HYDROLOGY AND WATER QUALITY OF THE PRINCIPAL SPRINGS IN PUERTO RICO

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

The following conversion table is included for the convenience of those who prefer to use the SI (International System of Units or metric units) rather than the inch-pound system of units. Concentrations of chemical parameters are given in milligrams per liter (mg/L) or micrograms per liter (ug/L), which are for the values presented numerically equal to parts per million (ppm) and parts per billion (ppb) respectively. Specific conductance values are given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Multiply inch-pound units	By	To obtain metric units
	Length	
inches (in.)	25.40	millimeters (mm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	4,047	square meters (m^2)
miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	liters (L)
acre-feet (acre-ft)	1,233	cubic meters (m^3)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
cubic miles (mi^3)	4.168	cubic kilometers (km^3)
million gallons (Mgal)	3,785	cubic meters (m^3)
	Volume Per Unit Time	
gallons per minute (gal/min)	0.06308	liters per second (L/s)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
	Temperature	
degrees Fahrenheit (°F)	°C = 0.56 (°F-32)	degrees Celsius (°C)
	Specific Conductance	
micromhos per centimeter at 25 degrees Celsius (umhos/cm at 25°C)	1.0	microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C)

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ABSTRACT

Springs are a valuable natural resource in Puerto Rico that can be utilized to supplement domestic water-supply sources or for recreational purposes. The hydrology and water quality of the principal springs in Puerto Rico were investigated from 1982-84. Seventeen springs were selected for the study to determine flow and physical, chemical, and bacteriological characteristics of spring-water. Most of the springs (14) are located in the north coast limestone area. Two springs on the south coast have thermal properties. Maximum recorded springflow occurred at San Pedro Spring near Arecibo, where as much as 35 cubic feet per second (about 22.6 million gallons per day) were discharged. Average springflow from the 17 springs totals 36 cubic feet per second (approximately 23.5 million gallons per day).

Calcium, bicarbonate, sodium, chloride, and sulfate are the principal ions in spring water. Most of the springs along the north coast have waters of the calcium-magnesium-bicarbonate type. Several springs in coastal areas are affected by seawater intrusion and the waters are of the sodium-chloride type. Baños de Coamo near Coamo are the most important thermal springs, discharging from 0.05 to 0.13 cubic feet per second (32,000 to 83,000 gallons per day). Mean daily water temperature at this spring is 43 degrees Celsius. Fecal coliform and fecal streptococci bacteria are present in most of the springs in concentrations ranging from 1 to 2200 colonies per 100 milliliters of sample.

INTRODUCTION

There are a large number of fresh and saline-water springs throughout Puerto Rico, some of which discharge significant amounts of water. The springs are a valuable natural resource that could be utilized to supplement domestic water supply sources or used for recreational purposes.

Until recently, the magnitude of the flow and quality of the water from those springs had not been investigated in detail. In 1982, in cooperation with the Water Resources Research Institute of the University of Puerto Rico (WRRI-UPR) and the Puerto Rico Department of Natural Resources, the U.S. Geological Survey began a two-year study of the hydrology and geochemistry of the principal springs of the island. Preliminary results of the data collected through 1983 were published in the report "Reconnaissance of the Principal Springs of Puerto Rico, 1982-83" (Guzmán-Ríos, 1983). This report summarizes the data collected during the project and presents an analyses of the hydrology and water quality of the springs included in the investigation.

INTRODUCTION (Continued)

Purpose and Scope

The principal objectives of the investigation were to determine the principal physical, chemical and bacteriological characteristics of the springs and to evaluate their use for water supply or recreational purposes.

The objectives were accomplished by measuring the instantaneous discharge from the springs at different times during the year and to determine any seasonal variations. At selected springs, discharge was measured on a continuous basis to establish a data base necessary for future development of water resources. Water samples were collected from the 17 springs twice during the study and analyzed to better define the chemistry and quantify the concentrations of possible contaminants in ground waters. Bacteriological analyses were also performed to quantify the fecal coliform and fecal streptoccocal bacteria in ground waters and better define the suitability of the water for human consumption and recreational purposes. Field determinations were made for pH, total alkalinity, specific conductance, and temperature.

Continuous-recording gaging stations were installed at three of the springs to record water stage and relate it to discharge measurements. At one of the springs, continuous monitoring devices were installed to record specific conductance and temperature on an hourly basis. Records of springflow and water quality provide a good measure of long-term hydrologic trends. A spring is more representative of the character of a large part of an aquifer than a ground-water well.

Methods and Procedures

Water samples from each of the springs included in the investigation were collected at least twice during the study period. The samples were collected as close to the spring's source as possible utilizing methods described by Wood (1976). During the August 1983 sampling, La Cambija Spring at Caño Tiburones was sampled 100 ft. below the previous sampling site for reasons of inaccessibility. Pozo de la Virgen near Sabana Grande was not sampled because it was dry. Determinations made in the field included pH, specific conductance, temperature, total alkalinity as $CaCO_3$, and concentration of the fecal coliform and fecal streptoccocal group of bacteria. Raw water samples were filtered at the site and preserved for further analyses according to procedures described by Brown and others (1970). The samples were analyzed at the U.S. Geological Survey National Water Quality Laboratory-Atlanta in Doraville, Georgia for most common ions (Ca, Mg, Na, K, Cl, SO_4, F, SiO_2, Br), trace metals (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Se, Sr, V, Zn), nutrients (total nitrogen, nitrite plus nitrate, ammonia, ammonia plus organic nitrogen, and phosphorus), dissolved cyanide organic carbon (DOC) and dissolved cyanide (CN), and total sulfide (S). Results for nutrients, DOC, CN, and S were published in a previous report (Guzmán-Ríos, 1983). Procedures described by Greeson and others (1977) were used for the collection and analyses of the bacteria samples. Immediately after filtering through 0.70 micrometers filters, incubation of the bacteria samples began.

Methods and Procedures (Continued)

Springflow measurements were made at most of the springs at least five times during the study period. Methods described by Rantz and others (1982) were utilized for the flow measurements. At three of the springs (Ojo del Agua at Vega Baja, San Pedro near Arecibo, and Baños de Coamo near Coamo) recording devices were installed to measure the springflow on a continuous basis. The temperature and specific conductance at the Baños de Coamo spring was also monitored on a continuous basis with a recording instrument.

Previous Investigations

A previous study by Giusti (1978) showed that virtually hundreds of springs existed throughout Puerto Rico. Most of the springs occur along the north-coast limestone belt from Aguada to Loíza. A field reconnaissance in November 1982 led to the selection of 17 springs to meet the objectives of this study. The main selection criterion was spring discharge greater than 0.01 cubic ft^3/s (approximately 6,500 gal/d).

Springs Numbering System

Locations of the springs included in this survey and the geologic formations of Puerto Rico are shown in figure 1. Fourteen (14) of the springs occur within the limestone formations of the north coast. An arbitrary numbering system was utilized to identify the springs in this report. The spring closest to San Juan was assigned the number one (1). Numbering of the springs proceeds in a counterclock-wise direction around the island. Latitude-longitude identifiers were determined and are included in table 1 with the name of each spring.

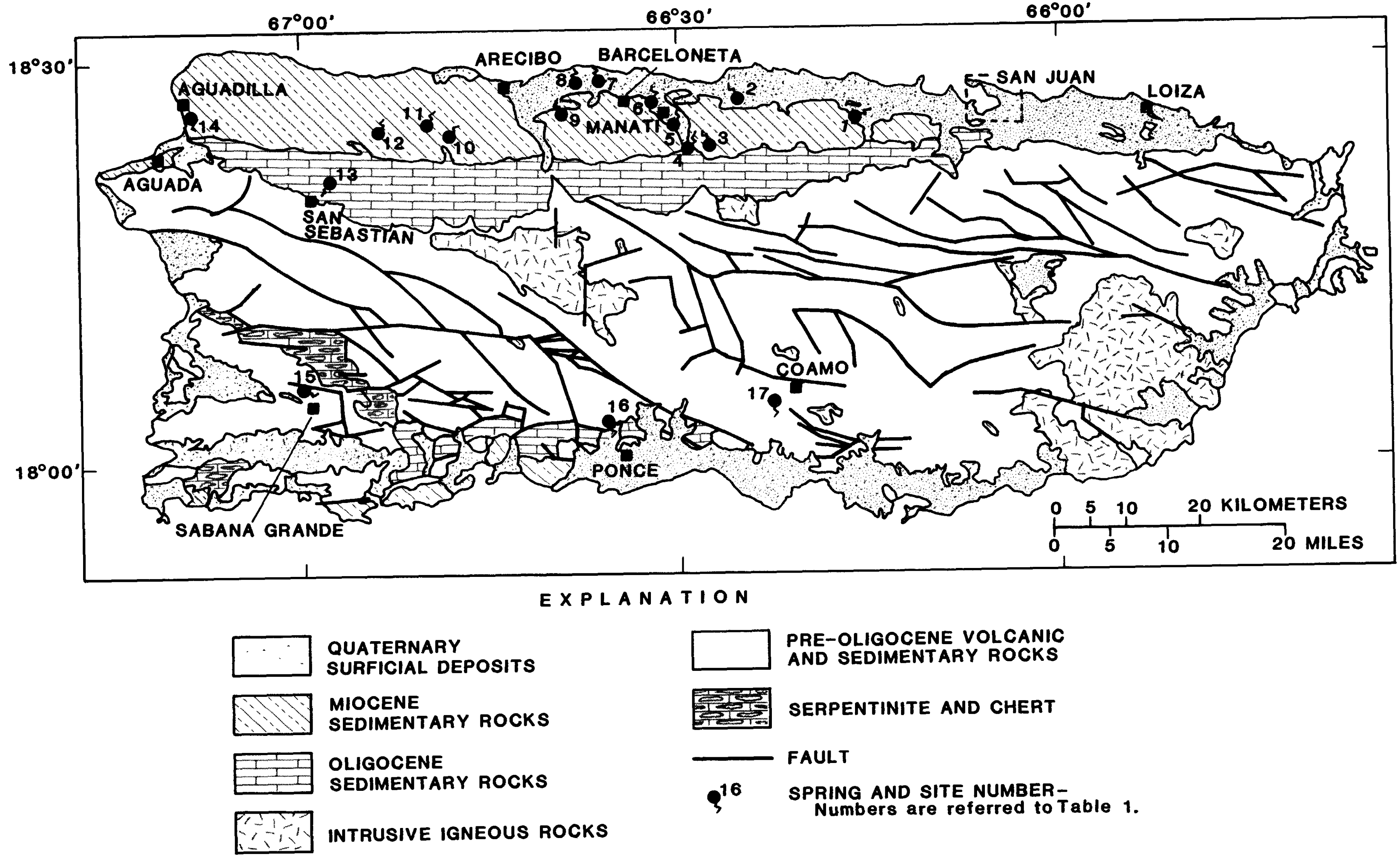

Figure 1.--Surficial geology and location of springs.

Table 1. Site number, latitude and longitude, and name of principal springs in Puerto Rico

Map No.	Latitude & Longitude	Spring Name
1	18°24'46"N. 66°15'55"W.	Maguayo spring at highway 693 near Dorado
2	18°26'57"N. 66°25'06"W.	Ojo de Agua spring at Vega Baja
3	18°20'04"N. 66°26'38"W.	Ojo de Agua at Torrecillas near Morovis
4	18°20'19"N. 66°28'53"W.	Represa Sonadora de Ciales at Ciales
5	18°22'18"N. 66°29'10"W.	Aguas Frías spring near Ciales
6	18°25'41"N. 66°31'36"W.	Ojo de Guillo spring near Manatí
7	18°28'25"N. 66°35'53"W.	La Cambija spring at Caño Tiburones
8	18°27'24"N. 66°39'20"W.	Zanja Fría spring at Caño Tiburones
9	18°24'35"N. 66°41'45"W.	San Pedro spring near Arecibo
10	18°24'10"N. 66°47'43"W.	Sonadora spring near Camuy
11	18°23'59"N. 66°48'16"W.	Tiburón spring near Camuy
12	18°23'44"N. 66°53'44"W.	Sumbadora spring at Los Puertos near Camuy
13	18°20'06"N. 66°56'46"W.	Salto Collazo spring near San Sebastián
14	18°26'02"N. 67°09'17"W.	Ojo de Agua spring at Aguadilla
15	18°05'43"N. 66°56'50"W.	Pozo de la Virgen near Sabana Grande
16	18°02'24"N. 66°36'42"W.	Baños Quintana near Ponce
17	18°02'19"N. 66°22'25"W.	Baños de Coamo near Coamo

HYDROGEOLOGIC SETTING

The Origin of Springs in Puerto Rico

Springs occur in many geologic settings and have been classified as to their source, cause, discharge, temperature, and variability. Springs may result from volcanic activity, rock fissures, depressions in the terrain, artesian conditions, contact between formations of different porosity, solution channels, or fractures in the rocks (Bryan, 1919). The water discharging from springs is one element in the hydrologic cycle (fig. 2). Water that infiltrates to the subsurface may eventually be discharged as springflow.

