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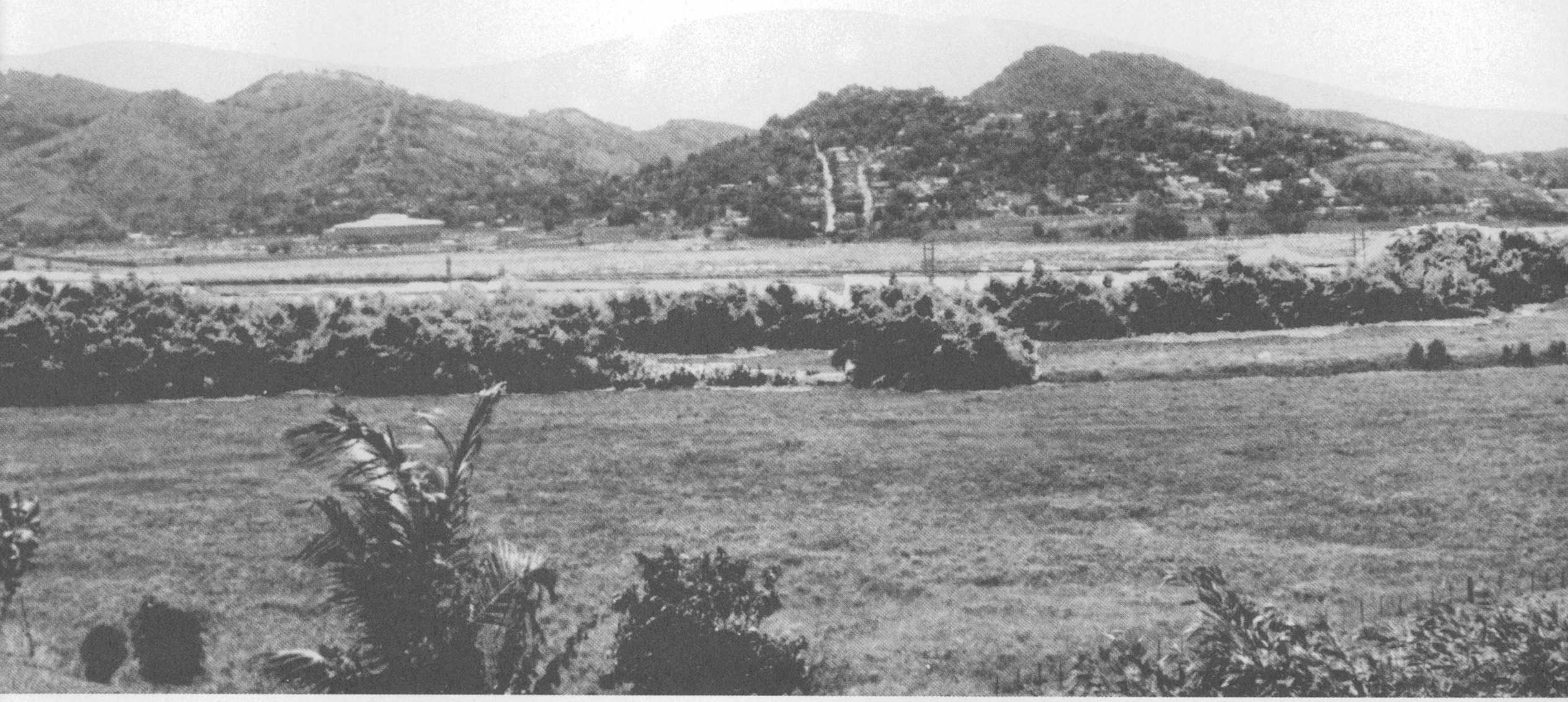
Ground-Water Resources of Alluvial Valley in Northeastern Puerto Rico -- Río Espíritu Santo to Río Demajagua Area



U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

UNITED STATES GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4201

Prepared in cooperation with the
PUERTO RICO AQUEDUCT AND SEWER AUTHORITY

Cover Photograph
Fajardo Valley in Fajardo, Puerto Rico, June 1996
(Photograph by Rafael Dacosta)

Ground-Water Resources of Alluvial Valleys in Northeastern Puerto Rico -- Río Espíritu Santo to Río Demajagua Area

By Francisco Pérez-Blair

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San Juan, Puerto Rico
1997

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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[Plates are in pocket]

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
square kilometer (km^2)	0.3861	square mile
cubic meter (m^3)	0.0008107	acre-foot
cubic meter per second (m^3/s)	35.31	cubic foot per second
liter per second (L/s)	15.85	gallon per minute
million liters per day (ML/d)	0.2640	million gallons per day
meter per day (m/d)	3.281	foot per day
meter per kilometer (m/km)	5.279	foot per mile
meter squared per day (m^2/d)	10.76	foot squared per day

Temperature: Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8 \times °C + 32$$

Abbreviated water-quality units used in this report:

col/100 mL	colonies per 100 milliliters
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 °C
mg/L	milligrams per liter

Acronyms used in report:

NWS	National Weather Service
PRASA	Puerto Rico Aqueduct and Sewer Authority
USGS	United States Geological Survey

Ground-Water Resources of Alluvial Valleys in Northeastern Puerto Rico -- Río Espíritu Santo to Río Demajagua Area

By **Francisco Pérez-Blair**

Abstract

A ground-water resources assessment was conducted in several alluvial valley aquifers associated with the principal streams in an area of about 290 square kilometers in northeastern Puerto Rico. The alluvial deposits in the stream valleys are composed mostly of clay and silt with minor amounts of sand and gravel. The estimated maximum thickness of unconsolidated deposits in the alluvial aquifers is about 60 meters. Estimates of horizontal hydraulic conductivity at test wells in the area range from 0.25 to 21 meter per day.

Concentrations of dissolved solids range from 72 to 1,210 milligrams per liter. Locally, ground water in the alluvial valley aquifers contains concentrations of iron and manganese which may constitute a water-quality limitation for some uses. Dissolved iron concentrations in samples obtained from observation wells ranged from 9 to 6,300 micrograms per liter and for dissolved manganese from 47 to 4,400 micrograms per liter. Saline water is common in the lower part of the alluvial valley aquifers near the coast. The ground-water resource development potential was estimated on the basis of the discharge rate of the alluvial valley streams, using the discharge computed for the 98 percent flow duration minus the 7-day, 10-year low-flow. The flow-duration data were determined from mean-daily discharges at gaging stations and were adjusted to estimate the values near the coast at Highway PR 3 bridge crossings for the following partial record stations: 1) 0.09 cubic meter per second at Río Mameyes at Mameyes, 2) 0.02 cubic meter per second at Río Sabana at Luquillo, 3) 0.01 cubic meter per second at Río Pitahaya near Luquillo, and 4) 0.07 cubic meter per second at Río Fajardo at Fajardo. If the amount of streamflow capture is limited by the 7-day, 2-year low-flow requirement for dilution of wastewater, only the Río Mameyes alluvial valley has any potential for ground-water development.

INTRODUCTION

Between 1980 and 1990, the population within the municipios of Río Grande, Luquillo, Fajardo, and Ceiba increased by 22 percent (from 92,000 to 118,000), or at approximately twice the average rate for Puerto Rico (Bureau of the Census, 1990). In conjunction with this population growth the Puerto Rico Aqueduct and Sewer Authority (PRASA), which supplies almost all the potable water in the area, increased production of potable water by 27 percent from about 276 to 350 L/s. This supply is provided by eight surface-water filtration plants tapping perennial streams with headwaters in the Sierra de Luquillo. Although plant capacity is sufficient to provide the water needs, the water demand in this service area increases significantly during the summer months as a result of a large transient population. This seasonal peak demand is most significant at Luquillo and Fajardo as a result of the recreational and tourism facilities and the large number of vacation homes (mainly apartment complexes). The summer population increases by as much as 10,000 during the months of June, July, and August, and by as much as 20,000 to 30,000 during weekends. The subsequent seasonal increase in public water-supply demand is expected to become critical in both Luquillo and Fajardo and will also affect the towns of Río Grande and Ceiba unless alternate water-supply sources are made available. Based on regional analysis of hydrologic and geologic conditions, it is possible that the surface-water supplies within this PRASA service area can be augmented during peak demand periods by development of ground-water resources.

Purpose and Scope

The purpose of this report is to describe the hydrogeology and determine the ground-water resource development potential of the alluvial valley aquifers and discontinuous coastal plain in the area from the Río Espíritu Santo to the Río Demajagua in northeastern Puerto Rico. Low flow and flow-duration characteristics at selected stream sites were also determined and stream water quality was assessed during base flow conditions. This report considered primarily the discontinuous alluvial deposits in valleys of the following streams on the northeastern coast: Río Espíritu Santo, Quebrada Juan González, Río Mameyes, Quebrada Mata de Plátano, Río Sabana, Río Pitahaya, Río Juan Martín, Quebrada Fajardo, Río Fajardo, and Río Demajagua.

Description of Study Area

The study area is comprised of approximately 290 km^2 in northeastern Puerto Rico (fig. 1). The major geographic features are the alluvial valleys of the principal streams. The headwaters of these streams all rise in the Sierra de Luquillo mountains. Most of the land use in the valleys consists of pasture and vegetable crops except within the Río Fajardo alluvial valley, where most arable land is used to grow sugar cane. The Commonwealth of Puerto Rico, through the Puerto Rico Land Authority, is the owner of most of the land within the alluvial valleys.

Northeastern Puerto Rico is being developed as a major attraction for the tourism industry, due to the areas large expanse of beaches and tropical rain forest (Caribbean National Forest). Several tourist resorts already exist in the area, and others are being expanded or considered for construction.

CLIMATE

The study area contains the Sierra de Luquillo mountains where the Caribbean National Forest (El Yunque), administered by the U.S. Forest Service, is located. El Yunque has been identified as one of the four areas in Puerto Rico with an average annual precipitation of 4,572 mm or more (Calvesbert, 1970). However the northeast coast is the driest region on the northern side of the insular hydrologic divide and receives an average rainfall ranging 1,524 to 2,032 mm per year (Calvesbert, 1970). Rainfall distribution in the study area varies significantly as a result of orographic effects, but total annual precipitation is principally controlled by easterly tropical waves and cold fronts. Easterly tropical waves are common in the Caribbean region from May to November; some of which become depressions, tropical storms, or hurricanes. Cold fronts are common from November to April. There is no distinctly wet or dry season, but only a relatively wet and a relatively dry season. Along the north coast of Puerto Rico the dry season normally begins in February and ends in April. During those years in which there are relatively few easterly tropical waves and cold fronts, annual rainfall is generally below average.

The National Weather Service maintains two daily rain gage stations within the study area. These rain gage stations are located at Fajardo and Paraíso (fig. 2). For the period of study a weather observation site was established at the Paraíso rain gage station to supplement the rainfall data with wind velocity and pan-evaporation data. The monthly precipitation for 1994 at the Paraíso rain gage is plotted in figure 3. Annual rainfall at Paraíso during 1994 was 1,780 mm, significantly below the 1993 rainfall of 2,463 mm (National Climatic Data Center, 1994).

