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

U.S. GEOLOGICAL SURVEY
WATER RESOURCES INVESTIGATIONS REPORT 83-4199

Prepared in Cooperation with the
PUERTO RICO DEPARTMENT OF AGRICULTURE

Hacienda La Esperanza (1830–1880)

Located at Barrio Tierras Nuevas Poniente, in lower Río Grande de Manatí valley . Among the islands sugar cane plantations to use steam driven machinery. The Hacienda possibly had the most powerfull steam mill on the island in the early 1860's.

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By Fernando Gómez-Gómez

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San Juan, Puerto Rico
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use the International System of Units (SI), the data may be converted by using the following factors:

Muitiply inch-pound units	by	To obtain SI units
inches (in.)	25.4	millimeters (mm)
inches per hour (in/h)	25.4	millimeters per hour (mm/h)
	2.54	centimeters per hour (cm/h)
feet (ft)	0.3048	meters (m)
feet per mile (ft/mi)	0.1894	meters per kilometer (m/km)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	4047.	square meters (m^2)
acre-feet (acre-ft)	1233.	cubic meters (m^3)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
	3785.	cubic meters per day (m^3/d)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
pounds (lb)	453.6	grams (g)
tons (short)	0.9072	metric tons
micromhos per centimeter at 25° Celsius (umhos/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)

Specific Combinations

1 Acre-ft = 226.2 gal/min, during one day

1 ft^3/s = 448.8 gal/min

1 ft^3/s = 0.65 Mgal/d

1 lb/acre-ft = 0.37 parts per million

1 Mgal/d = 694 gal/min

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By Fernando Gómez-Gómez

ABSTRACT

A 1-year study of the water resources of the lower Río Grande de Manatí Valley was initiated in July 1980. Río Grande de Manatí is the area's major water resource. Its mean-annual flow is about 267,000 acre-feet. Lack of flow-control structures limits water-supply developments to run-of-the-river flow. Analysis of data from U.S. Geological Survey gaging stations show that the 7 day minimum flow occurs in July, and 90 percent of the time is equal to or greater than 65 cubic feet per second. The lowest flow on record (9 years) is 51 cubic feet per second. On the other extreme, the river may overflow its bank on an average of once every two years. Major floods in the valley occur on an average of about once every 7 years, or a probability of 13 percent for any given year.

Water from the Río Grande de Manatí is of good quality and suitable for most purposes. Dissolved-solids concentrations are low with the maximum specific conductance value of 355 micromhos per centimeter at 25°C as obtained from 111 observations in a span of 10 years. Suspended-sediment concentrations are relatively low averaging about 100 pounds per acre-foot at base flows of 100 cubic feet per second, and about 1,000 pounds per acre-foot at flood flows of 2,000 cubic feet per second. Fecal contamination may be the only major water-quality problem, analyses indicate concentrations from 4,000 to as high as 200,000 colonies per 100 milliliters.

Ground water occurs in both a water table and a deep artesian aquifer. The water-table aquifer exists as a lens of freshwater overlying saline water. This lens is thickest at inland areas at least 6 miles from the coast and away from Río Grande de Manatí, which is a gaining stream northward from this point. In the valley proper the aquifer consists of alluvial deposits composed mainly of fine sand and silt and limestone underlying the alluvium. The hydraulic conductivity of the alluvium was estimated in the range of 20 to 30 feet per day. This is at least one order of magnitude less than that typically found in the Aymamón Limestone which is a prolific aquifer but contains mostly saline water in the lower alluvial valley. An artesian freshwater aquifer within the Montebello Limestone Member of the Cibao Formation lies at a depth of approximately 1,100 to 1,700 feet below land surface in the valley. The piezometric head in this aquifer is about 300 feet above mean sea level. Fresh ground water in the alluvial valley is of good quality with total dissolved solids usually below 325 milligrams per liter where unaffected by upward coning of saline water at wells.

No water is being withdrawn at present (1981) from Río Grande de Manatí. The only major constraint on water withdrawals from the river is the inland advance of the salt-water wedge with a reduction of flow. Fifty percent of the time the wedge lies at least 3.5 miles upstream from the mouth. At zero discharge the maximum inland extent of the wedge would be 6.8 miles upstream.

Ground-water withdrawals in the valley are estimated at 3.7 million gallons per day. Various wells already show saline-water intrusion through upward coning of saline water. Future potential exists for development only at areas where the fresh ground-water lens exceeds 200 feet in thickness, or essentially at sites greater than 6 miles from the coast.

1.0 INTRODUCTION

1.1 Purpose and Scope

AVAILABILITY OF WATER INVESTIGATED WITHIN THE LOWER RIO GRANDE DE MANATI VALLEY

The study included surface and ground water resources in the area.

The Puerto Rico Department of Agriculture (DOA) has initiated a program to develop land for rice cultivation. Pilot studies have been performed which indicate that yields of at least 30 hundred weight per crop per acre can be obtained with sprinkler irrigation (Vicente-Chandler, 1977). This system of irrigation, nevertheless, has commercial limitations due to proliferation of weeds and relatively low yield. By using flooded fields (paddies) yields averaging 50 hundred weight per crop per acre can be obtained, but at the expense of more water. Studies conducted by the Agricultural Experimental Station at flooded fields indicate irrigation requirements for optimum yield is approximately 4 ac-ft per crop, comparable with the water requirements of sugarcane if two crops of rice are harvested in a year.

On the basis of one hundred weight per year, the Department of Agriculture has identified 50,000 acres of land mostly on the island's north coast, which can be used in the program. Most acreage is either fallow or dedicated to sugarcane with production yields too low to make it profitable.

The U.S. Geological Survey, in cooperation with the Puerto Rico Department of Agriculture conducted hydrologic investigations at several sites throughout Puerto Rico--Río Grande to Canovanas, Sabana Seca to Cibuco, Manatí to Barceloneta, Caño Tiburones, Arecibo, Añasco and Guanajibo--to determine the availability of water (fig. 1.1-1). This report summarizes the results of the study in the Manatí-Barceloneta area. The study includes an analysis of the availability of water from both surface and ground-water sources, and water quality. The major focus of the study was the alluvial valley of Río Grande de Manatí north of Highway 2. Areas outside of the valley were included as necessary only to the degree in which these influence the local hydrology.

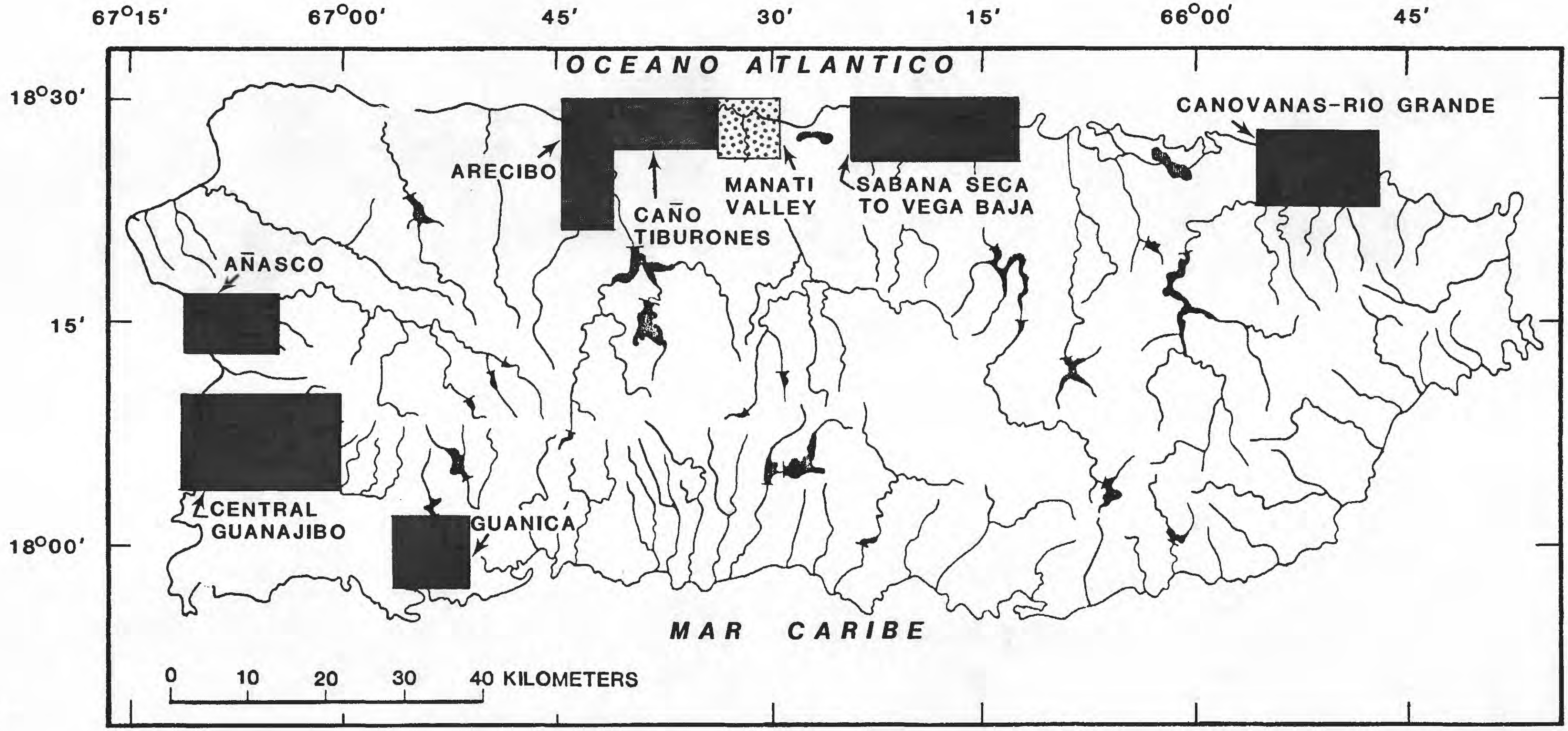


Figure 1.1-1 Areas at which hydrologic investigations were conducted.

1.2 Description of the Study Area

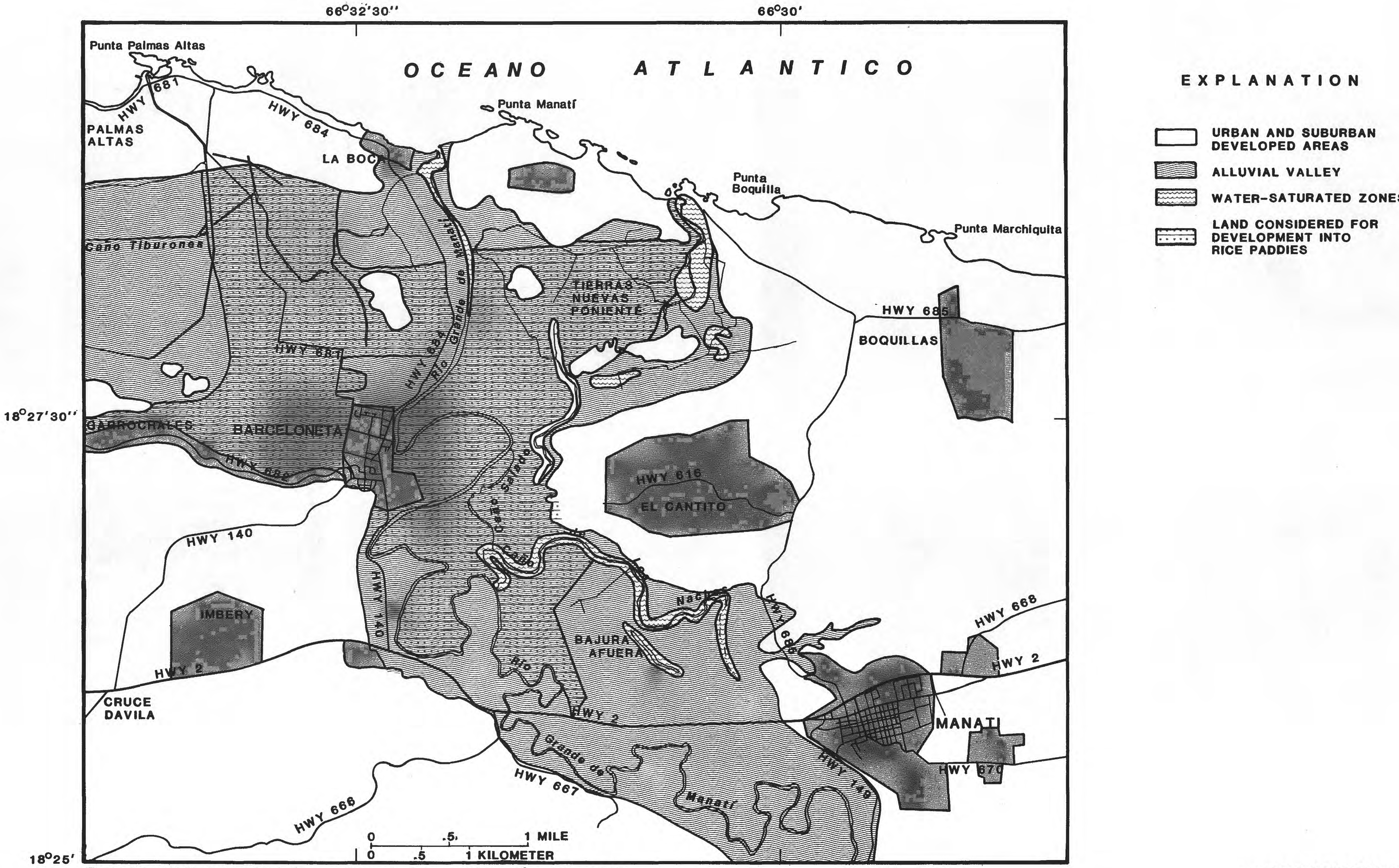
MOST LAND IN THE VALLEY IS DESIGNATED FOR AGRICULTURAL USE

Of the 5,000 arable acres within the lower alluvial valley, 2,800 acres are being considered for agricultural development into rice paddies.

The study included an area of approximately 25 mi^2 in the vicinity of the towns of Manatí and Barceloneta (fig. 1.2-1). The major geographic feature is the Río Grande de Manatí alluvial valley which merges near the coast to the northwest with an extensive plain, Caño Tiburones--a former marine slough. Most of the land in the valley is ideal for agricultural development due to its relative flatness. Along Highway 2 the land elevation is about 30 ft above mean sea level (msl). This conforms to a seaward slope of approximately 10 ft/mi.

Sugarcane was the major agricultural enterprise in the valley until about 1965, the year when Central Monserrate (sugar-mill) ceased operations. Within several years sugarcane cultivation was abandoned throughout most of the area, the land was left fallow or used as pasture for dairy cattle. Since the early 70's major economic changes have occurred with the concentration of pharmaceutical industries in the upland areas on both sides of the valley in the municipalities of Manatí and Barceloneta. Since the entire valley is subject to frequent flooding it is most probable that urban and industrial expansion will be limited to the upland areas.

The Commonwealth government through the Department of Agriculture and Puerto Rico Land Authority has ownership of about 70 percent of the lands in the alluvial valley. A total of 2,800 acres are planned for development into rice paddies. Of these, about 1,300 acres are west of Río Grande de Manatí in the vicinity of Barceloneta.



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 1.2-1 Study area.

2.0 CLIMATE

2.1 General Description

RIO GRANDE DE MANATI VALLEY IS WITHIN THE NORTH COASTAL CLIMATIC DIVISION OF PUERTO RICO

Low relief and direct exposure to the northeast trade winds exert the major climatic influence.

The Río Grande de Manatí valley lies within the North Coast Division of Puerto Rico as classified by the National Weather Service. This division is characterized by being mostly flat-coastal land exposed to the trade winds which blow almost incessantly from the northeast (fig. 2.1-1). As a result, rainfall in this division is on an average twice that of the south-coast plains, which lie in a rain shadow (fig. 2.1-2). The trade winds are also the cause of the slight temperature changes registered throughout the year. Mean-monthly temperatures on the north coast vary by only 3°C from a mean of about 25.5°C.

Pan evaporation rates on the Island show a cyclic trend, with maximum-monthly values in the spring and early summer months and the lowest monthly averages during November and December. The northern plains receive on an average about twice the rainfall of the southern plains, but the wind exposure is so severe that pan evaporation is equivalent to that on the south coast (fig. 2.1-2).

Rainfall may be the most variable of climatic factors in the Island of Puerto Rico. Major phenomena as cold fronts usually affect the Island from about November to April, and can produce sufficient rain to cause floods even during the relatively dry months of December to March. Between May and November, easterly waves which develop to the southeast of the Island exert a similar effect. On occasions these may evolve into tropical storms or hurricanes. The relative number of cold fronts or easterly waves on any given year is essentially the difference between relatively wet and relatively dry periods.

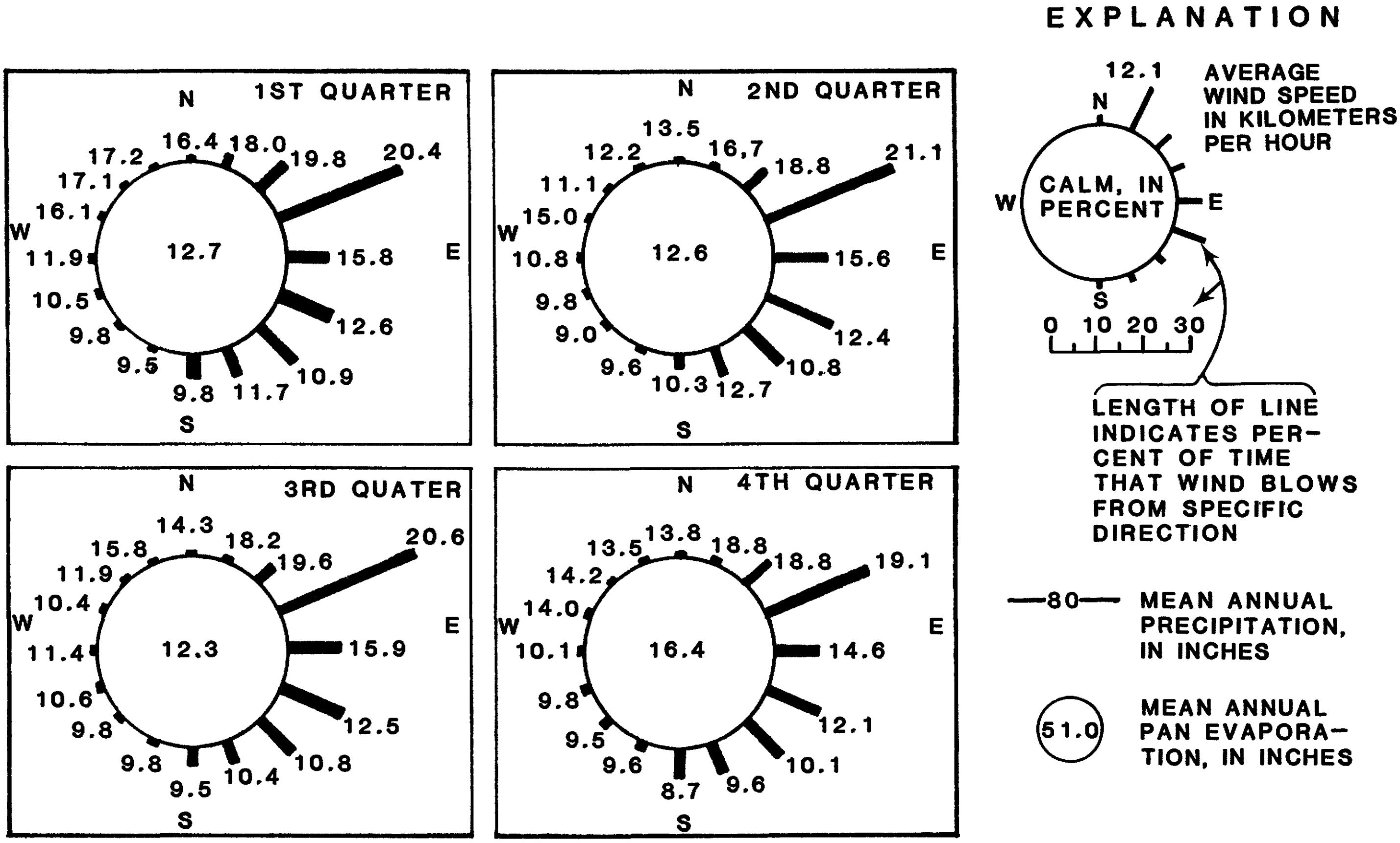


Figure 2.1-1 Average wind roses, by quarter, at Isla Verde International Airport (Mean for period 1955-1974)

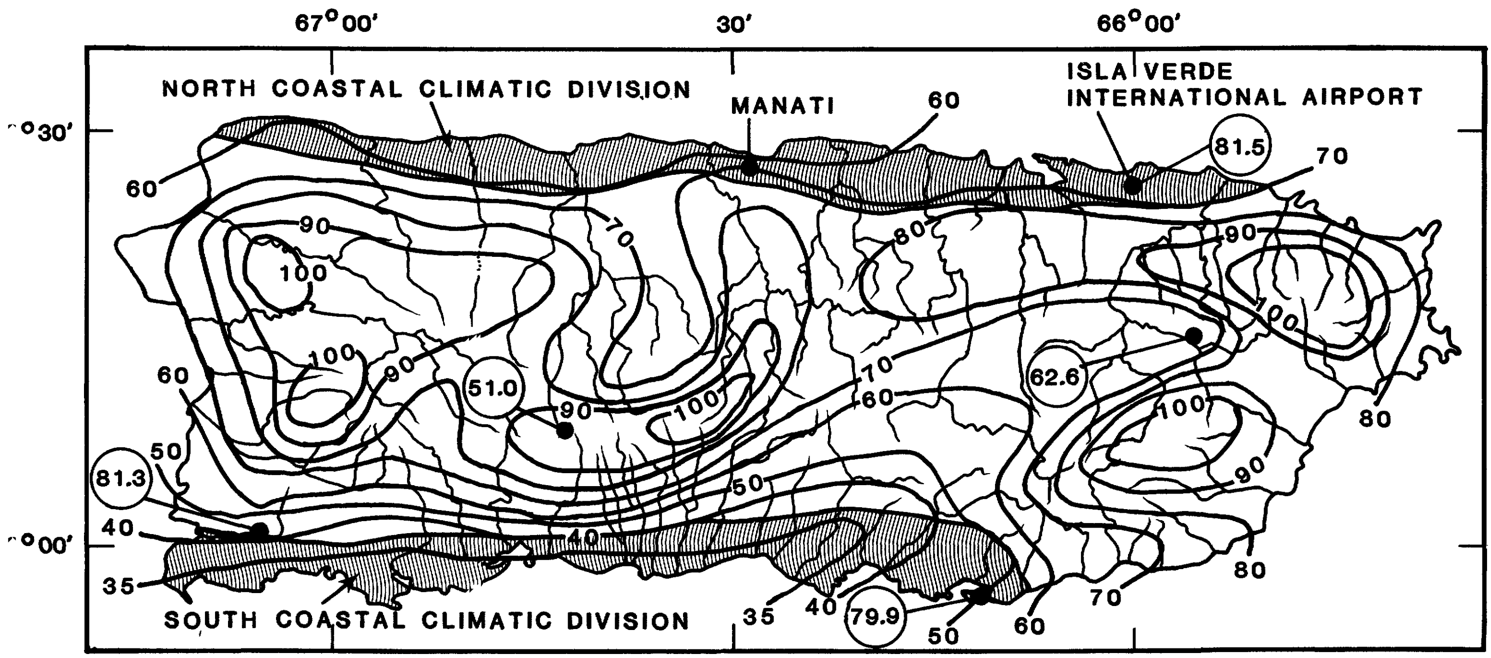


Figure 2.1-2 Rainfall distribution and pan evaporation throughout Puerto Rico (National Weather Service Data).

