WATER RESOURCES OF THE SABANA SECA TO VEGA BAJA AREA, PUERTO RICO

By Arturo Torres-González and José R. Díaz

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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 International System of Units (SI), the data may be converted by using the following factors:

Multiply inch-pound units	By	To obtain SI units
inches (in)	25.4	millimeters (mm)
feet (ft)	0.3048	meters (m)
square feet (ft^2)	0.09290	square meters (m^2)
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 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)
pounds per acre (lb/acre)	0.1121	grams per square meter (g/m^2)
tons, short (tons)	0.9072	Megagrams (mg)
tons per square mile ($tons/mi^2$)	0.03753	Megagrams per square kilometer (tkm^2)

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ABSTRACT

An assessment of the water resources of the Sabana Seca to Vega Baja was made from 1978-80 in cooperation with the Puerto Rico Department of Agriculture. The area is under intense agricultural development with plans for eventual planting of nearly 10,000 acres in rice.

The geology of the area consists of a sequence of limestone formation overlain by alluvium and blanket-sand deposits. The surficial deposits and the Aymamón and Aguada Limestones form a water-table aquifer, which supplies most of the water in the area. The alluvial valleys of Río de la Plata and Río Cibuco, the two principal streams, comprise 50 percent of the area. Karst solution features are abundant to the south, with lagoons, marshes, and swamps adjacent to the coast.

Streamflow of Río de la Plata and Río Cibuco, varies seasonally with precipitation. The climate of the area is marine-tropical, with an average annual rainfall of 65 inches. The Río de la Plata, flow is regulated at de la Plata reservoir, upstream from Toa Alta. Although the average annual flow of Río de la Plata at Toa Alta is about 279 cubic feet per second, regulation reduces flows to as low as 3.4 cubic feet per second. Flow at the site exceeds 12 cubic feet per second 90 percent of the time. Río Cibuco flow at Vega Baja exceeds 18 cubic feet per second 90 percent of the time. The flow at Río Cibuco is more sustained than at Río de la Plata, with a 7-day, 10-year minimum flow of 7.5 cubic feet per second.

A water-table aquifer system, composed of Aymamón Limestone and underlying Aguada Limestone, and alluvial and sand deposits, is present throughout the study area. Depth to water below the land surface ranges from 16 feet near the coast to 120 feet near Highway 2. Ground-water flows in a general northerly direction to the ocean. Storage coefficients vary from 0.01 to 0.05 in the limestone, and 0.1 and higher in the alluvium. Transmissivities in the limestone are as high as 100,000 feet squared per day, due to local cavernous conditions. In the alluvium, transmissivities range from 100 to 10,000 feet squared per day.

Ground-water flows were estimated at a minimum of 1.6 million gallons per day per mile. Yields to wells range from 10 to 4,000 gallons per minute, generally exceeding 300 gallons per minute. Ground-water levels fluctuate seasonally with precipitation and pumpage, but declined about 7 feet from 1973 to 80.

The surface waters from Río Cibuco and Río de la Plata are suitable for most uses including irrigation. Calcium and bicarbonate are the principal ions, with dissolved-solids concentration ranging from 135 to 325 milligrams per liter. Suspended-sediment yields from Río Cibuco and Río de la Plata basins are less than 85 tons per square mile per year. Seawater is a major problem in canals and the lower reaches of the rivers. The salt-water wedge was detected 1.75 river miles upstream from the mouth of Río Cibuco and 3.0 river miles upstream from the mouth of Río de la Plata.

ABSTRACT (Continued)

The quality of ground water varies from excellent to very poor. Water from shallow wells tapping the limestone and alluvial aquifers is mostly of a calcium-bicarbonate type, with dissolved-solids concentrations ranging from 250 to 350 milligrams per liter. The water is suitable for most uses. Seawater intrusion is a major problem toward the coast due to the cavernous nature of the limestone aquifer. In the vicinity of Highway 2, near the southern boundary of the study area, the depth to the fresh-salt water mixing zone is about 210 feet. Overpumping of wells in the Campanilla area has resulted in sea-water encroachment into the aquifer.

Although abundant water supplies are available in the study area, better management practices are essential to optimize their use and prevent further sea-water encroachment.

1.0 INTRODUCTION

1.1 Objective

SABANA SECA TO VEGA BAJA AREA WATER RESOURCES ASSESSMENT

A study of the water resources
in the Sabana Seca to Vega Baja area was conducted
in support of the Puerto Rico Department of Agriculture rice program.

This report describes the general hydrology of the Sabana Seca to Vega Baja area, in north-central Puerto Rico (fig. 1.1-1). It summarizes the findings of a 2-year study of the water resources of the area conducted from 1978 to 1980. The study was conducted in cooperation with the Puerto Rico Department of Agriculture (PRDOA) as part of the cooperative water resources program between the U.S. Geological Survey, and agencies of the Commonwealth of Puerto Rico.

The Sabana Seca to Vega Baja area is one of several coastal valleys selected by the Commonwealth government for the production of rice on a commercial scale. Rice, one of the staple foods in Puerto Rico, is imported mostly from California and Louisiana. The Commonwealth's program envisions the substitution of the imported rice by locally produced crops. The climate of Puerto Rico will allow for higher yields than at most other rice-growing areas in the world (Vicente-Chandler and others, 1977). Vicente-Chandler estimated yields as high as 5,000 (lb/acre)/crop. From 2 to 2½ crops can be obtained per year. This production however, will require large amounts of water. The PRDOA, in charge of the Commonwealth's rice program, requested an assessment to determine the availability of water from the proposed rice production areas, including the Sabana Seca to Vega Baja valleys. Other areas under investigation are also shown in figure 1.1-1.

The main objectives of the study were to determine the quantity and quality of surface and ground-water supplies, their occurrence, and movement. The extent of saline-water intrusion was also investigated.

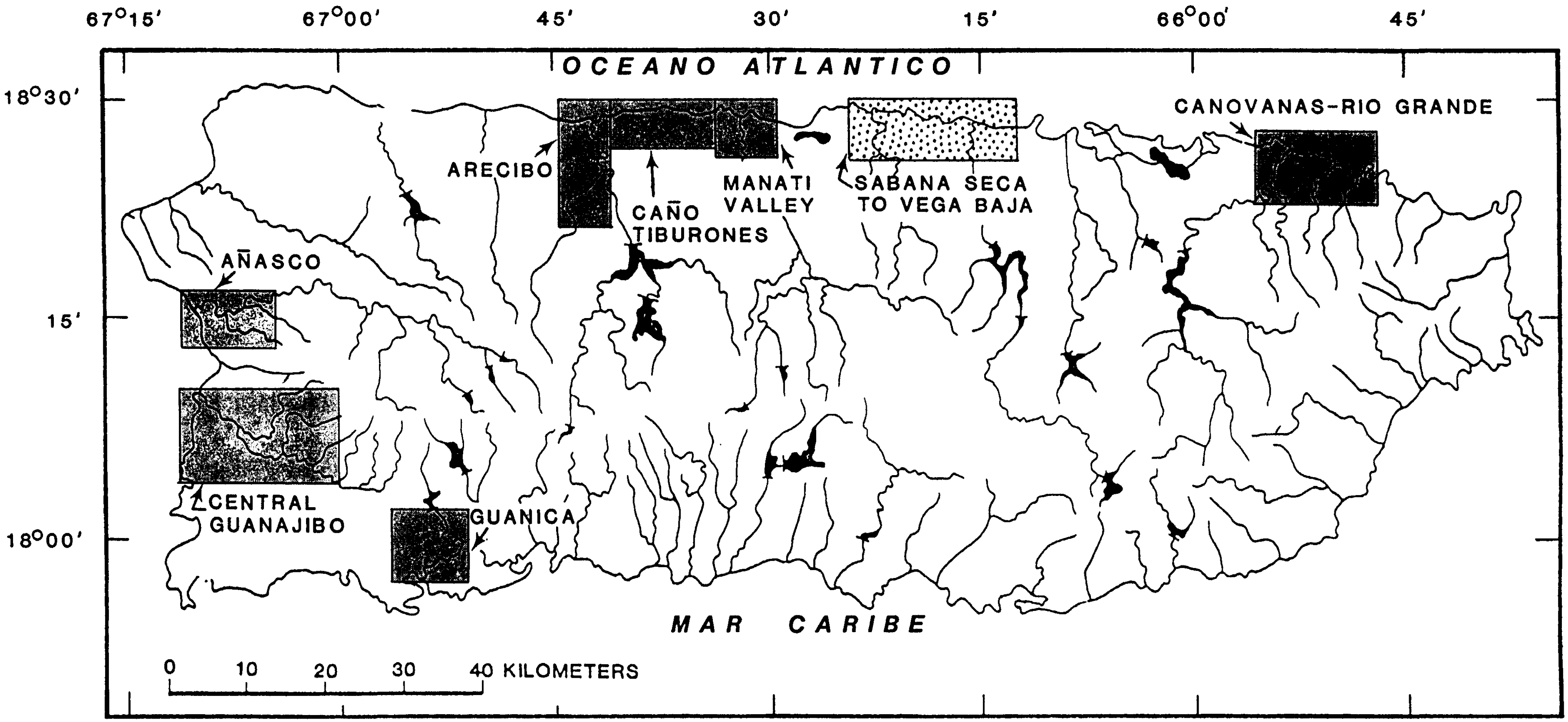


Figure 1.1-1.--Study area and other areas under investigation designated for rice cultivation.

1.2 Description of the Area

STUDY AREA LOCATED IN NORTH COAST LIMESTONE REGION

The area includes about 57 square miles between Sabana Seca and Vega Baja. Most of the land in the area is used for sugarcane and pastures.

The area includes about 57 mi^2 along the coastal plain, between the towns of Sabana Seca and Vega Baja, bordered by Highway 2 along most of its south edge and the Atlantic Ocean to the north (fig. 1.2-1). Two main rivers, Río Cibuco and Río de la Plata, flow into the area from the limestone hills to the south. Both rivers cross the area in a nearly south-to-north direction, discharging into the Atlantic Ocean.

The principal urban areas are the towns of Toa Baja, Dorado, Vega Alta, and Vega Baja. Other communities in the area are Sabana Seca, Campanilla, Higuillar, Espinosa, and Monserrate. The population of the area is about 115,000 (1980 Census).

Most of the land, in rural areas, is used for sugarcane and pastures. The cultivation of rice will reduce significantly the sugarcane acreage. The Constancia and San Vicente sugar mills, now closed, operated until recently. Light industry, such as the manufacture of pharmaceuticals, food products, clothing, and furniture are now the principal industrial and employment sources. Water demands for these activities are small when compared to prior sugarcane irrigation and milling requirements.

Water in the area is provided from a combination of shallow wells (about 40) and streams. The most important well fields are near Campanilla and Vega Baja. Domestic supplies for Vega Baja are augmented by pumpage from Río Indio, a tributary of Río Cibuco.

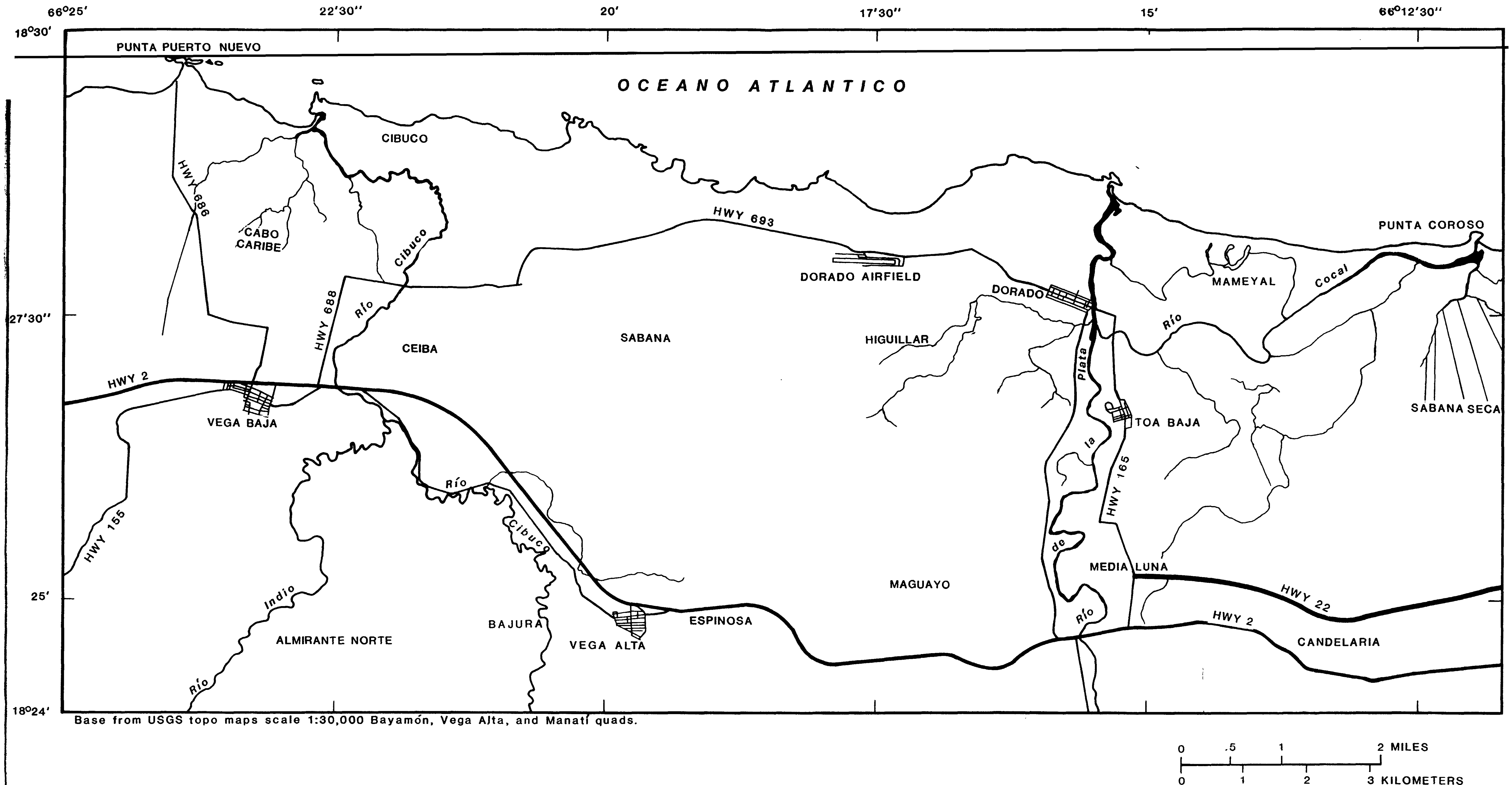


Figure 1.2-1.--The Sabana Seca to Vega Baja area.

2.0 GENERAL FEATURES

2.1 Geology

LIMESTONE FORMATIONS AND ALLUVIUM FORM GEOLOGIC FRAMEWORK

The geology of the area consists of a thick sequence of predominately limestone formations: the Lares Limestone, the Cibao Formation, the Aguada Limestone, and the Aymamón Limestone; overlain in places by alluvium and other surficial deposits.

The surface and pertinent subsurface geology in the area of investigation consists of predominently limestone formations of Oligocene to Miocene age. The formations dip gently to the north, and are overlain by unconsolidated to semi-consolidated Quaternary deposits on the coastal plain and in stream valleys (figs. 2.1-1, 2.1-2). The following description of the geologic formations from oldest to youngest was adapted from Briggs and Akers (1965). Thickness of the formations was determined from Monroe (1980).

The Lares Limestone is composed of thick-bedded to massive dense limestone and calcarenite. Its thickness ranges from near 0 at Toa Alta to about 500 ft in the western part of the study area. The Cibao Formation is composed of inter-bedded marl, chalk, and limestone, some thin sand and clay beds, and occasional conglomerate lenses. It is 500-600 ft thick. The Aguada Limestone is composed mostly of hard thick-bedded to massive calcarenite and dense limestone interbedded with chalky limestone and marl. It commonly contains some quartz grains. It is about 300 ft thick. The Aymamón Limestone is composed of thick-bedded and massive dense limestone, calcarenite, and some dolomite beds. It is 600-700 ft thick.

Quaternary deposits are subdivided into three types. Blanket deposits of quartz sand, clayey sand, and sandy clay occur principally in the coastal plan and in areas of karst topography. Beach and dune deposits are largely sand, composed of calcite, quartz, volcanic rock fragments, and some magnetite, and locally include cemented sand (beachrock) in bands parallel to the shore. Alluvial deposits are composed of sand, silt, clay, gravel, and flood-plain and terrace deposits.

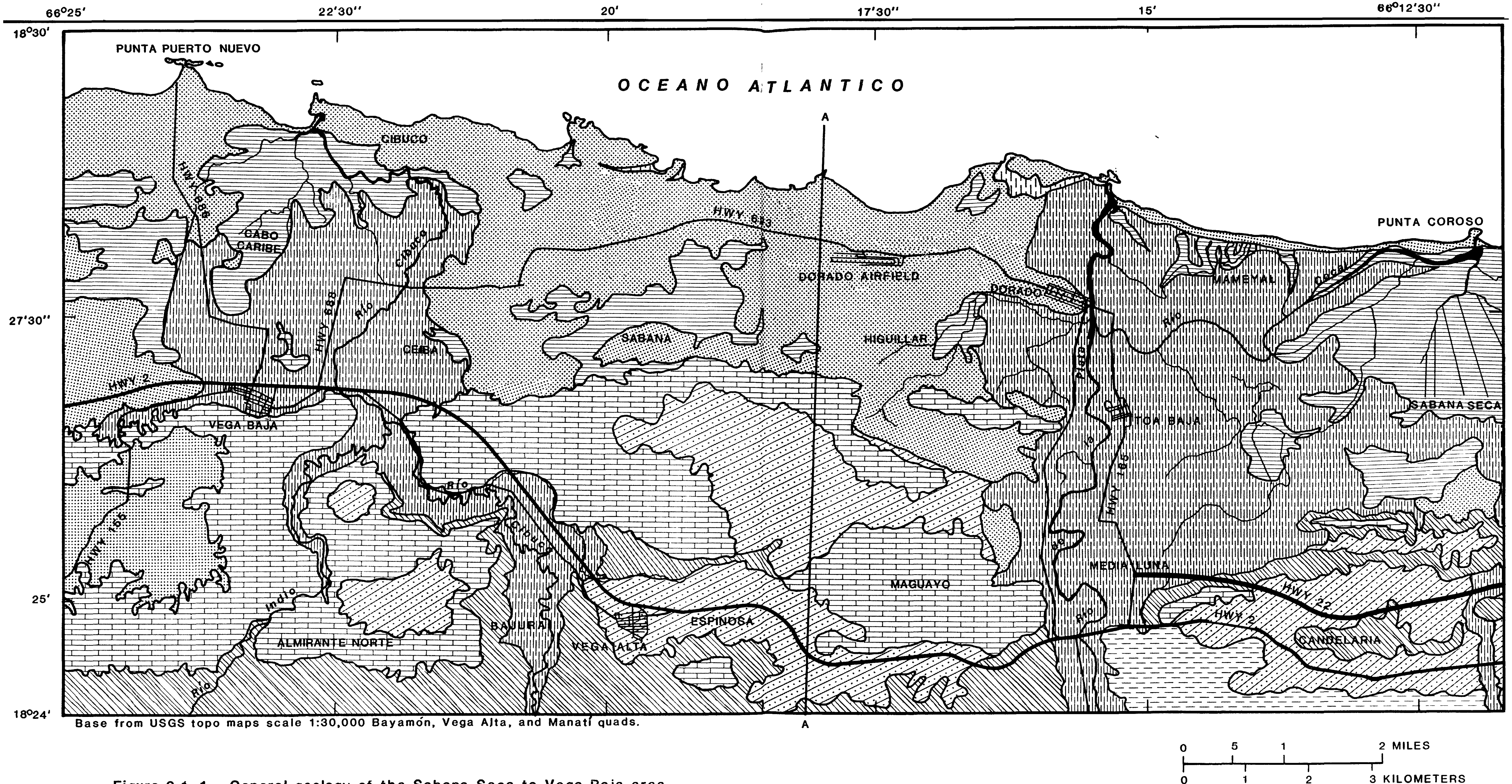


Figure 2.1-1.--General geology of the Sabana Seca to Vega Baja area.

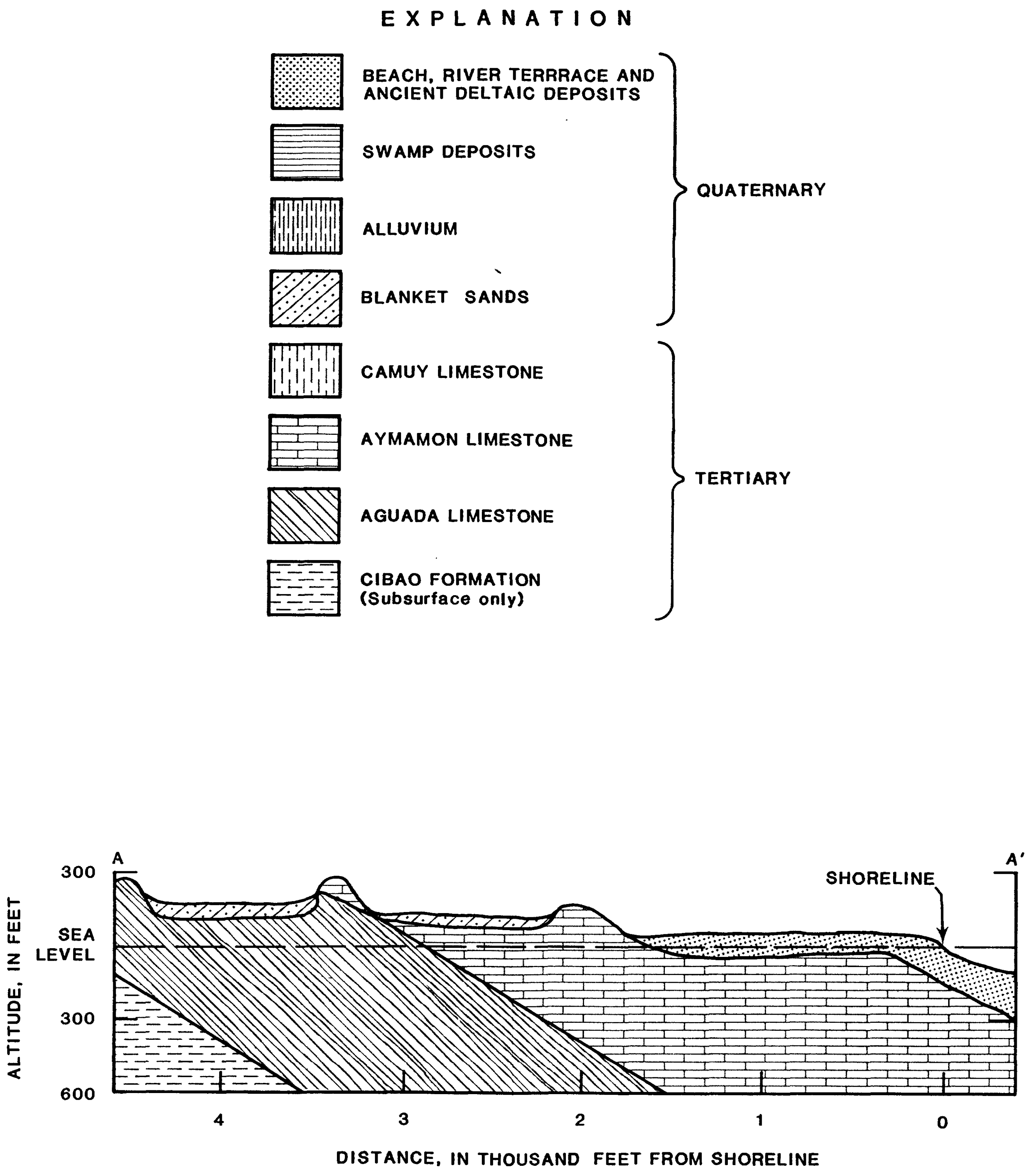


Figure 2.1-2.--Typical geologic section through A-A
(See fig. 2.1-1 for section location.)

