WATER RESOURCES OF THE RIO GRANDE DE AÑASCO - LOWER VALLEY, PUERTO RICO

By

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and
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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

For the use of readers who prefer to use metric units, conversion factors for the inch-pound units used in this report are listed below.

Multiply	By	To Obtain
inches (in.)	25.4	millimeter (mm)
feet (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square miles (mi^2)	2.590	square kilometer (km^2)
acres	0.4047	hectare (ha)
gallons per minute (gal/min)	0.06308	liters per second (L/s)
million gallons per day (Mgal/d)	0.0438	cubic meters per second (m^3/s)
cubic feet per second (ft^3/s) (ft^3/s)	0.02832	Cubic meters per second (m^3/s)
feet squared per day (ft^2/d)	0.0929	meters squared per day (m^2/d)

U.S. DEPARTMENT OF THE INTERIOR · GEOLOGICAL SURVEY

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ABSTRACT

A large amount of water suitable for most uses is available in the lower Río Grande de Añasco Valley. The major source is the Río Grande de Añasco which contributes about 95 percent of the surface water inflow to the lower valley. River flow at El Espino will exceed 100 cubic feet per second about 85 percent of the time and 200 cubic feet per second 50 percent of the time. Average daily flow for the dryest months of the year (February, March, and April), is almost always less than 100 cubic feet per second. In contrast, the average daily flow for the wettest months of the year (September, October, and November), is greater than 120 cubic feet per second.

The Rio Cañas, which enters the lower valley from the south is the only other stream with significant perennial flow. During the study period, flows of the Río Cañas averaged about 5 cubic feet per second.

The lower valley is underlain by igneous rocks that have been eroded to depths of 350 feet or more below sea level. The valley is filled with 250 feet or more of limestone and clay, that in turn is overlain by as much as 100 feet of alluvium.

The amount of ground water available is unknown. There are large volumes of water in the saturated mostly fine-grained alluvium of Zone II, but as a whole the alluvium does not yield water readily to wells. Sand and gravel deposits associated with former river channels will yield an estimated 100 to 150 gallons per minute to wells.

The principal source of ground water is the limestone of Zone III, that reportedly will yield as much as 500 gallons per minute to wells.

The quality of surface water especially that of Río Grande de Añasco is very good. Specific conductance seldom exceeds 250 microsiemens per centimeter, even at low flows. Both salinity and sodium are low, falling in the C1 - S1 irrigation water classification. Water quality in the lower 5,000 feet or so of the river is affected by saltwater encroachment from the sea. The water quality of the other streams and canals in the lower valley is variable depending on susceptability of saltwater encroachment, contamination from man-made sources, and concentration of minerals by evapotranspiration. Specific conductance however seldom exceeds 500 microsiemens per centimeter and the water usually falls in the C1 - S2 classification.

The quality of ground water in the alluvial aquifer is about the same as that of the water of the Río Grande de Añasco except where encroached by saltwater or contaminated. The water from the limestone is more mineralized than that of the alluvium (about 600 to 700 microsiemens per centimeter), and is somewhat similar to that of the smaller streams and canals in the valley.

INTRODUCTION

In 1978, the Puerto Rico Department of Agriculture began an intensive program to foster agricultural development on the Island. One of the components of the program was the development of a rice industry in Puerto Rico capable of reducing or eliminating most of the rice imports (whose value totaled about 100 million dollars per year). The rice program was developed under the direction of the Administration for Agricultural Development (AFDA) and the Puerto Rico Rice Corporation, a public corporation of AFDA. Agricultural programs, in particular the rice project, required accurate and updated information about the water resources of the valleys selected for development.

The lower Río Grande de Añasco valley was among several areas identified for potential agricultural development (fig. 1). The valley has been dedicated traditionally to sugarcane cultivation. However, the overall decline of the sugar industry in Puerto Rico has resulted in only partial utilization of the land in the valley.

Purpose and Scope

A reconnaissance of the water resources of the lower Río Grande de Añasco valley was begun in August 1981 by the U.S. Geological Survey. The project, done in cooperation with AFDA and the Puerto Rico Rice Corporation, included a preliminary appraisal of the surface and ground-water resources of the area. The principal objectives of the investigation were to:

1. Define the flow characteristics and water quality of the Río Grande de Añasco and other streams and canals within the project area;

2. Determine and describe the movement, occurrence, quality, and availability of ground water in the lower valley;

3. Evaluate areas of potential seawater encroachment and the upriver extent of saltwater in the lower reaches of the Río Grande de Añasco, and other streams or canals that discharged to Bahía de Añasco; and,

4. Document results of the above.

To accomplish these objectives a number of sites were established on the streams in the lower valley at which discharge measurements were made and samples collected for water quality analyses. A series of shallow wells, penetrating about 10 feet (ft) into the surficial alluvial aquifer, were drilled to obtain water level and water quality information. Five seismic lines were run in different parts of the valley to obtain better knowledge of the subsurface geology. Published information concerning the valley was reviewed and data available in the files of the Geological Survey were examined.

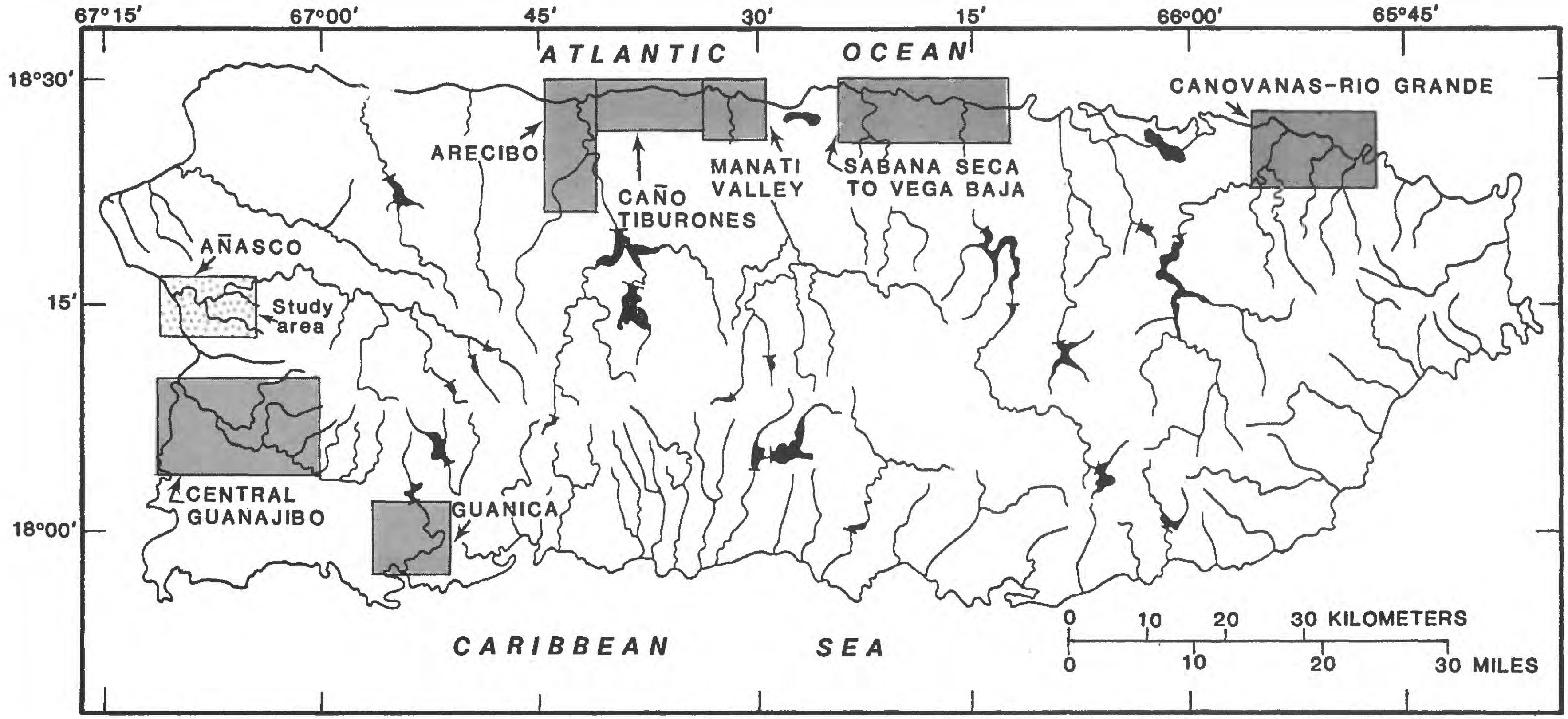


Figure 1.--Location of study area and other water resources investigations by the U.S. Geological Survey in cooperation with the Puerto Rico Department of Agriculture.

Geographic Setting

The Río Grande de Añasco, located in west central Puerto Rico, drains an area of about 201 square miles (mi^2). The river rises in the mountains near Lares, enters the lower valley at El Espino, and discharges to the sea in Bahía de Añasco (fig. 2). The lower valley, the study area, is a flat-lying alluvial plain of about 10,500 acres, of which, about 6,000 acres are planted in sugarcane. The remaining land is either pasture or fallow. The alluvial plain is flanked on the north by the Cadena de San Francisco and the Atalaya Mountains, and on the south by the Uroyan Hills.

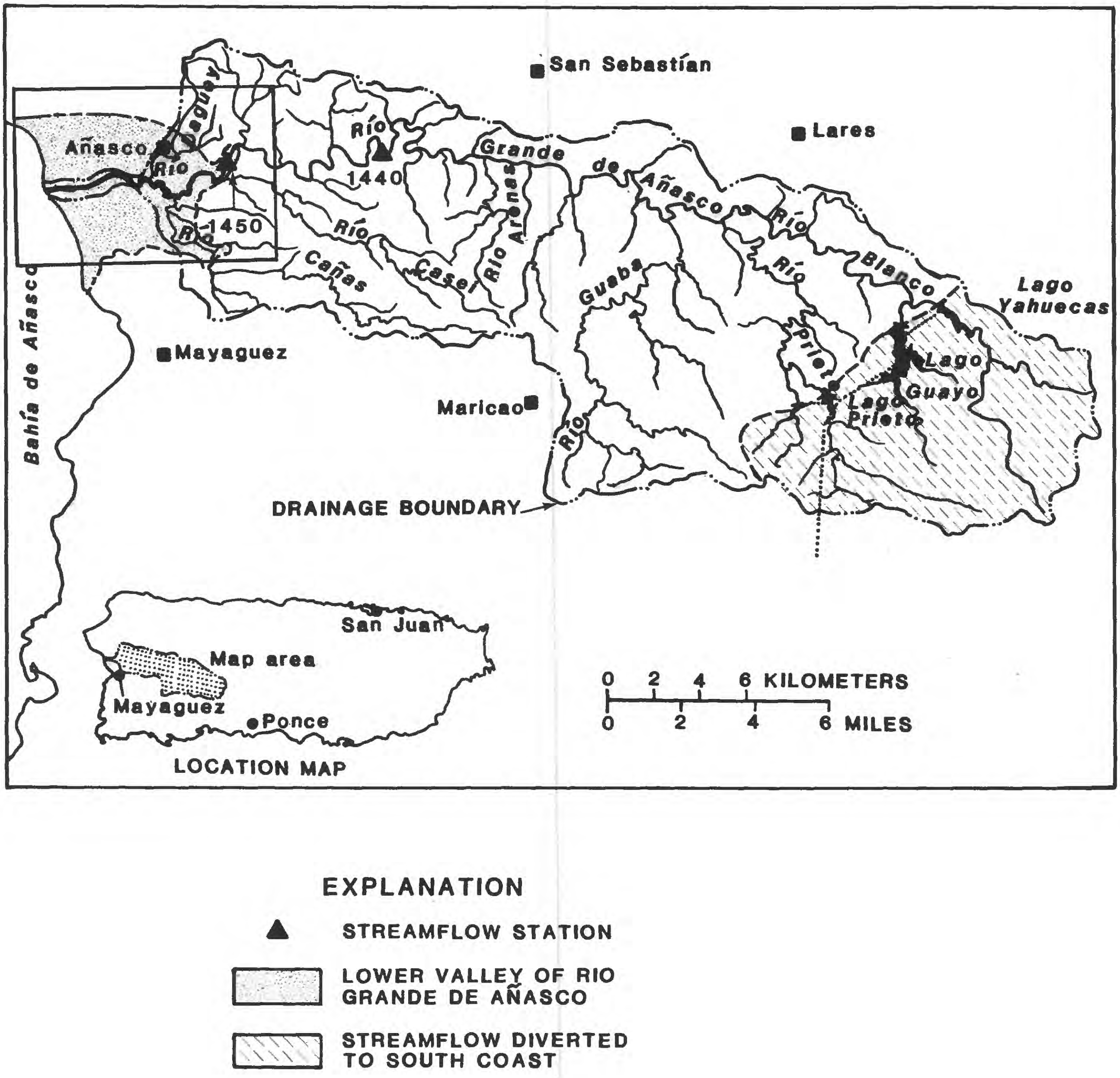


Figure 2.--Río Grande de Añasco basin and that part of the basin diverted to the south coast.

CLIMATE

The lower Río Grande de Añasco valley lies within the southwestern slopes of the humid-physiographic climatic area as classified by Colon (1970). The climate of the valley is characterized by warm, wet summers followed by a warm dry period in the months of January to April. Average daily temperatures in the valley range from 23 to 26 degrees Celsius.

Rainfall varies seasonally and geographically in the lower valley. The wet season extends from about May to October. Orographic effects caused by the mountainous features surrounding the valley are evident throughout the year. During the rainy season recurrent showers of 10 to 20 minutes and occasionally 1 to 2 hours duration occur almost every afternoon. During the dry season, less frequent showers usually occur in the afternoon. The area is also affected by general weather systems. These are usually low-pressure systems moving inland from the Atlantic Ocean. Intense rains sometimes lasting 1 to 2 days can result from these systems.

Rainfall averages about 93 inches (in.) at Lares in the upper valley of the Río Grande de Añasco and exceeds 100 in. annually in the mountains near waters of the river basin.

The average annual precipitation at the Mayaguez Airport in the lower valley for the period 1973-82 was about 68 in. Rainfall at the Airport during the study period (August 1981 through July 1982) was 70.72 in. (fig. 3); data were

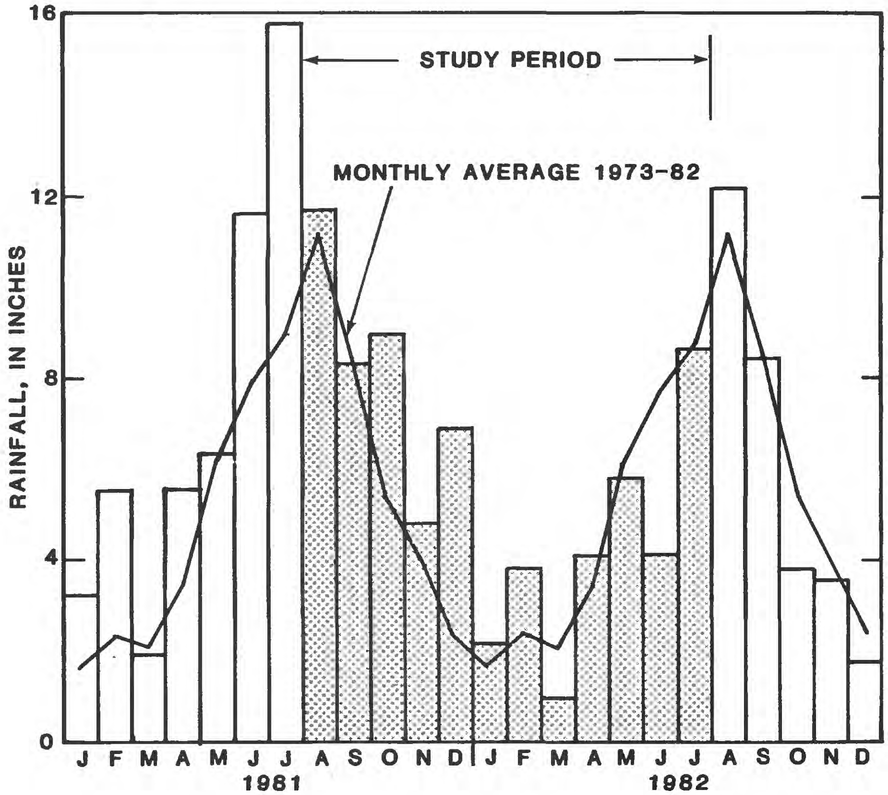


Figure 3.--Rainfall at Mayaguez airport, 1981-82 and monthly average for 1973-82.

CLIMATE (Continued)

obtained at eight other stations in the valley from August through December 1981 (fig. 4). Rainfall was the least at stations in the rain shadow of the hills on the north and south margins of the lower valley. In the central part of the lower valley, rainfall may be 10 to 20 in. greater than that at the Mayaguez Airport, which is located in a rain shadow.

The climate has an important role in the water resources of the lower Río Grande de Añasco Valley as direct precipitation is a significant component of the water budget. The precipitation during the study period at the Mayaguez Airport (70.72 in.), for example, would contribute about 61,000 acre-feet (acre-ft) of water directly to the alluvial valley.

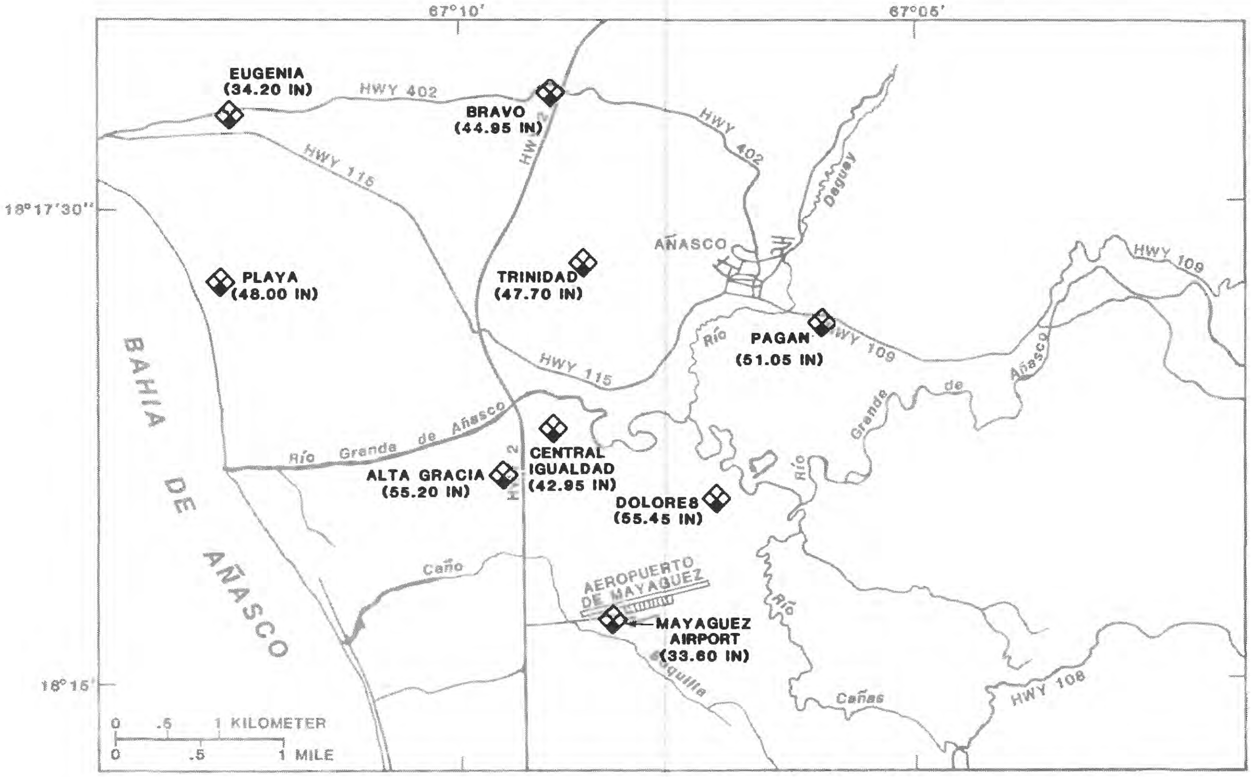


Figure 4.--Rainfall stations in the lower valley during August-December 1981. (Values in inches).