2.2 Local Conditions

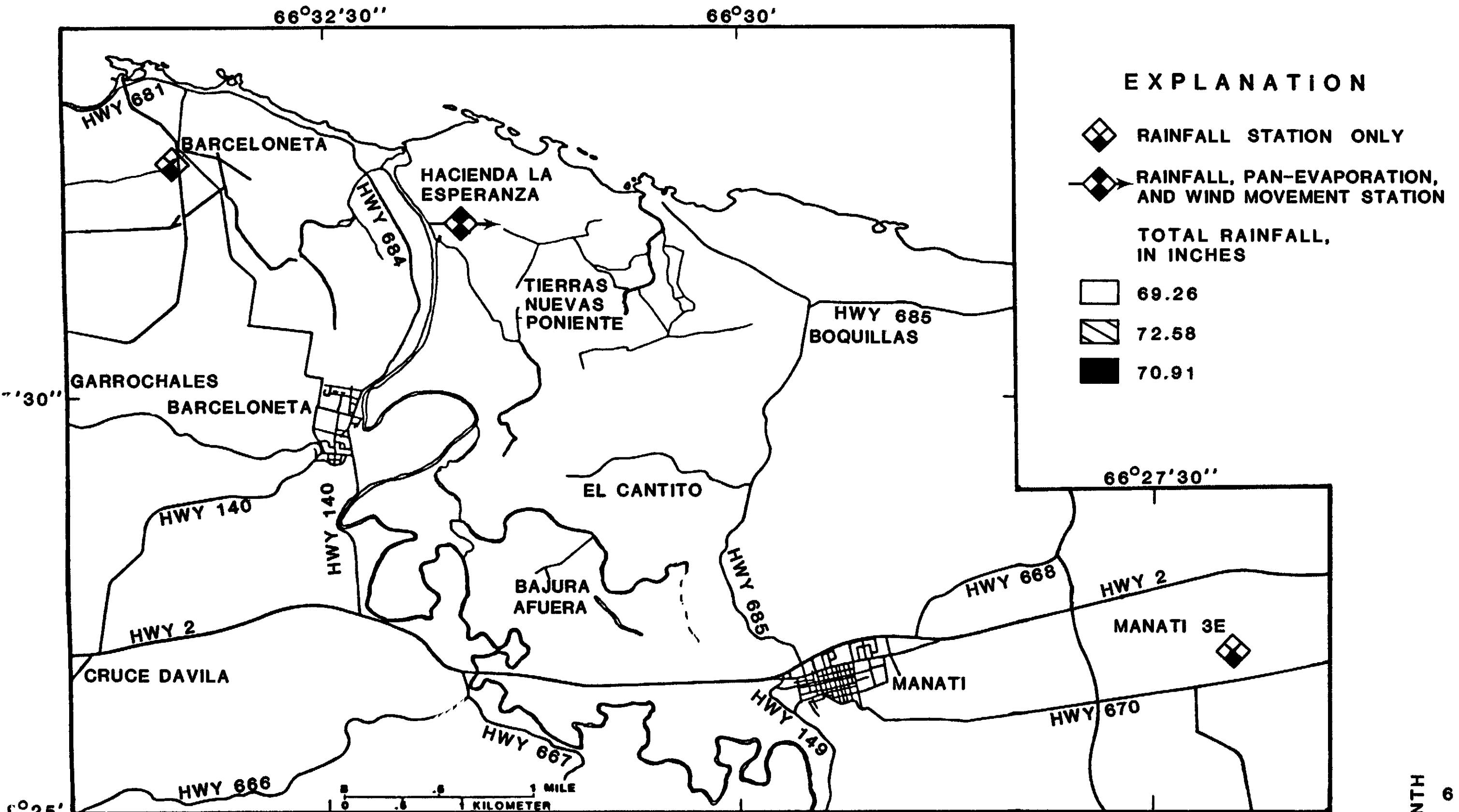
LONG-TERM RAINFALL RECORDS AVAILABILITY FOR THE AREA

Long-term rainfall records in the area indicate that mean-annual rainfall ranges from 54 inches near the coast to 61 inches 6 miles inland. However, pan evaporation exceeded rainfall for 64 percent of the days during this study.

The National Weather Service (NWS) maintains two daily rain gages within the Manatí-Barceloneta area. For the period of study an additional weather observation site was established at Hacienda La Esperanza to obtain daily rainfall, wind movement and pan evaporation data (fig. 2.2-1). The data show a significant rainfall variability between the three sites even on a monthly basis, but in general annual totals increase slightly inland (fig. 2.2-2). Barceloneta has an annual mean rainfall of about 54 in. while at Manatí it is about 61 in. Statistics from long-term data at Manatí (table 2.2-1) show that the annual-rainfall amount of 72.58 in. measured during the study at Manatí 3E occurs on less than 50 percent of the years of available record. This indicates that the period of study was relatively wet.

Pan evaporation of 49.92 in. was recorded at Hacienda La Esperanza during the study. Pan evaporation followed a cyclic pattern closely related to wind movement (fig. 2.2-3). Analysis of daily-meteorological data obtained at Hacienda La Esperanza showed that during 233 days of the year, pan evaporation exceeded rainfall. The total number of days pan evaporation exceeded rainfall varied between 13 and 25 days per month.

Another meteorological statistic of importance especially in assessing crop damages due to rainstorms is the occurrence interval for given rainfall intensities. This information is not available for the Manatí to Barceloneta area, but generalized estimates for the island have been computed (U.S. Department of Commerce, 1961). Generalized estimates for the Río Grande de Manatí valley, indicate that rainfall intensities having a recurrence interval of 5 years, (or 20 percent probability of occurring on any given year; 1/5), can be from 2.00 inches in 1/2 hour to about 6.00 inches in a 24-hour period (fig. 2.2-4).



Base from U.S. Geological Survey Barceloneta and Manati quads., 1969.

Figure 2.2-1 Weather observation stations.

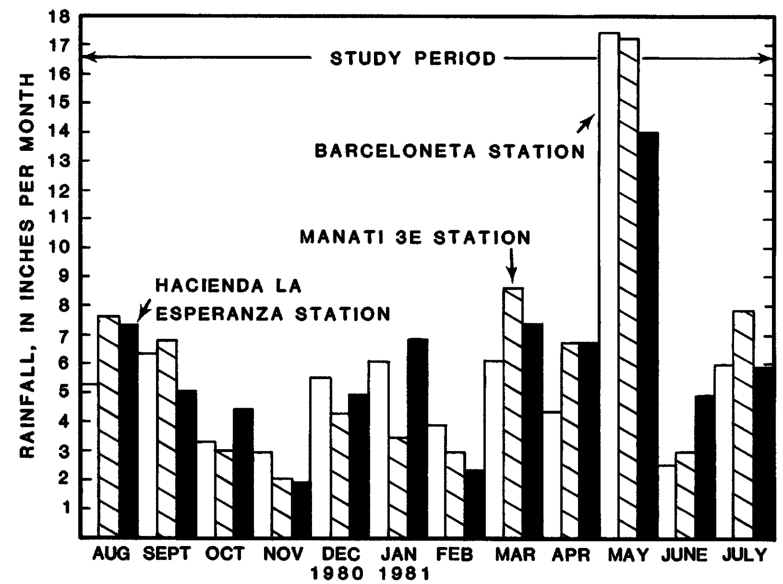


Figure 2.2-2 Monthly rainfall for study period at Barceloneta, Manatí 3E and Hacienda La Esperanza.

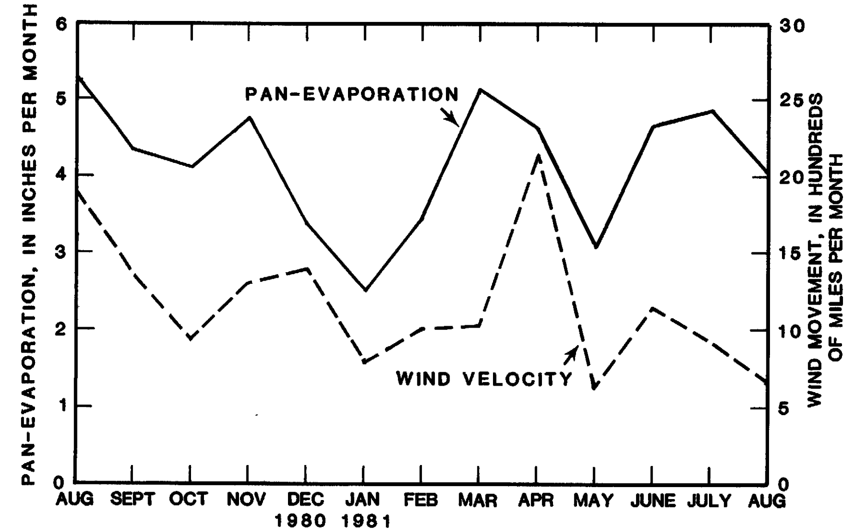


Figure 2.2-3 Monthly total pan-evaporation and wind velocity at Hacienda La Esperanza.

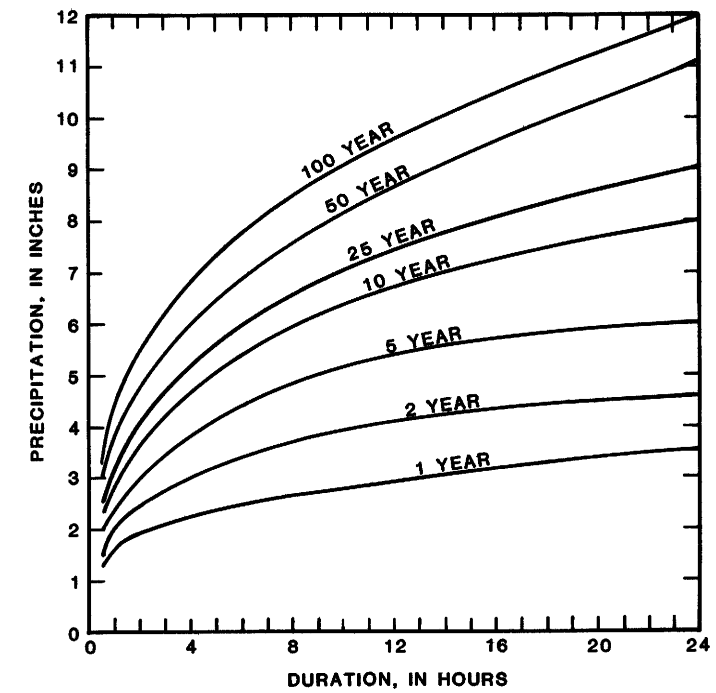


Figure 2.2-4 Estimated rainfall intensites and recurrence intervals for Manatí. (Modified from U.S. Department of Commerce, 1961.)

Table 2.2-1 Long term annual rainfall at National Weather Service sites in the Manatí-Barceloneta area and monthly rainfall probabilities. (From annual reported data: Manatí 1955-1979, station relocated Feb 1969, listed as Manatí 2E: Barceloneta 1950-1963, Sept 1971-Dec 1979).

MEAN ANNUAL RAINFALL BY MONTH, IN INCHES														
STATION	P	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL
BARCELONETA	P	4.47	3.06	3.18	5.41	4.34	3.69	4.26	4.88	4.50	5.48	5.83	5.34	54.44
MANATI		4.95	3.14	3.23	5.49	6.17	4.19	4.69	5.29	5.14	5.49	6.82	6.61	61.21
PRECIPITATION PROBABILITY, VALUES INDICATE AMOUNT OF RAINFALL EQUALED OR EXCEEDED AT INDICATED PROBABILITY (P). VALUES IN INCHES														
BARCELONETA	10	10.52	7.32	7.92	11.00	7.97	8.44	7.95	10.87	7.77	9.31	9.73	9.59	72.60
	50	3.85	2.14	2.81	4.42	4.74	2.82	3.96	4.08	4.83	5.04	4.94	5.27	52.97
	90	1.15	1.19	0.89	2.38	1.08	1.05	1.79	2.20	1.86	3.05	2.83	2.24	34.56
MANATI	10	8.33	6.24	6.42	10.60	14.06	9.06	6.93	8.22	8.14	10.62	12.56	14.84	85.99
	50	4.51	2.26	2.87	5.60	5.68	3.92	4.56	5.57	4.92	4.81	6.08	5.74	61.92
	90	2.00	1.35	1.32	2.00	1.63	0.66	2.52	2.48	2.94	2.12	3.16	2.00	42.89

3.0 GEOLOGY

3.1 Surficial Geology

ALLUVIUM AND SWAMP DEPOSITS COVER THE VALLEY FLOOR

Lower Río Grande de Manatí Valley is incised into thick limestone deposits. Outcrops of the Camuy, Aymamón and Aguada Limestones are exposed within the area.

The watershed of the Río Grande de Manatí lies almost equally within volcanic rocks of Cretaceous age and thick-limestone deposits of Tertiary age (fig. 3.1-1). This feature is of major importance to the hydrology of the basin especially within the alluvial valley. Surficial deposits consisting of flood-plain alluvium and the Aymamón Limestone predominate in the lower valley (fig. 3.1-2). A general description of these and other deposits in the area are as follows:

Flood-plain alluvium - Qa, gravel, sand, silt and clay. chiefly composed of volcanic rock fragments, quartz grains, and silicified and nonsilicified volcanic rock pebbles.

Beach deposits - Qb, sand composed of grains of quartz, volcanic rock, and shell fragments. Includes deposits of beachrock, small coastal-swamp deposits, and longitudinal sand dunes of beach sand.

Swamp deposits - Qs, Clay, sandy clay, and silty clay, commonly with high organic content. Qsp, peat and peaty muck.

Cemented dunes - Qe, eolionite; friable to consolidated highly crossbedded calcareous eolian sandstone composed of fine to coarse grains of shell fragments and quartz.

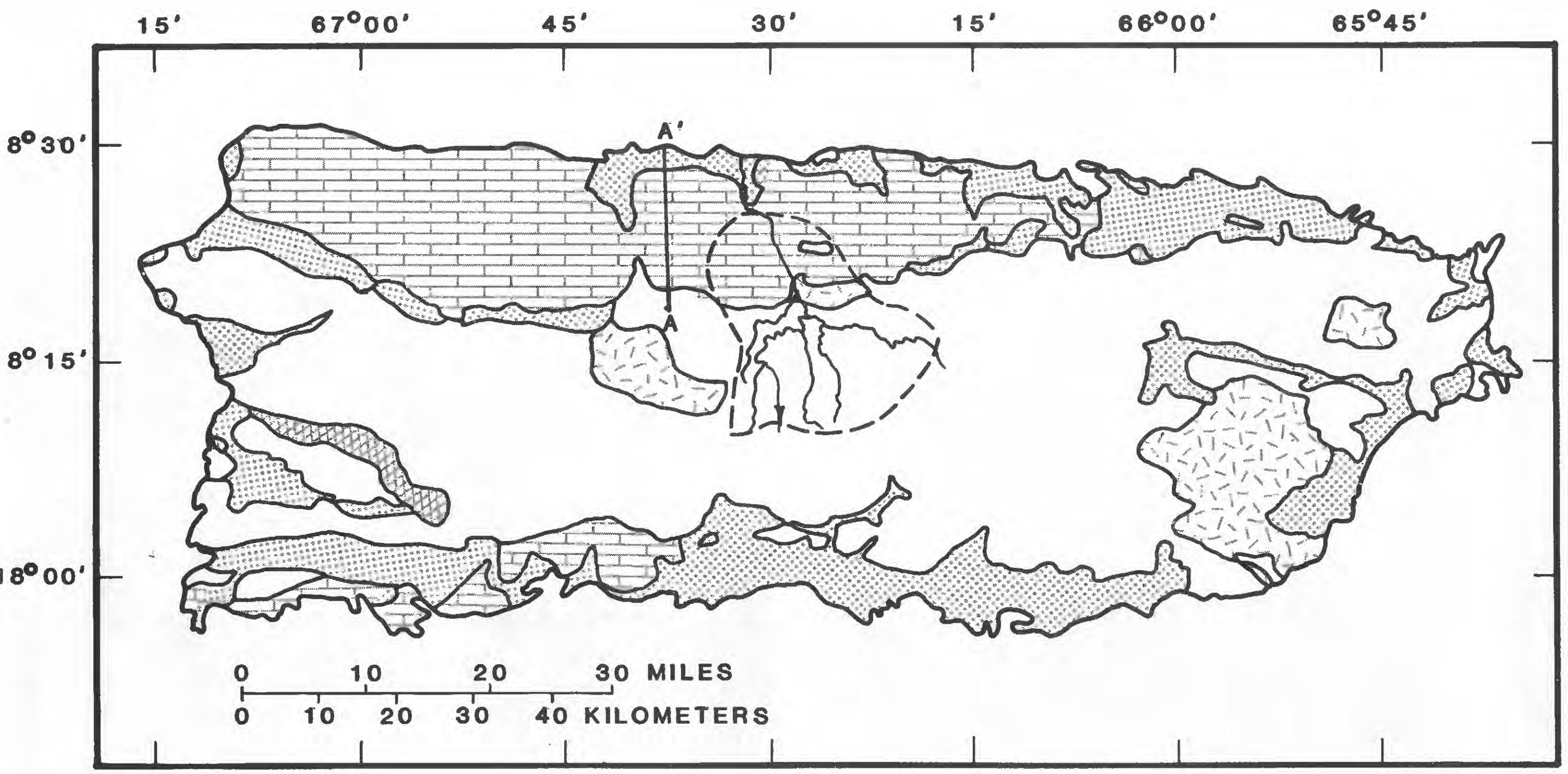
Blanket deposits - Qss, Quartz sand, medium-and fine grained; commonly contains less than 2-percent clay and other impurities ("silica sand").

Undifferentiated Surficial Deposit - QT, clay, sandy clay, and deposits. Locally may contain blanket deposits, marine-terrain deposits, and other miscellaneous Quaternary deposits only shown in more detailed geologic maps.

Camuy Formation - Tca, limestone medium to fine grained, pure and somewhat clayey, interbedded with clayey chalk, and marl.

Aymamón Limestone - Tay, limestone generally very pure and fine-grained, solution of this limestone typically develops a karst topography featuring mogotes and steep sided ridges parallel to joint systems or to the strike, with intervening plains covered by blanket deposits.

Aguada Limestone - Ta, limestone generally medium and fine-grained interbedded with chalk and marl. Deep steep-sided sinkholes separated by typical sharp ridges and towers have developed.



EXPLANATION

QUATERNARY

UNCONSOLIDATED ALLUVIAL AND OLD ALLUVIAL DEPOSITS

TERTIARY

LIMESTONE

CRETACEOUS AND TERTIARY

MASSIVE ANDESITIC TUFFS, SHALES, AND STRATIFIED ASH AND TUFF

VOLCANIC AND IGNEOUS ROCKS, GRANITOID INTRUSIVES INCLUDING DIORITES, QUARTS DIORITES, GRANITES, AND OTHER HOLOCRYSTALLINE TYPES

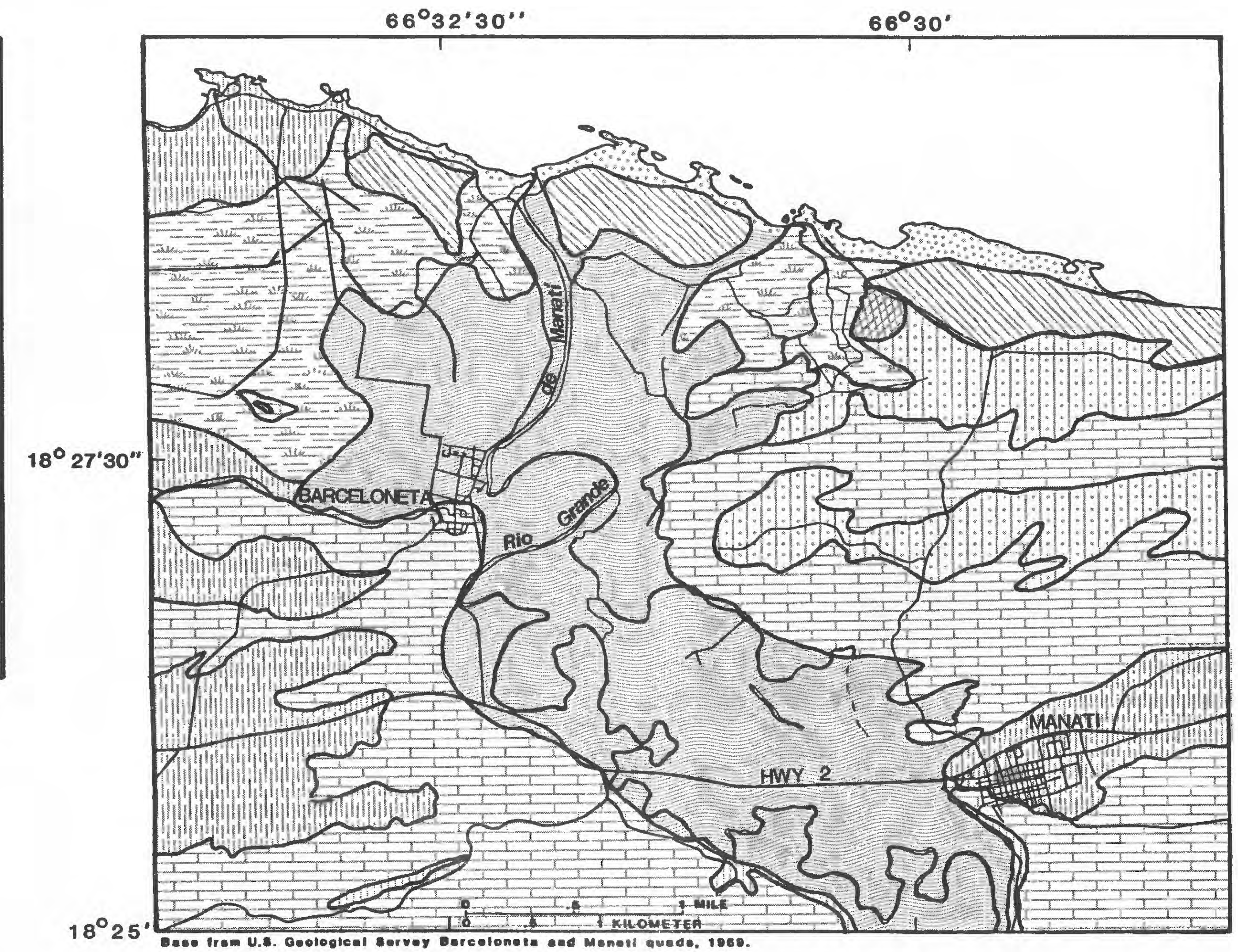
CRETACEOUS?

