HYDROGEOLOGY OF THE PRINCIPAL SPRINGS IN PUERTO RICO

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CONTENTS

ILLUSTRATIONS

TABLES

APPENDICES

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ABSTRACT

The hydrogeology of the principal springs throughout Puerto Rico was investigated from 1982-84. Seventeen springs were included in the study designed to determine the flow, chemical, physical and bacteriological characteristics of the springwater. Most of the springs (14) are located along the north coast limestone area. Two springs in the south coast have thermal properties. Maximum springflow occurs at San Pedro Spring near Arecibo, where as much as 29 cubic feet per second (about 19 milion gallons per day) are discharged. Average total available springflow from the 17 springs is about 36 cubic feet per second (about 23.5 million gallons per day). Calcium, bicarbonate, sodium, chloride, and sulfate are the principal ions in springwater. Water from most of the springs along the north coast are 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. Banos de Coamo near Coamo are the most important thermal springs, discharging from 40,000 to 100,000 gallons per day. Temperature of the thermal water averages 43 degrees Centigrade. Fecal coliform and fecal streptococci bacteria are present in most of the springs in concentrations ranging from 0 to 1900 colonies per 100 milliliters of sample.

INTRODUCTION

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

Until recently, the magnitude of the flow and quality of the water from the springs in Puerto Rico 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 Department of Natural Resources, the US Geological Survey began a two-year study of the hydrology and geochemistry of the principal springs in 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" (Guzman-Rios, 1983). This report summarizes the data collected during the project including interpretations of the hydrology and geochemistry of the springs selected for the investigation.

The principal objectives of the investigation were:

1. To determine the principal physical, chemical, and bacteriological characteristics of samples of water from the springs.

2. To measure the instantaneous discharge from the springs at different times during the year and determine any seasonal variations.

3. At selected springs, to measure spring discharge on a continuos basis.

Previous investigations by Giusti (1978) had demonstrated that there are virtually hundreds of springs throughout Puerto Rico. The majority of the springs occur along the north-coast limestone belt from San Juan to Aguadilla. A field reconnaissance in 1982 showed that unless a criteria was established as to which springs would be included in the project, the resources available would be inadequate to accomplish the objectives. Only those springs that discharged more than 0.01 ft3/s (about 6,500 gal/d) were selected. Seventeen (17) springs were included on the basis of this criteria. It is important to recognize that the limitations of the project may have precluded the inclusion of springs either difficult to access or unknowun to the investigator.

The locations of the springs included in the survey relative to 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 closer to the USGS District Office in San Juan was assigned the number one (1). Numbering of the springs proceeds in a counterclockwise direction around the Island. Latitude-longitude identifiers were determined and are included in table 1 with the common name of each spring.

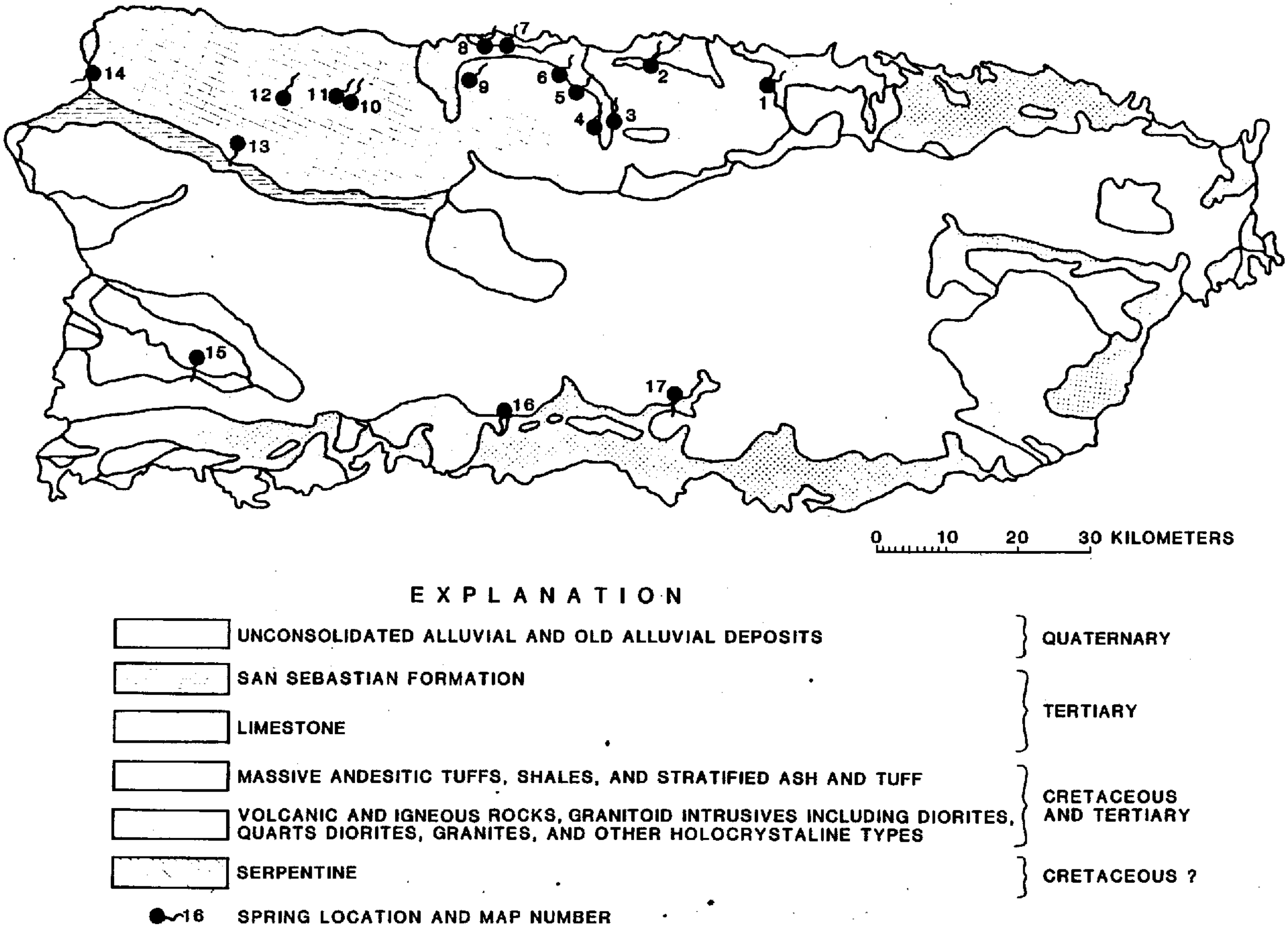

Figure 1.- Geologic surficial formation and springs location.

Table 1.- Latitude, longitude and name of principal springs in Puerto Rico.