GEOLOGY

The valley of the Río Grande de Añasco is underlain largely by igneous rocks of early Tertiary and Cretaceous age. When weathered, these rocks break down into clay, silt, or sand--materials that comprise both the soil and part of the subsurface deposits that fill the lower valley. The remainder of the valley fill is limestone interbedded with clay. The surficial deposits can be classified, based upon soil type into: (1) sand and gravel of alluvial origin, (2) beach and dune deposits, (3) clay, silt and marsh deposits, and (4) material disturbed by urban development (fig. 5). Most of the soils, with the exceptions of the clays are moderately permeable, although all soils are poorly drained because of high ground-water levels.

Seismic data from the valley indicate four subsurface zones of materials with distinct velocity differences (figs. 6a and b). The uppermost zone (Zone I) can be roughly correlated with the soil and underlying alluvial material that is above the water table. The second zone (Zone II) is probably saturated alluvium. Data from well logs in the valley indicate that the alluvium is largely composed of clay and silt with some sand (Table 1, wells 5 and 7). Occasionally zones of gravel are encountered during drilling that are probably the remnants of former stream channels (table 1, well 8). The seismic profiles indicate that this second zone generally ranges from 50 to 100 ft in thickness. Near the sea the alluvial deposits of Zone II apparently interfinger with beach and dune sands and other marine deposits (Table 1, well 6).

Zone III has a velocity nearly twice that of the overlying alluvium of Zone II, indicating that material comprising Zone III is much denser. Based upon data from several wells (Table 1, well 7, for example), Zone III is composed principally of layers of hard dense clay and soft limestone. These materials probably were deposited during the Pleistocene Epoch with the limestones being laid down during transgressions of the sea into the embayment. The clays were likely deposited in a marine environment but could also be terrestrial deposits laid down during regressions of the sea. Zone III appears to be present throughout the deeply incised central part of the lower valley. The zone reaches a thickness of as much as 250 ft and a depth of as much as 350 ft below sea level.

Zone IV is composed of Early Tertiary and Cretaceous rocks (predominately of igneous origin) that underlie this part of Puerto Rico. The surface of zone IV is a valley deeply incised in the bedrock to depths of as much as 350 ft below sea level. It is likely that the cutting of this valley was associated with a Pleistocene sea level that was more than 300 ft lower than the present sea level (Fairbridge, 1960).

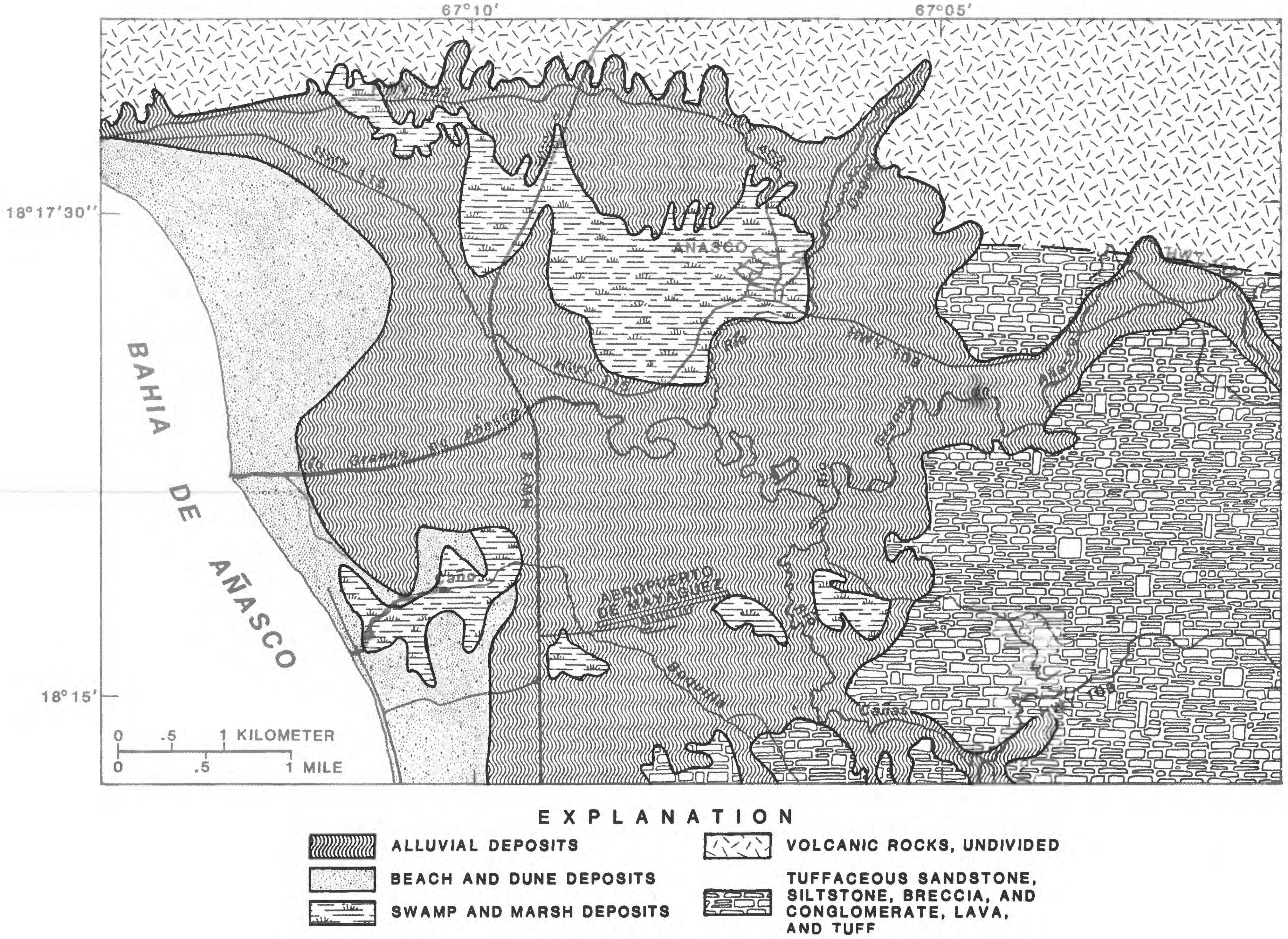


Figure 5.--Surficial geology of the lower valley

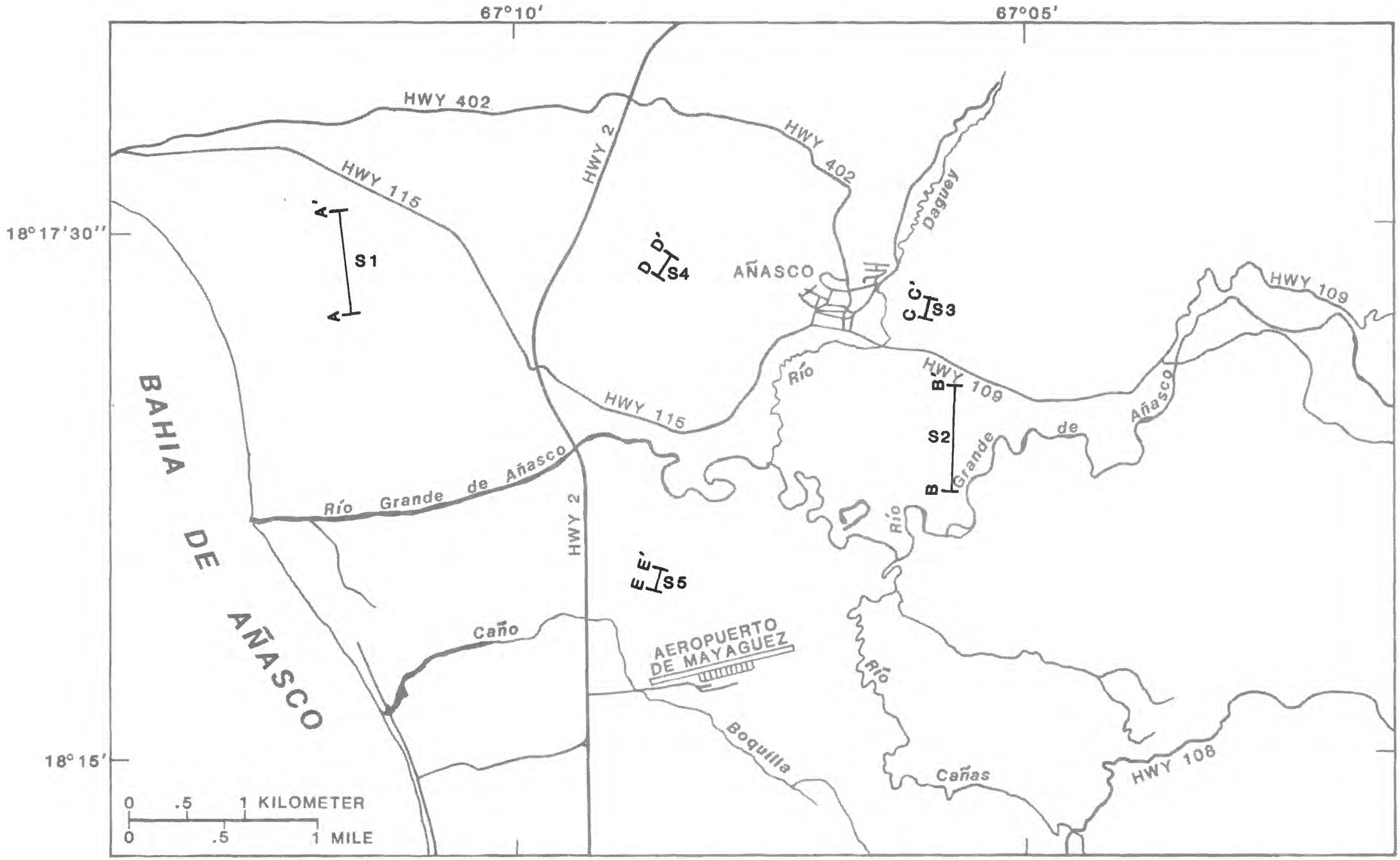


Figure 6a.--Location of seismic profiles in the lower valley.

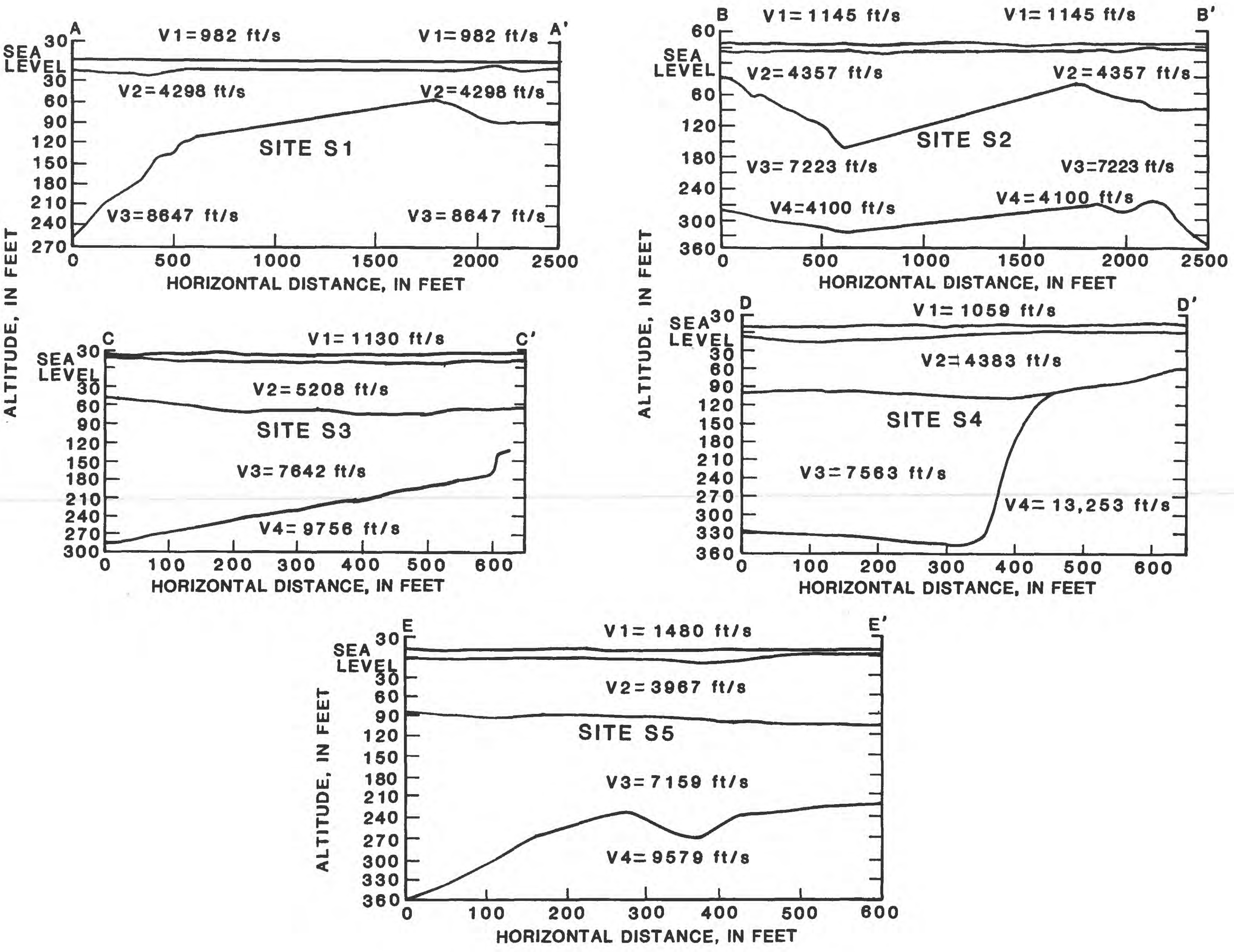


Figure 6b.--Seismic profiles in the lower valley.

Table 1.--Driller's log of selected wells.

Well 4: Eli Lilly

Material	Thickness (Feet)	Depth (Feet)	Remarks
Top soil	3	3	
Black clay	97	100	
Yellow clay w/rocks	45	145	
Loose rocks	5	150	Like river bed
Yellow clay, yellow rocks, tosca	60	210	
black clay		210	

Well 5: Puerto Rico Aqueduct and Sewer Authority test.

Material	Thickness (Feet)	Depth (Feet)	Remarks
Top soil	2	2	
Gravel and silt	11	13	
Gravel, clay, & silt	25	38	
Clay, brown	2	40	
Clay, with some gravel	10	50	
Clay with gravel	15	65	
Clay, brown, with sand	20	85	
Clay, brown	16	101	

Well 6: Tres Hermanos

Material	Thickness (Feet)	Depth (Feet)	Remarks
Top soil	3	3	
Sand and quartz	22	25	
Silt, dark	15	40	
Silt, dark gray	15	55	
Silt, grayish brown	11	66	
Clay with shells (Coquina)	18	84	
Clay, dark, plastic	37	111	Water
Clay, red and brown, shell fragments	13	124	
Clay, black and brown	15	139	

Table 1.--Driller's log of selected wells (Continued).

