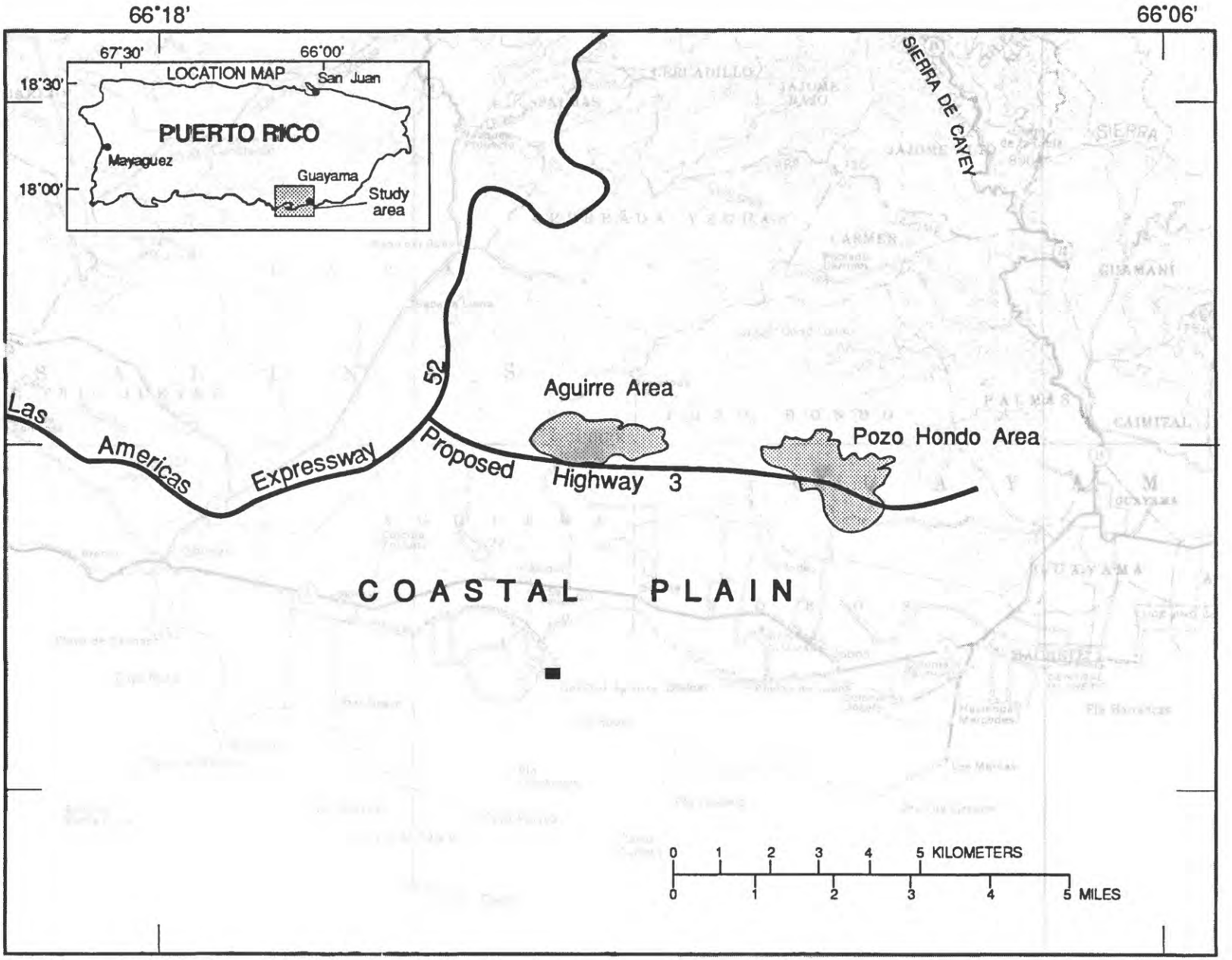


EXPLANATION

Area identified as unsuitable for development into a hazardous-waste facility.

Area identified as possibly suitable for development into a hazardous-waste facility.

Figure 5.--Areas identified as unsuitable or possibly suitable for development into a hazardous-waste facility.



Base map compiled from USGS topographic maps, scale: 1:20,000
Contour interval is 50 meters. Datum is mean sean level.

Figure 6.--Location of the Aguirre and Pozo Hondo study areas.

During phase two, 27 test holes were completed at nine of the previously mentioned sites (sites 3 through 11) and at eight additional sites (sites 16 through 23) in the Aguirre area. In the Pozo Hondo area three test holes were completed at the two previously mentioned sites. Depth of test holes drilled during phase two ranged from 28 to 210 feet below land surface. Of these test holes, all were completed as test wells. Phase two drilling was completed using the reverse-air circulation drilling method with an open-center reverse-air drill bit. Reverse-air circulation drilling is accomplished using a dual-wall drill stem (fig. 7). As drilling progresses, pressurized air is pumped between the annulus of the dual-wall pipe forcing formation water and cuttings up the center of the inner pipe. Except where the subsurface rock is extremely hard and indurated, an open-center reverse-air drill bit can be used. When an open-center reverse-air drilling bit is used, continuous cores return to land surface in place of the cuttings. This method of drilling permits the collection of continuous geologic cores plus hydrologic and water-quality data.

During phase two drilling, continuous cores were also collected from the indurated bedrock material underlying the aquifer in the Aguirre area. Because of the resistance of the bedrock material, drilling was completed using a water-cooled diamond-bit core barrel. The coring was completed by using the dual-wall drill stem as a temporary well sleeve which cased off the aquifer material down to the top of the bedrock. The diamond-bit core barrel was then passed through the center of the inner pipe of the dual-wall drill stem and cores were collected in 10-foot increments.

Twelve of the test wells completed were instrumented with continuous recorders to monitor ground-water level fluctuations. Further, single-well slug injection and removal, and multiple-well aquifer tests were conducted to determine the transmissivity and storage properties of the underlying aquifer.

Water samples were collected at selected intervals in 15 test holes. These samples were analyzed for major cations and anions and the trace elements of iron, manganese, barium, and aluminum.

The location of all drilling sites in the Aguirre and Pozo Hondo areas are shown in figures 8 and 9. Well numbers and well-construction information is given in tables 1 and 2. The well numbers in tables 1 and 2 apply only to this report.

Acknowledgments

The author gratefully acknowledges the assistance of Rafael Ignacio, President of PRIDCO 1984 to 1990, and Felix Prieto, Environmental Advisor to PRIDCO's President 1984 to 1990, for their continued support of this project.

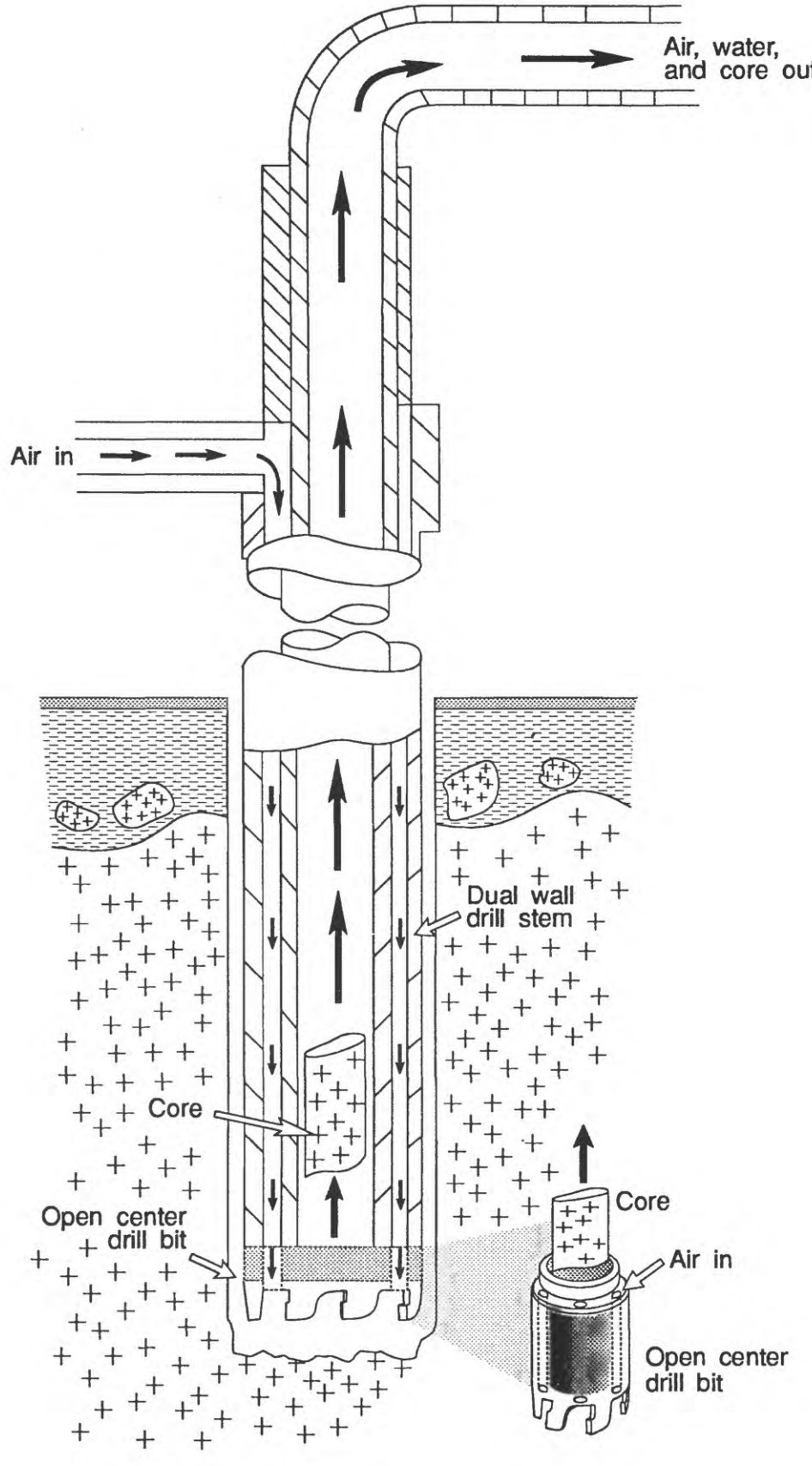
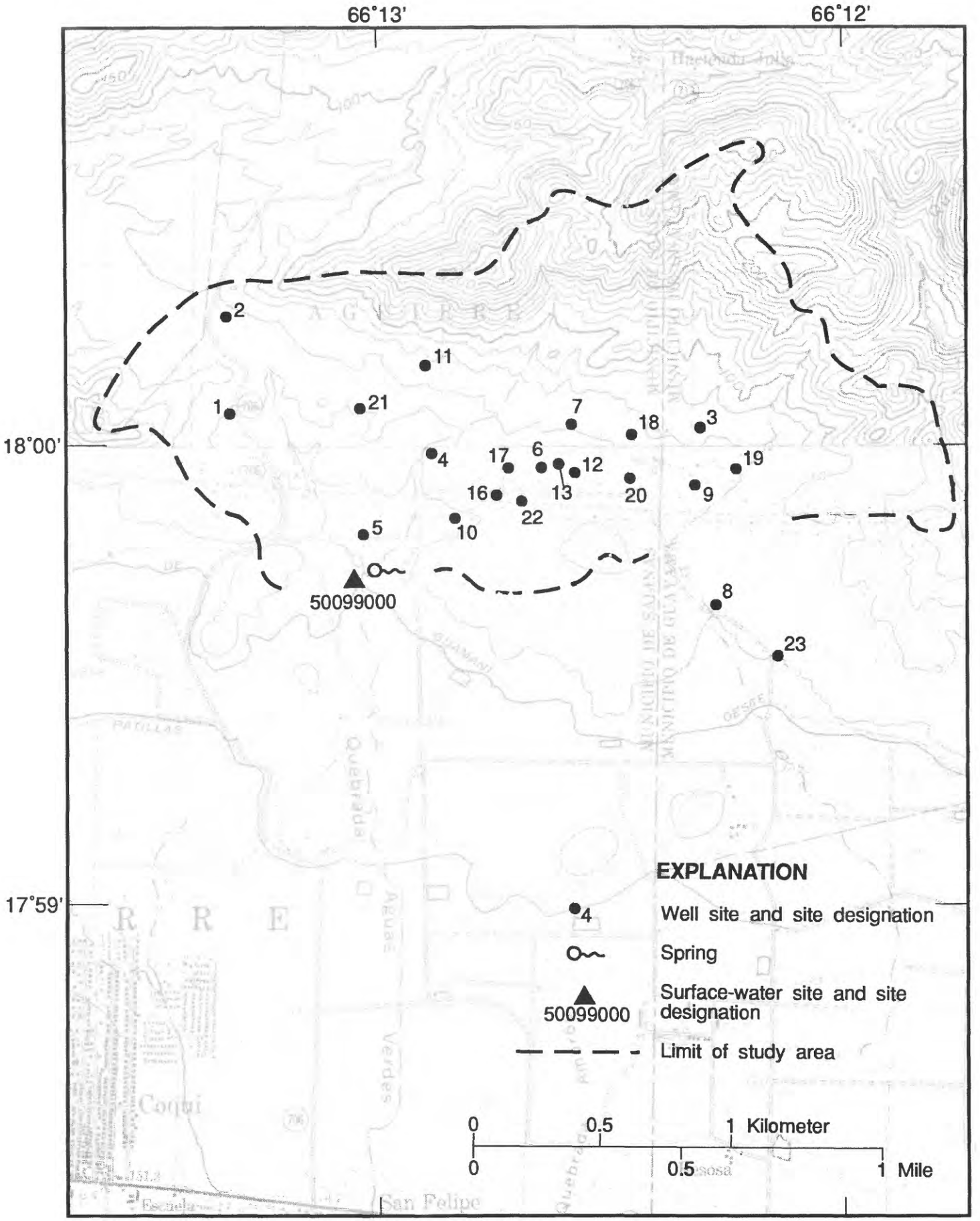
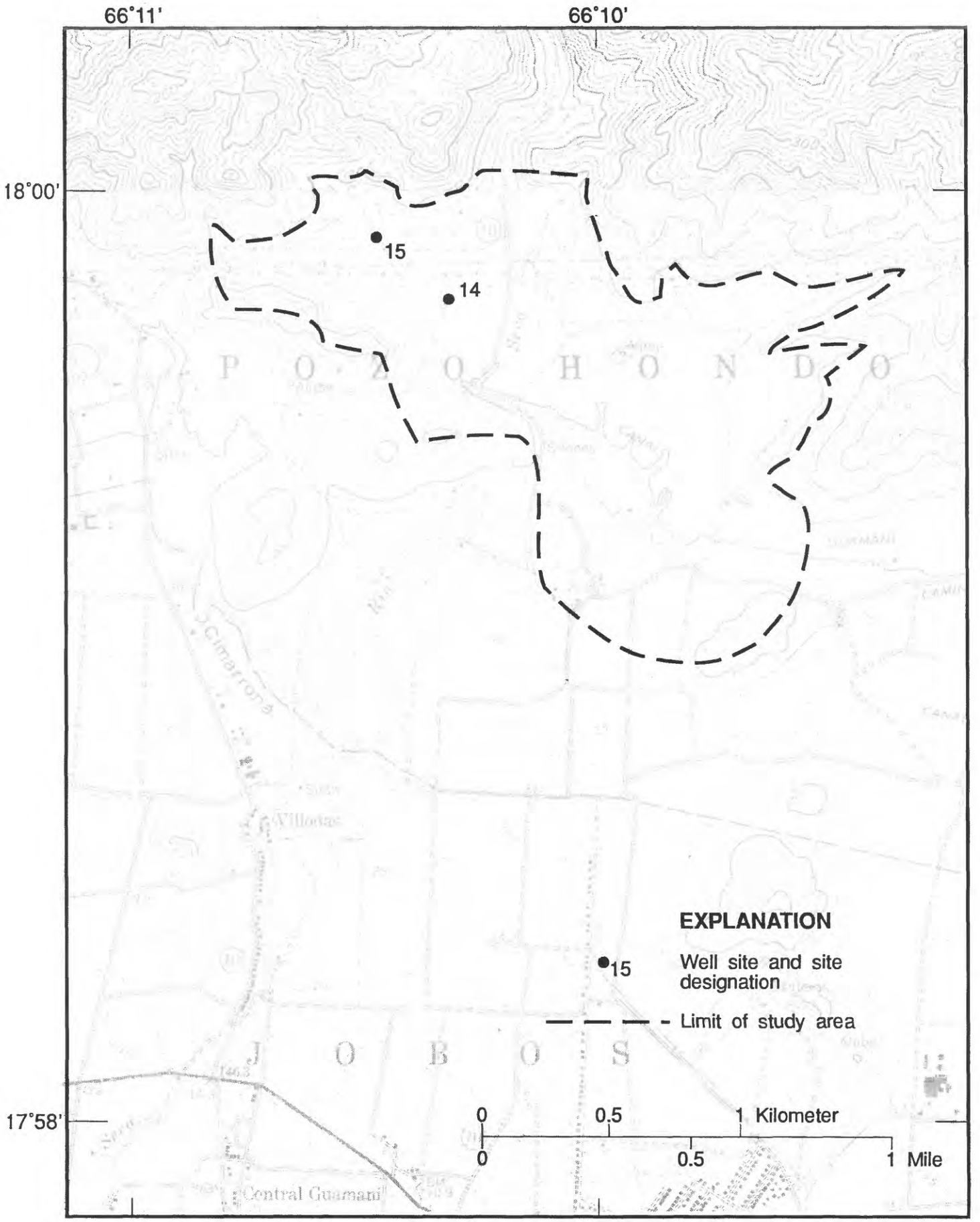