MAP NO	LATITUDE/ LONGITUDE	SPRING NAME
1	182446661555	MAGUAYO SPRING AT HWY 693 NEAR DORADO, PR
2	182657662506	OJO DE AGUA SPRING AT VEGA BAJA, PR
3	182004662638	OJO DE AGUA AT TORRECILLAS NEAR MOROVIS, PR
4	182019662853	REPRESA SONADORA DE CIALES AT CIALES, PR
5	182218662910	AGUAS FRIAS SPRING NEAR CIALES, PR
6	182541663136	OJO DE GUILLO SPRING NEAR MANATI, PR
7	182825663553	LA CAMBIJA SPRING AT CANO TIBURONES, PR
8	182724663920	ZANJA FRIA SPRING AT CANO TIBURONES, PR
9	182435664145	SAN PEDRO SPRING NEAR ARECIBO, PR
10	182344665344	SUMBADORA SPRING AT LOS PUERTOS NEAR CAMUY, PR
11	182410664743	SONADORA SPRING NEAR CAMUY, PR
12	182359664816	TIBURON SPRING NEAR CAMUY, PR
13	182006665646	SALTO COLLAZO SPRING NEAR SAN SEBASTIAN, PR
14	182602670917	OJO DE AGUA SPRING AT AGUADILLA, PR
15	180543665650	POZO DE LA VIRGEN SPRING NEAR SABANA GRANDE, PR
16	180224663642	BANOS QUINTANA NEAR PONCE, PR
17	180219662225	BANOS DE COAMO NEAR COAMO, PR

HYDROGEOLOGIC SETTING

The Origin of Springs in Puerto Rico

Springs occur in many forms and have been classified as to the source, cause, discharge, temperature, and variability. Springs may have their origin by volcanic activity, rock fissures, depressions in the terrain, artesian conditions, contact between formations of different porosity, solution channels, or fractures in the rocks. The water discharging from springs is one element in the hydrologic cycle (fig. 2). Water that infiltrates to the ground may eventually be discharged as springflow. Springs that originate from volcanic activity and associated fractures, or under artesian conditions result from non-gravitational forces. In the case of a volcano, the thermal energy in the volcanic core may overheat the ground water in the vicinity resulting in pressure gradients that may force the water to the surface. Similar conditions may produce springs from fissures. Thermal springs may also be produced by chemical reactions (nuclear and non-nuclear) below the surface. Energy-producing reactions (exothermic) may heat the ground water, which may escape to the surface through fissures due to the temperature-pressure gradient. Depression, contact, artesian, and solution-tubular springs are gravity springs affected by hydrostatic pressures. Springs that flow in a land depression may intercept the water table. Contact springs result from the difference in porosity between two adjoining geologic formations. Water moving from a formation of higher porosity to one less permeable may be unable to infiltrate into the lower formation, discharging to the surface in response to building heads. Artesian springs result from the head-building effects of a confining layer on an aquifer. In an artesian system a head of water builds up until it reaches a discharge point at an elevation equal to the hydrostatic head. A fissure or fracture in the rocks may be the outlet for an artesian spring. Tubular or solution channel springs occur when the aquifer or soil material is easily dissolved, creating a pathway for water to discharge to the surface. Hydrostatic head is still required to produce the flow. In Puerto Rico, with the exception of volcanic springs, most of the other types 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 in/year, springflow occurs from each of the limestone formations described by Monroe (1980). In the south coast an annual average precipitation of about 35 inches, combined with aquifers consisting principally of thick alluvial deposits, limits the formation of springs.

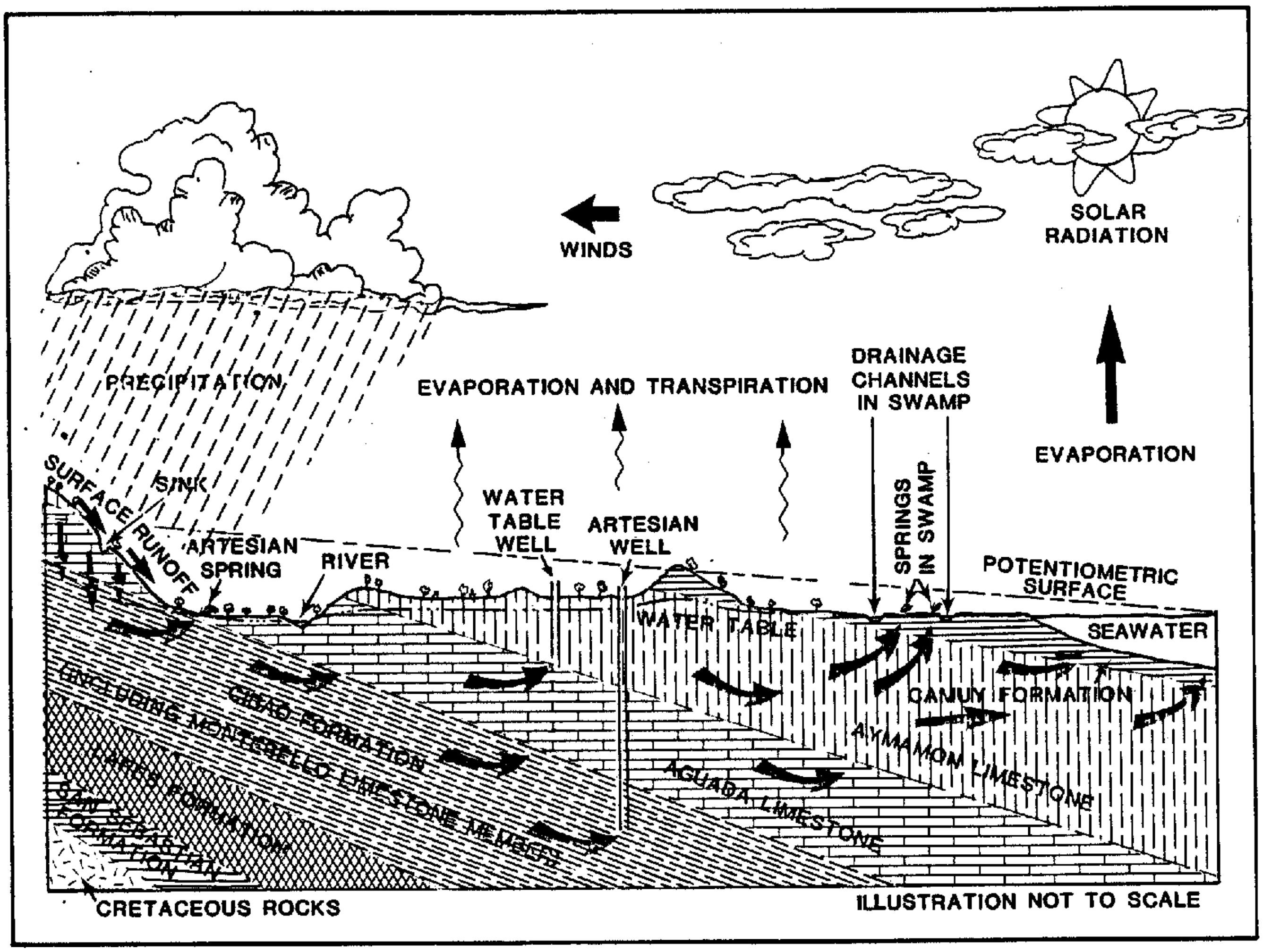

Figure 2.- The hydrologic cycle.

