Cover photograph

View from Barrio Piñas looking northwest and showing the dissected uplands of Barrio Palomas in the background. In the right hand side of the photograph the narrow alluvial valley of the Río de la Plata is in the foreground and the gorge is in the background. Photograph taken by Jesús Rodríguez-Martínez on March 27, 2001.

U.S. Department of the Interior
U.S. Geological Survey

Surface-Water, Water-Quality, and Ground-Water Assessment of the Municipio of Comerío, Puerto Rico, 1997-99

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

Water-Resources Investigations Report 01-4083

Prepared in cooperation with the

MUNICIPIO OF COMERÍO

San Juan, Puerto Rico: 2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
GSA Center, Suite 400-15
651 Federal Drive
Guaynabo, Puerto Rico 00965-5703

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

PLATES

[Plates are in pocket]

FIGURES

TABLES

CONVERSION FACTORS, DATUMS, WATER-QUALITY UNITS, AND ACRONYMS

Multiply	By	To obtain
acre (acre)	1,233.489	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	30.4785	centimeter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3045	meter per day
gallon (gal)	3.785	liter
gallon per day (gal/d)	0.00378	cubic meter per day
gallon per minute (gal/min)	0.00378	cubic meter per minute
inch (in.)	2.540	centimeter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
million gallon per day (Mgal/d)	0.04381	cubic meter per second
square foot per day (ft^2/d)	0.0929	square meter per day
square mile (mi^2)	2.590	square kilometer

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

$$°F = (°C \times 1.8) + 32$$

Datums:

Horizontal Datum - Puerto Rico Datum, 1940 Adjustment

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."

Abbreviated water-quality units used in this report:

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

Acronyms used in this report:

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

Surface-Water, Water-Quality, and Ground-Water Assessment of the Municipio of Comerío, Puerto Rico, 1997-99

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

Abstract

To meet the increasing need for a safe and adequate supply of water in the municipio of Comerío, an integrated surface-water, water-quality, and ground-water assessment of the area was conducted. The major results of this study and other important 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-resource data.

Because the supply of safe drinking water was a critical issue during recent dry periods, the surface-water assessment portion of this study focused on analysis of low-flow characteristics in local streams and rivers. Low-flow characteristics were evaluated at one continuous-record gaging station based on graphical curve-fitting techniques and log-Pearson Type III frequency curves. Estimates of low-flow characteristics for 13 partial-record stations were generated using graphical-correlation techniques. Flow-duration characteristics for the continuous- and partial-record stations were estimated using the relation curves developed for the low-flow study. Stream low-flow statistics document the general hydrology under current land- and water-use conditions.

A sanitary quality survey of streams utilized 24 sampling stations to evaluate about 84 miles of stream channels with drainage to or within the municipio of Comerío. River and stream samples for fecal coliform and fecal streptococcus analyses were collected on two occasions at base-flow conditions to evaluate the sanitary quality of streams. Bacteriological analyses indicate that about 27 miles of stream reaches within the municipio of Comerío may have fecal coliform bacteria concentrations above the water-quality goal established by the Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental de Puerto Rico) for inland surface waters. Sources of fecal contamination may include illegal discharge of sewage to storm-water drains, malfunction of sanitary sewer ejectors, clogged and leaking sewage pipes, septic tank leakage, unfenced livestock, runoff from livestock pens, and seepage from pits containing animal wastes. Long-term fecal coliform data at two sampling stations on the Río de la Plata indicate that since 1984, the geometric mean of five consecutive samples commonly has been at or below 2,000 colonies per 100 milliliters (established as the sanitary quality goal in Puerto Rico for Class SD type waters). At the sampling station upstream of Comerío, the geometric mean concentration has been near 500 colonies per 100 milliliters; downstream of the town of Comerío, the geometric mean concentration has been near 2,000 colonies per 100 milliliters concentration. The data at these stations also indicate that fecal coliform concentrations increase commonly above 2,000 colonies per 100 milliliters during storm-runoff events, ranging from 1,000 to 100,000 colonies per 100 milliliters at both stations.

Geologic, topographic, soil, hydrogeologic, and streamflow data were used to divide the municipio of Comerío into five hydrogeologic terranes. The integrated database was then used to

evaluate the ground-water development potential of each hydrogeologic terrane. Analysis suggests that areas with slopes greater than 15 degrees have relatively low ground-water development potential. Fractures may be important locally in enhancing the water-bearing properties in the hydrogeologic terranes containing igneous rocks.

The integrated hydrogeologic approach used in this study can serve as an important tool for regulatory agencies of Puerto Rico and the municipio of Comerío to evaluate the ground-water resource development potential, examine ground- and surface-water interaction, and determine the effect of land-use practices on ground-water quantity and quality.

Stream low-flow statistics document the general hydrology under current land and water uses. Low-flow characteristics may substantially change as a result of streamflow diversions for public supply, increase in ground-water development, waste-water discharges, and flood-control measures; this current analysis provides baseline information to evaluate these impacts and develop water budgets.

Sumario

Para satisfacer la necesidad cada vez mayor de un abasto de agua adecuado y seguro en el municipio de Comerío, se ha llevado a cabo un estudio integrado para evaluar las fuentes de agua superficial, la calidad del agua y las fuentes de agua subterránea en esa área. Los resultados más significativos de este estudio, así como información adicional hidrológica y de calidad de agua, fueron entrados a un sistema de información geográfica y se muestran en dos mapas a escala 1:30,000 para facilitar la interpretación y el uso de información variada sobre recursos de agua.

Debido a que el abasto seguro de agua potable fue un asunto de suma importancia durante recientes períodos de sequía, la parte correspondiente a la evaluación del recurso de agua superficial en este estudio se concentró en el análisis de características de flujos mínimos en los ríos de la localidad. Se evaluaron las características de flujos mínimos en una estación fluviométrica de registro continuo, a partir de técnicas para ajustar curvas gráficas y curvas de frecuencia log-Pearson Tipo III. Se generaron estimados de características de flujos mínimos para 13 estaciones de registro parcial utilizando técnicas de correlación gráfica. Las características de duración de flujo se computaron para la estación de registro continuo y se estimaron para las estaciones de registro parcial, utilizando las curvas de relación desarrolladas para el estudio de flujos mínimos. Las estadísticas de flujos mínimos documentan la hidrología general bajo condiciones actuales de uso de terreno y de agua.

Se realizó un estudio para medir la calidad sanitaria de los ríos de la localidad, utilizando 24 estaciones de muestreo para evaluar unas 84 millas de cauces de ríos con drenaje hacia o dentro del municipio de Comerío. En dos ocasiones se tomaron muestras de agua en ríos y tributarios de éstos en condiciones de estiaje para análisis de coliformes del grupo fecales y estreptococos. Los análisis bacteriológicos indican que unas 27 millas de tramos de ríos y arroyos dentro del municipio de Comerío pueden tener concentraciones de bacterias de coliformes fecales que superan el límite establecido por la Junta de Calidad Ambiental de Puerto Rico para asegurar la calidad del agua. Entre las fuentes de contaminación fecal pueden encontrarse la descarga ilegal de aguas residuales en los sistemas de alcantarillado pluvial, mal funcionamiento de eyectores de alcantarillas de aguas usadas, alcantarillados sanitarios tapados y con filtraciones, filtraciones en tanques sépticos, ganado libre (sin proteger con cercado de alambre), escorrentía proveniente de corrales de ganado y filtraciones de los estanques para la retención de desperdicios de animales. Los datos sobre coliformes fecales a largo plazo recogidos en dos estaciones de muestreo en el Río de la Plata, indican que desde 1984 la media geométrica de cinco muestras tomadas secuencialmente ha sido, por lo general, de 2,000 colonias en 100 mililitros o menos (ésta es la media geométrica establecida como límite para determinar la calidad sanitaria de las aguas de clase SD en Puerto Rico). En la estación de muestreo aguas arriba de Comerío, la concentración de media geométrica ha sido cercana a 500 colonias en 100 mililitros; aguas abajo del pueblo de Comerío, la concentración de media geométrica ha sido cercana a 2,000 colonias en

100 mililitros. Los datos recogidos en estas estaciones también indican que las concentraciones de coliformes fecales, por lo general, superan las 2,000 colonias en 100 mililitros durante eventos de escorrentía de agua de lluvia; los valores fluctúan entre 1,000 y 100,000 colonias en 100 mililitros en ambas estaciones.

Se utilizaron datos geológicos, topográficos, de suelo, hidrogeológicos y fluviométricos para dividir el municipio de Comerío en cinco unidades hidrogeológicas. Luego, se utilizó la base de datos de forma integrada para evaluar el potencial de desarrollo de agua subterránea en cada unidad hidrogeológica. El análisis indica que en general, los terrenos con declive topográfico mayor de 15 grados tienen un potencial bajo de desarrollo de agua subterránea. Además, las fracturas pueden ser importantes localmente para incrementar las propiedades para producción de agua en pozos hincados en regiones hidrogeológicas que contienen rocas ígneas.

El enfoque hidrogeológico integrado que se ha utilizado en este estudio puede servir como una herramienta importante para las agencias reguladoras de Puerto Rico y del municipio de Comerío para evaluar el potencial de desarrollo del recurso de agua subterránea, examinar la interacción entre el agua subterránea y la superficial y determinar el efecto de las prácticas de uso del terreno en la cantidad y la calidad del agua subterránea del municipio de Comerío. Las estadísticas de flujos mínimos en ríos y arroyos documentan la hidrología general bajo los usos de terreno y de agua en la actualidad. Las estadísticas de flujos mínimos pueden cambiar sustancialmente como resultado de desviaciones del caudal para abasto público, aumento en el desarrollo del agua subterránea, descargas de aguas residuales y medidas para el control de inundaciones; el presente análisis provee información fundamental para evaluar estos impactos y desarrollar balances de agua.

INTRODUCTION

The municipio of Comerío, with an estimated population of 20,965 in 1998 (U.S. Department of Commerce, 1998a), covers an area of 28.5 square miles (mi^2) (fig. 1). Most of the municipio is characterized by steep topography with approximately 77 percent of the land area having slopes greater than 21 percent (21 feet of vertical displacement per 100 feet in horizontal plane; Larsen and Parks, 1998). Much of the town of Comerío is located on the flatter terrace and alluvial plain of the Río de la Plata, but a substantial part of the urbanized area has spread onto the slopes of the adjacent valley (plate 1). Approximately 25 percent of the municipio population is concentrated within the town limits and the adjacent urban communities. About 35 percent of the population is concentrated within rural communities at Barrios Palomas and Doña Elena with the remaining 40 percent about equally distributed within the other six barrios of the municipio (plate 1). The average population density of Comerío is 735 people per square mile (people/mi^2); but varies from about 2,140 people/mi^2 at Barrio Palomas to about 310 people/mi^2 at Barrio Río Hondo (U.S. Department of Commerce, 1991).

The geographic distribution of the population in the municipio of Comerío has contributed toward one of the major problems affecting Comerío's residents: an unreliable delivery of potable water, 80 percent of which is provided from the Puerto Rico Aqueduct and Sewer Authority (PRASA) public water-supply filtration plant at Comerío (Comerío filtration plant, plate 1). The remaining 20 percent of the available supply is provided from the Cedrito partial treatment water-supply plant at Barrio Cedrito, and the Palomas Rural Aqueduct at Barrio Palomas (plate 1). In 1990, the total public water-supply withdrawal in Comerío by PRASA was estimated at 1.80 million gallons per day (Mgal/d) or equivalent to about 90 gallons per person per day (gal/p-d). However, billed customers accounted for only 62 percent of the public water-supply withdrawals (among these, metered and estimated use by domestic, commercial, industrial, and government institutions) and domestic purposes accounted for 80 percent of the use. This indicates that potable water available for household use was about 45 gal/p-d (90 X 0.62 X 0.80). In 1998, total public water-supply withdrawal at Comerío was approximately 1.25 Mgal/d and was generally distributed as follows: 0.91 Mgal/d at the Comerío filtration plant, 0.33 Mgal/d at the Cedrito partial treatment water-supply plant, and 0.01 Mgal/d at the Palomas Rural Aqueduct.

As in 1990, however, 1998 use accounted for approximately 62 percent of the public water-supply withdrawals (Wanda Molina, USGS, written commun., 1999). Since the population of Comerío has remained relatively unchanged between 1990 and 1998, the total available public water supply for all uses (domestic, commercial, industrial, and government institutions) may have decreased on a per capita basis from about 90 to 60 gal/d-p. Similarly, the per capita potable water available for household use within the municipio may have decreased from about 45 gal/d-p in 1990 to 30 gal/d-p in 1998 (60 X 0.62 X 0.80). This reduction in potable water supply would not be equally distributed within the municipio, but would affect primarily those users farthest from the filtration plants.

As a result of the unreliability of the public water-supply distribution system and the apparent decline in potable water availability, several communities have developed their own water-supply source. In 1998, there were six self-supplied community water-supply systems in Comerío serving approximately 1,000 people (Wanda Molina, USGS, written commun., 1999); the source for five of these systems was ground water (well or spring) and one system was supplied by a stream. Moreover, many residents in rural areas have installed rudimentary taps at nearby streams and springs to augment their household supply. These solutions, however, may constitute a health risk, because the possibility of gastrointestinal illness from fecal contamination of local raw water-supply sources could be substantial, given the high population density. In addition, ground-water and spring flow in Comerío occurs primarily in bedrock aquifers, which are highly vulnerable to contamination. In these aquifers, the water flows too rapidly and is not in contact with the surrounding material long enough for purification to occur (Tarbuck and Lutgens, 1990). In Comerío, areas of most vulnerability are the unsewered rural communities, because water moves within fractures or the regolith and along bedding planes (Chapter C); and where intensive animal husbandry and poultry breeding enterprises are located. Outside of the rural areas, the greatest susceptibility of sanitary wastes contamination is at surface-water supply intakes located along stream courses that do not meet the standards for public water-supply sources, and at wells sited near streams with degraded water quality. In the bedrock and shallow alluvial aquifers of Comerío, the source of water at wells near streams is derived wholly or in part from streams (Chapter C). This susceptibility became evident when the reported occurrence of 7,800 cases of fever with acute gastroenteritis at Comerío in 1977 were related to improper chlorination and general bacteriological contamination of surface waters (Hunter and Arbona, 1995).