Clay, brown, rock fragments	10	149	
Clay, reddish brown, silt	6	155	
Clay, gray, silty, shell fragments	14	169	
Limestone, porous	9.5	178.5	

Well 7: Trinidad

Material	Thickness (Feet)	Depth (Feet)	Remarks
Top soil	2	2	
Clay, red	3	5	
Decomposed rock	5	10	Water, probably boulder bed
Clay, gray, sandy	7	17	
Rock, yellow, decomposed	4	21	
Clay, gray, rock fragments	9	30	
Clay, yellow	16	46	
Clay, red, sandy, soft	21	67	
Clay, gray, sticky, dry	21	88	
Clay, gray, soft, with shells	4	92	
Coral rock	3	95	
Clay, gray, soft	19	114	
Clay, limey, and rock fragments	6	120	
Clay, gray, soft	5	125	
Clay, very dark gray, soft	3	128	
Clay, gray, with shells	14	142	
Decomposed rock, yellow, sandy	6	148	
Limestone, hard	47	195	Static water level dropped from 2.5 ft to 18.5 ft at 185 ft

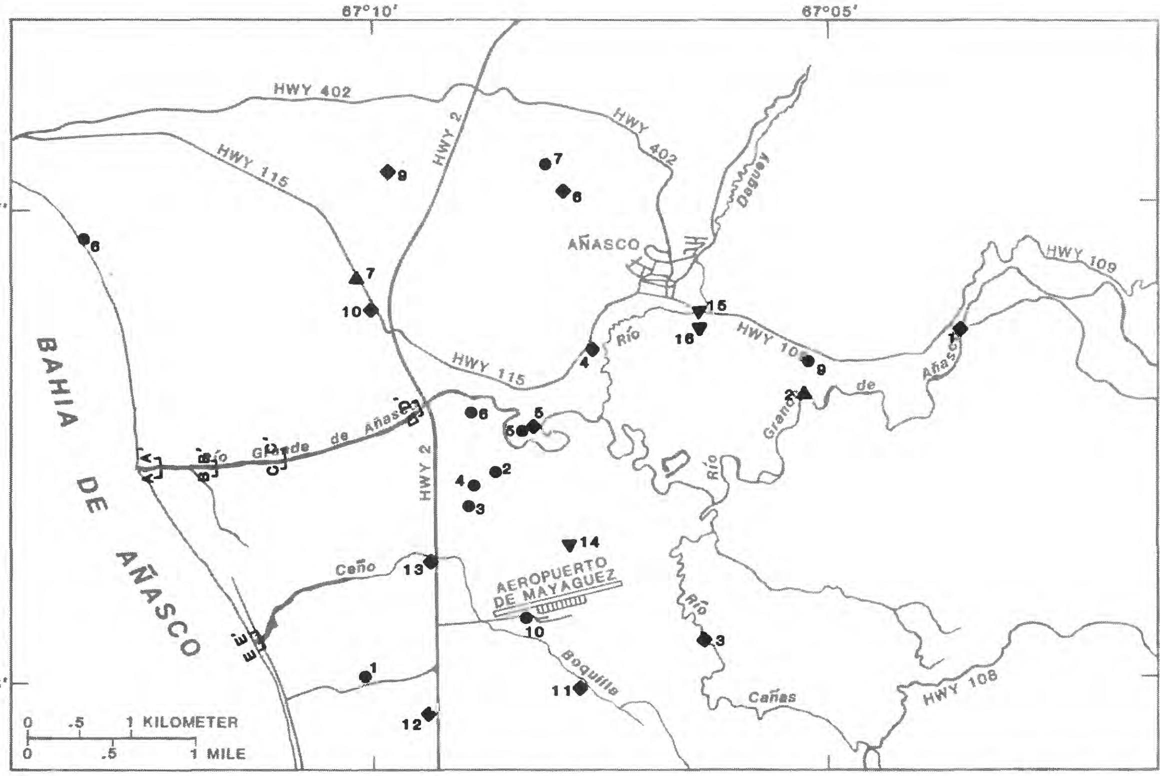
Well 8: Central Igualdad

Material	Thickness (Feet)	Depth (Feet)	Remarks
Soil	10	10	
Sand, dry	1	11	
Clay	15	26	
Sand, coarse, and fine gravel	6	32	Water
Clay	220	252	
Limestone, soft with coral, shells, and yellow clay	48	300	Water
Clay	100	400	
Clay	45	445	
Sand, yellow	4	449	
Sand and clay	6	455	

SURFACE WATER

Drainage

The Río Grande de Añasco, including the lower valley that comprises the study area, has a drainage basin of 201 mi^2. The water from a 36.2 mi^2 area of the upper basin is diverted by a series of dams and tunnels to Puerto Rico's south coast (fig. 2). The 36.2 mi^2 of the upper basin contributes water to the lower basin only when flood flows cause the upper basin reservoirs to spill. An additional 3.5 mi^2 contributes to the lower basin during periods of storm runoff. At El Espino, where the Río Grande de Añasco leaves the mountains, the effective drainage basin is 108 mi^2 excluding the 39.7 mi^2 of the upper basin and storm-runoff area. The lower valley drainage basin consists of a flood plain of about 16.4 mi^2 and the surrounding hills and mountains that add another 36.9 mi^2 to the lower valley for a total area of 53.3 mi^2 (fig. 2). At El Espino the river is about 70 ft wide, with nearly vertical banks and bed material composed mostly of boulders and gravel. Downstream from El Espino, the river flows through a series of meanders to the vicinity of the Central Igualdad sugar mill (fig. 7). From this point, it



EXPLANATION

◆12 DISCHARGE AND WATER QUALITY MEASUREMENT COLLECTION SITE

▲2 DISCHARGE MEASUREMENT SITE

▼14 SURFACE-WATER QUALITY COLLECTION SITE

●1 PRODUCTION OR TEST WELL

A A' SPECIFIC CONDUCTANCE CROSS SECTION

Figure 7.--Principal streams and canals, streamflow measurement sites, surface-water quality sites, production and test well sites, and specific conductance cross sections in Río Grande de Añasco and Caño Boquilla.

Drainage (Continued)

flows in nearly a straight line to the Bahia de Añasco. In this reach the river varies in width from about 60 to 80 ft. Longshore currents flowing southward cause sand to be deposited as a bar at the mouth of the river. On occasions the sandbar has been reported to reduce the opening of the river to the sea to as little as 20 ft. The sandbar usually develops during the dry winter season when flow in the river is low.

The principal tributary to the Río Grande de Añasco within the study area is Río Cañas, flowing into the main stream in the vicinity of Oveja. The Miradero public water supply filtration plant is located at the confluence of the streams. About 0.44 million gallons per day (Mgal/d) of water are pumped at this site to supply the town of Añasco (Gómez-Gómez and others, 1983).

Río Daguey, the second most important tributary to the lower Río Grande de Añasco, flows into the main stream about 3,000 ft downstream from the town of Añasco. Although the drainage area of Río Daguey is only about 3 mi^2, intense storms in its basin can cause flash floods in the northeastern part of the town of Añasco.

Drainage of the Río Hondo, Quebrada Boquillas, and Quebrada La Harga (fig. 7), formerly tributaries to the Río Grande de Añasco and several canals have been diverted toward Caño La Puente and Caño Boquillas. Both caños flow westward to the Bahía de Añasco.

Streamflow Stations

For this study streamflow data was collected at 13 sites on streams and canals in the lower valley (fig. 7). Discharge measurements made at these sites are given in Table 2. Daily stage and discharge records are available for the Río Grande de Añasco at El Espino (drainage area 108 mi^2) from 1959 to 1966, and for the station near San Sebastián (drainage area 94.3 mi^2) from 1963 to the present (1982).

Table 2.--Streamflow measurements in lower valley, 1981-82. (See fig. 7 for location of sites.)

Map no.	Station name	Date	Discharge ft^3/s
1	Río Grande de Añasco at El Espino	11-23-81	351.0
		01-27-82	184.
		02-15-82	113.
		03-09-82	90.
		04-06-82	162.
		09-02-82	281.
		09-04-82	332.
2	Río Grande de Añasco at Añasco, Highway 430 bridge	01-22-81	150.
		03-25-81	180.
		05-08-81	178.

Table 2.--Streamflow measurements in lower valley, 1981-82 (Continued).

Map no.	Station name	Date	Discharge ft^3/s
3	Río Canas at end of Highway 342	03-25-81	6.56
		04-29-81	9.68
		05-08-81	3.21
		05-20-81	6.92
		09-02-81	18.7
		10-21-81	27.0
		11-21-81	16.8
		01-26-82	5.26
		02-19-82	5.91
		03-09-82	4.08
		04-06-82	3.33
4	Río Daguey above confluence with Río Grande de Añasco	03-10-81	1.42
		03-26-81	1.43
		04-05-81	1.99
		04-29-81	1.75
		05-08-81	1.54
		05-20-81	13.3
		09-02-81	2.33
		10-20-81	5.45
		11-23-81	3.50
		01-26-82	2.69
5	Río Grande de Añasco above Highway 2 near Central Igualdad	01-26-82	199.
		03-09-82	103.
		04-06-82	169.
6	Río Hondo at Las Marias	03-26-81	.82
		04-20-81	4.27
		09-03-81	1.46
		11-24-81	1.98
		01-26-82	1.73
		02-27-82	.81
		04-05-82	.46
7	Quebrada Abad at Highway 115	05-21-81	1.73
		09-03-81	.59
		10-21-81	2.02
		11-24-81	.85
8	Quebrada Abad near Las Marias	04-21-81	.30
		10-21-81	2.63
		11-24-81	.34
		01-26-82	.06
9	Quebrada Golzadora at Cienaga Guayabal	03-25-81	1.14
		05-20-81	.31
		09-03-81	.58
		01-26-82	.33
		03-10-82	.24

Table 2.--Streamflow measurements in lower valley, 1981-82 (Continued).

Map no.	Station name	Date	Discharge ft^3/s
10	Quebrada La Puente at Highway 115	03-26-81	.48
		04-24-81	.00
		05-20-81	.00
11	Quebrada Boquilla at Highway 342 near Mayaguez Airport	03-27-81	.34
		05-21-81	.92
		09-03-81	1.10
		10-21-81	2.69
		11-24-81	1.17
		01-26-82	.61
		03-10-82	.91
		04-07-82	.40
12	Caño La Boquilla at Highway 2, Km. 149.50	05-21-81	.54
13	Quebrada La Boquilla at Highway 2, Km. 147.85	05-21-81	3.58
		10-21-81	11.5
		02-27-82	2.59

Daily-mean Streamflow

Streamflow in the study area is essentially the flow of the Río Grande de Añasco. Although many of the lesser streams and canals have perennial flow; the volume is minor compared to the Río Grande de Añasco. For example the Río Cañas, the largest of all the lesser streams had a flow of about 5 cubic feet per second (ft^3/s) in the dry season during the study. Efforts were concentrated on determining the relation of the flow of the Río Grande de Añasco at El Espino to that at the station near San Sebastián.

A hydrograph of the mean daily discharge of the Río Grande de Añasco near San Sebastián from August 1981 to July 1982 is shown in figure 8. Rainfall was about

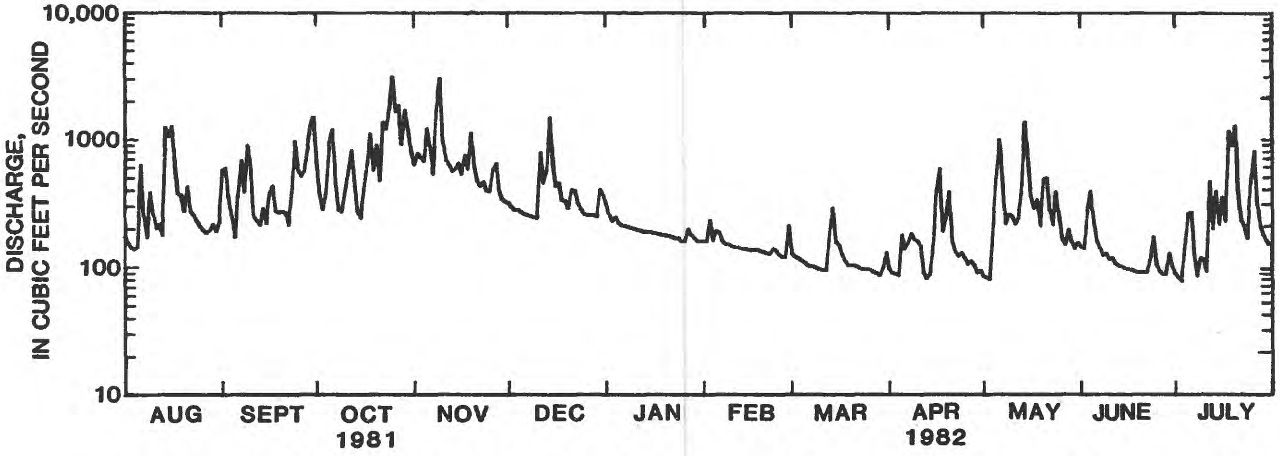


Figure 8.--Mean daily discharge of Río Grande de Añasco near San Sebastián August 1981 through July 1982.

Daily-mean Streamflow (Continued)

average both in the mountains and in the lower valley during this time. The hydrograph is considered typical in which February and March are the months of low flow, flows increase with the May rains, decline during June and early July, and a period of high flow occurs from August through November during the rainy season. Flow generally declines from December through January.

Flow behavior between the two gaging sites at San Sebastián and El Espino is variable. Discharge data at both stations is considered fair (15 percent) at discharges of less than 200 ft^3/s, and poor (greater than 15 percent) at discharges greater 200 ft^3/s. A comparison of monthly discharges during times of low flow at the stations, when both were in operation in 1963-66, shows considerable scatter in flow (fig. 9) but little apparent change in discharge

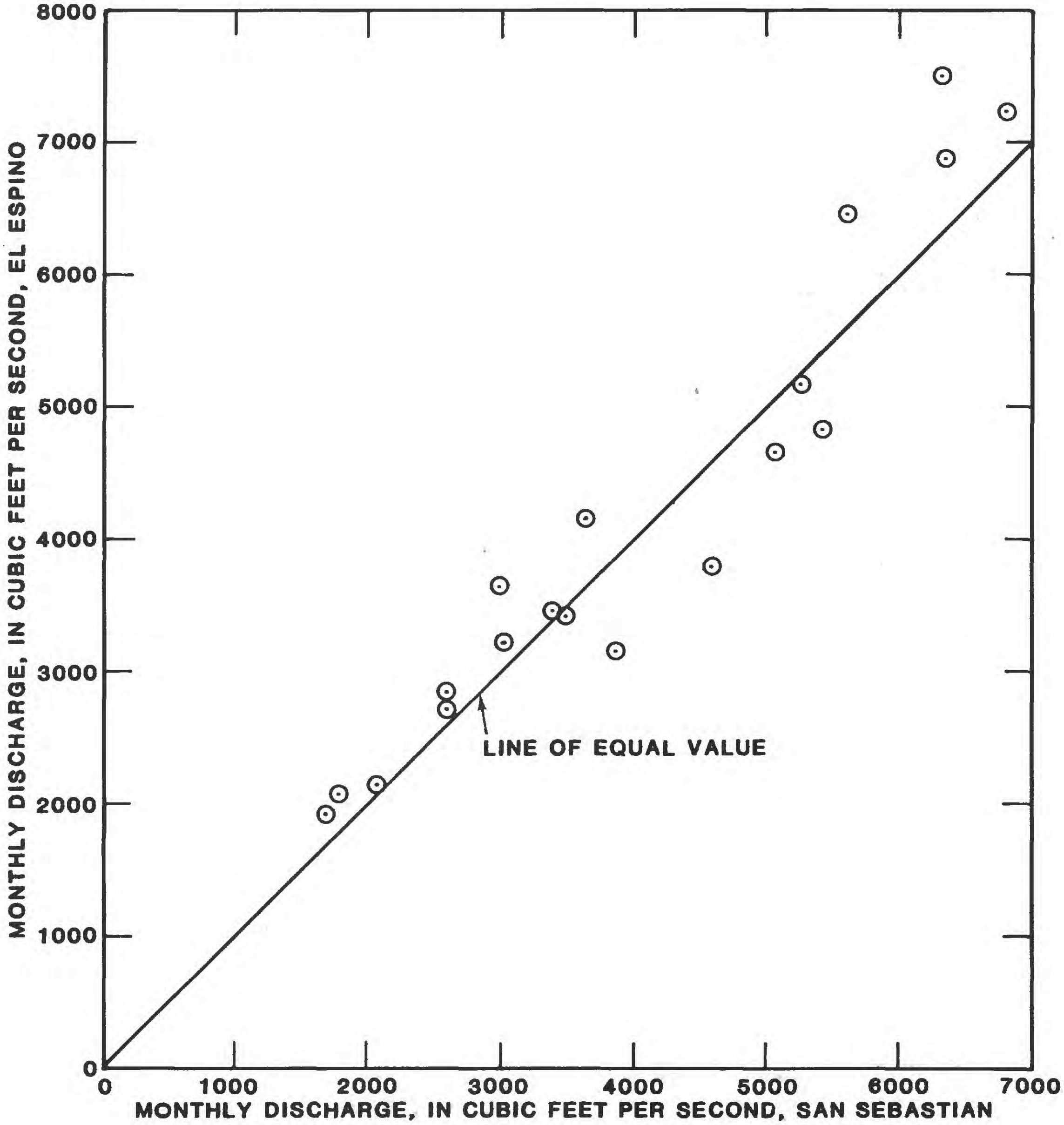


Figure 9.--Monthly discharge, Río Grande de Añasco near San Sebastián versus El Espino, 1963-66.

Daily-mean Streamflow (Continued)

between the stations. Figure 10 shows a double-mass curve based on monthly cumulative discharge at the two stations. The early part of the curve reflects the extended wet season from May through November that occurred in 1963. Discharge at El Espino was greater (by as much as 26 percent in July 1963) throughout the wet period. By contrast 1964 and the first part of 1965 was a time of extended drought. Stream flow at times was less at El Espino than at San Sebastián. For example, there was a 17 percent loss in discharge between the two sites in October 1964. The double-mass curve also shows a shift that would suggest that stream losses of approximately 15 percent between the two sites during periods of extended low flow, and a gain of approximately 15 percent during periods of extended high flow. The apparent loss of low flow may reflect leakage to the alluvium that fills the valley and limestone that may underlie the alluvium upstream of El Espino.

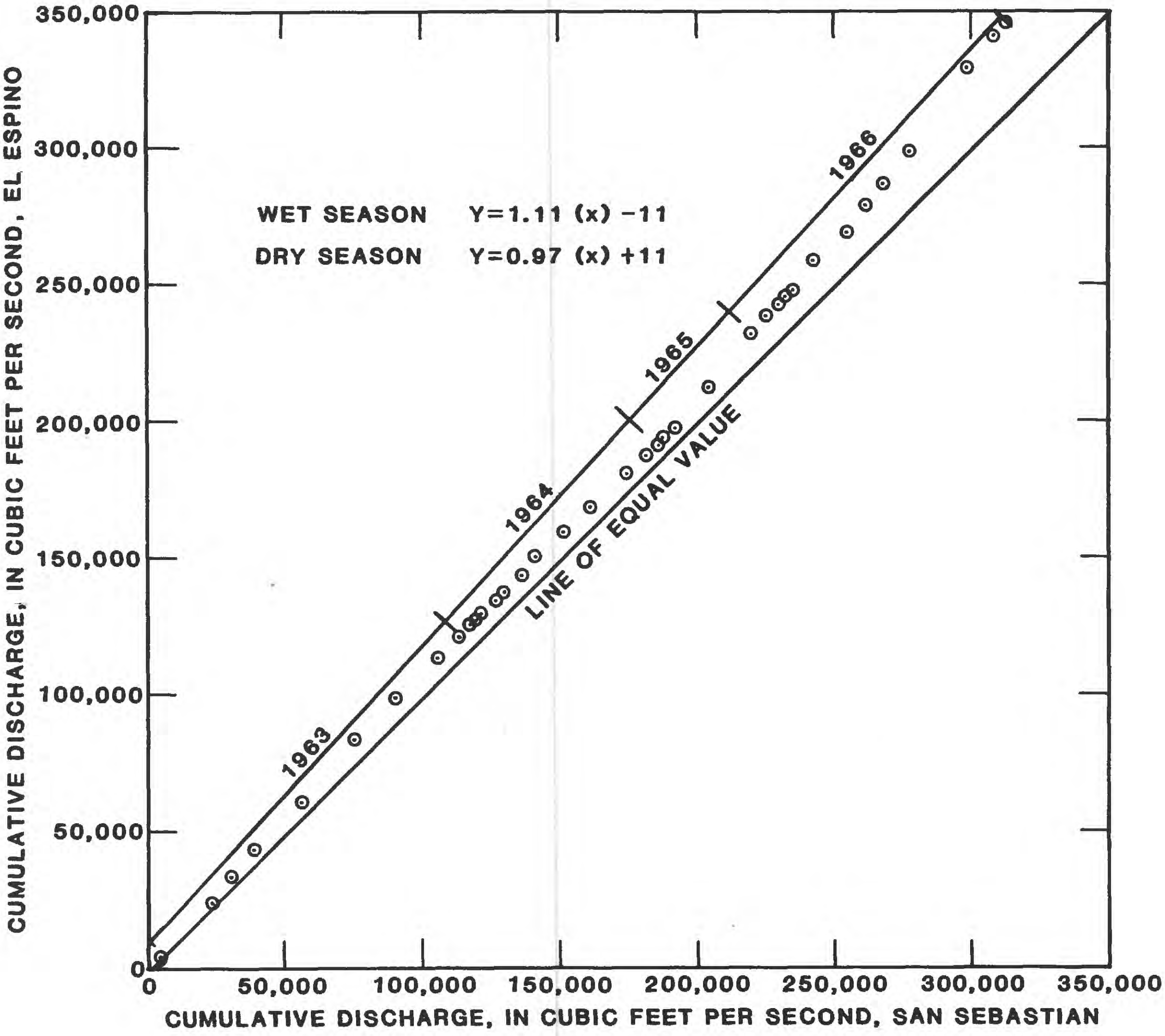


Figure 10.--Double-mass curve Río Grande de Añasco near San Sebastián and at El Espino April 1963, November 1965 to December 1966.