The springs of the north coast appear to be associated with the various limestone formations. The limestone formations of the north coast (fig. 3) occupy an area of about 900 mi2 between San Juan and Aguadilla. The San Sebastian formation, although not entirely composed of limestone rocks, underlies all the other limestone formations (Monroe, 1978). Layers of poorly cemented clay, siltstone, sandstone, conglomerates, and shale interbed with limestone. The formation has a low permeability and in many areas acts as a confining layer. The spring Ojo de Agua at Torrecilla (map number 3 in fig. 1) flows at the contact between the San Sebastian Formation and the overlaying Lares Limestone.

Three of the most important springs in Puerto Rico flow from the Lares limestone formation. Represa Sonadora Spring near Ciales, Aguas Frias Spring near Ciales, and Salto Collazo Spring near San Sebastian (map numbers 4, 5, and 13) flow from rocks within the Lares Limestone. Sonadora and Salto Collazo springs flow from the vicinity of the contact with the San Sebastian Formation, and may result from the differences in permeabilities between the two geologic formations. The rocks of the Lares Limestone are mostly pure calcium carbonate ($CaCO_3$) with varying permeability, but in general much more transmissive than the San Sebastian Formation (Giusti, 1978).

Two springs near Camuy (Sonadora and Tiburon) and one of the largest springs in the Island (San Pedro near Arecibo) emerge from rocks within the Cibao Formation (fig. 1). The Cibao Formation exhibit the most variable permeability characteristics of the area. The rocks are nearly impermeable in some areas, acting as confining layers to the artesian aquifer near Barceloneta (Giusti, 1978). The Montebello Limestone Member of the Cibao Formation (Monroe, 1980) is one of the most productive artesian zones of the north coast. The springs flowing from the Cibao Formation are not artesian and appear to result from diferences in permeability between limestone beds.

Sumbadora Spring near Camuy and Maguayo Spring near Dorado (map numbers 1 and 10, fig. 1) flow from the rocks of the Aguada Limestone. The Aguada Limestone is generally a hard-thick-bedded layer of clayey limestone with fair to poor permeability. The springs emanate from the vicinity of the contact with the overlaying Aymamon Limestone.

The most important springs along the north coast flow from the rocks of the Aymamon Limestone or its contact with the Aguada Limestone. Ojo de Agua near Vega Baja, Ojo de Guillo near Manati, La Cambija and Zanja Fria at Cano Tiburones, and Ojo de Agua near Aguadilla (map numbers 2, 6, 7, 8, and 14) flow from these formations. The Aymamon Limestone is the most permeable of the limestone formations of the north coast. Secondary permeability due to prior erosion and weathering, sinkholes, and solution channels abound in the outcrops of the formation. Four of the springs flowing from the Aymamon (map numbers 2, 6, 7, 8) are located near the contact zone with the blanket deposits that overlie the area in the coastal plains. Ojo de Agua near Aguadilla flows in an area elevated over the rest of the formation, close to the ocean and the natural zones of discharge of the aquifer (Giusti, 1978).

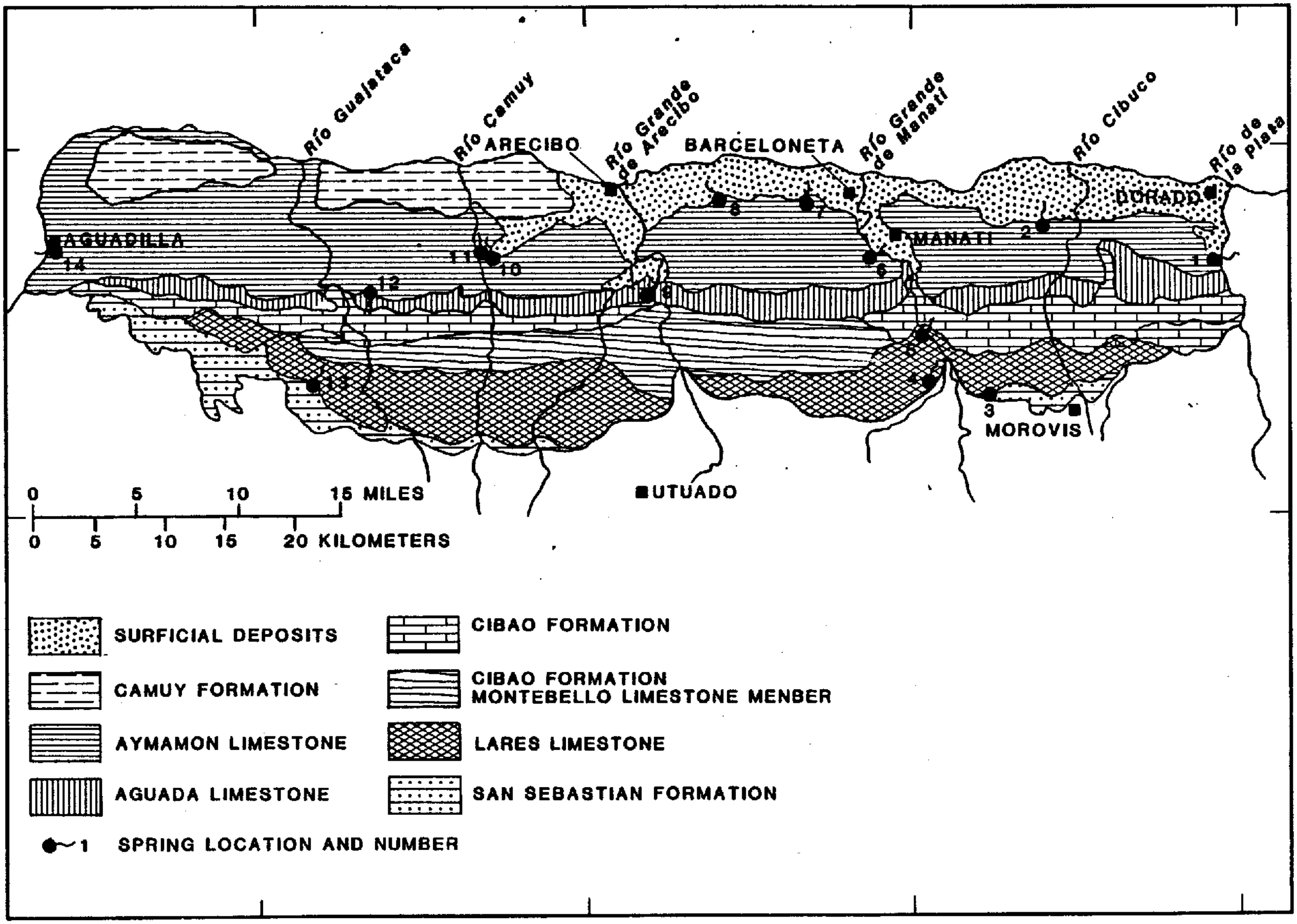

Figure 3.- Geologic formations of the North Coast Limestone area (adapted from Giusti, 1978).

