WATER-RESOURCES INVESTIGATIONS IN PUERTO RICO

AND THE U.S. VIRGIN ISLANDS, 1986-1988

By Thalia D. Veve and Joseph W. Troester, Editors

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for inch-pound units used in this report are listed below:

Multiply	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot per day (ft^2/d)	0.09294	square meter per day (m^2/d)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic feet per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot (gal/min/ft)	0.2070	liter per second per meter (L/s/m)
	Pressure	
pound per square foot (lb/ft^2)	4.88	kilogram per square meter (Kg/m^2)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (Kg/m^3)
	Temperature	
degree Fahrenheit (°F)	5/9 (°F-32)	degree Celsius (°C)

U.S. GEOLOGICAL SURVEY MISSION

The mission of the U.S. Geological Survey is to provide geologic, topographic, and hydrologic information that contributes to the wise management of the Nation's natural resources and that promotes the health, safety, and well-being of the people. This information consists of maps, data bases, and descriptions and analyses of the water, energy, and mineral resources, land surface, underlying geologic structure, and dynamic processes of the Earth.

To accomplish its mission, the Survey:

- Conducts and sponsors research in geology, hydrology, mapping and related sciences.
- Produces and updates geographic, cartographic, and remotely sensed information in graphic and digital forms.
- Describes the onshore and offshore geologic framework and develops an understanding of its formation and evolution.
- Assesses energy and mineral resources, determines their origin and manner of occurrence, and develops techniques for their discovery.
- Collects and analyzes data on the quantity and quality of surface water and ground water, on water use, and on quality of precipitation.
- Assesses water resources and develops an understanding of the impact of human activities and natural phenomena on hydrologic systems.
- Evaluates hazards associated with earthquakes, volcanoes, floods, droughts, toxic materials, landslides, subsidence, and other ground failures, and develops methods for hazards prediction.
- Participates in the exploration of space and prepares geologic and other maps of the planets and their satellites.
- Publishes reports and maps, establishes and maintains earth-science data bases, and disseminates earth-science data and information.
- Provides scientific and technical assistance for the effective use of earth-science techniques, products, and information.
- Coordinates topographic, geologic, and land-use mapping, digital cartography, and water-data activities.
- Develops new technologies for the collection, coordination, and interpretation of earth-science data.
- Provides scientific support and technical advice for legislative, regulatory, and management decisions.
- Cooperates with other Federal, State, and local agencies, and with academia and industry.

These missions and activities of the survey are described in more detail in U.S. Geological Survey Circular 1010 (U.S. Geological Survey, 1986).

WATER RESOURCES DIVISION MISSION AND PROGRAM

The mission of the Water Resources Division, which supports the overall mission of the U.S. Department of the Interior and the Geological Survey, is to provide the hydrologic information and understanding needed for the best use and management of the Nation's water resources for the benefit of the people of the United States.

To accomplish its mission, the Water Resources Division in cooperation with State and local governments and other Federal agencies:

- Systematically collects data needed for the continuing determination and evaluation of the quantity, quality, and use of the Nation's water resources.
- Conducts analytical and interpretive water-resources appraisals to describe the occurrence, availability, and physical, chemical, and biological characteristics of surface and ground water and their inter-relationship.
- Conducts supportive basic and problem-oriented research in hydraulics, hydrology, and related fields of science and engineering to improve the basis for field investigations and measurement techniques and to understand hydrologic systems sufficiently well to predict quantitatively their response to stress, either natural or manmade.
- Disseminates water data and the results of investigations and research through reports, maps, computerized information services, and other forms of public releases.
- Coordinates the activities of all Federal agencies in the acquisition of certain water data.
- Provides scientific and technical assistance in hydrologic fields to State, local, and other Federal agencies, to licensees of the Federal Energy Regulatory Commission, and, on behalf of the U.S. Department of State, to international agencies.
- Acquires, develops, and disseminates information on water-related natural hazards such as droughts, floods, landslides, land subsidence, mudflows, and volcanoes.
- Administers the provisions of the Water Resources Research Act of 1987 which include the State Water Resources Research Institutes and the Research Grants and Contracts programs.
- Supports the provisions of the National Environmental Policy Act of 1969 and manages Geological Survey conduct of natural-resources surveys in response to the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund Act) of 1980.

More information on the activities of the Water Resources Division of the U.S. Geological Survey, is available in Water Resources Division Information Guide: U.S. Geological Survey published in 1988.

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WATER-RESOURCES INVESTIGATIONS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

by Thalia D. Veve and Joseph W. Troester, editors

ABSTRACT

This report reviews the activities of the Caribbean District of the U.S. Geological Survey, Water Resources Division, from 1986 to 1988. Each project in the District conducted during this period is described and the publications released in each project are listed. The report includes also a complete list of publications released during this period, and tables and maps showing all the surface-water, ground-water, and water-quality stations in the data-collection program in the District.

INTRODUCTION

The Caribbean District was established in 1958 to carry out the mission of the Water Resources Division of the U.S. Geological Survey in Puerto Rico and the U.S. Virgin Islands (fig. 1). District activities include research and the dissemination of information in the field of hydrology. Ninety-five scientists, technicians, and support staff are employed at the Caribbean District Office in the San Juan metropolitan area and the U.S. Virgin Islands Field Headquarters on St. Croix.

Hydrologic stations are maintained at selected locations throughout Puerto Rico and the U.S. Virgin Islands to obtain records on stream flow and stage, reservoir and lake elevations and storage, ground-water levels, spring discharge, sediment loads, and quality of surface and ground water. From 1986 to 1988, the Survey, in cooperation with government agencies in Puerto Rico and the U.S. Virgin Islands, increased its network to 52 continuous surface-water sites, 5 continuous reservoir sites, 65 ground-water observation wells, and 71 water-quality sites. Water-resources data are stored in the Survey's National Water Data Storage and Retrieval System. These data are integrated with other hydrogeologic observations and water-resources investigations and used by water planners and others involved in making decisions that affect water resources in Puerto Rico and the U.S. Virgin Islands.

About 125 hydrologic investigations have been conducted in Puerto Rico and the U.S. Virgin Islands since the Caribbean District office opened. These investigations have resulted in the publication of more than 250 abstracts, articles, books, and maps. During fiscal years 1986 to 1988, the Survey entered into agreement with 17 Federal and local agencies involving 29 hydrologic investigations in Puerto Rico and the U.S. Virgin Islands. These investigations will provide information needed to answer hydrologic questions that are specific to the water-resource issues in the region. Additionally, some of the investigations will provide information on nationwide hydrologic

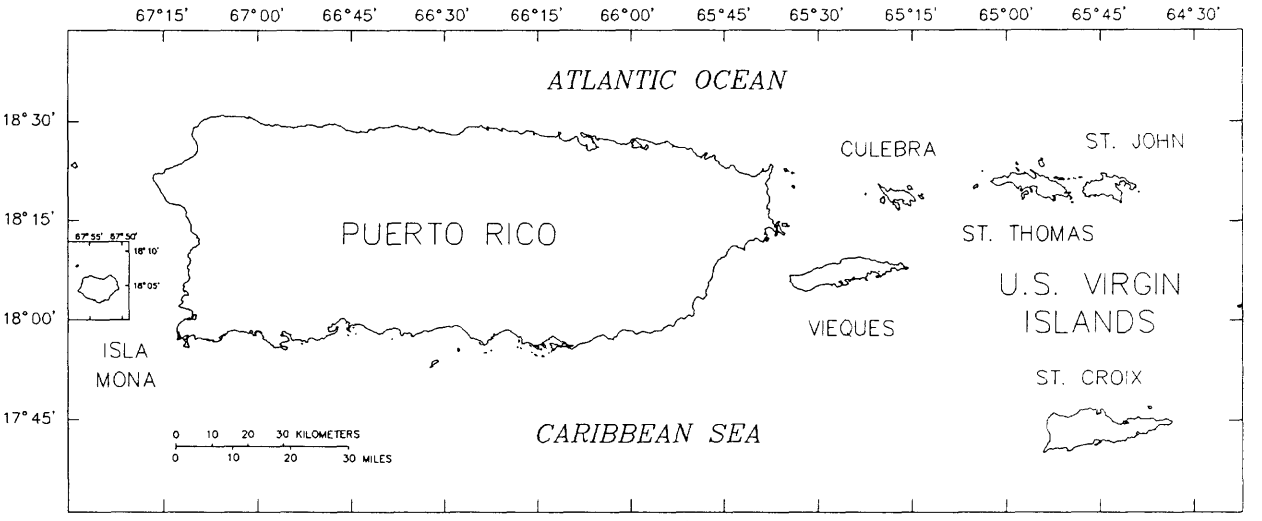


Figure 1. Location map of Puerto Rico and the U.S. Virgin Islands.

problems. A list of publications released from 1985 to 1988 by the Caribbean District office is given in Appendix A.

During 1986 to 1988 the following Federal and local agencies entered into interagency or cooperative cost-sharing agreements with the U.S. Geological Survey to conduct water-resource investigations in Puerto Rico and the U.S. Virgin Islands:

Center for Energy and Environmental Research, University of Puerto Rico (CEER)

Center for Sport Health and Exercise Science - University of Puerto Rico Medical Science Campus (CSHES)

Puerto Rico Environmental Quality Board (PREQB)

Puerto Rico Aqueduct and Sewer Authority (PRASA)

Puerto Rico Department of Agriculture (PRDOA)

Puerto Rico Industrial Development Company (PRIDCO)

Puerto Rico Highway Authority (PRHA)

Puerto Rico Industrial Association (PRIA)

Puerto Rico Department of Natural Resources (PRDNR)

Puerto Rico Planning Board (PRPB)

United States Corps of Engineers (USCOE)

United States Department of Agriculture (USDA)

United States Environmental Protection Agency (USEPA)

United States Soil Conservation Service (USSCS)

Water Resources Research Institute, University of Puerto Rico (WRRI-UPR)

Water Resources Research Institute, College of the Virgin Islands (WRRI-CVI)

Department of Public Works of the U.S. Virgin Islands (DPW-USVI)

HYDROLOGIC RECORDS SECTION

The Hydrologic Records Section of the U.S. Geological Survey, Caribbean District, operates several networks of data collection stations. The information gathered at these stations is used extensively by those responsible for the management and planning of the water resources of Puerto Rico and the U.S. Virgin Islands. The availability of these data is also important for the support of ongoing and future projects within the Survey.

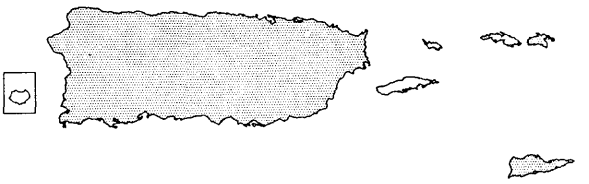
The data collected at stations in these networks by the Hydrologic Records Section include stream stage and discharge, suspended sediment, ground-water levels, and water quality. As of September 1988, the data included (1) stage and discharge records for 52 continuous streamflow gaging stations (48 in Puerto Rico and 4 in the U.S. Virgin Islands); (2) continuous stage records for 5 lakes; (3) water-quality records for 16 streamflow-gaging stations, 45 ungaged streamsites, 11 lake sites, 1 lagoon, and 1 bay; and (4) water-level records for 65 observation wells. The Hydrologic Records Section also collects data at many sites not in specific networks in support of ongoing projects. Most of the data are published in the annual report series entitled "Water Resources Data for Puerto Rico and the U.S. Virgin Islands." Prior to publication the data are available in a provisional form from a computerized data storage and retrieval system which can be accessed by the Survey and several cooperating agencies.

The Hydrologic Records Section began compiling and publishing data in the report entitled "Water Resources Data for Puerto Rico and the U.S. Virgin Islands," in 1970. The data report for Water Year 1988 was the latest release in this series. The data report for Water Year 1989 is in preparation.

Since 1958, many agencies of the Commonwealth of Puerto Rico and the territorial government of the U.S. Virgin Islands have cooperated with the Survey in the data collection. Data collection activities of the Hydrologic Records Section are carried out by a staff of 30 employees under the supervision of Russell Curtis.

SURFACE-WATER STREAMFLOW NETWORK

Date Project Began: 1958
Principal Investigator: Zaida Aquino
Cooperating Agencies: Almost all the agencies in the cooperator list



The Caribbean District operates a network of streamflow stations throughout Puerto Rico and the U.S. Virgin Islands (fig. 2). In Puerto Rico the network is operated under the general water-resources investigations programs coordinated by the Environmental Quality Board in cooperation with many commonwealth and federal agencies. During Water Year 1987, the network was composed of 41 stations. This number increased to 52 in 1988. Four additional stations are financed by the U.S. Geological Survey (USGS) as part of the federally-funded National Stream Quality Accounting Network (NASQAN). In the U.S. Virgin Islands the network consists of four recording streamflow stations.

