U.S. Department of the Interior
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PREPARED IN COOPERATION WITH THE
MUNICIPIO AUTÓNOMO DE MAYAGÜEZ, PUERTO RICO, OFFICE OF THE MAYOR

Surface-Water, Water-Quality, and Ground-Water Assessment of the Municipio of Mayagüez, Puerto Rico, 1999-2002

WATER-RESOURCES INVESTIGATIONS REPORT 03-4317

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Cover photograph

View from Cerro Las Mesas looking northwest. In the foreground is a portion of the Mayagüez urban area that includes, towards the right, the campus of the University of Puerto Rico at Mayagüez and the Palacio de los Deportes Coliseum. In the background toward the left, is the dock area of the Bahía de Mayagüez adjoining Punta Algarrobo. Also in the background toward the right, is the Bahía de Añasco bordered in the north by the Punta Higuero.
Photograph taken by Francisco Maldonado on February 24, 2004.

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By Jesús Rodríguez-Martínez, Luis Santiago-Rivera, Senén Guzmán-Ríos, Fernando Gómez-Gómez, and Mario L. Oliveras-Feliciano

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By Luis Santiago-Rivera and Fernando Gómez-Gómez

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Chapter C

Hydrogeologic Terranes and Ground-Water Resources in the Municipio of Mayagüez, Puerto Rico, 1999-2002

By Jesús Rodríguez-Martínez

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Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [(gal/d)mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per hour (in/h)	0 .0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F = (1.8 \times °C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) - a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929".

Horizontal Datum - Puerto Rico Datum, 1940 Adjustment

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Abbreviated water-quality units used in this report:

µg/L	microgram per liter
µS/cm	microsiemen per centimeter
mL	milliliter

Acronyms used in this report:

CAPR	Compañía de Aguas de Puerto Rico
FEMA	Federal Emergency Management Agency
PR	Puerto Rico
PRASA	Puerto Rico Aqueduct and Sewer Authority
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Translations:

Commonly used Spanish terms and their equivalent in English

Spanish	*English*
barrio	ward
caño	usually equivalent to river, channel, or drainage ditch
lago	lake
municipio	usually equivalent to county
pozo	well
quebrada	stream or creek
río	river

Surface-Water, Water-Quality, and Ground-Water Assessment of the Municipio of Mayagüez, Puerto Rico, 1999-2002

By Jesús Rodríguez-Martínez, Luis Santiago-Rivera, Senén Guzmán-Ríos, Fernando Gómez-Gómez, and Mario L. Oliveras-Feliciano

Abstract

The surface-water assessment portion of this study focused on analysis of low-flow characteristics in local streams and rivers, because the supply of safe drinking water was a critical issue during recent dry periods. Low-flow characteristics were evaluated at one continuous-record gaging station based on graphical curve-fitting techniques and log-Pearson Type III frequency curves. Estimates of low-flow characteristics for 20 partial-record stations were generated using graphical-correlation techniques. Flow-duration characteristics for the continuous- and partial-record stations were estimated using the relation curves developed for the low-flow study. Stream low-flow statistics document the general hydrology under current land use, water-use, and climatic conditions.

A survey of streams and rivers utilized 37 sampling stations to evaluate the sanitary quality of about 165 miles of stream channels. River and stream samples for fecal coliform and fecal streptococcus analyses were collected on two occasions at base-flow conditions. Bacteriological analyses indicate that a significant portion of the stream reaches within the municipio of Mayagüez may have fecal coliform bacteria concentrations above the water-quality goal (standard) established by the Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental de Puerto Rico) for inland surface waters. Sources of fecal contamination may include: illegal discharge of sewage to storm-water drains, malfunctioning sanitary sewer ejectors, clogged and leaking sewage pipes, septic tank leakage, unfenced livestock, and runoff from livestock pens. Long-term fecal coliform data from five sampling stations located within or in the vicinity of the municipio of Mayagüez have been in compliance with the water-quality goal for fecal coliform concentration established in July 1990.

Geologic, topographic, soil, hydrogeologic, and streamflow data were compiled into a database and used to divide the municipio of Mayagüez into five hydrogeologic terranes. This integrated database then was used to evaluate the ground-water potential of each hydrogeologic terrane. Lineament-trace analysis was used to help assess the ground-water development potential in the hydrogeologic terranes containing igneous rocks. Analyses suggest that areas with slopes greater than 15 degrees have relatively low ground-water development potential. The presence of fractures, independent of the topographic slope, may locally enhance the water-bearing properties in the hydrogeologic terranes containing igneous rocks. The results of this study indicate that induced streamflow generally is needed to sustain low to moderate ground-water withdrawal rates in the five hydrogeologic terranes. The ground-water flow systems in the hydrogeologic terranes are only able to sustain small withdrawal rates that rarely exceed 50 gallons per minute. Areas with a high density of fractures, as could be the case at the intersection of lineament traces in the upper parts of the Río Cañas and Río Yagüez watersheds, are worthy of exploratory drilling for ground-water development.

Sumario

El U.S. Geological Survey, en cooperación con la oficina del Alcalde del Municipio Autónomo de Mayagüez, llevó a cabo un estudio de los recursos de agua superficial y subterránea en dicho municipio. Los planificadores municipales necesitaban un documento integrador que le permitiera la seleción de alternativas para satisfacer las demandas presentes y futuras de agua, así como la identificación de fuentes adicionales de abasto de agua. Los resultados principales de este estudio fueron entrados a un sistema de información geográfica y se muestran en dos mapas a escala de 1:30,000 para facilitar la interpretación y el uso de la información diversa sobre los recursos de agua.

La parte de este estudio correspondiente al agua superficial se concentró en el análisis de los flujos mínimos en los ríos y arroyos del municipio, ya que el abasto de agua potable fue un asunto crítico durante periodos recientes de sequía. Se evaluaron las características de flujos mínimos en una estación fluviométrica de registro continuo utilizando técnicas para ajustar curvas gráficas y curvas de frequencia log-Pearson Tipo III. Estimados de flujos mínimos para 20 estaciones de registro parcial fueron determinados usando técnicas de correlación gráfica. Las características de duración de flujo se computaron para la estación de registro continuo y se estimaron para las estaciones de registro parcial, utilizando las curvas de relación desarrolladas para el estudio de flujos mínimos. Las estadísticas de flujos mínimos obtenidas durante este estudio documentan la hidrología general bajo las presentes condiciones climáticas y los usos actuales de terrenos y agua.

Se utilizaron 37 estaciones de muestreo para evaluar la calidad sanitaria de aproximadamente 264 kilómetros de ríos y arroyos. Muestras de agua fueron tomadas en ríos y arroyos durante condiciones de estiaje para determinar la concentración de bacterias coliformes de los grupos fecales y estreptococos. Los análisis bacteriológicos indican que una porción significativa de tramos de ríos y arroyos en el municipio de Mayagüez superan los límites de coliformes fecales establecidos por la Junta de Calidad Ambiental de Puerto Rico para aguas interiores y que estuvieron vigentes durante la duración de este estudio (estos límites estuvieron vigentes hasta marzo del 2003, cuando fueron enmendados para hacerlos más restrictivos). Entre las fuentes de contaminación fecal se encuentran: la descarga ilegal de aguas residuales en los sistemas de alcantarillado pluvial, operación de eyectores defectuosos de alcantarillados de aguas usadas, alcantarillados sanitarios tapados y con filtraciones, filtraciones en tanques sépticos, ganado libre (fuera de cercados) y escorrentía proveniente de corrales de ganado. Los datos a largo plazo sobre concentraciones de coliformes fecales en cinco estaciones de muestreo localizadas en o cerca a el municipio de Mayagüez satisfacen los estándares para coliforme fecales de la Junta de Calidad Ambiental vigentes hasta marzo del 2003.

Se utilizaron datos geológicos, topográficos, de suelo, hidrogeológicos y fluviométricos para dividir el municipio de Mayagüez en cinco unidades hidrogeológicas. Esta base de datos se utilizó de manera integrada para evaluar el potencial de desarrollo de agua subterránea en cada unidad hidrogeológica. El análisis de lineamentos fue usado para evaluar el potential de desarrollo de agua subterránea en unidades hidrogeológicas constituídas por rocas igneas. Los resultados indican que áreas con pendientes mayores de 15 grados tienen relativamente poco potencial de desarrollo de agua subterránea. La presencia de fracturas, independientemente de la pendiente topográfica, puede localmente mejorar las propiedades de almacenamiento y transmissión de agua subterránea en aquellas unidades hidrogeológicas de rocas igneas. Los resultados de este estudio indican que la inducción de flujo de ríos o arroyos cercanos es necesario para sostener tasas de extraciones bajas y moderadas de agua subterránea en las cinco unidades hidrogeológicas. Los sistemas de flujo de agua subterránea en la unidades hidrogeológicas solamente pueden sostener tasas de extracción que raramente exceden 3 litros por segundos.

Introduction

The municipio of Mayagüez in western Puerto Rico (fig. 1) covers a land area of 78 square miles (mi^2) and a resident population of about 114,000 (W. Molina-Rivera, U.S. Geological Survey, written commun., 2001). Filtration plants are the major source of potable water for the municipio the city of Mayagüez (98,343 in 2000, U.S. Department of Commerce, 1998) and its barrios. Recently, there have been concerns within the central (municipio) government about the apparent deterioration of reliable service of the public water-supply system. This deterioration has affected the economic and social development of the municipio of Mayagüez, by substantially reducing the number of housing units and industries that can be constructed within the municipio. Although the entire municipio experiences the problem of deficiencies in the public water-supply system, the situation is considerably more severe in the upland areas, which constitute about 50 percent of the total municipio area. The upland communities can be divided into two sub-areas: (1) the relatively less developed rural barrios of Canas Arriba, Bateyes, Naranjales, Montoso, and Rosario (with a total population of about 6,000 as of 1999) at altitudes ranging between 650 to 1,000 feet above sea level and with a public water-supply demand of about 0.4 million gallons per day (Mgal/d); and (2) the rural barrios of Limón, Quemado, Leguisamo, Río Canas Abajo, and Juan Alonso (with a total population of about 10,000 as of 1999) at altitudes averaging 750 feet above seal level and with a public water-supply demand of about 0.7 Mgal/d. The populated lowland areas of the city of Mayagüez use about 10 to 15 Mgal/d.

A series of short- and long-term remedial measures are being implemented by the municipal and central government to upgrade the public water-supply production and distribution infrastructure, minimize the amount of water lost, and improve the service reliability. However, the filtration plants that serve the municipio of Mayagüez and the adjacent municipios of Añasco, Hormigueros, and Cabo Rojo cannot meet the water demand during periods of low surface-water flows.

To satisfy the present water demand, particularly of the upland areas, and to ensure an adequate supply of safe drinking water for the expected demand increase in the near future, the municipal government of Mayagüez requested that the U.S. Geological Survey (USGS) conduct an assessment of the surface- and ground-water resources and sanitary quality of the streams within the territorial limits of the municipio. The results of this study will provide the information needed for the municipal government to adopt and implement policies to conserve and enhance the existing water resources within the municipio for their potential development in times of drought or emergencies, and to sustain short- and long-term socio-economic expansions. The results of this study will be incorporated into the land-use development plan of the municipio of Mayagüez to ensure sustainable development of local water resources.

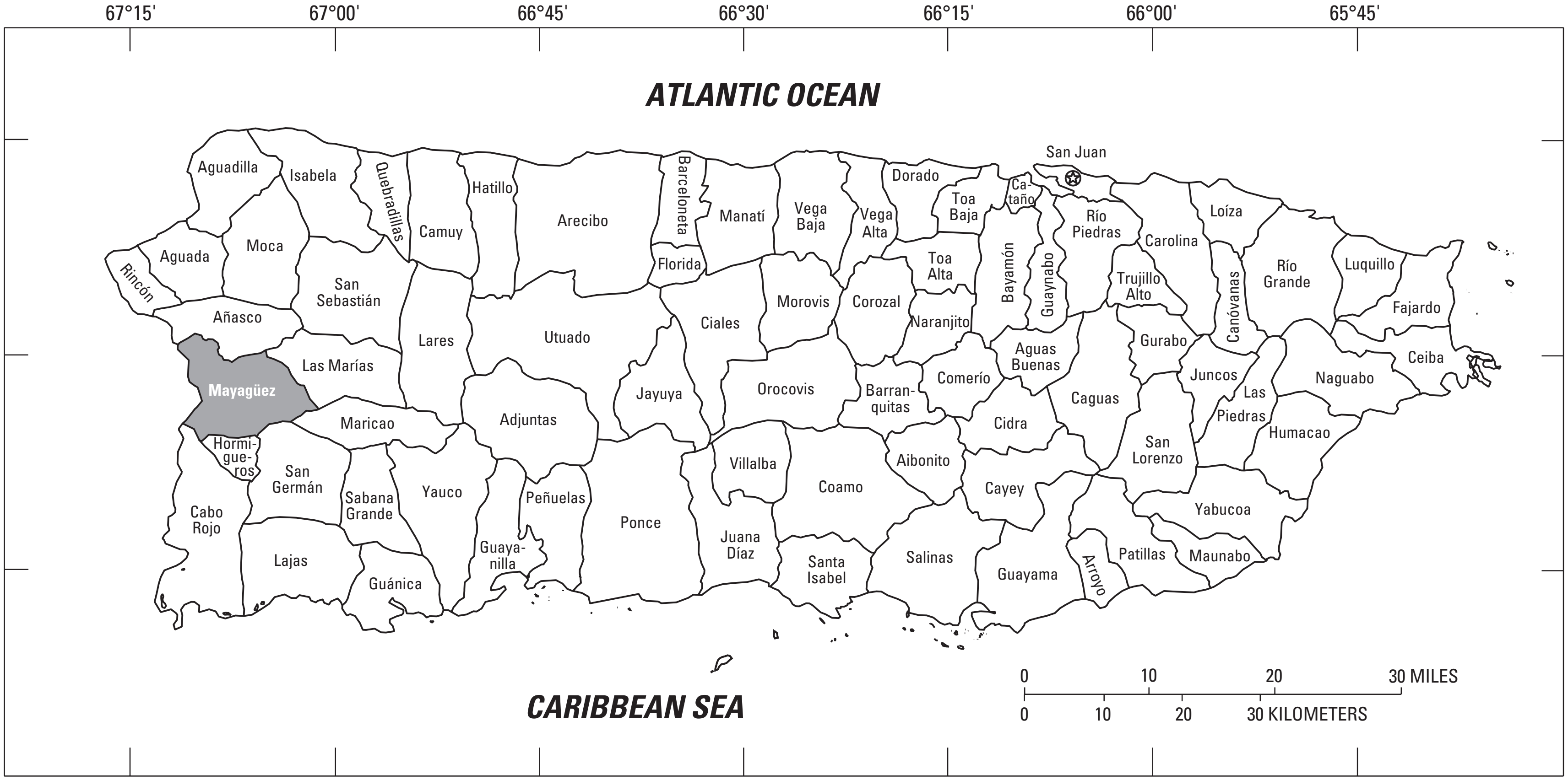

Figure 1. Location of the municipio of Mayagüez, Puerto Rico.

Several products are included in this report. Thematic maps with explanatory text were developed to delineate the hydrologic and stream sanitary (bacteriological) conditions, and to define the water-bearing properties of major rock units. A description of the methods and techniques used in the analyses and interpretation are given in separate chapters of this report. Chapter A documents the results of the surface-water assessment, Chapter B documents stream bacteriological conditions, and Chapter C documents ground-water availability.

Previous Studies

Prior to this study, the water resources of the municipio of Mayagüez had not been formally assessed. Only the coastal northwestern portion of the municipio had been evaluated as part of a study by Díaz and Jordan (1987), which focused on the water resources of the lower reaches of the Río Grande de Añasco alluvial valley. Before conducting the present study, the only continuous hydrologic data were collected at a water-quality station (station number 50138800) on the Río Yagüez near the town of Mayagüez. The data collected from this station are published annually by the USGS (Díaz and others, 1995, 1996, 1997, 1998, 1999, 2000, and 2001).

Chapter A:
Surface-Water Resources Assessment of the Municipio of Mayagüez, Puerto Rico, 1999-2002

By Luis Santiago-Rivera and Fernando Gómez-Gómez

Purpose and Scope

The U.S. Geological Survey (USGS), in cooperation with the municipio of Mayagüez, conducted an investigation of the surface- and ground-water resources from October 1, 1999, to September 30, 2002, in the area primarily within the geographic limits of the municipio of Mayagüez (plate 1). A major component of the study was an assessment of the magnitude and frequency of stream low-flow and flow-duration characteristics, which are important for storage-facility design, waste-load allocation, water-supply planning, recreation, and wildlife conservation. In addition, the current assessment provides reference conditions to assess future changes in flow magnitude, duration, and frequency.

The low-flow and flow-duration monitoring network in Mayagüez included 1 long-term continuous-record (index) gaging station and 20 partial-record stations (tables 1 and 2, respectively, at end of chapter). The continuous-record gaging station (50136400) is located on Río Rosario, a second-order tributary of Río Guanajibo (plate 1). The 20 partial-record stations are distributed among a number of streams within the geographic limits of the municipio of Mayagüez (plate 1). Streamflow was measured concurrently eight times at the index station and partial-record stations at selected base-flow recessions during a 2-year period, from March 2000 to March 2002. These data were used to obtain low-flow and flow-duration estimates. The 7-day, 10-year ($7Q_{10}$) and 7-day, 2-year ($7Q_2$) low-flow frequency characteristics were computed for the continuous-record gaging station and estimated for the partial-record stations. Flow-duration characteristics for 99-, 95-, and 90-percent probability of exceedance also were computed for the continuous-record gaging station and estimated for the 20 partial-record stations.

Pertinent information regarding surface-water hydrology within the municipio of Mayagüez is presented on a thematic map (plate 1). The map displays the following information:

- streamflow data-collection sites;
- drainage-basin boundaries for the streamflow sites in which the low flows were determined;
- potential public-water supply reservoir sites (Black and Veatch, 1976);
- flood-prone areas as delineated by the Federal Emergency Management Agency (1996);
- water filtration plants; and
- active and closed public waste-water treatment facilities.

Methodology

A series of eight discharge measurements were taken concurrently at 1 continuous- and 20 partial-record stream-gaging stations, to provide the data for a systematic low-flow and flow-duration analysis. A number of techniques were applied to compute low-flow characteristics at continuous- and partial-record stations. Analyses of low-flow characteristics for the continuous-record gaging station (index station) were based on frequency analyses of the annual minimum 7-day low flows (table 1). Using the streamflow data generated during this study, the partial-record station base-flow measurements were related to concurrent base-flow discharge measurements or daily mean flows at the nearby index station (Riggs, 1972) (fig. 2). The low-flow characteristics at partial-record stations then were estimated using the corresponding characteristics at the index station (table 2). This methodology has been applied elsewhere in Puerto Rico (Santiago-Rivera, 1992, 1996, 1998).

Flow-duration characteristics were computed for the index station at Río Rosario (50136400), using techniques described by Searcy (1959); flow-duration characteristics were estimated for the partial-record stations using flow-duration characteristics of the index station in conjunction with the relation curve previously developed by correlation methods used for the low-flow study. All low-flow and flow-duration characteristics for the index station and partial-record stations were calculated without incorporating the effects of public water-supply withdrawals and (or) waste-water discharges upstream from stations. Estimated withdrawals and effluent discharges, however, were compiled from data furnished by the Puerto Rico Sewer Authority (PRASA) and reported by Black and Veatch (1996), and are presented in the header of each recording station in tables 1 and 2.

Results and Interpretation

Low Flow at a Continuous-Record Gaging Station

A continuous-record gaging station (index station) is a site where daily flow data are systematically collected over a period of years. A low-flow frequency curve was derived for one index station using the method described by Riggs (1972) and by adapting the log-Pearson Type III flood-frequency program described by the Interagency Advisory Committee on Water Data (1982). Examples of the methodology, as applied to Puerto Rico streams, are given in Santiago-Rivera (1992, 1996, 1998). The $7Q_{10}$ and the $7Q_2$ low-flow frequency characteristics computed for the index station used in this report are presented in table 1. The index station used in this analysis is affected by public water-supply withdrawals and waste-water treatment facilities discharges. During the time of this study, public water-supply withdrawals upstream from the index station were estimated at 1.1 cubic foot per second (ft^3/s), and waste-water return flow was estimated at 0.10 ft^3/s (W. Molina, U.S. Geological Survey, written commun., 2000). The net stream low-flow capture of 1.0 ft^3/s upstream from the index station can result in computational underestimates of low-flow statistics at partial-record sites, for which gaging station Río Rosario near Hormigueros (50136400) was used as the index station. As no alternate gaging station exists in the vicinity of the study area, the user of the flow statistics should take into consideration that stated discharge rates could be underestimated by 10 to 15 percent.

Low Flow at Partial-Record Stations

A partial-record station is a site where limited streamflow and (or) water-quality data are collected systematically over a period of time for use in hydrologic analysis. At these stations, sufficient base-flow measurements are made to define an adequate relation with concurrent flows at a nearby index station. Low-flow characteristics for partial-record stations were estimated using the graphical correlation technique of Riggs (1972) (fig. 2). This technique relates base-flow discharge measurements made at partial-record stations with concurrent flows measured at the index station. This estimating technique transfers low-flow characteristics computed by the log-Pearson Type III frequency distribution for the index station to the graphically determined relation curve to determine the corresponding low-flow characteristics at the partial-record stations (fig. 2) (Santiago-Rivera, 1998). Low-flow characteristics were estimated for 20 partial-record stations and are presented in table 2. Partial-record stations are located within the same geographic area of the index station; ideally the partial- and continuous-record stations should have similar drainage-basin land-use characteristics and geologic setting. In general, the drainage areas throughout the study area consist mostly of secondary forest with moderate agricultural activity, and are underlain by igneous rocks of low permeability. At these stations, streamflow was measured concurrently eight times at different base-flow recessions from March 2000 to March 2002. Instantaneous streamflow measurements made at partial-record stations are presented in Díaz and others (2000, 2001).

Flow-Duration Characteristics

A flow-duration characteristic is the daily mean discharge for a given stream that has been exceeded for a specified percentage of days during the period of record. Flow-duration characteristics were computed for the index station using techniques developed by Searcy (1959). The analysis of the index station was based on daily streamflow records for complete water years (from October 1 to September 30), and the results are presented in table 1. Flow-duration characteristics were estimated for 20 partial-record stations using flow-duration characteristics derived for the index station in conjunction with the relation curves developed for the low-flow study. Index station discharges for the 99-, 95-, and 90-percent flow duration were used as the explanatory variable in the relation curve to estimate the discharges for the corresponding percent-duration points at the 20 partial-record stations (table 2).

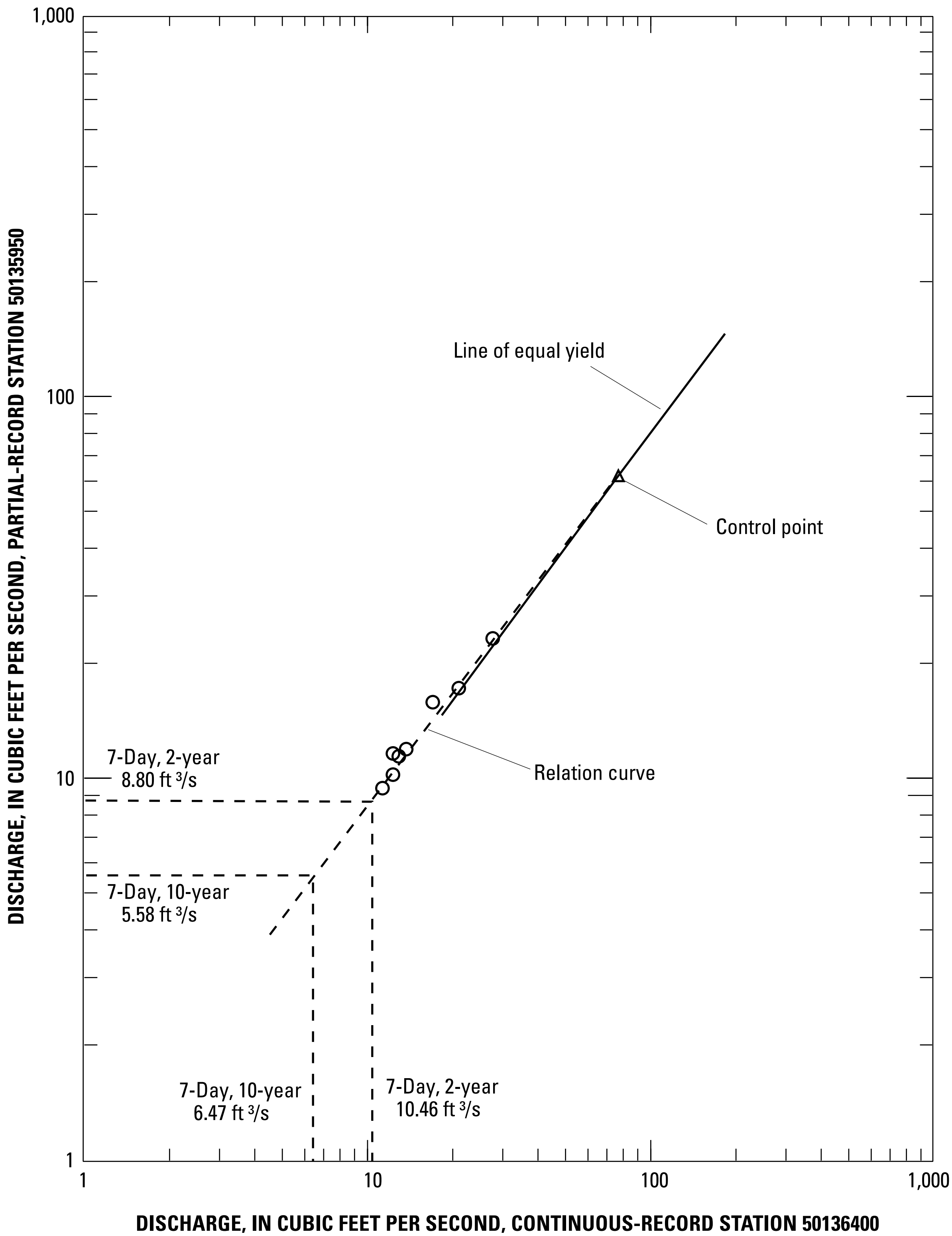

Figure 2. Relation between concurrent discharges at a partial-record station and a nearby continuous-record station, municipio of Mayagüez, Puerto Rico.

Drainage-Basin Area/Discharge Relation

Using the drainage-basin size contributing to each monitoring station and the low-flow statistics, a preliminary analysis of discharge yield per unit-drainage area was conducted using the 99^{th}-percentile discharge yield. This analysis provides a means to evaluate effective rainfall recharge within the study area. Discharge yields per unit of area are highest in the drainage basins of Río Casey, Río Yagüez (average unit-area yield of 0.52 $ft^3/s\text{-}mi^2$ for stations 50138400, 50138425, 50138500, 50138800), Río Rosario (average unit-area yield of 0.42 $ft^3/s\text{-}mi^2$ for stations 50135950 and 50136400), and Río Cañas (average unit-area yield of 0.45 $ft^3/s\text{-}m^2$ for partial-record stations 50146035 and 50146036). The rest of the stations have an average 99-percentile discharge-per-unit area, ranging from less than 0.01 to 0.33 $ft^3/s\text{-}mi^2$. Discharge yields at the 99^{th} percentile calculated flow duration of Río Casey at Río Cañas Arriba (station 50145390), the Río Cañas upstream of Quebrada Cojolla (station 50146036), and the Río Yagüez basin to station 50138800 contribute a total of 11.2 ft^3/s (about 7 Mgal/d) from a drainage area of 21.7 mi^2 (equivalent to 0.52 $ft^3/s\text{-}mi^2$ or 7.0 inches per year (in/yr)).