Principal Springs of the South Coast

The other three springs included in the investigation flow from volcanic rocks along the south coast of Puerto Rico. Springflow along the south coast is limited by the lesser precipitation as compared to the north coast. Two of the springs (Banos de Quintana near Ponce and Banos de Coamo near Coamo, (map numbers 16 and 17) have thermal properties. The origin of these springs is unknown, although several hypothesis have been postulated. Giusti (1973) suggested that the natural temperature gradient of the earth could be the source of the heat in the water from these springs. Fractures or faults in the volcanic rocks to a depth of 4-5,000 ft could be acting as a conduit to transport the water from the recharge area at the surface. Ground water would emerge downgradient from the recharge area in a similar manner but at a higher temperature reflecting the depth reached. The springflow is produced by the difference in head between the recharge and discharge areas and temperature-pressure differentials. The second hypothesis suggests that a chemical reaction could be occurring with a large amount of heat been generated and absorbed by the water. Another possibility suggests that the springflow could be of meteoric origin. According to Monroe (1978) in late Oligocene Times, the Puerto Rican platform subsided below mean sea level. Faults and fractures containing freshwater may be undergoing dewatering by the buoyant force of the migrating seawater sorrounding the subsided mass.

The Pozo de la Virgen Spring near Sabana Grande (map number 15) is a small spring that is intermittent during periods of low rainfall. The spring is located within the volcanics of central Puerto Rico. Its ephemeral flow indicates that it originates from small fractures replenished by recharge from rainfall. It is more important as an atraction to religious groups than as a potential water resource.

CHEMICAL, PHYSICAL, AND BACTERIOLOGICAL CHARACTERISTICS OF SPRING-WATERS

Methods and Procedures

Water samples at 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). Determinations made in the field included pH, specific conductance, temperature, alkalinity, and concentration of the coliform group of bacteria. Raw 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 USGS Central Laboratory in Doraville, Georgia for most common ions (Ca, Mg, Na, K, Cl, SO4, F, SiO2, Br), trace elements (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Se, Sr, V, Zn), and nutrients (N total, NO2, NO3, NH4, P). Samples for organic carbon analyses were also collected at each site. Procedures described by Greeson and others (1971) were used for the collection and analyses of the bacteria samples. Incubation of the bacteria samples was begun at the site within minutes after collection and filtration.

Springflow measurements were made at most of the springs at least five times during the study period. Methods described by Rantz and Others (1983) were utilized for the flow mesurements. At three of the springs (Ojo del Agua at Vega Baja, San Pedro near Arecibo, and Banos de Coamo near Coamo) recording devices were installed to measure the springflow on a continuos basis. The temperature and specific conductance a the Banos de Coamo spring was also monitored on a continuous basis with a recording instrument.

Physical Characteristics

Springflow

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

ORDER OF MAGNITUDE	AMOUNT OF FLOW ft3/s
1	> 100
2	10 to 100
3	1 to 10
4	0.22 to 1.0
5	0.02 to 0.22
6	0.002 t0 0.02
7	< 0.002
8	< 0.0002

On the basis of the above classification system, the following is the breakdown for the principal springs in Puerto Rico:

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

Except for the Pozo de la Virgen Spring near Sabana Grande (map number 15), all of the springs were perennial during the study period (app. 1). Interviews with local residents indicate that perennial flow appears to prevail 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 must respond to other factors than precipitation, as they are not affected significantly by limited rainfall.

Springflow in general varies seasonally in response to precipitation. Data from the recording instruments at the gaged springs, as well as the instantaneous mesurements at the other springs, show seasonal fluctuations. At Ojo del Agua at Vega Baja (map number 2) the mean daily flow ranged from 0.20 to 7.3 ft3/s (app. 2 and fig. 4). Springflow was maximum during the rainy season (October to December), declining there after. In early May springflow increased in response to higher rainfall recharge.

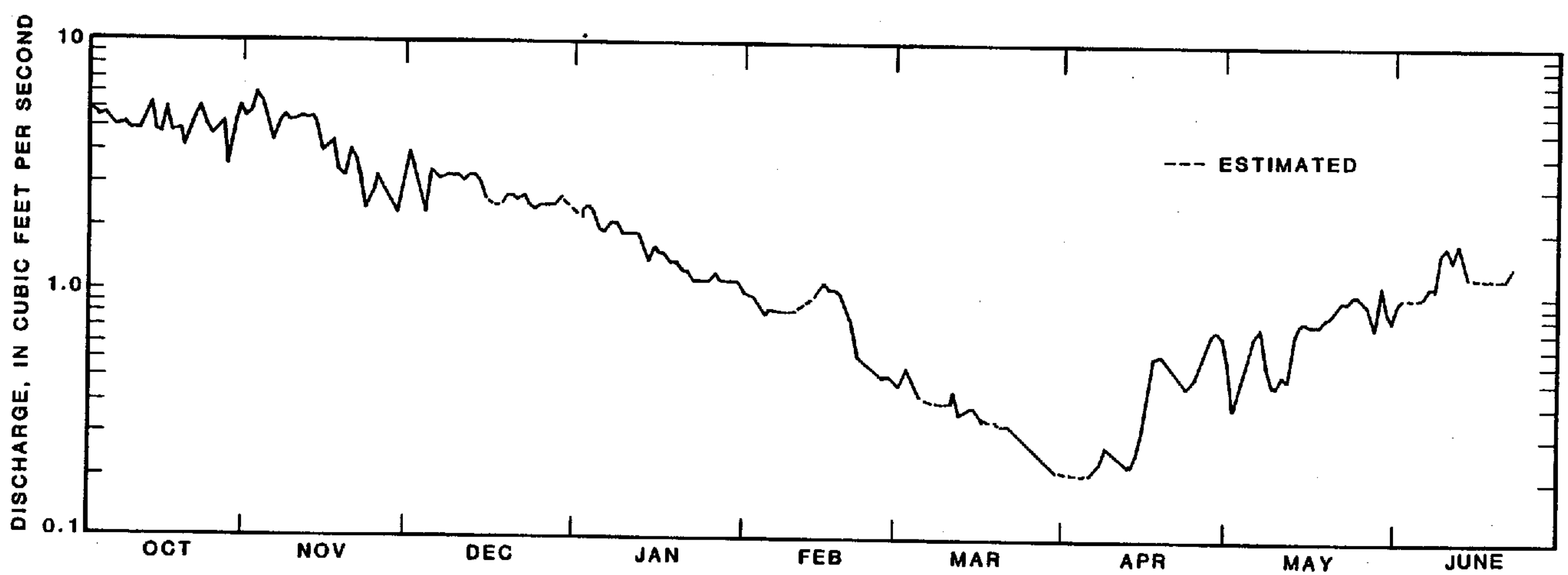

Figure 4.- Springflow at Ojo de Agua at Vega Baja.