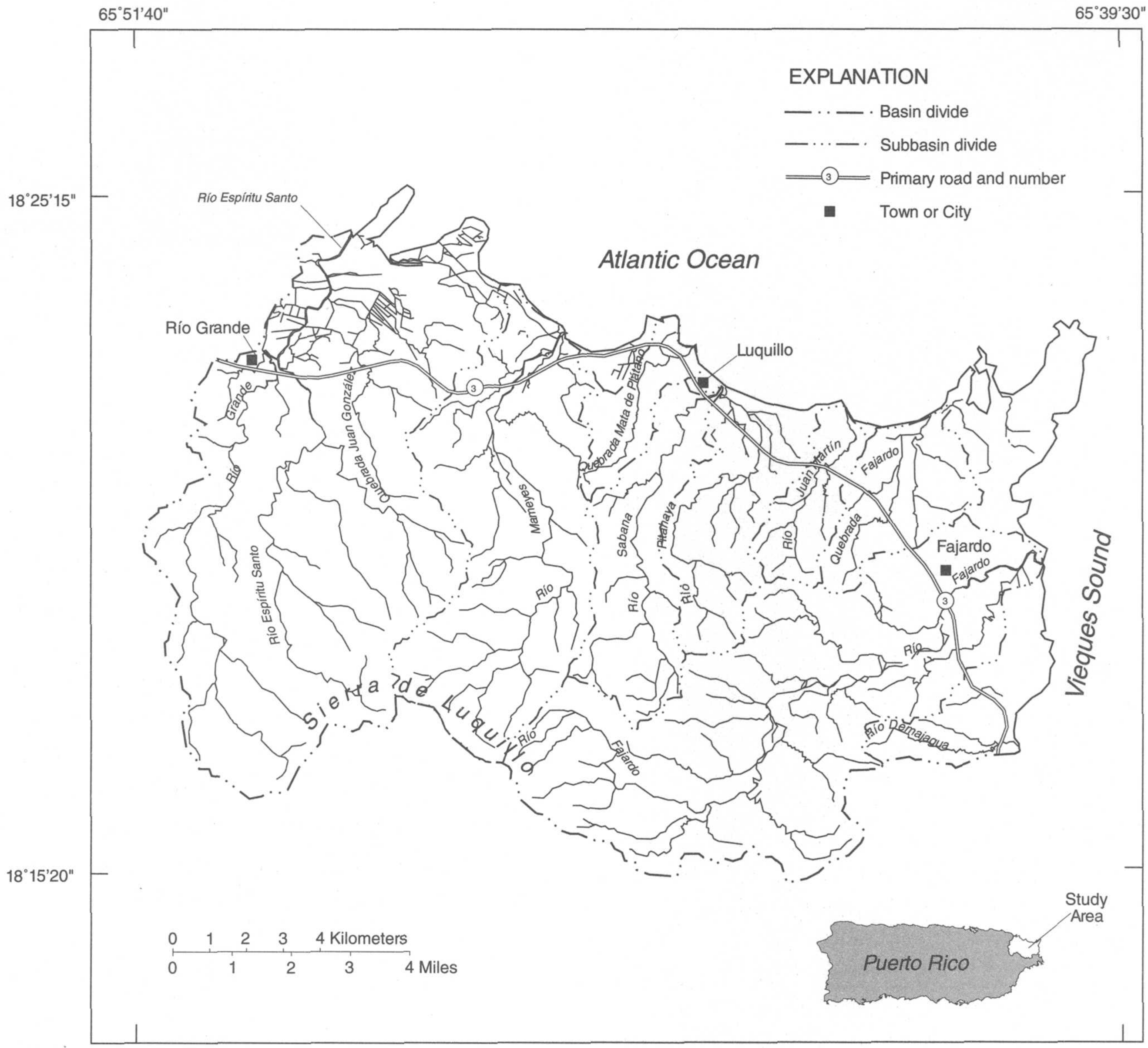

Figure 1. Location of study area and principal physiographic features in northeastern Puerto Rico.

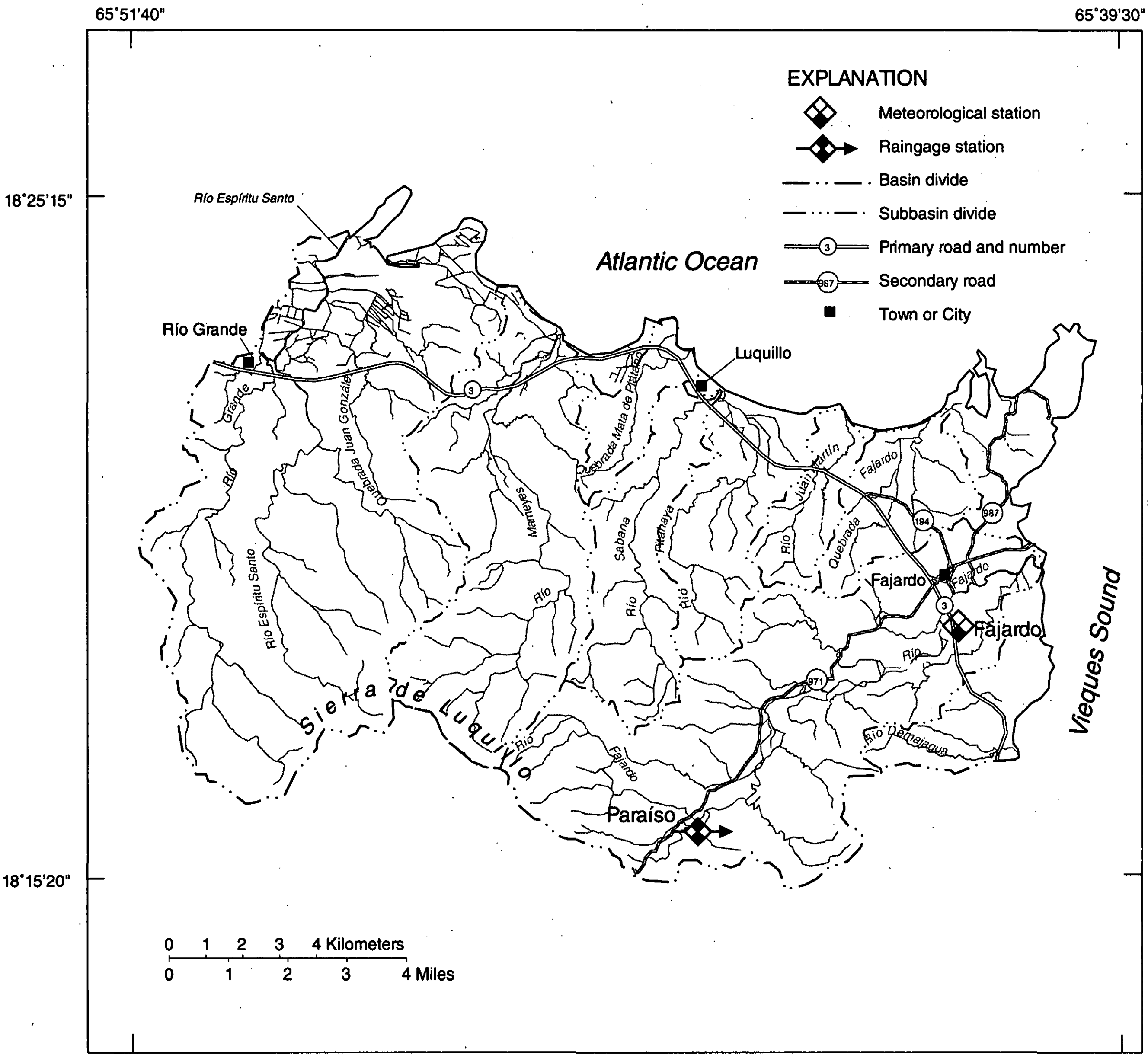

Figure 2. Location of the National Weather Service rain gage at Fajardo and the Paraíso meteorological station in northeastern Puerto Rico.

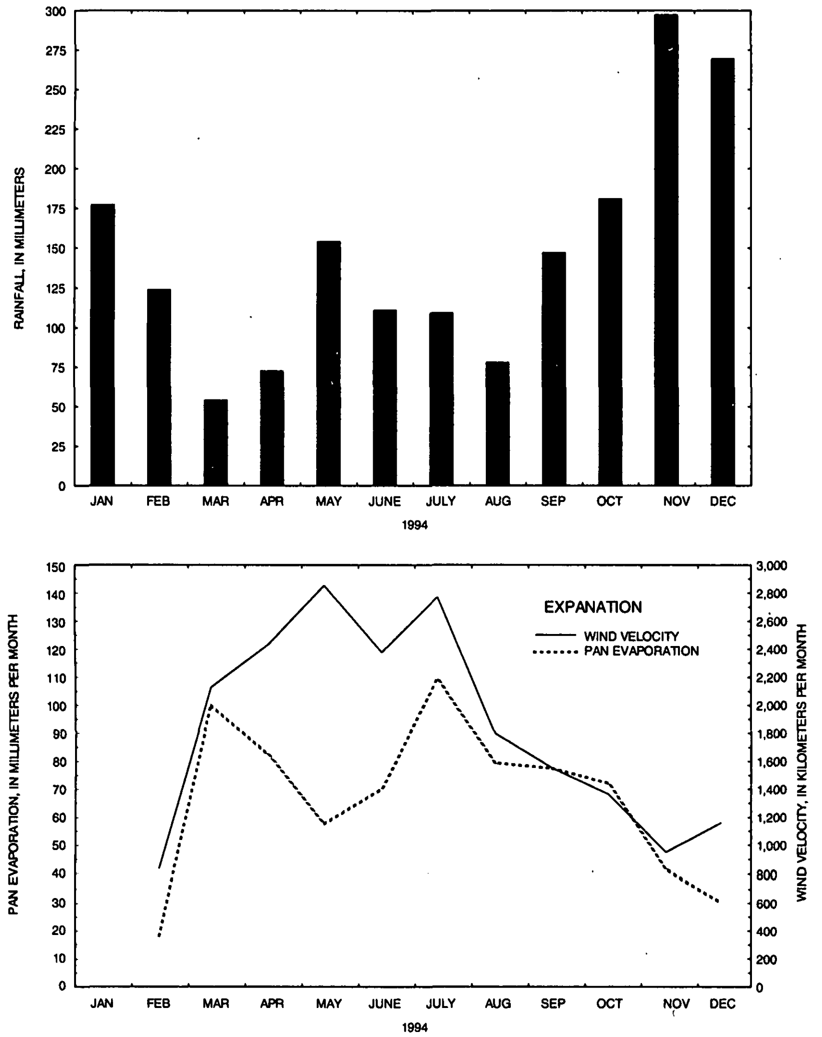

Figure 3. Monthly rainfall, pan evaporation, and wind velocity at the Paraíso meteorological station, Puerto Rico, during 1994.

Pan evaporation of 1,570 millimeters was recorded at Paraíso from January to December 1994. Pan evaporation followed a cyclic pattern closely related to wind velocity (fig. 3).