Map Features

A 1:30,000-scale map (plate 1) was developed to show the location of hydrologic data-collection stations; drainage basins, potential reservoir sites (Black and Veatch, 1976), the 100- and 500-year flood-prone areas (Federal Emergency Management Agency, 1996), and the documented inland extent of the saltwater wedge at principal streams. The thematic map also summarizes stream and estuary bacteriological (sanitary) quality during low-flow conditions (see Chapter B for discussion of water quality).

Potential Reservoir Sites

Potential reservoir sites (plate 1) have been located on the Río Rosario, Río Yagüez, and Río Cañas (Black and Veatch, 1976). The potential reservoir site on the Río Rosario (CE-13, official designation by Black and Veatch, 1976) would have a contributing area of approximately 17.7 mi^2, a potential storage capacity of about 16,000 acre-feet (acre-ft) at an elevation of 443 ft (135.0 meters on a topographic map), and a safe yield of approximately 20 Mgal/d (Black and Veatch, 1971, 1976) calculated on the basis of a mean annual runoff of 38 in/yr. An additional site on Río Rosario (14-3, not shown on plate 1) was located about 2.5 mi downstream from Highway 348, and was estimated to have a safe yield of about 30 Mgal/d at a pool elevation of 230 feet (ft) (70 meters on a topographic map). However, this site may not be feasible at present due to the need to relocate numerous residences and other structures within the potentially inundated area.

The potential reservoir site on the Río Yagüez (8-6) would have a contributing area of approximately 6.05 mi^2, a potential storage capacity of about 8,000 acre-ft at an elevation of 268 ft (81.7 meters on a topographic map), and a safe yield of approximately 7 Mgal/d (Black and Veatch, 1971, 1976) calculated on the basis of a mean annual runoff of 36 in/yr for the basin. The remaining potential reservoir site is located on the Río Cañas (8-5). This site would have a contributing area and potential storage of about 5.16 mi^2 and 11,000 acre-ft, respectively, at a pool elevation 612 ft (186.5 meters on a topographic map), and would have a safe yield of approximately 8 Mgal/d (with a mean annual runoff estimate of 37 in/yr for the basin). Two gravity surface-water intakes are located on the Río Yagüez and Río Cañas to supply water to the Ponce de León and Miradero filtration plants, respectively. The Río Yagüez intake is located 2.6 mi upstream, and Río Cañas intake is located 1.4 mi downstream from the respective potential reservoir sites shown in plate 1. Development within the maximum pool elevations delineated could possibly inhibit consideration of these sites as future water-supply alternatives.

Flood-Prone Areas

The Federal Emergency Managment Agency (FEMA) has designated five different types of flood-prone areas for the town of Mayagüez (Federal Emergency Management Agency, 1996). These areas are shown on plate 1 as (1) Zone VE, a coastal area inundated by a 100-year flood (equivalent to a 1-percent annual chance of flooding) that has additional hazards associated with wave action and for which Base Flood Elevations (BFEs) have been determined; (2) Zone A, an area inundated by a 100-year flood (equivalent to a 1-percent annual chance of flooding) and for which no BFEs have been determined; (3) Zone AE, an area inundated by a 100-year flood (equivalent to a 1-percent annual chance of flooding) and for which BFEs have been determined; (4) Zone X500, an area inundated by a 500-year flood (equivalent to a 0.2-percent annual chance of flooding) or an area inundated by a 100-year flood with average depths of less than 1 ft or with a drainage area less than 1 mi^2, or an area protected from a 100-year flood by levees; and (5) Zone AO, an area inundated by the 100-year flood (equivalent to a 1-percent annual chance flooding usually with sheet flow on sloping terrain) with flood depths ranging from 1 to 3 ft.

Saltwater Wedge at Streams

The saltwater wedge in coastal streams moves inland in direct relation to diminished streamflow. The point of maximum saltwater intrusion is controlled by the altitude of the streambed and zero flow. The approximate inland extent of the saltwater wedge was made by conducting a specific conductivity survey of streams during base-flow conditions, because of the unavailability of data on the location at which the streambed is at an altitude equivalent to the maximum elevation of high tide (plate 1). It is important to define the maximum inland extent of the saltwater wedge at zero stream discharge, especially at streams such as the Río Grande de Añasco, where base flows are captured for public water-supply use.

Public Water-Supply Filtration Plants and Waste-Water Treatment Facilities

There are two public water-supply filtration plants within the municipio of Mayagüez (plate 1). The Ponce de León filtration plant has a gravity intake on Río Yagüez, and the Miradero filtration plant has a gravity intake on Río Cañas and pump station on Río Grande de Añasco. Prior to 1989, there were four waste-water treatment facilities in Mayagüez: Alturas de Mayagüez, Guanajibo Homes, Valle Hermoso, and Zona Libre. These facilities are no longer in operation (table 3, plate 1). Currently, waste-water discharge is conveyed by pipelines and pump stations to a regional waste-water treatment facility at Barrio Sabanetas, north of the town of Mayagüez. The regional waste-water treatment facility had a daily mean discharge of 10.7 Mgal/d in 1995 (Puerto Rico Aqueduct and Sewer Authority, 1995); discharge is to the Bahía de Mayagüez through an ocean outfall located approximately 1 mi offshore and 1.5 mi to the south of the mouth of Río Grande de Añasco. The location of public water-supply filtration plants, waste-water treatment facilities, and other pertinent data are listed in table 3 and shown on plate 1.

Table 1. Summary of drainage-basin, low-flow, and flow-duration characteristics for a continuous-record gaging station near the municipio of Mayagüez, Puerto Rico.

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; Mgal/d, million gallons per day]

RÍO GUANAJIBO BASIN
50136400 Río Rosario near Hormigueros, Puerto Rico

LOCATION--Lat 18°09'36", long 67°05'08", Hydrologic Unit 21010003 at bridge on Highway 348, 0.5 mi (0.38 km) southwest of Rosario plaza.

DRAINAGE AREA--18.3 mi^2 (47.4 km^2).

PERIOD OF RECORD ANALYZED--October 1985 to September 2000.

LOW-FLOW ANALYSIS--Log-Pearson Type III frequency distribution.

REMARKS--A diversion of 0.72 Mgal/d is made upstream from station for public-water supply and 0.06 Mgal/d is recovered from waste-water treatment plant return flow.

LOW-FLOW CHARACTERISTICS
[Based on 1985-2000 water years]

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	10
7-day, 10-year	6.5

FLOW-DURATION CHARACTERISTICS
[Based on 1985-2000 water years]

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	7.3	10	12

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; Mgal/d, million gallons per day; <, less than]

RÍO GUANAJIBO BASIN

50135950 Río Rosario at Limón, Puerto Rico

LOCATION--Lat 18°10'33", long 67°03'07", Hydrologic Unit 21010003 at barrio Limón, 3.4 mi (5.5 km) southwest of Pico San Bernardo, 1.8 mi (2.9 km) northwest of El Cerro Avispa, and2.4 mi (3.9 km) southeast of Represa de Mayagüez.

DRAINAGE AREA--14.6 mi^2 (37.8 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--A diversion of 0.72 Mgal/d is made upstream from station for public-water supply and 0.06 Mgal/d is recovered from waste-water treatment plant return flow.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	8.8
7-day, 10-year	5.6

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	6.3	8.3	10

50138150 Río Hondo at Río Hondo, Puerto Rico

LOCATION--Lat 18°09'59", long 67°07'17", Hydrologic Unit 21010003 at barrio Río Hondo, 3.6 mi (5.8 km) northwest of Los Peñones, 3.7 mi (6.0 km) southwest of Represa de Mayagüez, and 2.6 mi (4.2 km) northwest of Rosario plaza.

DRAINAGE AREA--1.61 mi^2 (4.17 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.2
7-day, 10-year	0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.1	0.2	0.3

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO GUANAJIBO BASIN—Continued
50138190 Río Hondo near Mayagüez, Puerto Rico

LOCATION--Lat 18°09'53", long 67°08'32", Hydrologic Unit 21010003 at barrio Guanajibo, 2.0 mi (3.2 km) northwest of Hormigueros plaza, 1.8 mi (2.9 km) east of Cerro Cornelia, and 2.9 mi (4.7 km) south of Mayagüez plaza.

DRAINAGE AREA--2.93 mi^2 (7.59 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.2
7-day, 10-year	0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.1	0.2	0.3

QUEBRADA SÁBALOS BASIN
50138285 Quebrada Grande at Quebrada Grande, Puerto Rico

LOCATION--Lat 18°10'44", long 67°06'56", Hydrologic Unit 21010003 at barrio Quebrada Grande, 2.9 mi (4.7 km) southwest of Represa de Mayagüez, 3.6 mi (5.8 km) northwest of Los Peñones, and 2.6 mi (4.2 km) northwest of Rosario plaza.

DRAINAGE AREA--0.72 mi^2 (1.86 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.2
7-day, 10-year	0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.1	0.2	0.3

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

QUEBRADA SÁBALOS BASIN—Continued
50138375 Caño Majagual at Highway 348, Puerto Rico

LOCATION--Lat 18°11'32", long 67°08'15", Hydrologic Unit 21010003 at barrio Quebrada Grande, 3.3 mi (5.3 km) northeast of Cerro Cornelia, 3.5 mi (5.6 km) northwest of Hormigueros plaza, and 0.8 mi (1.3 km) southeast of Mayagüez plaza.

DRAINAGE AREA--0.20 mi^2 (0.52 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARK.--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	< 0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	< 0.1	< 0.1	< 0.1

RÍO YAGÜEZ BASIN
50138400 Río Yaguez at Montoso, Puerto Rico

LOCATION--Lat 18°12'06", long 67°02'30", Hydrologic Unit 21010003 at barrio Montoso, 1.6 mi (2.6 km) south of Pico San Bernardo, 3.0 mi (4.8 km) northwest of El Cerro Avispa, and 2.4 mi (3.9 km) northeast of Represa de Mayagüez.

DRAINAGE AREA--0.63 mi^2 (1.63 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--Consumo pump station is not in use.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.5
7-day, 10-year	0.3

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.4	0.5	0.6

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO YAGÜEZ BASIN—Continued

50138425 Río Yagüez at Naranjales, Puerto Rico

LOCATION--Lat 18°12'08", long 67°03'00", Hydrologic Unit 21010003 at barrio Naranjales, 3.2 mi (5.1 km) northwest of El Cerro Avispa, 1.6 mi (2.6 km) southwest of Pico San Bernardo, and 1.9 mi (3.0 km) northeast of Represa de Mayagüez.

DRAINAGE AREA--1.32 mi^2 (3.42 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	1.1
7-day, 10-year	0.8

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.8	1.1	1.3

50138500 Río Yagüez at Presada de Mayagüez, Puerto Rico

LOCATION--Lat 18°12'02", long 67°04'42", Hydrologic Unit 21010003 at barrio Bateyes, 2.9 mi (4.7 km) southwest of Pico San Bernardo, 4.2 mi (6.8 km) northwest of El Cerro Avispa, and 2.5 mi (4.0 km) north of Rosario plaza.

DRAINAGE AREA--4.38 mi^2 (11.3 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--One hundred percent of the flow is diverted to Ponce de León filtration plant during low-flow periods.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.7
7-day, 10-year	1.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.9	2.6	3.2

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO YAGÜEZ BASIN—Continued
50138785 Quebrada Gandel at Mayagüez Arriba, Puerto Rico

LOCATION--Lat 18°12'42", long 67°06'57", Hydrologic Unit 21010003 at Mayagüez Arriba, 4.0 mi (6.4 km) northwest of Rosario plaza, 2.6 mi (4.2 km) southwest of Cerro Leclerc, and 2.6 mi (4.2 km) northwest of Represa de Mayagüez.

DRAINAGE AREA--1.83 mi^2 (4.74 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.6
7-day, 10-year	0.3

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.4	0.6	0.8

50138800 Río Yagüez near Mayagüez, Puerto Rico

LOCATION--Lat 18°12'32", long 67°05'07", Hydrologic Unit 21010003 at steel-truss bridge about 800 ft (244 m) south of Highway 106, 1.8 mi (2.9 km) west of Highways 106 and 352 junction, and 1.4 mi (2.2 km) east northeast from Mayagüez plaza.

DRAINAGE AREA--4.15 mi^2 (11 km^2). Does not include area upstream from station 50138500 Río Yagüez at Presada de Mayagüez.

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--Río Yagüez basin drainage area (4.38 mi^2) upstream from Presada de Mayagüez does not contribute any flow during low-flow periods to station 50138800 Río Yagüez near Mayagüez, because all flow is diverted to Ponce de León filtration plant.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.3
7-day, 10-year	1.4

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.6	2.2	2.7

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO YAGÜEZ BASIN—Continued

50138815 Quebrada Caricosa near Represa de Mayagüez, Puerto Rico

LOCATION--Lat 18°11'27", long 67°05'18", Hydrologic Unit 21010003 at barrio Juan Alonso, 0.9 mi (1.4 km) southwest of Represa de Mayagüez, 2.9 mi (4.7 km) northwest of Los Peñones, and 1.9 mi (3.0 km) northwest of Rosario plaza.

DRAINAGE AREA--0.57 mi^2 (1.48 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	< 0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	< 0.1	< 0.1	< 0.1

50138840 Quebrada Caricosa near Mayagüez, Puerto Rico

LOCATION--Lat 18°11'50", long 67°06'45", Hydrologic Unit 21010003 at barrio Juan Alonso, 2.3 mi (3.7 km) southwest of Represa de Mayagüez, 2.9 mi (4.7 km) southwest of Cerro Leclerc, and 3.1 mi (5.0 km) northwest of Rosario plaza.

DRAINAGE AREA--2.40 mi^2 (6.22 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.7
7-day, 10-year	0.4

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.5	0.7	0.9

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO YAGÜEZ BASIN—Continued

50138845 Tributario de Quebrada Caricosa at Highway 105, Puerto Rico

LOCATION--Lat 18°11'48", long 67°06'56", Hydrologic Unit 21010003 at Mayagüez Arriba, 2.5 mi (4.0 km) southwest of Represa de Mayagüez, 3.1 mi (5.0 km) southwest of Cerro Leclerc, and 3.2 mi (5.1 km) northwest of Rosario plaza.

DRAINAGE AREA--0.17 mi^2 (0.44 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	< 0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	< 0.1	< 0.1	< 0.1

50138860 Quebrada Caricosa at mouth, Puerto Rico

LOCATION--Lat 18°12'31", long 67°07'27", Hydrologic Unit 21010003 at Mayagüez Arriba, 3.1 mi (5.0 km) northwest of Represa de Mayagüez, 3.2 mi (5.1 km) southwest of Cerro Leclerc, and 4.2 mi (6.8 km) northwest of Rosario plaza.

DRAINAGE AREA--2.92 mi^2 (7.56 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.8
7-day, 10-year	0.4

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.5	0.8	1.0

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

QUEBRADA DEL ORO BASIN

50139625 Quebrada del Oro at Miradero, Puerto Rico

LOCATION--Lat 18°13'15", long 67°08'00", Hydrologic Unit 21010003 at barrio Miradero, 2.0 mi (3.2 km) southeast of Peña Cortada, 4.9 mi (7.9 km) northeast of Cerro Cornelia, and 2.3 mi (3.7 km) northeast of Mayagüez plaza.

DRAINAGE AREA--0.69 mi^2 (1.79 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.2
7-day, 10-year	0.1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.1	0.2	0.3

50139650 Quebrada del Oro at Highway 2, Puerto Rico

LOCATION--Lat 18°12'50", long 67°08'48", Hydrologic Unit 21010003 at Highway 2, 0.8 mi (1.3 km) upstream from mouth, 4.0 mi (6.4 km) northeast of Cerro Cornelia, and 0.9 mi (1.4 km) northwest of Mayagüez plaza.

DRAINAGE AREA--1.49 mi^2 (3.86 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.8
7-day, 10-year	0.5

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.5	0.7	0.9

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO GRANDE DE AÑASCO BASIN
50145390 Río Casey at Río Cañas Arriba, Puerto Rico

LOCATION--Lat 18°14'58", long 67°04'00", Hydrologic Unit 21010003 at barrio Río Cañas Arriba, 2.3 mi (3.7 km) northwest of Pico San Bernardo, 1.9 mi (3.0 km) northeast of Cerro Leclerc, and 3.4 mi (5.5 km) northeast of Represa de Mayagüez.

DRAINAGE AREA--7.03 mi^2 (18.2 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	6.2
7-day, 10-year	4.2

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	4.7	6.0	7.0

50146015 Río Cañas at Camino Charluisant, Puerto Rico

LOCATION--Lat 18°12'57", long 67°02'48", Hydrologic Unit 21010003 at barrio Río Cañas Arriba, 0.6 mi (1.0 km) southwest of Pico San Bernardo, 2.2 mi (3.5 km) southeast of Cerro Leclerc, and 2.3 mi (3.7 km) northeast of Represa de Mayagüez.

DRAINAGE AREA--1.76 mi^2 (4.56 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.9
7-day, 10-year	0.5

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.6	0.8	1.0

Table 2. Summary of drainage-basin, low-flow, and flow-duration estimates for partial-record stations within the municipio of Mayagüez, Puerto Rico.—Continued

RÍO GRANDE DE AÑASCO BASIN—Continued
50146035 Río Cañas at Highway 352, Puerto Rico

LOCATION--Lat 18°14'10", long 67°05'28", Hydrologic Unit 21010003 at barrio Río Cañas Arriba, 3.3 mi (5.3 km) northwest of Pico San Bernardo, 1.2 mi (1.9 km) northwest of Cerro Leclerc, and 2.6 mi (4.2 km) northwest of Represa de Mayagüez.

DRAINAGE AREA--5.83 mi^2 (15.1 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	4.2
7-day, 10-year	2.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	3.0	4.0	4.9

50146036 Río Cañas upstream of Quebrada Cojolla, Puerto Rico

LOCATION--Lat 18°14'08", long 67°06'01", Hydrologic Unit 21010003 at barrio Río Cañas Abajo, 4.3 mi (6.9 km) northwest of Pico San Bernardo, 2.0 mi (3.2 km) northwest of Cerro Leclerc, and 3.1 mi (5.0 km) northwest of Represa de Mayagüez.

DRAINAGE AREA--6.18 mi^2 (16.0 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50136400.

REMARKS--PRASA intake is located downstream from station 50146036. All flow is diverted to Miradero filtration plant during low-flow periods.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	4.2
7-day, 10-year	2.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	3.0	3.9	4.8

Table 3. Principal features of public water-supply filtration plants, surface-water intakes, a public waste-water treatment facility, and treated waste-water outlets within the municipio of Mayagüez, Puerto Rico.

[Mgal/d, million gallons per day; est., estimate; --, no data or not applicable]

Public water-supply filtration plants and surface-water intakes (plate 1)	Latitude	Longitude	Safe yield (Mgal/d)	Water available for use (Mgal/d)	Mean daily withdrawal rate (Mgal/d)	Source stream
Río Yagüez gravity intake	--	--	[1]0.53	[2]1.23	--	Río Yagüez
Río Cañas gravity intake	--	--	[1]0.68	[2]1.94	--	Río Cañas
Río Grande de Añasco intake pump	--	--	--	--	--	Río Grande de Añasco
Miradero filtration plant	18°13'42"	67°08'25"	--	--	[3]18.8	Río Cañas and Río Grande de Añasco
Ponce de León filtration plant (PRASA Vieja)	18°12'17"	67°07'36"	--	--	[3]1.4	Río Yagüez

Public waste-water treatment facilities and effluent-discharge points (plate 1)	Latitude	Longitude	Discharge capacity (Mgal/d)	Mean daily discharge rate (est. 2000) (Mgal/d)	Receiving stream
Mayagüez regional waste-water treatment plant	18°15'07"	67°09'30"	--	--	--
Mayagüez regional waste-water treatment plant ocean outfall	18°14'33"	67°11'27"	--	10.7	Bahía de Mayagüez
Alturas de Mayagüez (closed in 1988)	18°14'22"	67°09'34"	--	--	Caño Boquilla
Guanajibo Homes (closed in 1987)	18°10'45"	67°10'13"	--	--	Caño Corazones
Valle Hermoso (closed in 1987)	18°09'34"	67°09'17"	--	--	Río Hondo
Zona Libre (Sábalos) (closed in 1987)	18°10'26"	67°09'10"	--	--	Caño Merle

[1] Black and Veatch (1996).

[2] Given value is the Q-99 flow-duration estimate obtained in this assessment.

[3] Reported by Compañía de Aguas de Puerto Rico for calendar year 2000.

Chapter B: Sanitary Quality of Surface Water During Base-Flow Conditions in the Municipio of Mayagüez, Puerto Rico, 2000-01

By Senén Guzmán-Ríos, Fernando Gómez-Gómez, and Mario L. Oliveras-Feliciano

Purpose and Scope

A survey of stream sanitary quality was conducted by the USGS in cooperation with the municipio of Mayagüez, to define the extent of fecal contamination in streams. The assessment was made by obtaining and analyzing samples for fecal coliform and fecal streptococcus bacteria from 37 stream locations during base-flow conditions between July and November 2000, in April 2001, and in February 2002. Although the synoptic surveys were conducted in streams that have headwaters outside the municipio boundary, most of the sampling was conducted within the territorial limits of the municipio of Mayagüez. This chapter describes the methods and techniques used in conducting the survey at the 37 sampling stations, and provides interpretations of the fecal coliform and fecal streptococcus indicator bacteria concentrations by developing a classification procedure to rank the sanitary quality of stream courses. The data were incorporated into a thematic map (plate 1) that also includes other important hydrologic features that (a) serve as an initial source of information to guide future efforts by municipal and Commonwealth authorities in implementing measures to enhance the sanitary quality of contaminated streams and conserve those with an acceptable quality; and (b) provide reliable scientific information to planners and managers of the water and biological resources.

The sampling network within the municipio of Mayagüez was divided into six drainage basins. These basins are: Upper Río Guanajibo, Caño Corazones, Río Yagüez, Quebrada del Oro, Caño Boquilla, and Río Grande de Añasco.

Background

Water-quality standards for surface waters in Puerto Rico have been established by the Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental de Puerto Rico, 1990) on the basis of the designated use (for example, fishing, source of raw water for public supply, and secondary contact recreation, among others). All perennial fresh surface waters in Puerto Rico inland of their estuary segments have been classified as Class SD waters. This classification includes surface water intended for use (or potential use) as a raw source of public water supply, for propagation and preservation of desirable aquatic species, and for primary (swimming) and secondary (boating and fishing) contact recreation. The sanitary quality standard for Class SD surface water is based on the fecal coliform or total coliform indicator bacteria (Junta de Calidad Ambiental de Puerto Rico, 1990). All coastal water bodies within the territorial limits of the municipio of Mayagüez (Caños Boquilla, Majagual, Merle, and Corazones), and the estuary segments of Río Guanajibo, Río Yagüez, and Río Grande de Añasco are designated as Class SB surface waters. Class SB-designated use waters are intended for use in primary and secondary recreation and for the propagation and preservation of desirable aquatic species. This designated use also applies to the coastline at Mayagüez from the mean tide level to a distance up to 1,650 ft (500 meters) offshore north of Punta Algarrobo (plate 1). Along the coast from Punta Algarrobo to Punta Guanajibo and extending offshore 10.3 nautical miles, the coastal waters are designated as Class SC surface waters. Class SC surface waters are intended for use where human contact with the water is indirect (such as fishing or boating), and for use in the propagation and preservation of desirable species.

Fecal coliform bacteria are used as an indicator of pathogens in surface waters and to indicate the potential for public health problems. There is abundant epidemiological evidence of gastrointestinal disorders that result from the ingestion of contaminated surface water. Contact with contaminated water can lead to ear or skin infections, and inhalation of contaminated water can cause respiratory diseases. Typical concentrations of two common indicator bacteria in contaminated water are given in table 4. Fecal coliform (FC) and fecal streptococcus (FS) bacteria are native to the intestines of warm-blooded animals, including humans, and are considered non-pathogenic. However, these bacteria have been correlated to the presence of waterborne, infectious disease-causing organisms present in wastes from warm-blooded animals (Myers and Sylvester, 1997). The pathogens responsible for these diseases include bacteria, viruses, protozoans, fungi, and parasites that can live in the gastrointestinal tract and are shed in the feces of warm-blooded animals. Thus, the concentration of these indicator bacteria is a measure of fecal contamination and indicates the suitability of a water body for consumption or for body contact.

Table 4. Ranges of fecal indicator bacteria concentrations typically found in contaminated surface water (modified from Myers and Sylvester, 1997).

Bacteriological group	Fecal-contaminated surface water, colonies per 100 milliliters
Fecal coliform	200 to greater than 2 million
Fecal streptococcus	400 to greater than 1 million

With the exception of surface waters to be used for primary contact recreation (Class SB), the sanitary quality standard of Class SD-designated use surface waters is based on total coliform and fecal coliform bacteria concentrations as follows: (1) the geometric mean concentration of at least five samples obtained in sequential order should not exceed 10,000 colonies per 100 milliliters (col/100 mL) for total coliform bacteria or 2,000 col/100 mL for fecal coliform bacteria, and (2) not more than 20 percent of the samples (one in a set of five) should exceed 4,000 col/100 mL of fecal coliform bacteria (Junta de Calidad Ambiental de Puerto Rico, 1990, Article 3, Section 2.4, as amended July 20, 1990). The standard for fecal coliform bacteria was lowered to 200 col/100 mL by the Environmental Quality Board of Puerto Rico in March 2003 (Junta de Calidad Ambiental, 2003, Article 3, Section 2.4, as amended on March 2003). Unlike other regions in the United States, Puerto Rico regulations do not constrain the time period during which the sequential samples must be obtained. In Puerto Rico, these standards are applicable only to samples taken when streamflows are greater than the 7-day, 2-year (7-d, Q-2y) discharge (Junta de Calidad Ambiental de Puerto Rico, 1990). The 7-d, Q-2y discharge corresponds to the discharge at the 2-year recurrence interval taken from a frequency curve of annual values of the lowest mean discharge for 7 consecutive days (the 7-day low flow). The sanitary quality of Class SC-designated saltwater is based on total coliform and fecal coliform concentrations similar to the requirements of Class SD-designated freshwaters.

The sanitary quality standard for Class SB-designated use surface waters, with the exception of primary use contact recreation, is based on the fecal coliform bacteria concentrations as follows: (1) the geometric mean concentration of at least five samples obtained in sequential order should not exceed 200 col/100 mL of water sample, and (2) no more than 20 percent of the samples (one in a set of five samples) should exceed 400 col/100 mL of water sample. For class SB surface waters used intensively for primary contact recreation, the sanitary quality constraints are more stringent. In addition to the above requirements for fecal coliform bacteria concentration, class SB waters used for primary contact recreation must have, for five representative samples obtained sequentially, a geometric mean concentration of enterococcus indicator bacteria less than 35 col/100 mL, and must meet other statistically based constraints. The sanitary quality requirements for primary contact recreation in SB-designated use waters, are described in detail in the “Reglamento de Estándares de Calidad de Agua de Puerto Rico” (Puerto Rico Environmental Quality Standards Regulations) by the Junta de Calidad Ambiental de Puerto Rico (1990).