At the San Pedro Spring near Arecibo, mean daily flows ranged from 3.1 to 28 ft3/s (app. 3 and fig.5). Seasonal effects of rainfall are also evident at the spring. The San Pedro spring is also affected by high stages at Rio Tanama, located a few hundred feet from the spring outlet. A comparison of the flow at the spring and at the Rio Tanama near Utuado and at Charco Hondo gaging stations show a graphical correlation between the stream and the spring (fig. 6). The Tanama River drains through the Aymamon Limestone, where cavities and underground sections of the river occur. A hydraulic or hydrostatic connection between the river and the spring could exist at high stages. The effects of high stages (or tides) combined with high pressure systems are known to affect an aquifer through compression of the pore spaces. The reduction in the amount of pore space may force water from the aquifer, increasing the yield of springs. High stages may act as backwater, reducing the spring's yield. A spring connected hydraulically to a sediment ladden river will discharge turbid water during high stage periods. Also in areas where sinkholes exist, runoff from blanket sands deposits containing suspended sediment may be conveyed to nearby springs. This has been observed at Ojo de Guillo near Manati and Aguas Frias near Ciales.

Springflow can also 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 Banos de Coamo spring suggests that the earthquake of 30 June 1984 significantly increased the flow from the springs. Prior to the earthquake, the average discharge was about 60 gal/min. A mesurement on 10 July 1984 resulted in a discharge of 110 gal/min. The number of seeps in the spring's area increased significantly after the earthquake. However, termination of the project prevented final confirmation of this effect. Mean daily flows from 32,000 to 80,000 gallons per day in the period of record (app. 4 and fig. 7).

Specific Conductance, pH, and Temperature

The specific conductance, pH, and temperature are among the most important physical properties 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 not only when investigating thermal waters, but also it can provide information on the source of water to a well or spring.

The specific conductance of the springs investigated ranged from 360 to 12,100 micromhos per centimeter (umhos/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 Fria springs at Cano Tiburones indicate that some saltwater occurs in the adjacent surficial sediments. A recent investigation (V.Quinones-Aponte, personal communication) indicates that these springs receive flow from Rio Grande de Arecibo. A relatively high specific conductance in waters from Banos Quintana spring near Ponce could be due to connate saltwater in the aquifer. At Banos de Coamo springs, chemical species other than those related to seawater account for a large portion of the high dissolved solids. This is discussed in another section of the report.

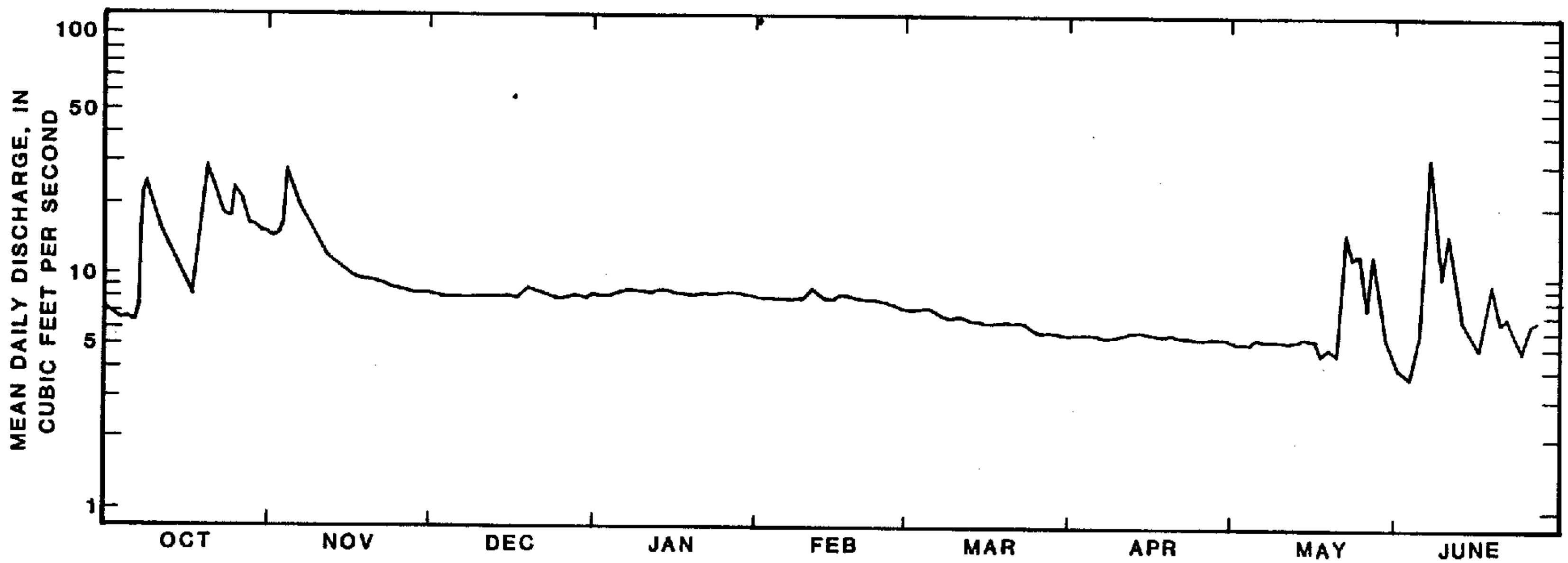

Figure 5.- Hydrograph for San Pedro near Arecibo, P.R. (Oct, 1983-June, 1984).