GEOLOGY

The geology of northeastern Puerto Rico has been described by Seiders (1971), Pease and Briggs (1972), M'Gonigle (1979), and Briggs and Aguilar-Cortés (1980). The rocks that crop out in this part of the island are largely igneous: volcaniclastic and intrusives that range in age from Late Cretaceous to early Tertiary (fig. 4). Also present are minor amounts of lavas, metamorphic rocks, and limestone of Late Cretaceous and middle Tertiary ages (not shown in fig. 4). In river valleys and other low lying regions of the study area these rocks are overlain by surficial deposits of Quaternary age.

Volcaniclastic and Intrusive Rocks

The volcaniclastic rocks (tuffaceous sandstone, siltstone, volcanic conglomerate and breccia) are the most abundant rock types in the study area. They are formed from the deposition of primary or reworked volcanogenic material in shallow and deep marine waters and are of Late Cretaceous age. The stratigraphic and structural relations of the volcaniclastic rocks are complex and individual units have not been completely established. Consequently, these rocks will be described as undifferentiated. Volcaniclastic rocks are mostly mafic in composition, rich in ferromagnesian minerals with very little quartz. The difference in texture and the intercalation of lavas represent changes in the type of volcanism and the occurrence of irregular periods of volcanic quiescence. The lavas associated with the volcaniclastic rocks range in composition from basalt to andesite.

Intrusive rocks are present in the study area in the form of sills, dikes, and stocks, and range in age from Late Cretaceous to early Tertiary. Intrusive rocks are most abundant in the Luquillo and Río Grande area. The lithologic composition of these rocks varies from moderately- to highly-rich in quartz, such as quartzdiorite and granodiorite, to rocks with no or very little quartz such as diorite. Intrusive rocks generally are less abundant than volcaniclastic rocks and only one intrusive body, the Río Blanco Stock in the Luquillo area, is of significant areal extent. Metamorphic rocks occur infrequently in the study area and were formed as a result of the emplacement of intrusive rocks into the volcanic rocks. Consequently, metamorphic rocks are not mapped and their occurrence is limited to the contact zones between

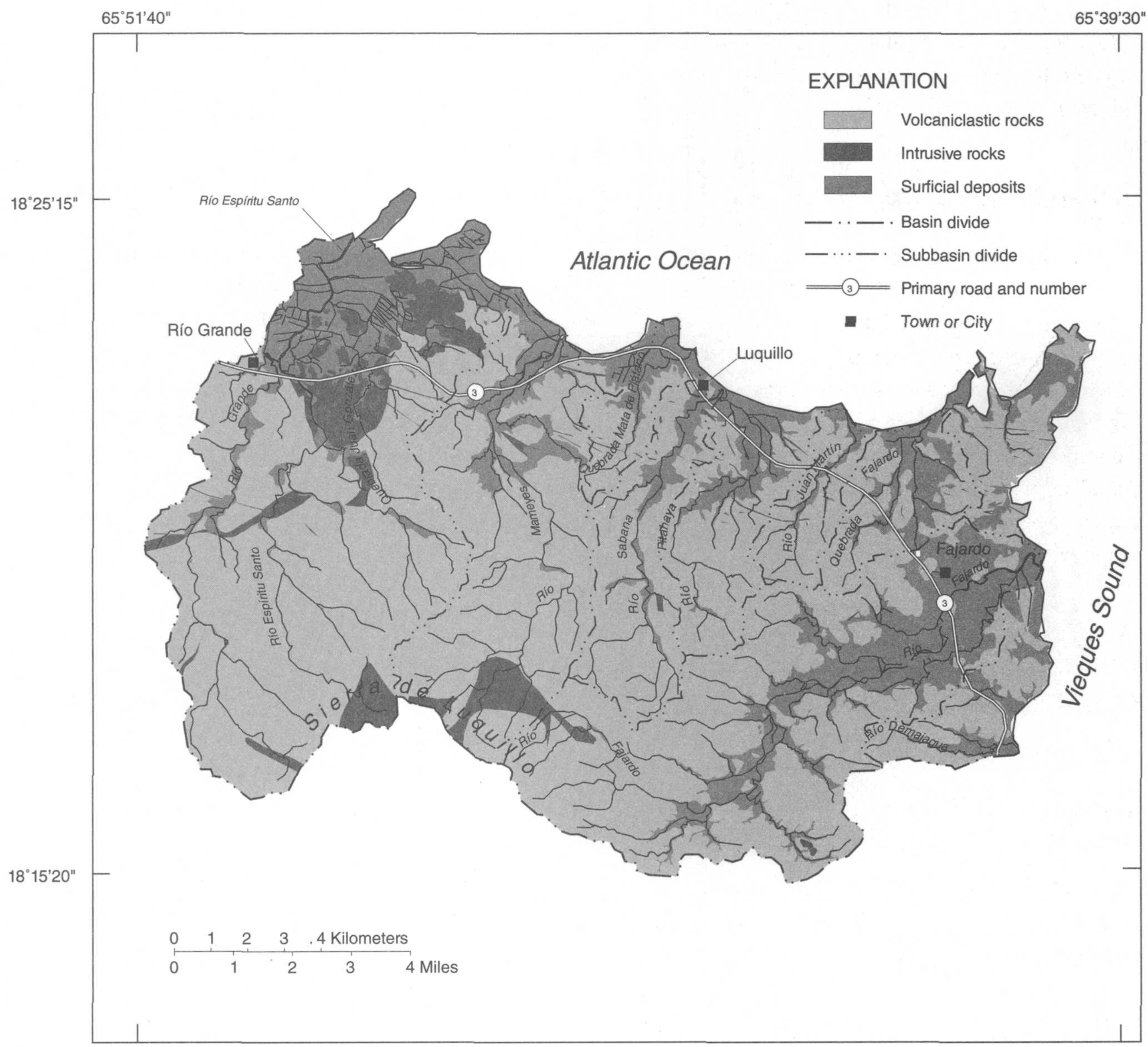

Figure 4. Generalized surficial geology of northeastern Puerto Rico.

intrusive and volcaniclastic rocks. The Late Cretaceous and early Tertiary rocks are moderately faulted. The Cerro Mula fault zone is the major structural feature in the study area and is characterized by a series of associated subsidiary small faults. Normal faulting and local folding are also present and appear to be related to both the regional faulting and the emplacement of intrusive bodies.

Surficial and Alluvial Deposits

The Quaternary surficial deposits are unconsolidated and are predominantly alluvial in origin. However, some surficial deposits of small areal extent are of lagoonal and eolian origin (wind-blown deposits) and are restricted to near shore and coastal areas. In general, the alluvial and terrace deposits are mostly composed of clay, silt, and less commonly of pebbly and cobbly gravel of volcanic origin. The alluvium characterized by a high percentage of gravel and sand is limited to the vicinity of active river channels.

A major hydrogeologic feature of the study area is the thickness of the surficial, mostly alluvial, deposits. This thickness was determined based on interpretation of data from 20 surface electrical resistivity surveys (fig. 5). The resistivity surveys were used in conjunction with drillers well logs and lithological and geophysical data collected at two test holes drilled as part of the study to estimate depth to bedrock at selected sites (table 1; fig. 5).

The direct current resistivity method using the Schlumberger electrode configuration (Zohdy and others, 1974) was used and consists of introducing an electrical current into the subsoil through two current electrodes. The difference in the electrical potential between the electrodes is measured to determine the specific resistance (expressed in ohm-meters; Ω-m) of the material(s) in the subsoil. The Schlumberger array produces a detailed resistivity sounding curve for subsurface interpretations. A computer program (Zohdy, 1973) was used to assist in the interpretation of the resistivity sounding results obtained for each surveyed site.

The electrical properties of the subsoil depend primarily on its porosity, the amount of water in the subsoil, and the salinity of the water. Thus, more properly, electrical resistivity values are referred to as apparent resistivity (also expressed in Ω-m). The presence of clays and saline ground water reduces the

Table 1. Well logs used as controls to verify interpretation of geophysical data collected in northeastern Puerto Rico
[USGS, U.S. Geological Survey; m, meters; MSL, mean sea level]

Well identification	USGS site identification number	Latitude	Longitude	Altitude of land surface, reference to MSL (m)	Depth to bedrock (m)	Estimated bottom of top of bedrock, referenced to MSL (m)
RS–2	182138065431800	18°21'38"	65°43'18"	10	17	-7
RP–7	182120065421000	18°21'20"	65°42'11"	6	20	-14
RF–5	181832065403500	18°18'32"	65°40'35"	29	24	5
FESA–3	181948065385800	18°19'48"	65°38'58"	9	36	-27
FESA–1	181934065385400	18°19'34"	65°38'54"	4	16	-12
Eastern Shore–2	181707065385600	18°17'07"	65°38'56"	20	30	-10
Eastern Shore–1	181706065382800	18°17'06"	65°38'28"	5	27	-22

