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

Surface-Water, Water-Quality, and Ground-Water Assessment of the Municipio of Ponce, Puerto Rico, 2002-2004

Scientific Investigations Report 2005-5243

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Cover photograph

View towards the southeast of Lago Cerrillos from Highway 505. Highway 139 is in the foreground. Highway 52 is in distance to the right. Removal of earth material for a housing development is occurring near the Río Inabón to the left hand side of the photograph. Photograph taken by Jesús Rodríguez-Martínez on November 27, 2001.

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By Jesús Rodríguez-Martínez, Luis Santiago-Rivera, José M. Rodríguez, and Fernando Gómez-Gómez

Chapter A

Surface-Water Resources Assessment of the Municipio of Ponce, Puerto Rico, 2002-2004

By Luis Santiago-Rivera and Fernando Gómez-Gómez

Chapter B

Sanitary Quality of Surface Water During Base-Flow Conditions in the Municipio of Ponce, Puerto Rico, 2002

By José M. Rodríguez and Fernando Gómez-Gómez

Chapter C

Hydrogeologic Terranes and Ground-Water Resources in the Municipio of Ponce, Puerto Rico, 2002-2004

By Jesús Rodríguez-Martínez and Fernando Gómez-Gómez

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U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

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Contents

Plates

[In pocket]

Figures

Tables

Conversion Factors, Datum, Water-Quality Units, Acronyms, and Translations

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)
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)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

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

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:

FEMA	Federal Emergency Management Agency
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Services
PR	Puerto Rico
PRASA	Puerto Rico Aqueduct and Sewer Authority
PREQB	Puerto Rico Environmental Quality Board

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 Ponce, Puerto Rico, 2002-2004

By Jesús Rodríguez-Martínez, Luis Santiago-Rivera, José M. Rodríguez, and Fernando Gómez-Gómez

Abstract

The U.S. Geological Survey in cooperation with the Municipio Autónomo de Ponce conducted a comprehensive surface- and ground-water resource assessment, and bacteriological analysis of rivers and streams within the territorial limits of this municipio. The main objective of this study was to acquire a database that will help the municipal government of Ponce ensure an adequate supply of drinking water at present and meet future demand. The study consisted of the evaluations of the surface-water resources, streams sanitary conditions, and ground-water resources.

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 for three index stations based on graphical curve-fitting techniques and log-Pearson Type III frequency curves. Estimates of low-flow characteristics for 27 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 specific-land use, water-use, and climatic conditions.

A survey of streams and rivers utilized 27 sampling stations to evaluate the sanitary conditions of about 130 stream miles. River and stream samples for fecal coliform and *Escherichia coli* analyses were collected on two occasions at base-flow conditions to identify potential sources of contamination. Bacteriological analyses indicate that a significant portion of the rivers and streams in Ponce comply with the fecal coliform sanitary quality goal established for inland surface waters in July 1990 by the Puerto Rico Environmental Quality Board. Long-term monitoring of bacterial concentration of surface waters at three sampling stations in the municipio of Ponce have been in compliance with the water-quality goal for fecal coliform concentration established in July 1990. Long-term monitoring of bacterial concentration of surface water at another sampling station has mostly exceeded the fecal coliform sanitary quality goal established in July 1990. Approximately 40 percent of the rivers and streams reaches, particularly in the headwaters of the main rivers, comply with the water-quality goals of the Puerto Rico Environmental Board of fecal coliform for inland waters, as amended in 2003.

Potential sources of fecal contamination in urbanized areas include illegal discharge of waste water to storm-water drains, overflows from sewer mains into the storm-sewer drains, ruptured sewer mains, and leakage from sewer mains into the local aquifer. In rural areas, the potential sources of fecal contamination include gray-water discharge from residences and commercial establishments along stream channels, septic tank leakage or overflows, fecal contamination directly into streams by unfenced livestock, and runoff from restrained animals and poultry pens near stream courses.

Geologic, topographic, soil, hydrogeologic, and streamflow data were compiled in a database and used to divide the municipio of Ponce into six 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 terrains containing igneous rocks. This study indicates that further ground-water development in the municipio of Ponce is hindered by the potential of water-quality deterioration caused by the occurrence of brackish and saline ground water, particularly in the coastal plain.

Sumario

El U.S. Geological Survey, en cooperación con la oficina del Alcalde del Municipio Autónomo de Ponce, 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 selección de alternativas para satisfacer las demandas presentes y futuras de agua, así como la identificación de fuentes adicionales de abastos 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 quebradas del municipio, ya que el abasto de agua potable ha sido un asunto crítico durante periodos recientes de sequía. Se evaluaron las características de flujos mínimos en tres estaciones fluviométricas de registro continuo utilizando técnicas para ajustar curvas gráficas y curvas de frecuencia log-Pearson Tipo III. Estimados de flujo mínimos para 27 estaciones de registro parcial fueron determinados usando técnicas de correlación gráfica. Las características de duración de flujo se computaron para las tres estaciones de registro continuo y se estimaron para las 27 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 27 estaciones de muestreo para evaluar la calidad sanitaria de aproximadamente 130 millas (208 kilómetros) de ríos y quebradas. Muestras de agua fueron tomadas en ríos y quebradas durante condiciones de estiaje para determinar la concentración de bacterias coliformes y *E. coli* y determinar las fuentes de contaminación. Los análises bacteriológicos indican que una porción significativa de los ríos y quebradas cumple con los límites de coliformes fecales para aguas interiores establecidos por la Junta de Calidad Ambiental de Puerto Rico en julio 1990. La concentracion de coliformes fecales a largo plazo en tres estaciones de muestreo de aguas superficiales en el municipio de Ponce han cumplido con los límites establecidos por la Junta de Calidad Ambiental en el 1990. En otra estación de muestreo a largo plazo de aguas superficiales las concentraciones de coliformes fecales han excedidos los límites de la Junta de Calidad Ambiental de Puerto Rico establecidos en julio 1990. Los análisis bacteriológicos indican que aproximadamente un 40 porciento de los tramos de ríos y quebradas, particularmente en las partes altas de sus cuencas, cumplen con los límites de coliformes fecales para aguas interiores según enmendados por La Junta de Calidad ambiental en el 2003. Entre las fuentes potenciales de contaminación fecal en áreas urbanas se encuentran: descargas ilegales de aguas residuales en los sistemas de alcantarillado pluvial, desbordamientos del alcantarillado sanitario al alcantarillado pluvial, alcantarillados sanitarios tapados y con filtraciones. En áreas rurales, las fuentes potenciales de contaminación fecal incluyen, entre otras, descargas de aguas usadas de residencias y establecimientos comerciales en ríos y quebradas, filtraciones o desbordamientos de pozos sépticos, contaminación fecal directa en los ríos y quebradas por ganado suelto y escorrentías de la cría de animales de corral.

Se utilizaron datos geológicos, topográficos, de suelos, hidrogeológicos y fluviométricos para dividir el municipio de Ponce en seis 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 potencial de desarrollo de agua subterránea en unidades hidrogeológicas constituidas por rocas ígneas. Los resultados de este estudio indican que el desarrollo adicional de agua subterránea en la parte costera del municipio de Ponce está limitado por la presencia de agua subterránea salobre y salina de orígenes diversos.

Introduction

The municipio of Ponce, with a population of 186, 475 as of 2000 (U.S Department of Commerce, 2001), covers an area of about 116 square miles (mi^2) in the south coast of Puerto Rico (fig. 1). Approximately 43 mi^2 of the municipio is in the coastal plains with the remaining 73 mi^2 situated within the upper plains limestone hills and uplands of the central mountainous region of Puerto Rico. The upland area is characterized by steep slopes, with most of the slopes generally exceeding 20 percent. The coastal portion consists of flat land with slopes not exceeding 10 percent. About 77 percent of the population is concentrated in the coastal and upper plains. The average population density of Ponce, as of 2000, is 1,608 persons per mi^2 but varies from about 14,000 persons per mi^2 in the city proper to about 120 persons per mi^2 in some barrios of the mountainous interior and coastal plain.

The water demand for the municipio of Ponce in 2004 was about 36 millions gallons per day (Mgal/d). The future social and economic development of Ponce is hindered by a deteriorating public-supply water infrastructure, loss of ground-water supplies to salinization, and the potential degradation in the quality and biological integrity of its surface sources. Historically the municipio of Ponce, particularly the coastal area, has relied on ground water to satisfy its public-supply water needs. During the last 20 years, however, the trend has been to change to surface-water sources as a result of a widespread deterioration of ground-water quality.

Deficits in the water supply for the municipio of Ponce arise occasionally because of operational problems in the distribution system. Such was the case during the drought of 1995 that affected most of Puerto Rico, when the annual rainfall was more than 30 percent below the long-term average (U.S. Geological Survey, unpublished data, 2002), and during the early months of 2002 and 2003, when water had to be withdrawn from the Cerrillos reservoir because of insufficient water delivery from the Lago Toa Vaca reservoir in the neighboring municipio of Villalba owing to low levels. In the recent past, communities in the mountainous upland areas have experienced recurrent problems in the water delivery service.

To ensure an adequate supply of drinking water at present and to meet future demand, the municipio of Ponce requested the U.S. Geological Survey (USGS) to conduct a comprehensive surface- and ground-water resource assessment, and bacteriological analysis of rivers and streams. This information will be an essential component of the territorial development plan being developed by the municipio of Ponce, which will take into consideration the sustainable use of land and water resources.

Thematic maps were developed to delineate the hydrologic and stream bacteriological (sanitary) conditions, and to define the water-bearing properties of major rock units. A description of the methods and techniques used to conduct the analysis and interpretations made 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.

Figure 1. Location of the municipio of Ponce, southern Puerto Rico.

Acknowledgments

The authors honor the memory of Rafael Cordero Santiago, Mayor of the municipio of Ponce, who passed away in 2004 and was aware of the need for the development of land-use strategies to help sustain and enhance the land and water resources of Ponce. The authors also acknowledge the support of Edualdo Questel, a retired geologist of the municipio of Ponce, particularly in the early phases of this study. The authors also acknowledge the support provided by the municipal functionaries José Valenzuela and Patrick Urbain of the Territorial Development Office of the municipio of Ponce. The authors thank Marilyn Santiago and Awilda Ortíz of the USGS for the preparation of the spatial databases presented in this report, and Francisco Maldonado, also of the USGS, for the final compilation and editing of the plates.

Description of the Study Area

The municipio of Ponce has an area of 116 mi^2, and its main physiographic features from north to south, are the mountainous interior with the headwaters of the main river systems, an upper plain, a series of limestone hills trending predominantly east-west, a coastal plain, and a coastal flat. The rocks within the municipio of Ponce can be divided into three major groups: Cretaceous and early Tertiary rocks that crop out only in the mountainous interior; middle Tertiary-age rocks that comprise the limestone hills; and Quaternary-age fan-delta deposits with subordinate amounts of alluvium, colluvium, and terrace deposits present in the upper and coastal plains. The long-term mean annual rainfall in the municipio of Ponce ranges from 36 inches (in.) in the coastal plain to 100 in. at the highest elevations of the mountainous interior, at the insular hydrologic divide. The mean annual temperature in the municipio of Ponce is 26 degrees Celsius (ºC).

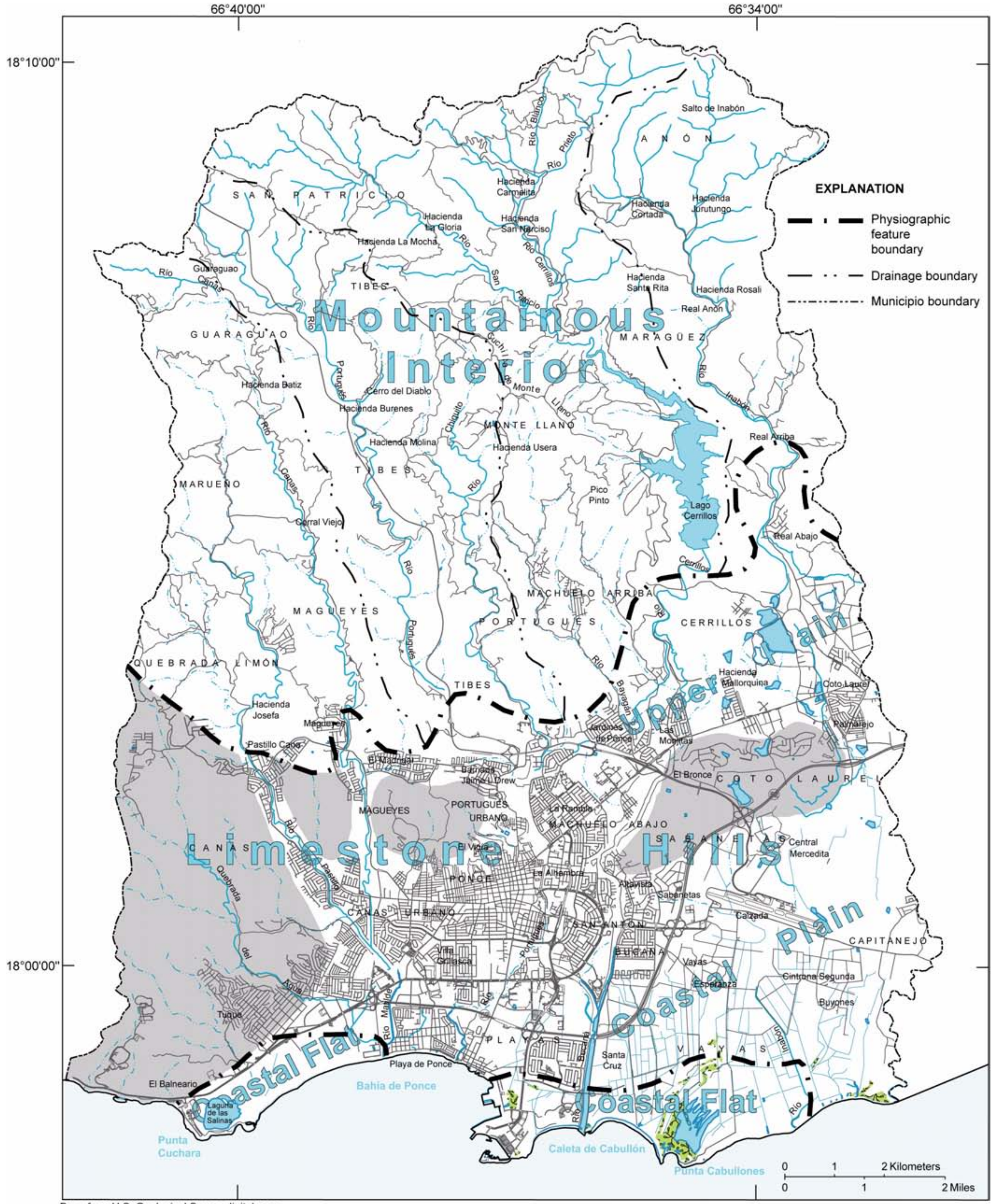
Physical Features

The main physiographic features of the municipio of Ponce in a southward direction are: (1) the mountainous interior containing the headwaters of the main river systems, (2) an upper plain, (3) a range of predominantly east-west trending limestone hills, (4) a coastal plain, and (5) a coastal flat (fig. 2). The mountainous interior of the municipio of Ponce is part of the Cordillera Central mountain range. The mountainous interior of Ponce includes a portion of the southern slopes of Cerro de Punta, the highest peak in Puerto Rico reaching 4,390 feet (ft) in elevation. The ridge of the Cordillera Central constitutes most of the northern boundary of the municipio. A substantial portion of the ridge ranges from 2,500 to 3,500 ft in elevation. In the mountainous interior, the valleys are deeply incised with as much as 1,500 ft difference in elevation between ridges and adjacent valleys. In general, there is a sharp boundary between the foot of the Cordillera Central mountain range and the upper coastal plain. The upper plain consists of rolling hills separated by alluvial terrace deposits. The stream valleys formed between the rolling hills have an altitude of about 200 ft. At the southern edge of the stream valleys, where these merge into the South Coastal Plain, the elevation is about 100 ft. Limestone hills dominate in the southwestern part of Ponce from Punta Cuchara to the Río Canas. East of the Río Canas, isolated clusters of limestone hills separate the upper plain from the coastal plain. The coastal plain has a maximum elevation of 100 ft and gently slopes to the coastline. Areas within the coastal plain below an elevation of 10 ft, however, have a distinct physiography. McClymonds (1972) referred to this area as coastal flats. The coastal flats are differentiated from the coastal plain by having soils and shallow ground water that are generally salty. Coastal flats have poor drainage and when flood irrigation was applied to sugar cane, the soils became water-logged. At present (2003), flood irrigation is not used in the coastal plain and the water table may rise to the land surface immediately after the occurrence of heavy rains. Nevertheless, evaporation from the shallow ground water in the coastal flats is high enough to produce salt crusts in some areas.

There are four major river basins within the municipio of Ponce that drain to the Caribbean Sea. From east to west they are the Río Inabón, Río Bucaná, Río Portugués, and Río Matilde (fig. 2 and plate 1). The drainage divides between these four rivers basins are well defined in the interior uplands but not in the coastal plain. This is mainly due to substantial changes in topography resulting from intense land development.

General Geology

The discussion that follows on the general geology of the municipio of Ponce was taken mostly from Krushensky and Monroe (1975a, 1975b) and Mattson (1968a, 1968b). The rocks within the municipio of Ponce can be divided into three major groups: a Cretaceous and early Tertiary sequence cropping out only in the mountains; a middle Tertiary-age sequence found in the limestone hills and underlying the delta-fan, alluvial, and terrace deposits of Quaternary age of the upper and coastal plains; and the Quaternary alluvial and terrace deposits (fig. 3). Although not confirmed by drilling, it is presumed that the Cretaceous and early-Tertiary age rocks cropping out in the mountains also underlie the middle Tertiary-age sequence in the upper and coastal plains.



Base from U.S. Geological Survey digital map.

Figure 2. Physiographic features and stream basins of Ponce (modified from McClymonds, 1972).

Base from U.S. Geological Survey digital map.

Figure 3. Surficial geology of the municipio of Ponce (modified from McClymonds, 1972).

The Cretaceous rocks consist mostly of volcaniclastics, igneous extrusives, igneous intrusives, pyroclastic material, and limestone units. The volcaniclastic rocks are the most widespread throughout the sequence and include conglomerates, breccias, siltstones, mudstone, and sandstones. The igneous extrusives are limited in their distribution and usually are present as subordinates to volcaniclastics and igneous intrusives. The igneous intrusives in the form of dikes, sills, and stocks are quite common, particularly in the northern part of the municipio of Ponce. The most prominent of these igneous intrusives are the granodioritic bodies in the upper Río Cerrillos and Río Inabón drainage basins. The granodioritic bodies are the southern extensions of the Utuado batholith. The limestone units are minor and generally contain volcanic clasts in their basal parts. In general, the Cretaceous and early Tertiary-age rocks are highly faulted and folded.

The middle Tertiary sequence is constituted by the Juana Díaz Formation and the Ponce Limestone. The Juana Díaz Formation, Oligocene to Miocene in age, uncomfortably overlaps the older Cretaceous and early Tertiary-age rocks. This formation has been described as consisting of calcareous and detrital units. The calcareous unit is composed of lenticular calcareous sandstone overlain by chalk and chalky limestone. The detrital unit is composed of light blue-gray calcareous sandy clay, sand, and sandy gravel. The gravel is preferentially present in the lower part of the detrital unit. In the Ponce area, the Juana Díaz Formation is thickest near the Río Inabón in the eastern part of the municipio. The Ponce Limestone is of Miocene age and generally is crudely and thickly bedded, locally rubbly, light grayish-orange calcarenite that is moderately to locally highly fossiliferous. The Ponce Limestone overlies and, locally in the western part of Ponce, may interfinger with the Juana Díaz Formation. North of the Central Mercedita sugar mill and westward, the lower part of the Ponce Limestone is composed of intercalating layers of limestone and mudstone and is overlain by a massive layer of white or yellow limestone. The structural deformation in the middle Tertiary sequence, at least in the outcrop areas, is less than in the Cretaceous early-Tertiary sequence of the mountainous interior. However, moderate to local faulting has taken place as evidenced by the surficial expression of subsurface ruptures of strata and the highly irregular and steep nature of the strata attitudes in the Ponce Limestone and Juana Díaz Formation.

The uppermost unit is of Quaternary age and composed mainly of fan-delta deposits with subordinate amounts of alluvium, terrace, and colluvium deposits (Renken and others, 2002). These occupy the coastal and upper plain areas of the municipio of Ponce. The terrace deposits are generally restricted to the upper plains and the alluvium is found mostly as narrow bands along the streams. Minor swamp and beach deposits of limited extent are found along the coast margin. The fan-delta deposits extend an unknown distance offshore. The subaerial fan-delta deposits include thick to very thick, crudely stratified, clast-supported conglomerates; horizontal and planar cross-stratified boulders, cobbles, pebbles, sand, and thickly bedded to massive silt (Renken and others, 2002). According to lithologic logs in USGS files, field reconnaissance, and Renken and others (2002), these facies may be present as thick horizontal beds, but also may be present as channel-fill deposits enclosed within thickly bedded and massive silt and clay. Generally, the coarser-grained deposits are found in the proximal facies of the fan-delta deposits in the upper plains. The thickness of the fan-delta deposits increases coastward from a featheredge in the upper plains, generally between 30 and 100 ft, to a maximum of about 500 ft in the more coastal reaches. The largest increase in thickness of these deposits towards the coast occurs in what was formerly the interstream area of the Río Bucaná and Río Portugués.

The municipio of Ponce lies within the Great Southern Puerto Rico fault zone. This fault zone, which contains a wide variety of fault structures, is formed by parallel to subparallel sinistral faults that strike northwest and extend diagonally across the south-central part of Puerto Rico (Renken and others, 2002). The courses of the streams in the municipio of Ponce, particularly in the headwaters, seem to be surface expressions of the Great Southern Puerto Rico fault zone. Gravity and seismic data indicate that this regional fault system extends beneath the fan-delta plain and the Isla de Caja de Muertos shelf (Renken and others, 2002). The thickness of the fan-delta plain deposits, however, may conceal partially or completely the occurrence of the Great Southern Puerto Rico fault zone in the more coastal areas.

Climate

The coastal area of the municipio of Ponce lies within the south coastal climatic subdivision (National Oceanic and Atmospheric Administration, 2002). This climatic subdivision is on the leeward side of the Cordillera Central within a rain shadow zone. The long-term average annual rainfall in the municipio of Ponce ranges from 36 in. on the coastal plain to about 100 in. at the highest elevations of the mountainous interior (McClymonds, 1972). During 2002 and 2003, the total annual rainfall measured at Hogares Seguros Puerto Rico Aqueduct and Sewer Authority (PRASA) filtration plant (USGS station number 180944066363700) at an elevation of 2,900 ft was 81 and 103 in., respectively (fig. 4). The Hogares Seguros raingage is located on the insular hydrologic divide, which is also the boundary between the municipios of Ponce and Jayuya (plate 1). Continuous recording rainfall gages are maintained by the USGS at several streamflow gaging stations (table 1). Daily rainfall data are collected near the coast by OHM Remediation Services Corporation in the neighboring municipio of Peñuelas (OHM Remediation Services Corporation, written commun., 2003). There is a general increase in rainfall with elevation in Ponce as shown by the relation between elevation and rainfall for 2002 and 2003 at the rainfall gages listed in table 1 and included in Díaz and others (2001). The total annual rainfall collected at the OHM Remediation Services Corp. in Peñuelas during 2002 and 2003 exceeded the historical long-term annual average rainfall record at Ponce city rainfall station of 27.5 in. from 1970 to 1998

(National Oceanic and Atmospheric Administration, 2002). The rainfall data collected at the Hogares Seguros and Peñuelas rainfall stations and published by McClymonds (1972) indicate the occurrence of seasonal variations in rainfall. January, February, and March are usually relatively dry months, while April and May constitute the first relatively wet period. April and May are generally followed by a rainfall decrease in June and July. August, September, and October are usually the wettest period of the year. Rainfall in November and December is very erratic and December can either be a relatively wet or dry month. As shown in figure 4, April was the rainiest month during 2002 and 2003 at the Peñuelas rainfall gage station, with 7 and 14 in., respectively. November was also a rainy month during 2003 at the Peñuelas rainfall gage station with 11 in. of rainfall. At the Hogares Seguros rainfall gage station, the rainfall during April, November, September, and November ranged between 8 and 17 in. during 2002 and 2003.

The average annual air temperature in the municipio of Ponce is 26ºC, as reported by the National Oceanic and Atmospheric Administration (2002). Long-term temperature data collected by the National Oceanic and Atmospheric Administration (NOAA) indicate that air temperature in the Ponce area also varies with elevation; mean annual temperature at the coastal plain averages 5ºC warmer than at the hydrologic divide on the northern boundary of the municipio.

Previous Studies

Previous to this water-resource assessment, the USGS conducted two studies of note on the water resources in the municipio of Ponce (McClymonds, 1972; Bennett, 1972). The Caribbean Islands Regional Aquifer System Analysis (CI-RASA) assessment included aspects of the water resources in the municipio of Ponce as part of a more comprehensive study of the regional South Coastal Plain Aquifer System (Gómez-Gómez, 1990; Renken and others, 2002).

McClymonds (1972) presented a water budget for the municipio of Ponce for the year 1964. As part of this water budget, the results of McClymonds' study included the average estimates of streamflow and water diverted from the main streams for irrigation, domestic, and public consumption during the late 1960s. This study also included an overview of the spatial pattern in the occurrence and additional development potential of ground water as well as its withdrawal regime during the 1960s. Ground-water withdrawals from August 1964 to July 1965 within the municipio of Ponce were estimated at about 29 Mgal/d; aquifer recharge from furrow irrigation return flow for this same period was estimated at about 27 Mgal/d. The magnitude of this recharge component, according to McClymonds (1972), made ground-water withdrawal feasible in an otherwise hydrologic setting where recharge from precipitation infiltration and river seepage alone are not sufficient to sustain long-term pumping rates like those of the early 1960s when rainfall averaged about 70 percent of normal. The study by McClymonds (1972) also includes a generalized potentiometric map of the aquifer at Ponce for conditions during October-November 1964. During this time period, the furrow irrigation return flow was the main recharge source to the aquifer. Major flood-control works, such as the channelization and truncation of the lower Río Portugués channel by diversion of flow to the Río Bucaná in the coastal plain had not been done. As evidenced in McClymonds' (1972) potentiometric-surface map, the net regional movement of ground water was coastward and streamflow from the rivers contributed recharge to the aquifer in the upper plain areas near the contact between the fan-delta deposits and the Cretaceous rocks.

The ground-water assessment by Bennett (1972) consisted of evaluating the effect of a proposed flood control channel in the Río Bucaná on the ground-water movement and quality in the coastal plain. The analysis was mostly based on the results of an electric analog model representing a coastal narrow band of aquifer that included strips on both sides of the proposed Río Bucaná flood channel. This modeling effort indicated that the Río Bucaná along the upper plain, near the contact between the fan-delta deposits and the Cretaceous rocks, provided recharge to the aquifer whereas in the coastal reaches, the stream functioned mostly as a drain to the aquifer. The modeling effort also indicated that the effect of the proposed flood channel would not affect ground-water flow and chemical quality as long as the furrow irrigation method and the prevailing pumping regime were not substantially altered.

Table 1. Raingage stations in the municipio of Ponce operated by the U.S. Geological Survey.

[USGS, U.S. Geological Survey]

Raingage station identification number	Latitude/Longitude	Elevation in feet above mean sea level	Total rainfall, in inches during 2002	Total rainfall, in inches during 2003
USGS 50115900	18°01’09”/66°36’26”	67	22	38
USGS 50113950	18°04’41”/66°34’38”	611	36	42
USGS 50113800	18°07’01”/66°36’17”	720	58	58
USGS 50114900	18°06’00”/66°38’34”	918	42	88

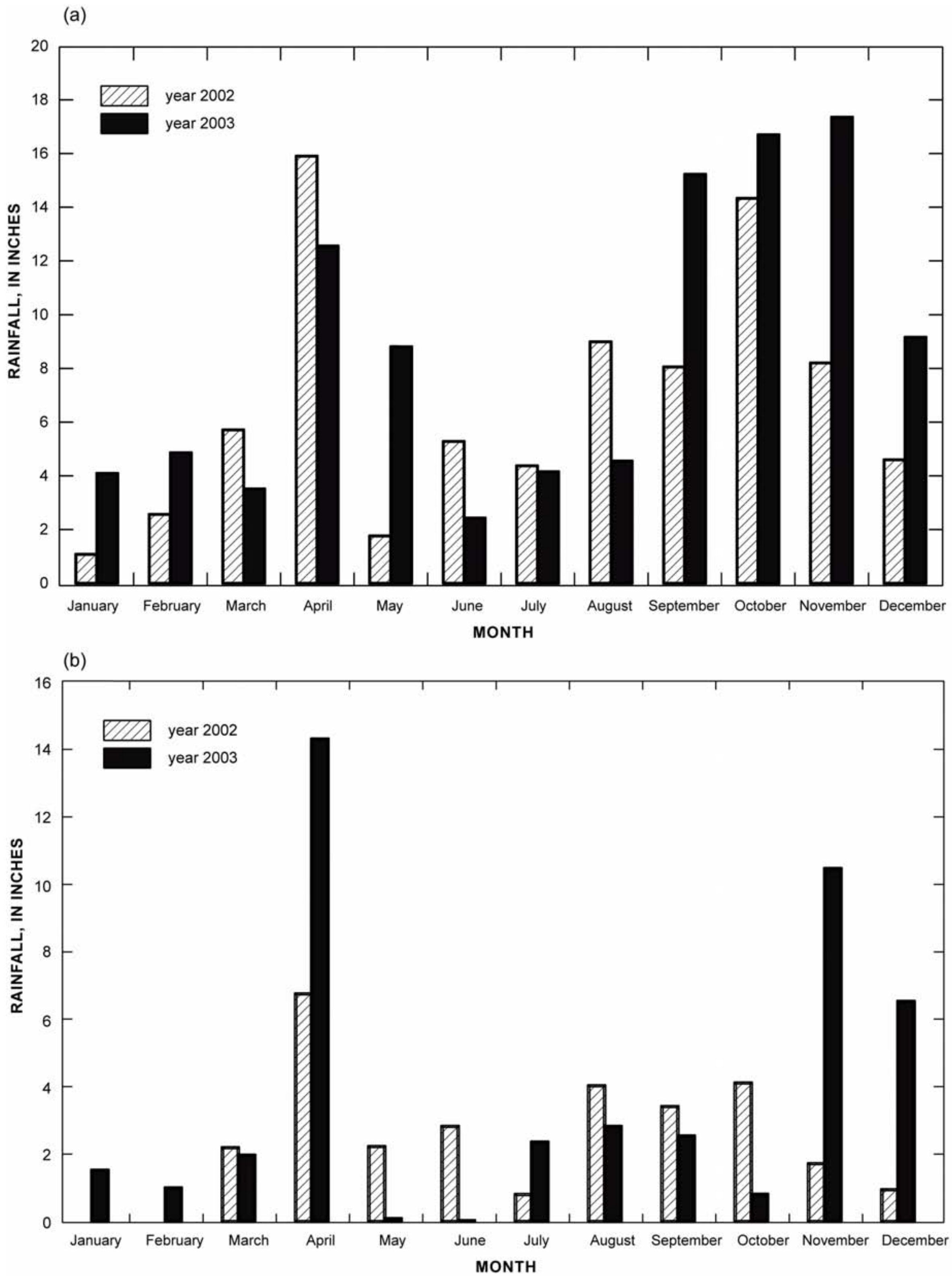


Figure 4. Monthly rainfall distribution during 2002 and 2003 at (a) the Hogares Seguros and (b) Peñuelas rainfall gage stations.

Gómez-Gómez (1990) included Ponce as part of a study on the geochemical evolution of the ground water in the regional South Coastal Plain Aquifer System, owing to changes in land use and increased development of the ground-water resources. The results of this study indicated that in Ponce, as in the rest of the south coast, a decrease in irrigated farmland in conjunction with a major change from surface water-derived furrow irrigation of sugar cane to ground water-derived drip irrigation of vegetables caused a significant decrease in recharge to the aquifer. In addition, these changes were expected to cause a gradual upconing of lower-quality ground water and eventually saline water intrusion. The change in irrigation practice with the resulting decrease in recharge to the aquifer combined with high pumping rates might cause a serious deterioration in the ground-water quality in Ponce as in the rest of the south coast.

Rodríguez-del-Río and Quiñones-Aponte (1990) delineated the potentiometric surface representative of the hydrologic conditions in the main aquifer of the Ponce area during April-May 1987. The publication by Rodríguez-del-Río and Quiñones-Aponte (1990) indicates that by April-May 1987 furrow irrigation, although significantly less than during the study by McClymonds (1972), was still predominant in areas where agricultural activity, mainly sugar cane cultivation, was still active in the Ponce area. Nonetheless, by April-May 1987 excess furrow irrigation return flows, although at a much lower scale than in 1964, still provided substantial recharge to the aquifer in the Ponce area. By 1989, farmland using drip irrigation, was mainly restricted to small areas planted in fruits and vegetables in the vicinity of the Barrio Coto Laurel in the southeastern part of Ponce (plate 2). Also during 1987, about 1,000 acres of farmland in the vicinity of the Central Mercedita sugar mill were being irrigated with effluent from the mill and rum distillery. The ground-water withdrawal rate estimated by Rodríguez-del-Río and Quiñones-Aponte (1990) was about 24.5 Mgal/d. The potentiometric-surface map by Rodríguez-del-Río and Quiñones-Aponte (1990) indicated a general coastward movement of the ground water as in the map prepared by McClymonds (1972). A comparison of both potentiometric-surface maps, however, indicates that ground-water levels generally declined by as much 5 ft in the more coastal reaches of the coastal plain within the period between October-November 1964 and April-May 1987.

Renken and others (2002) presented information on the depositional environments and their influence on the lithologic and hydraulic characters of the fan-delta deposits and underlying limestone in the municipio of Ponce. The information presented by Renken and others (2002) included data collected and interpreted prior to 1992. Of particular importance among the new findings included in this report is the offshore extent of the delta-fan deposits, which may reach the Isla Caja de Muertos shelf. This finding indicates that the fresh ground-water zone of the coastal aquifer may also extend a certain distance offshore. Richards (2003) related the response of water levels at selected wells to changes in barometric pressure to infer the presence of confining conditions at various localities in Puerto Rico. The data analyzed by Richards (2003) indicates the occurrence of ground water under confined conditions at several wells in the study area.