Flow Duration

The variability of the flows can also be investigated from flow-duration analyses. Statistically, the flow-duration distribution is a cumulative frequency curve of the samples of a particular parameter (Searcy, 1959). In streamflow analysis, flow duration is expressed either as a series of curves or tables showing the percent of the time that a known discharge was equalled or exceeded. Flow-duration data can be derived from daily, weekly, monthly, or miscellaneous measurements of discharge at a fixed station in a stream. However, the use of mean-daily discharges is preferable because it provides better coverage of the flow regime during the year (or years) used in the distribution.

Flow duration of the Río Grande de Añasco at El Espino and near San Sebastián are shown in figure 11. The analyses are based on the respective periods when both stations were in operation. Low flow at El Espino was 100 ft^3/s and near San Sebastián, 90 ft^3/s at 85 percent duration, and 200 ft^3/s and 190 ft^3/s, respectively at 50 percent duration. Because of the greater drainage area (about 15 percent) the discharge of the river at El Espino would be expected to be greater than at San Sebastián. The duration curve (fig. 11) shows that at higher discharges the reverse is true. This apparent discrepancy, however, could be due to the short period of record at El Espino and the lack of flood flows during that period or simply due to the general accuracy of the discharge measurements used in the calculations.

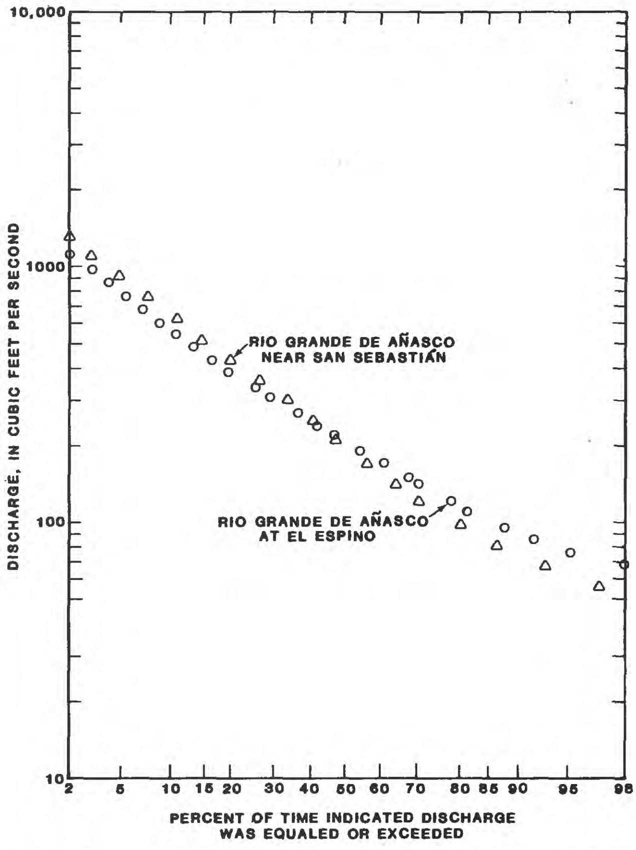


Figure 11.—Flow duration of Río Grande de Añasco near San Sebastián (1963-82) and at El Espino (1959-66).

Flow Duration (Continued)

Flow duration at San Sebastián and El Espino for the periods of record by month are given in table 3. March usually is the month of lowest streamflow duration and October the greatest. Duration curves for these months are shown in figure 12. During extreme low flows there is little difference in flow between San Sebastián and El Espino. For all practical purposes they can be considered the same except for about 10 percent of the time when flow exceeds 150 ft^3/s. The sudden increase in the March discharge at El Espino at less than 10 percent duration is attributed to local rainstorms in the drainage basin between San Sebastián and El Espino. The duration curves do not reflect the apparent loss between the stations at low flow indicated by plots of the double-mass curves (fig. 10).

Flow duration during October indicates that the discharge at El Espino is less than that at San Sebastián even though El Espino is downstream. This apparent discrepancy is most likely due to the great difference in the length of record for the two sites. If the records were comparable on the basis of increased drainage area, discharge at El Espino would be about 10 to 15 percent greater than that at San Sebastián. This would occur during the wet season when losses due to leakage would likely be over shadowed by the increase in discharge.

Minimum Flows

Minimum flows are an important parameter in water-resources management. The frequency and intensity of minimum flows are used in the design of water-supply works, irrigation systems, and in the implementation of waste-allocation programs. The 7-day, 10-year frequency minimum flow (7Q,10) is one of the most widely used parameters for these purposes (representing the minimum average daily flow occurring during a period of 7 consecutive days with a recurrence interval of 10 years). Techniques described by Cobb (1978) are used for the computation of the frequency of minimum flows.

In the lower Río Grande de Añasco Valley, data are inadequate for the computation of the 7Q,10 minimum flow. The 7Q,10 at the gaging station near San Sebastián is about 40 ft^3/s based on 19 years of record (1964-82). An estimate of the 7Q,10 at El Espino of about 43 ft^3/s was determined utilizing the data from the San Sebastián station (1964-82) in combination with drainage area information. The possible losses due to leakage are not considered. If there are losses due to leakage then the 7Q,10 at El Espino would be less than 43 ft^3/s.

Table 3.--Monthly and annual-flow duration, Río Grande de Añasco near San Sebastián and at El Espino period of record.

CLASS CUBIC FEET PER SECOND (FT3/S)	DURATION FOR PERIOD OF RECORD (PERCENT)	MONTHLY DURATIONS FOR PERIOD OF RECORD 1959-1966 REGULATED PERCENT											
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
>= 2500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
>= 2200.0	0.1	0.5	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
>= 1900.0	0.4	1.1	0.0	1.6	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.6
>= 1700.0	0.6	1.1	1.0	1.6	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	2.2
>= 1500.0	0.7	3.8	1.0	1.6	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	2.8
>= 1400.0	1.0	3.8	1.0	2.0	0.0	0.0	0.0	1.1	1.1	0.0	0.0	1.1	3.3
>= 1200.0	1.6	4.3	1.9	2.4	0.0	0.0	0.0	1.1	4.3	0.0	0.0	2.2	5.0
>= 1100.0	1.9	10.2	1.9	2.8	0.0	0.0	0.0	1.7	5.4	0.0	0.0	2.2	5.6
>= 970.0	3.0	12.9	2.4	3.2	0.0	0.0	0.0	2.8	7.0	1.1	0.0	4.8	8.9
>= 870.0	4.0	14.5	4.8	4.0	0.0	0.0	0.9	3.9	9.7	1.1	1.6	5.4	10.6
>= 770.0	5.3	17.2	5.7	4.8	0.0	0.0	0.9	4.4	10.3	2.8	2.2	5.9	15.6
>= 690.0	6.7	19.4	8.6	5.6	0.0	0.0	1.4	5.6	12.4	4.4	2.7	7.0	19.4
>= 610.0	8.4	23.7	12.4	6.4	0.0	0.0	1.4	6.1	13.4	5.6	3.8	9.1	23.9
>= 550.0	10.5	28.0	15.2	9.7	0.0	0.0	2.3	7.2	15.6	7.2	4.8	12.9	26.1
>= 490.0	13.0	35.5	20.5	9.7	0.0	0.0	2.8	8.9	17.2	10.0	8.1	16.7	30.6
>= 430.0	15.8	42.5	25.2	11.3	0.0	0.0	3.2	10.6	21.5	15.0	9.7	21.0	33.3
>= 390.0	18.9	51.1	29.0	13.3	0.0	0.0	4.2	10.6	24.7	18.9	14.5	25.3	40.0
>= 340.0	24.9	66.7	47.1	20.6	0.0	0.5	4.6	13.3	29.6	24.4	13.3	33.9	46.1
>= 310.0	28.4	71.0	53.3	23.4	0.5	1.0	5.5	13.9	33.9	28.9	13.8	41.9	53.3
>= 270.0	35.3	77.4	61.4	28.6	3.2	1.0	6.9	17.8	40.3	41.7	25.8	54.3	66.7
>= 240.0	41.1	86.6	69.0	34.3	4.6	1.0	8.8	19.4	44.6	52.8	36.0	64.5	75.0
>= 220.0	46.0	90.3	76.2	41.9	6.0	1.5	8.8	22.8	49.5	63.9	46.2	68.8	78.3
>= 190.0	53.4	93.6	84.3	52.0	11.5	3.5	8.8	26.1	59.1	78.9	60.8	78.5	86.7
>= 170.0	60.4	97.3	90.0	63.7	16.1	6.1	9.2	35.6	65.6	84.4	72.0	88.2	93.9
>= 150.0	67.4	99.5	100.0	71.8	36.4	7.6	10.1	41.1	74.2	90.0	80.1	92.5	97.8
>= 140.0	70.3	99.5	100.0	75.4	44.7	10.6	11.5	45.6	77.4	91.7	83.9	94.6	98.3
>= 120.0	77.4	99.5	100.0	83.5	65.4	29.8	14.3	54.4	85.0	94.4	87.6	97.8	99.4
>= 110.0	81.0	100.0	100.0	87.9	68.7	42.9	18.0	62.2	87.1	95.6	90.9	98.9	100.0
>= 96.0	87.7	100.0	100.0	96.4	78.8	64.6	35.9	67.2	88.2	96.7	95.7	100.0	100.0
>= 86.0	91.6	100.0	100.0	100.0	96.3	74.8	46.1	74.4	90.3	98.9	98.4	100.0	100.0
>= 76.0	95.1	100.0	100.0	100.0	100.0	90.9	54.8	89.4	91.4	100.0	100.0	100.0	100.0
>= 68.0	98.0	100.0	100.0	100.0	100.0	98.5	77.4	95.6	93.0	100.0	100.0	100.0	100.0
>= 61.0	99.4	100.0	100.0	100.0	100.0	100.0	90.3	96.7	97.8	100.0	100.0	100.0	100.0
>= 54.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
>= 0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 3.--Monthly and annual-flow duration, Río Grande de Añasco near San Sebastián and at El Espino for period of record (Continued).

CLASS CUBIC FEET PER SECOND (FT3/S)	DURATION FOR PERIOD OF RECORD (PERCENT)	MONTHLY DURATIONS FOR PERIOD OF RECORD 1963-1982 REGULATED PERCENT											
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
>= 15000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
>= 12000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
>= 10000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
>= 8600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2
>= 7100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.2
>= 5900.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.2	0.3
>= 4900.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.2	0.3
>= 4100.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.2	0.2	0.7
>= 3400.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.2	0.2	1.0
>= 2800.0	0.3	0.6	0.3	0.2	0.0	0.0	0.0	0.0	0.3	0.3	0.2	0.2	1.0
>= 2300.0	0.4	1.3	0.7	0.2	0.0	0.0	0.0	0.0	0.5	0.3	0.2	0.2	1.0
>= 1900.0	0.7	2.6	1.3	0.2	0.0	0.0	0.0	0.2	0.8	0.3	0.3	0.3	2.2
>= 1600.0	1.1	4.8	1.8	0.3	0.0	0.0	0.0	0.2	1.9	0.3	0.6	0.3	2.8
>= 1300.0	2.0	8.2	2.8	0.5	0.0	0.0	0.0	0.3	2.9	1.0	1.3	1.9	5.2
>= 1100.0	3.0	11.6	3.3	0.8	0.0	0.0	0.0	0.7	3.7	1.7	1.9	3.2	7.8
>= 920.0	4.7	18.2	6.0	1.0	0.0	0.0	0.3	1.0	6.6	2.5	3.6	5.3	12.0
>= 760.0	7.2	24.0	11.3	1.4	0.0	0.2	0.5	2.0	8.4	4.0	5.8	6.8	20.7
>= 630.0	10.6	32.9	18.5	2.4	0.2	0.2	0.7	2.8	12.3	5.7	9.4	12.6	29.7
>= 520.0	14.2	42.4	25.3	3.9	0.5	0.2	0.8	4.5	14.8	9.0	12.7	17.4	38.3
>= 430.0	19.6	53.2	36.2	6.6	0.6	0.5	1.2	6.7	19.0	16.2	18.7	24.7	50.8
>= 360.0	25.8	67.6	43.7	10.3	1.0	0.5	2.0	8.7	25.3	22.0	25.5	32.6	65.2
>= 300.0	32.8	83.9	67.0	17.9	2.1	0.9	2.5	10.7	29.5	28.5	34.5	41.9	75.5
>= 250.0	39.9	93.2	73.8	32.6	2.9	1.4	4.4	12.8	35.5	37.8	42.4	53.2	84.2
>= 210.0	46.5	96.9	88.5	46.4	5.3	1.8	5.5	17.3	41.6	47.0	52.6	63.9	91.3
>= 170.0	55.5	99.0	97.0	65.2	20.3	4.6	8.0	22.7	49.4	60.3	65.8	76.9	97.2
>= 140.0	64.1	99.8	99.7	81.1	43.2	12.4	10.0	29.7	59.0	71.7	76.8	89.2	99.5
>= 120.0	70.8	100.0	100.0	93.4	60.5	28.8	13.7	34.2	64.8	77.2	85.2	93.9	100.0
>= 98.0	79.4	100.0	100.0	99.2	89.2	53.6	26.2	40.8	72.9	85.3	91.6	96.4	100.0
>= 81.0	86.5	100.0	100.0	100.0	97.6	77.5	49.0	52.0	79.0	90.7	96.6	98.6	100.0
>= 67.0	92.8	100.0	100.0	100.0	100.0	93.3	75.3	69.7	85.2	94.5	99.0	99.7	100.0
>= 56.0	96.9	100.0	100.0	100.0	100.0	100.0	91.3	82.7	94.2	96.2	100.0	99.8	100.0
>= 46.0	99.0	100.0	100.0	100.0	100.0	100.0	99.2	93.8	97.6	98.5	100.0	100.0	100.0
>= 39.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	98.7	99.7	100.0	100.0	100.0	100.0
>= 32.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
>= 0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

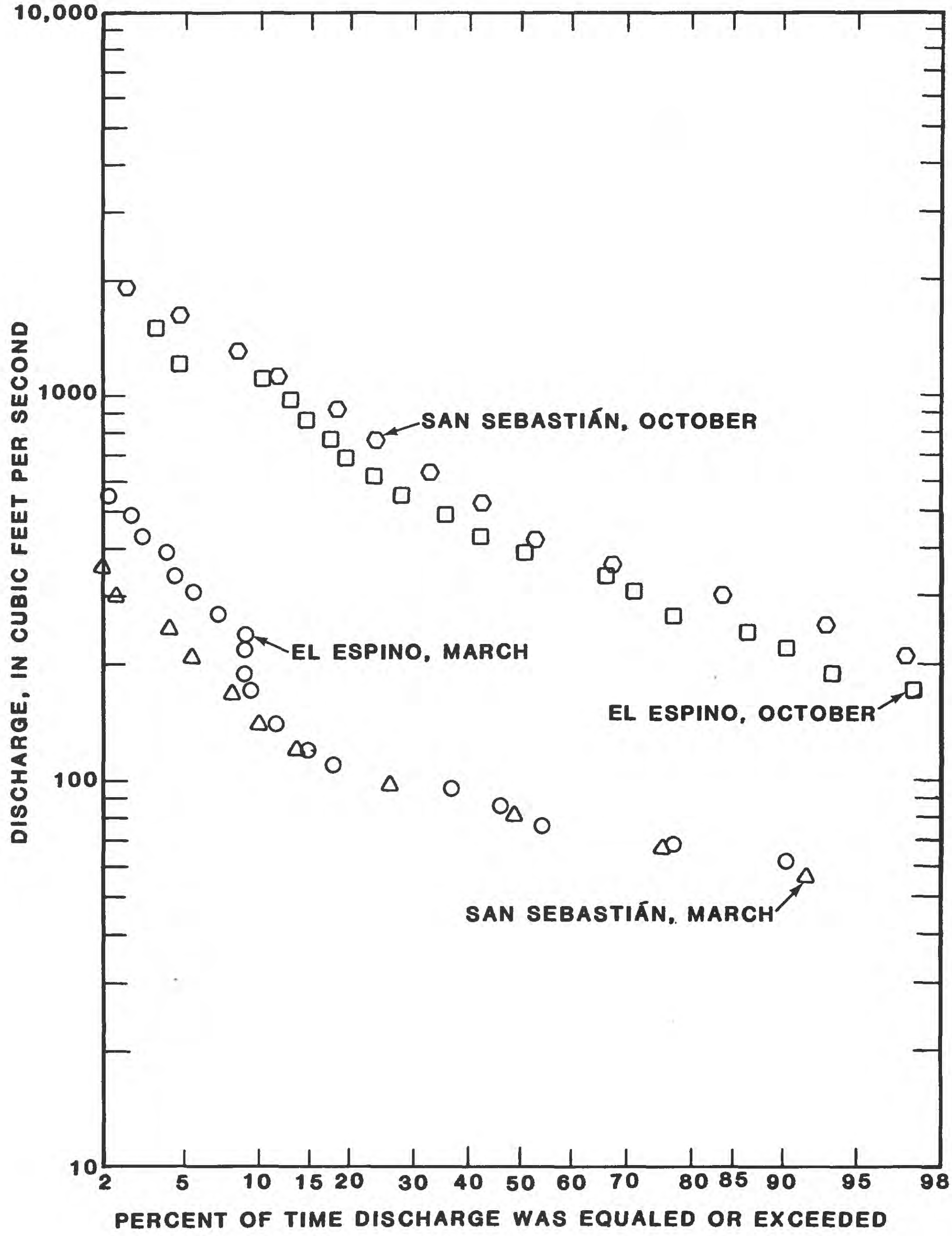


Figure 12.--Flow duration of daily discharge, Río Grande de Añasco near San Sebastián (1963-82) and El Espino (1959-66) for months of March and October.