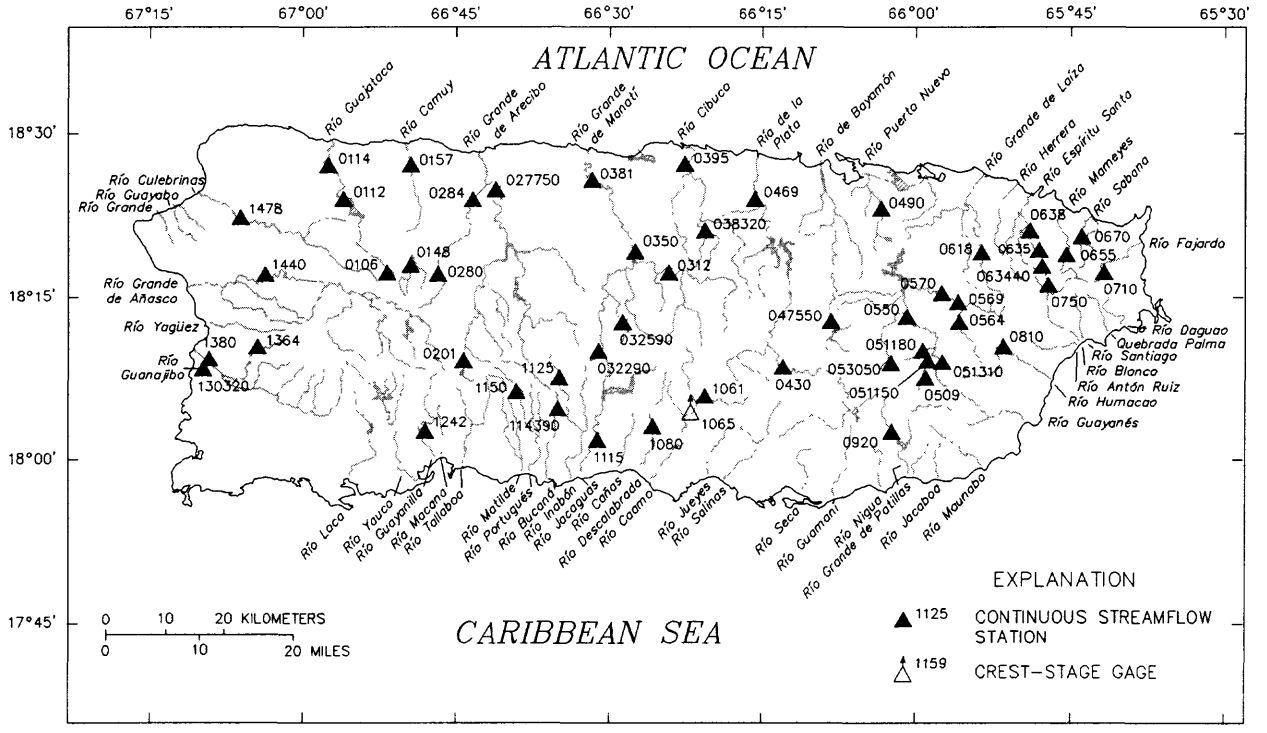
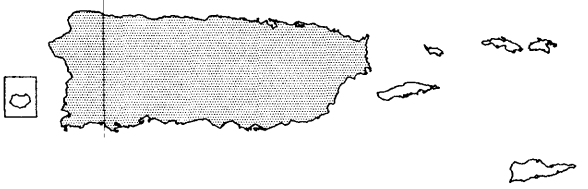


Figure 2. Location of continuous streamflow and crest-stage gage stations in Puerto Rico.

SUSPENDED-SEDIMENT DATA COLLECTION

Date Project Began: 1964
Principal Investigator: Pedro Díaz
Cooperating Agencies: USCOE, PREQB, and PRASA



Suspended-sediment data collection activities continued during water years 1986-1988. In 1986-87, suspended-sediment samples were collected daily at Río Fajardo near Fajardo, Río Tanamá near Utuado and Río Rosario near Hormigueros (fig. 4). The Río Fajardo and Río Rosario stations were operated in cooperation with the USCOE while the Río Tanamá station was operated in cooperation with the PREQB. Automatic sediment samplers were used at Río Fajardo and Río Rosario.

Significant changes occurred in the data collection network during Water Year 1988. The sediment station at Río Fajardo was discontinued. However, three automatic sediment samplers were installed and operated in the Río Grande de Loíza basin in an effort to determine the sedimentation rate at Lago Carraízo. These stations are operated in cooperation with PRASA.

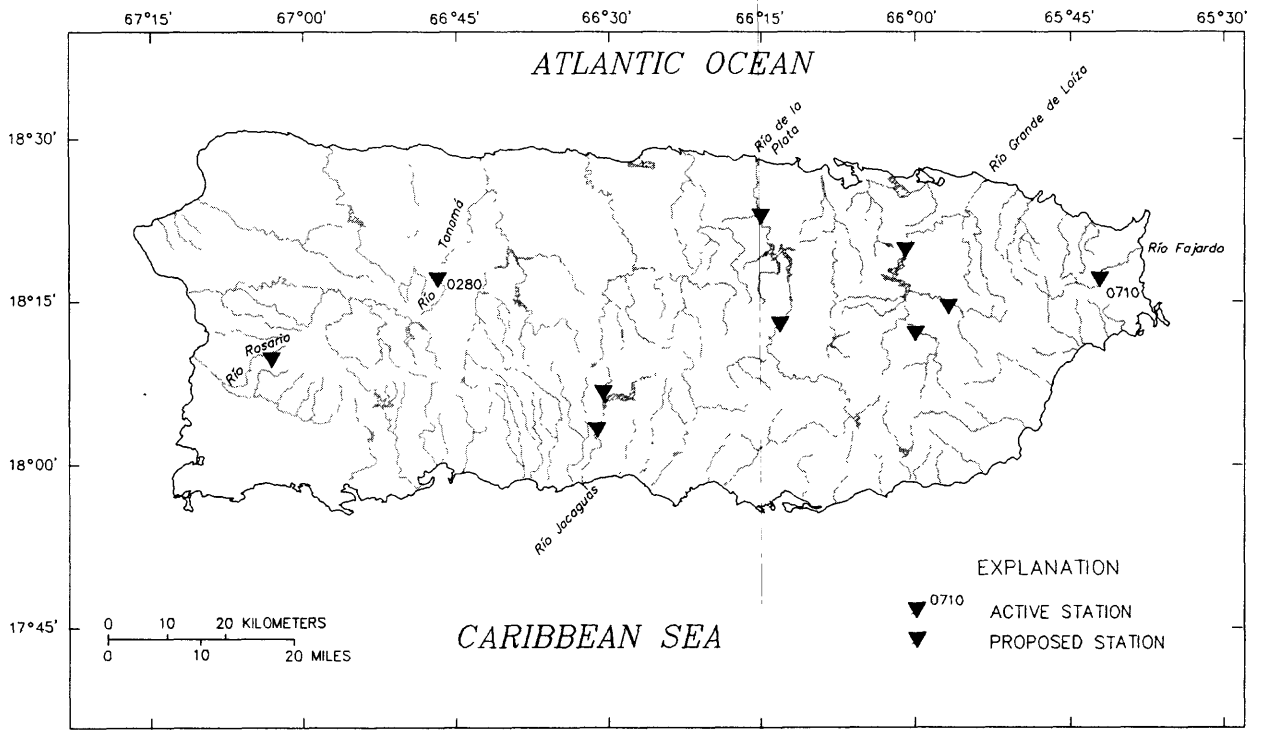


Figure 3. Location of daily suspended-sediment stations.

LOW FLOW NETWORK

Date Project Began: 1983

Principal Investigator: Luis Santiago-Rivera

A knowledge of the frequency and magnitude of low flows is needed by managers of waste-allocation programs for the design of water-supply facilities and for water resource assessments. In 1983, the Caribbean District initiated, as part of the data collection program, a project to define the magnitude and frequency of low flows in Puerto Rico. A network of approximately 100 streamflow sites was selected on the eastern part of the island (fig. 3). Discharge measurements during drought and low flow conditions at these sites were made in 1983, 1984 and 1985. In 1986, 1987, and 1988, attempts to make low-flow measurements were unsuccessful because of heavy rains during the measurement periods. The project will continue over the next few years and will extend to other areas in Puerto Rico.

Publications released:

Colón-Dieppa, Eloy, and Quiñones-Aponte, Vicente, 1985, Estimates of 7-Day, 10-year low flows at ungaged streams in Puerto Rico: U.S. Geological Survey, Water-Resources Investigation Report 84-4089.

Colón-Dieppa, Eloy, Quiñones, Ferdinand, and Juarbe, Max, 1984, Flow duration at streamflow gaging stations in Puerto Rico: U.S. Geological Survey, Open-File Report 84-127.

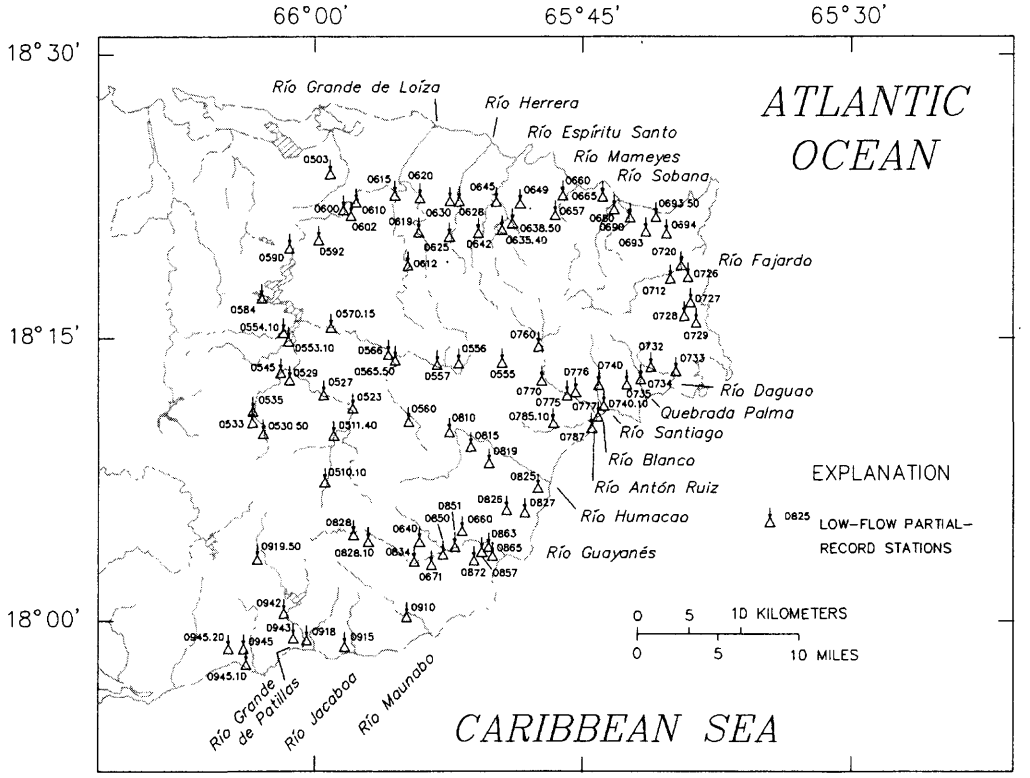


Figure 4. Location of low-flow partial-record stations in eastern Puerto Rico.

GROUND-WATER LEVELS NETWORK

Date Project Began: 1956
Principal Investigator: Pedro Díaz
Cooperating Agencies: PRASA and many other agencies in the cooperator list

The determination of long-term changes in ground-water levels is an important aspect of the ground-water data-collection program in the District. Ground-water levels provide insight into the withdrawal and recharge rates of aquifers and are essential to the design, construction, and updating of ground-water flow models.

The ground-water levels network in Puerto Rico increased from 7 to 31 recorder-equipped wells during Water Year 1986. The twenty-four additional wells were installed as part of the North Coast Limestone Regional Aquifer System project discussed later in this report. During Water Year 1987, four additional wells equipped with recorders were added to the network in the south coast alluvial aquifers and two wells were discontinued, leaving a balance of 38 wells by the end of the year.

In the U.S. Virgin Islands, the ground-water levels network consisted of 7 wells equipped with recorders and 21 wells in which water levels were measured periodically during water years 1985-87. During Water Year 1988, the number of wells measured periodically was reduced to 18 but the number of recorder-equipped wells remained unchanged.

As of September 1988, the ground-water levels network in Puerto Rico and the U.S. Virgin Islands consisted of a total of 45 wells equipped with recorders and 18 wells measured periodically. Locations of these wells are shown in figure 5.