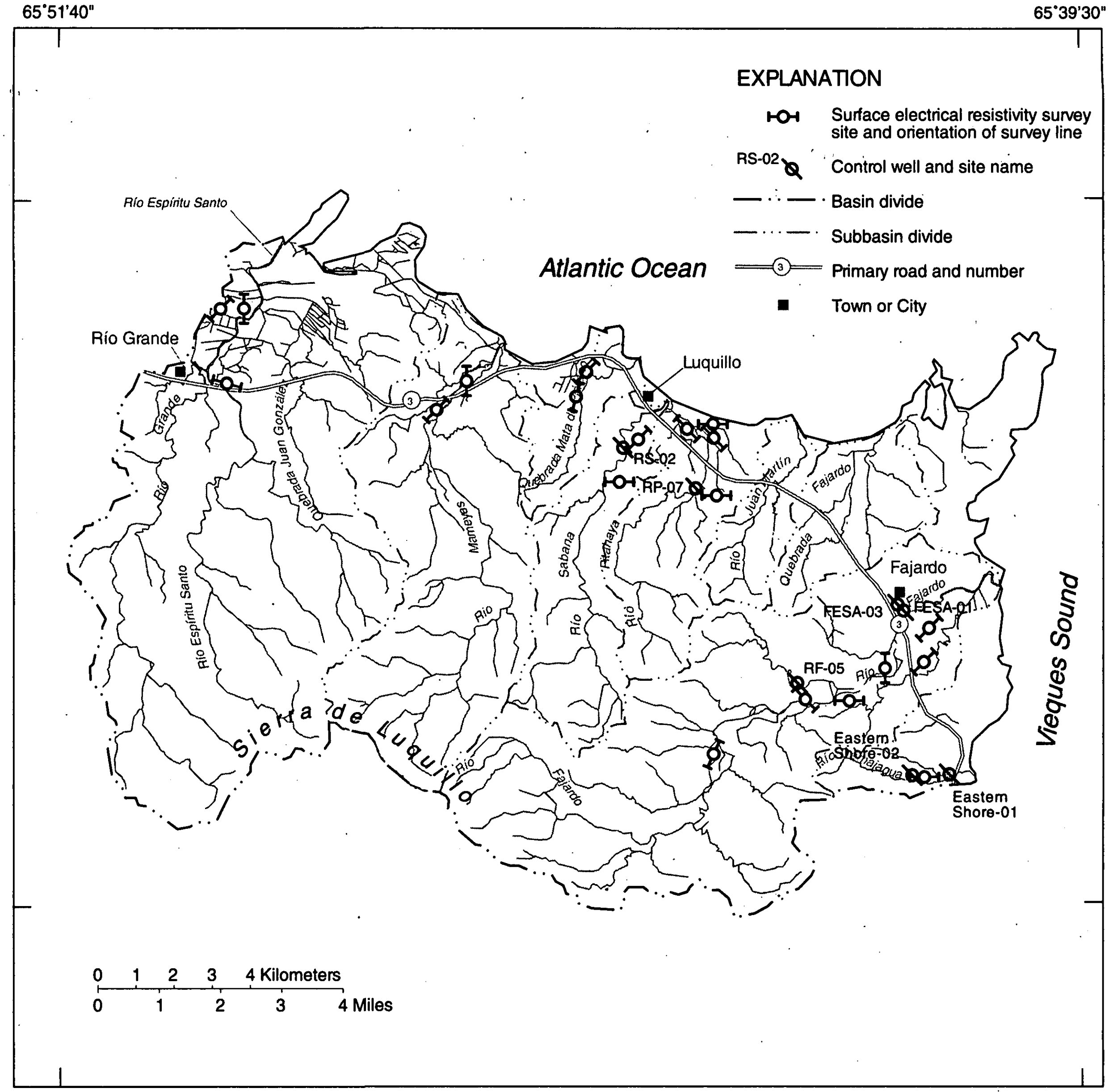

Figure 5. Location of the surface electrical resistivity survey sites and control wells in northeastern Puerto Rico.

resistivity of the subsoil. Resistivity values range from less than 1 Ω-m for clays and saturated sands to several thousand Ω-m for dry basalt and dry sand and gravel (Zohdy and others, 1974). Resistivity values ranging from 20 to 150 Ω-m identify areas of: 1) dry-unsaturated clay and clay-sand deposits, 2) freshwater saturated sands, gravels and limestone, and 3) weathered zones in the volcanic bedrock (Torres-González, 1985). The value used in this investigation to define the depth to bedrock is 100 Ω-m, which is typical of the apparent resistivity of zones in the volcanic bedrock.

The estimated altitude of unconsolidated deposits, referenced to mean sea level, was determined at 14 of the 20 sites at which surface resistivity surveys were conducted. The resistivity was interpreted in conjunction with drillers well logs (used as stratigraphic control) to develop a subsurface structure map showing the estimated altitude at the base of the unconsolidated surficial and alluvial deposits (plate 1). The estimated altitude of the unconsolidated deposits indicates that the maximum thickness of the alluvium may be as much as 60 m within the Río Fajardo alluvial valley and generally not greater than 30 m near the coast in other alluvial valleys in the study area.

The Río Mameyes alluvial valley deposits contain large number of boulders. Under this condition, the surface resistivity technique cannot be used to determine with sufficient resolution the depth to bedrock. The high conductivity of saline water in the Río Espíritu Santo alluvial valley also limits the application of surface resistivity to the mapping of stratigraphy only in the freshwater saturated section.

SURFACE-WATER HYDROLOGY

The northeastern Puerto Rico study area is characterized by numerous perennial streams that drain toward the ocean from the Sierra de Luquillo mountains. Channel slopes in the mountains are steep (about 270 m/km at an altitude of 385 to 655 m) and streamflow velocities are relatively high at all flow magnitudes. Toward the coast the slopes become less steep, ranging from 20 to 1.3 m/km within the alluvial valleys. The U.S. Geological Survey (USGS) maintains seven continuous streamflow-gaging stations and one water-quality partial-record station in the study area (fig. 6). The streamflow-gaging stations and the corresponding altitudes of the gage datum are; Río Grande near El Verde (50642000) at an altitude of 40 m; Quebrada Sonadora near El Verde (50063440) at an altitude of 375 m; Quebrada Toronja at El Verde (50063500) at an altitude of 267 m; Río Espíritu Santo near Río Grande (50063800) at an altitude of 12 m; Río Mameyes near Sabana (50065500) at an altitude of 84 m; Río Sabana at Sabana (50067000) at an altitude of 80 m; and Río Fajardo near Fajardo (50071000) at an altitude of 42 m. The water-quality station is the Río Fajardo below Fajardo (50072500) at an altitude of 2 m. The gaging stations below an altitude of 45 m are within the alluvial valleys.

Flow duration analysis of records for the index stations on the Río Mameyes, Río Sabana, and Río Fajardo was used to estimate the minimum streamflow available at the gaging stations at least 98 percent of the time. The 98 percent of time discharge is used by the Puerto Rico Aqueduct and Sewer Authority for the design capacity of surface-water supply intakes. The USGS also maintains partial-record stations at Highway PR 3 bridge crossings at the Río Mameyes, Río Sabana, Río Pitahaya, and Río Fajardo. The 98 percent flow duration discharge at these partial-record stations was determined from a correlation with the corresponding discharge at the index gaging stations. Because the Río Pitahaya does not have an index gaging station, the index gaging station on the Río Sabana was used. The 98 percent flow duration discharge at the four partial-record stations at bridge crossings on Highway PR 3 is 0.30 m^3/s at the Río Mameyes at Mameyes; 0.07 m^3/s at the Río Sabana at Luquillo; 0.05 m^3/s at the Río Pitahaya near Luquillo; and 0.26 m^3/s at the Río Fajardo at Fajardo.

The 98 percentile discharge near Highway PR 3 provides a close approximation of the maximum sustainable amount of ground water that can be captured by wells from the streams within each of the stream valleys studied. However, there are waste-water discharges at locations downstream of the partial-record stations on the Río Mameyes, Río Sabana, and Río Fajardo. This will limit the capture of streamflow by wells to an amount which will not decrease the 7-day, 10-year low-flow requirements at stream sites which receive sewage treatment plant discharges. In Puerto Rico, for water quality planning purposes, the water quality standards were related to the 7-day, 10-year low flow (Puerto Rico Environmental Quality Board, 1976). Thus, this prior approbation of flow must be subtracted from the 98 percentile statistic to obtain an estimate of the maximum amount of water which can be captured from streams by wells.

Estimates of the 7-day, 10-year low flow at selected sites in eastern Puerto Rico are presented by Santiago (1992). This streamflow-frequency characteristic is defined as the discharge at a 10-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for seven consecutive days. Estimates of the 7-day, 10-year low flow are primarily used to establish the dependable flow that is available at streams for dilution of discharge from wastewater treatment plants. The 7-day, 10-year low flow values estimated at Highway PR 3 bridge crossings are: 0.21 m^3/s for the Río Mameyes at Mameyes; 0.05 m^3/s for the Río Sabana at Luquillo; 0.04 m^3/s for the Río Pitahaya near Luquillo; and 0.19 m^3/s for the Río Fajardo at Fajardo. There are no wastewater treatment plant discharges at the Río Pitahaya. However, for the purposes of this analysis it is assumed that a minimum flow equal to the 7-day, 10-year low flow would serve to guarantee the availability of minimum flow requirement for future wastewater discharges.

The estimated sustainable amount of water which can be captured from streams by wells sited within the alluvial valley aquifers in the vicinity of Highway PR 3 bridge crossings consists of the difference between the 98 percentile discharge and the 7-day, 10-year low flow. Thus the estimated sustainable aquifer yield (under the stated constraints) to wells will be as follows: 0.09 m^3/s for the Río Mameyes at Mameyes; 0.02 m^3/s for the Río Sabana at Luquillo; 0.01 m^3/s for the Río Pitahaya near Luquillo; and 0.07 m^3/s for the Río Fajardo at Fajardo.

The previous discussion may not be in agreement with the current minimum streamflow requirement legally adopted by the Puerto Rico Environmental Quality Board in the waste water quality standard regulations of 1990. At present the 7-day, 2-year low-flow statistic is used for estimating the assimilative capacity of receiving streams for water quality planning. If the 7-day, 2-year low-flow values estimated at Highway PR 3 bridge crossings are used for the analysis, the amount of discharge that must be substracted from the 98 percentile of flow would be as follows: 0.27 m^3/s for the Río Mameyes at Mameyes; 0.09 m^3/s for the Río Sabana at Luquillo; 0.07 m^3/s for the Río Pitahaya near Luquillo; and 0.43 m^3/s for the Río Fajardo at Fajardo. Thus, the estimated sustainable aquifer yield (under the stated constraints) to wells will be as follows: 0.03 m^3/s for the Río Mameyes at Mameyes; -0.02 m^3/s for the Río Sabana at Luquillo; -0.02 m^3/s for the Río Pitahaya near Luquillo; and -0.17 m^3/s for the Río Fajardo at Fajardo (in each case the negative sign indicates that development of the aquifer would result in reducing the 7-day, 2-year by the corresponding amount). Thus, it becomes evident that the 7-day, 2-year low-flow statistic while permitting a larger waste load allocation to streams will result in a reduction of the potential of ground-water development where streamflow capture provides the primary source of water to wells.

GROUND-WATER HYDROLOGY

A network of 42 observation wells was established within the alluvial valley aquifers associated with the principal streams in the area (fig. 7; table 2). The observation-well network was established to collect and supplement hydrogeologic and hydraulic data. A measuring point at each of the observation wells was referenced to mean sea level datum. Ground-water levels were measured on a monthly basis at the observation wells from July 1993 to May 1995 and the data were archived in the U.S. Geological Survey Ground-Water Site Inventory (GWSI) data base. Two continuous ground-water level recorders were installed in the study area; one in the Río Espíritu Santo alluvial valley (RE-1; fig. 7) and the other in the Río Fajardo alluvial valley (RF-4; fig. 7).