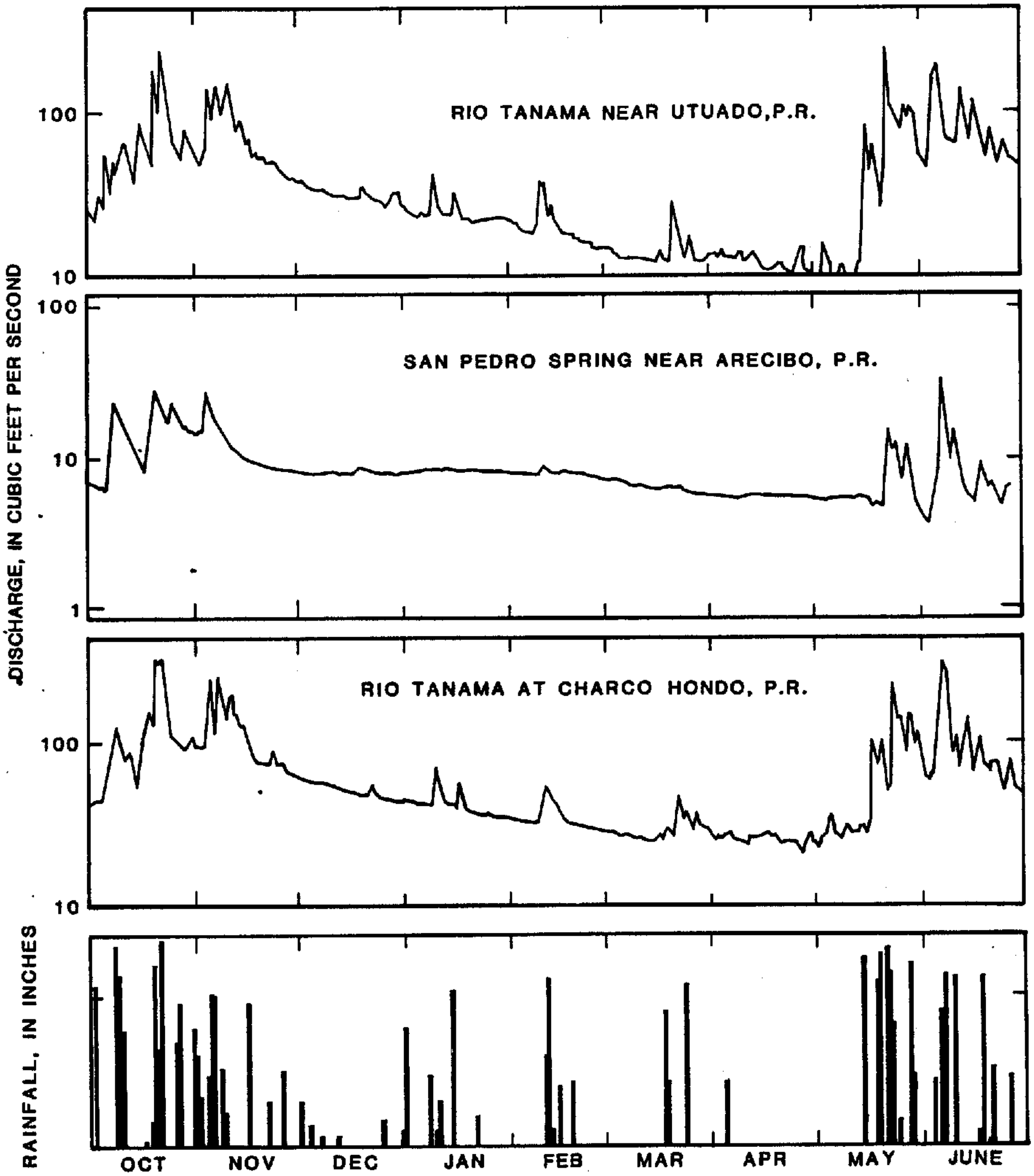

Figure 6.- Comparison of rainfall and discharge at Rio Tanama near Utuado, San Pedro Spring near Arecibo and Rio Tanama at Charco Hondo.

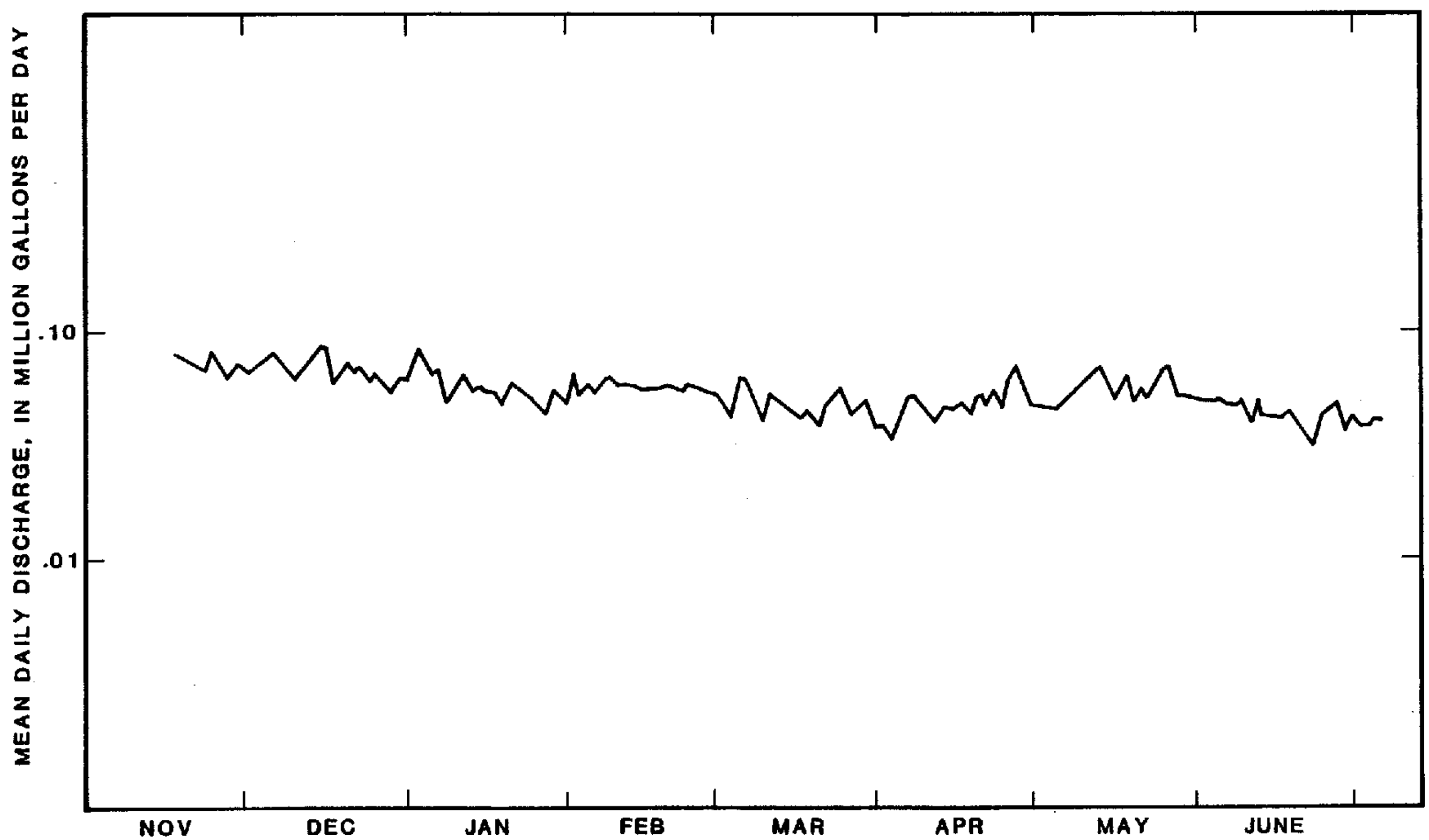

Figure 7.- Hydrograph for Banos de Coamo near Coamo, Puerto Rico.

The pH of the water from the springs ranged from slightly acid to moderate alkaline (6.7 to 9.3 pH units). The springs along the north coast contain high concentrations of calcium carbonate, 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 sulfates, 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 ressembling air temperatures. The near uniform temperatures in Puerto Rico account for this condition.

At the Banos de Coamo thermal springs, data from the specific conductance continuous recorder show nearly constant values (app. 5). 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 to the sampling location. The specific conductance is nearly equal to any instantaneous values collected during prior samplings.

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

Chemical Characteristics

Calcium, chloride, sodium, and sulfate are the principal ions in spring waters throughout Puerto Rico. Calcium concentrations range from 30 mg/L at Pozo de La Virgen to 220 mg/L at Banos de Coamo (app. 6, 7). Among the springs in 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 ($CaCO3$) occurs, and precipitation of the solid phase is evident. At Banos de Coamo, seawater does not appear to be the source of calcium (as demonstrated in a later section of this report).