2.2 Landforms

AREA IS MARGINAL TO THE KARST BELT GEOGRAPHIC REGION

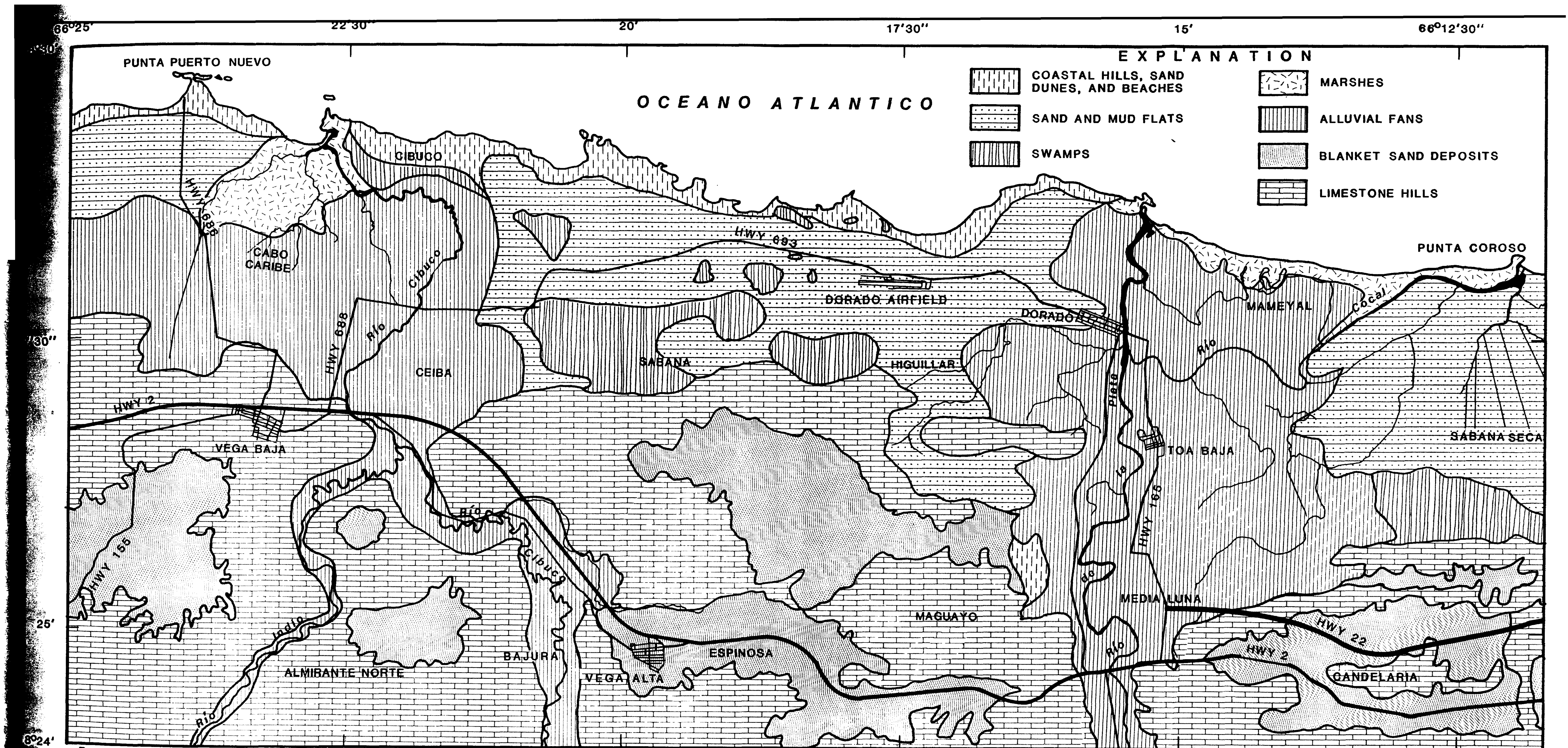
The alluvial valleys of Río Cibuco and Rio De La Plata comprise 50 percent of the area. Karst solution features are abundant; lagoons, mangrove swamps and marshes are common along the coastline.

Puerto Rico can be divided into three main geographic regions (Monroe, 1976 p. 6); a mountainous area that constitutes most of the southern two thirds of the island, a belt of rugged karst topography in the north-central and northwestern parts of the island, and a discontinued fringe of relatively flat coastal plains (Fig. 2.2-1).

The karst region in north-central and northwestern Puerto Rico is an area underlain by limestone, in which the topography is formed chiefly by solution. The topography varies from extremely rugged karst terrain with a relief of as much as 1,000 ft to gently rolling hills.

The coastal plain slopes gently from the shore to an altitude of about 50 ft at the foothills. Depressions are common; several lagoons, marshes, and mangrove areas have developed. A relatively continuous line of marshes, mangrove swamps, and small lagoons lie just inland from the shoreline.

The Sabana Seca-Vega Baja area lies in the lowlands of the north-coastal plain. The plain is about 3 mi wide in the study area. It has been built up by surficial deposits consisting of sand, silt, clay, and muck overlying a dissected older surface. Isolated limestone hills called "mogotes" project out of the plain. Round limestone hills of the Aguada and Aymamón Limestones, bordered by patches of blanket deposits, are conspicuous in the southern part of the area. The alluvial valleys of Río Cibuco and Río de la Plata on the west and east boundaries of the area, respectively, are incised through the foothills and extend to the coast. The valleys comprise about 50 percent of the study area.



Base from USGS topo maps scale 1:30,000 Bayamón, Vega Alta, and Manatí quads.

Figure 2.2-1.--Landforms of the Sabana Seca to Vega Baja area.

2.0 GENERAL FEATURES

2.3 Land Use

AGRICULTURAL LANDS COVER MOST OF THE SABANA SECA TO VEGA BAJA AREA

Nearly half of the study area, 16,000 acres, is used for agriculture. The remaining land, 22,000 acres, is used for urban and rural housing, hotels, and recreational facilities.

Most of the coastal plain and alluvial valleys have been utilized by agriculture for many years. Sugarcane, pastures, and ornamental plant nurseries predominate. Urban and industrial development are centered in the towns of Toa Baja, Dorado and Vega Alta. Numerous villages are scattered among the agricultural lands. The northern section includes two large hotels, three golf courses, recreational beach areas, and several housing projects.

Land use in the study area as of 1978 is shown in figure 2.3-1. Agricultural areas included 15,000 acres. The remaining 22,000 acres included communities, industry, scattered housing, hotels and coastal recreational areas. About 10,000 acres have been proposed by PRDOA for the rice program. Most of this land was originally planted in sugarcane. Dairy farms in the central part of the area account for about 6,000 acres.

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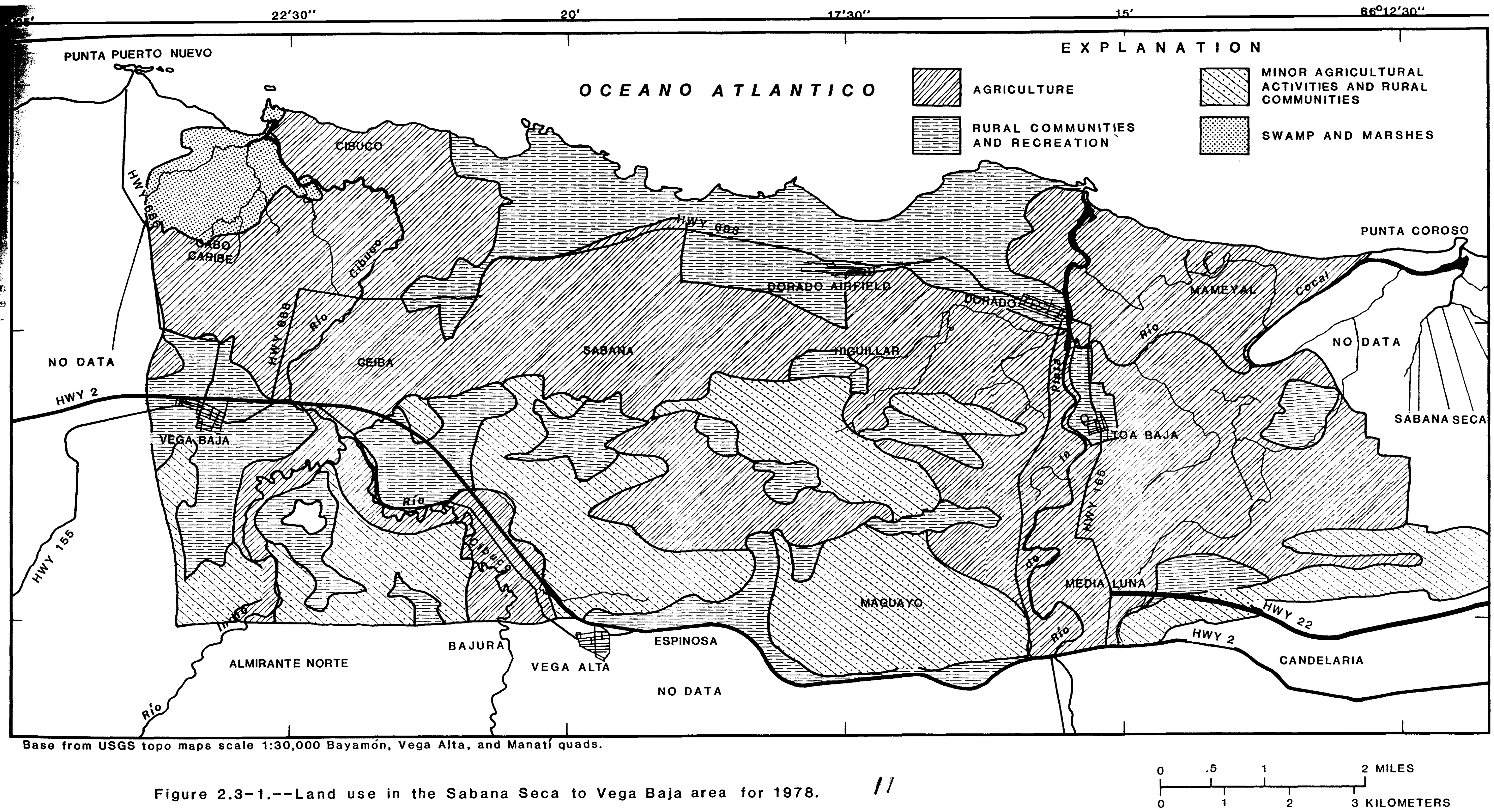

Figure 2.3-1.--Land use in the Sabana Seca to Vega Baja area for 1978.

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2.0 GENERAL FEATURES (Continued)

2.4 Climate

AREA CHARACTERIZED BY A TROPICAL MARINE CLIMATE

Temperature ranges from 23 to 27°Centigrade. Precipitation ranges from 60 to 70 inches per year.

The climate of the Sabana Seca to Vega Baja area is tropical marine with mean daily temperatures ranging from 23° during the winter to 27°C during the summer. Temperature is nearly uniform and very similar to the San Juan Metropolitan area.

Precipitation over the area ranges from 60 to 70 in/year (Calvesbert, 1970) (fig. 2.4-1). The persistent easterly and southeasterly tradewinds contribute to produce precipitation throughout the year, although seasonal variations occur. Precipitation records at 3 sites in or near the study area (fig. 2.4-2) show monthly fluctuations and seasonal patterns. The most intense rain storms occur early in the spring (April), and during the rainy season from August to December. Normally, about two thirds of the annual precipitation occurs during the rainy season. The driest period is from January to March.

Average actual evapotranspiration in the study area is about 45 inches/year. This value was estimated from data collected along the north coast by Giusti (1978). Giusti concluded that the ratio of pan evaporation (EP) to actual evapotranspiration (ET), is about 0.76. Wind effects in the Sabana Seca to Vega Baja area may contribute to higher than average actual evapotranspiration values. The need to conduct studies to measure ET is evident. This data will be essential to planners and developers involved in the irrigation projects now under contruction for the rice program.

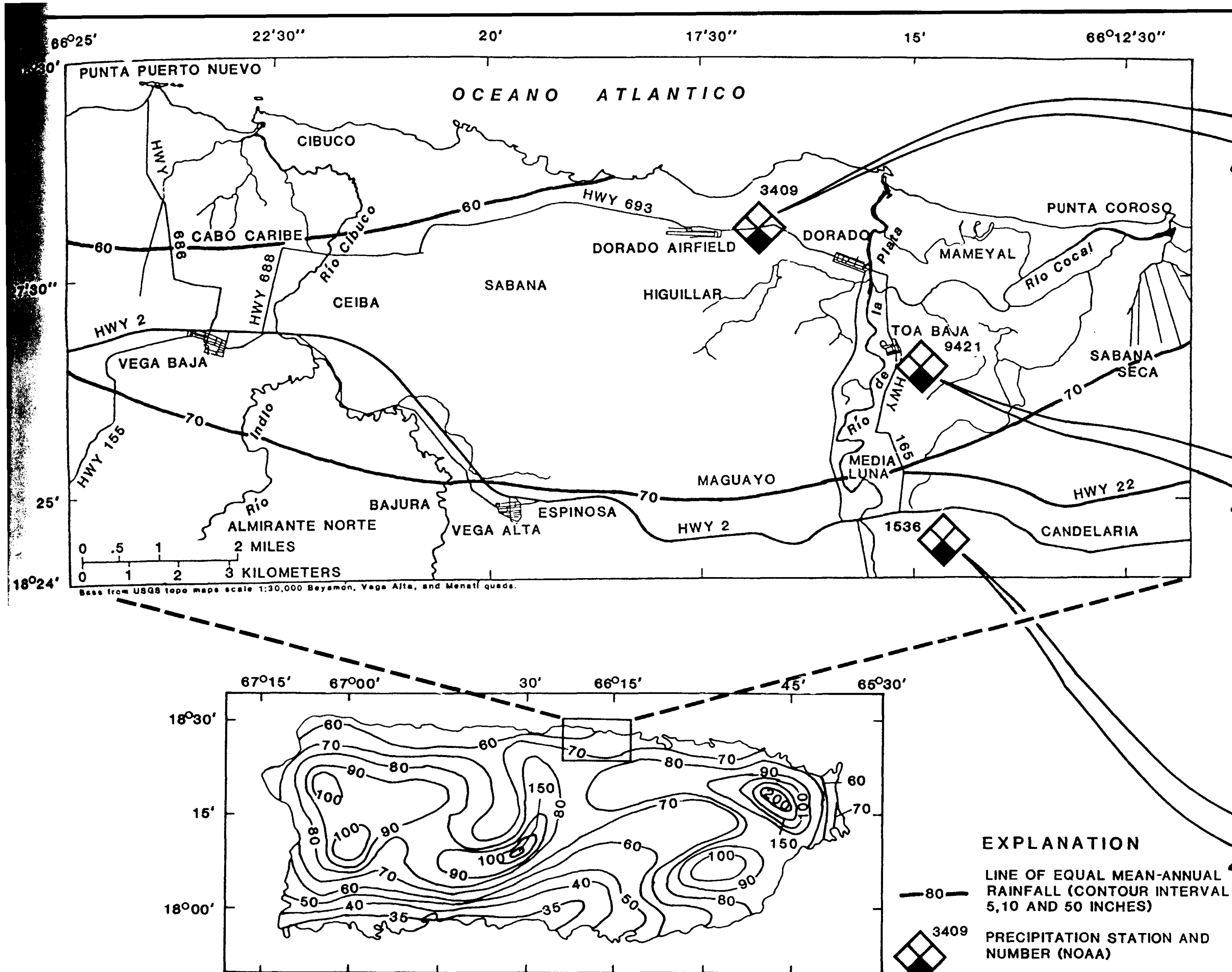

Figure 2.4-1.--Mean-annual precipitation 1931-60 in and near the study area. (Data from NOAA)

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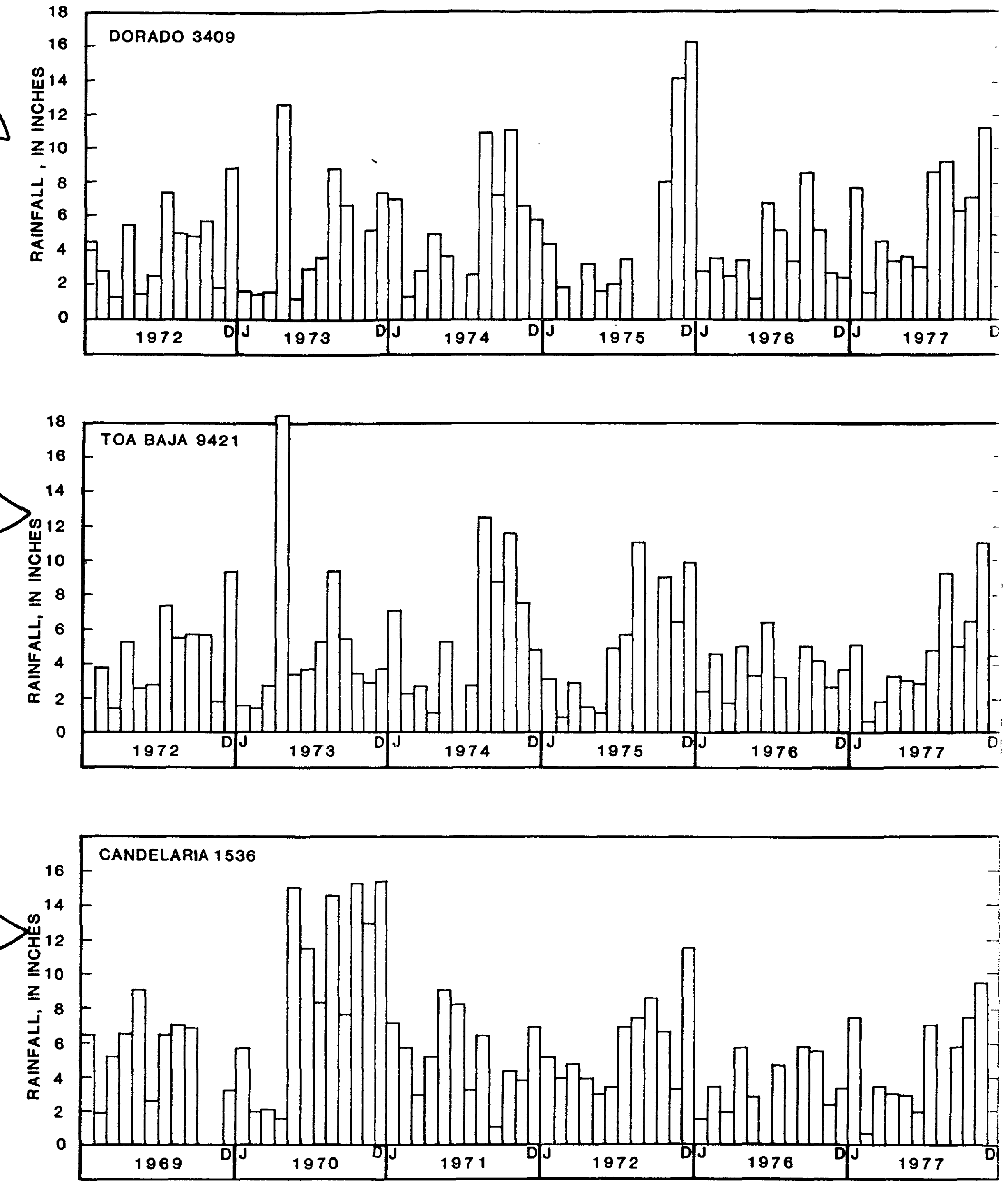

Figure 2.4-2.--Monthly rainfall in and near the study area.(Data from NOAA).

3.0 SURFACE WATER

3.1 Streamflow

STREAMFLOW VARIES SEASONALLY

Streamflow at Río Cibuco and Río de la Plata fluctuate seasonally with precipitation. Base flows at Río de la Plata are affected by regulation.

The two principal streams in the study area, Río Cibuco and Río de la Plata, flow abundantly in response to seasonal precipitation. Most of the higher flows occur during the rainy season (September to December), but equally high discharges can occur in almost any month (figs. 3.1-1 and 3.1-2).

Río de la Plata is affected by significant regulation. Flow from about 8.2 mi^2 of drainage in the basin is diverted to the south coast at Lago Carite. In 1974, a water-supply reservoir was built upstream from Toa Alta. About 40 Mgal/d (62 ft^3/s) are diverted from the reservoir to the San Juan metropolitan area. This has resulted in lower base flows at the Toa Alta gaging station. In the Río Cibuco basin, about 24 mi^2 of drainage are partly undefined contributing area in the limestone zone. Low flows in the Río Cibuco are probably affected by the undefined area. Runoff from this area is probably minimal during periods of scarce rainfall.

The average-annual discharge of Río Cibuco at the Vega Baja gaging station (50039500) is about 85 ft^3/s (5 years of record). At Río de la Plata at Toa Alta gaging station (50046000), with a drainage area twice as large as the Río Cibuco at Vega Baja (200 versus 90 mi^2), the average-annual discharge is 279 ft^3/s (17 years of record). Prior to the construction of the reservoir the annual average flow at this site was about 319 ft^3/s.

Monthly-mean discharges at Río Cibuco (table 3.1-1) range from 12.8 ft^3/s (June 1977) to 382 ft^3/s (Oct 1975). At Río de la Plata, the monthly means (table 3.2-2) ranges from 11.4 to 4,813 ft^3/s. The monthly means, together with flow-duration and low-flow data (sections 3.3 and 3.4), can be used to estimate maximum volume of water that can be withdrawn from the streams. A long-term record of monthly means can also provide an insight into the effects of withdrawals at a stream site. This is evident for Río de la Plata (table 3.1-2) after 1974. Monthly means have declined dramatically after the reservoir for water supply was built.

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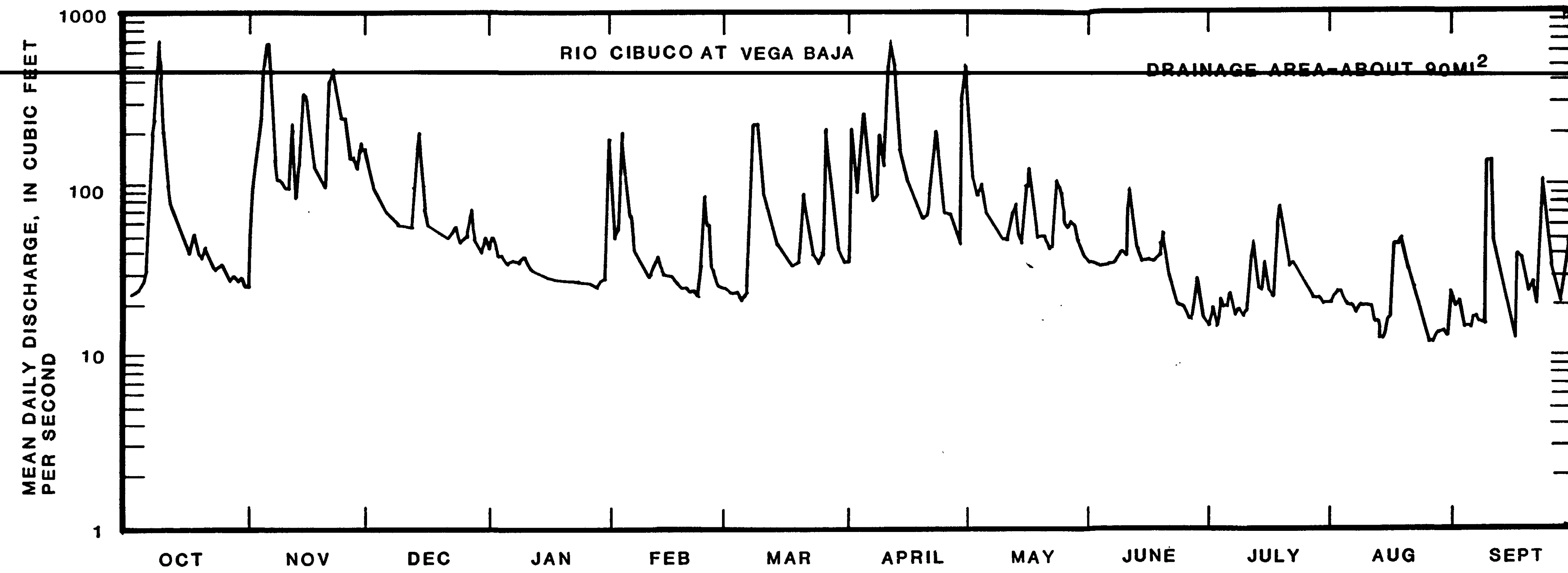
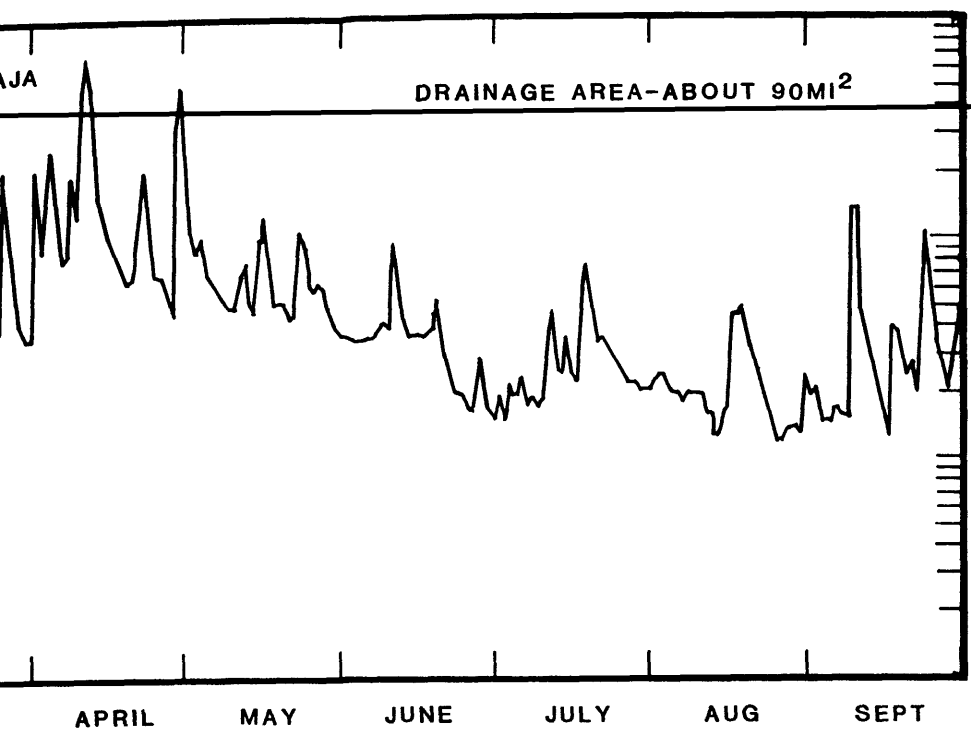


Figure 3.1-1.--Typical mean discharge hydrograph of Río Cibuco at Vega Baja, 1978

Table 3.1-1.--Monthly mean discharge of Río Cibuco at Vega Baja (50039500).