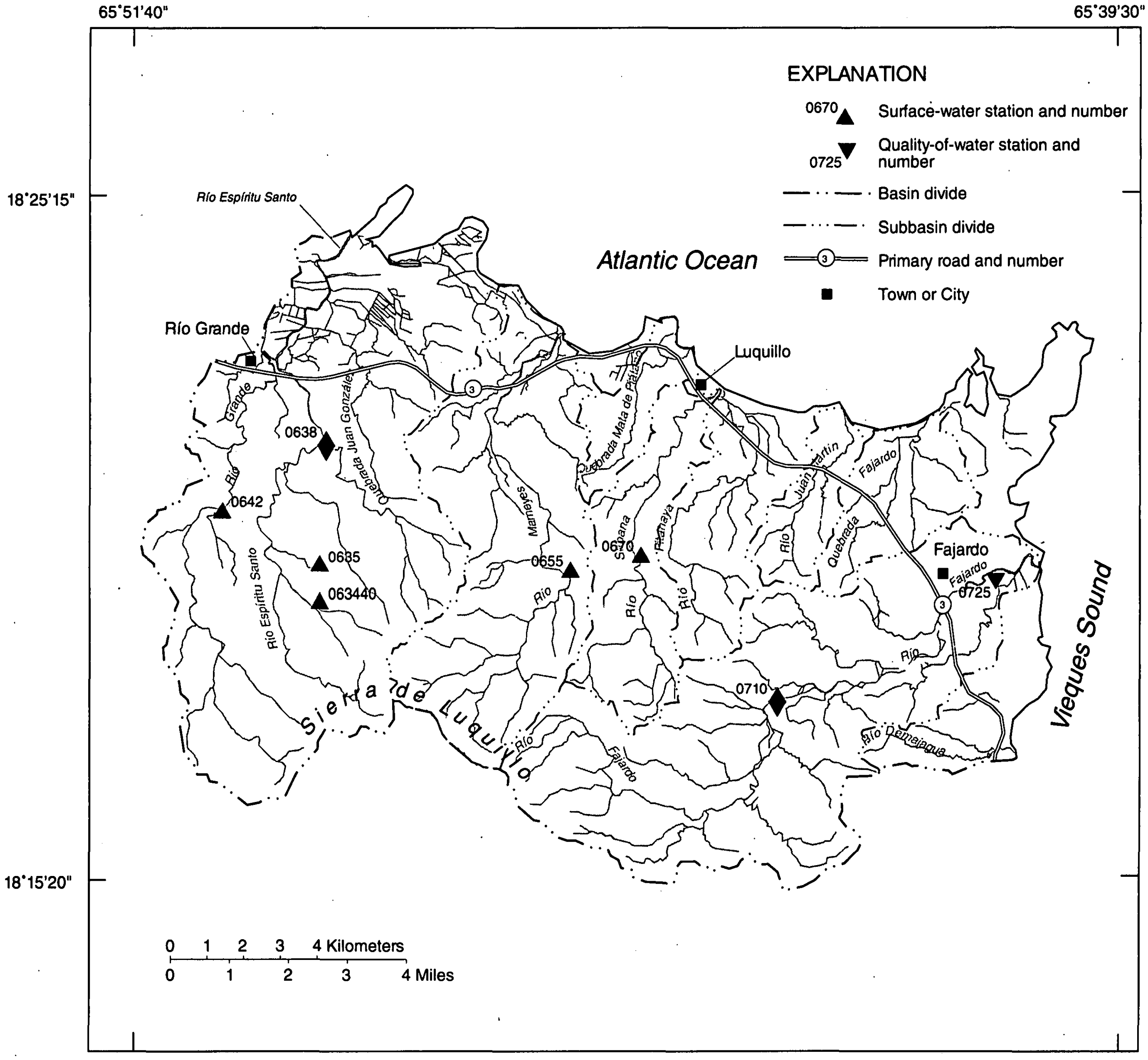

Figure 6. Location of selected U.S. Geological Survey gaging stations in northeastern Puerto Rico.

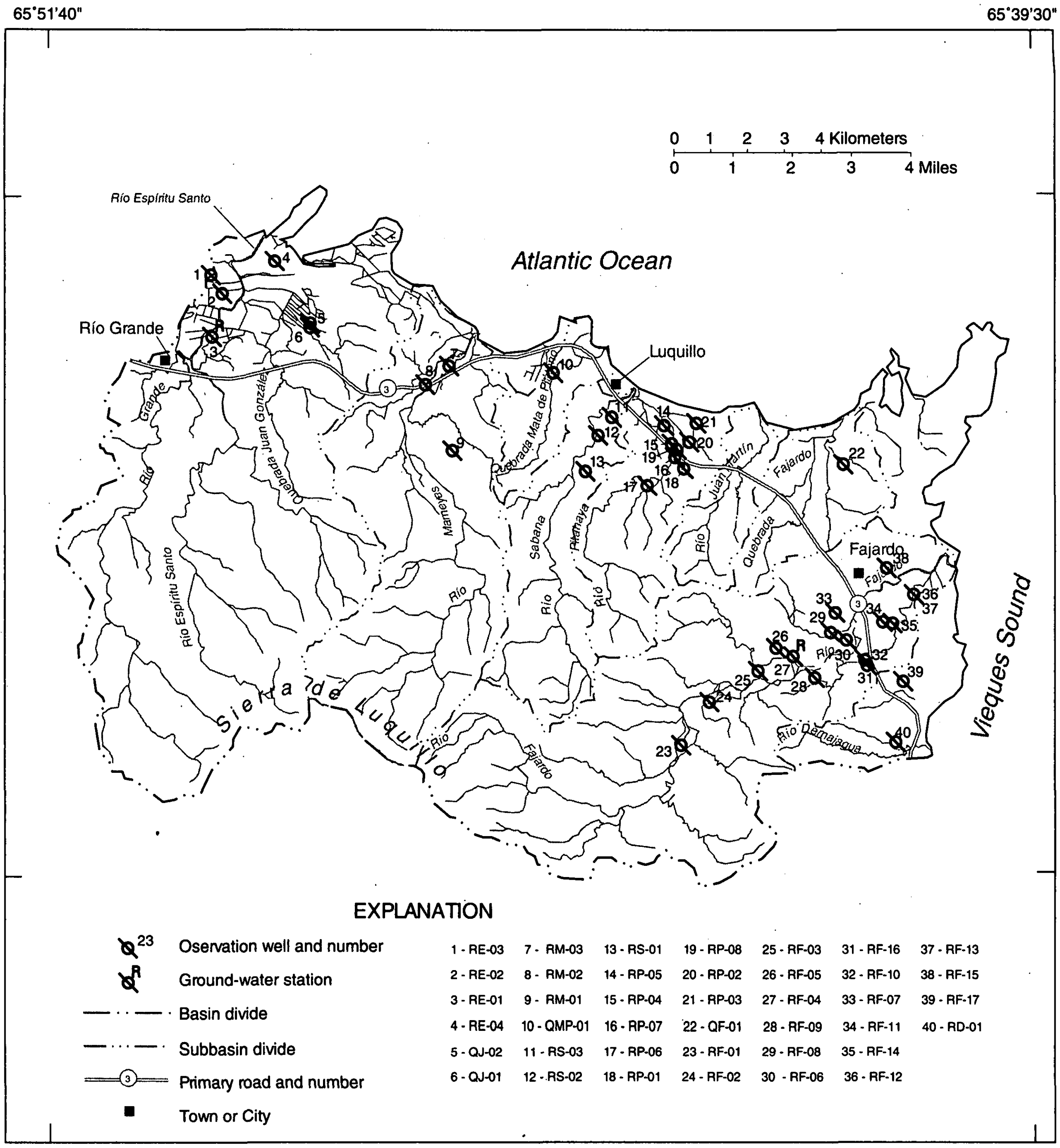

Figure 7. Location of selected observation wells and ground-water stations in northeastern Puerto Rico.

Table 2. Description of selected observation wells in northeastern Puerto Rico

[Note: RM–4 well was not included in the table due to a lack of data; cm, centimeter; m, meter]

Well	USGS site identification number	Date drilled	Casing diameter (cm)	Depth of well (m)	Screened interval (m)
RE–1	182306065491500	03-29-93	10.16	14.02	4.87 - 14.02
RE–2	182344065490801	03-24-93	5.08	6.70	1.52 - 6.70
RE–3	182405065491600	03-25-93	5.08	5.79	0.30 - 5.49
RE–4	182412065481200	04-02-93	5.08	6.70	0.92 - 5.79
QJ–1	182313065474600	06-23-93	5.08	4.27	2.74 - 4.27
QJ–2	182317065474600	06-23-93	10.16	6.40	2.74 - 6.40
RM–1	182125065453500	07-13-94	5.08	16.46	7.93 - 15.55
RM–2	182223065455900	06-22-93	5.08	7.32	3.97 - 7.32
RM–3	182240065453800	04-06-93	5.08	7.32	1.22 - 7.32
QMP–1	182234065440000	04-05-93	10.16	7.62	1.52 - 7.62
RS–1	182108065433100	04-23-93	10.16	8.03	1.93 - 8.03
RS–2	182138065431800	07-19-94	10.16	17.07	3.35 - 15.55
RS–3	182155065430600	04-28-93	10.16	9.45	3.35 - 9.45
RP–1	182109065420000	04-22-93	10.16	9.45	3.35 - 9.45
RP–2	182130065415400	04-26-93	10.16	7.93	1.83 - 7.93
RP–3	182150065414900	04-27-93	5.08	8.03	1.93 - 8.03
RP–4	182131065421100	05-05-93	5.08	11.89	5.79 - 11.89
RP–5	182147065421800	04-04-93	5.08	6.71	2.14 - 6.71
RP–6	182056065423300	07-11-94	5.08	13.11	4.57 - 12.19
RP–7	182120065421000	June 94	20.32	50.30	10.97 - 14.63
RP–8	182126065420600	June 94	20.32	44.21	14.33 - 26.52
QF–1	182113065393300	07-07-94	5.08	14.63	5.49 - 13.11
RF–1	181706065420400	05-06-94	10.16	10.06	3.96 - 10.06
RF–2	181744065413700	05-07-93	5.08	5.79	1.22 - 5.79
RF–3	181813065405200	05-11-93	5.08	9.15	3.05 - 9.15
RF–4	181823065401900	06-09-93	5.08	12.20	6.10 - 12.20
RF–5	181832065403500	05-17-93	10.16	24.39	12.20 - 23.18
RF–6	181840065393100	05-18-93	10.16	10.37	4.27 - 10.37
RF–7	181901065394000	05-20-93	5.08	9.30	3.05 - 9.30
RF–8	181845065394500	05-12-93	5.08	8.84	2.74 - 8.84
RF–9	181806065395900	06-02-93	5.08	6.89	0.79 - 6.89
RF–10	181817065391200	06-01-93	10.16	10.52	4.42 - 10.52
RF–11	181856065385600	05-19-93	5.08	7.01	0.91 - 7.01
RF–12	181917065382701	06-04-93	10.16	10.37	4.27 - 10.37
RF–13	181917065382700	06-08-93	10.16	12.50	3.35 - 12.50
RF–14	181854065384600	06-09-93	10.16	7.47	1.37 - 7.47
RF–15	181942065385300	06-15-93	10.16	7.47	1.37 - 7.47
RF–16	181819065391300	06-08-94	10.16	29.27	12.04 - 27.28
RF–17	181802065383800	06-02-94	10.16	30.49	12.20 - 28.97
RD–1	181710065384600	05-26-93	10.16	9.91	3.81 - 9.91
RD–2	181710065385600	No data	30.48	36.28	No data

Occurrence and Movement of Ground Water

Ground-water level fluctuations generally followed the trend of the hydrographs recorded at sites RE-1 and RF-4 (fig. 8). Throughout the study area, the lowest ground-water levels occurred between June and September 1994, generally coinciding with the end of a period of drought. Water level measurements at observation well RE-1 indicate a response to tidal oscillations on the Río Espíritu Santo, which is about 50 meters from the observation well.