Figure 7.--Schematic diagram of reverse-air, dual-wall drill stem and open-center bit.



Base from the USGS topographic map, scale: 1:20,000,Cayey and Central Aguirre quadrangles, 1982. Contour interval 10 meters, dashed lines represent 5-meter contours, dotted lines represent 1-meter contours. Datum is mean sea level.

Figure 8.-Location of well sites, spring, and surface-water site in the Aguirre area.



Base from USGS topographic map, scale: 1:20,000, Cayey and Central Aguirre quadrangles, 1982. Contour interval 10 meters, dashed lines represent 5-meter contours, dotted lines represent 1-meter contours. Datum is mean sea level.

Figure 9.--Location of well sites in the Pozo Hondo study area.

Table 1.--*Description of test holes in the Aguirre area*

[All wells drilled during 1987 were completed during phase one of the drilling program with the USGS hollow-stem auger. All wells drilled during 1988 were completed during phase two of the drilling program with a reverse-air circulation drill rig. Unless noted, continuous cores collected to the bottom of each test hole drilled]

Site number	Well number	Date drilled	Depth of test hole (feet)	Depth of casing (feet)	Screen or open-hole interval (feet)	Subsurface material (feet)
1	1	08-18-87	40	38	Screen 32 - 37	Top soil 0 - 3 Alluvial deposits 3 - 4 Regolith 4 - 13 CORES UNAVAILABLE BELOW 13 FEET
1	1B	08-25-87	25	23	Screen 17 - 22	Top soil 0 - 3 Alluvial deposits 3 - 4 CORES UNAVAILABLE BELOW 4 FEET
2	2	08-19-87	74	70	Screen 60 - 65	Top soil 0 - 2? Alluvial deposits 2?- 11 Regolith 11 - 21 CORES UNAVAILABLE BELOW 21 FEET
2	2B	08-25-87	30	30	Screen 24 - 28	CORES UNAVAILABLE FOR THIS WELL
3	3	08-20-87	60	59	Screen 53 - 58	Top soil 0 - 1? Alluvial deposits 1?- 5? Regolith 5?- 12 CORES UNAVAILABLE BELOW 12 FEET
3	3B	11-04-87	79	07	Open hole 7 - 79	Top soil 0 - 1? Alluvial deposits 1?- 5? Regolith 5?- 29 CORES UNAVAILABLE BELOW 29 FEET
3	3C	06-10-88 - 06-17-88	210	150	Open hole 150 - 210	Top soil 0 - 2 Alluvial deposits 2 - 17 Regolith 17 - 47 Transition zone 47 - 155 Bedrock 155 - 210
3	3D	06-21-88 - 06-23-88	150	92	Open hole 92 - 150	Top soil 0 - 3 Alluvial deposits 3 - 8 Regolith 8 - 83 Transition zone 83 - 100 Bedrock 100 - 150
3	3E	06-27-88 - 06-28-88	90	90	Screen 79 - 89	Top soil 0 - 4 Alluvial deposits 4 - 14 Regolith 14 - 54 Transition zone 54 - 90
4	4	08-26-87	49	48	Screen 42 - 47	Top soil 0 - 2? Regolith 2? - 16 CORES UNAVAILABLE BELOW 16 FEET
4	4B	09-09-87	20	20	Screen 16 - 19	Top soil 0 - 1? Regolith 1? - 20? UNABLE TO DRILL BELOW 20 FEET.
4	4C	09-10-87	27	27	Screen 23 - 26	CORES UNAVAILABLE FOR THIS WELL
4	4D	10-06-87	20	3	Open hole 3 - 20	Top soil 0 - 3 Regolith 3 - 10 CORES UNAVAILABLE BELOW 10 FEET
4	4E	04-06-88 - 04-11-88	95	33	Open hole 33 - 95	Top soil 0 - 2 Regolith 2 - 9 Transition zone 9 - 31 Bedrock 31 - 95
4	4G	04-26-88	31	31	Screen 25 - 31	Top soil 0 - 2 Regolith 2 - 21 Transition zone 21 - 31
4	4F	04-25-88	30	30	Screen 20 - 29	CORES UNAVAILABLE FOR THIS WELL

Table 1.--*Description of test holes in the Aguirre area*--Continued

[All wells drilled during 1987 were completed during phase one of the drilling program with the USGS hollow-stem auger. All wells drilled during 1988 were completed during phase two of the drilling program with a reverse-air circulation drill rig. Unless noted, continuous cores collected to the bottom of each test hole drilled]

Site number	Well number	Date drilled	Depth of test hole (feet)	Depth of casing (feet)	Screen or open-hole interval (feet)	Subsurface material (feet)
5	5	08-27-87	13	13	Screen 10 - 13	Top soil 0 - 1 Regolith 1 - 10 CORES UNAVAILABLE BELOW 10 FEET
5	5B	08-27-87	52	51	Screen 41 - 46	Top soil 0 - 1 Regolith 1 - 12 CORES UNAVAILABLE BELOW 12 FEET
5	5C	09-09-87	9	0	TEST HOLE BACK-FILLED AND SEALED WITH CEMENT	Top soil 0 - 1 Regolith 1 - 9
5	5D	09-09-87	21	21	Screen 17 - 20	Top soil 0 - 1 Regolith 1 - 8 CORES UNAVAILABLE BELOW 8 FEET
5	5E	05-04-88 - 05-10-88	100	20	Open hole 20 - 100	Regolith 0 - 11 Transition zone 11 - 20 Bedrock 20 - 100
5	5F	05-10-88	30	30	Screen 24 - 29	Top soil 0 - 1 Regolith 1 - 14 CORES UNAVAILABLE BELOW 14 FEET
6	6	08-31-87	53	49	Screen 43 - 48	Top soil 0 - 1 Alluvial deposits 1 - 4 Regolith 4 - 13 CORES UNAVAILABLE BELOW 13 FEET
6	6B	05-16-88	55	55	Screen 49 - 54	Regolith 0 - 39 Transition zone 39 - 55 Bedrock 55
7	7	09-01-87	88	82	Screen 69 - 77	Top soil 0 - 2 Regolith 2 - 12 CORES UNAVAILABLE BELOW 12 FEET
7	7B	10-20-87	45	4	Open Hole 4 - 45	Top soil 0 - 1 Regolith 1 - 17 CORES UNAVAILABLE BELOW 17 FEET
7	7C	05-17-88 - 05-18-88	80	80	Screen 69 - 79	Top soil 0 - 1 Regolith 1 - 11 Transition zone 11 - 80 Bedrock 80
7	7D	05-20-88	43	43	Screen 35 - 42	Regolith 0 - 12 Transition zone 12 - 43
8	8	09-03-87	49	49	Screen 43 - 48	Top soil 0 - 3 Alluvial deposits 3 - 16 Regolith 16 - 18 CORES UNAVAILABLE BELOW 18 FEET
8	8B	09-08-87	30	26	Screen 22 - 25	Top soil 0 - 4 Alluvial deposits 4 - 11? Regolith 11?- 21 CORES UNAVAILABLE BELOW 21 FEET
8	8C	10-27-87	46	4	Open hole 4 - 46	Top soil 0 - 2? Alluvial deposits 2?- 18? Regolith 18?- 20 CORES UNAVAILABLE BELOW 20 FEET
8	8D	07-13-88	83	60	Open hole 60 - 83	Top soil 0 - 8 Regolith 8 - 28 Transition zone 28 - 83
9	9	09-09-87	23	21	Screen 17 - 20	Top soil 0 - 2? CORES UNAVAILABLE BELOW 2 FEET

Table 1.--*Description of test holes in the Aguirre area*--Continued

[All wells drilled during 1987 were completed during phase one of the drilling program with the USGS hollow-stem auger. All wells drilled during 1988 were completed during phase two of the drilling program with a reverse-air circulation drill rig. Unless noted, continuous cores collected to the bottom of each test hole drilled]

Site number	Well number	Date drilled	Depth of test hole (feet)	Depth of casing (feet)	Screen or open-hole interval (feet)	Subsurface material (feet)
9	9B	09-15-87	24	0	TEST HOLE BACK FILLED AND SEALED WITH CEMENT	Top soil 0 - 2? Regolith 2? - 8 CORES UNAVAILABLE BELOW 8 FEET
9	9C	06-20-88 - 07-26-88	104	45	Open hole 45 - 104	Top soil 0 - 4 Regolith 4 - 14 Transition zone 14 - 30 Bedrock 30 - 104
10	10	09-15-87	55	54	Screen 48 - 53	Top soil 0 - 4 Alluvial deposits 4 - 9 Regolith 9 - 17 CORES UNAVAILABLE BELOW 17 FEET
10	10B	11-4-87	35	6	Open hole 6 - 35	Top soil 0 - 3 Alluvial deposits 3 - 4 Regolith 4 - 11 CORES UNAVAILABLE BELOW 11 FEET
10	10C	04-27-88 - 04-29-88	100	43	Open hole 43 - 100	Top soil 0 - 2 Alluvial deposits 2 - 5 Regolith 5 - 30 Transition zone 30 - 50 Bedrock 50 - 100
10	10D	05-02-88	41	41	Screen 25 - 40	Top soil 0 - 2 Alluvial deposits 2 - 8 Regolith 8 - 32 Transition zone 32 - 41 Bedrock 41
10	10E	05-02-88	28	27	Screen 21 - 26	Top soil 0 - 2 Alluvial deposits 2 - 6 Regolith 6 - 20 Transition zone 20 - 28
11	11	9-16-87 - 10-07-87	95	94	Screen 79 - 89	Top soil 0 - 4 Regolith 4 - 38 CORES UNAVAILABLE BELOW 38 FEET
11	11B	11-02-87 - 12-04-87	85	10	Open hole 10 - 85	Top soil 0 - 5 Regolith 5 - 34 CORES UNAVAILABLE BELOW 34 FEET
11	11C	05-20-88 - 06-01-88	200	95	Open hole 95 - 200	Top soil 0 - 1 Regolith 1 - 48 Transition zone 48 - 90 Bedrock 90 - 200
11	11D	06-03-88 - 06-07-88	96	96	Screen 56 - 95	Top soil 0 - 3 Regolith 3 - 52 Transition zone 52 - 94 Bedrock 94 - 96
11	11E	06-02-88 - 06-03-88	75	75	Screen 64 - 74	Top soil 0 - 2 Regolith 2 - 59 Transition zone 59 - 75
12	12	10-13-87	24	22	Screen 18 - 21	Top soil 0 - 4 Regolith 4 - 9 CORES UNAVAILABLE BELOW 9 FEET
13	13	10-15-87	69	4	Open hole 4 - 69	Top soil 0 - 4 CORES UNAVAILABLE BELOW 4 FEET
16	16	05-03-88 - 05-04-88	147	137	Screen 121 - 135	Top soil 0 - 1 Alluvial deposits 1 - 21 Regolith 21 - 129 Transition zone 129 - 147 Bedrock 147