To ensure an adequate supply of safe drinking water, the municipio of Comerío requested the U.S. Geological Survey (USGS) to conduct a comprehensive surface- and ground-water resource assessment and water-quality analyses of streams. This information will be an integral part of the territorial development plan being developed by the municipio of Comerío, which will take into the sustainable use of water resources.

To facilitate this effort, 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 analyses 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.

ACKNOWLEDGMENTS

The authors acknowledge the Honorable Emiliano Rivera, former Mayor of the Municipio of Comerío, and Honorable Carmín L. Berríos, former Senator for the District of Guayama, for their awareness of the need of this assessment to help develop land-use strategies by municipio authorities and to promote the sustainable use of water resources. Special thanks, as well, to Ms. Ivelise Mejías, staff member of the mayor’s office, for her assistance in contacting landowners to gain access to data collection sites. The authors also thank Marilyn Santiago and Betzaida Reyes from the USGS Caribbean District’s Geographic Information System Unit, for the preparation of the spatial data bases and maps presented in this report, and Francisco Maldonado, USGS Caribbean District Scientific Illustrator, for the final editing of the plates.

CHAPTER A:

Surface-Water Resources Assessment of the Municipio of Comerío, Puerto Rico, 1997-99

By **Luis Santiago-Rivera**

PURPOSE AND SCOPE

The USGS in cooperation with the municipio of Comerío conducted an investigation of the surface-water resources from October 1, 1997 to September 30, 1999, primarily within the geographic limits of the municipio of Comerío. A major component of the study consisted of an assessment of the magnitude and frequency of low-flow and flow-duration characteristics, which are important for storage-facility design, waste-load allocation, water-supply planning, recreation planning, and conservation of wildlife. In addition, the current assessment provides reference conditions to assess future changes in flow magnitude, duration, and frequency.

The low-flow and flow-duration network used for this study includes one long-term, continuous-record gaging station and 13 partial-record stations. The continuous-record gaging station (50044830) is located in Río Guadiana (a second-order tributary of Río de la Plata) and the 13 partial-record stations are distributed among a number of second- to third-order streams within the Río de la Plata drainage basin (plate 1). Streamflow was measured concurrently at the continuous- and partial-record stations at least eight times during selected base-flow recessions from January 1998 to March 1999, 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 station and estimated for the partial-record stations. Flow duration for 90-, 95-, and 99-percent probability of exceedance were computed for the continuous-record gaging station and estimated for the 13 partial-record stations.

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

- stream discharge data-collection sites;
- drainage basins for the streamflow sites where low flows were estimated;
- existing and potential reservoir sites (Black and Veatch, 1976);
- flood-prone areas as delineated by the Federal Emergency Management Agency (FEMA, 1996);
- public water-supply intakes;
- water-filtration plants; and
- the waste-water treatment facility at Comerío and waste-water point of discharge.

This information can be used by planners, water managers, and the general public to promote the sustainable use of water resources.

METHODOLOGY

A series of eight discharge measurements were taken concurrently at the one continuous- and the 13 partial-record stream-gaging stations, to provide a basis for a systematic low-flow and flow-duration analysis. A number of techniques were then applied to compute low-flow characteristics at the continuous- and partial-record stations. Analysis of low-flow characteristics for the continuous-record gaging station (index station) was based on frequency analysis of the annual minimum 7-day low flows (table 1). Using the streamflow data generated during this study, the partial-record station base-flow measurements were related to concurrent base-flow discharge measurements or daily mean flows at the nearby index station (Riggs, 1972). The low-flow characteristics at partial-record stations were then estimated using the corresponding characteristics at the index station (table 2).

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

RESULTS AND INTERPRETATION

Low Flow at Continuous-Record Gaging Station

A continuous-record gaging station (index station) is a site where daily flow data are systematically collected over a period of years. A low-flow frequency curve was derived for one index station using the method described by Riggs (1972) and by adaptation of the log-Pearson Type III flood-frequency program described by the Interagency Advisory Committee on Water Data (1982). The $7Q_{10}$ and the $7Q_2$ low-flow frequency characteristics computed for the index station are presented in table 1. The index station used in this analysis is affected by upstream public water-supply withdrawals and waste-water treatment facility discharge. During the time of this study, public water-supply withdrawals upstream of this station were estimated to be 0.63 cubic foot per second (ft^3/s), and waste-water return flow was estimated to be 0.31 ft^3/s (Wanda Molina, USGS, written commun., 2000). The net stream low-flow capture of 0.32 ft^3/s upstream of the index station can result in computational underestimates of low-flow statistics at partial-record stations.

Low Flow at Partial-Record Stations

A partial-record station is a site where streamflow and/or water-quality data are collected systematically over a period of time for use in hydrologic analyses. At these stations, sufficient base-flow measurements are made to adequately define a relation with concurrent flows at a nearby index station. Low-flow characteristics for partial-record stations were estimated using a graphical correlation technique (Riggs, 1972). This technique relates base-flow discharge measurements made at partial-record stations with concurrent discharges measured at the index station. This estimating technique transfers low-flow characteristics computed by the log-Pearson Type III frequency distribution for the index stations to the graphically determined relation curve to determine the corresponding low-flow characteristics at the partial-record stations. Low-flow characteristics were estimated for 13 partial-record stations and are presented in table 2. Partial-record stations were located as near as possible to the corresponding index station; the partial- and continuous-record stations have similar drainage basin sizes and geologic settings. At the partial-record stations, streamflow was measured concurrently at least eight times (except one station, which was measured seven times) at different low-flow recessions from January 1998 to March 1999. Instantaneous discharge measurements made at partial-record stations are given in Díaz and others (1998).

Flow-Duration Characteristics

Flow-duration characteristics were computed for the index station using techniques developed by Searcy (1959). The analysis of the index station was based on daily discharge records for complete water years (October 1 to September 30), and the results are presented in table 1. Flow-duration characteristics were estimated for 13 partial-record stations using flow-duration characteristics derived for the index station in conjunction with the relation curves developed from the low-flow study. Index station discharges for the 90-, 95-, and 99-percent flow duration were used as the independent variable in the relation curves to estimate the discharges for the corresponding percent-duration points at the 13 partial-record stations (table 2).

Drainage-Basin Area/Discharge Relation

Using the drainage-basin size contributing to each monitoring station and the low-flow statistics, a preliminary analysis of discharge yield per unit-drainage area was conducted. This analysis provides a means to evaluate effective recharge within the study area. The mode of the 99-percentile discharge yield for the drainage basins studied in or in the vicinity of the municipio of Comerío was 0.15 cubic foot per second per square mile ($ft^3/s\text{-}mi^2$). The Quebrada Higüero basin, with a drainage area of 3.7 mi^2, has a distinctively high 99-percentile discharge yield per unit area of 0.40 $ft^3/s\text{-}mi^2$. The surface-water contribution of this basin is 1.5 ft^3/s, which is equivalent to 48 percent of the total flow available (3.1 ft^3/s), based on the 99 percent of time discharge of second-order tributaries to the Río de la Plata in the study area.

MAP FEATURES

A 1:30,000-scale map (plate 1) was developed to show the location of hydrologic data-collection stations, drainage basins, the 100- and 500-year flood-prone areas as delineated by FEMA (1996) as the 1.0 and 0.2 percent chance of flooding in any given year, and existing or potential reservoir sites (Black and Veatch, 1976). The thematic map also summarizes hydrologic monitoring-station characteristics and stream bacteriological (sanitary) quality during low-flow conditions (see Chapter B for discussion of water quality).

Reservoir Sites

There are two existing reservoirs in the study area, both on the Río de la Plata; the larger of these is Represa de Comerío (also referred to as Comerío 1) and the smaller is Comerío 2. The dams were constructed in 1907 and 1913, respectively, for hydroelectric power generation. Both impoundments are completely filled with sediment.

One potential reservoir site having an operating pool level at an altitude of about 890 feet (ft) (271-meter contour on the topographic map) was identified by Black and Veatch (1976) (plate 1). A reservoir at this location would have a drainage area of 106.9 mi^2 and an estimated storage capacity of 50,000 acre-feet (acre-ft) (Black and Veatch, 1976). The safe yield of the potential reservoir site would be about 65 Mgal/d (Black and Veatch, 1971). A reservoir at the same location, but with an operating pool level at an altitude of about 820 ft (250-meter contour on the topographic map) would have a storage of about 25,000 acre-ft with an estimated safe yield of 30 to 40 Mgal/d (Black and Veatch, 1971).

Flood-Prone Areas

FEMA (1996) identifies three different types of flood-prone areas for the town of Comerío: Zones A, AE, and X500. Zone A is an area inundated by 1 percent annual chance flooding, for which no Base Flood Elevations (BFEs) have been determined; Zone AE is an area inundated by 1 percent annual chance flooding, for which BFEs have been determined; and Zone X500 is an area inundated by 0.2 percent annual chance flooding; an area inundated by 1 percent annual chance flooding with average depths of less than 1 ft or with a drainage area less than 1 mi^2, or an area protected by levees from 1 percent annual chance flooding.

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

There are three public water supply plants located in the municipio of Comerío. These are the Cedrito partial treatment water-supply plant with a gravity intake at Quebrada Cedrito, the Palomas Rural Aqueduct with an intake at Quebrada Higüero, and the Comerío filtration plant with an intake at Río de la Plata (table 3; plate 1). One public waste-water treatment facility is located in the municipio of Comerío, the Comerío waste-water treatment facility with discharge to the Río de la Plata.

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

[lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile, km^2, square kilometer; ft^3/s, cubic feet per second; <, less than]

RÍO DE LA PLATA BASIN

50044830 Río Guadiana at Guadiana, Puerto Rico

LOCATION--Lat 18°18′08", long 66°13′24", Hydrologic Unit 21010005, on left bank, 1.3 mi (2.1 km) east of Naranjito Plaza, 0.9 mi (1.4 km) west of the intersection of Highways 167 and 164 at km 8.9, and 2.9 mi (4.7 km) northwest of Represa Comerío.

DRAINAGE AREA--9.2 mi^2 (24 km^2).

PERIOD OF RECORD ANALYZED--July 1990 to September 1997.

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

REMARKS--A diversion of 0.63 ft^3/s is made upstream of station for public water supply and 0.31 ft^3/s is recovered from waste-water treatment plant return flow.

LOW-FLOW CHARACTERISTICS
[Based on 1990-97 water years]

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	< 2.5
7-day, 10-year	< 1.3

FLOW-DURATION CHARACTERISTICS
[Based on 1990-97 water years]

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	2.4	1.7	1.2

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

[lat, latitude; long, longitude; mi, mile; km, kilometer; mi^2, square mile, km^2, square kilometer; ft^3/s, cubic feet per second; <, less than]

RÍO DE LA PLATA BASIN

50043500 Quebrada Prieta at Barrio Río Hondo, Puerto Rico

LOCATION--Lat 18°12′27", long 66°14′38", Hydrologic Unit 21010005, at Barrio Río Hondo, 0.3 mi (0.5 km) upstream from Río de la Plata, 1.9 mi (3.0 km) southwest of Cerro Lazo, 1.4 mi (2.2 km) southwest of Comerío plaza.

DRAINAGE AREA--1.2 mi^2 (3.0 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	< 0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	< 0.1	< 0.1	< 0.1

50043575 Río Hondo at Highway 776 at Barrio Río Hondo, Puerto Rico

LOCATION--Lat 18°13′18", long 66°15′07", Hydrologic Unit 21010005, at Barrio Río Hondo on Highway 776, 0.4 mi (0.6 km) north of Escuela Segunda Unidad de Río Hondo, 4.3 mi (6.9 km) northeast of Barranquitas, and 4.4 mi (7.1 km) northeast of Cañón San Cristóbal.

DRAINAGE AREA--9.1 mi^2 (24 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 20 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.23 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	2.8
7-day, 10-year	1.5

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	2.7	2.0	1.4

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

RÍO DE LA PLATA BASIN—Continued

50043600 Río Hondo near Comerío, Puerto Rico

LOCATION--Lat 18°12′38", long 66°14′37", Hydrologic Unit 21010005, at Highway 156 at Barrio Río Hondo, 0.6 mi (1.0 km) upstream of Río de la Plata, and 1.3 mi (2.1 km) southwest of Comerío plaza.

DRAINAGE AREA--10 mi^2 (27 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 7 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.23 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	2.0
7-day, 10-year	1.0

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	2.0	1.4	0.9

50043790 Quebrada Piñas at Highway 775 at Comerío, Puerto Rico

LOCATION--Lat 18°13′00", long 66°13′37", Hydrologic Unit 21010005, at Comerío, 0.2 mi (0.3 km) upstream from Río de la Plata, 0.7 mi (1.1 km) west of Cerro Lazo, and 0.3 mi (0.5 km) south of Comerío plaza.