SERPENTINE

A' – A SECTION SHOWN IN FIGURE 3.2-1

----- OUTLINE SHOWS UPPER-DRAINAGE AREA: LIMESTONE BOUNDARY APPROXIMATE (GIUSTI, 1978)

Figure 3.1-1 Watershed of the Río Grande de Manatí and generalized geology.



EXPLANATION

QUATERNARY

FLOOD-PLAIN ALLUVIUM

BEACH DEPOSITS

SWAMP DEPOSITS

CEMENTED DUNES

BLANKET DEPOSITS

UNDIFFERENTIATED SURFICIAL DEPOSITS

TERTIARY

CAMUY FORMATION

AYMAMON LIMESTONE

AGUADA LIMESTONE

Figure 3.1-2 Major surficial geologic formations in the study area.

3.2 Subsurface Geology

ALLUVIUM MAY BE AS MUCH AS 300 FEET THICK IN THE VALLEY

Eustatic sea level changes may have controlled the depth to which Río Grande de Manatí eroded the limestones to form the alluvial valley.

Interpretation of the stratigraphy underlying the surficial deposits was made possible through available geologic maps, well logs, test borings and surface-resistivity surveys.

The limestone belt along most of the Island's north coast, in general, consists of a series of six formations of Tertiary age. The formations and their thickness were described for an oil test well (No. 4CPR) drilled near the coast at Arecibo, approximately 10 mi west of Manatí (Briggs, 1961). The formations penetrated and their thickness at the test well site were as follows (fig. 3.2-1):

Geologic formation	Depth of penetration, in feet	Thickness, in feet
Camuy Formation	Land surface to 560 feet	560
Aymamón Formation	560 - 1,479	919
Aguada Limestone	1,479 - 1,850	371
Cibao Formation	1,850 - 2,852	1,002
Lares Formation	2,852 - 4,505	1,653
San Sebastián Formation	4,505 - 5,580	1,075

In the Río Grande de Manatí Valley, most of the Camuy Formation and Aymamón Limestone have been eroded. The Montebello Limestone Member of the Cibao Formation is not continuous towards the east of the Río Grande de Manatí Valley and inter-tongues with chalky limestone and calcareous clay typical of the the Cibao Formation (Monroe, 1980).

Sometime after the deposition of the limestones (about 65 million years ago), the Island was uplifted and tilted to the northeast. Río Grande de Manatí since that time has eroded the limestones to a depth of about 265 ft below mean sea level, which is the maximum depth to which alluvium has been penetrated by a well in the valley. Logs of wells, test holes drilled in the valley and surface resistivity surveys were used to define the thickness of alluvium in the valley.

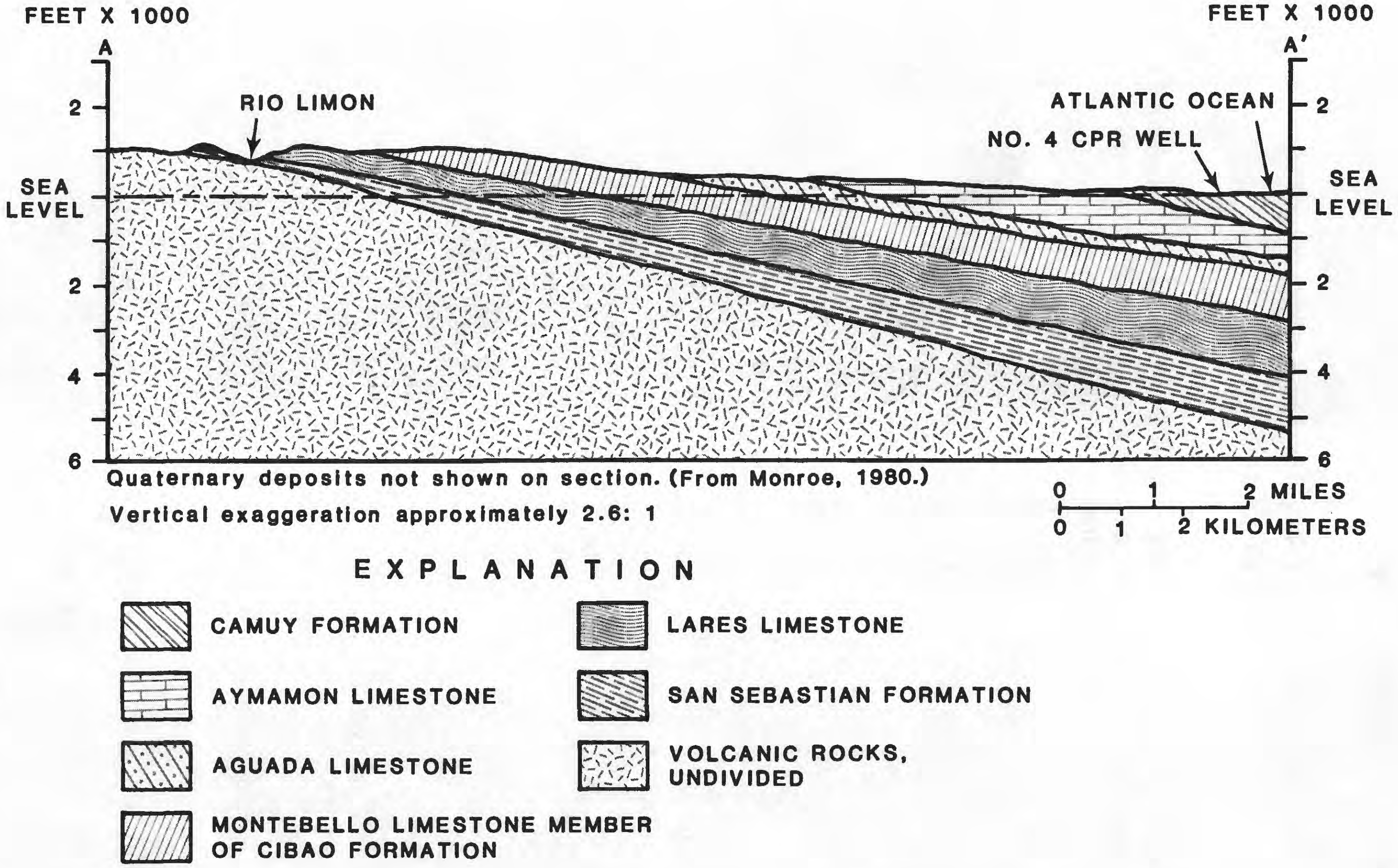


Figure 3.2-1 Cross-sectional view of north coast limestone formations (section A-A' in figure 3.1-1).

ALLUVIUM MAY BE AS MUCH AS 300 FEET THICK IN THE VALLEY

Eustatic sea level changes may have controlled the depth to which Río Grande de Manatí eroded the limestones to form the alluvial valley.

A generalized cross-section view of the depth to limestone (or bedrock) below the valley floor was obtained by interpretation of surface resistivity survey data with available logs, geologic maps and ground water quality analyses (figs. 3.2-2 and 3.2-3). The maximum depth of the alluvium penetrated by a well in the valley is about 265 ft. Nevertheless, the maximum depth of alluvium may be about 300 ft below mean sea level, corresponding to the sea level minima of the last glaciation. A well defined limestone "terrace" exists along the valley flanks at an elevation of about 130 ft below mean sea level. The limestone "terrace" is a common feature throughout the islands north coast and could correspond to the 22 fathom (132 ft) marine terrace documented by Kaye (1959) off Mona Island, to the west of Puerto Rico. This information indicates that eustatic sea level changes may have controlled the depth to which Río Grande de Manatí cut its valley.

Indurated sand dunes similar to those which exist today most probably lined the primeval coast during sea level rise. This may account for the apparent lesser depth to bedrock in the alluvial valley near the coast which does not seem to be deeper than 200 ft as interpreted by surface-resistivity techniques.

Alluvium in the valley seems to be composed chiefly of fine sand, silt, and clay, although several wells have penetrated lenses of medium to fine gravel. These lenses seem to be randomly sorted in the valley, but may be more common on the eastern edge and possibly south of Highway 2.

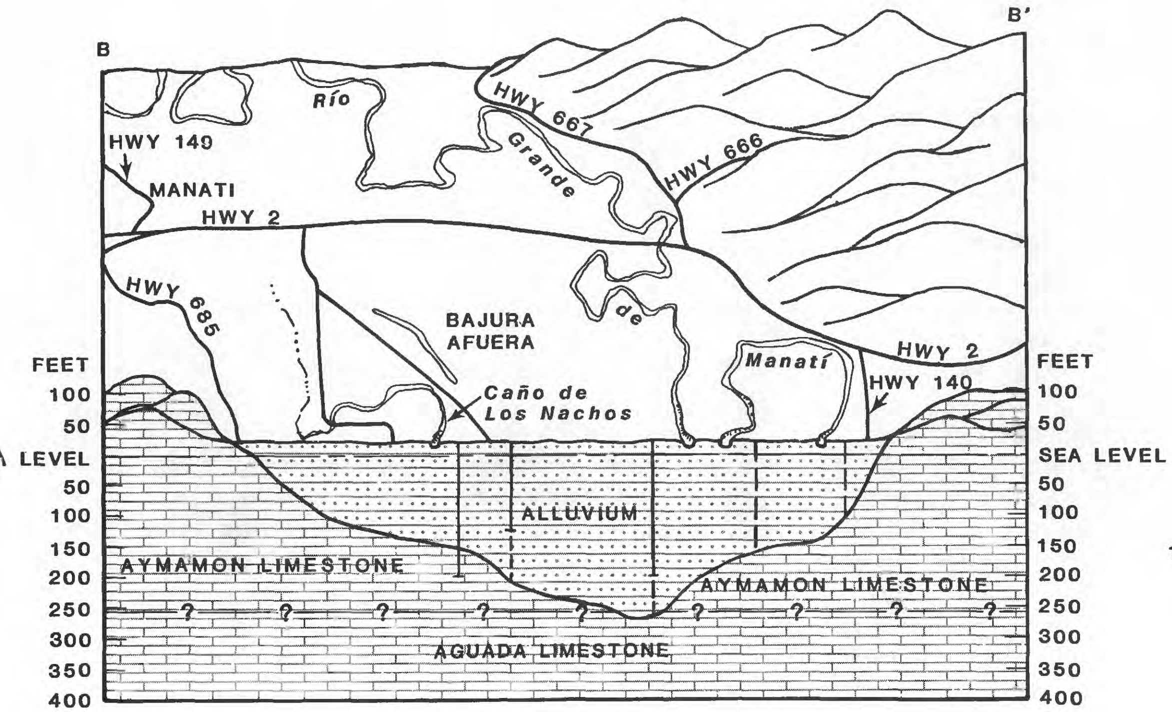
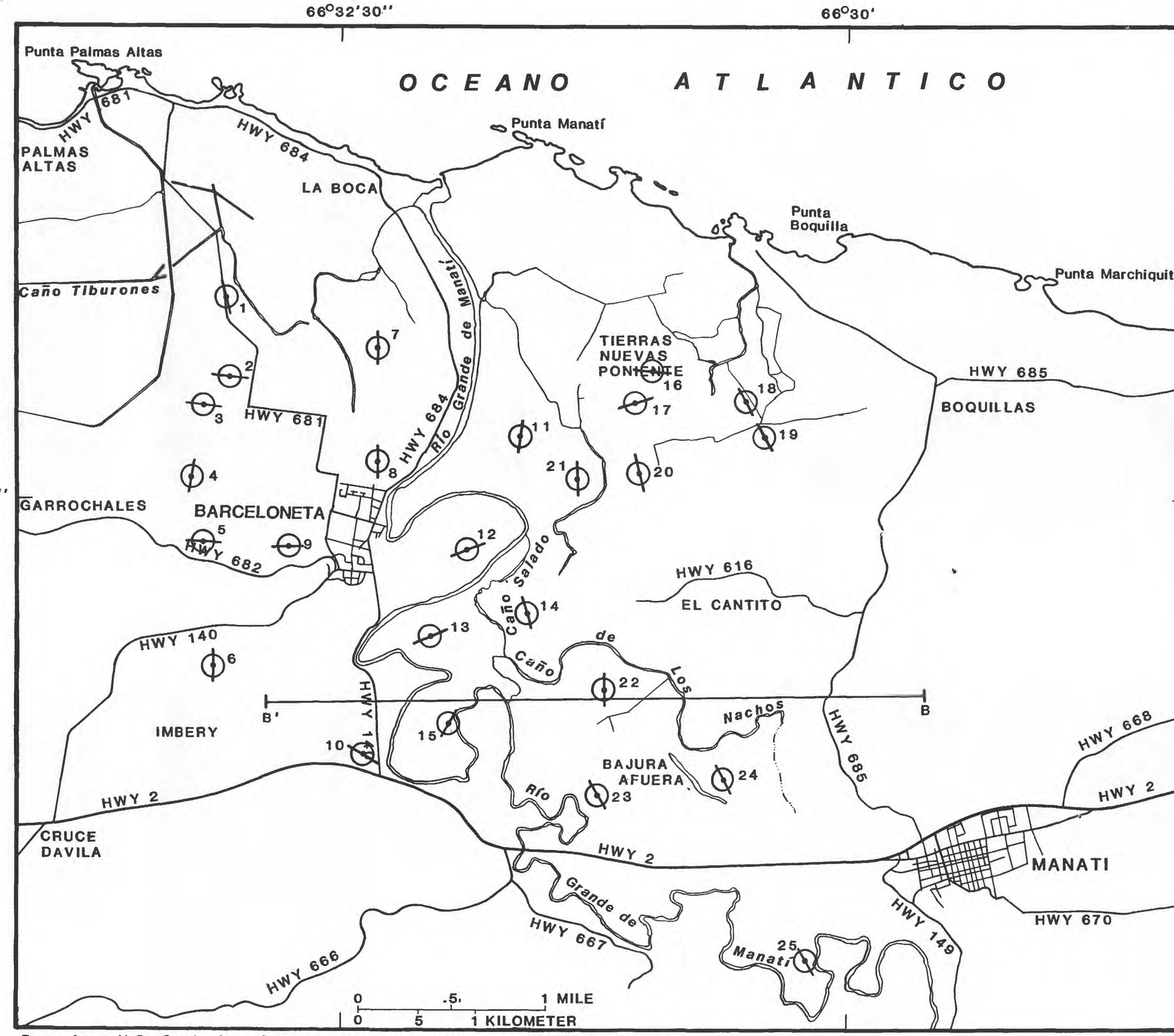


Figure 3.2-2 Generalized cross-sectional view along latitude 182627 at Río Grande de Manatí (view to south).

EXPLANATION

- BORE OR WELL
- SURFACE RESISTIVITY INTERPRETATION
- —?— APPROXIMATE CONTACT OF LIMESTONE FORMATIONS
- 7 SURFACE RESISTIVITY SITE AND NUMBER
- B B' SECTIONAL VIEW SHOWN IN FIGURE 3.2-2



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 3.2-3 Surface resistivity-survey sites.

4.0 HYDROLOGY

4.1 Surface Water

4.1-1 Streamflow

RIO GRANDE DE MANATI IS THE PRINCIPAL FRESHWATER RESOURCE

Río Grande de Manatí is only surface-water resource with potential for large-scale development.

The mean annual flow of Río Grande de Manatí (10 years of record) at the U.S. Geological Survey gaging station at Highway 2 (Station 50038100) is 267,000 ac-ft. This corresponds to a mean-daily discharge of 368 ft^3/s. At present, two relatively small dams exist on the Río Grande de Manatí watershed in its headwaters. These have an estimated long-term annual yield of 20,000 ac-ft, which is diverted to the south coast.

Río Grande de Manatí at Highway 2, had a flow of 304,000 ac-ft during the period August 1, 1980 to July 31, 1981. Although the annual-total discharge was higher than the long-term average, the hydrograph (fig. 4.1.1-1) is typical of the flow variation which can be expected at this site. The potential of a stream as a water-supply source can be better evaluated from an analysis of mean-daily flows and percent probabilities of recurrence. A tabulation of this type was prepared using records available from January 1970 to March 1982 at gaging station 50038100 (table 4.1.1-1). The probability of being able to withdraw a given amount from run-of-the-river flow for any given month can be obtained from the table. As an example, the probability that the mean-daily discharge will be at least 100 ft^3/s in January is 95 percent (quite certain), but only 75 percent (less certain) in June and 70 percent in July.

There are other streams in the valley originating at ephemeral or perennial springs (fig. 4.1.1-2). Caño de Los Nachos, the largest, possibly an extinct channel of Río Grande de Manatí, receives flow from the river during floodflows and at times conveys flow from an ephemeral spring southwest of Manatí. North of Highway 2, Caño de Los Nachos receives the effluent from the Manatí sewage treatment plant, (3 ft^3/s), and saline-cooling water return flow from an industrial operation, (1.8 ft^3/s). These two sources may be the streams major "perennial" flow. The water from both sources is of poor quality.

Another surface-water body is the abandoned stream channel north of Caño de Los Nachos. This channel contains ponded water essentially derived from rainfall (fig. 4.1.1-3). The dissolved-solids content of the ponded water is the lowest of all waters in the valley, more closely related to rainfall quality than to surface or ground water (Section 4.1-4).

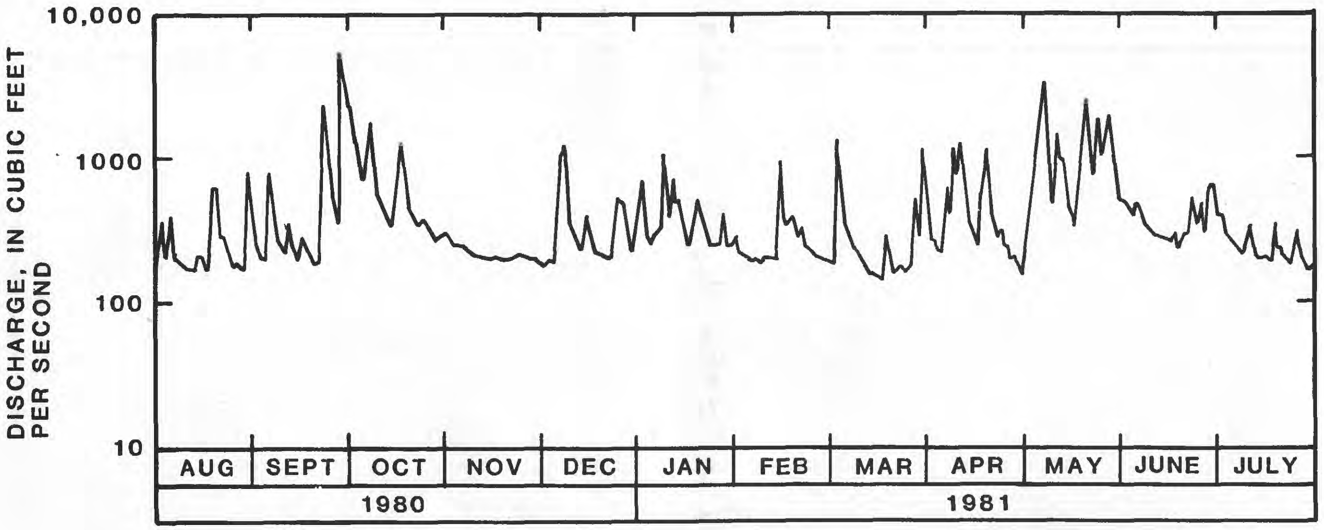


Figure 4.1.1-1 Hydrograph for gaging station 50038100 at highway 2 for period August 1,1980 to July 31,1981.

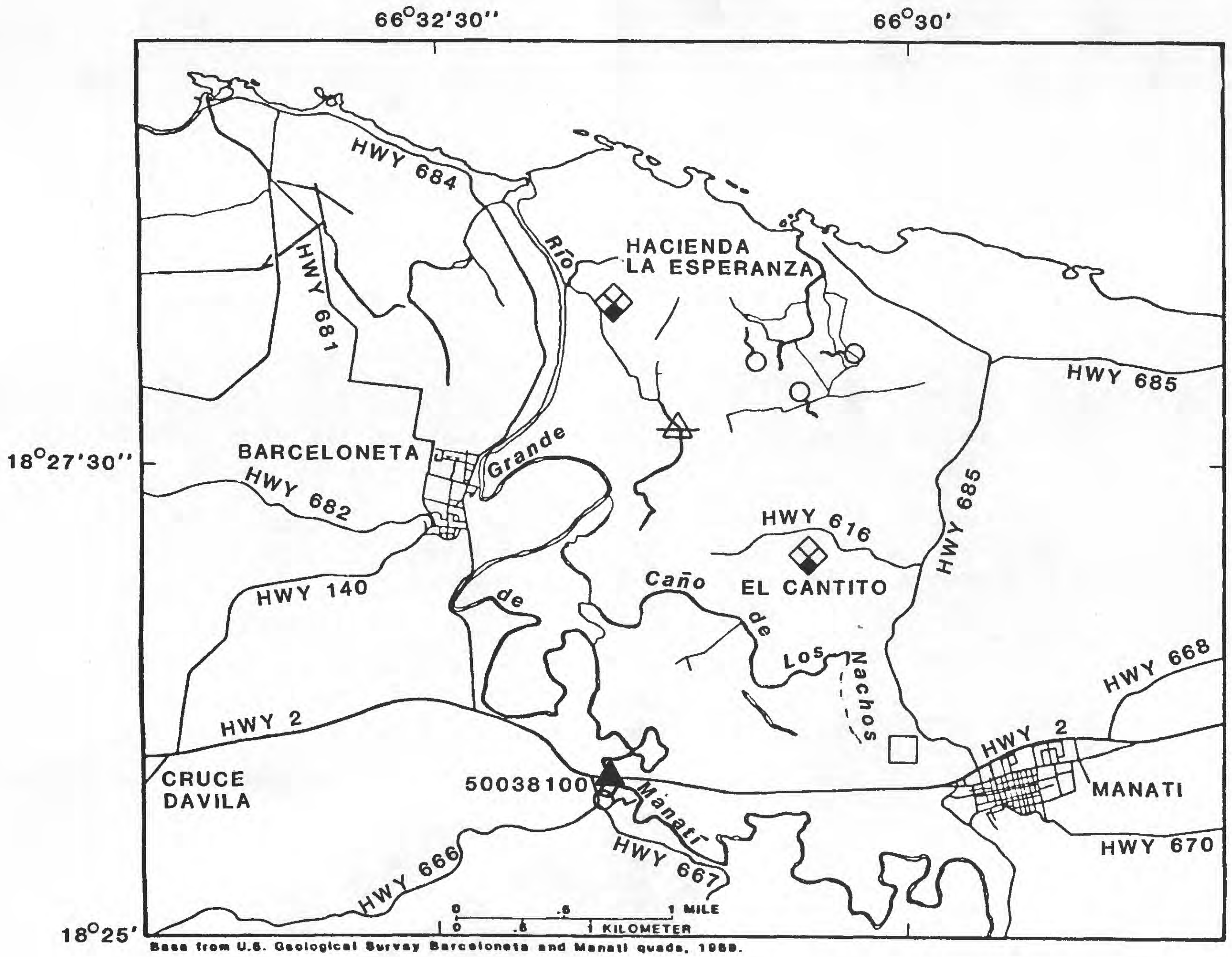


Figure 4.1.1-2 Major surface-water sources in the Río Grande de Manatí valley, USGS gage 50038100 and, and the Manati sewage treatment plant.