Contamination sources that affect stream sanitary quality during base-flow conditions are distinct for urbanized and rural areas of Mayagüez. In urbanized areas, probable major sources of fecal contamination are (1) illegal discharge of sewage to storm-water drains, especially within the older sectors of the city of Mayagüez; (2) overflows from sewer mains into the storm-water drains as a result of malfunctioning sanitary sewer ejectors or clogged mains; (3) seepage from ruptured sewer mains into the local aquifer; and (4) seepage or overflow from septic tanks in communities along the inland perimeter of the city limits of Mayagüez that are not connected to the waste-water sewer system. In rural areas, major sources of fecal contamination include gray-water discharges (gray water includes waste water exclusive of sanitary wastes) from residential and commercial establishments along stream channels, septic tank seepage or overflows, feces contamination introduced directly into streams from unfenced livestock, and runoff from livestock pens near stream courses.

Long-term baseline data on the sanitary quality of surface waters within or in the vicinity of the municipio of Mayagüez are primarily from the monitoring stations at Río Guanajibo (USGS station 50133600 and 50138000), Río Rosario (USGS station 50136400) (fig. 3), Río Yagüez (USGS station 50138800), and Río Grande de Añasco (USGS station 50146000). Systematic sampling for selected physical, chemical, and bacteriological properties has been carried out at these stations by the USGS in cooperation with the Puerto Rico Environmental Quality Board (PREQB) since 1979, except for station 50138000 where data have been collected since 1958 (data available in USGS annual Water Resources Data for Puerto Rico and U.S. Virgin Islands series). The trend of geometric mean concentrations for fecal coliform bacteria of five sequential samples at these stations for the period 1985 to 2000 is shown in figures 4a-4e (refer to fig. 2 for locations).

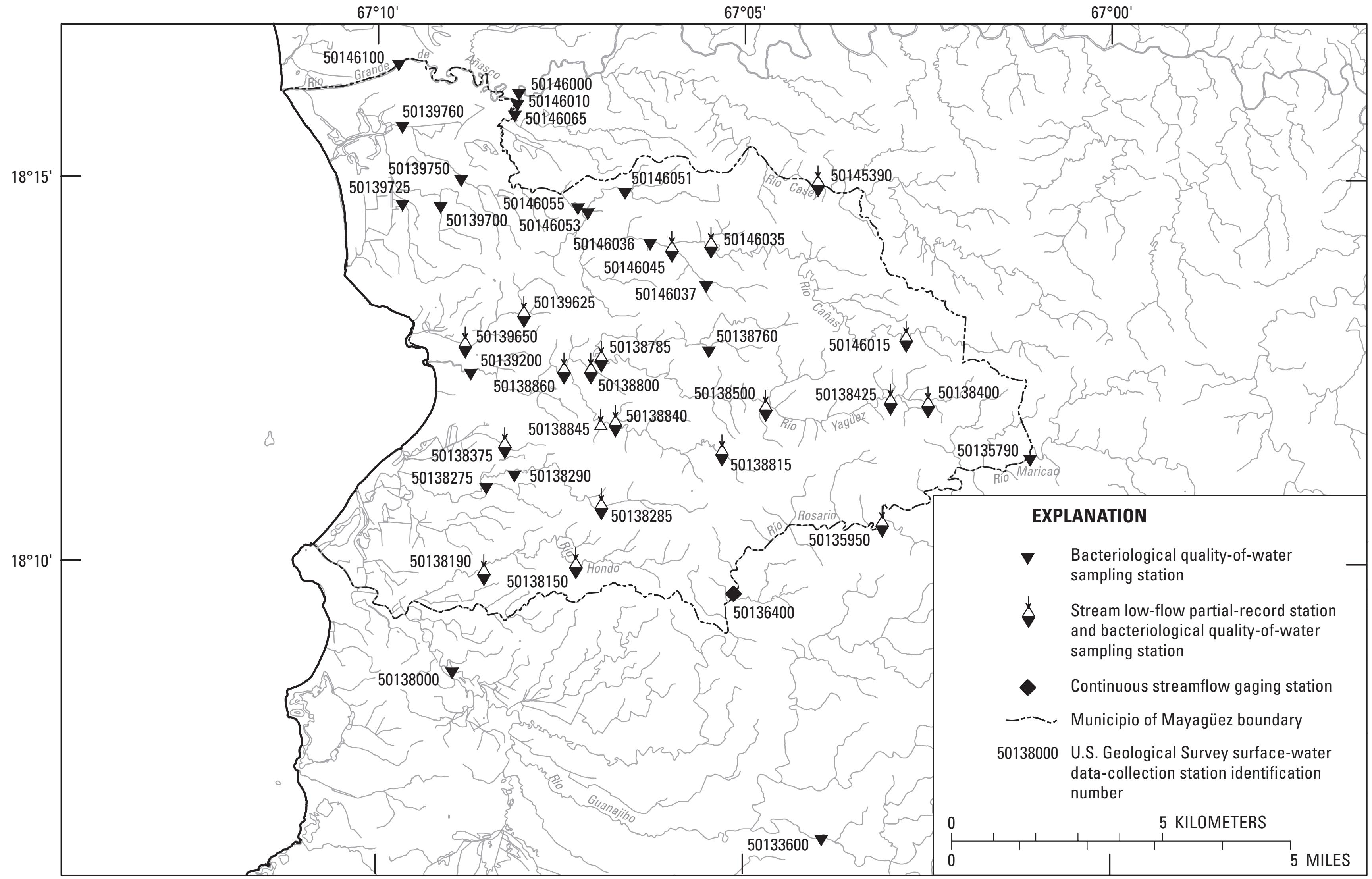

Figure 3. Locations of bacteriological quality-of-water sampling stations, including the long-term stations at which bacteriological quality data have been obtained at or near the municipio of Mayagüez, Puerto Rico.

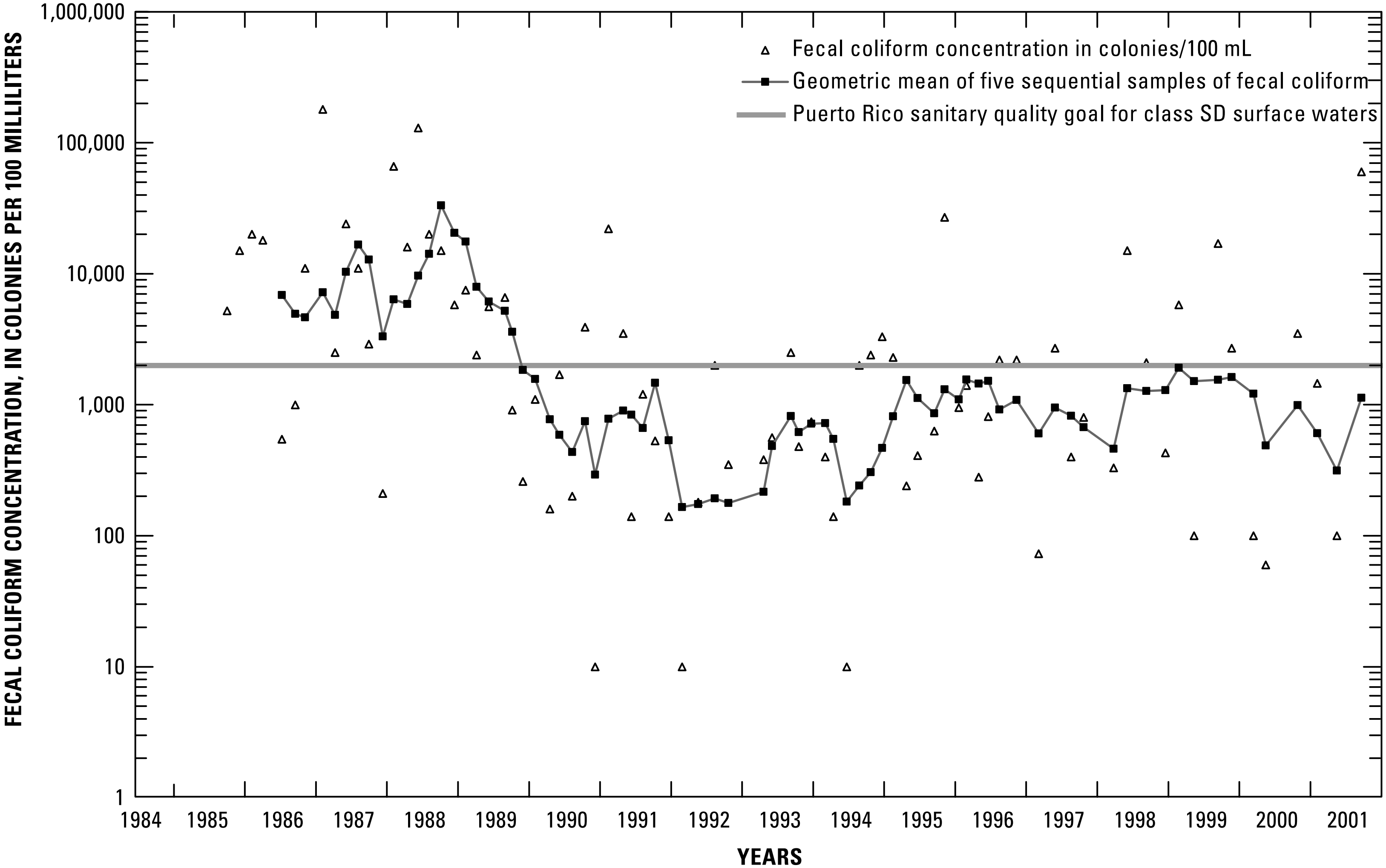

Figure 4a. Long-term geometric mean concentration of fecal coliform bacteria at Río Guanajibo near San Germán, October 1985 to August 1999.

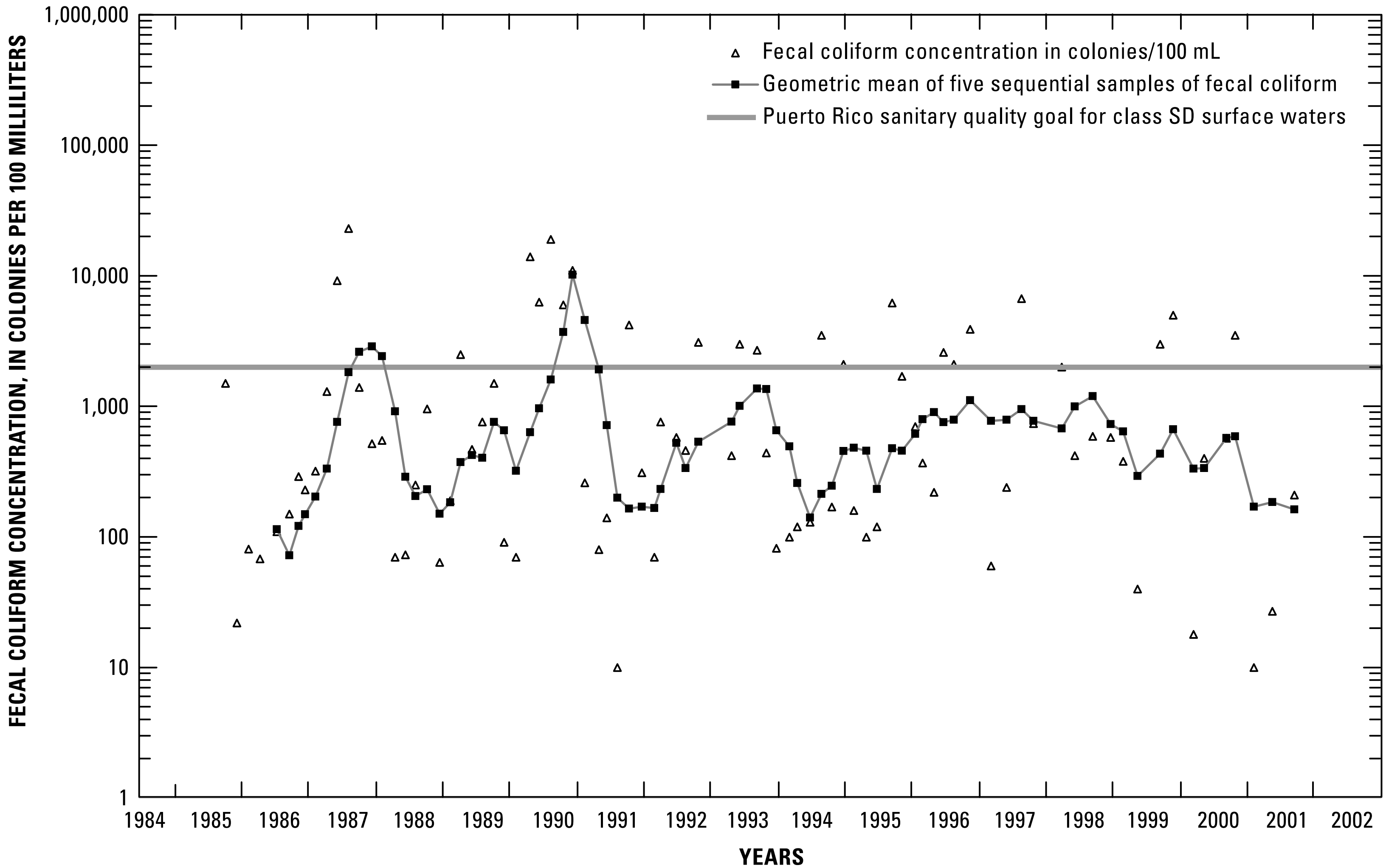

Figure 4b. Long-term geometric mean concentration of fecal coliform bacteria at Río Rosario near Hormigueros, October 1985 to August 1999.

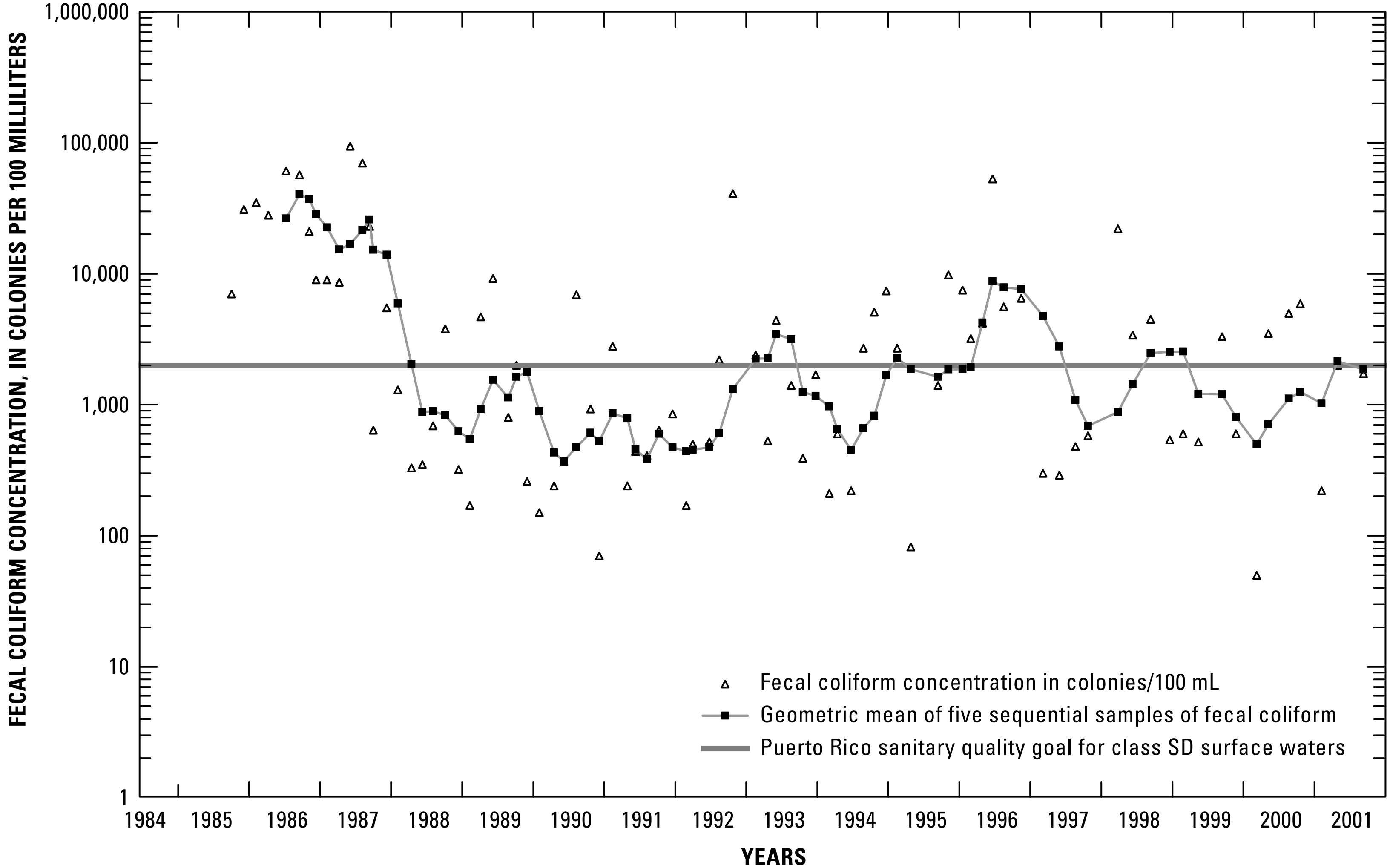

Figure 4c. Long-term geometric mean concentration of fecal coliform bacteria at Río Guanajibo near Hormigueros, October 1985 to August 1999.

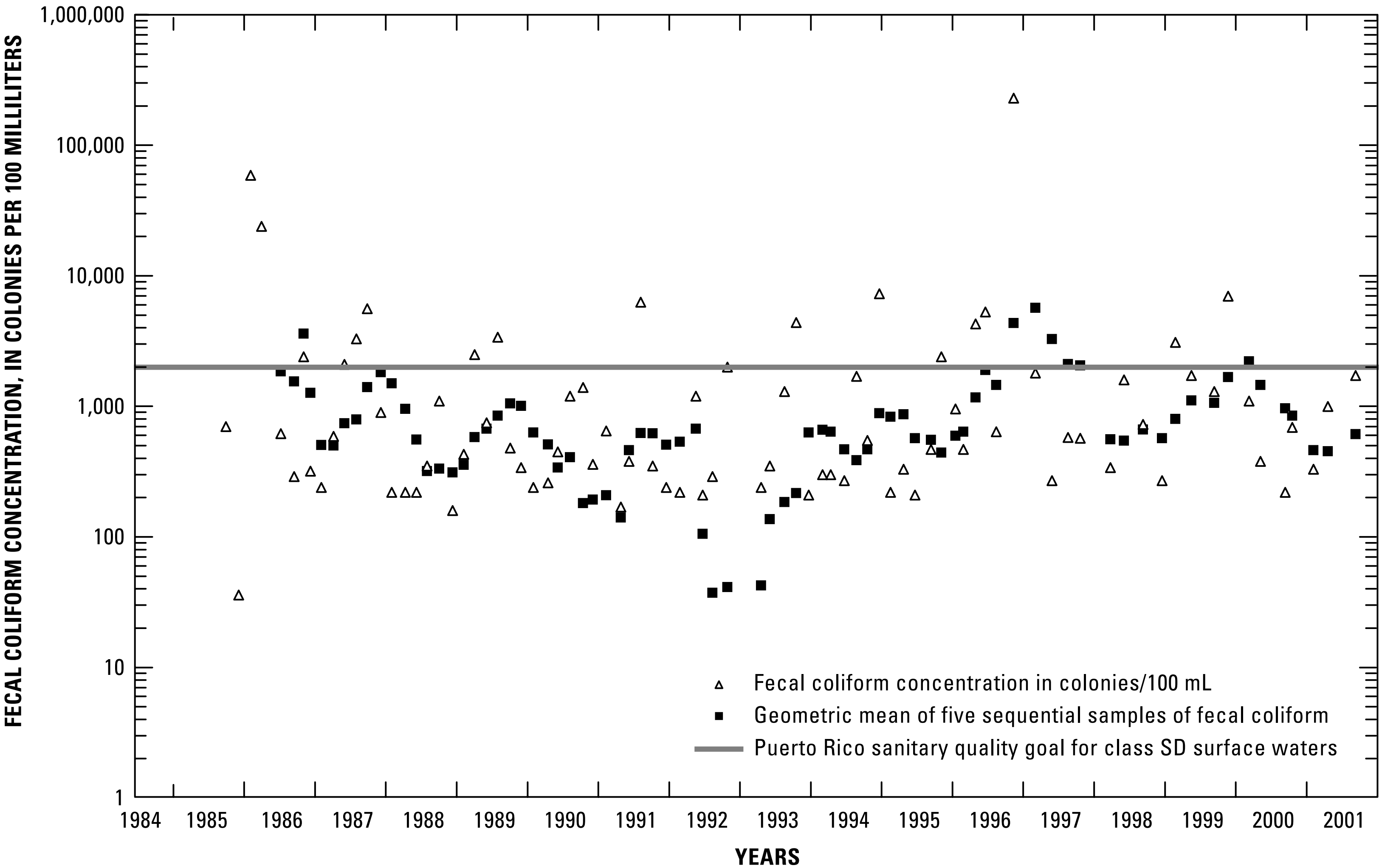

Figure 4d. Long-term geometric mean concentration of fecal coliform bacteria at Río Yagüez near Mayagüez, October 1985 to August 1999.

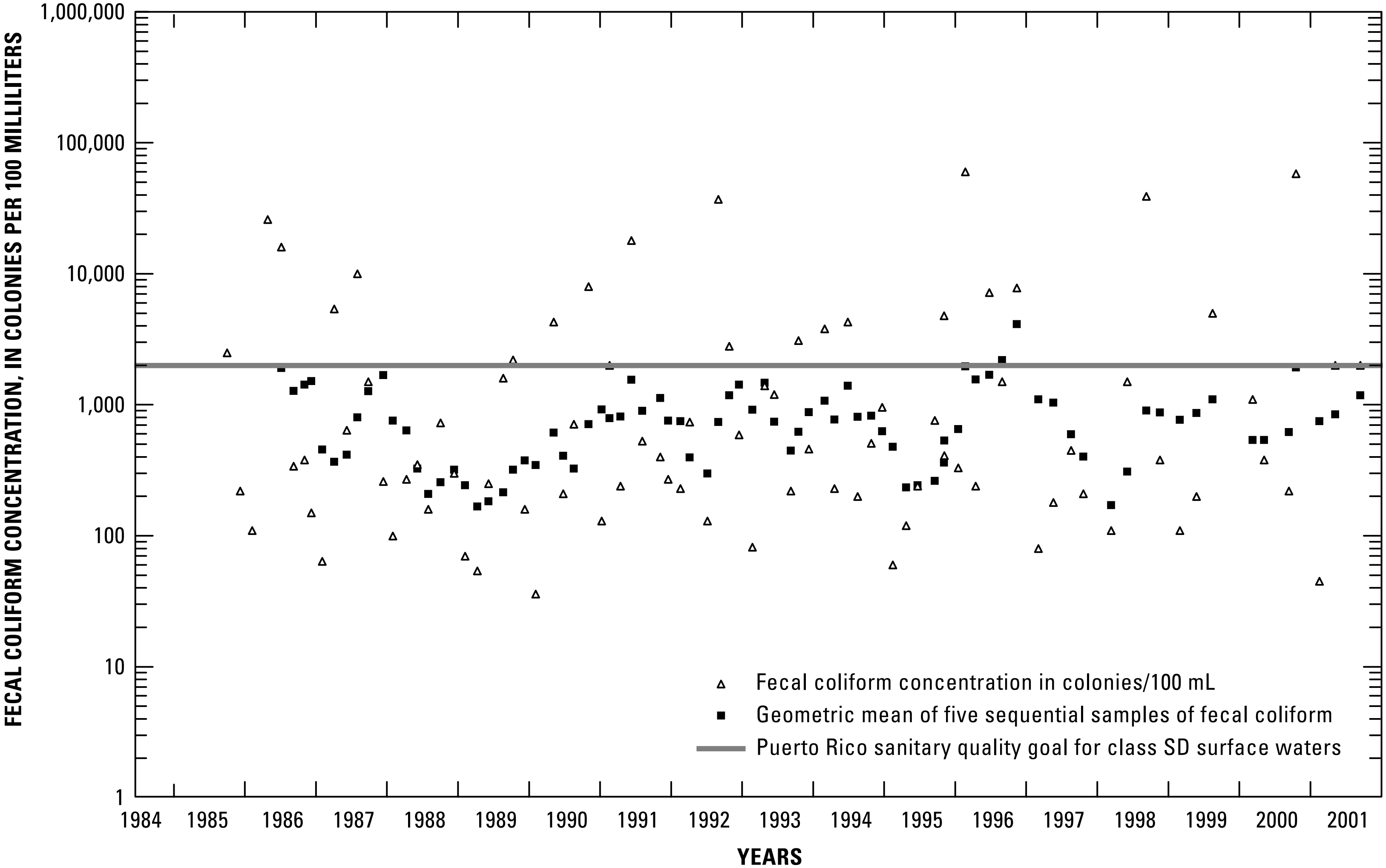

Figure 4e. Long-term geometric mean concentration of fecal coliform bacteria at Río Grande de Añasco near Añasco, October 1985 to August 1999.

The quality-of-water historical database (1985-2001) was used for a preliminary assessment of the sanitary quality of streams in the Mayagüez area. The data indicate (1) substantial improvement towards achieving the sanitary water-quality goals established for fresh surface waters in the amended regulations enacted in July 1990 (Junta de Calidad Ambiental de Puerto Rico, 1990) at stations 50133600 and 50136400; (2) deteriorating sanitary quality at stations 50138000 and 50138800, although the geometric means for fecal coliform bacteria concentrations have, for the most part, remained below 2,000 col/100 mL; and (3) acceptable sanitary quality at station 50146000 with a long-term geometric mean of about 700 col/100 mL. Baseline fecal coliform data are insufficient to identify sources of fecal contamination within the study area. The data also indicate that the greatest improvement in the bacteriological quality has been at station 50133600 on the Río Guanajibo near San Germán where the geometric mean concentration of fecal coliform indicator bacteria for five sequential samples for the period from 1986 to 1989 was near 8,000 col/100 mL, substantially above the PREQB goal established in 1990 for class SD-designated use waters. The geometric mean since 1990 has been less than the established goal of 2,000 col/100 mL.

Methodology

More than 100 water samples were collected at selected streams within the municipio of Mayagüez and analyzed for indicator bacteria concentrations. The water samples were collected and analyzed following the methods and procedures established by the USGS. The results were used to classify the sanitary water quality of 165 of the approximately 200 stream miles within the municipio of Mayagüez. Each sample was labeled according to station identification number, station name, collector, date, and time. A local chain of custody was followed using a form designed for that purpose.

Field-Data Collection

Instantaneous discharge measurements were made simultaneously during sample collection using a AA standard current meter or a pigmy current meter and following the current meter method (Carter and Davidian, 1968), except in a few cases where flow was stagnant. Twenty one of the bacteriological sampling stations correspond with stations also used in the surface-water low-flow statistics assessment (Chapter A). Among the low-flow statistics estimated at these sampling stations is the 7-day, 2-year discharge. This statistical discharge value is included with the instantaneous discharge measurements made during sampling to indicate the minimum discharge rate at which the fecal coliform concentration standards are applicable in Puerto Rico (Junta de Calidad Ambiental de Puerto Rico, 1990).