Chapter A: Surface-Water Resources Assessment of the Municipio of Ponce, Puerto Rico, 2002-2004

By Luis Santiago-Rivera and Fernando Gómez-Gómez

Purpose and Scope

The USGS in cooperation with the Municipio Autónomo de Ponce conducted an investigation of the surface- and ground-water resources from October 1, 2002, to September 30, 2004, in the area primarily within the geographic limits of the municipio of Ponce (plate 1). A major component of the study consisted of 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 Ponce included 3 long-term continuous-record (index) gaging stations and 27 partial-record stations (tables 2 and 3, respectively, at end of chapter). The index stations are located on the Río Inabón (50112500), Río Cerrillos (50113800), and Río Portugués (50115000, inactive since 1997) (plate 1). The 27 partial-record stations are distributed among a number of streams within the geographic limits of the municipio of Ponce (plate 1). Streamflow was measured concurrently eight times at the index and partial-record stations during selected base-flow recessions over a 2-year period, from March 2002 to July 2003. These data were used to obtain low-flow and flow-duration estimates. The 7-day, 10-year ($7Q_{10}$) and the 7-day, 2-year ($7Q_2$) low-flow frequency characteristics were computed for the continuous-record gaging stations and estimated for the partial-record stations. Flow-duration characteristics for 99-, 95-, and 90-percent probability of exceedance also were computed for the 3 continuous-record gaging stations and estimated for the 27 partial-record stations.

The following pertinent information regarding surface-water hydrology within the municipio of Ponce is presented on a thematic map (plate 1):

- streamflow data-collection sites;
- drainage-basin boundaries for the streamflow sites in which the low flows were determined;
- potential reservoir sites;
- flood-prone areas as delineated by the Federal Emergency Management Agency (1996);
- an active public waste-water treatment facility and effluent discharge point; and
- the inland extent of the salt-water wedges along the main streams and rivers.

Methodology

A series of eight discharge measurements were taken concurrently at 3 index- and 27 partial-record streamgaging 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 index- and partial-record stations. Analyses of low-flow characteristics for the index stations were based on frequency analyses of the annual minimum 7-day low flows (table 2). Using the streamflow data generated during this study, the partial-record stations base-flow measurements were related to concurrent base-flow discharge measurements or daily mean flows at the nearby index stations (Riggs, 1972) (fig. 5). The low-flow characteristics at partial-record stations then were estimated using the corresponding characteristics at the index stations (table 3). This methodology has been applied elsewhere in Puerto Rico (Santiago-Rivera, 1992, 1996, 1998).

Flow-duration characteristics were computed for the index stations using techniques described by Searcy (1959); flow-duration characteristics were estimated for the partial-record stations using flow-duration characteristics of the index stations 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 stations and partial-record stations were calculated without incorporating the effects of public-supply water withdrawals and waste-water discharges upstream from stations. Estimated withdrawals and effluent discharges were compiled from data furnished by the PRASA and data reported by Black and Veatch Consulting Engineers (1996) and are presented in the header of each index and partial-record station in tables 2 and 3.

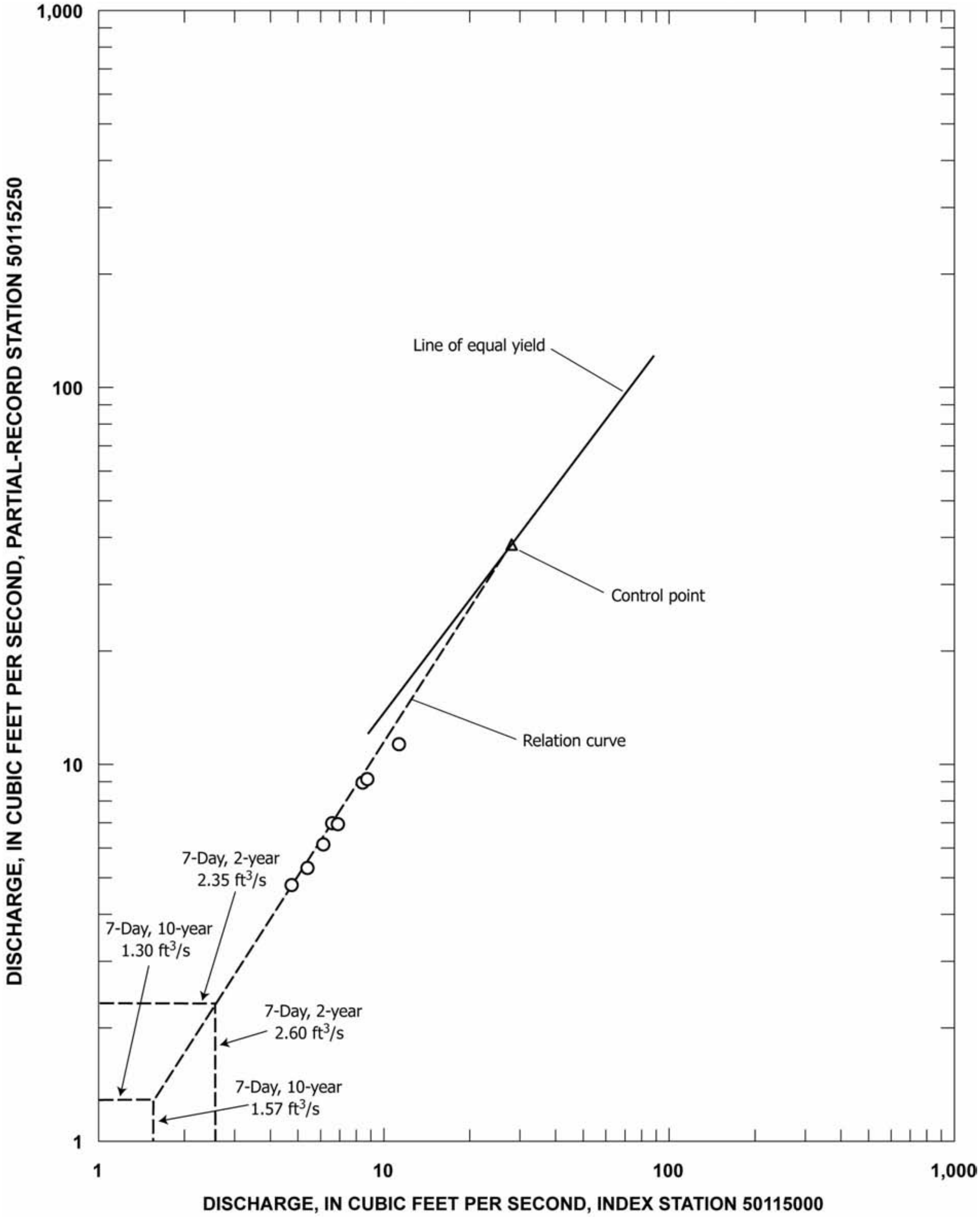


Figure 5. Relation between concurrent discharges at a partial-record station and a nearby continuous-record station of the municipio of Ponce, Puerto Rico.

The reliability of the low-flow and flow-duration estimates for index stations is affected by the length of the streamflow record on which the estimates are based and by potential trends within those data. Annual minimum 7-day averages for the three index gaging stations used in this analysis were tested for trends by comparison of $7Q_{10}$ statistics for various 10 year periods. None of these tests revealed any trends in the data for any of the index stations.

Results and Interpretation

Flow-duration characteristics were estimated for 27 partial-record stations using flow-duration characteristics derived for the index stations in conjunction with the base-flow relation developed for the low-flow study. Index stations' discharges for the 99-, 95-, and 90-percent flow duration were used as the explanatory variables for the corresponding percent-duration points at the 27 partial-record stations.

Low-Flow Characteristics at Continuous-Record Gaging Stations

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 three index stations 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 stations used in this report are presented in table 2. The index stations used in this analysis are affected by public-supply water withdrawals. During the time of this study, public-supply water withdrawals upstream from index station 50112500 were estimated at 1.1 cubic feet per second (ft^3/s), and 0.73 ft^3/s for index station 50115000 ((PRASA), filtration plant records for the year 2000). The net stream low-flow off-stream diversion of 1.83 ft^3/s upstream from these two index stations can result in computational underestimates of low-flow statistics at partial-record sites for which index stations Río Inabón at Real Abajo (50112500) and Río Portugués near Ponce (50115000) were used as the index stations.

Low-Flow Characteristics at Partial-Record Stations

A partial-record station is a site where limited streamflow and water-quality data are collected systematically over a period of time for use in hydrologic analysis. At the partial-record stations used in this study, base-flow measurements were made from March 2002 to July 2003 to define an adequate relation with concurrent flows at a nearby index station. Using this relation, low-flow characteristics were estimated by graphical correlation (Riggs, 1972) (fig. 5). This estimating technique transfers flow characteristics computed by the log-Pearson Type III frequency distribution for the index station through the base-flow relation to determine the corresponding low-flow characteristics at the partial-record stations (fig. 5, for details of this figure please refer to Santiago-Rivera, 1998). 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 light agricultural activity and are underlain by igneous rocks of low permeability. Instantaneous streamflow measurements made at partial-record stations are presented in Díaz and others (2004). Low-flow characteristics were estimated for 27 partial-record stations and are presented in table 3.

Flow-Duration Characteristics

A flow-duration characteristic is the daily mean discharge for a given stream that has been exceeded a specified percentage of days during the period of record. Flow-duration characteristics were computed for the index stations using techniques developed by Searcy (1959). The analysis of the index stations was based on daily streamflow records for complete water years (from October 1 to September 30), and the results are presented in table 2. Flow-duration characteristics were estimated for 27 partial-record stations using flow-duration characteristics derived for the 3 index stations in conjunction with the base-flow relation developed for the low-flow study. Index stations' discharges for the 99-, 95-, and 90-percent flow duration were used as the explanatory variable to estimate the discharges for the corresponding percent-duration points at the 27 partial-record stations (table 3).

Drainage-Basin Area/Discharge Relation

Dividing the 99th-percentile discharge by the contributing drainage area provides a preliminary estimate of discharge yield per unit-drainage area. This analysis ratio can be used to evaluate effective rainfall recharge within the study area. Discharge yields per unit of area are highest in the upper drainage basin of the Río Inabón, (average unit-area yield of 0.42 cubic feet per second per square mile ($ft^3/s\text{-}mi^2$) for stations 50112200, 50112225, and 50112250). In the upper drainage basin of the Río Cerrillos the average unit-area yield is 0.39 $ft^3/s\text{-}mi^2$ for stations 50113640, 50113650, 50113725, and 50113780. At the Río Portugués the average unit-area yield is 0.31 $ft^3/s\text{-}mi^2$ for partial-record stations 50114750 and 50114850. The upper drainage basin of the Río Canas has an average unit-area yield of 0.39 $ft^3/s\text{-}mi^2$ for partial-record station 50116600. The remaining stations have an average 99th-percentile discharge-per-unit area ranging from 0.03 to

1.2 $ft^3/s\text{-}mi^2$. Discharge yields at the 99th percentile for the Río Inabón at Real Abajo (index station 50112500), the Río Cerrillos upstream of the Lago Cerrillos (index station 50113800), and the Río Portugués near Ponce basin to index station 50115000 contribute a total of 6.80 ft^3/s (about 4.4 Mgal/d) from a drainage area of 30.4 mi^2 (equivalent to 0.22 $ft^3/s\text{-}mi^2$).

Map Features

A 1:30,000-scale map (plate 1) shows the location of hydrologic data-collection stations, drainage basin boundaries, existing or potential reservoir sites (U.S. Corps of Engineers, 1988), the 100- and 500-year flood-prone areas (Federal Emergency Management Agency, 1996), and the documented inland extent of the salt water wedge at principal streams. This map also summarizes the flow characteristics and stream and estuary bacteriological (sanitary) quality during low-flow conditions (see Chapter B for discussion of water quality).

Reservoir Sites

One existing reservoir and one potential reservoir site are shown in plate 1. The Lago Cerrillos reservoir, located in the Río Cerrillos basin, has a drainage area at spillway of about 17.4 mi^2 and is a major source of public-supply water for the Ponce metropolitan area. This reservoir was built for flood control, water supply, and recreational use. Construction work was completed in 1992. The reservoir had an initial total storage capacity of 47,900 acre-feet (acre-ft), of which 25,200 acre-ft of storage are for flood control purposes and about 17,000 acre-ft available for public-supply water use.

The Portugués reservoir has not been completed, but construction has been initiated. The reservoir when completed will have a drainage area at the spillway of about 10.4 mi^2; the reservoir is being built for flood control, public-supply water, and to provide recreation. The reservoir maximum storage capacity will be 24,200 acre-ft with 8,250 acre-ft for flood control and 14,100 acre-ft for public-supply water (U.S. Corps of Engineers, 1988).

A series of small privately owned, impoundments, located near the Río Inabón lower basin and used for irrigation purposes were field checked during this study to verify their present status. Seven of these impoundments were found to be dry, whereas the others were still in use as indicated on plate 1.

Two surface-water intakes are presently operating on the Río Portugués basin upstream from the Lago Portugués reservoir to supply water to the Guaraguao and Tibes filtration plants, respectively. A third surface-water intake located in the Río Portugués downstream of the Lago Portugués proposed spillway location has been abandoned.

Flood-Prone Areas

The FEMA has designated seven different types of flood-prone areas for the town of Ponce (Federal Emergency Management Agency, 1996). These areas are shown on plate 1. Zone A is the flood insurance rate zone that corresponds to the 1-percent annual chance flooding that is determined in a Flood Insurance Study by approximate methods of analysis. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone. Mandatory flood insurance purchase requirements apply. Zones AE and A1-A30 (A8 to A12 and A15 to A17) are the flood insurance rate zones that correspond to the 1-percent annual chance flooding that are determined in the Flood Insurance Study by detailed methods of analysis. In most instances, base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone. Mandatory flood insurance purchase requirements apply. Zone AO is the flood insurance rate zone that corresponds to the areas of 1-percent shallow flooding (usually sheet flow on sloping terrain), where average depths are between 1 and 3 ft. Average flood depths derived from the detailed hydraulic analyses are shown within this zone. Alluvial fans subject to flood hazards are shown as Zone AO on Flood Insurance Rate Maps. Mandatory flood insurance purchase requirements apply. Zone VE is the flood insurance rate zone that corresponds to areas within the 1-percent annual chance of flooding that have additional flood hazards associated with storm waves. Base flood elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone. Mandatory flood insurance purchase requirements apply. Zone B is the flood insurance rate zone that corresponds to areas outside the 1-percent annual chance of flooding, areas of 1-percent annual chance sheet flow flooding where average depths are less than 1 foot, areas of 1-percent annual chance stream flooding where the contributing drainage area is less than 1 mi^2, or areas protected from the 1-percent annual chance flood by levees. No base flood elevations or depths are shown within this zone. Flood insurance is not required in these zones.

Salt Water Wedge at Streams

Freshwater is lighter than, and tends to float over, salt water. As a result, where streams discharge into the ocean, a wedge of salt water may lie underneath the freshwater in the stream channel. The landward extent of this wedge may move upstream when the discharge of the stream is diminished. Therefore, it is important to define the maximum inland extent of the salt water wedge at zero stream discharge, especially at streams such as the Río Bucaná, where base flows are captured for irrigation and public-supply water use. The maximum inland extent of the salt wedge should occur when stream discharge is zero and would be located at the point along the stream where the altitude of the stream channel is equivalent to the altitude of the maximum high tide. Because of the sparsity of channel bathymetric data and the difficulty of determining where the stream beds intercept the elevation of maximum high tides, the approximate inland extent of the salt water wedge was made by conducting a survey of specific conductivity of streams during base-flow conditions (plate 1). The inland extent of the salt water wedge was determined for five rivers as indicated in plate 1.

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

There are seven public-supply water filtration plants within the municipio of Ponce (table 4, plate 1). These are the Nueva filtration plant supplied from Lago Toa Vaca reservoir at the municipio of Juana Díaz (Lago Toa Vaca is outside of Ponce municipal boundary); Vieja filtration plant also supplied from the Lago Toa Vaca reservoir and previously a gravity intake on the Río Portugués that has been abandoned; Coto Laurel filtration plant also supplied from the Lago Toa Vaca reservoir; Guaraguao filtration plant with a pump station on the Río Portugués; Tibes filtration plant with a gravity intake on a tributary of the Río Portugués; Real Anón filtration plant with gravity intakes on the Río Anón (Raíces intake) and the Quebrada Emajagua (Jurutungo intake); Hogares Seguros filtration plant with a pump station on the Río Jauca (Río Jauca intake is outside of Ponce municipal boundary). There is one waste-water treatment facility in Ponce. The Ponce Regional Waste-Water Treatment facility is located at Barrio Canas and adjacent to the mouth of the Río Matilde (table 4, plate 1). The Ponce Regional Waste-Water Treatment facility was reported to have a daily mean discharge of 14 Mgal/d in 2001 (Puerto Rico Aqueduct and Sewer Authority, 2001). Plant effluent discharges to the Caribbean Sea through an ocean outfall located offshore and to the southwest of the mouth of the Río Matilde. The location of the public waste-water treatment facility and other pertinent data are listed in table 4 and shown on plate 1.

Table 2. Summary of drainage-basins, low-flow, and flow-duration characteristics for continuous-record gaging stations within the municipio of Ponce, Puerto Rico.

[Lat, latitude; long, longitude; ft^3/s, cubic feet per second; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; Mgal/d, million gallons per day]

RIO INABON BASIN
50112500 Río Inabón at Real Abajo, Puerto Rico

LOCATION--Lat 18°05'10", long 66°33'46", Hydrologic Unit 21010004, at bridge on private road, off Highway 511 at Hacienda La Concordia, 0.4 mi (0.6 km) upstream from diversion canal, 0.5 mi (0.8 km) north of Real Abajo, and 6.1 mi (9.8 km) northeast of Plaza Degetau in Ponce.

DRAINAGE AREA--9.70 mi^2 (25.1 km^2).

PERIOD OF RECORD ANALYZED--April 1971 to September 2000.

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

REMARKS--A diversion of 0.69 Mgal/d (1.06 ft^3/s) is made upstream from station for public-supply water.

LOW-FLOW CHARACTERISTICS
[Based on 1971-2000 water years]

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.6
7-day, 10-year	1.6

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	1.7	2.6	3.3

Table 2. Summary of drainage-basins, low-flow, and flow-duration characteristics for continuous-record gaging stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; ft^3/s, cubic feet per second; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; Mgal/d, million gallons per day]

RIO BUCANA BASIN

50113800 Río Cerrillos above Lago Cerrillos near Ponce, Puerto Rico

LOCATION--Lat 18°07'01", long 66°36'17", Hydrologic Unit 21010004, on right bank, 0.3 mi (0.5 km) downstream from confluence with Río San Patricio, 0.1 mi (0.2 km) southwest of Highway 139, and 2.4 mi (3.7 km) northwest of Maragüez.

DRAINAGE AREA--11.9 mi^2 (30.8 km^2).

PERIOD OF RECORD ANALYZED--December 1988 to September 2000.

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

REMARKS--None.

LOW-FLOW CHARACTERISTICS
[Based on 1971-2000 water years]

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	5.5
7-day, 10-year	3.4

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	3.4	4.4	5.4

50115000 Río Portugués near Ponce, Puerto Rico

LOCATION--Lat 18°04'45", long 66°38'01", Hydrologic Unit 21010004, at right bank, upstream from bridge on Highway 504, 0.2 mi (0.3 km) upstream from small unnamed tributary, 4.4 mi (7.1 km) upstream from Río Chiquito, and 4.7 mi (7.6 km) north of Plaza Degetau in Ponce.

DRAINAGE AREA--8.82 mi^2 (22.0 km^2).

PERIOD OF RECORD ANALYZED--July 1964 to September 1997.

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

REMARKS--A diversion of 0.47 Mgal/d (0.72 ft^3/s) is made upstream from station for public-supply water. Station 50115000 was discontinued in 1997, due to the construction work of Lago Portugués.

LOW-FLOW CHARACTERISTICS
[Based on 1971-2000 water years]

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.6
7-day, 10-year	1.6

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	1.7	2.3	2.9

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO INABON BASIN

50112200 Río Inabón near Salto de Inabón, Puerto Rico

LOCATION--Lat 18°08'35", long 66°34'41", Hydrologic Unit 21010004, at barrio Anón, 1.8 mi (2.9 km) southwest of Cerro Maravilla, 2.3 mi (3.7 km) southeast of Cerro de Punta, and 1.8 mi (2.9 km) south of Monte Jayuya.

DRAINAGE AREA--1.30 mi^2 (3.37 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50112500.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	.8
7-day, 10-year	.6

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	.6	.8	1.0

50112225 Quebrada Emajagua near Anón, Puerto Rico

LOCATION--Lat 18°08'34", long 66°34'28", Hydrologic Unit 21010004, at barrio Anón, 1.5 mi (2.4 km) southwest of Cerro Maravilla, and 1.9 mi (3.1 km) south of Monte Jayuya, and 2.5 mi (4.0 km) southeast of Cerro de Punta.

DRAINAGE AREA--0.91 mi^2 (2.36 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50112500.

REMARKS--Discharge measurements were made about 30 ft upstream from Real Anón filtration plant gravity intake.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.4
7-day, 10-year	0.2

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.3	0.4	0.5

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO INABON BASIN—Continued
50112250 Río Anón at Anón, Puerto Rico

LOCATION--Lat 18°08'45", long 66°35'38", Hydrologic Unit 21010004, at barrio Anón, 2.7 mi (4.3 km) southwest of Cerro Maravilla, 2.1 mi (3.4 km) southwest of Monte Jayuya, and 2.0 mi (3.2 km) south of Cerro de Punta.

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 50112500.

REMARKS--Discharge measurents were made about 100 ft upstream from Real Anón filtrarion plant gravity intake.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.8
7-day, 10-year	0.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.7	0.8	0.9

50112300 Río Anón near Anón, Puerto Rico

LOCATION--Lat 18°08'29", long 66°35'13", Hydrologic Unit 21010004, at barrio Anón, 2.3 mi (3.7 km) southwest of Cerro Maravilla, 2.1 mi (3.4 km) southwest of Monte Jayuya, and 2.3 mi (3.7 km) southeast of Cerro de Punta.

DRAINAGE AREA--1.58 mi^2 (4.09 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50112500.

REMARKS--A diversion of 0.62 Mgal/d (0.95 ft^3/s) is made upstream of site to Real Anón filtration plant for public-supply water.

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	0.3	0.5	0.6

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO INABON BASIN—Continued
50112425 Río Inabón near Real Anón, Puerto Rico

LOCATION--Lat 18°07"06", long 66°34'29", Hydrologic Unit 21010004, at barrio Anón, 1.9 mi (3.0 km) northwest of Cerro Augustinillo, 0.7 mi (1.1 km) east of Cerro Santo Domingo, and 2.6 mi (4.2 km) northeast of Pico Pinto.

DRAINAGE AREA--6.46 mi^2 (16.7 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50112500.

REMARKS--A diversion of 0.69 Mgal/d (1.06 ft^3/s) is made upstream of site to filtration plant Real Anón for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.0
7-day, 10-year	1.2

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.3	2.0	2.5

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN

50113640 Río Prieto at Anón, Puerto Rico

LOCATION--Lat 18°09'19", long 66°35'56", Hydrologic Unit 21010004, at barrio Anón, 1.4 mi (2.2 km) southwest of Cerro de Punta, 1.8 mi (2.9 km) southwest of Monte Jayuya, and 2.9 mi (4.7 km) west of Cerro Maravilla.

DRAINAGE AREA--1.22 mi^2 (3.16 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	.9
7-day, 10-year	.6

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	.6	.7	.8

50113650 Río Prieto at Highway 139, Puerto Rico

LOCATION--Lat 18°08'48", long 66°36'25", Hydrologic Unit 21010004, at barrio Anón at Highway 139, 2.1 mi (3.4 km) southwest of Cerro de Punta, 2.6 mi (4.2 km) southwest of Monte Jayuya, and 3.5 mi (5.6 km) southwest of Cerro Maravilla.

DRAINAGE AREA--1.67 mi^2 (4.32 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	1.0
7-day, 10-year	0.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.7	0.8	1.0

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50113700 Quebrada Jamiel near Ponce, Puerto Rico

LOCATION--Lat 18°08'51", long 66°36'42", Hydrologic Unit 21010004, at barrio Anón at Highway 139, 2.2 mi (3.5 km) southwest of Cerro de Punta, 2.9 mi (4.7 km) southwest of Monte Jayuya, and 3.8 mi (6.1 km) southwest of Cerro Maravilla.

DRAINAGE AREA--0.54 mi^2 (1.40 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

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	.1	.2

50113710 Río Blanco at Highway 139, Puerto Rico

LOCATION--Lat 18°08'49", long 66°36'34", Hydrologic Unit 21010004, at barrio Anón at Highway 139, 2.2 mi (3.5 km) southwest of Cerro de Punta, 2.7 mi (4.3 km) southwest of Monte Jayuya, and 3.7 mi (6.0 km) southwest of Cerro Maravilla.

DRAINAGE AREA--0.54 mi^2 (1.40 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	0.3
7-day, 10-year	0.2

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.2	0.2	.3

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50113725 Río Cerrillos at Anón, Puerto Rico

LOCATION--Lat 18°08'16", long 66°36'47", Hydrologic Unit 21010004, at barrio Anón, 2.8 mi (4.5 km) southwest of Cerro de Punta, 3.3 mi (5.3 km) southwest of Monte de Jayuya, and 4.1 mi (6.6 km) southwest of Cerro Maravilla.

DRAINAGE AREA--3.76 mi^2 (9.74 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.2
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	1.4	1.8	2.2

50113780 Río San Patricio near San Patricio, Puerto Rico

LOCATION--Lat 18°07'34", long 66°37'04", Hydrologic Unit 21010004, near barrio San Patricio, 3.7 mi (6.0 km) southwest of Cerro de Punta, 4.1 mi (6.6 km) southwest of Monte Jayuya, and 4.6 mi (7.4 km) southwest of Cerro Maravilla.

DRAINAGE AREA--4.97 mi^2 (12.9 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARK--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.8
7-day, 10-year	1.8

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.8	2.3	2.7

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued
50113792 Río Cerrillos near Anón, Puerto Rico

LOCATION--Lat 18°07'11", long 66°36'26", Hydrologic Unit 21010004, downstream of confluence with Río San Patricio, 2.2 mi (3.5 km) northwest of Pico Pinto, 1.4 mi (2.2 km) northwest of Cerro Santo Domingo, and 3.9 mi (6.3 km) northwest of Cerro Augustinillo.

DRAINAGE AREA--11.4 mi^2 (29.5 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	6.0
7-day, 10-year	3.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	3.8	4.8	5.8

50114140 Quebrada Ausubo at Machuelo Arriba, Puerto Rico

LOCATION--Lat 18°04'06", long 66°35'44", Hydrologic Unit 21010004, at barrio Machuelo Arriba, 1.3 mi (2.1 km) southeast of Pico Pinto, 3.8 mi (6.1 km) southwest of Cerro Augustinillo, and 4.0 mi (6.4 km) northeast of Plaza Degetau in Ponce.

DRAINAGE AREA--0.53 mi^2 (1.37 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	< .1
7-day, 10-year	< .1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	< .1	< .1	< .1

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued
50114175 Río Bayagán downstream of Highway 505, Puerto Rico

LOCATION--Lat 18°04'31", long 66°36'39", Hydrologic Unit 21010004, at barrio Machuelo Arriba, 1.2 mi (1.9 km) southwest of Pico Pinto, and 4.4 mi (7.1 km) southwest of Cerro Augustinillo, and 4.2 mi (6.8 km) north of Plaza Degetau in Ponce.

DRAINAGE AREA--1.74 mi^2 (4.51 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	< .1
7-day, 10-year	< .1

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	< .1	< .1	< .1

50114190 Río Bayagán at Machuelo Arriba, Puerto Rico

LOCATION--Lat 18°03'38", long 66°36'04", Hydrologic Unit 21010004, at barrio Machuelo Arriba, 1.9 mi (3.1 km) south of Pico Pinto, 4.4 mi (7.1 km) southwest of Cerro Augustinillo, and 3.3 mi (5.3 km) northeast of Plaza Degetau in Ponce.

DRAINAGE AREA--2.82 mi^2 (7.30 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50113800.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	.1
7-day, 10-year	< .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	.1

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50114750 Río Portugués at Guaraguao, Puerto Rico

LOCATION--Lat 18°08'13", long 66°40'27", Hydrologic Unit 21010004, at barrio Guaraguao, 3.6 mi (5.8 km) southeast of Cerro El Gigante, 1.8 mi (2.9 km) northeast of Cerro Garrote, and 2.3 mi (3.7 km) southwest from La Pica.

DRAINAGE AREA--2.30 mi^2 (5.96 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--Discharge measuring site was located about 75 ft upstream from Guaraguao filtration-plant pump intake.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	1.4
7-day, 10-year	1.0

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.1	1.3	1.5

50114850 Río Portugués at Highway 503, Puerto Rico

LOCATION--Lat 18°06'17", long 66°38'38", Hydrologic Unit 21010004, at barrio Tibes at Highway 503, 0.6 mi (1.0 km) west of Cerro del Diablo, and 3.9 mi (6.3 km) southeast of Cerrote de Peñuelas.

DRAINAGE AREA--5.35 mi^2 (13.8 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--A diversion of 0.42 Mgal/d (0.65 ft^3/s) is made upstream of site to Guaraguao filtration plant for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.0
7-day, 10-year	1.2

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.3	1.8	2.2

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50114880 Tributario de Río Portugués at Tibes, Puerto Rico

LOCATION--Lat 18°06'46", long 66°38'20", Hydrologic Unit 21010004, at barrio Tibes, 0.9 mi (1.4 km) upstream from Río Portugués, 0.7 mi (1.1 km) northwest of Cerro del Diablo, and 4.1 mi (6.6 km) southeast of Cerrote de Peñuelas.

DRAINAGE AREA--1.17 mi^2 (3.03 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--Discharge measuring site was located about 100 ft upstream from Tibes filtration-plant gravity intake.

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	0.2

50114950 Río Portugués downstream of Highway 10, Puerto Rico

LOCATION--Lat 18°05'20", long 66°38'30", Hydrologic Unit 21010004, at barrio Tibes, 0.9 mi (1.4 km) northeast of Corral Viejo, 1.2 mi (1.9 km) southwest of Cerro del Diablo, and 4.5 mi (7.2 km) southeast of Cerrote de Peñuelas.

DRAINAGE AREA--8.18 mi^2 (21.2 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--A diversion of 0.47 Mgal/d (0.72 ft^3/s) is made upstream of site to Guaraguao and Tibes filtration plants for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.4
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 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50115225 Río Portugués near Portugués, Puerto Rico

LOCATION--Lat 18°03'24", long 66°38'00", Hydrologic Unit 21010004, at barrio Tibes, 0.8 mi (1.3 km) east of Escuela Industrial de Niñas, 1.2 mi (1.9 km) north of El Madrigal, and 3.3 mi (5.3 km) south of Cerro del Diablo.

DRAINAGE AREA--10.6 mi^2 (27.4 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARK--A diversion of 0.47 Mgal/d (0.72 ft^3/s) is made upstream of site to Guaraguao and Tibes filtration plants for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.5
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	2.8

50115250 Río Portugués near Magüeyes, Puerto Rico

LOCATION--Lat 18°02'36", long 66°37'08", Hydrologic Unit 21010004, at barrio Portugués, 3.3 mi (5.3 km) southwest of Pico Pinto, 1.0 mi (1.6 km) southwest of Cerro El Gato, and 2.1 mi (3.4 km) northwest of Plaza Degetau in Ponce.

DRAINAGE AREA--12.1 mi^2 (31.3 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--A diversion of 0.47 Mgal/d (0.72 ft^3/s) is made upstream of site to Guaraguao and Tibes filtration plants for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.4
7-day, 10-year	1.3

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.4	2.1	2.6

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO BUCANA BASIN—Continued

50115475 Río Chiquito near Portugués, Puerto Rico

LOCATION--Lat 18°03'41", long 66°37'16", Hydrologic Unit 21010004, at barrio Portugués, 2.3 mi (3.7 km) southwest of Pico Pinto, 0.9 mi (1.4 km) northwest of Cerro El Gato, and 3.3 mi (5.3 km) northwest of Plaza Degetau in Ponce.

DRAINAGE AREA--3.40 mi^2 (8.81 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

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

50115895 Río Portugués near Caserio Dr. Pila, Puerto Rico

LOCATION--Lat 18°01'17", long 66°36'28", Hydrologic Unit 21010004, at Ponce at Highway 14, 2.3 mi (3.7 km) southeast of Cerro El Gato, 2.9 mi (4.7 km) west of Central Mercedita, and 0.7 mi (1.1 km) northeast of Plaza Degetau in Ponce.

DRAINAGE AREA--18.2 mi^2 (47.1 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--A diversion of 0.47 Mgal/d (0.72 ft^3/s) is made upstream of site to Guaraguao and Tibes filtration plants for public-supply water.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	2.1
7-day, 10-year	1.0

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	1.2	1.8	2.4

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than]

RIO MATILDE BASIN

50116600 Río Canas at Guaraguao, Puerto Rico

LOCATION--Lat 18°06'34", long 66°39'50", Hydrologic Unit 21010004, at barrio Guaraguao at Highway 501, 2.0 mi (3.2 km) northeast of Corral Viejo, 2.6 mi (4.2 km) southeast of Cerrote de Peñuelas, and 1.9 mi (3.1 km) northwest of Cerro del Diablo.

DRAINAGE AREA--1.79 mi^2 (4.64 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	1.0
7-day, 10-year	0.7

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.7	0.9	1.1

50116802 Río Canas near Magüeyes, Puerto Rico

LOCATION--Lat 18°04'20", long 66°39'10", Hydrologic Unit 21010004, at barrio Magüeyes about 300 ft (91 m) west of Highway 123, 4.6 mi (7.4 km) southeast of Cerrote de Peñuelas, 2.5 mi (4.0 km) southwest of Cerro del Diablo.

DRAINAGE AREA--4.02 mi^2 (10.4 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (cubic feet per second)
7-day, 2-year	1.0
7-day, 10-year	0.6

FLOW-DURATION CHARACTERISTICS

Discharge, in cubic feet per second, which was exceeded for indicated percentage of days			
Percent	99	95	90
Discharge	0.6	0.9	1.1

Table 3. Summary of drainage-basins, low-flow, and flow-duration estimates for partial-record stations within the municipio of Ponce, Puerto Rico.—Continued

[Lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile; km^2, square kilometer; ft, feet; m, meter; Mgal/d, million gallons per day; ft^3/s, cubic feet per second; <, less than.

RIO MATILDE BASIN—Continued
50116900 Río Canas at Magüeyes, Puerto Rico

LOCATION--Lat 18°02'45", long 66°38'44", Hydrologic Unit 21010004, at barrio Magüeyes, 0.7 mi (1.1 km) south of Escuela Industrial de Niñas, 6.3 mi (10.1 km) southeast of Cerrote de Peñuelas, and 4.1 mi (6.6 km) southwest of Cerro del Diablo.