A survey of ground-water levels in piezometers in the principal alluvial aquifers of the study area made during March 23-24, 1994, was used to develop a potentiometric surface map of the local aquifers (plate 1). Streamflow discharge measurements were synoptically made at 37 sites to complement the piezometric data by defining the gaining and loosing reaches of the monitored streams. Gaining reaches of streams generally correspond to that part of the stream along which potentiometric contour lines are concave upstream (apex of contour pointing upstream). Loosing reaches of streams generally correspond to that part of the stream along which potentiometric contour lines are concave downstream (apex of contour pointing downstream). The potentiometric surface map indicates that the direction of ground-water flow in the valleys is generally toward the streams where the potentiometric contours are concave-shaped inland, and away from the main course of streams where these contours are concave-shaped toward the coast. No significant ground-water withdrawals for industrial or public water-supply exist in the study area, although some minor domestic self-supplied ground-water withdrawals may be occurring.

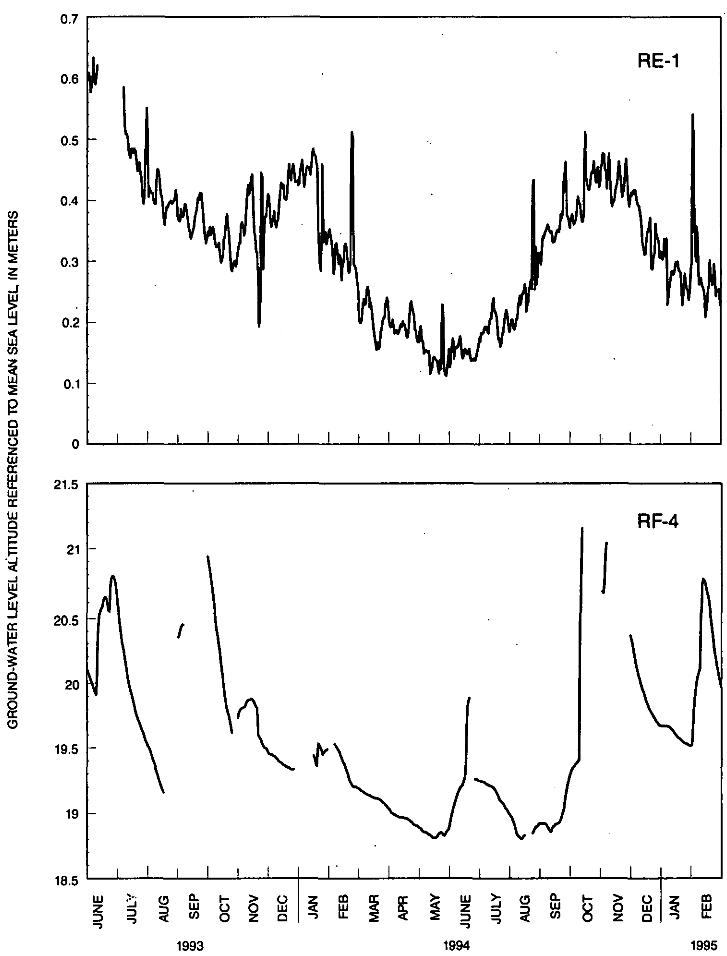

Figure 8. Ground-water level in wells RE–1 and RF–4 in northeastern Puerto Rico from July 1993 to March 1995. Gaps indicate that no data were available for that period of time.

Aquifer Properties

Seven single-well aquifer tests were conducted in observation wells completed in the alluvial valley aquifers of the study area (fig. 9). The purpose of these tests was to estimate the average horizontal hydraulic conductivity for that part of the aquifer penetrated and screened by the wells (table 3). The average horizontal hydraulic conductivity values calculated ranged from 0.25 to 21 m/d.

Table 3. Estimated average horizontal hydraulic conductivity and saturated thickness of the alluvial valley aquifers at selected observation wells

[m, meter; m^2/d, meter squared per day; m/d, meter per day; --, value not determined; <, less than; ≤, less than or equal]

Well identification	Screened interval (m)	Average horizontal hydraulic conductivity (m/d)	Estimated saturated thickness of the aquifer at site (m)
RE–3	1.52 - 7.01	9.1	--
RP–2	3.05 - 9.15	1.2	< 30
RP–7	10.98 - 14.63	20.0	≤ 30
RF–7	3.96 - 10.21	0.25	≤ 30
RF–12	5.49 - 11.59	2.3	30
RF–13	4.57 - 13.72	7.80	30
RF–16	13.11 - 28.35	0.35	30
RD–2	--	--	15

QUALITY OF SURFACE WATER

Stream waters in northeastern Puerto Rico generally are of acceptable quality for most purposes as determined from water samples obtained at nine sites during February 6-13, 1995, (fig. 10). Field determinations were made for specific conductance, pH, temperature, and alkalinity. Samples were collected and analyzed in the laboratory for common constituents. The chemical composition of the surface water at sampled sites is fairly uniform throughout the region (table 4). In general, the water in streams contains from 72 to 258 mg/L of dissolved solids with the lowest concentrations occurring at the inland-most stream sites. Dissolved solids are the mineral constituents dissolved from the weathering of rocks and soils.

A bacteriological water-quality survey was conducted during March 23-24, 1994, on the following streams: Río Grande, Río Espíritu Santo, Canal Castañon, Quebrada Juan González, Río Mameyes, Quebrada Tabonuco, Quebrada Mata de Plátano, Río Sabana, Río Pitahaya, Río Juan Martín, Quebrada Fajardo, Río Fajardo and Río Demajagua (fig. 10). The purpose of this bacteriological assessment was to determine if the sanitary quality of streams represents a contamination threat to ground water. Results obtained from the bacteriological analyses were published by Pérez-Blair and Carrasquillo-Nieves (1996). In general, the bacteriological quality of streams in the area of study does not constitute a significant water-quality problem. Fecal coliform counts ranged from 10 to 6,000 col/100 mL. Fecal streptococci ranged from 9 to 6,900 col/100 mL. The highest fecal coliform counts were detected at Quebrada Fajardo at Convento (6,000 col/100 mL); the highest fecal streptococci counts were detected at Río Fajardo below the wastewater treatment plant (6,900 col/100 mL). A maximum contaminant level of 2,000 col/100 mL for fecal coliform has been established by the Puerto Rico Environmental Quality Board for raw water to be used as a primary source of drinking water and for preservation of biological species (Puerto Rico Environmental Quality Board, 1990). Most streams in Puerto Rico have fecal coliform bacteria counts generally greater than 1,000 col/100 mL (Díaz and others, 1994). Only 3 of 37 surface-water quality sites surveyed as part of this study had fecal coliform counts of greater than or equal to 1,000 col/100 mL (Pérez-Blair and Carrasquillo-Nieves, 1996).

A common phenomena occurring at the mouth of rivers near the ocean is the intrusion of seawater beneath freshwater along the river channel. This is known as a salt water wedge (Thurman, 1985). The inland advance of the salt water wedge depends on the tidal activity of the ocean, the streamflow discharge, the streambed slope, and the difference in density between fresh water and salt water. A survey to determine the location of the salt water wedge in major streams in the study area was made during December 15-20, 1993. Definition of the inland extent

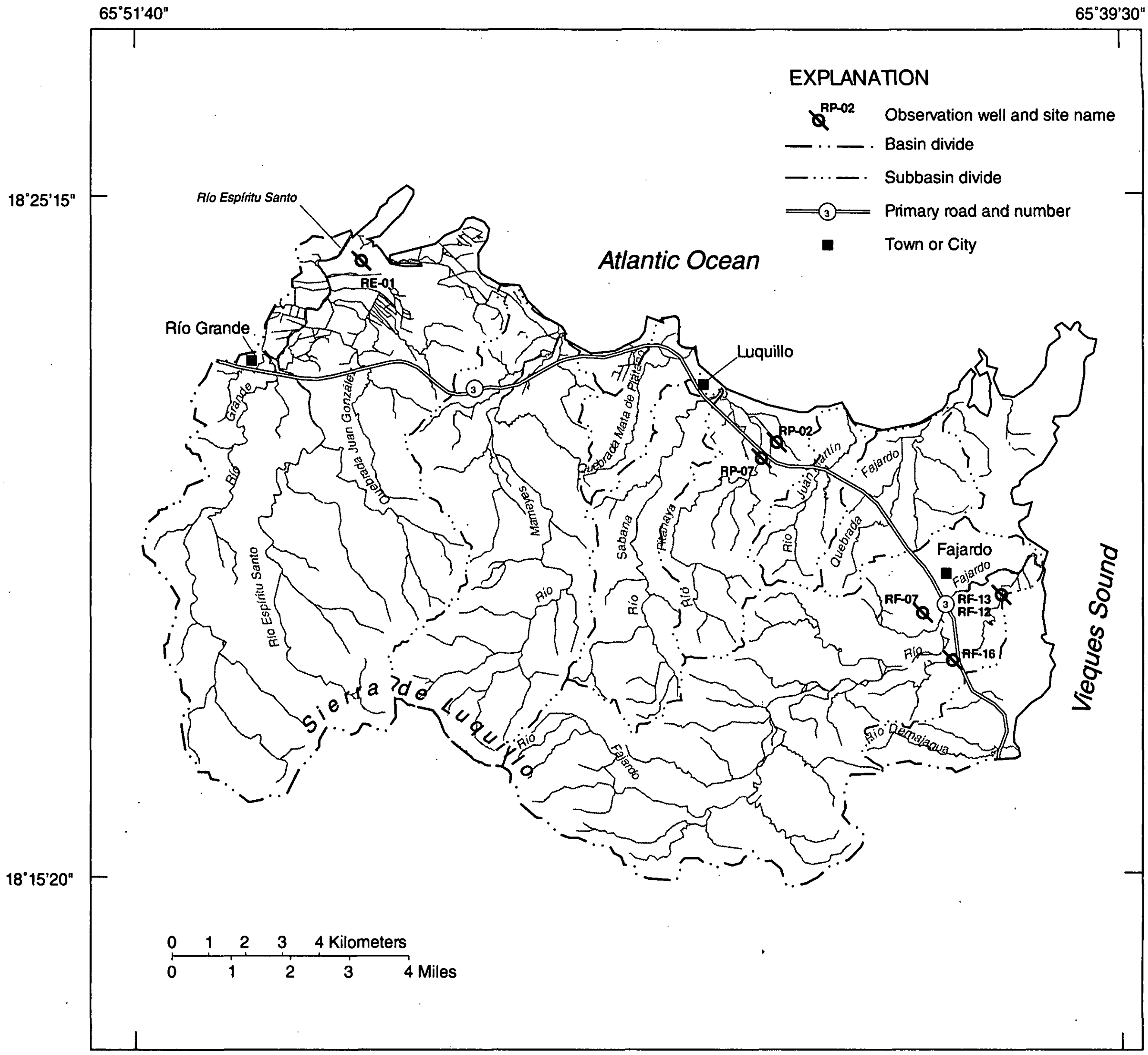

Figure 9. Observation wells at which single well aquifer tests were conducted in northeastern Puerto Rico.