DRAINAGE AREA--2.3 mi^2 (6.0 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 9 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	< 0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	< 0.1	< 0.1	< 0.1

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

RÍO DE LA PLATA BASIN—Continued

50043803 Quebrada Convento at Comerío, Puerto Rico

LOCATION--Lat 18°13′31", long 66°13′36", Hydrologic Unit 21010005, at Comerío, 0.5 mi (0.8 km) south of Cerro Magüeyes, 0.1 mi (0.2 km) upstream from Río de la Plata, and 0.3 mi (0.5 km) north of Comerío plaza.

DRAINAGE AREA--1.0 mi^2 (2.5 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.1
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.1	< 0.1	< 0.1

50043820 Quebrada Higüero at Highway 780 at Barrio Doña Elena, Puerto Rico

LOCATION--Lat 18°14′37", long 66°14′51", Hydrologic Unit 21010005, at Barrio Doña Elena, 1.5 mi (2.4 km) northwest of Cerro Magüeyes, 0.8 mi (1.3 km) northwest of Escuela Segunda Unidad de Palomas, and 2.1 mi (3.4 km) northwest of Comerío plaza.

DRAINAGE AREA--1.2 mi^2 (3.1 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS-- A diversion of 0.02 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.4
7-day, 10-year	0.2

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.4	0.3	0.2

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

RÍO DE LA PLATA BASIN—Continued

50043840 Tributario de Quebrada Higüero at Barrio Palomas, Puerto Rico

LOCATION--Lat 18°14′10", long 66°14′35", Hydrologic Unit 21010005, at Barrio Palomas, 1.1 mi (1.8 km) west of Cerro Magüeyes, 0.2 mi (0.3 km) northwest of Escuela Segunda Unidad de Palomas, and 1.5 mi (2.4 km) of Comerío plaza.

DRAINAGE AREA--0.5 mi^2 (1.2 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.02 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.2
7-day, 10-year	< 0.1

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.1	< 0.1	< 0.1

50043845 Quebrada Higüero at Highway 156 near Comerío, Puerto Rico

LOCATION--Lat 18°14′15", long 66°12′55", Hydrologic Unit 21010005, at Barrio Palomas, 0.8 mi (1.3 km) northeast of Cerro Magüeyes, 2.1 mi (3.4 km) southwest of Cerro La Tiza, and 1.4 mi (2.2 km) northeast of Comerío plaza.

DRAINAGE AREA--3.7 mi^2 (9.4 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.02 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	2.4
7-day, 10-year	1.6

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	2.3	1.9	1.5

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

RÍO DE LA PLATA BASIN—Continued

50043950 Río Arroyata at Highway 7774 near Cidra, Puerto Rico

LOCATION--Lat 18°12′04", long 66°12′34", Hydrologic Unit 21010005, at Barrio Vega Redonda on Highway 7774, 1.5 mi (2.4 km) northwest of Cerro Almirante, 1.6 mi (2.6 km) north of Cerro Viento Caliente, and 1.8 mi (2.9 km) southeast of Comerío plaza.

DRAINAGE AREA--9.4 mi^2 (24 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of 17 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.8
7-day, 10-year	0.3

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.7	0.4	0.2

50043970 Quebrada Cejas at Barrio Vega Redonda, Puerto Rico

LOCATION--Lat 18°12′56", long 66°12′04", Hydrologic Unit 21010005, at Barrio Vega Redonda, 1.0 mi (1.6 km) east of Cerro Lazo, 2.2 mi (3.5 km) southwest of Cerro La Tiza, and 1.7 mi (2.7 km) southeast of Comerío plaza.

DRAINAGE AREA--1.3 mi^2 (3.3 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.02 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	<0.1
7-day, 10-year	<0.1

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	< 0.1	< 0.1	< 0.1

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

RÍO DE LA PLATA BASIN—Continued

50043980 Río Arroyata at Barrio Naranjo, Puerto Rico

LOCATION--Lat 18°13′30", long 66°12′12", Hydrologic Unit 21010005, at Barrio Naranjo, 1.1 mi (1.8 km) northeast of Cerro Lazo, 1.8 mi (2.9 km) southwest of Cerro La Tiza, and 1.6 mi (2.6 km) northeast of Comerío plaza.

DRAINAGE AREA--13 mi^2 (33 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--A diversion of 0.02 ft^3/s is made upstream of station for public water supply.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.8
7-day, 10-year	0.3

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.7	0.4	0.2

50043995 Quebrada Naranjo at Barrio Naranjo, Puerto Rico

LOCATION--Lat 18°13′54", long 66°12′06", Hydrologic Unit 21010005, at Barrio Naranjo, 1.5 mi (2.4 km) northeast of Cerro Lazo, 1.4 mi (2.2 km) southwest of Cerro La Tiza, and 1.8 mi (2.9 km) northeast of Comerío plaza.

DRAINAGE AREA--2.6 mi^2 (6.7 km^2).

LOW-FLOW FLOW-DURATION ESTIMATES--Based on correlation of 8 base-flow measurements with concurrent base flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.7
7-day, 10-year	0.3

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.6	0.4	0.3

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

RÍO DE LA PLATA BASIN—Continued

50044050 Quebrada Doña Elena at Highway 167 near Comerío, Puerto Rico

LOCATION--Lat 18°15'04", long 66°12′29", Hydrologic Unit 21010005, at Barrio Doña Elena, 0.2 mi (0.3 km) upstream from Río de la Plata, 2.4 mi (3.9 km) southeast of Cerro Avispa, and 4.3 mi (6.9 km) southeast of Comerío plaza.

DRAINAGE AREA--1.3 mi^2 (3.3 km^2).

LOW-FLOW AND FLOW-DURATION ESTIMATES--Based on correlation of 9 base-flow measurements with concurrent low flows at gaging station 50044830.

REMARKS--None.

LOW-FLOW CHARACTERISTICS

Low-flow characteristics	Discharge (ft^3/s)
7-day, 2-year	0.4
7-day, 10-year	0.2

FLOW-DURATION CHARACTERISTICS

Discharge (ft^3/s) that was exceeded for indicated percentage of days			
Percent	90	95	99
Discharge	0.4	0.2	0.2

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

[Mgal/d, million gallons per day; --, no data]

Public water-supply filtration plants and surface-water intakes	Latitude [1]	Longitude [1]	Safe-yield [2] (Mgal/d)	Mean daily withdrawal rate (Mgal/d)	Source stream
Cedrito fitration plant	18°12′52"	66°13′43"	--	--	--
Cedrito partial treatment water-supply plant intake	18°12′48"	66°13′52"	0.01	0.33	Quebrada Cejas
Palomas Rural Aqueduct	18°13′48"	66°14′02"	--	0.01	Spring
Comerío filtration plant	18°12′51"	66°13′43"	--	0.91	--
Comerío filtration plant pump station	18°12′48"	66°13′51"	2.9	--	Río de la Plata
Public waste-water treatment facility and effluent discharge point	**Latitude [1]**	**Longitude [1]**	**Discharge capacity (Mgal/d)**	**Mean daily discharge rate (Mgal/d)**	**Receiving stream**
Comerío waste-water treatment plant	18°14′39"	66°12′26"	1.00	--	Río de la Plata
Comerío waste-water treatment plant outlet	18°14′38"	66°12′23"	--	0.30	Río de la Plata

[1] Datum for latitude and longitude is NAD 27.

[2] Safe yield from Black and Veatch (1996).

CHAPTER B:

Sanitary Quality of Surface Water During Base-Flow Conditions in the Municipio of Comerío, Puerto Rico, 1998-99

***By* Fernando Gómez-Gómez *and* Mario L. Oliveras-Feliciano**

BACKGROUND

Water-quality standards for surface waters in Puerto Rico have been established by the Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental de Puerto Rico, 1990) on the basis of the designated use (for example, fishing, source of raw water for public supply, and secondary contact recreation, among others). All perennial fresh surface waters in Puerto Rico inland of their estuary segments have been classified as Class SD waters. This classification includes surface water intended for use (or with the potential for use) as a raw source of public water supply, for propagation and preservation of desirable aquatic species, and for primary and secondary contact recreation. The sanitary quality standard for Class SD surface water is based on the fecal coliform or total coliform indicator bacteria (Junta de Calidad Ambiental de Puerto Rico, 1990).

With the exception of surface waters to be used for primary contact recreation, the sanitary quality standard of Class SD-designated use surface waters is based on total coliform and fecal coliform bacteria concentrations as follows: the geometric mean concentration of at least five samples obtained in sequential order should not exceed 10,000 colonies per 100 milliliters (mL) for total coliform bacteria, or 2,000 colonies per 100 mL for fecal coliform bacteria, and not more than 20 percent of the samples (one in a set of five) can exceed 4,000 colonies per 100 mL of fecal coliform bacteria (Junta de Calidad Ambiental de Puerto Rico, 1990, Article 3, Section 2.4, as amended July 20, 1990). 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, however, these standards are applicable only to samples taken when streamflows are greater than the 7-day, 2-year ($7Q_2$) discharge (Junta de Calidad Ambiental de Puerto Rico, 1990). The $7Q_2$ 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 seven consecutive days (the 7-day low flow).

Typical concentrations of the two most common indicator bacteria in contaminated water are given in table 4. Fecal coliform and fecal streptococcus bacteria are not pathogenic, but have been correlated to the presence of several waterborne, infectious disease-causing organisms present in wastes from warm-blooded animals, including humans (Myers and Sylvester, 1997). Thus, the concentration of these indicator bacteria is a measure of water safety for consumption or for body contact.

Contamination sources that affect stream sanitary quality during base-flow conditions are distinct for urbanized and rural areas of Comerío. In urbanized areas, probable major sources of fecal contamination are illegal discharge of sewage to storm-water drains, especially within the older sectors of the town of Comerío, overflows from sewer mains into the storm-water drains as a result of malfunctioning of sanitary sewer ejectors or clogged mains, rupture and seepage from sewer mains into the local aquifer. In rural areas, major sources of fecal contamination include gray-water discharges (gray water includes all waste water from household uses except sanitary wastes) from residential and commercial establishments along stream channels, septic tank seepage or overflows, direct contamination by unfenced livestock, runoff from restrained livestock pens near stream courses, and seepage from pits containing animal wastes.

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

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

Sanitary-quality baseline data within the municipio of Comerío are primarily from the two long-term monitoring stations along the Río de la Plata: one located 2.0 mi downstream of the urban limit of Comerío (USGS station 50044000) at Highway PR-156 and the other located at Proyecto La Plata (USGS station 50043000) at Highway PR-173, approximately 6.5 mi upstream of the surface-water intake for the Comerío public supply filtration plant (plate 1). Systematic sampling for selected physical, chemical, and bacteriological properties has been conducted at these sites by the USGS in cooperation with the Puerto Rico Environmental Quality Board, data available in USGS annual Water Data Report series (for example, Díaz and others, 1998).

Using this historical database (1984 to 1998) as an initial source to assess the sanitary quality of streams in the Comerío area, it was determined that (1) the fecal coliform geometric mean concentration in Río de la Plata downstream of the town of Comerío has generally been at or below 2,000 colonies per 100 mL since 1990, with the exception of a 2-year period from 1995 to 1997, when the geometric mean concentration was between 2,000 and 6,000 colonies per 100 mL; (2) the fecal coliform geometric mean concentration in Río de la Plata at Proyecto La Plata has generally been near 500 colonies per 100 mL, with only a slight improvement since about June 1994; however, the geometric mean concentrations have been within the Puerto Rico sanitary water-quality goals established for fresh surface waters since the regulations were promulgated in 1990 (Junta de Calidad de Puerto Rico, 1990); and (3) these baseline fecal coliform data are insufficient to identify sources of fecal contamination within the study area (figs. 2a and 2b in plate 1).

The historical data at the two long-term stations on Río de la Plata also indicate that the probability for fecal coliform concentrations to exceed the Puerto Rico sanitary quality goal of 2,000 colonies per 100 mL is substantially increased during storm-runoff events. At the Comerío station (USGS station 50044000), samples collected for fecal coliform analyses during storm-runoff events (18 from a total of 64 samples obtained between October 1984 and August 1998) indicate that there is about a 70 percent probability of exceeding a fecal coliform concentration of 2,000 colonies per 100 mL during storm-runoff events (fig. 3a). At the Proyecto La Plata long-term sampling station (USGS station 50043000), the sparse fecal coliform data obtained during storm-runoff events (only 10 samples of a total of 81 obtained between November 1984 and August 1998) indicate that there is about a 90 percent probability of exceeding a concentration of 2,000 colonies per 100 mL during storm-runoff events (fig. 3b). Thus, the data available for both long-term sampling stations indicate that the best sanitary quality conditions occur during base-flow conditions when the water in stream courses is primarily derived from ground-water discharge.

PURPOSE AND SCOPE

A survey of stream sanitary quality was conducted by the USGS in cooperation with the municipio of Comerío to define the magnitude and extent of fecal contamination in streams. The assessment was made by obtaining and analyzing samples for fecal coliform and fecal streptococcus bacteria from 26 stream locations during base-flow conditions between March 1998 and July 1999.

Although the synoptic surveys were conducted in streams that have headwaters outside the municipal boundary, most of the sampling was conducted within the territorial limits of the municipio of Comerío. The study area included 44.9 mi^2 of drainage area, of which 27.8 mi^2 are within the municipio of Comerío.

This chapter describes the methods and techniques used in conducting the survey at 26 sampling stations, and provides interpretations of the fecal coliform and fecal streptococcus indicator bacteria concentrations by developing a classification procedure to rank the sanitary quality of stream courses. The data were incorporated into a thematic map (plate 1) that also includes other important hydrologic features to (a) serve as an initial source of information to guide future efforts by municipio and Commonwealth authorities in implementing measures to improve the sanitary quality of contaminated streams and conserve those with acceptable quality; (b) provide reliable scientific information to planners and managers of the water and biological resources; and (c) encourage local citizens to serve as stewards of water resources within their municipio.