Thermal springs can be produced by chemical reactions (nuclear and non-nuclear) below the surface (Young and Lewis, 1982). Energy-producing reactions (exothermic) may heat the ground water, which may escape to the surface through fissures due to the temperature-pressure gradient.

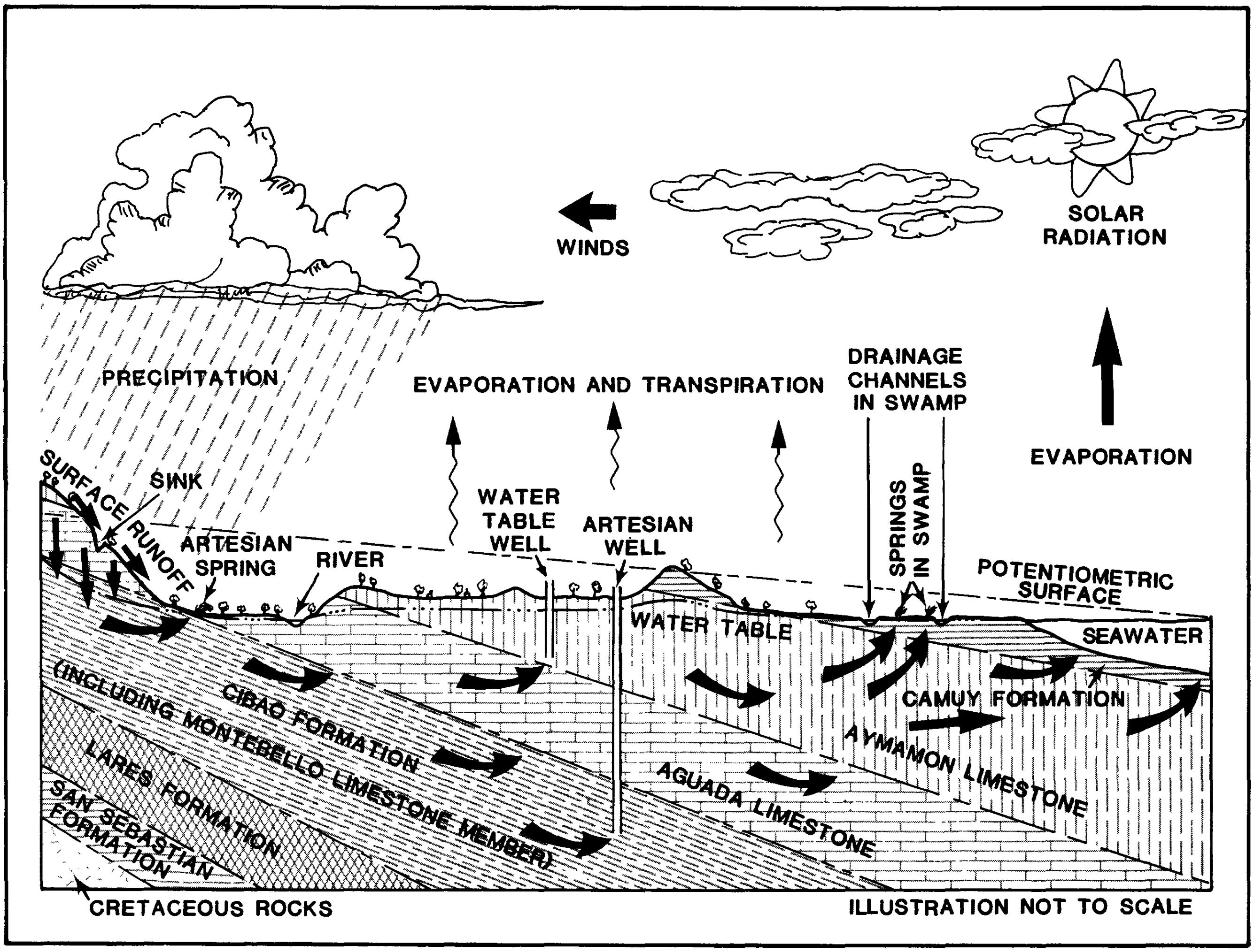

Figure 2.--The hydrologic cycle on the north coast of Puerto Rico.

The Origin of Springs in Puerto Rico (Continued)

Depression, contact, artesian, and solution conduit springs are all affected by hydrostatic pressures. Depression springs occur when the land surface slopes down to the water table. Contact springs result from the difference in porosity between two adjoining geologic formations. Water moving from one formation into another of less permeability may not infiltrate completely. This excess water may discharge to the surface in response to increasing hydrostatic head. Artesian springs result from the effects of a confining layer on an aquifer. The water under pressure from the confined aquifer may be released at an outcrop of the aquifer. A fissure, fracture, or a more permeable facies may also be the outlet for the artesian spring. Conduit or solution-channel springs occur when the aquifer or soil material is easily dissolved, creating a pathway for water to discharge to the surface. A hydrostatic head greater than the elevation of the outlet is required to produce the flow. In Puerto Rico, all of these types of springs are known to occur.

The principal springs in Puerto Rico occur mostly in limestone or volcanic rocks. Along the north coast, where the average annual precipitation is about 70 inches per year, (Calvesbert, 1961) springflow occurs from each of the limestone formations described by Monroe (1980). Although precipitation is high (80 in/yr) in the central part of the island, springflow issuing from the volcanic rocks is low. Along the south coast a much lower average annual precipitation rate (35 in/yr), and aquifers of much lower permeability (limestone and alluvial sediments), inhibit spring occurrence.

Principal Springs of the North Coast

Springs of the north coast are associated with various limestone formations that occupy an area of about 620 mi^2 between Aguada and Loíza (fig. 3). About one fifth of the island is covered by a tropical karst formed on a series of six limestone formations: San Sebastián Formation, Lares Limestone, Cibao Formation, Aguada Formation, Aymamón Limestone, and Camuy Formation. The San Sebastián formation underlies all the other limestone formations (Monroe, 1980). It consists primarily of clay and sandy clay, has a low permeability and in many areas acts as a confining layer. The Ojo de Agua spring at Torrecilla (number 3 in fig. 3) issues from the San Sebastián Formation.

The springs Represa Sonadora near Ciales, Aguas Frías near Ciales, and Salto Collazo near San Sebastián (numbers 4, 5, and 13, fig. 3) emerge from the Lares Limestone. Aguas Frías spring is the resurgence of the Río Encantado cave system. Represa Sonadora and Salto Collazo springs flow from the vicinity of the contact with the San Sebastián Formation, and may result from the differences in permeabilities between the two geologic formations. The Lares Limestone is predominantly calcium carbonate ($CaCO_3$) with varying permeability, but in general is much more permeable than the San Sebastián Formation (Giusti, 1978).

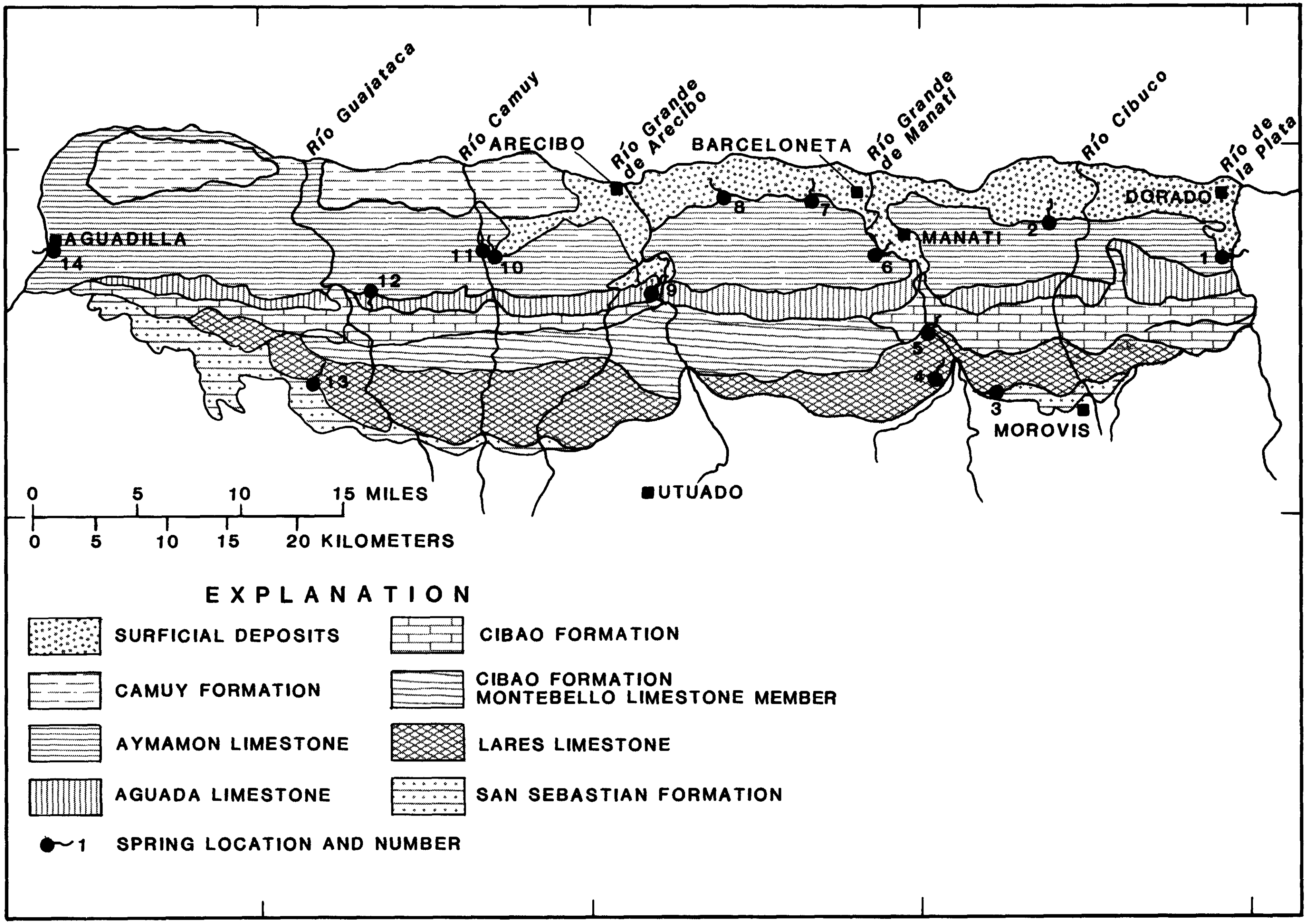

Figure 3.--Geologic formations of the north coast limestone area. (Adapted from Giusti, 1978.)

HYDROGEOLOGIC SETTING (Continued)

Principal Springs of the North Coast (Continued)

The San Pedro spring near Arecibo, one of the largest springs in the island, and Sonadora and Tiburon springs near Camuy, emerge from the Cibao Formation (numbers 9, 10, and 11, fig.3). San Pedro spring issues from the top of the Montebello Limestone Member of the Cibao Formation. This limestone is confined by clastic layers in the upper Cibao Formation (Giusti, 1978). The Montebello Limestone Member is one of the most productive artesian aquifers of the north coast of Puerto Rico (Monroe, 1980). Sonadora spring and Tiburon spring emerge from the upper part of the Cibao Formation or from the contact zone between the Cibao Formation and the overlaying Aguada Limestone.

The Maguayo spring near Dorado, Sumbadora spring near Camuy, and Ojo de Agua at Aguadilla, discharge from the upper part of the Aguada Limestone (numbers 1, 12 and 14, fig. 3). The Aguada Limestone is generally a hard, thick-bedded, layered limestone, alternating with chalky and rubbly layers and fair to poor permeability. Ojo de Agua at Aguadilla is near the coast, higher in the formation than the other locations of ground-water discharge from the aquifer (Giusti, 1978).

The more numerous springs along the north coast issue from the Aymamón Limestone. Ojo de Agua near Vega Baja, Ojo de Guillo near Manatí, La Cambija and Zanja Fría at Caño Tiburones, (numbers 2, 6, 7, and 8, fig.3) flow from this formation. The Aymamón Limestone is the most permeable of the limestone formations of the north coast. Permeability due to solution is common in the outcrops of the formation. These four springs flowing from the Aymamón are located near the contact zone with the blanket sands that overlie the Aymamón Limestone in the north coastal plains.