Table 1.--*Description of test holes in the Aguirre area*--Continued

[All wells drilled during 1987 were completed during phase one of the drilling program with the USGS hollow-stem auger. All wells drilled during 1988 were completed during phase two of the drilling program with a reverse-air circulation drill rig. Unless noted, continuous cores collected to the bottom of each test hole drilled]

Site number	Well number	Date drilled	Depth of test hole (feet)	Depth of casing (feet)	Screen or open-hole interval (feet)	Subsurface material (feet)	
17	17	05-11-88 - 05-13-88	63	21	Open hole 21 - 63	Top soil	0 - 1
						Alluvial deposits	1 - 6
						Regolith	6 - 9
						Transition zone	9 - 21
						Bedrock	21 - 63
18	18	06-09-88 - 06-10-88	106	106	Screen 95 - 105	Top soil	0 - 2
						Regolith	2 - 29
						Transition zone	29 - 103
						Bedrock	103 - 106
19	19	07-07-88 - 07-08-88	60	60	Screen 49 - 60	Top soil	0 - 4
						Regolith	4 - 52
						Transition zone	52 - 60
						Bedrock	60
20	20	07-11-88 - 07-12-88	100	56	Open hole 56 - 100	Top soil	0 - 2
						Regolith	2 - 21
						Transition zone	21 - 54
						Bedrock	54 - 100
21	21	07-15-88 - 07-18-88	120	75	Open hole 75 - 120	Top soil	0 - 1
						Regolith	1 - 67
						Bedrock	67 - 120
22	22	07-19-88 - 07-21-88	123	62	Open hole 62 - 123	Top soil	0 - 1
						Regolith	1 - 48
						Transition zone	48 - 80
						Bedrock	80 - 123
23	23	09-01-88 - 09-06-88	120	120	Screen 40 - 100	Top soil	0 - 3
						Transition zone	3 - 80
						Bedrock	80 - 120

Table 2.--*Description of test holes in the Pozo Hondo area*

[All wells drilled during 1987 were completed during phase one of the drilling program with the USGS hollow-stem auger. All wells drilled during 1988 were completed during phase two of the drilling program with a reverse-air circulation drill rig. Unless noted, continuous cores collected to the bottom of each test hole drilled]

Site number	Well number	Date drilled	Depth of test hole (feet)	Depth of casing (feet)	Screen or open-hole interval (feet)	Subsurface material (feet)
14	14	10-21-87	79	79	Screen 71 - 78	Top soil 0 - 2 Alluvial deposits 2 - 21 CORES UNAVAILABLE BELOW 21 FEET
14	14B	12-14-87 - 12-17-87	47	7	Open hole 7 - 47	Top soil 0 - 2 Alluvial deposits 2 - 21 CORES UNAVAILABLE BELOW 21 FEET
14	14C	07-28-88 -	32	7	Open hole 7 - 32	Alluvial deposits 0 - 32
14	14D	07-29-88 - 08-03-88	110	110	Screen 99 - 109	Alluvial deposits 0 - 69 Transition zone 69 - 108 Bedrock 108 - 110
15	15	12-14-87 - 12-17-87	85	85	Screen 70 - 80	Top soil 0 - 1 Alluvial deposits 1 - 16 Regolith 16 - 52 CORES UNAVAILABLE BELOW 52 FEET
15	15B	12-15-87 - 21-16-87	30	10	Open hole 10 - 30	Top soil 0 - 1 Alluvial deposits 1 - 15 Regolith 15 - 30
15	15C	12-15-87 - 12-16-87	26	10	Open hole 10 - 26	CORES UNAVAILABLE FOR THIS WELL
15	15D	09-08-88	86	82	Screen 50 - 80	Top soil 0 - 2 Regolith 2 - 85 Bedrock 85 - 86

DESCRIPTION OF THE AREAS

The Aguirre and Pozo Hondo areas are characterized as small basins located on the south coast of Puerto Rico. The mean annual temperature of the study areas is 78.5 degrees Fahrenheit. Average annual rainfall is 46.85 inches.

Landforms and Drainage in the Aguirre Area

The Aguirre area (figs. 6 and 8) is an 818-acre, semi-enclosed basin, located on the south coast of Puerto Rico within a narrow piedmont belt of hills that lie between the southern coastal plain and the Sierra de Cayey (Berryhill, 1960; Berryhill and Glover, 1960). The basin length is approximately two miles and the width ranges from 0.40 to 0.90 miles. The hills of the piedmont form a continuous border to the north and east of the basin. The highest altitude of the hills is approximately 850 feet above sea level. A series of discontinuous hills, which have an altitude of approximately 425 feet above sea level, lie south and southwest of the basin. The altitude of the basin floor ranges from 131 to 328 feet above sea level.

The Aguirre area is open to the west and south where the hills of the piedmont are discontinuous. Surface drainage out of the basin flows south (fig. 8). All streamflow within the basin is ephemeral; however, a perennial spring is located at the headwaters of Quebrada Aguas Verdes at the southern boundary of the study area (fig. 8).

Landforms and Drainage in the Pozo Hondo Area

The Pozo Hondo study area (figs. 6 and 9) is a 646-acre, semi-enclosed basin, located on the south coast of Puerto Rico within a narrow piedmont belt of hills that lie between the southern coastal plain and the Sierra de Cayey (Berryhill,1960; Berryhill and Glover, 1960). The basin measures approximately 1.5 miles across at its widest point and approximately 1.3 miles in length. The hills of the piedmont form a continuous border to the north, east, and west of the basin, leaving the basin open only to the south. The study area extends to the base of the hills, which have an altitude of approximately 427 feet above sea level. To the south, the Pozo Hondo study area extends into the coastal plain. The altitude of the floor of the Pozo Hondo area ranges from approximately 125 feet above sea level in the coastal plain to approximately 300 feet above sea level in the north.

Surface drainage out of the basin is to the south and is the headwaters of Río Seco. The headwaters of the Río Seco are ephemeral.

Climate

The mean annual air temperature recorded by the National Oceanic and Atmospheric Administration (NOAA) for 1982 to 1988 at the Central Aguirre Station (located approximately three miles south of the Aguirre area, fig. 6) is 78.5 degrees Fahrenheit (U.S. Department of Commerce, 1982 - 1988). Average annual rainfall for 1982 to 1988 at the Central Aguirre Station was 46.85 inches. This is compared to an average annual rainfall of 42.77 inches reported by NOAA from 1931 through 1960. Two seasons occur within the study areas, a dry season that extends from December to April, and a wet season from May to November (fig. 10).

GEOLOGY

The subsurface geology in the Aguirre and Pozo Hondo areas is a fractured igneous volcanic rock (andesite). Alluvial deposits occur locally in each area. In the Aguirre area, remnants of weathered low-grade metamorphosed volcanic rock with a schistose texture and a vertical plane of foliation are also found associated with the regolith.

Aguirre Area

The subsurface geology of the Aguirre area is primarily a fractured igneous volcanic rock (andesite) with three distinct divisions. These divisions are regolith, transition zone, and bedrock.

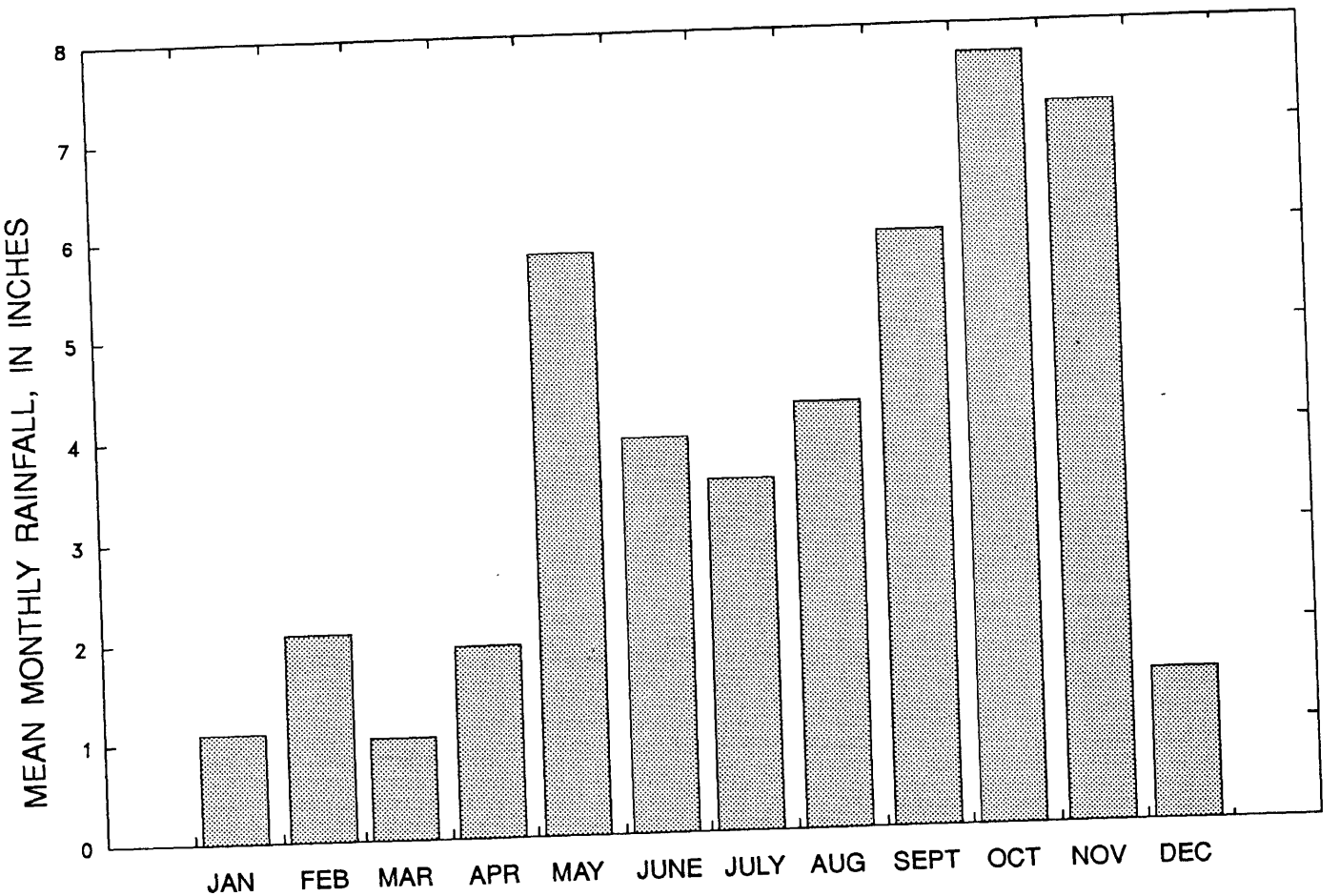


Figure 10.-- Mean monthly rainfall for Central Aguirre station, 1982 to 1988. (Data from U.S. Department of Commerce, 1982 to 1988)

Geologic cross sections were constructed to show the geologic framework at depth (figs. 11, 12, and 13). These sections were constructed from data obtained from drilling test holes (tables 1 and 3).

The regolith is a highly weathered volcanic material occurring as saprolite or very friable and highly weathered volcanic rock. The regolith ranges in thickness from 5 to 108 feet and is a weathered product of the underlying volcanic parent rock, with much of the original structure still intact. Dense indurated volcanic boulders, unweathered remnants of the parent rock, are found locally in the regolith.