YEAR	DISCHARGE IN CUBIC FEET PER SECOND											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
1973	*	*	*	59.00	124.00	49.50	369.00	95.00	58.00	38.90	46.00	48.40
1974	45.90	40.00	52.10	65.50	76.70	43.40	42.20	29.30	18.20	19.90	47.60	114.00
1975	382.00	339.00	174.00	129.00	76.30	61.00	34.10	31.30	21.10	31.70	35.70	82.90
1976	103.00	195.00	381.00	92.50	120.00	126.00	132.00	77.60	38.60	26.00	24.90	45.80
1977	162.00	67.70	48.50	78.80	32.60	27.30	34.60	24.70	12.80	15.50	154.00	45.50
1978	77.70	223.00	65.00	38.20	43.70	63.20	175.00	68.40	34.60	27.90	21.20	36.30
1979	46.20	46.40	30.50	148.00	101.00	105.00	152.00	361.00	151.00	162.00	461.00	450.00
1980	168.00	523.00	225.00	112.00	115.00	92.60	75.70	104.00	77.70	42.70	79.00	109.00
1981	115.00	45.60	150.00	92.20	73.80	298.00	225.00	566.00	156.00	85.80	121.00	83.90
1982	231.00	409.00	1316.0	110.00	120.00	54.90	66.20	232.00	72.30	64.60	55.00	85.10

* INDICATES A NO-VALUE MONTH



rograph of Río Cibuco at Vega Baja, 1978

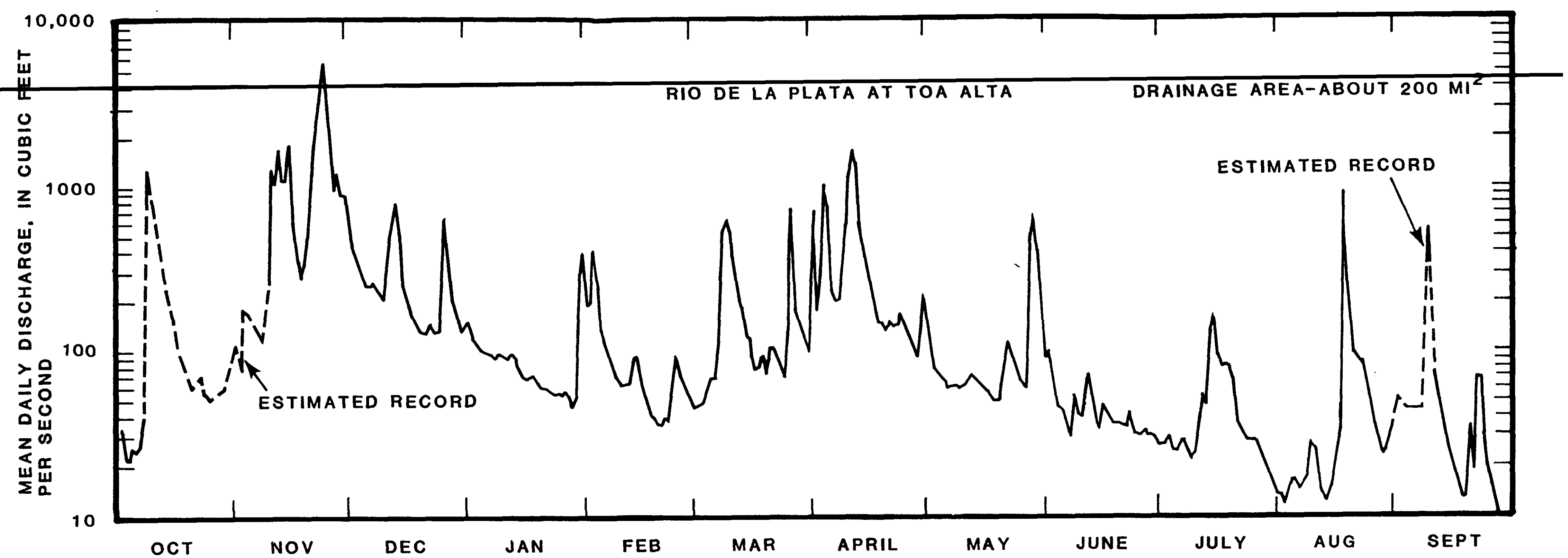


Figure 3.1-2.--Typical mean-daily discharge hydrograph of Río de la Plata at Toa Alta, 1978.

Río Cibuco at Vega Baja (50039500).

BIC FEET PER SECOND

IAR	APR	MAY	JUNE	JULY	AUG	SEPT
9.50	369.00	95.00	58.00	38.90	46.00	48.40
3.40	42.20	29.30	18.20	19.90	47.60	114.00
1.00	34.10	31.30	21.10	31.70	35.70	82.90
6.00	132.00	77.60	38.60	26.00	24.90	45.80
7.30	34.60	24.70	12.80	15.50	154.00	45.50
3.20	175.00	68.40	34.60	27.90	21.20	36.30
5.00	152.00	361.00	151.00	162.00	461.00	450.00
2.60	75.70	104.00	77.70	42.70	79.00	109.00
3.00	225.00	566.00	156.00	85.30	121.00	83.90
4.90	66.20	232.00	72.30	64.60	55.00	85.10

Table 3.1-2.—Monthly mean discharge of Río de la Plata at Toa Alta (50046000).

DISCHARGE IN CUBIC FEET PER SECOND

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
1960	*	*	*	90.10	109.00	84.40	243.00	177.00	114.00	162.00	401.00	1691.0
1961	555.00	508.00	1135.0	362.00	161.00	146.00	208.00	149.00	113.00	690.00	899.00	269.00
1962	546.00	488.00	775.00	362.00	156.00	112.00	270.00	562.00	408.00	250.00	414.00	501.00
1963	462.00	158.00	154.00	197.00	220.00	157.00	336.00	548.00	224.00	211.00	361.00	383.00
1964	300.00	249.00	125.00	112.00	78.90	48.70	89.70	60.10	101.00	182.00	262.00	150.00
1965	151.00	35.20	68.40	83.40	41.00	31.50	67.80	899.00	461.00	258.00	673.00	343.00
1966	222.00	308.00	1184.0	254.00	133.00	283.00	372.00	390.00	176.00	136.00	270.00	494.00
1967	555.00	295.00	382.00	166.00	160.00	113.00	79.60	83.50	50.50	61.60	105.00	64.00
1968	181.00	220.00	57.00	125.00	115.00	65.20	61.80	151.00	119.00	146.00	341.00	134.00
1969	47.90	641.00	308.00	518.00	343.00	468.00	462.00	881.00	189.00	278.00	300.00	399.00
1970	301.00	1145.0	328.00	266.00	98.10	72.80	66.10	560.00	847.00	446.00	716.00	365.00
1971	4813.0	1161.0	1352.0	472.00	371.00	187.00	547.00	256.00	156.00	146.00	225.00	115.00
1972	218.00	155.00	131.00	154.00	111.00	282.00	164.00	80.80	40.90	49.50	66.80	91.10
1973	283.00	121.00	271.00	92.10	151.00	78.70	349.00	71.30	76.00	39.30	129.00	78.20
1974	35.10	74.30	29.50	89.50	117.00	41.00	34.20	39.10	33.70	35.40	138.00	287.00
1975	856.00	1144.0	421.00	247.00	73.20	52.20	27.80	38.60	16.20	32.80	51.30	*
1976	270.00	483.00	848.00	123.00	130.00	85.50	111.00	87.00	32.60	13.90	16.50	76.60
1977	74.40	47.40	36.60	40.30	16.90	19.00	15.40	12.70	11.40	21.70	80.90	56.10
1978	177.00	1137.0	283.00	94.20	95.20	167.00	371.00	114.00	41.70	43.70	69.90	54.40
1979	499.00	207.00	54.10	153.00	148.00	101.00	88.40	552.00	620.00	592.00	1677.0	1574.0
1980	401.00	592.00	378.00	137.00	144.00	134.00	109.00	156.00	77.20	60.30	49.00	121.00
1981	142.00	31.00	88.10	68.50	33.80	127.00	291.00	838.00	460.00	201.00	164.00	124.00
1982	267.00	257.00	1071.0	137.00	167.00	34.50	27.00	379.00	35.50	73.10	54.50	330.00

* INDICATES A NO-VALUE MONTH

3.2 Floods

FLOODS ARE FREQUENT AND SEVERE

Río Cibuco and Río de la Plata flood significant parts of the study area. At Vega Baja, the maximum known flood of Río Cibuco occurred in 1965, with a peak discharge of 28,000 cubic feet per second. At Toa Alta, Río de la Plata had a peak discharge 120,000 cubic feet per second in 1928.

Effective planning for the development and management of flood plains requires studies and analyses of their flooding potential and characteristics. The two principal streams in the study area, Río Cibuco and Río de la Plata, produce severe and frequent floods that inundate large tracts of land.

The floods of Río Cibuco in the Vega Alta and Vega Baja areas were described by Hickenlooper (1968). The most severe flood of record occurred on December 11, 1965 when a peak discharge of 28,000 ft^3/s was recorded at the Highway 2 bridge (tables 3.2-1 and 3.2-2). This discharge corresponds to a recurrence interval of 25 years (4 percent chance of occurring in any given year). The area inundated was about 10 mi^2 (fig. 3.2-1). However, a levee was built in 1966 in the vicinity of Vega Baja, with the intention of reducing the area inundated by future floods.

The largest known flood of Río de la Plata in the study area occurred in 1928. A peak discharge of 120,000 ft^3/s at Hwy 165 near the Toa Alta bridge was estimated from historical data (Lopez, 1964). The flood of 1899 was probably higher, but the data are insufficient to estimate the discharge. The flood of 1960 was the second largest known, with a peak discharge of 95,500 ft^3/s (table 3.2-3) and a recurrence interval of about 32 years (a 3 percent chance of occurrence in any given year). An area of about 18 mi^2 was flooded in 1960, including the towns of Dorado, Toa Baja, and agricultural areas in the vicinity.

The flooding potential of Río Cibuco and Río de la Plata is an important factor in the selection of areas for agricultural development. Most of the flood plain north and east of Vega Bàja, planned for intense rice cultivation, would be subject to flooding. Depth of flood waters in this area could be as much as 6 to 8 ft. Areas considered for rice cultivation south of Dorado would also be subject to similar flooding.

3.3 Low Flow

MINIMUM FLOWS OF RIO CIBUCO AT VEGA BAJA AND RIO DE LA PLATA AT TOA ALTA OCCUR FROM JUNE THROUGH AUGUST

Monthly minimum 7-day consecutive flows of Río de la Plata are as low as 6.5 cubic feet per second and of Río Cibuco are as low as 7.4 cubic feet per second.

The minimum flow at a selected site of a stream is an important factor for water resources planning and management. The 7-day, 10-year minimum flow is used as an index to determine the capacity of streams to assimilate wastes. Minimum flows also are essential for the proper design of water supply facilities. The frequency of occurrence of selected minimum flows, such as the 1,3,7, 14, and 30-consecutive-day minimum flows are often criteria for design of projects. In agriculture, the design of irrigation facilities must include minimum flow data.

The 7-day, 10-year minimum flow at a specific stream site in Puerto Rico can be obtained from a frequency analysis of 7-day consecutive minimum flows (Cobb, 1978). The technique normally applies to streamsites with a minimum of 10 years of record and with no significant regulation.

The minimum-flow data for Río Cibuco at Vega Baja include only six years of record (1973-78). A preliminary analysis of the data indicates that the 7-day, 10-year minimum flow is about 7.5 ft^3/s (fig. 3.3-1). At Río de la Plata at Toa Alta, the 7-day, 10-year minimum was not determined due to the significant regulation from the La Plata reservoir.

A further insight into the low-flow regimes at the two sites in the study area can be obtained from the monthly variations in the 7-day consecutive minimum flows. Lowest mean daily flows for 1, 3, 7, 14, and 30-consecutive days of Río Cibuco and Río de la Plata are shown in tables 3.3-1 and 3.3-2. At Río Cibuco at Vega Baja the lowest flow during 1, 3, and 7-consecutive days occurred during July. The 14 and 30-days minimum flows were recorded in June. The 1 and 3-consecutive-day minimum flows of Río de la Plata at Toa Alta occurred in August whereas the 7, 14, and 30-consecutive day minimum flows occurred in June (table 3.3-2).

The data from both tables show that low flows are more sustained in the Río Cibuco than in the Río de la Plata. Further reductions in the low flows of Río de la Plata may occur upon completion of the ongoing enlargement of the Río de la Plata reservoir and additional withdrawals for the San Juan metropolitan area. However, low flows possibly could be augmented by increasing releases from the reservoir.

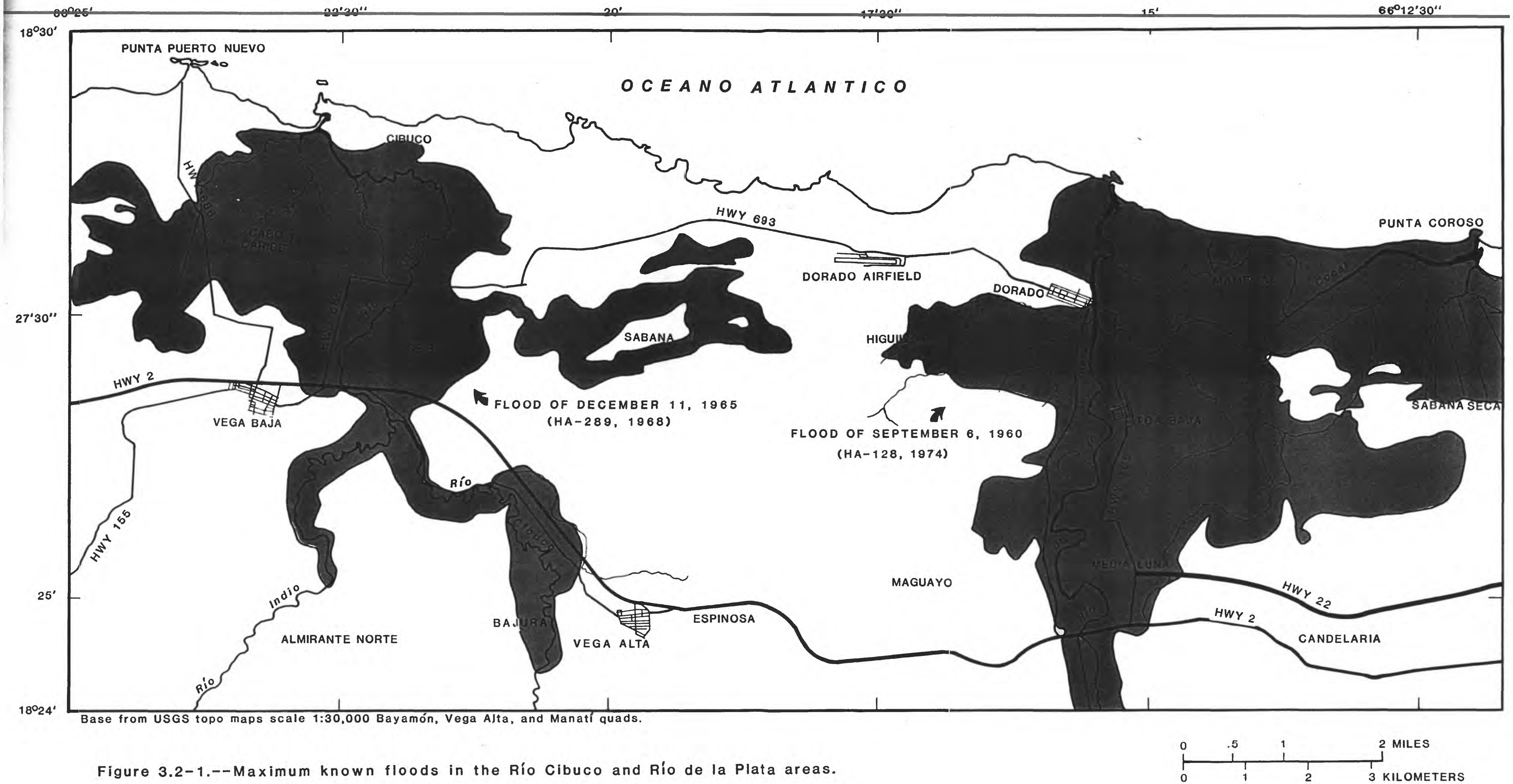


Figure 3.2-1.--Maximum known floods in the Río Cibuco and Río de la Plata areas.
(Refer to tables: 3.2-1, 3.2-2, and 3.3-3)

Table 3.2-1.--Log Pearson Type III flood frequency discharge at Río Cibuco at Vega Baja and Río de la Plata at Toa Alta.

* RECURRENCE INTERVAL (RI), IN YEARS	PEAK DISCHARGE, IN CUBIC FEET PER SECOND	
	RIO CIBUCO AT VEGA BAJA (50039500)	RIO DE LA PLATA AT TOA ALTA (50046000)
2	6600	13,500
10	19,200	58,300
25	28,300	101,000
50	36,500	145,000
100	45,800	202,000

* TO OBTAIN THE PERCENTAGE CHANGE OF OCCURRENCE IN ANY GIVEN YEAR, OBTAIN THE INVERSE OF THE RI AND MULTIPLY BY 100.

Table 3.2-2.--Río Cibuco floods

DATE OF FLOOD	APR. 8, 1915	MAY 4, 1959	SEPT. 6, 1960	DEC. 6, 1961	OCT. 18, 1962	MAY 23, 1963	APR 1964	DEC.11, 1965	APR.20, 1966
ELEVATION ABOVE MEAN SEA LEVEL AT THE DOWN — STREAM SIDE OF HIGHWAY 2, IN METERS	—	7.40	7.26	7.52	—	7.34	< 6.50	8.00	7.83
DISCHARGE, IN CUBIC FEET PER SECOND	—	6800	4600	9100	—	6000	< 2600	28,000	19,000

Table 3.2-3.--Río de la Plata floods

FLOOD ELEVATION REACHED AT HIGHWAY 165 AT TOA ALTA. OVERFLOW LIMITS FOR ONLY THE 1899 AND 1960 FLOODS ARE SHOWN ON THE MAP.

DATE OF FLOOD	AUG 8,1899	AUG 22,1916	SEPT 13,1928	JUNE 16,1943	OCT 14,1943	SEPT 6,1960	AUG 27,1961
ELEVATION ABOVE MEAN SEA LEVEL, IN METERS	13.6	12.8	14.0	13.1	12.1	13.5	12.7
DISCHARGE, IN CUBIC FEET PER SECOND		70,000	120,000	82,000	52,000	95,000	68,000

3.3 Low Flow

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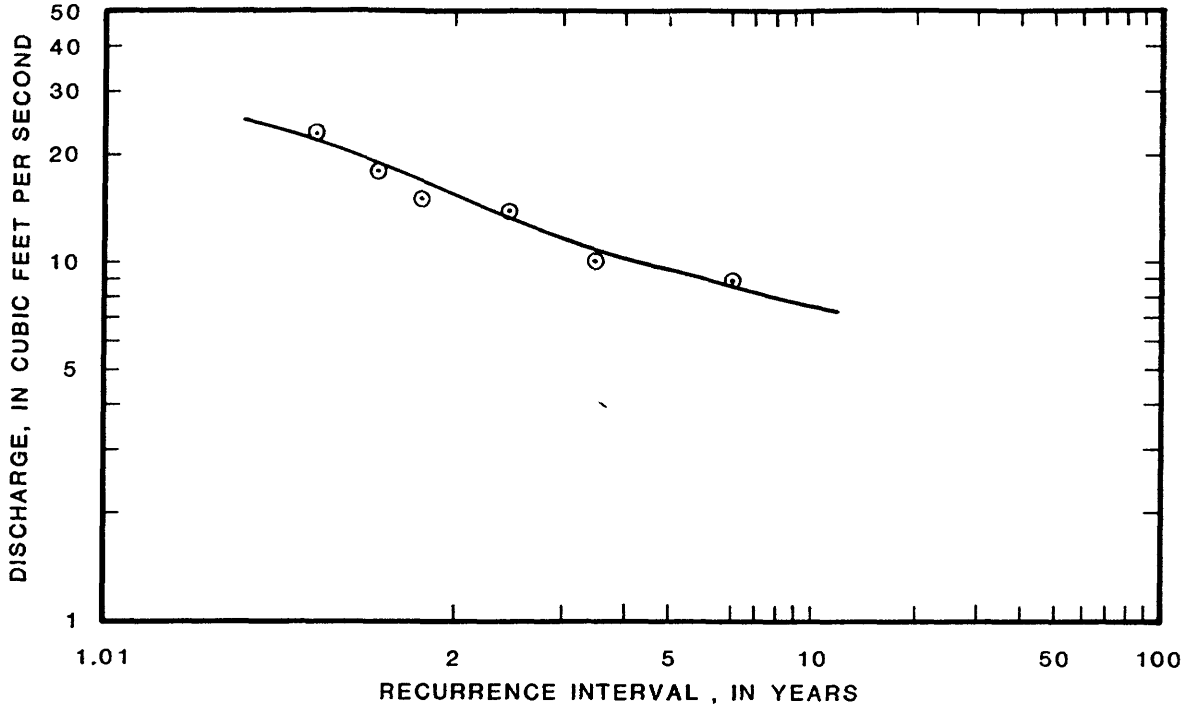


Figure 3.3-1.--7-Day low-flow frecuency of Río Cibuco at Vega Baja.

Table 3.3-1.--Minimum flows of Río Cibuco at Vega Baja.

MONTH	LOWEST MEAN DAILY DISCHARGE FOR THE INDICATED NUMBER OF CONSECUTIVE DAYS, IN FT ^{3}/s — DAYS: 1	3	7	14	30
JAN	27	28	28	29	30
FEB	23	24	26	29	—
MAR	13	13	13	23	27
APR	18	19	22	23	34
MAY	11	11	13	15	25
JUNE	93	9.8	10	11	13
JULY	7.4	7.6	8.5	13	15
AUG	9.2	9.5	10	12	21
SEPT	8.8	11	15	21	36
OCT	22	24	29	34	46
NOV	29	29	30	33	40
DEC	28	32	33	35	48

Table 3.3-2.--Minimum flows of Río de la Plata at Toa Alta.

MONTH	LOWEST MEAN DAILY DISCHARGE FOR THE INDICATED NUMBER OF CONSECUTIVE DAYS, IN FT ^{3}/s — DAYS: 1	3	7	14	30
JAN	11	11	11	14	41
FEB	12	12	14	15	—
MAR	8.4	9.3	13	15	19
APR	9.2	9.5	10	11	15
MAY	8.0	8.1	8.3	9.3	13
JUNE	60	60	6.5	7.6	11
JULY	5.2	6.0	7.0	92	14
AUG	3.4	3.8	8.4	15	16
SEPT	83	8.9	13	23	54
OCT	15	15	17	31	64
NOV	13	13	15	21	47
DEC	14	14	14	16	36

3.4 Flow Duration

FLOWS AT RIO CIBUCO AND RIO DE LA PLATA EXCEED 10 CUBIC FEET PER SECOND ALMOST 95 PERCENT OF THE TIME

Flows of Río Cibuco near Vega Baja are fairly well sustained, with a 90-percent duration of 18 cubic feet per second. Flow regulation and withdrawals have reduced low flows of Río de la Plata at Toa Alta, by two thirds to a 90 percent duration of 12 cubic feet per second.

The streamflow at a given point in a basin is an integration of the effects of climate, topography, and geology. Streamflow provides a distribution of runoff in time and magnitude. This distribution can be expressed by means of a flow duration curve. The duration curve is a cummulative frequency that indicates the percent of the time that a particular value (in this case, streamflow) has been equaled or exceeded. The curve shows no chronological order and applies only to the period of record for which the data were collected. Flow-duration data can be used for comparing flow characteristics of streams. The slope of the curve is a measure of the variability of flow. A steep slope indicates highly variable flow, while a flat slope indicates more sustained flow possibly from ground and surface-water storage.

A flow-duration curve for a particular station usually is based on mean daily discharges for a period of record. This curve, referred as the "period of record curve", provides no insight into seasonal effects on streamflow nor other changes such as flow regulation. Partial-record curves can be derived to study regulation effects. In this type of analysis, the periods before and after regulation are studied independently. The seasonal variation of streamflow can be studied from partial monthly curves, in which the data for individual months for all the years of record are analyzed.

The flow duration data for Río Cibuco at Vega Baja (fig. 3.4-1 and table 3.4-1) indicate fairly sustained but highly variable flows. A discharge of at least 10 ft^3/s is exceeded 99 percent of the time. The 90 percent duration is about 18 ft^3/s. The monthly data show a significant variability in middle flows between the dry and wet seasons. The 50- and 20-percent duration lines (table 3.4-1) illustrate this variability. The importance of the monthly analyses is more significant if the 50 percent duration for the period of record (1973-78) is compared with that for the driest and wettest months. For the period of record the 50 percent duration is about 40 ft^3/s. During November (wet) it is about 110 ft^3/s, while during July (dry) it is about 25 ft^3/s.

The flows of Río de la Plata at Toa Alta are affected by regulation at the Puerto Rico Aqueduct and Sewer Authority reservoir upstream from Toa Alta. Flow duration curves before and after regulation began in 1974 (fig. 3.4-1) show that low and middle flows at the gaging station decreased about two thirds. The after-regulation data of Río de la Plata (table 3.4-2) show that for the period of record (1974-78), 10 ft^3/s is exceeded about 94 percent of the time. However, during the dry June-July months, only about 8 ft^3/s flowed by the gage 90 percent of the time. The variability in the middle flows is more severe than that of Río Cibuco. The 50 percent duration of Río de la Plata during July (dry) was about 23 ft^3/s. During November (wet) the same duration was about 460 ft^3/s.