Principal Springs of the South Coast

The other three springs included in this investigation flow from volcanic rocks along the south coast near Sabana Grande, Ponce, and Coamo where springflow is limited by lower precipitation. Two of the springs (Baños Quintana near Ponce and Baños de Coamo near Coamo), (numbers 16 and 17, fig.1) have higher than normal water temperatures (thermal properties). The source of these springs is unknown, although several hypotheses have been suggested. Giusti (1973) suggested that the natural geothermal gradient of the earth with depth could be the heat source. The springs are recharged locally probably along fault zones where water may travel to depths of 4,000 to 5,000 ft. The water would be heated by the increase in temperature in the Earth's crust. A fault or fracture would allow the water to reach the surface at a temperature much higher than when it entered the recharge area. The springflow is produced by the head differential between the points of recharge and discharge, and temperature-pressure differentials. The water temperature probably decreases slightly as it rises and mixes with infiltration from local rainfall.

HYDROGEOLOGIC SETTING (Continued)

Principal Springs of the South Coast (Continued)

Another hypothesis suggests that exothermic chemical reactions could be occurring with a large amount of heat generated, absorbed and transported by the water. A typical example of this condition is the reduction of sulfate (SO_4^{2-}) by sulfate bacteria in anaerobic condition as occurs in sanitary landfills. In those places, the temperature is known to increase by as much as 12 degrees Celsius (°C) above mean ambient temperature (Gómez-Gómez, 1980). However, a source of organic carbon would have to be available for this process.

The third spring investigated along the south coast (Pozo de la Virgen Spring near Sabana Grande, number 15, fig. 1) is small and intermittent during periods of low rainfall. The spring is located within the volcanics rocks of central Puerto Rico. Its ephemeral flow indicates that it originates from small fractures replenished by recharge from rainfall. It has more importance as an attraction to religious groups than as a potential water resource.

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS

Physical Characteristics

Springflow

Flow magnitude is the most important physical characteristic of a spring that may be developed as a water-supply source. A system for spring classification based on discharge magnitude was developed by Meinzer (1927). An order of magnitude from 1 to 8 was assigned on the basis of flow as follows (modified from Meinzer):

ORDER OF MAGNITUDE	AMOUNT OF FLOW ft^3/s
1	> 100
2	10 to 100
3	1 to 10
4	0.222 to 1.0
5	0.022 to 0.222
6	0.002 to 0.02
7	<0.002
8	<0.0002

On the basis of the above classification system, the breakdown for the seventeen springs considered in this study is as follows:

ORDER OF MAGNITUDE	NUMBER OF SPRINGS
3	6
4	5
5	4
6	2

Table 2. Instantaneous water discharge of the principal springs of Puerto Rico, 1982-84

[Abbreviations: ft^3/s=cubic feet per second; Mgal/d=Million gallons per day; --- no data available]

SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)
1	Dec. 6, 1982	0.52 (0.34)	4	Aug. 5, 1983	0.16 (0.10)	9	Apr. 26, 1983	12 (7.8)	12	Nov. 23, 1983	0.36 (0.23)
	Mar. 3, 1983	.40 (.26)		Jan. 25, 1984	.27 (.17)		June 24, 1983	16 (10)	13	Dec. 1, 1982	.44 (.28)
	Apr. 28, 1983	1.7 (1.1)	5	Dec. 16, 1982	10 (6.5)		July 21, 1983	8.1 (5.2)		Feb. 23, 1983	.17 (.11)
	Aug. 5, 1983	.77 (.50)		Mar. 3, 1983	10 (6.5)		Aug. 3, 1983	8.4 (5.4)		Apr. 27, 1983	.17 (.11)
	Jan. 30, 1984	.80 (.52)		May 3, 1983	11 (7.1)		Sept. 7, 1983	5.0 (3.2)		Aug. 3, 1983	.03 (.02)
2	Nov. 30, 1982	.63 (.41)		Aug. 11, 1983	6.1 (3.9)		Dec. 6, 1983	7.7 (5.0)		Jan. 24, 1984	.09 (.06)
	Mar. 3, 1983	.90 (.58)		Jan. 25, 1984	5.3 (3.4)		Mar. 23, 1984	3.3 (2.1)	14	Dec. 2, 1982	2.1 (1.4)
	Apr. 28, 1983	1.3 (.84)	6	Nov. 30, 1982	1.6 (1.1)		May 18, 1984	4.2 (2.7)		Feb. 23, 1983	.70 (.45)
	July 21, 1983	.33 (.21)		Mar. 2, 1983	.95 (.61)		June 26, 1984	6.5 (4.2)		Apr. 28, 1983	1.0 (.65)
	Aug. 11, 1983	3.9 (2.5)		Apr. 28, 1983	1.5 (.98)	10	Dec. 14, 1982	.24 (.16)		Aug. 3, 1983	1.0 (.65)
	Dec. 6, 1983	3.0 (1.9)		Aug. 4, 1983	1.5 (.98)		Mar. 2, 1983	.03 (.02)		Jan. 30, 1984	.48 (.31)
	Jan. 30, 1984	--- ---		Jan. 30, 1984	.94 (.61)		Apr. 27, 1983	.10 (.06)	15	Dec. 2, 1982	.01 (.01)
	Mar. 23, 1984	.29 (.19)	7	Dec. 8, 1982	9.2 (6.0)		Aug. 9, 1983	.14 (.09)		Feb. 23, 1983	.00 (.00)
	May 18, 1984	.98 (.63)		Feb. 24, 1983	9.0 (5.8)		Nov. 23, 1983	.16 (.10)		Apr. 29, 1983	.00 (.00)
	June 26, 1984	1.2 (.78)		Apr. 26, 1983	9.4 (6.1)	11	Dec. 7, 1982	.58 (.37)		Aug. 10, 1983	DRY
3	Dec. 9, 1982	.18 (.12)		Aug. 4, 1983	9.9 (6.4)		Mar. 2, 1983	.29 (.19)	16	Dec. 15, 1982	.03 (.02)
	Feb. 24, 1983	.17 (.11)		Mar. 29, 1984	7.5 (4.8)		Apr. 27, 1983	.67 (.43)		Feb. 25, 1983	.01 (.01)
	May 3, 1983	.19 (.12)	8	Dec. 8, 1982	10 (6.5)		Aug. 8, 1983	.53 (.34)		Apr. 29, 1983	.02 (.01)
	Aug. 5, 1983	.04 (.03)		Feb. 24, 1983	7.3 (4.7)		Nov. 23, 1983	.72 (.42)		Aug. 10, 1983	.02 (.01)
	Jan. 25, 1984	.02 (.01)		Apr. 26, 1983	9.3 (6.0)	12	Dec. 7, 1982	.58 (.37)	17	Dec. 3, 1982	.11 (.07)
4	Dec. 9, 1982	.54 (.35)		Aug. 4, 1983	9.5 (6.1)		Mar. 2, 1983	.23 (.15)		Feb. 25, 1983	.06 (.04)
	Feb. 24, 1983	.27 (.17)	9	Dec. 1, 1982	16 (10)		Apr. 27, 1983	.36 (.23)		Apr. 29, 1983	.09 (.06)
	May 3, 1983	.26 (.17)		Feb. 23, 1983	8.4 (5.4)		Aug. 9, 1983	.38 (.25)		Aug. 10, 1983	.06 (.04)

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS (Continued)

Physical Characteristics (Continued)

Springflow (Continued)

Except for the Pozo de la Virgen Spring near Sabana Grande all of the springs were perennial during the study period (table 2). Interviews with local residents indicate that perennial flow occurs in the other springs even during long droughts. Along the north coast, the abundance and uniformity of rainfall is probably the main factor for maintaining perennial flow conditions. The flow of the thermal springs of the south coast appears to respond to factors other than precipitation, as they are not affected significantly by limited rainfall.

Average springflow from the 17 springs totals 36 ft^3/s (23.5 Mgal/d). However, the total amount of springflow available from springs throughout Puerto Rico may be as much as 50 ft^3/s (32 Mgal/d) including known springs not considered in this study.

Springflow throughout Puerto Rico generally varies seasonally in response to precipitation. Data from continuous recording instruments at the gaged springs, as well as the instantaneous measurements at the other springs, show seasonal fluctuations. At Ojo del Agua at Vega Baja the mean daily flow ranged from 0.42 to 9.4 ft^3/s (table 3 and fig. 4). Springflow was maximum during the rainy season (October to December), and declined thereafter. In early May, springflow increased in response to higher rainfall recharge.

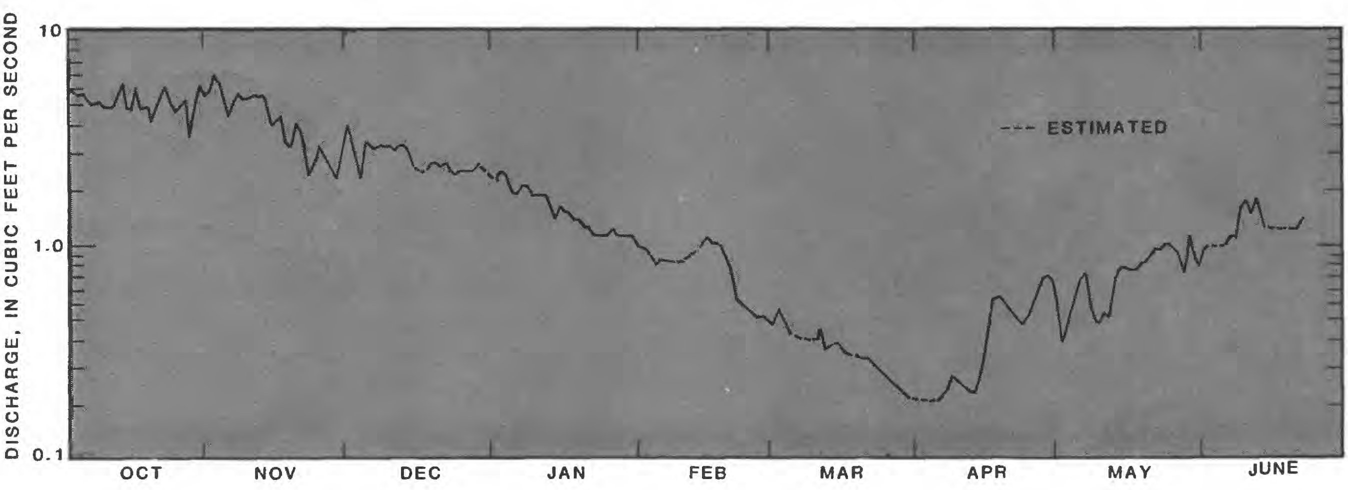

Figure 4.--Springflow at Ojo de Agua at Vega Baja.

Table 3. Mean daily discharge of Ojo de Agua at Vega Baja, in million gallons per day (Mgal/d), July 1983-June 1984

DAY	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE
1		2.8	5.4	5.9	5.8	3.6	2.6	2.0	0.74	0.56	0.58	0.88
2		3.7	5.2	5.5	9.4	3.0	2.9	2.0	.76	.60	.54	.85
3		4.1	5.2	5.4	6.2	2.5	3.1	1.8	1.3	.80	.52	.70
4		4.7	5.4	5.1	5.2	2.0	2.9	1.7	.76	.84	.56	.73
5		4.6	5.5	5.2	5.0	3.0	2.4	1.8	.78	.70	.67	.85
6		5.8	5.2	5.8	5.1	2.9	2.3	1.9	.76	.72	.65	.98
7		5.4	5.4	4.8	4.3	2.9	2.7	1.9	.74	.56	.61	.98
8		3.9	5.4	4.3	5.0	3.0	2.7	1.9	.78	.78	.69	1.5
9		3.9	5.0	5.0	5.4	3.1	2.5	1.9	.74	.52	.54	1.8
10		2.0	4.7	5.8	5.7	3.2	2.5	1.8	.74	.46	.98	1.5
11		2.5	6.0	5.9	5.0	3.0	2.5	1.9	1.3	.56	.75	1.9
12		3.4	3.5	5.8	5.0	3.4	2.6	1.9	1.1	.62	.86	1.5
13		2.6	3.7	5.8	5.2	3.3	2.4	1.5	1.0	.66	.91	1.1
14		3.0	3.7	6.2	5.3	3.0	2.5	1.6	.96	.70	.89	1.0
15		3.5	3.8	6.4	5.4	3.1	2.8	1.4	.80	.56	.78	.96
16		3.6	3.9	7.1	3.2	3.2	2.7	1.3	.98	.50	.72	.88
17		4.3	4.2	7.4	3.6	3.4	2.5	1.2	.76	.56	.69	.84
18		4.4	5.2	6.3	2.9	3.3	2.3	1.2	.70	.57	.69	1.0
19		4.4	5.3	5.3	3.6	3.6	2.2	1.0	.82	.54	.69	1.2
20		6.3	5.5	7.4	4.3	3.6	2.1	1.0	.96	.50	.76	1.0
21	1.8	5.0	5.6	6.5	3.1	3.4	1.9	1.3	.80	.47	.85	1.2
22	2.0	3.8	6.1	6.0	2.6	3.5	1.8	1.8	.54	.44	.86	
23	.95	4.6	6.4	6.5	2.2	3.1	1.8	1.6	.54	.42	.93	
24	1.7	4.7	6.0	7.2	2.4	2.9	1.9	1.5	.58	.45	.86	
25	2.2	5.2	5.5	6.1	2.9	3.0	1.8	1.4	.60	.55	.81	
26	.90	3.8	5.4	5.2	2.7	3.2	1.8	1.0	.88	.62	.71	
27	1.0	3.5	5.3	5.8	2.4	3.3	1.9	.75	.84	.71	.62	
28	1.1	3.0	5.4	6.6	2.2	5.1	1.9	.78	.58	.70	1.0	
29	1.3	2.7	5.3	7.7	2.0	5.5	2.0	.74	.54	.63	.72	
30	2.0	3.6	5.8	7.1	2.8	6.0	2.0	--	.52	.61	.63	
31	2.3	5.4	--	6.8	--	3.4	2.0	--	.54	--	.81	