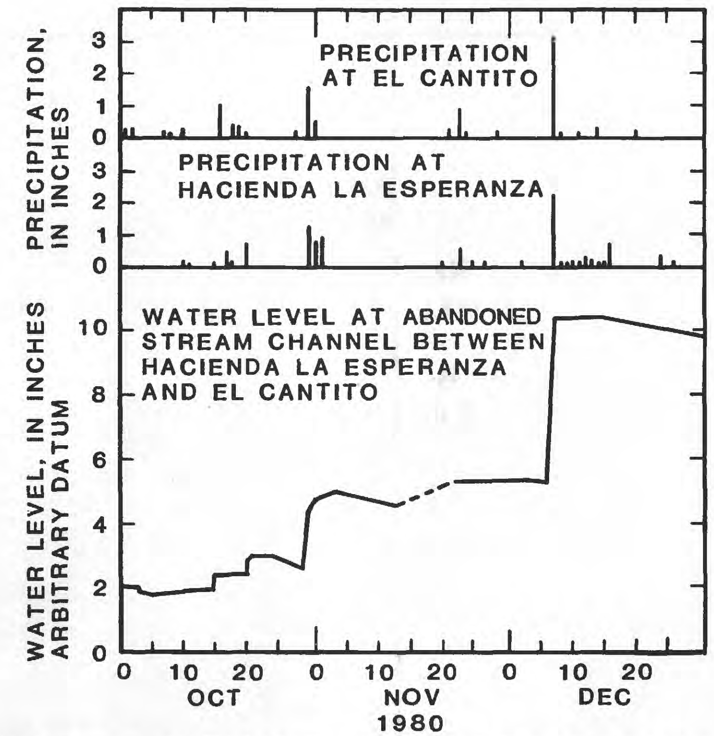


Figure 4.1.1-3 Rainfall at Hacienda La Esperanza and at El Cantito, and water-surface fluctuation at abandoned stream channel near Hacienda La Esperanza.

Table 4.1.1-1 Percentage probability of recurrence of mean daily discharge at gaging station 50038100. Data, in cubic feet per second. Percentage of time indicated value is exceeded.

MONTHS	PERCENT OF TIME						
	95	90	75	70	50	25	10
JAN	100	110	140	150	210	280	420
FEB	96	110	130	140	170	220	330
MAR	82	90	110	120	140	190	280
APR	78	83	110	120	190	400	870
MAY	82	96	140	150	200	400	1100
JUNE	70	80	100	110	150	300	450
JULY	70	78	95	100	130	190	280
AUG	75	80	99	110	130	200	380
SEPT	80	95	140	150	240	480	760
OCT	120	130	150	160	260	420	850
NOV	160	160	190	200	250	380	790
DEC	180	180	190	200	210	240	280

DATA USED: JANUARY, 1970 TO MARCH, 1982

4.0 HYDROLOGY (Continued)

4.1 Surface Water (Continued)

4.1.2 Minimum Flows

7-DAY MINIMUM-MONTHLY FLOWS AT RIO GRANDE DE MANATI OCCUR BETWEEN APRIL AND JULY

Analysis of discharge records available for Río Grande de Manatí indicate that 90 percent of the time the 7-day minimum-monthly flow will be equal to or greater than 65 cubic feet per second during July, the month that typically has the lowest flow.

A streamflow-discharge parameter commonly used in assessing a streams potential in supplying a required flow at a given moment is the 7-day minimum-monthly flow. This statistical value is defined as the minimum-flow rate for seven-consecutive days of a given month. Minimum-flow statistics, such as 7-day flows, can be determined from daily- discharge records at a gaging station.

Daily-discharge records are available for 8 years at the Río Grande de Manatí gaging station on Highway 2 (50038100). Analysis of the data show that 90 percent of the time the 7-day minimum-monthly discharge can be expected to be greater than 65 ft^3/s during July, the dryest month of flow (fig. 4.1.2-1). Similarly there is a 50 percent chance for a 7-day minimum-monthly flow of 90 ft^3/s or more will occur. The relatively short period of record available at station 50038100 limits the reliability of these estimates. To improve the reliability of the results a regression analysis was performed between the Highway 2 gaging station and upstream station 50035000 near Ciales, which has been in operation since 1960 (fig. 4.1.2-2). The analysis indicate that station 50035000 can be used to predict 7-day minimum monthly flows at station 50038100 within a maximum error of 30 percent (90 percent confidence interval). The 7-day minimum-monthly flows at the Highway 2 Station were synthesized from the upstream gage (fig. 4.1.2-3). The estimated values show that for the period June to July there is a 90 percent chance (probability) that the 7-day minimum-monthly flow will be equal to or greater than 65 ft^3/s, (or a 10 percent chance of being less than this amount). The 7-day minimum-monthly flow for each month at 50 and 90 percent probability of occurrence can be estimated on this basis (fig. 4.1.2-3).

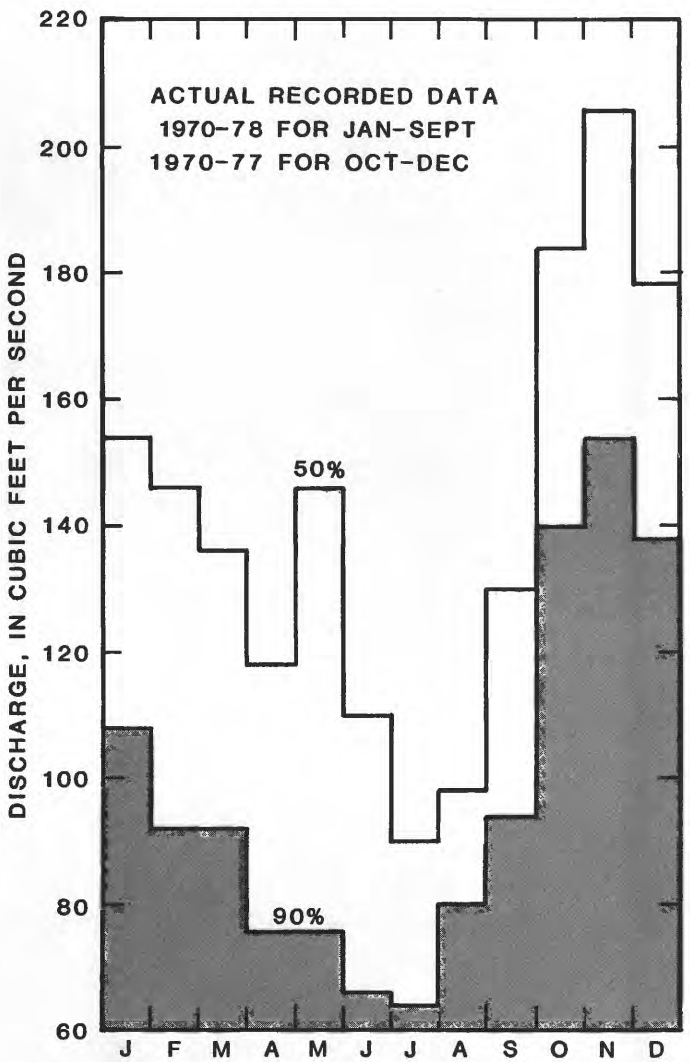


Figure 4.1.2-1 Seven day-minimum monthly flows at gaging station 50038100 at 50 and 90 percent flow probability.

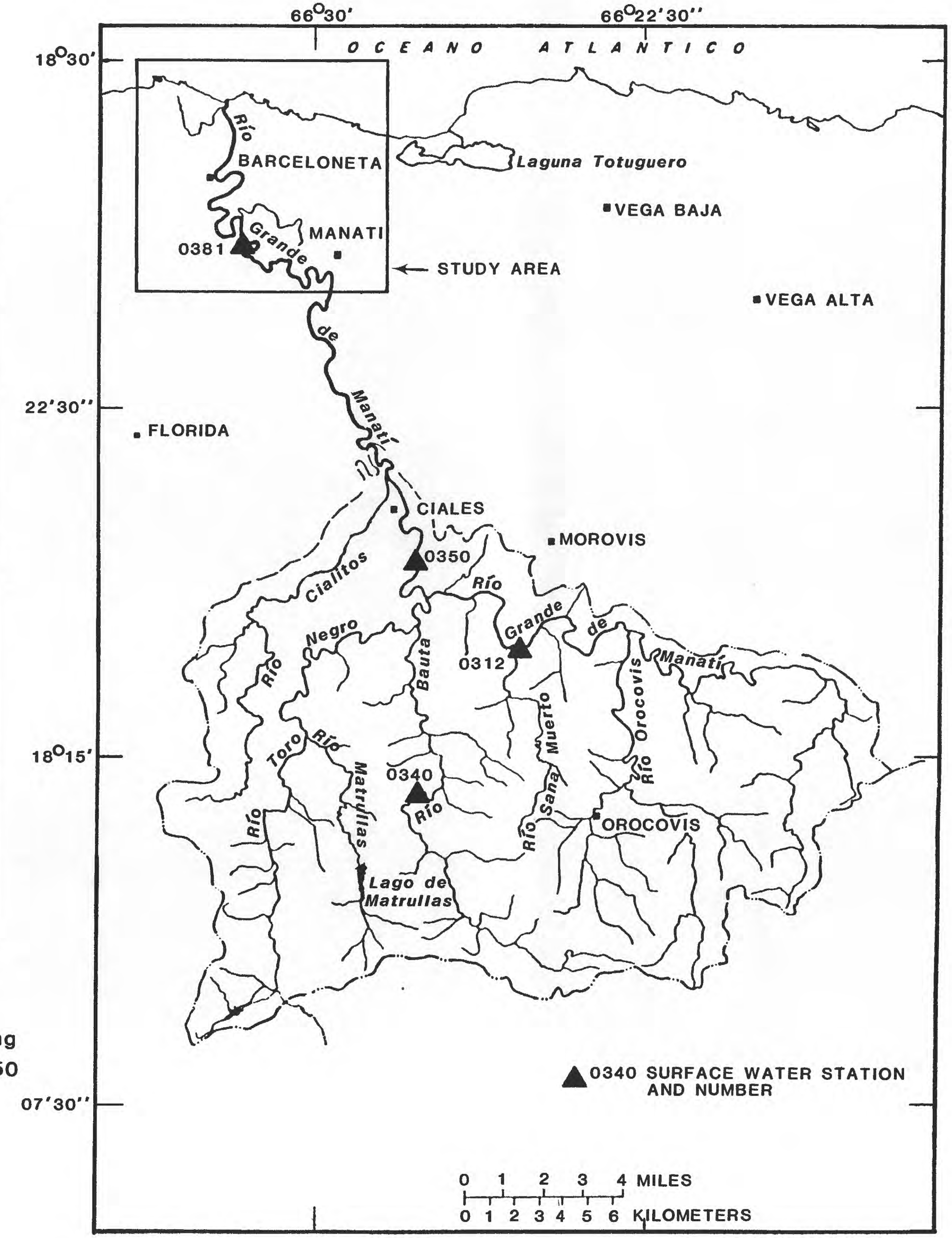


Figure 4.1.2-2 U.S. Geological Survey gaging stations on the Río Grande de Manatí watershed.

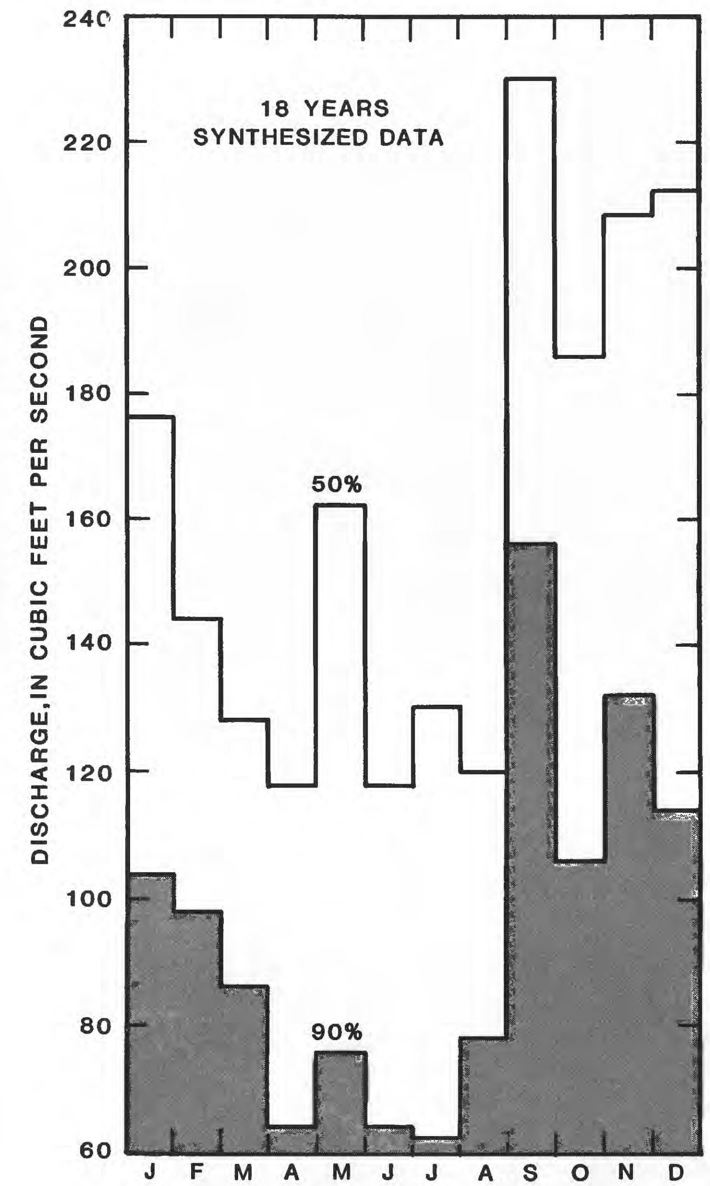


Figure 4.1.2-3 Predicted 7-day minimum-monthly flows at gaging station 50038100 at 50 and 90 percent flow probability (Regression with long-term station 5003500).

4.1.3 Flood Flows

THE ENTIRE ALLUVIAL VALLEY IS SUBJECT TO FLOODING

Major floods in the valley can be expected at a frequency of at least once every seven years.

Río Grande de Manatí Valley is subject to severe flooding. Within the past 82 years (1899-1980) 12 major floods have occurred in the valley, or about once every seven years (table 4.1.3-1). The largest flood of record occurred during the San Felipe hurricane, on September 13, 1928. At its peak, this flood inundated most of the valley with at least 6 ft of water (figure 4.1.3-1). A more typical flood (one with a higher incidence of recurrence) was that of December 11, 1965, which inundated most of the valley with at least 3 feet of water (fig. 4.1-3-1). This flood had a measured peak discharge of 70,000 ft^3/s at the gaging station on Highway 2. Floods of this magnitude have a probability of recurrence of about 12 percent on any given year (López and others, 1979).

Flood-peak data at the Río Grande de Manatí at Highway 2 gaging station are available since 1959. López and others (1979, p.28) developed a flood frequency distribution at the site (fig. 4.1.3-2). The distribution shows that the river overflows its banks at a discharge higher than 20,000 ft^3/s. This discharge is equivalent to a recurrence interval of two years, or a probability of exceedance of 50 percent. Although floods in the valley may occur on any month of the year, the available data from historical accounts (1899-1958) and actual records (1959 to present) indicate that no major-river overflow has occurred in the months of January to April (table 4.1.3-1).

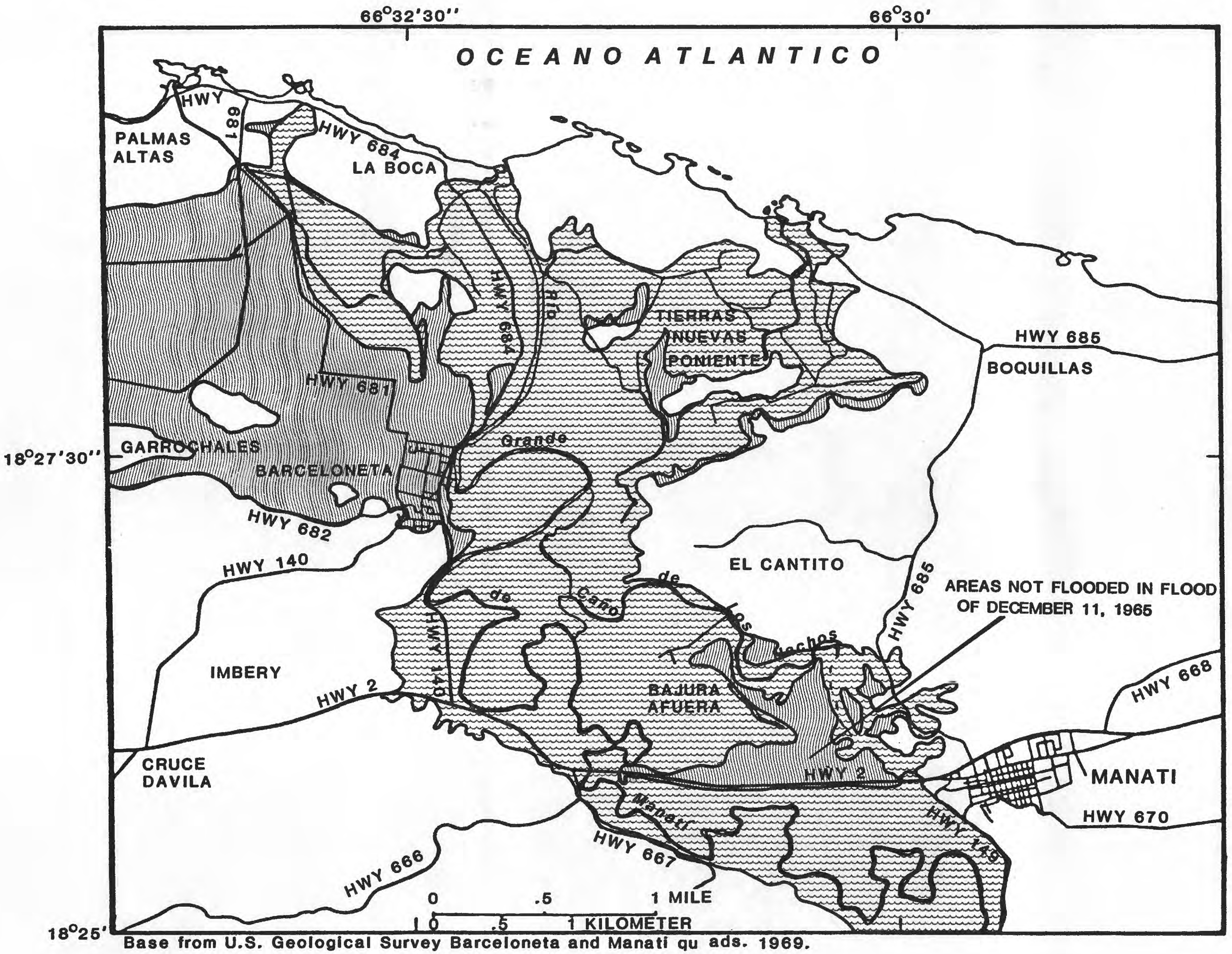


Figure 4.1.3-1 Area flooded by Río Grande de Manatí, in September 13, 1928 and December 11, 1965. (Hickenlooper, 1967).

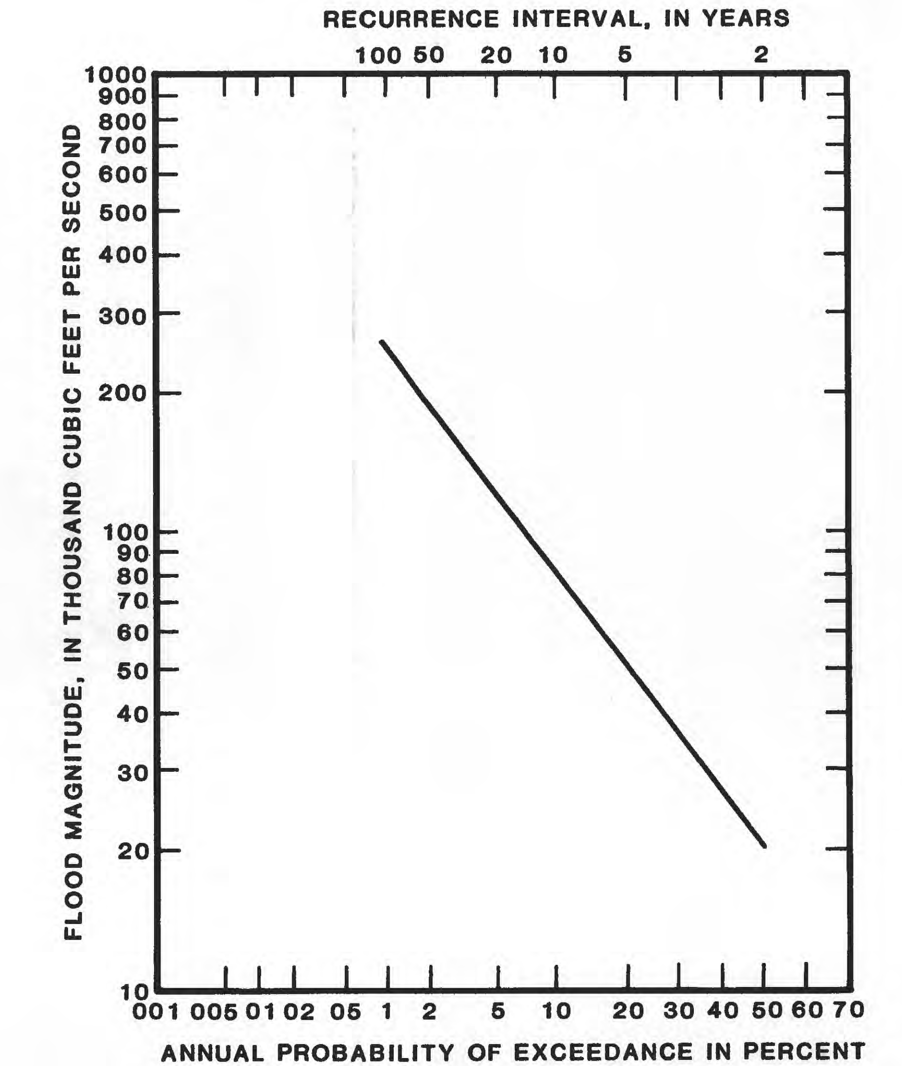


Figure 4.1.3-2 Flood frequency curve for Río Grande de Manatí at Highway 2, gaging station 50038100. Log pearson Type III, data from 1959 to 1975.

Table 4.1.3-1 Major floods at Río Grande de Manatí Valley between 1899 and 1980 and peak discharges.

DATE	PEAK DISCHARGE, IN CUBIC FEET PER SECOND	DATE	PEAK DISCHARGE, IN CUBIC FEET PER SECOND
AUG. 8,1899	-?-	MAY 3,1959	76,000
JULY 14,1916	-?-	SEPT. 6,1960	62,000
SEPT. 14,1928	148,000 e	AUG. 27,1961	53,000
SEPT. 27,1932	134,000 e	DEC. 11,1965	70,000
AUG. 4,1945	68,000 e	NOV. 9,1969	50,000
AUG. 12,1956	-?-	OCT. 9,1970	119,000

e-ESTIMATED DISCHARGE

4.0 HYDROLOGY (Continued)

4.1 Surface Water (Continued)

4.1.4 Water Quality

WATER FROM RIO GRANDE DE MANATI IS SUITABLE FOR MOST PURPOSES

The dissolved-solids content of water in Río Grande de Manatí is relatively low. High concentrations of fecal-coliform bacteria occur.