Table 3.4-1.--Flow-duration at Río Cibuco at Vega Baja (for period of record and by individual months, 1973-78).

FLOW, IN CUBIC FEET PER SECOND ≧	* PERCENT OF TIME 1973-78	PERCENTAGE OF TIME FLOW WAS EQUALED OR EXCEEDED FOR THE MONTH INDICATED											
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
7.4	100	100	100	100	100	100	100	100	100	100	100	100	100
10	99.3	100	100	100	100	100	96	93	97	99	100	100	100
21	85.6	100	100	96	98	77	58	62	68	84	100	100	100
30	70.9	89	92	87	69	62	45	37	45	66	86	98	99
42	51.4	73	67	57	48	53	20	6.2	31	37	55	79	77
50	43.3	60	55	44	44	42	13	3.5	23	27	50	70	67
60	35.1	51	21	30	37	35	6.7	2.7	18	23	43	65	55
85	22.6	29	17	16	27	16	1.0	0.5	13	14	26	58	45
100	18.6	21	8.3	13	23	9.1	0.6	0.5	12	13	23	54	44
140	12.4	10	2.5	6.5	18	4.8	0.0	0.0	5.4	8.3	19	42	33
200	7.9	3.0	0.6	3.0	10	1.4	.0	.0	5.4	5.2	13	26	18
290	4.5	1.6	0.5	1.1	8.3	0.5	.0	.0	2.7	3.3	11	18	12
410	2.3	0.5	0.5	0.0	5.0	0.0	.0	.0	2.1	1.6	7.7	7.3	6.4
580	1.3	0.0	0.0	.0	3.5	.0	.0	.0	1.0	0.5	5.0	3.0	5.2
820	0.6	.0	.0	.0	2.5	.0	.0	.0	0.0	0.0	4.2	2.0	1.0
1200	0.2	.0	.0	.0	2.2	.0	.0	.0	.0	.0	1.9	0.6	0.0

NOTE: 90, 50 AND 20 PERCENTAGE DURATIONS INDICATED BY LINES ON MONTHLY DATA.

Table 3.4-2.--Flow-duration at Río de la Plata at Toa Alta after regulation began, 1974-78 (for indicated period and by individual months).

FLOW, IN CUBIC FEET PER SECOND ≧	* PERCENT OF TIME 1974-78	PERCENTAGE OF TIME FLOW WAS EQUALED OR EXCEEDED FOR THE MONTH INDICATED											
		JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
3.4	100	100	100	100	100	100	100	100	100	100	100	100	100
4.5	99.7	100	100	100	100	100	100	100	98	100	100	100	100
5.9	99.3	100	100	100	100	100	100	99	96	100	100	100	100
7.8	97.6	100	100	100	100	100	88	90	95	100	100	100	100
10	94.2	100	100	99	94	87	76	79	94	98	100	100	100
13	89.0	95	98	91	85	77	71	72	92	97	100	100	100
18	81.0	93	87	85	77	66	59	58	74	92	96	95	90
23	73.2	87	81	76	66	56	54	52	66	82	93	92	87
31	63.0	78	78	69	53	50	38	24	46	72	84	83	85
41	53.0	74	65	62	44	46	18	15	34	61	80	78	82
53	43.5	70	55	48	37	38	8.7	8.6	30	44	75	78	80
70	36.5	60	39	36	34	21	4.0	6.0	21	36	64	73	79
93	30.0	47	30	24	29	14	2.0	3.3	15	29	47	70	78
120	25.0	33	21	12	27	10	0.0	1.3	12	25	40	68	75
160	20.5	20	14	5.2	19	7.7	.0	0.0	7.1	19	31	65	68
280	13.0	7.7	3.5	2.6	7.3	2.5	.0	.0	3.9	10	21	58	48
480	7.6	3.2	0.7	2.0	4.6	0.6	.0	.0	2.5	5.8	16	48	25
840	4.3	0.0	0.0	0.0	3.0	0.0	.0	.0	1.2	2.5	10	33	10
1500	1.6	.0	.0	.0	1.2	.0	.0	.0	0.0	0.8	3.5	12	4.0
2200	0.7	.0	.0	.0	0.0	.0	.0	.0	.0	0.0	3.0	4.0	2.0

: 90, 50 AND 20 PERCENTAGE DURATIONS INDICATED BY LINES ON MONTHLY DATA.

* FLOW WAS EQUALED OR EXCEEDED IN PERIOD OF RECORD

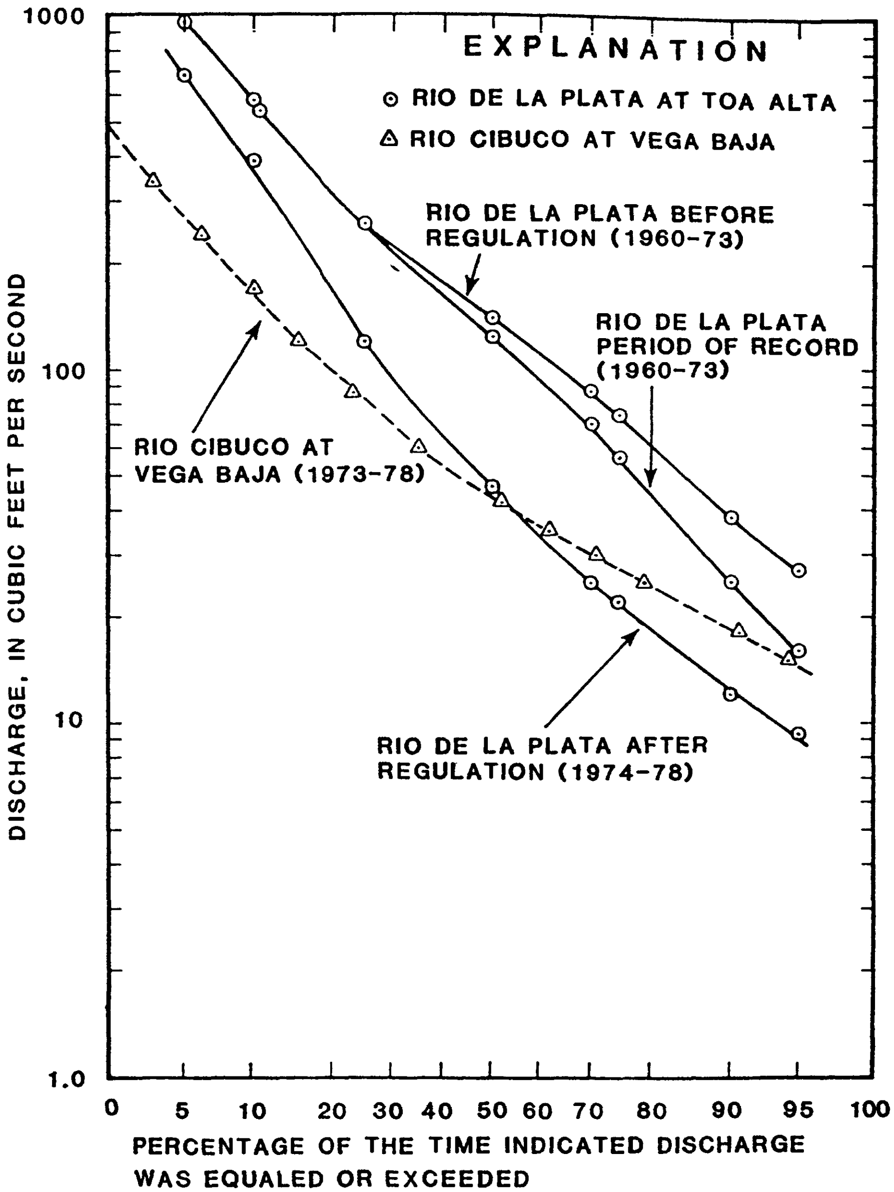


Figure 3.4-1.--Flow-duration curves for Río Cibuco at Vega Baja and Río de la Plata at Toa Alta.

4.0 GROUND WATER

4.1 Occurrence

ALLUVIAL AND CAVERNOUS LIMESTONE AQUIFER SYSTEM UNDERLIES STUDY AREA

A water-table aquifer system, possibly underlain by a deep artesian system, is present in the Sabana Seca to Vega Baja area. The northward movement of water to the sea is controlled locally by orientation of solution cavities in the limestone.

An unconfined or water-table aquifer system, composed primarily of the Aguada Limestone, Aymamón Limestone, and alluvial, dune, and blanket deposits, is present throughout the study area. Locally confined (artesian) conditions exist in the Aymamón Limestone in the coastal part of the Río Cibuco valley. This is due to overlying alluvial silt and clay deposits. Similar conditions may exist elsewhere in the area.

Although unverified by drilling, water is believed to occur in the deeper Lares Limestone and Cibao Formation. Such water may be in hydraulic continuity with the overlying water-table system, in which case it is probably saline. It may also be a separate freshwater confined system under high artesian pressure as in the Barceloneta area. At present no information on yield, pressure, or aquifer characteristics is available for the deeper formations.

In general, water in the alluvium, dune, and blanket deposits occurs in intergranular pore spaces, and water in the limestones occurs in fractures and solution channels (fig. 4.1-1; 4.1-2). Although ground-water movement in cavernous limestones is locally controlled by orientation of solution-formed channels, its general direction is north--from the mountains to the Atlantic Ocean (Giusti, 1978).

Depth to water in the water-table system ranges from 16 to 20 ft below land surface in wells near Toa Baja and Higuillar to about 100 to 120 ft in wells drilled in the limestone near Highway 2. At present only the water-table aquifer and the locally confined aquifer in the Río Cibuco valley are developed.

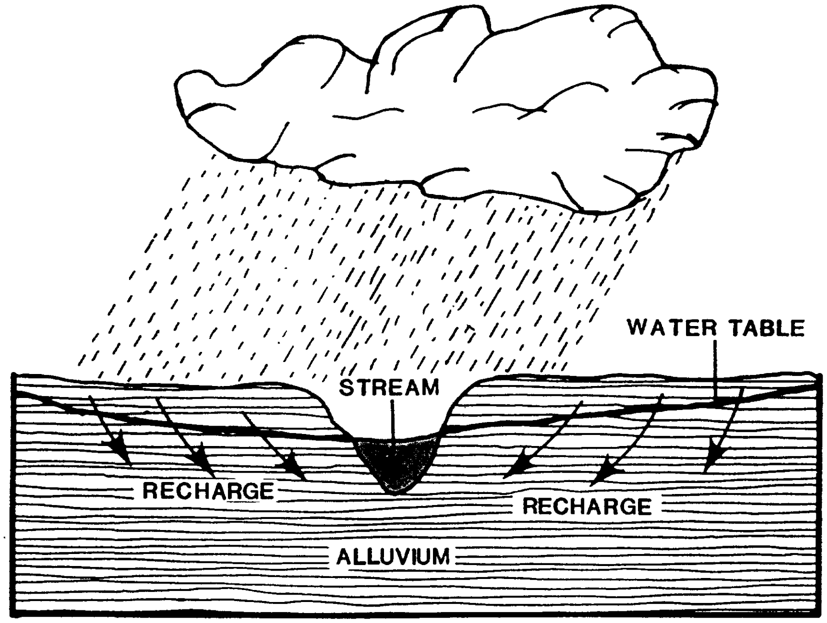


Figure 4.1-1.--Water movement in alluvial aquifers.

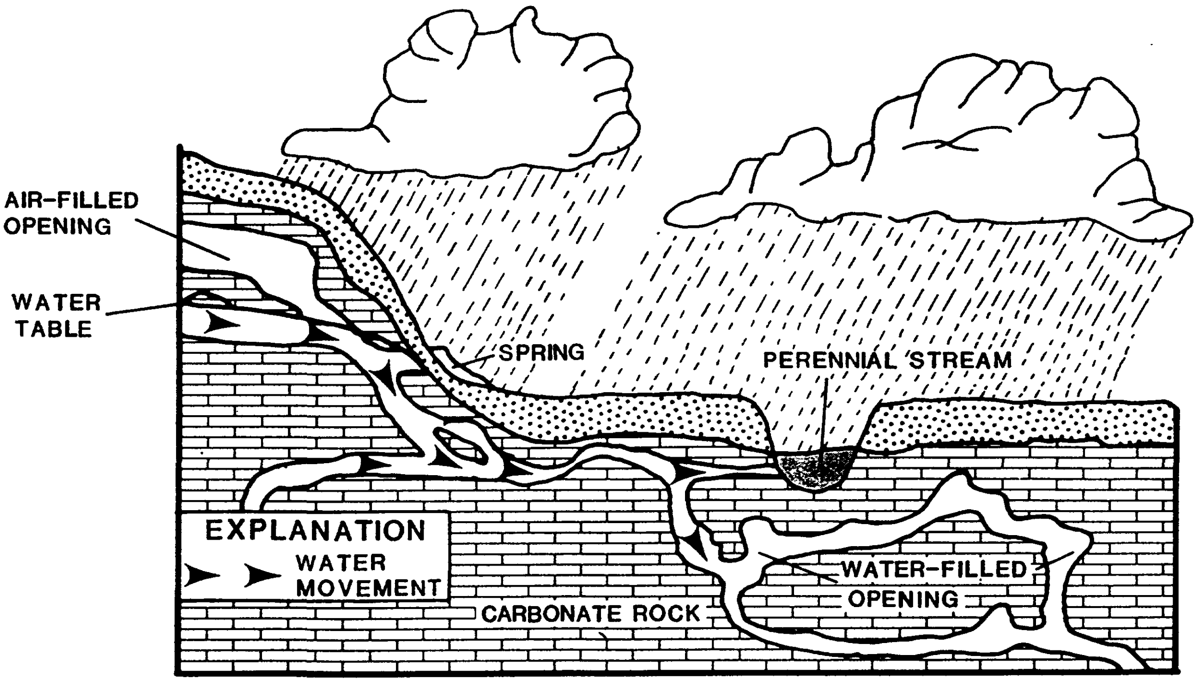


Figure 4.1-2.--Water movement in cavernous aquifers.

4.0 GROUND WATER (Continued)

4.2 Aquifer Characteristics

AQUIFER CHARACTERISTICS VARY WITH LOCATION

Specific capacities of wells within the study area indicate that cavernous conditions in the limestone aquifer are localized.

Aquifer characteristics useful in understanding how an aquifer responds to stresses are transmissivity (T) and storage coefficient (S). The transmissivity of an aquifer is defined as the rate of flow of water at the prevailing kinematic viscosity (u) through a unit width of the aquifer and extending the full saturated thickness of the aquifer under a unit hydraulic gradient. The storage coefficient of an aquifer is the volume of water that is released from or taken into storage per unit change in head per unit surface area of the aquifer. These characteristics can be computed from mathematical analysis of aquifer tests and from laboratory tests of aquifer materials. Transmissivity can also be estimated from the specific capacity (well discharge per unit drawdown) (Heath, 1980).

Storage coefficients in the water-table aquifer of the study area range from about 0.01 to 0.05 in the limestone, and 0.1 or higher in the alluvium. Where local artesian conditions exist in the limestone, storage coefficients could be in the order of 0.001. Transmissivities higher than 100,000 ft^2/d are not unusual in cavernous limestone and range from 100 to 10,000 ft^2/d in the alluvium of Río Cibuco and Río de la Plata valleys.

An aquifer test was conducted in a locally confined, limestone artesian aquifer near the Río Cibuco with one pumping well and 4 observation wells (fig. 4.2-1 and 4.2-2). The pumping and observation wells were open to the sand, gravel, and limestone deposits in the area (fig. 4.2-2). The test lasted 16 days. Drawdown curves corrected for tidal changes are shown in figure 4.2-3. Drawdown in the test well, pumped at 1,800 gal/min, reached 4.3 ft in the first 2 minutes and remained essentially constant. Data from the observation wells indicate a shallow, nearly flat, cone of depression with a maximum drawdown of 0.45 ft at 80 ft from the pumped well, and 0.3 ft at a distance of 860 ft. After 16 days of continuous pumping, the water level throughout the cone of depression was dropping at a rate of less than 0.01 ft/d. The extremely low rate of water-level decline is due to cavernous conditions of the limestone at that specific site. The transmissivity obtained from the test, 200,000 ft^2/d, is not representative of the aquifer in general. Specific capacities for other wells in the area (fig. 4.2-1) indicate that such cavernous conditions are localized. The Cibuco test does indicate, however, the high production potential of the aquifer in cavernous areas. Individual aquifer tests at other locations in the study area are needed to define local aquifer characteristics.

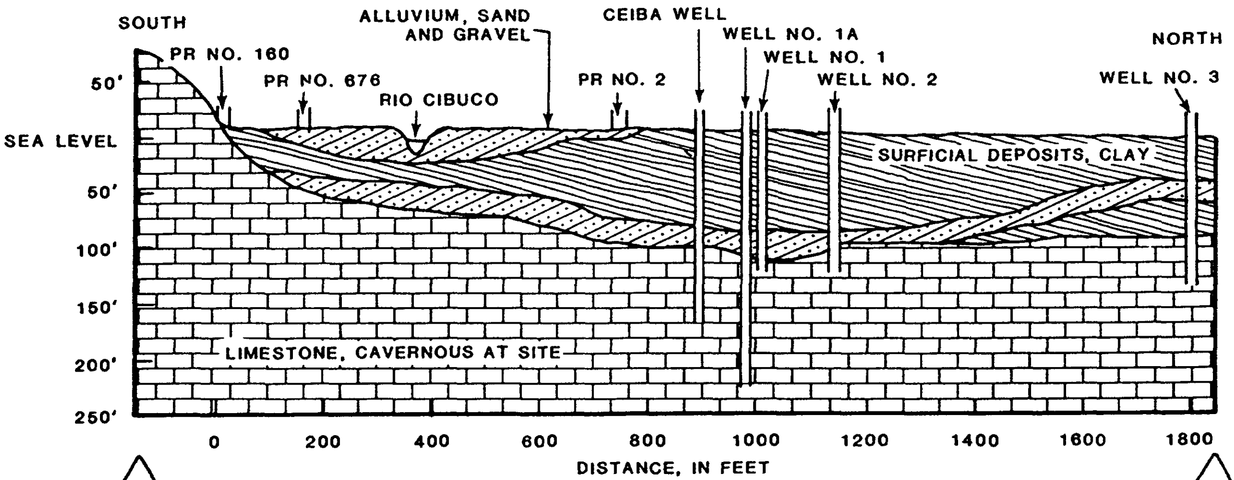


Figure 4.2-2.--Vertical section of observation wells and pumping well of the Cibuco aquifer test.

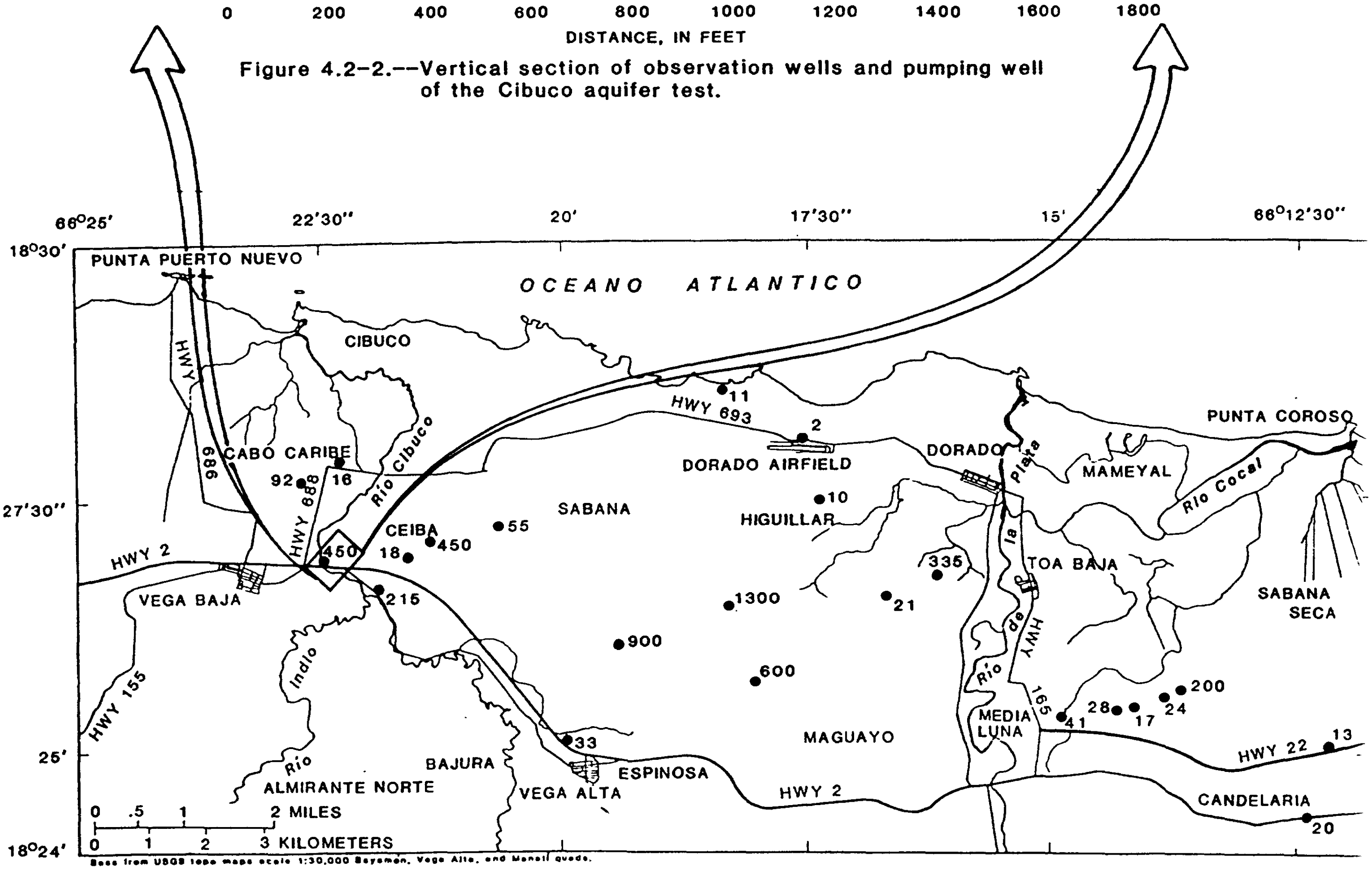


Figure 4.2-1.--Location of Cibuco aquifer test and specific capacity values, in gallons per minute per feet of drawdown, for selected wells (•).

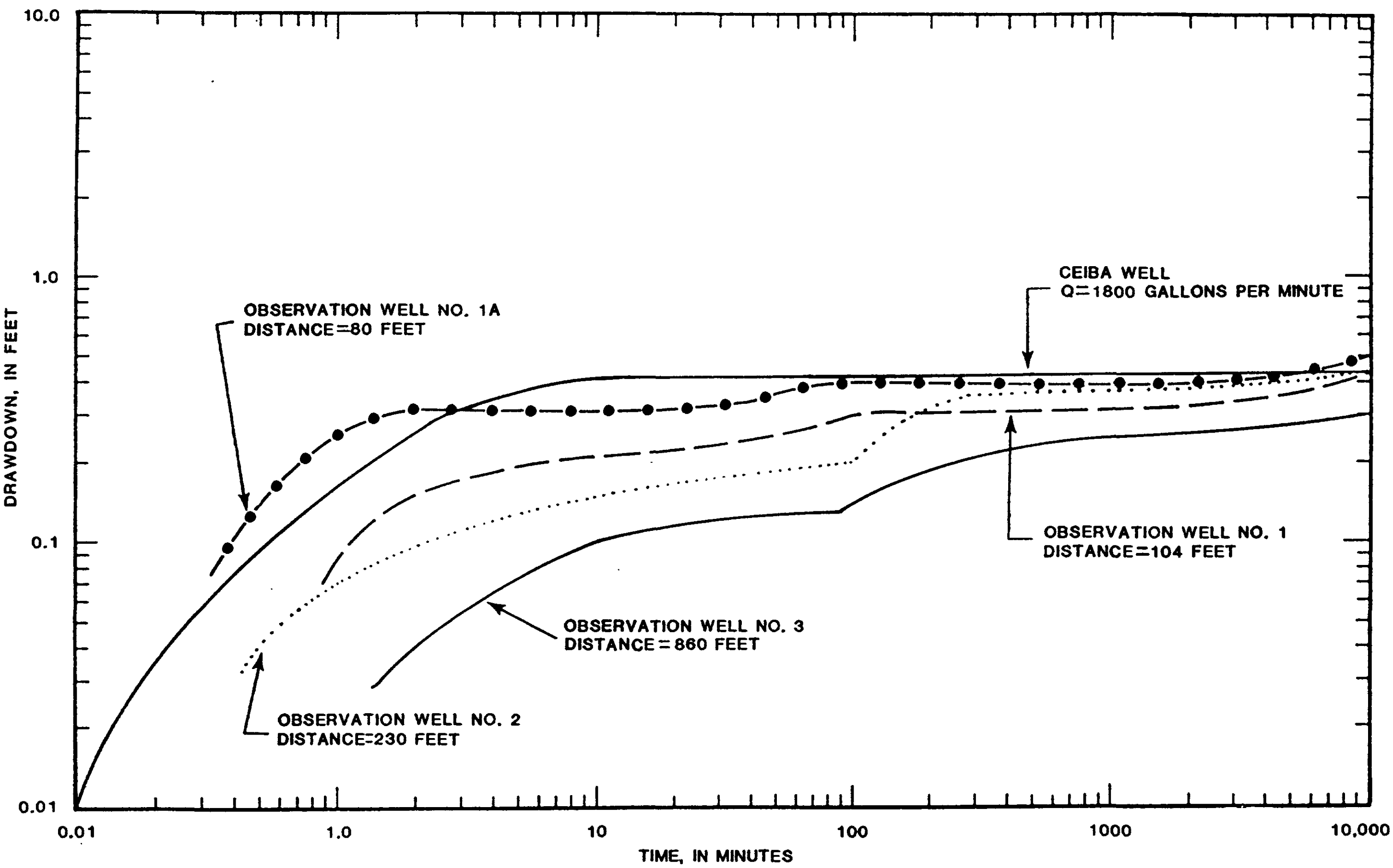


Figure 4.2-3.—Drawdown curves at Ceiba well and observation wells 1A, 1, 2, and 3.