Springflow (Continued)

At the San Pedro Spring near Arecibo mean daily flows ranged from 3.1 to 35 ft^3/s (table 4 and fig. 5). Seasonal effects of rainfall are also evident at this spring. The San Pedro spring is also affected by high stages of Río Tanamá, located about two kilometers from the spring outlet. A comparison of the flow at the spring with precipitation at Arecibo Observatory Station (NOAA) and with flow in the Río Tanamá near Utuado headwaters and at Charco Hondo (near the spring) shows a significant correlation (fig. 6). The Río Tanamá drains through the Aymamón Limestone, where cavities are common. A hydraulic or hydrostatic connection between the river and the spring apparently exists as indicated by the movement to the spring of dye placed in the Río Tanamá (Jordan, 1970).

A loss in water discharge of Río Tanamá occurs between the gaging station (50028400), at Charco Hondo, and a point about 2.5 miles upstream (Jordan, 1970). The amount of water lost from the river is probably delivered to San Pedro spring.

Table 4. Mean daily discharge of San Pedro Spring near Arecibo, in million gallons per day (Mgal/d), June 1983-June 1984

DAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE
1		14	8.5	7.1	6.5	15	7.4	6.3	5.3	5.1	3.4	4.2	4.3
2		14	8.5	6.8	6.3	14	7.4	6.2	5.3	4.7	3.4	4.2	4.2
3		14	8.4	6.7	6.1	15	7.5	6.2	5.3	4.1	3.4	4.4	4.1
4		13	8.3	6.8	6.0	28	7.5	6.5	5.2	4.1	3.3	4.7	5.8
5		15	7.7	6.8	6.0	25	7.6	6.4	5.1	4.0	3.5	4.5	7.4
6		14	7.4	6.8	5.9	20	7.6	6.5	5.1	4.0	3.5	4.6	35
7		13	7.5	6.4	6.8	18	7.6	6.5	5.1	3.9	3.4	4.6	33
8		13	7.4	6.2	20	17	7.6	6.5	5.0	3.7	3.5	4.5	18
9		12	7.6	6.2	24	16	7.5	6.5	5.1	3.7	3.6	4.8	11
10		10	7.3	6.0	17	14	7.5	6.2	5.4	3.8	3.6	4.7	18
11		9.7	7.2	6.0	15	10	7.5	6.2	5.7	3.8	3.7	4.7	13
12		9.7	8.4	6.1	14	9.5	7.5	6.2	5.2	3.6	3.8	4.8	9.6
13		9.0	7.4	6.0	13	9.1	7.4	6.5	5.0	3.5	3.8	4.9	7.3
14		8.9	7.5	5.9	12	9.0	7.4	6.3	5.4	3.5	3.8	5.1	6.9
15		8.9	7.5	5.9	11	8.7	7.4	6.1	6.0	3.5	3.9	5.0	6.4
16		8.7	7.2	6.0	8.9	8.4	7.2	6.2	6.1	3.5	3.9	5.2	6.1
17		8.8	7.8	6.0	7.7	8.3	7.5	6.0	6.1	3.6	3.9	4.5	9.8
18		8.5	7.5	12	10	8.0	7.8	5.9	6.0	3.5	4.0	4.8	11
19		8.2	7.0	15	21	7.9	7.4	5.9	5.8	3.6	4.0	4.8	9.3
20		8.0	7.0	6.7	29	7.9	7.0	5.9	5.9	3.6	4.0	4.5	7.9
21		8.1	7.2	6.4	26	7.8	6.9	5.9	5.8	3.4	4.0	6.6	8.7
22		8.2	7.3	6.0	22	7.7	6.6	5.8	6.0	3.6	4.1	16	7.8
23		8.2	7.0	6.0	18	7.6	6.5	5.8	5.5	3.2	4.0	11	6.7
24	16	8.6	6.9	6.0	17	7.6	6.5	5.8	5.5	3.2	4.0	13	6.3
25	16	8.3	6.8	6.8	24	7.6	6.5	5.8	5.5	3.1	4.0	7.5	6.1
26	16	8.2	7.0	12	21	7.6	6.5	5.6	5.4	3.3	4.2	7.2	6.3
27	16	8.2	7.3	12	17	7.6	6.6	5.6	5.3	3.2	4.4	13	6.3
28	15	8.2	7.2	11	16	7.6	6.4	5.7	5.1	3.2	4.3	10	6.2
29	15	8.3	6.7	12	16	7.6	6.4	5.8	5.1	3.3	4.3	5.8	6.1
30	14	8.3	7.3	7.7	15	7.5	6.3	5.6	--	3.3	4.3	5.0	6.0
31	--	8.4	7.4	--	15	--	6.5	5.5	--	3.3	--	4.6	--

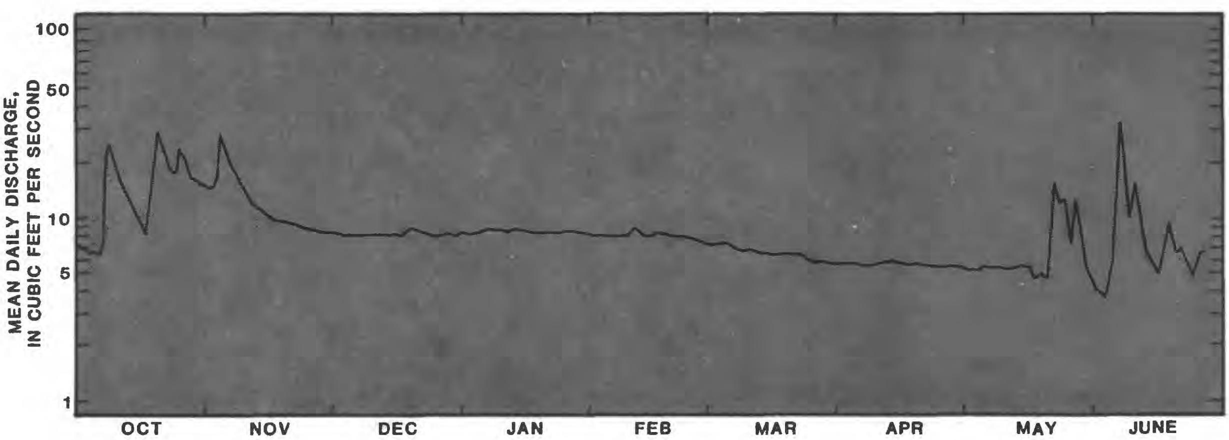

Figure 5.--Hydrograph for San Pedro Spring near Arecibo, October 1983-June 1984.

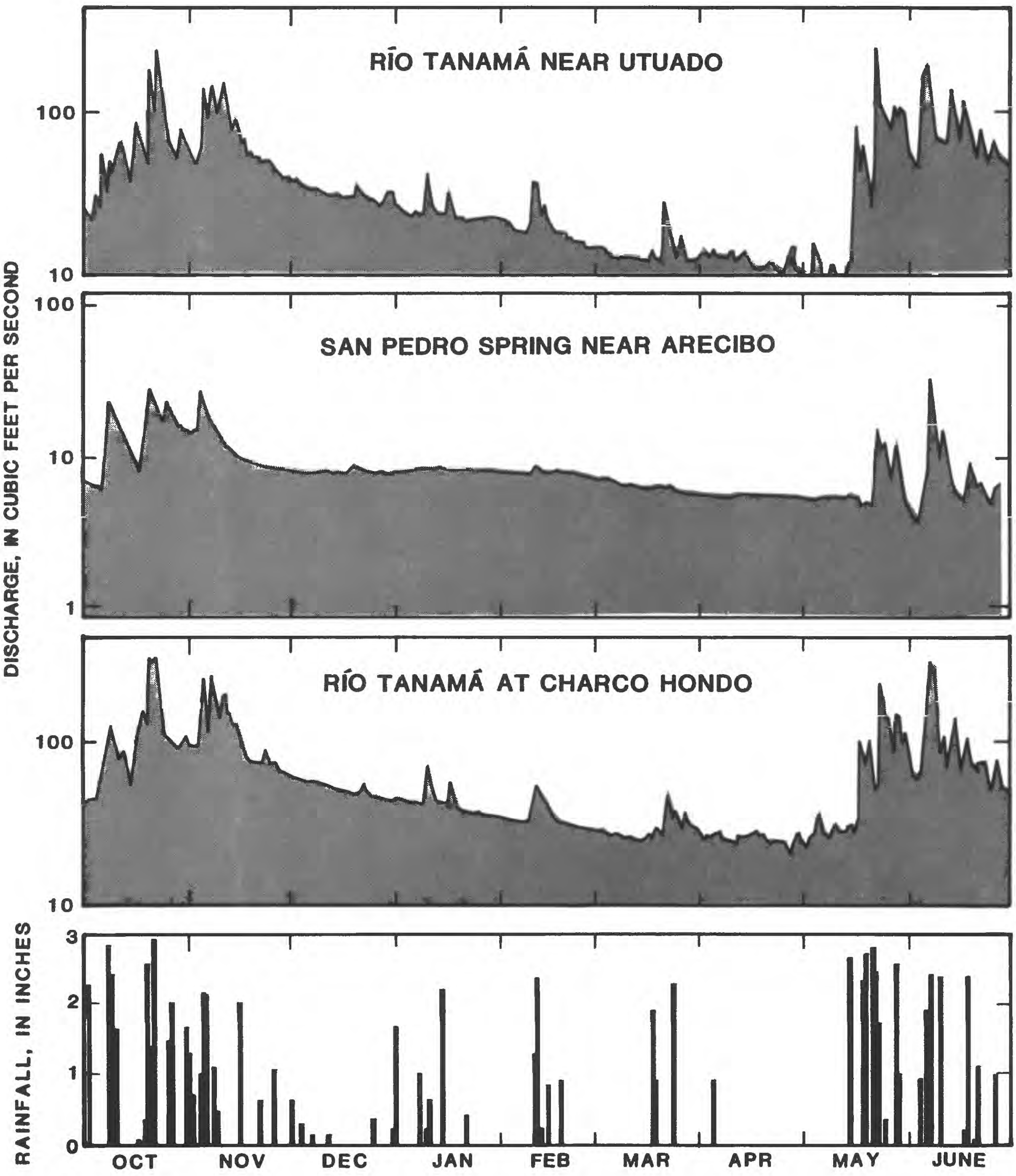

Figure 6.--Comparison of rainfall at Arecibo Astronomical Observatory and discharge at Río Tanamá near Utuado, San Pedro Spring near Arecibo, and Río Tanamá at Charco Hondo, October 1983-June 1984.

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING-WATERS (Continued)

Physical Characteristics (Continued)

Springflow (Continued)

Turbid flow occasionally occurs in some springs in Puerto Rico. At springs that are hydraulically connected to a sediment-laden river, turbid discharge may occur during high river flow. When high river stages inundate the spring opening, the spring flow is decreased. As the river stage lowers, the water that inundated the spring is discharged along with suspended-sediment. In sinkhole areas flooding due to high river stages and surface runoff containing suspended-sediment may recharge shallow aquifers and move quickly through solution channels to discharge from nearby springs. This sediment-laden discharge has been observed at Ojo de Guillo near Manatí and Aguas Frías near Ciales springs.