Three long-term quality-of-water baseline stations 50133600, 50138000, and 50146000 were not sampled during these study, because the stations are outside of the study limits (boundary); however, data at these stations could serve to indicate fecal coliform concentration trends at streams near the study area. The only quality-of-water long-term baseline station sampled regularly is station 50136400, which lies in the vicinity of the study area. This station was also sampled three times during this study.

Most samples were obtained during stream base-flow periods in July 2000, November 2000, April 2001, and February 2002 for two hydrologic conditions: (1) near the annual stream low-flow discharge, and (2) during base-flow conditions after a rainfall event. Samples obtained during these flow regimes were used to rank approximately 165 stream miles within the municipio of Mayagüez or with drainage into the municipio. During stream base-flow conditions, fecal contamination in streams is principally from sources that discharge directly to stream channels (especially during periods of annual low flow), or are washed into stream channels from sources adjacent (within hundreds of feet) to stream banks. To conduct the assessment, 28 stream sampling stations were established initially, and sampled on at least two occasions near the annual low flow or at base flow to comply with the requisite of base-flow conditions. Nine sampling stations were added to the network later to improve spatial coverage of bacteriological data. The nine sampling stations were sampled at least once. One of the nine sampled stations (50136400) on the Río Rosario is part of the USGS long-term monitoring program and is sampled on a quarterly basis every year. The analytical results from May 9, 2000, and on September 8, 2000, from station 50136400 were used for this study. This station was sampled once more during the study. The sanitary condition of stream courses was classified using data obtained from a total of 37 stream sampling stations.

Water samples for fecal coliform and fecal streptococcus bacteria analyses were collected from a total of 37 locations at streams with drainage to or within the municipio of Mayagüez (fig. 3 and plate 1). Water samples were collected at all stream stations using the “hand-dip” method (Britton and Greeson, 1989). This method is most applicable under the low-flow stream-conditions characteristic of this study. The equal discharge increment (EDI) or equal width increment (EWI) method is not warranted in streams where the depth is less than 0.8 ft and/or the velocity is less than 1.5 ft per second. The streams in the area during base-flow conditions are generally less than 2 ft deep and 25 ft wide. The only stream sampling sites where the depths and widths at which “hand-dip” samples may not be representative of the stream cross sections are stations 50146010 on the Río Grande de Añasco above Río Cañas and 50146100 on the Río Grande de Añasco at Highway PR-2. Following the “hand-dip” sampling method, a sterile narrow-mouth plastic 100-mL bottle was dipped 1 to 2 inches (in.) below the water surface with the bottle opening pointed slightly upward towards the current and with the hand and arm on the downstream side of the bottle. Once filled, the bottle containing the water sample was removed from the stream, keeping the opening pointed upward and tightly capped, allowing about 2.5 to 5 centimeters (cm) of headspace. Water samples were placed in an ice chest and chilled to 1 to 4°C. Water samples were processed for analysis in the field within 6 hours after collection to minimize potential changes in the concentration of the indicator bacteria.

Quality-control samples collected during the study included the collection and processing of replicates, sterile buffered water (SBW) blanks, filter blanks, field blanks, and procedure blank samples. The primary and the replicate samples were collected sequentially at the same point from the stream using the hand-dip method. A set of SBW, filter, and procedure blanks were processed on each sampling date during the study, except for the procedure blank samples, which were processed only during the first sampling in July 2000.

Analytical Techniques

Processing water samples for fecal indicator bacteria required procedures and analytical methods that prevented fecal contamination by maintaining a sterile environment; reduced analytical bias by ensuring that subsamples used in preparing dilutions were withdrawn from a well-mixed sample bottle; and ensured accuracy of results by minimizing false positives and false negatives.

The membrane-filter immediate incubation test was used to measure fecal coliform and fecal streptococcus bacteria concentrations following standard USGS procedures (Britton and Greeson, 1989; Myers and Sylvester, 1997). Materials such as the sterile, narrow-mouth, plastic, 100-mL sampling bottle, distilled water, m-FC agar, sodium hydroxide solution and rosolic acid crystals for fecal coliform tests and distilled water, KF agar, and triphenyltetrazolium crystals for fecal streptococcus tests were obtained from the USGS Water Quality and Research Laboratory in Ocala, Florida. Dehydrated media was prepared and poured into 50 x 11 millimeter (mm) petri dishes at the Caribbean District Laboratory in Guaynabo, Puerto Rico. A 0.65-micrometer (µm) pore size (47 mm diameter) membrane filter was used for fecal coliform bacteria analysis and a 0.45-µm pore size (47 mm diameter) membrane filter was used for fecal streptococcus bacteria.

Based on previous sampling experience, at least three dilution ratios were prepared for each primary and replicate sample at each station to maximize the probability of obtaining an ideal count of 20 to 60 colonies per filter for fecal coliform bacteria and 20 to 100 colonies per filter for fecal streptococcus bacteria. The lower limit is an arbitrary base number below which statistical validity is questionable. The higher limit is a value above which effects of crowding, debris, insufficient media to support full development of colonies, and various other occurrences on the membrane filtration may prevent proper analysis. All samples were incubated immediately after analysis using solid-block incubators at the USGS mobile laboratory. Fecal coliform bacteria are defined as the organisms that produce blue colonies in whole or part within 24 hours (+/- 2 hours when incubated at 44.5 (+/-0.2)) °C on m-FC medium. Fecal streptococcus bacteria are defined as the organisms that produce light pink, flat to smooth, dark red with pink margin colonies within 48 hours (+/- 2 hours) when incubated at 35.0 (+/-0.2) °C on KF medium. The results for the ideal count were reported in terms of fecal coliform bacteria or fecal streptococcus bacteria colony counts per 100 milliliters (col/100 mL) of raw water sample using the following formula:

$$NCC per 100 mL = (NCC/VOSF) X 100,$$

where

NCC is the bacteria colony counts in the membrane filter, and

$VOSF$ is the volume of original sample filtered.

If there was more than one ideal count, then the colony counts were averaged using the following formula:

$$NCC \text{ per } 100 \text{ mL} = (NCC_{sum} / VOSF_{sum}) \times 100,$$

where

NCC_{sum} is the sum of the indicator colony counts, and

$VOSF_{sum}$ is the volume of the original sample filtered.

If colony counts were not in the ideal range, then concentrations were reported as non-ideal, using the following rationale:

1. If the colony counts were outside the ideal colony range (20-60 for FC and 20-100 for FS), the colony counts were averaged using the same formula used to calculate the colony counts when there was more than one ideal count, and the result was reported as "estimated count based on non-ideal colony count." The filters with zero counts or too numerous to count (TNTC) were not included in the final calculation.
2. If there were no typical colonies on any of the filters, then a colony count of 1 was assumed for the filter with the largest sample volume (smallest dilution ratio). The final calculation was made and the result was reported as "less than (<) the calculated number per 100 mL." The result is a maximum estimated value.
3. If all filters showed colony counts that were TNTC, then it was assumed a maximum ideal count (60 for FC or 100 for FS) on the filter with the smallest volume filtered (highest dilution ratio). The final calculation was made, and the result was reported as "greater than (>) the calculated number per 100 mL." The result is a minimum estimated value.

The quality-control (QC) samples for bacteriological analyses constitute from 5 to 30 percent of the total number of samples collected from each station over the study period. The QC samples for bacteriological analyses in this study included: (a) field replicate samples, and (b) filter and procedure blank samples.

The field replicate sample is used to measure the precision of the entire process (for example, dilution procedures and variability of bacteriological concentrations resulting from dip sampling). Field replicate samples collected and analyzed during this study represented 21 percent of the number of primary samples collected. Precision of field data is measured by comparing the results of the primary samples with the field replicate samples. Relative percent difference (RPD) of primary and replicate samples are calculated as:

$$RPD = S_1 - S_2 / [(S_1 + S_2)/2]\ X\ 100,$$

where

RPD is the relative percent difference,
S_1 is the primary sample value, and
S_2 is the field replicate sample value.

The analytical results indicate that the RPD of the sequential replicate samples obtained as part of this survey ranged from about 3 to 67 percent with a median value of 14 percent (table 5).

Filter blanks were obtained by placing a sterile, gridded-membrane filter on the funnel base and rinsing the funnel of the filtration assembly equipment with 100 mL of sterile buffered water. This filter blank is processed through the filtration equipment before the water sample is filtered. The result of the analysis of the filter blank should be negative (no development of colonies); if positive, then the filtration equipment was not sterile.

A procedure blank, which measures the effectiveness of the rinsing techniques, was obtained by placing a sterile, gridded-membrane filter on the funnel base and rinsing the funnel of the filtration assembly equipment with 100 mL of sterile buffered water. This blank was collected and processed after collecting and processing all other samples. The result of this analysis should be negative; the positive presence of indicator colonies on the procedure blank indicates either inadequate rinsing or contamination of equipment or buffered water during sample processing.

In summary, results for filter, field, and procedure blank samples, which are measures of the effectiveness of sterilization, should be negative; if results were positive, then analytical results of samples obtained between negative QA/QC blanks (before and after the positive blank) were reviewed for suspect data results (for example, high counts or significant discrepancy between the number of colonies developed for sample dilutions with ideal and non-ideal counts). During this study, no bacteriological results were discarded. The results of the analysis of sterile buffered water, filter, field, and procedure blanks conducted during the study were negative (showed no development of colonies).

Table 5. Relative percent difference for fecal coliform bacteria counts between primary and field replicate samples collected at streams in the municipio of Mayagüez, Puerto Rico, 2000-2002.

[S_1, primary sample value; S_2, field replicate sample value; RPD relative percent difference]

Station number	Station name	S_1	S_2	RPD
50135950	Río Rosario at Limón	610	740	19
50138190	Río Hondo near Mayagüez	88	110	22
50138500	Río Yagüez at Presada	190	200	5
		2,100	3,400	47
		72	83	14
		80	84	5
50138800	Río Yagüez near Mayagüez	100	150	40
50138860	Quebrada Caricosa at mouth	280	217	25
		780	760	3
50145390	Río Casey at Río Cañas Arriba	230	200	14
50146036	Río Cañas upstream Quebrada Cojolla	490	390	23
		8,700	9,100	4
		100	200	67
50146045	Río Cañas at Represa	120	160	29
		2,800	3,000	7
		270	300	10
		61	68	11
		88	84	5

Results and Interpretation

A major assumption in the interpretation is that streamflow during low-flow conditions is derived from ground-water discharge, and that the fecal contamination during stream base-flow conditions is primarily derived from sources discharging directly into stream courses or near the riparian zone. It is also assumed that, with an average of two samples obtained at least several months apart during stream low-flow recession periods at numerous locations throughout a watershed, it is possible to define, on a qualitative basis, the relative sanitary quality at the site with respect to the other sampling locations.

Based on these assumptions, the analytical results for fecal coliform and fecal streptococcus bacteria concentrations from the 37 stream sampling stations are used to characterize the sanitary quality of about 175 miles of perennial stream channels within the municipio of Mayagüez (table 5). The sanitary quality of approximately 8 stream miles could not be assessed using indicator bacteria data, because streamflow was slow or non-existent (stagnant). These 8 stream miles are primarily drainage canals located in the lower part of Caño Corazones basin within the municipio de Mayagüez.

A relative ranking of the stream sanitary quality was used to delimit stream channels as being either **good, acceptable, fair, or poor** (Rodríguez and others, 2002) (table 6). This relative ranking was established using the Puerto Rico Water Quality Standards for fecal coliform of 2,000 col/100 mL, in use during the study, and the following rationale: if both samples had fecal coliform bacteria concentrations less than 200 col/100 mL and fecal streptococcus concentrations less than 400 col/100 mL, then the **good** classification was assigned to the sampling station. The stream segment given the same classification was extended upstream and downstream as follows.

If the upstream and/or downstream reach within the same order stream had been sampled and the results were comparable, then the same classification was given for the entire stream segment between both sampling stations; if the upstream station and/or downstream station was classified differently, then the classification was extended to the mid-point of the stream; and if no other sampling station was located upstream, then the same classification was extended upstream not more than 0.6 mi (1.0 km) along the main trunk of the stream. For stream segments with an upstream distance greater than 0.6 mi from the sampling station and for its tributaries, the same classification was assigned, but using the terminology of **presumed good**. If no other sampling station was established downstream, then the same classification was used up to a distance of 0.6 mi along the main channel of the stream (same stream order), with the **presumed good** classification assigned downstream of the 0.6-mi distance. The **presumed** ranking was not assigned to any stream (or tributary) in which no fecal coliform and fecal streptococcus analyses were obtained, given the low likelihood of bacteriological concentrations being within the classification of **good** or **presumed good**.

For sampling stations where fecal coliform bacteria concentrations were equal to or less than 2,000 col/100 mL on both sampling occasions, stream segments were classified as **acceptable**. The classification of **presumed acceptable** was assigned for stream segments upstream and downstream of the sampling station using the same rationale described previously.

For sampling stations where fecal coliform bacteria concentrations were equal to or greater than 2,000 col/100 mL for one sampling occasion, but less than 2,000 col/100 mL for the second sampling, stream segments were classified as **fair**. The classification of **presumed fair** was extended upstream and downstream of the sampling station following the same rationale as stated previously for **good** and **presumed good**.

Sampling stations with fecal coliform bacteria concentrations greater than 2,000 col/100 mL for both sample dates were considered **poor**. Within the city of Mayagüez, an exception was made where the stream classification of **presumed poor** was extended upstream to the urban limits and at various streams to the stream mouth. This classification was justified because four sampling stations were established within the urban reaches of streams; three of the stations had fecal coliform concentrations ranked as **poor** (stations 50139200, 50139625, 50139650) and eight samples collected had fecal coliform concentrations greater than 2,000 col/100 mL (concentrations ranged from 3,100 to 100,000 col/100 mL, table 7).

Table 6. Classification rationale used in ranking the sanitary quality of streams in the municipio of Mayagüez, Puerto Rico.

[>, greater than; <, less than; mL, milliliters; mi, mile; k, non-ideal bacteria count]

Ranking	Fecal coliform concentration for stream reach during base-flow conditions, in colonies per 100 mL	Rationale	Range of concentrations measured during synoptic surveys		
				Fecal coliform concentration, in colonies per 100 mL	Fecal streptococcus concentration, in colonies per 100 mL
Good	< 200	Samples obtained at site also had fecal streptococcus concentrations less than 400 colonies per 100 mL.	**Maximum**	150	350
			Minimum	100	240
			Geometric mean	120	293
			Number of samples	3	3
Presumed good	< 200	Samples obtained at a distance greater than 0.6 mi upstream or downstream were used to infer that equal concentrations are probable within the delimited stream reach.	**Maximum**	160	370
			Minimum	50	70
			Geometric mean	98	180
			Number of samples	5	5
Acceptable	< or equal to (=) 2,000	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	900	2,600
			Minimum	k53	200
			Geometric mean	230	506
			Number of samples	47	47
Presumed acceptable	< or equal to (=) 2,000	Samples obtained at a distance greater than 0.6 mi upstream or downstream were used to infer that equal concentrations are probable within the delimited stream reach.	**Maximum**	370	510
			Minimum	210	460
			Geometric mean	260	490
			Number of samples	3	3
Fair	Equal probability for < or > 2,000	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	5,200	2,100
			Minimum	k58	k31
			Geometric mean	470	205
			Number of samples	6	5
Presumed fair	Equal probability for < or > 2,000	Samples obtained at a distance greater than 0.6 mi upstream or downstream were used to infer same conditions are likely within the delimited stream reach.	**Maximum**	0	0
			Minimum	0	0
			Geometric mean	0	0
			Number of samples	0	0
Poor	> 2,000	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	100,000	65,000
			Minimum	2,700	530
			Geometric mean	8,600	2,900
			Number of samples	12	12
Presumed poor	> 2,000	Samples obtained at a distance greater than 0.6 mi upstream or downstream of delimited stream reach were used to infer that similar concentrations are likely within delimited stream reach; also applied within stream reaches in the urbanized part of municipio of Mayagüez, since all three sampled sites in urban reaches of the stream had concentrations above 2,000 colonies per 100 mL.	**Maximum**	3,500	3,500
			Minimum	2,300	2,300
			Geometric mean	2,800	2,800
			Number of samples	2	2

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.

[m/d/y, month, day, year; USGS, U.S. Geological Survey; *, result not used in station classification, only two with lowest discharge were used; NDM, no discharge measurement was made; E, estimated instantaneous discharge; K, indicates non-ideal plate count, either the number of colonies developed were less than ideal number (dilution too high) or greater than ideal number (dilution too low); >, greater than; <, less than; mL, milliliters; ft^3/s, cubic feet per second; mi^2, square mile; µS/cm, microsiemens per centimeter; ^{o}C, degree Celsius; 7-d, Q-2, 7-day, 2-year low flow; R, replicate sample; PR, Puerto Rico; --, no data. The numbers in bold represent low-flow or base-flow discharge conditions and were used to determine the stream segment classification]

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drainage area (mi^2)	Instantaneous discharge (ft^3/s)	7-d, Q-2 mean daily discharge (ft^3/s)	Specific conductance (µS/cm at 25 ^{o}C)	Water temperature (^{o}C)	Fecal coliform (colonies per 100 mL)	Fecal streptococcus (colonies per 100 mL)	Station sanitary quality ranking
Río Guanajibo Basin											
50135790	Río Maricao at Montoso, PR	07/10/00	1500	7.33	11.7	--	238	27.0	**240**	**210**	Acceptable
		11/20/00	1240		23.6		231	23.2	**160**	**230**	
50135950	Río Rosario at Limón, PR	07/10/00	1330	14.6	20.8	8.8	232	27.6	**610**	**250**	Acceptable
		07/10/00	1332R		20.8		232	27.6	740	--	
		11/20/00	1100		39.4		246	22.2	200*	210*	
		04/03/01	0945		11.9		295	21.9	**K120**	**210**	
50136400	Río Rosario near Hormigueros, PR	05/09/00	1245		78		192	24.3	400*	**840***	Acceptable
		09/08/00	1320		51		295	29.5	**570**	**320**	
		04/03/01	0750	18.3	14.0	10	297	22.5	**120**	**550**	
50138150	Río Hondo at Río Hondo, PR	07/07/00	0750	1.61	0.41	0.2	645	23.4	**340**	**510**	Acceptable
		11/16/00	0730		1.08		420	22.7	>60,000	>100,000*	
		04/05/01	0810		0.37		630	21.5	**900**	**1,400**	
50138190	Río Hondo near Mayagüez, PR	02/12/02	0655	2.93	1.01		690	22.0	**88**	**200**	Presumed good
		02/12/02	0657R		1.01		690	22.0	**110**	**370**	
Caño Corazones Basin											
50138275	Quebrada Guifén at Sábalos, PR	07/13/00	1045	0.47	1.12	--	469	30.3	**11,600***	**5,300***	Poor
		11/16/00	0930		2.43		426	24.2	8,000*	5,200*	
		02/12/02	0915		1.35		473	22.4	**9,800**	**4,100**	

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.—Continued

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drain-age area (mi^2)	Instanta-neous discharge (ft^3/s)	7-d, Q-2 mean daily dis-charge (ft^3/s)	Specific conduc-tance (μS/cm at 25 °C)	Water temper-ature (°C)	Fecal coliform (colonies per 100 mL)	Fecal strepto-coccus (colonies per 100 mL)	Station sanitary quality ranking
Caño Corazones Basin—Continued											
50138285	Quebrada Grande at Quebrada Grande, PR	07/07/00	0930	0.72	0.48	0.2	393	23.7	81	500	Acceptable
		11/16/00	0830		0.80		248	22.2	410	1,200	
50138290	Quebrada Grande at Highway PR-348, PR	02/11/02	1320		1.17		408	22.1	K210	500	Presumed acceptable
50138375	Caño Majagual at Highway PR-348, PR	02/12/02	0940	0.20	0.20	< 0.1	575	23.1	**3,500**	**1,800**	Presumed poor
Río Yagüez Basin											
50138400	Río Yagüez at Montoso, PR	07/11/00	0845	0.63	1.03	0.5	252	21.5	**140**	**510**	Acceptable
		11/14/00	1225		2.59		233	22.8	620*	810	
		04/03/01	1125		0.55		224	22.3	**K72**	**510**	
50138425	Río Yagüez at Naranjales, PR	07/11/00	1040	1.32	1.89	1.1	262	22.6	**280**	**470**	Acceptable
		11/15/00	0825		4.68		247	21.4	960*	400*	
		04/03/01	1300		1.19		117	23.1	**K73**	**220**	
50138500	Río Yagüez at Presada de Mayagüez, PR	07/11/00	1210	4.38	5.02	2.7	288	24.1	**190**	**690**	Acceptable
		07/11/00	1212R		5.02		288	24.1	200	720	
		11/15/00	1010		NDM		273	22.8	2,100*	600*	
		11/15/00	1012R		NDM		273	22.8	3,400*	1,400*	
		04/03/01	1520		2.79		294	24.9	**K72**	**320**	
		04/03/01	1522R		2.79		294	24.9	K83	310	
		02/11/02	0940		5.50		302	20.7	80*	180*	
		02/11/02	0942R		5.50		302	20.7	84*	170*	
50138760	Tributario de Quebrada Gandel at Quemado, PR	07/14/00	0910	0.35	0.26		344	23.4	**340**	**900**	Acceptable
		11/22/00	0835		0.64		333	22.0	**820**	**990**	
		04/04/01			Dry	Dry					

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.—Continued

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drain-age area (mi^2)	Instanta-neous discharge (ft^3/s)	7-d, Q-2 mean daily dis-charge (ft^3/s)	Specific conduc-tance (µS/cm at 25 °C)	Water temper-ature (°C)	Fecal coliform (colonies per 100 mL)	Fecal strepto-coccus (colonies per 100 mL)	Station sanitary quality ranking
					Río Yagüez Basin—Continued						
50138785	Quebrada Gandel at Mayagüez Arriba, PR	07/14/00	0820	1.83	1.43	0.6	314	24.6	**120**	**510**	Acceptable
		11/21/00	1340		2.38		316	24.3	**330**	**630**	
50138800	Río Yagüez near Mayagüez, PR	07/14/00	1350	4.15	4.64	2.3	305	27.5	**110**	**240**	Good
		11/15/00	1215		12.6		285	24.1	1,300*	1,100*	
		04/05/01	0930		3.27		322	22.3	**100**	**350**	
		04/05/01	0932R		3.27		322	22.3	150	300	
50138815	Quebrada Caricosa near Represa de Mayagüez, PR	07/18/00	1020	0.57	0.09	< 0.1	378	22.8	**110**	**980**	Acceptable
		11/21/00	0900		0.22		364	21.2	**210**	**540**	
50138840	Quebrada Caricosa near Mayagüez, PR	07/18/00	1100	2.40	1.06	0.7	347	25.9	**130**	**450**	Acceptable
		11/21/00	1000		1.89		325	23.3	**680**	**630**	
50138860	Quebrada Caricosa at mouth, PR	07/18/00	1230	2.92	1.32	0.8	340	26.8	**280**	**560**	Acceptable
		07/18/00	1232R		1.32		340	26.8	217	560	
		11/21/00	1130		2.54		335	25.9	780*	1,000*	
		11/21/00	1132R		2.54		335	25.9	760*	1,400*	
		02/11/02	1150		2.18		317	25.0	**K53**	**200**	
50139200	Río Yagüez at Highway PR-2, PR	07/12/00	0815	13.3	12.3		339	25.1	**7,800**	**2,000**	Poor
		11/27/00	1015		18.0		326	25.4	**6,100**	**2,000**	
					Quebrada del Oro Basin						
50139625	Quebrada del Oro at Miradero, PR	07/12/00	1023	0.69	0.55	0.2	376	24.7	**3,100**	**3,800**	Poor
		11/27/00	1110		0.74		359	23.5	**3,500**	**7,900**	
		02/07/02	0805		0.78		367	21.9	4,500*	3,600*	

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.—Continued

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drainage area (mi^2)	Instantaneous discharge (ft^3/s)	7-d, Q-2 mean daily discharge (ft^3/s)	Specific conductance (µS/cm at 25 °C)	Water temperature (°C)	Fecal coliform (colonies per 100 mL)	Fecal streptococcus (colonies per 100 mL)	Station sanitary quality ranking
					Quebrada del Oro Basin—Continued						
50139650	Quebrada del Oro at Highway PR-2, PR	07/12/00	0930	1.49	1.30	0.8	390	28.1	**9,400**	**910**	Poor
		11/27/00	0930		1.91		390	24.6	4,000*	820*	
		02/07/02	0730		1.56		391	21.7	**100,000**	**2,800**	
					Caño Boquilla Basin						
50139700	Caño Boquilla at Sabanetas, PR	07/13/00	1200	0.77	NDM	--	1,020	25.7	**>60,000**	**65,000**	Poor
		11/17/00	0920		NDM		429	23.1	**2,700**	**2,000**	
		02/07/02	0905		0.38		448	22.1	870*	2,000*	
50139725	Tributario de Caño Boquilla at Highway PR-2 near Sabanetas, PR	02/20/02	0940		2.78		304	23.8	**2,300**	**4,800**	Presumed poor
50139750	Tributario de Caño Boquilla at Highway PR-342, PR	02/05/02	1000		E0.40	--	285		**K50**	**K70**	Presumed good
50139760	Tributario de Caño Boquilla at Highway PR-2 at Sabanetas, PR	02/05/02	1015		E0.50		321	23.5	**370**	**460**	Presumed acceptable
					Río Grande de Añasco Basin						
50145390	Río Casey at Río Cañas Arriba, PR	07/13/00	1300	7.03	15.2	6.2	180	27.0	**230**	**210**	Acceptable
		07/13/00	1302R		15.2		180	27.0	200	220	
		11/16/00	1055		25.7		180	22.5	**240**	**570**	

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.—Continued

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drainage area (mi^2)	Instantaneous discharge (ft^3/s)	7-d, Q-2 mean daily discharge (ft^3/s)	Specific conductance (µS/cm at 25 °C)	Water temperature (°C)	Fecal coliform (colonies per 100 mL)	Fecal streptococcus (colonies per 100 mL)	Station sanitary quality ranking
Río Grande de Añasco Basin—Continued											
50146010	Río Grande de Añasco above Río Cañas, PR	07/05/00	1300		NDM	--	178	27.5	**2,800**	**1,100**	Fair
		07/05/00	1302R		NDM		178	27.5	3,000	—	
		11/13/00	1215		NDM		240	25.6	K270*	K140*	
		11/13/00	1217R		NDM		240	25.6	K300*	K120*	
		04/02/00	1130		E103		255	26.8	**K61**	**84**	
		04/02/00	1132R		E103		255	26.8	**K68**	**K60**	
		02/05/02	1035		E150		245	23.2	88*	180*	
		02/05/02	1037R		E150		245	23.2	84*	190*	
50146015	Río Cañas at Camino Charluisant, PR	07/06/00	1410	1.76	4.11	0.9	198	25.0	**110**	**370**	Acceptable
		11/14/00	1145		6.12		200	22.7	**700**	**790**	
50146035	Río Cañas at Highway PR-352, PR	07/06/00	1300	5.83	9.28	4.2	242	25.1	**380**	**660**	Acceptable
		11/14/00	1025		17.2		218	21.8	4,700*	7,200*	
		04/04/01	1050		4.35		270	22.3	**230**	**490**	
50146036	Río Cañas upstream Quebrada Cojolla, PR	07/06/00	1100	6.18	9.44	4.2	238	24.5	**490**	**790**	Acceptable
		07/06/00	1102R		9.44		238	24.5	**390**	**1,000**	
		11/14/00	0830		17.4		206	21.5	8,700	10,000	
		11/14/00	0832R		17.4		206	21.5	9,100	9,700	
		04/04/01	0950		4.64		266	22.1	**K100**	**460**	
		04/04/01	0952R		4.64		266	22.1	**K200**	**470**	
50146037	Quebrada Cojolla at Quemado, PR	07/14/00	0945	0.58	0.56	--	313	23.3	**5,500**	**530**	Poor
		11/22/00	0920		0.87		289	22.0	82,000*	3,900*	
		04/04/01	1148		0.33		344	21.9	**3,300**	**840**	