METHODOLOGY

Field-Data Collection

Water samples for fecal coliform and fecal streptococcus analyses were obtained from a total of 26 locations at streams with drainage into or within the municipio of Comerío. Sampling was conducted at all stream stations using the “hand-dip” method (Britton and Greeson, 1989), which is applicable to the stream low-flow conditions used in this study. This sampling method consists of dipping a sterile narrow-mouth borosilicate 99-mL bottle 1 to 2 inches (in.) below the water surface with the bottle opening pointed slightly upward towards the current and with the hand and arm on the downstream side of the bottle.

The samples were obtained between March 1998 and July 1999 for two hydrologic conditions (1) near the annual stream low-flow discharge, and (2) during base-flow conditions following a rainfall event (base-flow recession). Of the 26 stream sampling stations, 11 were sampled under both hydrologic conditions; 10 were sampled on two separate occasions when discharge was near the annual low flow; and 5 stations were sampled only once, all during stream low-flow conditions.

Instantaneous discharge measurements were made simultaneously during sample collection events using the current meter method (Carter and Davidian, 1968). Eleven of the sampling stations correspond to stations also used in the surface-water low-flow statistical analysis (Chapter A). Among the low-flow statistics estimated at these sampling stations is the $7Q_2$ discharge. This statistical discharge value is included with the instantaneous discharge measurements made during the sample runs (table 5) to indicate the minimum discharge at which the fecal coliform concentration standards are applicable in Puerto Rico (Junta de Calidad Ambiental de Puerto Rico, 1990); the $7Q_2$ discharge also can be used to compare the instantaneous discharge made at the time of sampling with the low-flow discharge. In order to differentiate the samples collected under stream low-flow conditions from those collected under base-flow recession conditions, field data included a physical description of streamflow clarity (turbidity). In general, all samples were obtained under clear streamflow conditions, which are representative of low-flow conditions. Nevertheless, rainfall events during both synoptic surveys were patchy within the study area, as seen in daily rainfall data obtained from USGS hydrologic stations (table 6; fig. 4).

Analytical Techniques

The analytical procedure used to measure fecal coliform and fecal streptococcus bacteria concentrations consisted of the membrane-filter method immediate incubation test following standard USGS procedures (Britton and Greeson, 1989; Myers and Sylvester, 1997). Sterile buffered water, culture media, and other culture-specific reagents (for example, rosolic acid crystals, 0.2 N sodium hydroxide for fecal coliform tests, and triphenyltetrazolium crystals for fecal streptococcus tests) were provided by the USGS Water Quality and Research Laboratory in Ocala, Florida. Hydrated incubation media in petri dishes and sterile sample bottles were prepared at the Caribbean District laboratory in Guaynabo, Puerto Rico.

Table 5. Fecal coliform and fecal streptococcus bacteria concentrations at selected stations in the municipio of Comerío, Puerto Rico

[*, 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); †, sample not used in station ranking, only two with lowest discharge; Hwy., highway; Pre-fair, presumed fair ranking; Pre-poor, presumed poor ranking; Pre-acceptable, presumed acceptable ranking; RS, stream in rapid rising stage not measured; discarded, possible error in sample dilutions; mL, milliliters; ft^3/s, cubic feet per second; mi^2, square mile; Instant., instantaneous; LF, low flow; BF, base flow; R, rainfall; $7Q_2$, 7-day, 2-year low flow; m/d/y, month/day/year; (a), public water-supply diversion upstream of about 0.71 cubic feet per second, $7Q_2$ not adjusted for diversion; --, no data; <, less than]

Sampling station USGS identification number	Station name	Sample date (m/d/y)	Time	Fecal coliform colonies per 100 mL	Fecal streptococcus colonies per 100 mL	Instant. discharge (ft^3/s)	Streamflow condition during discharge measurement	$7Q_2$ mean daily discharge (ft^3/s)	Drainage area (mi^2)	Station sanitary quality ranking
50043498	Quebrada Prieta at Hwy. PR-774	3/23/98	1400	11,000*	2,500	0.16	LF	--	0.8	Poor
		6/16/98	1445	2,100	3,500	0.04	LF	--		
50043500	Quebrada Prieta at Barrio Río Hondo	3/20/98	1430	1,400	5,300	1.03	BF/R	< 0.1	1.16	Acceptable
		6/16/98	1400	110*	240*	0.17	LF	--		
50043570	Río Hondo near Barranquitas	7/1/99	1000	140	320	5.91	LF	--	7.6	Pre-good
50043575	Río Hondo at Hwy. PR-776	3/20/98	1300	3,200	3,000	8.32	BF/R†	2.8	9.07	Good
		6/16/98	1300	80*	130*	4.92	LF	--		
		7/1/99	1130	100*	200	7.05	LF	--		
50043600	Río Hondo at Hwy. PR-156	7/1/99	1230	340	440	6.84	LF	2.8	10.47	Pre-acceptable
50043780	Quebrada Piñas at Barrio Piñas	3/23/98	1030	120	250	0.08	LF	--	0.7	Good
		6/15/98	1110	30*	360	0.03	LF	--		
50043790	Quebrada Piñas at Hwy. PR-775	3/23/98	1200	580	670	0.28	BF/R	--	2.31	Fair
		6/15/98	1200	2,400	400	0.16	LF	< 0.1		
50043800	Río de la Plata at Comerío	3/20/98	1200	7,600*	5,600	33.30	BF/R	--	108.14	Fair
		6/16/98	1100	360	100*	21.70	LF	--		

Table 5. Fecal coliform and fecal streptococcus bcteria concentrations at selected stations in the municipio of Comerío, Puerto Rico–Continued

Sampling station USGS identification number	Station name	Sample date (m/d/y)	Time	Fecal coliform colonies per 100 mL	Fecal streptococcus colonies per 100 mL	Instant. discharge (ft^3/s)	Streamflow condition during discharge measurement	$7Q_2$ mean daily discharge (ft^3/s)	Drainage area (mi^2)	Station sanitary quality ranking
50043803	Quebrada Convento at Comerío	3/17/98	900	3,200	2,700	0.60	LF	0.1	0.98	Poor
		6/11/98	1500	5,500	2,300	0.46	LF	--		
50043815	Quebrada Higüero above Hwy. PR-780	3/25/98	1340	1300	350	0.62	LF	--	0.89	Fair
		6/22/98	1230	3,000	4,000	0.68	BF/R	--		
50043820	Quebrada Higüero at Barrio Palomas	3/25/98	1020	400	450	0.42	LF	0.4	1.19	Fair
		6/22/98	1330	3,400	3,500	0.70	BF/R	--		
50043840	Tributary to Quebrada Higüero at Barrio Palomas	3/23/98	1530	900*	550	0.15	LF	0.2	0.47	Fair
		6/22/98	1100	2,500	2,900	0.33	BF/R	--		
50043845	Quebrada Higüero at Hwy. PR-156	3/17/98	1100	2,400	320	2.16	LF	2.4	3.65	Poor
		6/11/98	1400	2,600	2,400	2.54	BF/R	--		
50043880	Río Arroyata at Barrio Río Abajo	3/18/98	1000	2,800	100*	0.78	LF†	--	3.09	Fair
		6/10/98	1030	570	400	0.76	LF	--		
		7/7/99	1150	130*	210	1.29	LF	--		
50043948	Río Arroyata above Hwy. 7774	3/18/98	1125	270	20*	2.38	LF	--	9.34	Good
		6/10/98	1230	210	60	2.08	LF	--		
		7/7/99	1100	800*	200	3.78	LF†	--		
50043998	Río Arroyata at mouth	7/1/99	955	45*	64*	7.24	LF	--		not used in ranking

Table 5. Fecal coliform and fecal streptococcus bacteria concentrations at selected stations in the municipio of Comerío, Puerto Rico–Continued

Sampling station USGS identification number	Station name	Sample date (m/d/y)	Time	Fecal coliform colonies per 100 mL	Fecal streptococcus colonies per 100 mL	Instant. discharge (ft^3/s)	Streamflow condition during discharge measurement	$7Q_2$ mean daily discharge (ft^3/s)	Drainage area (mi^2)	Station sanitary quality ranking
50043970	Quebrada Cejas at Barrio Vega Redonda	3/18/98	1400	600	550	0.68	LF	< 0.1 (a)	1.29	Fair
		6/10/98	1630	2,200	3,500	0.82	BF/R	--		
50043995	Quebrada Naranjo at Barrio Naranjo	3/18/98	1430	30*	60*	1.08	LF	0.7	2.58	Good
		6/10/98	1530	140*	290	0.86	BF/R	--		
50043998	Río Arroyata at mouth	7/7/99	0955	45*	64*	7.24				not used in ranking
50044000	Río de la Plata near Comerío	3/18/98	1600	discarded	10*	22.70	LF	--	139.15	Pre-acceptable
		6/10/98	1400	260	54	39.70	BF/R	--		
50044020	Quebrada Blanca at Barrio Cedrito	3/24/98	1100	80*	380	0.62	LF	--	1.05	Acceptable
		6/12/98	1100	920*	1,550*	0.70	BF/R	--		
50044050	Quebrada Doña Elena at Hwy. PR-167	3/20/98	1000	2,700	750	0.70	LF	0.4	1.28	Fair
		6/11/98	1300	560	680	0.67	LF	--		
50044205	Quebrada Cedrito at Barrio Cedrito	3/24/98	1020	120*	300	0.04	LF	--	0.06	Acceptable
		6/12/98	1300	670*	1,400*	0.09	LF	--		
50044212	Quebrada Ciénaga at Barrio Doña Elena	3/25/98	1230	20*	250	0.06	LF	--	0.39	Acceptable
		6/22/98	1430	250	810	0.07	LF	--		
50044218	Quebrada Mula at Hwy. PR-167	3/17/98	1130	290	80*	0.46	LF	--	2.69	Acceptable
		6/11/98	1130	280	300	0.79	LF	--		
50043490	Quebrada Tigre at mouth	7/8/99	1200	45*	290	0.25	LF	--	1.49	Pre-good

Table 6. Daily rainfall at selected USGS gaging stations in and near the municipio of Comerío during stream sanitary quality synoptic surveys, March and June 1998, June and July 1999. Rain gage locations are shown in figure 4.

[Comerío, Río de la Plata at Comerío; Proyecto, Río de la Plata at Proyecto La Plata; Cidra, Río de Bayamón below Cidra Dam; daily rainfall in inches; days in which bacteriological sampling was conducted are shaded; --, missing record]

Day	1998 sampling period					
	March			June		
	Comerío (50043800)	Proyecto (50043000)	Cidra (50047560)	Comerío (50043800)	Proyecto (50043000)	Cidra (50047560)
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	2.68	0.01	0.00
3	0.56	0.11	0.05	0.08	0.00	0.00
4	0.00	0.00	0.00	1.18	0.00	0.06
5	0.00	0.00	0.54	0.00	0.02	0.17
6	0.00	0.00	0.00	0.05	0.03	0.02
7	0.59	0.04	0.29	0.00	0.00	0.00
8	0.00	0.01	0.00	0.72	0.04	0.03
9	0.00	0.00	0.00	1.17	0.14	0.27
10	0.00	0.02	0.00	0.05	0.05	0.00
11	0.00	0.00	0.00	0.00	0.02	0.00
12	0.00	0.00	0.00	1.08	0.11	0.68
13	0.03	0.04	0.13	0.04	0.00	0.01
14	1.15	0.06	0.09	0.00	0.00	0.00
15	0.30	0.01	0.00	0.00	0.00	0.01
16	0.03	0.00	0.00	0.51	0.15	0.22
17	0.00	0.00	0.00	1.41	0.04	0.23
18	0.03	0.00	0.00	0.08	0.01	0.01
19	0.25	0.02	0.13	0.00	0.04	0.01
20	5.37	0.68	2.01	0.00	0.00	0.00
21	0.12	0.02	0.08	2.70	0.41	0.62
22	0.31	0.17	0.08	0.84	0.25	0.04
23	0.00	0.01	0.00	0.00	0.00	0.03
24	0.00	0.00	0.00	0.00	0.00	0.04
25	0.68	0.03	0.22	0.00	0.02	0.00
26	0.00	0.00	0.01	0.00	0.00	0.00
27	0.82	0.36	0.31	0.00	0.00	0.03
28	0.00	0.05	0.06	0.00	0.00	0.00
29	3.28	0.65	1.06	0.00	0.00	0.00
30	4.54	1.09	0.76	0.00	0.00	0.00
31	1.25	0.01	0.02	0.00	0.00	0.00
Totals	19.31	3.38	5.84	12.59	1.34	2.48

Table 6. Daily rainfall at selected USGS gaging stations in and near the municipio of Comerío during stream sanitary quality synoptic surveys, March and June 1998, June and July 1999–Continued.
Rain gage locations are shown in figure 4.