Table 4. Surface-water quality at selected sites in the northeastern alluvial valleys of Puerto Rico
[μS/cm, microsiemens per centimeter at 25 °C; °C, degree Celsius; mg/L, milligrams per liter]

Site number	USGS station number	Date of sampling	Specific conductance (μS/cm)	pH, field	Alkalinity, field (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)
1	50063800	02-06-95	112	6.5	34	7.5	3.9
2	50064900	02-07-95	320	7.2	123	26	11.0
3	50066000	02-07-95	152	7.4	61	15	3.1
4	50067000	02-08-95	135	6.5	47	9.8	3.5
5	50069000	02-08-95	198	6.9	64	13	5.7
6	50069300	02-09-95	381	8.9	119	19	9.7
7	50069400	02-09-95	525	8.9	139	31	13.0
8	50071000	02-13-95	133	7.2	38	7.7	3.7
9	50072700	02-13-95	385	7.2	101	11	7.7

Table 4. Surface-water quality at selected sites in the northeastern alluvial valleys of Puerto Rico–Continued

Site number	USGS station number	Date of sampling	Sodium dissolved (mg/L as Na)	Sulfate dissolved (mg/L as SO_4)	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids (mg/L)
1	50063800	02-06-95	7.9	0.7	10	0.1	21	.72
2	50064900	02-07-95	21	4.9	22	0.1	39	200
3	50066000	02-07-95	8.4	3.1	11	0.1	25	99
4	50067000	02-08-95	10	2.3	11	0.1	30	95
5	50069000	02-08-95	16	3.3	18	0.1	35	129
6	50069300	02-09-95	38	7.6	35	0.2	32	213
7	50069400	02-09-95	47	9.0	55	0.2	19	258
8	50071000	02-13-95	13	3.4	13	0.1	26	90
9	50072700	02-13-95	56	10	51	0.2	29	225

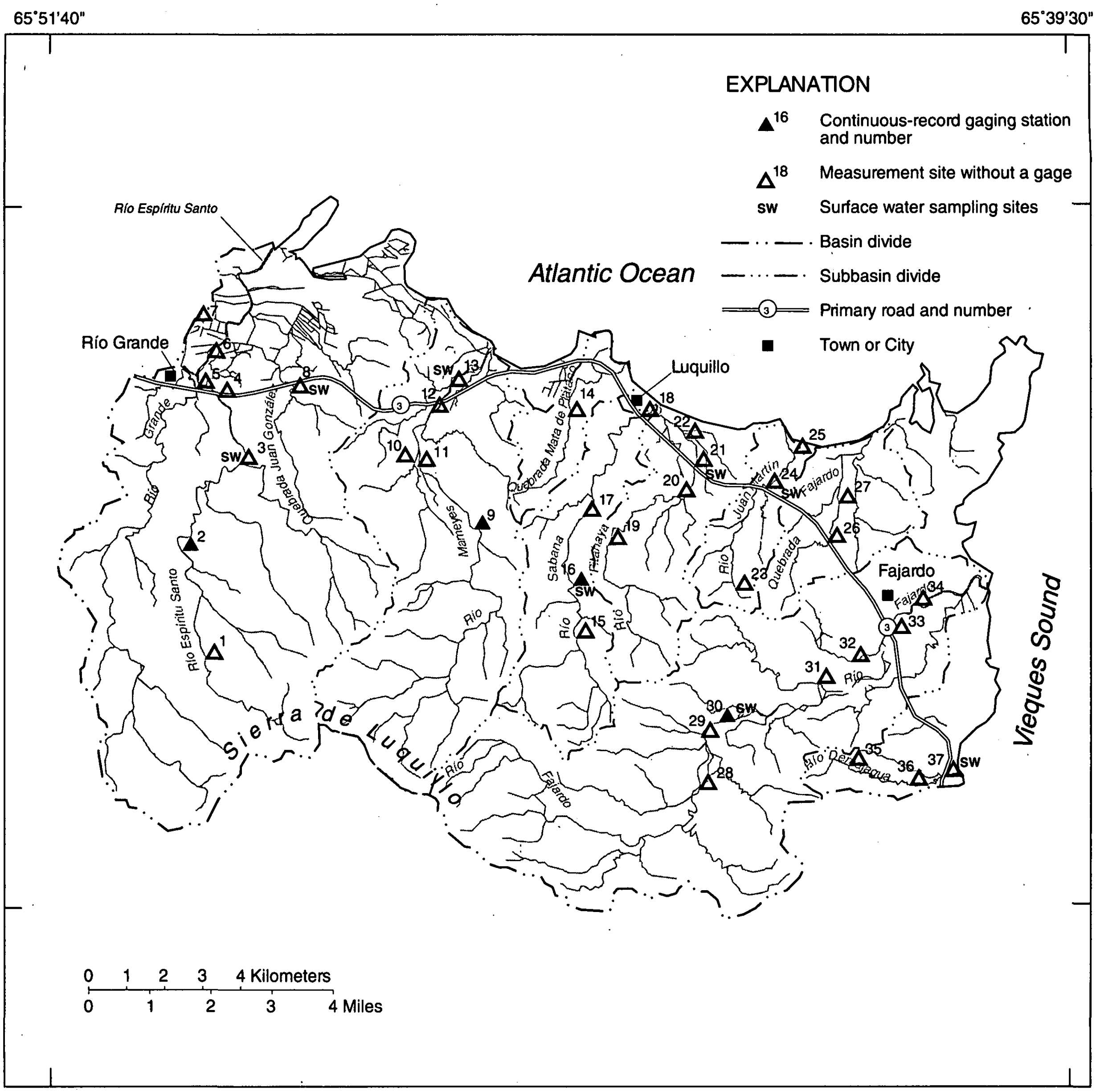

Figure 10. Location of selected surface-water sampling sites in northeastern Puerto Rico.

of the salt water wedge in streams was made by obtaining specific conductance measurements along the stream centerline. Results are presented in table 5 and plate 2. In the Río Espíritu Santo, the inland-most extent of the salt water wedge is limited by a concrete weir upstream from Highway PR 3 where the Río Grande public water-supply intake is located. In the Río Pitahaya, freshwater with a specific conductance of 315 µS/cm was measured at a distance of about 15 m from the mouth of the river. Because the inland extent of the salt water wedge in a stream is controlled primarily by streamflow, an additional survey was made to define the point of zero altitude of the streambed. The point of zero altitude in a stream can be interpreted as the maximum inland extent at which saltwater can penetrate into the stream if streamflow equalled zero. The point of zero altitude was defined for each principal stream in the study area (plate 2). As seen from plate 2, in the Quebrada Mata de Plátano and the Río Juan Martín the inland extent of the saltwater wedge is located inland of the point of zero altitude. This is a consequence of the lateral saline water flow from the mangrove area located in the vicinity of both river reaches.

Table 5. Location of salt water wedge in principal streams in northeastern Puerto Rico during December 16-20, 1993
[m^3/s, cubic meters per second; °C, degrees Celsius; µS/cm, microsiemens per cm at 25 °C; m, meters; --, no flow; >, greater than]

Stream	Date	Hour	Discharge (m^3/s)	Temperature (°C)	Specific conductance (µS/cm)	Distance from mouth of stream (m)
Río Espíritu Santo	12-16-93	1308	--	23.8	128	5,862
				26.5	19,300	5,861
Quebrada Juan González	12-20-93	1536	0.34	25	120	358
					187	473
Río Mameyes	12-15-93	1115	0.51	27	210	1,143
					39,500	1,082
Quebrada Mata de Plátano	12-20-93	1100	0.12	27	600	640
				27	> 50,000	46
Río Pitahaya	12-17-93	1335	0.14	27	210	305
				27	315	15
Río Sabana	12-15-93	1300	1.30	24	325	755
				25	29,000	731
Río Juan Martín	12-17-93	1227	0.01	24.5	575	167
				27	34,900	106
Río Fajardo	12-16-93	1025	0.12	26.5	265	2,218
				26.5	1,200	2,134
Río Demajagua	12-17-93	1036	0.01	24	400	533
				24	1,450	518

QUALITY OF GROUND WATER

Chemical analysis was performed on water samples obtained at 23 observation wells. Ground-water quality within the unconsolidated deposits throughout the study area generally is of acceptable quality for most uses. Fresh water (1,000 mg/L or less of dissolved solids) can be pumped from wells within 20 to 100 feet below land surface at most sites. However, the concentration of manganese (principally) and iron may constitute a water quality limitation for some uses (table 6). Dissolved manganese ranged from 47 to 4,400 µg/L and dissolved iron concentrations ranged from 9 to 6,300 µg/L. Dissolved chloride concentrations ranged from 16 to 160 mg/L, which is well below the 250-mg/L standard for public water-supply sources (Puerto Rico Environmental Quality Board, 1990). The lowest pH value obtained was 5.3 at the RP–1 and RF–9 wells and the highest value was 7.7 at the RP–3 well. The recommended pH standard for public water-supply sources is between 6 and 9 (Puerto Rico Environmental Quality Board, 1990).

Water samples from 8 of the 23 observation wells contained dissolved solids at concentrations exceeding 500 mg/L, which is the recommended standard for public water-supply sources in Puerto Rico (Puerto Rico Environmental Quality Board, 1990). Dissolved-solids concentrations ranged from 73 to 1,200 mg/L. The lowest concentration was obtained at observation well RP–1 and the highest concentration at observation well QJ–2. Except for the dissolved solids concentration at the QJ–2 observation well the rest of the observation wells sampled contained dissolved solids at concentrations of less than 600 mg/L. The dissolved solids concentration throughout the study area is shown on plate 2. In the Río Fajardo alluvial valley aquifer, ground water with an anomalous concentration of dissolved solids was detected at two areas. One of these areas is at observation well RF–9 where the dissolved solids concentration was 353 mg/L within an area at which the concentration was expected to be near 280 mg/L. At this location the anomaly may be the result of a previous land use in which sulfate was used (possibly fertilizer storage area). The other area at which the concentration of dissolved solids is anomalous encompasses an area of about 3 km^2 in the vicinity of observation wells RF–4, RF–6, RF–7, and RF–8, and is generally contained in the area to the west of the Río Fajardo stream course. Observations by Seiders and others (1972) and Taggart (1992) suggest that during the Holocene (between 1.4 to 3.3 thousand years ago) the sea level in Puerto Rico was as much as 3 m higher than it is presently. Therefore, this 3 km^2 area could represent an area in which connate saltwater exists at depth.

Saline water is occasionally present within all the aquifers in the study area in the coastward direction of the alluvial valleys. As a preliminary estimate, the Ghyben-Herzberg principle was used to determine the depth of fresh water in the aquifer. The Ghyben-Herzberg principle states that the interface between fresh water and salt water is located at a depth, below mean sea level, equal to 40 times the altitude of the freshwater potentiometric surface. The Ghyben-Herzberg principle was applied in conjunction with the estimated altitude at the top of bedrock beneath the unconsolidated deposits (plate 1) and the potentiometric-surface map (plate 1) to delineate the inland extent of the leading edge of the salt-water lens within the unconsolidated deposits in the alluvial valley aquifers (plate 2).