Table 7. Fecal coliform and fecal streptococcus bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Mayagüez, Puerto Rico.—Continued

Sample site USGS identification number	Site name	Sample date (m/d/y)	Time	Drain-age area (mi^2)	Instanta-neous discharge (ft^3/s)	7-d, Q-2 mean daily dis-charge (ft^3/s)	Specific conduc-tance (µS/cm at 25 °C)	Water temper-ature (°C)	Fecal coliform (colonies per 100 mL)	Fecal strepto-coccus (colonies per 100 mL)	Station sanitary quality ranking
Río Grande de Añasco Basin—Continued											
50146045	Río Cañas at Represa, PR	02/06/02	0940		12.1		260	21.3	**120**	**210**	Presumed good
		02/06/02	0942R		12.1		260	21.3	**160**	**170**	
50146051	Tributario de Río Cañas at Leguisamo, PR	07/06/00	0930	1.18	0.95	--	201	23.9	**210**	**370**	Acceptable
		11/14/00	0730		1.89		193	21.8	360*	710*	
		04/02/01	1230		0.47		241	23.7	**K53**	**230**	
50146053	Tributario de Río Cañas near mouth, PR	07/05/00	1430	1.44	1.94	--	197	27.0	**780**	**530**	Acceptable
		11/13/00	1430		2.33		209	25.4	4,600*	400*	
		02/06/02	0845		1.74		235	21.3	**300**	**2,600**	
50146055	Río Cañas at Highway PR-108, PR	02/06/02	0750		5.91		278	21.5	**220**	**510**	Presumed acceptable
50146065	Río Cañas near mouth, PR	07/05/00	1330	14.3	13.1	--	200	25.2	**900**	**1,200**	Acceptable
		11/13/00	1320		13.2		251	24.4	**440**	**K380**	
50146100	Río Grande de Añasco at Highway PR-2 near Añasco, PR	07/05/00	1230		NDM	--	175	28.5	**5,200**	**2,100**	Fair
		11/13/00	1145		E540		237	25.4	280*	250*	
		04/02/01	1045		E149		383	27.7	**K58**	**K31**	

Upper Río Guanajibo Basin

The section of the upper Río Guanajibo basin that is contained within the study area is forested and not densely populated. The sampling network for the upper Río Guanajibo basin included three sampling stations in the Río Rosario sub-basin and two in the Río Hondo sub-basin (plate 1 and table 7). The Río Hondo station near Mayagüez (50138190) in the Río Hondo sub-basin, was sampled only once and the sanitary water quality at this station was classified as **presumed good**. The sanitary water quality at the stations Río Maricao at Montoso (50135790), Río Rosario at Limón (50135950), and Río Rosario near Hormigueros (50136400) in the Río Rosario sub-basin and station Río Hondo at Río Hondo (50138150) in the Río Hondo sub-basin were classified as **acceptable.**

Quebrada Sábalos Basin (Barrios Sábalos and Río Hondo)

The Quebrada Sábalos basin is more densely populated than the upper Río Guanajibo basin. It includes the drainage basins of Quebradas Guifén, Grande, and Pulida, and Caños Merle and Majagual. The stream network in this basin has a total length of about 30 stream miles of which 13.5 stream miles were ranked in this study (table 8). Water samples were collected at sampling stations at Quebrada Grande, Quebrada Guifén and Caño Majagual. The sanitary water quality at Quebrada Grande at Quebrada Grande (50138285) was classified as **acceptable** or **presumed acceptable**, while the sanitary water quality at station Quebrada Guifén at Sábalos (50138275) was classified as **poor** and at Caño Majagual as **presumed poor**. Water quality at Quebrada Guifén may be affected by the high density of housing units and presence of livestock. The sanitary water quality at station Caño Majagual at Highway PR-348 (50138375) was classified as **presumed poor**. The water quality at Caño Majagual may be affected by the dense population in the area, grazing cattle, and urban runoff.

The sanitary water quality at Caño Merle and the lower part of Quebrada Sábalos was classified on the basis of the sanitary quality obtained at the upstream sampling stations. Caño Merle discharges part of its flow into the Quebrada Sábalos. Taking into consideration the classifications given to the sampling station at Quebrada Guifén (**poor**) and the sampling stations at Quebrada Grande (**acceptable and presumed acceptable**), at best, the sanitary water quality at Caño Merle can be classified as **fair**. The downstream portion of Quebrada Sábalos, close to its mouth, is part of an estuary, and as such, the sanitary water-quality standard for this part of Quebrada Sábalos must meet the class SB goal to be classified as **acceptable**. The class SB sanitary quality goal, which is based on a geometric mean not greater than 200 fecal coliform bacteria per 100 mL of water sample, was applied to the lower segment of the Quebrada Sábalos, thus, the classification of **poor**.

Caño Corazones Basin (Barrios Sábalos and Río Hondo)

Bacteriological data were insufficient to properly classify the numerous drainage channels in the lower part of the Caño Corazones.

Río Yagüez Basin

The sampling network in this basin consists of 10 sampling stations: 5 stations along the main stem of the Río Yagüez, 3 along Quebrada Caricosa, and 2 along the Quebrada Gandel. A total of 43.2 stream miles were classified in this basin (table 8). In general, the sanitary water quality in the Río Yagüez basin is the best in the study area (plate 1 and table 7). The results indicate that 8 of the 10 stations, with a total 12.6 stream miles (29.2 percent), were classified as **acceptable**. A total of 19.2 stream miles upstream or downstream of these eight sampling stations were classified as **presumed acceptable**. The results indicate fecal coliform bacteria concentrations substantially below the requirements for SD class surface waters established as the Puerto Rico standard. The sanitary water quality at one of the sampling stations, Río Yagüez near Mayagüez (station 50138800), was classified as **good** (table 7). This station is located upstream from a densely populated urban area. However, the Río Yagüez traverses a densely populated and industrialized area downstream of sampling station 50138800 and the sanitary water quality deteriorates substantially. The sanitary water quality at sampling station Río Yagüez at Highway PR-2 (station 50139200), located downstream from the city, was classified as **poor** (table 7). This classification also was extended to the estuary part of the stream since the standard for class SB waters is 200 fecal coliform col/100 mL of water sample.

Quebrada del Oro Basin (Barrio Miradero)

The Quebrada del Oro basin was classified on the basis of two sampling stations in the 8.3 stream miles in the basin. Although the upper portion of Quebrada del Oro basin is not densely populated and is primarily forested, the sanitary water quality at the representative station was classified as **poor**. This suggests that the water quality may be affected by runoff or discharge originating from a confined animal facility, located upstream from the sampling station. Downstream from this station, the water quality deteriorates as the creek flows through a highly urbanized area. The sanitary water quality at sampling station, Quebrada del Oro at Highway PR-2 (station 50139650), has a higher fecal coliform concentration than the upstream station and was also classified as **poor** (table 7). This classification was extended to the estuary part of the stream, which must meet the standard for class SB waters, which is 200 fecal coliform bacteria col/100 mL of water sample.

Caño Boquilla Basin (Barrios Sabanetas, Río Cañas, and Miradero)

Four sampling stations were used to classify 14.6 stream miles in this basin (table 8). Results from the sampling station on the northeast branch of Caño Boquilla (50139750) indicate that sanitary water quality is **presumed good**. However, once the stream reaches the coastal area, the water quality deteriorates and was classified as **poor**. The results of the sampling stations on the southwest branches of the Caño Boquilla (50139700 and 50139725) indicate the sanitary water quality is **poor** and **presumed poor**, respectively. The **poor** classification was extended to the estuary part of Caño Boquilla. The estuary was classified as **poor** based on the sanitary quality standard established for estuarine zones. This lower part of Caño Boquilla is under consideration to be designated in the near future as a natural reserve by the Department of Natural and Environmental Resources. Some parts of the Caño Boquilla were not flowing and were considered stagnant. Land use within the drainage area of the southwest branches of the Caño Boquilla is primarily suburban housing. The Mayagüez municipal landfill, which covers approximately 52 acres and was established in 1974 (Torres-González and Gómez-Gómez, 1982), also is located in this drainage basin (plate 1). Part of the east branch of Caño Boquilla was filled in and at present is part of the Mayagüez sanitary landfill.

Río Grande de Añasco Basin

The sampling network for streams within the Río Grande de Añasco Basin consists of 12 sampling stations on three tributaries: Río Casey, Quebrada Cojolla, and Río Cañas. The general sanitary water quality in the stream reaches was classified as **acceptable**. Only one sampling station established at Quebrada Cojolla (station 50146037), a tributary to the Río Cañas, was classified as **poor**. Field observations upstream from this station indicate that the deteriorated sanitary water quality could be from untreated animal wastes from a small agricultural area. However, the stream segment on the Río Cañas, from its junction with the Quebrada Cojolla to the downstream sampling station (50146065), was classified as **acceptable**. This suggests that once the effected stream discharges into the Río Cañas, the sanitary quality of the water improves as a result of dilution effects caused by the higher streamflow in the Río Cañas. The sanitary water quality at the five sampling stations along the Río Cañas was classified as **acceptable** and as **presumed acceptable** where only one sample was collected. A classification of **acceptable** also was given to the two sampling stations established on the tributaries of the Río Cañas. Quebrada Casanova, an important tributary of Río Cañas, was not sampled; however, based on similar land use, the sanitary water quality of 3.6 stream miles in this stream was classified as **presumed acceptable**.

The two stations located on the Río Grande de Añasco were classified as **fair.** The sanitary water quality in the coastal segment from Highway PR-2 to the mouth of Río Grande de Añasco was classified as **poor**, according to the standard applicable for estuarine zones (200 fecal coliform bacteria col/100 mL of sample). The estuary portion of the Río Grande de Añasco extends inland at least to the Highway PR-2 bridge as determined by field inspections made as part of this study (plate 1).

A summary of the bacteriological results, the classification assigned at sampling stations, and stream miles classified under each ranking is presented in table 8. Approximately 20 stream miles (stream miles not rated plus the undetermined) were not classified because of insufficient data. Only 13.6 stream miles of a total of 164 stream miles were classified as good or presumed good.

Potential contaminant sources from unsewered rural communities in proximity to stream courses, especially along stream segments where fecal coliform concentrations were below 2,000 col/100 mL, are indicated on plate 1. Coliform bacteria in samples collected downstream of unsewered rural communities may be adversely affected by household waste-water discharges, rendering them incapable of growth and colony formation (American Public Health Association, 1998). Hence, riparian zones possibly contaminated by household waste-water discharges were identified along 38 stream miles using 1994 aerial photographs. Stream segments delimited as riparian zones on plate 1 can be affected by "gray-water" discharges and septic tank effluent from housing communities bordering the riparian zones of streams or from relatively dense housing developments (generally, with one or more housing units per 1/5th-acre lot) that are located within 300 ft of the stream courses. The adequacy of the 300-ft setback distance between houses with septic tanks and stream courses is unknown. In determining an adequate setback distance, factors to consider include rainfall infiltration and runoff, recharge, hydrogeology, housing density, and soil percolation rates typically used in designing septic tank systems. The 300-ft distance, however, can be used as an initial estimate to delimit potential sources of contamination to streams from unsewered communities, because research indicates that viruses can move as far as 215 ft from a septic tank in sandy soils (Vaughn and others, 1983) and persist up to 131 days in ground water (Stramer, 1984).

Table 8. Total stream miles classified as to their sanitary water quality on the basis of bacteriological analysis determined for sampling stations at selected streams in the municipio of Mayagüez, Puerto Rico.

[G, good; PG, presumed good; A, acceptable; PA, presumed acceptable; F, fair; PF, presumed fair; P, poor; PP, presumed poor; SMR, stream miles ranked; SMNR, stream miles not ranked; TSM, total stream miles; --, not applicable]

Stream name	Classification										
	G	PG	A	PA	F	PF	P	PP	SMR	SMNR	TSM
					Streams in the Río Guanajibo Basin						
Río Maricao	--	--	1.52	2.95	--	--	--	--	4.47	--	4.47
Río Rosario	--	--	6.95	11.71	--	--	--	--	18.66	--	18.66
Río Hondo	--	--	3.57	5.82	--	--	--	--	9.39	--	9.39
Quebrada Maga	--	--	--	--	--	--	--	--	--	5.94	5.94
					Streams in the Quebrada Sábalos Basin						
Quebrada Guifén	--	--	--	--	--	--	0.61	1.20	1.81	--	1.81
Quebrada Grande	--	--	1.67	7.83	--	--	--	--	9.50	--	9.50
Quebrada Pulida	--	--	--	--	--	--	--	--		1.73	1.73
Quebrada Sábalos	--	--	--	--	--	--	--	--	--	1.65	1.65
Caño Majagual	--	--	--	--	--	--	--	2.22	2.22	--	2.22
Caño Merle									undetermined	undetermined	undetermined
					Streams in the Caño Corazones Basin						
Caño Corazones									undetermined	undetermined	undetermined
					Streams in the Río Yagüez Basin						
Quebrada Gandel	--	--	3.16	3.71	--	--	--	--	6.87	--	6.87
Quebrada Caricosa	--	--	4.94	3.38	--	--	--	--	8.32	--	8.32
Río Yagüez	4.58	4.05	4.55	12.13	--	--	1.66	1.06	28.03	--	28.03
					Streams in the Quebrada del Oro Basin						
Quebrada del Oro	--	--	--	--	--	--	2.37	5.96	8.33	--	8.33
					Streams in the Caño Boquilla Basin						
Caño Boquilla	--	5.02	--	--	--	--	2.53	7.04	14.59	--	14.59
					Streams in the Río Grande de Añasco Basin						
Río Casey	--	--	1.20	3.82	--	--	--	--	5.02	--	5.02
Quebrada Cojolla	--	--	--	--	--	--	1.25	1.27	2.52	--	2.52
Quebrada Casanova	--	--	3.57	--	--	--	--	--	3.57	--	3.57
Río Cañas	--	--	14.61	20.98	--	--	--	--	35.59	--	35.59
Río Grande de Añasco	--	--	--	--	3.44	0.60	1.16	--	5.20	--	5.20
Station with same classification	1	3	20	3	2	--	6	2	37	--	37
Percent of total stations ranked	2.7	8.11	54.1	8.11	5.4	--	16.2	5.4	100	--	100
Stream miles with same classification	4.58	9.07	45.74	72.33	3.44	0.60	9.58	18.75	164.09	9.32	173.41
Percent of total stream miles ranked	2.79	5.53	27.87	44.08	2.10	0.37	5.84	11.43	100	--	--

Chapter C: Hydrogeologic Terranes and Ground-Water Resources in the Municipio of Mayagüez, Puerto Rico, 1999-2002

By Jesús Rodríguez-Martínez

Purpose and Scope

The U.S. Geological Survey, in cooperation with the municipio of Mayagüez, conducted an investigation of the ground-water resources in the area encompassed by the municipio from October 1, 1999, to September 30, 2002 (fig. 1). As part of this study effort, the municipio of Mayagüez was divided into five areas of similar homogeneous hydrogeologic characteristics, referred to in this report as hydrogeologic terranes. Geologic, topographic, soil, hydrogeologic, and streamflow data (obtained from field reconnaissance, topographic and geologic maps, or from other published reports) were used to delineate the different hydrogeologic terranes. The resulting information will be useful to the municipio of Mayagüez in developing its land and water resources in a sustainable manner.

The concept of hydrogeologic terrane was used by Berg and others (1997) to divide the State of Illinois into areas of similar hydrogeologic properties as part of a regional evaluation of ground-water and surface-water interactions. The municipio of Mayagüez was divided into five hydrogeologic terranes that are denoted by the acronym MayHT, followed by the numbers 1 through 5. For example, MayHT1 refers to Mayagüez hydrogeologic terrane number 1.

Methodology

Ground-water resources in the municipio of Mayagüez were differentiated into areas of similar hydrogeologic properties, referred to in this report as hydrogeologic terranes. Ground-water zones containing saline water were defined using water-quality and surface-geophysical data. Approximate ground-water flow rates in the interior uplands were obtained from analysis of flow duration data obtained as part of this assessment. A lineament-trace analysis also was conducted in the interior uplands to help locate subsurface fractures that may be potential zones of enhanced yields.

Hydrogeologic Terranes

The municipio of Mayagüez was divided into five hydrogeologic terranes based on the following factors, in decreasing order of importance: (a) type of geologic bedrock, (b) soil thickness and infiltration capacity, (c) ground-water flow rate, (d) general depth to ground water, and (e) land-surface slope. The geologic substratum and associated attributes, such as the presence of fractures, joints, and stratification, were determined from USGS geologic maps and lineament-trace analysis conducted as part of this study (Sanders and others, 1997). Soil thickness and infiltration capacity were obtained from soil maps published by the Soil Conservation Service (U.S. Department of Agriculture, 1975). The ground-water flow rate was estimated by using stream base-flow measurements and calculating flow duration statistics at the 98^{th} (Q-98) and 90^{th} (Q-90) percentiles (streamflows equaled or exceeded 98 and 90 percent of the time, respectively). The general depth to ground water was estimated from data available in USGS databases and from actual measurements made during this study. The land-surface slope was obtained by computer processing a digitized topographic map of Mayagüez using the ARC/INFO GRID System. Information on the subsurface geology of the hydrogeologic terranes was obtained by examining lithologic logs available from the USGS, independent water-well drillers' records, and by using surface geophysics methods. An inventory of commercial, industrial, and public supply wells and springs in the municipio of Mayagüez was conducted as part of the study (table 9). Well hydraulic data were obtained from the USGS records and from outside sources, such as water-well drillers, to help characterize the water-bearing potential of the various hydrogeologic terranes. Water-level data were collected from selected wells to determine seasonal variations in ground-water levels in the hydrogeologic terranes.

Table 9. Wells and springs in the municipio of Mayagüez, Puerto Rico, that are included in this study.

[Locations of wells and springs are shown on plate 2. Site identification numbers are unique numbers based on the latitude and longitude of the site. Latitude and longitude are given in degrees, minutes, and seconds. First eight digits are latitude, next eight digits are longitude. CROEM, Centro Residencial de Oportunidades Educativas de Mayagüez; Ab, abandoned; UPR-RUM, Universidad de Puerto Rico-Recinto Universitario de Mayagüez; ---, data not available; NA, non applicable]

Well or spring map number	Well or spring name	Site identification number	Depth, in feet below land surface	Water level, in feet below land surface	Dissolved solids, in milligrams per liter (value obtained during this study)
1	Pozo Bristol-Myers	180938/670918	---	6.6	412
2	Pozo Colón	181015/670938	75	7.8	---
3	Pozo Rochelaise (Ab)	181018/670917	100	---	---
4	Pozo Sultanita	181037/670843	300	13.3	---
5	Pozo Río Hondo	181020/670726	90	13	468
6	Pozo Quebrada Grande	181232/670835	125	6.4	423
7	Pozo Cervecería India	181015/670938	75	7.8	---
8	Pozo UPR-RUM 1	181241/670826	---	---	---
9	Pozo UPR-RUM 2	181307/670852	105	24.6	---
10	Pozo Mayagüez Resort	181317/670914	---	86.2	485
11	Pozo Zoológico	181314/670758	---	29.1	233
12	Pozo Cesaní	181501/670959	---	0	---
13	Pozo Alturas de Mayagüez	181414/670913	--	38.9	---
14	Pozo Santa Rosa de Lima	181538/671030	25	4.1	---
15	Pozo Eli Lily 1	181604/670927	---	---	404
16	Pozo Eli Lily 2	181602/670927	---	---	---
17	Pozo Barrio Malezas	181017/670642	---	---	---
18	Pozo Hospital Bella Vista	181118/670707	263	74.4	222
19	Pozo Rosario 1	180935/670508	---	---	---
20	Pozo Rosario 3	180934/670505	---	---	---
21	Santana Spring	181114/670647	NA	NA	---
22	Pozo CROEM	181015/670517	400	107.2	---
23	Pozo Marini 1	181249/670528	---	---	290
24	Pozo Marini 2	181337/670531	---	---	189
25	Marini 3 Spring	181322/670523	NA	NA	---
26	Marini 1 Spring	181330/670515	NA	NA	---
27	Pozo Bateyes	181220/670427	400	---	---
28	Marini 2 Spring	181307/670459	NA	NA	
29	Pozo Pilones	181118/670227	---	---	---
30	José Rodríguez Spring	181401/670319	NA	NA	132
31	Pozo Las Vegas	181117/670204	300	15	---
32	Pozo Consumo	181248/670152	---	---	---

Ground-Water Quality

Ground water in the municipio of Mayagüez was analyzed for common dissolved chemical constituents that can be related to local hydrogeologic conditions (table 10). Samples were collected from a selected subset of wells and springs in the study area representative of hydrogeologic terranes. Similarly, a subset of the inventoried wells, springs and surface-water data collection sites were sampled for analyses of nutrient concentrations (table 11).

Delineation of Coastal Saline Ground-Water Zone

Electrical resistivity measurements of subsurface earth materials combined with analysis of water samples collected from selected wells were used to delineate the coastal saline ground-water zone and shallow features, such as alluvial channel deposits in the coastal zone of the municipio. Schlumberger-array soundings were conducted to determine the presence of saltwater in the subsurface (Patra and Nath, 1999). According to previous studies (Patra and Nath, 1999), resistivity values less than 12 ohm-meters, obtained by the Schlumberger soundings, may indicate the presence of brackish or saline water. Similarly, chloride concentrations exceeding 250 milligrams per liter (mg/L) in water samples collected from wells in the coastal zone were considered as indicators of brackish or saline waters. To further define the potential of saltwater intrusion in the coastal areas of the municipio of Mayagüez resulting from ground-water withdrawals, the inland extent of the saltwater wedge was determined along the main coastal streams and creeks during low-tide and low-flow conditions (see Chapter A). Specific conductance measurements were collected between March 5 and 8, 2001, to define the inland extent of the saltwater wedges. A specific conductance value of 30,000 microsiemens per centimeter (μS/cm) was used as an indicator of the presence of marine saltwater within the stream channels.

Lineament-Trace Analysis

Lineament-trace analysis may be used to identify linear topographic features such as drainages, geologic contacts, and subtle tonal differences in soil color. Identification of these features may serve to aid in locating subsurface fractures that are potential zones of enhanced ground-water flow common within bedrock of low permeability (Lattman, 1958). Investigators have shown that zones of relatively high transmissivity may occur at the intersection of fractures (Lattman, 1958). Consequently, when selecting potential sites for wells, preference often is given to areas with a high density of lineaments or lineament intersections, which may indicate the presence of fracture intersections in the subsurface. Using this approach can reduce drilling costs associated with the trial-and-error method often used in well site selection. As part of this study, lineaments were identified by two independent observers from analysis of 1:20,000-scale aerial photography. Lineaments recognized by both observers are considered to have the highest hydrologic importance (Sanders and others, 1997). Lineaments identified from analysis of aerial photos were subsequently evaluated in the field.

Base-Flow Measurements

Stream base-flow measurements approximate the rate of ground-water flow in the corresponding drainage basin and can be used to infer the ground-water development potential of a particular area (Berg and others, 1997; Farvolden and Nunan, 1970; Ineson and Downing, 1964). This equivalence or low-flow approximation of ground-water flow rates assumes that (a) the ground-water discharge into the stream and tributaries is restricted to the aquifer(s) in the corresponding drainage basin, and (b) the contributing ground-water catchment(s) area does not vary seasonally and extend into an adjacent drainage basin(s) as a result of fluctuating ground-water levels. Base-flow measurements were made in the study area at stream junctions and, where possible, at locations along stream reaches that coincided with the boundaries of different rock units delineated on 1:20,000-scale geologic quadrangles. This discharge-measurement strategy provides the low-flow discharge values required to calculate the contribution of ground-water flow from the contributing area of a basin between a set of measurement points. The measured low-flow values were normalized by dividing the discharge rate (measured in cubic feet per second and converted into gallons per day) by the contributing drainage basin area (expressed in square miles) to remove the effect of increasing drainage basin area, and thus, low-flow values are expressed as gallons per day per square mile and in the equivalent effective recharge unit of in/yr. The Q-98 flow rate (streamflow rate that is equaled or exceeded 98 percent of the time) is an indicator of ground-water flow discharge into a stream under low base-flow conditions, and consequently an approximation of the ground-water flow in the contributing area of the corresponding drainage basin (Pérez-Blair, 1997). Berg and others (1997) used the Q-90 flow rate (streamflow rate that is equaled or exceeded 90 percent of the time) determined from 30 years of streamflow data for their regional evaluation of ground-water and surface-water interactions in Illinois. For this study, the range of streamflow between the Q-90 and Q-98 flows was used to approximate the ground-water flow in the aquifer(s) in the contributing area of the corresponding drainage basin. The Q-90 and Q-98 flows were obtained using a graphical correlation method (L. Santiago-Rivera, U.S. Geological Survey, written commun., 1999). In this method, low-flow discharge measurements at partial-record gaging stations are related to concurrent low-flow discharge measurements or daily mean-flows at nearby continuous-record gaging stations referred to as index stations. The Q-90 and Q-98 flows at the partial-record gaging stations then are determined through correlation using the corresponding values at the continuous-record gaging stations.

Table 10. Summary of results from chemical analyses of water samples collected from selected wells in the municipio of Mayagüez, Puerto Rico.