Water from Río Grande de Manatí is suitable for most purposes. Analyses of samples collected since 1969 at the gaging station on Highway 2 indicate that fecal contamination may be the most serious water-quality problem (table 4.1.4-1). Major sources of fecal contamination are probably from dairy cattle within the valley proper, and from sewage outfalls from towns in the upper basin (Ciales and Orocovis). High fecal-coliform concentrations by themselves are not indicative of the presence of pathogens. However, bilharzia ("Schistossoma Manzoni"), a debilitating disease transmitted from the feces of infested persons through a host snail (Biomphalaria glabarata), is common in many streams throughout Puerto Rico with high fecal-coliform concentrations. Although the host snails were not observed in the valley, they could be transported on the hoofs of dairy cattle and rapidly propagate if proper conditions are present.

Chemical analyses from water samples collected at other points in the valley (fig. 4.1.4-1) are shown in table 4.1.4-2. The source of water at the abandoned stream channel north of Caño de Los Nachos (site 1) is essentially rainfall. This is evident from the low dissolved-solids content. Samples from the other two sites, although obtained in flowing streams is ground-water discharge. Site 2 is springflow from Ojo de Agua Guillo. During major rainstorms this spring exhibits a high variability of flow and an increase in turbidity. The typical low-flow rate at this spring is about 2 ft^3/s. The flow at site 3, is very stable, averaging 4 ft^3/s and is contributed by two- major seeps along the edge of the limestone outcrop, locally known as Mamey and Palo de Pana Springs.

The suspended-sediment load of Río Grande de Manatí is of concern in irrigation water-use. A correlation was developed between the suspended-sediment load, expressed in tons per day (tons/d) versus instantaneous discharge at the gaging station (fig. 4.1.4-2). Flow-frequency distribution data and the correlation were used to estimate the annual mean suspended-sediment discharge at the Highway 2 station. The load was estimated at approximately 100,000 tons per year. A more convenient correlation, pounds of sediment per acre-feet of water diverted (lb/ac-ft) versus instantaneous discharge at the gaging site was also developed (fig. 4.1.4-3). As an example, if the mean discharge rate of Río Grande de Manatí on a given day is 500 ft^3/s, the estimated sediment load would be 400 lbs/ac-ft. A pump withdrawing water from the river (at Highway 2) at a rate of 450 gal/min would deliver two ac-ft of water with a total of 800 lbs of sediment at the discharge point in a 24-hour period.

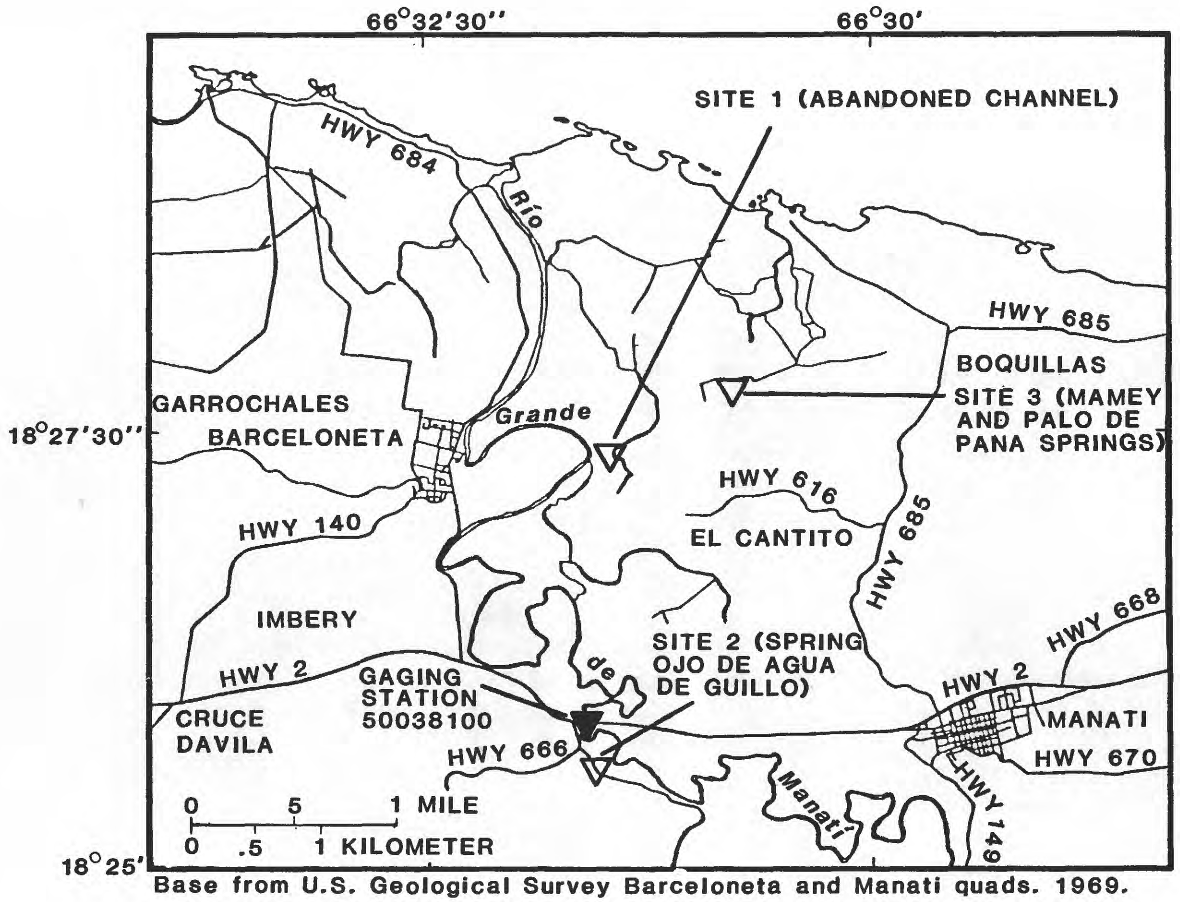


Figure 4.1.4-1 Location of surface water sampling sites.

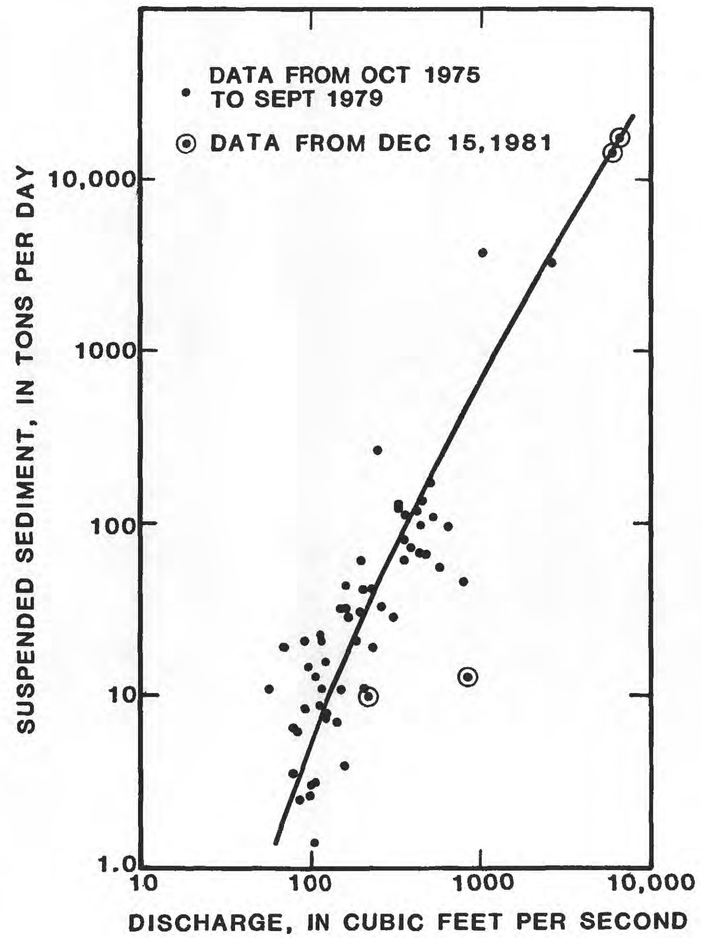


Figure 4.1.4-2 Sediment load-discharge relation for station 50038100.

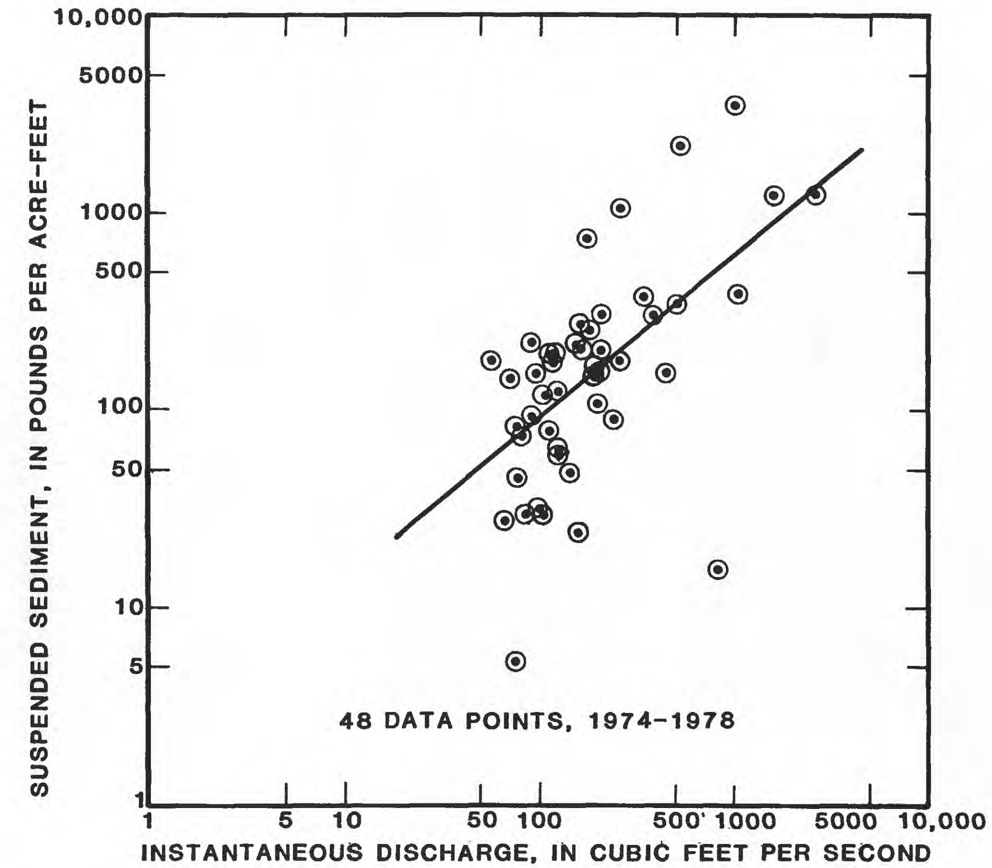


Figure 4.1.4-3 Suspended-sediment concentration in pounds per acre-feet of water withdrawn from Río Grande de Manatí at stated river-flow rate in cubic feet per second.

Table 4.1.4-1 Physical chemical, and bacteriological quality of water from Río Grande de Manatí at gaging station 50038100.

Note: pH and specific conductance determined in field. Constituent values in milligrams per liter, except coliform counts in colonies per 100 milliliter per sample

CONSTITUENT	NUMBER OF SAMPLES	MINIMUM	MAXIMUM	MEAN	90TH PER-CENTILE
pH, UNITS	111	6.7	8.6	—	7.9
SPECIFIC CONDUCTANCE, IN MICROMHOS PER CENTIMETER	111	95	355	274	329
TEMPERATURE, °C	110	22	30	26.1	28.5
RESIDUE SUSPENDED AT 180 °C	37	131	232	169	
CALCIUM, TOTAL	86	8.8	50	36.2	46
MAGNESIUM, TOTAL		2.9	11	7.4	8.3
SODIUM, DISSOLVED	92	1.1	20	10.5	12
SILICA AS SIO2	94	10	24	19.4	22
ALKALINITY AS BICARBONATE	104	35	225	140	172
CHLORIDE, DISSOLVED	94	6.8	34	12.6	14
FLUORIDE, DISSOLVED	94		0.90	0.14	0.20
SULFATE, DISSOLVED	94		32	9.2	12
NITRATE, TOTAL AS N	8	0.0	6.2	2.31	3.5
PHOSPHORUS, TOTAL AS P	64	0.05	0.77	.17	.29
IMMEDIATE COLIFORM	74	1400	450,000	59,000	150,000
FECAL COLIFORM	17	4300	200,000	38,000	71,000
FECAL STREPTOCOCCI	17	700	44,000	19,000	41,000

Table 4.1.4-2 Surface-water quality at miscellaneous sites in the study area.

Note: Constituents in milligrams per liter except Fe and Mn, in micrograms per liter, and pH, in pH units. Specific conductance (SC), in micromhos per centimeter at 25°C.

* Also contained 55 milligrams of carbonate alkalinity.

(a) TDS is total dissolved solids, sum of constituents in milligrams per liter.

SITE	DATE	TIME	pH	SC	T°C	Ca	Mg	Na	K	HCO_3
1	4-16-80	11:40	9.6	387	30	19	17	36	0.5	56 *
2	9-11-80	11:15	7.0	470	28	90	2.7	11	3.0	270
3	4-16-80	13:20	7.0	2079	26.5	130	42	250	5.6	310

SITE	DATE	TIME	Cl	SO_4	F	SiO_2	TDS(a)	Fe	Mn
1	4-16-80	11:40	58	16	0.2	0.5	258	20	5
2	9-11-80	11:15	18	6.4	0.1	7.0	408	—	—
3	4-16-80	13:20	500	56	0.1	20	1314	20	10

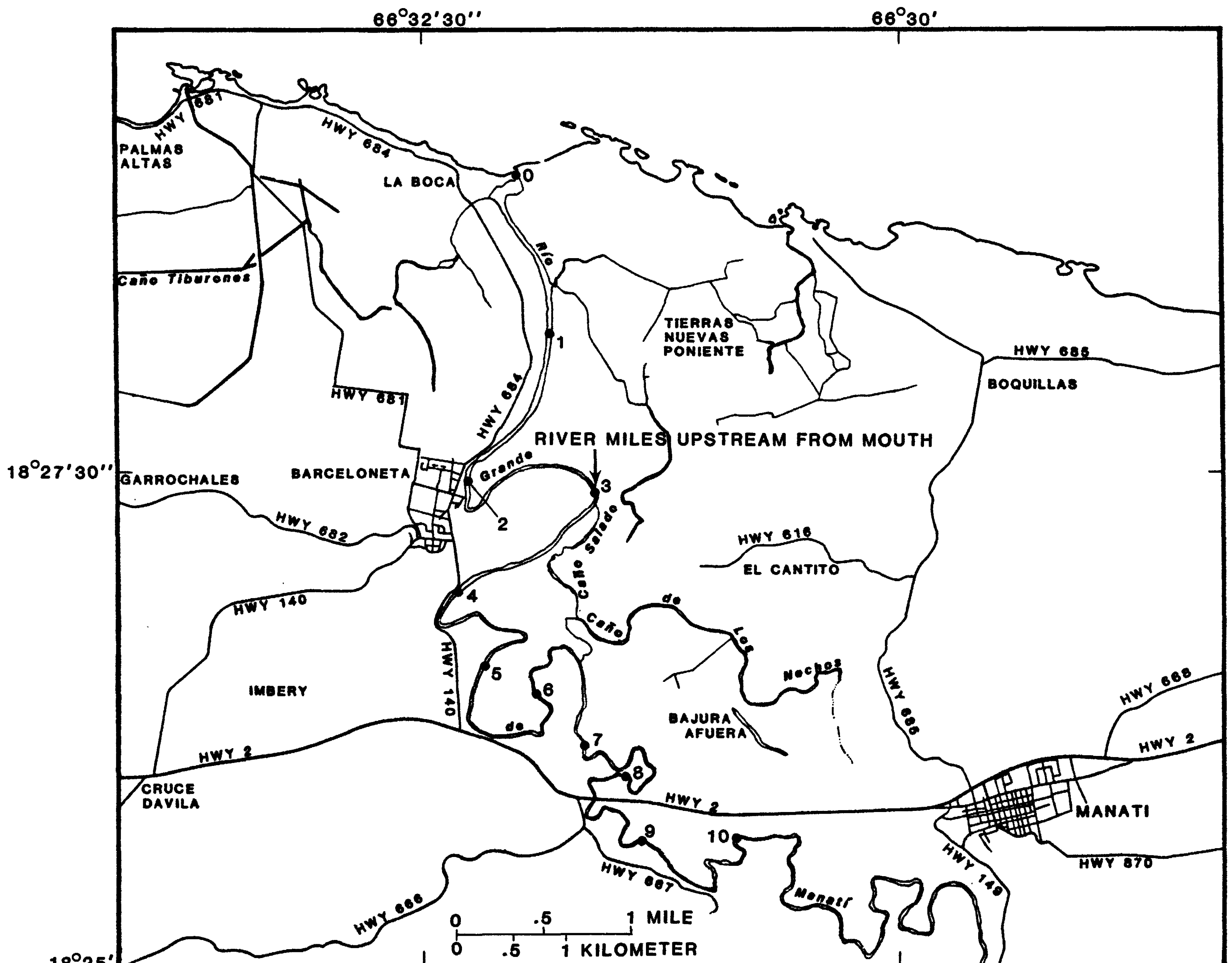
4.1.5 Salt-Water Wedge

THE LOWER 5.3 MILES OF RIO GRANDE DE MANATI LIE WITHIN THE ESTUARY PART OF THE STREAM

Saline water has been detected 4.2 river miles upstream from the mouth of Río Grande de Manatí: Since the relative position of the salt-water wedge is controlled by streamflow, zero discharge could cause the wedge to move to river mile 6.8.

Most of the Río Grande de Manatí north of Highway 2 lies within the estuary part of the river. Tidal effects have been observed up to river mile 5.3 (José González, U.S. Geological Survey, oral commun., 1980, fig. 4.1.5-1), but actual inland advance of the salt-water wedge has been detected only to river mile 4.2. Data collected by the Puerto Rico Department of Natural Resources (Carvajal, J., written commun., 1976) and during this study were used to obtain a correlation of the salt-water wedge front (in miles) versus discharge at gaging station 50038100 (fig. 4.1.5-2). The correlation can be used to predict the position of the saltwater wedge front on the stream, given the discharge rate at Highway 2. The maximum possible inland extent of the wedge, if all flow was diverted at Highway 2, would be limited to the upstream distance at which the river bed lies below sea level. This point was defined as river mile 6.8 above the mouth (Novas & Assoc., 1980). As a reference point, the Highway 2 bridge is located at river mile 8.3.

The position of the salt-water wedge on Río Grande de Manatí also affects to some extent all drainage ditches and streams connected to the river along the estuary reach. Therefore, any reduction in discharge of the river to the sea will affect the position of the salt-water wedge in tributaries and drainage ditches as well. The extent of the movement of the salt water in the waterways of the estuary could be monitored by continuous and (or) periodic measurements of the specific conductivity of the water at various sites.



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 4.1.5-1 River mileage points on Río Grande de Manatí.

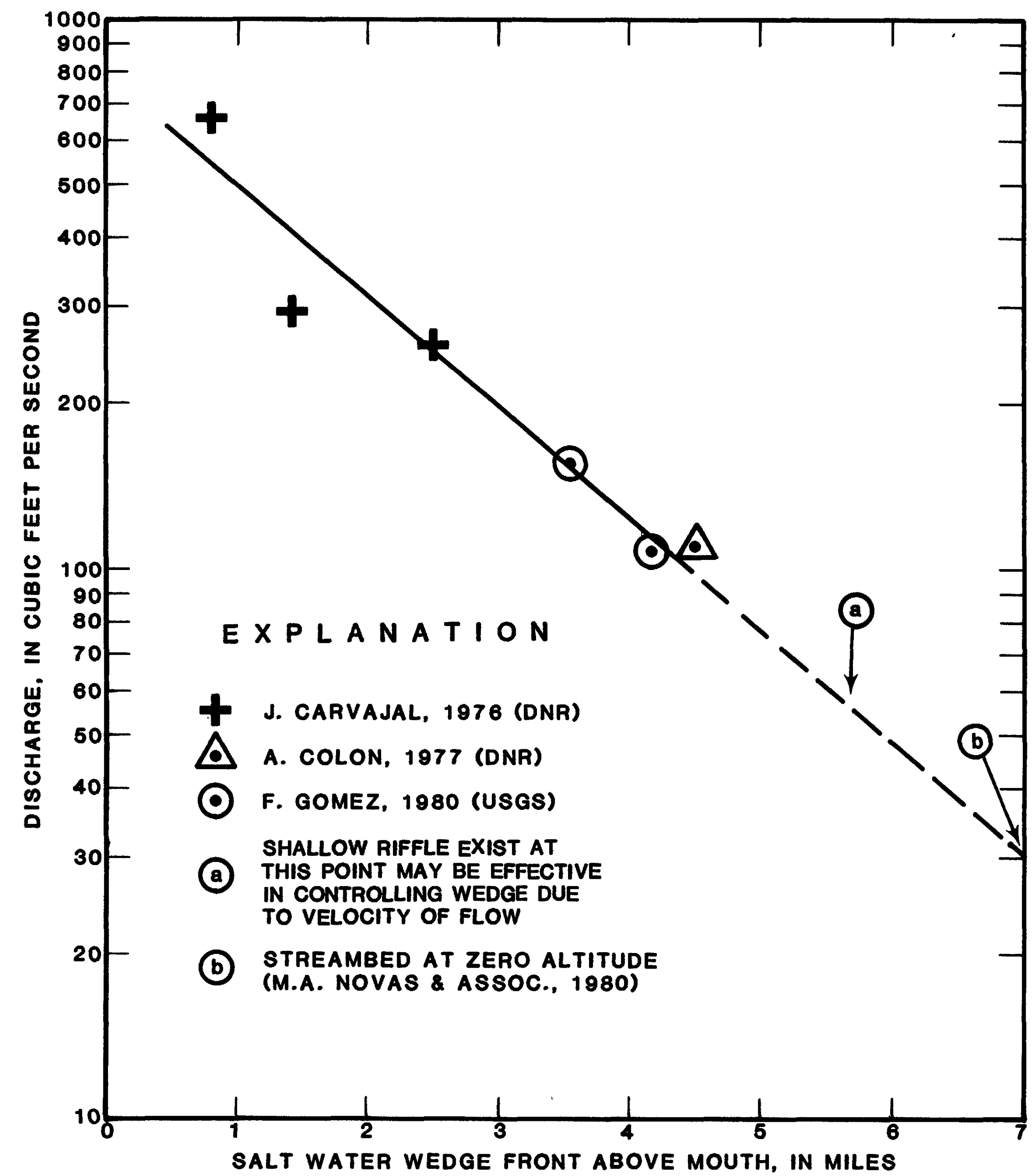


Figure 4.1.5-2 Relationship of position of the salt-water wedge front on Río Grande de Manatí versus discharge at gaging station 50038100.