Day	1999 sampling period					
	June			July		
	Comerío (50043800)	Proyecto (50043000)	Cidra (50047560)	Comerío (50043800)	Proyecto (50043000)	Cidra (50047560)
1	0.54	--	1.28	0.36	0.38	0.12
2	0.00	--	0.01	3.99	3.54	2.43
3	0.00	--	0.00	0.00	0.00	0.00
4	0.73	--	0.19	0.00	0.00	0.03
5	0.00	--	0.08	0.01	0.09	0.40
6	0.00	--	0.00	0.01	0.01	0.00
7	0.04	--	0.50	0.09	0.00	0.02
8	0.02	--	0.80	0.78	0.18	0.01
9	0.02	--	0.07	1.19	2.94	0.09
10	0.05	--	0.20	0.00	0.00	0.00
11	0.02	--	0.00	0.51	0.58	0.22
12	0.01	--	0.71	0.00	0.04	0.08
13	0.01	--	0.03	0.53	0.89	0.01
14	0.01	--	0.00	1.28	1.06	0.11
15	0.01	0.12	0.01	1.15	0.99	0.20
16	0.01	0.12	0.01	0.00	0.00	0.00
17	0.02	0.37	0.00	0.01	0.50	0.02
18	0.01	0.00	0.00	0.00	0.00	0.00
19	0.01	0.10	0.00	0.00	0.00	0.03
20	0.02	0.33	0.01	0.08	0.00	0.85
21	0.02	0.00	0.01	0.00	0.00	0.00
22	0.02	0.13	0.00	0.00	0.00	0.01
23	0.00	0.05	0.00	0.01	0.10	0.00
24	0.05	0.00	0.06	0.02	0.14	0.00
25	0.01	0.00	0.00	0.04	0.21	0.01
26	0.04	0.00	0.00	0.00	0.00	0.00
27	0.08	0.00	0.00	0.00	0.00	0.00
28	0.10	0.00	0.01	0.00	0.00	0.00
29	0.06	0.00	0.18	0.09	0.00	0.00
30	0.00	0.00	0.00	0.15	0.00	0.08
31	0.00	0.00	0.00	0.01	0.04	0.04
Totals	1.91	1.22	4.16	10.31	11.69	4.76

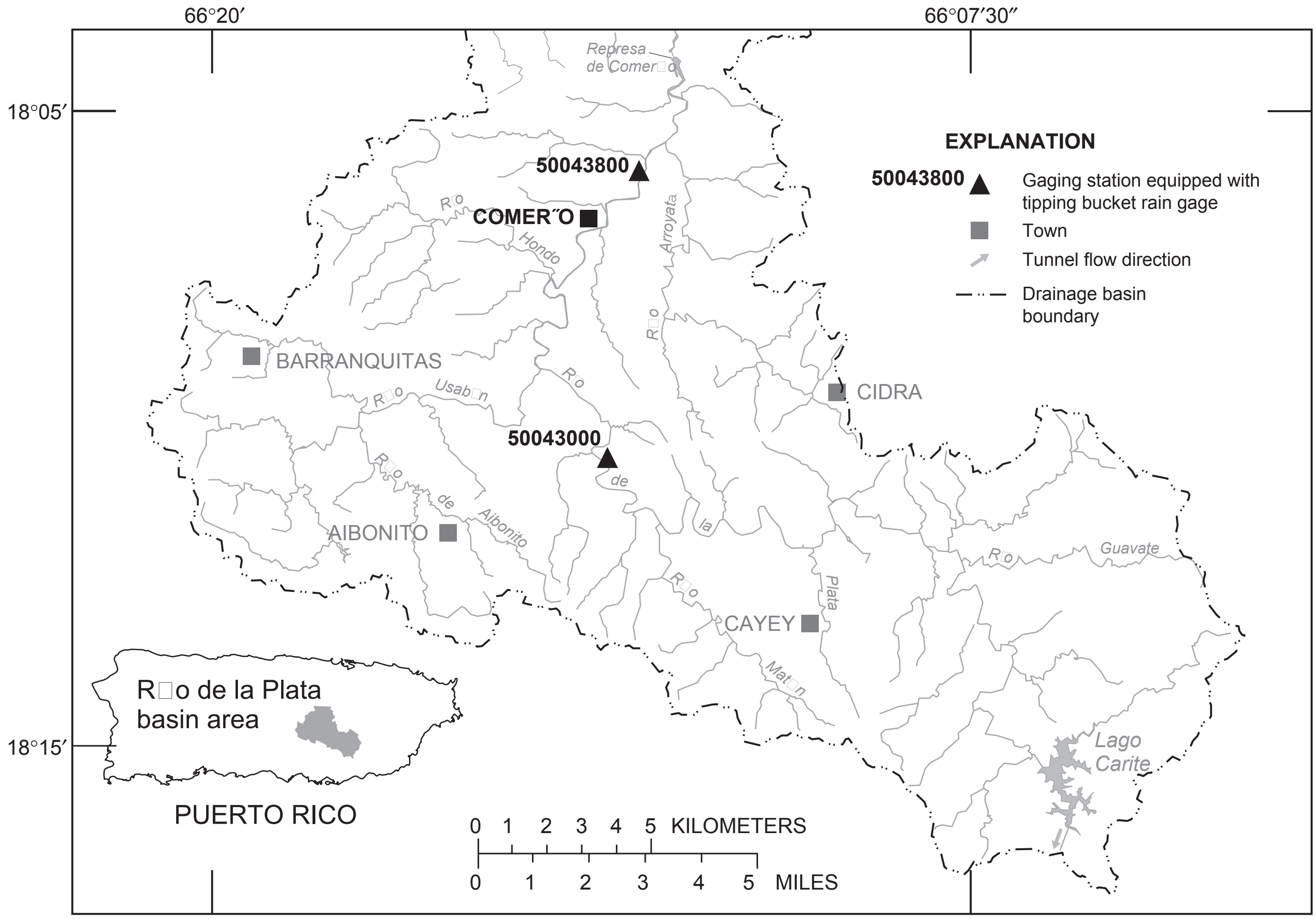

Figure 4. Location of USGS streamflow-gaging stations equipped with rainfall gages in the vicinity of the municipio of Comerío, Puerto Rico.

Based on previous sampling experience, dilution ratios for membrane filtration analyses at each station were prepared to maximize the probability of obtaining about 20 to 60 colonies per filter for fecal coliform bacteria and 20 to 100 colonies per filter for fecal streptococcus bacteria. If colony counts were not in the ideal range, concentrations were reported as non-ideal. With few exceptions, most samples were processed and incubated immediately after collection using the field laboratory. Where the field laboratory was not used, samples were preserved in an ice chest (ice water) at 1 to 4 °C and processed at the Caribbean District laboratory within 6 hours of sample collection.

The quality-assurance and quality-control (QA/QC) protocols for bacteriological analyses included (a) incubation of sterile buffered water in culture media at the Caribbean District laboratory as a check primarily on the sterile conditions of buffer, media, and filters; (b) field procedure blanks to check sterile conditions of field equipment; and (c) processing of sequential replicate samples as a check on dilution procedures and variability of bacteriological concentrations resulting from dip sampling. QA/QC samples represented on average 55 percent of all samples processed (laboratory and field blanks for part (a) and (b)). Sequential replicate sample dilutions were only two per sample run. Ideally, the sterile buffered water should show no colony development; if colonies are present, then the media or buffered-water dilution bottles are not acceptable for use. Results for (b) should be negative; if not, analytical results of samples obtained between negative QA/QC blanks (before and after the positive blank) are 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). Questionable data were obtained at one station that was sampled on only one occasion, Río Arroyata at mouth (USGS station 50043998). In this case, both the fecal coliform and fecal streptococcus colony counts at this sampling station were non-ideal counts and, in addition, were judged to be too low in comparison to results of upstream stations. Results for this sampling station were not used in the interpretation, but are presented in table 5. Sequential replicate samples obtained as part of this survey were within the 15 percent relative percent difference, which is typical for replicate samples having fecal coliform and fecal streptococcus concentrations in the range of 100 to low thousand colonies per 100 mL obtained under similar conditions by the Caribbean District in Puerto Rico. Relative percent difference (RPD) of primary and replicate samples are calculated as:

$$RPD = S1-S2 / [(S1+S2)/2] \times 100,$$

where S1 is the primary sample and S2 is the replicate sample of colony counts in media plates with the number of colonies in the ideal range of 20 to 60 for fecal coliform, and 20 to 100 for fecal streptococcus.

RESULTS AND INTERPRETATION

Major assumptions in the interpretation of the water-quality data are that streamflow during low-flow conditions is derived from ground-water discharge, and that fecal contamination during stream base-flow conditions is primarily derived from sources discharging directly into stream courses or near the riparian zone, such as sewage effluent or animal wastes. It is also assumed that, with an average of two samples obtained at least more than one month apart during stream low-flow recession periods at numerous locations throughout a watershed, it is possible to define, on a qualitative basis, the relative sanitary quality of the site with respect to the other sampling locations.

Based on these assumptions, the analytical results for fecal coliform and fecal streptococcus bacteria concentrations from 24 of the 26 stream sampling stations established for the synoptic surveys were used to characterize the sanitary quality of 84 mi of perennial stream channels mostly within the municipio of Comerío (table 5). Bacteriological data were insufficient to adequately assess the sanitary quality of approximately 34 stream mi within the Río Hondo and Río Arroyata drainage basins, outside the municipio boundary.

Based on the analytical results, a relative ranking of the stream sanitary quality was established to delimit stream channels as being either **poor**, **fair**, **acceptable**, or **good** (table 7). This relative ranking was based on the Puerto Rico Water Quality Standards for fecal coliform of 2,000 colonies per 100 mL, using the following rationale:

Sampling stations with fecal coliform bacteria concentrations greater than 2,000 colonies per 100 mL for both sample dates were considered **poor**. The stream segment given the same classification was extended upstream and downstream as follows:

> If another sampling station upstream and/or downstream within the same order stream had results that were comparable, the same classification was given for the entire stream segment between both sampling stations; if the upstream station and/or downstream station was classified differently, the classification was extended to mid-point; and if no other sampling stations were located upstream, the same classification was extended upstream not more than 0.6 mi along the main trunk of the stream. For stream segments in which the upstream distance was greater than 0.6 mi from the sampling station, the same classification was assigned to the trunk stream and tributaries, but using the terminology **presumed poor**. If no other sampling station was established downstream, 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 poor** classification assigned downstream of the 0.6-mi distance.
>
> Sampling stations where fecal coliform bacteria concentrations were equal to or greater than 2,000 colonies per 100 mL in one sample, but below 2,000 colonies per 100 mL in the second sample run 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 **poor** and **presumed poor**.
>
> Sampling stations at which fecal coliform bacteria concentrations were equal to or less than 2,000 colonies per 100 mL on both sample occasions 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.
>
> If both samples had fecal coliform bacteria concentrations below 200 colonies per 100 mL and fecal streptococcus concentrations below 400 colonies per 100 mL, the **good** and **presumed good** classifications were assigned in the same manner as the other rankings, only if at least one sample was obtained at the flow conditions required in this synoptic survey. The **presumed** prefix was used in the ranking of several streams having drainage areas of less than 3 mi^2. At these streams, the classification was based on sampling results obtained at streams draining adjacent watersheds with similar land-use conditions as determined from field inspections and 1994 aerial photographs. The **presumed** prefix was also used at stations sampled only once at stream base-flow conditions.

Results from the 24 stream-sampling stations ranked were extrapolated to classify a total of 84 mi of stream courses including the 10.3 mi of Río de la Plata within the municipio of Comerío (table 8; plate 1). The only sampling stations classified as having a **good** sanitary quality were at Río Hondo (station 50043575), Quebrada Piñas (station 50043780), and Quebrada Naranjo (station 50043995). The only stations classified as having a **presumed good** sanitary quality was Quebrada Tigre (station 50043490). Quebrada del Banco, a tributary to the Río Arroyata was not sampled, but was classified as good. Land use in the less steep areas of Quebrada del Banco is mostly forest; land use in the upland is pasture. At several stations, the sanitary quality ranking changed within relatively short distances. At sampling stations having higher indicator bacteria concentrations, the cause could have been directly related to antecedent rainfall sufficient to produce localized runoff. During the synoptic surveys, an areally extensive rainfall occurred during March 19 to 20, 1998, with as much as 5.37 in. recorded at Comerío on March 20 (refer to table 6). Patchy rainfall events were common several days before and during the synoptic surveys conducted in March and June 1998, and in June and July 1999. Thus, for more detailed interpretation of the apparent anomalies in the sanitary quality classification displayed on plate 1, daily rainfall totals are given for three geographic locations in table 6 and more detailed data on indicator bacteria concentrations and streamflow conditions are presented in table 5. Approximately 34 stream mi, all outside the municipio boundary, were not classified because of insufficient data. No classification was made for most of the Río Hondo upstream of the Comerío–Barranquitas municipio boundary and the headwater tributaries of the Río Arroyata within the municipio of Cidra.