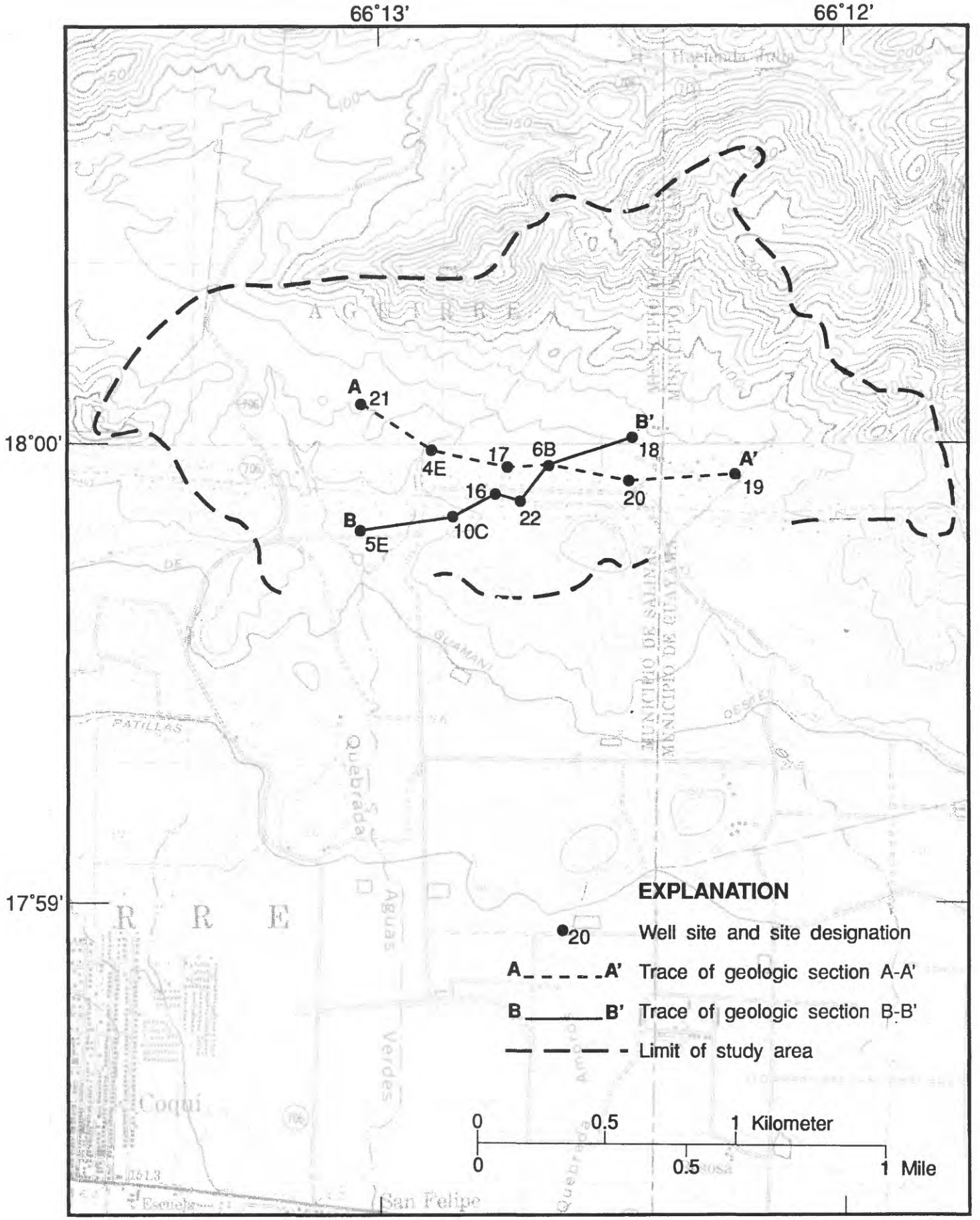
Also found locally within the regolith are weathered low-grade metamorphosed volcanic rock. This metamorphic rock displays a schistose texture with a vertical plane of foliation. The low-grade metamorphism is due to hydrothermal activity (Berryhill, 1960). The regolith is found beneath a thin layer of top soil which can range up to 8 feet in thickness and, locally, a 1- to 20-foot thick unit of alluvial deposits.

The transition zone is a zone of shattered to highly fractured volcanic rock underlying the regolith, and contains areas of highly weathered volcanic rock that grade upward to saprolite. The fractures have no dominant orientation. Abundant iron staining and calcite precipitate are associated with the fractured and shattered zones. Locally, chlorite has precipitated in the fracture zones. The transition zone ranges in thickness from non-existent (regolith lies directly on the bedrock) to 108 feet.

Bedrock in the Aguirre area is a dense, indurated, volcanic rock (andesite), locally containing horizontal and vertical fractures. Depth to bedrock ranges from 20 to 155 feet below land surface. The depth to bedrock in well 16, (155 feet below land surface, fig. 12) is anomalous compared to depths in nearby wells. This anomalous depth to bedrock is probably related to hydrothermal activity that formed the low-grade metamorphic rock found at this site, and could indicate the location of a fracture zone.

Pozo Hondo Area

The results of test-hole drilling at two sites in the Pozo Hondo area revealed the same three distinct divisions as described in the Aguirre area; however, several distinct differences in the geology were identified. The first of these distinctions is the presence of alluvial deposits of stratified clay, silt, sand, gravel, and cobbles which can range up to 69 feet in thickness (table 2). Further distinctions of the Pozo Hondo area are the absence of the regolith at site 14 and the absence of the transition zone at site 15 (table 4). At Pozo Hondo site 14, depth to the top of the transition zone is 69 feet below land surface feet and the zone has a thickness of 39 feet. At site 15, the regolith is 2 feet below land surface and is 83 feet thick. The depth to the top of the andesite bedrock ranges from 85 feet below land surface at site 15 to 108 feet below land surface at site 14.



Base from the USGS topographic map, scale: 1:20,000,Cayey and Central Aguirre quadrangles, 1982. Contour interval 10 meters, dashed lines represent 5-meter contours, dotted lines represent 1-meter contours. Datum is mean sea level.

Figure 11.-Location of geologic sections A - A' and B - B' in the Aguirre area.

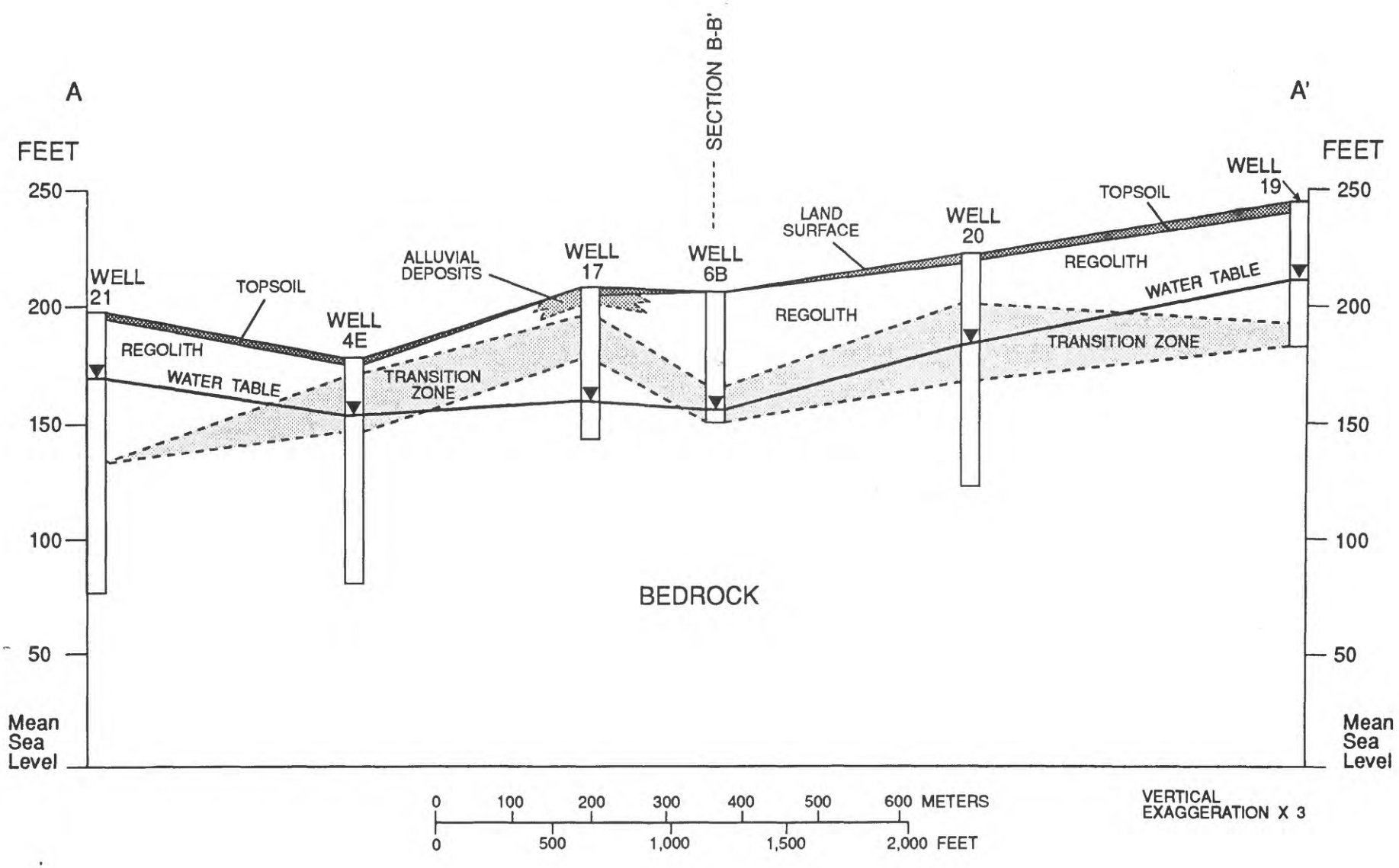


Figure 12.--Generalized geologic section through A - A' and water table for August 25, 1989. (See figure 11 for location of section).

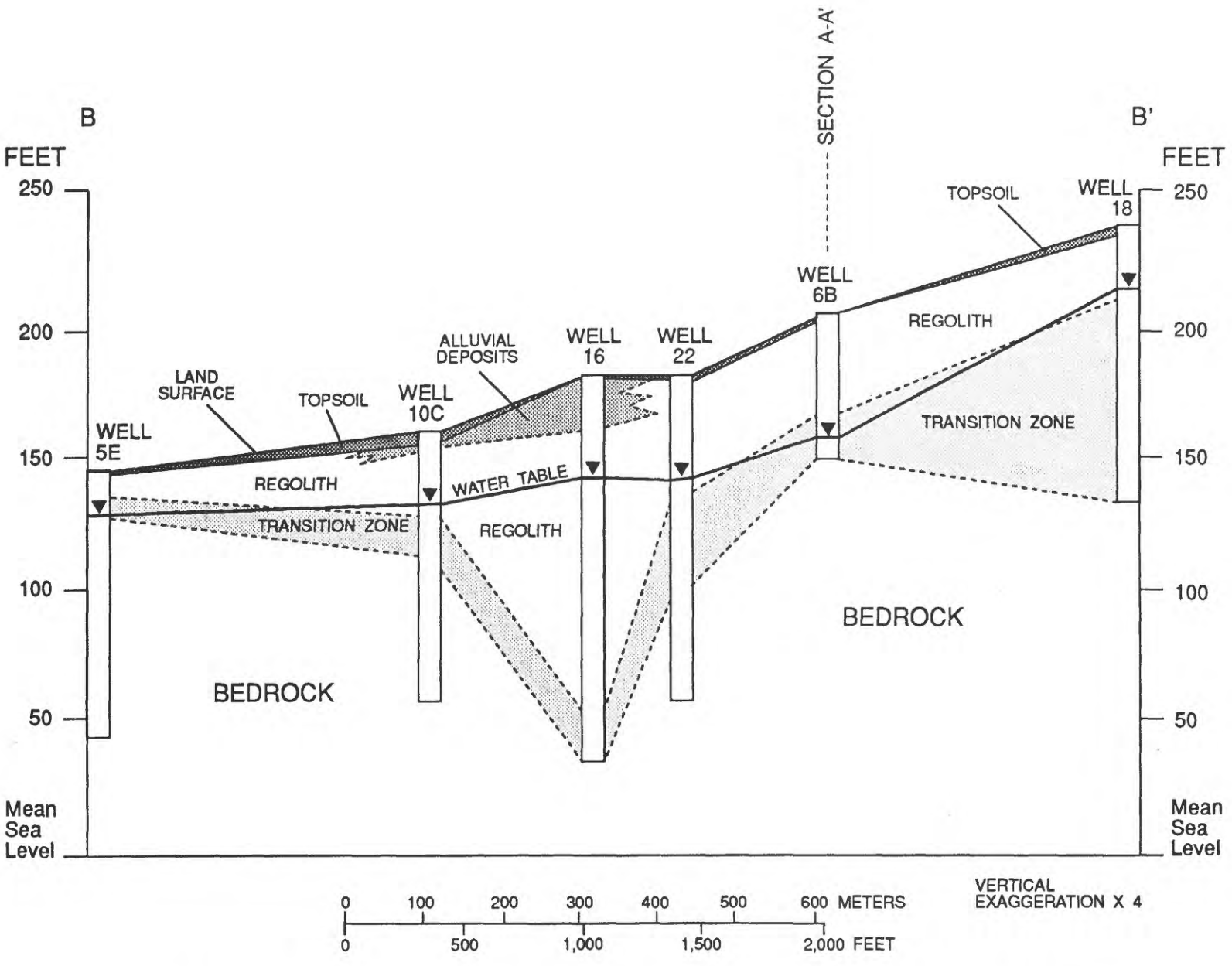


Figure 13.--Generalized geologic section through B - B' and water table for August 25, 1989. (See figure 11 for location of section).