4.2 Ground Water

4.2.1 Occurrence and Movement

FRESH GROUND WATER IS AVAILABLE WITHIN THE ALLUVIUM AND LIMESTONE WATER-TABLE AQUIFER AND DEEP ARTESIAN AQUIFER

The water-table aquifer contains freshwater as a lens slightly greater than 200 feet thick near Highway 2, thinning to zero near the coast. The artesian aquifer lies about 1,100 feet below sea level datum.

Ground water occurs at depths varying from less than 20 ft in the alluvial valley, to as much as 320 ft below land surface in the limestone-upland areas. Piezometric data obtained within the alluvial valley and adjacent areas was used to develop a water-table map (fig. 4.2.1-1). From this map several flow conditions can be inferred.

- Ground water flows in a general northeast direction, from the limestone area on the west side of the valley to that on the east.

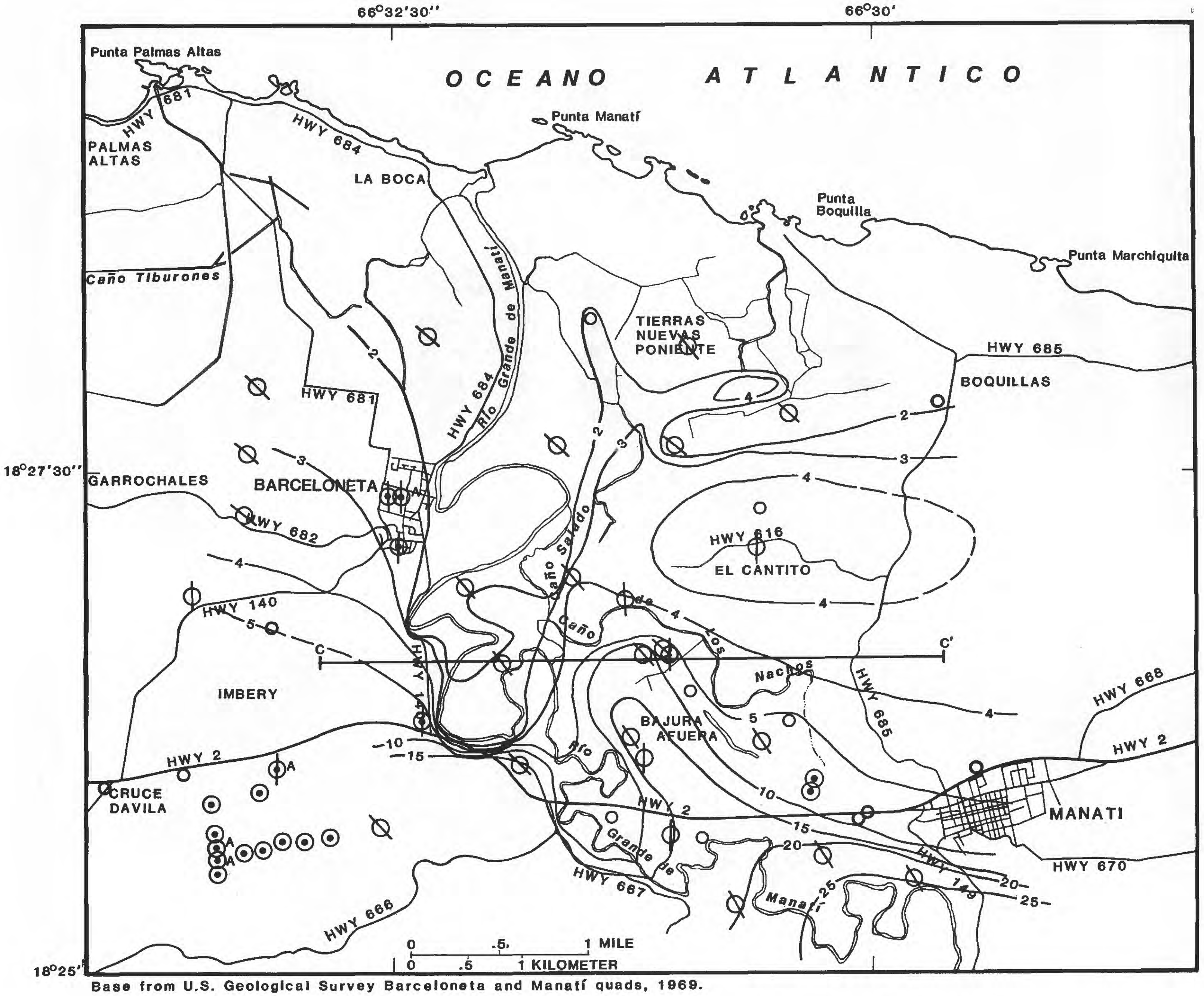
- Río Grande de Manatí seems to be a gaining stream from about river mile 9.0 downstream. This is approximately 1-mile upstream from the gaging station.

- The water-supply wells at this site may be inducing seepage from the river towards the wells.

Freshwater exists in the water-table aquifer within the alluvium and limestones to depths in excess of 200 ft below sea level at areas south of Highway 2. North of the highway, this fresh-water lens thins out rapidly in response to local hydrologic drainage features (gaining streams, springs, and so forth) and geologic conditions. The effect of these features on the ground-water flow net can be surmised from: piezometric head data from various depths, surface-resistivity data, well logs, water-table maps and water-quality analyses. A generalized ground-water flow net along latitude 18°26'27" (cross section C-C') was prepared from existing data (fig. 4.2.1-2). The diagram provides a general view of ground-water flow in the vertical plane and complements the information that is obtained from a water-table map (in the horizontal plane).

A freshwater-artesian aquifer also exists within the Montebello Limestone Member of the Cibao Formation at a depth of approximately 1,100 to 1,700 ft below land surface in the valley. This aquifer has been tapped since 1968 and has undergone extensive development in the Manatí to Barceloneta area. As a consequence, head at wells have dropped from 450 ft (1968) to about 300 ft (1980) above mean sea level (fig. 4.2.1-3).

Only one well, (for industrial use) has been drilled to the artesian zone in the immediate Manatí valley at the town of Barceloneta. The well is unused and recorded a head of 295 ft above mean sea level (125 lbs/in^2) in 1980. The head at this well is similar to that of wells in the Cruce Dávila area (to the west). Preliminary estimates using an analog-digital ground-water model show that an additional 10 Mgal/d, could be withdrawn from the artesian aquifer indefinitely, (Heisel and others, 1982).



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 4.2.1-1 Wells in study area and water-table configuration (data July 11-15, 1980).

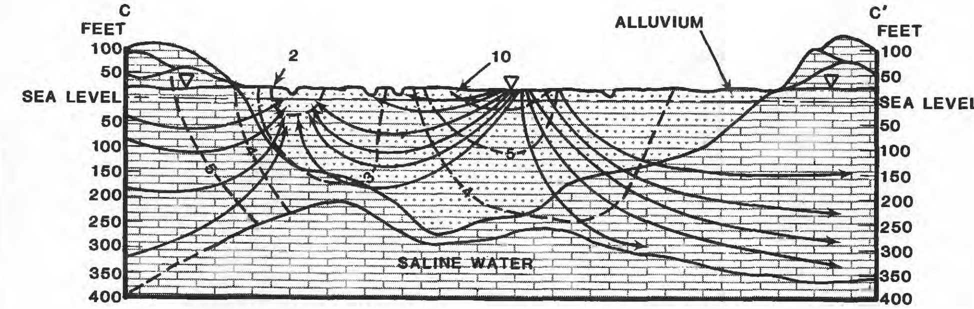


Figure 4.2.1-2 Generalized flow-net in the freshwater table aquifer at Río Grande de Manatí valley along cross-section B-B'.

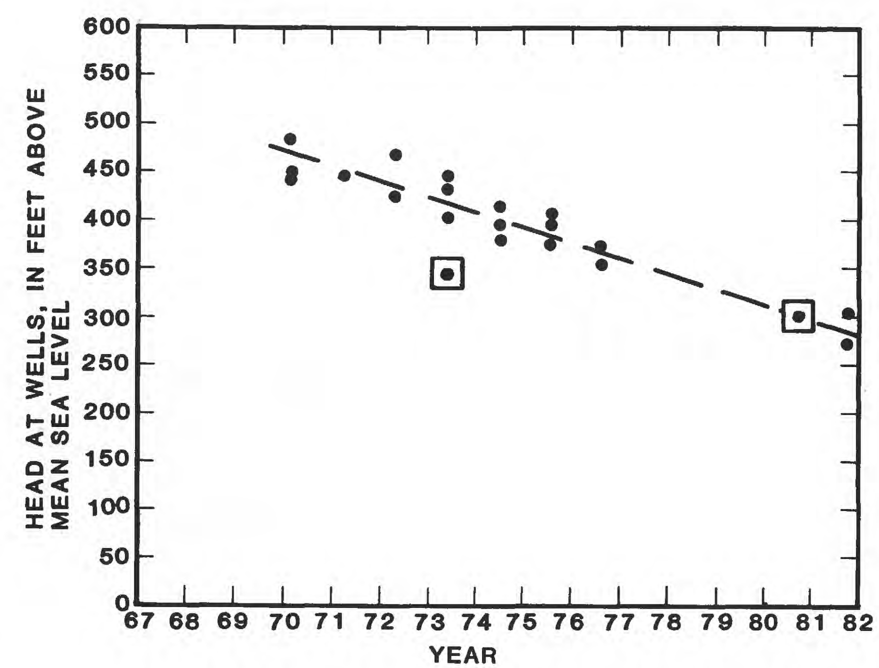
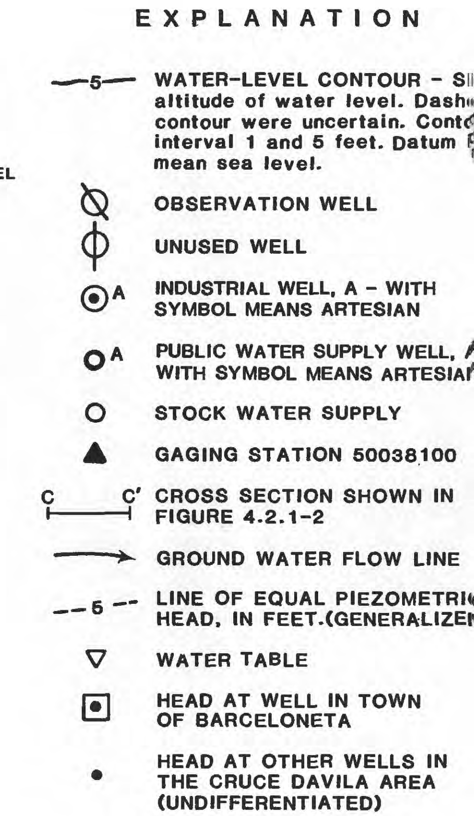


Figure 4.2.1-3 Head at wells tapping the aquifer in the Montebello Limestone member of the Cibao Formation and head loss.



4.2.2 Aquifer Hydraulics

THE FRESH WATER-TABLE AQUIFER WITHIN THE VALLEY ALLUVIUM HAS A HYDRAULIC CONDUCTIVITY IN THE RANGE OF 20 TO 30 FEET PER DAY

The best water yielding aquifer formations are deeper than 200 feet within the alluvial valley. North of Highway 2 these formations lie mainly within the saline-water zone, thus limiting fresh ground-water development to shallow low-yield wells.

The yield of an aquifer can best be estimated by performing controlled aquifer tests, with one or more observation wells within the radius of influence of the pumped well. Such tests typically last several days and are expensive if observation wells must be drilled. Usually these tests are conducted after preliminary evaluation of an aquifer and if large scale ground-water development is planned. The Río Grande de Manatí valley poses two major constraints to large scale ground-water development as based on analysis of the available well logs and surface-resistivity surveys. The most critical being the shallow depth to saline water at most areas north of Highway 2, and the presence of predominately fine-grained material (fine gravel, fine sand, silt, and clay) in the fresh water-table aquifer.

An estimate of the hydraulic conductivity of the aquifer was made by utilizing the Thiem equation for steady-state conditions as shown in figure 4.2.2-1 (Lohman,1972, p. 11),

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$$K_H = 2.3\,Q \frac{\log_{10} r_2/r_1}{(h_2^2 - h_1^2)}$$

where, Q = pumping well discharge rate, in cubic feet per day;
r_2 = distance to observation well furthest from the pumping well, in feet;
r_1 = distance to nearest observation well, in feet;
h_2 = saturated thickness of the aquifer at r_2, in feet;
h_1 = saturated thickness of the aquifer at r_1, in feet;
K_H = hydraulic conductivity of the medium in the horizontal plane, in cubic feet per square foot per day;

This equation may be used when a well is pumped continuously (24 hours per day, 7 days per week), thus satisfying the steady-state requirements.

An estimate of K_H was possible using the industrial well tapping the alluvium and the upper 25 ft of the limestone at Central Monserrate (fig. 4.2.2-2), which is pumped continuously, and an unused well tapping the alluvium 103 ft away. A second observation well was not available, but this was overcome by assuming a conservative value for r_2 = 500 ft, which is a typical radius of influence of water-table wells. A second estimate was calculated using r_2 = 1,200 ft, which was obtained from the water-table contour map (fig. 4.2.1-1). This value was assumed as the maximum radius of influence of the pumping well. Values used in the equation were,

Q = 154,000 ft^3/d (800 gal/min)
h_1 = 242 ft
h_2 = 250 ft
r_1 = 103 ft
r_2 = 500 & 1,200 ft

THE FRESH WATER-TABLE AQUIFER WITHIN THE VALLEY ALLUVIUM HAS A HYDRAULIC CONDUCTIVITY IN THE RANGE OF 20 TO 30 FEET PER DAY

The best water yielding aquifer formations are deeper than 200 feet within the alluvial valley. North of Highway 2 these formations lie mainly within the saline-water zone, thus limiting fresh ground-water development to shallow low-yield wells.

the resulting estimates of K_H were, 20 and 31 ft/d. Such values are typical for alluvium consisting predominately of fine-grained material. The logs of the wells used in this calculation indicate such lithologic conditions in the alluvium at the observation well and pumping well as well as a poorly permeable limestone in the pumping well from 175 to 200 ft.

Wells which penetrate the Aymamón Limestone can be expected to have K_H values in the order of 280-570 ft/d (Giusti, 1978, p. 25). Unfortunately, within the valley only the basal part of the Aymamón Limestone exists (fig. 3.2-2). Its water-bearing properties are similar to that of the Aguada Limestone which range from poor to fair with K_H values ranging from about 6 ft/d to 60 ft/d (Giusti, 1978, p. 25). North of Highway 2, ground water is saline at this depth or if initially fresh, saline water may be induced through upward coning in high-capacity wells.

The available information indicates that within the fresh water-bearing alluvium of water-table aquifer at Río Grande de Manatí Valley, the lateral hydraulic conductivity in general is within 20 to 30 ft/d. Aquifers with such hydraulic-conductivity values yield only moderate amounts of water to wells, unless the stratigraphic depth of the material and fresh-water zone is more extensive than found within the valley.

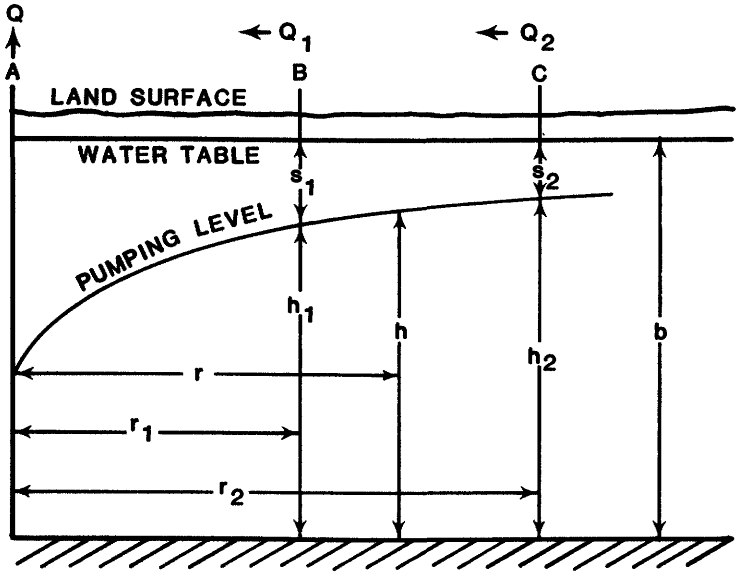
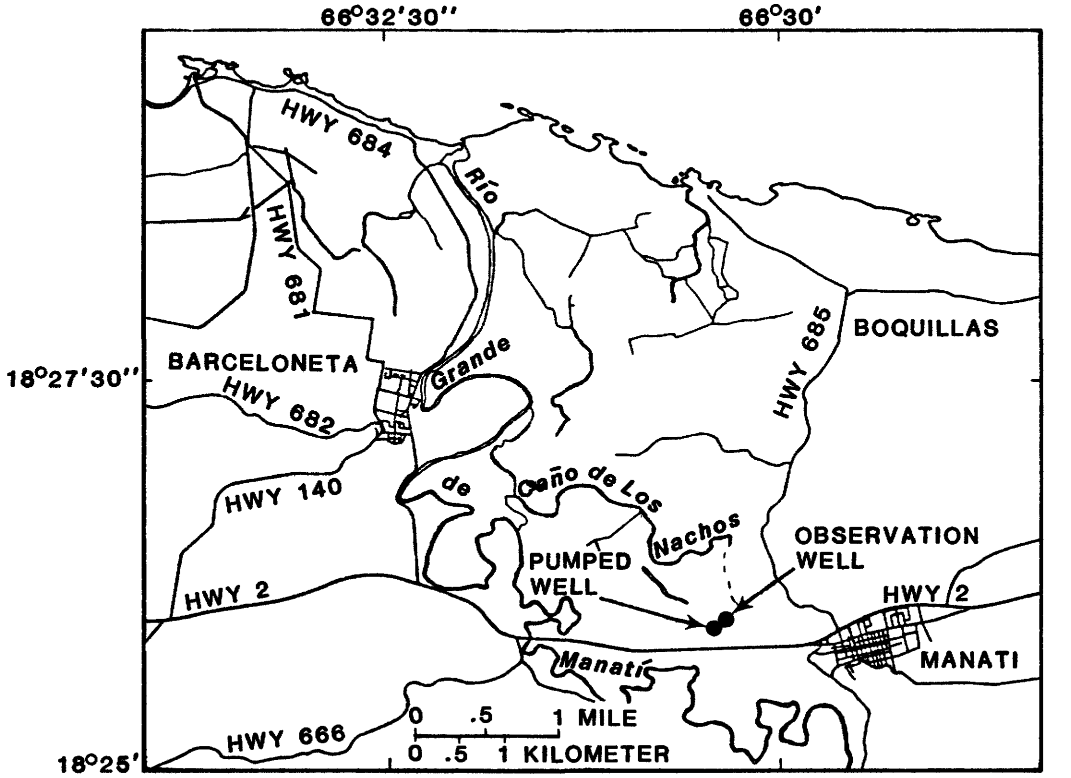


Figure 4.2.2-1 Steady-state conditions used for estimating horizontal-hydraulic conductivity.



Base from U.S. Geological Survey Barceloneta and Manati quads, 1969.

Figure 4.2.2-2 Location of wells used for aquifer test in the lower Manatí valley.

4.2.3 Chemical Quality

4.2.3-1 Freshwater

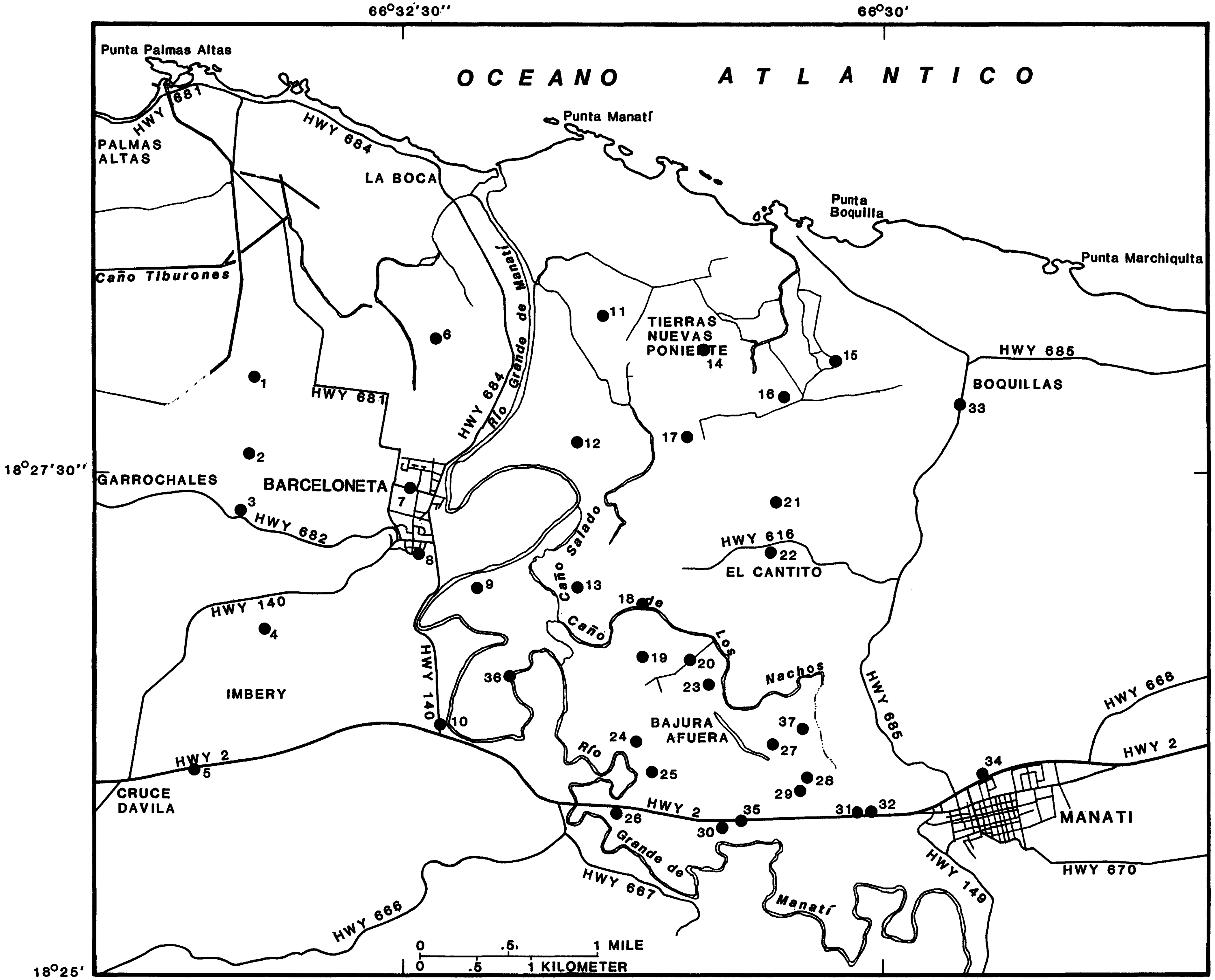
QUALITY OF GROUND WATER VARIES AREALLY WITH DEPTH

The complex hydrologic conditions in the area influence the relative thickness of the fresh-water lens in the water-table aquifer. North of Highway 2, this lens thins out rapidly or is absent at localized areas.