DRAINAGE AREA--5.68 mi^2 (14.7 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

REMARK--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	0.5	0.8	1.0

50117600 Río Pastillo at Highway 501, Puerto Rico

LOCATION--Lat 18°03'56", long 66°39'51", Hydrologic Unit 21010004, at barrio Marueño at Highway 501, 1.4 mi (2.2 km) northwes of Escuela Industrial de Niñas, 3.3 mi (5.3 km) southwest of Cerro del Diablo, and 4.5 mi (7.2 km) southeast of Cerrote de Peñuelas.

DRAINAGE AREA--2.95 mi^2 (7.64 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of eight base-flow measurements with concurrent base flows at gaging station 50115000.

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

Table 4. Principal features of public-supply water filtration plants, surface-water intakes, a public waste-water treatment facility, and treated waste-water outlets within the municipio of Ponce, Puerto Rico.

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

Public-supply water filtration plants and surface-water intakes (plate 1)	Plant design capacity [a] (Mgal/d)	Safe yield [b] (Mgal/d)	Water available for use [c] (Mgal/d)	Mean daily withdrawal rate [d] (Mgal/d)	Source stream
Nueva	20.0	--	--	18.0	Lago Toa Vaca Lago Cerrillos
Vieja	4.00	--	--	4.72	Lago Toa Vaca Lago Cerrillos
Vieja gravity intake	--	--	--	--	Río Portugués (abandoned)
Coto Laurel	1.00	--	--	1.59	Lago Toa Vaca
Guaraguao intake (old)	--	--	--	--	Río Canas (abandoned)
Guaraguao (new)	0.36	--	--	0.42	--
Guaraguao pump intake	--	--	0.71	--	Río Portugués
Tibes	0.29	--	--	0.05	--
Tibes gravity intake	--	0.16	0.06	--	Río Portugués
Real Anón	0.36	--	--	0.69	--
Real Anón Jurutungo gravity intake	--	--	0.19	0.07	Quebrada Emajagua
Real Anón Raices gravity intake	--	0.12	0.45	0.62	Río Anón
Hogares Seguros	0.14	--	--	0.16	--
Hogares Seguros pump intake	--	--	--	--	Río Jauca
Public waste-water treatment facilities and effluent-discharge points (plate 1)		**Discharge capacity (Mgal/d)**	**Mean daily discharge rate (estimate 2001) (Mgal/d)**	**Receiving stream**	
Ponce regional waste-water treatment facility		18	--	--	
Ponce Regional Waste-Water Treatment facility ocean outfall		--	14	Caribbean Sea	

[a] Puerto Rico Aqueduct and Sewer Authority / Professional Service Group, written commun., 1997-98.

[b] Black and Veatch, 1996.

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

[d] 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 Ponce, Puerto Rico, 2002

By José M. Rodríguez and Fernando Gómez-Gómez

Purpose and Scope

A survey of stream sanitary quality was conducted by the USGS in cooperation with the municipio of Ponce, to define the extent of fecal contamination in streams within the municipal boundaries of Ponce. This chapter describes the methods and techniques used in conducting the survey, and describes a classification procedure to rank the sanitary quality of stream reaches using the fecal coliform and *Escherichia coli* (*E. coli*) indicator bacteria concentrations.

The synoptic surveys were conducted in streams within the municipio of Ponce, however, one of the streams has its headwaters outside of the municipio. The assessment was made by obtaining and analyzing water samples for fecal coliform and *E. coli* bacteria from 27 stream locations during base-flow conditions between March and May 2002, and in September 2002. The sampling network within the municipio of Ponce was divided into three drainage basins; these basins are the Río Inabón, the Río Bucaná, and the Río Matilde. Twelve samples were collected in 6 stream reaches in the Río Inabón basin, 28 samples in 14 stream reaches in the Río Bucaná basin, and 14 samples in 7 stream reaches in the Río Matilde basin.

The sanitary quality stream ranking was incorporated into a thematic map (plate 1) that also includes other important hydrologic features (drainage basins, potential reservoir sites, flood-prone areas, and inland extent of the saltwater wedge at principal streams) 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.

Background

Water-quality standards for surface waters in Puerto Rico have been established by the Puerto Rico Environmental Quality Board (1990 and 2003) on the basis of the designated use (for example, fishing, source of raw water for public supply, and secondary contact recreation). All perennial fresh surface waters in Puerto Rico inland of their estuary segments have been classified as Class SD waters. This classification includes surface waters intended for use (or potential use) as a raw source of public-supply water, 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 concentrations of fecal coliform or total coliform indicator bacteria (Puerto Rico Environmental Quality Board, 1990, 2003).

All coastal water bodies (except the Port of Ponce) within the municipio of Ponce and the estuary segments of the Río Bucaná and Río Inabón 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 including threatened or endangered species. This designated use also applies to the coastline at Ponce from the mean tide level to a distance up to 1,650 ft (500 meters) offshore (plate 1). Along the coastal segment of the Port of Ponce (from Punta Carenero to Punta Cuchara) 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. When large fecal coliform populations are present in the water, it is assumed that there is likelihood that pathogens are present (U.S. Environmental Protection Agency, 2001). Contact with fecal-contaminated water can lead to ear or skin infections, and inhalation of contaminated water can cause respiratory infection. Typical concentrations of two common indicator bacteria in contaminated water are (1) fecal coliform (FC), 200 to greater than 2 million colonies per 100 milliliters (col/100 mL), and (2) *E. coli*, 126 to greater than 2 million col/100 mL (Myers, 2003). The fecal coliform (FC) bacteria group includes several types of bacteria including *E. coli* bacteria. Several of the fecal coliform bacteria including *E. coli* are native to the intestines of warm-blooded animals, including humans, and are considered non-pathogenic.

The *E. coli* bacteria were chosen as the secondary indicator of bacterial contamination because they are the most abundant of the fecal coliform bacteria and are a better indicator of fecal contamination. The U.S. Environmental Protection Agency (1986) has set a criterion for *E. coli* on the basis of the intended use of the water body. For bathing (full-body contact) in recreational freshwater, on the basis of a statistically sufficient number of samples (generally not less than five samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities of *E. coli* should not exceed 126 col/100 mL. When present in water, *E. coli* is an indicator of contamination from human or animal feces and is an indicator of the risk of exposure to pathogenic organisms. 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.

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 col/100 mL for total coliform bacteria or 200 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 (Puerto Rico Environmental Quality Board, 2003, Article 3, Section 2.4, as amended March 28, 2003). The Puerto Rico water-quality standards were last amended on March 2003 and included a modification to the standard for coliforms for Class SD waters. The amendment maintains the limit of 10,000 col/100 mL for total coliforms, but modifies the limit for fecal coliform from 2,000 col/100 mL to 200 col/100 mL. The sanitary quality standards for surface water are summarized in table 5.

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 (7Q2) discharge (Puerto Rico Environmental Quality Board, 2003). The 7Q2 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 salt water is based on total coliform and fecal coliform concentrations as follows: (1) the geometric mean concentration of at least five samples obtained in sequential order should not exceed 10,000 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 (Puerto Rico Environmental Quality Board, 2003). 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 Water Quality Standards Regulations) by the Junta de Calidad Ambiental de Puerto Rico (2003).

Table 5. Puerto Rico sanitary surface water-quality standards.

[col/100 mL, colonies per 100 milliliters; NA, not applicable]

Water body classification	Total coliform (col/100 mL)	Fecal coliform (col/100 mL)
SD, surface waters intended for use (or potential use) as a raw source of public-supply water, for propagation and preservation of desirable aquatic species, and for primary (swimming) and secondary (boating and fishing) contact recreation	10,000	200
SB, coastal and estuarine waters intended for use in primary and secondary recreation and for propagation and preservation of desirable aquatic species including threatened and endangered species	NA	200
SC, coastal waters 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.	10,000	2,000

Contamination sources that affect stream sanitary quality during base-flow conditions are distinct for urbanized and rural areas of Ponce. In urbanized areas, probable major sources of fecal contamination are (1) illegal discharge of sewage to stormwater drains, especially within the older sectors of the city of Ponce; (2) overflows from sewer mains into the stormwater 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 Ponce 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 domestic-use waste-water discharges other than 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 the municipio of Ponce are available from the monitoring stations at the Río Portugués (USGS stations 50115000 and 50116200) and the Río Cerrillos (USGS station 50114000). Systematic sampling for selected physical, chemical, and bacteriological constituents has been carried out at these stations by the USGS in cooperation with the Puerto Rico Environmental Quality Board (PREQB) since 1985. The long-term data for the stations mentioned above are available in the USGS annual Water Resources Data for Puerto Rico and U.S. Virgin Islands report series (Curtis and others, 1988-1991; Díaz and others, 1993-2002) and in the online National Water Information System (NWISWeb - http://waterdata.usgs.gov/pr/nwis). The trend of geometric mean concentrations for fecal coliform bacteria of five sequential samples at these stations for the period 1985 to 2001 is shown in figures 7a-7c (refer to fig. 6 for locations).

Historical data (1985-2001) for fecal coliform were used for a preliminary assessment of the sanitary quality of streams in the Ponce area. The data indicate (1) acceptable sanitary quality at station 50114000 with a long-term geometric mean fecal coliform bacteria concentration below 2,000 col/100 mL for the whole period of record and below 200 col/100 mL since 1996; (2) acceptable sanitary quality at station 50115000 with a long-term geometric mean fecal coliform concentration below 2,000 col/100 mL for the period of record and below 200 col/100 mL since year 2000; and (3) deteriorated sanitary quality at station 50116200, in which the geometric means for fecal coliform bacteria concentrations have, for the most part, remained above the 2,000 col/100 mL.

Methodology

Fifty-four primary water samples were collected at selected streams within the municipio of Ponce and analyzed for indicator bacteria concentrations. The water samples were collected and analyzed following the methods and procedures established by the USGS (Myers, 2003). The results were used to classify the sanitary water quality of approximately 130 mi of perennial streams within the municipio of Ponce.

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). Fourteen 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 7Q2, 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 (Puerto Rico Environmental Quality Board, 2003). The 7Q2 value also approximates to the stream discharge under base-flow conditions.

One long-term quality-of-water baseline station (50114000) located within the study area was not sampled as part of this study; however, this station is sampled on a regular basis as part of the cooperative program between the USGS and the Puerto Rico Environmental Quality Board. A sampling station was established for this study 0.74 mi downstream from the station 50114000, because stream-reach conditions at this station were not adequate for data collection at the time of the study. Two other quality-of-water long-term baseline stations sampled regularly and that lie within the study area are stations 50115000 and 50116200. These stations were sampled twice during this study.

Most samples were obtained during stream base-flow periods between March and May 2002, and September 2002, for two hydrologic conditions: (1) near the annual stream low-flow discharge, and (2) during base-flow conditions after a rainfall event. The base flow is the sustained low flow of a stream, which in most streams is composed largely of ground-water inflow to the stream channel (Langbein and Iseri, 1972). Samples obtained during these flow regimes were used to rank approximately 130 stream miles within the municipio of Ponce 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, 27 stream sampling stations were established and sampled on two occasions near the annual low flow or at base flow to comply with the requisite of base-flow conditions. The sanitary condition of stream courses was classified using data obtained from a total of 27 stream sampling stations.

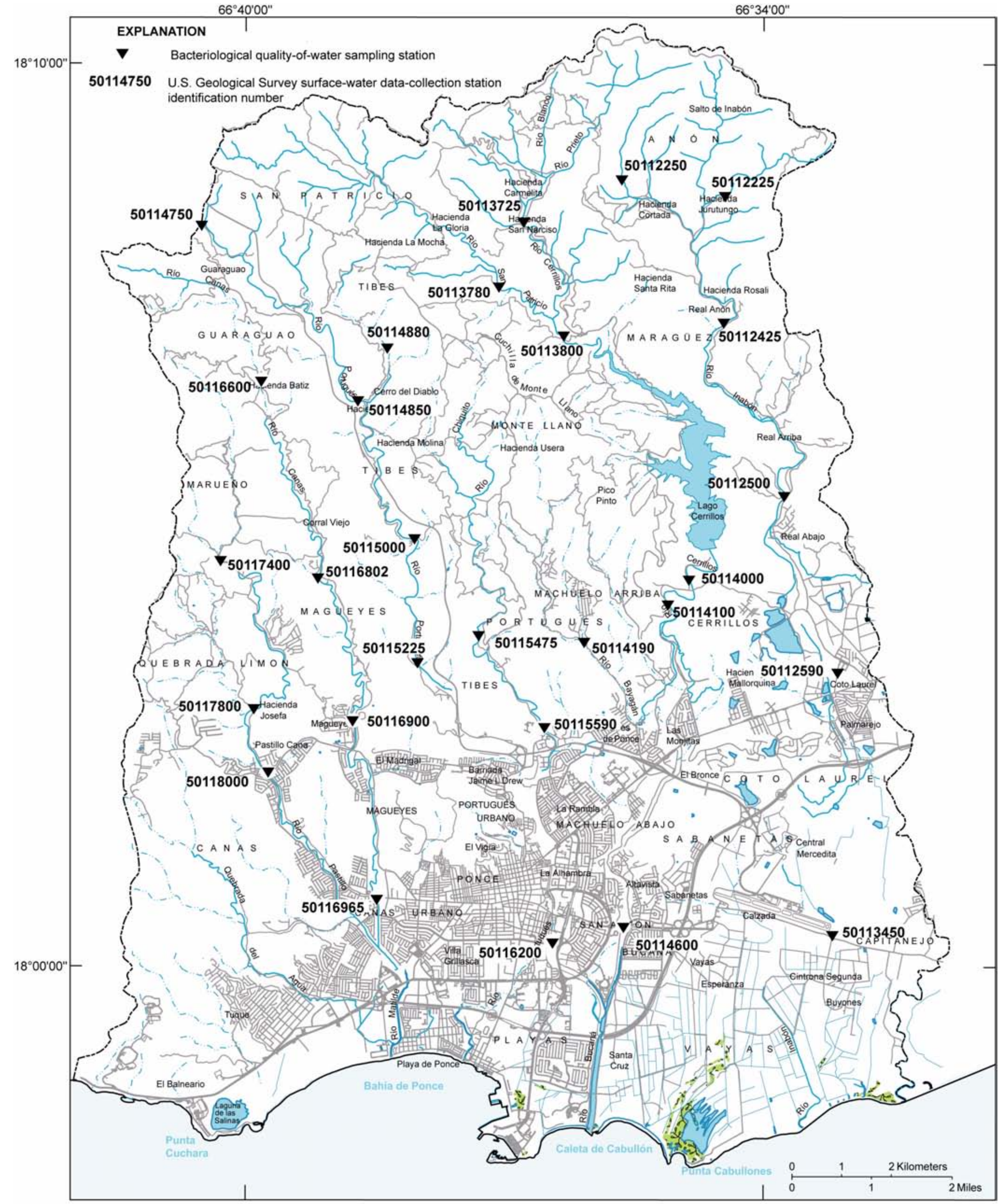


Figure 6. Locations of bacteriological quality-of-water sampling stations, including the long-term stations at which bacteriological quality data have been obtained at or near the municipio of Ponce, Puerto Rico.

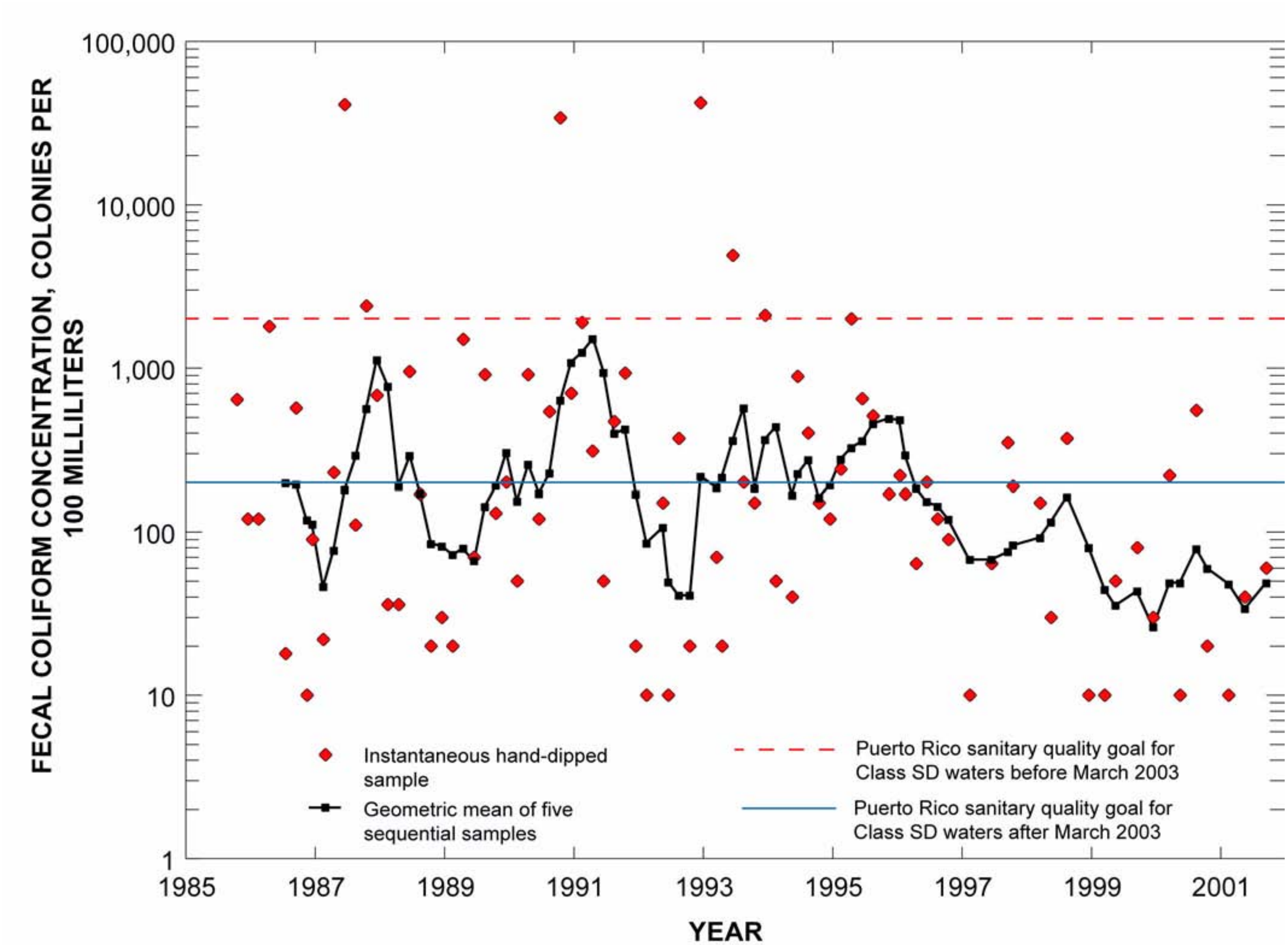


Figure 7a. Geometric mean concentration of fecal coliform at Río Cerrillos near Ponce (USGS station 50114000), 1985-2001 (from Water Resources Data, Puerto Rico and the U.S. Virgin Islands, Colón-Dieppa and others, 1987; Curtis and others, 1988-1991; Díaz and others, 1993-2002).

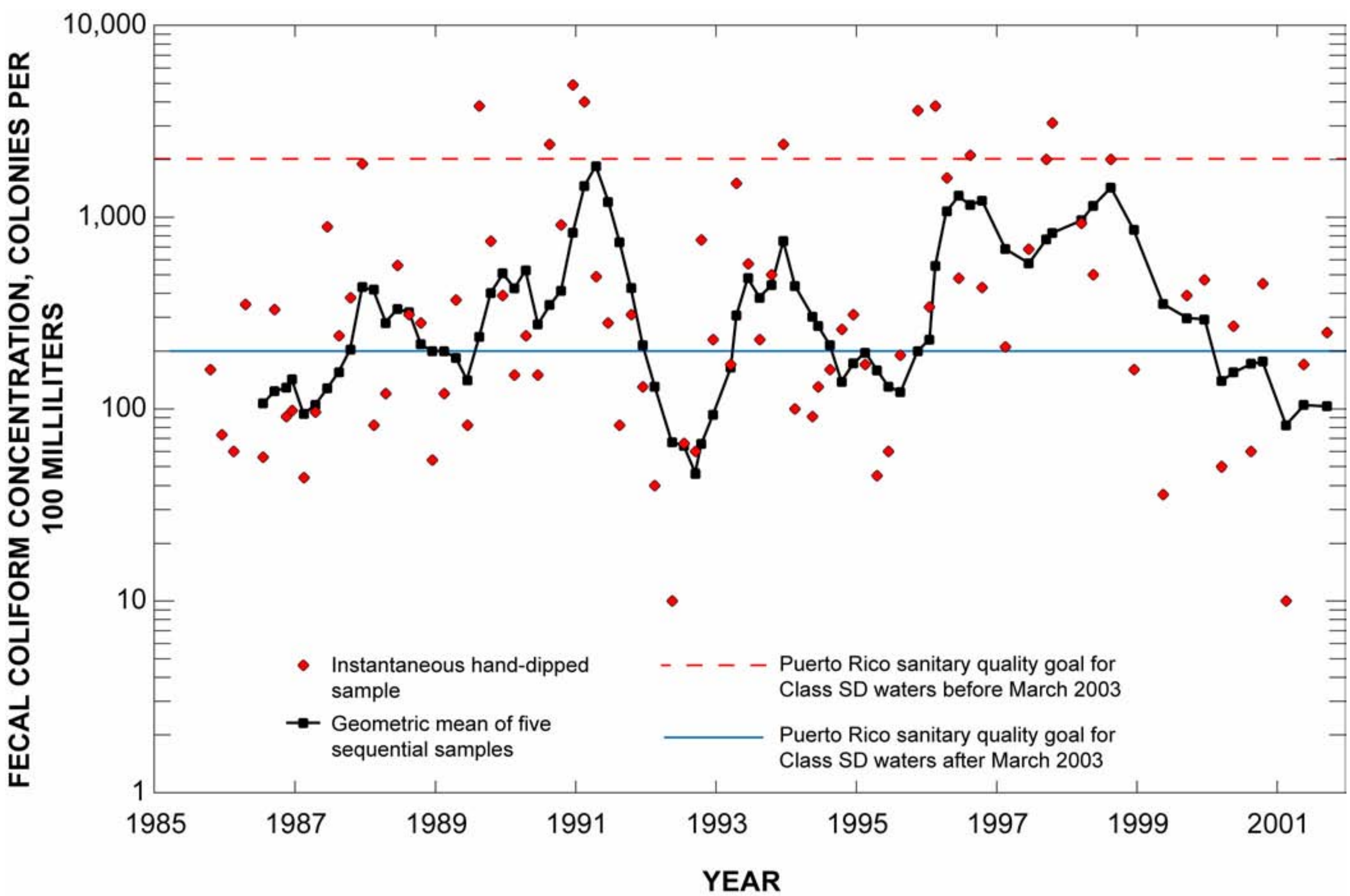


Figure 7b. Geometric mean concentration of fecal coliform at Río Portugués near Ponce (USGS station 50115000), 1985-2001 (from Water Resources Data, Puerto Rico and the U.S. Virgin Islands, Colón-Dieppa and others, 1987; Curtis and others, 1988-1991; Díaz and others, 1993-2002).

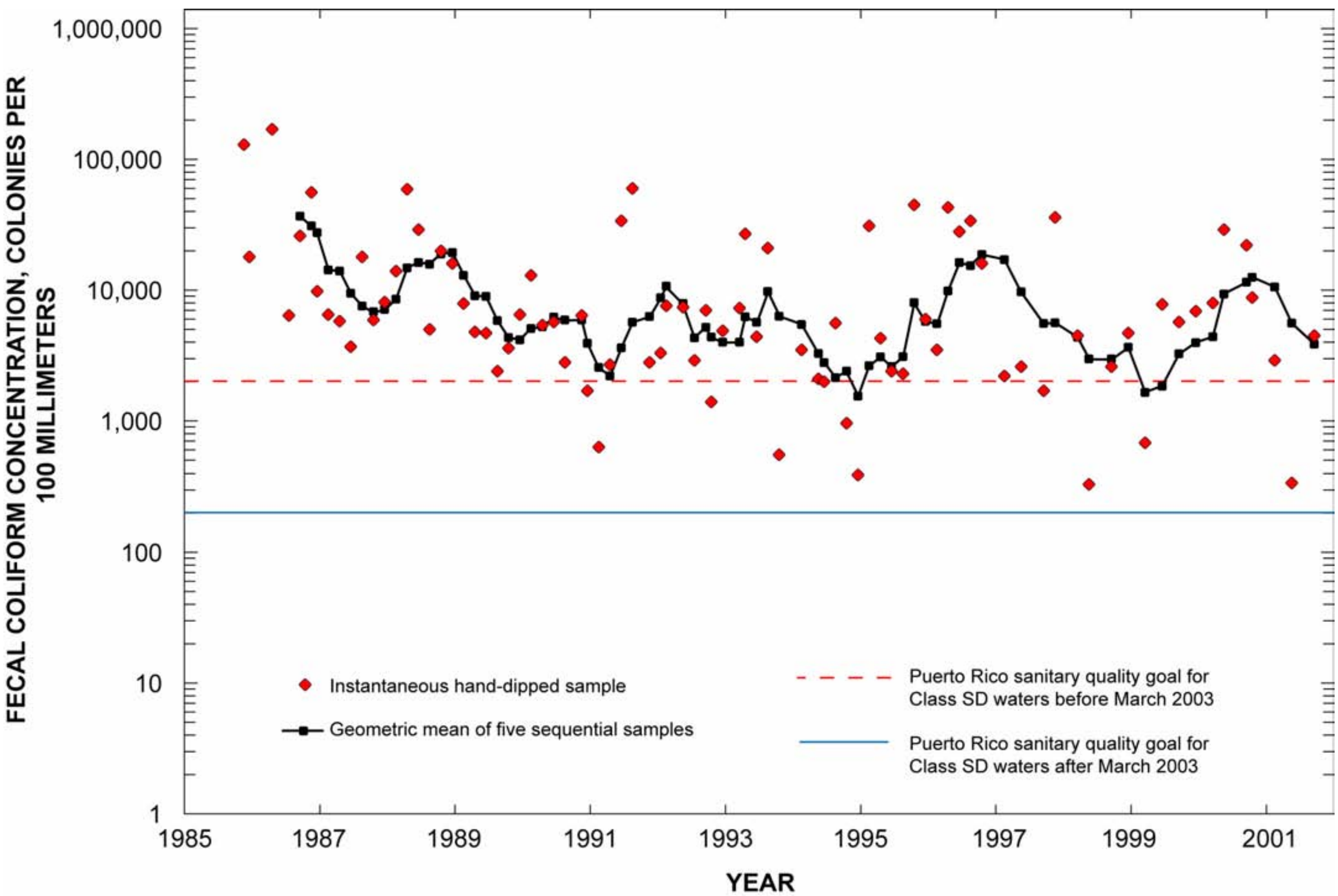


Figure 7c. Geometric mean concentration of fecal coliform at Río Portugués at Ponce (USGS station 50116200), 1985-2001 (from Water Resources Data, Puerto Rico and the U.S. Virgin Islands, Colón-Dieppa and others, 1987; Curtis and others, 1988-1991; Díaz and others, 1993-2002).

Water samples for fecal coliform and *E. coli* bacteria analyses were collected from a total of 27 locations at streams with drainage to or within the municipio of Ponce (fig. 6 and plate 1). Water samples were collected at all stream stations using the "hand-dip" method (Britton and Greeson, 1989; Myers, 2003). This method is most applicable under the low-flow stream conditions characteristic of this study. Other sampling methods commonly used by the USGS are the equal discharge increment (EDI) or equal width increment (EWI) method. These methods are not warranted in streams where the depth is less than 0.8 ft or the velocity is less than 1.5 ft per second (Myers, 2003). The streams in the area during base-flow conditions are generally less than 2 ft deep and 25 ft wide. Following the "hand-dip" sampling method, a sterile narrow-mouth borosilicate glass 100 milliliter (mL) bottle was dipped 1 to 2 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 (Myers, 2003). Once filled, the bottle containing the water sample is removed from the stream, keeping the opening pointed upward, and tightly capped, allowing about 1 to 2 in. 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. In addition to the collection of the water samples for the bacteriological analyses, measurements of water temperature, specific conductance, and pH were conducted in the field.

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.

Analytical Techniques

The analytical techniques include the methods and procedures used to determine the fecal indicator bacteria concentrations and the quality control measures applied during the samples analyses. A clean, sterile environment is required while processing water samples for fecal indicator bacteria. Handling and analytical bias is reduced by preparing dilutions that are withdrawn from a well-mixed sample bottle. Proper agar preparation and incubator temperature minimize false positives and false negatives.

The membrane-filter immediate incubation test was used to measure fecal coliform and *E. coli* bacteria concentrations following standard USGS procedures (Britton and Greeson, 1989; Myers, 2003). Materials such as the sterile narrow-mouth borosilicate glass 100-mL sampling bottle, distilled water, m-FC agar, sodium hydroxide solution and rosolic acid crystals for fecal coliform tests and distilled water, M-TEC agar, and urea substrate for *E. coli* 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 Water Science Center 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 *E. coli* bacteria. The filtration equipment used during this study (Millipore Hydrosol ™) is made of stainless steel and was flame sterilized with methanol between each sampling station. Sterile buffered water was used to dilute samples and rinse the membrane filtration apparatus. Phosphate buffer solution was used for the fecal coliform test and saline buffer solution was used for *E. coli* tests.

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 80 colonies per filter for *E. coli* 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 filtration using solid-block incubators at the USGS mobile laboratory. Fecal coliform bacteria are defined as the organisms that produce blue colonies in whole or in part within 24 hours (+/-2 hours) when incubated at 44.5 (+/-0.2) °C on m-FC medium. For the *E. coli* bacteria test, samples in the M-TEC medium are incubated at 35.0 (+/-0.5) °C for 2 hours (resuscitation) and then for 22 to 24 hours at 44.5 (+/-0.2) °C. *E. coli* bacteria are defined as the organisms that produce yellow or yellow-brown, round, raised, and smooth colonies that remain so when placed on filter pad saturated with urea substrate broth for 15 minutes after the incubation process described above. The results for the ideal count were reported in terms of fecal coliform bacteria or *E. coli* bacteria colony counts per 100 milliliters of raw water sample using the following formula:

$$NCC \text{ per } 100\ mL = (NCC / VOSF) \times 100, \qquad (1)$$

where

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

VOSF is the volume of original sample filtered for the dilution that gives the ideal count.

If there was more than one ideal count, then the colony counts were averaged using the following formula (Myers, 2003):

$$NCC\ per\ 100\ mL = (NCC_{sum} / VOSF_{sum}) \times 100, \qquad (2)$$

where

NCC_{sum} is the sum of the indicator colony counts, and
$VOSF_{sum}$ is the sum of the volumes of the original samples 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 to 60 for fecal coliform and 20 to 80 for *E. coli*), the colony counts were averaged using equation (2), 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 80 for *E. coli*) 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 the bacteria analyses constitute 37 percent of the total number of samples collected over the study period. The QC samples for bacteriological analyses in this study included (a) field sequential 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, stream variability, dilution, and analytical procedures). Field replicate samples collected and analyzed during this study represented 18 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 sequential replicate samples. Relative percent difference (RPD) of primary and replicate samples is calculated as:

$$RPD = \{[S_1 - S_2] / [(S_1 + S_2)/2]\} \times 100, \qquad (3)$$

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 4 to 46 percent with a median value of 27 percent (table 6).

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.

Table 6. Relative percent difference for fecal coliform bacteria counts between primary and field replicate samples collected at streams in the municipio of Ponce, Puerto Rico, 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
50112225	Quebrada Emajagua near Anón	10	8	22
		8	11	31
50112250	Río Anón at Anón	20	30	40
		16	10	46
50115225	Río Portugués near Portugués	140	100	33
		46	44	4
50114750	Río Portugués at Guaraguao	100	122	20
		110	95	15
50114880	Tributario de Río Portugués at Tibes	50	40	22
50117400	Río Pastillo at Marueño	150	100	40

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).

Stream Ranking Rationale

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 base-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 *E. coli* bacteria concentrations from the 27 stream sampling stations are used to characterize the sanitary quality of about 130 mi of perennial stream channels within the municipio of Ponce.

A relative ranking of the stream sanitary quality was used to delimit stream channels as being either **good**, **acceptable**, **fair**, or **poor** (Rodríguez-Martínez and others, 2002) (table 7). This relative ranking was established using the Puerto Rico Water Quality Standards for fecal coliform of 200 col/100 mL (Puerto Rico Environmental Quality Board, 2003), and the following rationale: If both samples had fecal coliform bacteria concentrations less than 200 col/100 mL and *E. coli* concentrations less than 126 col/100 mL, the **good** classification was assigned to the sampling station. The 126 col/100 mL is the quality criterion for recreational water established by the USEPA (1986). 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 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 kilometer) 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.

For sampling stations where fecal coliform bacteria concentrations were equal to or less than 200 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 200 col/100 mL for one sampling occasion, but less than 200 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 200 col/100 mL for both sample dates were considered **poor**. The classification of **presumed poor** was extended upstream and downstream of the sampling station following the same rationale as stated previously for **good** and **presumed good**.

Table 7. Classification rationale used in ranking the sanitary quality of streams in the municipio of Ponce, Puerto Rico (modified from Rodríguez-Martínez and others, 2002).

[>, 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	*Escherichia coli* concentration, in colonies per 100 mL
Good	< 200	Samples obtained at site also had *Escherichia coli* concentrations less than 126 colonies per 100 mL.	**Maximum**	100	110
			Minimum	8	6k
			Geometric mean	22	22
			Number of samples	10	10
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**	100	110
			Minimum	8	6k
			Geometric mean	22	22
			Number of samples	10	10
Acceptable	< or equal to (=) 200	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	200	570
			Minimum	46	60
			Geometric mean	89	153
			Number of samples	10	10
Presumed acceptable	< or equal to (=) 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**	110	570
			Minimum	60	82
			Geometric mean	88	225
			Number of samples	4	4
Fair	Equal probability for < or > 200	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	4,000	6,500
			Minimum	10	<10
			Geometric mean	164	142
			Number of samples	16	16
Presumed fair	Equal probability for < or > 200	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**	4,000	6,500
			Minimum	<10	<10
			Geometric mean	157	176
			Number of samples	12	12
Poor	> 200	Samples obtained within 0.6 mi upstream or downstream of delimited reach.	**Maximum**	70,000	62,000
			Minimum	230	130
			Geometric mean	1,200	1,200
			Number of samples	18	18
Presumed poor	> 200	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.	**Maximum**	11,000	12,000
			Minimum	230	130
			Geometric mean	792	868
			Number of samples	10	10

Results and Interpretation

The analytical results for fecal coliform and *E. coli* bacteria concentrations from the 27 stream sampling stations were used to characterize the sanitary quality of about 130 mi of perennial stream channels within the municipio of Ponce (plate 1 and table 8). The characterization of the stream sanitary quality was based on the assumptions of the stream ranking rationale described in the previous section.