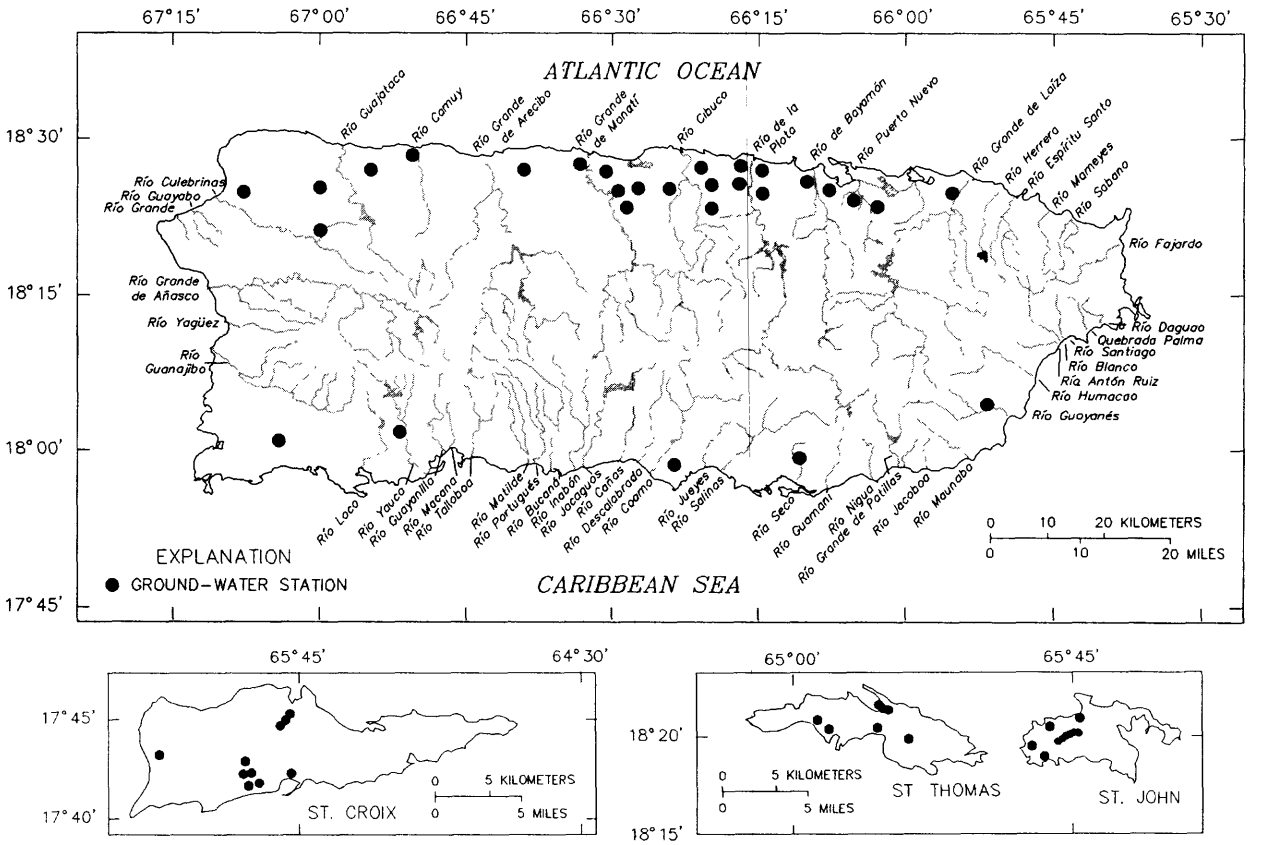
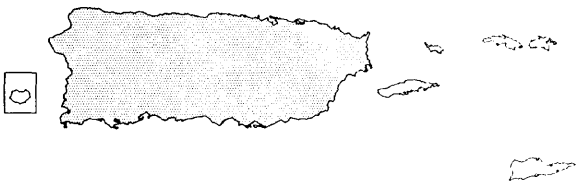


Figure 5. Location of ground-water stations in Puerto Rico and the U.S. Virgin Islands.

SURFACE-WATER QUALITY NETWORK

Date Project Began: 1968
Principal Investigator: Pedro Díaz
Cooperating Agencies: PREQB, USCOE, and PRDOA



The District operated a network of 71 long-term water-quality stations in Puerto Rico in Water Year 1988 (fig. 6). Samples were collected bi-monthly from 56 streamflow stations and lagoons, and quarterly from six of the principal lakes in Puerto Rico. The surface-water quality network also included four stations supported by the Geological Survey as part of the National Stream Quality Accounting Network (NASQAN). Samples were collected bi-monthly at two of those stations and quarterly at the other two stations.

Samples collected as part of the surface-water quality network are analyzed for a variety of constituents, including copper, manganese, cyanide, sulfide, phenols, iron and methyl blue active substance (MBAS). Analytical field and laboratory results indicate that some streams commonly have high concentrations of fecal coliform, fecal streptococcus bacteria, and suspended sediment.

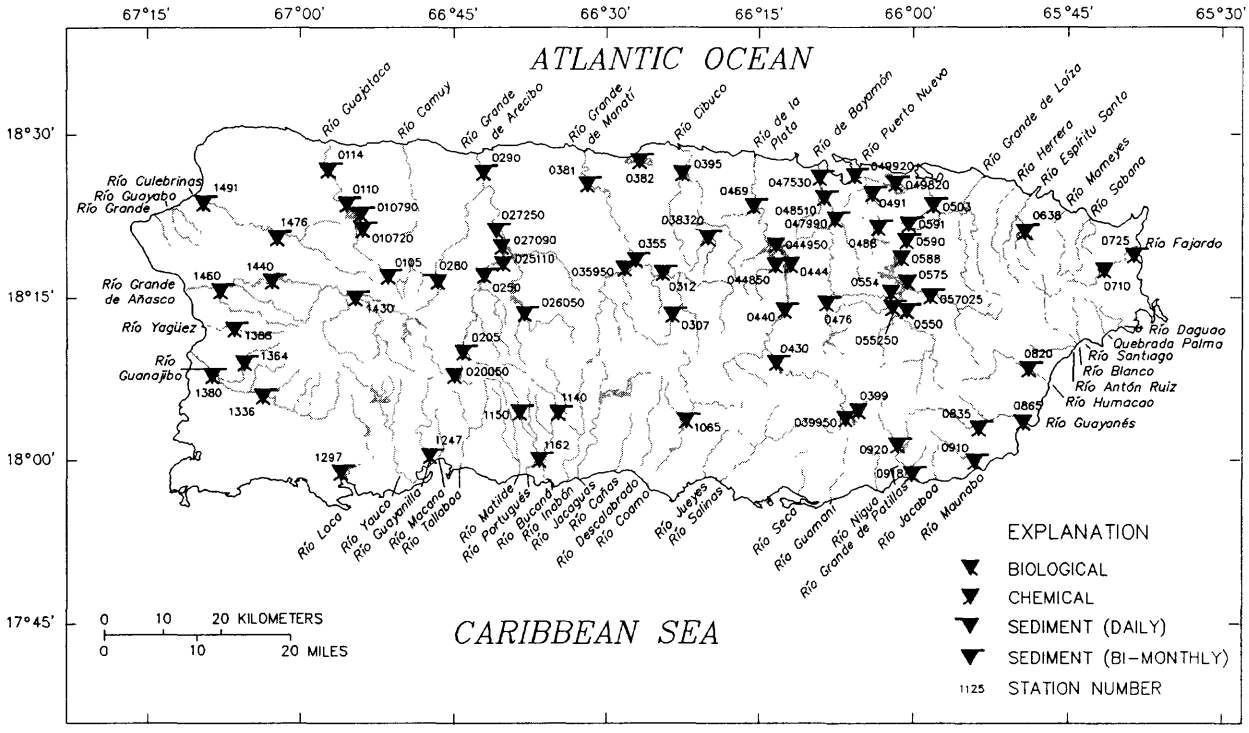


Figure 6. Location of water-quality stations in Puerto Rico

GROUND-WATER QUALITY MONITORING

Date Project Began: October 1982
Principal Investigator: Senén Guzmán-Ríos
Cooperating Agency: PRASA

The ground-water quality monitoring program is a continuing program. In 1982, ground-water samples were collected from various wells around the island. From this preliminary reconnaissance it was determined that the water quality at some sites warranted frequent monitoring. In 1983, a water sampling program was established in Vega Alta (fig. 7) where some wells had been abandoned because of the presence of organic chemicals. Samples have been collected monthly from five wells and from three sites in the water distribution system at this site since 1983. Additional sites were added to the sampling program in 1984. Since that time, water samples have been collected quarterly from 5 wells in Ponce, and one each in Santa Isabel, Guayama and Arecibo. The samples from all five sites have been analyzed for volatile synthetic organic chemicals (VOCs).

Recent laboratory results showed concentrations of trichloroethylene (TCE) in some ground-water samples as high as 40 micrograms per liter (μg/L). The maximum allowable level established by the U.S. Environmental Protection Agency is 5 μg/L.

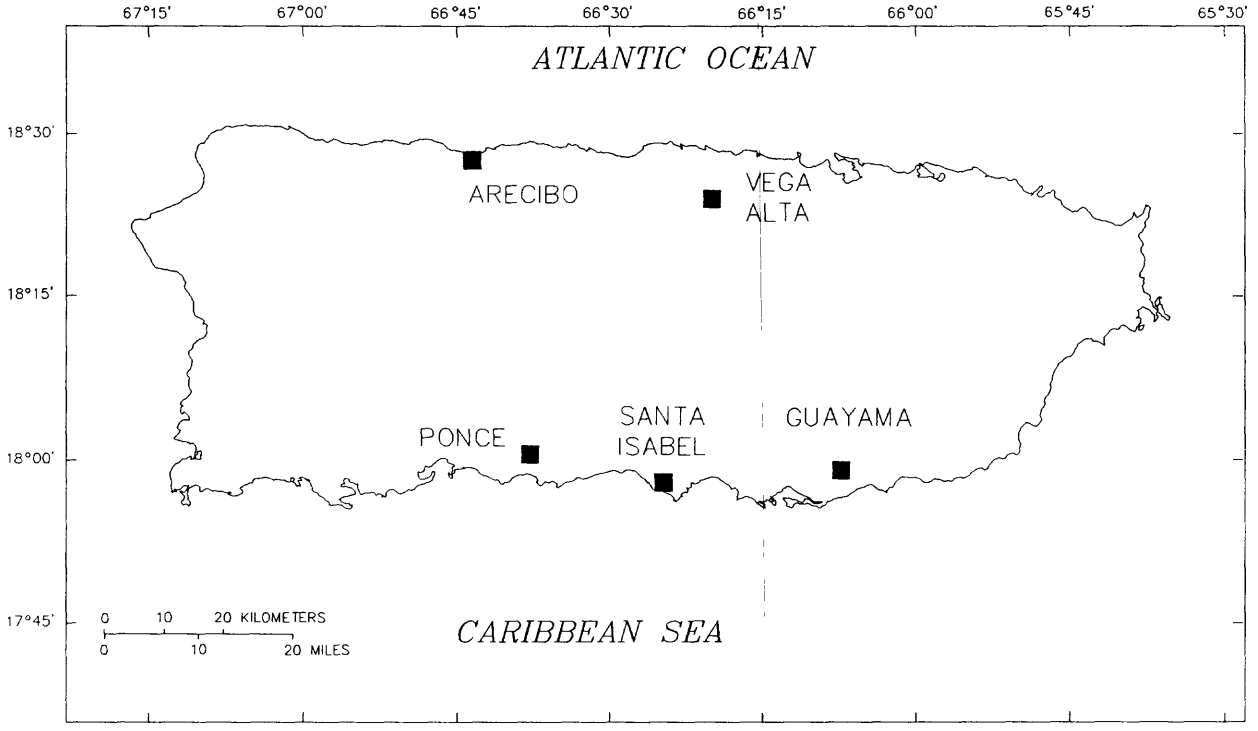
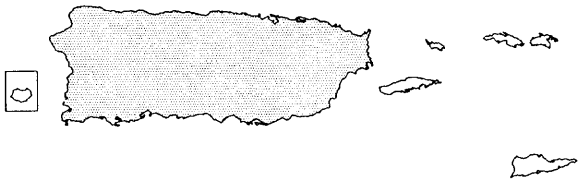


Figure 7. Towns in Puerto Rico where wells are being monitored for organic compounds.

DATA COLLECTION PLATFORMS NETWORK

Date Project Began: 1985
Principal Investigator: Pedro Díaz
Cooperating Agencies: PRDNR



The Data Collection Platform (DCP) program began in Puerto Rico as a method to obtain real-time data of various types from stations throughout the island. The DCP is part of a satellite telemetry system which allows the Survey to monitor the behavior of selected streams with data updates every five minutes.

The system transmits the information from a field station to a geostationary satellite, and then from the satellite to the computer system. The first station equipped with a DCP in Puerto Rico is located at the Río Grande de Loíza at Caguas. Data transmitted from this site was used as part of a demonstration at the 1984 World's Fair in New Orleans. By the end of Water Year 1986, the District had installed 12 DCPs throughout the island.

The DCP program increased during Water Year 1987 with the establishment of a flood alert-system operated in cooperation with the PRDNR. This system consists of a network of rainfall and river-stage sensors that provide real-time data during heavy rains (fig. 8). This information is used by Commonwealth agencies responsible for issuing flood alerts. By the end of Water Year 1987, 18 DCP stations had been installed.

During 1988, the DCP program was expanded with the installation of three stations at reservoirs operated by PREPA (Garzas, Matrullas, and Guineo) and two stations at reservoirs operated by PRASA (Carraízo and Cidra) to provide real-time elevation and rainfall data. In addition, six new river-stage/rainfall stations were installed and equipped with DCPs in support of the flood-alert system operated in cooperation with commonwealth and federal agencies.