Ground-water quality throughout the valley in the water-table aquifer differs mainly in the concentration of dissolved solids and the relative proportion of ionic species. In general, freshwater occurs as a lens of lower density (less mineralized) water floating above higher-density water. Freshwater, or water with less than 1,000 mg/L of dissolved solids, can be encountered within shallow depth (10 to 30 ft) in the aquifer at most sites east of Río Grande de Manati.

Chemical analyses were made on samples collected at numerous sites at piezometers and existing wells tapping alluvium or alluvium and limestone within the valley and tapping limestone in the upland areas (fig. 4.2.3-1-1, table 4.2.3-1-1). The analyses, if reviewed in conjunction with piezometric data and the water-table map, can be used to better define local hydrologic conditions. The following can be concluded from the analyses:

1) Ground water from the water-table aquifer in the town of Barceloneta and the plain, north of the town and west of the river is mainly saline (dissolved solids greater than 1,000 mg/L).



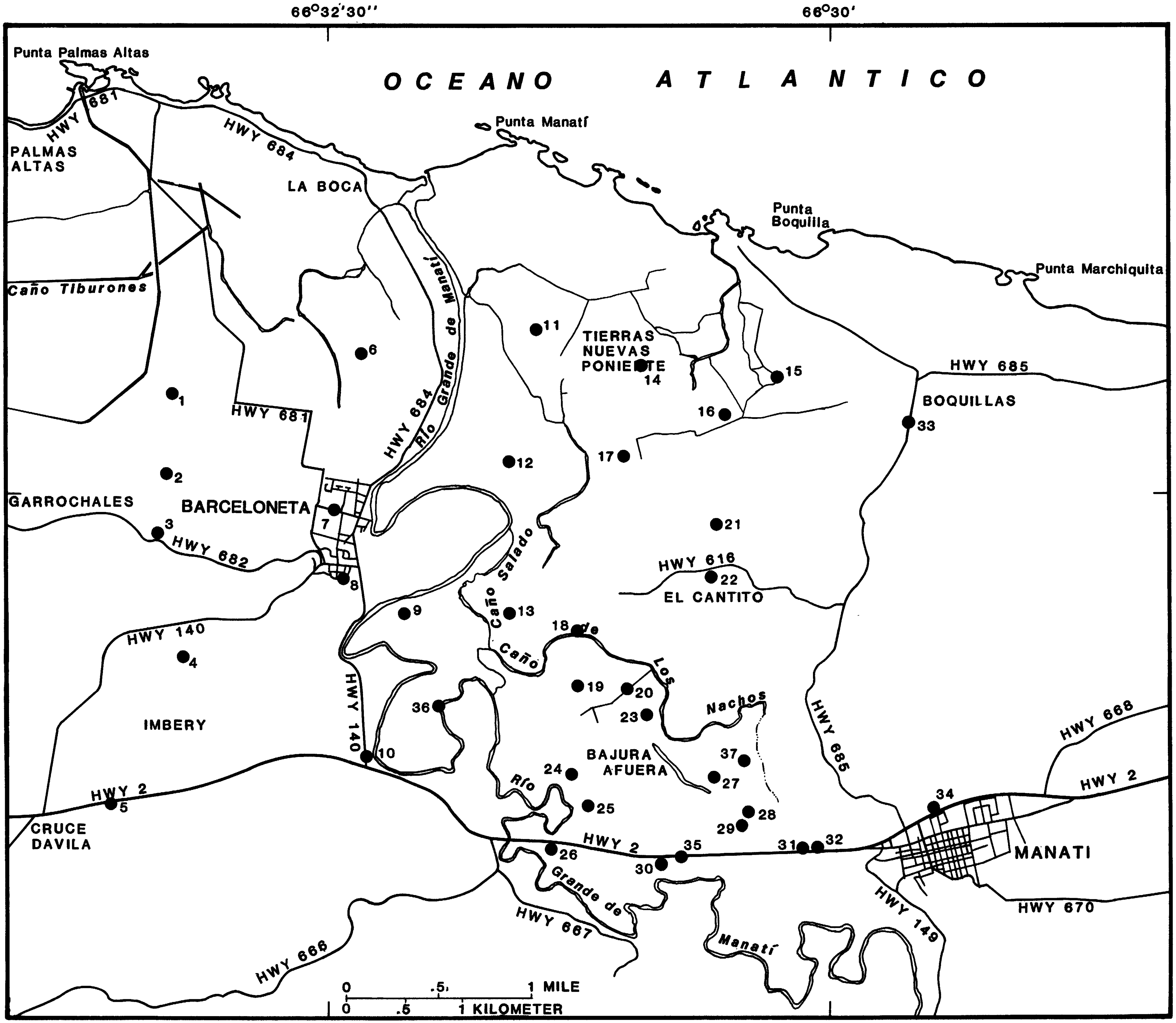
Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 4.2.3-1-1 Location of ground-water sample sites.

Table 4.2.3-1-1 Chemical analyses

SITE NO.	DATE MO-D-YR	DEPTH FEET	pH UNITS	SC µMHO/CM	TE °
1	4/8/80	132	6.5	11,424	24
2	4/11/80	S	6.6	1,650*	25
2(5)	4/11/80	142	6.6	22,185	24
3	4/8/80	135	6.7	5,300	24
4a	9/11/80	135(1)	7.0	1,354	
4b	3/3/59	135(4)	7.1	-	-
5a	9/11/80	235(1)	6.9	713	-
5b	1/11/65	235(1)	7.5*	635*	25
6	4/11/80	134	7.0	4,020*	25
7(5)	9/15/70	80	7.4*	1,770	-
7a	9/15/70	113	7.4*	4,190	-
8	1/30/63	120	8.1*	489	-
9	4/9/80	S	6.7	936	26
10	4/17/50	96(1)	6.9*	-	-
11	4/16/80	40e	6.8	2,351	26
12	4/15/80	S	6.6	1,350	26
13	4/16/80	S	6.6	1,417	
14	4/15/80	142	6.7	5,880	26
15	8/9/79	spring	6.9	882	26
16	8/9/79	spring	6.9	1,240	26
17	4/16/80	S	6.6	1,417	27
18	4/15/80	106(1)	-	1,000	25
18(4)	8/12/80	130(3)	7.2*	6,700*	
19	4/9/80	137	6.9	828	
20(4)	8/7/80	170	7.2*	6,600*	
21	9/20/81	100e	8.0	1,160	27
22(2)	3/16/78	126(1)	7.1*	-	
23	4/17/80	200e	7.0	1,363	
24	4/9/80	S	6.4	805	26
25(4)	7/3/80	170	7.0*	840*	
26	4/17/80	150e	6.8	686	
27	4/8/80	S	6.6	1,436	26
28	10/21/59	266		Reportec	
29	4/17/80	200	7.2	1,104	26
30	4/17/80	147(1)	7.2	528	
31	9/11/80	210	7.2	470	
32	9/11/80	212	7.1	474	
33	9/11/80	132	7.3	837	
34a	9/11/80	200	7.0	663	
34(2,b)	1/23/69	200	7.7*	-	
35	6/17/81	130(1)	-	-	
35	4/22/81	130(1)	-	-	
36	4/9/80	5	6.7	700	26
37a	4/17/80	202(1)	7.2	2,744	26
37	5/16/80	100	7.1	2,113	
37	5/16/80	160	6.9	2,018	
37b	5/16/80	196	6.9	2,417	

* Laboratory pH or specific conductance va
** Sodium plus potassium.
S Shallow piezometer at water-table depth.
(1) Screened interval unknown; depth is maxi of well below land surface.



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 4.2.3-1-1 Location of ground-water sample sites.

Table 4.2.3-1-1 Chemical analyses of ground-water from the Manatí-Barceloneta area.

SITE NO.	DATE MO-D-YR	DEPTH FEET	pH UNITS	SC µMHO/CM	TEMP °C	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	ALK AS $CaCO_3$, mg/L	Cl mg/L	SO_4 mg/L	F mg/L	SiO_2 mg/L	CO_2 mg/L	Fe µg/L	Mn µg/L	RESIDUE CALCULATED SUM mg/L	COMMENTS
1	4/8/80	132	6.5	11,424	24.0	430	170.0	1,400	21.0	180	3,000	350.0	0.0	10.0	112	150	60	5,490	Screened 128-132
2	4/11/80	S	6.6	1,650*	25.0	130	29	200	7.3	350	330	2.7	0.1	17	173	250	310	929	Shallow piezometer adjacent to 2
2(5)	4/11/80	142	6.6	22,185	24.0	770	440	3,000	48	250	6,800	690	0.0	10	121	290	1,600	11,900	Screened 138-142 ft
3	4/8/80	135	6.7	5,300	24.0	220	76	640	16	240	1,300	170	0.1	8.5	92	10	50	2,570	Screened 131-135 ft
4a	9/11/80	135(1)	7.0	1,354		120	21	150	7.7	250	240	150	0.1	6.9	51	-	-	858	Pumping; Public water supply
4b	3/3/59	135(4)	7.1	-	-	124	15	81**		218	216	23	0.8	9.5	-	-	-	603	Idem
5a	9/11/80	235(1)	6.9	713	-	130	4.2	23	0.7	230	70	15	0.1	8.2	57	-	-	478	Idem
5b	1/11/65	235(1)	7.5*	635*	25.0	106	6.2	14**		242	46	1.6	0.2	7.0	-	-	-	330	Idem
6	4/11/80	134	7.0	4,020*	25.0	160	78	450	17	310	1,000	1.5	0.6	12	60	0	820	1,900	Screened 130-134 ft
7(5)	9/15/70	80	7.4*	1,770	-	148	50	120	1.4	256	388	39	0.5	31	-	-	-	935	Pumping; Industrial well
7a	9/15/70	113	7.4*	4,190	-	293	93	403	12	218	1,200	92	0.3	15	-	-	-	4,350	Well is 100 ft from 7
8	1/30/63	120	8.1*	489	-	19	21	43**		114	78	1.6	0.2	2.0	-	-	-	235	Abandoned, screen 73-120 ft
9	4/9/80	S	6.7	936	26.0	54	32	57	2.9	290	67	38	0.2	33	114	90	2,400	463	
10	4/17/50	96(1)	6.9*	-	-	130	14	55**		259	208	24	-	-	-	-	-		
11	4/16/80	40e	6.8	2,351	26.0	100	110	190	48	530	320	100	0.5	25	162	40	370	1,210	Pumping; stock use
12	4/15/80	S	6.6	1,350	26.5	79	51	79	0.8	370	120	62	0.3	31	182	70	2,800	650	Shallow piezometer
13	4/16/80	S	6.6	1,417		89	62	68	1.2	500	89	13	0.3	26	247	10	1,300	653	Shallow piezometer
14	4/15/80	142	6.7	5,880	26.0	270	130	570	16	220	1,500	110	0.1	20	87	20	120	2,750	Screened 138-142 ft
15	8/9/79	spring	6.9	882	26.0	-	-	-	-	188	145	-	-	-	-	-	-	-	
16	8/9/79	spring	6.9	1,240	26.5	-	-	-	-	254	207	--							
17	4/16/80	S	6.6	1,417	27.0	-	-	-	-	503	-	-	-	-	-	-	-	-	Shallow piezometer
18	4/15/80	106(1)	-	1,000	25.5	-	-	-	-	-	-	-	-	-	-	-	-	-	Abandoned; no pump
18(4)	8/12/80	130(3)	7.2*	6,700*	-	-	-	658	-	297	1,893	-	-	-	-	-	-	-	Analyses, pumped
19	4/9/80	137	6.9	828		72	23	56	3.4	360	78	1.5	0.1	29	89	330	1,100	481	
20(4)	8/7/80	170	7.2*	6,600*	-	-	-	480	-	262	2,052	-	-	-	-	-	-	-	Test well, screen 70-170 ft
21	9/20/81	100e	8.0	1,160	27.5	110	25	110	3.8	244	240	21	0.1	16	-	10	20	1,200	
22(2)	3/16/78	126(1)	7.1*	-	-	113	18	101	-	236	221	27	0	2	42	420	120	---	Abandoned PRASA well
23	4/17/80	200e	7.0	1,363		78	27	150	3.9	270	270	39	0.1	21	53	40	50	754	Pumping; dairy use
24	4/9/80	S	6.4	805	26.0	52	31	24	.7	260	31	76	0.2	29	204	110	210	402	
25(4)	7/3/80	170	7.0*	840*	-	-	-	61	-	531	80	-	-	-	-	-	-	-	Test well, pumped 4 hrs
26	4/17/80	150e	6.8	686	-	87	14	25	1.3	290	32	7.0	0.1	15	90	0	9	357	Pumping; dairy use
27	4/8/80	S	6.6	1,436	26.5	53	41	140	4.1	260	220	8.5	0.2	26	128	320	1,200	1,146	
28	10/21/59	266		Reported poor quality, H_2S smell, used for cooling (1959)															Standby, fire protection
29	4/17/80	200	7.2	1,104	26.0	70	24	120	4.1	240	190	31	0.2	22	29	20	90	604	Pumping, industrial, open 150-175 ft
30	4/17/80	147(1)	7.2	528	-	68	11	13	1.3	250	15	7.8	0.1	20	30	10	8	284	Pumping; dairy use
31	9/11/80	210	7.2	470	-	75	14	11	1.3	230	14	11	0.2	25	32	-	-	293	Pumping, public water supply, screen 105-210
32	9/11/80	212	7.1	474	-	74	15	12	1.1	230	16	12	0.2	27	36	-	-	299	Pumping, PWS, screen 80-212
33	9/11/80	132	7.3	837	-	100	21	52	2.7	230	120	18	0.1	21	23	-	-	498	Pumping, PWS
34a	9/11/80	200	7.0	663	-	100	15	28	1.5	260	49	18	0.1	20	46	-	-	422	Pumping, PWS, open hole 130-200 ft
34(2,b)	1/23/69	200	7.7*	-	-	97	9	23**		240	50	15	-	20	39	-	-	-	
35	6/17/81	130(1)	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	PRASA well not in use, iron & manganese high (2)
35	4/22/81	130(1)	-	-												990	450		
36	4/9/80	5	6.7	700	26.0	44	27	32	1.5	290	30	2.6	0.2	49	112	350	830	360	Shallow piezometer
37a	4/17/80	202(1)	7.2	2,744	26.0	140	60	320	7.2	230	670	78	0.1	25	28	50	10	1,440	Pumping; dairy use
37	5/16/80	100	7.1	2,113	-	64	49	270	5.9	170	580	7.4	0.1	5.9	26	4,500	570	1,090	Pump dismantled; pt sample
37	5/16/80	160	6.9	2,018	-	110	46	230	5.2	240	480	48	0.1	21	58	5,500	200	1,090	point sample
37b	5/16/80	196	6.9	2,417	-	130	54	290	6.2	230	620	66	0.1	22	56	7,900	230	1,330	point sample

EXPLANATION

- * Laboratory pH or specific conductance value.
- ** Sodium plus potassium.
- S Shallow piezometer at water-table depth.
- (1) Screened interval unknown; depth is maximum penetration of well below land surface.
- 2) Analyses by P.R. Aqueducts and Sewer Authority.
- 3) Well deepened to increase yield.
- 4) Analyses by P.R. Department of Agriculture.
- 5) Not same well, see comments.

NOTE: Letter subscripts refer to fig. 4.2.3-1-2.

QUALITY OF GROUND WATER VARIES AREALLY WITH DEPTH

The complex hydrologic conditions in the area influence the relative thickness of the fresh-water lens in the water-table aquifer. North of Highway 2, this lens thins out rapidly or is absent at localized areas.

2) The high chlorides in wells near Central Monserrate indicate upward coning of saline water from the underlying limestone. The high chloride concentration at the shallow piezometer (number 27 in fig. 4.2.3-1-2) may be derived by seepage of saline cooling water pumped at Central Monserrate and possibly discharged in past years into the adjacent depression northwest of the mill, or as at present the water is discharged to Caño de Los Nachos.

3) Silica concentrations are less than 10 mg/L at wells tapping the limestone aquifer to the west of Río Grande de Manatí and greater than 10 mg/L at wells tapping the limestone aquifer to the east. The concentration increase of silica, may be due to contribution of ground-water flow from the alluvial aquifer in the valley where concentrations are greater than 20 mg/L and as much as 49 mg/L.

Further interpretations from chemical data can be obtained using a trilinear diagram (Piper, 1944). Using this technique, the water from samples can be classified into one of four types: calcium carbonate, calcium chloride, sodium chloride or sodium bicarbonate (fig. 4.2.3-1-2). Most of the freshwater is of a calcium carbonate type. Ground-water analyses which show calcium chloride or sodium chloride types can be considered to contain seawater derived from a connate source and induced into wells by excessive ground-water pumpage or a natural condition. In the study area no evidence exists of lateral seawater intrusion.

Trilinear diagrams are useful not only in classifying water types but also in "tracing" the history of ground water especially where sea-water intrusion (or upward coning) is a threat. If samples taken through time at a given point, show a linear trend towards that point on the graph which represents seawater, it can be assumed that water at the point of sampling, is essentially a mixture of freshwater and seawater. This may be the case in the vicinity of Central Monserrate, where probably the ground water in well 29 was similar to that at sites number 19 and 36 (fig. 4.2.3-1-1), but is changing slowly as pumpage continues (as shown by the arrow in figure 4.2.3-1-2). Due to cation-exchange capacity of clays, waters first may exhibit an increase in calcium as lattice points are replaced by sodium in seawater (common ion effect) and follow a calcium chloride pattern before shifting to a sodiumchloride water type. If aquifer materials have low cation exchange properties (silts, sand, gravel, or cavernous limestone) it is probable that water will follow a line similar to that shown in the graph.

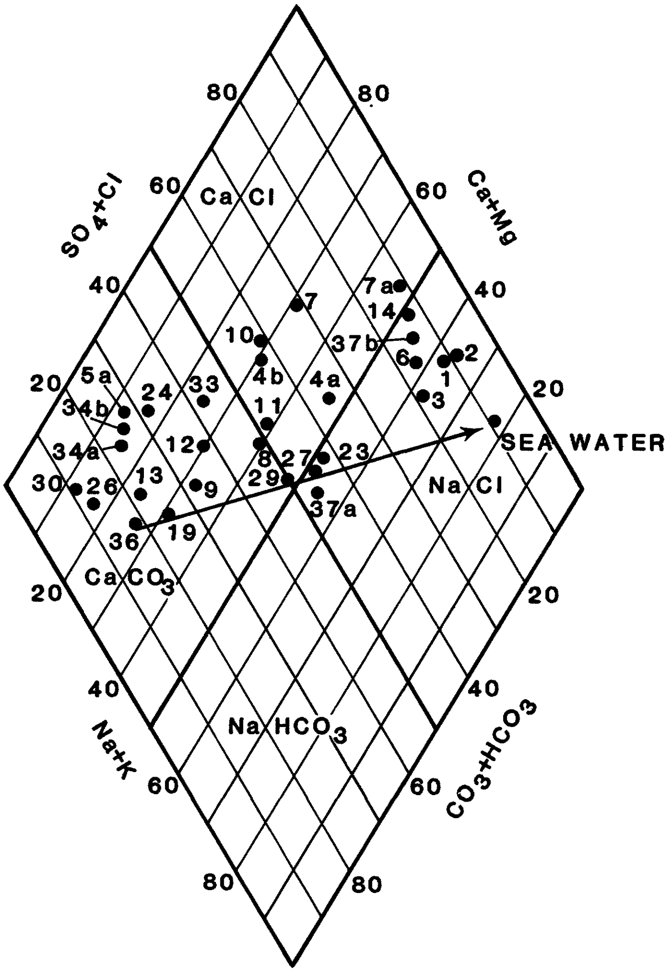


Figure 4.2.3-1-2 Selected ground-water analyses using trilinear diagram, in milliequivalent per liter of indicated sum of ions. (Numbers refer to data in table 4.2.3-1-1.)

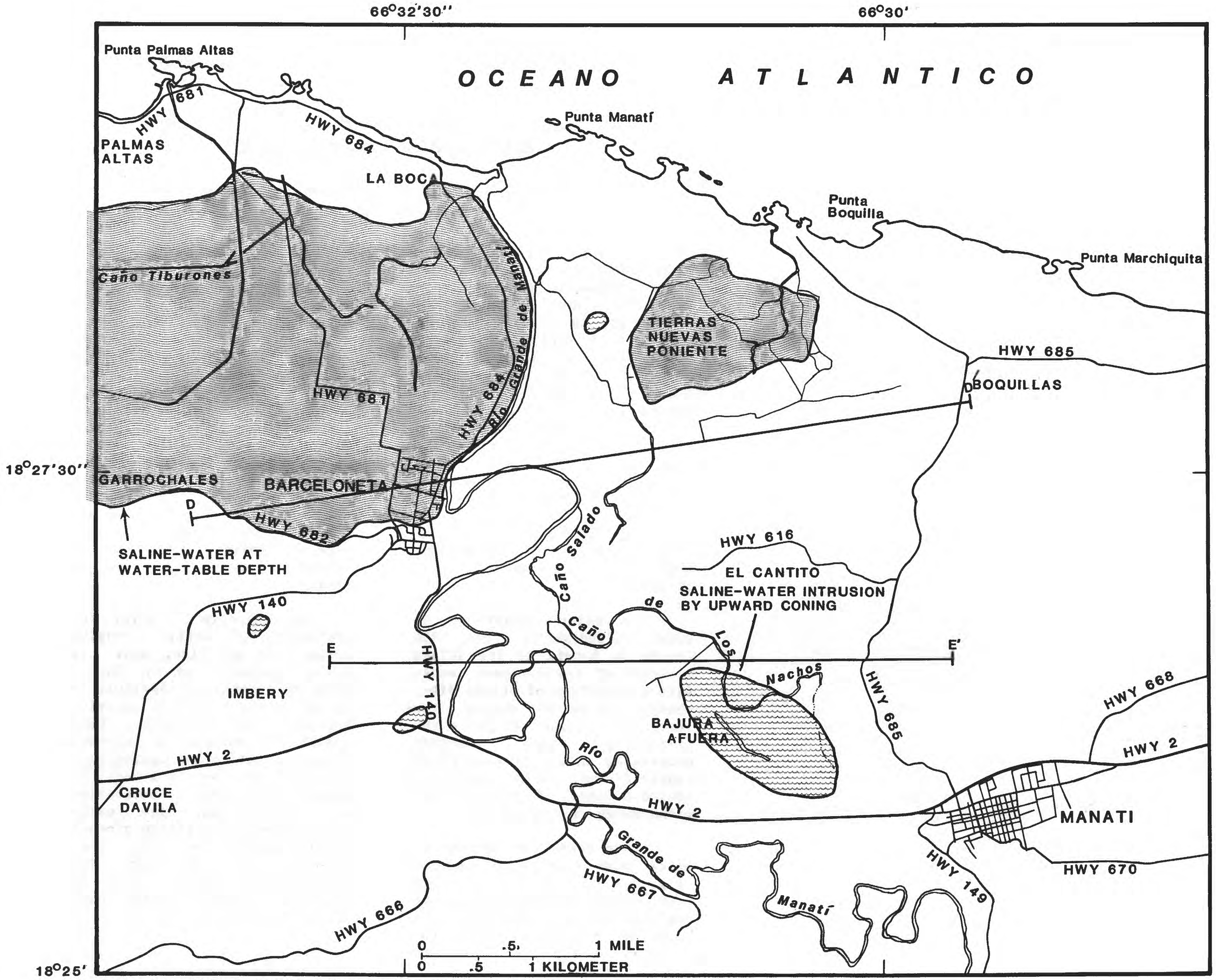
4.2.3-2 Saline Water

SALINE WATER CAN BE FOUND ANYWHERE IN THE VALLEY

Saline water lies within 200 feet throughout most parts of the valley and at water-table depth near the coast. South of Highway 2, it may lie at depths in excess of 300 feet below land surface.