4.3 Ground-water flow

AT LEAST 19 MILLION GALLONS PER DAY OF GROUND WATER FLOW SEAWARD THROUGH STUDY AREA

Aquifer characteristics based on non-cavernous conditions are used to compute volume of underflow in the water-table aquifer between Sabana Seca and Vega Baja.

Estimates of ground-water flow through the water-table aquifer in the study area (figure 4.3-1) were made from Darcy's law using the potentiometric gradient near Highway 2 and the transmissivity computed from hydraulic conductivities (Giusti and Bennett, 1976). Transmissivity values are for noncavernous limestones and are considered conservative. A thickness of 200 ft was assumed for the fresh-water zone. The discharges for different sectors of the area (table 4.3-1) were estimated as follows:

$$Q = TIL$$

Where Q = Flow, in cubic feet per day
T = Transmissivity, in feet squared per day
I = Gradient of potentiometric surface (dimensionless)
L = Width of aquifer under consideration, in feet

Dorado-Sabana Seca sector, 3 mi wide, gradient [1/] 0.003

$Q = 13{,}400 \times 0.003 \times 5280 = 212{,}250\ (ft^3/d)/mi\ (1.6\ (Mgal/d)/mi)$
$Q_{D-SS} = 1.6\ (Mgal/d)/mi \times 3\ mi = 4.8\ Mgal/d$

Vega Alta-Dorado sector, 5 mi wide, gradient [1/] 0.003

$Q = 13{,}400 \times 0.003 \times 5280 = 212{,}250\ (ft^3/d)/mi\ (1.6\ (Mgal/d)/mi)$
$Q_{VA-D} = 1.6\ (Mgal/d)/mi \times 5\ mi = 7.9\ Mgal/d$

Vega Baja-Vega Alta sector, 3.5 mi wide, gradient [2/] 0.00076

$Q = 54{,}000 \times 0.00076 \times 5280 = 216{,}700\ (ft^3/d)/mi\ (1.6\ (Mgal/d)/mi)$
$Q_{VB-VA} = 1.6\ (Mgal/d)/mi \times 3.5 = 5.7\ Mgal/d$

The average ground-water flow through a section one mile wide is about 213,000 ft^3/d. Total flow in the 11.5 mile section is about $2.5 \times 10^6\ ft^3/d$ or 18.3 Mgal/d (Fig. 4.3-2).

These estimates are based on flow in a non-cavernous limestone, and are therefore considered conservative. Actual flow may be greater than the above estimates.

1/ From Anderson (1976), gradient in Aguada Limestone east of Dorado.
2/ From Giusti and Bennett (1976), gradient in Aymamón Limestone in Vega Baja-Vega Alta area.

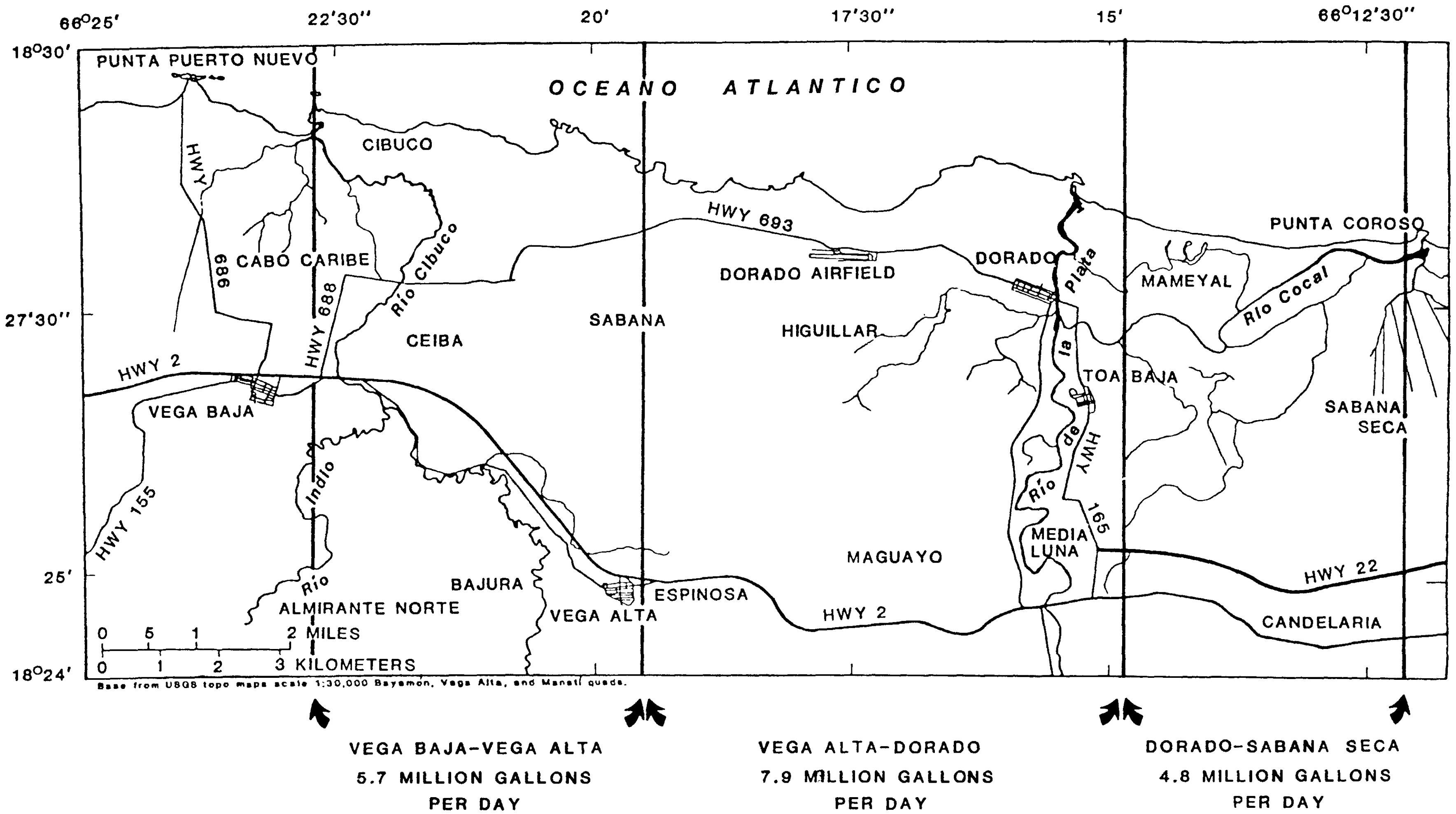


Figure 4.3-1.--Computed ground-water flow through sections, Sabana Seca to Vega Baja.

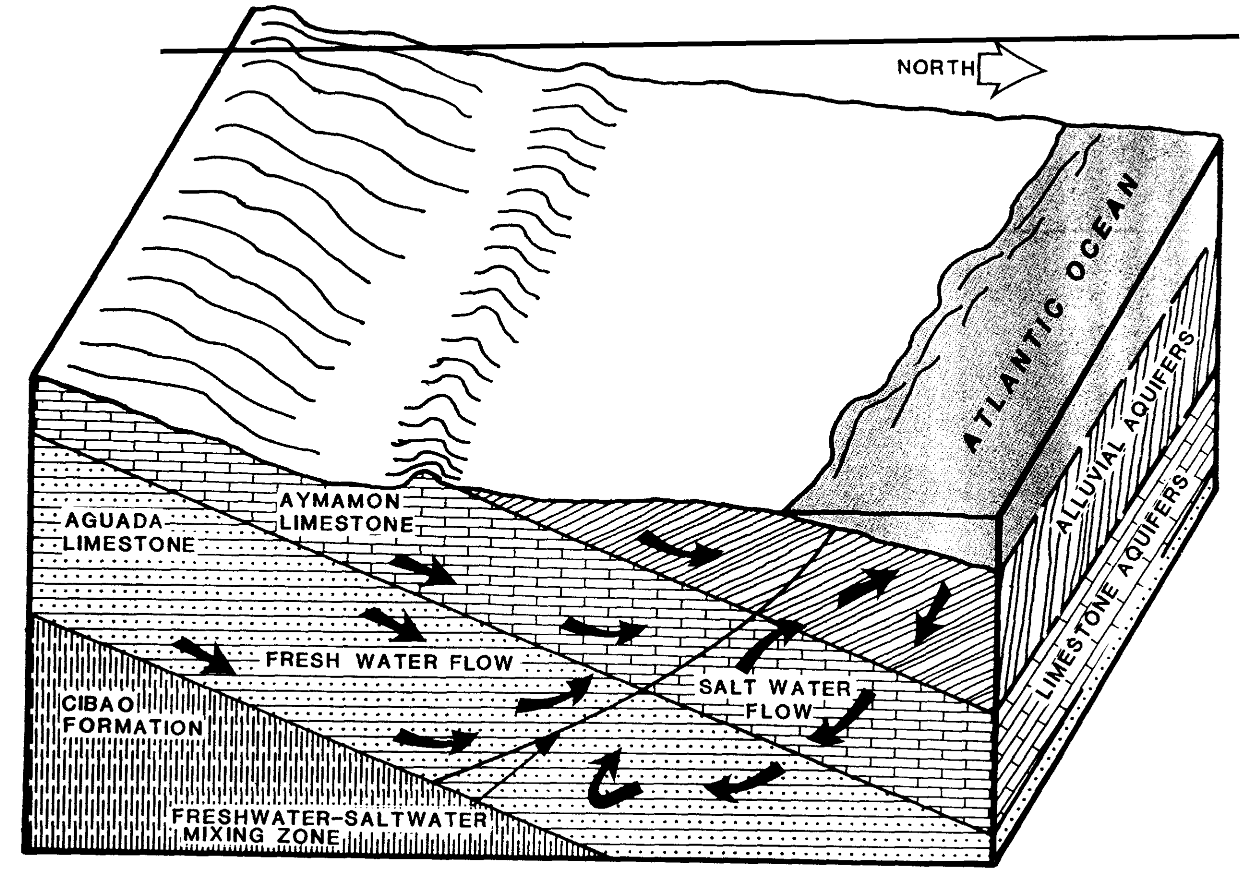


Figure 4.3-2.--Generalized ground-water flow in water-table aquifer.

Table 4.3-1.--Aquifer characteristics and computed ground-water flows through sections between Sabana Seca and Vega Baja.

SECTION	HYDRAULIC CONDUCTIVITY, IN FEET PER DAY (K)	THICKNESS OF FRESH-WATER ZONE, IN FEET	TRANSMISSIVITY, IN FEET SQUARED PER DAY (T)	HYDRAULIC GRADIENT (I)	WIDTH OF SECTION, IN FEET (L)	FLOW, IN MILLION GALS. PER DAY (Q)
DORADO-SABANA SECA	67	200	13,400	0.003	15,840	4.8
VEGA ALTA-DORADO	67	200	13,400	0.003	26,400	7.9
VEGA BAJA-VEGA ALTA	270	200	54,000	0.00076	18,480	5.7

4.4 Yields to wells

HIGHER YIELDS OBTAINED IN WESTERN PART OF THE STUDY AREA

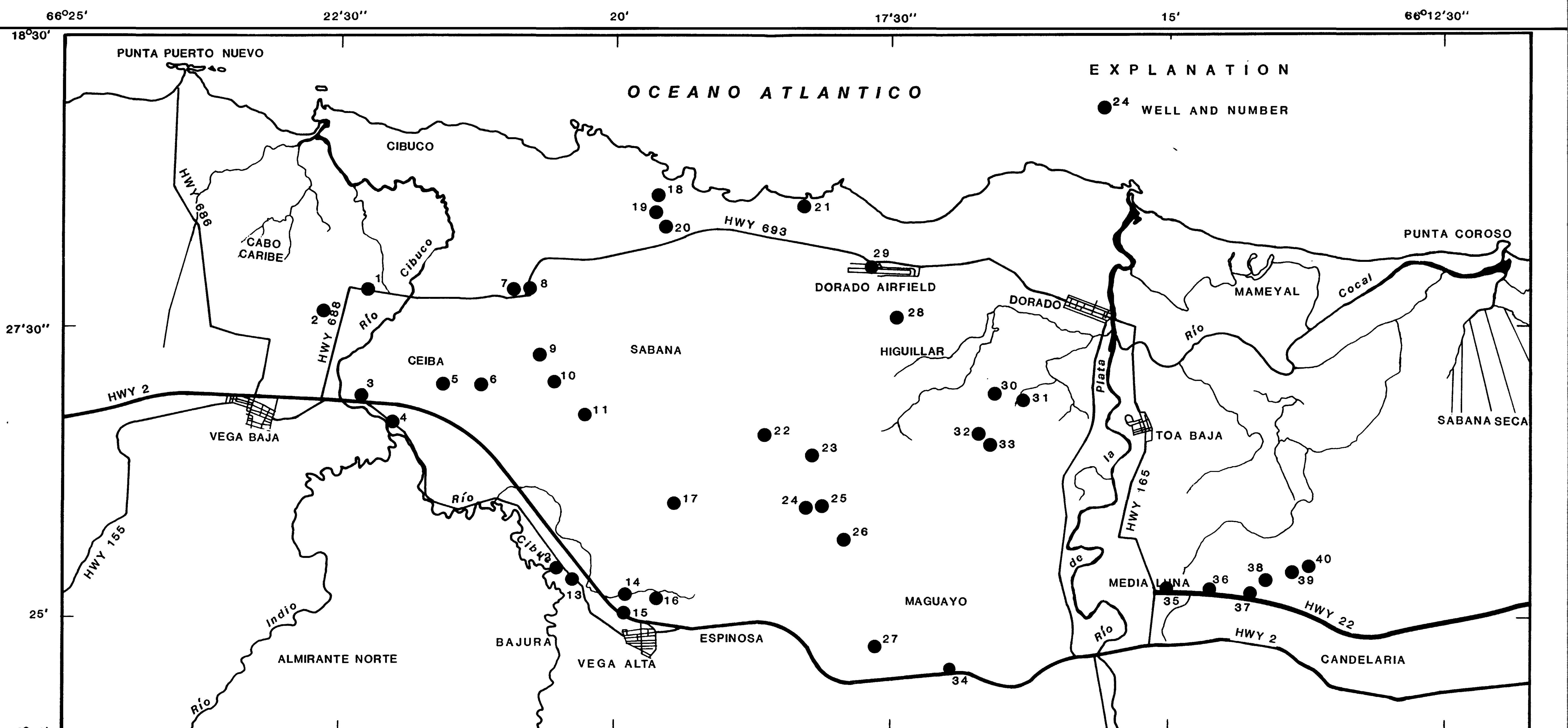
Yields to wells in the Sabana Seca to Vega Baja Area are highly variable and range from 10 to 4,000 gallons per minute. Yields from alluvial deposits are less than those from cavernous limestones.

Yields to wells tapping the Aymamón and underlying Aguada Limestones anywhere in the north coast area are variable because water in the limestone occurs in fractures and solution cavities. Yields between Vega Baja and Toa Baja range from 10 to 4,000 gal/min. Yields of 600 to 1,000 gal/min can be obtained between Campanilla and Sabana Seca.

The yields of alluvium and terrace deposits are also variable, depending on the thickness and grain size. Wells drilled in coarse alluvium of Río Cibuco valley yield as much as 300 gal/min, whereas the finer alluvium in the Río de la Plata valley yield less than 150 gal/min.

Beach and dune deposits usually contain saline water, but in some areas the wells in these deposits yield small quantities of potable water. The blanket deposits where underlain by impermeable beds may contain perched fresh water.

Data on yields of drilled wells are commonly obtained from well drillers whose figures often are based on short pumping tests. The tests are usually run for only a few hours, so long-term yields and water-level changes are not known. The reported yield of a well frequently is not a good measure of its capacity, nor of the characteristics of the aquifer. The reported capacity of a well may be affected by well construction and pump characteristics. Yields to wells must be accepted and used with understanding of the potential possible limitations involved. Yields to wells in the study area (fig. 4.4-1) are shown in table 4.4-1.



Base from USGS topo maps scale 1:30,000 Bayamón, Vega Alta, and Manatí quads.

Figure 4.4-1.--Location of wells in the Sabana Seca to Vega Baja area.

Table 4.4-1.--Depth, diameter, yield, and general water-quality characteristics of wells in the Sabana Seca-Vega Baja area.

WELL NO. ON MAP	DEPTH (FEET BELOW LAND SURFACE)	DIAMETER (INCHES)	YIELD (GALS PER MINUTE)	WATER-QUALITY
1	140	16	1000	FRESHWATER
2	150	16	1200	DO
3	175	12	1500-4000	DO
4	168	12	1500	DO
5	160	16	1000	DO
6	120	12	950-1500	DO
7	70	8	1500	DO
8	80	7	60	DO
9	—	—	300	DO
10	111	12	600	DO
11	94	8	360	DO
12	—	—	325	DO
13	148	12	450	DO
14	—	—	350	DO
15	210	12	500	DO
16	—	—	350	DO
17	350	12	600	DO
18	124	6	8	SALTYWATER
19	85	6	8	DO
20	84	6	8	DO
21	240	10	500	DO
22	250	10	100	FRESHWATER
23	400	12	650	DO
24	180	10	300	DO
25	200	10	400	DO
26	350	10	500	DO
27	800	12	300	DO
28	115	14	300	DO
29	98	8	75	DO
30	—	—	800	DO
31	86	12	1000	DO
32	200	10	150	DO
33	85	8	150	DO
34	303	10	225	DO
35	165	12	1200	DO
36	>200	12	800	FRESHWATER-SALTYWATER
37	160	16:12	1040	DO
38	155	16:12	1040	DO
39	—	—	600	FRESHWATER
40	70	6	500	DO

4.5 Water Levels

WATER LEVELS HAVE DECLINED ABOUT 7 FEET IN THE LAST 8 YEARS

The decline is probably in response to ground-water withdrawals. Water levels are also affected by recharge from rainfall.

Water levels are important where a stream channel is in direct contact with an aquifer. The stream may either lose water to, or gain water from, the aquifer depending on the relative elevations of the surface- and ground-water levels. Ground-water levels may also be used to determine flow direction and changes in the amount of water in storage in an aquifer. In coastal aquifers a knowledge of the ground-water surface elevation relative to mean sea level can help define the depths of the fresh-salt water mixing zone (see section 5.2-2).

Water levels in the study area range from 0 to 200 ft above mean sea level (fig. 4.5-1). In the western part along Río Cibuco Valley, the nearly flat water-level gradients indicate the high permeability of the Aymamón Limestone. The gradient, however, steepens to the east because the water-bearing formation in this part of the area (Aguada Limestone) is much less permeable. Water levels in between reflect the transitional change in geology from the Aymamón Limestone to the Aguada Limestone (fig. 2.1-1).

Water levels in the study area are affected by recharge from rainfall and ground-water withdrawals (fig. 4.5-2). Water levels in observation wells fluctuated as much as 10 ft at Campanillas and 6 ft at Sabana Hoyos. In 1979, as a result of excessive rainfall from hurricane David and tropical storm Frederick, ground-water levels increased from 5 to 10 ft. However, within the following year most of the gain had been lost. Water levels declined about 7 ft at both sites from 1971 to 1978, probably in response to regional pumpage.

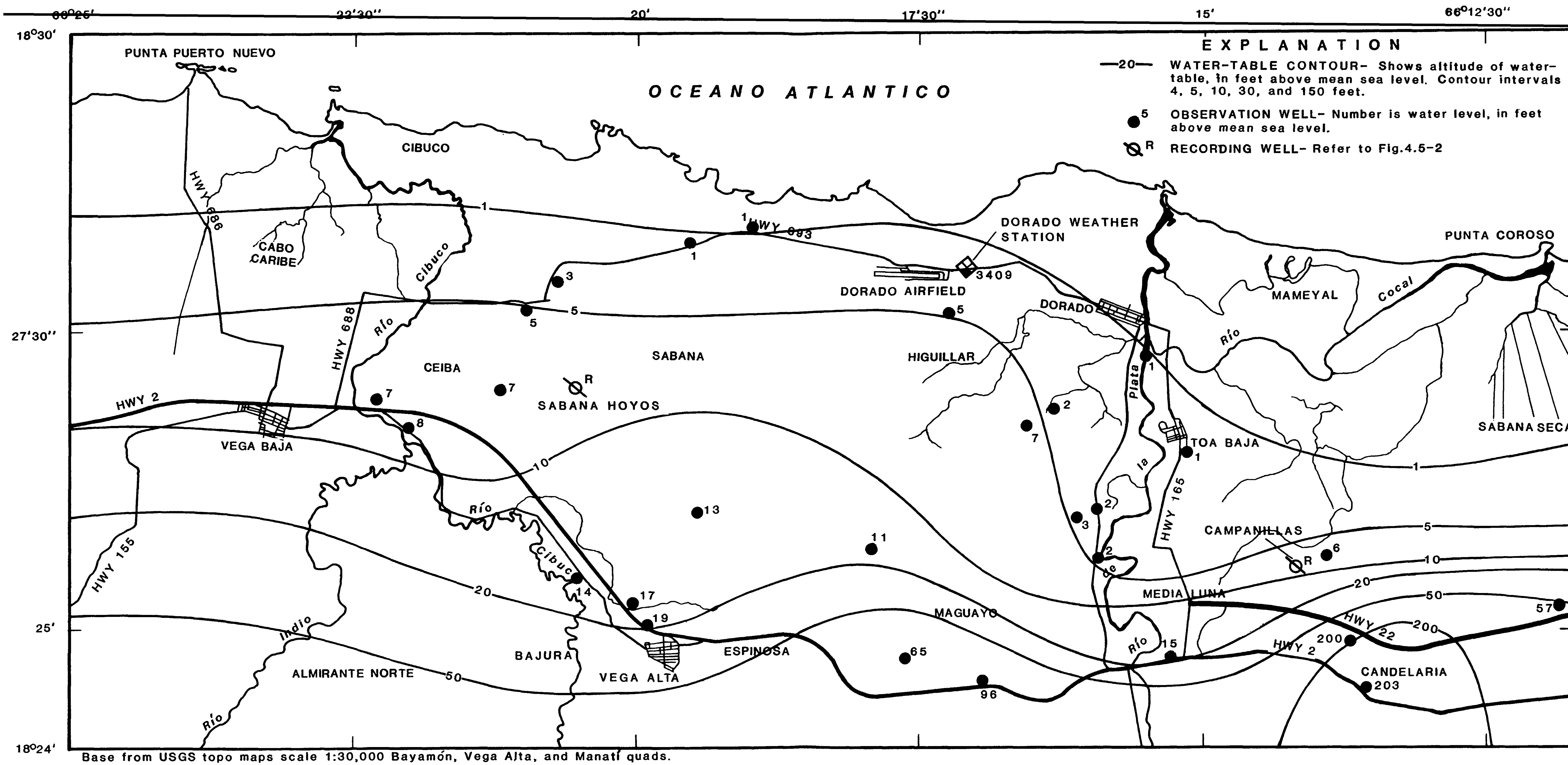


Figure 4.5-1.--Generalized water-table configuration in the Sabana Seca to Vega Baja area.