At Baños de Coamo near Coamo spring, the mean daily flow ranged from 32,000 to 83,000 gal/d during the period of record (fig. 7 and table 5). The Coamo area is in a zone of multiple faults and known seismic activity (Giusti, 1973). Springflow can be affected by earthquakes in areas where faults or fractures are the main source of the water. Seismic movements can increase or decrease the hydraulic connections between openings. Preliminary data from the Baños de Coamo spring suggests that the earthquake of June 30, 1984 may have significantly increased the flow from the springs. Prior to the earthquake, the average discharge was about 60 gal/min. A measurement on July 10, 1984 resulted in a discharge of 110 gal/min. The number of seeps in the spring's area also appears to have increased after the earthquake. Although changes in discharge of springs and appearance of new springs are among the variety of effects that earthquakes have on ground water, more study is necessary to determine this relationship.

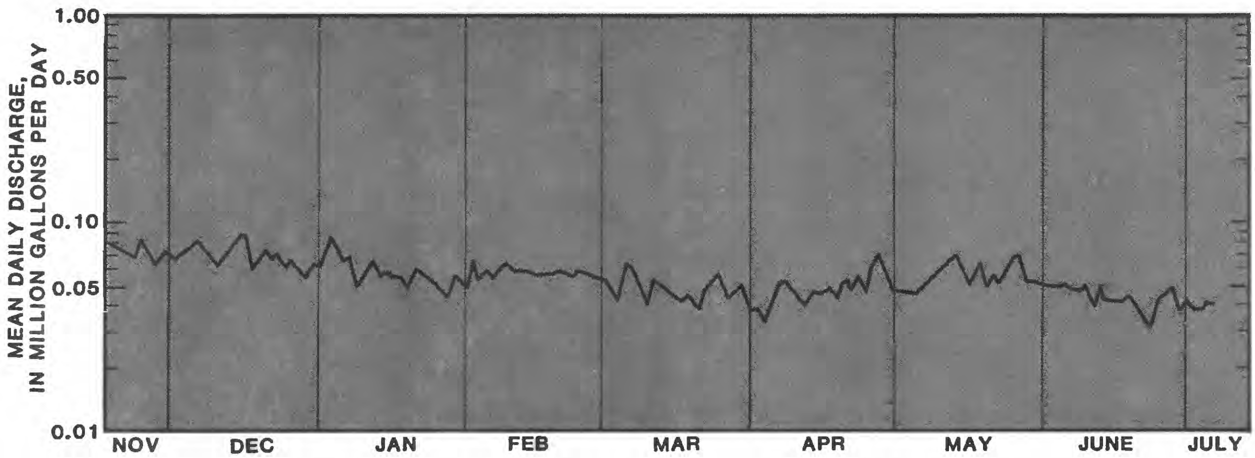

Figure 7.--Hydrograph for Baños de Coamo near Coamo, November 1983-July 1984.

Table 5. Mean daily discharge at Baños de Coamo, in million gallons per day (Mgal/d), November 1983-June 1984

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE
1		0.063	0.068	0.065	0.048	0.040	0.046	0.048
2		.067	.081	.051	.048	.037	.046	.048
3		.070	.075	.054	.041	.035	.046	.049
4		.072	.070	.058	.057	.040	.046	.051
5		.076	.063	.052	.062	.045	.048	.048
6		.078	.067	.055	.059	.051	.050	.048
7		.074	.058	.059	.050	.052	.053	.048
8		.070	.048	.062	.044	.049	.056	.052
9		.066	.053	.061	.040	.046	.059	.044
10		.060	.059	.057	.053	.043	.061	.038
11		.065	.065	.057	.051	.040	.065	.051
12		.069	.059	.057	.049	.043	.070	.043
13		.074	.053	.057	.047	.048	.062	.043
14		.080	.058	.055	.044	.046	.056	.043
15		.083	.053	.055	.044	.045	.050	.044
16		.080	.052	.056	.041	.049	.057	.044
17	0.078	.057	.052	.056	.046	.046	.065	.046
18	.076	.062	.048	.057	.044	.043	.048	.044
19	.073	.067	.052	.057	.041	.051	.053	.041
20	.072	.072	.059	.056	.038	.053	.056	.038
21	.069	.063	.057	.055	.047	.047	.050	.039
22	.067	.069	.054	.054	.052	.056	.056	.032
23	.075	.063	.052	.059	.052	.052	.062	.043
24	.080	.058	.051	.056	.057	.046	.069	.045
25	.073	.065	.048	.055	.049	.061	.069	.048
26	.065	.061	.045	.054	.043	.071	.059	.050
27	.059	.058	.043	.053	.045	.060	.051	.043
28	.066	.054	.055	.052	.048	.053	.051	.038
29	.070	.058	.053	.050	.050	.048	.050	.044
30	.065	.063	.049	--	.043	.047	.050	.043
31	--	.059	.047	--	.038	--	.050	--

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS (Continued)

Physical Characteristics (Continued)

Specific Conductance, pH, and Temperature

Specific conductance, pH, and temperature are among the most important physical properties measured in determining the suitability of springs as a water-supply source. The specific conductance provides an indirect estimate of the concentration of dissolved solids in water, while the pH provides information about the acidity or alkalinity of the sample. Temperature is an important factor when investigating thermal waters, and it can provide information on the source of water to a spring.

The specific conductance of the springs investigated ranged from 360 to 12,100 microsiemens per centimeter (μS/cm). The range indicates that most of the springs resemble ground-water from the areas where they flow. High specific conductance values at the La Cambija and Zanja Fría springs at Caño Tiburones indicate that some saltwater occurs in the adjacent surficial sediments. A recent investigation (Quiñones-Aponte, 1986) indicates that these springs receive flow from Río Grande de Arecibo. A relatively high specific conductance in waters from Baños Quintana spring near Ponce could be due to residual saltwater in the aquifer. At Baños de Coamo Spring, chemical species other than those related to saltwater account for a large portion of the high specific conductance. This is discussed in another section of this report.

The pH of the water from the springs ranged from slightly acid to moderate alkaline (6.7 to 9.3 standard units). The springs along the north coast contain high concentrations of calcium and bicarbonate, which provide a high buffering capacity and maintains the pH of the waters in the slightly alkaline range. Waters from the thermal springs at Ponce and near Coamo contain high concentrations of sulfate, and boron. These constituents form complexes that increase the pH value by hydrolysis and formation of weak bases.

The temperature of the springs other than those with thermal waters varied over a narrow range. Seasonal fluctuations were only a few degrees, with temperatures of the water resembling air temperatures. The near uniform air temperature in Puerto Rico accounts for this condition.

At the Baños de Coamo near Coamo, data from the specific conductance continuous recorder show nearly constant values (table 6). Daily fluctuations in the water temperature are minimal and probably associated with changes in air temperature that affect the water from the point of emergence. The specific conductance is nearly equal to instantaneous values collected during prior samplings.

The average daily temperature of the water at the Baños de Coamo near Coamo ranged from 42.5 to 43.0 °C (table 6). Comparison with the historical data collected by Giusti (1973) does not show any significant change in the temperature of the water. At Baños Quintana near Ponce, instantaneous temperature measurements ranged from 31 to 32 °C.

Table 6. Mean daily specific conductance and temperature of Baños de Coamo near Coamo, February 1983-March 1984

[Specific conductance in microsiemens per centimeter (uS/cm) snd temperature in degrees Celsius (°C)]

DAY	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE
	FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST	
1	2130	43.0	2310	42.6	2270	42.8	2230	43.0	2220	43.0	2220	43.0	2220	43.0
2	2210	42.7	2320	42.6	2270	42.8	2230	43.0	2220	42.9	2220	43.0	2220	43.0
3	2300	42.6	2300	42.6	2270	42.8	2230	43.0	2220	43.0	2220	43.0	2220	43.0
4	2310	42.7	2300	42.6	2270	42.8	2230	43.0	2220	43.0	2220	42.9	2220	43.0
5	2300	42.7	2310	42.6	2260	42.8	2230	43.0	2220	43.0	2220	42.9	2220	43.0
6	2300	42.6	2300	42.6	2260	42.8	2230	43.0	2220	42.9	2220	42.7	2220	43.0
7	2300	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.8	2220	43.0
8	2300	42.7	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.9	2220	43.0
9	2300	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.9	2220	43.0
10	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2220	43.0
11	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2220	43.0
12	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2220	43.0
13	2310	42.6	2290	42.7	2250	42.8	2230	42.9	2220	43.0	2220	43.0	2220	43.0
14	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	43.0	2220	43.0	2220	43.0
15	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	43.0	2220	43.0	2220	43.0
16	2310	42.6	2290	42.7	2250	42.8	2220	43.0	2220	43.0	2220	42.9	2220	43.0
17	2320	42.6	2290	42.7	2250	42.8	2220	42.9	2220	42.9	2220	42.9	2220	43.0
18	2300	42.6	2290	42.7	2250	42.8	2220	43.0	2220	42.6	2220	43.0	2220	43.0
19	2300	42.6	2290	42.7	2250	42.8	2220	43.0	2220	42.7	2220	43.0	2220	43.0
20	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	42.8	2220	43.0	2220	43.0
21	2320	42.5	2290	42.7	2240	42.8	2220	42.9	2220	42.9	2220	43.0	2220	42.8
22	2310	42.5	2280	42.7	2240	42.8	2230	42.8	2220	42.9	2220	43.0	2220	42.9
23	2300	42.6	2280	42.7	2240	42.9	2220	42.8	2220	43.0	2220	42.9	2220	42.7
24	2300	42.6	2280	42.7	2240	42.9	2220	43.0	2220	43.0	2220	42.9	2220	43.0
25	2320	42.6	2280	42.8	2240	42.8	2220	42.9	2220	43.0	2220	42.9	2220	42.9
26	2310	42.6	2280	42.8	2240	42.9	2220	43.0	2220	43.0	2220	42.9	2220	43.0
27	2320	42.6	2280	42.8	2230	42.9	2220	42.9	2220	43.0	2220	43.0	2220	43.0
28	2320	42.6	2280	42.8	2230	42.9	2220	42.9	2220	43.0	2220	43.0	2220	42.9
29	--	--	2280	42.8	2230	43.0	2220	42.9	2220	43.0	2220	43.0	2220	42.9
30	--	--	2280	42.8	2230	43.0	2220	42.9	2220	43.0	2220	43.0	2220	43.0
31	--	--	2270	42.8	--	--	2220	42.9	--	--	2220	43.0	2220	43.0

DAY	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE
	SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH	
1	2220	42.9	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2220	43.0	2220	42.9
2	2220	42.9	2220	42.9	2220	43.0	2220	43.0	2230	42.9	2220	43.0	2220	42.9
3	2220	42.9	2220	42.6	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	43.0
4	2220	43.0	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2220	42.9
5	2220	42.9	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2230	42.9
6	2220	42.8	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.8	2220	42.9
7	2220	43.0	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2220	42.9
8	2220	42.9	2220	43.0	2220	43.0	2220	43.0	2230	42.8	2220	43.0	2220	42.9
9	2220	43.0	2220	43.0	2220	43.0	2220	43.0	2230	42.9	2220	43.0	2220	42.9
10	2220	43.0	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2220	42.9
11	2220	43.0	2220	43.0	2220	43.0	2220	43.0	2230	42.9	2220	42.9	2220	42.9
12	2220	42.9	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2230	42.9
13	2220	42.9	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2230	42.8
14	2220	43.0	2220	43.0	2220	43.0	2220	43.0	2230	43.0	2220	42.8	2260	42.9
15	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2460	42.9
16	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.9	2220	42.9	2760	42.5
17	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.9	2290	42.9
18	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.9	2220	42.9	2220	42.5
19	2220	42.8	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	43.0	2220	42.5
20	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.9	2220	42.9	2220	42.9
21	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2220	42.9
22	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.5	2220	42.5	2220	42.9
23	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.5	2220	42.5	2220	42.5
24	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2220	42.5
25	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.9	2220	42.5
26	2220	42.8	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.9	2220	42.9
27	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2220	42.9
28	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.8	2220	42.9		
29	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2220	42.9	2220	42.9		
30	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2220	42.9	--	--		
31	--	--	2220	43.0	--	--	2230	43.0	2220	42.9	--	--		

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING-WATERS (Continued)

Chemical Characteristics

Chemical Characteristics of Spring water

The general chemical character of the waters from the springs investigated was defined utilizing Stiff diagrams (Hem, 1970). This method uses four parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of four cations can be plotted, one on each axis to the left of zero, and likewise four anion concentrations may be plotted, one on each axis to the right of zero. The concentrations are in milliequivalents per liter (meq/L), a measure of the equivalent weights or of the equivalent chemical reactivity. Normally the chemical constituents are reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milliequivalents per liter can be calculated by multiplying the amount of ion present in milligrams per liter by the reciprocal of the gram-equivalent weight of the ion. The factors for this conversion for the chemical constituents considered are:

Bicarbonate	HCO_3^-	0.01639
Calcium	Ca^{2+}	.04990
Chloride	Cl^-	.02821
Carbonate	CO_3^{2-}	.03333
Iron	Fe^{3+}	.05372
Magnesium	Mg^{2+}	.08226
Potassium	K^+	.02558
Sodium	Na^+	.04350
Sulfate	SO_4^{2-}	.02082

The plotted points are joined by straight segments, resulting in a geometrical figure characteristic of the particular water sample. The width of the geometrical figure is an approximate indication of the total ionic content.