Saline water or water with dissolved-solids concentration above 1,000 mg/L, can be found anywhere in the valley. Near the coast saline water occurs at water-table depth throughout most of the alluvial and swamp deposits; at other locations excessive ground-water withdrawals have induced upward coning of saline water (fig. 4.2.3-2-1).

Surface-resistivity surveys conducted throughout the valley, indicate that saline water lies within 200 ft at most areas and in excess of 300 ft below land surface south of Highway 2. The difference in depth to saline water between areas near the coast and farther inland are shown from cross sections D-D' and E-E' (fig. 4.2.3-2-1, 4.2.3-2-2, fig. 4.2.3-2-3).



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Figure 4.2.3-2-1 Aquifer areas containing saline water at water-table depth and zones affected by upward coning of saline water at wells.

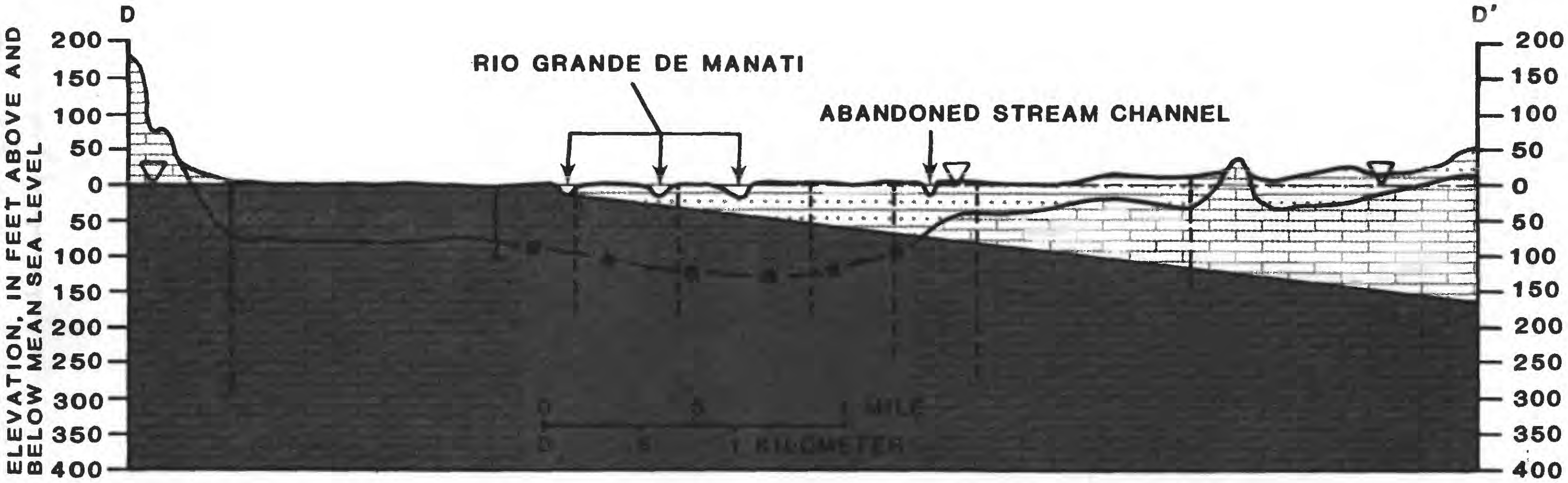


Figure 4.2.3-2-2 Cross section showing generalized depth to saline water along D-D'.

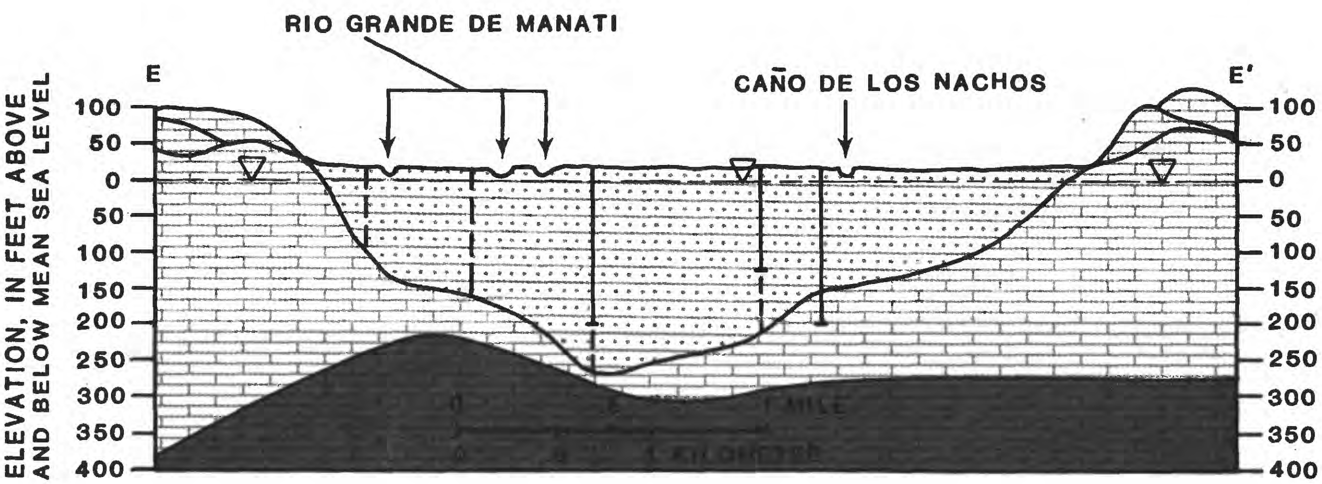
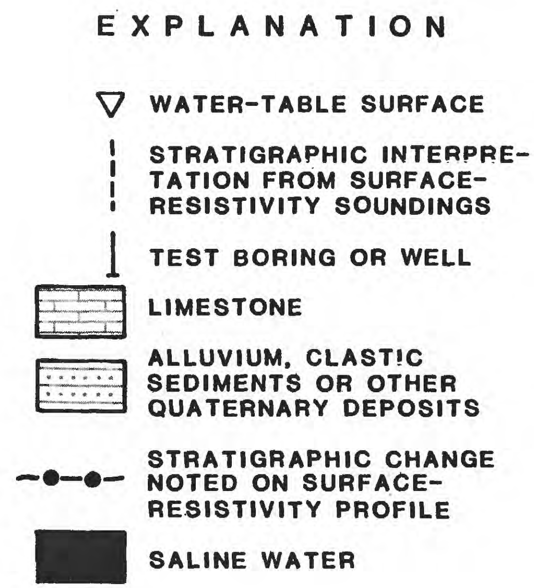


Figure 4.2.3-2-3 Cross section showing generalized depth to saline water along line E-E'.



5.0 WATER RESOURCES DEVELOPMENT POTENTIAL (SYNTHESIS)

5.1 Surface Waters

RIO GRANDE DE MANATI IS THE ONLY WATER RESOURCE WITH POTENTIAL TO SUPPLY NEEDS

Various spring-fed surface-water flows are also available to supply minor needs.

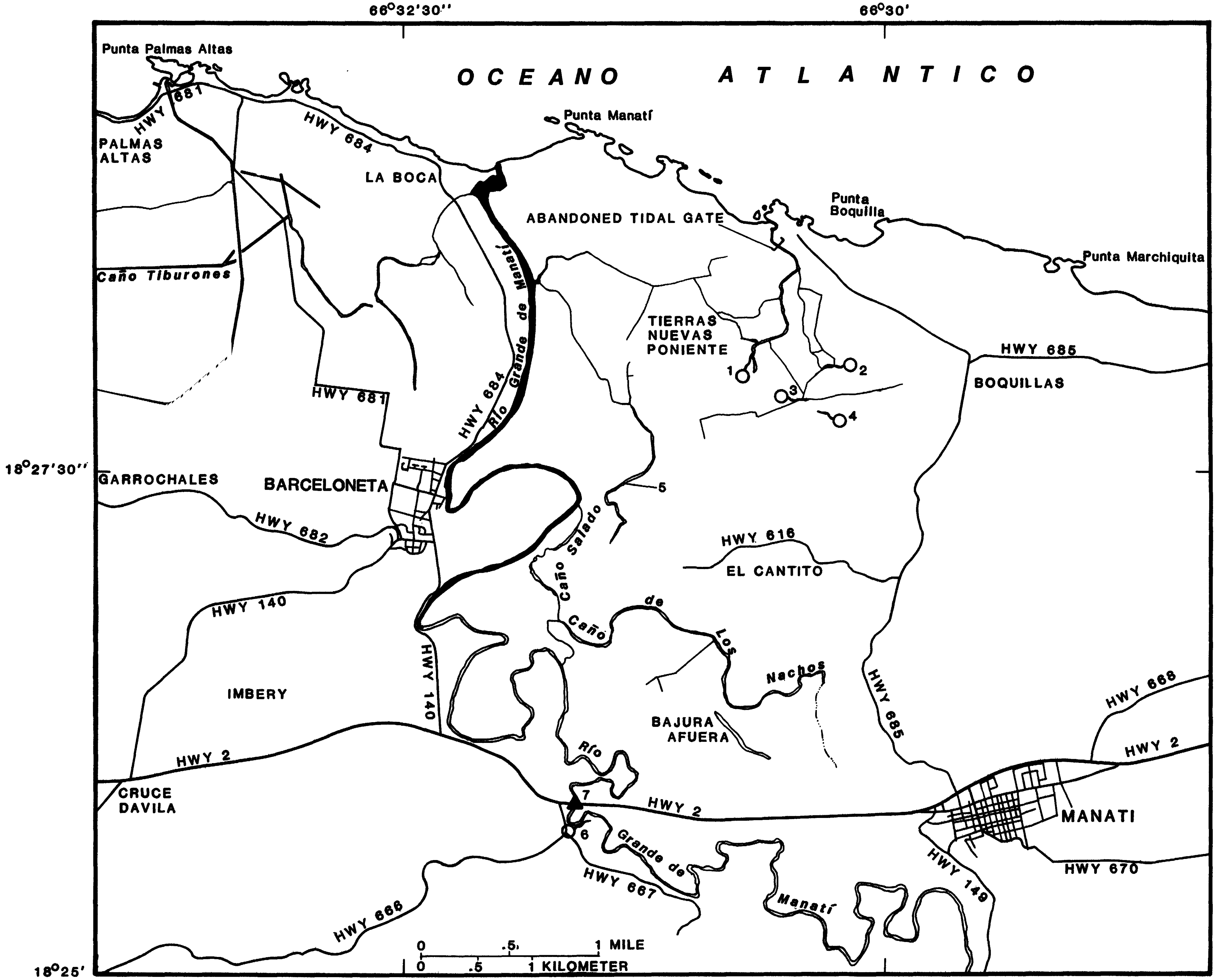
Río Grande de Manatí has a high potential for development of its streamflow for beneficial use. At present no water from the stream is being withdrawn. In the past various diversions were made for irrigation of sugarcane and as a cooling water source at both Central Monserrate and Central Plazuela (north of Barceloneta). The water available for use is limited to run-of-the-river flow. Records (9 years) show that 90 percent of the time the mean-daily discharge of the stream at the Highway 2 bridge has been at least 87 ft^3/s and the minimum mean-daily flow has been 51 ft^3/s.

The major constraint on water withdrawals from Río Grande de Manatí is the inland movement of the saltwater wedge with a reduction of stream discharge. Therefore, unless structures are provided to block the salt-water wedge, constant monitoring of the front will be required to avoid excessive inland movement of saltwater and withdrawing of saltwater.

Other potential sources of water are spring-fed streams (fig. 5.1-1). The use of water from springs or seepages may be limited not only by their flow quantity or annual variability, but also by the quality of the water (table 5.1-1).

Streams with no potential for development are Caño de Los Nachos and the abandoned stream channel north of the Caño. Caño de Los Nachos receives the effluent from the Manatí sewage-treatment plant (which also receives industrial effluents) and saline cooling water. These discharges possibly account for the total flow of the stream during dry periods. Water in the abandoned-stream channel consists essentially of ponded rain water. The channel is underlain by saline-ground water. Any withdrawal of water from the channel will cause the saline-ground water to migrate upward into the channel, comparable to upward coning of saline water at wells.

Availability of water for irrigation of water intensive crops such as rice, which is being considered by the Puerto Rico Department of Agriculture could be "stretched" by optimizing water recirculation. Data obtained at Hacienda La Esperanza indicate that if for approximately 1/3 of the days in a year the amount of rainfall compensates pan evaporation, the water requirements to maintain flooded paddies would be only that necessary to compensate for infiltration losses. This is assuming flooded paddies have evaporation losses similar to an evaporation pan. On those days, return flow from paddies will not contain higher-salt concentration due to evaporation loss, thus permitting re-use of irrigation water.



Base from U.S. Geological Survey Barceloneta and Manatí quads, 1969.

Table 5.1-1 Discharge and chloride concentrations at selected sites.

MAP NUMBER	LOCAL NAME OR LOCATION	DISCHARGE, IN FT3/S	CHLORIDE IN MG/L
1(a)	PALO DE PANA AND MAMEY SPRING	4	500
2	ISIDORO SPRING	0.5 e	145
3	OJO DE AGUA SPRING	0.2 e	207
4	MEDINA SPRING	PONDED	119
5	ABANDONED STREAM CHANNEL	PONDED	58
6	OJO DE AGUA GUILLO	2 *	8
7	U.S.G.S. GAGING STATION 50038100	87 *	14 **

EXPLANATION

SALT-WATER WEDGE RECORDED

6 SPRING

▲7 GAGING STATION

(a) SALINE WATER, TOTAL DISSOLVED SOLIDS ABOVE 1000 MILLIGRAMS PER LITER

e ESTIMATED

* VARIABLE DISCHARGE. FLOWS USUALLY GREATER THAN STATED VALUE.

** VARIABLE, 90 PERCENT OF SAMPLES OBTAINED IN 10 YEAR PERIOD HAVE CONCENTRATIONS EQUAL OR BELOW STATED AMOUNT.

Figure 5.1-1 Streams, springs and seepages in Río Grande de Manatí valley and chloride concentrations.

FUTURE DEVELOPMENT OF THE WATER-TABLE AQUIFER IN THE VALLEY LIMITED TO AREAS SOUTH OF HIGHWAY 2

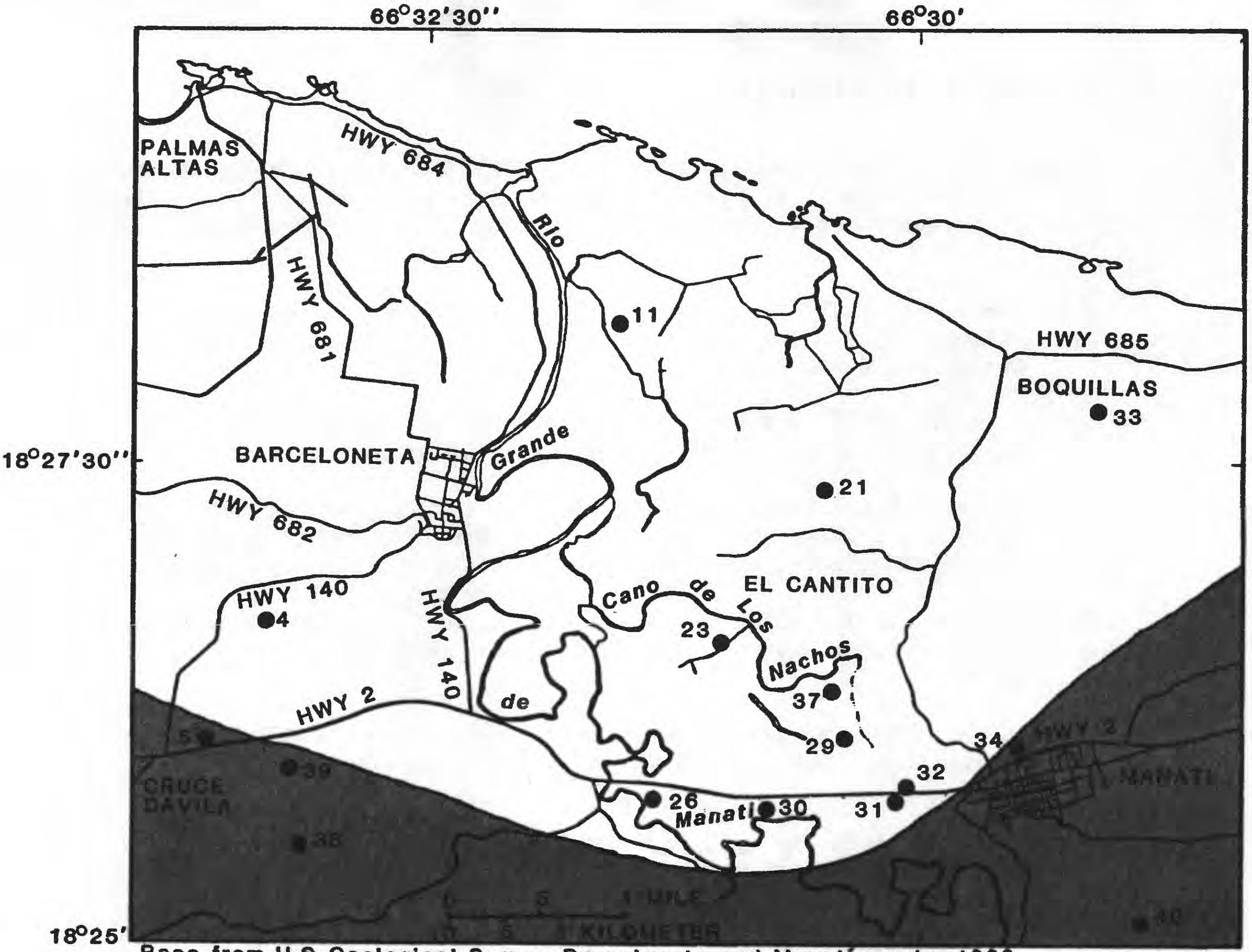
Ground-water withdrawals in the valley are estimated at 3.7 million gallons per day. The thickness of the freshwater lens and poor yield of the alluvial aquifer limit further development.

Ground-water withdrawals from the water-table aquifer is estimated at 3.7 Mgal/d from the alluvial valley and 3.1 Mgal/d from the upland limestone areas adjacent to the valley (fig. 5.2-1). These may be divided as follows:

Use		Withdrawal in Million gallons per day, estimate as of 1981
Public water supply	(WS)	5.5
Industrial	(IN)	1.3
Agricultural	(AG)	.04
Domestic	(DO)	Less than 100 gallons per day

Future development of fresh-water supplies in the alluvial valley is limited to areas south of Highway 2, and more properly away from the gaining stream section of Río Grande de Manatí. West of the river future ground-water development may be limited to the limestone upland areas and south of Highway 2. Northward, the freshwater lense thins out rapidly and is absent at Barceloneta. East of the river future ground-water development may be limited to the limestone uplands, but minor development potential exists toward the coast.

Large scale ground-water development in the Río Grande de Manatí valley is limited to wells tapping the deep-artesian system. The major constraint of future development of this deep-aquifer system is that at present, approximately 6 Mgal/d are being withdrawn. This rate of withdrawals has caused a rapid decline in the available head from 450 ft above mean sea level in 1968 to 300 ft at present.



Base from U.S Geological Survey Barceloneta and Manatí quads. 1969.

WELL NUMBER	USE	WITHDRAWAL, IN GALLONS PER DAY	WELL NUMBER	USE	WITHDRAWAL, IN GALLONS PER DAY
4	WS	600,000	31	WS	1,000,000
5	WS	600,000	32	WS	1,500,000
11	DO	100	33	WS	500,000
21	AG	5,000	34	WS	1,000,000
23	AG	10,000	37	AG	10,000
26	AG	10,000	38	IN	10,000
29	IN	1,200,000	39	IN	120,000
30	AG	10,000	40	WS	300,000

EXPLANATION

- ●11 ACTIVE WELL AND NUMBER
- ■ ZONE WITH GROUND-WATER DEVELOPMENT POTENTIAL
- WS PUBLIC WATER SUPPLY
- DO DOMESTIC
- AG AGRICULTURE (DAIRY)
- IN INDUSTRIAL

Figure 5.2-1 Producing wells tapping the water-table aquifer and areas with ground-water development potential.

6.0 LIST OF REFERENCES

Briggs, R. P., 1961, Geology of Kewanee Interamerican Oil Company, Test Well No. 4CPR, northern Puerto Rico, [in] Oil and Gas Possibilities of Northern Puerto Rico: San Juan, Puerto Rico Mining Commun., p. 1-23.

Calvesbert, R. J.,1970, Climate of Puerto Rico and U.S. Virgin Islands: U.S. Department of Commerce, Climatography of the United States no. 60-52, 29 p.

Giusti, E. V., 1978, Hydrogeology of the Karst of Puerto Rico: U.S. Geological Survey Profesional Paper 1012, 68 p.

Heisel, James H., González, José, and Cruz, Carlos, 1982, Analog model analyses of the north coast limestone aquifer, Puerto Rico: U.S. Geological Survey, Water-Resources Investigations 82-52, 49 p.

Hickenlooper, I. J., 1967, Floods at Barceloneta and Manatí, Puerto Rico: U.S. Geological Survey Hydrologic-Investigations Atlas HA-262.

Kaye, C. A., 1959, Shoreline features and quaternary shoreline changes, Puerto Rico: U.S. Geological Survey Professional Paper 317-B, 140 p.

Lohman, S. W., 1979, Ground-water hydraulics: U.S. Geological Survey Profesional Paper 708, 70 p.

López, M. A., and others, 1979, Floods in Puerto Rico, magnitude and frequency: U.S. Geol. Survey Water-Resources Investigations 78-141, 66 p.

Monroe, W. H., 1980, Geology of the Middle Tertiary Formations of P.R.: U.S. Geological Survey Prof. Paper 953, 93 p.

Novas, M. A., and Associates,1980, Map showing altitude of channel bed of Río Grande de Manatí: Puerto Rico

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analyses: American Geophysical Union Trans., v. 25, p. 914-923.

Strahler, A. N., 1967, Introduction to physical geography: New York, John Wiley, p. 341-351.

U.S. Weather Bureau, 1961, Generalized estimates of probable maximum precipitation and rainfall-frequency data for Puerto Rico and Virgin Islands: U.S. Department of Commerce Technical Paper no. 42, 94 p.

Van Nostrand, R. G., and Cook, K. L., 1966, Interpretation of resistivity data: U.S. Geological Survey Professional Paper 499, 310 p.

Vicente-Chandler, J., and others, 1977, Cultivo intensivo y perspectivas del arroz en Puerto Rico: University of Puerto Rico, Estación Experimental Agrícola, Boletín 250, Río Piedras, P.R. 71 p.