RAINFALL, DEPTH TO WATER, IN FEET

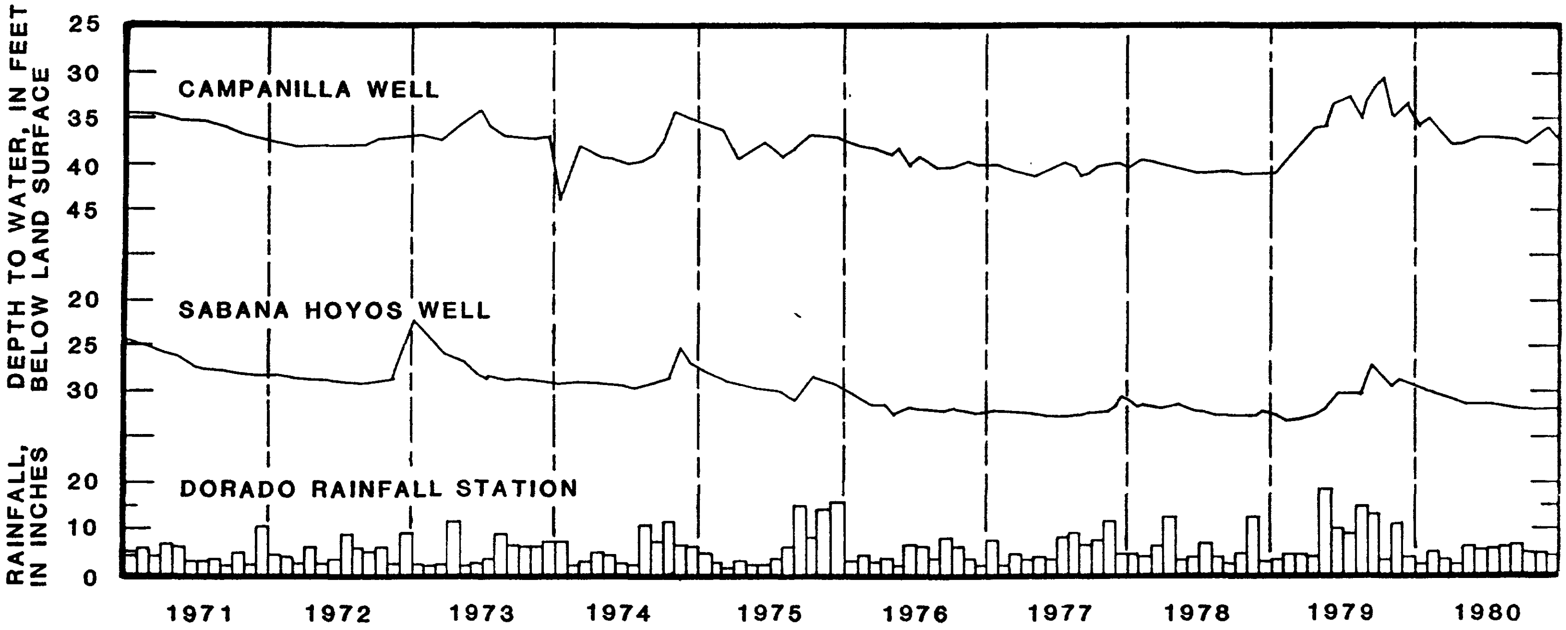


Figure 4.5-2.--Hydrographs of observation wells Campanilla and Sabana Hoyos and Rainfall at Dorado station.

5.0 QUALITY OF WATER

5.1 Surface Water

5.1-1 Chemical, Physical and Bacteriological Characteristics

QUALITY OF WATER FROM RIO CIBUCO AND RIO DE LA PLATA IS VERY SIMILAR

Geology is the major natural influence affecting the chemical characteristics of surface water in the area.

The geology upstream from the study area is the principal factor in the chemical characteristics of waters in the major streams. Water in drainage canals is affected by sea-water intrusion. Streams flowing into the area show physical and chemical characteristics typical of waters from the limestone formations to the south. These waters contain large amounts of dissolved carbonate salts; chiefly calcium carbonate, and high alkalinity and hardness values.

The chemical and physical characteristics of waters of Río Cibuco at Vega Baja and Río de la Plata at Toa Alta are very similar (Table 5.1-1-1, 5.1-1-2 and fig. 5.1-1-1). Calcium and bicarbonate are the principal ions. Dissolved solids range from about 130 to 325 mg/L at both streams. Sodium concentrations range from about 6 to 40 mg/L. Chloride concentrations, although usually not exceeding 40 mg/L, occasionally are as great as 70 mg/L in the Río De La Plata. The waters range from hard to very hard, are slightly alkaline, and are suitable for most uses, including irrigation.

Fecal coliform concentrations at Río Cibuco at Vega Baja range from 200 to 9,000, with an average of about 3,600 colonies/100 mL. At Río de la Plata, the range is from 53 to 26,000, with an average of 8,000 colonies/100 mL sample. These bacteria concentrations are typical of streams receiving human and animal fecal wastes.

Table 5.1-1-1.--Chemical and physical characteristics of Río Cibuco at Vega Baja P.R. 50039500 (1972-79)

ALL ANALYSES IN MILLIGRAMS PER LITER EXCEPT AS INDICATED. COLIFORMS, IN COLONIES PER 100 MILLILITER OF SAMPLE.

CONSTITUENT	MINIMUM	MAXIMUM	MEAN	* 90th PERCENTILE
pH, FIELD	6.5	7.9	7.4	7.7
SPECIFIC CONDUCTANCE, IN MICRO-MHOS PER CENTIMETER AT 25°C	302	550	404	460
TEMPERATURE,°C	22	31	25.6	28
RESIDUE SUSPENDED,@180°C	222	266	250	263
CALCIUM, TOTAL	44	64	56.1	61.2
MAGNESIUM, TOTAL	7.9	11	9.1	9.8
SODIUM, DISSOLVED	11	21	15.7	19
BICARBONATE	150	215	201	224
CHLORIDE, DISSOLVED	16	31	22.3	27
FLUORIDE, DISSOLVED	0.10	0.8	0.18	0.2
SULFATE, DISSOLVED	99	27	15.9	21
NITROGEN, TOTAL AS No_3	1.5	3.7	2.7	3.5
PHOSPHORUS, TOTAL AS P	0.10	0.6	0.3	0.4
IMMEDIATE COLIFORM	2800	1,700,000	77,000	160,000
FECAL COLIFORM	200	9000	3600	6180
FECAL STREPTOCOCCI	500	3100	1800	2900

* PERCENTAGE OF THE TIME INDICATED VALUE WAS EQUAL OR LESS.

Table 5.1-1-2.--Chemical and physical characteristics of Río de la Plata at Toa Alta,P.R. 50046000 (1958-79)

ALL ANALYSES IN MILLIGRAMS PER LITER EXCEPT AS INDICATED. COLIFORMS, IN COLONIES PER 100 MILLILITERS OF SAMPLE

CONSTITUENT	MINIMUM	MAXIMUM	MEAN	* 90th PERCENTILE
pH, FIELD	6.5	8.5	7.5	8.0
SPECIFIC CONDUCTANCE, IN MICRO-MHOS PER CENTIMETERAT 25°C	195	1400	889	550
TEMPERATURE,°C	20	32	26.7	29
RESIDUE SUSPENDED,@180°C	120	4100	230	3000
CALCIUM, TOTAL	14	87	38	55
MAGNESIUM, TOTAL	17	20	12	15
SODIUM, DISSOLVED	6.2	40	20	27
BICARBONATE	20	298	168	224
CHLORIDE, DISSOLVED	10	96	26.7	39.7
FLUORIDE, DISSOLVED	0.0	1.3	0.2	0.3
SILICA, DISSOLVED	8.3	30	21	26
SULFATE, DISSOLVED	8.0	32	15.5	18
NITROGEN, TOTAL AS No_3	0	3.2	0.6	2.3
PHOSPHORUS, TOTAL AS P	0.02	0.7	.13	0.27
IMMEDIATE COLIFORM	200	920,000	54,000	120,000
FECAL COLIFORM	53	26,000	8000	20,000
FECAL STREPTOCOCCI	32	42,000	4100	6100

* PERCENTAGE OF THE TIME INDICATED VALUE WAS EQUAL OR LESS.

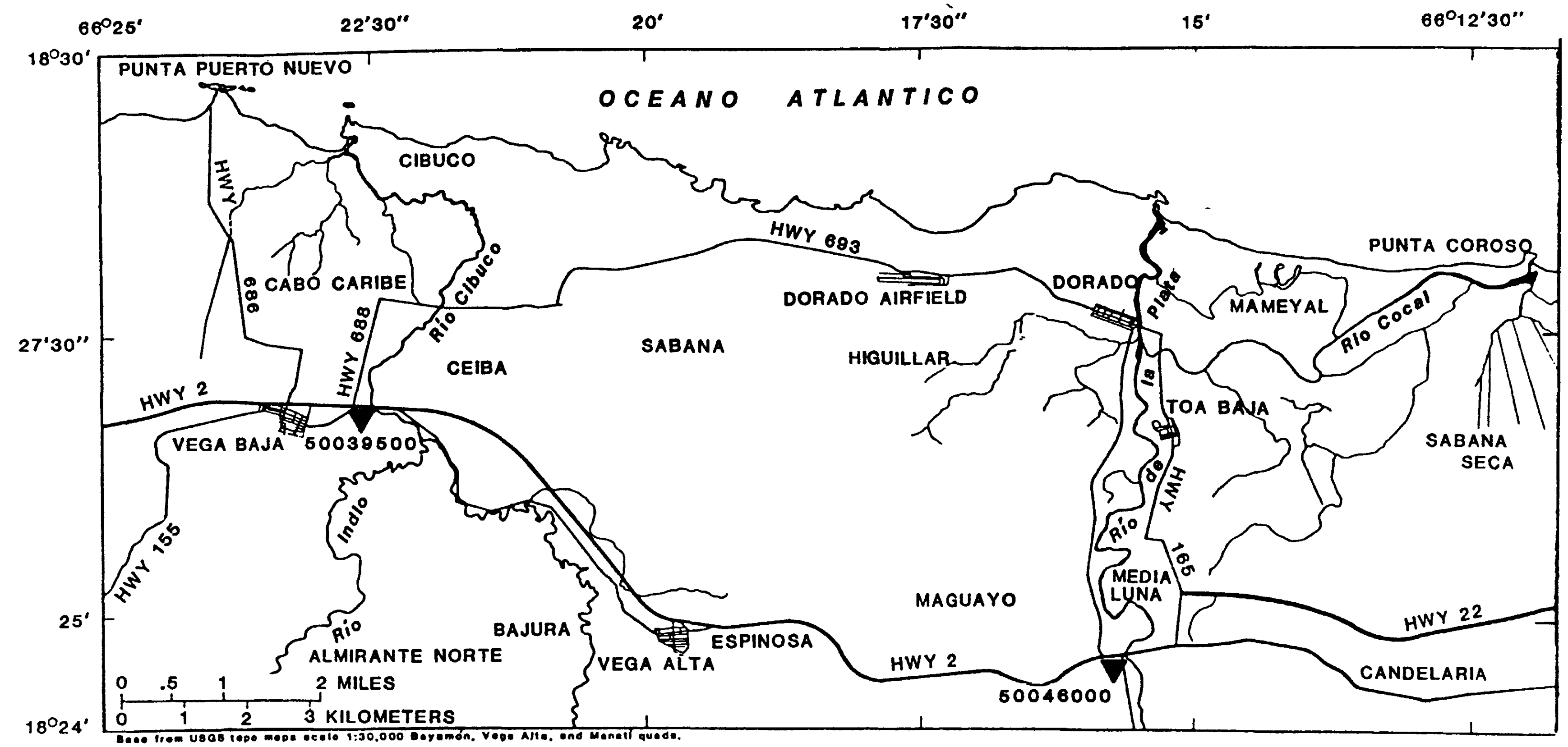


Figure 5.1-1.--Two quality-of-water stations located at Río Cibuco and Río de la Plata.

5.0 QUALITY OF WATER
5.1 Surface Water
5.1-1 Chemical, Physical, and Bacteriological Characteristics

5.1-2 Suspended Sediment

SUSPENDED-SEDIMENT LOADS AND YIELDS FOR BOTH RIVERS ARE ABOUT EQUAL

Suspended-sediment and water discharge data from 1973-78 indicate that the average annual sediment yield of Río Cibuco at Vega Baja is about 85 tons per square mile, while for Río de la Plata at Toa Alta it is about 82 tons per square mile.

The concentration of sediment affects the suitability of water for domestic, industrial, and agricultural uses. For irrigation purposes, a high sediment concentration is undesirable, more so if most of the sediment is in the silt-clay particle-size range (less than 0.062 mm).

Sediment data are very scarce for the two principal streams in the study area (Río Cibuco and Río de la Plata). Miscellaneous suspended-sediment samples have been collected at sites on both streams since 1973. There are no data on the bedload component of the transported sediment. Preliminary size analyses of medium to low-flow suspended-sediment samples indicate that about 90 percent of the sediment is silt and clay.

The miscellaneous suspended-sediment samples collected from Río Cibuco at Vega Baja and Río de la Plata at Toa Alta can be correlated against the instantaneous water discharge (figure 5.1-2-1. An approximate graphical correlation of the data points can be used to estimate the instantaneous suspended-sediment load (in tons per day). Seasonal effects in the transport of suspended sediment, which have been documented in other basins in Puerto Rico, are not considered in the correlation. The data available are inadequate for seasonal correlations. The estimate can be used as a guide to determine the amount of suspended sediment transported to irrigation areas if waters from the two rivers are utilized.

The mean annual suspended-sediment yield for both streams is about the same. These were computed using flow-concentration duration techniques described by Miller (1951). The effective drainage area of Río de la Plata at Toa Alta is about 200 mi^2, while for Río Cibuco at Vega Baja it is about 90 mi^2 (although about 24 mi^2 are entirely or partly non-contributing, mostly during periods of low flows). The average annual suspended-sediment yield for Río Cibuco is about 85 tons/mi^2 while for Río de la Plata it is about 82 tons/mi^2. The computations for Río de la Plata are based on the 1974-78 period, after regulation at the La Plata reservoir began. It is probable that prior to the construction of the reservoir, the yields from Río de la Plata basin were higher.

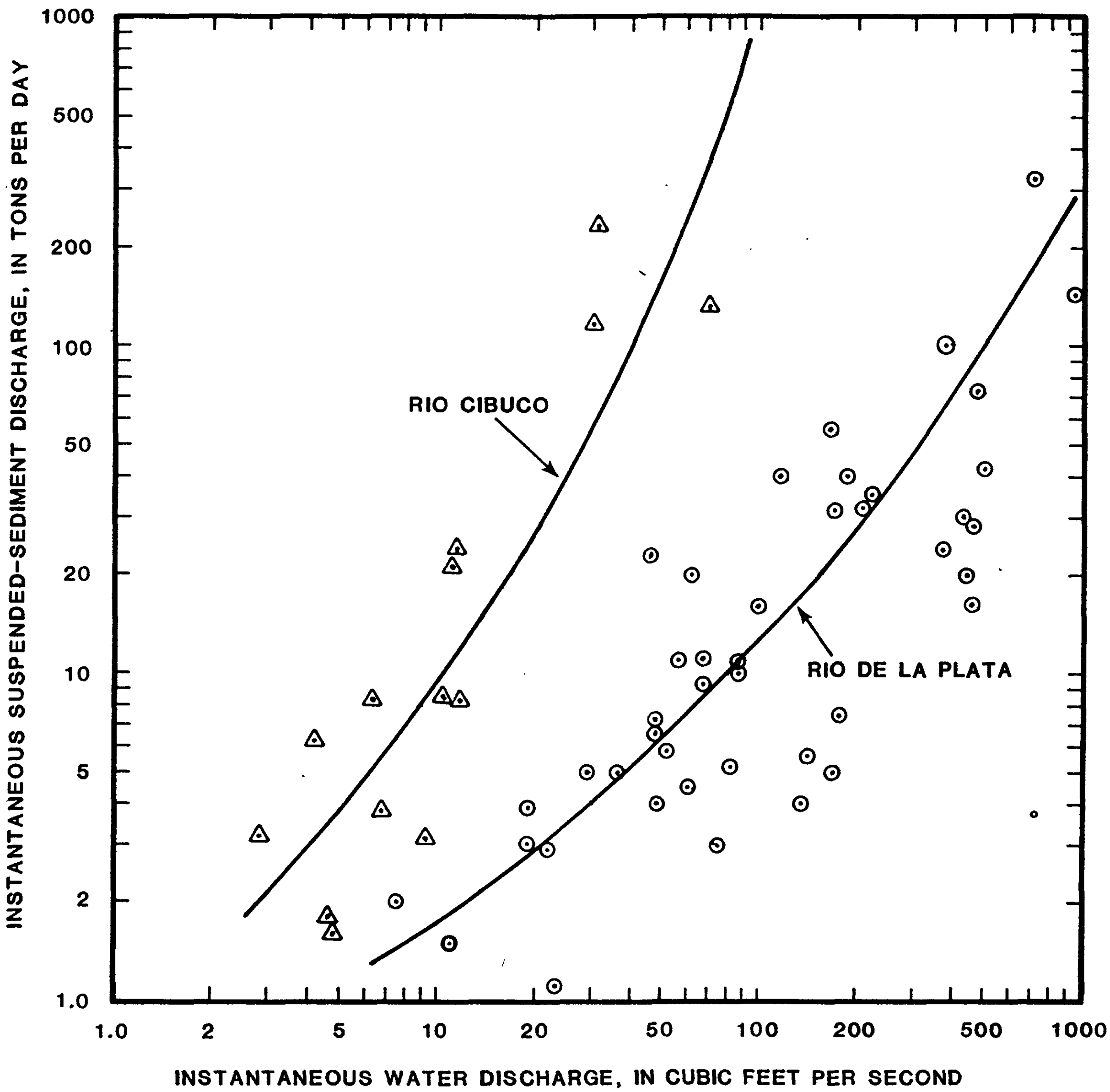


Figure 5.1-2-1.--Graphical correlation between instantaneous water and suspended-sediment discharges at Río Cibuco at Vega Baja, 1973-1981, and at Río de la Plata at Toa Alta, 1974-1981.

5.0 QUALITY OF WATER (Continued)

5.1 Surface Water (Continued)

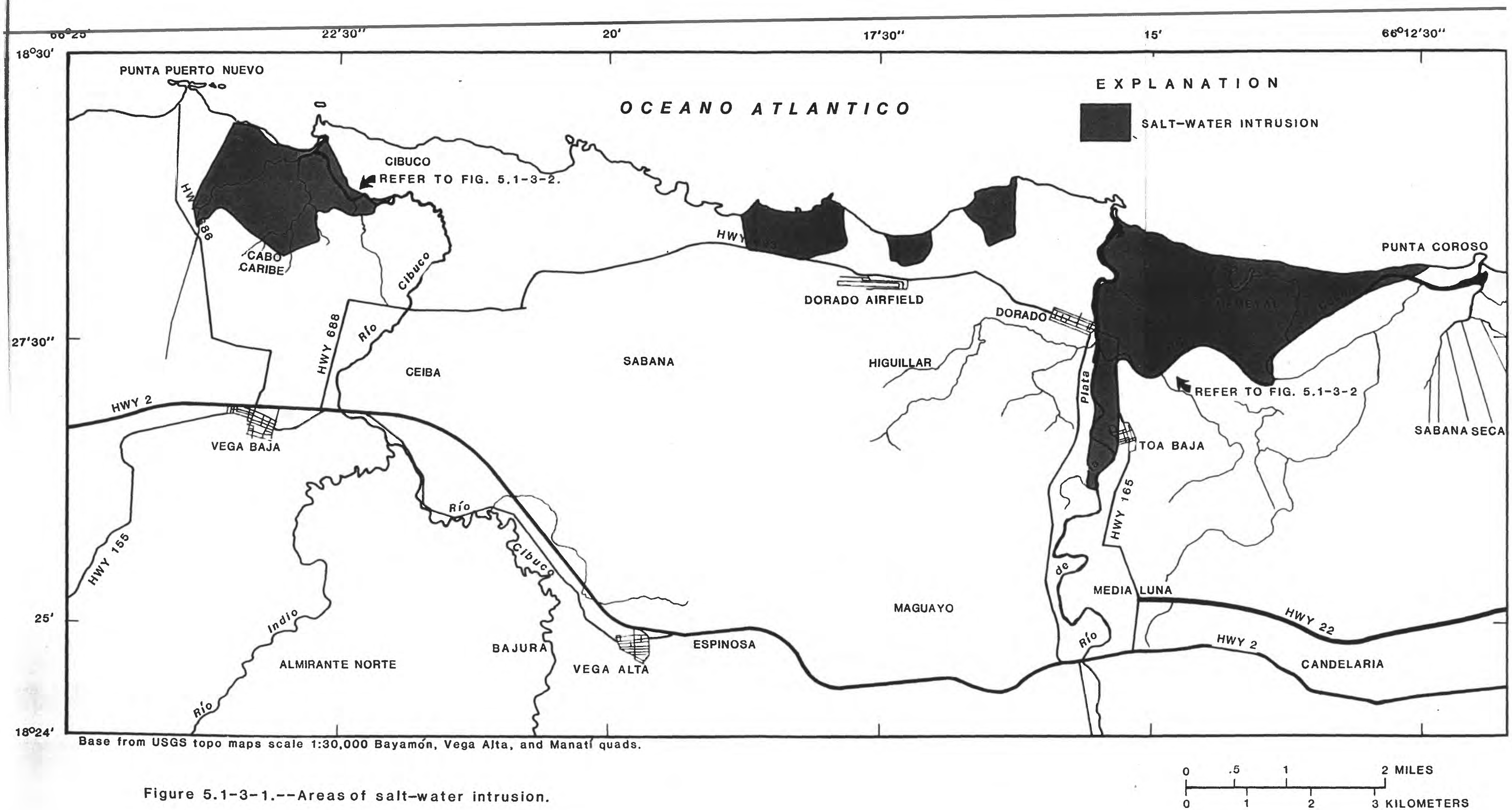
5.1-3 Saltwater Intrusion in Streams and Canals.

SEA-WATER ENTERS THE AREA THROUGH THE MOUTHS OF THE RIVERS AND COASTAL OPENINGS

The saltwater wedge was located 1.75 river miles upstream from the mouth of Río Cibuco and 3.0 river miles upstream from the mouth of Río de la Plata in 1978 surveys.

Seawater enters the study area through the mouths of Río Cibuco, Río de la Plata, Río Cocal, plus several other minor openings to the sea. The areas affected by seawater intrusion include the estuaries, and mangrove swampy areas bordering the beaches from Vega Baja to Sabana Seca (fig. 5.1-3-1).

Water from many drainage canals is relatively high in chloride (200 to 600 mg/L), sulfate (35 to 90 mg/L) and, total dissolved solids (850 to 1800 mg/L) concentrations. Most of the waters are of the sodium-chloride type, indicating seawater intrusion. This condition prevails in drainage canals at the lower ends of Río Cibuco and Río de la Plata valleys. A maximum-chloride concentration of 20,000 mg/L was determined from samples collected at Finca La Julia, in the Río de la Plata valley.



Base from USGS topo maps scale 1:30,000 Bayamón, Vega Alta, and Manatí quads.

Figure 5.1-3-1.--Areas of salt-water intrusion.

SEA-WATER ENTERS THE AREA THROUGH THE MOUTHS OF THE RIVERS AND COASTAL OPENINGS

The saltwater wedge was located 1.75 river miles upstream from the mouth of Río Cibuco and 3.0 river miles upstream from the mouth of Río de la Plata in 1978 surveys.

Specific conductance surveys were made in the Río Cibuco and Río de la Plata to determine the inland tidal effect and the extent of the salt-water wedge in the rivers during low and high tides. Two separate surveys at Río Cibuco, conducted on August 29 (high tide) and October 17, 1978 (low tide), showed that the wedge was located 1.75 river miles upstream from the mouth (fig. 5.1-3-2). In the Río de la Plata during a low tide on September 28, 1978, the wedge was located 2.75 river miles upstream from the mouth. During the storm-wave swash of December 20, 1978, the salt-water wedge at Río de la Plata was about 3.0 river miles upstream from the mouth (fig. 5.1-3-2). The maximum potential inland movement of sea water through both streams was not determined. Altitudes of the channel bottom of the Río Cibuco indicate that the salt-water wedge could advance about 3 miles upstream from the mouth. Reports from local residents suggest that the maximum potential inland seawater intrusion at Río de la Plata is about 3.5 miles upstream from the mouth.

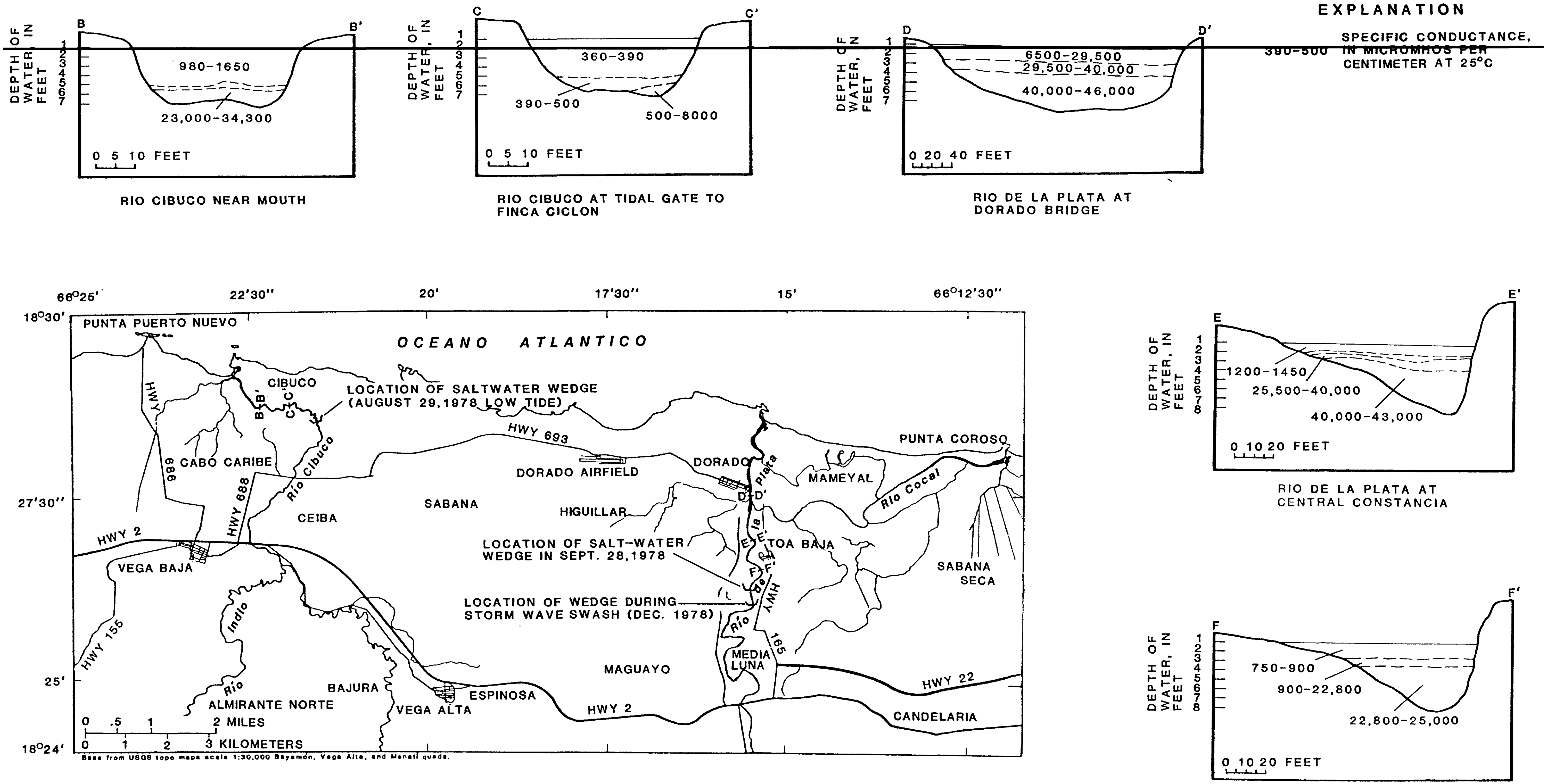


Figure 5.1-3-2.--Location of salt-water wedges in Río Cibuco and Río de la Plata, and sketches showing streams cross sections (B-B', C-C', D-D', E-E' and F-F') with specific conductance data.