Minimum Flows (Continued)

The lowest mean-daily values of Río Grande de Añasco for different periods of consecutive days are given in tables 4 and 5 for San Sebastián, and for El Espino for those years for which there is a full climatic year of record (a climatic year is from April 1 to March 31). March is usually the month of lowest flow followed closely by February and April.

Table 4.--Minimum flow for Río Grande de Añasco near San Sebastián for period of record (Climatic year, April 1 to March 31).

Climatic year	Lowest mean daily values for indicated number of consecutive days, cubic feet per second				
	1	3	7	14	30
1964	63.0	65.0	66.0	66.0	67.0
1965	39.0	39.0	44.0	47.0	54.0
1966	32.0	32.0	35.0	41.0	86.0
1967	60.0	60.0	62.0	67.0	72.0
1968	36.0	38.0	40.0	44.0	53.0
1969	36.0	38.0	41.0	44.0	49.0
1970	68.0	71.0	78.0	84.0	95.0
1971	63.0	66.0	68.0	71.0	79.0
1972	72.0	73.0	77.0	82.0	90.0
1973	65.0	66.0	69.0	76.0	98.0
1974	45.0	45.0	46.0	49.0	84.0
1975	45.0	46.0	51.0	54.0	65.0
1976	47.0	48.0	49.0	58.0	65.0
1977	49.0	51.0	52.0	54.0	55.0
1978	41.0	42.0	44.0	49.0	56.0
1979	60.0	61.0	62.0	65.0	65.0
1980	50.0	51.0	52.0	56.0	84.0
1981	61.0	61.0	63.0	87.0	96.0
1982	75.0	77.0	79.0	87.0	116.0

Table 5.--Minimum flow for Río Grande de Añasco at El Espino for period of record (Climatic year, April 1 to March 31).

Climatic year	Lowest mean daily values for indicated number of consecutive days, cubic feet per second				
	1	3	7	14	30
1961	89.0	93.0	95.0	98.0	112.0
1962	71.0	71.0	71.0	72.0	78.0
1963	54.0	57.0	63.0	68.0	72.0
1964	60.0	60.0	61.0	62.0	69.0
1965	57.0	57.0	57.0	59.0	61.0

Maximum Flows

The entire lower Río Grande de Añasco Valley is subject to frequent and intense floods. Five major floods have occurred since 1899, with lesser floods occurring on the average of 3 to 4 times every year. The greatest flood of record in the valley occurred on September 16, 1975 (Johnson and Quiñones-Aponte, 1981). The passage of hurricane Eloise in the vicinity of Puerto Rico resulted in 2-day precipitation totals in the upper Río Grande de Añasco basin of as much as 15 to 20 in. Flooding in the lower valley was intense (fig. 13), with the depth of flooding reaching 21 ft in the vicinity of Central Igualdad. Annual maximum floods in the valley (1963-82), including the recurrence

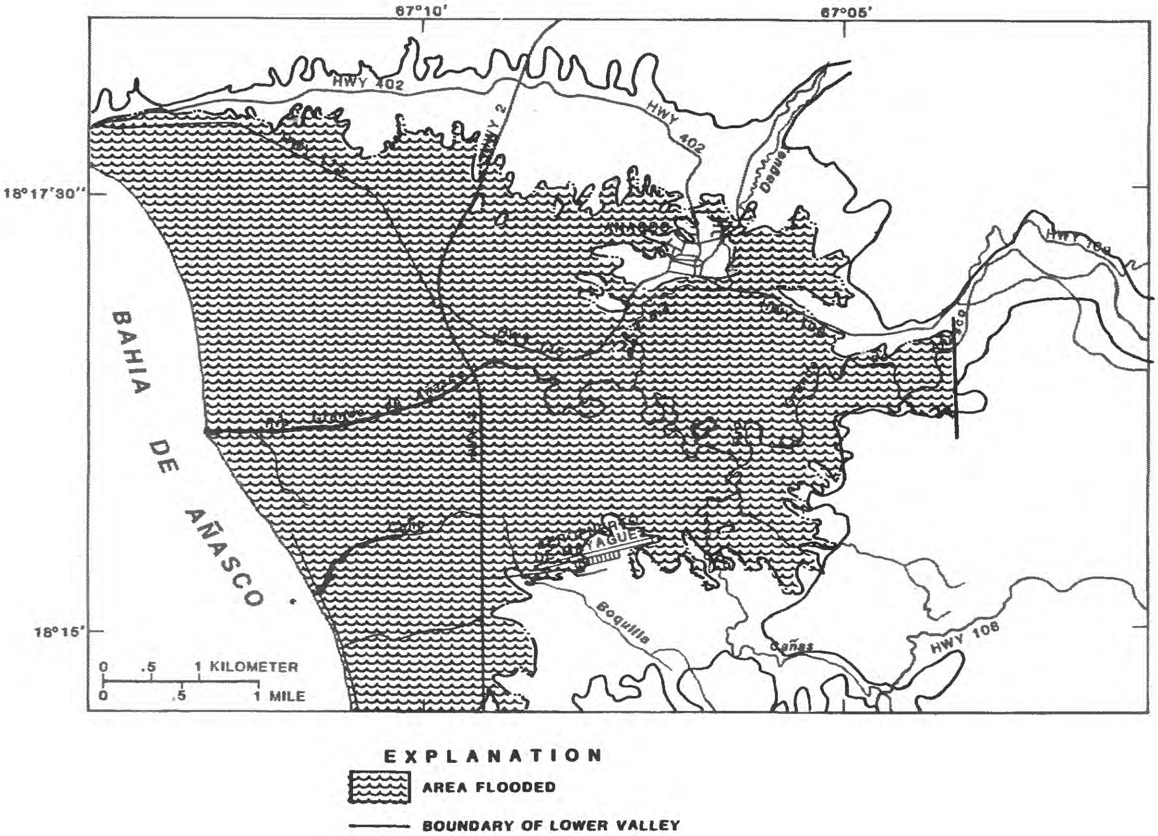


Figure 13.--Approximate area inundated in the lower Río Grande de Añasco valley, September 16, 1975.

Maximum Flows (Continued)

interval are listed in table 6 (Johnson and Quiñones-Aponte, 1981).

Field surveys made during this study showed that the river channel below Highway 2 will convey about 10,000 ft^3/s. Flood peaks of this magnitude occur at the San Sebastián gage with a frequency of about 2 years, that is, there is a 75 percent chance of occurrence in any particular year.

Table 6.--Annual maximum floods at the Río Grande de Añasco near San Sebastián gaging station.

Date	Elevation above mean sea level, meters	feet	Peak, discharge m^3/s	ft^3/s	Recurrence interval, in years
Sept. 27, 1963	36.80	120.75	440	15,500	2.2
Oct. 15, 1964	34.75	114.02	160	5,630	1.1
Aug. 25, 1965	36.09	118.42	330	11,600	1.7
June 18, 1966	35.53	116.58	250	8,800	1.4
Sept. 1, 1967	35.36	116.02	230	8,020	1.3
Nov. 8, 1968	35.78	117.38	280	9,990	1.5
May 17, 1969	36.62	120.15	410	14,400	2.0
Sept. 24, 1970	35.23	115.57	210	7,440	1.3
Oct. 26, 1971	37.59	123.33	580	20,300	2.8
Oct. 21, 1972	36.88	121.00	450	16,000	2.2
Aug. 11, 1973	35.33	115.90	220	7,860	1.3
Sept. 27, 1974	35.38	116.07	230	8,090	1.3
Sept. 16, 1975	41.95	137.6	4000	140,000	Greater than 100 yrs
Apr. 29, 1976	35.61	116.84	260	9,320	1.4
Sept. 13, 1977	35.61	113.54	260	9,300	1.4
Sept. 24, 1978	35.60	112.63	250	8,960	1.2
Aug. 31, 1979	39.20	128.62	1,100	38,000	4.8
May 27, 1980	38.40	125.99	810	28,600	4.5
July 14, 1981	35.33	115.92	220	7,830	1.3
Sept. 13, 1982	38.55	126.48	840	29,700	4.7

GROUND WATER

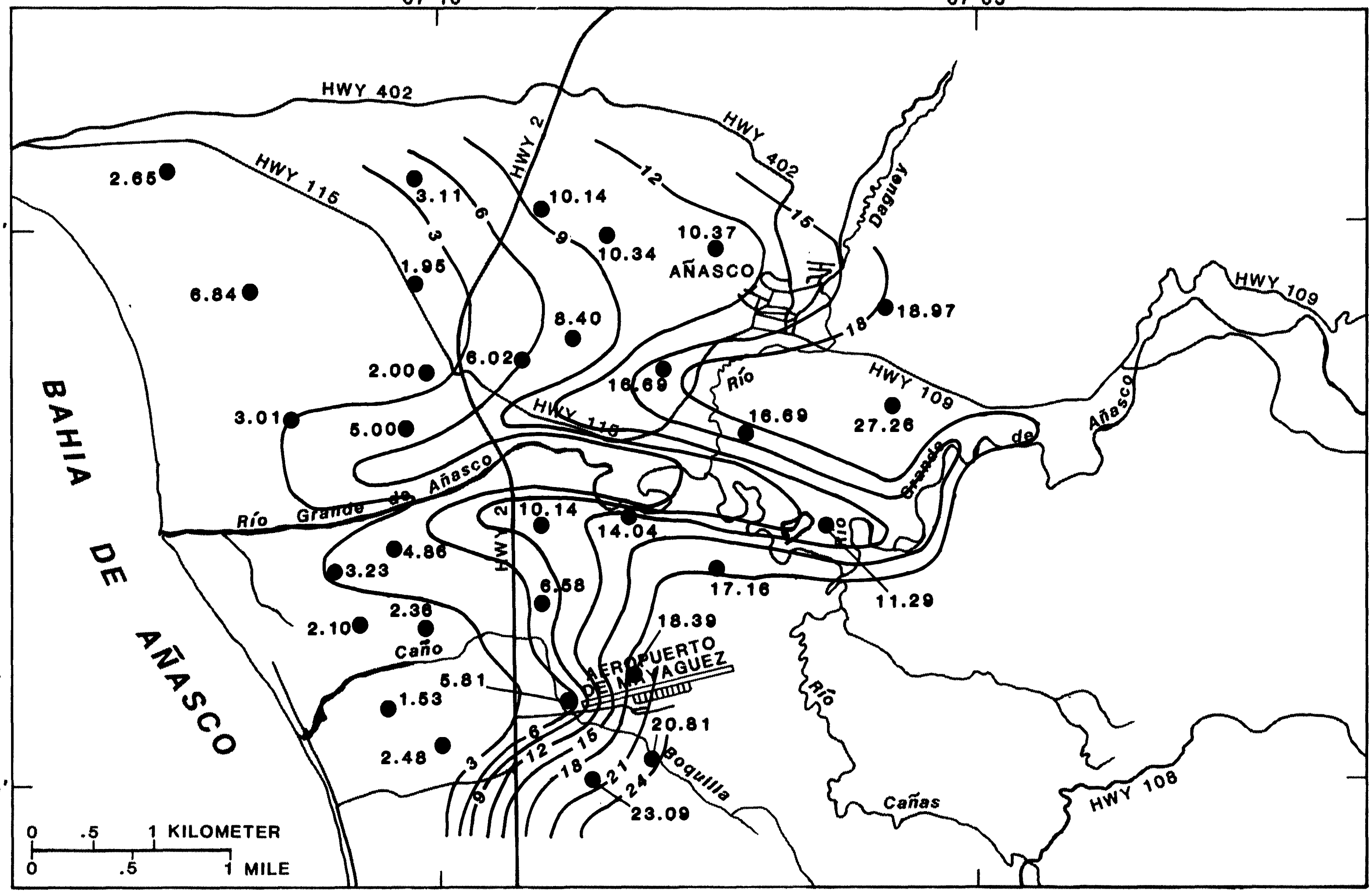
There are two water-bearing units in the lower valley of the Río Grande de Añasco. The uppermost unit (Zone II) is alluvium consisting primarily of silt, clay, and lesser amounts of sand. Some gravel is present, apparently deposited in former stream channels. Underlying the alluvium is hard dense clay containing beds of soft limestone (Zone III). The limestone is the source of water in the lower unit.

Alluvium (Zone II)

The water-bearing alluvium generally ranges in thickness from about 50 to 100 ft throughout the central part of the valley; thinning to a featheredge at the bedrock boundaries. The alluvium is composed predominately of fine-grained material and therefore has a high porosity. It can retain large amounts of water probably on the order of 20 to 30 percent by volume. However, the alluvium has a very low permeability because of its fine grain, and will yield water very slowly. The principal water-yielding zones in the alluvium are layers of sand or gravel; both are probably deposits laid down in former channels of the Río Grande de Añasco. Near the sea, some of the sand is possibly buried beach or dune deposits.

A network of 30 shallow piezometers was installed throughout the lower valley during the study (figs. 14 & 15). The piezometers were used to monitor the fluctuations of the water table, a relatively shallow ground-water table ranging from about 2 ft below the land surface in the western part of the valley, to about 15 ft below the land surface toward the east. The water-table surface showed little variation between the wet season (fig. 14) and the dry season (fig. 15). Significant features on both water-table maps are the area of discharge from the aquifer to the Río Grande de Añasco in the middle and lower parts of the valley, and areas of discharge centered around the Caño La Puente and Caño Boquilla. The water-table contours in the southern part of the valley show a steepening of slope from the vicinity of the Mayaguez Airport.

The close spacing of the water-table contours along the Río Grande de Añasco, and the lack of variation from wet to dry season is an indication of the low permeability of the alluvium there. Water does not move readily from the alluvium to the river. The broad reentrant in the contours around Caño la Puente reflect to a large extent the low lying land, swamp and marsh conditions, and the surface manifestation of the upward discharge of water from Zone II. The only major change in the water-table contours between the dry season and the wet season is in the vicinity of drainage canals. In the southern part of the valley in the vicinity of the Caño Boquilla marshes, conditions similar to those in the vicinity of Caño La Puente prevail. The close spacing of the contours south and west of the Mayaguez Airport, probably reflect a change in the composition of the alluvium from a very clayey alluvium through which water moves very slowly to a sandy alluvium which transmits water more readily.

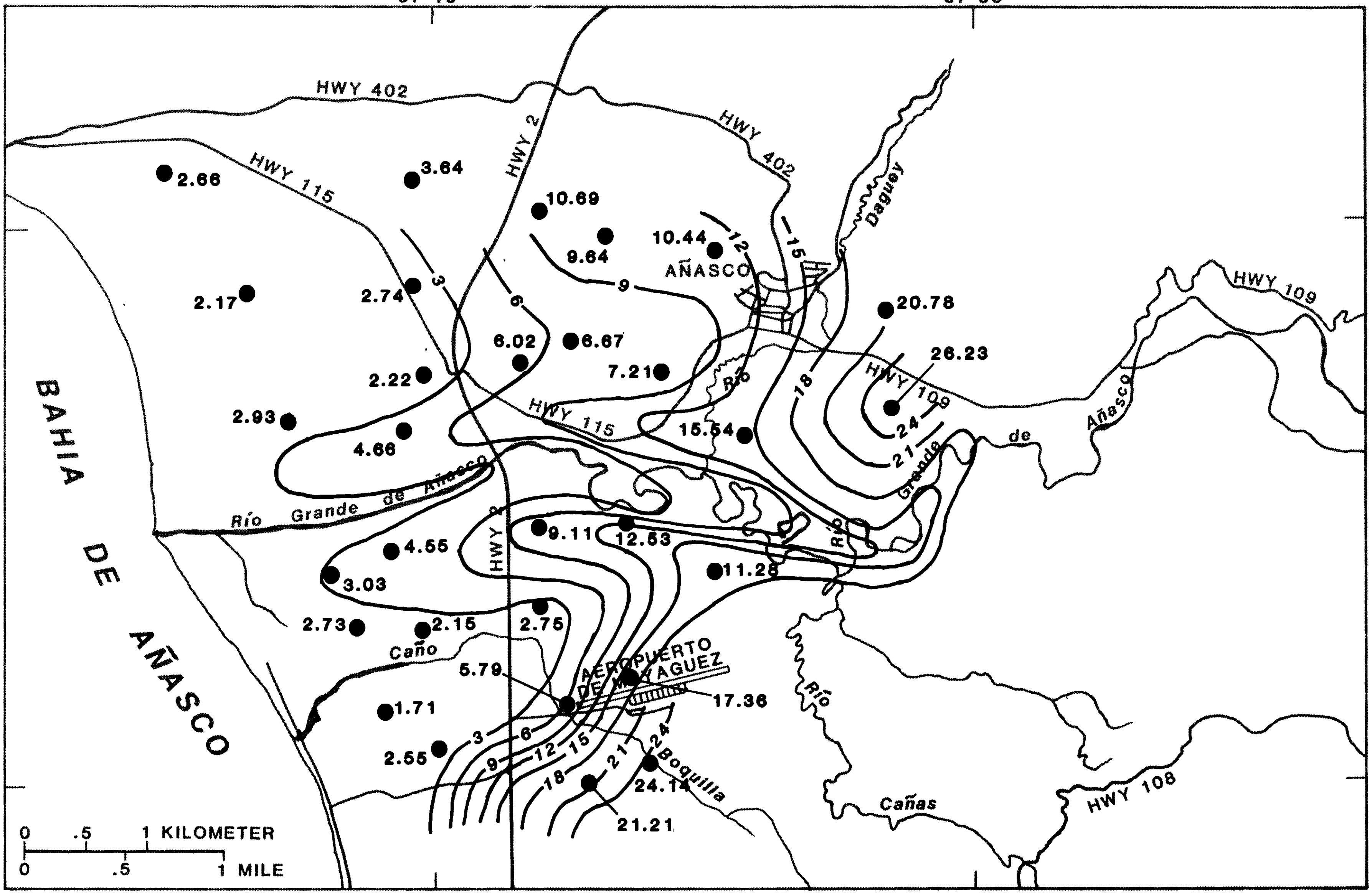


EXPLANATION

—21— WATER-TABLE CONTOUR -- Shows altitude of water table, September 3, 1975, contour interval 3 feet. Datum is mean sea level.

●23.09 PIEZOMETER AND ALTITUDE OF WATER LEVEL

Figure 14.--Altitude of water table in alluvial aquifer (zone II) in wet season, September 3, 1981.



EXPLANATION

—3— WATER-TABLE CONTOUR -- Shows altitude of water table in February 11, 1982. Contour interval 3 feet. Datum is mean sea level.

● 2.55 PIEZOMETER AND ALTITUDE OF WATER LEVEL

Figure 15.--Altitude of water table in alluvial aquifer (zone II) in dry season, February 11, 1982.