Table 3.--*Generalized geologic descriptions of selected test holes in the Aguirre area*

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
3C	0 - 2	TOP SOIL--dark brown to black, clayey loam	TOP SOIL
	2 - 15	ALLUVIAL DEPOSITS--unconsolidated silty gravel, angular, with clay, sand, and pebbles.	ALLUVIAL DEPOSITS
	15 - 17	ALLUVIAL DEPOSITS--clay, very dense.	
	17 - 47	SAPROLITE--volcanic, with angular gravel to cobble size volcanic rock fragments.	REGOLITH
	47 - 102	VOLCANIC ROCK--highly fractured, with much iron staining and calcite precipitate in the fractures, locally shattered, with angular, pebble to cobble size fragments, minor saprolite.	
	102 - 133	SAPROLITE--volcanic, with minor hydrothermally altered (metamorphosed) volcanic rock showing a schistose texture, plane of foliation is vertical.	TRANSITION ZONE
	133 - 155	VOLCANIC ROCK--fractured and shattered, with angular, gravel to cobble size fragments, minor hydrothermally altered (metamorphosed) volcanic rock showing a schistose texture, plane of foliation is vertical.	
	155 - 210	VOLCANIC ROCK--indurated, locally fractured	BEDROCK
4E	0 - 2	TOP SOIL-- black organic, very dense clay.	TOP SOIL
	2 - 9	SAPROLITE--volcanic, with much calcite powder, also angular gravel to cobble volcanic rock fragments.	REGOLITH
	9 - 31	VOLCANIC ROCK--indurated, locally shattered with angular, pebble to cobble size fragments, with highly weathered volcanics, some interlayered saprolite.	TRANSITION ZONE
	31 - 95	VOLCANIC ROCK--indurated with vertical and horizontal fractures with iron stain and calcite precipitate in the fractures.	BEDROCK
5E	0 - 11	VOLCANIC ROCK--fragments, very angular, gravel to cobble size, with saprolite.	REGOLITH
	11 - 20	VOLCANIC ROCK--highly shattered, angular, gravel to cobble size fragments, with much iron staining and calcite precipitate, some fractures.	TRANSITION ZONE
	20 - 100	VOLCANIC ROCK--indurated, with angular fractures, iron stain and calcite precipitate in the fractures.	BEDROCK
6B	0 - 39	SAPROLITE--volcanic, with large remnant boulders, some shattered rock fragments, angular material, pebble size.	REGOLITH
	39 - 55	VOLCANIC ROCK--indurated, intermittent zones of weathering, also zones of fractures with iron staining and calcite precipitate in the fractures, locally shattered, with pebble to cobble size fragments,	TRANSITION ZONE
	55	VOLCANIC ROCK	BEDROCK

Table 3.--*Generalized geologic descriptions of selected test holes in the Aguirre area*--Continued

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
7C	0 - 1	TOP SOIL--dark clayey loam.	TOP SOIL
	1 - 11	SAPROLITE--volcanic, with angular gravel and volcanic rock fragments.	REGOLITH
	11 - 80	VOLCANIC ROCK-fractured, also shattered, to angular, gravel to cobble size fragments, locally with iron staining and calcite precipitate in the fractures, locally highly weathered with minor saprolite.	TRANSITION ZONE
	80	VOLCANIC ROCK	BEDROCK
8D	0 - 8	TOP SOIL--dark brown clayey loam.	TOP SOIL
	8 - 28	VOLCANIC ROCK--fragments, angular, gravel to cobble size, with saprolite, locally dense, indurated volcanics.	REGOLITH
	28 - 83	VOLCANIC ROCK--fractured and shattered, to a angular gravel to cobble size fragments, fractures are iron stained.	TRANSITION ZONE
9C	0 - 4	TOP SOIL--clayey, organic brown loam.	TOP SOIL
	4 - 14	SAPROLITE--with very angular shattered gravel to pebble size rock fragments.	REGOLITH
	14 - 30	VOLCANIC ROCK--shattered, gravel to cobble size fragments, locally dense and indurated.	TRANSITION ZONE
	30 - 104	VOLCANIC ROCK--dense, with vertical fractures, iron staining and calcite precipitate associated with fractures.	BEDROCK
10C	0 - 2	TOP SOIL--black, clayey.	TOP SOIL
	2 - 5	ALLUVIAL DEPOSITS--Silty sand, with angular gravel, pebbles, and cobbles.	ALLUVIAL DEPOSITS
	5 - 30	SAPROLITE--volcanic, with angular gravel to cobble volcanic rock fragments.	REGOLITH
	30 - 50	VOLCANIC ROCK--shattered, with angular, gravel to pebble size fragments, locally fractured and weathered with minor saprolite.	TRANSITION ZONE
	50 - 100	VOLCANIC ROCK--locally fractured with iron stain, some calcite precipitate in the fractures.	BEDROCK

Table 3.--*Generalized geologic descriptions of selected test holes in the Aguirre area*--Continued

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
11C	0 - 1	TOP SOIL	TOP SOIL
	1 - 48	SAPROLITE--volcanic, with indurated but weathered volcanic rock.	REGOLITH
	48 - 62	VOLCANIC ROCK-fractured horizontally	
	62 - 71	VOLCANIC ROCK--indurated	
	71 - 75	SAPROLITE--volcanic	TRANSITION ZONE
	75 - 80	VOLCANIC ROCK--indurated with thin lenses of saprolite.	
	80 - 90	VOLCANIC ROCK--with fractures, locally with iron staining and calcite precipitate in the fractures.	
	90 - 200	VOLCANIC ROCK--with angular, vertical, and horizontal fractures, locally with iron stain and calcite precipitate in the fractures, locally weathered.	BEDROCK
16	0 - 1	TOP SOIL--brown clayey loam.	TOP SOIL
	1 - 21	ALLUVIAL DEPOSITS--gravel, sandy, angular, unconsolidated, with clay, and some pebbles and cobbles.	ALLUVIAL DEPOSITS
	21 - 56	VOLCANIC ROCK--fragments, angular, gravel to cobble size, with saprolite also weathered cores, locally hydrothermally altered (metamorphosed) volcanic rock.	
	56 - 100	METAMORPHIC ROCK--hydrothermally altered volcanic rock, (low grade metamorphic rock) very deteriorated, some saprolite. Displays a schistosity texture foliations are on a vertical plane.	REGOLITH
	100 - 129	SAPROLITE--volcanic, with minor highly weathered hydrothermally altered (metamorphosed) volcanic rock.	
	129 - 147	VOLCANIC ROCK--cores indurated, locally highly shattered with vertical fractures, chlorite and calcite precipitate in the fractures.	TRANSITION ZONE
	147	VOLCANIC ROCK	BEDROCK
17	0 - 1	TOP SOIL--dark (black), clayey loam.	TOP SOIL
	1 - 6	ALLUVIAL DEPOSITS--unconsolidated angular gravel, with silt and clay.	ALLUVIAL DEPOSITS
	6 - 9	SAPROLITE--volcanic.	REGOLITH
	9 - 21	VOLCANIC ROCK--with angular fractures, locally with shattered, angular fragments.	TRANSITION ZONE
	21 - 63	VOLCANIC ROCK--locally with angular and horizontal fractures, with iron stains and calcite precipitate in the fractures.	BEDROCK

Table 3.--*Generalized geologic descriptions of selected test holes in the Aguirre area*--Continued

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
18	0 - 2	TOP SOIL	TOP SOIL
	2 - 29	VOLCANIC ROCK--rock fragments, angular, gravel to cobble size, with zones of dense indurated volcanics, locally some saprolite.	REGOLITH
	29 - 103	VOLCANIC ROCK--highly fractured with angular and vertical fractures, iron stains and calcite and chlorite precipitate in the fractures, locally shattered, with angular pebble to cobble size fragments, some saprolite	TRANSITION ZONE
	103 - 106	VOLCANIC ROCK	BEDROCK
19	0 - 4	TOP SOIL--dark brown clayey loam.	TOP SOIL
	4 - 52	VOLCANIC ROCK--fragments, angular, gravel to cobble size, with saprolite, very clayey and dense, minor dense volcanic rock.	REGOLITH
	52 - 60	VOLCANIC ROCK--very weathered with angular and vertical fractures, with iron staining and calcite precipitate in the fractures.	TRANSITION ZONE
	60	VOLCANIC ROCK	BEDROCK
20	0 - 2	TOP SOIL--black organic, clayey loam.	TOP SOIL
	2 - 21	VOLCANIC ROCK--fragments, angular, gravel to cobble in size, with saprolite and dense volcanics.	REGOLITH
	21 - 54	VOLCANIC ROCK--fractured and shattered, angular fractures with iron stain and calcite precipitating in the fractures.	TRANSITION ZONE
	54 - 100	VOLCANIC ROCK--with vertical and angular fractures, with iron stain.	BEDROCK
21	0 - 1	TOP SOIL--dark clayey loam.	TOP SOIL
	1 - 67	SAPROLITE--volcanic, with angular gravel to cobble size volcanic rock fragments, minor dense volcanics with fractures, iron stain in fractures.	REGOLITH
	67 - 120	VOLCANIC ROCK--locally fractured, mostly angular fractures, some vertical fractures, iron stain and calcite precipitate in the fractures.	BEDROCK
22	0 - 1	TOP SOIL--organic brown, clayey loam, clay is very tight.	TOP SOIL
	1 - 48	SAPROLITE--volcanic, with angular gravel to cobble volcanic rock fragments.	REGOLITH
	48 - 80	VOLCANIC ROCK-- fractured, locally shattered, with angular, pebble to cobble size fragments.	TRANSITION ZONE
	80 - 123	VOLCANIC ROCK--very dense, some fractures.	BEDROCK

Table 3.--*Generalized geologic descriptions of selected test holes in the Aguirre area*--Continued

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
23	0 - 3	TOP SOIL--clay, red.	TOP SOIL
	3 - 80	VOLCANIC ROCK--fractured and shattered, shattered rock is angular, pebble to cobble size rock fragments, with iron staining and calcite precipitate in the fractures, with minor saprolite. Pyrite found in sample at 48 - 52 feet.	TRANSITION ZONE
	80 - 120	VOLCANIC ROCK--fractured, minor calcite and iron staining in the fractures.	BEDROCK

Table 4.--*Generalized geologic descriptions of selected test holes in the Pozo Hondo area*

Well number	Depth of test hole below land surface (feet)	Geologic description	Classification
14D	0 - 40	ALLUVIAL DEPOSITS (CLAY)--brick red, sandy, locally very dense, with angular gravel to cobble size rock fragments.	ALLUVIAL DEPOSITS
	40 - 69	ALLUVIAL DEPOSITS (ROCK FRAGMENTS)--angular, pebble to cobble size.	
	69 - 108	VOLCANIC ROCK--fractured, locally shattered, with angular, pebble to cobble size rock fragments, with iron stains and calcite precipitate in the fractures. precipitate in the fractures.	TRANSITION ZONE
	108 - 110	VOLCANIC ROCK--indurated.	BEDROCK
15D	0 - 2	TOP SOIL--dark brown, organic.	TOP SOIL
	2 - 14	SAPROLITE--volcanic, red, clayey.	
	14 - 20	TALC--white, very soft and powdery when dry, sticky clay when wet.	
	20 - 31	CLAY--gradual change from talc to very indurated clay.	REGOLITH
	31 - 60	SAPROLITE--volcanic, clayey.	
	60 - 80	VOLCANIC ROCK--fragments, angular, gravel to cobble size.	
	80 - 85	SAND--remnants of saprolite broken up by drill bit?	
	85 - 86	VOLCANIC ROCK--indurated.	BEDROCK

GROUND-WATER HYDROLOGY

Ground water occurs under water-table conditions in fractured volcanic rock aquifers in the Aguirre and Pozo Hondo areas. The principal direction of ground-water movement out of each area is south to the coastal plain.

Occurrence and Movement in the Aguirre Area

The Aguirre area contains a thin water-table aquifer. Ground water is found primarily in the regolith and the highly fractured and shattered transition zone. The top of the indurated volcanic rock (bedrock) underlying these divisions is defined as the bottom of the aquifer; however, small quantities of ground water can occur where the bedrock is fractured and in hydraulic contact with the overlying materials. The thickness of the aquifer in the Aguirre area varies significantly throughout the basin, ranging from approximately 20 to 110 feet in thickness.

From September 1987 to January 1990, seasonal ground-water fluctuations in the aquifer were observed to be as much as 38 feet (figs. 14 and 15). These fluctuations affect the thickness of the aquifer and depth below land surface to the top of the aquifer, which is defined by the water table. Depth to the top of the aquifer varies by season and location and, during the period of record for the wells, ranged from land surface at a spring located near well site 5 (fig. 8) to 75 feet below land surface. The configuration of depth to the water table during August 1989 is shown on figure 16.

The general direction of ground-water flow out of the Aguirre area is to the south (fig. 17). The elevation of the water table in feet above sea level for August 25, 1989, ranged from 218 feet in the northern part of the Aguirre area to 128 feet near the southern boundary. Ground-water flow out of the basin is controlled by the relatively impermeable piedmont hills to the south, which act as ground-water controls, forcing all ground-water movement through narrow "necks" located between the hills. The spring that is located in the neck just south of site 5 (fig. 8) is an example of this phenomenon.

The quantity of water recharging the Aguirre area is currently unknown. However, the results of heavy rains on November 24 - 30, 1987 (figs. 14 and 15), which deposited 13.75 inches of rain, indicated that significant recharge to the aquifer can occur during such extreme events. The rapid water-table rise followed by the slow recession of the aquifer heads (approximately 21 months to reach pre-November 1987 levels) observed in the Aguirre area gives some weight to describing the relatively impermeable piedmont hills as ground-water controls, with ground water moving only through the narrow necks of the basin; these narrow necks may control and limit ground-water flow out of the basin. Other factors that could influence this slow recession of ground-water levels could be the slow drainage of the low permeable regolith combined with the generally evenly distributed rainfall recorded at the Central Aguirre Station (figs. 14 and 15).