Río Inabón Basin

The upper section of the Río Inabón basin is well forested and not densely populated. The sampling network for the upper Río Inabón basin included one sampling station in the Quebrada Emajagua sub-basin and one in the Río Anón sub-basin (plate 1 and table 8). The Quebrada Emajagua at Anón station (50112225) and the Río Anón at Anón (50112250) sanitary water quality was classified as **good**. The sanitary water quality at the stations Río Inabón at Anón (50112425) was classified as **acceptable**. Various tracts of housing units border the stream, for about 1 mi above station Río Inabón at Anón (50112425). The sanitary water quality at the stations Río Inabón at Real Abajo (50112500) and Río Inabón at Coto Laurel (50112580) were classified as **fair**. Two 1-mi segments of housing communities bordering the stream were observed above station Río Inabón at Real Abajo (50112500). The sanitary water quality at the stations Río Inabón at Arus (50113450) was classified as **poor**. The uppermost segment of Río Inabón was not sampled; however, based on similar land use at the sub-basins sampled by stations 50112225 and 50112250, the sanitary quality of 5.98 mi in this segment of the stream was classified as **presumed good**. In the Río Inabón basin, 4.46 mi of stream segments were classified as **good** and **acceptable** and approximately 10 mi were classified as **fair** and **poor**.

Río Bucaná Basin

The Río Bucaná basin includes the drainage basins of Río San Patricio, Río Cerrillos, Río Bayagán, and Río Portugués. The stream network in this basin has a total length of 76.5 mi of perennial steams of which 75 mi were ranked in this study (table 9). Water samples were collected at sampling stations at Río San Patricio, Río Cerrillos, Río Bayagán, Río Chiquito, and Río Portugués. The sanitary water quality at station Río San Patricio (50113780) was classified as **good**. The sanitary water quality at station Río Cerrillos at Anón (50113725) and Río Cerrillos above Lago Cerrillos (50113800) were classified as **fair**. The sanitary water quality at the Río Cerrillos at Anón (50113725) station, although located at the headwaters of the Río Bucaná basin, may be affected housing units located along the stream.

Samples were not collected at four tributaries to the Río Cerrillos, which include the Río Prieto, Río Blanco, Quebrada Jamiel, and Quebrada Rosales. These streams, which have a total length of 10.6 mi, are in the headwaters of the Río Cerrillos. Distinct to the headwaters of the Río Inabón, this area is more populated and sections of the streams are bordered by housing units, especially at the Quebrada Jamiel. Based on this characteristic of the basin and the **fair** classification assigned to station 50113725, these stream segments were classified as **presumed fair**.

The sanitary water quality at station Río Cerrillos near Maragüez (50114100) was classified as **acceptable**. The improvement of the water quality observed at the Río Cerrillos near Maragüez station compared to upstream stations may be caused by the Lago Cerrillos reservoir, which is located 1.54 mi upstream from the station.

One sampling station located in the Río Bayagán was classified as **poor**. The station is located downstream of a densely populated area, with approximately 1 mi bordered by housing units.

The sampling network in the Río Portugués sub-basin consists of eight sampling stations: five stations along the main stem of the Río Portugués, two along the Río Chiquito, and one along an unnamed tributary to the Río Portugués. A total of 27.9 mi of perennial streams were classified in this sub-basin (table 9). In general, the sanitary water quality in the Río Portugués sub-basin is the best in the study area (plate 1 and table 8). The results indicate that five of the eight stations, with a total 12.5 mi of streams (45 percent), were classified as **good** and **acceptable**. A total of 3.7 mi upstream or downstream of these five sampling stations were classified as **presumed good** and **presumed acceptable**. The results at these five stations indicate fecal coliform bacteria concentrations substantially below the requirements for SD class surface waters established as the Puerto Rico water quality standard in March 2003.

The station Río Portugués at Guaraguao, which is located in the uppermost section of the Río Portugués main stem, was classified as **acceptable**. This station is located downstream from a segment of housing units bordering the stream. The sanitary water quality at two of the sampling stations—the Río Portugués at Highway 503 (station 50114850) and Tributario de Río Portugués at Tibes (50114880)—were classified as **good** (table 8). The stations Río Portugués near Ponce (50115000) and Río Portugués near Portugués (50115225) were classified as **acceptable**, although some segments of housing units border the stream 0.73 mi upstream of the station.

Two sampling stations were located in the Río Chiquito, which is a tributary to the Río Portugués. Station Río Chiquito near Portugués (50115475) was classified as **fair** and station Río Chiquito at Highway 504 (50115590) was classified as **poor**. A stream segment of 0.93 mi is bordered by housing units between stations 50115475 and 50115590.

The Río Portugués traverses a densely populated area downstream of sampling station 50115225 and the sanitary water quality deteriorates substantially. The sanitary water quality at sampling station Río Portugués at Ponce (station 50116200), located in the urban area of Ponce, was classified as **poor** (table 8).

The station Río Bucaná at Ponce (50114600), which is located in the urban area of Ponce, was the most downstream station where samples were collected within the Río Bucaná main stem above its confluence with the Río Portugués. The sanitary water quality at Río Bucaná at Ponce station was classified as **fair**.

Table 8. Fecal coliform and *Escherichia coli* bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Ponce, Puerto Rico.

[m/d/y, month, day, year; USGS, U.S. Geological Survey; 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; °C, degree Celsius; 7-d, Q-2, 7-day, 2-year low flow; R, replicate sample; PR, Puerto Rico; --, no data]

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 meandaily discharge (ft^3/s)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Fecal coliform (colonies per 100 mL)	*Escherichia coli* (colonies per 100 mL)	Station sanitary quality ranking
					Río Inabón Basin						
50112225	Quebrada Emajagua near Anón, PR	03/26/02	1325	0.91	0.51	0.4	159	20.6	10	<10	Good
		09/03/02	0955		3.33		139	20.3	8	6K	
50112250	Río Anón at Anón, PR	03/27/02	0945	0.57	0.78	0.8	258	20.0	20	10	Good
		09/03/02	1100		3.87		167	21.2	16K	20	
50112425	Río Inabón at Real Anón, PR	03/27/02	1045	6.46	2.76	2.0	261	22.8	91	82	Acceptable
		09/03/02	1215		38.3		216	23.4	60	260	
50112500	Río Inabón near Real Abajo, PR	03/27/02	1210	9.70	2.86	2.6	302	26.5	1,000	10K	Fair
		09/03/02	1315		47.0		232	26.3	<100	250	
50112590	Río Inabón near Coto Laurel, PR	03/27/02	1245	11.3	0.88	--	342	31.8	50	40	Fair
		09/04/02	0900		35.7		225	25.0	240	320	
50113450	Río Inabón near Arús, PR	04//01/02	1230	30.2	25.3	--	371	31.2	420	270	Poor
		09/04/02	0700		102		252	24.0	240	530	
					Río Bucaná Basin						
50113725	Río Cerrillos at Anón, PR	03/25/02	0945	3.76	2.82	2.2	233	20.7	<10	<10	Fair
		09/04/02	1110		12.8		171	24.2	330	440	
50113780	Río San Patricio near San Patricio, PR	03/26/02	1030	4.97	3.95	2.8	316	21.6	10	10K	Good
		09/05/02	0810		7.99		284	25.5	28	44	

Table 8. Fecal coliform and *Escherichia coli* bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Ponce, 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 meandaily discharge (ft^3/s)	Specific conductance (μS/cm at 25°C)	Water temperature (°C)	Fecal coliform (colonies per 100 mL)	*Escherichia coli* (colonies per 100 mL)	Station sanitary quality ranking
					Río Bucaná Basin—Continued						
50113800	Río Cerrillos above Lago Cerrillos near Ponce, PR	03/25/02	1145	11.9	6.13	5.5	286	24.4	10	<10	Fair
		09/04/02	1300		28.9		226	26.9	210	150	
50114100	Río Cerrillos near Maraguez, PR	03/25/02	1140	18.3	2.77	--	309	28.0	200	290	Acceptable
		09/05/02	1030		2.61		356	27.4	130	110	
50114190	Río Bayagán at Machuelo Arriba, PR	03/26/02	1145	2.82	0.26	0.1	832	25.0	390	130	Poor
		09/05/02	0750		0.52		754	25.5	590	1,200K	
50114600	Río Bucaná at Ponce, PR	04/03/02	1100	27.8	3.55	--	438	27.8	310	200	Fair
		09/09/02	0750		1.67		454	25.3	96	98	
50114750	Río Portugués at Guaraguao, PR	04/02/02	1000	2.11	2.10	1.4	273	21.5	100K	210	Acceptable
		09/09/02	0920		3.54		267	21.0	110	570	
50114850	Río Portugués at Highway 503, PR	04/03/02	0915	5.35	4.19	2.0	337	23.0	100	110	Good
		09/09/02	1050		6.15		340	23.4	16	60	
50114880	Tributario de Río Portugués at Tibes, PR	04/02/02	1115	1.10	0.28	0.1	384	21.7	50	10	Good
		09/09/02	1140		0.76		364	22.0	44	90	
50115000	Río Portugués near Ponce, PR	04/02/02	1400	8.82	5.06	2.6	344	26.9	64	140K	Acceptable
		09/09/02	1130		8.36		352	27.5	50	72	
50115225	Río Portugués near Portugués, PR	04/03/02	0815	10.6	6.50	2.5	363	22.5	140	140	Acceptable
		09/10/02	1200		7.50		330	25.2	46	60	
50115475	Río Chiquito near Portugués, PR	04/02/02	1245	3.40	0.78	<0.1	423	26.7	600	260	Fair
		09/10/02	1000		0.44		391	27.1	74	220	

Table 8. Fecal coliform and *Escherichia coli* bacteria concentrations, drainage areas, streamflow characteristics, selected water-quality measurements, and sanitary quality rankings at selected surface-water sampling stations in the municipio of Ponce, 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 meandaily discharge (ft^3/s)	Specific conductance (µS/cm at 25°C)	Water temperature (°C)	Fecal coliform (colonies per 100 mL)	*Escherichia coli* (colonies per 100 mL)	Station sanitary quality ranking
					Río Bucaná Basin—Continued						
50115590	Río Chiquito at Highway 504, PR	04/02/02	1200	4.35	0.74	--	492	28.0	1,400	500	Poor
		09/10/02	0920		0.16		437	28.1	460	1,100K	
50116200	Río Portugués at Ponce, PR	04/03/02	0830	18.9	11.19	--	427	25.0	390	220	Poor
		09/10/02	0740		8.10		502	28.0	240	200	
					Río Matilde Basin						
50116600	Río Canas at Guaraguao, PR	04/15/02	0930	1.79	1.28	1.0	323	20.7	27	27	Fair
		09/10/02	1300		2.84		285	25.7	1,500K	3,800	
50116802	Río Canas near Magüeyes, PR	04/15/02	1045	4.02	1.81	1.0	367	23.1	1,100	1,000	Poor
		09/11/02	1300		6.47		233	25.6	18,000	13,000	
50116900	Río Canas at Magüeyes, PR	04/15/02	1145	5.68	1.80	0.9	415	24.4	360	400	Poor
		09/11/02	0910		7.63		214	23.1	70,000	62,000	
50116965	Río Canas at Highway 132, PR	04/15/02	1230	8.14	6.26	--	265	28.3	230	200	Poor
		09/11/02	0750		17.00		290	26.1	11,000	12,000	
50117400	Río Pastillo at Marueño, PR	05/23/02	1000	2.52	0.34	--	508	25.0	150K	180	Fair
		09/01/02	1100		1.87		257	24.7	4,000	6,500	
50117800	Río Pastillo at Pastillo, PR	05/23/02	1045	4.32	0.30	--	611	26.9	260	330	Poor
		09/12/02	0905		1.39		369	25.7	2,000	2,100	
50118000	Río Pastillo near Ponce, PR	05/23/02	1200	7.32	0.97	--	449	28.7	2,000	9,000	Poor
		09/12/02	0805		2.74		389	24.6	8,800	11,500K	

Table 9. 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 Ponce, 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 Inabón Basin											
Río Inabón	--	5.98	2.31	2.59	6.91	--	3.11	2.95	23.85	--	23.85
Río Anón	1.24	4.74	--	--	--	--	--	--	5.98	--	5.98
Quebrada Emajagua	0.91	1.83	--	--	--	--	--	--	2.74	--	2.74
Summary for the basin	2.15	12.55	2.31	2.59	6.91	--	3.11	2.95	32.57	--	32.57
Streams in the Río Bucaná Basin											
Río Blanco	--	--	--	--	--	1.41	--	--	1.41	--	1.41
Río Prieto	--	--	--	--	--	4.66	--	--	4.66	--	4.66
Quebrada Jamiel	--	--	--	--	--	1.87	--	--	1.87	--	1.87
Quebrada Rosales	--	--	--	--	--	2.65	--	--	2.65	--	2.65
Río San Patricio	1.24	12.13	--	--	--	--	--	--	13.37	--	13.37
Río Bayagán	--	--	--	--	--	--	1.24	7.20	8.44	--	8.44
Tributario de Río Portugués	1.24	0.25	--	--	--	--	--	--	1.49	--	1.49
Río Chiquito	--	--	--	--	1.59	5.22	1.25	--	8.06	--	8.06
Río Portugués	3.47	1.87	7.81	1.57	--	--	3.07	0.52	18.31	--	18.31
Río Cerrillos-Río Bucaná	--	--	3.24	--	6.78	4.67	--	--	14.69	1.57	16.26
Summary for the basin	5.95	14.25	11.05	1.57	8.37	20.48	5.56	7.72	74.95	1.57	76.52
Streams in the Río Matilde Basin											
Río Canas	--	--	--	--	2.28	2.24	7.98	--	12.50	--	12.50
Río Pastillo	--	--	--	--	2.37	--	3.35	2.48	8.20	--	8.20
Río Matilde	--	--	--	--	--	--	--	1.66	1.66	--	1.66
Summary for the basin	--	--	--	--	4.65	2.24	11.33	4.14	22.36	--	22.36
Summary											
Station with same classification	5	--	5	--	8	--	9	--	--	--	--
Percent of total stations ranked	18.5	--	18.5	--	30	--	33	--	--	--	--
Stream miles with same classification	8.1	26.80	13.36	4.16	19.93	22.72	20.0	14.81	129.88	1.57	131.45
Percent of total stream miles ranked	6.27	20.6	10.3	3.20	15.34	17.49	15.39	11.40	--	--	--

Río Matilde Basin

The sampling network for streams within the Río Matilde Basin consists of seven sampling stations on two tributaries: the Río Canas and Río Pastillo. A third tributary to the Rio Matilde, the Quebrada del Agua, was dry during the time of the study. Four sampling stations located in the Río Canas were used to classify the general sanitary water quality of 12.5 mi of stream. Station Río Canas at Guaraguao (50116600), which is the uppermost station in the basin was classified as **fair**. Downstream from this station the sanitary water quality of the Río Canas deteriorates as it flows past housing units that border the stream. Sanitary water quality at stations Río Canas near Magüeyes (50116800), Río Canas at Magüeyes (50116900), and Río Canas at Highway 132 (50116965) was classified as **poor**.

The three stations located on the Río Pastillo were used to classify 8.2 mi of this stream. The general sanitary water quality in the Río Pastillo was classified as **fair** and **poor**. Although the upper portion of the Río Pastillo basin is not densely populated and is primarily forested, the sanitary water quality at the Río Pastillo at Marueño (50117400) station was classified as **fair**. Downstream from this station, the water quality deteriorates as the stream flows past approximately 2 mi of housing units that border the stream. The sanitary water quality at sampling station Río Pastillo at Pastillo (station 50118100) and Río Pastillo at Cañas (50118100) has higher fecal coliform concentration than the upstream stations and were classified as **poor** (table 8). Downstream from station 50118100 the Río Pastillo channel was dry.

A summary of the bacteriological results, the classification assigned at sampling stations, and stream miles classified under each ranking is presented in table 9. Only 34.9 mi of a total of approximately 130 mi of perennial streams in the study area were classified as **good** or **presumed good**. Bacteriological analyses indicate that approximately 20 percent of the stream reaches within the municipio of Ponce may have fecal coliform bacteria concentrations that exceed the water-quality standard established by the PREQB for inland surface waters applicable during the study period. The analyses also indicate that approximately 44 percent of stream reaches may have *E. coli* bacteria concentrations that exceed the quality criterion for recreational waters established by the USEPA. Potential contaminant sources from unsewered rural communities in proximity to stream courses, especially along stream segments where fecal coliform concentrations were below 200 col/100 mL, are indicated on plate 1. Riparian zones possibly contaminated by household waste-water discharges were identified along 14.6 mi of streams using 2001-2002 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).

Stream segments bordered by housing units were observed in approximately 4.61 mi in the Río Inabón Basin, 4.73 mi in the Río Bucaná Basin, and 5.31 mi in the Río Matilde Basin. The ratio of stream segments bordered by housing units to stream miles assessed ranged from 7 percent in the Río Bucaná Basin to 38 percent in the Río Matilde Basin. The Río Canas and Río Pastillo, two streams within the Río Matilde basin, were classified as **poor** in 41 and 64 percent of their stream miles, respectively.

Chapter C: Hydrogeologic Terranes and Ground-Water Resources in the Municipio of Ponce, Puerto Rico, 2002-2004

By Jesús Rodríguez-Martínez and Fernando Gómez-Gómez

Purpose and Scope

The USGS in cooperation with the municipio of Ponce conducted an investigation of the ground-water resources within the municipio from October 1, 2002, to September 30, 2004, (fig. 1). As part of this study effort, the municipio of Ponce was divided into six distinct areas based on hydrogeologic characteristics, referred to in this report as hydrogeologic terranes. Using methods developed by Berg and others (1997), 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 used by the municipio of Ponce in its territorial development plan.

Recent Impacts on the Ground-Water Flow Pattern in the Municipio of Ponce

The most important change in the ground-water flow pattern in the Ponce area has resulted from the substitution of furrow irrigation by drip irrigation. In Ponce, particularly in the coastal and upper plains, this was followed by an almost complete abandonment of agriculture as an economic activity of importance. Recharge during furrow irrigation was estimated to be as much as 30 percent of the water applied to the land surface, which in the case of sugar cane, could range from 12 to 18 inches per year (in/yr).

Ground-water flow in the aquifer has also been modified by the completion of major flood-control works consisting in the modification of stream courses by the deepening, straightening, widening, and concrete lining of portions of the Río Bucaná and Río Portugués, particularly in the coastal and upper plain areas. The Río Inabón was a tributary of the Río Jacaguas until 1837, when a major hurricane caused a major change in the location of its channel (Abbad y La Sierra, 1788; Questell-Rodríguez, 1999). Consequently, the Río Inabón ceased being a tributary to the Río Jacaguas and began flowing directly to the sea. To minimize the risk of flooding, the newly formed channel of the Río Inabón was deepened, widened, and straightened sometime between 1837 and 1852 (Questell-Rodríguez, 1999). Another impact to the aquifer has been the Río Cerrillos reservoir, which has modified streamflow to the coastal plain and aquifer recharge along upper plain areas. Similarly, the reduction or elimination of streamflow along the old Río Portugués channel in the coastal plain and its joining with that of the Río Bucaná may have altered the interaction of surface and ground water, the fresh-salt water interface boundary, especially in the part of the aquifer at Playa de Ponce and the inland extent of the salt water wedge in these two rivers.

Cessation of recharge derived from infiltration of surface water from furrow irrigation caused a major transformation of the ground-water flow system. The recharge to the aquifer has been significantly reduced. At present (2003), aquifer recharge is limited to rainfall infiltration and seepage from streams and the irrigation canal supplied from the Río Inabón (plate 1). During the study period, water from the Río Inabón was still diverted to a series of impoundments located in the upper plain, from where the water was delivered to irrigate fields of Bermuda grass in the upper and coastal plains. The recharge to the aquifer from the impoundments, the irrigation canal, and its network of distribution ditches is unknown.

The impact of the Río Cerrillos reservoir, whose construction ended in 1991, on the ground-water flow system of the coastal aquifer, particularly as to variations in recharge from streamflow, is unknown. It is reasonable to assume, however, that downstream from the dam, recharge from the river to the aquifer has been significantly reduced and that drainage of the aquifer near the coast, where streams have been channelized, has been enhanced. The diminished streamflow downstream from the dam may also have impacted the inland extent of the salt water wedge in the Río Bucaná flood channel. Results obtained as part of this study will provide information as to how the ground-water flow system has changed as the result of the changes mentioned above.

Methodology

Ground-water resources in the municipio of Ponce were differentiated into areas of similar hydrogeologic properties, referred to in this report as hydrogeologic terranes. Approximate ground-water flow rates in the interior uplands were obtained from analysis of stream low-flow discharge measurements obtained as part of this assessment. These ground-water flow rates were used in differentiating the hydrogeologic terranes in the mountainous interior. Ground-water samples were collected from selected wells to determine the composition of common dissolved constituents (cations and anions) and nutrients (phosphorus and nitrogen species). Samples were also collected for analysis of the stable isotope ratios of oxygen-18 and deuterium in monthly rainfall composites from the Hogares Seguros rainfall station, in ground water from selected wells, and in surface water from several sites. The stable isotope analyses were used in defining recharge sources. Seepage runs along selected stream courses were conducted to help define the surface/ground-water relations. Ground-water zones containing saline water were defined using analysis of common constituents and direct current (DC) surface resistivity surveys. A lineament trace analysis was also conducted in the interior uplands to help locate subsurface fractures that may be potential zones of preferential ground-water flow and storage. Ground-water level data were collected to construct a potentiometric-surface map representative of the hydrologic conditions prevailing during the study period. Current and historical ground-water withdrawal data were combined to determine the historical pattern of ground-water withdrawal in the municipio of Ponce.

Hydrogeologic Terranes

The municipio of Ponce was divided in six hydrogeologic terranes based on the following factors: (a) bedrock geology, (b) soil thickness and infiltration capacity, (c) ground-water flow rate, (d) general depth to ground water, and (e) the land-surface slope. The geologic substratum and associated attributes such as the presence of fractures, joints, and stratification were determined from USGS geologic maps, field reconnaissance, and lineament trace analysis conducted as part of this study (Sanders and others, 1997). Soil thickness and infiltration capacity were obtained from the soil maps published by the former Soil Conservation Service, now the Natural Resources Conservation Service (NRCS) (U.S. Department of Agriculture, 1979). Ground-water flow rates in hydrogeologic terranes delineated in the interior uplands and composed mainly of igneous rocks was estimated on the basis of stream base-flow measurements and calculation of flow duration statistics at the 98th (Q-98) and 90th (Q-90) percentiles (streamflows equaled or exceeded 98 and 90 percent of the time, respectively). The general depth to ground water was obtained from data available in USGS databases and from actual measurements made during this study. The land-surface slope was obtained by computer processing of 1:20,000 scale digitized topographic map of Ponce 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' logs, and by using surface geophysical methods. An inventory of commercial, industrial, and public-supply wells in the municipio of Ponce was conducted as part of the study (table 10). Well-hydraulic data were obtained from the USGS archives 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 at only a few selected wells to determine the seasonal variations in ground-water levels in the main hydrogeologic terranes.

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). The equivalence of using low flows as an approximation to ground-water flow rate assumes that (a) the ground-water discharge into the stream and its tributaries is restricted to aquifer(s) in the corresponding drainage basin, and (b) the contributing ground-water catchment(s) does not vary seasonally as a result of extending into adjacent drainage basin(s) caused by increased 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 as delineated in 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 drainage area of each of the 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 drainage basin area (expressed in square miles) to remove the effect of increasing drainage basin area. Thus, low-flow values are expressed as gallons per day per square mile and in the equivalent effective recharge of inches per year. 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 a good approximation of the ground-water flow in 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.

Table 10. Description of wells used to evaluate the geology, hydrogeology, and ground-water quality in the municipio of Ponce.

[*, shallow ponds dug in the coastal plains with depth between 10 and 20 feet; (**), altitude from 1:20,000 scale topographic map; AB, abandoned; PWS, public-supply wells; OBS, Observation; IND, Industrial; AG, Agriculture; INST, Institutional; DOM, domestic; COM, Commercial; ---, data not available; NA, not applicable]

Well name and identification number	Site identification number[1]	Use	Depth, in feet below land surface	Depth of screen, casing or open hole interval (feet below land surface)	Land surface elevation (feet above mean sea level) (**)
1. Joaquina	180038663505	AB	85	---	41
2. Candy	180032663541	AB	150	---	44
3. Altavista	180057663529	AB	125	---	62
4. Prángana	180020663521	AB	200	---	39
5. Saurí 1	180026663541	AB	185	60-175	43
6. Laboy 1	180031663518	AB	60	0-60	39
7. Unión 6	180014663253	AB	212	0-150	31
8. Fortuna	180005663224	AG	---	41-85	26
9. Unión 4	180013663315	AB	---	---	23
10. Sucesión Serrallés	180010663438	AB		---	20
10a. Esperanza 1	180003663435	AB		---	20
11. Esperanza 3	180019663443	AB		---	20
12. Alhambra (PRASA)	180057663610	PWS		---	52
13. Cafeteros de Puerto Rico-2	180017663647	AB	100	20-100	34
14. Abolition 1	180027663646	AB	85	0-85	37
15. Vivas 1	180051663640	AB	---	---	52
16. J. Chardón	180035663704	AB	---	---	34
17. Bomba Colones	180138663236	AB	227	---	99
18. Agregado-1	180132663544	AB	60	20-120	82
19. Agregado-3	180130663543	AB	60	20-60	82
20. Maruca 2	180202663238	AB	117	0-117	128
21. Estancia	180016663542	AB	150	---	43
22. Sucesión Serrallés 3	175809663416	AB	246	0-246	5
23. Mosquillas	175856663455	AB	80	0-80	4
24. Hacienda Santa Cruz	175835663539	AG	195	120-192	5
25. Bomba de la Quinta	175818663524	AB	---	---	8
26. La Guancha	175820663627	AB	215	103-215	7
27. Domestic Constancia	175856663616	AB	165	---	6
28. Constancia 8	175831663618	AB	---	---	7
29. Unión TW1	175930663240	AB	---	0-80	14
30. Auxiliary Fortuna	175908663227	AB	---	---	23
31. Domestic Esperanza 1	175952663427	AB	72	---	14
32. Platanal	175947663432	AB	263	0-256	11
33. Las Vallas 3	175949663455	AB	---	---	13
34. Bomba Muestra	175933663520	AB	93	8-85	11
35. Auger TW2	175923663530	AB	57	---	11

Table 10. Description of wells used to evaluate the geology, hydrogeology, and ground-water quality in the municipio of Ponce.—Continued

Well name and identification number	Site identification number[1]	Use	Depth, in feet below land surface	Depth of screen, casing or open hole interval (feet below land surface)	Land surface elevation (feet above mean sea level) (**)
36. Auger TW3	175907663526	AB	55.5	---	6
37. Auger TW4	175907663526	AB	34.5	---	16
38. Auger TW5	17595066531	AB	51	---	20
39. Restaurada 8B	175940663543	USGS OBS	170	20-130	19
40. Indian Head	175957663657	AB	150	38-150	21
41. Constancia 9	175948663646	AB	185	---	20
42. Constancia 2	175918663638	AB	---	---	24
43. Constancia 1	175902663614	AB	---	---	10
44. Constancia 3	175934663648	USGS OBS	150	0-150	16
45. Wilo 1	175957663651	AB	125	20-125	23
46. Iron Work 2	175906663711	AB	---	---	7
47. Ruiz Belvis (PRASA)	175913663712	AB	160	30-160	8
48. Oliver	175924663707	AB	178	0-158	11
49. Saurí 2	175930663702	AB	185	---	10
50. Matilde 2	180030663844	AB	160	---	56
51. Reparada	180030663821	AB	---	---	43
52. Angola 1	180052663900	AB	300	---	131
53. Ponce Cement #4	180107663822	IND	120	---	66
53a. Ponce Cement #2	180110663821	IND	266	---	62
54. Sucesión Serrallés 2	180111663839	AB	175	---	66
55. Angola 2	180102663907	AB	200	---	66
56. Colonia Santa Cruz	175956663558	AB	160	8-160	31
57. Restaurada 9 (PRASA)	175932663543	PWS	170	20-170	17
58. Restaurada 10 (PRASA)	175924663542	PWS	130	20-130	15
59. Luchetti	175950663605	AB	200	---	23
60. Restaurada 5 (PRASA)	175949663526	PWS	130	20-130	18
61. Restaurada 1 (PRASA)	175948663511	PWS	170	21-130	16
62. Fagot 2	180156663653	AB	75	0-45	98
63. Mercedita Norte	180126663355	AB	582	---	131
64. Zapater 1	180054663643	AB	115	49-60	54
65. Pietri 1	180035663658	AB	120	41-120	38
66. Toro 1	180026663649	AB	496	0-500	33
67. José Tormos	180009663646	AB	100	20-100	30
68. Mesa	175933663705	AB	150	---	10
69. UPR (PRASA)	175952663622	PWS		---	23
70. Santa María	180024663712	PWS		---	26
71. Fagot	180108663558	PWS		---	69
72. Restaurada 8 (PRASA)	175950663538	PWS	130	20-130	23

Table 10. Description of wells used to evaluate the geology, hydrogeology, and ground-water quality in the municipio of Ponce.—Continued

Well name and identification number	Site identification number[1]	Use	Depth, in feet below land surface	Depth of screen, casing or open hole interval (feet below land surface)	Land surface elevation (feet above mean sea level) (**)
73. Hacienda Teresa	180122663304	AG	212	---	74
74. Reparada 3	180016663743	AB	235	---	16
75. Catholic University-2	180013663710	INST	---	---	22
76. Tiburón Domestic	175911663225	Dom	---	---	13
77. Arjona 3 (PRASA)	180144663556	PWS	---	---	88
78. Ramos Antonini (PRASA)	180119663644	PWS	---	---	82
79. Chardón	175938663705		---	---	
80. Atómica (PRASA)	180023663640	PWS	---	---	33
81. Blasini (PRASA)	180051663843	PWS	---	---	59
82. Camino del Sur (PRASA)	175959663539	PWS	---	---	30
83. Restaurada 2 (PRASA)	175948663515	PWS	170	20-170	17
84. Restaurada 8A	175950663542	USGS OBS	165	20-165	24
85. Vayas Torres Domestic	180004663432	DOM	---	---	16
86. Valle Verde (PRASA)	180101663550	PWS	---	---	66
87. Bomba Cangrejo	175955663555	AB	150	0-150	30
88. Cuatro Calles-1	180028663518	AB	275	---	44
89. Central Mercedita-3	180105663349	IND	275	0-275	70
90. Instituto Tecnólogico	175951663712	AB	---	---	13
91. Nicoela	180008663201	COM	---	---	34
92. Betterroads	180023663412	IND	80	40-80	16
93. Hilton	175839663615	COM	---	---	5
94. Monagas 1	175957663544	INST	---	---	31
95. Monagas 2	175957663555	INST	---	---	33
96. Robles Ready Mix	180234663220	IND	---	---	148
97. Buyones	175952663317	DOM	---	---	13
98. Hacienda Unión 2	175924663230	AG	---	---	16
99. Pond 1*	175916663530	NA	---	NA	8
100. Pond 2*	175906663530	NA	---	NA	7
101. Pond 3*	175844663527	NA	---	NA	7
102. Pond 4*	175838663542	NA	---	NA	7
103. USSC	180031663501	IND	---	---	32.8
104. Ramal 5510	180027663230	DOM	---	---	38
105. Albergue de niños	180045663816	INST	---	---	49
106. Pozo Cristalia1	180318663358	IND	---	---	262
107. Interamerican University-Ponce	180042663434	INST	185	21-185	20

[1] Site identification number: Unique number for each site based on the latitude and longitude of the site. First six digits are latitude, next six digits are longitude. Latitude and longitude are given in degrees, minutes, and seconds.

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) contained within the corresponding drainage basin. The Q-90 and Q-98 flows were obtained using the graphical correlation method (L. Santiago-Rivera, U.S. Geological Survey, written commun., 2003). 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 were then determined through correlation using the corresponding values at the continuous-record gaging stations. By calculating the Q-98 and Q-90 flows for various drainage subbasins, as shown in table 11, a reasonable approximation of the ground-water flow rates was obtained for parts of selected basins within the hydrogeologic terranes contained within the municipio of Ponce. These approximated ground-water flow rates were converted into effective annual aquifer recharge and expressed as inches per year.

The base-flow measurements to determine the Q-90 and Q-98 were corrected for stream diversions, waste-water treatment plant discharge, and streamflow capture caused by withdrawals from wells. Low-flow stream contributions from basins outside the municipio of Ponce were not considered in the analysis. The fractions of the low flow resulting from direct ground-water discharge originating outside the municipio of Ponce 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 of limited extent and low permeability that are deeply incised by streams. Some hydrogeologic terranes extend beyond the boundaries of the study area, but discussion of these is limited to areas within the municipio of Ponce.

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. 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 an important 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, plays an important role in the enhancement of low flows in these highland areas. These storage compartments may include a litter layer (fallen plant debris), a root penetration zone, a soil zone, a "weathered-rock zone," and a fractured bedrock zone (fig. 8). The rainfall that infiltrates into these storage compartments is then discharged, at varying time scales, to the streams and is an important source of streamflow, particularly during low rainfall periods.

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) reported low-flow stream discharge in a drainage basin of Cidra, a municipio in central Puerto Rico, may have decreased from 6 to 2 in/yr as a result of conversion of a secondary-growth forest into an agricultural-rural area. Low flows in a specific drainage basin are affected to some degree by prevailing precipitation patterns excluding factors that could limit recharge in the basin (such as slope and land use). Accordingly, the ground-water flow or its equivalent low flow in any drainage basin can vary in direct response to changes in precipitation pattern and subsequent recharge, especially in watersheds where the orographic effect on rainfall amount and frequency is substantial as in the Ponce area.

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 may still have 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 basin uniformity contributes to irregular low-flow discharge across the basin. Accordingly, measured low-flow discharge alone can not be used to completely evaluate spatial variations of ground-water flow in the aquifers 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 10 to 100 mi^2. Therefore, the residual effect is considered to be of limited concern in this investigation because all but one of the drainage subbasins evaluated have areas less than 10 mi^2.

Ground-Water Quality

Ground water in the municipio of Ponce was analyzed for common dissolved chemical constituents that can be related to the local hydrogeology (table 12). Samples were collected from selected wells in the study area representative of the various hydrogeologic terranes. These analyses were used to define the prevalent hydrochemical facies of ground water. Similarly, a set of wells were sampled for analyses of nutrient concentrations (table 13).

Table 11. Hydrogeologic features of selected subbasins in the municipio of Ponce, Puerto Rico.