Alluvium (Zone II) (Continued)

The yields to wells developed in the alluvium are dependent upon the amount of sand or gravel penetrated. Well 8 (table 1, fig. 7) for example, reportedly produced some water from 6 ft of sand and gravel in hydraulic connection with the river. Elsewhere in the valley, sand and or gravel zones penetrated by wells are thinner, and yields to wells proportionally less. Yields (probably not exceeding 150 gal/min) to these wells from the alluvium probably are sustained, not so much by the water in storage in the sand or gravel, but by leakage of water to the sand or gravel from the surrounding saturated fine-grained alluvial material. Except as noted above (well 8), the alluvium of Zone II does not appear to be a productive source of water.

Clay and Limestone (Zone III)

Zone III underlies the alluvium throughout the lower valley. It is possible that the narrow part of the valley upstream of Josefa is also underlain by Zone III for a distance of several miles. The overall thickness of Zone III is as much as 250 ft, as determined from seismic surveys. Locally, wells reportedly have penetrated more than 350 ft of material assigned to Zone III. Logs of wells (table 1) show that Zone III is predominately clay with beds of limestone that vary greatly in vertical position as well as in thickness. Beds of limestone as much as 50 ft thick have been reported.

The wells in the valley producing from Zone III obtain water from the limestone. Yields of as much as 500 gal/min or more have been reported at Central Igualdad and a well at Colonia Trinidad (well 7). Estimated transmissivity reported from a pumping test of well 7 at Colonia Trinidad was 2,150 ft^2/d. (Vivas Well Corporation, written commun., 1970). The water was obtained from about 50 ft of hard limestone. Other wells drilled into Zone III that have encountered little or no limestone, produced water that contained so much colloidal or clay-size material that it was not useable.

Ground-water levels have been measured monthly since 1960 in Well 10 at the Mayaguez Airport that is completed in Zone III. The hydrograph of this well from 1978 through part of 1982 is shown in figure 16. Water levels fluctuated about 5 ft during the study period, somewhat greater than the fluctuations observed in the alluvium of the central part of the valley. There is apparently poor connection between the alluvium and Zone III in this part of the valley, as the water level in well 10 does not respond rapidly to rainfall, although seasonal fluctuations are evident.

Recharge

Recharge to the alluvial aquifer (Zone II) is largely from infiltration of rainfall. Some recharge also may occur in the small alluvial fans along the edges of the valley, where smaller streams emerge from the mountains. Such recharge would be minor, however, in comparison to that available from rainfall. The slight fluctuations in water levels, between the wet and the dry season, indicate that rainfall even in the dry season, in 1981-82, was sufficient to maintain water levels in the alluvium. It is doubtful that the excessive rains in the preceeding wet period had more than a temporary impact on the water level in the alluvium. It appears that the infiltration rate of the alluvium is a limiting factor and rainfall in excess of that rate is rejected, as direct runoff to streams.

The source and amount of recharge to the clay and limestone unit (Zone III) is unknown. Some of the shallower limestone beds may receive recharge from the overlying alluvium. Recharge from the alluvium to limestone overlain by clay most likely would be slight. One possible source of recharge would be from the bedrock where the limestone adjoins the valley walls. If Zone III extends into the narrow part of the valley where the Río Grande de Añasco emerges from the mountains, there may be recharge to Zone III from the river through the overlying alluvium. The lack of an increase and at times a decrease in discharge of Río Grande de Añasco between San Sebastián and El Espino during months of low flow may be an indication of recharge to the alluvium and to Zone III if it underlies the alluvium. The fluctuations of the observation well at the Mayaguez Airport indicate that recharge to Zone III is not rapid and takes place in an area remote from the well. When Well 7 was being drilled, the water level declined 16 ft when the principal water-bearing limestone was encountered, (table 1) showing that the limestone and alluvium are hydraulically separated there.

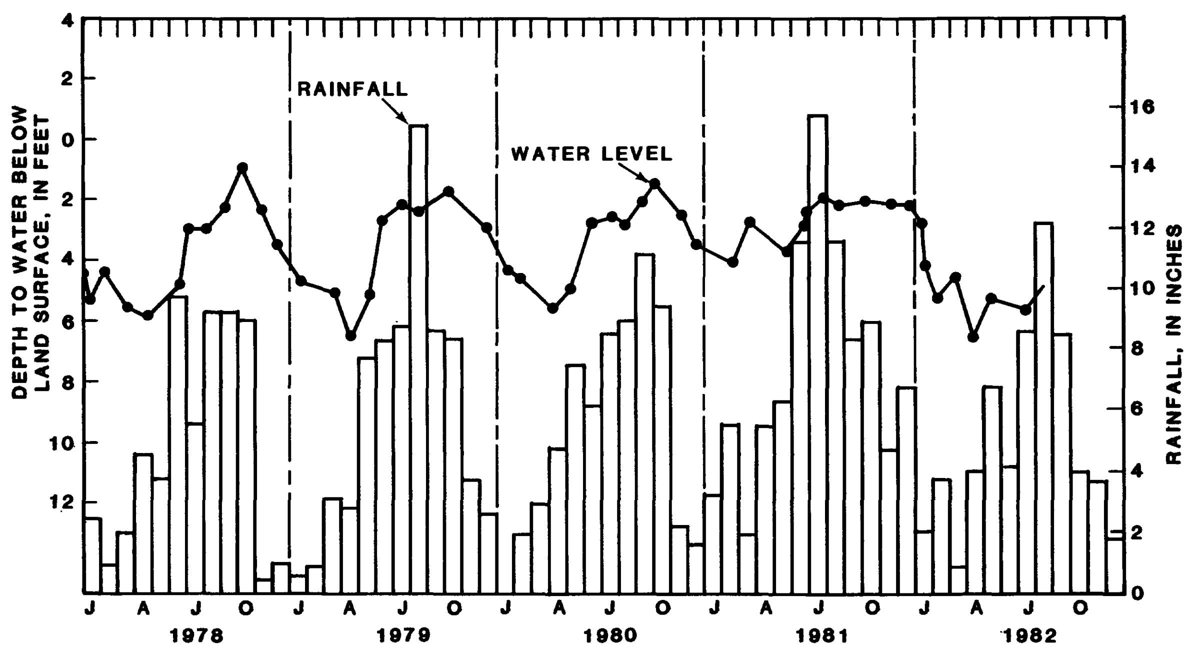


Figure 16.--Water-level fluctuations in well 10 and rainfall at Mayaguez airport.

QUALITY OF WATER

Information on the quality of water in the lower valley is limited principally to surface water. A number of piezometers about 10 ft deep were installed during the study to obtain water levels and chloride concentrations of the ground water in the upper part of the alluvium. Very few deep wells have been drilled in the valley and most of these have been abandoned. As a result, analyses of the chemistry of the ground water from the deep water-bearing zones are limited.

Surface water

Water samples for analysis of common mineral constituents have been collected from the Río Grande de Añasco at San Sebastián and El Espino since 1958. In this study, water-quality samples were collected from the Río Grande de Añasco and its tributaries and from other streams and drainage ditches within the valley. The locations of the sampling sites are shown in figure 7.

The chemical composition of the surface water from the streams and canals is similar throughout the valley (table 7). Variations occur only where there is contamination from sources such as seawater encroachment or sewage effluent, or where the water is from, or has passed through, swamps. In general the water contains concentrations of less than 250 milligrams per liter (mg/L) dissolved solids; concentrations range from about 150 to 400 mg/L. From 10 to 20 percent of the dissolved solids is silica which ranges from 20 to 45 mg/L in concentration. The water is moderately hard to very hard, but usually has less than 150 mg/L hardness as $CaCO_3$. Values of pH range from 7.1 to 8.6 units, with a median value of about 7.7 units. The water is a calcium-magnesium bicarbonate type. On the basis of milliequivalents per liter, bicarbonate comprises about 80 percent of the total anions. The concentration of chloride ranged from less than 10 mg/L in the Río Grande de Añasco, to 75 mg/L in some of the drainage ditches and small streams, to 1,800 mg/L in Quebrada Boquillas at Highway 2 (site 13), a site which is affected by seawater from Caño Boquillas.

Specific conductance of water is a measure of the ability of the water to conduct an electric current. Under certain conditions it is closely related to the sum of cations or anions as determined chemically, and usually correlates directly with the dissolved-solids concentrations of the water. Specific conductance can be readily and precisely determined and is very useful in showing short-term changes in the total mineral composition of water.

A graphical representation of the relation of conductance to concentrations of dissolved solids and the two major anions, chloride and bicarbonate, in surface water in the lower valley is shown in

Table 7.--Quality of surface water and ground water in the lower valley, 1981-82.
(All constituents in milligrams per liter except as noted.)

SITE NUMBER	STATION NAME	DATE	DISCHARGE ft³/s	CONDUCTANCE µS/cm	pH UNITS	DISSOLVED SOLIDS	SILICA	HARDNESS	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	BICARBONATE	SULFATE	CHLORIDE	FLUORIDE	MANGANESE µg/L
1	Río Grande de Añasco at El Espino	4-6-82	162	220	8.0	151	26	100	25	9.5	12	1.5	96	11	8.1	0.1	-
3	Río Cañas at end of Highway 342	3-25-81	6.56	195	7.7	-	27	90	26	6.1	9.0	1.8	116	5.4	7.7	.1	-
		4-6-82	3.33	250	7.8	173	32	110	30	8.5	14	1.8	120	5.0	9.3	.1	-
4	Río Daguey above confluence with Río Grande de Añasco	3-26-81	1.43	475	7.3	-	35	180	51	12	34	6.9	206	19	50	.2	-
5	Río Grande de Añasco above Highway 2 near Central Igualdad	4-6-82	169	230	7.8	151	26	100	25	9.3	12	1.5	97	11	8.1	.1	-
6	Río Hondo at Las Marías	3-26-81	.82	347	7.9	-	46	160	49	9.2	17	1.5	209	6.1	15	.2	-
		4-5-82	.46	353	7.6	233	43	150	43	9.5	20	1.8	160	5.0	14	.2	-
9	Quebrada La Colzadena at Cienaga Guayabal	3-25-81	1.14	567	8.0	-	39	220	72	9.2	28	1.6	239	4.9	56	.2	-
		4-5-82	-	600	7.9	422	40	300	105	10	31	.8	260	7.0	72	.3	-
10	Quebrada La Puente at Highway 115	3-26-81	.48	653	7.8	-	31	250	80	12	41	2.0	275	11	73	.2	-
11	Quebrada Boquilla at Highway 342 near Mayaguez Airport	4-7-82	.40	250	7.7	166	18	120	32	9.9	14	.8	130	3.0	10	.2	-
12	Caño Boquilla at Highway 2, Km 149.5	3-27-81	.54	270	7.9	-	19	-	34	9.7	14	.9	162	6.1	12	.1	-
13	Quebrada Boquilla at Highway 2, Km. 147.85	4-5-82	-	16,000	7.8	3,250	12	620	66	110	930	3.5	130	220	1,800	.3	-
14	Drainage ditch to Quebrada Boquilla	3-27-81	-	270	7.9	-	19	120	34	9.7	14	0.9	162	6.1	12	0.1	-
15	Río Daguey at Añasco Highway 109	3-27-81	-	274	8.0	-	35	130	36	9.7	17	1.7	177	5.0	13	.2	-
		4-7-82	-	500	6.3	312	32	150	41	12	47	6.6	190	9.0	50	.2	-
16	Drainage ditch to Río Daguay at Añasco	3-27-81	-	282	7.4	-	31	-	34	8.5	18	3.5	161	11	14	.1	-
	1	9-7-81	-	2,800	-	1,260	24	520	120	54	310	9.0	225	82	660	.1	-
	2	5-26-82	-	360	7.5	189	13	150	37	14	15	2.6	152	2.0	13	.1	440
	3	5-26-82	-	600	8.0	298	31	210	52	19	35	2.8	187	3.0	41	.1	920
	4	5-26-82	-	700	7.6	389	28	250	67	20	41	2.4	214	1.0	100	.1	552

REMARKS:

Site No. 1 - Production well 22.5 feet deep.
2 - Unused well, grab sample at 60 feet depth.
3 - Unused well, grab sample at 180 feet depth.
4 - Production well, 200 feet deep, casing perforated 100-140 feet, open hole 140-200 feet, yield 120-140 gallons per minute.

Surface water (Continued)

figure 17. An approximation of the concentration of these constituents can be obtained from conductance by using the equations shown in figure 17 for the respective constituents.

The Río Grande de Añasco is the principal source of surface water in the valley. A compilation of analyses of samples collected at El Espino and Highway 2 between 1979 and 1982, is given in table 8. At El Espino the water shows little variation in the common mineral constituents and physical properties. The differences between maximum and minimum are primarily related to the volume of streamflow as indicated by the relation of

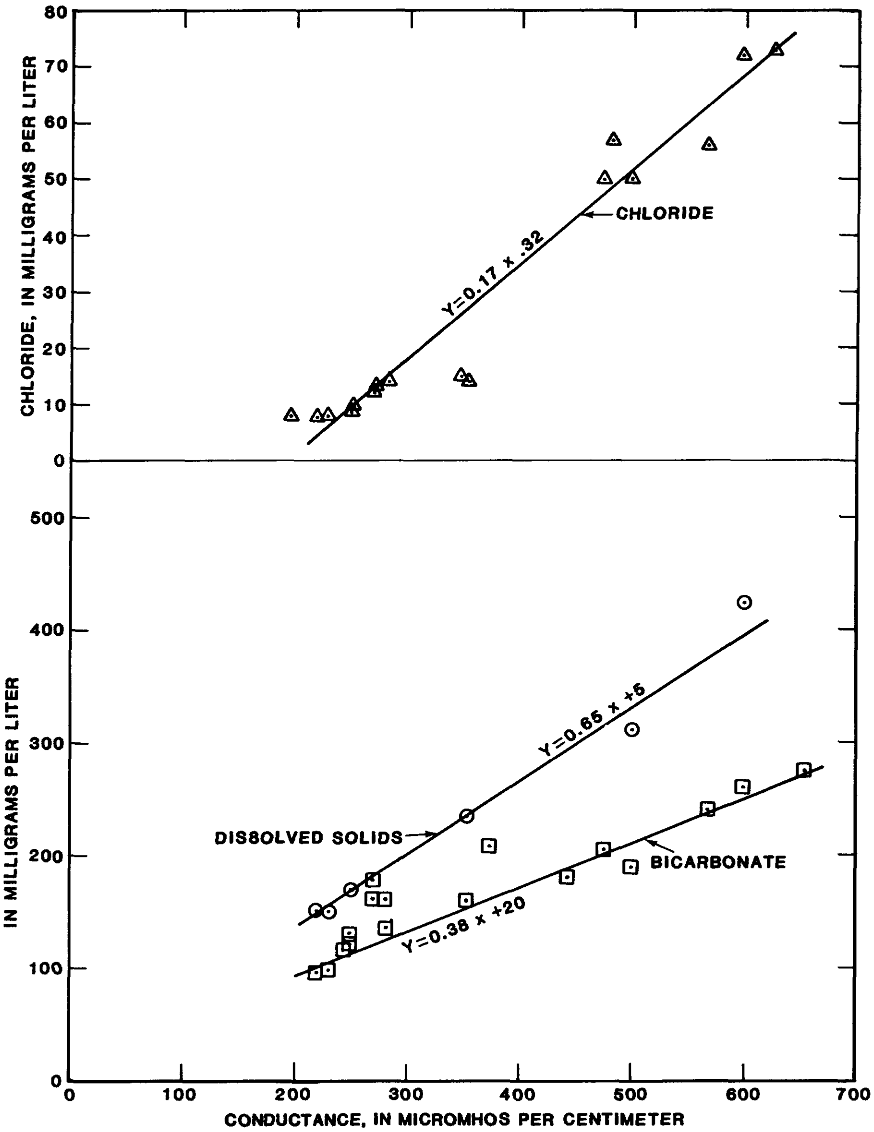


Figure 17.--Relation of specific conductance to dissolved solids, chloride, and bicarbonate in streams and canals of lower valley, 1981-82.

Surface water (Continued)

discharge to conductance in figure 18. Downstream at Highway 2 variations are again primarily related to discharge but the maximum values for several of the common constituents shows the influence of saltwater moving up the river at times of low flow (table 8).

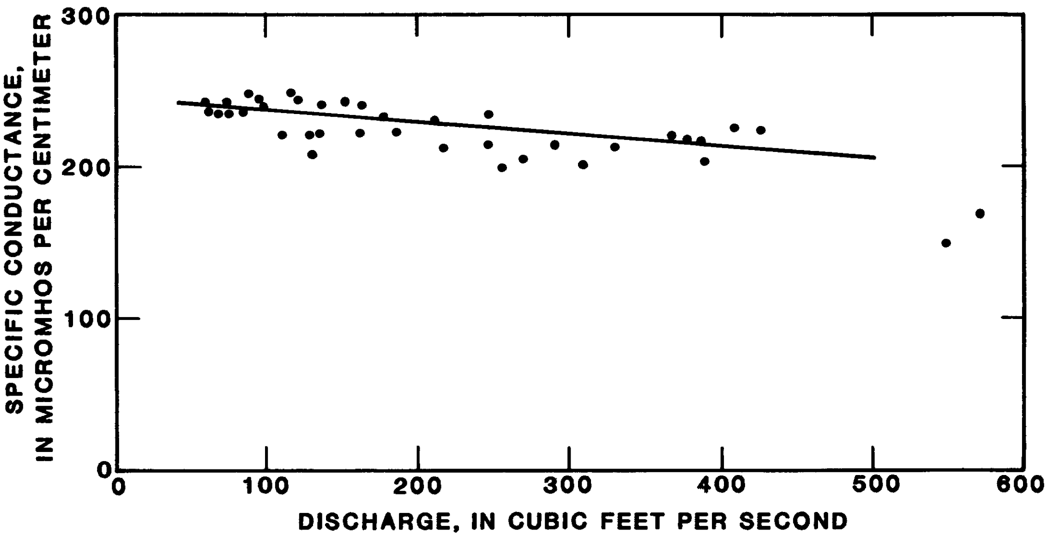


Figure 18.--Relation of discharge to specific conductance, Río Grande de Añasco at El Espino, February 1959 to December 1966.

Table 8.--Compilation of water quality analyses of Río Grande de Añasco at Highway 2 at Central Igualdad and at El Espino.

Components	Río Grande de Añasco at Hwy 2 at Central Igualdad				Río Grande de Añasco at El Espino			
	Maximum	Minimum	Mean	*N	Maximum	Minimum	Mean	*N
Specific conductance uS/cm at 25°	8,500.0	142.0	593.0	37	263.0	27.0	213.0	27
pH (Units)	7.8	4.8	7.3	37	8.6	7.1	7.7	27
Temperature (Degrees Celsius)	32	20	26.2	38	28	21	25.2	27
Oxygen dissolved (Milligrams per liter)	9.4	0	6.3	24	11.4	7	8.3	20
Oxygen demand, biochemical, 5 days, (Milligrams per liters)	330	0	32.8	33	4.2	1.3	2.6	4
Coliform, fecal, 0.7UM-MF (Cols./100 milliliters)	19,000	230	6,770	9	28,000	46	4,691	18

* N = Number of observations.