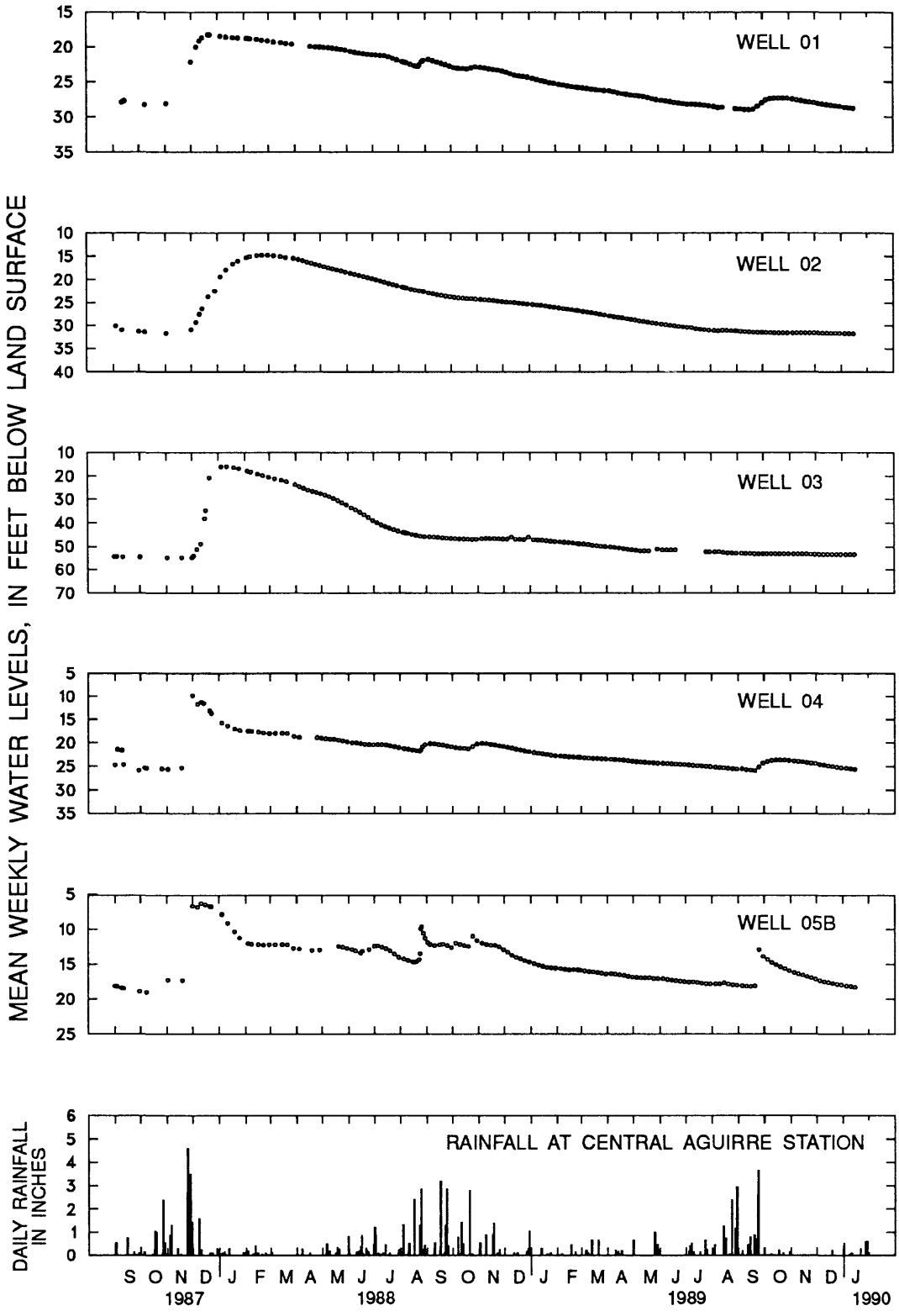


Figure 14.-- Water level in wells 01, 02, 03, 04 and 5B in the Aguirre area and total daily rainfall at Central Aguirre Station, September 1987 to January 1990.

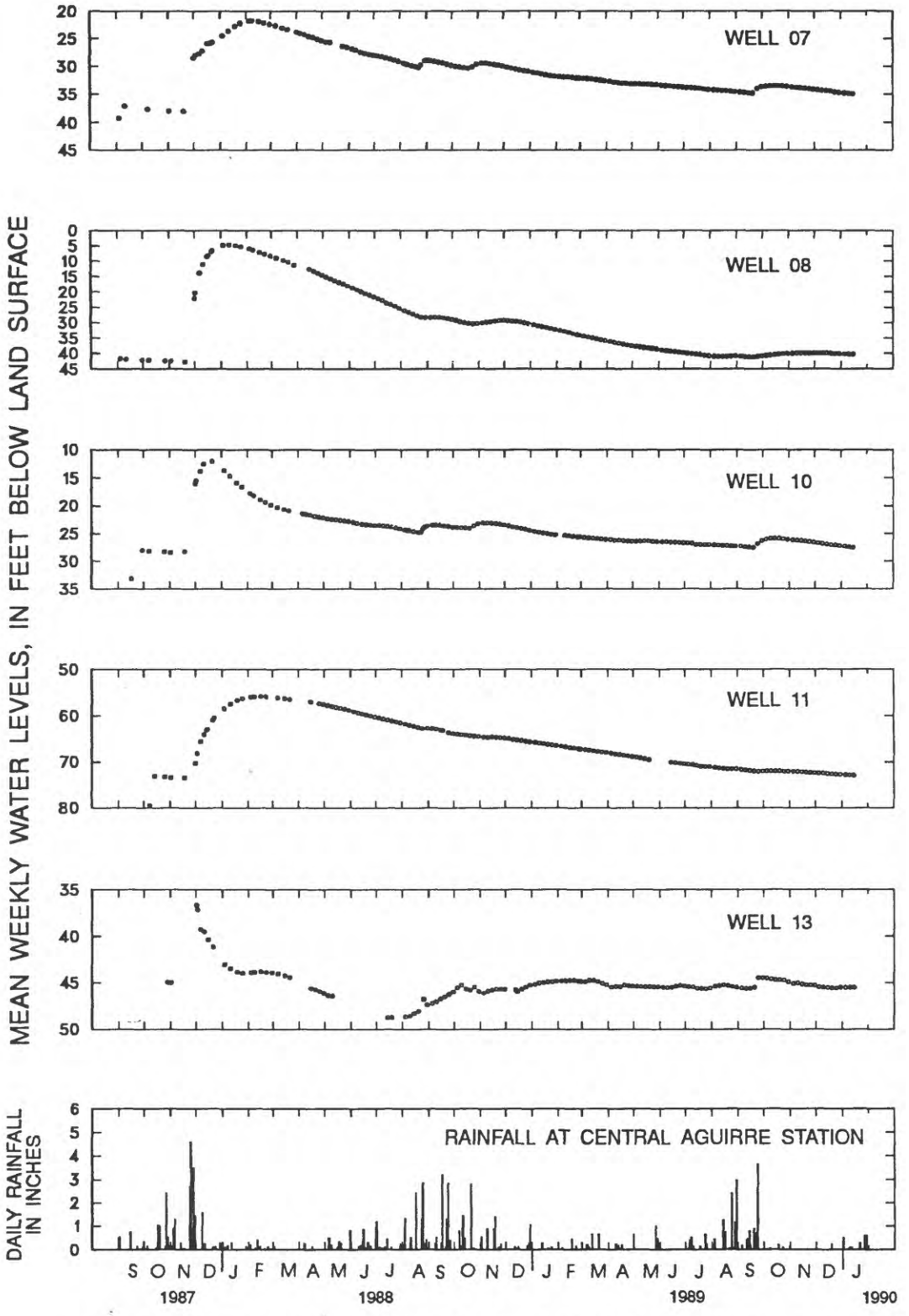
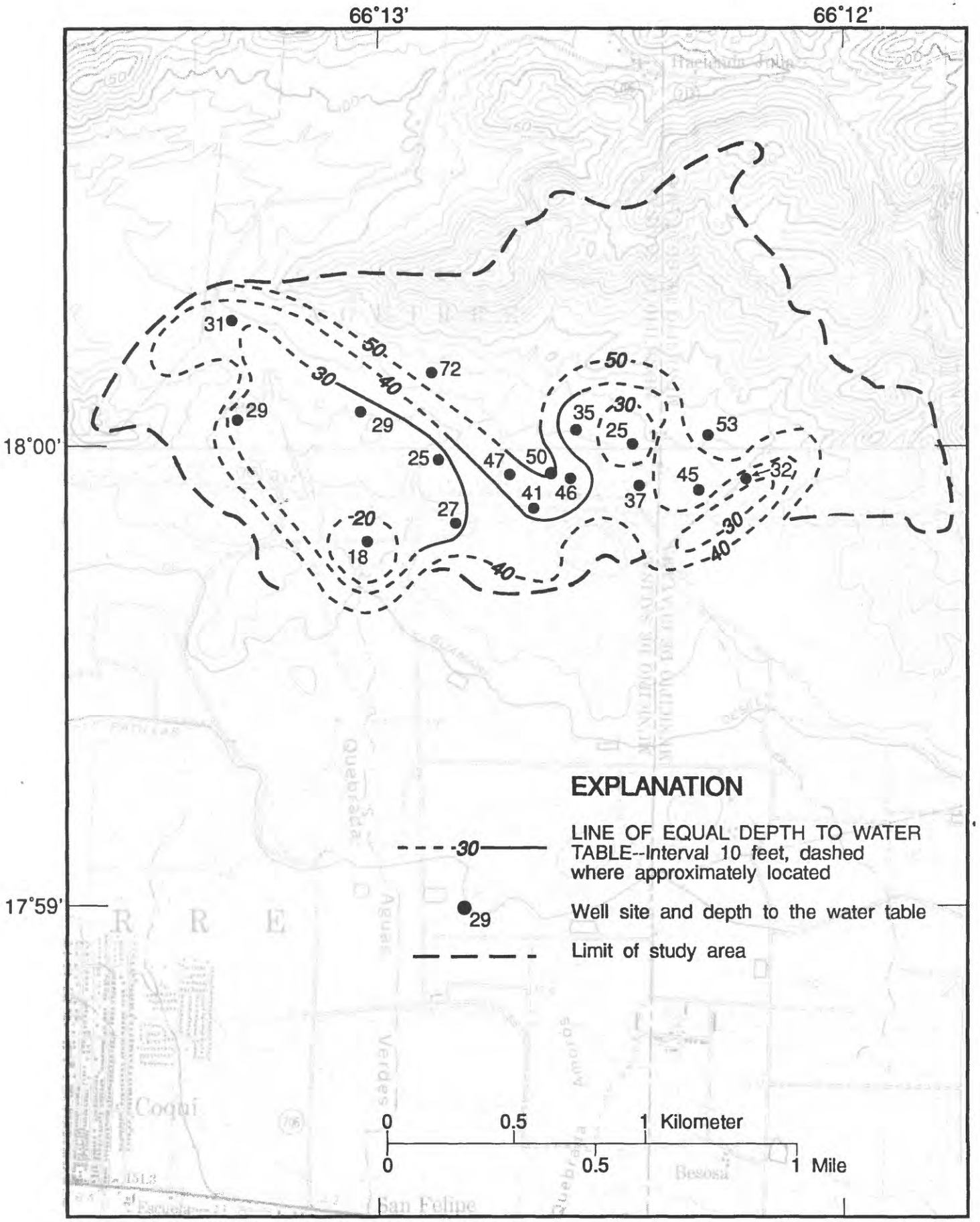
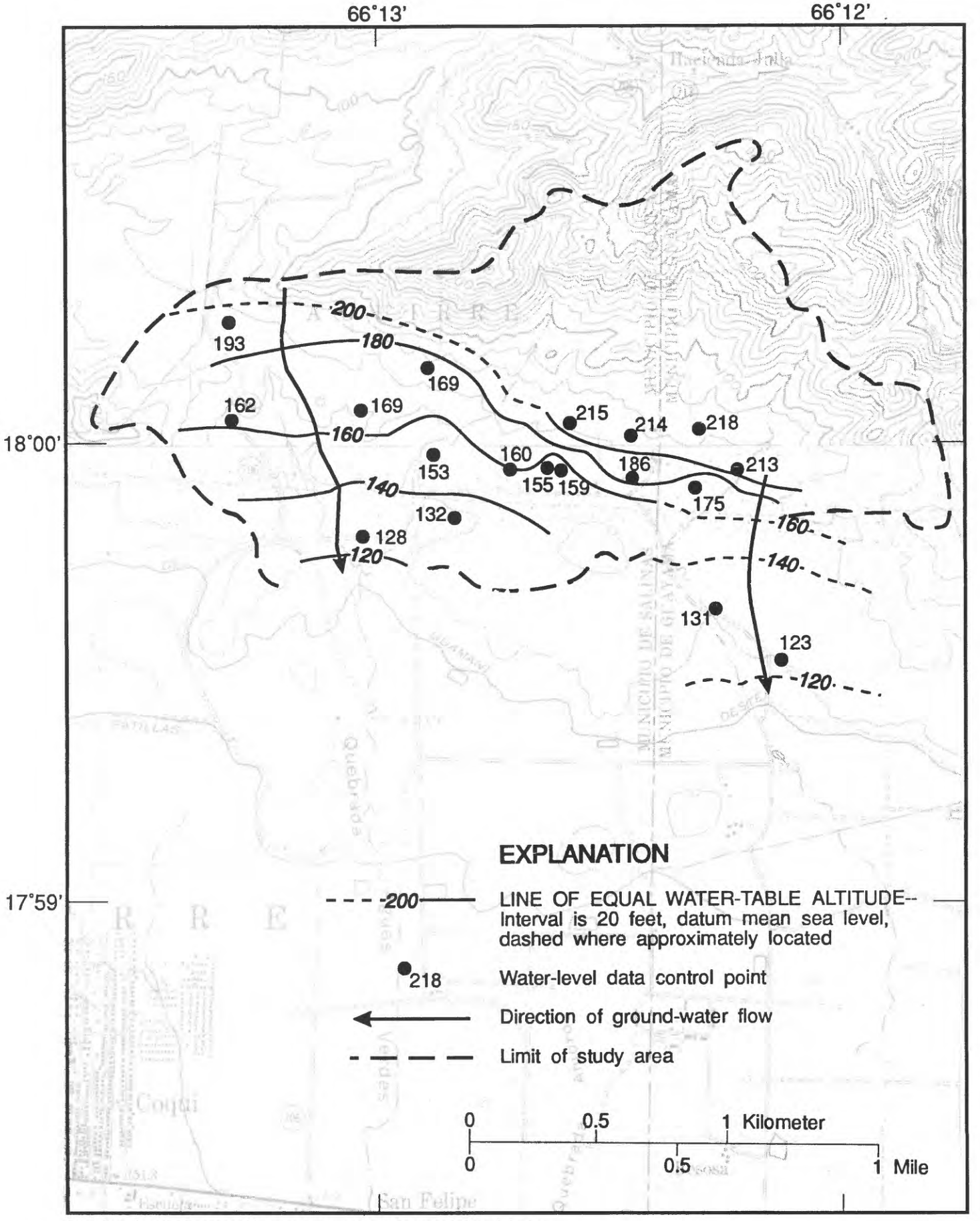


Figure 15.-- Water level in wells 07, 08, 10, 11 and 13 in the Aguirre area and total daily rainfall at Central Aguirre Station, September 1987 to January 1990.