The chemical types of water determined by the analyses are: 1) Calcium-magnesium-bicarbonate ($Ca-Mg-HCO_3$), 2) Sodium-chloride (Na-Cl), and 3) Sodium-chloride-sulfate ($Na-Cl-SO_4$). Results are shown on figure 8.

Chemical Characteristics of Spring water (Continued)

The predominant water type of springwater in Puerto Rico is calcium-magnesium-bicarbonate. Thirteen of the springs studied are within this group (numbers 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 14, and 15, fig. 8). The first twelve springs issue from the north coast limestone area. The chemistry of the water from these springs is related to the solution of the carbonate rocks that comprise the aquifers. The solubility of limestone ($CaCO_3$) or dolomite [$CaMg(CO_3)_2$] increases in natural waters that contain carbon dioxide (CO_2). Carbon dioxide dissolves in rain water as it falls through the atmosphere and its concentration is further increased as it percolates through the soil zone. In the soil, its concentration is more than one order of magnitude greater than in the atmosphere due to plant respiration and decaying plant material in the soil zone. The CO_2 reacts with water to form carbonic acid according to the following reaction:

$$CO_2 + H_2O \text{ ----> } H_2CO_3 \qquad (1)$$

The carbonic acid dissociates to form bicarbonate:

$$H_2CO_3 \text{ ----> } H^+ + HCO_3^- \qquad (2)$$

The hydrogen ion lowers the pH of the solution. If a common alkaline substance, like carbonate minerals, is present, the hydrogen ion will dissolve it according to the reaction:

$$CaCO_3(s) + H^+ \text{ ----> } Ca^{+2} + HCO_3^- \qquad (3)$$

By this mechanism the H^+ will be removed from solution allowing the formation of additional bicarbonate ions. This is the predominant carbon species in natural water. If the water originally contains carbon dioxide and comes in contact with carbonate minerals, the following reaction will take place:

$$CO_2 + H_2O + CaCO_3(s) \text{ ----> } Ca^{+2} + 2HCO_3^- \qquad (4)$$

This is the most important reaction in controlling the chemical character of the springs waters in the north coast limestone area.

The other spring in the Ca-Mg-HCO_3 type of water issues from the volcanic rocks in the south-western part of the island. The Pozo de la Virgen spring near Sabana Grande derives its water from rocks that are abundant in serpentinite, a hydrated magnesium silicate mineral ($H_4Mg_2SiO_2$) that may include small amounts of nickel or iron.

The second dominant type of water in the springs is sodium-chloride (Na-Cl). There are two springs that discharge water of this type. The first one, La Cambija Spring at Caño Tiburones is located in the middle of Caño Tiburones swampy area, near the coast (fig. 3). The water is moderate to strongly saline, affected by saltwater intrusion and saline residues from the time when the area was flooded with saltwater.

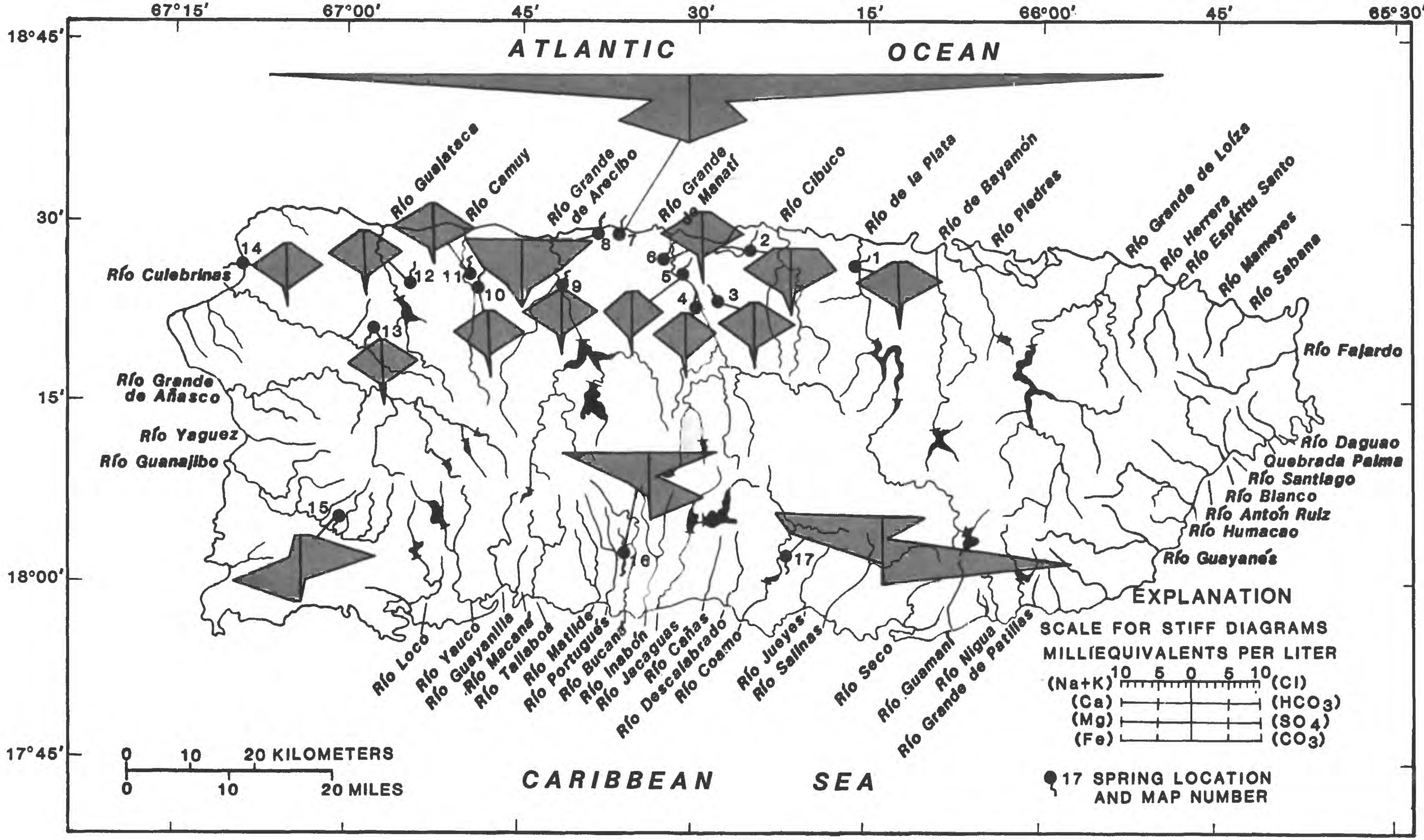

Figure 8.--Stiff diagrams for chemical character of the principal springs in Puerto Rico.

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS (Continued)

Chemical Characteristics (Continued)

Chemical Characteristics of Spring water (Continued)

The second spring, Zanja Fría at Caño Tiburones is also located at Caño Tiburones. The water that flows from this spring is a mixture of freshwater migrating from the recharge areas in the mountains mixing with residual saltwater in the discharge areas.

The Baños de Coamo near Coamo and Baños Quintana near Ponce are the only springs that discharge water of sodium chloride sulfate type. The origin of the sulfate in the water of Baños de Coamo near Coamo is unknown.

The Baños Quintana near Ponce is located in the south coast area several miles inland. It discharges water that is a mixture of local recharge water that moves slowly through the rocks acquiring their chemical characteristics, and water that travels very deep and rises very quickly. This water acquires the chemical characteristics of buried crystalline rock and probably mixes with residual seawater that remains in parts of the ground water system.

The quality of the water from the springs in Puerto Rico does not vary significantly with time. Comparison of the data collected by Giusti along the north coast (Giusti, 1978), and at Baños de Coamo (Giusti, 1973) show that the chemical character of the water has not changed significantly. Seasonal variations at springs affected by saline water probably occur in response to pumpage in nearby wells and recharge.

General Water Quality

Calcium, chloride, sodium, and sulfate are the principal ions in spring waters throughout Puerto Rico (table 7). Calcium concentrations range from 30 mg/L at Pozo de La Virgen spring to 220 mg/L at Baños de Coamo. Among the springs on the north coast, the calcium concentration ranged from 61 to 130 mg/L. These concentrations are very similar to those of ground water samples collected by Giusti (1978). At most of the springs, supersaturation of calcium carbonate ($CaCO_3$) occurs, and precipitation of the solid phase is evident. At Baños de Coamo, saltwater does not appear to be the source of calcium (as discussed in a later section of this report).

Chloride concentrations in water determine the suitability of the water for various uses. Chloride is derived in large part from sodium chloride and to a lesser part from magnesium chloride that is present in some rocks. Among the springs investigated, chloride concentrations ranged from 6.7 mg/L at Salto Collazo near San Sebastián to 3,800 mg/L at La Cambija at Caño Tiburones. However, the samples collected at La Cambija spring may have been affected by saltwater intrusion into the spring opening from the salty Caño Tiburones. In addition to the La Cambija spring, the Zanja Fría at Caño Tiburones (200 mg/L), Baños Quintana near Ponce (260 mg/L), and Baños de Coamo near Coamo (140 mg/L) springs also contain water with high chloride concentrations.

Table 7. Physical, chemical, and bacteriological characteristics of the principal springs of Puerto Rico, 1982-83

[Abbreviations: FT^3/SEC=cubic feet per second; US/CM=microsiemens per centimeter; STD UNITS=standard units; DEG C=degrees (°) celsius; 0.7 UM/MF=0.7 micrometers per membrane filter; COLS/100 ML=colonies per 100 milliliters; KF AGAR=culture media for fecal streptococcus bacteria; MG/L= milligrams per liter; AS $CACO_3$=as Calcium carbonate; AS MG=as magnesium; AS NA=as Sodium; AS K=as Potassium; AS SO_4=AS Sulfate; AS CL=as Chloride; AS F=as Fluoride; AS SIO_2=as Silica; AS N=as Nitrogen]

SPRING MAP NUMBER	DATE	SPRING-FLOW, INSTAN-TANEOUS (FT3/SEC)	SPE-CIFIC CON-DUCT-ANCE (US/CM)	PH (STD UNITS)	TEMPER-ATURE (DEG C)	COLI-FORM, FECAL, 0.7 UM/MF (COLS/100 ML)	STREP-TOCOCCI FECAL KF AGAR (COLS/100 ML)	HARD-NESS (MG/L AS CACO3)	HARD-NESS NONCAR-BONATE (MG/L CACO3)	CALCIUM, DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)
1	DEC. 6, 1982	0.52	572	6.7	24.5	450	320	250	9	92	5.8	16
	AUG. 5, 1983	.77	585	7.0	25.0	660	510	260	15	93	5.6	15
2	NOV. 30, 1982	.63	860	6.8	24.5	41	58	310	57	110	9.5	48
	AUG. 11, 1983	3.9	820	7.1	25.0	4	1	320	60	110	11	47
3	DEC. 9, 1982	.18	470	7.7	24.0	72	96	220	1	82	3.2	8.8
	AUG. 5, 1983	.04	470	7.2	24.5	430	210	230	9	85	4.1	9.9
4	NOV. 30, 1982	.54	390	7.8	23.0	20	50	180	4	70	1.9	6.0
	AUG. 5, 1983	.16	388	7.5	23.5	95	310	180	12	69	2.2	6.7
5	DEC. 16, 1982	10	360	7.7	22.5	1,800	830	160	0	61	2.0	6.4
	AUG. 11, 1983	6.1	384	7.3	23.0	340	360	190	10	72	2.5	6.7
6	NOV. 30, 1982	1.6	525	6.8	24.0	51	4	240	17	93	2.9	12
	AUG. 4, 1983	1.5	522	7.0	24.5	15	10	250	17	94	2.9	12
7	DEC. 8, 1982	9.2	5,470	7.2	24.0	28	100	710	460	130	92	930
	AUG. 4, 1983	9.9	12,100	7.1	24.0	22	72	1,400	1,100	190	220	2,200
8	DEC. 8, 1982	10	1,390	7.2	24.0	--	40	320	77	95	19	160
	AUG. 4, 1983	9.5	1,420	7.4	25.5	78	670	330	92	100	20	150
9	DEC. 1, 1982	16	430	7.0	23.5	380	130	200	0	72	4.8	5.8
	AUG. 3, 1983	8.4	470	7.4	24.0	42	52	230	19	83	5.1	5.6
10	DEC. 14, 1982	.24	465	7.5	23.5	380	640	210	3	80	3.1	7.6
	AUG. 9, 1983	.14	518	7.3	24.5	360	1,000	230	16	85	3.2	7.9
11	DEC. 7, 1982	.58	460	7.7	23.5	100	240	220	4	84	2.5	7.5
	AUG. 9, 1983	.53	445	7.3	23.5	220	630	200	2	78	1.7	7.1
12	DEC. 7, 1982	.58	465	7.4	23.5	580	220	220	35	86	1.4	7.0
	AUG. 9, 1983	.38	517	7.4	24.0	400	550	250	7	96	1.7	7.9
13	DEC. 1, 1982	.44	455	7.4	23.0	100	40	220	0	84	2.9	4.2
	AUG. 3, 1983	.03	410	6.9	23.5	260	610	200	1	76	2.5	4.0
14	DEC. 2, 1982	2.1	540	6.9	25.0	74	4	250	0	94	4.5	8.6
	AUG. 3, 1983	1.0	555	7.2	25.0	270	2,200	250	0	91	4.6	8.7
15	DEC. 2, 1982	.01	825	6.8	24.5	1,900	1,000	460	19	30	93	15
	AUG. 10, 1983	DRY	--	--	--	--	--	--	--	--	--	--
16	DEC. 15, 1982	.03	1,520	9.3	31.0	480	850	170	150	69	.05	270
	AUG. 10, 1983	.02	1,490	9.2	32.0	1,500	410	170	150	68	.08	230
17	DEC. 3, 1982	.11	2,250	8.8	43.0	4	--	550	530	220	.15	340
	AUG. 10, 1983	.06	2,210	9.0	43.0	10	1	550	530	220	.10	300
	SEAWATER	--	35,000	--	--	--	--	--	--	400	1,350	10,500