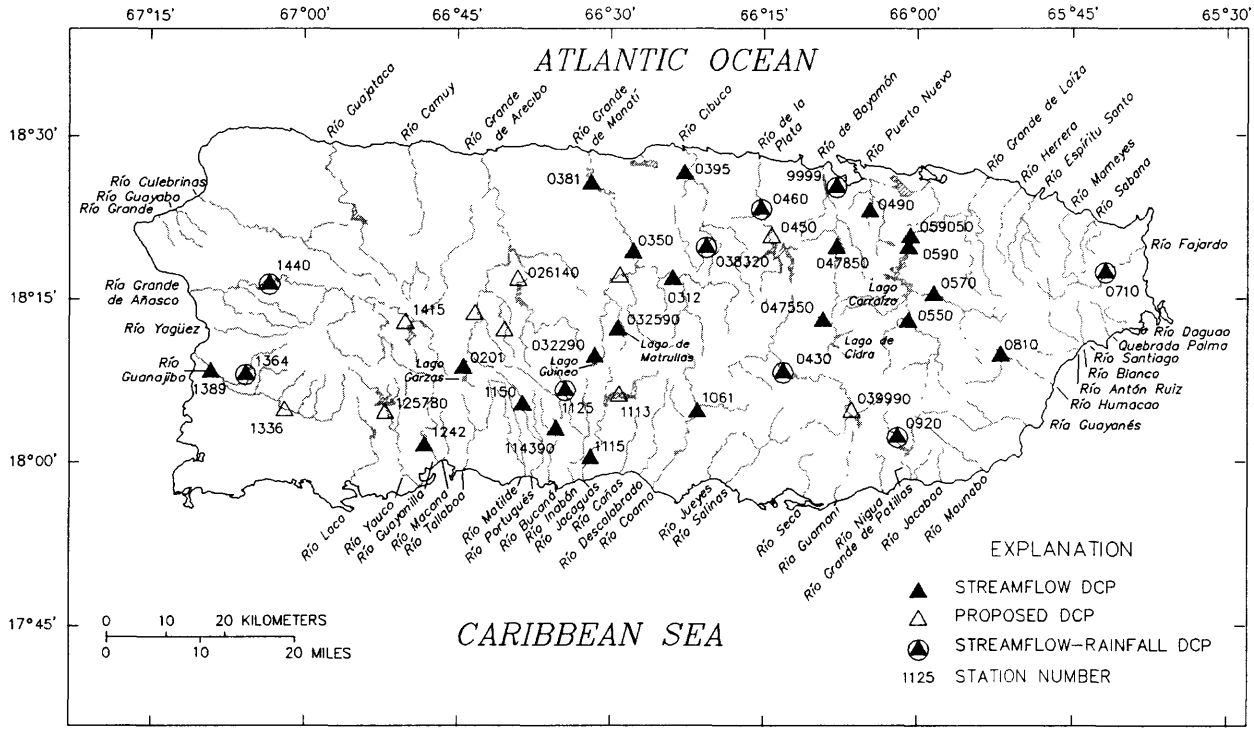
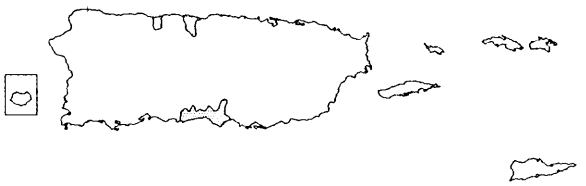


Figure 8. Location of Data Collection Platform (DCP) stations in Puerto Rico.

FLOOD STUDIES FOR SELECTED AREAS AFFECTED BY THE MAY 17-18, AND OCTOBER 6-7, 1985 FLOODS.

Date project began: 1985
Principal Investigators: Heriberto Torres and Karl Johnson
Cooperating Agencies: PRHA, PRDNR, and PREQB



Considerable flooding along the north coast of Puerto Rico occurred during May 17-18, 1985. Particularly affected were the lower reaches of the Río Grande de Manatí and the Río Grande de Arecibo. Significant flooding also occurred at Utuado and Jayuya. The floods of October 6-7, 1985 affected mostly rural areas in southern Puerto Rico. The most severe flooding was between Ponce and Santa Isabel. Flooding was also severe in Barceloneta on the north coast. Reports doumenting the extent and severity of these floods in some areas have been published. Flood maps describing the inundated areas in the lower Río Grande de Manatí valley and in the south coast are in preparation.

Publications released:

Quiñones, Ferdinand, and Johnson, Karl G., 1987, The floods of May 17-18, 1985 and October 6-7, 1985 in Puerto Rico: U.S. Geological Survey, Open-File Report 87-123.

Johnson, Karl G., Quiñones, Ferdinand, and González, Ralph, 1987, Hydraulic analyses of water-surface profiles in the vicinity of the Coamo Dam and Highway 52 bridge, southern Puerto Rico: Flood analyses as related to the flood of October 7, 1985: U.S. Geological Survey, Water-Resources Investigation Report 87-4039.

STAGE-DISCHARGE RELATIONS AT CULVERTS

Date Project Began: June 1987
Principal Investigators: Heriberto Torres and Karl Johnson
Cooperating Agencies: USDA

The U.S. Forest Service requested the assistance of the U.S. Geological Survey to determine the stage-discharge relation in three creeks crossed by the Bisley Road in the El Yunque rain forest. The stage-discharge relation was determined using the indirect method of discharge measurement at culverts. This method uses measured stage upstream and downstream of the culvert and the culvert geometry to compute discharge based on hydraulic formulae.

The stage-discharge relations developed during this study were completed in 1988 and provided to the U.S. Forest Service. The project is completed.

HYDROLOGIC INVESTIGATIONS SECTION

The Hydrologic Investigations Section of the Caribbean District is composed of a staff of 21 employees under the supervision of Arturo Torres, Assistant District Chief. The Section worked on a total of 27 water-resources investigations during 1986-88. The subjects of these investigations ranged from the general hydrology of Puerto Rico and the U.S. Virgin Islands to more site-specific water-resources problems. Of these investigations, 5 percent dealt with surface water, 85 percent with ground water, and 10 percent with water quality.

SUSPENDED-SEDIMENT TRANSPORT IN THE UPPER RIO GRANDE DE LOIZA BASIN, PUERTO RICO

Date Project Began: October 1983
Principal Investigator: Senén Guzmán-Ríos
Cooperating Agencies: PREQB, PRASA, PRDNR, USCOE, and USSCS

The Río Grande de Loíza basin is the largest drainage basin in Puerto Rico. The river was dammed in 1953 to build a water-supply reservoir. Lago Loíza (also known locally as Lago Carraízo) supplies about 50 percent of the water for the San Juan metropolitan area (about 110 million gallons per day (Mgal/d)).

Fluvial sediment carried into reservoirs by tributary streams is reducing the efficiency and useful life of almost all reservoirs in Puerto Rico. Lago Loíza had an original capacity of 21,763 acre-feet in 1953, but in July 1985 a bathymetric survey conducted at Lago Loíza indicated that the capacity of the reservoir had been reduced to 10,100 acre-feet. At that time the storage capacity of the reservoir was being reduced at a rate of 1.8 percent per year. At this rate, the useful life of Lago Loíza is estimated at 23 more years. Other bathymetric surveys were conducted in 1963, 1971, and 1979.

Plans are being developed for three additional dams in the basin: Río Grande de Loíza at Quebrada Arenas, Río Cayaguas at Cerro Gordo, and Río Valenciano near Juncos. The useful life of Lago Loíza and the design and construction of the new reservoirs will be greatly influenced by the amount of sediment transported along the system.

The purpose of this investigation is to collect and analyze sediment data in conjunction with land-use data. Results of the investigation may be used by Commonwealth agencies to design and implement soil-conservation practices in the basin and other measures to reduce erosion and sedimentation rates.

The first phase of an investigation on the subject was completed in 1988. Information was obtained on fluvial sediment transported from ten small- to medium-size drainage areas within the east-central part of Puerto Rico, ranging from less than 1 to about 90 m^2 in size. The study covered an area of 208 m^2 from the headwaters of Río Grande de Loíza to the Lago Loíza. It included the main stream and selected tributaries.

The first phase of the investigation included three years of data collection from a network of two daily-record stations and eight partial-record stations. Data collected during this phase indicates that most of the sediment transported by the streams is in suspension. Concentrations of suspended sediment exceeded 56,000 milligrams per liter in some samples. Suspended sediment in the streams is composed mostly of silt and clay. Sand content during high flows ranged from 6 to 80 percent.

HYDROLOGY OF LAGUNA JOYUDA AT CABO ROJO, PUERTO RICO

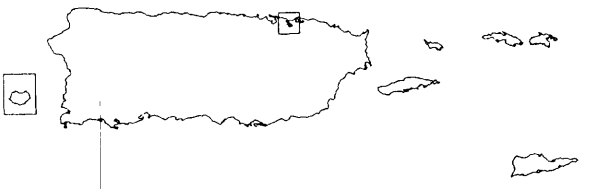
Date Project Began: October 1985
Principal Investigator: Luis Santiago-Rivera
Cooperating Agencies: CEER-UPR

In 1985 the District initiated a comprehensive study of the hydrology of Laguna Joyuda, a State Natural Reserve in western Puerto Rico. This shallow water lagoon is the habitat of many plants and animal species protected by local and federal agencies. The lagoon is relatively undisturbed by urban and industrial development that affects most coastal ecosystems. Human activities in the drainage basin include a few family dwellings on the southern and western edges of the lagoon and some cattle production. About 50 percent of the basin is used for pasture.

During the first two years of the study the emphasis was on the collection of surface water, ground water, precipitation, and tidal-flow data necessary to determine the overall hydrologic budget for the lagoon. Surface water inflow, ground water levels, precipitation and tidal-flow in the lagoon were measured. The one-dimensional Branch-Network flow model is being used to estimate tidal-flow through the lagoon's discharge channel. Much of 1988 was spent analyzing the data collected and calibrating the tidal-flow model. The results will assist CEER and other agencies to better understand the hydrology of tropical coastal ecosystems so these areas can be protected from degradation.

LAGUNA SAN JOSE BATHYMETRIC AND WATER QUALITY SURVEY

Date Project Began: July 1986
Principal Investigator: Carlos Conde-Costas
Cooperating Agency: PRHA



A bathymetric and water quality survey of Laguna San José, located between the municipios of San Juan and Carolina, was conducted in cooperation with the P.R. Highway Authority (PRHA). This agency is planning to relocate Highway PR-26. One segment of the proposed relocation of the highway would run along the northern shore of the lagoon. The elimination of some mangroves will be necessary to construct this segment of the highway. The PRHA has been requested to develop a series of islets where new mangroves could be grown.

The objective of the study was to assist PRHA in defining the best areas in the lagoon from which materials could be dredged and where the islets could be located. The investigation included a bathymetric survey of the entire lagoon, a more detailed survey in selected areas, and a sampling program to determine selected chemical and physical characteristics of the water and bottom sediments. The variation in velocity with depth was also studied at several stations.

Results of the study indicate that concentrations of selected water quality constituents vary only slightly throughout the lagoon. Organic pesticide concentrations in bottom sediments were relatively low throughout the lagoon but were somewhat higher at the northeastern section of the lagoon than in other areas. The organic chemicals detected most frequently were PCB, DDT, and Lindane. This study was completed and results were given to PRHA in 1986.

SUSPENDED SEDIMENT TRANSPORT DATA IN THE RIO PUERTO NUEVO BASIN, PUERTO RICO

Date Project Began: December 1987
Principal Investigator: Carlos Figueroa-Alamo
Cooperating Agency: USCOE

The Río Puerto Nuevo basin is a small, highly developed urban basin in the metropolitan San Juan area, located in north-central Puerto Rico. The river runs from south to north through the town of Guaynabo, draining into San Juan Bay.

The objectives of this 2-year project are to determine the amount and particle size distribution of suspended-sediment moving past sediment stations along the Río Puerto Nuevo and entering San Juan Bay. In addition, the particle size distribution of the bed material in the river is under study.

During 1988, four surface water and suspended-sediment stations were installed and operated. Each sediment station has a depth-integrated sampler as well as an automatic sampler. Collection of surface-water data, suspended-sediment samples, and bed material also began in 1988. Laboratory analyses were performed on both suspended-sediment and bed material samples.

The data obtained in this study will be used by the USCOE in the design of a debris basin. The purpose of the debris basin is to trap sediment before it can accumulate in the concrete channel that is part of the Río Puerto Nuevo Flood Control project.

GROUND-WATER RECHARGE IN THE LOWER RIO GRANDE DE ARECIBO VALLEY, PUERTO RICO

Date Project Began: 1981
Principal Investigator: Vicente Quiñones-Aponte
Cooperating Agencies: PRDOA

The feasibility of injecting, storing, and recovering excess streamflow in an aquifer by artificial recharge through an injection well was investigated for a well site in the lower Río Grande de Arecibo Valley, in Arecibo, Puerto Rico. Results of these tests indicated that although a reasonable percent of the injected freshwater can be recovered, further studies are necessary to test the effect of large-scale freshwater injection. Prevention of the inland migration of saline water may be an additional benefit of injection wells. This study was completed in 1988. Two additional reports have been approved for publication.

Publications released:

Whitesides, D.V., Quiñones-Aponte, Vicente, and Zack, A.L., 1985, Estimating the capacity of a salty limestone aquifer in Puerto Rico to receive, store, and release injected freshwater using chloride mass balance: International Symposium on Tropical Hydrology and 2nd Caribbean Islands Water-Resources Congress, San Juan, Puerto Rico, May 5-8, 1985, American Water Resources Association Technical Publication Series TPS-85-1, p. 50-55.