Base from the USGS topographic map, scale: 1:20,000,Cayey and Central Aguirre quadrangles, 1982. Contour interval 10 meters, dashed lines represent 5-meter contours, dotted lines represent 1-meter contours. Datum is mean sea level.

Figure 16.-Depth to the water table in the Aguirre area, August 25, 1989.



Base from the USGS topographic map, scale: 1:20,000,Cayey and Central Aguirre quadrangles, 1982. Contour interval 10 meters, dashed lines represent 5-meter contours, dotted lines represent 1-meter contours. Datum is mean sea level.

Figure 17.-Configuration of the water table and generalized direction of ground-water movement in the Aguirre area, August 25, 1989.

Ground-water discharge out of the Aguirre area was observed to occur from a spring at the boundary of the study area just south of site 5 (fig. 8). Surface-water station 50099000, Quebrada Aguas Verdes near Salinas, constructed downstream from this spring, confirmed flow out of the basin (fig. 18). Long-term surface-water data collection was prevented, due to the destruction of the station. However, between July 1988 and April 1989, the mean daily flow ranged from a high of 6.5 cubic feet per second for August 23, 1988, to a low of 0.01 cubic feet per second for February 22 through March 7, 1989 (discharge measurements are determined from rating curves on the basis of step-backwater analysis, a rating of 0.01 cubic feet per second could be no flow).

Occurrence and Movement in the Pozo Hondo Area

Ground water occurs under water-table conditions in the Pozo Hondo area and is found in the regolith and transition zone of the volcanic rock as well as in alluvial deposits. Although data are limited, the estimated thickness of the aquifer in the Pozo Hondo area ranges from 35 to 70 feet. Depth to the top of the aquifer defined by the water table varied by season and location and ranged from 15 to 74 feet below land surface from December 1987 to January 1990 (fig. 19). Seasonal ground-water fluctuations in the aquifer of as much as 45 feet were observed during this same time period.

Because the configuration of the Pozo Hondo basin is similar to the Aguirre basin, direction of ground-water flow out of the basin is assumed to be south. The elevation of the water table in feet above mean sea level on August 25, 1989, ranged from a high of 209 feet at site 15 to a low of 130 feet at site 14.

Hydraulic Characteristics

Hydraulic characteristics of the aquifer are transmissivity and storage coefficient. Transmissivity is a measure of the ability of the aquifer to transmit water and is defined as a product of the hydraulic conductivity and the aquifer thickness. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. The mathematical definitions of these hydraulic characteristics are beyond the scope of this investigation but are presented in Lohman (1979).

The aquifer characteristics of a heterogeneous fractured rock aquifer are complex. Conventional methods used to define aquifer hydraulic characteristics in a porous homogeneous system can be inadequate and should be used with caution when defining aquifer characteristics in a fractured rock media (Gringarten, 1982; Daniel and Sharpless, 1983). The high degree of weathering in the regolith and the presence of shattered to highly fractured rock in the transition zone of the study area permits the assumption of ground-water flow through a porous media.

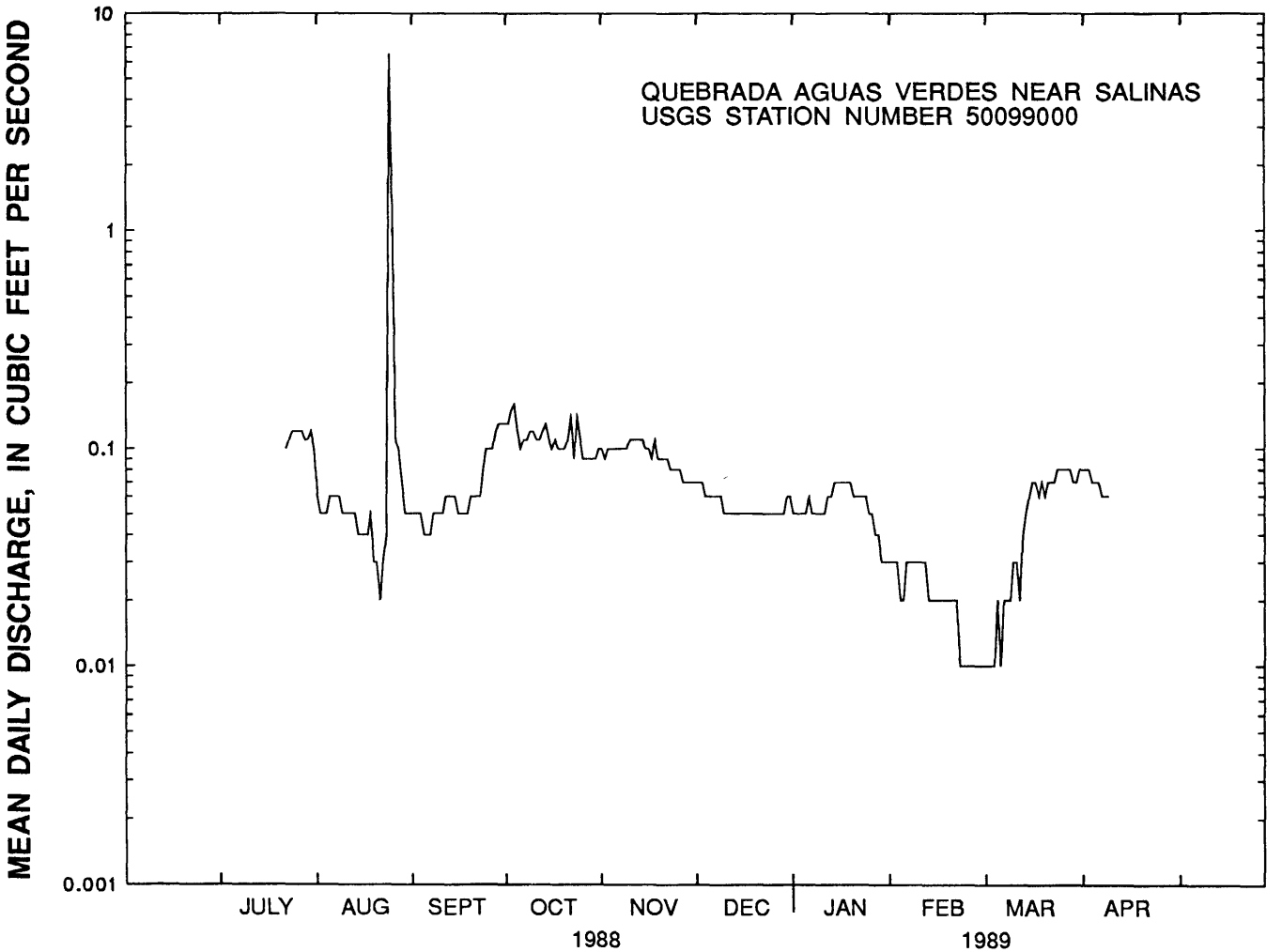


Figure 18.--Daily mean discharge on Quebrada Aguas Verdes in the Aguirre basin, July 1988 to April 1989.

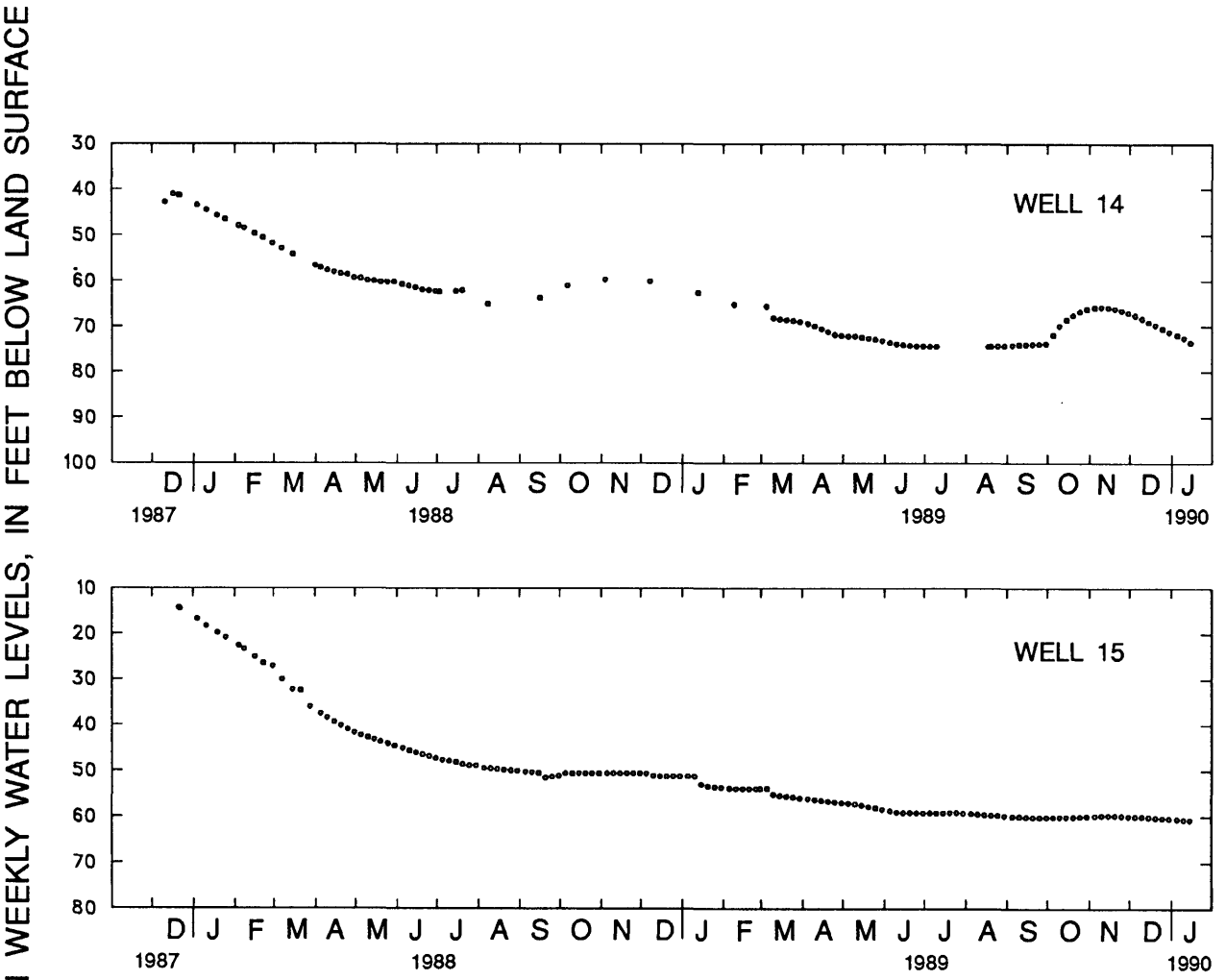


Figure 19.-- Water level in wells 14 and 15 in the Pozo Hondo area, December 1987 to January 1990.

However, the inconsistent lateral extent of these structural features prevents a generalized discussion of aquifer hydraulic characteristics. Therefore, the hydraulic characteristics in this report are discussed only as localized features at each well site where aquifer tests were conducted. These aquifer characteristics were determined using Theis' assumptions (Lohman, 1979) combined with supplemental models to define aquifer characteristics as defined by Stallman (1965), and Bouwer and Rice (1976).

Hydraulic characteristics of the aquifers in the Aguirre and Pozo Hondo areas were determined from two multiple-well aquifer tests conducted at sites 3 and 10, and 21 single-well slug injection and removal tests conducted at sites 1, 2, 4, 5, 7, 8, 10, 11, 14, 15, 20, and 21 (figs. 8 and 9). The results of the pumping-well aquifer tests indicated a range of transmissivities from 175 to 5,700 feet squared per day, and storage coefficients of 0.02, 0.06, 0.08, and 0.2 (table 5). The single-well aquifer tests indicated a range of hydraulic conductivities of 0.02 to 160 feet per day (table 6). The low storage coefficients values of 0.02, 0.06, and 0.08 probably reflect late-time, compressible storage coefficients. The wide range of hydraulic conductivity values is explained by the heterogeneous aquifer material.