[mi^2, square miles, gal/min-mi^2, gallons per minute per square miles; in/yr, inches per year; <, less than; Q-98, streamflow value equaled or exceeded 98 percent of the time; Q-90; streamflow value equaled or exceeded 90 percent of the time; *, watershed extends beyond borders of the municipio]

Identification number and description of subbasin (subbasin with identification number is shown in plate 2)	Area (mi^2)	Ground-water flow as derived from the Q-98 flow (gal/min-mi^2)	Effective recharge (in/yr) as derived from the Q-98 flow	Ground-water flow as derived from the Q-90 flow (gal/min-mi^2)	Effective recharge (in/yr) as derived from the Q-90 flow	Hydrogeologic terranes that comprise the drainage subbasin, in order of areal extent
1. Upper watershed of Río Inabón including Salto de Inabón at Barrio Anón	1.30	240	7	350	11	3
2. Quebrada Emajagua at Barrio Anón above the Jurutungo Intake	0.91	150	5	250	8	3
3. Upper watershed of Río Anón at Barrio Anón above the Raíces Intake	0.57	600	18	700	20	3
4. Upper watershed of Río Anón at Barrio Real Anón	2.67	80	2	100	3	4, 3
5. Río Prieto at Anón in the upper watershed of Río Cerrillos at Barrio Anón	1.22	200	7	300	9	3
6. Río Prieto at Anón in the upper watershed of Río Cerrillos above bridge on Highway 139 in Barrio Anón	0.45	100	3	200	5	3
7. Quebrada Jamiel in the upper watershed of Río Cerrillos in Barrio Anón	0.54	100	3	130	4	3
8. Río Blanco in the upper waterhed of Río Cerrillos in Barrio Anón	0.54	200	5	240	7	3
9. Upper watershed of Río Cerrillos at Barrio Anón	1.01	230	7	330	10	3
10. Río San Patrico in the upper watershed of Río Cerrillos in Barrio Anón	4.97	170	5	240	7	3
11. Upper watershed of Río Cerrillos including lower portion of Río San Patricio in Barrio Anón	3.17	35	1	67	2	4
12. Upper watershed of Quebrada Ausubo	0.53	<100	<1	<100	<1	6
13. Upper watershed of Río Bayagán at Barrio Machuelo Arriba	1.74	<50	<1	<50	<1	6
14. Lower watershed of Río Bayagán at Barrio Machuelo Arriba	1.08	<20	<1	<20	<1	6
15. Lower watershed of Río Portugués at Barrio Tibes	1.78	<20	<1	<20	<1	6
16. Lower watershed of Río Portugués at Barrio Portugués	1.50	<20	<1	<20	<1	6

Table 11. Hydrogeologic features of selected subbasins in the municipio of Ponce, Puerto Rico.—Continued

Identification number and description of subbasin (subbasin with identification number is shown in plate 2)	Area (mi^2)	Ground-water flow as derived from the Q-98 flow (gal/min-mi^2)	Effective recharge (in/yr) as derived from the Q-98 flow	Ground-water flow as derived from the Q-90 flow (gal/min-mi^2)	Effective recharge (in/yr) as derived from the Q-90 flow	Hydrogeologic terranes that comprise the drainage subbasin, in order of areal extent
17. Río Chiquito in Barrio Portugués	3.40	<10	<1	<10	<1	6
18. Upper watershed of Río Portugués at Barrio Guaraguao*	2.30	230	7	300	9	3
19. Upper watershed of Río Portugués at Barrio Tibes	1.88	230	7	300	9	3
20. Watershed of tributary to Río Portugués at Barrio Tibes	1.17	<50	<1	<100	2	6
21. Río Portugués at Barrio Tibes including a portion of Monte Marqueño	2.83	170	5	200	6	4,3
22. Lower watershed of Río Portugués at Barrio Tibes	0.64	<10	<1	10	<1	6, 5, 2
23. Upper watershed of Río Canas at Barrio Guaraguao	1.79	200	6	300	8	3
24. Río Canas at Barrio Magüeyes	2.23	<10	<1	<20	<1	6
25. Upper watershed of Río Pastillo at Barrio Marueño	2.95	<20	<1	<20	<1	6
26. Lower watershed of Río Canas at Barrio Magüeyes	1.66	<10	<1	<10	<1	6
27. Middle watershed of Río Inabón at Barrio Real	3.24	70	2	120	4	4
28. Middle watershed of Río Portugués at Barrio Tibes	0.64	100	3	150	4	4

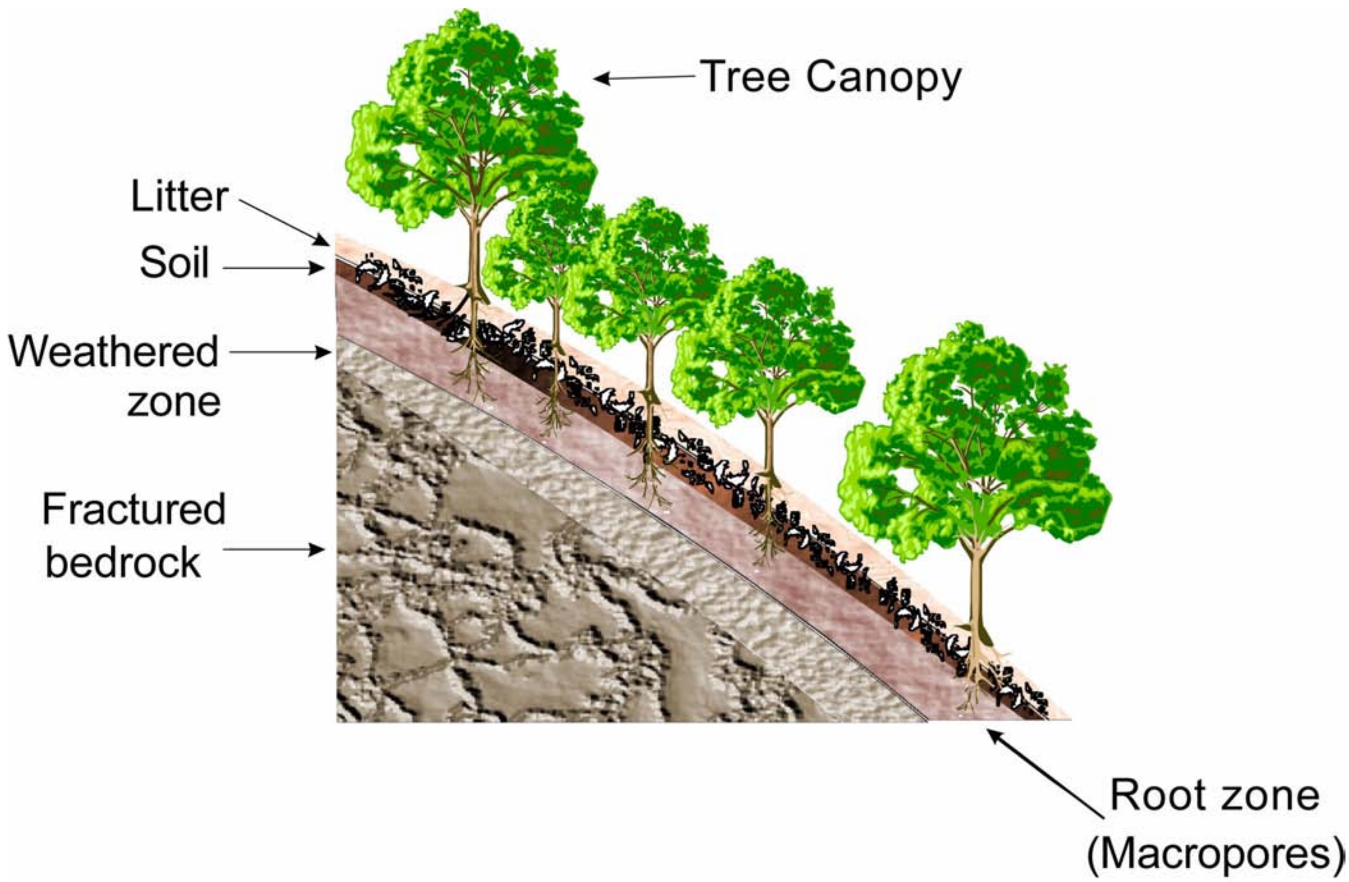


Figure 8. Schematic representation of main storage compartments within a drainage basin.

Table 12. Summary of chemical results of water samples from selected wells in the municipio of Ponce, Puerto Rico.

[Concentrations are given in milligrams per liter (mg/L) unless otherwise noted; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; $CaCO_3$, calcium carbonate; Ca, Calcium; Mg, Magnesium; Na, Sodium; K, potassium; HCO_3, bicarbonate; Cl, Chloride; SO_4, Sulfate; F, Fluoride; SiO_2, Silica]

Well name and identification number as shown in table 1	Date	Latitude longitude	Conductivity in µS/cm at 25°C	pH	Ca	Mg	Na	K	Cl	Alkalinity as $CaCO_3$	SO_4	F	SiO_2	Dissolved solids sum of constituents
8. Fortuna	12/10/02	18°00'05" 66°32'24"	531	8.0	67	17.7	31.3	0.52	24	240	48	0.17	34.3	367
12. Alhambra	12/10/02	18°00'57" 66°36'10"	1,172	7.4	105	19.6	130	1.47	109	340	167	0.17	31.1	767
24. Hacienda Santa Cruz	12/12/02	17°58'35" 66°35'39"	2,177	7.9	90	20.1	300	21.6	610	310	37.2	0.17	28.8	1295
32. Platanal	06/03/03	17°59'47" 66°34'32"	1,645	7.6	117	31.3	170	1.8	291	403	164	0.17	37.6	1055
69. UPR-Ponce	06/30/03	17°59'52" 66°36'22"	910	7.1	114	21.5	56	1.04	63	370	105	0.17	35.7	619
73. Hacienda Teresa	12/10/02	18°01'22" 66°33'04"	1,049	7.4	102	25.6	109	1.45	56	360	109	0.34	38.7	658
74. Reparada 3	12/11/02	18°00'16" 66°37'43"	1,903	7.4	120	30.2	251	3.31	314	420	166	0.28	33.7	856
75. Catholic University-2	12/11/02	18°00'13" 66°37'10"	784	7.4	87	13.4	63.2	2.10	65	270	75.8	0.17	28.2	496
76. Tiburón Domestic	12/10/02	17°59'11" 66°32'25"	540	7.5	77	13.1	24.9	1.16	18	315	28.9	0.17	25.0	377
77. Arjona 3	12/10/02	18°01'44" 66°35'56"	687	7.4	86	18.8	36.9	0.05	34	290	52.6	0.20	28.8	433
78. Ramos Antonini	12/11/02	18°01'19" 66°36'44"	986	7.6	96	20.8	96.7	4.63	64	401	214	0.37	28.8	766
79. Chardón	12/10/02	17°59'38" 66°37'05"	1,127	7.4	147	25.5	51.9	1.45	174	470	80.8	0.17	32.9	795
80. Atómica	12/11/02	18°00'23" 66°36'40"	807	7.4	100	16.2	50.8	1.89	54	320	85.4	0.17	29.5	529

Table 12. Summary of chemical results of water samples from selected wells in the municipio of Ponce, Puerto Rico.—Continued

Well name and identification number as shown in table 1	Date	Latitude longitude	Conductivity in µS/cm at 25°C	pH	Ca	Mg	Na	K	Cl	Alkalinity as $CaCO_3$	SO_4	F	SiO_2	Dissolved solids sum of constituents
81. Blasini 2	12/11/02	18°00'51" 66°38'43"	814	7.4	88	22.0	61	1.63	66	310	46	0.24	32.1	503
82. Camino del Sur	12/11/02	17°59'59" 66°35'39"	565	7.5	81	14.2	25	0.96	31	260	41	0.17	31.1	380
83. Restaurada 2	12/12/02	17°59'48" 66°35'15"	760	7.7	105	20.8	33	0.58	59	350	77	0.17	34.3	541
85. Vayas Torres	12/11/02	18°00'04" 66°34'32"	1,580	7.4	194	48.2	79	3.65	219	680	236	0.17	39.8	1230
92. Better roads	06/03/03	18°00'37" 66°34'13"	9,900	7.4	388	238	1946	3.4	1759	1900	2495	0.29	32.9	8000
93. Hilton	06/03/03	17°58'39" 66°36'15"	2,230	7.4	284	39.2	75	2.7	553	870	88	0.17	32.4	1600
103. USSC Industries	06/03/03	18°00'31" 66°35'01"	1,690	6.7	203	28.7	123	2.1	243	620	206	0.17	30.5	1210

Table 13. Nutrient concentrations at selected wells in the municipio of Ponce.

[Concentrations are given in milligrams per liter. NH3, Ammonia; NO3, Nitrate; NO2, Nitrite; P, Phosphorous; <, less than; m/d/y, month/day/year]

Identification number and name of well	Sample date (m/d/y)	Latitude/Longitude	Nitrogen, NH3 plus organic, total (as N)	Nitrogen, as NH3, total (as N)	Nitrogen as NO2, total (as N)	Nitrite and nitrate total (as N)	Phosphorus total (as P)
12. Alhambra	04-03-03	18°00'57"/66°36'10"	<0.2	<0.01	<0.01	3.3	0.03
69. University of Puerto Rico	04/03/03	17°59'52"/66°36'22"	<0.2	<0.01	<0.01	3.5	0.03
70. Santa María	04-02-03	18°00'24"/66°37'10"	<0.2	<0.01	<0.01	6.7	0.02
74. Reparada 3	04-03-03	18°00'16"/66°37'43"	<0.2	<0.01	<0.01	11	0.03
75. Catholic University-2	04-02-03	18°00'13"/66°37'10"	<0.2	<0.01	<0.01	3	0.02
77. Arjona -3	04-02-03	18°01'44"/66°35'56"	<0.2	<0.01	<0.01	2.5	0.03
78. Ramos Antonini	04/03/03	18°01'19"/66°36'44"	<0.2	<0.01	<0.01	2.3	0.11
81. Blasini 2	04-03-03	18°00'51"/66°38'43"	<0.2	<0.01	<0.01	2.5	0.02
83. Restaurada 2	04-02-03	17°59'48"/66°35'15"	<0.2	<0.01	<0.01	2.2	0.04
86. Valle Verde	04-02-03	18°01'01"/66°35'50"	<0.2	<0.01	<0.01	1.1	<0.02
91. Nicoela	04-03-03	18°00'08"/66°32'00"	<0.2	<0.01	<0.01	6.2	0.02
92. Betterroads	04-02-03	18°00'37"/66°34'13"	<0.2	0.01	<0.01	0.11	0.04

Oxygen-18 and Deuterium Composition

Ground-water samples from selected wells in the municipio of Ponce were also analyzed for the stable isotopic composition of oxygen-18 and deuterium (tables 14a-14c). The monthly rainfall composites at the Hogares Seguros rainfall station and water samples collected at selected surface-water sites were also analyzed for the ^{18}O and the ^{2}H composition (tables 14a-14c). Information on the use of ^{18}O and ^{2}H in hydrologic analysis to help define recharge sources and effects of evaporation on surface and ground water can be readily obtained from Clark and Fritz (1997).

Information on the ^{18}O and ^{2}H composition of the ground water, surface water, and rainfall were used in conjunction with hydrologic data to better define the spatial and temporal character of the recharge to the aquifers in the study area. The ^{18}O and ^{2}H composition was determined for monthly rainfall composites from a rainfall gage installed at the Hogares Seguros public-supply water filtration plant (plates 1 and 2). Similarly, the ^{18}O and ^{2}H composition was also determined for ground- and surface-water samples collected from selected wells and stream sites. The determination of the ^{18}O and ^{2}H concentrations was done at the USGS Isotope Fractionation Project Laboratory in Reston, Virginia. The concentrations or activities of ^{18}O and ^{2}H in water are expressed as the ratios of the main isotopes that comprise the water molecule $^{18}O/^{16}O$ and $^{2}H/^{1}H$ (Clark and Fritz, 1997). The stable isotope ratios are expressed as the relative difference to the Vienna Standard Mean Ocean Water (VSMOW):

$$\delta (‰) = [(R - R_{standard})/R_{standard}] \times 1,000,$$

where δ is expressed in units of per mil, ‰, and *R* and *R* standard are the isotope ratios, $^{2}H/^{1}H$ or $^{18}O/^{16}O$, of the sample and the standard, respectively. The accuracy of measurement is usually better than plus or minus 0.2‰ for $\delta^{18}O$ and plus or minus 2‰ for $\delta^{2}H$.

Streamflow Seepage Surveys

A series of seepages surveys were conducted during stream base-flow conditions at the major streams along the upper and coastal plains to improve the understanding on the surface-water/ground-water relations in the study area. These stream base-flow measurements were obtained in addition to the base-flow measurements mentioned earlier that were used in estimating streamflow duration statistics. The stations identification numbers and flow measurements are listed in table 15.

Table 14a. Deuterium and Oxygen-18 at selected ground-water sites in the Ponce study area, southern Puerto Rico.

[m/d/y; month/day/year]

Ground Water				
Name and identification number of site as in table 10	Sample date m/d/y	Latitude/Longitude	Delta deuterium per mil	Delta oxygen-18 per mil
8. Fortuna	12/10/02	18°00’05”/66°32’24”	-6.9	-1.79
	02/27/03		-8.5	-2.23
	02/17/04		-9.02	-2.19
12. Alhambra	12/10/02	18°00’57”/66°36’10”	-11.4	-2.86
24. Hacienda Santa Cruz	12/12/02	17°58’35”/66°35’39”	-11.4	-3.1
32. Platanal	03/18/03	17°59’47”/66°34’32”	-12.7	-3.06
69. UPR-Ponce	12/10/02	17°59’52”/66°36’22”	-12.8	-2.86
70. Santa María	12/11/02	18°00’24”/66°37’12”	-12.2	-2.92
71. Fagot	12/10/02	18°01’08”/66°35’58”	-10.7	-2.42
72. Restaurada 8	12/12/02	17°59’50”/66°35’38”	-12.9	-2.78
	02/27/03		-13.1	-2.78
	02/17/04		-11.79	-2.64
73. Hacienda Teresa	12/10/02	18°01’22”/66°33’04”	-8.6	-2.07
74. Reparada 3	12/11/02	18°00’16”/66°37’43”	-12.3	-2.76
	2/17/04		-13.31	-2.8
75. Catholic University-2	12/11/02	18°00’13”/66°37’10”	-11.2	-2.54
76. Tiburón Domestic	12/10/02	17°59’11”/66°32’25”	-11.6	-2.56
77. Arjona 3	12/10/02	18°01’44”/66°35’56”	-9.3	-2.07
78. Ramos Antonini	12/11/02	18°01’19”/66°36’44”	-5	-1.44
79. Chardón	12/10/02	17°59’38”/66°37’05”	-11.7	-2.73
80. Atómica	12/11/02	18°00’23”/66°36’40”	-11.2	-2.59
81. Blasini	12/11/02	18°00’51”/66°38’43”	-11.5	-2.87
82. Camino del Sur	12/11/02	17°59’59”/66°35’39”	-10.6	-2.68
83. Restaurada 2	12/12/02	17°59’48”/66°35’15”	-11.7	-2.82
	02/27/03		-11.3	-2.87
85. Vayas Torres	12/11/02	18°00’04”/66°34’32”	-11.6	-2.6
86. Valle Verde	01/24/03	18°01’01”/66°35’50”	-12.2	-2.96
89. Central Mercedita 3	03/18/03	18°01’05”/66°33’49”	-8.8	-2.31
92. Betterroads	03/13/03	18°00’37”/66°34’13”	-12.3	-2.72
	02/17/04		-10.62	-2.4
93. Hilton	03/18/03	17°58’39”/66°36’15”	-11.7	-2.79
96. Robles Ready Mix	06/25/03	18°02’34”/66°32’20”	-10.1	-2.14
	02/17/04		-9.78	-2.19
103. USSC	03/27/03	18°00’31”/66°35’01”	-11.5	-2.68
104. Ramal 5510	03/27/ 03	18°00’27”/66°30’30”	-8.9	-2.35
106. Pozo Cristalia 1,2, and 3	06/25/03	18°03’18”/66°33’58”	-0.7	-0.67
107. Interamericana Univ	06/25/03	18°00’42”/66°34’34”	-14.2	-3.03
	02/17/04		-10.73	-2.99

Table 14b. Deuterium and Oxygen-18 at selected surface-water sites in the Ponce study area, southern Puerto Rico—Continued.

[m/d/y; month/day/year]

Surface Water				
Name and identification number of site as in table 1	Sample date m/d/y	Latitude/Longitude	Delta deuterium per mil	Delta oxygen-18 per mil
Río Canas Station 50113200	03/19/03	18°00’49”/66°38’28”	-7.4	-2.32
Río Inabón Station 50113200	03/17/03	18°02’32”/66°32’18”	-3.1	-1.35
Río Cerrillos Station 5011410	03/19/03	18°00’22”/66°33’13”	-6.5	-2.04
Lago Ana María	06/25/03	18°03’30”/66°33’36”	4.8	0.20

Table 14c. Deuterium and Oxygen-18 at the Hogares Seguros raingage in the Ponce study area, southern Puerto Rico—Continued.

Sample date	Delta deuterium per mil	Delta oxygen-18 per mil
January 2002	6.77	-0.78
February 2002	7.21	-1.03
March 2002	2.36	-1.6
April 2002	1.03	-2.1
May 2002	-1.34	-1.56
June 2002	0.37	-2.03
July 2002	-7.82	-2.55
August 2002	-4.41	-2.25
September 2002	-12.86	-3.16
October 2002	-2.54	-2.13
November 2002	-1.7	-2.06
December 2002	-3.67	-2.47
January 2003	5.81	-1.42
February 2003	0.12	-1.92
March 2003	3.87	-1.35
April 2003	0.5	-2.08
May 2003	1.04	-1.49
June 2003	-3.12	-2.27
August 2003	-6.73	-2.14
September2003	-6.34	-2.31
October 2003	-15.78	-3.76
November 2003	-25.62	-5.02
December 2003	-9.46	-3.14

Table 15. Discharge measurements collected during seepage runs conducted at various rivers in the municipio of Ponce, Puerto Rico.

Site name	Station identification number	Latitude longitude	Date and time of measurement	Streamflow in cubic feet per second
Río Inabón downstream of Diversion Canal	50112550	18°04’36” 66°33’52”	06/12/02 -0600	17.3
			07/24/02-0840	2.61
			12/10/02-0935	0.36
			02/26/03-1240	0.63
			03/10/03-1215	0.62
			03/17/03-1220	0.67
			03/24/03-0840	0.25
Río Inabón near Coto Laurel	50112590	18°03’17” 66°33’08”	03/27/02-1220	0.88
			09/04/02-0910	35.7
Río Inabón at Highway 52	50113200	18°02’32” 66°32’18”	06/12/02-0705	51.8
			12/10/02-0750	4.11
			02/26/03-1340	3.23
			03/10/03-1300	3.22
			03/17/03-1400	2.54
			03/24/03-0730	2.74
Río Inabón near Arús	50113450	18°00’22” 66°33’13”	04/01/02-1240	25.1
			06/12/02-0825	52.8
			07/24/02-0730	7.05
			12/11/02-1035	5.5
			12/16/02-0945	6.2
			02/26/03-1430	3.1
			03/10/03-1410	2.6
			03/17/03-1310	2.3
			03/24/03-1400	3.7
Río Cerrillos near Maragüez	50114100	18°04’01” 66°35’05”	03/25/02-0930	2.8
			03/25/02-1135	2.8
			09/05/02-1030	2.6
Río Cerrillos near Vayas	50114110	18°00’22” 66°33’13”	06/12/02-1105	4.2
			12/11/02-0945	2.8
			03/19/03-0645	3.1
Río Bucaná at Hwy 14 bridge	50114390	18°02’29” 66°34’58”	06/12/02-1010	8.1
			12/11/02-0825	2.9
Río Bucaná at Alta Vista	50114595	18°00’52” 66°35’35”	06/12/02-0930	9.4
			12/11/03-1130	2.5
Río Bucaná at Ponce	50114600	18°00’28” 66°35’36”	04/03/02-1045	3.6
			09/09/02-0730	1.7
Río Chiquito at Hwy 504	50115590	18°02’39” 66°36’33”	04/02/02-1345	0.7
			09/10/02-0900	0.2
Río Portugués at Ponce	50116200	18°00’20” 66°36’28”	04/03/02-0800	11.2
			09/10/02-0705	8.1

Table 15. Discharge measurements collected during seepage runs conducted at various rivers in the municipio of Ponce, Puerto Rico.—Continued

Site name	Station identification number	Latitude longitude	Date and time of measurement	Streamflow in cubic feet per second
Río Canas at Hwy 132	50116965	18°00’49”	03/21/02-1100	5.8
		66°38’28”	04/15/02-1230	6.3
			05/24/02-1000	1.6
			06/13/02-1015	3.9
			09/11/02-0755	17.0
			12/12/02-0925	4.3
			03/03/03-1215	5.1
			03/12/03-1355	2.6
			03/19/03-1345	1.8
Río Pastillo at Marueño	50117400	18°04’34”	05/23/02-1000	0.3
		66°40’18”	09/11/02-1055	1.9
Río Pastillo at Pastillo	50117800	18°02’53”	05/23/02-1040	0.3
		66°39’52”	09/12/02-0850	1.4
Río Pastillo near Ponce	50118000	18°02’11”	05/23/02-1130	1.0
		66°39’46”	09/12/02-0810	2.7

Mechanisms of Salinization and Delineation of Saline Ground-Water Zones

Surface direct-current (DC) resistivity soundings, using the Schlumberger array, in conjunction with analysis of water samples collected from selected wells were used to delineate the saline ground-water zones in the coastal zone of Ponce following procedures as given in Patra and Nath (1999). In DC resistivity soundings, the depth of investigations is directly proportional to the current electode spacing (Patra and Nath, 1999). The latitude and longitude, as well as the maximum current electrode spacing are shown in table 16. Generally, resistivity values less than 3 Ohm-meters obtained by the Schlumberger soundings may indicate the presence of saline water. In the south coastal plain aquifer, which includes the Ponce aquifer(s), saline ground water typically has a specific conductivity that exceeds 10,000 microsiemens per centimeter (µS/cm) at 25ºC and a chloride equal or greater than 250 milligrams per liter (mg/L).The inland extent of the salt water wedges during low and high tide conditions were determined along the main coastal streams and creeks to further define the potential of salt water intrusion in the coastal areas of Ponce, owing to ground-water withdrawals, (see Chapter A). A specific conductance value of 20,000 µS/cm was used as an indicator of the presence of marine salt water within the stream channels.

Lineament-Trace Analysis

Lineament-trace analysis can be used to identify linear topographic features such as drainages, geologic contacts, and subtle tonal differences in soil color. Identification of these subsurface features may serve to aid in locating subsurface fractures that are potential zones of enhanced ground-water flow commonly contained 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

Table 16. Resistivity lines conducted during the Ponce study. The locations of these resistivity lines are shown on figures 13a to 13e.

[Coordinate NAD27 corresponds to mid-point in transect survey line. * The data obtained is unreliable because of equipment failure.]

Resistivity line number	Latitude	Longitude	Maximum current electrode spacing (AB/2), in feet
1	17°59’49”	66°34’55”	200
2	17°59’23”	66°35’12”	300
3	17°58’55”	66°35’03”	450
4	17°59’15”	66°34’51”	450
5	17°58’55”	66°35’33”	1,000
6	17°58’47”	66°35’09”	300
7	17°59’05”	66°35’10”	700
8	17°59’23”	66°35’16”	300
9	17°59’25”	66°34’48”	700
10	17°59’44”	66°34’49”	300
11	17°59’04”	66°34’40”	300
12	17°58’21”	66°34’15”	700
13	17°58’35”	66°34’16”	1,000
14*	17°59’43”	66°34’20”	450
15	17°59’41”	66°35’18”	450
16	17°59’57”	66°34’17”	700
17	17°59’21”	66°38’54”	450
18	17°59’31”	66°36’46”	700
19	17°59’11”	66°37’03”	450
20	17°59’15”	66°37’19”	1,000
21	17°58’38”	66°36’00”	700

potential sites for wells consideration should be given to areas with a high density of lineaments or lineaments intersections, which may indicate the presence of fracture intersections in the subsurface. This approach has been used to reduce drilling costs associated with the trial-and-error method in well site selection. As part of this study, lineaments were identified by two observers from the analysis of 1:20,000-scale aerial photography. Lineaments recognized by both observers were considered to have the highest hydrological importance (Sanders and others, 1997). Lineaments thus identified were subsequently evaluated in the field.

Delineation of Potentiometric Surface

Water-level data were collected at selected wells in the coastal and upper plains to construct a map showing the elevation and configuration of the potentiometric surface during the study period. The resulting potentiometric-surface map was used to interpret the regional ground-water movement and the surface- and ground-water relations in the study area. The potentiometric-surface map was also used to define changes with respect to previous potentiometric maps of the study area and infer changes in the occurrence and movement of ground water that could have resulted from changes in the pumpage regime, recharge, stream channelization, and land use.

Estimates of Ground-Water Withdrawals

The ground-water withdrawals from the public-supply wells in the municipio of Ponce during the study period were either measured in the field or obtained from the PRASA. Ground-water data of previous years from the municipio of Ponce, obtained from USGS published and unpublished data, were used to define historical changes in ground-water withdrawals.

Results and Interpretation

The municipio of Ponce can be differentiated into six hydrogeologic terranes (PonHT), according to their hydrogeologic characteristics and ground-water development potential. The ground-water development potential in the mountainous areas of Ponce is enhanced in those zones where lineaments are concentrated or have similar lengths and orientation. In the coastal areas, the potentiometric surface defined for the study period indicates a predominant southward ground-water movement. The presence of saline ground water in the coastal zone of Ponce may limit the ground-water development potential in these areas. Analysis of historical data indicates that ground-water withdrawals in the municipio of Ponce have decreased. This decrease in ground-water withdrawal may be due to saline water encroachment at wells; and as a result, the dependence on surface-water resources to meet public-supply water demand has increased.

Hydrogeologic Terranes

The municipio of Ponce was differentiated into six hydrogeologic terranes (PonHT), according to their hydrogeologic characteristics and ground-water development potential. The areal extent of these hydrogeologic terranes is shown on plate 2. These are described in the following pages in descending order of ground-water resource-development potential.

Ponce Hydrogeologic Terrane 1 (PonHT1)

This hydrogeologic terrane was assigned to the coastal and upper plains and the interior narrow alluvial valleys within the municipio of Ponce where the topographic slope is generally less than 15 degrees (about 17 percent slope). This hydrogeologic terrane consists mostly of fan delta, alluvium, and terrace deposits of Quaternary age and the underlying limestone of middle Tertiary age. The thickness of these siliciclastic deposits increases toward the coast and locally may exceed 300 ft (Renken and others, 2002). Discontinuous gravel and sand beds are present and can be as thick as 70 ft (fig. 9). The soil cover thickness ranges from 28 to 68 in. (U.S. Department of Agriculture, 1979). The average infiltration capacity ranges from 0.06 to 6 inches/hour (in/hr). Locally, the infiltration capacity can exceed 20 in/hr. The depth to the water table in the PonHT1 ranges from less than 10 ft below land surface in the more coastal reaches to about 30 ft below land surface in the northernmost parts. The underlying limestone units are presumably the time-stratigraphic equivalent of the Ponce Limestone and Juana Díaz Formation with outcrops to the north and west of the PonHT1 hydrogeologic terrane.

The major water-bearing units in the PonHT1 hydrogeologic terrane are the gravel and sand strata within the fan-delta deposits and locally within the alluvial deposits. The terrace deposits, because of their limited aerial extent, have minimum importance as water-bearing units. Beach deposits, although rich in sand, are not sufficiently thick and mostly overlie salt water, which minimizes their freshwater-bearing potential. The swamp deposits because of their fine-grained nature are not considered water-bearing units and partially confine the aquifer along the coast. The swamp deposits have a low permeability and may serve as localized discharge zones to the underlying aquifer. Although the water-bearing properties of the underlying limestone in the more coastal reaches of the PonHT1 are unknown, it is presumed that the limestone is a poor water-bearing unit as compared to the overlying gravel and sand strata, previously mentioned. Generally, the wells sited in the PonHT1 are open to beds of gravel and sand, thus, the discussion on the water-bearing properties of the PonHT1 is focused on the overlying fan-delta deposits, particularly the gravel and sand strata. The underlying limestone constitutes the main ground-water bearing zone within the Ponce Hydrogeologic Terrane (PonHT2), which is discussed later in this report.

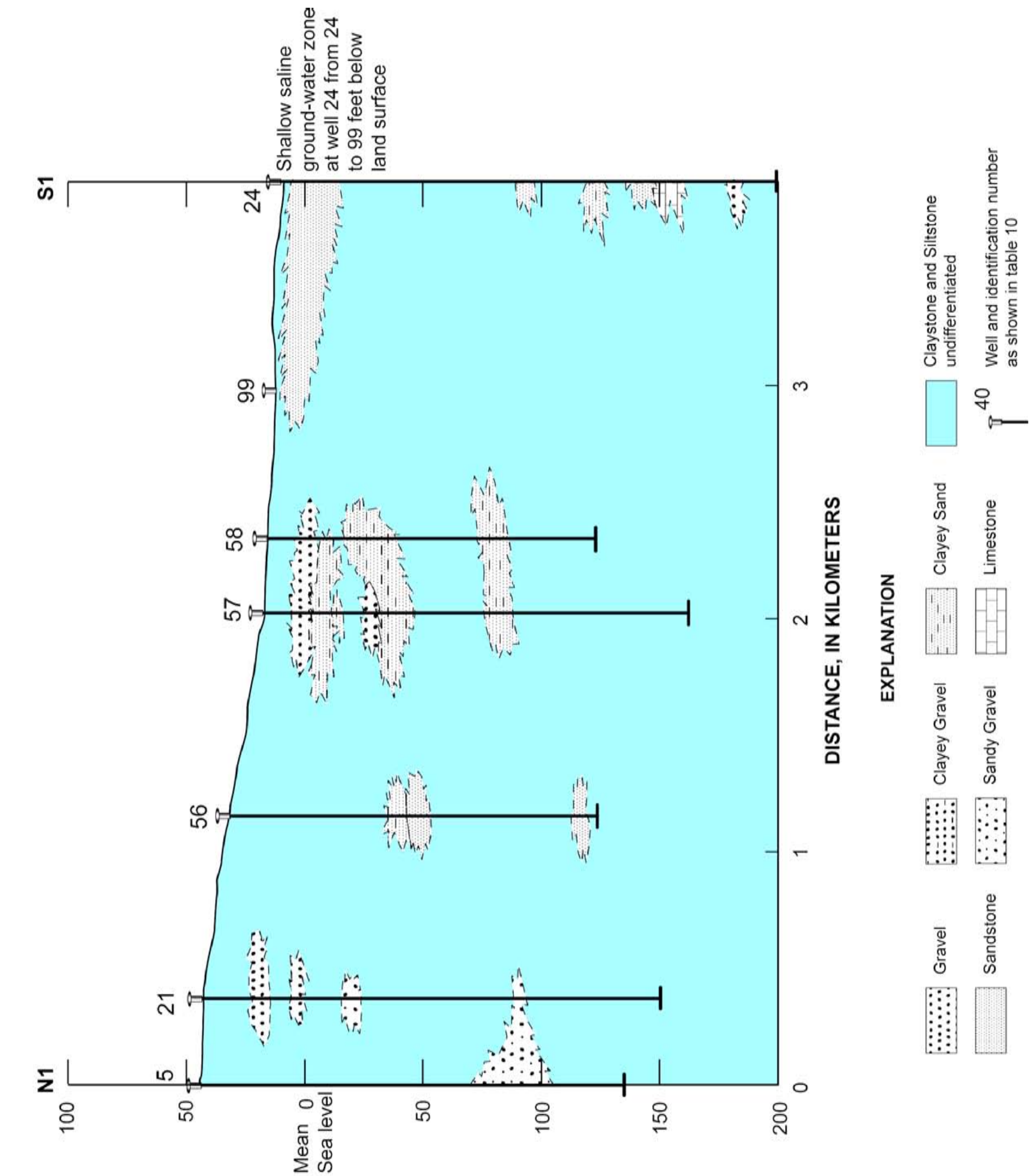


Figure 9a. Geologic cross sections showing subsurface distribution of main lithologies along line of section N1-S1. Line of section shown in plate 2.