WATER RESOURCES OF THE HUMACAO-NAGUABO AREA, EASTERN PUERTO RICO

Date Project Began: October 1982
Principal Investigator: Robert P. Graves
Cooperating Agency: PRIDCO

The objective of the water-resources investigation of the Humacao-Naguabo area was to define the occurrence, availability, and quality of surface and ground water in the Humacao-Naguabo area. Surface water is the principal water-supply source in the study area. Río Humacao and Río Blanco are the major drainage networks and have the potential of supplying 13.7 Mgal/d. The quality of the surface water, however, is generally poor. Bacteria counts as high as 10,300,000 colonies per 100 milliliters for coliform and 1,900,000 colonies per 100 milliliters for streptococci have been observed in samples from Río Humacao.

Ground-water use in the Humacao-Naguabo area in 1984 was 0.93 Mgal/d. The principal aquifer in the study area occurs within alluvial sediments, under water-table conditions. Values of aquifer transmissivity range from 600 to 2,000 square feet per day (ft^2/d); storage coefficient of the aquifer is approximately 0.02. Water-quality analyses of the ground water revealed that at several sites the USEPA Drinking Water Standards for iron, manganese, and total dissolved solids were exceeded.

A two-dimensional, mathematical ground water flow model of the Río Humacao basin was developed to simulate the ground-water flow system and to determine the effects of additional ground-water withdrawals on the aquifer. Model results indicate that in the lower Río Humacao basin if current ground-water use is increased by more than 0.72 Mgal/d, saltwater intrusion into the aquifer could occur.

INVENTORY OF WELLS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Date Project Began: October 1983
Principal Investigator: Héctor M. Colón-Ramos
Cooperating Agencies: PRDNR, and PRASA

An inventory of ground-water wells in Puerto Rico and the U.S. Virgin Islands was conducted from October 1983 to September 1986. Information was gathered on approximately 4,215 ground-water wells. Although this number may include some abandoned or destroyed wells, the inventory indicated that the number of wells in Puerto Rico had almost doubled since 1964. The number of wells increased from 2,282 in 1964 to 4,215 in 1986. In the north-coast province aquifers the number of wells increased from 761 in 1964 to 1,556 in 1986 and in the south-coast alluvial aquifers from 1,277 to 2,156 during this period.

GROUND-WATER RESOURCES IN LAJAS VALLEY, PUERTO RICO

Date Project Began: October 1983
Principal Investigator: Robert P. Graves
Cooperating Agencies: PRDOA and PRIDCO

The objectives of the study were to define the occurrence, availability, and quality of ground-water in the Lajas Valley. Field work for the water-resources investigation of the Lajas Valley was completed in September 1987.

The principal aquifer in the Lajas Valley is a nonhomogeneous, anisotropic confined aquifer consisting of alluvial deposits of Quaternary age. The potentiometric head in monitor wells can range from more than 3 feet (ft) above land surface to 30 ft below land surface. Values of aquifer transmissivity range from 700 to 8,000 ft^2/d; the storage coefficient of the aquifer is approximately 9.3×10^{-4}.

Ground-water use in the Lajas Valley for 1986 was estimated to be 2.95 Mgal/d. Depending on the location of a well in the valley, pumpage rates can range from 5 to 300 gallons per minute (gal/min).

Ground-water quality varies greatly in the Lajas valley. Ground water in several wells exceeded the Environmental Protection Agency's limit for iron, manganese, and total dissolved solids. Chloride concentrations in excess of 5,000 milligrams per liter were measured in water samples from several wells. In general, high quality, ground-water supplies are limited in the Lajas Valley.

ATLAS OF SELECTED AQUIFERS IN PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Date Project Began: 1984
Principal Investigator: Thalia Veve
Cooperating Agency: USEPA

The U.S. Environmental Protection Agency has the responsibility for overseeing the implementation of the Underground Injection Control Program in Puerto Rico and the U.S. Virgin Islands. To implement this program, a knowledge of the hydrogeologic characteristics of the aquifers is needed to prevent contamination of water supplies. The objectives of this project are:

1. to describe the hydrogeologic framework, areal extent, and regional flow system of selected aquifers that are major sources of drinking water supplies;
2. to quantify ground-water use and describe land use and population distribution; and
3. to assess the effects of present and potential problems of ground-water contamination from underground wastes.

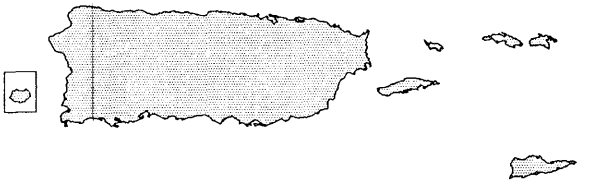
These objectives will be accomplished by preparing hydrogeologic and geographic maps describing the aquifers and identifying potential problem areas. The atlas which is in preparation covers Puerto Rico and its offshore islands of Vieques, Culebra, and Mona; and the U.S. Virgin Islands of St. Croix, St. Thomas, and St. John.

The information in the atlas is organized by ground-water provinces: North-Coast Province, South-Coast Province, West-Coast Province, East-Coast Province, Puerto Rico Offshore Islands, and U.S. Virgin Islands. Some of these are divided into smaller areas that are described separately.

THE CARIBBEAN ISLANDS AQUIFER REGIONAL AQUIFER SYSTEM ANALYSIS

Date Project Began: October 1984

Principal Investigator: Fernando Gómez-Gómez



The Regional Aquifer System Analysis (RASA) program represents a systematic effort by the Survey to study the Nation's major aquifer systems. The Caribbean Islands RASA project includes an area of more than 3,600 m^2 within Puerto Rico and the U.S. Virgin Islands. The principal aquifers are the carbonate rocks of northern Puerto Rico, the carbonate rocks of central St. Croix, (Kingshill aquifer) and the alluvial deposits of the southern coastal plain in Puerto Rico.

In October 1984, the Survey began this 5-year study to: 1) describe the hydrogeology of the principal aquifers, (2) define the hydraulics of the principal ground-water flow systems, (3) define the geochemistry of each principal aquifer system and its relation to the mineral components within the geologic framework, (4) describe the original aquifer systems as they existed prior to development and analyze the changes which have led to their present conditions, (5) combine, in a regional analysis, the results of this and previous studies, and (6) provide the capabilities through which the effects of future changes on the ground-water-flow systems can be estimated.

Six reports have been released and several others have been approved for publication or are in preparation.

Publications released:

Gómez-Gómez, Fernando, 1987, Planning Report for the Caribbean Islands Regional Aquifer-System Analysis Project: U.S. Geological Survey Water-Resources Investigation Report 86-4074, 50 p.

Quiñones-Aponte, Vicente, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Salinas Quadrangle, Puerto Rico, March 1986: U.S. Geological Survey, Water-Resources Investigation Report 87-4161, 1 plate.

Torres-González, Sigfredo, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Central Aguirre Quadrangle, Puerto Rico, March 1986: U.S. Geological Survey, Water-Resources Investigation Report 87-4160, 1 plate.

Dacosta, Rafael, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Guayama Quadrangle, Puerto Rico, March 1986: U.S. Geological Survey, Water-Resources Investigation Report 87-4162, 1 plate.

Román-Más, Angel, and Lee, Roger W., 1987, Geochemical evolution of waters within the north coast limestone aquifers of Puerto Rico: A conceptualization based on a flow path in the Barceloneta area: U.S. Geological Survey, Water-Resources Investigation Report 86-4080, 28 p.

Román-Más, Angel, and Ramos-Ginés, Orlando, 1988, Compilation of water-quality data for the north coast limestone aquifers, Puerto Rico, 1951 to 1987: U.S. Geological Survey Open-File Data Report 87-533, 133 p.

HYDROLOGY AND EFFECT OF CHANGES FROM FURROW TO DRIP IRRIGATION IN THE SANTA ISABEL TO JUANA DIAZ AREA, SOUTH CENTRAL PUERTO RICO

Date Project Began: October 1984
Principal Investigator: Orlando Ramos-Ginés
Cooperating Agency: PRDOA

In the 1980's, the PRDOA initiated an intensive agricultural development plan along the south central coastal plain of Puerto Rico. Sugar cane was formerly the most important crop in this area; today, however, about 90 percent of the former sugar cane area is cultivated with other crops, mainly vegetables. In addition, irrigation techniques have been changed from furrow to more efficient drip methods.

An investigation of the present hydrologic conditions in the Santa Isabel-Juana Díaz area was conducted from 1984 to 1988. The study area extends from Río Jueyes to Río Jacaguas covering about 50 m^2. The PRDOA was concerned that inadequate management of the water resources in this area could diminish the ground-water supplies, cause subsequent shortages during droughts, and induce seawater-intrusion problems. A two-dimensional, finite-difference ground-water flow simulation model was constructed to help assess the effects caused by changes from furrow to drip irrigation in terms of aquifer water levels. In 1988, efforts were directed toward locating the saline-freshwater mixing zone and in determining the interaction between streams and the aquifer in the study area. Preparation of the report summarizing the results of this study is underway.

Publications released:

Román-Más, Angel, and Ramos-Ginés, Orlando, 1987, Elevation of the water-table surface for the alluvial aquifer and hydrologic conditions in the Santa Isabel-Juana Díaz area, Puerto Rico, March 1986: U.S. Geological Survey Water-Resources Investigation Report 87-4123.

HYDROGEOLOGIC FRAMEWORK OF THE NORTH COAST LIMESTONE REGIONAL AQUIFER SYSTEM OF PUERTO RICO

Date Project Began: 1985
Principal Investigator: Arturo Torres-González, Ingrid Padilla and Jesús Rodríguez
Cooperating Agencies: PRDNR

The North Coast Limestone Regional Aquifer System is the most important ground-water reservoir in Puerto Rico. It is composed of hydrogeologic units of Middle Tertiary age, and extends from Aguadilla in western Puerto Rico to Loíza in the east. A well-developed karst topography characterizes the outcrop areas of this predominantly carbonate aquifer system.

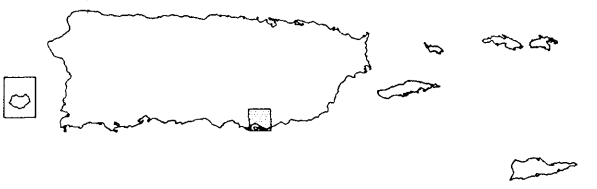
A study of the hydrogeology of the North Coast Limestone Regional Aquifer System was initiated in 1985. It was divided into two phases: (1) an exploratory drilling phase, which has been completed, and (2) the development of a series of digital ground-water flow models, currently in progress. Fifteen deep test holes that penetrated both the water table and deep artesian aquifers were drilled using a dual tube drilling method that allowed retrieval of continuous lithologic cores, measurement of head and hydraulic properties, collection of water samples, and collection of borehole geophysical logs. Studies of the age and environments of deposition of the rocks are being conducted by the Department of Geology at the University of New Orleans using the lithologic cores obtained while drilling the deep test holes.

A preliminary hydrogeologic framework of this regional aquifer system has been outlined. The system is composed of three hydrogeologic units of regional extent: an uppermost water-table aquifer, a middle confining unit, and a deep artesian aquifer. These units were delineated based on their confining and water yielding properties, as well as their considerable lateral continuity.

Important tasks that remain, besides the ground-water flow modeling effort, are the mineralogical analysis and estimates of the amount and distribution of porosity and permeability in the different hydrogeologic units, the characterization of the different lithologic units using geophysical data, and the demonstration of time equivalency between outcrop and downdip facies described from the test holes cores. This work is being conducted in a cooperative effort by the Survey and the University of New Orleans.

GROUND-WATER FLOW MODEL IN THE JOBOS AREA

Date Project Began: 1985
Principal Investigator: Sigfredo Torres
Cooperating Agency: PRIDCO



A two-dimensional ground-water flow model for the alluvial aquifer between Río Seco and Río Guamaní, along the south coast of Puerto Rico, was calibrated using predevelopment (approximately 1910) water levels. The model was then used to simulate flow in the aquifer in 1986 and to assess the effects of increased ground-water withdrawals of 3.6 ft^3/s (2.2 Mgal/d). The model was also used to estimate the effects of dredging of the former Laguna Las Mareas during 1970. The investigation was completed in February 1987.

GROUND-WATER RESOURCES OF THE CAGUAS-JUNCOS ALLUVIAL VALLEY, PUERTO RICO

Date Project Began: October 1985
Principal Investigator: Juan C. Puig
Cooperating Agencies: PRASA and PRDNR

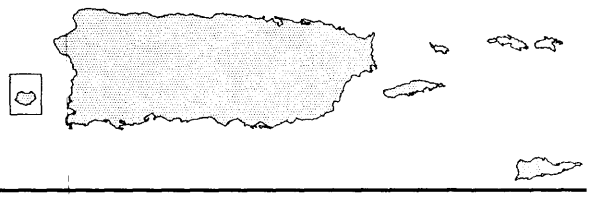
The objective of this three-year study was to define the occurrence, availability, and quality of ground water resources of the Caguas-Juncos alluvial valley. Field activities for the study, including the acquisition of basic hydrogeologic data, have been completed. A comprehensive well and water-use inventory in the area was conducted and ground-water levels are being monitored at four continuous recording stations and by monthly measurements at selected wells.