Table 8.--Compilation of water quality analyses of Río Grande de Añasco at Highway 2 at Central Igualdad and at El Espino (Continued).

Components	Río Grande de Añasco at Hwy 2 at Central Igualdad				Río Grande de Añasco at El Espino			
	Maximum	Minimum	Mean	*N	Maximum	Minimum	Mean	*N
Streptococci fecal, KF agar (Cols. per 100 Milliliters)	17,000	190	2,860	9	34,000	10	6,673	17
Hardness (Milligrams per liter as $CaCO_3$)	157	78	103	11	112	65	93.7	15
Calcium, dissolved (Milligrams per liter as Ca)	43	21	26.8	10	31	16	25.1	15
Magnesium, dissolved (Milligrams per liter as Mg)	6.9	190	22.6	22	11	3.2	7.0	5
Sodium, dissolved (Milligrams per liter as Na)	1,600	6.3	88.2	35	21	6.6	10.8	13
Potassium, dissolved (Milligrams per liter as K)	90	1.5	6.0	33	1.9	1.4	1.7	8
Bicarbonate, PPI-FLD (Milligrams per liter as HCO_3)	186	51.0	121	37	156	42	115	21
Sulfate, dissolved (Milligrams per liter as SO_4)	170	3.9	18.7	36	10	.4	5.7	14
Chloride dissolved (Milligrams per liter as Cl)	2,600	4.5	136	37	9	4.5	5.7	15
Fluoride, dissolved (Milligrams per liter as F)	0.40	0	0.14	36	0.2	0	0.08	13
Silica, dissolved (Milligrams per liter as SiO_2)	38	17	26.9	35	34	20	28.0	14
Solids, residue at 180 degrees Celsius, dissolved (Milligrams per liter)	233	148	179	5	173	160	167	2
Nitrogen-Nitrate, total (Milligrams per liter as N)	1.4	0	0.64	31	1.1	0.05	0.6	15
Nitrogen-ammonia, total (Milligrams per liter as N)	0.37	0.01	0.15	31	0.19	0.01	0.06	18
Nitrogen-organic, total (Milligrams per liter as N)	6.8	0.09	0.94	31	0.79	0.04	0.30	18
Phosphorus, total (Milligrams per liter as P)	8.5	0.04	0.42	31	0.63	0.02	0.15	18

* N = Number of observations.

Saltwater Intrusion

The potential for intrusion of seawater into the lower reaches of the Río Grande de Añasco was investigated during periods of minimum flows. Specific conductance cross-sections in the river channel were determined on two dates (February 2, 1982 and March 11, 1982). The February profiles were made during a high tide, while the March profiles were made during low tide. Cross sections were surveyed in the channel at about 1,000, 2,800, 5,000, and 9,500 ft upstream from the mouth (fig. 7). The river discharge was measured at the same time at a site about 500 ft upstream from the uppermost specific conductance profile section (section D-D'). The February discharge was 200 ft^3/s, while in March the discharge was 109 ft^3/s.

In February conductance measurements were made only at the mid-point of the river. The saltwater wedge extended upstream to a point about 5,000 ft from the mouth (section C-C' fig. 19).

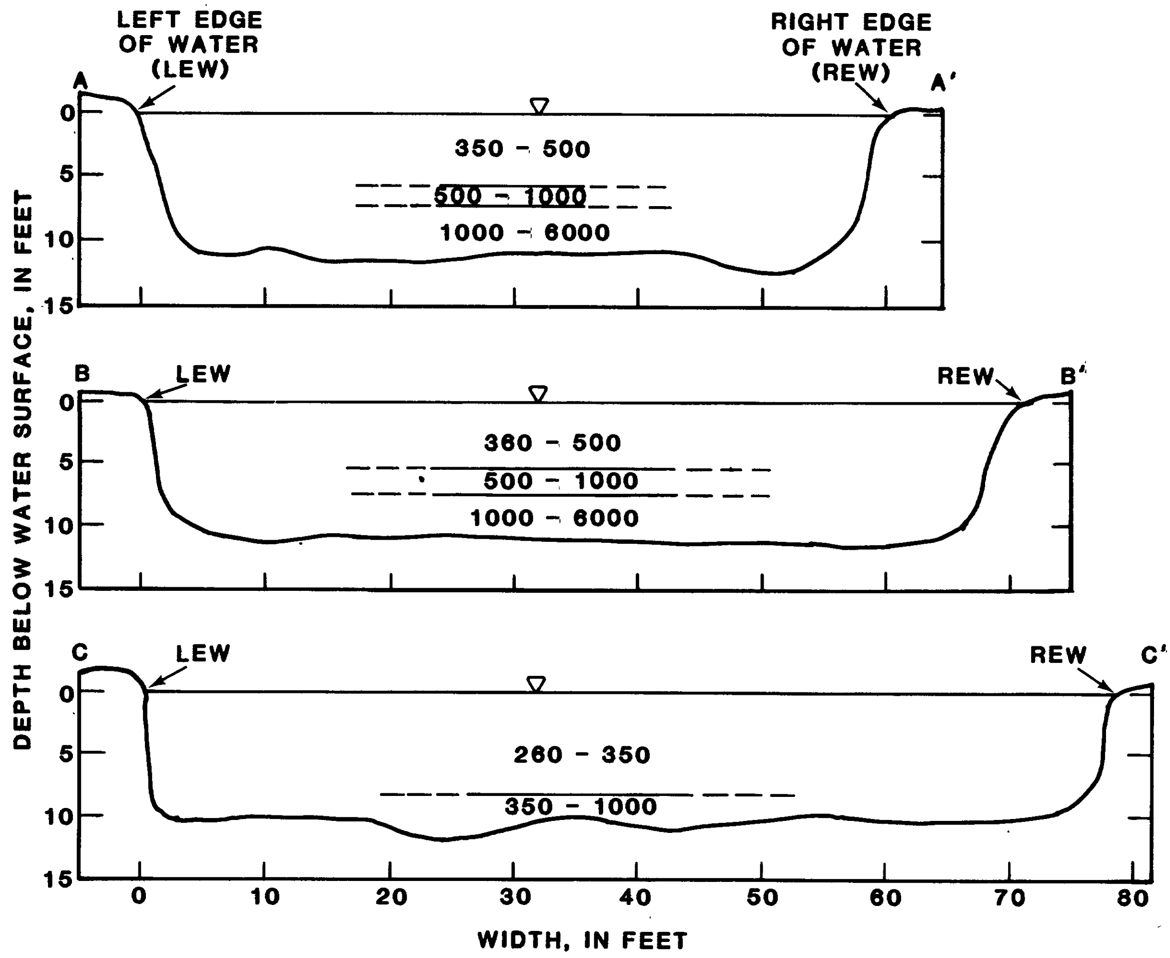


Figure 19.—Río Grande de Añasco salinity survey during high tide, February 2, 1982 discharge 200 cubic feet per second, (specific conductance in microsiemens per centimeter).

Saltwater Intrusion (Continued)

Maximum conductivity was 1,000 microsiemens per centimeter (uS/cm) equivalent to a chloride concentration of approximately 110 mg/L. Although discharge was 200 ft^3/s, the freshwater had a tendency to slide over the top of the saltwater wedge, which was driven upstream by tidal action. The maximum conductance of 6,000 uS/cm at section A-A' is well below that of seawater (about 40,000 uS/cm) and is evidence that considerable mixing takes place.

The conductance measurements made in March were more comprehensive and were taken at several locations along each cross section (fig. 20). These measurements were

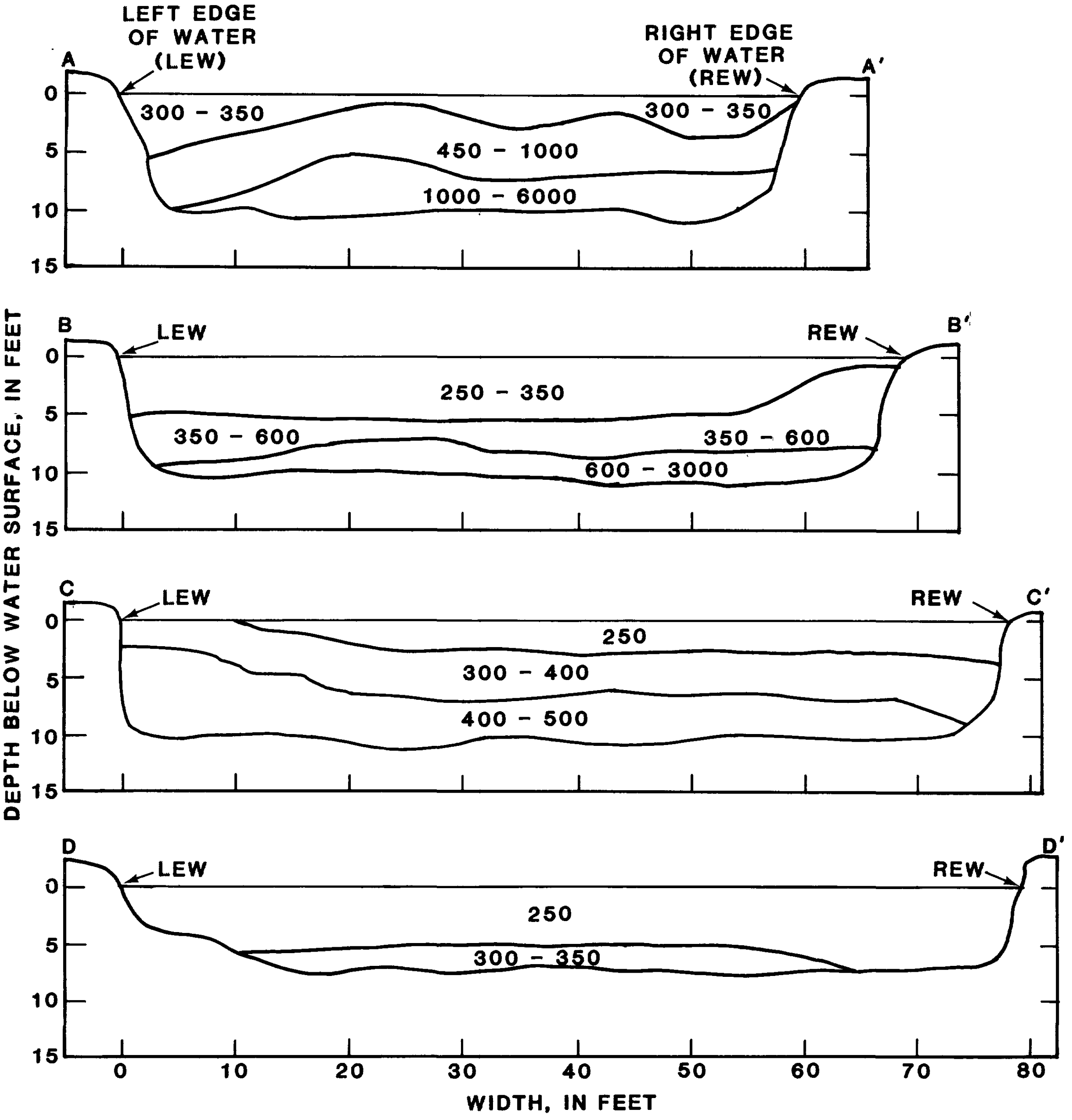


Figure 20.--Río Grande de Añasco salinity survey during low tide, March 11, 1982 discharge 109 cubic feet per second. (Specific conductance in microsiemens per centimeter).

Saltwater Intrusion (Continued)

made at low tide when river discharge was 109 ft^3/s. Although discharge of the river was less than in February, the falling tide that occurred prior to the measurements apparently aided in flushing the saltwater wedge from the river. Maximum conductivity at section C-C' was 500 uS/cm, the equivalent of a chloride concentration of about 55 mg/L.

The results of the specific conductance profiles show that seawater intrusion into the lower reaches of Río Grande de Añasco is minimal even during periods of low flow. The upriver extent of the saltwater wedge apparently is related to both the discharge of the river and tidal action even though tidal fluctuations are only a foot or so.

Because the 7-day, 10-year minimum flow of the river is about 43 ft^3/s the saltwater wedge should at times extend farther upriver than measured. The maximum conductance measured at Highway 2 was 8,500 uS/cm on April 6, 1977 at an estimated discharge of 53 ft^3/s. The duration curve of flow at El Espino (fig. 10) indicated that flow would be less than 100 ft^3/s about 15 percent of the time and less than 80 ft^3/s about 7 percent of the time. On the basis of the data available it is unlikely that the saltwater wedge will extend upstream farther than section D-D' (just below Highway 2) more than 1 or 2 percent of the time.

On February 3 and March 10, 1982, specific conductance surveys were made at two other sites in Caño La Boquilla and Caño La Puente to determine the inland movement of the saltwater wedge.

The measurement at Caño La Boquilla in February, was made at low tide, at a time when the mouth of the Caño was open to the sea. Freshwater inflow to the Caño was estimated to be less than 0.5 ft^3/s. At section E-E', 500 ft upstream from the mouth, conductance ranged from 6,000 to 9,000 uS/cm (fig. 21). Top and bottom conductance measurements elsewhere in the main body of the Caño ranged from 5,000 to 10,000 uS/cm. Specific conductance in Quebrada Boquilla at Highway 2, 7,000 ft upstream from the mouth was 600 uS/cm.

On March 10, specific conductance measurements were made during high tide, and at a time when the mouth of the Caño was partly closed by a sandbar. Discharge to the Caño from Quebrada Boquilla at Highway 2 was estimated to be less than 0.5 ft^3/s. Specific conductance at Section E-E' ranged from 21,000 to 40,000 uS/cm (fig.21). Conductance of water near the bottom of the Caño approached that of seawater. Specific conductance in Quebrada Boquilla at Highway 2 was 16,000 uS/cm. Salinity in the Caño was affected by inland movement of seawater during high tide, and also likely by the partial blockage of the mouth, which allowed seawater to enter but prevented its being flushed to the sea.

The mouth of Caño La Puente was closed by sandbars during both measurements. Water in the lower reaches of the Caño was fresh or nearly so with specific conductance ranging from 800 to 1,200 uS/cm.

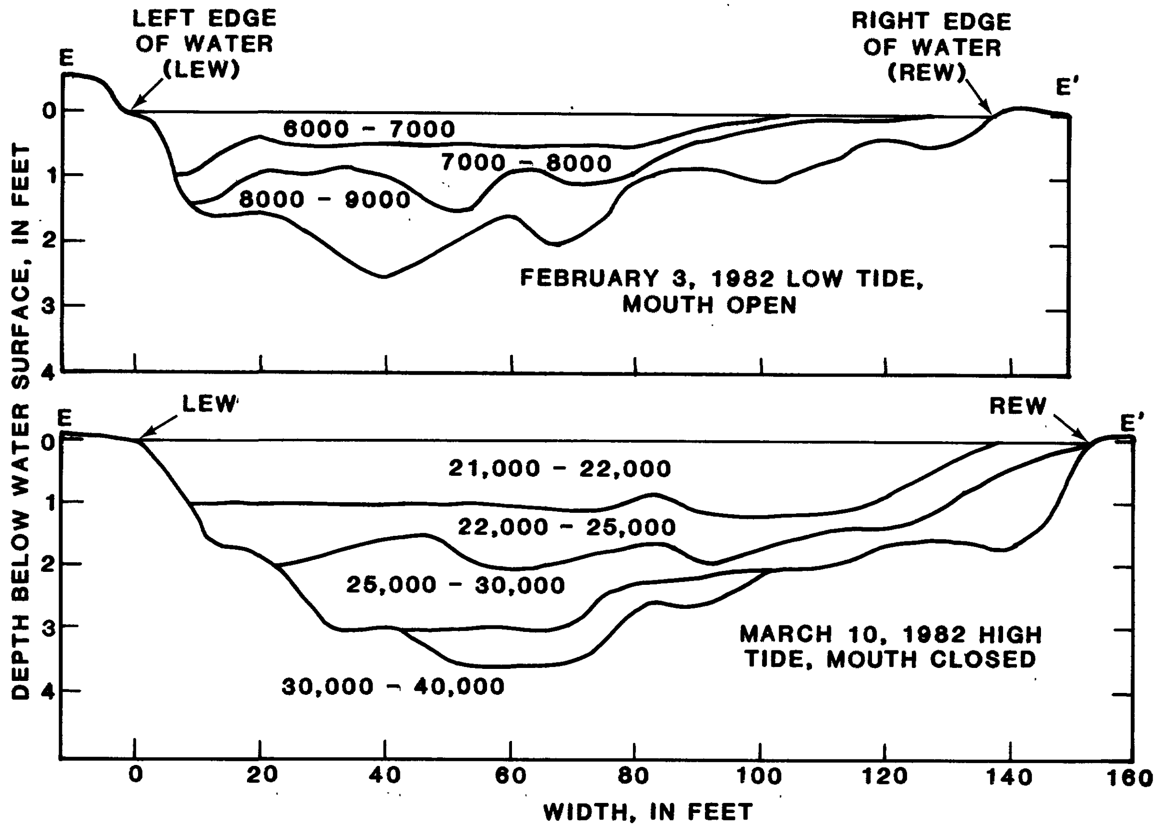


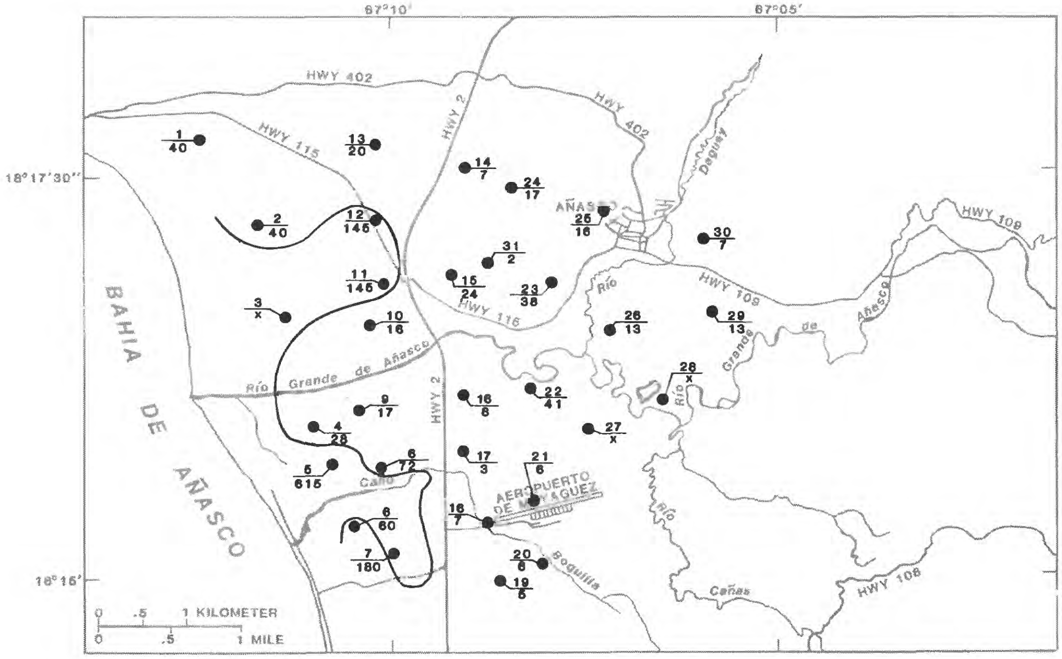
Figure 21.--Caño la Boquilla salinity surveys, February 3, 1982 and March 10, 1982 (Specific conductance in microsiemens per centimeter.)