GROUND-WATER RESOURCES DEVELOPMENT POTENTIAL

The alluvial valley aquifers within northeastern Puerto Rico have the potential to supplement the available surface-water resources for public-water supply. The results presented in this report provide the necessary analysis on the occurrence, availability, and quality of ground water in the area. Development of ground-water supplies in the principal alluvial valley aquifers is affected by the capacity of the aquifers to transmit water (transmissivity) and the inland location of the saline-water lens. Ground-water development near the streams will increase the hydraulic gradient from the river into the aquifer and induce seepage from the river, which may improve well yield and decrease streamflow. However, a minimum streamflow is necessary to sustain the integrity of the ecological system and provide the required streamflow

Table 6. Ground-water quality at selected sites in the alluvial valleys of northeastern Puerto Rico

[m, meter; µ S/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter]

Well number	USGS Site ID number	Date of sampling	Depth of well (m)	Specific conductance (µS/cm)	pH, field	Calcium dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium dissolved (mg/L as Na)	Alkalinity field (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)
RE–2A	182344065490801	11-07-94	6.70	882	7.3	100	28	43	372	15
QJ–2	182317065474600	11-04-94	6.40	1,932	7.5	49	33	390	871	52
RM–1	182125065453500	12-13-94	16.46	398	6.6	44	12	16	139	3.9
RM–2	182223065455900	10-28-94	7.32	846	7.5	91	31	47	351	17
RM–3	182240065453800	11-18-94	7.32	429	6.9	47	11	27	131	28
QMP–1	182234065440000	10-14-94	7.62	632	7.1	59	30	64	349	13
RS–3	182155065430600	11-23-94	9.45	752	6.2	36	17	78	107	16
RP–1	182109065420000	10-27-94	9.45	202	5.3	4	4.8	18	0.82	2.3
RP–2	182130065415400	11-21-94	7.93	564	6.0	21	19	49	99	3.0
RP–3	182150065414900	12-14-94	7.11	1,020	7.7	62	26	110	346	12
RP–5	182147065421800	10-25-94	6.70	1,030	6.5	27	35	120	405	3.5
QF–1	182113065393300	12-12-94	13.72	373	6.0	13	3.4	57	45	49
RF–2	181744065413700	11-16-94	5.79	217	6.2	13	5.2	18	67	14
RF–6	181840065393100	12-06-94	10.37	940	7.0	15	11	150	177	21
RF–7	181901065394000	11-15-94	9.29	946	6.5	18	11	170	159	120
RF–9	181806065395900	11-17-94	6.89	570	5.3	37	23	26	12	190
RF–11	181856065385600	11-09-94	7.01	270	6.6	17	6.5	15	68	8.9
RF–13	181917065382700	12-07-94	12.50	635	6.6	43	24	42	158	47
RF–14	181854065384600	10-26-94	7.49	495	6.2	28	18	44	132	25
RF–15	181942065385300	11-14-94	7.47	910	7.0	120	34	22	466	13
RF–16	181819065391300	12-15-94	29.29	528	7.2	37	13	50	164	7.7
RF–17	181802065383800	12-08-94	30.49	960	7.4	33	23	120	198	27
RD–1	181710065384600	11-10-94	9.91	888	6.4	28	17	120	125	26

Table 6. Ground-water quality at selected sites in the alluvial valleys of northeastern Puerto Rico–Continued

Well number	USGS Site ID number	Date of sampling	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica dissolved (mg/L as SiO_2)	Iron dissolved (µg/L as Fe)	Manganese dissolved (µg/L as Mn)	Dissolved solids (mg/L)	Total hardness (mg/L of $CaCO_3$)
RE–2A	182344065490801	11-07-94	67	0.2	24	640	190	500	365
QJ–2	182317065474600	11-04-94	110	1.2	55	18	790	1,212	258
RM–1	182125065453500	12-13-94	32	<0.1	29	18	180	220	159
RM–2	182223065455900	10-28-94	58	0.2	28	46	3,100	483	355
RM–3	182240065453800	11-18-94	27	0.1	25	43	950	244	163
QMP–1	182234065440000	10-14-94	160	0.5	34	14	210	570	271
RS–3	182155065430600	11-23-94	150	0.2	50	120	860	411	160
RP–1	182109065420000	10-27-94	17	<0.1	26	68	170	73	30
RP–2	182130065415400	11-21-94	17	<0.1	42	540	4,400	210	131
RP–3	182150065414900	12-14-94	110	0.7	44	9.0	190	572	262
RP–5	182147065421800	10-25-94	68	0.4	55	1,700	1,400	552	211
QF–1	182113065393300	12-12-94	47	<0.1	22	31	220	218	46
RF–2	181744065413700	11-16-94	17	0.1	44	6,300	1,100	152	54
RF–6	181840065393100	12-06-94	160	0.3	38	18	1,400	501	83
RF–7	181901065394000	11-15-94	120	0.1	47	140	730	581	90
RF–9	181806065395900	11-17-94	24	<0.1	46	270	1,300	353	187
RF–11	181856065385600	11-09-94	16	0.1	27	36	260	131	69
RF–13	181917065382700	12-07-94	63	0.2	40	45	1,800	354	206
RF–14	181854065384600	10-26-94	53	0.2	38	470	1300	285	144
RF–15	181942065385300	11-14-94	18	0.4	34	17	47	520	439
RF–16	181819065391300	12-15-94	61	0.2	34	16	240	301	145
RF–17	181802065383800	12-08-94	150	0.5	32	6.0	440	504	177
RD–1	181710065384600	11-10-94	160	0.3	35	620	1,500	461	140

for conveyance of waste-water treatment plant discharges within those streams at which these discharges exist (the Río Mameyes, Río Sabana, and Río Fajardo).

In areas where the average horizontal hydraulic conductivity of the aquifer is low, an infiltration gallery may permit adequate development of ground water. Preliminary estimates of the maximum ground-water development potential within the study area can be made by assuming that it is feasible to capture that part of the streamflow (either by wells or infiltration galleries) equal to the discharge rate at the 98 percent flow duration calculated near the coast for each of the major streams minus the 7- day, 10-year low flow (assumed as the minimum flow rate required to maintain acceptable quality of waters within streams downstream of the point for which the flow rates are estimated – Highway PR 3). The available ground-water development potential under such conditions is limited to the amount of water that can be captured from the streamflow. Estimates of ground-water development potential in the study area are 0.09 m^3/s for the Río Mameyes at Mameyes, 0.02 m^3/s for the Río Sabana at Luquillo, 0.01 m^3/s for the Río Pitahaya near Luquillo, and 0.07 m^3/s for the Río Fajardo at Fajardo.

Water from production wells located in areas where ground-water quality may not be suitable for public-water supply as a result of high concentrations iron or manganese, may require physical or chemical treatment or dilution with surface water in order to comply with secondary water-quality standards. Furthermore, adequate measures should be taken to maintain the bacteriological quality of the streams.

SUMMARY AND CONCLUSIONS

A ground-water resources assessment was made of the alluvial valley aquifers from the Río Espíritu Santo to the Río Demajagua in northeastern Puerto Rico. The total area overlain by unconsolidated deposits which constitute the principal ground-water bearing unit considered in the 290 km^2 study area is 68 km^2. The municipios in this area have an estimated permanent population of more than 100,000. The tourism industry is undergoing a significant growth and this growth is expected to continue with the development of new hotels and resorts. Water supply is from surface-water intakes located at the principal streams. There is no significant ground-water development. Fresh ground water occurs at altitudes ranging from zero to 60 m above mean sea level within the alluvial valley aquifers.

Ground water within the unconsolidated deposits of northeastern Puerto Rico is generally of acceptable quality for most uses. Water with less than 1,000 mg/L of dissolved solids can be obtained from within 20 to 100 feet of the land surface in the aquifers at most sites. The major ground-water quality concerns are dissolved manganese concentrations ranging from 47 to 4,400 µg/L and dissolved iron concentrations ranging from 9 to 6,300 µg/L in some parts of the aquifers. Saline water is present in the lower part of the alluvial valley aquifers near the coast.

Preliminary estimates of the sustainable amount of ground-water development potential was determined from the difference between the 98 percent flow duration and the 7-day, 10-year low flow estimated for all major streams in the area at the Highway PR 3 bridge crossings where partial record stations are located. The estimated sustainable amounts of water which can be captured from streams by wells at these sites are 0.09 m^3/s at the Río Mameyes at Mameyes, 0.02 m^3/s at the Río Sabana at Luquillo, 0.01 m^3/s at the Río Pitahaya near Luquillo, and 0.07 m^3/s at the Río Fajardo at Fajardo.

The discharges occurring 98 percent of the time at the four partial-record stations at Highway PR 3 bridge crossings are 0.30 m^3/s at the Río Mameyes at Mameyes, 0.07 m^3/s at the Río Sabana at Luquillo, 0.05 m^3/s at the Río Pitahaya near Luquillo, and 0.26 m^3/s at the Río Fajardo at Fajardo. Estimates of the 7-day, 10-year low flow at these partial-record stations are: 0.21 m^3/s at the Río Mameyes at Mameyes, 0.05 m^3/s at the Río Sabana at Luquillo, 0.04 m^3/s at the Río Pitahaya near Luquillo, 0.19 m^3/s at the Río Fajardo at Fajardo. At present the 7-day, 2-year low-flow statistic is used for estimating the assimilative capacity of receiving streams for water quality planning (Puerto Rico Environmental Quality Board, 1990). If the 7-day, 2-year low-flow values estimated at Highway PR 3 bridge crossings are used for the analysis, the amount of discharge that must be subtracted from the 98 percentile of flow would be as follows: 0.27 m^3/s for the Río Mameyes at Mameyes; 0.09 m^3/s for the Río Sabana at Luquillo; 0.07 m^3/s for the Río Pitahaya near Luquillo; and 0.43 m^3/s for the Río Fajardo at Fajardo. Thus, the estimated sustainable aquifer yield (under the stated constraints) to wells will be as follows: 0.03 m^3/s for the Río Mameyes at Mameyes, -0.02 m^3/s for the Río Sabana at Luquillo, -0.02 m^3/s for the Río Pitahaya near Luquillo, and -0.17 m^3/s for the Río Fajardo at Fajardo (in each case the negative sign indicates that development of the aquifer would result in reducing the 7-day, 2-year by the corresponding amount). Thus, it becomes evident that the 7-day, 2-year low-flow statistic while permitting a larger waste load allocation to streams will result in a reduction of the potential for ground-water development where streamflow capture provides the primary source of water to wells.

The direction of ground-water flow in the alluvial valleys is generally toward the streams. Estimates of average horizontal hydraulic conductivity in the area range from 0.25 to 21 m/d, indicating that development of the aquifer as a public-water supply source may require more detailed analysis at specific sites within the study area where transmissivity is most favorable.

The surface water quality of streams in northeastern Puerto Rico is fairly uniform throughout the region. Water in the streams contains from 72 to 258 mg/L of dissolved solids with the lowest concentrations occurring at the inland-most part of the alluvial valley aquifers. Bacteriological quality of streamflow does not constitute a significant water quality problem.

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