The Caguas-Juncos alluvial aquifer is an unconfined system with a strong stream-aquifer hydraulic connection. The transmissivity of the aquifer is relatively low, with estimate values ranging between 50 and 3,000 ft^2/d. Higher transmissivity values occur along river channels. The aquifer's physical dimensions were estimated from well logs and geophysical surveys. Transmissivity was estimated from specific capacity data and slug tests. Seepage studies, in conjunction with saturation runs and ground-water level measurements, were helpful in defining the stream-aquifer hydraulic connection. Finally, a network of surface and ground-water sites were monitored for physical, chemical, and biological water-quality characteristics.

A ground-water flow model of the western part of the alluvial aquifer system was developed and calibrated. Preliminary results of the ground-water flow model indicate that the amount of ground-water available from this alluvial aquifer may be substantially greater than the 3 Mgal/d withdrawn for public supply. A report documenting the results of this investigation is in preparation.

GROUND WATER SITE INVENTORY

Date Project Began: April 1986
Principal Investigator: Philip González
Cooperating Agencies: EQB



Hydrologic data collected during investigations conducted by the Survey provide valuable information that can be used for the management of water resources. Easy access to hydrologic data facilitates that management process.

The Ground-Water Site Inventory (GWSI) is part of the National Water Information System (NWIS) which is a data storage and retrieval system for hydrologic data collected by the Survey and its cooperators. The Ground-Water Site Inventory is an interactive system on the Survey's minicomputer. The GWSI provides a vehicle to update existing sites and enter new sites into the local data base and, at the same time, to update the national data storage and retrieval system. The GWSI also provides a vehicle to selectively retrieve and display, in several formats, ground- and surface-water data stored in the local data base.

The GWSI contains approximately 300 descriptive data elements containing information about sites where ground water data is collected. These data elements are stored in one general data file called the Site File and eight GWSI data files. The Site File contains identification parameters, physical and political descriptions, and data-collection methods at the sites. The information in the Site File is available to all members of the NWIS. The eight GWSI data files contain information related to well-construction, ground-water levels, ground-water discharge, hydrogeology, observation wells, hydraulics, and water use.

In the Caribbean District, GWSI has been functional for only a few years. During that period, more than 75 percent of the historic ground water data in the District (data for an estimated 4,000 to 4,500 wells and springs) has been entered into GWSI.

GEOHYDROLOGY OF POTENTIAL HAZARDOUS-WASTE SITES IN PUERTO RICO

Date Project Began: October 1986
Principal Investigator: Robert P. Graves
Cooperating Agency: PRIDCO

A geohydrologic investigation of potential sites for a hazardous-waste treatment, stabilization, and storage facility was conducted for the Commonwealth of Puerto Rico. The project is a three-year study. The principal sites under investigation are the Aguirre and Pozo Hondo areas located on the south coast of Puerto Rico. The objectives of the program are to define the geology and hydraulic characteristics of the aquifer underlying each site.

Accomplishments during the latter part of 1986 through 1987 included the completion of 33 test wells at 15 sites. These wells were shallow, generally less than 95 feet. Data collected from these wells were used to prepare preliminary potentiometric and subsurface geologic maps. To help define aquifer hydraulic characteristics, single well aquifer tests were performed in each well. Also, during 1987, 12 continuous-recording ground-water stations and 2 continuous-recording surface-water stations were installed.

Work completed during 1988 included the drilling of 30 test wells at 19 sites. Using a dual-tube coring rig, continuous cores were collected from each well. Depth of drilling for these wells ranged between 28 to 210 feet. Water-quality data was collected from 19 of the test wells drilled. Single-well aquifer tests were completed at 19 of the test wells drilled.

Further plans for the project include multi-well aquifer tests to accurately define aquifer characteristics. For further definition of the subsurface geology, surface geophysical surveys will be completed.

POTENTIOMETRIC SURFACE OF THE TURPENTINE RUN BASIN AQUIFER IN THE TUTU AREA, EASTERN ST. THOMAS, SEPTEMBER 11, 1987

Date Project Began: August 1987
Principal Investigators: Robert P. Graves and Ralph González
Cooperating Agency: USEPA

Following the detection of volatile organic compounds in water withdrawn from wells tapping the Turpentine Run aquifer in St. Thomas, U.S. Virgin Islands, the Survey was requested by the U.S. Environmental Protection Agency to prepare a potentiometric map of the aquifer to define the direction of ground-water flow. The aquifer is comprised of fractured-volcanic rock overlain by alluvial deposits. The alluvial deposits can reach a thickness of 40 feet. Wells have been drilled into the fractured volcanics to depths of 325 feet. Ground water in the aquifer occurs under water-table conditions. To prepare the potentiometric map, ground-water levels were measured in 32 wells on September 11, 1987. The altitude of water levels in these wells was referenced to known land surface altitude benchmarks. The potentiometric map was completed and published in 1988.

Publications released:

Graves, Robert, and González, Ralph, 1988, Potentiomentric Surface of the Turpentine Run Basin Aquifer in the Tutu area, Eastern St. Thomas, September 1987: U.S. Geological Survey, Water-Resources Investigation Report 88-4131.

AQMAN3D: A GROUND-WATER SIMULATION/MANAGEMENT MODEL

Date Project Began: October 1987
Principal Investigators: Juan C. Puig and Lourdes Rolón
Cooperating Agencies: PRASA

Ground-water management can be defined as the process by which efficient ground-water development is achieved by optimizing well locations and withdrawals within the constraints of cost, water quality, water law, and the physical laws governing the ground-water system. A ground-water management model can be designed to interact with a ground-water flow model in order to incorporate the dynamics of the aquifer as system constraints.

The AQMAN3D aquifer management model is a modified version of the original AQMAN model proposed by Lefkoff and Gorelick (1987), which utilizes as its ground-water flow simulation subroutine the "Finite-Difference Model for Aquifer Simulation in Two Dimensions" by Trescott, Pinder, and Larson (1976). The modification consists in making the AQMAN model fully compatible with the MODULAR Three Dimensional Ground-Water Flow Model by McDonald and Harbaugh (1984).

The idea of coupling the AQMAN model with the MODULAR model arose because many ground-water systems need to be simulated in three-dimensions, and MODULAR is the model most commonly used by the Survey for this purpose. Additionally, many of the aquifer systems on the island have already been simulated using the MODULAR model.

The AQMAN3D model is being applied in the previously described ground-water resources investigation in the Caguas-Juncos valley. The model will be developed, tested, and verified and a report will be published.

The use of aquifer management models is a relatively new methodology in the science of hydrology. A reliable and accurate method for decision making is essential for water managers in areas where ground-water availability may be limited by water allocation conflicts or poor water quality.

GROUND WATER/SURFACE WATER RELATIONS

Date Project Began: October 1987
Principal Investigator: Vicente Quiñones-Aponte
Cooperating Agency: PRASA

Aquifer recharge and stream base-flow conditions depend on the interaction between streams and adjacent, shallow aquifers. Base-flow conditions are sustained by an elevated water table in comparison to stream stage; aquifer recharge is sustained by elevated stream stage in comparison to the water table. This information is important in formulating water-supply management criteria for the aquifer or the stream.

Field work is being conducted in an effort to determine the ground-water/surface-water relations at two representative sites in the north- and south-coast aquifer systems. Part of the lower Río Grande de Manatí Valley is being studied as representative of the north coast stream-aquifer systems. The upper reach of the Río Jacaguas alluvial valley in Juana Díaz is considered representative of the south coast stream-aquifer systems. The study in the Río Grande de Manatí Valley is being conducted in conjunction with the Survey's Caribbean Islands Regional Aquifer-System Analysis project.

In the Juana Díaz area, continuous information on water levels in streams and wells was collected. Channel flow information was also obtained concurrently with streamflow data in Río Jacaguas. A mass balance approach is being used to analyze the streamflow infiltration rates to the aquifer. In the Manatí area, a network of nested observation wells was installed at three different locations within the valley. Analyses of water level fluctuations in wells is being compared with water level fluctuations in the river. A ground-water hydraulic approach is being used to analyze the surface/ground water interrelation and its significance to further ground-water development within the area. The data collection has been completed and a report is preparation.

INTER-AQUIFER WATER MOVEMENT WITHIN THE LIMESTONE AQUIFER, NORTH COAST OF PUERTO RICO

Date Project Began: October 1987
Principal Investigators: Angel Román-Más and Carlos Conde-Costas
Cooperative Agencies: PRIDCO, PRDNR, and PRASA

The objective of this investigation is to quantitatively demonstrate that the extraordinary decline in the potentiometric surface of the North Coast Artesian Aquifer is not the result of ground-water withdrawals through wells, but rather from inter-aquifer water movement through poorly grouted wells, corroded or ruptured casing, or improperly abandoned water wells. Artesian-well records and water-level information were compiled as part of the project. Pilot tests were conducted at artesian wells in two areas. Results of this investigation indicate that the principal cause of the water-level decline is leakage from the artesian aquifer into the water-table aquifer through damaged wells. Although the total amount of water being transferred is presently unknown, it is probably in excess of 10 Mgal/d. In addition, it is believed that each artesian well may represent a point of water transfer.

As part of this project all existing wells (operating and abandoned) that are screened in the artesian aquifer will be evaluated with respect to inter-aquifer transfer of water. The information gathered will define the areal extent of the inter-aquifer water movement and quantify the amount of water being transferred. This information can help well owners and water managers to reduce or minimize the water lost through leaky wells. Leaky wells can be sealed with cement grout and new production wells drilled. The information collected during this study can also guide decisions regarding drilling and screening of new production wells.

MANGANESE AND IRON CHEMISTRY IN THE VALLE DE YABUCOA ALLUVIAL AQUIFER, SOUTHEASTERN PUERTO RICO

Date Project Began: October 1987
Principal Investigators: Joseph W. Troester
Cooperating Agency: PRASA

Elevated concentrations of manganese and iron which produce an objectionable taste have been observed in the water of the Valle de Yabucoa alluvial aquifer in southeastern Puerto Rico. The alluvium in the valley is composed of rocks derived from the mineralized San Lorenzo batholith, which appears to be the source of the iron and manganese. Furthermore, the alluvium contains organic swamp deposits which may control the oxidation state of iron and manganese as well as other multivalent species.

The objectives of this study are (1) to determine the source of the iron and manganese as well as other multivalent ionic species in the Valle de Yabucoa alluvial aquifer, (2) to describe the chemical and physical processes that control the behavior of iron and manganese, and (3) to determine the location of any sources of fresh ground water in the Valle de Yabucoa alluvial aquifer that are low in iron and manganese.

A complete well inventory in the Valle de Yabucoa was conducted. A comprehensive water-quality sampling program to document the extent of the problem is underway. Drill sites have been selected to test various chemical hypotheses for the origin of the iron and manganese concentrations and the controls upon their distribution in the ground water through space and time.

VERTICAL CONTINUUM OF AQUIFER COMPRESSIBILITY AND ITS RELATION TO SPECIFIC STORAGE

Date Project Began: June 1988
Principal Investigator: Nicasio Sepúlveda
Allen Zack
Cooperating Agency: PRASA

The purpose of this investigation is to study the range of specific storage values that can occur in an aquifer. Values of specific storage are usually assigned according to the degree of confinement of the aquifer. Artesian aquifers usually have values around 10^{-6}/ft while water table aquifers have values that usually range from 0.01 to 0.3/ft.

A laboratory model was constructed to measure the specific storage directly from a simulated aquifer. In this model a saturated aquifer material sample is maintained at a given hydrostatic pressure while subjected to a particular effective stress provided by a dead load which simulates the weight of overburden. By reducing the hydrostatic head in the pressure cylinder, a certain quantity of water is released by compression of the aquifer matrix and some "subsidence" of the aquifer can be measured. This quantity of water represents the amount of compressional storage of the sample at the prevailing effective stress and hydrostatic pressure. By varying the effective stress, measured values of specific storage for different simulated depths of burial can be obtained.

The knowledge of the pore volume compressibility of the aquifer material, the thickness of the aquifer, and the value of the specific storage at the bottom of the aquifer uniquely determine the specific storage profile used in the model. The effects of this depth-dependent specific storage profile will be studied from the type-curves obtained from the model. A turning point in the type curves would support the hypothesis of the existence of vertical differences in specific storage since the hydraulic conductivity will be kept constant throughout the model runs.

A cross-sectional Galerkin finite element algorithm allowing a depth- dependent specific storage profile has been coded and tested for an artesian aquifer. The code was tested for the particular case of constant specific storage and the model results were compared with Theis' dimensionless analytical solutions.

WATER RESOURCES OF THE RIO MAJADA AND RIO LAPA ALLUVIAL VALLEYS, SOUTH COAST, PUERTO RICO

Date Project Began: June 1988
Principal Investigator: Orlando Ramos-Ginés
Cooperating Agencies: PREQB, and CSHES

In 1986 the Puerto Rico Olympic Committee inaugurated the Albergue Olímpico, a training facility for athletes. Although water supply needs of the Albergue Olímpico are presently met from shallow aquifers in the Río Majada alluvial valley, the development of new facilities will require additional water supplies. The purpose of this study is to determine if the alluvial aquifer in the water resources in the Río Lapa valley can provide the additional water needed to satisfy future demands.