Ground Water

Ground water quality data collection was limited to measurement of the concentration of chloride in water from piezometers placed in the alluvium of the lower valley and analyses of water from one active and several abandoned production wells.

Chloride concentrations were usually less than 20 mg/L in the upper few feet of the saturated zone in the alluvial aquifer (Zone II). Figure 22 shows chloride concentrations in the alluvium during a relatively wet period, and figure 23 shows the chloride concentrations during the dry part of the year. In both dry and wet periods the inland movement of seawater into the alluvium through Caño La Puente and Caño La Boquilla is evident. Other areas of high chloride concentrations are associated with swamps or marshes and probably represent concentration of minerals in the ground water due to evapotranspiration.

Analyses of water from abandoned or active production wells are given in Table 7. Analyses of wells 1 to 3 are of water taken by a thief sampler. Because of limitations in the sampling technique, the water may or may not represent ground water at the sample depth indicated, although the chemical composition and concentrations appear reasonable for depth and location. The chloride concentration in well 1 indicates saltwater encroachment either through the beach and dune sands that form the surficial deposits at the well site or from upward movement of saltwater from deeper water-bearing zones penetrated by the well.

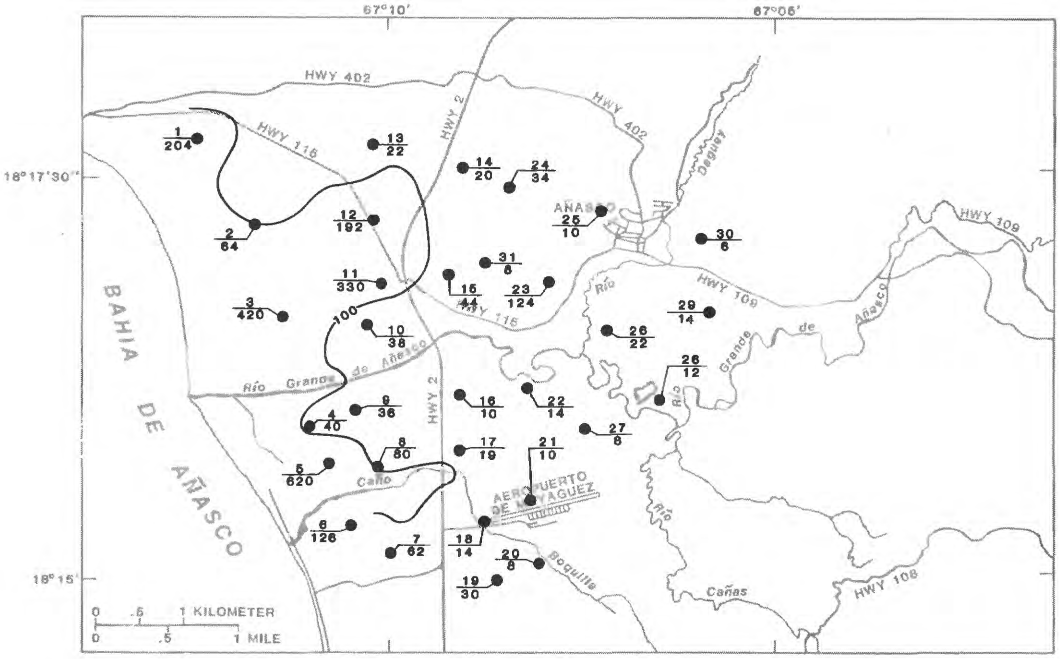


EXPLANATION

●19/5 PIEZOMETER - Top number is piezometer number, bottom number is chloride concentration in milligrams per liter

—100— APPROXIMATE LIMIT OF 100 MILLIGRAMS PER CHLORIDE CONCENTRATION

Figure 22.--Chloride concentration in ground water in shallow alluvium (zone II), lower valley, June 1981.



EXPLANATION

●7/126 PIEZOMETER - Top number is piezometer number, bottom number is chloride concentration in milligrams per liter

—100— APPROXIMATE LIMIT OF 100 MILLIGRAMS PER LITER CHLORIDE CONCENTRATION

Figure 23.--Chloride concentration in ground water in shallow alluvium (zone II), lower valley, February 1982.

Ground Water (Continued)

The analysis of water from well 2 is considered to be typical of water from the alluvium (Zone II). In many ways the water resembles water in the Río Grande de Añasco and other streams in the lower valley. The manganese concentration is higher than usual for alluvium and probably is derived from buried swamp deposits.

The thief sample from well 3 is from approximately the same water-bearing horizon as the major producing zone for well 4. The difference in the two analyses is probably related to the lack of water movement in the non-pumping well. Also the sample from well 3 is from a shallower part of zone III. The chloride concentrations (100 mg/L) in the water from both wells probably represent residual seawater.

Water Useability

Stiff diagrams of the water from the wells, Río Grande de Añasco, and Quebrada la Golzadena show the general relation of the principal mineral constituents (fig. 24). Water from the river and from the alluvial aquifer (Well 2, Zone II) are quite similar; the major difference being a slight increase in calcium and bicarbonate in the ground water. Wells 3 and 4 in the marine deposits of Zone III show a general increase in mineralization with depth (well 4 is deeper) and an increase in sodium and chloride that is probably related to residual seawater. Well 1, although in the alluvium - beach and dune sands of Zone II, shows a pattern that is typical of a calcium bicarbonate type water mixed with seawater. The water from Quebrada La Golzadena shows apparent concentration of minerals by evaporation possibly mixed with some saltwater from Caño la Puente. Any contribution of water from the alluvium to the stream is totally overshadowed by the saltwater.

Both ground water and surface water are chemically suitable for most purposes with little or no treatment. Manganese, in the concentrations found in the ground water of Zones II and III, can impart a taste to the water and also cause staining. Other than the manganese in ground water, the principal constituents in both ground and surface water are well within drinking water limits (U.S. Environmental Protection Agency, 1976, 1979).

Several methods have been employed to classify water for irrigation on the basis of its chemical characteristics. Specific constituents used to evaluate the suitability of the water for purposes of this study are: (1) the total concentration of soluble salts, (salinity of the water), usually expressed in terms of electrical conductivity; and (2) the relative proportion of sodium to other cations (percent sodium).

Sodium in water replaces calcium and magnesium in the soil through ion exchange. As a result the soil becomes dense and hard, affecting both water movement through the soil and plant growth. The sodium-adsorption ratio (SAR) is used extensively to predict the extent that sodium in water will enter into cation-exchange with elements in the soil (U.S. Department of Agriculture Salinity Laboratory, 1954).

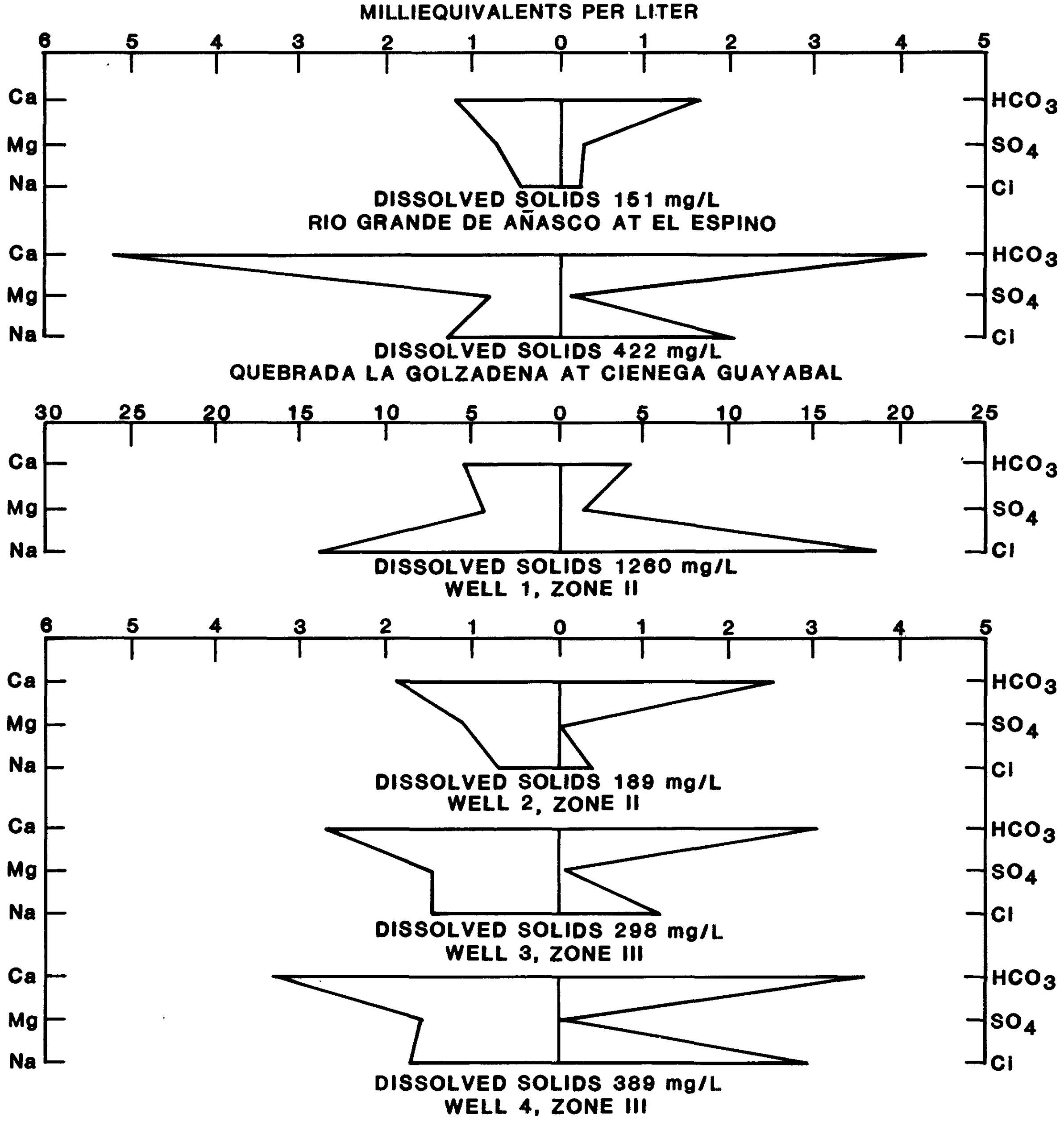


Figure 24.--Stiff diagrams of water from selected streams and wells.

Water Useability (Continued)

Using the SAR relation, surface-water and ground-water analyses were evaluated. Water from the Río Grande de Añasco at El Espino and Río Cañas at Highway 342 was consistently the best quality surface water sampled, falling into the low sodium, low salinity hazard classification of irrigation water (type C1-S1, fig. 25). Water from the other streams and canals in the lower valley falls in the low sodium, medium salinity hazard classification (C2-S1, fig. 25). Water from Well 1 in the alluvium is contaminated by saltwater and accordingly falls in the C4-S2 classification on figure 25. Water from Well 2, also in the alluvium, is similar to surface water and falls in the low sodium,-low salinity hazard (C1-S1) classification. Water from the limestones is in the low sodium-median salinity hazard (C2-S1) classification. The class ratings for the C1 and C2 salinity hazards are as follows:

Low-salinity water (C-1).--can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop.

Medium-salinity water (C-2). --can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can grow in most cases without special practices for salinity control.

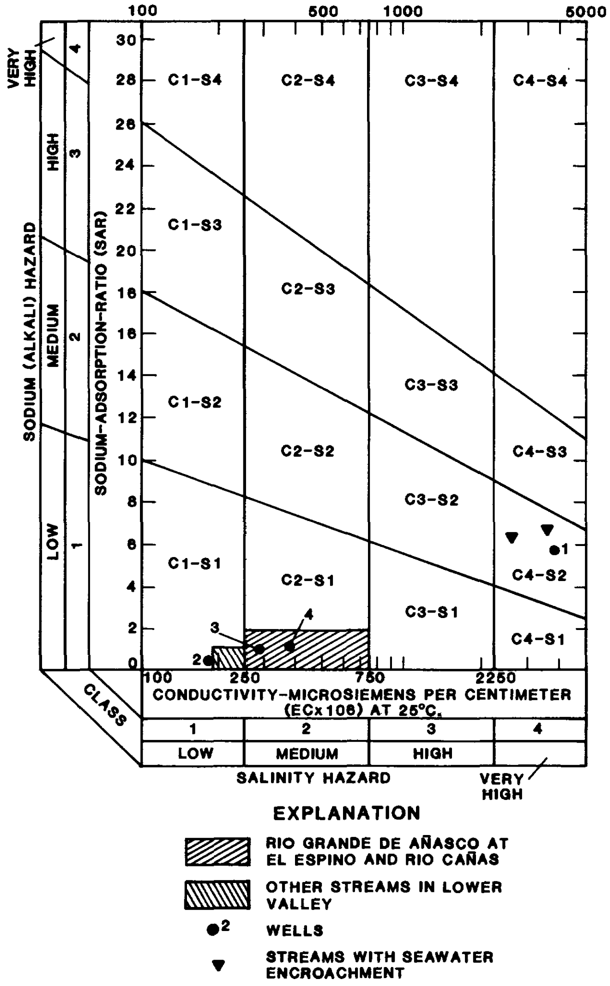


Figure 25.--Classification of surface and ground water of lower valley for irrigation.

SUMMARY

The lower valley of the Río Grande de Añasco is a flat-lying alluvial plain of about 10,500 acres bordered by the sea on the west and by ranges of hills and mountains on the remaining sides. The valley has been identified as having potential for the growing of rice.

Rainfall at the Mayaguez Airport, located in the lower valley, averaged about 68 in. annually in the 10 years preceeding this study. In the upper valley of the Río Grande de Añasco, rainfall averages about 93 in. at Lares and exceeds 100 in. annually in the mountainous areas near the head waters of the river. Rainfall shows a definite seasonal trend with a wet season from May through September in the lower valley and May through October in the upper valley. About 70 percent of the annual rainfall in the lower valley occurs during the wet season.

The lower valley is underlain by igneous rocks that have been eroded to depths of 350 ft or more below sea level. The valley is filled with 250 ft or more of limestone and clay, probably deposited during the Pleistocene Epoch. Overlying these deposits is as much as 100 ft or more of alluvium consisting primarily of silt and clay with occasional beds of sand or gravel, swamp deposits, and interfingering beach and dune sand near the coast.

The Río Grande de Añasco is the major stream flowing through the valley. Many of the lesser streams and canals in the lower valley have slight perennial flow. Río Cañas, the largest tributary, had a flow of about 5 ft^3/s in the dry season. Flow of the Río Grande de Añasco at El Espino, where the river enters the lower valley, was 100 ft^3/s and 200 ft^3/s at 85 and 50 percent flow duration, respectively, when the stream was gaged in the early 1960's. Flow upstream, at the long-term station near San Sebastian was 90 ft^3/s and 190 ft^3/s at 85 and 50 percent flow duration, respectively, for 19 years of record. For practical purposes, flow to the lower valley is the amount measured at San Sebastian. Lowest flow is most likely to occur in March, followed closely by February and April. Flow in March at San Sebastián was about 65 ft^3/s and 80 ft^3/s at 85 and 50 percent duration, respectively. The 7-day, 10-year frequency minimum flow at San Sebastian is about 40 ft^3/s and is estimated to be about 43 ft^3/s at El Espino.

Flooding in the lower valley can be extensive. Five major floods have been recorded since 1899. The greatest occurred in September 1975 and covered practically the entire valley. Flood depths were as much as 21 ft at Central Igualdad in the center of the valley. Small overbank floods (greater than 10,000 ft^3/s) occur 3 to 4 times a year.

Water can be obtained from the alluvium and the limestone. The fine-grained alluvium will yield little water to wells; however, zones of sand or gravel may yield several hundred gallons per minute to wells. The limestone reportedly will yield 500 gal/min or more to wells. Yields, however, are erratic. Some wells have penetrated only clay and obtained no water; others penetrated some limestone but the water obtained contained collodial or clay particles making the water unfit for use.

SUMMARY (Continued)

Recharge to the alluvium is principally from rainfall on the land surface. The source and amount of recharge to the limestone are unknown. Some of the shallower limestone beds may receive some recharge from the overlying alluvium. Other sources of recharge may be where the limestones are in contact with volcanic rocks along the margins of the valley, or if the limestone extends beneath the alluvium into the upper Río Grande de Añasco valley in the vicinity of El Espino there may be recharge to the limestone from the river.

The chemical composition of the surface water is similar throughout the valley. Dissolved solids range from about 150 to 400 mg/L; specific conductance, which has a direct relation to dissolved solids, ranges from about 200 to 600 uS/cm; pH ranges from about 7.1 to 8.6 units. The water is a calcium magnesium type.

Water from the Río Grande de Añasco at El Espino consistently shows the best quality of any of the streams or canals. Specific conductance here ranged between 200 and 250 uS/cm at discharges ranging from 500 to 60 ft^3/s. Using a sodium adsorption ratio relation, water from the Río Grande de Añasco fell in the low salinity, low sodium hazard range, whereas water from the other streams fell in the medium salinity, low sodium hazard range.

Saltwater intrusion from the sea was evident in the Río Grande de Añasco and Caño la Boquilla. A saltwater wedge was observed about 5,000 ft upstream from the river mouth in February 1982. The wedge was 3,000 to 4,000 ft from the mouth in March 1982. Saltwater was present in Caño la Boquilla in March as far inland as Highway 2.

Ground-water quality was highly variable. Water in the alluvium, although slightly more mineralized was similar to that of the surface water in the adjacent streams and canals. Water from the limestone was predominately a calcium-bicarbonate water, but showed strong sodium- chloride tendencies. Two samples of water from the limestone ranked as medium salinity hazard and low sodium hazard in the classification of irrigation water.

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