5.0 QUALITY OF WATER
5.1 Surface Water
5.1-3 Saltwater Intrusion in Streams and Canals

5.2-1 Chemical and Physical Characteristics

GROUND WATER IN STUDY AREA IS MOSTLY OF A CALCIUM-BICARBONATE TYPE

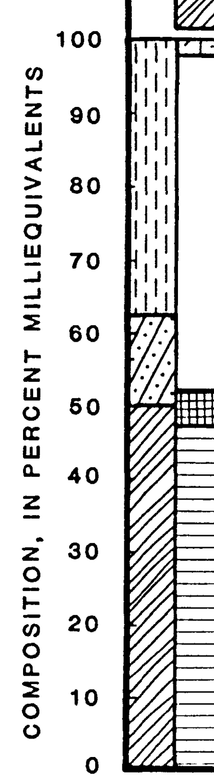
Ground water in the limestone and alluvium is predominantly of a calcium-bicarbonate type. In blanket and dune deposits it is usually a calcium-chloride or sodium-chloride type, depending upon proximity to the sea and the composition of the sand.

Water-quality data of wells in study area (fig 5.2-1) indicate that ground water is mostly of a calcium-bicarbonate type. The water from wells drilled in blanket and dune deposits is usually a calcium-chloride or a sodium-chloride type depending upon the proximity to the sea (fig. 5.2-1-1). The relative order of abundance of anions is chloride, bicarbonate, and sulfate. Chloride concentrations usually range from 50 to 800 mg/L. Sulfate concentrations are normally less than 25 mg/L, but in wells affected by sea water, can be as much as 100 mg/L or more. Temperature of the water ranges from 25 to 27°C.

Water from wells tapping the limestone aquifers is predominately of a calcium-bicarbonate type (fig. 5.2-1-2). Dissolved-solids concentration ranges from 250 to 300 mg/L, of which silica represents 3 percent, about 8 to 10 mg/L. Calcium and magnesium concentrations range from 70 to 150 mg/L, about 90 percent of the total cations in solution. The order of abundance of anions is: bicarbonate, chloride, and sulfate, of which bicarbonate is about 80 percent. Chloride concentrations are relatively low, ranging from 10 to 20 mg/L. However, chloride concentrations of 100 mg/L or more have been measured in wells near the coast tapping the Aguada Limestone. Nitrates usually are low, averaging from 5 to 15 mg/L. Ground-water temperature from pumping wells averages 26°C. Values of pH are on the order of 6.5 to 7.5 units.

Water in alluvial deposits of the Río Cibuco and Río de la Plata valleys is also of a calcium-bicarbonate type (fig. 5.2-1-3). Generally, the dissolved solids concentration ranges from 300 to 450 mg/L, of which silica is less than 25 mg/L. The water is very hard, usually greater than 200 mg/L hardness as $CaCO_3$. Bicarbonate is the predominant anion, about 80 percent of the total anions. The chloride concentration of the water ranges from 10 mg/L at wells in the southern part of the Río Cibuco valley to about 250 mg/L at a well near the coast. Sulfate and chloride concentrations usually are about equal ranging from less than 10 to 25 mg/L. Nitrate concentrations range from 3 to 20 mg/L. The waters are slightly alkaline, with pH values ranging from 7.2 to 7.5 units, similar to those of river water.

SITE OR LOCATION: PUERTO NUEVO, VEGA BAJA, P.R.
FORMATION: BLANKET AND DUNE DEPOSITS DEPTH: 50 TO 150 FEET
TYPICAL ANALYSIS



CONSTITUENTS OR PROPERTY		UNITS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
SPECIFIC CONDUCTANCE (μMHOS/CM AT 25°C)		956		
pH		7.2		
DISSOLVED SOLIDS, SUM			510	
SILICA	(SiO_2)		9.0	
IRON	(Fe^{+++})		.02	
CALCIUM	(Ca^{++})		98	4.89
MAGNESIUM	(Mg^{++})		14	1.15
SODIUM	(Na^{+})		76	3.31
POTASSIUM	(K^{+})		2.4	.06
BICARBONATE	(HCO_3^{-})		268	4.39
SULFATE	($SO_4^{=}$)		23	.48
CHLORIDE	(Cl^{-})		150	4.23
FLUORIDE	(F^{-})		0.3	.02
NITRATE	(NO_3^{-})		5.3	.09
ORTHOPHOSPHATE	(PO_4^{-})		0.0	.00
WATER TYPE CALCIUM CHLORIDE		$CaCl_2$		

Figure 5.2-1-1.--Typical analyses of water from blanket and dune deposits near the coast.

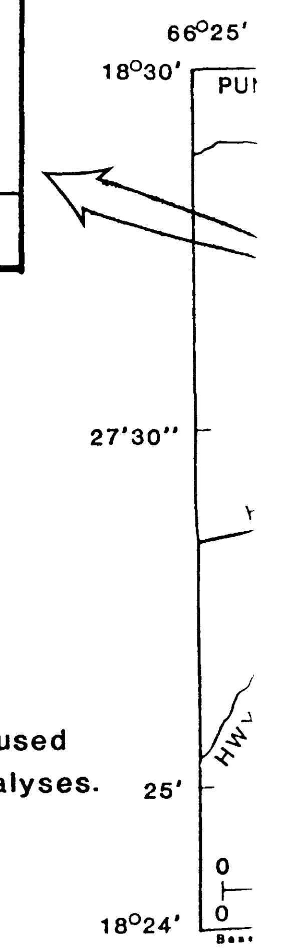
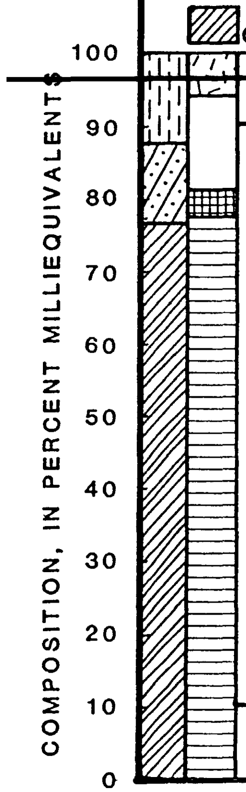


Figure 5.2-1.--Selected wells used for chemical analyses.

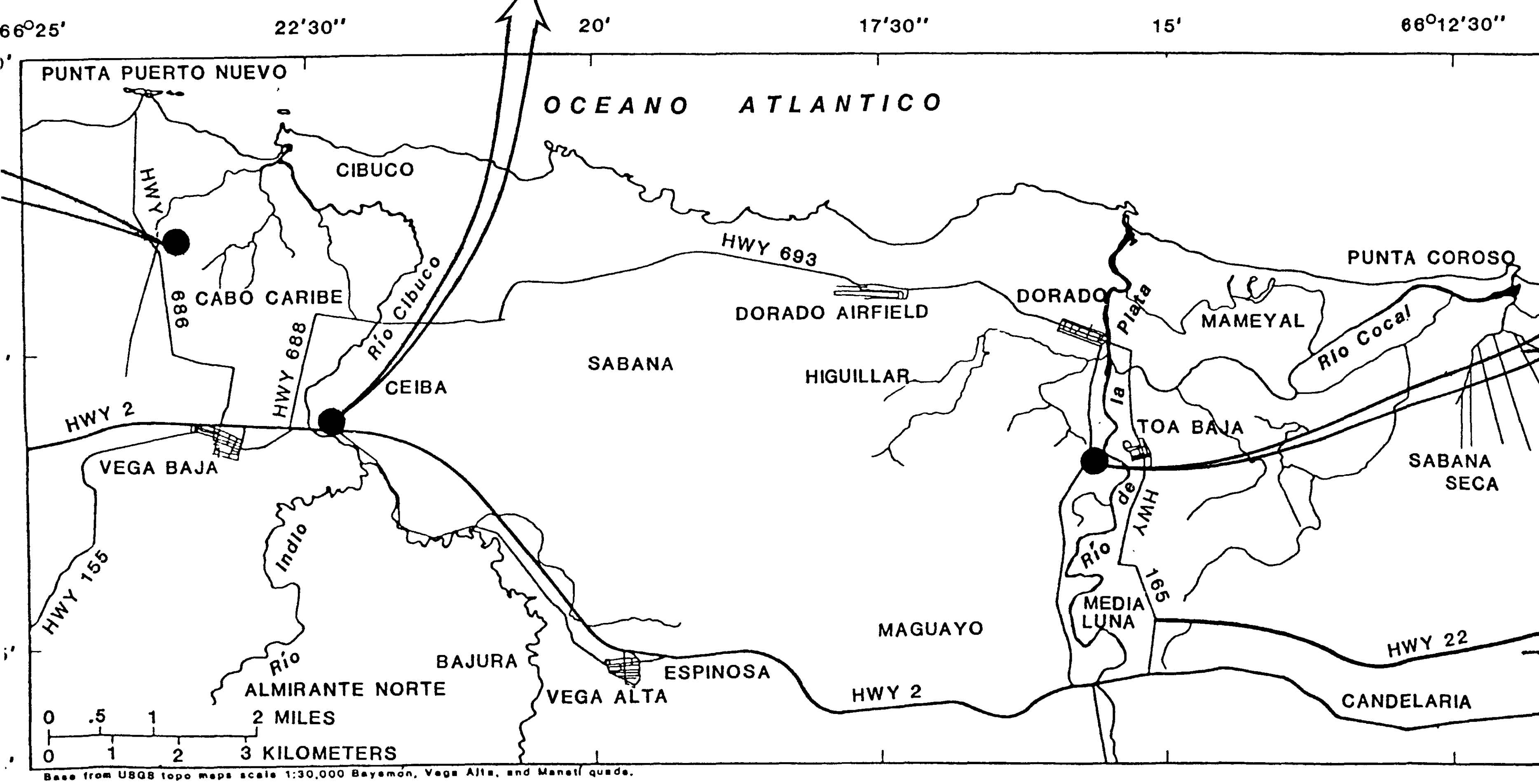
SITE OR LOCATION : FINCA CARIBE, VEGA BAJA, P.R.
FORMATION: AYMAMON LIMESTONE DEPTH: 100 TO 250 FEET
TYPICAL ANALYSIS



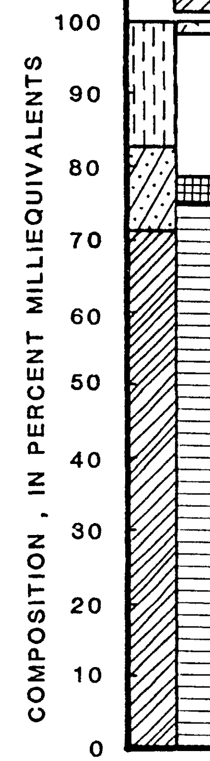
CONSTITUENTS OR PROPERTY		UNITS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
SPECIFIC CONDUCTANCE (μMHOS/CM AT 25°C)		564		
pH		7.3		
DISSOLVED SOLIDS, SUM			337	
SILICA	(SiO_2)		24	
IRON	(Fe^{+++})		.01	
CALCIUM	(Ca^{++})		98	4.89
MAGNESIUM	(Mg^{++})		8.4	.69
SODIUM	(Na^{+})		15	.65
POTASSIUM	(K^{-})		1.1	.03
BICARBONATE	(HCO_3^{-})		300	4.92
SULFATE	$(SO_4^{=})$		9.6	.20
CHLORIDE	(Cl^{-})		27	.76
FLUORIDE	(F^{-})		0.1	.01
NITRATE	(NO_3^{-})		16	.26
ORTHOPHOSPHATE	(PO_4^{-})		1.2	.01

WATER TYPE
CALCIUM BICARBONATE $Ca(HCO_3)_2$

Figure 5.2-1-2.--Typical analyses of water from the Aymamón Limestone



SITE OR LOCATION: DORADO AT HWY 165
FORMATION: ALLUVIUM DEPTH: 120 FEET
TYPICAL ANALYSIS



CONSTITUENTS OR PROPERTY		UNITS	MILLIGRAMS PER LITER	MILLIEQUIVALENTS PER LITER
SPECIFIC CONDUCTANCE (μMHOS/CM AT 25°C)		627		
pH		7.4		
DISSOLVED SOLIDS, SUM			357	
SILICA	(SiO_2)		16	
IRON	(Fe^{+++})			
CALCIUM	(Ca^{++})		94	4.69
MAGNESIUM	(Mg^{++})		9.1	.75
SODIUM	(Na^{++})		24	1.04
POTASSIUM	(K^{+})		1.8	.05
BICARBONATE	(HCO_3^{-})		291	4.85
SULFATE	$(So_4^{=})$		14	.29
CHLORIDE	(Cl^{-})		49	1.38
FLUORIDE	(F^{-})		0.0	0.0
NITRATE	(NO_3^{-})		3.0	.05
ORTHOPHOSPHATE	(Po_4^{-})		0.0	0.0

WATER TYPE
CALCIUM BICARBONATE $Ca(HCO_3)_2$

Figure 5.2-1-3.--Typical analyses of water from alluvium.

5.0 QUALITY OF WATER (Continued)

5.2- Ground Water (Continued)

5.2-2 Sea-water Intrusion in coastal Aquifers

SEA-WATER INTRUSION IS A MAJOR PROBLEM IN COASTAL AQUIFERS

Horizontal and vertical migration of the fresh-sea water mixing zone can occur as a result of uncontrolled pumpage.

In coastal aquifers, ground water usually discharges into the sea. Whenever pumpage exceeds recharge in these aquifers, seawater intrusion may result. If the seawater moves inland, potable ground-water supplies become useless. Contamination with saltwater may take years to remove even when fresh ground water is available to flush out the saline water.

The relative position between the freshwater and the seawater is controlled primarily by their differences in density. A boundary surface or zone of diffusion is formed whenever the fluids are in contact (figures 5.2-2-1, 5-2-2-2). The shape and movement of the zone of diffusion are governed by a hydrodynamic balance of the freshwater and the saltwater. The relative position of seawater migrates horizontally or vertically when uncontrolled pumpage of freshwater occurs. Upconing (vertical migration) of seawater beneath pumping wells (figure 5.2-2-3) is a more imminent problem in most areas than is lateral intrusion (Heath, 1980). A much larger volume of freshwater has to be displaced in lateral intrusion than in upconing.

In the Campanilla area the Puerto Rico Aqueduct and Sewer Authority (PRASA) has reported high chloride concentrations in some of the wells. A serious saltwater hazard to the ground water was indicated by results obtained from a quality of water survey made during 1973 (Diaz, oral commun., 1980). The chloride concentration in water from two wells (wells 88 and 89, fig. 4.4-1) increased from 16 to 720 mg/L between 1964 and 1973. The increase of more than 700 mg/L in the chloride concentration in these pumping wells was considered as evidence of seawater intrusion in the area. Water from the wells originally showed physical and chemical characteristics typical of freshwater from the Aymamón and Aguada Limestones.

Most of the wells in the Campanilla area affected by saline water intrusion (chlorides greater than 250 mg/L) were drilled to depths greater than 130 ft below mean sea level. Continuous uncontrolled pumpage has lowered the water surface substantially reducing the thickness of the freshwater lens. The wells are now withdrawing water from the fresh-saltwater mixing zone (fig. 5.2-2-3).

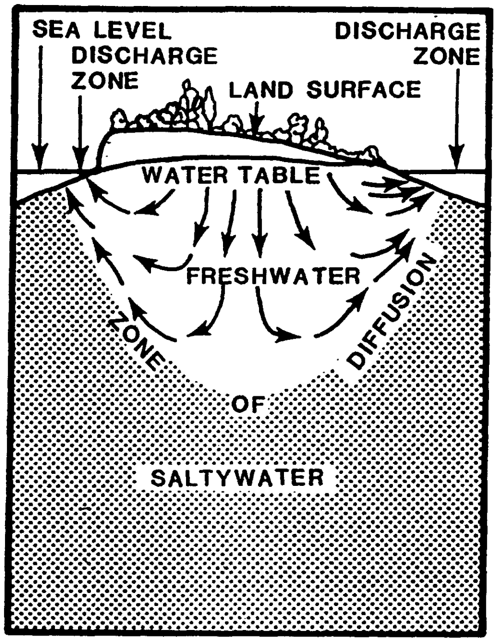


Figure 5.2-2-1.--Boundaries between fresh and salty-ground water. (From Cohen and others, 1968).

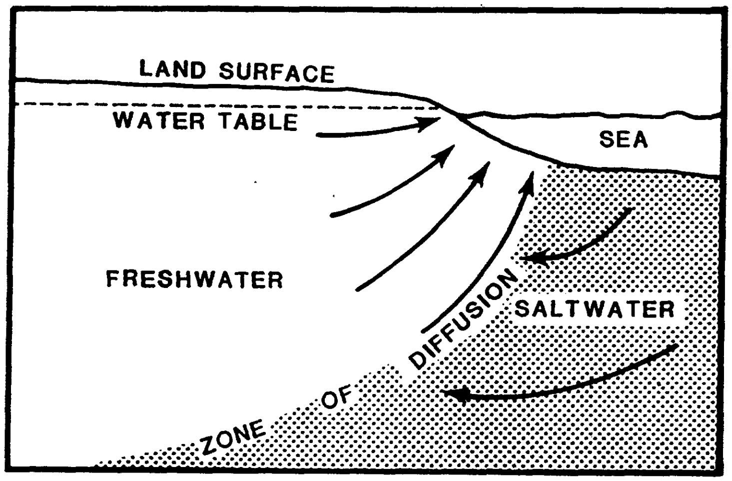


Figure 5.2-2-2.--Circulation of salt water from sea to the zone of diffussion and return. (From Cooper, Jr., 1964).

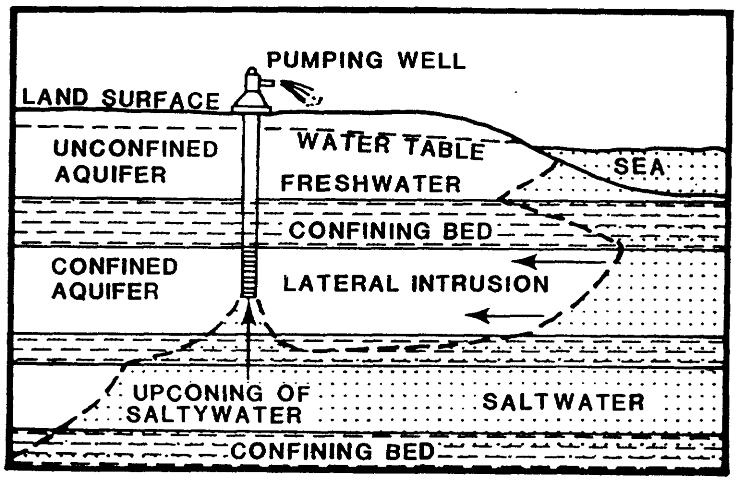


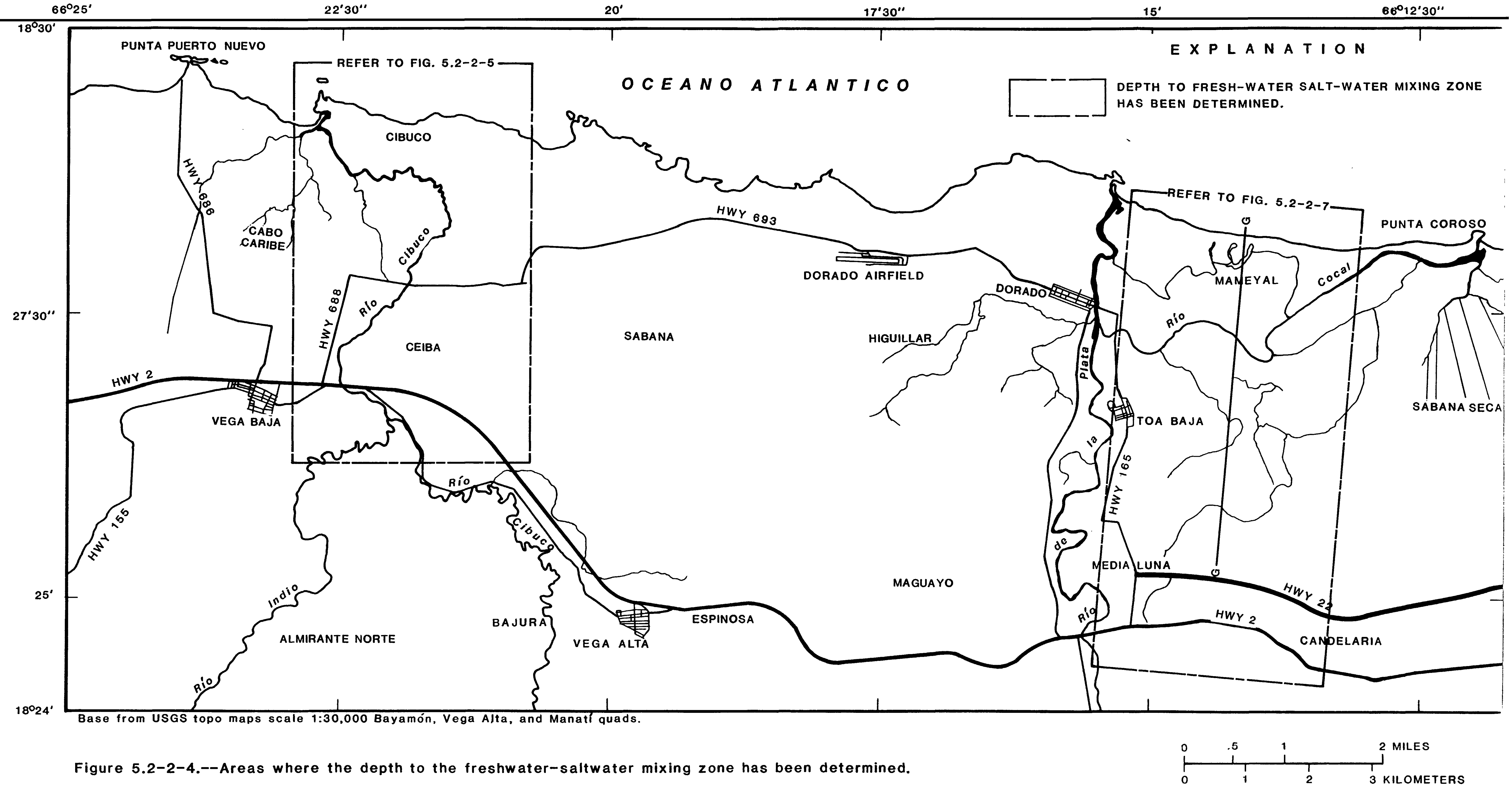
Figure 5.2-2-3.--Two aspects of salt-water intrusion. (From Heat, 1980).

SEA-WATER INTRUSION IS A MAJOR PROBLEM IN COASTAL AQUIFERS

Intrusion potential in study area is high due to the cavernous nature of the limestone aquifer and the shallowness of the fresh-salt water mixing zone.

In the design of water-supply wells in coastal areas, consideration must be given to the possibility of seawater intrusion. This may involve construction of shallow wells or low pumping rates to avoid upconing. The relocation of wells inland may be necessary to avoid lateral intrusion.

Seawater intrusion has been detected in the Cibuco and the Campanilla sectors of the Vega Baja to Sabana Seca area (fig. 5.2-2-4). The possibility of intrusion in other areas is relatively high due to the cavernous nature of the limestone aquifer and the shallowness of the fresh-salt water mixing zone.



Base from USGS topo maps scale 1:30,000 Bayamón, Vega Alta, and Manatí quads.

Figure 5.2-2-4.--Areas where the depth to the freshwater-saltwater mixing zone has been determined.

SEA-WATER INTRUSION IS A MAJOR PROBLEM IN COASTAL AQUIFERS

Intrusion potential in study area is high due to the cavernous nature of the limestone aquifer and the shallowness of the fresh-salt water mixing zone.

In the Río Cibuco valley, a surface geophysical technique was employed to define the depth to the fresh-salt water mixing zone (fig. 5.2-2-5). Electrical resistivity tests using the Schlumberger electrode array (Zohdy, and others, 1974) were conducted. The results were correlated with test holes, well logs, and ground-water quality data.