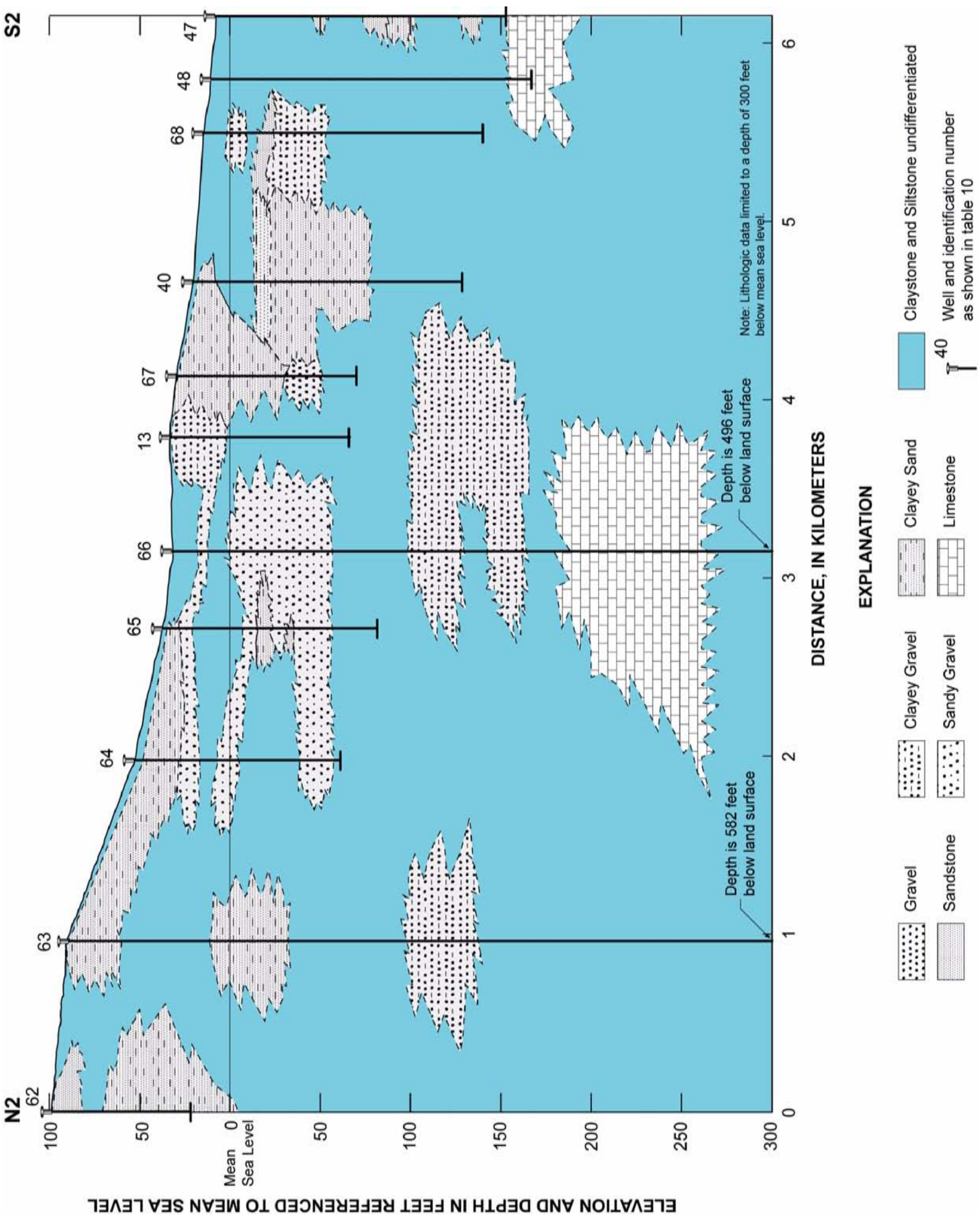


Figure 9b. Geologic cross sections showing subsurface distribution of main lithologies along line of section N2-S2. Line of section shown in plate 2.

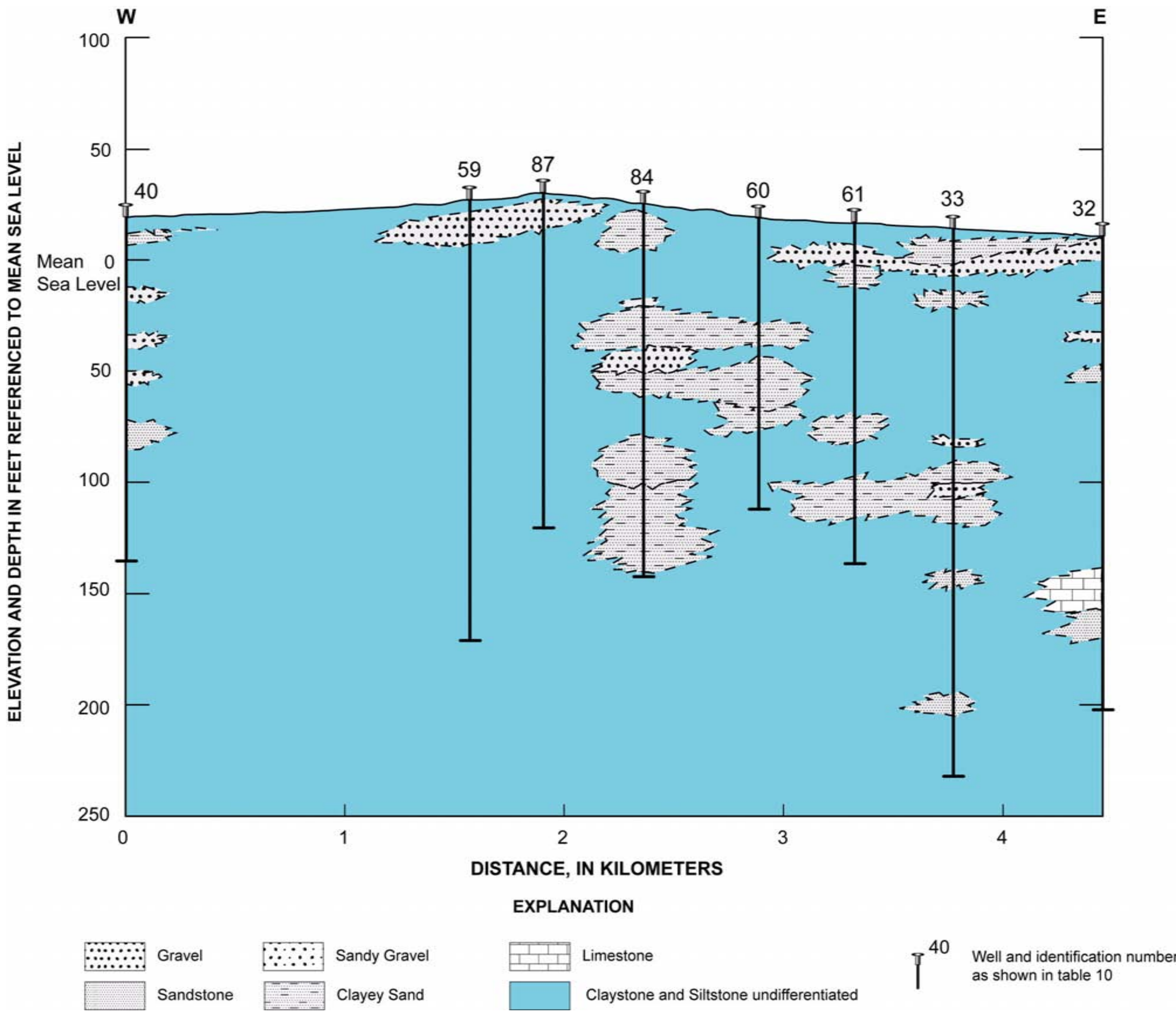


Figure 9c. Geologic cross sections showing subsurface distribution of main lithologies along line of section W-E. Line of section shown in plate 2.

Ground water in the PonHT1 hydrogeologic terrane, particularly for wells completed within the gravel and sand strata, mostly occurs under water-table conditions. Because of its highly stratified nature (vertical and horizontal juxtaposition of fine-grained facies such as silts and clays and coarse-grained facies such as gravels and sands (as shown in fig. 9)) the aquifer comprised within this hydrogeologic terrane is highly anisotropic, that is the horizontal permeability is substantially higher than the vertical permeability (Bennett, 1972). Ground water contained in the water-bearing units of this hydrogeologic terrane, however, lacks the degree of confinement necessary to be considered as confined. Bennett (1972) indicated that the increase in head with depth observed in the coastal flats occurs without the presence of a distinctive confining unit and is the result of the high anisotropy (horizontal to vertical). Moreover, drilling and hydraulic data do not indicate artesian flowing conditions after penetrating a particular strata while drilling a well in the coastal plain and coastal flats (U.S. Geological Survey, unpublished data, 1968). For the purposes of this report, the local aquifer contained in the PonHT1 hydrogeologic terrane consists of relatively permeable water-bearing units intercalated with poorer and non-water bearing units, and can be considered as an anisotropic unconfined aquifer.

The coastal flats were an important ground-water discharge zone when furrow irrigation was applied to the sugar cane crops (Bennett, 1972). Flood irrigation ceased as a result of the rapid decline in sugar cane cultivation by the late 1970s, and as a result, ground-water discharge in the coastal flats decreased considerably. At present (2004), the water table has been drawn-down substantially and ground-water discharge throughout the coastal flats is limited to periods of abundant rainfall.

The yield to wells drilled in the PonHT1 hydrogeologic terrane generally ranges between 100 and 200 gallons per minute (gal/min) in the interfluvial area of the Río Bucaná and Río Portugués, where well drillers' logs indicate a greater thickness of sand and gravel. The lowest yields in the PonHT1 are obtained in the proximity of the Río Pastillo. Wells in this general area indicate a sustainable pumping rate from the alluvium generally not exceeding 50 gal/min.

Estimates of the average horizontal hydraulic conductivity at wells in the Hacienda Restaurada area located near the coast and to the east of the Río Bucaná flood channel ranges from 22 to 62 feet per day (ft/d) (Bennett, 1972). Estimates of hydraulic conductivity in other wells located on the PonHT1 hydrogeologic terrane range from 11 to 65 ft/d (Bennett, 1972; U.S. Geological Survey, unpublished data, 1992). The greatest variation in estimates of the hydraulic conductivity is found between nearby wells rather than throughout the PonHT1 hydrogeologic terrane. The localized variability between nearby wells can be ascribed to the significant lateral heterogeneity and anisotropy of the aquifer resulting from the discontinuous gravel and sand strata. In general, the highest hydraulic conductivity values generally are associated with sand and gravel deposits of paleo river channels and in the vicinity of the Río Bucaná and Río Portugués (Bennett 1972). The average vertical hydraulic conductivity was estimated by Bennett (1972) to range from 0.26 to 0.0077 ft/d with a corresponding range in horizontal to vertical anisotropy from 127:1 to 4300:1. Analog model studies of the coastal alluvial aquifer yielded the most reasonable results when using an anisotropy of 1,000:1 (Bennet, 1972). Estimates of the specific yield from the aquifer comprised within the PonHT1 are lacking, but an average regional value of 0.16 determined from the coastal alluvium of the Coamo area by Giusti (1971), located about 12 mi east of the municipio of Ponce, seems reasonable considering that the sedimentary deposits of the two areas are similar in texture.

The main recharge source to the PonHT1 hydrogeologic terrane, after the cessation of furrow irrigation, is precipitation. Another recharge source of less importance may be seepage from rivers and streams. In the urbanized parts of Ponce, leakage of sewer and public-supply water pipelines may constitute a recharge source to the aquifer as evidenced in relatively unchanged ground-water levels between 1987 (Rodríguez-del-Río and Quiñones-Aponte, 1990) and 2003 (this study). Recharge from leaky sewer pipelines, if occurring, however, may be much less than recharge from leaky public-supply water pipelines as evidenced by the low concentrations of nitrate and ammonia in water samples obtained at selected wells in the urban area of Ponce (discussed in the ground-water quality section of Chapter C).

The determination of the average annual rainfall fraction that recharges the PonHT1 is unknown and is beyond the scope of this study; however, results from ground-water flow models for similar coastal alluvial aquifers in the south coast of Puerto Rico indicate that about 10 percent of the annual rainfall recharges the aquifer (Bennett, 1972). This estimate of 10 percent for a long-term average annual rainfall between 40 and 50 in. yields an estimated annual precipitation recharge to the PonHT1 between 4 and 5 in. A maximum of 7 in/yr was obtained from a modeling effort in the Santa Isabel-Coamo aquifer, located east of Ponce with a similar type of aquifer material and precipitation regime (Kuniansky and others, 2003). Continuous water-level data collected at USGS observation well 105 indicate that recharge in the PonHT1 is unevenly distributed throughout the year, but in general is highest during the months of August through November (fig. 10). Recharge during this period may result mainly from infrequent rainfall of substantial intensity and duration as indicated by stable isotope data collected during this study (see section on Oxygen-18 and Deuterium Composition). Recharge from precipitation in the PonHT1 occurs both as diffuse spatial infiltration of recharge and as a line-source of recharge. The line-source recharge occurs mostly as infiltration of rainfall runoff along the mostly abandoned network of drainage ditches and irrigation laterals that crisscross the coastal plain.

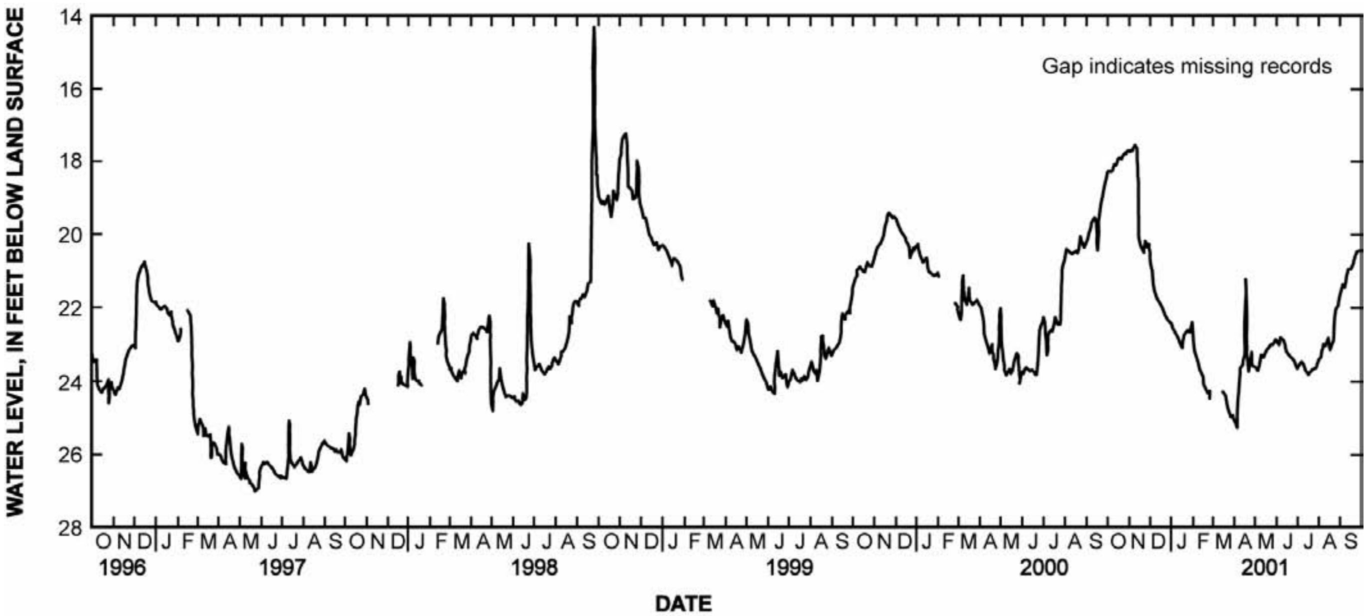


Figure 10. Selected portion of the historical water-level record of well 105. The location of well 105 is shown in plate 2 and included in table 10.

The importance of intense rainfall on aquifer recharge was evidenced in the November 2003 rainfall which averaged 11 in. in the coastal and upper plains. Ground-water levels measured at selected wells during February 11, 2004, when the resulting ground-water rising trend at observation wells had reached its maximum, indicated a total increase in the potentiometric surface of 5 ft at well 84, while the smallest increase was of less than 1 ft and was registered at well 76 (table 10, plate 2). Similar or greater recharge effects should have occurred in the Ponce aquifer as a result of the April 2002 and April 2003 rainfall events, discussed in the section on Climate.

Aquifer recharge provided by the rivers and streams to the PonHT1 hydrogeologic terrane has been estimated by use of an analog model (Bennett, 1972). Prior to the construction of the Cerrillos reservoir and the flood-mitigation works, the Río Portugués and Río Bucaná provided an estimated 120 to 600 acre-feet per year (equivalent to a range of 100,000 to 500, 000 gallons per day) of recharge to the aquifer. After the construction, recharge from the Río Bucaná and Río Portugués to the aquifer throughout the PonHT1 hydrogeologic terrane must have been reduced and mostly restricted to the abandoned stream reaches of these river channels, particularly during rainfall-runoff events along the truncated lower reaches of the Río Portugués. Recharge to the aquifer from the Río Bucaná to the PonHT1 may still occur, however, as a result of controlled releases from the Cerrillos dam. Because of the high degree of flow regulation in the river segments across the PonHT1, collection of seepage data to further define the aquifer-stream relations in this hydrogeologic terrane were not feasible.

Ponce Hydrogeologic Terrane 2 (PonHT2)

The PonHT2 hydrogeologic terranes lies to the north of and is hydraulically continuous with the PonHT1 hydrogeologic terrane. The PonHT2 hydrogeologic terrane is made up by middle Tertiary limestone overlain by upper fan-delta siliciclastic deposits of Quaternary age. The thickness of the soil cover ranges from 21 to 60 in. The infiltration capacity of the soil cover ranges from 0.06 to 6 in/hr. The depth to the water table, unaffected by pumpage, ranges from approximately 10 to 20 ft below land surface. The topographic slope is generally less than 15 degrees (less than 17 percent slope). Together, PonHT1 and PonHT2 compose the coastal aquifer in the Ponce area. Siliciclastic deposits in the PonHT2, however, are thinner than in the PonHT1 and the main ground-water bearing units are the underlying limestone units. The vast majority of the wells in the PonHT2 hydrogeologic terrane are completed either entirely or partially within the limestone units.

The limestone units in the PonHT2 are the northward extension of the limestone units that serve as the aquifer bedrock in the PonHT1. These limestone units, as mentioned earlier in the discussion on the PonHT1, are the downdip stratigraphic equivalents of the Ponce Limestone and Juana Díaz Formation. The depth to these limestone units generally decreases northward from a maximum of about 75 to 100 ft below land surface in the southern part of the PonHT2. Data on the hydraulic properties of these limestone units are sparse. The lithofacies distribution of the Juana Díaz Formation and Ponce Limestone (Monroe, 1980; and Renken and others, 2002) and data on the well yields available from drillers' logs in the USGS files indicate that, in general, the Juana Díaz Formation is a poorer water-bearing unit than the Ponce Limestone with hydraulic conductivity, in general, less than 4 ft/d (Renken and others, 2002). Localized increases in the hydraulic properties of these limestone units may occur, however, owing to the presence of lithofacies, which have a high primary porosity or have developed secondary porosity by dissolution, within reef tracts of limited extent, fractures and fissure zones embedded in an otherwise poorly permeable matrix. Localized karst development may occur in these zones as a result of enhanced secondary dissolution (U.S. Geological Survey, unpublished data, 1963) by infiltrating meteoric water. Thus, hydraulic conductivities in these karstified zones may be several orders of magnitude greater than that of non-karstic limestone.

The high concentration of dissolved solids and low permeability in the Juana Díaz Formation, resulting from its depositional environment, has been a major obstacle in maximizing the ground-water development potential of the PonHT2 (U.S. Geological Survey, unpublished data, 1976). Wells completed in the Juana Díaz Formation usually are abandoned because, in addition to low yields, water quality deteriorates rapidly with substantial increases in chloride and sodium concentrations. Even wells completed in the Ponce Limestone and within the reefal facies of the Juana Díaz Formation, which normally are more permeable than the typical clayey Juana Díaz Formation, exhibit the same water-quality deterioration problem. This deterioration in water quality occurs as soon as the ground water from the typical Juana Díaz Formation with its characteristic high concentration in dissolved solids is induced toward pumping wells.

Sustainable yields in the PonHT2 are restricted to the Ponce Limestone. As mentioned earlier, the low permeable character and high dissolved solids concentration makes the Juana Díaz Formation unsuitable for ground-water development. Reported sustainable yields at wells completed largely or entirely within the Ponce Limestone average about 100 gal/min.

Water-level data in USGS files indicate that artesian flow occurs at various wells completed either partially or completely within these underlying limestone units, particularly the Ponce Limestone. In these cases, the overlying alluvial deposits may serve as confining or semiconfining units to the underlying limestone. This may be the case of the Reparada domestic well (well 74 in plate 2), which has artesian flow and, according to local residents, the flow increases after rainfall. The occurrence of water under confined or semiconfined conditions within these limestone units is not continuous, and seemingly depends on the thickness of the overlying fine-grained material.

Aquifer recharge to the PonHT2 hydrogeologic terrane, as in the PonHT1, is mainly from rainfall infiltration. Prior to the flood mitigations works, mentioned earlier, seepage from rivers in the upper plain was the major recharge source (McClymonds, 1972; Bennett, 1972). Stream low-flow data collected during 2002 and 2003 indicate that at present seepage from the major streams during low-flow conditions is not an important recharge source to the PonHT2 with the exception of the Río Pastillo (table 15). Recharge from streams, however, could be substantial during high stream flows, occurring after rainfall/runoff events or by controlled releases from the Río Cerrillos Reservoir. The configuration of the potentiometric surface in the vicinity of the Río Inabón indicates that this stream may be a source of recharge to the aquifer within the PonHT2 hydrogeologic terrane; however, this could not be confirmed by the seepage data mentioned earlier (table 15). The Río Inabón may also be a recharge source to the aquifer within the PonHT2 hydrogeologic terrane only during rainfall/runoff events. The Río Pastillo, undoubtedly, is a source to the aquifer within the PonHT2 hydrogeologic terrane where streamflow in the channel disappears into the subsurface above Highway 2. This condition was observed most of the time during this study.

Ponce Hydrogeologic Terrane 3 (PonHT3)

The Ponce hydrogeologic terrane 3 (PonHT3) occupies the headwaters or uppermost reaches of the Río Canas, Río Portugués, Río Cerrillos, and Río Inabón in the northernmost part of the municipio of Ponce. The geologic substratum of PonHT3 is composed mostly of Cretaceous and Tertiary-age volcaniclastic rocks intruded by dioritic and gabbroic dikes and stocks, also of Cretaceous and Tertiary age, which are southward extensions of the Utuado Pluton (Mattson, 1968a). Locally, faulting is pervasive. The thickness of the soil cover ranges from about 12 to 30 in. The infiltration capacity of the soil cover ranges from 0.06 to 0.17 in/hr. The topographic slope is highly variable and ranges from less than 15 to more than 45 degrees, however, most of the topographic slopes in the PonHT3 range between 30 and 45 degrees.

The ground-water flux in the PonHT3 (an indicator of the ground-water development potential) was estimated from the Q-90 and Q-98 flow-duration statistics calculated in selected basins or subbasins lying completely within this hydrogeologic terrane. The estimates of the ground-water flux are highly variable and range from about 100 to about 700 gal/min-mi^2, which is equivalent to an effective rainfall recharge ranging from 3 to 20 in/yr (table 11).

The geologic substratum, type of soil, and topographic slope are similar in the subbasins contained within the PonHT3 hydrogeologic terrane. The annual as well as the seasonal variations in rainfall can reasonably be assumed to be similar in all the subbasins of the PonHT3. Consequently, the variation in ground-water flux within the PonHT3 may be related primarily to differences in the amount and type of vegetative cover among the subbasins contained in this hydrogeologic terrane. For example, subbasins 6 and 7 (plate 2 and table 11) have a ground-water flux equivalent to an effective rainfall recharge ranging from 2 to 5 in/yr. Both subbasins are characterized by a fragmented forest cover with parcels of land once cultivated with coffee and bananas and now left fallow and covered by grass. Within the same area, but with a land cover of mature secondary forest is subbasin 3 (plate 2 and table 11). The ground-water flux in subbasin 3 is significantly different to subbasins 6 and 7, ranging from 18 to 20 in/yr in equivalent rainfall recharge. This high effective rainfall recharge may also be due to ground-water transfer through fractures from contiguous subbasins.

As of 2003, there were no active wells in the PonHT3 hydrogeologic terrane. The remoteness of the area and the steep terrain may be factors against the feasibility of developing ground-water supplies in most of the subbasins of the PonHT3. The potential for ground-water development at a minor scale could exist in areas with a topographic slope less than 15 degrees. Any future development of the ground-water resources in PonHT3 should take into consideration that ground-water flow in this hydrogeologic terrane may occur primarily along discrete zones such as fractures and associated weathering zones. In order to maximize potential well yields, however, the most favorable areas should be where the density of lineaments, particularly lineament intersections, is high (plate 2). Wells located near streams may obtain their yield, either partially or entirely, from induced streamflow.

The ground-water discharge from the PonHT3 has served to maintain the base flows sufficiently high at the main rivers of Ponce. This ground-water discharge helps ensure stable base-flow conditions and year-round streamflow, particularly during periods of rainfall deficiency, as supply sources for public supply, to help sustain biologic systems, satisfy recreation needs, and maintain the capability to assimilate organic wastes discharges.

Ponce Hydrogeologic Terrane 4 (PonHT4)

The PonHT4 hydrogeologic terrane located south of the PonHT3 hydrogeologic terrane partially occupies the upper and middle reaches of the Río Portugués, Río Cerrillos, and Río Inabón. The geologic substratum is similar to that of the PonHT3, consisting of volcaniclastic and intrusive rocks. The soil cover thickness ranges from 12 to 60 in. The infiltration capacity of the soil cover ranges from 0.6 to 2 in/hr and the land slope ranges mostly from 15 to 45 degrees.

No wells are known to have been drilled in the PonHT4 hydrogeologic terrane. The ground-water flux in the PonHT4 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 estimate ground-water flux ranges from 65 to 200 gal/min-mi^2, which is equivalent to an effective rainfall recharge ranging from 2 to 6 in/yr (table 11). As in PonHT3 hydrogeologic terrane, an undetermined portion of the ground-water flux in the PonHT4 may be along fractures. Consequently, ground-water development potential in the PonHT4 are similar to those in PonHT3.

Ponce Hydrogeologic Terrane 5 (PonHT5)

The PonHT5 hydrogeologic terrane occupies the lower reaches of the main rivers in the municipio of Ponce and borders the northern side of the PonHT2 hydrogeologic terrane. The PonHT5 is made up of the Juana Díaz Formation and the Ponce Limestone and includes their outcrop areas. The overlying fan-delta deposits, as in PonHT2, are either thin or absent. The Juana Díaz Formation is the most aerial extensive unit, in outcrop area, of the PonHT5. The land slope ranges from less than 15 to 30 degrees, but locally, may reach 45 degrees. The soil cover thickness ranges from 11 to 60 in. The infiltration capacity of the soil cover ranges from 0.07 to 0.10 in/hr.

Information on the hydraulic properties of the Juana Díaz Formation and Ponce Limestone in the PonHT5 is scarce, but is assumed to be similar to their downdip equivalents in the PonHT2. Hydraulic conductivities determined for the Juana Díaz Formation in the PonHT5, obtained as part of the environmental assessment for an industrial wastes facility in the adjacent municipio of Peñuelas to the west of Ponce ranges from 2.8 x 10^{-6} to 2.8 ft/d (OHM Remediation Corp., 1992). Examination of lithologic logs and formation outcrops indicate that the transmissive and storage properties of the Ponce Limestone in the PonHT5 are similar to those of the downdip equivalent facies in the PonHT2, previously discussed (U.S. Geological Survey, unpublished data, 1966).

The limited information available indicates that ground water in the PonHT5 occurs under water-table conditions. Locally, ground water may occur under semiconfined or confined conditions where isolated water-bearing strata are overlain by clayey and silty beds within the Juana Díaz Formation and the Ponce Limestone.

The ground-water flux in the PonHT5 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 estimated ground-water flux is less than 30 gal/min-mi^2, which is equivalent to an effective rainfall recharge of less than 1 in/yr (table 11).

The ground-water development potential of the Juana Díaz Formation in the PonHT5, as in its downdip equivalents, is hindered by the low permeability and the high concentration in dissolved solids. The ground-water development potential of the Ponce Limestone in the PonHT5 is hindered by the small extent of its outcrop areas and juxtaposition with the Juana Díaz Formation. The absence of a well-developed soil cover over the Ponce Limestone in the PonHT5 may have limited the localized development of karstic porosity as in the PonHT2 (Giusti, 1978). Limited ground-water development has occurred, and is still feasible, in the vicinity of streams by constructing shallow wells that may induce streamflow. Shallow wells, not deeper than 25 ft below land surface, with yields that generally do not exceed 25 gal/min, have been completed in areas overlain by a thin alluvium cover along the margins of the Río Pastillo and Quebrada del Agua (U.S. Geological Survey, unpublished data, 1965). Most of these shallow wells have been abandoned, however, mainly as a result of water-quality deterioration. In addition, the feasibility of sustaining moderate well yields by induced streamflow is limited by the low hydraulic conductivity of the Juana Díaz Formation.

Ponce Hydrogeologic Terrane 6 (PonHT6)

The PonHT6 hydrogeologic terrane encompasses an area located north of the PonHT5 and west of the PonHT2. This hydrogeologic terrane is made up mostly of volcaniclastic rocks with minor intrusive rocks. The land slope is variable, but generally is greater than 45 degrees. The thickness of soil cover ranges from 12 to 60 in. and the infiltration capacity of the soil cover ranges from 0.6 to 6 in/hr.

The ground-water flux in the PonHT6 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 estimated ground-water flux is less than 30 gal/min-mi^2, which is equivalent to an effective rainfall recharge of less than 1 in/yr (table 11). Ground-water flow may occur along fractures, as in the other hydrogeologic terrane composed of igneous rocks, particularly in areas where the density of lineaments/lineaments intersections is high.

The ground-water development potential of the PonHT6 is minimal. As in other study areas with similar geologic substratum, the low permeability of the volcaniclastic rocks will only sustain yields that are generally less than 20 gal/min (U.S. Geological Survey, unpublished data, 1976). The low permeability of the volcaniclastic rocks may also limit the potential of inducing streamflow as a reliable water-supply source.

Ground-Water Quality

Water samples were collected at selected wells in the study area to determine the concentration of main dissolved constituents and nutrients (table 12 and 13). There are two primary and three secondary ground-water types in the Ponce area (fig. 11). The primary ground-water types are calcium-carbonate and calcium-sulfate-chloride. The secondary ground-water types are sodium-chloride, sodium-bicarbonate, and calcium-chloride.

Calcium-sulfate-chloride type ground water is present in the deeper parts of the coastal aquifer within the PonHT1 and PonHT2 hydrogeologic terranes. The calcium-sulfate-chloride type ground water is apparently associated with geochemical facies of the Juana Díaz Formation enriched in gypsum and locally containing sea water (connate water). The calcium-carbonate type ground water is prevalent in the Ponce Limestone. Calcium carbonate is more enriched in the Ponce Limestone than in the Juana Díaz Formation. The sodium-bicarbonate type ground water is essentially restricted to the Santa Cruz well (well 24 in table 10 and plate 2). The sodium-chloride ground-water type is present at Reparada 3 and Betterroads (wells 74 and 92, respectively, in table 10 and plate 2) of the PonHT1 and PonHT2 hydrogeologic terranes. The sodium-chloride ground-water type apparently is not associated with any particular lithologic facies and results from intrusion by saline water. In the case of well 24, the sodium-bicarbonate ground-water type may result from mixing of the shallow, saline ground-water zone in the vicinity of the Río Bucaná and fresh ground water underneath. The nature of this shallow, saline water zone is discussed in the section entitled "Mechanisms of Salt Water Encroachment and Delineation of Saline Ground-Water Zones." The origin of the sodium-chloride type ground water in well 92 is unknown. This is discussed in the report section "Delineation of Saline Ground-Water Zones." The calcium-chloride type is restricted to the Hilton well (well 93 in table 10 and plate 2) in the more coastal reaches of the PonHT1 hydrogeologic terrane. The calcium-chloride type ground water could also represent a mixture of saline ground water from the shallow, saline ground-water zone, mentioned above, with underlying fresh ground water. The proportion of saline ground water may be higher in well 93 than in well 24, which would account for the higher concentration of chloride. Finally, the concentration of common ions and nutrients in fresh ground water (ground water with a concentration of dissolved solids less than 1,000 mg/L is within the maximum contamination levels (MCLs) recommended by the U.S. Environmental Protection Agency (1973) as secondary drinking water standards. The secondary drinking water standard for total dissolved solids of 500 mg/L was exceeded at wells 12, 69, 73, 74, 78, 79, 80, 81, and 103 (table 12).

In general, water withdrawn from wells placed within the area affected by the shallow, saline water zone may be unsuitable for human use. In wells 24 and 93, with chloride concentrations of 610 and 553 mg/L, respectively, sea water content may slightly exceed 2 percent. Because of the high salt content of sea water, however, a concentration of only 2 percent of sea water may be sufficient to make ground-water supplies unfit for human consumption (Sophocleous, 2001).