[Concentrations are given in milligrams per liter unless otherwise noted. µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; Ca, Calcium; Mg, magnesium; Na, sodium; K, potassium; Cl, chloride; SO_4, sulfate; F, fluoride; SiO_2, silica; Fe, iron; Mn, manganese]

Well name and identification number as shown on plate 2	Date of sample collec-tion	Latitude longitude	Specific conduc-tance (µS/cm)	pH	Total hard-ness (as $CaCO_3$)	Dissolved constituents											Hydro-geologic terrane
						Ca	Mg	Na	K	Cl	SO_4	F	SiO_2	Fe (µg/L)	Mn (µg/L)	Total dis-solved solids (sum of constitu-ents)	
1. Pozo Bristol-Myers	12/04/00	18°09'38" 67°09'18"	664	7.8	282	61	33	40	1.3	36	23.4	0.1	49	75	111	412	MayHT1
5. Pozo Río Hondo	12/04/00	18°10'20" 67°07'26"	857	7.5	306	90	44	26	1.0	41	23.4	0.2	58	27	3	468	MayHT5
7. Pozo Cervecería India	12/05/00	18°12'32" 67°08'35"	740	7.7	255	69	29	37	1.9	75	19	0.1	40	308	526	423	MayHT1
10. Pozo Mayagüez Resort	12/04/00	18°13'17" 67°09'14"	851	7.3	200	86.7	15	62	1.9	142	18.1	0.2	40	11	14	485	MayHT3
11. Pozo Zoológico	12/05/00	18°13'13" 67°0758	371	6.7	148	43.9	11	17	1.5	13	7.5	0.1	50	10	3.2	233	MayHT3
15. Pozo Eli Lily 1	12/04/00	18°16'04" 67°09'27	742	7.8	216	72	20	46	2.3	97	4.8	0.2	31	76	526	404	MayHT1
18. Pozo Hospital Bella Vista	12/05/00	18°11'18" 67°07'07"	431	7.9	178	8	43	15	1.1	18	9.9	0.2	20	10	3	222	MayHT4
23. Pozo Marini 1	12/06/00	18°12'49" 67°05'28"	469	7.6	220	75	7	12	1.0	12	6.5	0.2	44	10	3.2	290	MayHT2
24. Pozo Marini 2	12/06/00	18°13'37" 67°05'31"	286	7.4	130	37	8	9	1.2	7	3.2	0.2	45	10	3.2	189	MayHT2
30. José Rodríguez Spring	12/05/00	18°14'01" 67°03'19"	132	7.1	49	10	5	8	1.2	6	1.1	0.2	48	10	3	132	MayHT2

Table 11. Nutrient concentrations in water samples collected from selected wells, springs, and surface-water sites in the municipio of Mayagüez, Puerto Rico.

[Concentrations are given in milligrams per liter unless otherwise noted. <; less than; N, nitrogen; NH^3, ammonia; NO^3, nitrate; P, phosphorus; NA, not applicable]

Name and identification number of well[1], spring, and surface-water site[2]	Date of sample collection	Latitude longitude[3]	Surface-water site identification number	Nitrogen, ammonia plus organic, total (as N)	Nitrogen, as NO^3, total (as N)	Nitrogen, as NH^3, total (as N)	Phosphorus, total (as P)
Pozo Marini 1 (23)[4]	12/06/00	18°12'49" 67°05'28"	NA	0.2	6.1	0.03	0.03
Pozo Marini 2 (24)[4]	12/06/00	18°13'37" 67°05'31"	NA	<0.2	6.1	0.01	0.03
Pozo Colón (2)[4]	07/10/01	18°10'15 67°09'38	NA	0.35	2.6	0.12	1.2
Tributario Quebrada Gandel [2] (shown in plate 1)	12/06/00	181248 670529	50138760	<0.2	6.3	0.02	<0.02
Pozo Hospital Bella Vista (18)[4]	12/05/00	18°11'18" 67°07'07"	NA	<0.2	19	0.15	<0.02
Pozo Hospital Bella Vista (18)[4]	07/10/01	18°11'18" 67°07'07"	NA	0.2	4.7	0.01	0.02
Pozo Santa Rosa de Lima (14)[4]	07/10/01	18°15'38" 67°10'30"	NA	0.98	1.03	0.2	0.21
Pozo Cesaní (12)[4]	07/10/21	18°15'03" 67°09'58"	NA	1.6	0.02	1.7	0.05
José Rodríguez Spring (30)[4]	12/05/00	18°14'00" 67°03'18"	NA	<0.2	2.1	0.03	0.08

[1] Locations of wells and springs are shown on plate 2.

[2] Locations of surface-water sites are shown on plate 1.

[3] Datum for latitude and longitude is North American Datum (NAD) 1927.

[4] Number shown in parenthesis is well or spring map number as shown on plate 2.

By calculating the Q-98 and Q-90 flows for various drainage subbasins, as shown in table 12, a reasonable approximation of the ground-water flow rate was obtained for parts of selected basins within the hydrogeologic terranes contained within the municipio of Mayagüez.

The base-flow measurements to determine the Q-90 and Q-98 flows were corrected for stream diversions, waste-water treatment plant discharge, and streamflow capture caused by withdrawals from wells or springs. Low-flow stream contributions from basins outside the municipio of Mayagüez were not considered in the analysis. The fractions of the low flow resulting from direct ground-water discharge originating outside the municipio of Mayagüez and regional ground-water inflow are poorly understood and defined. Local ground-water flow systems are assumed to predominate, particularly in the volcanic uplands, given the dominant occurrence of water-bearing units having limited extent and low permeability that are deeply incised by draining streams. Some hydrogeologic terranes extend beyond the boundaries of the study area, but discussion of these is limited to areas within the municipio of Mayagüez.

The effect of vegetative cover on low flows in tropical settings is complex and not well understood (Bruijnzeel, 1990). Studies conducted in tropical forests around the world have produced contradictory results as to the effects of plant cover removal on changes in the low-flow characteristics at downstream locations (Bruijnzeel, 1990). In general, results obtained by the USGS in similar water assessments conducted in other municipios of Puerto Rico indicate a directly proportional relation between well-developed forest cover and enhanced low flows, particularly in the headwaters of rivers where topographic slope generally exceeds 30 degrees

(Gómez-Gómez and others, 2001). Although the geologic substrate may be a significant contributing factor, it is reasonable to assume that the intercepting capacity of the tree canopy, in conjunction with the presence of a series of other storage compartments of variable thickness, play an important role in the enhancement of low flows in these highland areas. These storage compartments include a litter layer (fallen plant debris), a root penetration zone, a soil zone, a saprolite layer, a "young" weathered-rock zone, and a fractured bedrock zone. Locally, some of these storage compartments may be absent. The rainfall infiltration held in these storage compartments is then discharged, at varying time scales, to the streams and is an important source of streamflow particularly during the low rainfall season.

Variability in measured stream flow and estimated ground-water flow rates within similar hydrogeologic terranes may be the result of differences in land cover and evapotranspiration rates that result from differences in vegetation. Removal of forest cover by land-use conversion for agricultural purposes often results in a reduction of low-flow stream discharge. Ramos-Ginés (1997) reports low-flow stream discharge in a drainage basin in Cidra, a municipio in central Puerto Rico, may have decreased from 6 to 2 in/yr as a result of conversion of secondary-growth forest into an agricultural area. Low flows in a specific drainage basin reflect prevailing precipitation patterns and the resulting recharge in the basin. Accordingly, the ground-water flow or its equivalent low flow in any drainage basin will vary in direct response to changes in precipitation patterns and subsequent recharge.

Base-flow measurements were made during this study and normalized for drainage subbasins of variable size. Despite normalization on a unit area basis to allow comparison of different hydrogeologic terranes, drainage basin size has an effect on the low-flow discharge rate. For example, as the basin size increases, the hydrologic and geologic factors that influence transmissivity and storage such as porosity, fractures and joint patterns, bedding planes, thickness of the weathered bedrock zone, precipitation, and evapotranspiration become increasingly non-uniform. In addition, land cover may vary within the basin. This lack of uniformity contributes to irregular low-flow discharges across the basin. Accordingly, measured low-flow discharge alone cannot be used to completely evaluate spatial variations of ground-water flow in the aquifer(s) contained within the basin. This after-normalization effect has been referred to as the "residual effect" (Farvolden and Nunan, 1970). The residual effect seems to be more apparent in basins encompassing tens to hundreds of square miles. Therefore, the residual effect is considered to be of limited concern in this investigation, because none of the drainage basins evaluated exceed 10 mi^2. A more thorough multivariate statistical analysis including other variables such as channel slope, relief ratio, and drainage density would better define the empirical relations between the different geologic and hydrologic variables at the basin scale used in this assessment. However, collection and analysis of these data and the development of a multivariate statistical analysis was beyond the scope of this study.

Table 12. Hydrogeologic features of selected subbasins in the municipio of Mayagüez, Puerto Rico.

[gal/d/mi^2, gallons per day per square mile; in/yr, inches per year; MayHT, Mayagüez hydrogeologic terrane; <, less than; *, extends beyond the boundaries of the municipio of Mayagüez; Bo., Barrio; Q-98, streamflow equaled or exceeded 98 percent of the time; Q-90, streamflow equaled or exceeded 90 percent of the time]

Subbasin identification number and name[1]	Approximate normalized Q-90 ground-water flow (gal/d/mi^2)	Q-90 effective recharge (in/yr)	Approximated normalized Q-98 ground-water flow (gal/d/mi^2)	Q-98 effective recharge (in/yr)	Hydrogeologic terrane(s) contained within the drainage basin, in order of areal extent
1. Portion of Río Rosario watershed in Bo. Rosario and Limón*	350,000	7.4	175,000	3.7	MayHT2 MayHT5 MayHT4
2. Upper portion of Río Rosario watershed in Bo. Limón *	443,000	9.3	279,000	5.9	MayHT2 MayHT5
3. Upper portion of Río Hondo watershed in Bo. Malezas	121,000	2.5	40,000	1.0	MayHT5 MayHT3
4. Lower portion of Río Hondo watershed in Bo. Río Hondo	<10	<0.1	<10	<0.1	MayHT5 MayHT3

Table 12. Hydrogeologic features of selected subbasins in the municipio of Mayagüez, Puerto Rico.—Continued

Subbasin identification number and name[1]	Approximate normalized Q-90 ground-water flow (gal/d/mi^2)	Q-90 effective recharge (in/yr)	Approximated normalized Q-98 ground-water flow (gal/d/mi^2)	Q-98 effective recharge (in/yr)	Hydrogeologic terrane(s) contained within the drainage basin, in order of areal extent
5. Upper portion of Quebrada Grande watershed in Bo. Quebrada Grande	270,000	5.6	90,000	1.9	MayHT4 MayHT5 MayHT3
6. Lower portion of Quebrada Grande watershed in Bo. Quebrada Grande	300,000	6.3	103,000	2.1	MayHT4 MayHT5 MayHT3
7. Upper portion of Río Yagüez watershed in Bo. Montoso	617,000	13	411,000	8.6	MayHT2
8. Upper portion of Río Yagüez watershed in Bo. Naranjales	648,000	13.7	431,000	9.1	MayHT2
9. Portion of Río Yagüez watershed above dam in Bo. Bateyes	402,000	8.5	232,000	4.9	MayHT2
10. Lower portion of Quebrada Gandel watershed in Bo. Quemado	283,000	6.0	141,000	3.0	MayHT2 MayHT3
11. Portion of Río Yagüez watershed in Bo. Quemado and Bo. Juan Alonso	421,000	9.0	249,000	5.3	MayHT2 MayHT3
12. Upper portion of Quebrada Caricosa watershed in Bo. Juan Alonso	---	<1	---	<1	MayHT5 MayHT4
13. Middle portion of Quebrada Caricosa watershed in Bo. Juan Alonso	283,000	6	259,000	3	MayHT4 MayHT5 MayHT3
14. Watershed of tributary to Quebrada Caricosa in Bo. Juan Alonso	---	<1	---	<1	MayHT4
15. Lower portion of Quebrada Caricosa watershed in Bo. Mayagüez Arriba	175,000	3.7	---	<1	MayHT3 MayHT5
16. Upper portion of Quebrada del Oro watershed in Bo. Miradero	281,000	6.0	93,000	2.0	MayHT3
17. Lower portion of Quebrada del Oro in Bo. Miradero	486,000	10.2	324,000	7.0	MayHT3
18. Upper portion of Río Casey watershed in Bo. Río Cañas Arriba in the neighboring municipio of Las Marías*	645,000	13.6	433,000	9.2	MayHT2
19. Upper portion of Río Cañas watershed in Bo.Naranjales*	367,000	7.8	220,000	4.7	MayHT2
20. Middle portion of Río Cañas watershed in Bo. Río Cañas Arriba and Bo. Río Cañas Abajo	716,000	15.1	421,000	9.0	MayHT2

[1] Subbasin identification number shown as blue block numbers on plate 2.

Results and Interpretation

The municipio of Mayagüez can be differentiated into five hydrogeologic terranes, according to their hydrogeologic characteristics and ground-water development potential. In general, the concentration of dissolved constituents in ground water does not exceed 500 mg/L. The presence of saline ground water in the coastal portions of the municipio of Mayagüez may limit the ground-water development potential in these areas. A significant portion of the ground water withdrawn within the municipio of Mayagüez may be supplied by induced streamflow and not from the regional ground-water flow system. The highest ground-water development potential in the interior uplands can be expected to be in the vicinity of streams and in those areas where bedrock is fractured as indicated by the high density of lineament traces.

Hydrogeologic Terranes

The municipio of Mayagüez can be differentiated into five hydrogeologic terranes (MayHT). The areal extent of these terrains is shown on plate 2, and they are described in the following pages in descending order of ground-water resource development potential.

Mayagüez Hydrogeologic Terrane 1 (MayHT1)

The MayHT1 hydrogeologic terrane consists of an upper and lower zone. This hydrogeologic terrane is restricted to the lowlands, which includes the coastal areas and alluvial terraces along the rivers and creeks in the mountainous interior.

Upper Zone

The upper zone is composed mostly of Quaternary alluvium and to a lesser extent, Quaternary mangrove and swamp deposits. The soil cover thickness ranges from about 51 to 71 in. The infiltration capacity of the soil cover ranges from 0.06 to 2.0 in/hr. Locally, the infiltration rate may be as high as 20 in/hr. Wetland-type environments are irregularly present because of the low infiltration associated with the fine-grained texture of the surficial material, which results in transient ponding of rainfall. The alluvium of the upper zone is predominantly fine grained and is composed largely of silt and clay with minor amounts of sand. Minor deposits of gravel and sand are mostly restricted to what appear to be localized ancient river channels as indicated by surface apparent resistivity values exceeding 75 ohm-meters (figs. 5 and 6). The thickness of the upper zone generally is between 50 and 100 ft and thins towards outcrops of serpentinite and volcaniclastic rocks. The Quaternary-age alluvial terraces along the rivers and creeks in the mountainous interior generally are coarser grained than the equivalent deposits of the upper zone in the coastal portion of the municipio of Mayagüez.

Ground water in the upper zone occurs under water-table conditions. Ground-water level data indicate that depth to the water table generally is less than 10 ft below land surface (see Pozo Colón, Pozo Santa Rosa de Lima, and Pozo Cesaní in table 9). During the two annual relatively rainy seasons (May and August through November), ground-water levels in the upper zone may reach the ground surface in some areas (for example, Pozo Cesaní, table 9). The fluctuations in the potentiometric surface between the typically wet and dry seasons (generally between March and September) are minimal, generally less than 5 ft.

Potentiometric data collected by Díaz and Jordan (1987) in the Río Grande de Añasco Valley indicate that the regional ground-water flow in the southern part of the valley is towards the west with local flow components to the Río Grande de Añasco and Caño Boquilla. Ground-water development from the upper zone in this part of the study area has been minimal since the study by Díaz and Jordan (1987). Furthermore, the ground-water levels have remained essentially the same since the 1987 study. Thus, it is reasonable to assume that ground-water flow patterns in the upper zone within this portion of the study area have remained the same. Potentiometric data are sparse for the remaining southern portion of the MayHT1; however, a predominant westward movement of ground water toward the coast may occur with probable local flow components toward nearby streams and creeks.

Recharge to the upper zone is largely from precipitation, which is about 80 in. in the coastal areas, according to the National Oceanic and Atmospheric Administration (NOAA). The annual rainfall recorded by NOAA during 2001 at stations located in the city of Mayagüez and Mayagüez airfield (now named Eugenio María de Hostos Airport) during 2001were 80 and 121 in., respectively (U.S. Department of Commerce, 2002). Minor recharge may occur along the eastern edges of the MayHT1 hydrogeologic terrane through small alluvial fan-type deposits that are in contact with small streams. Minor fluctuations in water levels between the dry and wet seasons is indicative of the limited effective aquifer recharge. The relatively low infiltration rate of the surficial material, low topographic relief, and generally high water levels seem to be limiting factors to recharge. Evapotranspiration from the coastal mangrove swamps may account for a substantial loss of shallow ground water, particularly during the dry season.

Data on the hydraulic properties of the upper zone are sparse. Only a few wells are known to have been completed in this zone. However, lithologic information, production data obtained from the few wells known to produce from this zone, field reconnaissance in the form of direct current (DC) resistivity surveys, and examination of outcrops in the area indicate that the upper zone has low permeability, and with a few exceptions, is able to meet only minor water demands.

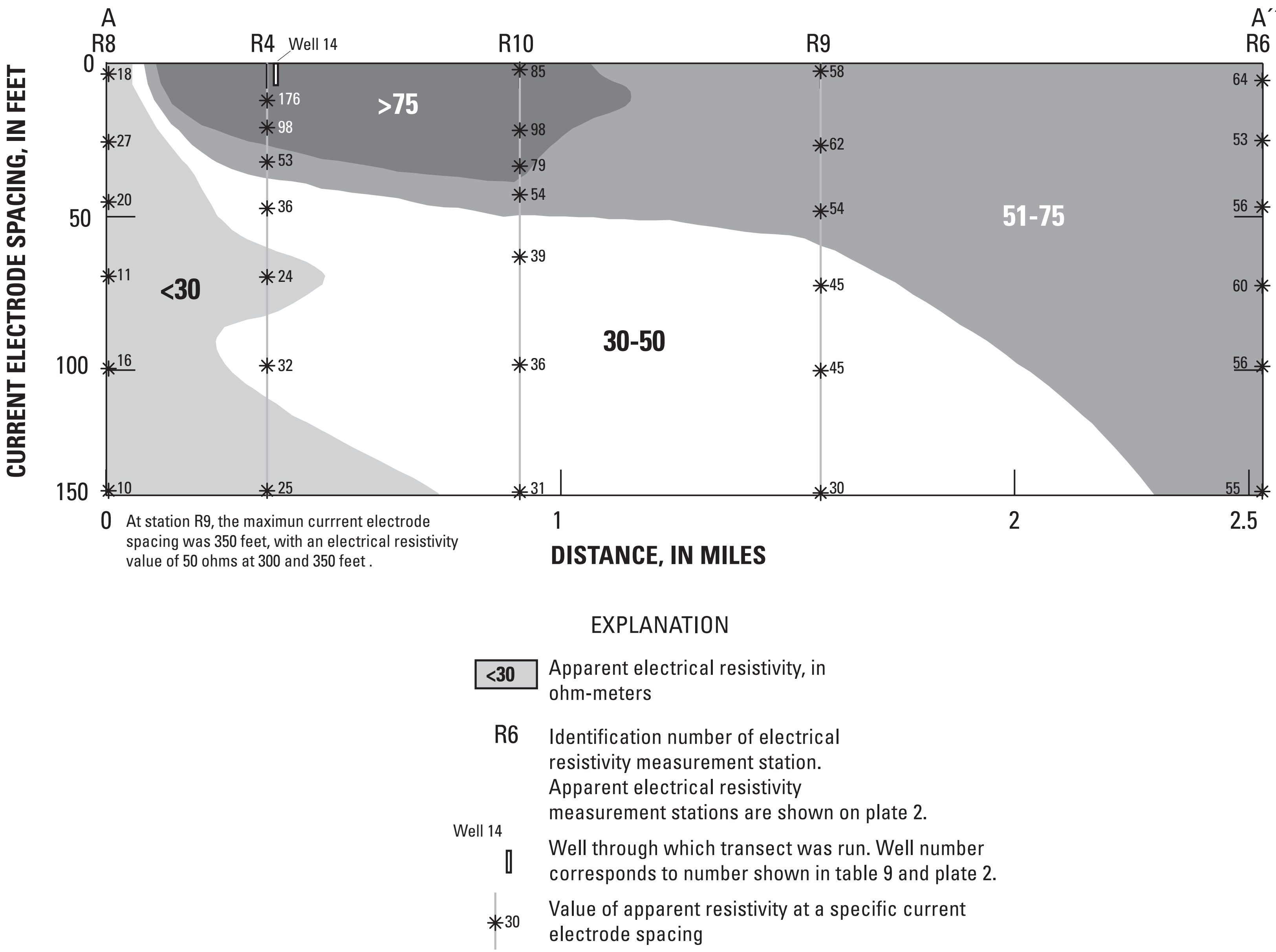

Figure 5. Changes in apparent surface electrical resistivity with current electrode spacing along section A-A".

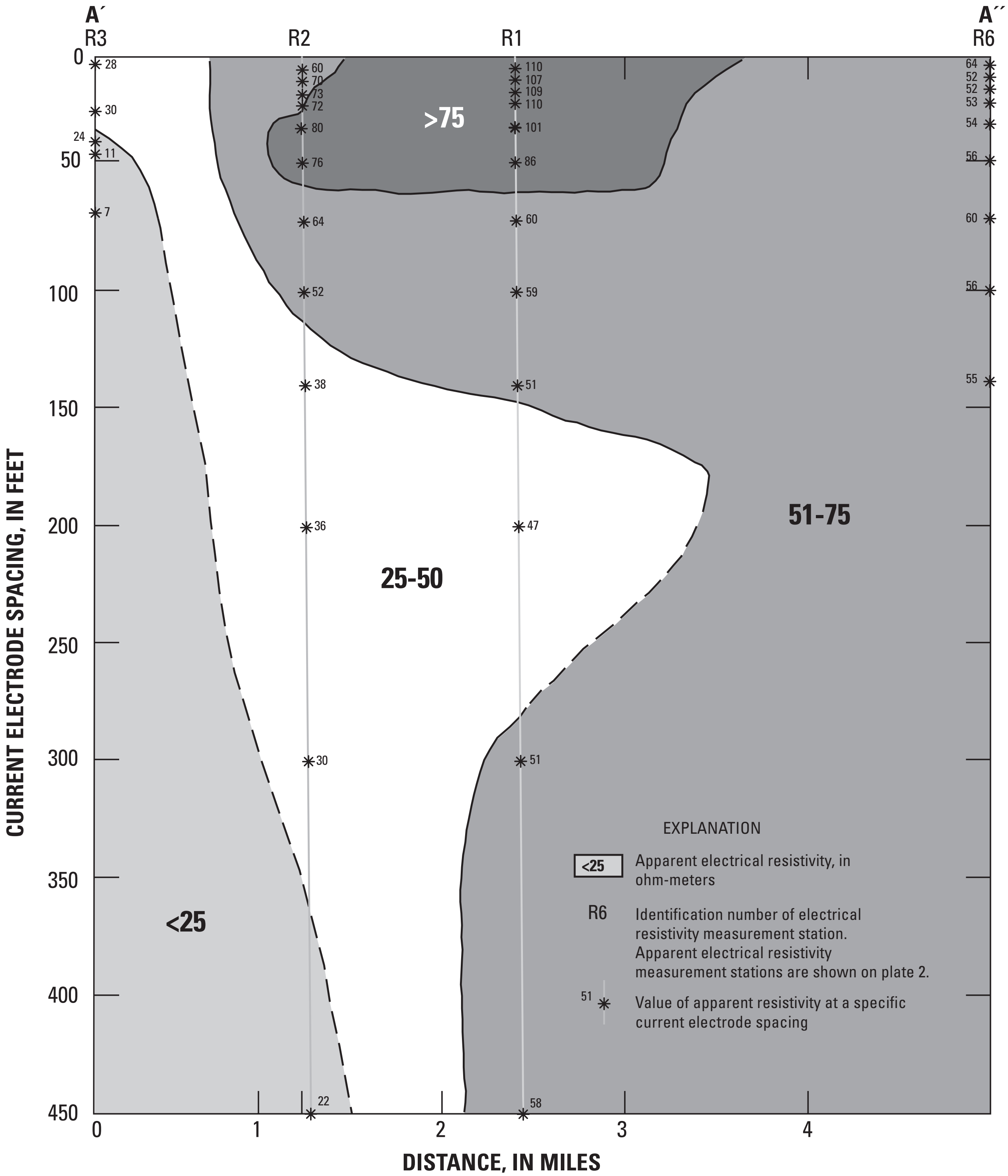

Figure 6. Changes in apparent electrical resistivity with current electrode spacing along section A´-A´´.

Moreover, the few wells completed in the upper zone are operated on only an intermittent basis, which is a general indicator of their limited potential. The high silt and clay content of the upper zone limits its ground-water development potential. The yields of wells completed in this water-bearing zone depend mainly on the amount of sand and gravel penetrated. Sand and gravel units of sufficient thickness are highly localized and are restricted mostly to the vicinity of present and ancient river-channel deposits. For example, wells completed in alluvial and terrace deposits adjoining rivers such as the Río Grande de Añasco, Río Cañas, Río Yagüez, and Río Guanajibo (plate 2) may sustain yields on the order of 100 gallons per minute (gal/min). Locally, the sustained yields of wells completed in these sand and gravel deposits hydraulically connected to perennial streams can exceed 200 gal/min, as evidenced by a 42-ft-deep public supply well screened within channel deposits of the Río Yagüez in 1949 in Barrio Mayagüez Arriba. During an aquifer test, this well had a drawdown of only 8 ft at a pumping rate of 450 gal/min (U.S. Geological Survey, unpub. data, 1962). After installation, the well was operated at a pumping rate of about 350 gal/min until its abandonment in 1957, about the time when the Miradero filtration plant started operations. Sustained yields of wells completed in former stream channels such as the ancient course of the Río Guanajibo, whose lower reach is presently the Caño Corazones (H. Santos, University of Puerto Rico at Mayagüez, oral commun., 2001) (plate 2), are expected to be less than those completed near present-day stream courses. In cases such as the ancient Río Guanajibo channel, where the alluvial sand and gravel deposits are not hydraulically connected with nearby streams, the yields to wells generally do not exceed 50 gal/min and may be sustained by induced leakage from the surrounding fine-grained material rather than by the limited storage of the sand and gravel units.

Water from shallow wells, generally not exceeding 30 ft in depth and completed in fine-grained material, in the upper zone of the MayHT1, usually is withdrawn using a manual pump or a low-power electric pump. For example, several shallow wells with yields ranging between 20 and 30 gal/min are pumped for a few hours a day before the water level drops substantially below land surface and pumping becomes unfeasible. Generally, several hours are required for water levels to recover to pre-pumping levels as a result of the low hydraulic conductivity of the fine-grained material. The ground-water development potential of the upper zone also decreases laterally toward the eastern edges of the MayHT1 hydrogeologic terrane, particularly towards the outcrops of the volcaniclastic rocks.

Lower Zone

The lower zone of the MayHT1 hydrogeologic terrane consists of pre-Quaternary fluvial and marine sandstones and Late Cretaceous and Early Tertiary-age volcaniclastics (sandstone, siltstone, claystone, and breccia) and limestones. The lower zone is underlain by Middle and Late Cretaceous-age serpentinite and intrusive igneous rocks (Curet, 1986).

The volcaniclastic and limestone rock, and minor fluvial and marine sandstones of the lower zone are presumed to be of limited aerial extent, discontinuous, and irregularly distributed (Curet, 1986). These volcaniclastics rock units are assumed to be the subsurface facies of the Sabana Grande Formation, the Yauco Formation, Maricao Formation, and Lago Formation (Curet, 1986). The exact range in thickness of these volcaniclastic, limestone, fluvial, and marine sandstone is unknown. The volcaniclastic rocks include sandstones, siltstones, claystones, breccias, and conglomerates. These rocks originated either from the deposition of volcanic-eruption materials directly to the sea or from erosion, transport, and final deposition of already existing volcanic rocks. The limestone units originate from intermittent and spatially irregular carbonate deposition in a sea basin otherwise dominated by volcaniclastic deposition (Curet, 1986).