Table 7. Classification rationale used in ranking the sanitary quality of streams in the Comerío area, Puerto Rico

[>, greater than; <, less than; =, equal to; mL, milliliters; *, value obtained from non-ideal plate count]

Ranking	Fecal coliform concentration for stream reach during base-flow conditions, in colonies per 100 mL	Rationale	Summary of the concentrations found during synoptic surveys	Fecal coliform concentration, in colonies per 100 mL	Fecal streptococcus concentration, in colonies per 100 mL
Poor	> 2,000	Samples obtained within 0.6 mile upstream or downstream of delimited reach.	**Maximum**	11,000*	3,500
Presumed poor	> 2,000	Samples obtained at a distance greater than 0.6 mile upstream or downstream of delimited stream reach were used to infer that similar concentrations are probable within delimited stream reach.	**Minimum**	2,100	320
			Geometric mean	3,698	1,858
			Number of samples	6	6
Fair	Equal probability for < or ≥ 2,000	Samples obtained within 0.6 mile upstream or downstream of delimited reach.	**Maximum**	7,600*	5,600
			Minimum	130*	100*
Presumed fair	Equal probability for < or ≥ 2,000	Samples obtained at a distance greater than 0.6 mile upstream or downstream were used to infer same conditions are probable within the delimited stream reach.	**Geometric mean**	1,076	698
			Number of samples	15	15
Acceptable	< or = 2,000	Samples obtained within 0.6 mile upstream or downstream of delimited reach.	**Maximum**	1,400	5,300
			Minimum	20*	80*
Presumed acceptable	< or = 2,000	Samples obtained at a distance greater than 0.6 mile upstream or downstream were used to infer that equal concentrations are probable within the delimited stream reach.	**Geometric mean**	254	442
			Number of samples	13	13
Good	< 200	Samples obtained at station also had fecal streptococcus concentrations less than 400 colonies per 100 mL; ranking was applied to entire stream upstream of sampling station.	**Maximum**	270	360
			Minimum	30*	20*
Presumed good	< 200	Samples obtained at a distance greater than 0.6 mile upstream or downstream were used to infer that equal concentrations are probable within the delimited stream reach.	**Geometric mean**	92	146
			Number of samples	10	10

Table 8. Sanitary-quality ranking determined for surface-water sampling stations, and stream miles classified under each ranking, municipio of Comerío, Puerto Rico

[Total miles include the segment of Río de la Plata within the municipal boundary and segment of stream channels outside the municipal boundary with drainage to Comerío; --, no data]

Classification	Sampling stations with same classification	Percent of total sampling stations ranked	Stream miles with same classification	Percent of total stream miles	Percent of total stream miles ranked
Poor	3	12.5	5.2	4.4	6.2
Presumed poor	0				
Fair	8	33.3	21.7	18.5	25.9
Presumed fair	0				
Acceptable	5	29.2	31.9	27.1	38.0
Presumed acceptable	2				
Good	4	25.0	25.1	21.3	29.9
Presumed good	2				
Not classified	1	--	33.8	28.7	--

Potential contaminant sources from unsewered rural communities located adjacent to stream courses, especially along stream segments where fecal coliform concentrations were below 2,000 colonies per 100 mL are delineated on plate 1. It is possible that the indicator bacteria became stressed or injured by household waste-water discharges (gray water). Gray water is all nonsanitary waste water from commercial and residential areas, and commonly contains relatively high concentrations of detergents and chemicals. Gray water may render the bacteria incapable of growth and colony formation because of structure and metabolic changes associated with high detergent and chemical concentrations in the untreated water (American Public Health Association, 1998). Hence, an additional symbol was added to plate 1 to show potential sources of household waste-water discharges that were evident within the municipio boundary during the field surveys. Stream course segments that may be affected by gray-water discharge were mapped using 1994 aerial photographs. These riparian segments are potential sources of contamination and were identified on plate 1 as "riparian zone with potential as a source of contamination from household waste-water discharges." Approximately 8.7 stream mi were delimited on plate 1 using this definition. Stream segments delimited with this symbol 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. Determination of adequate setback distance must consider rainfall recharge, hydrogeology, and housing density, in addition to the soil percolation rate 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 viruses can survive in ground water as far as 215 ft from a septic tank in sandy soils (Vaughn and others, 1983) and persist up to 131 days (Stramer, 1984).

Agricultural enterprises in Comerío that are most likely to impact the sanitary quality of streams are the breeding and raising of hogs, pigs, and poultry (primarily broilers). The 1997 agricultural census estimated 2,887 hogs and pigs (as compared to 4,407 in 1992) and 350,225 chickens (as compared to 549,516 in 1992) in the municipio of Comerío (U.S. Department of Commerce, 1998b). Breeding hogs and pigs at a commercial scale occurs primarily within the Río Higüero drainage basin. Commercial poultry breeding is essentially limited to the Río Higüero drainage basin within the municipio of Comerío, and also was observed in the Río Arroyata drainage basin within the municipio of Cidra and in the Río Hondo drainage basin within the municipio of Barranquitas. Grazing of dairy and beef cattle was observed to be relatively insignificant in the municipio, although the 1997 agricultural census estimated 221 head of dairy cattle and 2,004 head of beef cattle. The number of dairy and beef cattle has remained relatively unchanged since the agricultural census of 1992, when 279 head of dairy and 1,869 head of beef cattle were reported (U.S. Department of Commerce, 1994; U.S. Department of Commerce, 1998b). In 1998, there were no dairy operations in Comerío. Although the total head of dairy and beef cattle is not substantial, fecal contamination by herds may be significant locally because cattle are not restricted from wandering into stream courses.

CHAPTER C:

The Hydrogeologic Terranes and Ground-Water Resources in the Municipio of Comerío, Puerto Rico, 1997-99

By **Jesús Rodríguez-Martínez, Fernando Gómez-Gómez,** *and* **Mario L. Oliveras-Feliciano**

PURPOSE AND SCOPE

The USGS in cooperation with the municipio of Comerío conducted an investigation of the ground-water resources of the municipio area (fig. 1 in plate 2). As part of this study, the municipio of Comerío was differentiated into areas of similar hydrogeologic characteristics, referred to as hydrogeologic terranes. Geologic, topographic, soil, hydrogeologic, and streamflow data were used to delineate the various hydrogeologic terranes. These data were obtained from field reconnaissance, USGS topographic and geologic maps, collected streamflow data, and available published information.

The concept of hydrogeologic terrane was used by Berg and others (1997) to separate the state of Illinois into areas of similar hydrogeologic properties as part of a regional evaluation of the ground-water and surface-water interactions. The hydrogeologic terranes of the municipio of Comerío and denoted in this report by the acronym CoHT accompanied by an assigned number. For example, CoHT1 refers to the Comerío hydrogeologic terrane number 1.

The information compiled and generated during this study will help the municipio of Comerío in developing its land and water resources in a sustainable manner, and provide hydrogeologic information to the general public in a format that can be easily understood and utilized.

METHODOLOGY

The factors used to differentiate the municipio of Comerío into hydrogeologic terranes were, in order of importance, (a) the type of geologic bedrock, (b) land-surface slope, (c) ground-water flow rate, (d) depth to ground water below land surface, (e) hydraulic properties, such as specific capacity or transmissivity, and (e) soil thickness and infiltration capacity. The geologic substrata and associated attributes, such as the presence of fractures, joints, and stratification, were determined from field reconnaissance, USGS geologic maps, and lineament trace analyses (Pease and Briggs, 1960; Briggs and Gelabert, 1962; Pease, 1968; Nelson, 1967). The land-surface slope was obtained by computer processing a digitized topographic map of the municipio of Comerío area. The ground-water flow rate was estimated from stream low-flow measurements and using the Q-98 and Q-90 flows (streamflows equaled or exceeded 98 and 90 percent of the time, respectively) for the stream reaches investigated. Specific capacity and transmissivity values were obtained from hydraulic tests conducted as part of this study, from drillers's logs and reports, and from data available in the Ground Water Site Inventory data base of the USGS. The soil thickness and infiltration capacity were obtained from the soil maps published by the Soil Conservation Service (U.S. Department of Agriculture, Soil Conservation Service, 1973). The general depth to ground water was obtained from USGS historic data and field surveys.

The hydrogeologic terranes are delineated in a 1:30,000-scale map of the municipio of Comerío, which also includes drainage sub-basins (plate 2). Representative lithologic columns for the hydrogeologic terranes with the highest ground-water development potential (CoHT1 and CoHT4) are shown in figure 5 in plate 2. Water samples were collected from a series of private and public-supply wells to determine the concentration of the major anions and cations.

Lineament-trace analysis is used to identify land-surface features, such as rectilinear topographic drainage features, geologic contacts, and tonal differences in soil colors to indicate subsurface fractures that may be zones of enhanced ground-water flow in an otherwise low-permeability formation (Lattman, 1958). Studies indicate that the maximum development of permeability occurs at the intersection of fractures (Lattman, 1958). Consequently, when selecting potential well sites, preference is given to those areas with a high density of fractures or fracture intersections, which may reduce the costs associated with the trial-and-error approach usually used in drilling. The lineaments were derived from the analysis of aerial photos by two independent observers. Lineaments that were identified by both observers were verified in the field. These lineaments are considered to have the highest hydrologic potential (Sander and others, 1997) and are presented in plate 2.

Some of the factors mentioned above, although considered separately in this report, are generally interrelated. For example, while geology and topographic slope are interrelated, they also highly influence the type and thickness of soil cover present. Similarly, geology and topographic slope control, to a large degree, the ground-water flow rate. Low flows, an indirect measure of the ground-water flow rate in the corresponding ground-water basin, are highly dependent on geologic factors such as type of lithology, stratification, and the occurrence of fractures and joints.

Stream low-flow values can be used to approximate the ground-water flow rate in a corresponding drainage basin, and therefore, can be used to infer the ground-water development potential of a particular area (Berg and others, 1997; Farvolden and Nunan, 1970; Ineson and Downing, 1964). This equivalence or approximation of low flows to ground-water flow rate assumes that (a) ground water in a particular ground-water basin discharges entirely into the stream and its tributaries, and (b) ground-water discharge into the stream and tributaries is restricted to aquifer(s) in the corresponding drainage basin. This approximation also assumes that the contributing ground-water catchment area does not vary seasonally in extent, due to fluctuating ground-water levels. Low-flow measurements were preferentially made at stream junctions, and wherever possible, at stream sections coinciding with the boundaries of different geologic units as delineated in the 1:30,000-scale geologic quadrangle maps. This discharge-measurement strategy provided the low-flow values required to calculate the contribution of ground-water flow from the drainage area of each of the measurement points. The range of ground-water flow rate assigned to a particular hydrogeologic terrane is the low-flow discharge measured in the drainage basins contained in it. The measured low-flow values were normalized to remove the effect of drainage basin-area size, and thus, are expressed as gal/d-mi^2 and in the equivalent effective recharge in inches per year (in/yr).

Pérez-Blair (1997) used the Q-98 flow (streamflow value equaled or exceeded 98 percent of the time) as an indicator of ground-water discharge into a stream to provide an approximation of the ground-water flow in the adjacent aquifer. Berg and others (1997) used the Q-90 (streamflow value equaled or exceeded 90 percent of the time) determined from 30 years of streamflow data to estimate ground-water discharge into a stream. For this study, the range between the Q-98 and Q-90 flows was used as an indicator of the ground-water discharge contribution to a stream, and thus, as the ground-water flow in the aquifers of the adjacent drainage basin. The Q-98 and Q-90 flows were obtained using the graphical correlation method described in Chapter A. The Q-98 and Q-90 flows at the partial-record gaging stations were then determined through correlation using the corresponding values at the continuous-record gaging station. Table 9 lists a series of drainage basins and their approximated normalized ground-water flow as estimated from the range between the Q-98 and Q-90 flows, the equivalent effective recharge in in/year, and the hydrogeologic terranes represented within each drainage basin.

The flow measurements used to determine the Q-90 and Q-98 flows were corrected for stream diversions, waste-water treatment plant discharge, and ground-water flow captured by pumping wells or spring development. Low-flow stream contributions from outside the municipio of Comerío were not considered in the analysis. The fraction of the low flow contributed by direct ground-water discharge originating outside the municipio of Comerío is poorly understood. Given the limited extent of the water-bearing units, however, and their generally low permeability, it is assumed that local ground-water flow systems predominate.

Table 9. Hydrogeologic features of selected sub-basins in the municipio of Comerío, Puerto Rico

[mi^2, square miles; gal/d-mi^2, gallons per day per square mile; in/yr, inches per year; CoHT, Comerío hydrogeologic terrane; <, less than]

Sub-basin and identification number [1]	Area (mi^2)	Approximate normalized Q-90 ground-water flow (gal/d-mi^2)	Q-90 effective recharge (in/yr)	Approximate normalized Q-98 ground-water flow (gal/d-mi^2)	Q-98 effective recharge (in/yr)	Hydrogeologic terrane(s) contained within the drainage basin in order of areal extent
(1) Quebrada Naranjo	2.58	226,000	4.8	74,880	1.6	CoHT2, CoHT1
(2) Quebrada Cejas [2]	1.29	300,960	6.4	201,600	4.3	CoHT1, CoHT2
(3) Quebrada Piñas	2.31	<100,000	<1.0	<100,000	<1.0	CoHT5
(4) Quebrada Prieta [3]	1.26	<100,000	<1.0	<100,000	<1.0	CoHT5, CoHT3
(5) Río Hondo (upper portion)	[3] 9.07	192,960	4.1	113,760	2.4	CoHT3, CoHT4
(6) Quebrada Convento	0.98	<100,000	1.4	<100,000	<1.0	CoHT1, CoHT2
(7) Quebrada Higüero (upper portion)	1.66	195,840	4.1	78,048	<1.0-2.3	CoHT1
(8) Quebrada Higüero (lower portion)	1.99	586,080	12.4	423,360	9.0	CoHT2
(9) Quebrada Doña Elena	1.28	203,040	4.3	103,680	2.1	CoHT1, CoHT2

[1] Sub-basin identification number shown in gray block numbers in plate 2.
[2] Water is diverted by a dam.
[3] Drainage basin extends beyond the borders of the municipio of Comerío.

Locally, low flows (and equivalent ground-water flows) within similar hydrogeologic terranes can differ as a result of variable land cover and the resulting evapotranspiration. Typically, in tropical areas, stream low flow in volcanic terranes is controlled by relatively high rainfall infiltration, which is promoted by forest cover (Bruijnzeel, 1990). In the Lago de Cidra area, conversion of forest to agriculture may have resulted in a reduction of stream low flow from an equivalent of 6 to 2 in. of rainfall (Ramos-Ginés, 1997). The effects of evapotranspiration on shallow ground-water flow can be important during the dry season. Even with a constant land cover, variations may occur in the low flows, because low flows in any drainage basin reflect the prevailing precipitation pattern (effective recharge). Ground-water flow and equivalent stream low flow in any drainage basin will change as variations in effective recharge occur as a result of changes in the precipitation pattern.