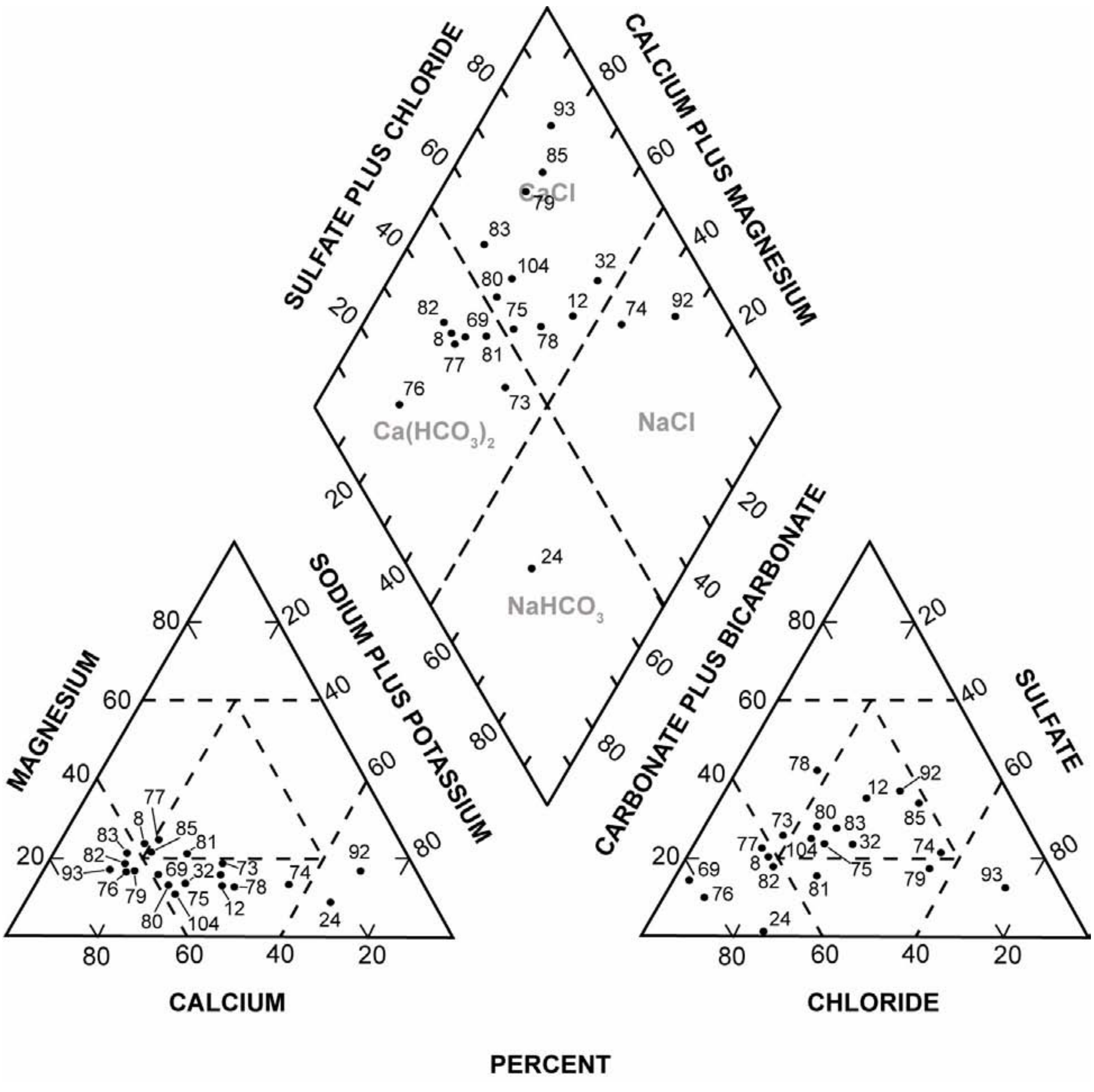


Figure 11. Piper diagram showing main ground-water constituents in the Ponce coastal aquifer.

Oxygen-18 and Deuterium Composition

The ^{18}O and ^{2}H isotopic data collected during this study are shown in tables 14a-14c and plotted in figure 12. The isotopic data collected at the surface- and ground-water sites plot below the Local Meteoric Water Line (LMWL) as defined by the isotopic compositional data of the monthly rainfall composites collected at the Hogares Seguros rainfall station (fig. 12). This departure from the LMWL indicates that the isotopic composition of the local precipitation, prior to and during its infiltration downward to the water table, is affected by evaporation, and consequently, becomes relatively enriched in the heavier isotopes of oxygen and hydrogen, as evaporation preferentially removes the lighter isotopes of ^{1}H and ^{16}O. The fraction of precipitation that ultimately recharges the aquifer is enriched in the heavier isotopes (more positive delta value in ^{18}O and in ^{2}H) than the original precipitation. The isotopic composition of the ground water may also be affected by evaporation because of the shallow depth to the water table.

The delta ^{18}O and delta ^{2}H ($\delta^{18}O$ and $\delta^{2}H$) of stream base-flow and ground-water samples plot along lines with slopes statistically different from that of the LMWL (fig. 12). The slope of the two lines representing stream base-flow and ground-water samples defined by the ^{18}O and ^{2}H data intersect the LMWL in the more depleted ^{18}O and ^{2}H values. As explained in Clark and Fritz (1997), this may indicate that the ground water in the coastal and upper plains aquifers (PonHT1 and PonHT2) results mainly from recharge of precipitation relatively depleted in the heavier isotopes of ^{18}O and ^{2}H, which may undergo slight to moderate evaporation. Precipitation depleted in ^{18}O and ^{2}H in Puerto Rico is generally associated with irregular rainfall events resulting from moisture moving into the Caribbean area from higher latitudes (Clark and Fritz, 1997). According to the isotopic data plotted in figure 12, it seems that precipitation other than that relatively depleted in ^{18}O and ^{2}H is generally restricted to the foothills and mountainous highlands and rarely extends into the coastal and upper plains.

The evaporation effect in the $\delta^{18}O$ and $\delta^{2}H$ is less pronounced in ground water at wells located within the current or past interfluvial area of the Río Bucaná and Río Portugués (wells like 69, 75, 70) or adjacent to abandoned channel segments of the Río Portugués (wells like 86, 82, 79, and 72), mostly within the PonHT1 (plate 2). The slight to moderate differences in the $\delta^{18}O$ and $\delta^{2}H$ values between ground water and the LMWL may be due to the presence of gravel and sand strata with sufficient thickness and at relatively shallow depths as indicated by the geologic sections shown in figure 9. Rainfall over coarse-grained surficial deposits (or at shallow depths) would infiltrate rapidly and minimize losses to evapotranspiration. Another factor that may facilitate recharge in these areas is the presence of abandoned river channels, which resulted from the flood mitigation works conducted during the 1960s and 1970s. The high infiltration rates in these areas is also evidenced by the documented water-level rises at observation wells after rainfall with intensities equal to or exceeding 2 in/hr. Local karstic development, particularly in the Ponce Limestone within the PonHT2 hydrogeologic terrane, may also serve as conduits or pathways as indicated by the relative depletion in $\delta^{18}O$ and $\delta^{2}H$ of the ground-water samples collected at well 74. This relative depletion in $\delta^{18}O$ and $\delta^{2}H$ is also indicative of minimum evaporation effects in the recharging rainfall.

Base flow in streams results from discharge of shallow ground water. Therefore, the ^{18}O and ^{2}H isotope concentration in the base flow mimics that of ground water. The line defined by the $\delta^{18}O$ and $\delta^{2}H$ relations for stream base-flow samples parallels the ground-water line. However, the $\delta^{18}O$ and $\delta^{2}H$ relation for stream base-flow samples has a slightly higher slope than the $\delta^{18}O$ and $\delta^{2}H$ relation of ground-water samples from active wells (fig. 12). This relative isotopic enrichment in $\delta^{18}O$ and $\delta^{2}H$ in stream base-flow with respect to ground water may be caused by the mixing of ground-water discharge to streams with runoff and (upland ground water) from areas upgradient of the sampling sites. The monthly rainfall composite samples obtained at the Hogares Seguros filtration plant rain gage indicate that runoff from the uplands is more enriched in ^{18}O and ^{2}H than the stream base-flow and ground-water samples.

The analysis of $\delta^{18}O$ and $\delta^{2}H$ proves to be useful in better understanding the source (relative mixing of ground and surface waters), as well as in the spatial and temporal character of the recharge in the Ponce study area. Additional analyses are needed, however to further refine the seasonal and temporal variations in the $\delta^{18}O$ and $\delta^{2}H$ composition in the various storage components of the hydrologic cycle including: monthly variability over an extended period; the relation of this variability to that in streamflow during base flows and storm runoff events; and the spatial and temporal variability in the aquifers.

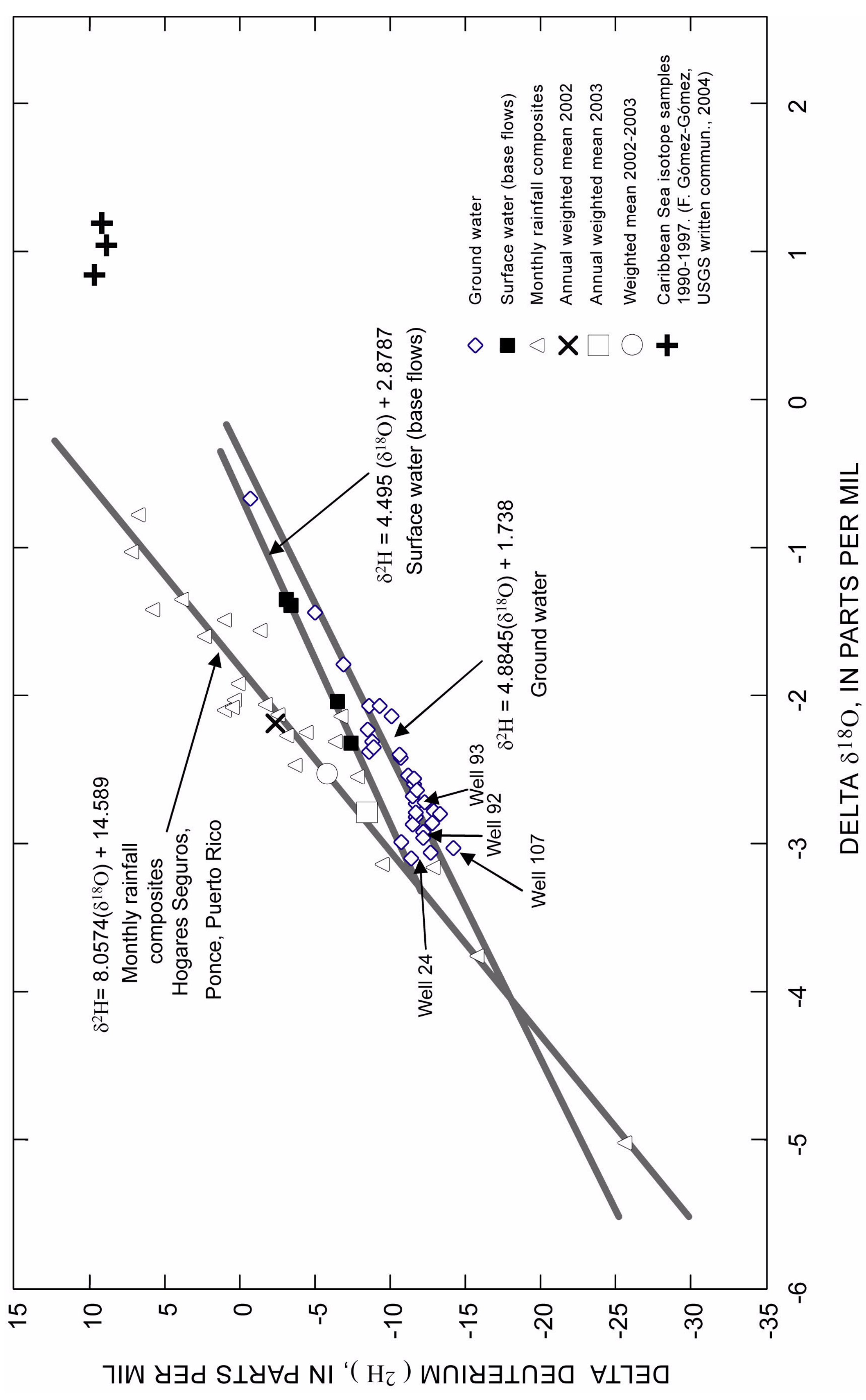


Figure 12. Delta values of oxygen-18 and deuterium for ground water, surface water (base flows), and monthly rainfall composites at the Hogares Seguros rainfall station in the Ponce study area.

Mechanisms of Salt Water Encroachment and Delineation of Saline Ground-Water Zones

Direct current (DC) surface-resistivity and water-quality data (current and historical) indicate that saline ground-water encroachment is widespread throughout the PonHT1 hydrogeologic terrane and also occurs at a smaller scale in the PonHT2 hydrogeologic terrane. The DC resistivity data also indicate that the occurrence of saline ground water within sub-areas of the PonHT1 may be stratified.

The presence of saline water within the PonHT1 and PonHT2 hydrogeologic terranes could be caused by the following: (1) upward coning of mineralized ground water, (2) displacement of sea water into the aquifer by the tidal-fluctuation effects on the salt water wedge along the Río Bucaná channel, and (3) evaporation and transpiration from the aquifer, especially where the water table is at or near the land surface. Another mechanism, which may not be important at present, is evaporation of the water applied as furrow irrigation; however, this irrigation method was completely abandoned in the late 1970s.

Each of the mechanisms mentioned earlier has been important at different temporal and spatial scales. Salt water encroachment and upconing of saline ground water from the basal part of the aquifer may not be occurring at a substantial scale at present since the main ground-water pumping centers, such as the Restaurada well field (include wells 57, 58, 60, 61, 72, and 83 in table 10 and plate 2) are located at sufficient distances from the coast. Further evidence that salt water encroachment and upconing of saline ground water is minimal or non-existent is provided by the stable isotope analyses obtained for $\delta^{18}O$ and $\delta^{2}H$ at wells 24 and 93 (table 14a, fig. 12, and plate 2). The $\delta^{18}O$ and $\delta^{2}H$ values at these wells indicate that the ground water pumped, despite the high dissolved solids concentrations is mostly infiltration from local freshwater sources (table 14a, fig. 12). This in turn indicates that fresh ground-water flow is still active in most of the coastal reaches of the PonHT1. Similarly, DC resistivity data, discussed below, indicates that fresh ground-water flow may occur at depth throughout most of the PonHT1.

Saline ground water may occur naturally at depth in the Juana Díaz Formation. This geologic formation, because of its very low permeability, contains interstitial saline water (connate or depositional water) that accompanied its deposition in a mixed marine-terrestrial sedimentary environment (Monroe, 1980). The depositional environment and post-sedimentary changes (diagenetic processes) also favored the occurrence of evaporite deposits whose dissolution also contributes to the saline character of the ground water contained within the Juana Díaz Formation. In the PonHT1 hydrogeologic terrane, historical water-quality data in USGS data files indicate that in wells completed either a short distance above or entirely within the Juana Díaz Formation, once pumping is initiated ground-water discharge becomes saline over time as a result of the migration of solutes.

The DC surface-resistivity data using an electrode spacing of 100 ft in conjunction with available lithologic logs and ground-water quality data indicate that with the exception of areas with apparent resistivity values greater than 3 ohms-meters and chloride concentration values less than 100 mg/L, saline ground water in the PonHT1 exists within the shallow parts of the aquifer in most of the area between the Río Bucaná and Río Inabón (fig. 13a). At depths equivalent to electrode spacings greater than 100 ft, the apparent resistivity values can be interpreted to indicate that the shallow, saline water zone is underlain by freshwater (fig. 13b-e). The shallow, saline ground-water zone in the vicinity of the Río Bucaná flood channel is well defined by the apparent resistivity values. The apparent resistivity values that define the shallow, saline zone are generally less than 5 ohm-meters (fig. 14). At present, the vertical extent of this shallow, saline ground-water zone is unknown, but at the site of survey sounding R5, the vertical extent may range between 20 and 30 ft (figs. 13 and 14). The vertical extent of this shallow, saline zone may thicken toward the coast.

The diffusion and dispersion of sea water into the aquifer, caused by the tidal fluctuation of the salt water wedge along the Río Bucaná flood channel, may have been responsible for saline water encroachment in the shallow parts of the coastal aquifer between the Río Bucaná flood channel and the Río Inabón. Saline water was found in artificial ponds constructed as part of the golf course landscape in the vicinity of the Río Bucaná channel. The specific conductivities at these four shallow ponds (identified as features 99, 100, 101, and 102 in table 10, fig. 13, and plate 2) were 16,400, 14,000, 16, 200, and 35,400 µS/cm at 25°C, respectively. The chloride concentrations of 610 and 553 mg/L measured at wells 24 and 93, respectively (see sections on Ground-Water Quality and Oxygen-18 and Deuterium Composition), may result from the mixing of fresh ground water contained at depth with ground water from this shallow, saline water zone.

The occurrence and origin of this shallow, saline ground-water zone was recognized by Bennett (1972). In the late 1960s and prior to the major flood remediation works of the 1970s, the salt water wedge in the Río Bucaná extended to about 0.63 mi upstream (Bennett, 1972) and the inland extent of the shallow, saline ground-water zone prior to the 1970s was about 0.38 mi (Bennett, 1972). The straightening and deepening of the Río Bucaná channel and its confluence with the Río Portugués in the early 1970s, contributed to the upstream displacement of both the salt water wedge and the inland movement of saline ground water. In 2002, the inland location of the salt water wedge in the Río Bucaná flood channel was estimated to be 1.88 mi inland and the shallow, saline ground-water zone as much as 1.63 mi (plate 1 and fig. 13). The extent of salt water encroachment to the west and east of the Río Bucaná flood channel is unknown.

Base from Space Imagine (Ikonos) Ponce, Puerto Rico 2001-2002

Figure 13a. Distribution of apparent resistivity at current electrode spacings of 100 feet in the coastal plain of Ponce, Puerto Rico.

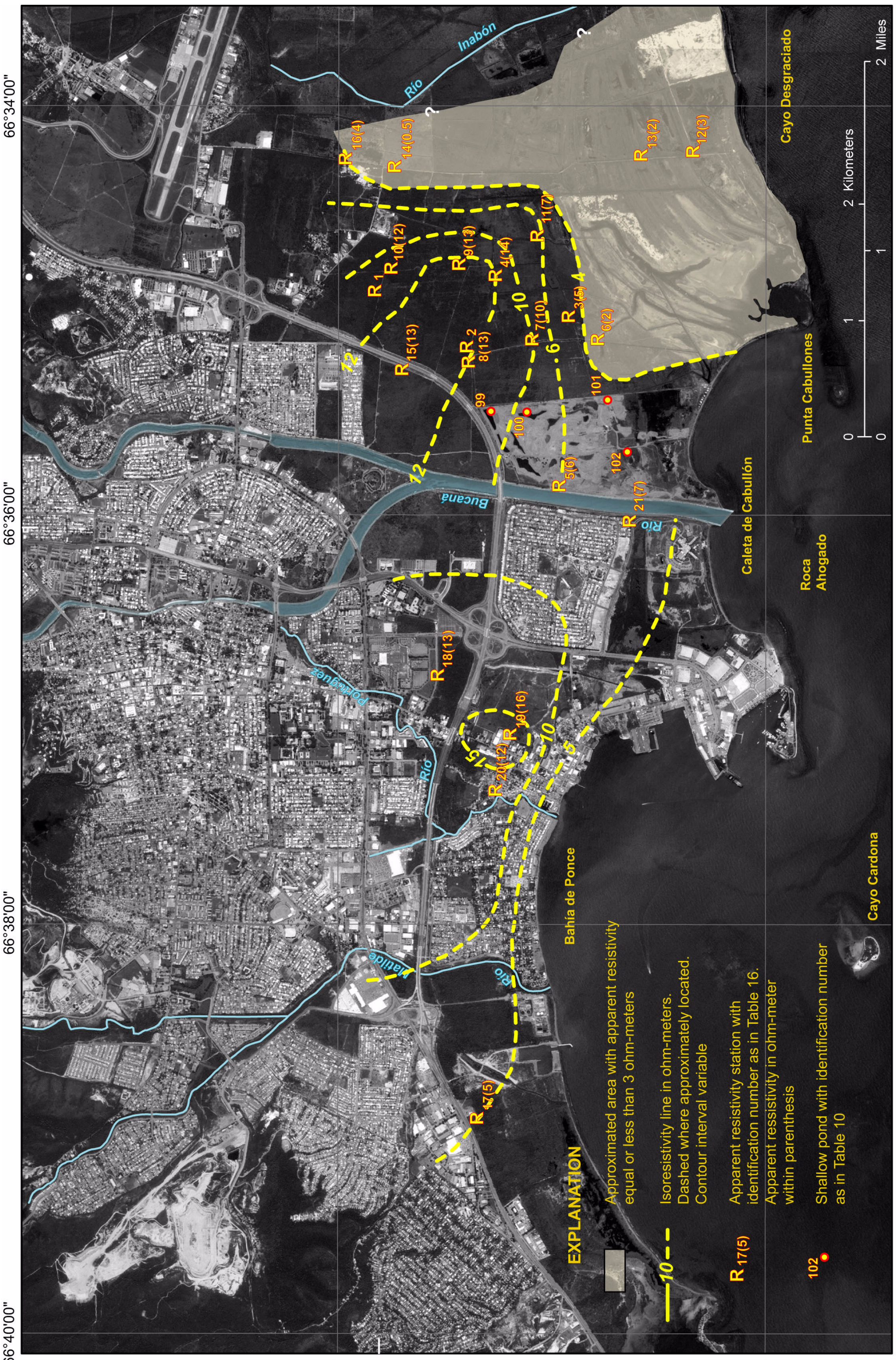


Figure 13b. Distribution of apparent resistivity at current electrode spacings of 200 feet in the coastal plain of Ponce, Puerto Rico.

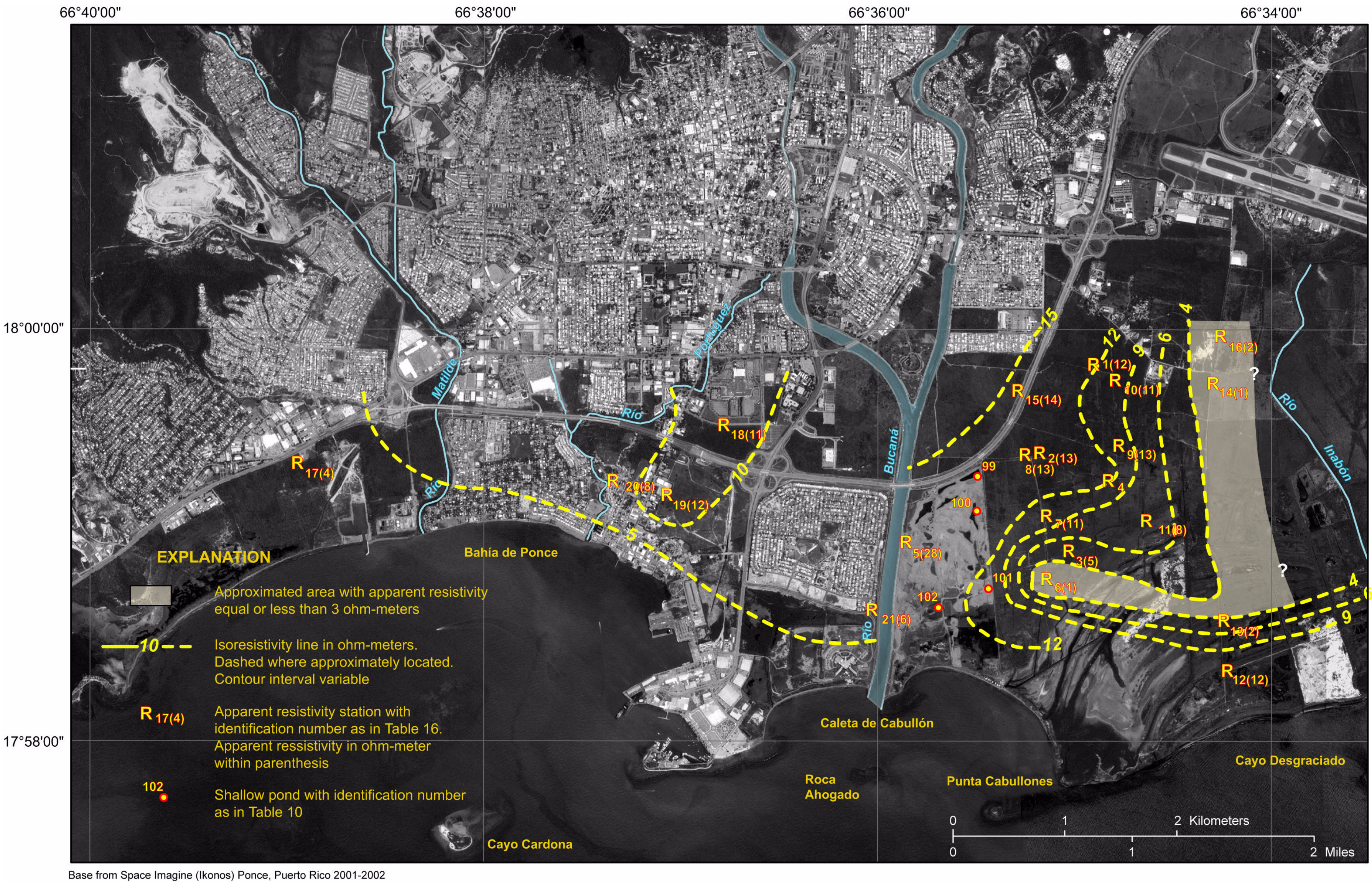
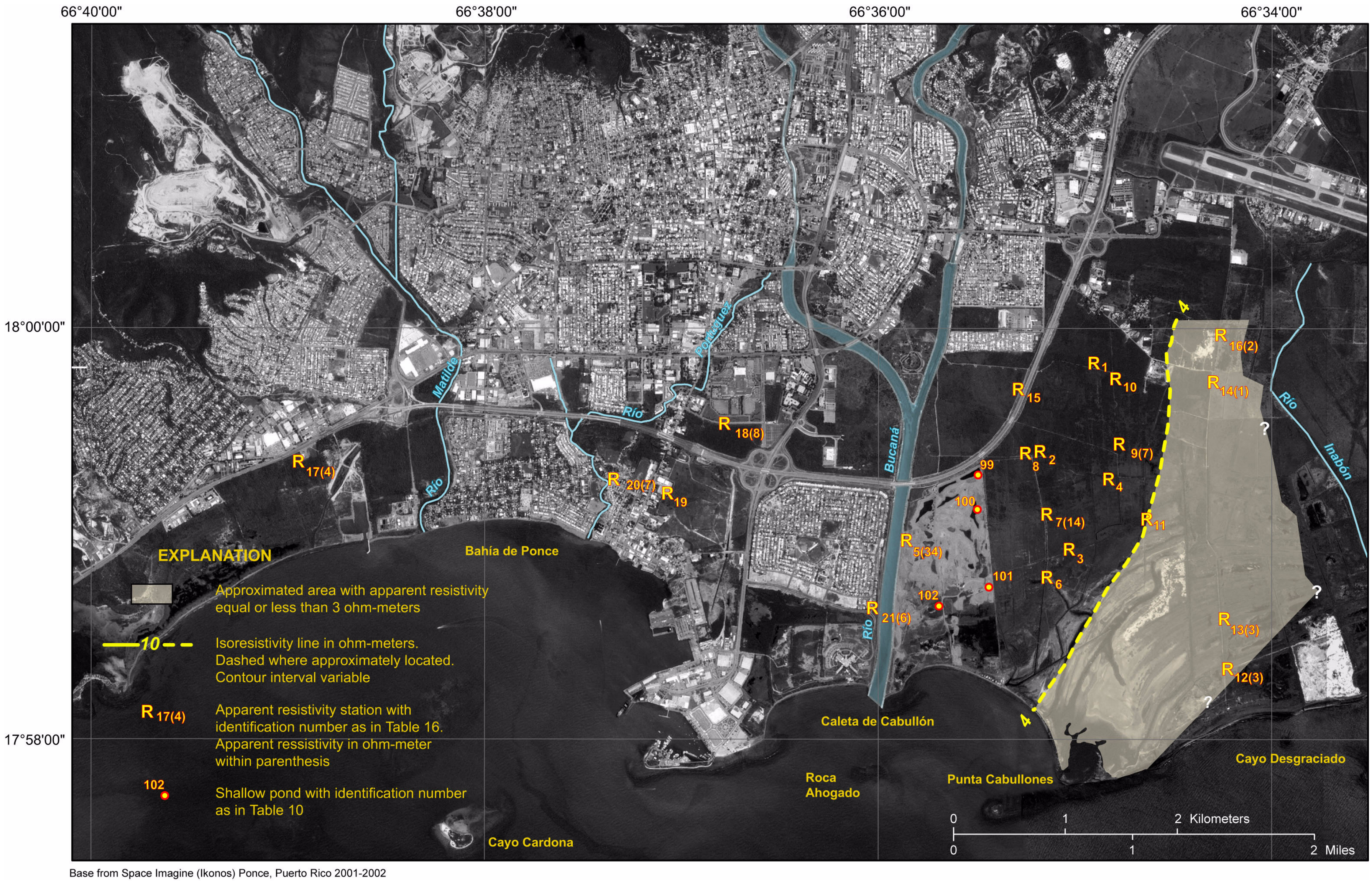


Figure 13c. Distribution of apparent resistivity at current electrode spacings of 300 feet in the coastal plain of Ponce, Puerto Rico.

Figure 13d. Distribution of apparent resistivity at current electrode spacings of 450 feet in the coastal plain of Ponce, Puerto Rico.



Base from Space Imagine (Ikonos) Ponce, Puerto Rico 2001-2002

Figure 13e. Distribution of apparent resistivity at current electrode spacings of 700 feet in the coastal plain of Ponce, Puerto Rico.

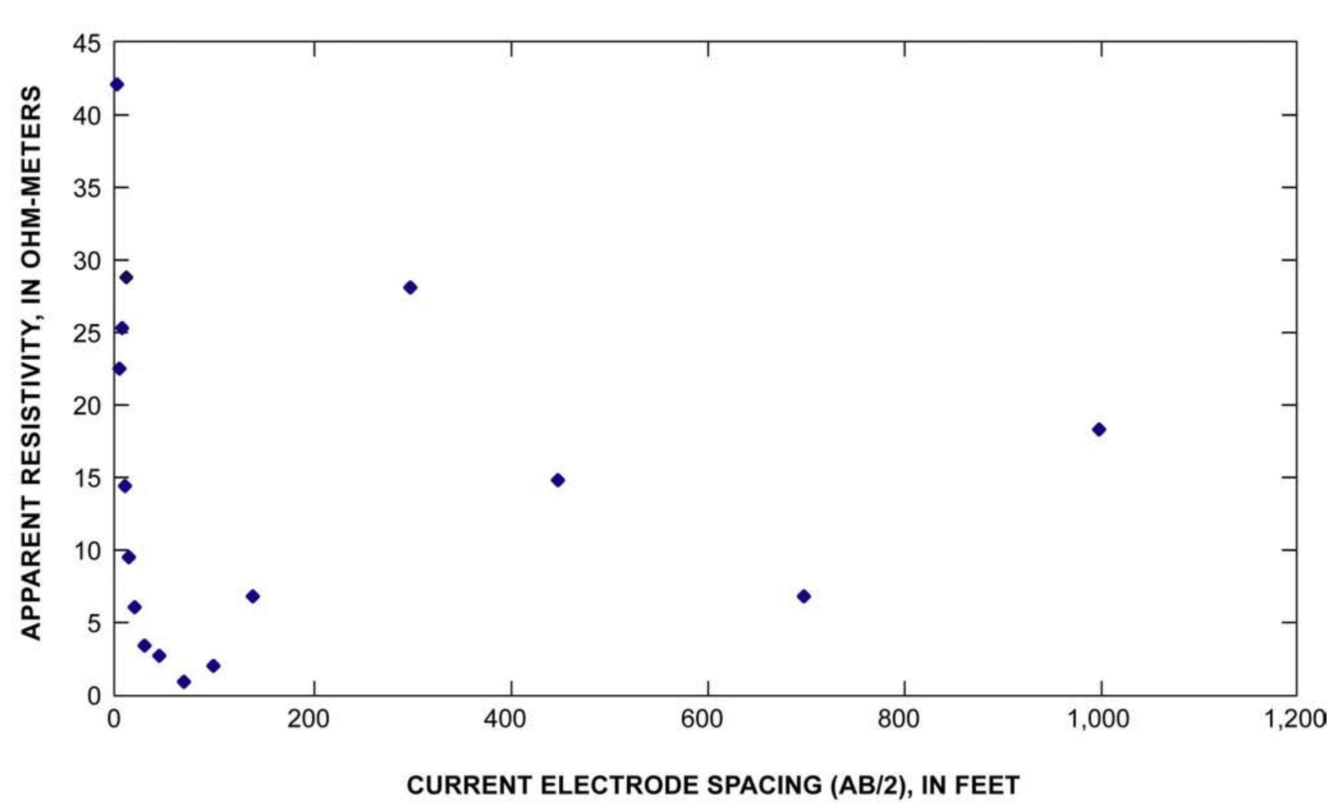


Figure 14. Distribution of apparent resistivity with current electrode spacing in sounding 5. Location of sounding 5 is shown in figure 13 and is included in table 16.

Indirect evidence of its possible eastward extent, however, is provided by the high specific conductivities measured at the four shallow ponds, mentioned earlier, dug in the PonHT1 as part of the landscape preparations for a golf course. Pond #3 (feature 101 in table 10 and plate 2) is about 0.56 mi east of the Río Bucaná. East of pond #3, the effects of the salt water encroachment into the aquifer by construction of the Río Bucaná flood channel is not as evident. The occurrence of the shallow, saline ground water is not as readily observed west of the Río Bucaná flood channel. It is highly probable that alluvial deposits west of the Río Bucaná flood channel are rich in clay, thus forming a hydraulic barrier and limiting the westward movement of saline water from the Río Bucaná into the aquifer. Another reason may be that the potentiometric gradient has not been affected by ground-water withdrawals along the west side as has occurred east of the Río Bucaná flood channel. The curve for apparent resistivity along survey sounding 21, near the Río Bucaná, indicates that ground water of marginal quality may occur at depths corresponding to electrode spacings between 300 and 450 ft (figs. 13 and 15b). The general low apparent resistivity values obtained at sounding 17 shows that in the vicinity of the coastal reach of the Río Matilde, the ground water is at best marginal in terms of quality (less saline than seawater) probably because of the reduced thickness of the overlying alluvium and the presence of the Juana Díaz Formation at shallow depth (figs. 13 and 15a). Fresh ground water in the Río Matilde coastal area, if present, must be restricted to a thin layer of the aquifer. Public supply-water wells west of the former course of the Río Portugués (wells 47 and 48 in table 10 and plate 2) have been abandoned (in the 1990s) because of reduced yields and water-quality degradation. Apparently, the reduction in the yields and deterioration of water quality at wells in the vicinity of the Río Portugués is closely associated with the coastal flood channelization projects, which have dissected the coastal segment of this river and diverted streamflow toward the Río Bucaná. Most public-supply wells at the Barrio Playa de Ponce sustained their yields with induced streamflow from the Río Portugués, therefore saline water intrusion was averted in the past.