Table 5.--*Aquifer transmissivities and storage coefficients determined from aquifer tests in the Aguirre area*

Site number	Well number	Construction data (feet)	Transmissivity (feet squared per day)	Storage coefficient
3	3D	Open hole 92 - 150	175	0.06
10	10	Screen 48 - 53	5,700	0.02
10	10B	Open hole 6 - 35	5,200	0.08
10	10C	Open hole 43 - 100	5,300	0.2

Table 6.--*Hydraulic conductivities, determined from single-well slug injection and removal aquifer tests in the Aguirre and Pozo Hondo areas*

Site number	Well number	Construction Data (feet)	Horizontal hydraulic conductivity (feet per day)
1	1	Screen 32 - 37	0.7
2	2	Screen 60 - 65	17
2	2B	Screen 24 - 28	7
4	4B	Screen 16 - 19	4
4	4C	Screen 23 - 26	20
4	4F	Screen 20 - 29	15
4	4G	Screen 25 - 31	30
5	5	Screen 10 - 13	3
5	5B	Screen 41 - 46	4
5	5D	Screen 17 - 20	3
7	7C	Screen 69 - 79	3
8	8	Screen 43 - 48	2
10	10E	Screen 21 - 26	160
11	11	Screen 79 - 89	0.1
11	11C	Open hole 95 - 200	0.02
11	11D	Screen 56 - 95	10
11	11E	Screen 64 - 74	9
14	14	Screen 71 - 78	2
15	15	Screen 70 - 80	50
20	20	Open hole 56 - 100	0.75
21	21	Open hole 75 - 120	5

WATER QUALITY

In order to collect basic water-quality data for ground water in the Aguirre and Pozo Hondo areas, 19 samples were collected from 15 wells (table 7). The ground-water type, defined using a procedure by Piper (1953), was found to be calcium carbonate (fig. 20). The quality of ground water complied with the U.S. Environmental Protection Agency (1986) drinking water criteria for limits of common constituents with the exception of dissolved solids, which ranged as high as 1,110 milligrams per liter. Drinking water criteria for dissolved solids (recommended to be less than 500 milligrams per liter) is only a recommendation based on an increase in the mineral taste in the water and possible economic consequences due to deterioration of plumbing and pipes, because of the high mineral content. Subsequently, the preliminary water-quality data indicate that ground water in the study areas is suitable for drinking-water supplies.

With the exception of agricultural use and current limited cattle grazing, the Aguirre and Pozo Hondo areas, and their upgradient drainage areas, are undeveloped. Therefore, the aquifer is not believed to be contaminated from surface-water infiltration. However, ground-water samples were not analyzed for volatile organic compounds, or herbicides and pesticides.

Table 7.--*Chemical quality of ground water in the Aguirre and Pozo Hondo areas*

[ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; deg °C, degrees Celsius; mg/L, milligrams per liter]

Well number	Date	Depth of well sample collected from (ft)	Specific conductance (field value) (µS/cm)	pH field value (standard units)	Temperature (deg °C)	Hardness (mg/L as CaCO3)	Alkalinity lab (mg/L as HCO3)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium dissolved (mg/L as Na)
03C	06-13-88	58	2,300	7.8	27.5	830	325	150	110	160
03C	06-15-88	166	2,000	7.6	27.0	750	226	140	96	130
04E	04-06-88	26	1,300	7.7	27.0	370	374	75	45	120
04E	04-07-88	49	1,300	7.8	27.0	390	395	83	44	120
05E	05-04-88	20	1,090	7.7	27.5	370	326	63	51	140
07C	05-17-88	30	1,200	7.5	28.0	340	322	77	36	77
07C	05-18-88	79	1,000	7.7	27.0	330	302	74	35	85
08D	07-13-88	30	1,700	7.8	28.5	500	408	73	77	160
10C	04-27-88	35	1,040	7.8	27.5	400	235	99	37	89
11C	05-23-88	75	814	7.9	27.0	280	238	73	24	72
14D	07-29-88	70	1,100	7.5	32.0	380	248	83	41	68
15D	09-08-88	65	1,000	7.6	29.0	370	206	98	31	52
16	05-03-88	39	1,610	7.6	27.0	550	256	110	66	130
18	06-09-88	35	1,000	7.5	27.0	380	355	79	44	89
18	06-10-88	105	1,100	7.6	27.0	380	359	84	42	91
19	07-07-88	50	1,200	7.7	27.5	420	380	81	53	96
20	07-11-88	45	1,500	7.8	28.5	450	341	81	61	140
21	07-15-88	30	900	7.8	28.5	300	242	73	28	82
23	09-02-88	40	920	7.8	29.0	350	294	81	36	69

Table 7.--*Chemical quality of ground water in the Aguirre and Pozo Hondo areas*--Continued

[ft, feet; mg/L, milligrams per liter; <, less than; --, data not available]

Well number	Date	Depth of well sample collected from (ft)	Sodium+ potassium, dissolved (mg/L as Na+K)	Potassium, dissolved (mg/L as K)	Sulfide total (mg/L as S)	Sulfate, dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO2)	Total dissolved solids (mg/L)
03C	06-13-88	58	160.6	0.6	<0.5	100	380	0.20	14	1,110
03C	06-15-88	166	130.4	0.4	<0.5	89	310	0.30	34	935
04E	04-06-88	26	121.2	1.2	<0.5	58	120	0.40	28	670
04E	04-07-88	49	121.0	1.0	<0.5	58	110	0.40	28	680
05E	05-04-88	20	141.0	1.0	<0.5	54	110	0.40	32	650
07C	05-17-88	30	77.6	0.6	<0.5	39	74	0.30	29	530
07C	05-18-88	79	85.9	0.9	<0.5	41	76	0.30	30	520
08D	07-13-88	30	160.8	0.8	<0.5	10	180	0.40	36	781
10C	04-27-88	35	89.7	0.7	--	44	140	0.20	37	590
11C	05-23-88	35	70.5	0.5	<0.5	30	65	0.30	27	435
14D	07-29-88	70	61.2	1.2	<0.5	28	140	0.20	33	543
15D	09-08-88	65	52.9	0.9	<0.5	25	79	0.20	32	442
16	05-03-88	39	131.1	1.1	<0.5	96	210	0.30	32	800
18	06-09-88	35	89.9	0.9	<0.5	47	93	0.30	32	598
18	06-10-88	105	91.9	0.9	<0.5	43	92	0.30	30	599
19	07-07-88	50	91.2	1.2	<0.5	37	90	0.30	34	620
20	07-11-88	45	140.9	0.9	<0.5	87	150	0.20	30	755
21	07-15-88	30	83.0	1.0	<0.5	35	61	0.20	28	453
23	09-02-88	40	70.1	1.1	2.7	44	46	0.30	33	487

Table 7.--*Chemical quality of ground water in the Aguirre and Pozo Hondo areas*--Continued

[ft, feet; mg/L, milligrams per liter; µg/L, micrograms per liter]

Well number	date	Depth of well sample collected from (ft)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese dissolved (µg/L as Mn)	Barium dissolved (µg/L as Ba)	Aluminium dissolved (µg/L as Al)
03C	06-13-88	58	49.0	10	20	100	10
03C	06-15-88	166	43.0	5	24	24	10
04E	04-06-88	26	2.3	6	27	30	10
04E	04-07-88	49	3.9	7	15	28	10
05E	05-04-88	20	3.4	8	9	23	20
07C	05-17-88	30	5.6	36	8	24	20
07C	05-18-88	79	5.5	5	10	22	20
08D	07-13-88	30	8.2	15	26	61	10
10C	04-27-88	35	24.0	12	20	14	20
11C	05-23-88	75	7.2	3	9	9	10
14D	07-29-88	70	8.0	5	70	9	20
15D	09-08-88	65	5.0	15	27	23	10
16	05-03-88	39	29.0	9	13	26	20
18	06-09-88	35	5.9	5	18	16	20
18	06-10-88	105	6.1	3	47	22	30
19	07-07-88	50	3.5	3	9	29	10
20	07-11-88	45	0.1	11	27	16	30
21	07-15-88	30	6.2	9	28	21	30
23	09-02-88	40	2.7	4	10	46	40

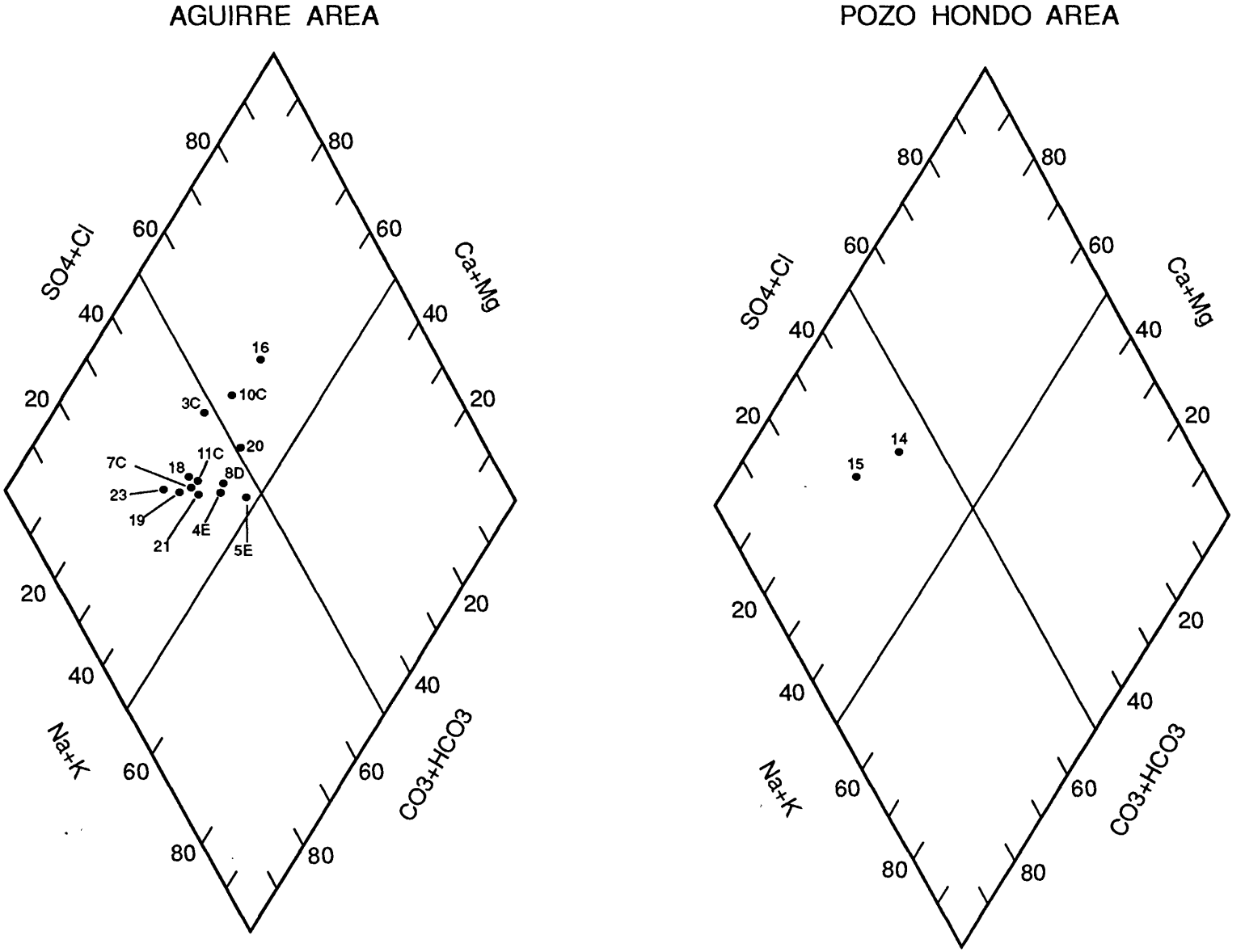


Figure 20.-- Diagrams showing major constituents in ground water from wells in the Aguirre and Pozo Hondo areas in milliequivalents per liter (numbers refer to wells in table 7).

SUMMARY

Since 1970, Puerto Rico has experienced significant industrial development. A consequence of this growth has been an increase in the generation of hazardous-waste material. Because of Puerto Rico's limited area and high population density, the proper storage and disposal of hazardous wastes on the island is difficult to identify. The Puerto Rico Industrial Development Company recently selected two sites in the Aguirre and Pozo Hondo areas, located on the south coast, to investigate for potential development as hazardous-waste containment facilities. In a cooperative study with the Puerto Rico Industrial Development Company, the U.S. Geological Survey completed a detailed geohydrologic evaluation of the areas to provide baseline data prior to further evaluation for suitability as hazardous-waste sites.

The subsurface geology in the Aguirre and Pozo Hondo areas is primarily a fractured igneous volcanic rock (andesite) with three distinct divisions: regolith, transition zone, and bedrock. Thin alluvial deposits occur locally in the Aguirre area, whereas in the Pozo Hondo area a section of alluvial deposits of stratified clay, silt, sand, gravel, and cobbles was found to be 69 feet thick. In the Aguirre area, weathered low-grade metamorphosed volcanic rock with a schistose texture and a vertical plane of foliation is found in association with the regolith.

A thin water-table aquifer has been defined in the Aguirre and Pozo Hondo areas. Ground water occurs, primarily, in the regolith and highly fractured and shattered transition zone. The thickness of the aquifer in the Aguirre area varied significantly throughout the basin, and ranged from approximately 20 to 110 feet. Limited data from the Pozo Hondo area indicated that the thickness of the aquifer can range between approximately 35 to 70 feet. Depth to the water table in the Aguirre area varied by season and location, and ranged from land surface (spring flow) to 75 feet below land surface during the period of September 1987 to January 1990. In the Pozo Hondo area, depth to the water table ranged from 15 to 74 feet below land surface during December 1987 to January 1990. Seasonal ground-water fluctuations in the water-table aquifers in the two areas were observed to be as much as 38 feet in the Aguirre area, and as much as 45 feet in the Pozo Hondo area. The direction of ground-water flow is generally to the south out of both areas.

Hydraulic characteristics of the aquifers in the Aguirre and Pozo Hondo areas were determined from two multiple-well aquifer tests and 21 single-well slug injection and removal tests. The results of the pumping-well aquifer tests showed a range of transmissivities from 175 to 5,700 feet squared per day, and of storage coefficients from 0.02 to 0.2. The single-well aquifer tests showed a range of hydraulic conductivities from 0.02 to 160 feet per day.

The ground water type in the Aguirre and Pozo Hondo areas was found to be calcium carbonate. The quality of ground water complied with the U.S. Environmental Protection Agency's (1986) drinking water criteria for limits of common constituents with the exception of dissolved solids, which ranged as high as 1,110 milligrams per liter.

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