The top of the fresh-saltwater mixing zone (chloride concentrations greater than 250 mg/L) was found to range from about 50 to 210 ft below the land surface. At Highway 2 (station 2) the mixing zone was encountered at a depth of about 210 ft (fig. 5.2-2-5 and 5.2-2-6). North of Highway 688 (station 6), the zone of diffusion was encountered at a depth of about 100 ft (fig. 5.2-2-5).

In the Campanilla area, data from existing wells was used to estimate the location of the fresh-saltwater zone of diffusion (fig. 5.2-2-7). In the vicinity of the Campanilla well field, the mixing zone is encountered at a depth of about 150 ft below the land surface. Seawater can also infiltrate into the aquifer through rivers and canals hydraulically connected to the sea.

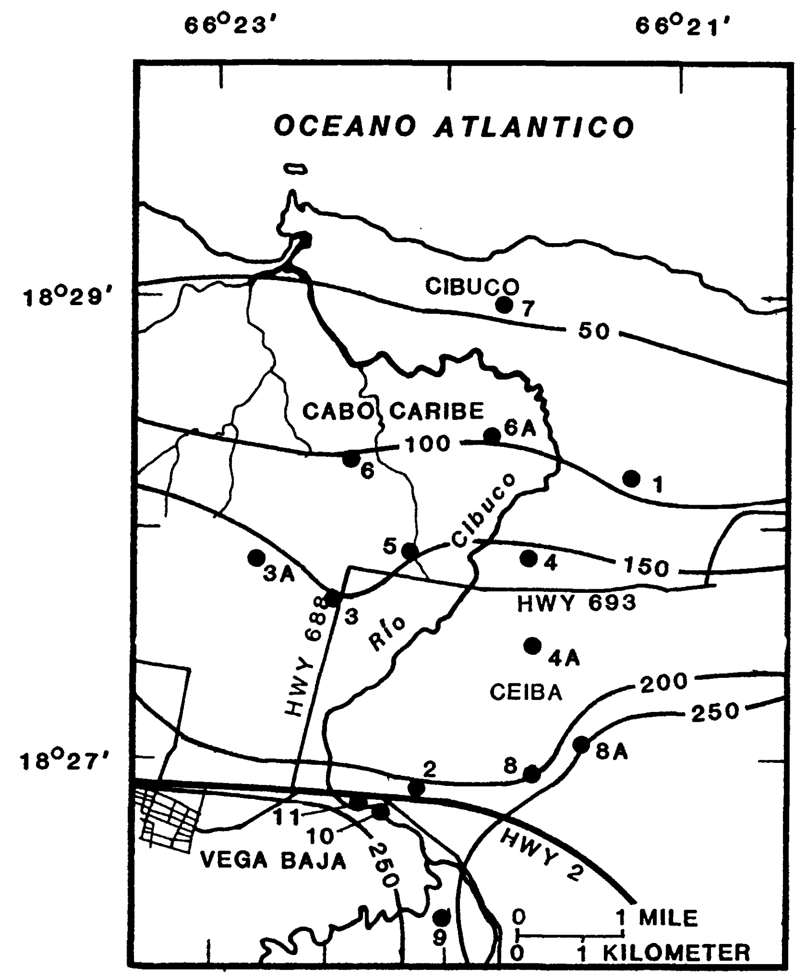


Figure 5.2-2-5.--Estimated depth of the fresh-saltwater zone in the Río Cibuco Valley.

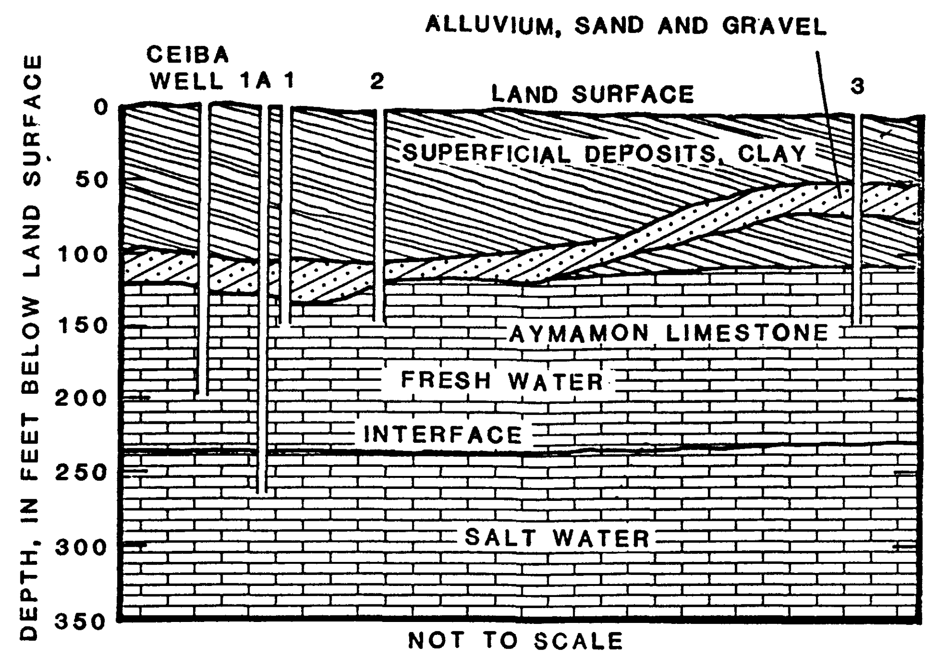


Figure 5.2-2-6.--Depth to the fresh-saltwater zone at aquifer test site in the Río Cibuco Valley. (See figure 4.2-1 for location of aquifer test site.)

EXPLANATION

—50— DEPTH CONTOUR. Number is value, in feet, determined from surface-resistivity profiles and test hole data. Datum is land surface. Contour interval 50 feet.

●7 RESISTIVITY STATION AND NUMBER

—·— LIMITS OF MIXING ZONE

FORMATION BOUNDARIES

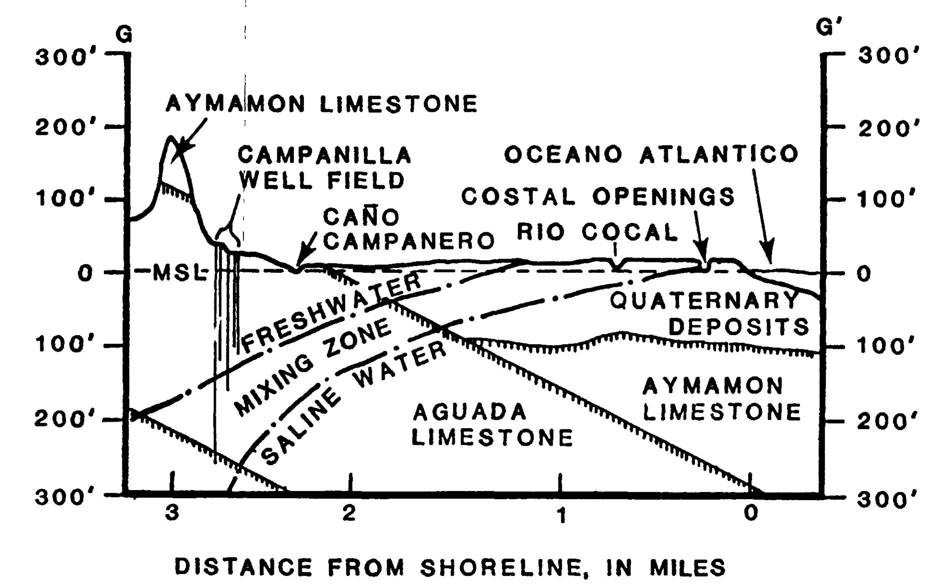


Figure 5.2-2-7.--Possible saltwater intrusion in the Campanilla area. (See figure 5.2-2-4 for location of section G-G'.)

5.0 QUALITY OF WATER (Continued)

5.2 Ground Water (Continued)

5.2-3 Classification for Irrigation

AREA CHARACTERIZED BY A MEDIUM-TO HIGH-SALINITY WATER

Waters classified according to specific conductance values.

The suitability of water for irrigation can be determined from the following characteristics: The total salinity of the water (salinity hazard), the ratio of sodium to other dissolved cations (sodium hazard), and the concentration of toxic elements. Some of the indices used to describe these characteristics include total dissolved solids, soluble sodium, sodium-adsorption ratio (SAR), residual sodium carbonate and soluble boron.

The concentration of soluble salts in irrigation waters can be expressed in terms of specific conductance, which is related to the total concentration of ions in solution. The percent of soluble sodium indicates the proportion of sodium ions in solution in relation to the total cation concentration. The sodium-adsorption ratio (SAR) expresses the relative activity of exchange reactions between sodium ions and the soil. High values of SAR indicate that a hazard exists for the replacement of calcium and magnesium by sodium. This accumulation of sodium damages soil structures and inhibits plant growth.

A correlation between the SAR, specific conductance, and suitability of waters for irrigation (fig. 5.2-3-1) was prepared by the U.S. Department of Agriculture (Methods of U.S. Salinity Laboratory Staff, 1954).

Groundwater in the area of investigation is suitable for irrigation although it is mostly classified as a medium to high-salinity water (fig. 5.2-3-2). For comparison purposes, surface-water sites other than the two main streamflow stations in the study area, are also shown in figure 5.2-3-2. Additional data for the sites are summarized in the appendix.

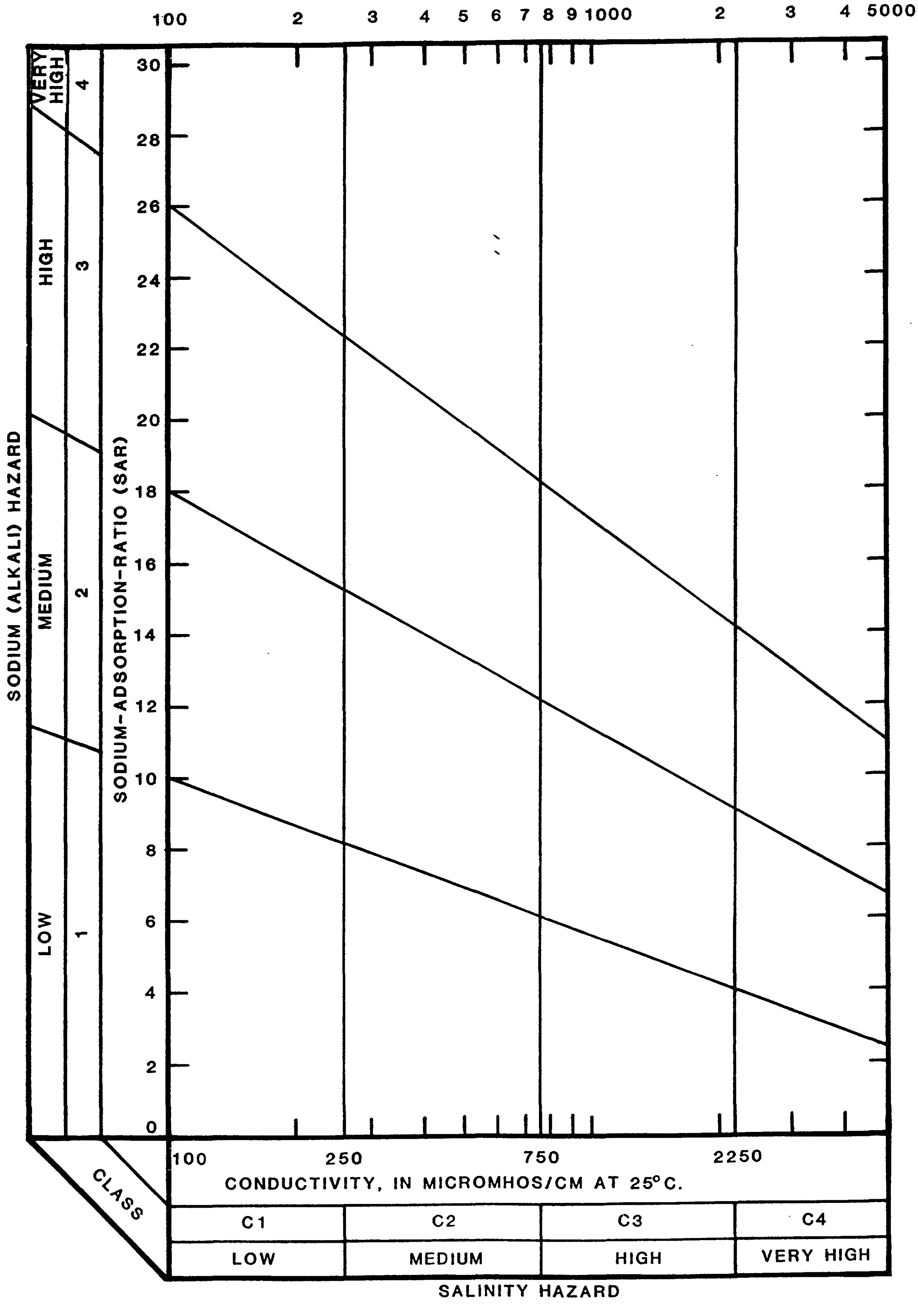


Figure 5.2-3-1.--Diagram for the classification of irrigation waters.
(Modified from U.S. Department of Agriculture, 1954.)

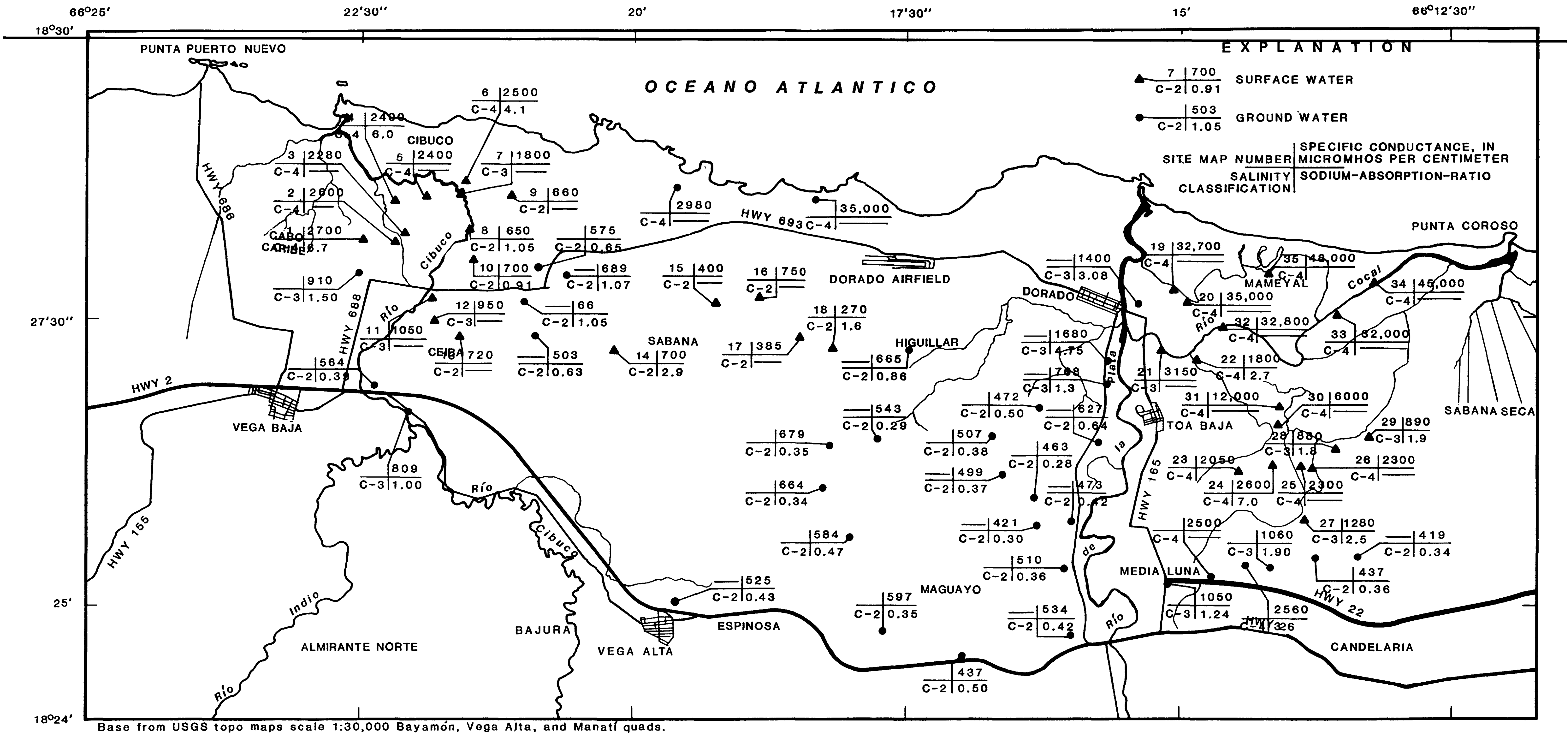


Figure 5.2-3-2.--Classification of water for irrigation, in the Sabana Seca to Vega Baja area.

5.0 QUALITY OF WATER
5.2 Ground Water
Classification for Irrigation

6.0 WATER AVAILABILITY AND MANAGEMENT

ABUNDANT WATER SUPPLIES EXIST IN THE AREA

Management practices to augment the available water and to prevent saltwater intrusion will be required. Further studies to define the ground-water system are needed.

How much water is available in the Sabana Seca to Vega Baja area? Río Cibuco is the principal source of surface water. It flows more than 18 ft^3/s 90 percent of the time. However, during the dry season, its flow may be as low as 7.5 ft^3/s. Río de la Plata, the other major stream, is affected by regulation and withdrawal of more than 40 Mgal/d (62 ft^3/s). Minimum flows are now as low as 3.4 ft^3/s, but will probably be reduced even more as additional water is withdrawn to supply metropolitan San Juan. Ground water from the water-table aquifer is relatively abundant, with a flow toward the coast of a minimum of about 19 Mgal/d. The most productive known areas appear to be in the lower Río Cibuco valley. In the overall water balance in the area, rainfall is also an important source of water, contributing as much as 0.25 in/d during the rainy season.

The estimated minimum ground-water flow throughout the area (19 Mgal/d) may not be available for pumpage. At least 10 Mgal/d are currently (1982) withdrawn for industrial, domestic and agricultural uses. Also seaward flow of freshwater must be maintained to prevent lateral saltwater encroachment. In some areas Campanilla, Dorado and Cibuco), evidence of seawater encroachment indicates that withdrawals are exceeding the available ground-water supplies.

What are some of the problems for the management of the water resources in the area? The lower reaches of Río Cibuco and Río de la Plata are affected by saltwater encroachment. The salt-water wedge can reach as far as 3 river miles upstream from the coast. Flow depletion could induce further encroachment. Perhaps as important are the severe floods produced by both streams, inundating most of the lower valleys. Additional water may be available from the Río de la Plata, if storage at La Plata Reservoir is optimized against seasonal runoff and releases.

The full potential of the ground-water resources in the area has not been determined. The limestone aquifer is not homogeneous and flow occurs through caverns and solution channels. These are localized conditions that will require specific site evaluations. The possible existence of a deep artesian aquifer throughout the area may mean an additional source of water is available.

Seawater intrusion is a major threat in the potential development of the coastal aquifers. Uncontrolled pumpage or poorly designed wells could induce additional saltwater intrusion either by lateral movement or by upconing such as has occurred in the Campanilla well field.

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APPENDIX

QUALITY OF SURFACE WATER IN THE SABANA SECA TO VEGA BAJA AREA.

MAP NUMBER	LOCATION: LATITUDE	LOCATION: LONGITUDE	DATE OF COLLECTION	CHEMICAL ANALYSES, MILLIGRAMS PER LITER: SILICA (SiO_2)	IRON (Fe)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM (Na)	POTASSIUM (K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	BORON	HARDNESS AS $CaCO_3$: CALCIUM, MAGNESIUM	HARDNESS AS $CaCO_3$: NON-CARBONATE	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	pH	S.A.R.	TEMPERATURE °C
1	18°28'12"	66°22'20"	8-29-78	10.0	0.20	120	52.0	350	13.0	118	93.0	730	0.0	9.0	0.15	513	0	2,700	-	-	25.0
2	18°28'10"	66°22'12"	Do.	-	-	-	-	-	-	-	-	640	-	-	-	-	-	2,600	7.1	6.7	25.0
3	18°28'09"	66°22'08"	do	-	-	-	-	-	-	-	-	620	-	-	-	-	-	2,280	-	-	26.0
4	18°28'33"	66°22'07"	do	-	-	-	-	-	-	-	-	600	-	-	-	-	-	2,400	-	-	26.5
5	18°28'35"	66°21'47"	do	7.2	0.65	93	45.0	280	70.0	90	67.0	590	.0	0.7	.16	417	0	2,400	7.8	6.0	27.0
6	18°28'40"	66°21'27"	do	20.0	0.56	220	39.0	250	10.0	224	35.0	560	.1	1.1	.11	710	0	2,500	8.0	4.1	28.0
7	18°28'44"	66°21'25"	do	-	-	-	-	-	-	-	-	325	-	-	-	-	-	1,800	-	-	26.0
8	18°28'25"	66°21'28"	do	10.0	1.2	83	6.0	37	2.4	134	4.9	51	.0	0.7	.04	232	0	660	6.9	1.1	33.0
9	18°28'26"	66°21'05"	do	-	-	-	-	-	-	-	-	50	-	-	-	-	-	650	-	-	27.0
10	18°27'57"	66°21'26"	do	9.0	0.36	75	4.9	30	3.1	112	9.8	46	.0	12.4	.02	207	0	700	-	0.9	30.0
11	18°27'38"	66°21'42"	do	-	-	-	-	-	-	-	-	120	-	-	-	-	-	1,050	-	-	27.2
12	18°27'28"	66°21'46"	do	-	-	-	-	-	-	-	-	120	-	-	-	-	-	950	-	-	28.0
13	18°27'15"	66°21'29"	Do.	-	-	-	-	-	-	-	-	117	-	-	-	-	-	720	-	-	27.5
14	18°27'07"	66°20'07"	8-31-78	4.1	3.8	41	9.2	80	10.0	62	3.3	130	.0	0.0	.07	140	0	700	6.4	2.9	25.0
15	18°27'37"	66°19'13"	Do.	-	-	-	-	-	-	-	-	52	-	-	-	-	-	400	-	-	26.0
16	18°27'39"	66°18'48"	do	-	-	-	-	-	-	-	-	48	-	-	-	-	-	750	-	-	26.2
17	18°27'18"	66°18'25"	do	-	2.0	-	-	-	-	-	-	36	-	-	-	-	-	386	-	-	27.8
18	18°27'11"	66°18'10"	Do.	5.6	2.4	14	5.1	27	5.1	25	6.1	42	.0	0.57	.15	56	0	270	6.6	1.6	28.0
19	18°27'48"	66°15'06"	8-10-78	-	-	-	-	-	-	-	-	12,500	-	-	-	-	-	32,700	-	-	30.0
20	18°27'42"	66°14'55"	Do.	-	-	-	-	-	-	-	-	14,000	-	-	-	-	-	35,000	-	-	30.0
21	18°27'13"	66°15'07"	8-09-78	-	-	-	-	-	-	-	-	760	-	-	-	-	-	3,150	-	-	28.0
22	18°27'08"	66°14'51"	8-10-78	18.0	0.55	150	26.0	140	3.3	146	12.0	370	.1	0.0	.05	522	0	1,800	7.2	2.7	30.0
23	18°26'18"	66°14'26"	Do.	-	-	-	-	-	-	-	-	510	-	-	-	-	-	2,050	-	-	28.5
24	18°26'20"	66°14'08"	8-07-78	12.0	0.87	87	40.0	330	17.0	123	71.0	600	.1	1.8	.05	415	0	2,600	7.1	7.0	30.0
25	18°26'21"	66°13'56"	Do.	-	-	-	-	-	-	-	-	550	-	-	-	-	-	2,300	-	-	-
26	18°26'18"	66°13'45"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2,300	-	-	-
27	18°25'48"	66°13'52"	8-09-78	12.0	0.52	97	16.0	100	13.0	106	51.0	200	.1	11.9	.04	310	0	1,280	6.9	2.5	28.5
28	18°26'27"	66°13'35"	Do.	10.0	1.6	73	13.0	65	6.6	112	48.0	110	.0	3.6	.07	236	0	880	6.8	1.8	30.0
29	18°26'32"	66°13'18"	8-10-78	18.0	8.6	60	11.0	60	4.3	90	8.9	98	.1	3.9	.05	195	0	890	6.1	1.9	30.0
30	18°26'48"	66°14'08"	Do.	-	-	-	-	-	-	-	-	3,100	-	-	-	-	-	6,000	-	-	29.0
31	18°26'53"	66°14'05"	do	-	-	-	-	-	-	-	-	5,500	-	-	-	-	-	12,000	-	-	30.0
32	18°27'26"	66°14'35"	do	-	-	-	-	-	-	-	-	18,500	-	-	-	-	-	32,800	-	-	30.0
33	18°27'34"	66°13'36"	do	-	-	-	-	-	-	-	-	18,000	-	-	-	-	-	32,000	-	-	30.0
34	18°27'44"	66°13'32"	do	-	-	-	-	-	-	-	-	20,000	-	-	-	-	-	45,000	-	-	28.0
35	18°27'57"	66°14'10"	Do.	-	-	-	-	-	-	-	-	20,000	-	-	-	-	-	48,000	-	-	29.0

Note: Map numbers as shown in figure 5.2-3-2