Lithologic logs of wells indicate that the limestone units of the lower zone vary in vertical position, type of biotic and lithic components, and thickness. Multiple limestone units with up to 70 ft of combined thickness and separated by claystone-mudstone beds locally may be found while drilling into the lower zone. In some places, beds of gravel and sand are intercalated with the limestone units. An argillaceous matrix with silt and fine-grained quartzose sand is present in varying proportions within the limestone. Reefs and mollusk fragments are the most common biotic components in the limestone units.

A local variation of the regional lithologic character described above is the occurrence of limestone strata irregularly interbedded with arkosic sand and overlain by mudstone at the site of what is now the Clínica Dr. Perea in the Marina Meridional Ward in the city of Mayagüez (U.S. Geological Survey, unpub. data, 1965) (fig. 7, plate 2). The combined thickness of limestone and sand at this site, as indicated by the well log shown in figure 7, was about 60 ft. Lithologic logs of the now abandoned Sultanita Bakery well and one of the Cervecería India wells, drilled in the 1950's, about 0.2 mi northwest and southwest of Clínica Dr. Perea, respectively, indicate the presence of limestone, sandstone, and pebbly gravel (fig. 8, plate 2).

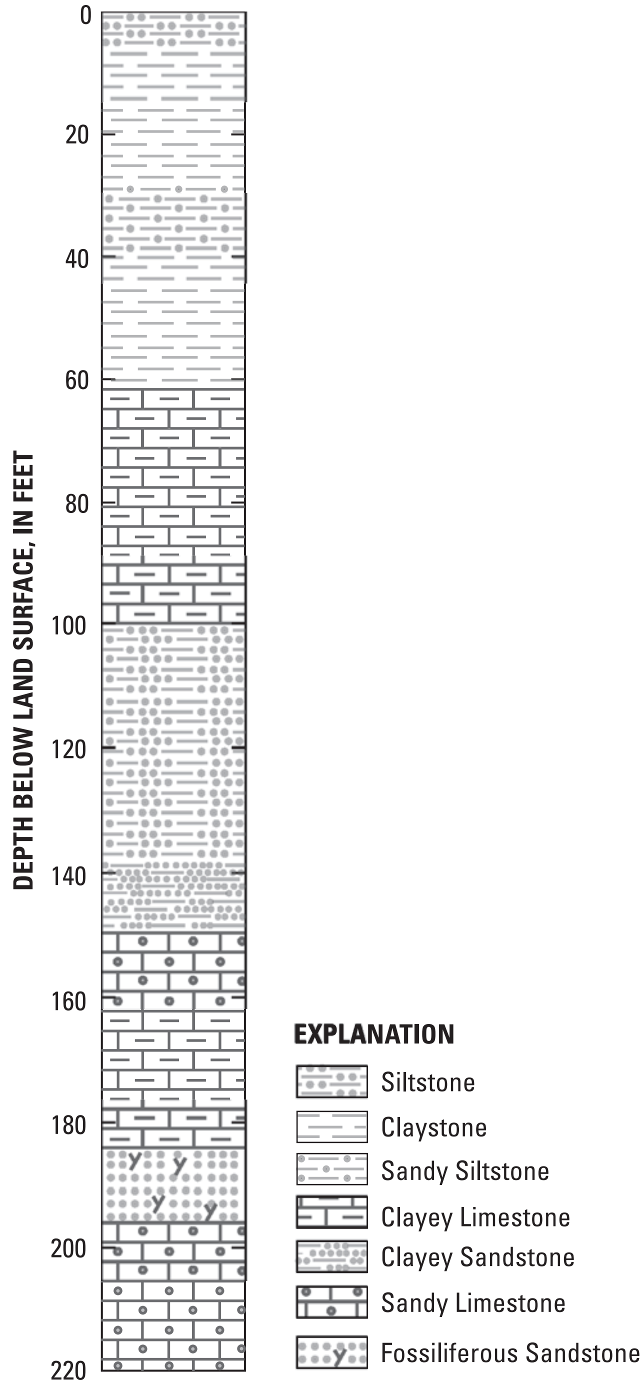

Figure 7. Lithologic log from the Clínica Dr. Perea well.

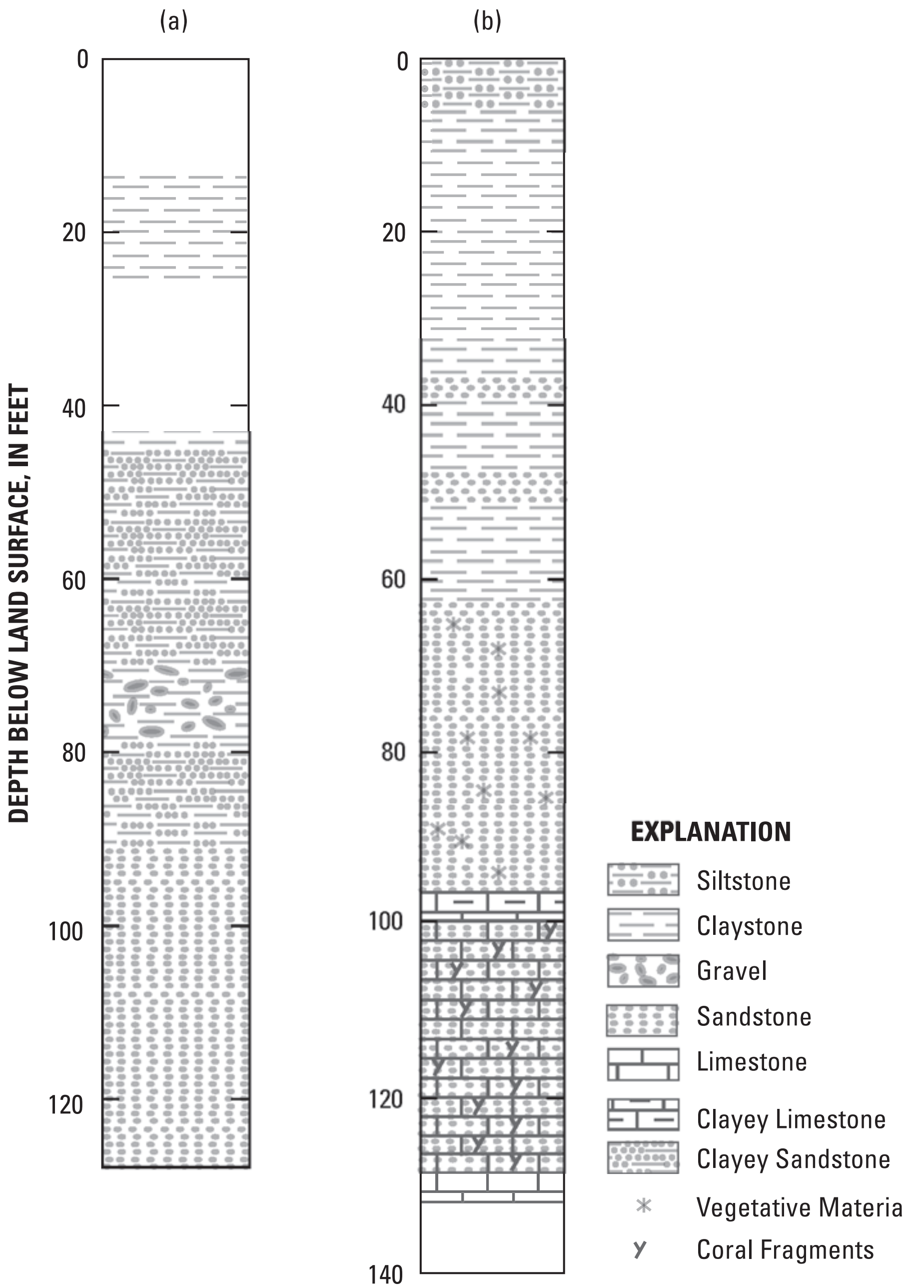

Figure 8. Lithologic log from (a) Pozo Cervecería India and (b) the Sultanita Bakery well.

The mode of occurrence of ground water in the lower zone is not well understood. Artesian heads near and above land surface exhibited in many wells can be attributed either to confined conditions or to an extremely high anisotropy of rock units in the lower zone. The irregular occurrence, both horizontally and vertically, of permeable and non-permeable lithologic units (volcaniclastic mudstones, sandstones, breccias, conglomerates, limestones, and minor fluvial and marine sandstones) account for the presence of confined or semiconfined ground-water conditions. Central Rochelaise, Cervecería India, Clínica Dr. Perea, Mayagüez airfield, and Central Igualdad (plate 2) are among several sites where ground water has been found under confined or semiconfined conditions. For example, the water level at the Central Rochelaise well in the Río Guanajibo Valley (a USGS observation well until 1985, shown as well 3 in plate 2) was measured between 3 ft below land surface to about 1 ft above land surface, suggesting artesian conditions. The lithologic logs of wells drilled and completed in the lower zone at these sites (now abandoned) indicate the presence of permeable limestone (except at the Central Rochelaise site) and subordinate sandstone overlain by volcanic claystone-mudstones (U.S. Geological Survey, unpub. data, 1982) (fig. 9). The overlying upper zone may be semiconfining the lower unit, particularly where the upper zone is thicker. Water-table conditions in the lower zone are expected to prevail toward the eastern edges of the MayHT1 hydrogeologic terrane, where the overlying fine-grained deposits thin out. As in the upper zone, annual fluctuations in ground-water levels in the lower zone are minimal, generally less than 10 ft. The ground-water flow pattern in the lower zone is complex as a result of the irregular presence of permeable and non-permeable units mentioned above. As in the upper zone, however, limited potentiometric data collected in the lower zone suggest a dominant regional westward movement of ground water.

The sources, amount, and mechanism(s) of recharge to the lower zone are not well known. The shallower, more permeable units (such as limestone strata) may be recharged from the overlying upper zone. However, in cases where the permeable units are separated from the overlying upper zone by impermeable units such as claystone or mudstone, recharge probably is minimal. Recharge to the lower zone also may occur from episodic flooding in the low-elevation coastal portion of the study area. Recharge to the lower zone, particularly along the eastern edges of the MayHT1 hydrogeologic terrane, may occur in the form of seepage from streams through the overlying alluvium of the upper zone. Indirect evidence of induced flow is provided by a well drilled in 1945 at the site of the former Central Igualdad, a sugarcane mill located near Río Grande de Añasco in the northwestern corner of the municipio of Mayagüez (plate 2). This well is reported to have been completed in limestone strata within the lower zone and to have yielded in excess of 800 gal/min during the sugar cane grinding season (generally January through March) (U.S. Geological Survey, unpub. data, 1956). On the basis of yields of other wells completed in the lower zone in the area, this relatively high sustained yield seems possible only if a source of water such as the Río Grande de Añasco is the source of water to the well. The limestone strata penetrated by this well could be in direct contact with the Río Grande de Añasco or separated from it by thin and permeable alluvium, thus favoring induced recharge.

Water levels from 1978 to 1982 were highest at the now discontinued Mayagüez airfield observation well (completed in the lower zone and about 1.5 mi southeast of Central Igualdad) 1 to 2 months after significant precipitation occurred in the area (Díaz and Jordan, 1987). The water-level response suggests that recharge to the lower zone in this well is not rapid and takes place at locations remote to the well. The water-bearing unit tapped in the Mayagüez airfield observation well is a limestone unit similar to that in which the Central Igualdad well was completed. In general, small differences in ground-water levels between the dry and wet seasons in the lower zone attest not only to the low rate of ground-water withdrawal that occurs throughout the year, but also to the low recharge rate in the lower zone.

For the purposes of this study, the lower zone is considered to be a heterogeneous aquifer containing multiple water-bearing units with varying hydraulic properties separated by confining and semiconfining strata. Lithologic data indicate that the water-bearing and the confining/semiconfining units are discontinuous and irregularly distributed both vertically and horizontally. However, neither their spatial distribution nor their spatial extent and thicknesses are well known. Hydraulic and well production data indicate that limestone strata are the most important water-bearing units in the lower zone. Fluvial and marine sandstones with subordinate gravels can be of local importance as aquifers. Volcanic sandstone and breccias are of minor importance as aquifers given their highly argillaceous and silty matrix, which severely limits their water storage and transmissive properties. Consequently, most volcaniclastic units in conjunction with associated claystone-mudstone strata act more as confining or semiconfining units. Unpublished data from the USGS (1982) indicate that wells completed in the volcaniclastic units of the lower zone (sandstone and breccias) have specific capacities that typically range between 1 and 2 gallons per minute per foot of drawdown (gal/min/ft). Sustainable yields of wells completed in the volcaniclastic units, as reported by well owners and from unpublished USGS data (1965), generally are less than 50 gal/min. The vast majority of wells have been abandoned. USGS data and information provided by residents and well owners in the study area indicate that the wells, when active, were used mostly as back-up systems, and thus, were usually pumped on a discontinuous basis generally to satisfy non-drinking water needs.

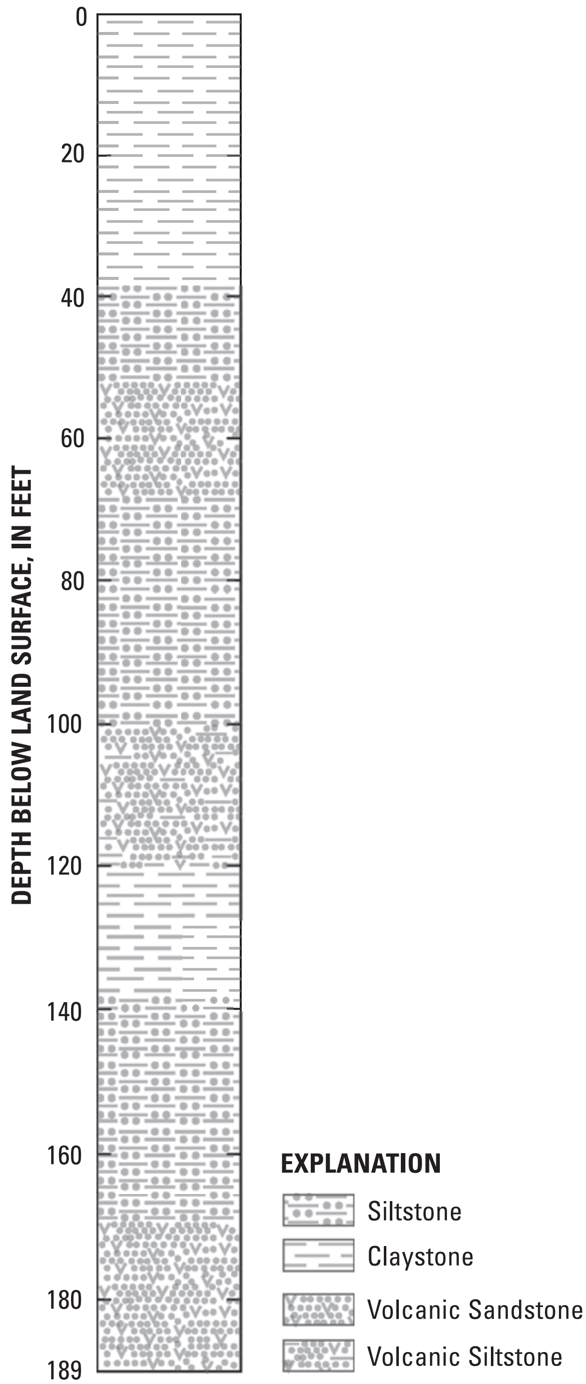

Figure 9. Lithologic log from Pozo Rochelaise.

A saltwater zone was delineated in the coastal portion of the hydrogeologic terrane MayHT1 (plate 2). The inland extension of this zone varies from a minimum of about 0.3 mi in Barrio Marina to a maximum of about 0.7 mi in Barrio Sabaneta. The narrowing of the saltwater zone in Barrio Guanajibo in the southern part of the study area (plate 2), determined from DC resistivity surveys, may result from shallow bedrock that acts as a barrier, restricting the inland movement of brackish or saltwater. In cross section B-B', a well-delineated zone of apparent resistivity values between 26-50 ohms-meters may indicate the presence of a freshwater lens in this area (fig. 10).

Mayagüez Hydrogeologic Terrane 2 (MayHT2)

The hydrogeologic terrane MayHT2 consists of volcaniclastic rocks intruded by intrusive igneous rocks in the Barrios of Río Cañas Abajo, Montoso, Bateyes, and Naranjales, located in the headwaters of the Río Cañas and Río Yagüez (plate 2). The volcaniclastic and intrusive rocks are Cretaceous and Tertiary in age (Curet, 1986). The volcaniclastic units in order of decreasing aerial extent are the Yauco Formation and the Maricao Formation (Curet, 1986). The Yauco Formation contains interbedded and calcareous volcaniclastic sandstone, siltstone, mudstone, claystone, limestone, and subordinate breccia and conglomerate. These units generally are thin- to medium-bedded and fine- to medium-grained. The Maricao Formation consists mostly of breccia with minor amounts of conglomerate, volcaniclastic sandstone, and limestone. The Yauco Formation and the Maricao Formation are intruded by diorite and basalt bodies of Tertiary and Cretaceous age. The intrusive bodies are grouped as discontinuous units mostly in two subsets oriented predominantly northwest and northeast. The presence of intrusive igneous rocks that, in turn, had been intruded indicates that at least two distinct episodes of intrusion occurred in this hydrogeologic terrane, particularly in the headwaters of Río Cañas and Río Yagüez (plate 2). This dual occurrence of intrusive activity may have caused numerous fractures, not only in the surrounding volcaniclastic rocks, but also in some of the intrusive igneous rocks. The relatively high number of intersected lineaments identified during this study might reflect the structural effect of these two distinct intrusive episodes (plate 2). Land slopes in this hydrogeologic terrane vary but most exceed 15 degrees. The soil-cover thickness also is variable but in most areas ranges between 22 and 60 in. The infiltration capacity of the soils ranges from 0.63 to 2.0 in/hr.

The ground-water flux in the MayHT2 hydrogeologic terrane was estimated from the Q-90 and Q-98 flow-duration statistics calculated in selected basins or subbasins lying completely or mostly within this hydrogeologic terrane. The estimates range from 220,000 to 716,000 gal/min/mi^2, equivalent to an effective recharge of 4.7 to 15.1 in/yr (table 12). This high ground-water flow and equivalent effective recharge rate might be explained by the pervasive presence of fracture intersections and a thick weathered zone that are strongly indicated by the presence of intercepted lineaments (plate 2). Locally, fractures may enhance the development of thick weathered layers. The combination of fractures, particularly fracture intersections, and overlying thick layers of weathered material apparently have increased both the transmissivity and storage capacity in the MayHT2. An annual average precipitation of about 100 in. (U.S. Department of Commerce, 2002) in conjunction with a well-developed forest cover overlying the thick weathered and fractured zones may substantially enhance the overall storage capacity of the MayHT2 (Bruijnzeel, 1990).

The areas in the MayHT2 with a high density of lineament intersections (and consequently presumed fracture intersections) and intrusive bodies in the headwaters of Río Cañas and Río Yagüez can be conceptualized as a series of ground-water reservoirs within the volcaniclastic rock and fractured intrusive igneous rock that are semi-compartmentalized by much less permeable, either unfractured or less fractured intrusive rocks. The presence of Marini 1, Marini 2, and Marini 3 springs (table 9, plate 2) may be the result of permeability contrasts between the intrusive and volcaniclastic rocks. A similar occurrence of ground water has been documented in the Hawaiian Island of Oahu (Fetter, 1994). The apparently enhanced water storage and transmissive properties resulting from the factors mentioned above essentially have contributed to sustain and maintain relatively high base flows in streams within the hydrogeologic terrane, particularly in the headwaters of Río Cañas and Río Yagüez, as indicated in table 12.

Mayagüez Hydrogeologic Terrane 3 (MayHT3)

As in MayHT2, the hydrogeologic terrane MayHT3 consists primarily of the Yauco Formation, subordinate amounts of the Maricao Formation, and minor intrusive igneous rocks of basaltic and dioritic composition (Curet, 1986). The subsurface units in the MayHT3 hydrogeologic terrane are similar in lithologic composition to those in the MayHT2 but with considerably less apparent structural dislocation as evidenced by less lineament traces and apparent faulting. The geologic units present in the MayHT3 are the outcrop equivalents of those units present in the lower zone of the MayHT1 hydrogeologic terrane. The land slopes in the MayHT3 also are variable, but the portion with slopes equal to or less than 15 degrees is higher than in MayHT2. The soil thickness ranges from 10 to 60 in. The soil infiltration capacity ranges from 0.63 to 2.0 in/hr. The MayHT3 hydrogeologic terrane predominantly occupies the middle and lower reaches of Río Cañas and Río Yagüez (plate 2). The MayHT2 and MayHT3 hydrogeologic terranes are continuous and separated by a poorly defined transitional zone, mainly in the Barrios of Leguísamo, Río Cañas Abajo, and Quemado (plate 2).

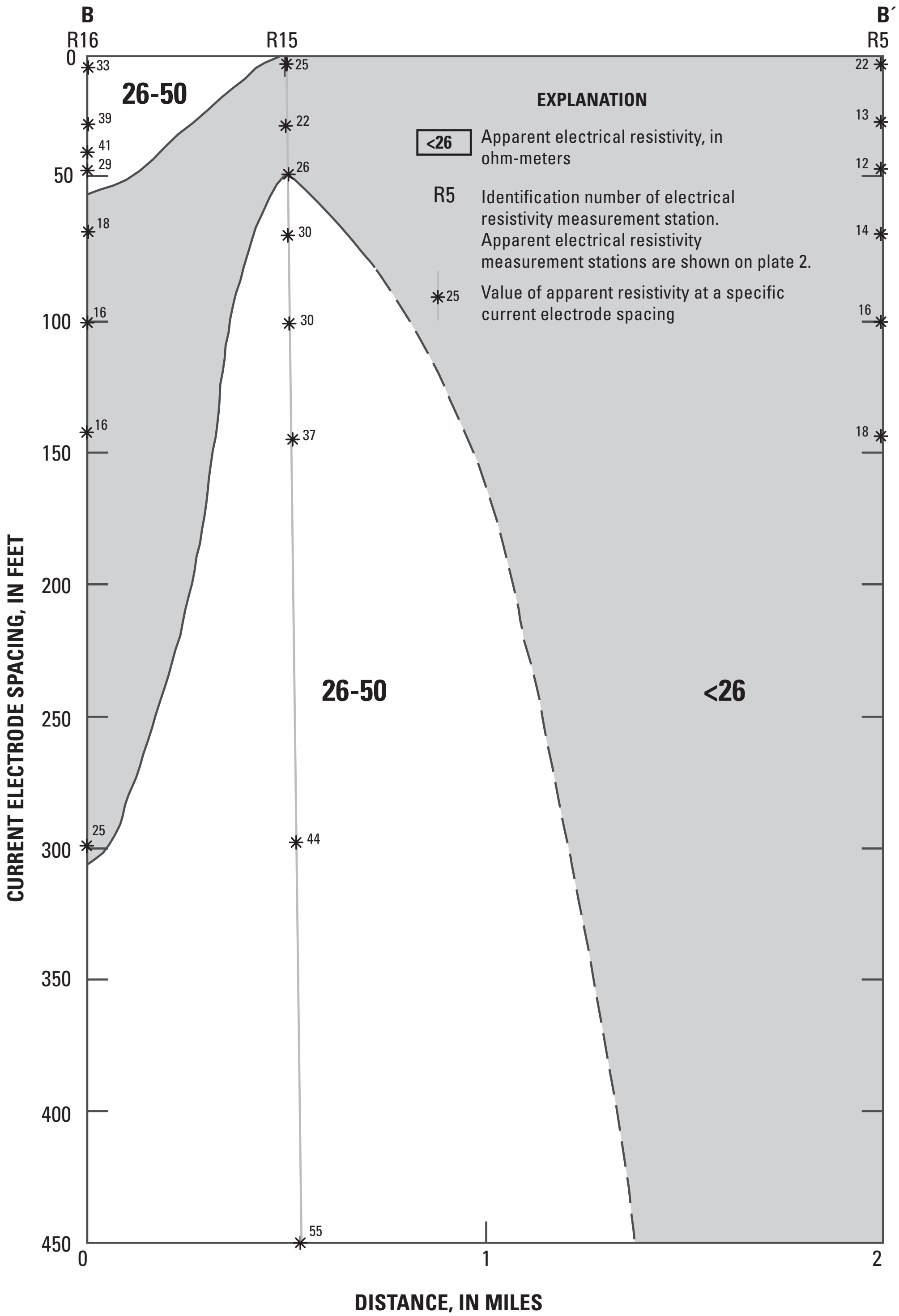

Figure 10. Change in apparent electrical resistivity with current electrode spacing along section B-B′.

Water levels in the few wells drilled and completed in the MayHT3 range in depth from about 6 to 90 ft below land surface (see Pozo Cervecería India, Mayagüez Resort, and Pozo Zoológico in table 9). Limited lithologic and hydrogeologic data suggest that ground water probably occurs under confined conditions in the MayHT3 hydrogeologic terrane. Claystone-mudstone units, which can function as confining units to underlying water-bearing limestone and volcanic sandstone, are irregularly distributed both spatially and with depth throughout the MayHT3 hydrogeologic terrane. Ground-water movement is assumed to be preferentially intergranular and (or) along bedding planes. Fracture flow, although less common than in MayHT2, may be important locally.

The estimates of ground-water flux range from 93,000 to 486,000 gal/d/mi^2, equivalent to an effective recharge of 2 to 10 in/yr (table 12). Induced streamflow may be an important source of recharge for wells completed in this hydrogeologic terrane that are located close to streams. This seems to be the case of the Zoológico well (well 11 in table 9 and plate 2), adjacent to Quebrada de Oro, as inferred from specific conductance values averaging 345 μS/cm at 25°C. The specific conductance of the ground water in the MayHT3 generally ranges between 600 and 900 μS/cm at 25°C. Scarce aquifer test data indicate that the specific capacity of wells completed in the MayHT3 ranges from about 1 to a local maximum of 2.5 gal/min/ft (U.S.Geological Survey, unpub. data, 1989). Production data obtained from the USGS, water well drillers, and well owners indicate that sustainable yields of wells in this hydrogeologic terrane mostly are in the range of 20-30 gal/min.

Mayagüez Hydrogeologic Terrane 4 (MayHT4)

The hydrogeologic terrane MayHT4 consists mostly of serpentinite, a rock consisting mostly of the mineral serpentine, and other minor intrusive igneous rocks. This hydrogeologic terrane mostly is restricted to the Cerro de Las Mesas upland, a plateau-type physiographic feature oriented southeast-northwest and located in the southern part of the municipio of Mayagüez (plate 2). Land slopes range from less than 15 to more than 45 degrees within the MayHT4. Some scattered lineament traces in the Cerro Las Mesas suggest the presence of irregularly distributed fractures in a rock matrix with generally low permeability. Locally, an epiclastic (eroded and moderately transported rock material) facies in the form of a conglomeratic-breccia is present in the southern margin of the Cerro de Las Mesas serpentinite body (Curet, 1986). Locally, the epiclastic facies may overlie fractured rock. Lateritic soils (rich in iron, aluminum, and manganese oxides) overly most of this hydrogeologic terrane and generally range in thickness from 10 to 80 in. The soil thickness may exceed 100 in. locally. The infiltration rate ranges from 0.63 to 2.0 in/hr. The serpentinite bedrock is directly exposed with no soil cover in large areas of the MayHT4 hydrogeologic terrane.