SPRING MAP NUMBER	DATE	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	SULFATE, DIS-SOLVED (MG/L AS SO4)	ALKA-LINITY, FIELD (MG/L AS CACO3)	CHLOR-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE DIS-SOLVED (MG/L AS F)	SILICA, DIS-SOLVED (MG/L AS SIO2)	SOLIDS, RESIDUE AT 180 DEG C, DIS-SOLVED (MG/L)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, DIS-SOLVED (TONS PER DAY)	NITRO-GEN, NITRATE TOTAL (MG/L AS N)
1	DEC. 6, 1982	1.6	9.0	220	32	0.1	7.8	303	312	0.42	--
	AUG. 5, 1983	1.8	8.5	240	28	.1	7.5	333	303	.69	--
2	NOV. 30, 1982	2.4	15	280	88	.1	9.0	555	437	.94	--
	AUG. 11, 1983	2.1	18	260	100	.1	9.3	494	455	5.20	--
3	DEC. 9, 1982	.9	13	240	13	.1	12	290	264	.14	--
	AUG. 5, 1983	1.0	9.6	220	13	.2	17	281	274	.03	--
4	NOV. 30, 1982	.2	7.0	180	9.9	.1	3.6	222	207	.32	--
	AUG. 5, 1983	.4	6.1	170	12	.1	4.0	253	205	.11	1.0
5	DEC. 16, 1982	.5	3.0	160	10	.1	5.4	197	186	5.3	--
	AUG. 11, 1983	.4	3.5	180	10	.1	3.7	214	208	3.52	2.4
6	NOV. 30, 1982	1.6	4.0	250	18	.1	6.4	317	275	1.36	--
	AUG. 4, 1983	.9	4.8	230	19	.1	6.5	348	282	1.42	3.4
7	DEC. 8, 1982	31	270	250	1,900	.1	6.3	3,360	3,510	83.4	--
	AUG. 4, 1983	79	540	280	3,800	.1	5.9	7,550	7,180	201	--
8	DEC. 8, 1982	4.9	41	240	280	.1	6.8	788	751	21.3	--
	AUG. 4, 1983	5.1	38	240	280	.1	6.7	881	746	22.6	--
9	DEC. 1, 1982	1.5	9.0	200	8.8	.1	8.3	216	231	9.33	--
	AUG. 3, 1983	1.0	7.7	210	10	.1	7.4	239	247	5.42	--
10	DEC. 14, 1982	1.1	11	210	13	.1	5.1	224	251	.17	--
	AUG. 9, 1983	1.6	17	210	18	.1	5.8	304	268	.11	2.2
11	DEC. 7, 1982	.6	8.0	220	13	.1	5.1	224	251	.35	--
	AUG. 9, 1983	.7	6.4	200	14	.1	4.6	261	236	.37	.964
12	DEC. 7, 1982	.2	8.0	220	11	.1	4.9	246	231	.39	--
	AUG. 9, 1983	.7	6.9	240	15	.1	5.4	309	281	.32	1.2
13	DEC. 1, 1982	.5	6.0	230	6.7	.1	4.6	237	244	.28	--
	AUG. 3, 1983	.5	9.1	200	7.8	.2	4.1	225	222	.02	--
14	DEC. 2, 1982	.5	7.0	250	15	.1	6.2	300	244	1.70	--
	AUG. 3, 1983	.6	6.4	260	16	.1	6.4	305	287	.82	--
15	DEC. 2, 1982	.6	12	430	26	1.0	49	478	491	.01	--
	AUG. 10, 1983	DRY	--	--	--	--	--	--	--	--	--
16	DEC. 15, 1982	1.2	300	24	250	.4	26	874	--	.07	--
	AUG. 10, 1983	1.3	300	23	260	.4	26	970	901	.05	--
17	DEC. 3, 1982	2.2	1,000	17	130	1.1	30	1,860	--	.30	--
	AUG. 10, 1983	2.2	1,000	20	140	1.1	30	1,880	1,710	.30	.010
	SEAWATER	380	2,700	116	19,000	1.3	6.4	--	--	--	--

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS (Continued)

Chemical Characteristics (Continued)

General Water Quality (Continued)

The ratio of chloride in spring water to chloride in sea water can be used as an indicator of the degree of mixing between fresh and seawaters. Ratios of other ions such as boron and sulfate can also be used with the chloride ratio to establish seawater as the source of the ions. Ratios of chloride, boron and sulfate ions in these two springs to seawater are as follows:

RATIO OF ELEMENT CONCENTRATION IN SPRING TO SEAWATER

Constituent	Zanja Fría	La Cambija
Chloride	0.02	0.10
Boron	.02	.08
Sulfate	.02	.10

The similarity of the ratios shows that the springs are discharging near the fresh-seawater interface. The chemistry of these springs show about two percent seawater at Zanja Fría and eight percent at La Cambija. Most of the other springs along the north coast are further inland and exhibit chloride concentrations typical of ground water.

Sodium ion concentrations correlate with those of chloride, mainly because of the chemical association with sodium chloride from seawater. Many sodium compounds are highly soluble. Also, sodium is a common constituent of many minerals like sodium feldspars. Higher sodium concentrations in some of the spring waters could be due to cation exchange reactions in which sodium is exchanged by other positively charged ions:

$$Ca^{2+} + Na_2X \text{ ------> } CaX + 2Na^+$$

where X = substrate in which the exchange occurs.

Sulfate ion is the next most abundant dissolved constituent in spring waters in Puerto Rico. The source of sulfate in ground or spring waters is usually from seawater intrusion or contamination from sewage discharges. Occasionally, minerals in the rocks may yield high sulfate concentrations. Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$) deposits can be a source of sulfate ions in ground water. Also the oxidation of sulfide minerals such as pyrite and marcasite are sources of sulfate ions. Sulfate is usually present in mine waters and some industrial waters. Concentrations of sulfate in springflow throughout Puerto Rico range from 3 mg/L at Aguas Frías near Ciales to 1,000 mg/L at Baños de Coamo. High sulfate concentrations are also present at La Cambija and Zanja Fría, springs affected by saltwater intrusion.

PHYSICAL, CHEMICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING WATERS (Continued)

Chemical Characteristics (Continued)

General Water Quality (Continued)

An analysis of the ratios of chloride, boron, strontium, and sulfate ions for the Baños de Coamo and Baños Quintana thermal springs compared to seawater shows the following:

RATIO OF ELEMENT CONCENTRATION IN SPRING TO SEAWATER

Constituent	Baños Coamo	Baños Quintana
Chloride	0.007	0.014
Boron	.543	.283
Strontium	.225	.125
Sulfate	.370	.111

If the discharges from these springs were a mixture with seawater, these ionic ratios should be about the same for each spring.

The concentration of boron in seawater is about 4,600 µg/L. The ratios above show that at Baños de Coamo, if the boron was from seawater an ion such as chloride should have a concentration of about 10,000 mg/L. It is evident then that seawater is not a component in the thermal springs. High concentrations of boron, sulfate, and other constituents are probably from minerals in volcanic rocks and from overlaying alluvium. Similar concentrations have been observed in other thermal springs in Nevada and California (Hem, 1970).

Other ions of importance in spring waters include silica (SiO_2), bicarbonate (HCO_3^-) and magnesium (Mg). High silica concentrations in the thermal springs (Baños de Coamo and Baños Quintana) are probably derived from high solubility of silica in hot waters. The Pozo de la Virgen spring exhibits the highest silica concentration among the springs studied (49 mg/L). Water from this spring emerges from rock with a high content of silicate. Spring waters throughout Puerto Rico are generally moderately hard, with $CaCO_3$ hardness values ranging from 170 to 1,400 mg/L, but with a median value of about 225 mg/L.

Nutrients (nitrogen and phosphorus) and organic carbon can be used as an indicator of contamination of ground waters. Spring waters in Puerto Rico contain relatively high concentrations of nitrogen, but low phosphorus and organic carbon levels. The highest nitrogen concentrations were measured at Ojo de Agua at Vega Baja (5.9 mg/L), Ojo de Guillo near Manatí (3.4 mg/L), and Ojo de Agua at Aguadilla (3.1 mg/L). These concentrations, although relatively high, are below the safe drinking water standard of 10 mg/L of nitrate as nitrogen (USEPA, 1972, 1976). These springs are in the vicinity of highly urbanized areas where the potential for contamination from sewage is high.

General Water Quality (Continued)

Field investigations at Ojo de Guillo near Manatí indicate that wastewater from the sewage-treatment plant near the town of Florida could be flowing into the spring. The partially treated sewage from the plant is discharged into a nearby sinkhole and drainage patterns from the area indicate that an ancient channel could be serving as a hydraulic connection between the spring and the sinkhole. The spring opening shows excessive algal growth and gray-turbid water, typical of sewage. Crustaceans and other aquatic life are killed occasionally, possibly by chlorine or other disinfectants in the spring discharge.

Analyses of trace metals (table 8) indicate that with the exception of the thermal springs, concentrations are generally low, typical of ground waters, and never exceed the Safe Drinking Water Act standards (EPA, 1972, 1976). The highest boron concentrations ranged from 90 μg/L at Zanja Fría to 2,500 μg/L at Baños de Coamo.

Bacteriological Characteristics

Fecal coliform (FC) and fecal streptococci (FS) bacteria are present in most of the spring waters throughout Puerto Rico. Concentrations of FC bacteria range from 4 to 1,900 colonies per 100 mL sample.

The FS concentrations range from 1 to 2,200 col/100 mL of sample. Drinking water standard recommends that the geometric mean of fecal coliform bacteria density in raw waters for public supply should not exceed 2,000 col/100 mL of water (USEPA, 1973). The standard for contact and recreational purposes is 1,000 col/100 mL. Except for Aguas Frías near Ciales and the Pozo de la Virgen spring near Sabana Grande, the bacteria concentrations are relatively low. Both of these springs are affected by bird rookeries very close to the spring mouths.