Chloride concentrations in water determine the suitability of the water for various uses. Among the springs investigated, chloride concentrations ranged from 6.7 mg/L at Salto Collazo near San Sebastian to 3,800 mg/L at La Cambija at Cano Tiburones. However, the samples collected at La Cambija spring may have been affected by seawater backing from the Salty Cano Tiburones into the spring opening. In addition to the La Cambija spring, the Zanja Fria at Cano Tiburones (200 mg/L), Banos de Quintana near Ponce (260 mg/L), and Banos de Coamo near Coamo springs also contain water with high chloride concentrations (140 mg/L).

The ratio of chloride in springwater as compared to sea water can be used as an indicator of the degree of mixing between fresh and sea waters. These ratios are 0.02 for the Zanja Fria and 0.10 at La Cambija. Similar ratios of other ions such as boron sulfate can also be used with the chloride ratio to establish whether seawater is the source of the ions. Ratios of these elements and sulfate ions in the two springs are as follows:

CONSTITUENT	ZANJA FRIA	LA CAMBIJA
Chloride	0.02	0.10
Boron	0.02	0.03
Sulfate	0.02	0.10

The similarity of the ratios show that the springs are discharging near the fresh-seawater interface. Most of the other springs along the north coast are further inland and exhibit chloride concentrations typical of ground water.

Sodium ion concentrations parallel those of chloride, mainly because its chemical association in sodium chloride from seawater. Unbalanced sodium concentrations from some of the spring-waters could be due to ion exchange reactions. In such reactions alkaline substances such as $CaCO_3$ can exchange ions with solid species such as clay minerals. The calcium ion is then liberated into the solution.

Sulfate ion is the next most important 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. Ocassionally, minerals in the rocks may yield high sulfate concentrations. Gypsum ($CaSO_4$) and Sodium Sulfate (Na_2SO_4) deposits can be a source of sulfate ions in ground water. Sulfate concentrations range from 3 mg/L at Aguas Frias near Ciales to 1000 mg/L at Banos de Coamo. High sulfate concentrations are also present at La Cambija and Zanja Fria, springs affected by sewater intrusion.

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

RATIO OF ELEMENT CONCENTRATION
IN SPRING TO SEAWATER

CONSTITUENT	Banos Coamo	Banos Quintana
Chloride	0.007	0.014
Boron	0.543	0.283
Strontium	0.200	0.125
Sulfate	0.370	0.111

If the discharges from these springs were a mixture with seawater, these ratios should be about the same as determined for Zanja Fria and La Cambija springs. The concentration of boron in seawater is about 4,600 ug/L. The ratios above show that at Banos 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. 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). 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 near Vega Baja (5.9 mg/L), Ojo de Guillo near Manati (3.4 mg/L), and Ojo de Agua near Aguadilla (3.1 mg/L). These springs are in the vicinity of highly urbanized areas where the potential for contamination with sewage is high. Field investigations at Ojo de Guillo near Manati indicate that sewage 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 sinkhole. Drainage patterns from the area indicate the presence of an ancient channel that could connect the spring and the sinkhole. Field observations at the spring opening showed algal growth and gray-turbid water typical of sewage. Crustaceans and other aquatic life are killed occasionally by what appear to be slugs of chlorine or other disinfectants.

Analyses of trace elements indicate that with the exception of the thermal springs, concentrations are in general low and typical of ground-waters. The highest boron concentrations ranged from 90 ug/L at Zanja Fria to 2500 ug/L at Banos de Coamo springs.

The general chemical character of the waters from the springs investigated was defined utilizing "Stiff" diagrams (Hem, 1970). The diagram summarizes the concentration of the principal dissolved ions in terms of milliequivalents per liter (meq/L) on an x-axis. The specific ions are plotted on the y-axis on an established order. The plotted points are joined by straight segments, resulting in a geometrical figure characteristic of the particular water. Different waters will be represented by different shapes in the geometrical pattern (fig. 8).

The diagrams show that the chemistry of spring waters in Puerto Rico is dominated by calcium-magnesium-bicarbonate ions. As other indicators show, waters from springs along the north coast (except those affected by sewater) are very similar. At La Cambija, Zanja Fria, and Banos de Quintana, sodium-chloride type waters are predominant. The third type of water among the springs occurs at Banos de Coamo, where a sodium-sulfate type of water is discharged.

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 Banos 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 and recharge.