The ground-water flow estimates included low-flow measurements from drainage sub-basins of variable size. Even though ground-water flow estimates were normalized on a unit area basis for comparison between hydrogeologic terranes, it is possible that the size of the drainage sub-basins could have some effect on the low-flow values used in the analysis. For example, as the size of the basin increases, the distribution of elements that determine ground-water transmissivity and storage (primary porosity, fractures, joints, bedding planes, thickness of the weathered zone), and climatological factors (precipitation and evapotranspiration) become increasingly heterogeneous. Similarly, land cover may vary within the basin. This departure from uniformity in these factors may result in an uneven generation of low flow across the basin. Thus, measured low flows may only partially represent the spatial variation in ground-water flow in the aquifer(s). This effect, after normalization, is referred to as the residual effect (Farvolden and Nunan, 1970). The residual effect seems to be important in basins covering tens to hundreds of square miles. Because the basins in the current study do not exceed 10 mi^2 in area, the residual effect may be minimal or none.

RESULTS AND INTERPRETATION

The municipio of Comerío can be differentiated into five hydrogeologic terranes (CoHT). These are delineated on plate 2 and described below in descending order of ground-water development potential.

CoHT1- This hydrogeologic terrane consists of volcaniclastic rocks with minor lavas and limestone units. The topographic slope is generally less than 15 degrees. The clay-soil cover generally exceeds 30 ft in thickness. The soil cover may grade downward into the weathered material capping the underlying igneous basement rock, which is presumed to be highly fractured. The weathered material or regolith constitutes the water-bearing unit in this hydrogeologic terrane. The weathered material or regolith may locally thicken over fractures enhancing the storage and transmissive properties in an otherwise generally low permeability environment. This hydrogeologic terrane comprises the “dissected” uplands in the headwaters of Quebrada Higüero, Quebrada Cejas, Quebrada Naranjo, Quebrada Convento, and Quebrada Doña Elena. The ground-water flow in sub-basins composed of or mostly of this hydrogeologic terrane ranges from less than 100,000 to 300,960 gal/d-mi^2, which is equivalent to 1.4 to 6.4 in/yr (table 9). Most drilled wells in this hydrogeologic terrane have been installed in the vicinity of streams. The specific capacity calculated from wells drilled in this hydrogeologic terrane ranges from 2.1 to 4 gallons per minute per foot of drawdown (gal/min-ft). In general, the data suggest that the maximum depth for wells drilled in this hydrogeologic terrane should not be much greater than 120 ft (fig. 5 in plate 2). At depths greater than 120 ft, the weathered material or regolith usually is replaced by basement rock and consequently, the water yield is substantially reduced.

CoHT2- This hydrogeologic terrane consists of volcaniclastic rocks with minor lavas and limestone units. The topographic slope exceeds 15 degrees, which enhances rainfall runoff but reduces the potential for ground-water recharge. The thickness of the soil cover generally varies from less than 20 to more than 30 ft. Stratification seems to be well developed. Locally, fracturing appears to be substantial as suggested by the high degree of structural deformation observed in the field and registered in the geologic quadrangle maps (Pease and Briggs, 1960; Nelson, 1967). Ground-water flow along fractures and bedding planes is extremely important and is manifested principally as springflow emerging from stream banks and along slopes at higher altitudes. In sub-basins composed of or mostly composed of this hydrogeologic terrane, ground-water flow ranges from less than 100,000 to 586,080 gal/d-mi^2 or its equivalent in effective recharge of less than one to 12.4 in/yr (table 9). A specific capacity value of 5.1 gal/min-ft has been reported from one of the few wells drilled in this hydrogeologic terrane. A reported yield of 50 gal/min was derived from a spring in the lower section of the Quebrada Higüero drainage basin for public supply.

CoHT3- This hydrogeologic terrane, similar to CoHT2, consists of volcaniclastics and minor lavas with slopes exceeding 15 degrees. The soil cover is variable, but is generally less than 20 ft thick. Stratification is generally more massive and less differentiated than in CoHT2. CoHT3 contains less fractures and joints than CoHT2, as determined by field reconnaissance and examination of the Comerío geologic map (Pease and Briggs, 1960). It would seem that this hydrologic terrane has less favorable conditions for rainfall recharge into the subsurface than hydrogeologic terrane CoHT2 and consequently, a much lower effective recharge. However, in sub-basins composed of or mostly of this hydrogeologic terrane, ground-water flow ranges from 113,760 to 192,960 gal/d-mi^2 or its equivalent in effective recharge of 2.1 to 4 in/yr (table 9). No wells are known to have been drilled in this hydrogeologic terrane.

CoHT4- This hydrogeologic terrane consists of Quaternary alluvium and terrace deposits. Locally, it may include small limestone units and the weathered zone of underlying igneous rocks. This hydrogeologic terrane is restricted to lowland areas adjacent to streams, where slopes do not exceed 15 degrees. The Quaternary alluvium and terrace deposits are generally of limited lateral extent with a reported maximum thickness of 50 ft. Figure 5 shows the typical lithologic column with the recommended maximum depth for a well drilled in this hydrogeologic terrane. The spatial dimensions of these deposits are limited, and consequently, yields from wells are mostly sustained by induced flow from nearby streams and not from aquifer storage. The yields from active wells are highly variable and usually range from about 20 to 50 gal/min. Measured water levels normally range from less than 10 to 30 ft below land surface. In general, data indicate that alluvial and terrace deposits do not extend beyond a depth of 100 ft, and so, maximum depth for wells drilled and installed in this hydrogeologic terrane should not exceed this depth (fig. 5).

CoHT5- This hydrogeologic terrane consists of massive volcanic breccia with lava flows and intrusives. Slopes generally exceed 15 degrees and consist of a variable soil cover. Stratification and fracturing are poorly developed in CoHT5. In sub-basins where this hydrogeologic terrane predominates, ground-water flow is estimated to be less than 100,000 gal/d-mi^2. Ground-water flow in this hydrogeologic terrane is negligible considering that it is equivalent to an effective recharge of less than 1 in/yr (table 9). The few wells drilled in this hydrogeologic terrane have been installed in the vicinity of streams; however, the yields from these wells are generally low and some are dry for most of the year.

Excluding CoHT4, in which the main water-bearing material is alluvium, the remaining four hydrogeologic terranes are composed essentially of volcaniclastic rocks with minor intrusives and limestone units of limited aerial extent. In general, variations in type and thickness of soil cover are not important and minor variations seem to be more dependent on the topographic slope than the type of geologic bedrock. Similarly, variations in the infiltration capacity of the soils in the municipio of Comerío are minor; consequently, this factor was not used in the differentiation process. The ground-water flow, and thus, the ground-water development potential of each hydrogeologic terrane seems to be highly dependent on secondary permeability resulting from fractures and joints generally associated with faults (an indicator of structural deformation). In the municipio of Comerío, a topographic slope angle generally less than 15 degrees also seems to be a factor enhancing the infiltration of rainfall. A slope of 15 degrees seems to be a threshold value beyond which ground-water development potential is considerably reduced.

According to the results of this study, CoHT1 and CoHT2 seem to be the hydrogeologic terranes most suitable for ground-water development in the municipio of Comerío. Presently, the majority of ground-water source development in the municipio of Comerío occurs within CoHT1, which includes the upper portions of the drainage basins of Quebrada Higüero, Quebrada Convento, Quebrada Cejas, Quebrada Naranjo, and Doña Elena. CoHT1 occupies most of the dissected uplands of Barrios Cejas and Palomas, and extends beyond the borders of Comerío westward of the Barrio Palomas into the neighboring municipio of Barranquitas. Ground water is withdrawn from CoHT1 at an estimated average daily rate of 186,000 gal/d (129 gal/min). CoHT2 is similar to CoHT1, but differs primarily in that it has a much steeper topographic slope and thinner soil cover. CoHT2 occupies the steep canyons of the main trunks of the Quebrada Higüero, the Quebrada Doña Elena, the Quebrada El Convento, the Quebrada Cejas, the Quebrada Naranjo, the Quebrada Blanca, and Quebrada Cedrito. In general, this hydrogeologic terrane exhibits substantial structural deformation, and as a result, ground-water flow is predominantly along fractures, joints, and bedding planes. Despite having the highest ground-water base contribution to streams of all the differentiated hydrogeologic terranes in the municipio of Comerío, historically CoHT2 has not been seriously considered for ground-water development because of the very steep slopes. Ground-water development in CoHT2 has been limited to a few wells and tapped springs. It is possible that the high low-flow gain in the lower portion of the Quebrada Higüero drainage basin, indicative of an effective recharge of about 9.0 to 12.4 in/yr (estimates from Q-98 and Q-90, respectively) results from the capture of ground-water flow beyond the drainage basin boundaries as a result of the pervasive presence of fractures and joints produced by substantial structural dislocation (table 9). The likelihood that interbasinal ground-water flow occurs, while enhancing the low flows, also represents an avenue by which contaminants, such as untreated human and animal wastes (from septic tanks, poultry, and hog farms), may affect both ground and surface water.

The hydrogeologic terrane CoHT3, although having a similar geologic bedrock, slope, and clay cover, has lower ground-water flow than CoHT2. This lower ground-water flow may be the result of less structural deformation as compared to CoHT2. Consequently, the development of secondary permeability due to faulting and associated fracturing and jointing has been substantially reduced in CoHT3. This hydrogeologic terrane occupies a substantial portion of the Río Hondo drainage basin. No wells are known to have been drilled in CoHT3.

The ground-water development potential of the hydrogeologic terrane CoHT4 is hindered by its limited areal extent, local ground-water recharge to this hydrogeologic terrane is of less importance to sustaining flow at wells tapping this hydrogeologic terrane than is induced infiltration from perennial streams. The yield of wells drilled in CoHT4 is sustained by induced ground-water flow from nearby streams such as the Río de la Plata, the Río Arroyata, and the Río Hondo.

The hydrogeologic terrane CoHT5, limited to the southern part of the municipio of Comerío, and includes part of the drainage basin of the Quebrada Prieta and Quebrada Piñas, has the lowest ground-water flow of all the hydrologic terranes. The limited structural deformation in this hydrogeologic terrane has inhibited the common occurrence of fractures and joints which, in turn, has limited the development of secondary permeability. The rocks generally are massive with poorly developed bedding planes.

Water samples from eight private- and public-supply wells were analyzed to determine the concentration of dissolved major cations and anions (table 10). The concentrations of all principal constituents comply with drinking-water standards established by the U.S. Environmental Protection Agency (USEPA). Because fecal bacteria concentrations regularly exceed the USEPA drinking-water standards in most of the surface waters of the municipio of Comerío (Chapter B), wells completed near streams are highly susceptible to contamination with fecal bacteria. This is particularly evident in the hydrogeologic terrane COHT4, where aquifers are well connected hydraulically with nearby streams, the result of the permeable nature and limited lateral extent of the alluvial deposits. A series of the Puerto Rico Aqueduct and Sewer Authority wells completed in this hydrogeologic terrane were closed several years ago, because of serious contamination with fecal bacteria that resulted from discharge of improperly treated sewage in the Río de la Plata (Chapter B).

Table 10. Summary of chemical analysis results of water samples from selected wells in the municipio of Comerío, Puerto Rico

[Concentrations are given in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; µS/cm; microsiemens per centimeter at 25 degrees Celsius; Ca, Calcium; Mg, Magnesium; Na, Sodium; K, Potassium; Cl, Chloride; SO_4, Sulfate; F, Fluoride; SiO_2, Silicate; Fe, Iron; Mn, Manganese; $CaCO_3$, calcium carbonate]

Well name and identification number[1]	Date	Latitude Longitude[2]	pH	Total hardness as $CaCO_3$	Dissolved constituents											Specific conductance (µS/cm)
					Ca	Mg	Na	K	Cl	SO_4	F	SiO_2	Fe (µg/L)	Mn (µg/L)	Solids	
(1) Comunidad Doña Elena #2	3/17/99	18°15'31" 66°13'41"	7.5	120	25	13	12	1.6	12	4	0.1	39	10	3	180	291
(2) De la Rosa	3/17/99	18°14'36" 66°16'00"	7.4	100	18	13	11	2.1	13	2	0.1	57	27	3	173	263
(3) PRASA Naranjo	3/17/99	18°13'15" 66°10'36"	7.4	93	22	9.3	13	1.0	17	3	0.1	56	7	3	174	255
(4) Comunidad Cedrito	3/17/99	18°15'05" 66°11'06"	7.5	150	32	16	13	1.8	20	6	0.2	49	10	3	222	359
(5) Ismael Sáez	3/17/99	18°15'04" 66°14'22"	7.7	170	30	23	8	1.3	33	1	0.1	33	10	3	205	384
(6) Comunidad La Prieta	3/17/99	18°14'57" 66°11'24"	7.9	140	32	14	16	1.3	14	10	0.2	39	10	8	213	347
(7) Pedro Zayas	3/17/99	18°14'00" 66°14'60"	7.1	95	20	11	12	2.0	13	1	0.1	60	10	3	176	252
(8) William Pérez	3/17/99	18°14'13" 66°15'35"	6.8	130	21	19	9	2.0	10	1	0.1	50	10	8	170	310

[1] Locations of wells and identification numbers are shown in plate 2.
[2] Datum for latitude and longitude is NAD 27.

SUMMARY AND CONCLUSIONS

To meet the need for an adequate supply of safe drinking water, the USGS in cooperation with the Office of the Mayor of the Municipio of Comerío, conducted an integrated surface-water, water-quality, and ground-water assessment of the municipio of Comerío. Because the supply of safe drinking water is critical during dry periods, the surface-water assessment focused on low-flow characteristics of rivers in the municipio of Comerío.