Efforts during the first year have been directed towards (1) updating the well inventory in the area, (2) construction of two real-time surface-water stations at Río Majada and Río Lapa, (3) establishment of four continuous ground-water stations, (4) definition of the areal distribution in thickness of the alluvial deposits in both valleys through seismic refraction surveys and test hole drilling, and (5) sampling of the major production wells in the Albergue Olímpico.

PUERTO RICO WATER-USE INFORMATION PROGRAM

Date Project Began: June 1977
Principal Investigator: Héctor Colón-Ramos
Cooperating Agencies: PRASA, PREQB, and PRDNR

The Puerto Rico Water-Use information program was started in 1977 to place all available water-use information into a single usable format to meet the needs of Commonwealth and federal agencies. Reliable water-use information is needed by the Commonwealth agencies for the effective planning and management of the island's water resources. The objectives of the water-use program are to collect, analyze, and store water-use data and to disseminate water-use data for about 12 different water-use categories. Comprehensive reports documenting water use in Puerto Rico are available for 1980, 1980-82, and 1984. Two additional reports, covering years 1984-85 and 1986-90 separately, are in preparation.

Publications released:

Gómez-Gómez, Fernando, Dacosta, R., and Orona, M., 1983, Estimated Water Use in Puerto Rico, 1980--U.S. Geological Survey water-use information program: U.S. Geological Survey Water Resources Division Miscellaneous Map Series.

Torres-Sierra, H., and Aviles, A., 1986, Estimated Water Use in Puerto Rico, 1980-82: U.S. Geological Survey, Open-File Data Report 85-557 (1 plate).

Gómez-Gómez, F., Quiñones, F., and López, M., 1984, Public Water Supply in Puerto Rico 1983: U.S. Geological Survey, Open-File Report 84-126, 101 p.

QUANTITATIVE ASSESSMENT OF LANDSLIDE HAZARDS IN THE RIO BLANCO, RIO CIBUCO AND RIO COAMO BASINS, PUERTO RICO

Date Project Began: October 1987

Principal Investigators: Matthew Larsen, Andrew Simon, and Cliff Hupp

Cooperating Agency: PRPB

A three-year study of landslide potential in the Río Blanco, Río Cibuco and Río Coamo basins is being conducted with the dual purpose of advising the Commonwealth of Puerto Rico on landslide potential in relation to existing and future development and creating maps showing a quantitative estimate of landslide hazard on the island. The multidisciplinary study will utilize techniques from the fields of geomorphology, soil mechanics, geophysics, ground-water hydraulics, botany, plant ecology, and climatology. The knowledge gained will be applicable to similar basins in Puerto Rico and will be the most extensive quantitative analysis to date, of landslide hazard on the island. Previous studies have been either broad and qualitative in nature or locally focused.

A key element of the project will be the measurement of shear strength of soil on slopes with the Iowa Borehole Shear Tester. This portable tool measures resistance to shear at depths of up to 30 ft, and generates data which will give both the angle of internal friction and soil cohesion. Seismic refraction methods are being utilized to assess the thickness of soil over bedrock.

In addition to written reports, one of the products of the investigation will be composite maps, using the Geographic Information System, showing slope stability, depth to and type of bedrock, slope angle and aspect, precipitation amount and intensity, and vegetation, as well as previous areas of slope failure. Through this computer assisted overlay of various data types, relative risk ratings can be estimated for various areas within the study basins. The maps and a final written report will be produced in 1990, the last year of the project.

Publications released:

Guariguata, M.R., and Larsen, M.C., 1989, Preliminary map showing locations of landslides in El Yunque quadrangle, Puerto Rico: U.S. Geological Survey Open-File Report 89-257, scale 1:20,000, 1 plate.

Larsen, M.C., 1989, Use of seismic refraction tecniques for investigating the morphology of recent landslides in a tropical rain forest in Puerto Rico: Geological Society of America, Abstracts with Programs, v. 21, no. 3, p. 46.

Simon, Andrew, and Larsen, Matthew C., 1988, Shear strength determination and slope stability at sites in the Caribbean National Forest and Coamo area, Puerto Rico (abs.): Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A144.

COMPUTER SECTION

The District's minicomputer was enhanced with the upgrade from a one million instructions per second (MIPS) unit to a five MIPS unit in 1988 allowing faster processing of hydrologic data. The upgrade included an interchange of the old 630 megabytes (MB) and 300MB disk drives for three new 773MB disks which are much smaller and about three times more efficient in access time. This equipment, combined with new computer graphics devices, including a digitizer, two graphic terminals, twenty interactive terminals, and a workstation, support hydrologic investigations and the development of a new analytical tool called a Geographic Information System (GIS).

Data communication lines have been installed to provide three cooperating agencies, the PRDNR, PRASA, and the PREQB, access to the District's minicomputer. Other agencies including agencies from the U.S. Virgin Islands, have expressed interest in tying into the District's minicomputer and may be provided access in the future.

GEOGRAPHIC INFORMATION SYSTEM PROGRAM

Date Project Began: January 1988
Principal Investigator: Agustín Sepúlveda
Cooperating Agencies: Almost all the agencies in the cooperator list

The development of a Geographic Information System (GIS) in the Caribbean District has been made possible by a combined effort between several Commonwealth agencies. An analytical tool such as GIS will help in hydrologic analysis and information processing for a wide variety of water-resources investigations. GIS will store attribute information tied to geographic locations or areas having different digitized layers or categories such as land use, topography, hydrography, transportation and other types of spatially distributed data. It will also support complex hydrologic studies through its sophisticated capacity to overlay various information grids.

Much of the data requirements for GIS consist of geographic information which can be digitized from topographic maps. The maps for Puerto Rico are currently being digitized. When this task is completed, the digitized data will be available to cooperating agencies.

APPENDIX A

PUBLICATIONS RELEASED BY THE CARIBBEAN DISTRICT FROM 1985 TO 1988

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Colón-Dieppa, Eloy, and Quiñones-Márquez, Ferdinand, 1985, A reconnaissance of the water resources of the central Río Guanajibo Valley, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 82-4050, 47 p.

Colón-Dieppa, Eloy, and Quiñones-Aponte, Vicente, 1985, Estimates of 7-day, 10-year low flow at ungaged streams in Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 84-4089, 1 plate.

Colón-Dieppa, Eloy, Díaz, P.L., and García, René, 1985, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1985: U.S. Geological Survey Open-File Report PR-85-1, 400 p.

Conde-Costas, Carlos, 1988, The effects of bat guano on the water quality of the Cueva El Convento stream in Guayanilla, Puerto Rico [abs.]: National Speleological Society, Annual Convention Program, p. 22-23.

Conde-Costas, Carlos, and Troester, J.W., 1988, The effects of bat guano on carbonate chemistry in Cueva El Convento, Guayanilla, Puerto Rico [abs.]: National Speleological Society, Annual Convention Program, p. 34.

Curtis, R.E., Jr., Aquino, Zaida, Díaz, P.L., and García, René, 1988, Water resources data for Puerto Rico and the U.S. Virgin Islands, Water Year 1986: U.S. Geological Survey Open-File Report PR-86-1, 362 p.

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Díaz, Pedro, Lugo, Ariel, and McDowell, William, 1985, General hydrology and water quality of Layou River in Dominica, Buccament River in St. Vincent, and Troumassee River in St. Lucia, British West Indies: Symposium on Tropical Hydrology and 2nd Caribbean Islands Water Resources Congress 1985, [Proceedings] American Water Resources Association Technical Publication Series TPS-85-1, p. 46-49.

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García, René, and Canoy, Michael, 1985, Reconnaissance of ground-water quality in the Virgin Islands, July 1984: U.S. Geological Survey Open-File Data Report 84-807, 1 plate.

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Quiñones-Aponte, Vicente, and Carrasquillo, R.A., 1986, Use of borehole neutron logs to estimate moisture content in the unsaturated zone of an alluvial aquifer: Third Caribbean Islands Water Resources Congress [Proceedings], St. Thomas, U.S. Virgin Islands, July 22-23, 1986, p. 57-60.

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Quiñones-Aponte, Vicente, and Torres-Sierra, Heriberto, 1985, Application of a ground water flow digital model in evaluating alternate dewatering systems in the Río Grande de Arecibo alluvial valley, Puerto Rico: Symposium on Tropical Hydrology and 2nd Caribbean Islands Water Resources Congress 1985, American Water Resources Association Technical Publication Series TPS-85-1, p. 129-134.

Quiñones-Márquez, Ferdinand, 1987, El Manejo y desarrollo de las aguas superficiales y subterráneas: U.S. Geological Survey Circular 1006, p. 150-159.

Quiñones-Márquez, Ferdinand, and Alicea-Ortiz, José, 1985, Agua subterránea en Puerto Rico: U.S. Geological Survey Open-File Report 85-642, 6 p.

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Román-Más, Angel, 1986, Role of blanket deposits on the hydrology and water chemistry of the limestone water-table aquifer within the north coast limestone of Puerto Rico through interpretation of geochemical data [abs.]: Third Caribbean Islands Water Resources Congress [Proceedings] Symposium -July 22-23, 1986, St. Thomas, U.S. Virgin Islands, p. 33.

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Román-Más, Angel, and Green, Bruce, 1987, Climatological data for the rice-growing areas along the north coast of Puerto Rico: U.S. Geological Survey Open-File Data Report 86-53, 90 p.

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Simon, Andrew, and Larsen, Matthew C., 1988, Shear strength determination and slope stability at sites in the Caribbean National Forest and Coamo area, Puerto Rico (abs.): Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A144.

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Torres-González, Sigfredo, and Gómez-Gómez, Fernando, 1987, Potentiometric surface of the alluvial aquifer and hydrologic conditions in the Central Aguirre quadrangle, Puerto Rico, March, 1986: U.S. Geological Survey Water-Resources Investigations Report 87-4160, 1 plate.

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APPENDIX B

SURFACE-WATER SITES

[mi^2, square miles; Lat., latitude; Long., longitude; Date Began, date the station was installed; Recorder Type, type of recorder on site; IND., indeterminate; D, digital recorder; *D, DCP and digital recorder; MGD, manometer, graphic and digital recorders; *MGD, DCP, manometer, graphic and digital recorders; CSG, crest-stage gage and partial record station]

Station Number	Name	Drainage Area (mi^2)	Lat.	Long.	Date Began	Recorder Type
	ACTIVE RECORDING STATIONS IN PUERTO RICO AS OF 12/31/88					
50010600	Río Guajataca above Lago de Guajataca	IND.	181957	665529	071184	MGD
50011200	Río Guajataca below Lago de Guajataca	IND.	182401	665540	081269	D
50011400	Río Guajataca above mouth nr. Quebrada	IND.	182831	665746	072569	D
50014800	Río Camuy near Bayaney	IND.	182348	664854	052384	MGD
50015700	Río Camuy near Hatillo	IND.	182744	664956	061984	MGD
50020100	Lago Garzas near Adjuntas	15.6	180820	664429	022188	*D
50027750	Río Grande de Arecibo above Arecibo	140	182529	664144	060782	MGD
50028000	Río Tanamá near Utuado	18.4	181802	664658	120159	D
50028400	Río Tanamá at Charco Hondo	57.6	182452	664252	022869	D
50031200	Río Grande de Manatí near Morovis	55.2	181745	662447	010165	
50032290	Lago El Guineo at damsite	1.64	180941	663134	051688	*D
50032590	Lago Matrullas at damsite	4.46	181245	662846	051688	*D
50035000	Río Grande de Manatí at Ciales	128	181926	662736	100160	*MGD
50038100	Río Grande de Manatí Hwy. 2 nr. Manatí	197	182552	663137	012370	*MGD
50038320	Río Cibuco below Corozal	15.1	182113	662007	050169	*MGD
50039500	Río Cibuco at Vega Baja	99.1	182653	662229	011273	*MGD
50043000	Río de la Plata at Proy. La Plata	54.8	180937	661344	040160	*MGD
50046000	Río de la Plata at Hwy. 2 nr. Toa Alta	200	182350	661517	010160	*MGD
50047550	Lago Cidra at damsite near Cidra	8.26	181157	660829	020888	*D
50047850	Río de Bayamón near Bayamón	41.8	182008	660813	060788	MGD
50048770	Río Piedras at El Señorial	7.49	182151	660356	032588	MGD
50049000	Río Piedras at Río Piedras	12.5	182348	660324	111387	*MGD
50049100	Río Piedras at Hato Rey	15.4	182432	660410	012588	MGD
50049300	Quebrada Josefina at Puerto Nuevo	3.66	182432	660432	022288	D
50050900	Río Grande de Loíza at Quebrada Arenas	6.00	180710	655922	100177	MGD
50051150	Quebrada Blanca at El Jagual	3.25	180939	655856	091184	D
50051180	Quebrada Salvatierra nr. San Lorenzo	3.74	181024	655838	050184	D
50051310	Río Cayaguas at Cerro Gordo	10.2	180927	655729	091577	MG
50053050	Río Turabo at Borinquen	7.89	181010	660237	122183	D
50055000	Río Grande de Loíza at Caguas	89.8	181433	660034	120159	*MGD