The predevelopment depths to water, in feet below land surface, reported for two wells completed in this hydrogeologic terrane—Hospital Bella Vista and Centro Residencial Oportunidades Educativas (CROEM) wells—are 64 and 109 ft, respectively (U.S. Geological Survey, unpub. data, 2000). Depths to water measured in these two wells during this study decreased slightly in 2001. For example, the depths to water (in feet below land surface) recorded for the Hospital Bella Vista well for the year 2001 were 77 ft on January 23, 74 ft on April 24, and 65 ft on November 26. The depths to water measured in the CROEM well during 2001 were 108 ft on January 28, 107 ft on April 24, and 102 ft on November 26 (U.S. Geological Survey, unpub. data, 2002).

Water storage and transmissivity in the hydrogeologic terrane MayHT4 are limited but locally might be enhanced by the presence of the epiclastic-fragmental facies and (or) a surface weathered zone in conjunction with fractures. The hydrogeologic character of the epiclastic facies is largely unknown but locally, with minor contribution from the soil cover, may contribute substantially to the water-bearing properties of the MayHT4 hydrogeologic terrane, particularly where it overlies fractured rock. The importance of the epiclastic-fragmental facies overlying a fractured zone in the MayHT4 is illustrated by the aquifer-test data from the Hospital Bella Vista well (fig. 11, plate 2). The Hospital Bella Vista well exhibited gradual dewatering during the first 5 hours of a 24-hour aquifer test, which was conducted at a pumping rate of 66 gal/min in 1999 by Caribbean Well and Pump Service. This initial, gradual decrease in water level seems to result from the progressive dewatering of an overlying granular facies corresponding to the epiclastic facies zone mentioned above (fig. 11). The specific capacity from the first 5-hour interval of the drawdown-time curve is 6 gal/min/ft. After about 12 hours, the rate of decline increased moderately as the water level in the pumped well declined to 110 feet below land surface, which coincides with a fractured zone; the water level did not stabilize during the remainder of the test, even when the pumping rate was reduced to between 41 and 46 gal/min. Because this well is located on a hilltop, the water withdrawn was derived from storage, which presumably was greatest in the epiclastic (granular) zone and least in the fractured zone. Based on the depth of the well and the results of the test, it is presumed that continuous pumping of the Hospital Bella Vista well would have caused the well to go dry. Detailed hydraulic and lithologic data are not available for the CROEM well; however, the well is likely to exhibit similar hydraulic characteristics as the Hospital Bella Vista well. The water level in the CROEM well decreased rapidly while being pumped during collection of water samples for this study, indicating that the water yield is limited and likely restricted to storage mainly within fractures. Also, the specific conductance of water samples collected from the CROEM well has been measured as low as 67 μS/cm at 25°C. The relatively low value is an indication that the recharge provided by rainfall infiltration has limited interaction with the soil and rock matrix because of rapid movement downward through fractures. If so, the overlying epiclastic facies apparently is not present at the CROEM well site. The epiclastic facies may be responsible for the higher average specific conductance of about 431 μS/cm at 25°C measured in samples collected from the Hospital Bella Vista well during this study (table 10). However, this well was found to yield water with a high nitrate concentration (discussed in a latter section of this report), and thus may be affected by waste-water infiltration to the local aquifer. The occurrence of ground-water flow along fractures in the Cerro de Las Mesas also is indicated by the presence of springs such as Santana Spring (table 9 and plate 2). Historic water-level data indicate the occurrence of artesian conditions in the few wells drilled and completed in the MayHT4 (U.S. Geological Survey, unpub. data, 1960). The artesian conditions may result from the intersection of dipping fractures at locations where these wells were drilled in the MayHT4.

Ground-water flux in the MayHT4 was estimated from the Q-90 and Q-98 flow-duration statistics determined for the Quebrada Carioca, which drains the Cerro de las Mesas. The estimates range from negligible to 283,000 gal/d/mi^2, and are equivalent to an effective recharge rate of less than 1 to 6 in/yr (table 12). The recharge mechanisms to this hydrogeologic terrane are not well understood. Direct infiltration of precipitation, although possible, is expected to be hindered by the relatively thick and low permeability soils and steep slopes. Downward movement of water from storage in the overlying soil layer and from the epiclastic-conglomeratic facies (where this facies is present) would be the predominant recharge mechanism. Direct infiltration through exposed fractures may locally be the most significant recharge mechanism to the underlying fractured aquifer where ground water has a low specific conductance, as measured at the CROEM well site. Sustained pumping of wells completed in the hydrogeologic terrane MayHT4 may not be feasible considering the presumed limited physical extent of the ground-water flow system, its low water storage and transmissive characteristics, and the topographic relief. Historical data (U.S. Geological Survey, unpub. data, 1960) indicate the existence of a few springs in this hydrogeologic terrane that have sustained flows of about 10 gal/min, and wells, now abandoned or destroyed, that yield about 5 gal/min for a few hours per day without substantial depletion of the aquifer. In general, the most appropriate pumping strategy in this hydrogeologic terrane seems to depend on which of the two water-bearing units in which the wells are completed—the fractured serpentinite bedrock, the epiclastic-conglomeratic facies, or both. Based on available data, a pumping rate that does not exceed about 30 gal/min for a few hours daily would be estimated as appropriate for wells completed in the epiclastic-conglomeratic facies to ensure that substantial dewatering of this zone does not occur. In the fractured bedrock aquifer, however, the estimated yield of wells would not be higher than about 10 gal/min and could be sustained for only a few hours daily to avoid excessive dewatering of this zone. The abundant and almost daily rainfall in the area of the Cerro de Las Mesas should provide sufficient recharge to the aquifer(s) within the MayHT4 hydrogeologic terrane, although much of this rainfall results in overland runoff within the MayHT4 hydrogeologic terrane during rainfall events, which are frequent in this area. Rainfall at the Cerro de Las Mesas between January 1 and November 30, 2001, was 80 in. with a minimum of 1.5 in. in January and a maximum of 16 in. in September (U.S. Geological Survey, unpub. data, 2001).

The presence of fractures, particularly where recharge occurs in the outcrop areas of the geologic units present in the MayHT4 hydrogeologic terrane, makes this hydrogeologic terrane susceptible to contamination by untreated wastes from leaking sewer pipes and effluent from septic tanks, among other sources. This is evidenced in the Hospital Bella Vista well (well 18 in table 11 and in plate 2) where the nitrate concentration of 19 mg/L exceeded the U.S. Environmental Protection Agency (USEPA) drinking standard of 10 mg/L. Further deterioration in the physical and chemical quality of the limited ground-water resources of the MayHT4 may occur as a result of the recent rapid urban development in this hydrogeologic terrane.

Mayagüez Hydrogeologic Terrane 5 (MayHT5)

The hydrogeologic terrane MayHT5 consists of intrusive igneous rocks of Tertiary and Cretaceous age (Curet, 1986). These igneous rocks are of basaltic and dioritic composition, similar to the MayHT2 and MayHT3 hydrogeologic terranes. The rocks are exposed at the surface as continuous belts, unlike the intrusive rocks in the MayHT2 and MayHT3 terranes, which are exposed as fragmented bodies. In the MayHT5, the intrusives are slightly to moderately fractured. The soil cover thickness ranges from 22 to 80 in., and soil infiltration capacity ranges from 0.63 to 2.0 in/hr.

Ground-water flux in the MayHt5 was estimated from Q-90 and Q-98 flow statistics determined for basins or subbasins located entirely or mostly in this terrane. The estimate ranges from negligible to 121,000 gal/d/mi^2 equivalent to an effective recharge that ranges from less than 1 to 2.5 in/yr (table 12). The PRASA Pozo Sultanita (table 9, plate 2) was drilled and later abandoned because of low yields. Pozo Río Hondo (table 9, plate 2), a private domestic well, is used only intermittently. Locally, fractures (particularly fracture intersections) may enhance both the transmissivity and storage characteristics of a terrane with otherwise low permeability. In general, the ground-water potential of this hydrogeologic terrane is limited and may serve only to satisfy limited domestic needs.

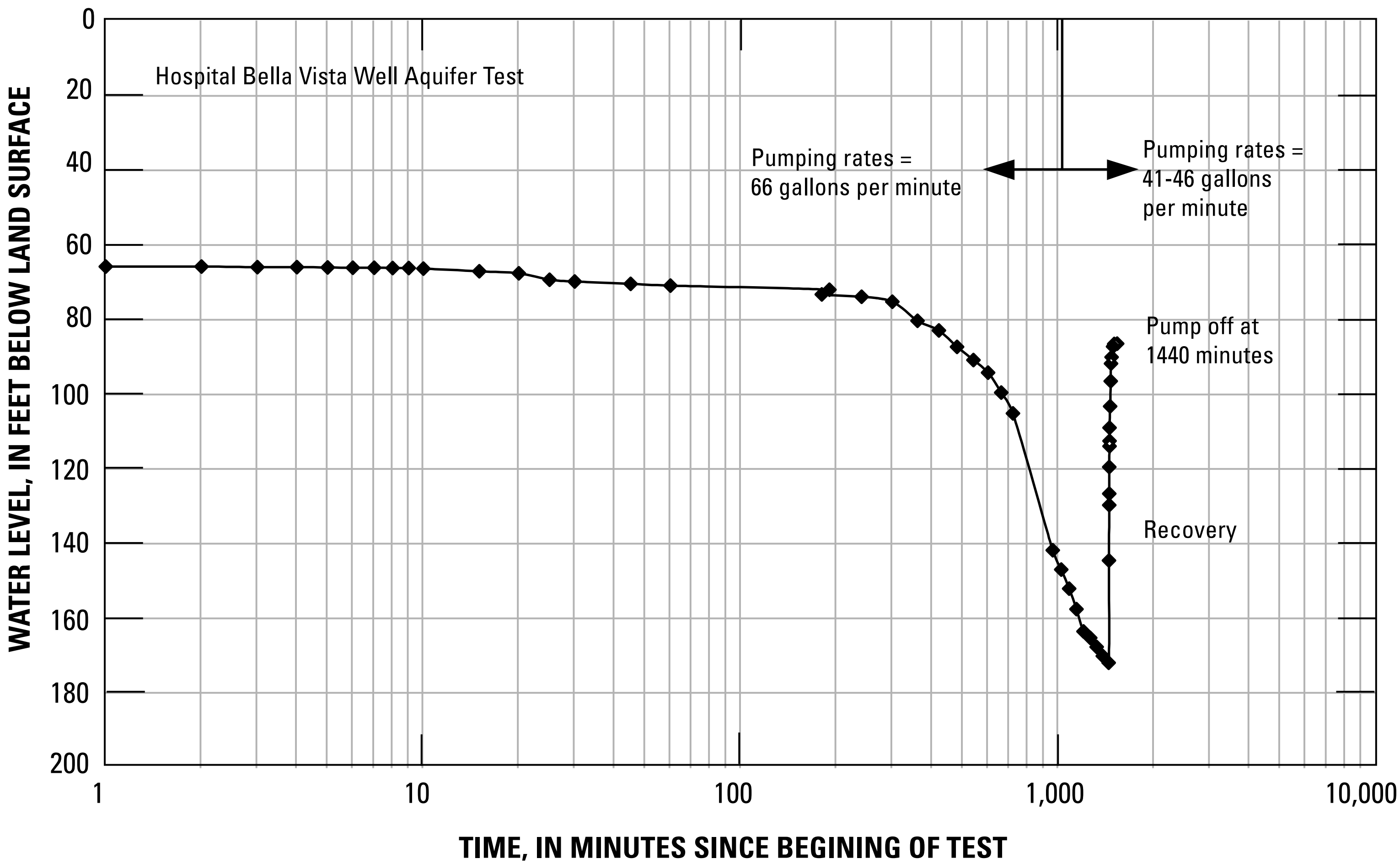

Figure 11. Relation between water level below land surface and pumping time in the Hospital Bella Vista well pumping test.

Ground-Water Quality

Water samples from nine wells and one spring were analyzed to determine the concentration of major dissolved constituents within all five hydrogeologic terranes. The concentrations for most of the major dissolved constituents comply with the drinking-water requirements established by the USEPA, with one exception. The nitrate concentration of 19 mg/L measured in water from the Hospital Bella Vista well in MayHT4 exceeded the USEPA maximum contaminant level of 10 mg/L (table 11) (U.S. Environmental Protection Agency, 1973). The concentrations of manganese and iron in the Cervecería India and Eli Lily 1 wells, both completed in the lower zone of MayHT1, exceeded the USEPA secondary drinking-water standards of 50 and 300 µg/L, respectively (U.S. Environmental Protection Agency, 1973).

Ground-Water Withdrawals

Ground-water withdrawals from the five hydrogeologic terranes described above were estimated at about 1.2 Mgal/d during 2001 (W. Molina, U.S. Geological Survey, written commun., 2002). About 90 percent of the ground-water withdrawals are from the MayHT1 hydrogeologic terrane. The PRASA, with an estimated withdrawal of 1.1 Mgal/d, is by far the largest ground-water user in the study area. The remaining 0.1 Mgal/d is the estimated withdrawal by users such as industries, commercial and government institutions, and private residences. The PRASA wells usually operate on a continuous basis and most have been installed in the vicinity of streams. The locations of these wells indicate that a substantial part, if not all, of the water withdrawn from these near-stream wells may be supplied by induced streamflow and not from the regional ground-water flow system. Ground-water withdrawals by other users generally occur on an intermittent basis for a few hours per day or less and the source of water primarily is captured from the regional ground-water flow system, with no induced flow from streams. The regional flow system throughout the study area rarely sustains well yields in excess of 50 gal/min and, thus, alternating periods of pumping and recovery generally are needed to avoid excessive dewatering of the aquifer(s).

Lineament-Trace Analysis

The lineaments traced in this study (plate 2) have been classified and grouped into two different types:

L_s-Lineaments of structural or geologic importance, including, but not limited to fault traces, fracture traces, lithologic contacts, failure escarpments, and terrace surfaces, and

L_t- Lineaments of topographic origin, including straight or linear mountain ridge tops, stream valleys, and gullies or erosional surfaces near major river valleys.

Some of the lineaments identified as L_t may, in fact, represent a fracture or fault trace (L_s). Linear stream valleys or gullies commonly form as a result of concentrated erosion through pre-existing fractures or shear zones. Not all structural or geologic lineaments have hydrogeologic importance. In this case, the lineaments are only natural geomorphic features with no structural or lithologic significance.

A total of 82 prominent lineament traces were identified for this study in the municipio of Mayagüez through photo analysis. The lineaments were classified and numbered 001 to 081 (plate 2). Three lineaments (LN002, LN003, and LN040) were verified through field inspections to be man-made features. Two lineaments corresponded to extensions and pathways of power lines (LN002 and LN003), while LN040 was a fence or property boundary. These three lineaments are not shown on plate 2.

Excluding the three man-made lineaments, the mapped traces reveal the presence of three distinctive groups of lineaments, based on their trend or azimuth. There is a large group of west- and slightly southwest-trending lineaments with lengths varying between approximately 0.3 to about 2.8 mi. These are located mainly in the northern half of the study area and include mostly L_s lineaments, with the exception of the L_t lineaments LN033, LN034, and LN044 (plate 2).

A second, smaller group of lineaments includes those generally oriented in a northwest and southeast direction. These lineaments vary in length from about 0.5 mi to an average of about 0.9 mi and are concentrated mostly in the south-central and northeast-central parts of the study area. A third distinctive group of lineaments trends northeast-southwest with average lengths varying from 0.3 to about 1.3 mi. These lineaments are present mostly in the central-northeast and central parts of the study area (plate 2).

The rough terrain and dense vegetation present throughout much of the study area seriously limits the correlation of lineament traces with geomorphologic and structural features in the field. Additionally, residual soil and saprolite layers, generally at least several feet thick, cover the structural features in most of the study area. Additional field studies, preferentially in the form of geophysical surveys and exploratory drilling at lineament intersections, would be needed in order to assess the water-bearing properties of those areas with a high density of lineaments.

Summary and Conclusions

The USGS, in cooperation with the Office of the Major of the Municipio Autónomo de Mayagüez, conducted an integrated surface-water, water-quality, and ground-water assessment of the water resources of the municipio de Mayagüez. Public water-resources managers in the municipio needed a comprehensive document to plan for present water demands and the increasing need for adequate supplies of safe drinking water. The major results of this study and other hydrologic and water-quality features were compiled in a Geopgraphic Information System, and are presented in two 1:30,000-scale map plates to facilitate interpretation and use of the diverse water-resources data. The surface-water assessment focused on low-flow characteristics of rivers and streams in the municipio of Mayagüez; low-flow and flow-duration characteristics were evaluated at 1 continuous-record gaging station and at 20 partial-record stations. The continuous-record gaging station is located along Río Rosario, which is a second-order tributary of Río Guanajibo. The 20 partial-record stations are distributed among a number of first- to third-order streams in the municipio of Mayagüez. The surface-water contribution of the Río Rosario (at the index station 50136400) is 7.3 ft^3/s (4.7 Mgal/d) based on the 99-percent of time discharge. The surface-water contribution at each of three partial-record stations was less than 0.1 ft^3/s; these stations were Caño Majagual at Highway 348 (50138375), Quebrada Caricosa near Represa de Mayagüez (50138815), and Tributario de Quebrada Caricosa at Highway 105 (50138845). The surface-water contribution at the Río Yagüez dam (station 50138500) and Río Cañas upstream of Quebrada Cojolla (station 50146036) are 1.9 and 3.0 ft^3/s, respectively, based on the 99-percent flow-duration discharge. This combined discharge is equivalent to a 99-percent of time discharge of 3.2 Mgal/d already withdrawn by the PRASA through gravity intakes. The surface-water contribution at the Río Casey at Río Cañas Arriba (station 50135490) is 4.7 ft^3/s, which is equivalent to 3.04 Mgal/d, based on the 99-percent of time discharge.

In addition to low-flow characteristics in the surface-water assessment, important surface-water resource information also was compiled, including locations of potential reservoir sites, flood hazard areas, water-supply filtration plants, waste-water treatment plants, drainage-basin boundaries, and stream-gaging station locations (plate 1). The stream low-flow statistics presented in this report document the general hydrology under current land and water uses. Similarly, these low-flow statistics also are a function of the current precipitation pattern. Low-flow statistics may change substantially as a result of streamflow diversions for public supply, increase in ground-water development, waste-water discharges, flood-control measures, and changes in precipitation. As a result, the current analysis provides baseline information to be used to determine impacts and to develop water budgets.

All perennial streams in the municipio of Mayagüez inland of their estuary segments are classified as Class SD on the basis of their designated use. This classification applies to surface waters intended for use (or potential for use) as a raw source of public supply and propagation and preservation of desirable aquatic species, as well as primary and secondary contact recreation. With the exception of surface waters used for primary contact recreation, the sanitary quality standard (goal) for Class SD waters in Puerto Rico is based primarily on fecal coliform concentrations (Junta de Calidad Ambiental de Puerto Rico, 1990). To meet the sanitary quality standard, the fecal coliform geometric mean concentration obtained from five samples collected in sequential order should not exceed 2,000 colonies per 100 mL, and not more than one in five samples should exceed a concentration of 4,000 colonies per 100 mL.

Long-term monitoring of bacterial concentrations of surface waters at five sampling stations, Río Guanajibo near San Germán (50133600), Río Rosario near Hormigueros (50136400), Río Guanajibo near Hormigueros (50138000), Río Yagüez near Mayagüez (50138800), and Río Grande de Añasco near Añasco (50146000), indicates that since 1997, sanitary quality generally has been in compliance with the fecal coliform sanitary quality goal established for Class SD waters in July 1990. For the current study, a sanitary quality survey was conducted during base-flow conditions to qualitatively classify streams on the concentrations of sanitary quality indicator bacteria and to identify potential sources of bacterial contamination. A qualitative classification method was based primarily on the fecal coliform concentration goal established for Class SD surface waters by the Junta de Calidad Ambiental de Puerto Rico (1990). The method was applied in order to rank the sanitary quality at sampling stations where water samples were collected during stream base-flow conditions.

It was necessary to develop a rationale to interpolate and extrapolate station classifications, because only 37 sampling stations were used to determine the sanitary quality of approximately 165 stream miles. This required using the prefix **presumed** before each of the rankings, because the bacteriological concentrations at various sampling stations along a given stream reach were substantially different at distances as little as 0.6 mi. In summary, about 165 stream miles of the nearly 173 stream miles within the municipio of Mayagüez were classified as follows: 4.6 stream miles as **good**; 9.1 as **presumed good**; 45.7 as **acceptable**; 72.3 as **presumed acceptable**; 3.4 as **fair**; 0.6 as **presumed fair**; 9.6 as **poor**; and 18.8 as **presumed poor** (table 8). About 7.7 stream miles in the upper parts of the basins were not ranked because of the lack of data. The classification was not applied to about 30 miles of drainage channels, referred to as caños, within the lower parts of the basins where flow is mostly stagnant. The geometric means of fecal coliform and fecal streptococcus concentrations in number of colonies per 100 mL for all stations classified within each of the established rankings were as follows: **good-** 120 and 240; **acceptable-** 230 and 210; and **poor-** 8,600 and 65,000 respectively.

It may be inferred that the stream courses classified as **acceptable, presumed acceptable, fair,** and **presumed fair** are contaminated from intermittent sources of fecal contamination, and those classified as **poor** or **presumed poor** from continuous sources, based on the current study and from more than 17 years of field observations and hydrologic analysis in the Mayagüez area. Potential sources of fecal contamination in urbanized areas include illegal discharge of waste waters to storm-water drains, especially within the older sectors of the municipio of Mayagüez; overflows from sewer mains into the storm-water drains as a result of malfunctioning sanitary sewer ejectors or clogged mains; ruptured sewer mains; and leakage from sewer mains into the local aquifer. In rural areas, the potential sources of fecal contamination include gray-water discharges (gray water includes all waste waters from household uses except sanitary waste) from residences and commercial establishments along stream channels; septic tank leakage or overflows; feces contamination directly into streams by unfenced livestock; and runoff from restrained animals and poultry pens near stream courses.

The stream segments classified as **acceptable** have the greatest potential for development as surface- and ground-water sources. However, if there are stream segments upstream classified as “riparian zone with potential as a source of contamination from household waste-water discharges,” then development of ground-water supplies in aquifers adjacent to these streams should not be encouraged without (a) more detailed analysis of bacteriological conditions to define diurnal variations and the application of more sensitive microbiological determinations, such as recovery enhancement tests for fecal coliform and fecal streptococcus bacteria; and (b) more in-depth evaluation of the bacteriological attenuation capacity of the ground-water bearing units. In addition, a more rigorous surface-water monitoring program, including fecal coliform, fecal streptococcus, and other indicator bacteria would be important to define the variability and sources of contamination in order to implement corrective measures.

The municipio of Mayagüez was divided into five hydrogeologic terranes, according to their ground-water development potential, based on geologic, topographic, soil, hydrogeologic, and streamflow data. The hydrogeologic terrane MayHT1 consists of an upper and lower zone. The upper zone is composed mostly of Quaternary alluvium and to a lesser extent of Quaternary mangrove and swamp deposits. The lower zone consists of pre-Quaternary fluvial and marine sandstones and Late Cretaceous and Early Tertiary-age volcaniclastics and limestones. The MayHT1 is restricted to the lowlands that includes the coastal plain and the narrow bands of Quaternary alluvium along the rivers and creeks in the mountainous interior.

The hydrogeologic terrane MayHT2 consists of volcaniclastics rocks intruded by igneous intrusive rocks, and is restricted mainly to the headwaters of the main rivers in the eastern portion of the municipio of Mayagüez. This hydrogeologic terrane seems to be the most affected by structural dislocation as indicated by the occurrence of numerous lineament intersections. The hydrogeologic terrane MayHT3 is similar to the MayHT2 hydrogeologic terrane, but with substantially fewer lineaments. The MayHT4 hydrogeologic terrane is restricted mostly to the Cerro Las Mesas, a moderately fractured uplifted serpentinite body, presumed to be of Early to Middle Tertiary age. The hydrogeologic terrane MayHT5 is composed mostly of igneous intrusive rocks of Cretaceous and Tertiary age.

Most concentrations of major constituents measured in water samples collected at wells in the five hydrogeologic terranes are within the recommended USEPA secondary drinking water standards. The exception was the concentration of nitrate measured in the water sample from Pozo Hospital Bella Vista in the MayHT4 hydrogeologic terrane, which exceeded the USEPA drinking water standards. Concentrations of manganese and iron exceeded USEPA secondary drinking water standards at some wells completed in the lower zone of the MayHT1 hydrogeologic terrane. The results of the sanitary quality survey of surface waters in the municipio of Mayagüez indicate that wells completed at less than an adequate distance near streams with high concentrations of fecal bacteria are highly susceptible to contamination.

A generalized relation between depth to water and topographic relief can be established for the study area based on water-level measurements for selected wells. The water level at wells sited in the coastal plain generally are less than 10 ft below land surface. The depths to water at those wells located in a river valley are most likely greater than 10 ft but equal to or less than 15 ft below land surface. In slopes with varying degrees, the depth to water generally lies between 15 and 40 ft below land surface. In wells installed in hilltops, the water level generally is greater than 40 ft but equal to or less than 110 ft below land surface.

The MayHT1 hydrogeologic terrane has the greatest ground-water development potential in the municipio of Mayagüez. However, the ground-water development potential is limited by the relatively high clay and silt content of the primary water-bearing units in the upper and lower zones and the potential of saltwater intrusion in the coastal areas. Most of the MayHT1 ground-water development potential depends on the interception of streamflow by wells completed in the small interior alluvial valleys, in the coastal plain, and by wells completed in the local sand-rich units of the upper zone and the limestone strata of the lower zone. Wells with yields that would be sustained by induced streamflow would need to be completed at an adequate distance from the source streams to account for the natural filtration and removal of viruses and bacteria in the source streams and the persistence period for these organisms in the ground-water environment (McFeters and others, 1974). Additionally, these wells would need to be designed in such a manner that water moving along the longest flow path would preferentially enter into the screened or open interval of the well (Torres-González and others, 2002). This would increase the probability that the travel time of the water being induced from the source stream would exceed the persistence period for any virus or bacteria present in the streamwater.

The presence of lineaments and possibly fractures and joints, associated with an increase in the presence of intrusive rocks, is greatest in the eastern part of the municipio of Mayagüez (plate 2). This eastward presence of fractures and joints may explain why ground-water flux is greater in the MayHT2 than in the MayHT3, despite having essentially the same geologic substratum. Considering the extent and density of fractures in the headwaters of Río Yagüez and Río Cañas in the eastern part of the municipio of Mayagüez, the possibility exists that the ground-water recharge zones extend beyond the surface-water divides.

Those areas with a high density of identified lineaments, particularly in the MayHT2, MayHT4, and to a lesser degree, MayHT3, are worth further analysis in order to better assess their ground-water development potential. Where intersections of identified lineaments occur, probabilities are high that intersecting fractures are overlain by water-bearing layers of weathered material. Excessive development of the ground-water resources in the headwaters of the Río Yagüez and Río Cañas may decrease the low base flows of the streams and consequently hinder the safe flow rates needed downstream for public supply, viability of aquatic biological systems, and the capacity of streams to assimilate and adequately dilute waste-water discharges.

The integrated surface-water, sanitary quality, and ground-water assessment presented in this report can be used as an integral part of the territorial development plan of the municipio of Mayagüez, and contribute to the implementation of measures for the sustainable development of surface- and ground-water resources. This systematic study also establishes baseline hydrologic information for the municipio of Mayagüez to monitor future changes in water availability and to evaluate the relation between land use, water use, and water availability.

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