Low-flow and flow-duration characteristics were evaluated at one continuous-record gaging station and at 13 partial-record stations (tables 1, 2). The continuous-record gaging station is located about 5.6 mi northwest of the town of Comerío on the Río Guadiana, a second-order tributary of Río de la Plata. The 13 partial-record stations are distributed among a number of second- and third-order streams in the Río de la Plata drainage basin (plate 1). Five of these stations contributed less than 0.1 ft^3/s each, based on the 99 percent of time discharge. One drainage basin, Quebrada Higüero at Barrio Palomas is a basin where the minimum streamflow study indicates a relatively high discharge per unit drainage area of 0.40 $ft^3/s\text{-}mi^2$. This unit area discharge rate is substantially above the mode for drainage basins in Comerío, which was 0.15 $ft^3/s\text{-}mi^2$. The surface-water contribution of Quebrada Higüero at Highway PR-156 (station 50043845) is 1.5 ft^3/s, which is equivalent to 48 percent of the 3.1 ft^3/s of the total flow available at the Q-99 flow duration of second-order tributaries to Río de la Plata in Comerío.

In addition to low-flow characteristics in the surface-water assessment, important surface-water resource information also was compiled, including the location of a potential reservoir site, flood-hazard areas, water-supply filtration plants, the Comerío waste-water treatment plant, drainage basin boundaries, and stream-gaging station locations (plate 1). The stream low-flow statistics presented document the general hydrology under the current land and water use. Low-flow statistics may change significantly as a result of streamflow diversions for public supply, land-use change, increase in ground-water development, waste-water discharges and flood-control measures. As a result, the current analysis will provide baseline information to quantify change and thereby develop water budgets.

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

The results of long-term monitoring of bacterial concentrations of surface water at two stream stations on Río de la Plata (plate 1) indicate that the sanitary quality of streams in the municipio of Comerío is generally within the sanitary quality goals established on the basis of the geometric mean concentration of fecal coliform indicator bacteria, and has remained relatively unchanged for over a decade (fig. 2a and 2b in plate 1). A sanitary quality survey was conducted during base-flow conditions primarily to locate fecal waste contamination sources that discharge directly to or in the vicinity of stream courses. A qualitative classification method was developed and was primarily based on the Puerto Rico fecal coliform concentration goal established for Class SD-designated use surface water (Junta de Calidad Ambiental de Puerto Rico, 1990). The method was applied to rank the sanitary quality at sampling stations where at least two samples were obtained during stream base-flow conditions. The geometric mean of fecal coliform and fecal streptococcus concentrations, respectively (in number of colonies per 100 mL), for each of the established rankings were as follows: **poor** – 3,698 and 1,858; **fair** – 1,076 and 698; **acceptable** – 254 and 442; and **good** – 92 and 146.

Because only 24 sampling stations were used to delimit the sanitary quality of approximately 84 stream miles, it was necessary to develop a rationale for extrapolating of the station rankings. This required using the prefix **presumed** before each of the rankings, since the bacteriological concentrations at various sampling stations along a given stream reach was significantly different at distances of as little as 0.6 mi. In summary, 84 of the 118 stream miles with drainage to or within the municipio of Comerío were ranked as follows: 5.2 mi, **poor**; 21.7 mi, **fair**; 31.9 mi, **acceptable**; and 25.1 mi, **good**. Of the 34.0 stream miles not ranked, 18.0 stream miles were outside the municipio boundary in the Río Hondo drainage basin within the municipio of Barranquitas, and 16.0 stream miles in the Río Arroyata drainage basin within the municipio of Cidra.

Based on more than 14 years of field observations and hydrologic analysis in the Comerío area, it may be inferred that the stream courses classified as **poor** (or **presumed poor**) are contaminated from continuous sources of fecal contamination, and those classified as **fair** (or **presumed fair**) and **acceptable** (or **presumed acceptable**) from intermittent sources. In urbanized areas, potential sources of fecal contamination include illegal discharge of sewage to storm-water drains especially within the older sectors of the town of Comerío; overflows from sewer mains into the storm-water drains as a result of malfunctioning of sanitary sewer ejectors or clogged mains; rupture and leakage from sewer mains into the local aquifer. In rural areas, potential sources of fecal contamination are gray-water discharges from residential and commercial establishments along stream channels; septic tank leakage or overflows; feces contamination directly into streams by unfenced livestock; and runoff from restrained livestock pens near stream courses and from animal-waste retention pits.

The stream segments with the greatest potential for development as surface- and ground-water sources are those classified as **good** or **acceptable**. If, however, upstream of these stream segments there are zones classified as "riparian zone with potential as a source of contamination from household waste-water discharges," then development of ground-water supplies in aquifers adjacent to these streams should not be encouraged without (a) more detailed analysis of bacteriological conditions to define diurnal variations and the application of more sensitive microbiological determinations, such as recovery enhancement tests for fecal coliform and fecal streptococcus bacteria; and (b) more in-depth evaluation of the bacteriological attenuation capacity of the ground-water bearing units. Also, a more rigorous surface-water monitoring program, including fecal coliform, fecal streptococcus, and other indicator bacteria should be conducted to define the variability and sources of contamination in order to implement corrective measures. Approximately 8.7 miles (mi) of a total of 72 stream miles within the municipio of Comerío were delimited as susceptible to contamination from household waste-water discharges, excluding the part of Río de la Plata bordering the town of Comerío.

The municipio of Comerío was separated into five principal hydrogeologic terranes based on geologic, topographic, soil, hydrogeologic, and streamflow data. The CoHT1 hydrogeologic terrane consists of volcaniclastic rocks with minor lavas. The CoHT2, CoHT3, and CoHT5 hydrogeologic terranes consist of igneous rocks including both stratified and nonstratified, fine- and coarse-grained volcaniclastics, intrusive rocks, and lava. The CoHT4 hydrogeologic terrane consists of Quaternary alluvium and terrace deposits. Limestones are minor constituents of the CoHT1, CoHT2, and CoHT4 hydrogeologic terranes.

The hydrogeologic terranes CoHT1 and CoHT4 typically do not develop slopes greater than 15 degrees, whereas other hydrogeologic terranes have slopes exceeding 15 degrees. Springs along streams in the CoHT2 hydrogeologic terrane are probably associated with water-bearing fractures. The CoHT3 hydrogeologic terrane is similar to CoHT2 but contains less fractures. The CaHT4 hydrogeologic terrane is restricted to lowland areas contiguous to streams.

Concentrations of iron and manganese in ground water locally exceed the USEPA secondary standards for drinking water. Because poor sanitary conditions are likely in most surface waters of the municipio of Comerío (see Chapter B), wells completed in rocks that underlie such streams are susceptible to fecal bacteria contamination.

Studies indicate that in relatively impermeable formations, the maximum development of transmissivity occurs at the intersection of fractures. Consequently, new wells should be located in areas with a high density of fractures or fracture intersections. Lineament-trace analysis can be used to identify areas of high fracture density to substantially reduce the costs associated with the trial-and-error method used in drilling, particularly in hydrogeologic terrane CoHT2.

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

REFERENCES

American Public Health Association, American Public Works Association and Water Environment Federation, 1998, Standard methods for the examination of water and wastewater, 20th Edition: American Public Health Association, Washington, D.C., p. 9-26 to 9-27.

Berg, R.C., Keefer, D.A., Demissie, M., and Ramamurphy, G., 1997, Regional evaluation of ground-water and surface-water interactions: Preliminary method development and analysis: Illinois State Water Survey Miscellaneous Publication 181, 37 p.

Black and Veatch Consulting Engineers, 1971, Water resources of Puerto Rico, Phase II Surface Water Appraisal Report, v. 1: Black and Veatch Consulting Engineers, Kansas City, Mo. Ten chapters, unnumbered pages.

Black and Veatch Consulting Engineers, 1976, Water supply study for entire island of Puerto Rico: prepared for the U.S. Army Engineer District, Jacksonville Department of the Army, contract DACW17-75-C-0059, 168 p.

Black and Veatch Consulting Engineers, 1996, Consulting Engineers Report: Puerto Rico Aqueduct and Sewer Authority Facilities Inspections, Appendices 1-4 (unnumbered pages).

Briggs, R.P., and Gelabert, P.A., 1962, Preliminary report of the geology of the Barranquitas quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-336, 1 sheet.

Britton, L.J., and Greeson, P.E., eds., 1989, Methods for collection and analysis of aquatic, biological, and microbiological samples: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Chapter A4, p. 37-50.

Bruijnzeel, L.A., 1990, Hydrology of moist tropical forests and effects of conversion: a state of knowledge review report: UNESCO International Hydrological Programme, A Publication of the Humic Tropics Programme, Faculty of Earth Sciences, Free University, Amsterdam, 224 p.

Carter, R.W., and Davidian, Jacob, 1968, General procedure for gaging streams: Techniques of Water-Resources Investigations of the U.S. Geological Survey, Chapter A6, p. 6-7, 13 p.

Díaz, P.L., Aquino, Zaida, Figueroa-Álamo, Carlos, Vachier, R.J., and Sánchez, A.V., 1998, Water Resources Data for Puerto Rico and the U.S. Virgin Islands, Water Year 1998: U.S. Geological Survey Water-Data Report PR-98-1, 629 p.

Farvolden, R.N., and Nunan, J.P., 1970, Hydrogeologic aspects of dewatering: at Wellan. Canadian. Geotechnical Journal, v. 7, p. 194-204.

Federal Emergency Management Agency, 1996, National Flood Insurance Program Q3 Flood Data: Disc 18, New Jersey, Puerto Rico, U.S. Virgin Islands, September 1996.

Hunter, J.M., and Arbona, S.I., 1995, Paradise lost: an introduction to the geography of water pollution in Puerto Rico: Society of Scientific Medicine, v. 40, no. 10, p. 1331-1355.

Ineson, J., and Downing, R.A., 1964, The ground water component of river discharge and its relationship to hydrogeology: Journal of the Institute of Water Engineering, v. 18, p. 519-541.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Bulletin 17B of the Hydrology Subcommittee, U.S. Geological Survey, Office of Water Data Coordination, Reston, Virginia, 183 p.

Junta de Calidad Ambiental de Puerto Rico, 1990, Reglamento de estándares de calidad de agua de Puerto Rico: (versión enmendada, 20 de julio de 1990), 104 p.

Larsen, M.C., and Parks, J.E., 1998, Map showing landslide susceptibility in the Comerío municipality, Puerto Rico: U.S. Geological Survey Open-File Report 98-566, 1 plate.

Lattman, L.H., 1958, Technique of mapping geologic fractures and lineaments on aerial photographs: Photogrametric Engineering, v. 24, p. 568-576.

Myers, D.N., and Sylvester, M.A., 1997, Section 7.1, Fecal indicator bacteria, *in* Myers, D.N., and Wilde, F.D., eds., National field manual for the collection of water-quality data: Techniques of Water Resources Investigations of the U.S. Geological Survey, Book 9, Chapter A7, 38 p.

Nelson, A.E., 1967, Geologic map of the Corozal quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-473, 1 sheet.

Pease, M.H., Jr., and Briggs, R.P., 1960, Geology of the Comerío quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-320, 1 sheet.

Pease, M.H., Jr., 1968, Geologic map of the Naranjito quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-508, 1 sheet.

Pérez-Blair, Francisco, 1997, Ground-water resources of alluvial valleys in northeastern Puerto Rico--Río Espíritu Santo to Río Demajagua area: U.S. Geological Survey Water-Resources Investigations Report 96-4201, 25 p.

Ramos-Ginés, Orlando, 1997, Water balance and quantification of total phosphorous and total nitrogen loads entering and leaving the Lago de Cidra, central Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 96-4222, 28 p.

Riggs, H.C., 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter B1, 18 p.

Sander, P., Minor, T.M., and Chesley, M.M., 1997, Ground-water exploration based on lineament analysis and reproducibility tests: Ground Water, v. 35, no. 5, p. 888-894.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Stramer, S.L., 1984, Fates of polio virus and enteric indicator bacteria during treatment in a septic tank including septage disinfection: Madison, University of Wisconsin, Ph.D. dissertation, 224 p.

Tarbuck, E.J., and Lutgens, F.K., 1990, The Earth: an introduction to physical geology: Charles E. Merrill Publishing Company, Columbus, Ohio, 594 p.

U.S. Department of Agriculture, Soil Conservation Service, 1973, Soil survey of San Juan area of Puerto Rico: Sheets 24, 25, 33, and 43; scale 1:20,000.

U.S. Department of Commerce, 1991, 1990 Census of population and housing: Summary population and housing statistics of Puerto Rico: 1990 CPH-1-53, 199 p.

U.S. Department of Commerce, 1994, 1992 Census of Agriculture: Puerto Rico, Bureau of the Census, AC 92-A-52, 211 p.

U.S. Department of Commerce, 1998a, Estimates of the population of Puerto Rico municipios, July 1, 1997, and demographic components of population change: April 1, 1990 to July 1, 1997: http://www.census.gov/ population/estimates/puertorico.

U.S. Department of Commerce, 1998b, 1997 Census of Agriculture: http://www.nass.usda.gov/census/census97/puertorico.

Vaughn, J.M., Landry, E.F., and Thomas, M.Z., 1983, The lateral movement of indigenous enteroviruses in a sandy sole-source aquifer, *in* Microbial health considerations of soil disposal of domestic wastewater: U.S. Environmental Protection Agency EPA-600/9-83-017, Washington, D.C., 402 p.