50056400	Río Valenciano near Juncos	16.4	181408	655212	012871	MGD
50056900	Quebrada Mamey near Gurabo	2.30	181452	655645	122983	D
50057000	Río Gurabo at Gurabo	60.2	181530	655805	100159	*MGD
50059000	Lago Loíza at damsite	208	181949	660100	122987	*D
50059050	Río Grande de Loíza below damsite	209	182033	660020	021987	*MGD
50061800	Río Canóvanas at Campo Rico	9.84	181908	655321	032867	MGD
50063440	Quebrada Sonadora near El Verde	1.04	181927	654906	032983	D
50063500	Quebrada Toronja at El Verde	.19	181946	654916	040783	D
50063800	Río Espíritu Santo near Río Grande	8.62	182137	654849	080166	D
50065500	Río Mameyes near Sabana	6.88	181946	654504	080167	MGD
50067000	Río Sabana at Sabana	3.96	181952	654352	102679	MGD
50071000	Río Fajardo near Fajardo	14.9	181756	654142	040161	*MGD
50075000	Río Icacos Near Naguabo	1.26	181638	654709	100179	D
5008100	Río Humacao at Las Piedras	6.65	181027	655211	122987	*MGD
50092000	Río Grande de Patillas near Patillas	18.3	180204	660158	010166	*MGD
50106100	Río Coamo at Coamo	43.5	180500	662116	050587	*MGD
50108000	Río Descalabrado near los Llanos	12.9	180308	662534	021784	D
50111500	Río Jacaguas at Juana Díaz	49.8	180316	663040	041484	*MGD
50112500	Río Inabón at Real Abajo	9.70	180510	663346	070164	*MGD
50114390	Río Bucaná at Hwy 14 near Ponce	24.9	180229	663458	081287	*MGD
50115000	Río Portugués near Ponce	8.82	180445	663801	070164	*MGD
50124200	Río Guayanilla near Guayanilla	18.9	180240	664753	022470	*MGD
50130200	Quebrada Mamey at Joyuda	.38	180751	671009	112685	D
50136400	Río Rosario near Hormigueros	16.4	181022	670431	051475	*MGD
50138000	Río Guanajibo near Hormigueros	120	180836	670857	011673	*MGD
50144000	Río Grande de Añasco near San Sebastián	94.3	181705	670305	040163	*MGD
50147800	Río Culebrinas at Hwy. 404 near Moca	71.2	182142	670533	071267	MGD

ACTIVE RECORDING STATIONS IN U.S. VIRGIN ISLANDS AS OF 12/31/88

50252000	Bonne Resolution Gut at B.R., St. Th.	0.49	182157	645734	112562	MGD
50276000	Turpentine Run at Mariendal, St. Th.	2.97	181948	645258	010163	D
50295000	Guinea Gut at Bethany, St. John	.37	181955	644650	010163	D
50345000	Jolly Hill Gut at Jolly Hill, St. Croix	2.10	174400	645147	010163	MGD

ACTIVE RECORDING STATIONS IN WEST INDIES AS OF 12/31/88

1350220-60572400	Troumassee River at Mahaut, St. Lucia	5.44	135022	605764	030884	D
1524500-61234400	Layou River at L. Valley, Dominica	27.1	152450	612344	031584	D

ACTIVE CREST STAGE STATION IN PUERTO RICO AS OF 12/31/88

50106500	Río Coamo near Coamo	46.0	180352	662210	022484	CSG

APPENDIX C

WATER-QUALITY SITES

[Lat., latitude; Long., longitude; Began, date the station was installed; P, Pollution; *, Pesticide; A, National Ambient Monitoring Program (NAMP, & Lakes); N, National Stream Quality Accounting Network (NASQAN); S/D, continuing sediment station (daily); S/W, continuing sediment station (weekly)]

Station Number	Name	Lat.	Long.	Began	Data Type
	ACTIVE STATIONS IN PUERTO RICO AS OF 12/31/88				
50010500	Río Guajataca at Lares	181801	665224	1975	P
50010720	Lago Guajataca No.3 nr Mouth nr Quebradillas	182205	665436	1980	A
50010790	Lago Guajataca No.1 nr dam nr Quebradillas	182356	665523	1980	A*
50011000	Canal Diversion at Lago Guajataca	182402	665525	1975	P
50011400	Río Guajataca near Quebradillas	182831	665746	1969	P
50020050	Lago Garzas No.1 near dam near Adjuntas	180821	664435	1980	A
50020500	Río Grande de Arecibo near Adjuntas	181054	664412	1979	P
50025000	Río Grande de Arecibo near Utuado	181811	664159	1979	P
50025110	Lago Dos Bocas No.3 at west branch nr Utuado	181915	664011	1980	A
50026050	Río Caonillas above Lago Caonillas	181326	663822	1979	P
50027090	Lago Dos Bocas No.1 nr dam nr Utuado	182009	664004	1980	A*
50027250	Río Grande de Arecibo bl Dos Bocas nr Florida	182050	664002	1975	P
50028000	Río Tanamá near Utuado	181802	664658	1975	P,S/W
50029000	Río Grande de Arecibo at Central Cambalache	182720	664210	1969	P*
50030700	Río Orocovis near Orocovis	181420	662258	1979	P
50031200	Río Grande de Manatí near Morovis	181745	662447	1979	P
50035500	Río Grande de Manatí at Hwy. 149 at Ciales	182046	662806	1976	P
50035950	Río Cialitos at Hwy. 649 at Ciales	182018	662828	1975	P
50038100	Río Grande de Manatí at Hwy 2 near Manatí	182552	663137	1969	A,N*
50038200	Laguna Tortuguero outlet near Vega Baja	182829	662650	1964	A
50038320	Río Cibuco below Corozal	182113	662007	1975	P
50039500	Río Cibuco at Vega Baja	182653	662229	1975	P
50039900	Lago Carite No.3 on Río La Plata near Cayey	180504	660603	1980	A
50039950	Lago Carite No.1 near dam near Cayey	180439	660619	1980	A*
50043000	Río de la Plata at Proyecto La Plata	180937	661344	1975	P
50044000	Río de la Plata near Comerío dam	181433	661228	1979	P
50044400	Lago La Plata No.5 near Naranjito	181933	661228	1980	A
50044850	Río Guadiana near Naranjito	181839	661328	1979	P
50044950	Lago La Plata No.3 near Naranjito	182018	661401	1980	A*
50046900#	Río de la Plata at Toa Alta	182441	661539	1958	N*
50047600	Río de Bayamón near Aguas Buenas	181439	660839	1974	P
50047990	Río Guaynabo near Bayamón	182232	660759	1975	P
50047530	Río Hondo at Flood Channel near Cataño	182613	660950	1979	P
50048510	Río de Bayamón at Bayamón Flood Channel	182439	660909	1974	P*
50048800	Río Piedras near Río Piedras	182215	660340	1972	P*

50049100	Río Piedras at Hato Rey	182434	660410	1971	P
50049820	Laguna San José No. 2	182550	660212	1974	A
50049920	Bahía de San Juan No. 5	182637	660516	1974	A
50050300	Quebrada Blasina near Carolina	182327	655828	1972	P
50055000	Río Grande de Loíza at Caguas	184535	660035	1972	P
50055250	Río Cagüitas at Hwy 30 at Caguas	181511	660126	1972	P
50055400	Río Bairoa near Caguas	181528	660213	1979	P
50057025	Río Gurabo near Gurabo	181556	655904	1979	P
50057500	Lago Loíza No. 4 near mouth near Caguas	181556	655904	1979	A
50058800	Lago Loíza No. 7 near dam near Trujillo Alto	181929	660047	1980	A*
50059000	Lago Loíza at dam site	181949	660100	1974	A
50059100	Río Grande de Loíza below Trujillo Alto	182135	660015	1980	P
50063800	Río Espíritu Santo near Río Grande	182137	654849	1979	P
50071000	Río Fajardo near Fajardo	181756	654142	1961	P*
50072500	Río Fajardo below Fajardo	181935	653847	1975	P
50082000	Río Humacao at Hwy 3 at Humacao	184938	654938	1969	P
50083500	Río Guayanés near Yabucoa	180333	655403	1979	P*
50086500	Río Guayanés at Playa Guayanés	180353	654944	1972	P
50091000	Río Maunabo at Maunabo	180024	655419	1975	P
50091800	Río Chico at Providencia	175916	660018	1979	P
50092000	Río Grande de Patillas near Patillas	180204	660158	1960	N
50106500	Río Coamo near Coamo	180352	662210	1979	P
50114000	Río Cerrillos near Ponce	180422	663453	1964	P
50115000	Río Portugués near Ponce	180445	663803	1975	P
50116200	Río Portugués at Ponce	180020	663628	1975	P*
50124700	Río Guayanilla at Central Rufina	180050	666704	1975	P*
50129700	Río Loco at Guánica	175833	665452	1975	P*
50133600	Río Guanajibo near San Germán	180718	670356	1979	P
50136400	Río Rosario near Hormigueros	180936	670508	1979	P,S/D
50138000	Río Guanajibo near Hormigueros	180836	670857	1969	P*
50138800	Río Yagüez near Mayagüez	181231	670707	1979	P
50143000	Río Grande de Añasco near Lares	181528	665505	1976	P
50144000	Río Grande de Añasco near San Sebastián	181700	670302	1963	N
50146000	Río Grande de Añasco above Río Cañas nr Añasco	181600	670805	1979	P*
50147600	Río Culebrinas near San Sebastián	182051	670240	1979	P
50149100	Río Culebrinas near Aguada	182403	670940	1969	P*

#Previously 50046000

APPENDIX D

GROUND-WATER SITES

[Lat., latitude; Long., longitude; *, well equipped with recorder]

Local Well Number	Station Name	Lat.	Long.
	ACTIVE WELLS NETWORK IN PUERTO RICO AS OF 12/31/88		
* 6	Juana 5	175858	661002
* 70	Sabana Hoyos	182647	662017
* 83	San Sebastián Well	182018	665932
* 87	Alomar 1	175829	662322
* 96	Yabucoa 7	180415	655139
*132	PPG 4 or Yauco 2	180133	665033
*143	Vivoni - Col. Amistad	180132	670338
*165	Mateo Pérez-Saltos #1	182422	670151
*200	Aguadilla Cement Well	182442	670917
*202	Carmelo Barreto	182647	665524
*204	Gilberto Rivera	182737	663709
*205	NC-5 Barceloneta	182544	663415
*206	Plazuela No. 2	182757	663256
*207	Cantito La Luisa	182710	663037
*210	Gelo Martínez	182308	662604
*211	Rosario No. 3	182615	662353
*212	Ponderosa TW-1	182515	661940
*213	Pampano No. 2	182330	661857
*214	Dorado Beach No. 7	182746	661708
*216	Pozo Navy	182530	661354
*217	Monserrate	182655	661424
*218	Levittown No. 7	182623	661110
*219	Fort Buchanan No. 1	182441	660826
*220	Parque San Luis Rey	182413	660440
*221	Hyde Park TW-10	182436	660312

*222	Campo Rico TW-1	182515	655941
*	HW-TW-01	180002	661322
*	HW-TW-02	180017	661321
*	HW-TW-03	180001	661220
*	HW-TW-04	180000	661252
*	HW-TW-05B	175947	661306
*	HW-TW-07	180006	661237
*	HW-TW-08	175939	661214
*	HW-TW-10	175950	661252
*	HW-TW-11	180012	661255
*	HW-TW-13	175957	661234
*	HW-TW-14	175946	661020
*	HW-TW-15	175955	661030

ACTIVE WELLS IN ST. CROIX, U.S. VIRGIN ISLANDS AS OF 12/31/88

1	Fairplains 6	174225	644719
2	*Fairplains 2/USGS 10	174225	644720
3	*Golden Grove 6	174243	644751
4	Golden Grove 1	174245	644758
6	*Adventure 28	174303	644844
7	Concordia 14	174525	644606
8	Concordia 1	174527	644601
9	Concordia 7	174532	644603
10	Barren Spot 5	174329	644547

ACTIVE WELLS IN ST. THOMAS, U.S. VIRGIN ISLANDS AS OF 12/31/88

1	Family Well/USGS-8	182050	645804
2	Mahogany Run 15	182138	645431
3	Mahogany Run 16	182138	645425
4	Mahogany Run 17	182136	645419
5	Donoe 3	182029	645352
6	*Grade School 3	182038	645503

ACTIVE WELLS IN ST. JOHN, U.S. VIRGIN ISLANDS AS OF 12/31/88

1	NPS 2/Cruz Bay	182010	644726
2	NPS 5/Trunk Bay	182109	644603
3	*NPS 6/Cinnamon Bay	182116	644510
5	*DPW 6/Sussanaberg	182042	644545
6	DPW 5/Sussanaberg	182044	644546
7	DPW 4/Sussanaberg	182044	644548
8	DPW 3/Sussanaberg	182044	644549
9	DPW 2/Sussanaberg	182044	644550
10	DPW 1/Sussanaberg	182044	644552
11	*Guinea Gut	181956	644645