Table 8. Trace metals at the principal springs of Puerto Rico, 1982-83

[Abbreviations: UG/L=micrograms per liter; As AL=as Aluminum; AS AS=as Arsenic; AS BA=as Barium, AS BE=as Beryllium; AS B=as Boron; AS CD=as Cadmium; AS CR=as Chromium; AS CO=as Cobalt; AS CU=as Copper; AS FE=as Iron; =less than; as PB=as Lead; AS LI=as Lithium; AS MN=as Manganese; AS HG=as Mercury; AS MO=as Molybdenum; AS SE= as Selenium; AS SR= as Strontium; AS V=as Vanadium; AS ZN= as Zinc]

SPRING MAP NUMBER	DATE	ALUMINUM, DISSOLVED (UG/L AS AL)	ARSENIC, DISSOLVED (UG/L AS AS)	BARIUM, DISSOLVED (UG/L AS BA)	BERYLLIUM, DISSOLVED (UG/L AS BE)	BORON, DISSOLVED (UG/L AS B)	CADMIUM, DISSOLVED (UG/L AS CD)	CHROMIUM, DISSOLVED (UG/L AS CR)	COBALT, DISSOLVED (UG/L AS CO)	COPPER, DISSOLVED (UG/L AS CU)	IRON, DISSOLVED (UG/L AS FE)
1	DEC. 6, 1982	10	1	28	<1	20	<1	<1	<3	<10	7
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	<3
2	NOV. 30, 1982	10	<1	41	<1	30	<1	<1	<3	<10	<3
	AUG. 11, 1983	--	--	--	--	--	--	--	--	--	4
3	DEC. 9, 1982	10	1	24	<1	70	<1	<1	<3	<10	8
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	4
4	NOV. 30, 1982	10	1	9	<1	30	<1	<1	<3	<10	5
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	6
5	DEC. 16, 1982	50	1	16	<1	70	<1	<1	<3	<10	<3
	AUG. 11, 1983	--	--	--	--	--	--	--	--	--	<3
6	NOV. 30, 1982	<10	3	19	<1	30	<1	<1	<3	<10	<3
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	6
7	DEC. 8, 1982	10	<1	24	<1	370	<1	<1	<3	<10	9
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	50
8	DEC. 8, 1982	20	1	16	<1	90	<1	<1	<3	<10	8
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	<3
9	DEC. 1, 1982	30	1	21	<1	10	2	3	<3	<10	19
	AUG. 3, 1983	--	--	--	--	--	--	--	--	--	10
10	DEC. 6, 1982	20	1	12	<1	30	<1	<1	<3	<10	<3
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	<3
11	NOV. 30, 1982	10	1	12	<1	10	<1	<1	<3	<10	9
	AUG. 11, 1983	--	--	--	--	--	--	--	--	--	15
12	DEC. 9, 1982	<10	1	12	<1	10	<1	<1	<3	<10	6
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	8
13	NOV. 30, 1982	30	1	19	<1	10	3	3	<3	<10	21
	AUG. 5, 1983	--	--	--	--	--	--	--	--	--	<3
14	DEC. 16, 1982	20	1	15	<1	10	<1	3	<3	<10	7
	AUG. 11, 1983	--	--	--	--	--	--	--	--	--	5
15	NOV. 30, 1982	10	3	79	<1	40	2	3	<3	<10	16
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	--
16	DEC. 8, 1982	50	<1	19	<1	1300	<1	<1	<3	<10	4
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	4
17	DEC. 8, 1982	20	5	32	<1	2500	<1	3	<3	<10	24
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--	20

SPRING MAP NUMBER	DATE	LEAD, DISSOLVED (UG/L AS PB)	LITHIUM, DISSOLVED (UG/L AS LI)	MANGANESE, DISSOLVED (UG/L AS MN)	MERCURY, DISSOLVED (UG/L AS HG)	MOLYBDENUM, DISSOLVED (UG/L AS MO)	SELENIUM, DISSOLVED (UG/L AS SE)	STRONTIUM, DISSOLVED (UG/L AS SR)	VANADIUM, DISSOLVED (UG/L AS V)	ZINC, DISSOLVED (UG/L AS ZN)
1	DEC. 6, 1982	<10	<4	3	<0.1	<10	<1	120	<6	<4
	AUG. 5, 1983	--	--	--	--	--	--	120	--	--
2	NOV. 30, 1982	<10	<4	1	.1	<10	<1	170	<6	5
	AUG. 11, 1983	--	--	--	--	--	--	--	--	--
3	DEC. 9, 1982	<10	5	<1	.1	<10	<1	200	<6	5
	AUG. 5, 1983	--	--	--	--	--	--	210	--	--
4	NOV. 30, 1982	<10	<4	<1	.1	<10	<1	150	<6	<4
	AUG. 5, 1983	--	--	--	--	--	--	150	--	--
5	DEC. 16, 1982	<10	<4	<1	.4	<10	<1	140	<6	5
	AUG. 11, 1983	--	--	--	--	--	--	170	--	--
6	NOV. 30, 1982	<10	<4	14	.1	<10	<1	110	9	<4
	AUG. 4, 1983	--	--	--	--	--	--	120	--	--
7	DEC. 8, 1982	<10	<17	1	.3	<10	<1	860	<6	<4
	AUG. 4, 1983	--	--	--	--	--	--	1700	--	--
8	DEC. 8, 1982	<10	7	1	.2	<10	<1	210	<6	<4
	AUG. 4, 1983	--	--	--	--	--	--	220	--	--
9	DEC. 1, 1982	20	<4	1	.1	<10	<1	330	<6	<4
	AUG. 3, 1983	--	--	--	--	--	--	470	--	--
10	DEC. 6, 1982	<10	<4	1	< .1	<10	<1	170	<6	<4
	AUG. 5, 1983	--	--	--	--	--	--	160	--	--
11	NOV. 30, 1982	<10	<4	1	.1	<10	<1	110	<6	<4
	AUG. 11, 1983	--	--	--	--	--	--	90	--	--
12	DEC. 9, 1982	<10	<4	1	< .1	<10	<1	110	<6	<4
	AUG. 5, 1983	--	--	--	--	--	--	120	--	--
13	NOV. 30, 1982	<10	<4	1	.1	<10	<1	700	<6	<4
	AUG. 5, 1983	--	--	--	--	--	--	790	--	--
14	DEC. 16, 1982	<10	<4	1	.2	<10	<1	230	<6	<4
	AUG. 11, 1983	--	--	--	--	--	--	220	--	--
15	NOV. 30, 1982	<10	<4	<16	.1	<10	<1	160	<6	<4
	AUG. 4, 1983	--	--	--	--	--	--	--	--	--
16	DEC. 8, 1982	<10	23	1	.4	<10	<1	1000	<6	26
	AUG. 4, 1983	--	--	--	--	--	--	1000	--	--
17	DEC. 8, 1982	<10	63	2	.3	<10	<1	1600	<6	<4
	AUG. 4, 1983	--	--	--	--	--	--	1800	--	--

CONCLUSIONS

Results of a 2-year investigation of the principal springs throughout Puerto Rico show the following:

Seventeen springs were included in the investigation on the basis of the amount of springflow. At these springs, average daily flow exceeds 6,400 gal/d.

The most important springs in terms of flow are located along the north coast. San Pedro near Arecibo and Aguas Frías near Ciales normally discharge in excess of 3 ft^3/s (about 2 Mgal/d). Maximum discharge was observed at San Pedro spring, with a mean daily of 35 ft^3/s (about 22.6 Mgal/d).

The total amount of springflow available from springs throughout Puerto Rico may be as much as 50 ft^3/s (about 32 Mgal/d). This would include known springs not included in this survey.

The slight change in springs temperature throughout the year is caused by the influence of the change in air temperature, following a cyclic pattern.

Thermal waters flow from the Baños de Quintana near Ponce and Baños de Coamo near Coamo. Flow from the Baños de Quintana seldom exceeds 0.03 ft^3/s (0.02 Mgal/d) with a temperature of about 32°C. Flow at Baños de Coamo ranges from 32,000 to 83,000 gal/d with an average temperature of about 43°C.

The water quality of the springs is related to their location. Most of the springs along the north coast exhibit excellent quality water with calcium, magnesium, and bicarbonate being the principal ions in solution. Several springs in coastal swampy areas are affected by sea water encroachment, with waters predominantly of the sodium-chloride type. Waters from the Baños de Coamo spring contain high dissolved sulfate concentrations and are mainly a sodium-sulfate type of water.

Bacteriological analyses show that fecal coliform and fecal streptococci bacteria are present in most springs at low to moderate concentrations (4 to 1,900 and 1 to 2,200 col/100 mL respectively).

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Table 2. Instantaneous water discharge of the principal springs of Puerto Rico, 1982-84

[Abbreviations: ft^3/s=cubic feet per second; Mgal/d=Million gallons per day; --- no data available]

SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)	SITE NUMBER	DATE	INSTANTANEOUS WATER DISCHARGE ft^3/s(Mgal/d)
1	Dec. 6, 1982	0.52 (0.34)	4	Aug. 5, 1983	0.16 (0.10)	9	Apr. 26, 1983	12 (7.8)	12	Nov. 23, 1983	0.36 (0.23)
	Mar. 3, 1983	.40 (.26)		Jan. 25, 1984	.27 (.17)		June 24, 1983	16 (10)	13	Dec. 1, 1982	.44 (.28)
	Apr. 28, 1983	1.7 (1.1)	5	Dec. 16, 1982	10 (6.5)		July 21, 1983	8.1 (5.2)		Feb. 23, 1983	.17 (.11)
	Aug. 5, 1983	.77 (.50)		Mar. 3, 1983	10 (6.5)		Aug. 3, 1983	8.4 (5.4)		Apr. 27, 1983	.17 (.11)
	Jan. 30, 1984	.80 (.52)		May 3, 1983	11 (7.1)		Sept. 7, 1983	5.0 (3.2)		Aug. 3, 1983	.03 (.02)
2	Nov. 30, 1982	.63 (.41)		Aug. 11, 1983	6.1 (3.9)		Dec. 6, 1983	7.7 (5.0)		Jan. 24, 1984	.09 (.06)
	Mar. 3, 1983	.90 (.58)		Jan. 25, 1984	5.3 (3.4)		Mar. 23, 1984	3.3 (2.1)	14	Dec. 2, 1982	2.1 (1.4)
	Apr. 28, 1983	1.3 (.84)	6	Nov. 30, 1982	1.6 (1.1)		May 18, 1984	4.2 (2.7)		Feb. 23, 1983	.70 (.45)
	July 21, 1983	.33 (.21)		Mar. 2, 1983	.95 (.61)		June 26, 1984	6.5 (4.2)		Apr. 28, 1983	1.0 (.65)
	Aug. 11, 1983	3.9 (2.5)		Apr. 28, 1983	1.5 (.98)	10	Dec. 14, 1982	.24 (.16)		Aug. 3, 1983	1.0 (.65)
	Dec. 6, 1983	3.0 (1.9)		Aug. 4, 1983	1.5 (.98)		Mar. 2, 1983	.03 (.02)		Jan. 30, 1984	.48 (.31)
	Jan. 30, 1984	--- ---		Jan. 30, 1984	.94 (.61)		Apr. 27, 1983	.10 (.06)	15	Dec. 2, 1982	.01 (.01)
	Mar. 23, 1984	.29 (.19)	7	Dec. 8, 1982	9.2 (6.0)		Aug. 9, 1983	.14 (.09)		Feb. 23, 1983	.00 (.00)
	May 18, 1984	.98 (.63)		Feb. 24, 1983	9.0 (5.8)		Nov. 23, 1983	.16 (.10)		Apr. 29, 1983	.00 (.00)
	June 26, 1984	1.2 (.78)		Apr. 26, 1983	9.4 (6.1)	11	Dec. 7, 1982	.58 (.37)		Aug. 10, 1983	DRY
3	Dec. 9, 1982	.18 (.12)		Aug. 4, 1983	9.9 (6.4)		Mar. 2, 1983	.29 (.19)	16	Dec. 15, 1982	.03 (.02)
	Feb. 24, 1983	.17 (.11)		Mar. 29, 1984	7.5 (4.8)		Apr. 27, 1983	.67 (.43)		Feb. 25, 1983	.01 (.01)
	May 3, 1983	.19 (.12)	8	Dec. 8, 1982	10 (6.5)		Aug. 8, 1983	.53 (.34)		Apr. 29, 1983	.02 (.01)
	Aug. 5, 1983	.04 (.03)		Feb. 24, 1983	7.3 (4.7)		Nov. 23, 1983	.72 (.42)		Aug. 10, 1983	.02 (.01)
	Jan. 25, 1984	.02 (.01)		Apr. 26, 1983	9.3 (6.0)	12	Dec. 7, 1982	.58 (.37)	17	Dec. 3, 1982	.11 (.07)
4	Dec. 9, 1982	.54 (.35)		Aug. 4, 1983	9.5 (6.1)		Mar. 2, 1983	.23 (.15)		Feb. 25, 1983	.06 (.04)
	Feb. 24, 1983	.27 (.17)	9	Dec. 1, 1982	16 (10)		Apr. 27, 1983	.36 (.23)		Apr. 29, 1983	.09 (.06)
	May 3, 1983	.26 (.17)		Feb. 23, 1983	8.4 (5.4)		Aug. 9, 1983	.38 (.25)		Aug. 10, 1983	.06 (.04)