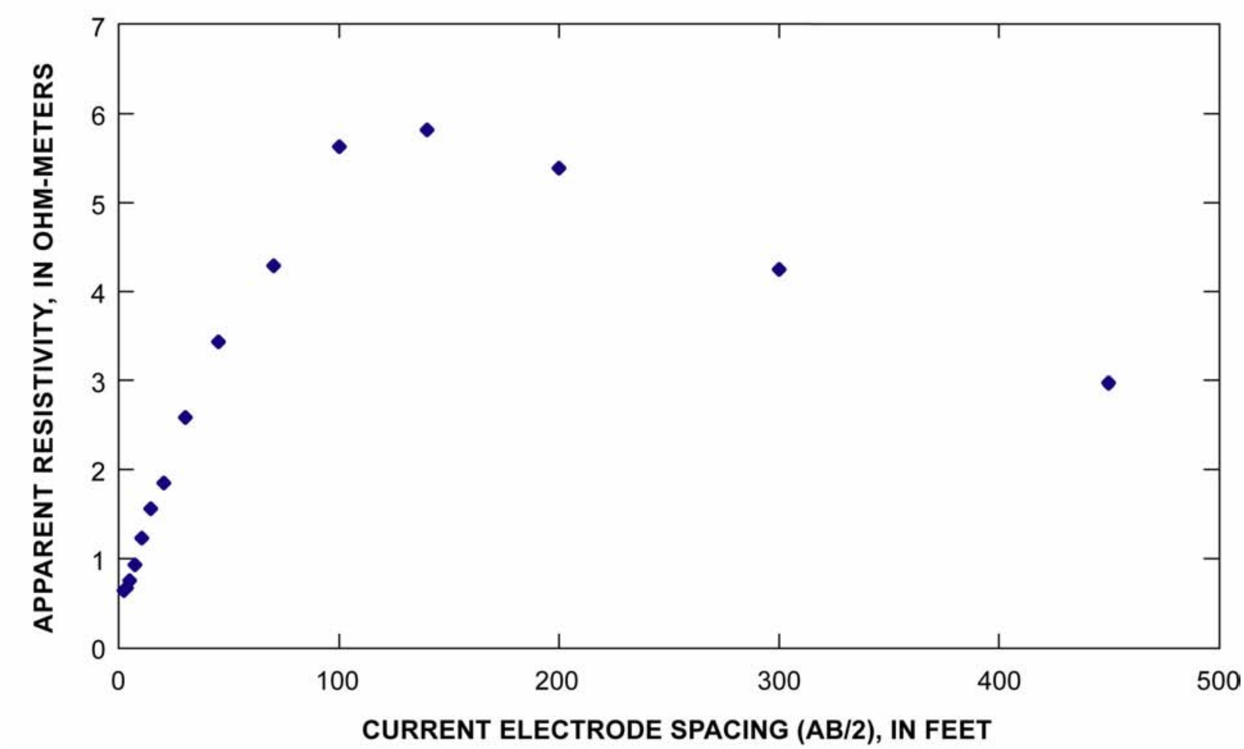


Figure 15a. Distribution of apparent resistivity with current electrode spacing in sounding 17. Location of sounding 17 is shown in figure 13 and is included in table 16.

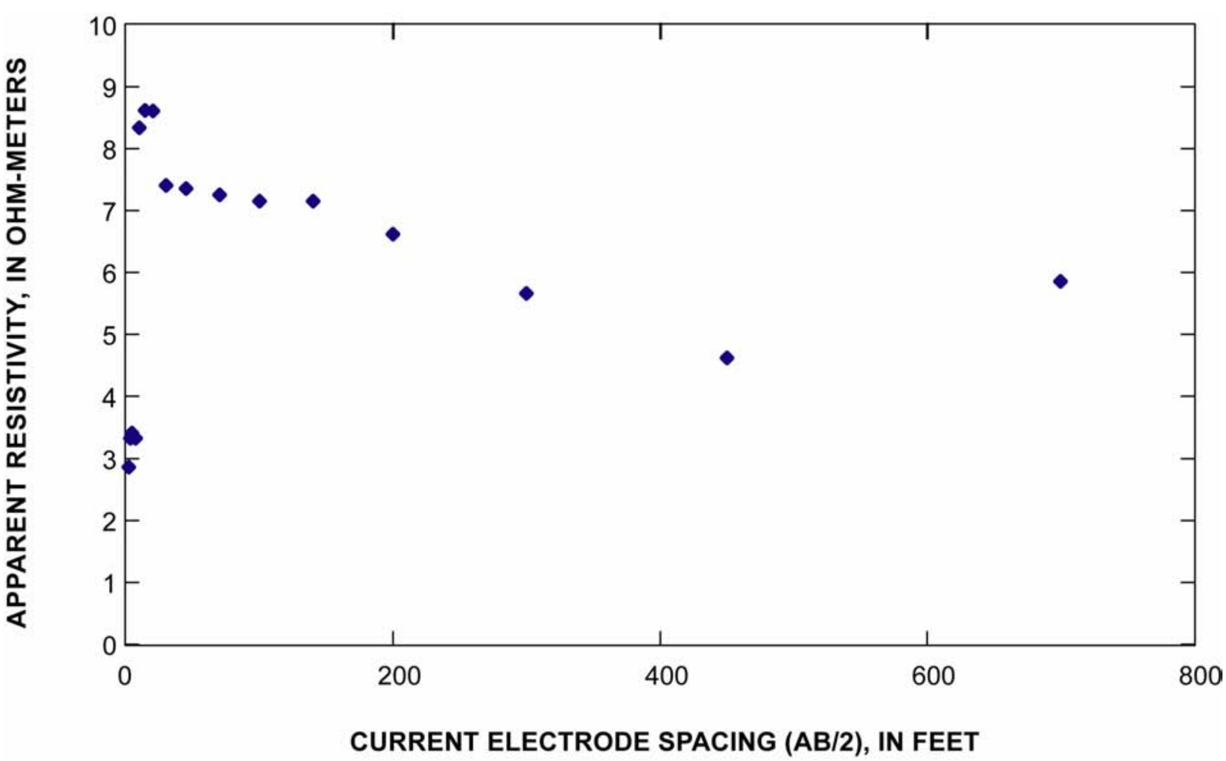


Figure 15b. Distribution of apparent resistivity with current electrode spacing in sounding 21. Location of sounding 21 is shown in figure 13 and is included in table 16.

The Restaurada public-supply water well field, with a total yield of about 2.0 Mgal/d, could be threatened by salt water encroachment from the Río Bucaná flood channel. Saline ground-water intrusion caused by the tidal fluctuations of the salt water wedge in the Río Bucaná channel has not been documented to this date (2004) at the Restaurada well field or at well 82 (table 10 and plate 2). These wells are outside the area where DC-resistivity values less than 3 ohm-meters and chloride values greater than 100 mg/L are indicative of saline ground water (fig. 13). The apparent isolation of these wells from the shallow saline ground-water zone may be explained by the fact that the surficial sand strata of medium grain size, where the dispersion of saline ground water occurs elsewhere, is replaced by a clayey strata in the vicinity of these wells (fig. 9). Similarly, saline water from the saltwater wedge in the Río Bucaná is not induced by pumpage into the Restaurada well field as a result of the presence of this clay layer.

Evapotranspiration by plants and evaporation of ground water may be an important mechanism of saltwater formation at shallow depths within the PonHT1 hydrogeologic terrane, particularly in the more coastal zone where the water table is less than 10 ft below land surface and regularly intersects the land surface. Evaporation and evapotranspiration may have been a more active and widely spread mechanism for saltwater formation during the flood irrigation period when water-logged conditions in most of the PonHT1 hydrogeologic terrane were common owing to prevailing high water-table conditions (Bennett, 1972). The formation of similar shallow saline ground-water zones have occurred in many agricultural areas of the world where surface-applied irrigation has been used (Skogerboe and Walker, 1981). These shallow, saline ground-water zones developed as salts (dissolved solids) accumulated in the surficial soils, as a result of evaporation of the applied irrigation water, and migrated downward to the water table. Gómez-Gómez (1990) may have found evidence of this evaporation effect on the applied irrigation water when using the stable isotopes ^{2}H and ^{18}O to define the hydrochemistry of the south coast alluvial aquifer. The gradual substitution of imported surface water with locally withdrawn ground water, having a higher dissolved solids concentration, may have enhanced the formation of this saline, shallow ground-water zone in the coastal reaches of the PonHT1.

The data collected during this study do not explicitly indicate that saltwater intrusion to the aquifer is substantial in the more coastal areas of Ponce. The differentiation between saltwater intrusion and the other saline water encroachment mechanisms, discussed earlier, in the more coastal reaches of the study area will require additional hydrogeologic data and a broader base of water quality and isotopic analyses. Bennett (1972) had stated that because of the high anisotropy of the aquifer, the analysis and understanding of potential saltwater intrusion in the coastal area of Ponce, particularly in the Río Bucaná area, would be a complex task. As of 2003, the only indication that saltwater intrusion has occurred or is actually an active process locally along the coast is provided by the limited DC-surface resistivity data, which indicate that saline water in some coastal areas of the PonHT1 may occur at depths equivalent to electrode spacings equal or greater than 100 ft. Water quality, stable isotope, and DC resistivity data collected during this study, however, indicate that there exists, as of 2003, a fresh, ground-water zone extending offshore along a substantial portion of the coastal area of the municipio of Ponce, although presumably thinner than that during the period of flood irrigation. These same data, however, are not sufficient to assume that the freshwater-saltwater interface lies mostly at an undetermined distance offshore, as was the case during the flood irrigation years.

The δ^{18}O and δ^2H and high sodium, chloride, and sulfate contents of the ground water sampled at well 92 (plate 2, table 14a, fig. 11, and table 12) indicate that a different mechanism, other than those described above, may be contributing locally to saline ground-water encroachment in the PonHT1 hydrogeologic terrane. In particular, the δ^{18}O and δ^2H values indicate that water in well 92 is from rainfall recharge, similar to wells 24 and 93. Well 92 is at a substantial distance from the coast and from the Río Bucaná flood channel, making it questionable as to whether the high dissolved solids concentration is derived from saltwater intrusion and tidal fluctuation, as previously discussed. Further studies are required to adequately identify the source of saline ground water at this well, which seems to extend along a north-south corridor about 1-mi wide (fig. 13).

Lineament-Trace Analysis

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

Structural lineaments (Ls)—Lineaments of structural or geologic importance, including, but not limited to fault traces, fracture traces, lithologic contacts, failure escarpments, and terraced surfaces. These lineaments are located near existing faults, thus appear to be continuations of mapped faults and show similar trends.

Topographic lineaments (Lt)—Lineaments of erosional origin including straight, linear or curvy-linear mountain ridge tops, stream valleys, gullies or terraced surfaces near major river valleys. Generally, these lineaments appear as subtle elements and cannot be readily associated with mapped geologic structures; however, their origin may be potentially associated to structural features.

A total of 136 lineaments were identified in the municipio of Ponce, either as Ls or Lt. Two lineaments, lineaments 93 and 117, were identified as caused by cultural artifacts and consequently are not presented on plate 2.

In general, the mapped traces in the study area reveal the presence of mainly two distinctive sets of Ls and Lt lineaments, based on their trends or azimuths. These are a prevalent northwest-southeast strike and a less common northeast strike. There is a large number of northwest-southeast trending lineaments located within the study area that show an apparent similarity in bearing to mapped faults.

Generally, the lineament-trace analysis indicates that most of the recognized structural or geologic (Ls) lineaments and possibly some Lt lineaments in the area are potentially related to unmapped large fractures or fault traces. The courses of major rivers in the upland areas of the municipio of Ponce appear to be strongly controlled by structure since most of these exhibit the same bearing as the Ls lineaments (plate 2).

In general, the lineaments traced during this study appear to correlate with the geologic setting of the Ponce upland area. In terms of its hydrologic importance, traced lineaments with parallel and sub-parallel, contiguous features appear to be the most common and valuable. The hydrologic importance of traced lineaments is enhanced in those zones where lineaments are concentrated or have similar lengths and orientation.

Potentiometric Surface

A map of the potentiometric surface was constructed of the South Coastal Plain aquifer within the Ponce area that is representative of the hydrologic conditions prevailing during December 2002 through March 2003 (plate 2). The elevation of the ground-water level, as indicated by the potentiometric contours, varied from a high of 65 ft above mean sea level in the upper plain to an elevation close to sea level in the coastal plain (plate 2). According to this potentiometric-surface map, the regional ground-water flow movement is predominantly southward, with minor southeastward and southwestward components. The inland displacement of the lower potentiometric contours in the vicinity of the confluence of the Río Bucaná and Río Portugués may result from a combination of the effects of ground-water withdrawal at the Restaurada public-supply water well field and the high hydraulic anisotropy of the aquifer, mentioned earlier (plate 2). Likewise, seaward displacements of the higher potentiometric contours may indicate seepage from the rivers into the aquifer, although, the seepage run conducted during December 2002 and discussed earlier did not find evidence of such relation, except in the Río Pastillo. It is also likely that the indicated inland- or seaward-displaced potentiometric contours, particularly those west of the Río Bucaná, may result from relatively impermeable strata in the subsurface, which serve as hydraulic barriers.

The potentiometric map of December 2002 through March 2003 represents hydrologic conditions substantially different from those represented by the potentiometric map prepared by McClymonds (1972). The potentiometric map by McClymonds (1972) was developed during November 1964. The December 2002 through March 2003 potentiometric map is representative of conditions after furrow irrigation was completely abandoned and the main recharge source to the aquifer was, as mentioned earlier, rainfall/runoff infiltration. The McClymonds map represents conditions in the 1960s when furrow irrigation throughout the coastal plain was at its maximum and the water applied at land surface was the most important source of recharge to the South Coastal Plain aquifer. A comparison of the two maps indicates that ground-water levels, in general, have declined since the 1960s. This decrease in ground-water levels indicates a depletion in aquifer storage. The decreases in ground-water levels have ranged from 5 to 25 ft (fig. 16). The greatest decrease in ground-water levels, ranging from 20 to 25 ft, seems to have occurred in Barrio Bucaná, located north of the Restaurada well field. An example of the decrease in ground-water level since the 1960s in the Restaurada area is provided in the hydrograph of USGS observation well 84 (fig. 17, table 10). Decreases in the potentiometric surface ranging from 5 to 10 ft have occurred in the coastal plain areas, south of the Restaurada well field and west of the confluence of the Río Bucaná and Río Portugués (fig. 16). There have been local increases in the ground-water levels as in Barrio Coto Laurel northeast of Central Mercedita that can be ascribed to changes in the ground-water pumping regime (fig. 16). Another area where an increase in ground-water levels is evident is in the Barrio Machuelo Abajo in the northern part of urban Ponce. Comparison of the potentiometric map of December 2002 through March 2003 and shown in plate 2 with that of McClymonds (1972) seems to confirm that during the 1960s, prior to the construction of the major flood mitigation works, the hydraulic connection between rivers and aquifers was greater, particularly in the upper plain (PonHT2), where rivers were important recharge sources to the aquifer.

Ground-Water Withdrawals

The main ground-water use in the municipio of Ponce is for public-supply purposes, with an estimated withdrawal during 2003 of about 4.4 Mgal/d (W. Molina-Rivera, U.S. Geological Survey, written commun., 2004, fig. 18). The combined amounts of ground water withdrawn for industrial, agricultural, and self-supplied domestic use are minor in comparison with that for public supply. All of the ground water withdrawn by PRASA for public-supply purposes is within the PonHT1 and PonHT2 hydrogeologic terranes.

Data on ground-water withdrawal rates from the aquifers at Ponce are sparse prior to 1980. The oldest reliable historical estimate is by McClymonds (1972), who reported a maximum ground-water withdrawal rate of about 30 Mgal/d in 1964 for irrigation and public-supply purposes. This withdrawal rate was sustained without any major ground-water degradation in part by the estimated 30 percent spatial aquifer recharge derived from excessive furrow irrigation. Afterward, ground-water withdrawal for irrigation purposes decreased as the major agricultural activity, sugar cane cultivation, declined and surface water gradually became the main public-supply source. This downward trend in ground-water withdrawal for public supply has become better documented since 1980 (fig. 18). The ground-water withdrawal rate for public-supply purposes decreased from an estimate 9.5 Mgal/d in 1980 to an estimate 4.4 Mgal/d in 2003 (W. Molina-Rivera, U.S. Geological Survey, written commun., 2004).

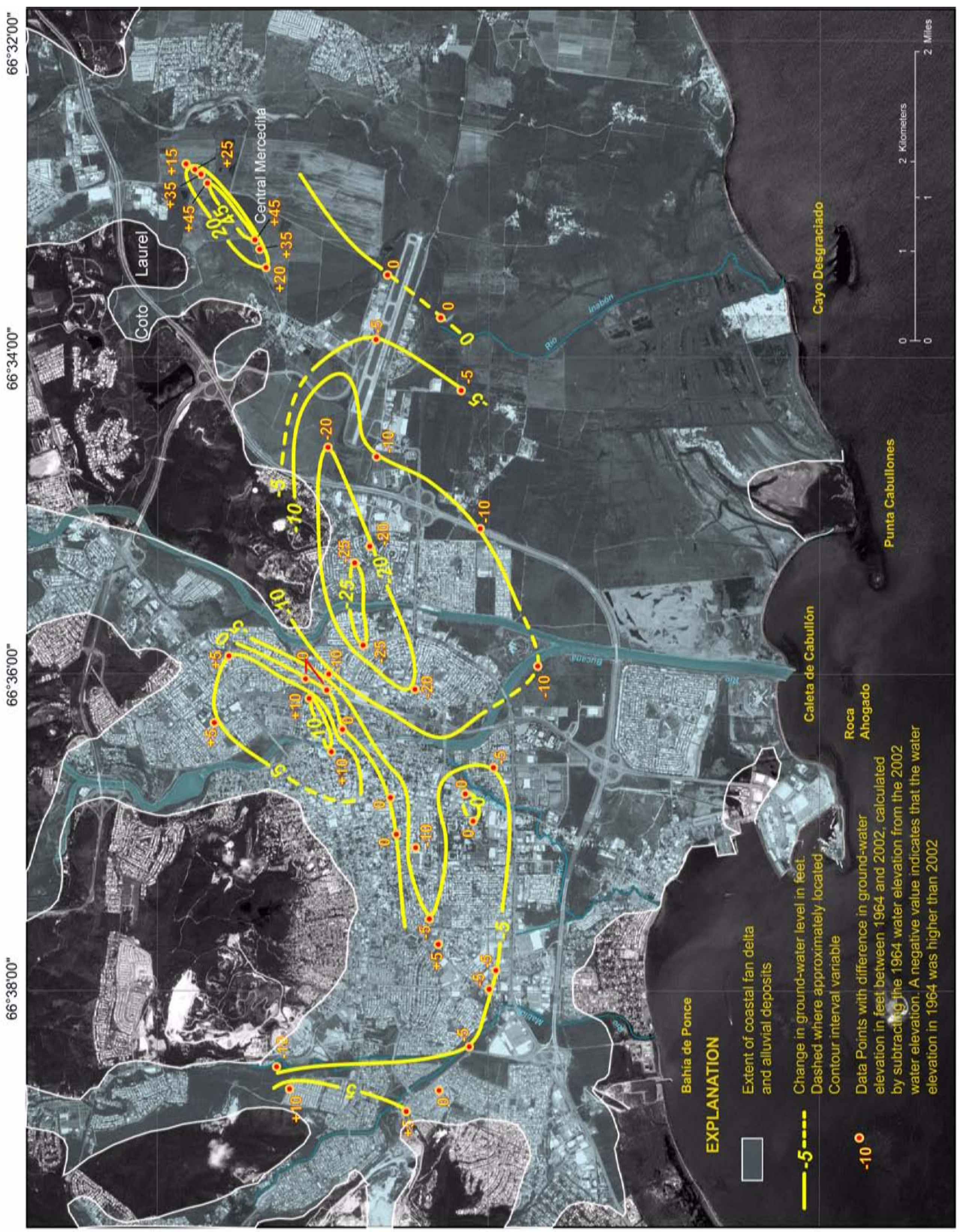


Figure 16. Difference in ground-water levels between 1964 and 2002 in the Ponce coastal aquifer.

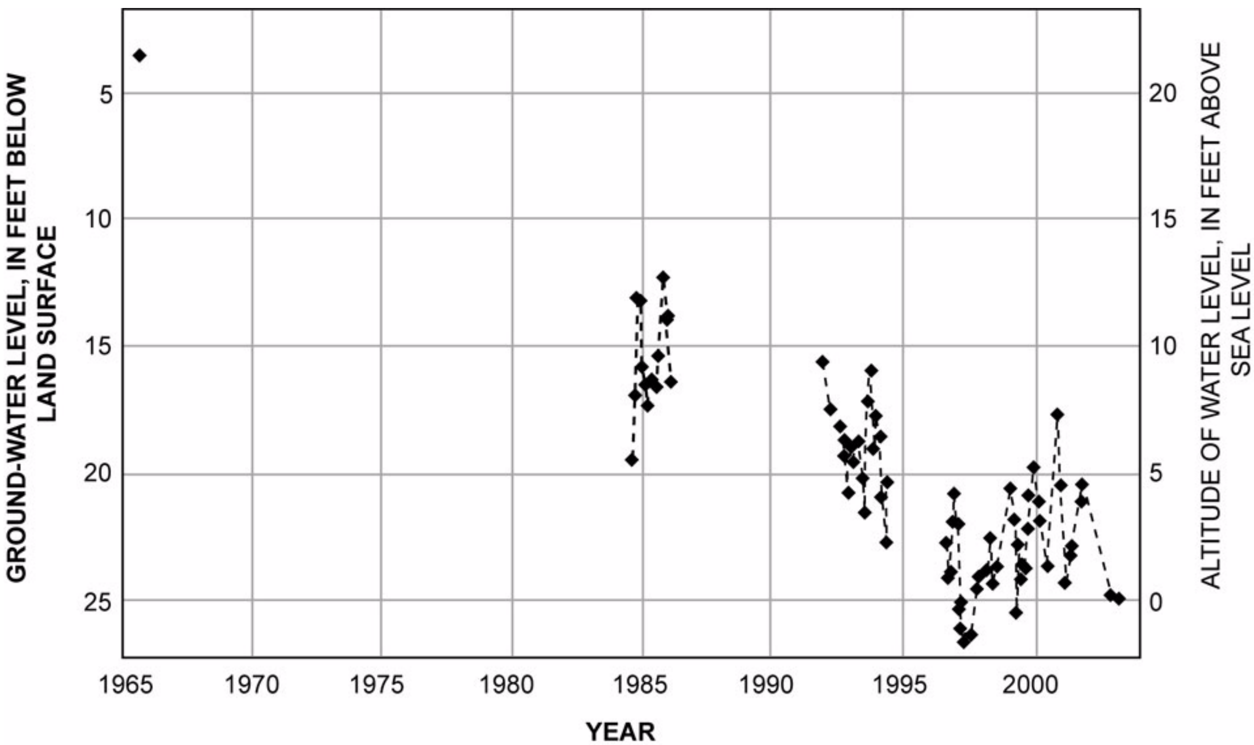


Figure 17. Historical hydrograph of well 84. The location of well 84 is shown on plate 2 and is included in table 10.

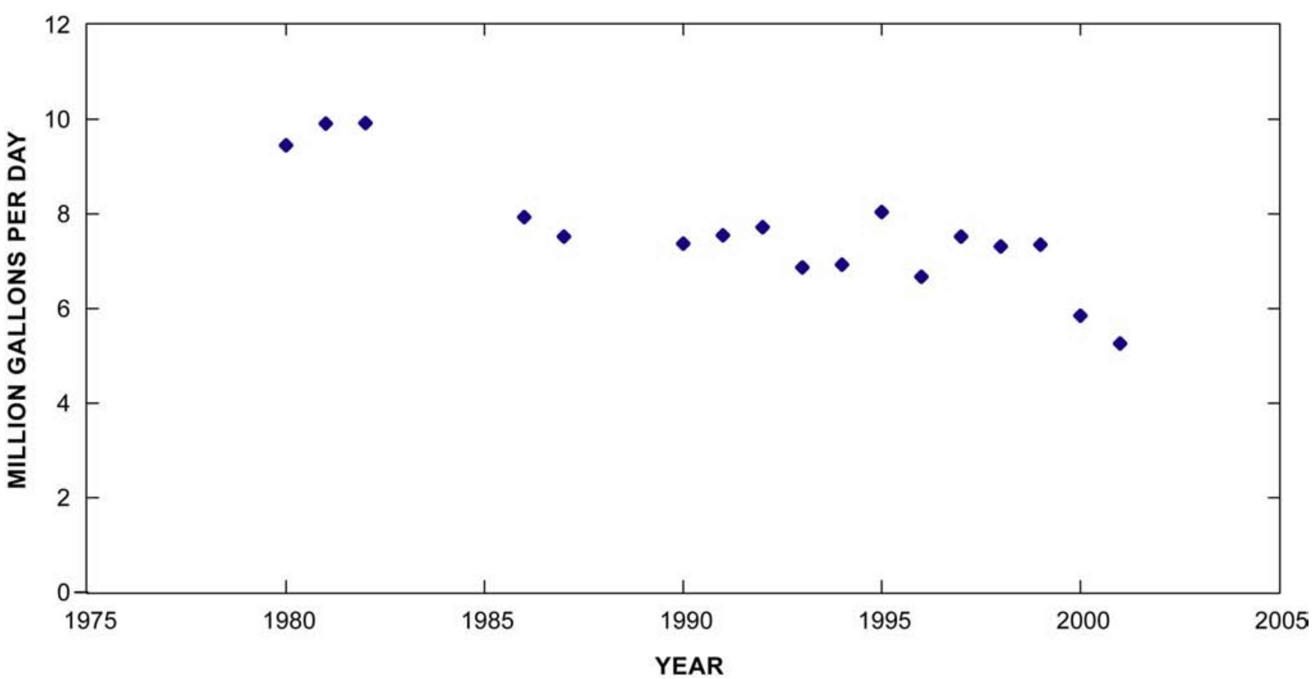


Figure 18. Historical changes in ground-water withdrawal rates by the Puerto Rico Aqueduct and Sewer Authority within the municipio of Ponce.

Summary and Conclusions

The USGS, in cooperation with the office of the Major of the Municipio Autónomo de Ponce, conducted an integrated assessment of the surface-water, water-quality, and ground-water resources of the municipio of Ponce. 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 from this study including other hydrologic and water-quality features were compiled in a Geographic 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 Ponce; low-flow and flow-duration characteristics were evaluated at 3 long-term continuous-record (index) gaging stations and 27 partial-record stations. The index stations are located on the Río Inabón, Río Cerrillos, and Río Portugués. The 27 partial-record stations are distributed among a number of streams within the geographic limits of the municipio. The surface-water contributions at the index stations, based on the 99-percent flow duration, of the Río Inabón (50112500), Río Cerrillos (50113800), and Río Portugués (50115000) are 1.7 cubic feet per second (ft^3/s), 3.4 ft^3/s, and 1.7 ft^3/s, respectively. The surface-water contribution, based on the 99-percent flow duration was less than 1 ft^3/s at each of the following partial stations: Río Inabón near Salto de Inabón (50112200), Quebrada Emajagua near Anón (50112225), Río Anón at Anón (50112250), Río Anón near Anón (50112300), Río Prieto at Anón (50113640), Río Prieto at Highway 139 (50113650), Quebrada Jamiel near Ponce (50113700), Río Blanco at Highway 139 (50113710), Quebrada Ausubo at Machuelo Arriba (50114140), Río Bayagán downstream of Highway 505 (50114175), Río Bayagán at Machuelo Arriba (50114190), and Tributario de Río Portugués at Tibes (50114880). The surface-water contribution, based on the 99-percent flow duration, is higher than 3 ft^3/s at each of these partial stations: Río Cerrillos above Lago Cerrillos near Ponce (50113800) and Río Cerrillos near Anón (50113792).

In addition to low-flow characteristics in the surface-water assessment, important surface-water resource information also was compiled, including locations of actual and potential reservoir sites, flood hazard areas, waste-water treatment plants, drainage-basin boundaries, and stream-gaging station locations. The stream low-flow statistics presented in this report document the general hydrology under current land and water uses. These low-flow statistics are also 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.

Long-term monitoring of bacterial concentrations of surface waters at three sampling stations in the municipio of Ponce indicates that since the beginning of the data collection in 1987, sanitary quality generally has been in compliance with the fecal coliform sanitary quality goal established for Class SD waters in July 1990 at stations Río Cerrillos near Ponce (50114000) and Río Portugués near Ponce (50115000); bacterial concentrations have mostly exceeded the fecal coliform sanitary quality goal established in 1990 at station Río Portugués at Ponce (50116200). Stations 50114000 and 50115000 also were in compliance since 1996 and 2000, respectively, with a stricter fecal coliform goal established in 2003. 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 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 (2003). The method was applied in order to rank the sanitary quality at sampling stations where water samples were collected during stream base-flow conditions. The ranking includes the classifications **good**, **acceptable**, **fair**, and **poor**.

It was necessary to develop a rationale to interpolate and extrapolate station classifications, because only 27 sampling stations were used to determine the sanitary quality of approximately 130 stream miles. This required using the prefix **presumed** before each of the rankings, to classify stream segments with a distance greater than 0.6 miles from the most upstream or most downstream sampling station. In summary, about 130 stream miles of the nearly 131 stream miles within the municipio of Ponce were classified as follows: 8.1 stream miles as **good**; 26.8 as **presumed good**; 13.4 as **acceptable**; 4.2 as **presumed acceptable**; 19.9 as **fair**; 22.7 as **presumed fair**; 20 as **poor**; and 14.8 as **presumed poor**. The geometric means of fecal coliform and Escherichia coli (*E. coli*) bacteria concentrations in number of colonies per 100 mL for all stations within each of the established rankings were as follows: **good**-22 and 22; **acceptable**- 89 and 153; **fair**- 164 and 142; and **poor**- 1,200 and 1,200, 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** are contaminated from continuous sources. 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 Ponce; overflows from sewer mains into the storm-sewer 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 **good** and **acceptable** have the greatest potential for development as surface- and ground-water sources. If there are, however, 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 indicator bacteria; and (b) more in-depth evaluation of the bacteriological attenuation capacity of the ground-water bearing units. In addition, more rigorous surface-water monitoring, including fecal indicator bacteria would be important to define the variability and sources of contamination in order to implement corrective measures.

The municipio of Ponce was divided into six main hydrogeologic terranes based on geologic, topographic, soil, hydrogeologic, and streamflow data. The most important hydrogeologic terrane as to ground-water resources in the municipio of Ponce, is designated as the PonHT1.

The aquifer in this unit is characterized by discontinuous sand and gravel strata embedded in clay and silt underlain by limestone. The other five hydrogeologic terranes are as follows: the PonHT2 hydrogeologic terrane consists mainly of locally karstified limestone overlain by sand and gravel deposits; the PonHT3 and PonHT4 hydrogeologic terranes are composed of volcaniclastic rocks intruded by dioritic and gabbroic dikes and stocks; the PonHT5 is composed of the outcrop areas of the Juana Díaz Formation and the Ponce Limestone; and the PonHT6 is composed of volcaniclastic rocks with minor intrusive rocks.

The PonHT1 and PonHT2 hydrogeologic terranes occupy the coastal and upper plain of the municipio of Ponce. The PonHT5 occupies mostly the foothills that lie north of the upper plain. The PonHT3 and PonHT4 occupy the upper and middle portions of the main rivers, respectively. The PonHT6 extends from the foothills into the middle portions of the watersheds of the main rivers. The hydrogeologic terranes PonHT1 and PonHT2 are characterized by land areas having slopes less than 15 degrees, whereas the other hydrogeologic terranes have slopes greater than 15 degrees.

There are two primary and three secondary ground-water types in the Ponce area. The primary ground-water types are calcium-carbonate and calcium- sulfate-chloride. The secondary ground-water types are sodium-chloride, sodium-bicarbonate, and calcium chloride. The concentration of the common dissolved constituents and nutrients found in fresh ground water in the study area is mostly within the recommended U.S. Environmental Protection Agency (1991) secondary drinking water standards.

The results of the stable isotope analyses indicate that saline ground water in the study area is not caused by saltwater intrusion. The deuterium and oxygen-18 data also indicate that the main recharge source is rainfall/runoff infiltration at the interfluvial area between the Río Bucaná and Río Portugués in the PonHT1 hydrogeologic terrane and in karstic zones of the PonHT2 hydrogeologic terrane.

The following mechanisms have led to saline ground water at present: (1) upward coning of mineralized ground waters (connate waters) enriched with dissolved evaporites contained in the Juana Díaz Formation and to a lesser extent from the Ponce Limestone (2) diffusion and dispersion of sea water into the aquifer by inland displacement of the salt water wedge along the Río Bucaná flood channel (3) evaporation and evapotranspiration from the relatively shallow water table along the coastal area, and (4) increase in dissolved solids caused by furrow irrigation with ground water.

The lineaments traced and confirmed in the field during this study appear to correlate well with the geologic setting of the Ponce upland area. The hydrologic importance of traced lineaments is enhanced in those zones where lineaments are concentrated or have similar lengths and orientation.

The potentiometric map constructed during this study, indicates that ground water in the study area moves preferentially southward with minor southwestward and southeastward components. This potentiometric map also indicates that decreases in ground-water levels ranging from 5 to 25 feet have occurred since 1964 in the coastal and upper plains of Ponce, which is indicative of storage depletion in the coastal aquifer. Local increases in ground-water levels have occurred and can be ascribed to reductions in ground-water withdrawal rates.

Public-supply water constitutes the principal use of ground water in the municipio of Ponce, particularly throughout the PonHT1 and PonHT2 hydrogeologic terranes. Documented withdrawal rates for public supply indicate that ground-water withdrawal from the aquifer(s) in the municipio of Ponce have decreased from an estimated 9.5 million gallons per day in the 1980 to an estimated 4.4 million gallon per day in the 2003. Further ground-water development in the municipio of Ponce is limited and must be conducted with caution to avoid deterioration of ground-water quality by saline water encroachment, which at present, occurs at several localities, particularly in the coastal plain aquifer.

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