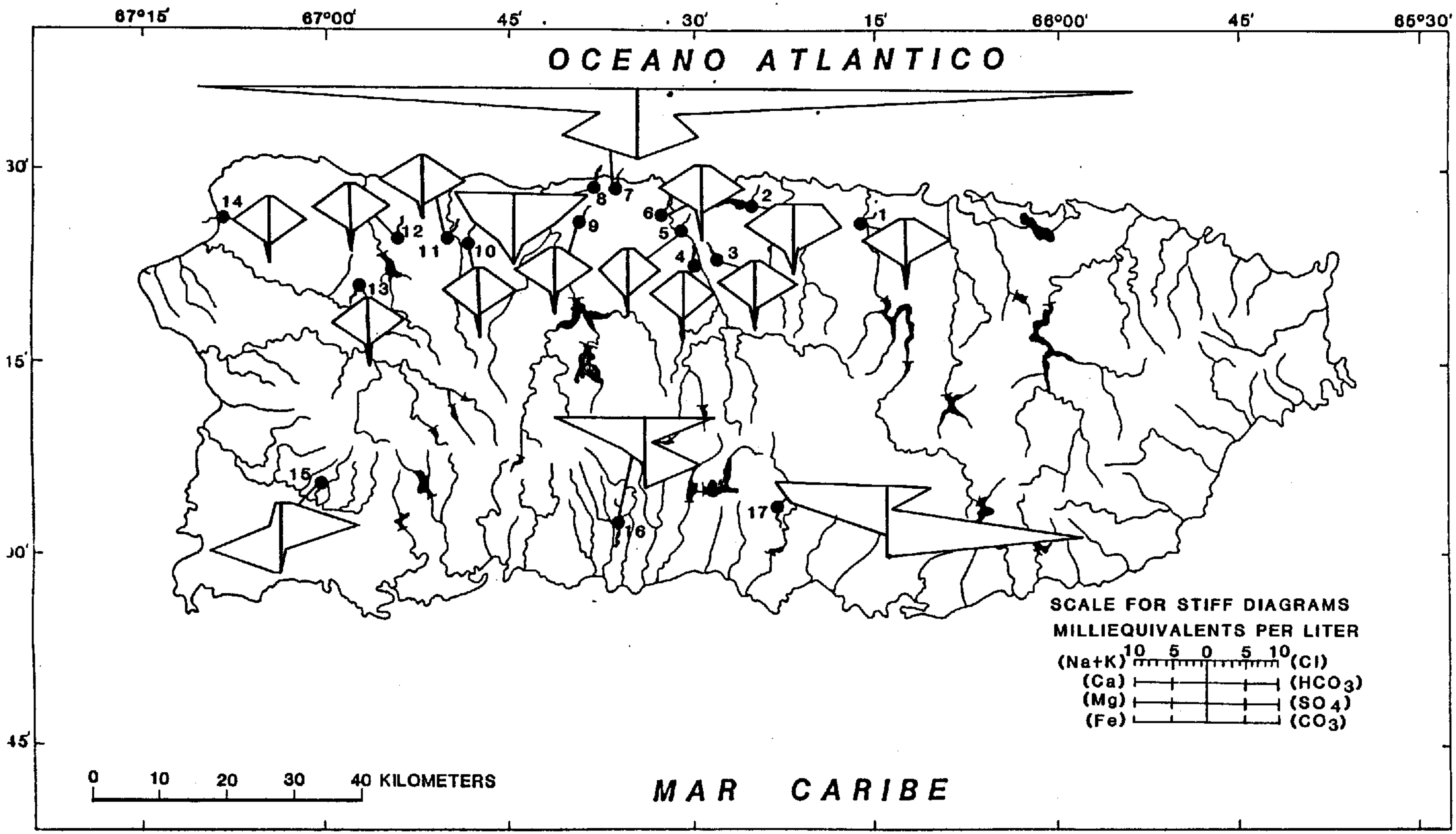

Figure 8.- Location of springs and stiff diagrams for chemical characters of the principal springs in Puerto Rico.

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 1900 colonies per 100 ml sample. The FS concentrations range from 1 to 2,200 colonies per 100 ml sample. Except for the Aguas Frias near Ciales and the Pozo de la Virgen near Sabana Grande springs, the bacteria concentrations are relatively low. At Pozo de la Virgen, a colony of pigeons breeding in the vicinity of the spring opening is probably the cause of the high bacteria concentrations. A rookery of birds is located close to the Aguas Frias spring, probably accounting for the high bacteria levels.

CONCLUSIONS

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

1. 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.

2. The most important springs in terms of flow are located along the north coast. San Pedro near Arecibo and Aguas Frias near Ciales normally discharge in excess of 3 ft3/s (about 2 Mgal/d). Maximum discharge was observed at San Pedro spring, with a daily average of 29 ft3/s (about 19 Mgal/d).

3. The total amount of springflow available from springs throughout Puerto Rico may be as much as 50 ft3/s (about 32 Mgal/d). This would include known springs not included in this survey.

4. Thermal waters flow from the Banos de Quintana near Ponce and Banos de Coamo near Coamo springs. Flow from the Banos de Quintana seldom exceeds 0.03 ft3/s (0.02 Mgal/d) with a temperature of about 32 degrees Centigrade. Flow at Banos de Coamo ranges from 40,000 to 110,000 gal/d with an average temperature of about 43 degrees Centigrade.

5. The quality of the water from the springs is related to their location. Most of the springs along the north coast exhibit excellent quality of water with calcium-magnesium-bicarbonate 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 Banos de Coamo spring contain high dissolved sulfate concentrations and are mainly a sodium-sulfate type of water.

6. Bacteriological analyses show that fecal coliform and fecal streptococci bacteria are present in most springs at low to moderate concentrations.

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APPENDIX 1

WATER DISCHARGE AT PRINCIPAL SPRINGS OF PUERTO RICO (WATER YEAR 1983)

SPRING MAP NO	DATE	WATER DISCHARGE Ft3/s(Mgal/d)	SPRING MAP NO	DATE	WATER DISCHARGE Ft3/s(Mgal/d)	SPRING MAP NO	DATE	WATER DISCHARGE Ft3/s(Mgal/d)
1	DEC 06	0.52 (0.34)	5	DEC 16	10 (6.5)	9	DEC 06	7.67 (4.96)
	MAR 03	0.40 (0.26)		MAR 03	10 (6.5)		MAR 23	3.28 (2.12)
	APR 28	1.7 (1.1)		MAY 03	11 (7.1)		MAY 18	4.24 (2.74)
	AUG 05	0.77 (0.50)		AUG 11	6.1 (3.94)		JUN 26	6.49 (4.19)
	JAN 30	0.80 (0.52)		JAN 25	5.3 (3.42)	10	DEC 14	0.24 (0.16)
2	NOV 30	0.63 (0.41)	6	NOV 30	1.6 (1.1)		MAR 02	0.03 (0.02)
	MAR 03	0.90 (0.58)		MAR 02	0.95 (0.61)		APR 27	0.10 (0.06)
	APR 29	1.3 (0.84)		APR 28	1.5 (0.97)		AUG 09	0.14 (0.09)
	JUL 21	0.33 (0.21)		AUG 28	1.51 (0.98)		NOV 23	0.16 (0.10)
	AUG 11	3.9 (2.52)		JAN 30	0.94 (0.61)	11	DEC 07	0.58 (0.37)
	DEC 06	2.95 (1.91)	7	DEC 08	9.2 (6.0)		MAR 02	0.29 (0.19)
	MAR 23	0.29 (0.19)		FEB 24	9.0 (5.8)		APR 27	0.67 (0.43)
	MAY 18	0.98 (0.63)		APR 26	9.4 (6.1)		AUG 09	0.53 (0.34)
	JAN 30	----------		MAR 29	7.49 (9.83)		NOV 23	0.72 (0.42)
	JUN 26	1.21 (0.78)		AUG 04	9.86 (6.37)	12	DEC 07	0.58 (0.37)
3	DEC 09	0.18 (0.12)	8	DEC 08	10 (6.5)		MAR 02	0.23 (0.15)
	FEB 24	0.17 (0.11)		FEB 24	7.3 (4.7)		APR 27	0.36 (0.23)
	MAY 03	0.19(.12)		APR 26	9.3 (6.0)		AUG 09	0.38 (0.25)
	JAN 25	0.02 (0.01)		AUG 04	9.43 (6.14)		NOV 23	0.36 (0.23)
	AUG 05	0.04 (0.03)	9	DEC 01	16 (10)	13	DEC 01	0.44 (0.28)
4	NOV 30	0.54 (0.35)		FEB 23	8.4 (5.4)		FEB 23	0.17 (0.11)
	MAR 02	0.27 (0.17)		APR 26	12 (7.8)		APR 27	0.17 (0.11)
	APR 28	0.26 (0.17)		JUN 24	16 (10.3)		AUG 03	0.03 (0.02)
	JAN 25	0.27 (0.17)		JUL 21	8.1 (5.23)		JAN 24	0.09 (0.06)
	AUG 05	0.16 (0.10)		AUG 03	8.4 (5.43)			
				SEP 07	4.95 (3.23)			

WATER DISCHARGE AT PRINCIPAL SPRINGS
OF PUERTO RICO (WATER YEAR 1983) --Continued

SPRING MAP NO	DATE	WATER DISCHARGE Ft3/s(Mgal/d)	SPRING MAP NO	DATE	WATER DISCHARGE Ft3/s(Mgal/d)
14	DEC 02	2.1 (1.4)	16	DEC 15	0.03 (0.02)
	FEB 23	0.70 (0.45)		FEB 25	0.01 (0.01)
	APR 28	1.0 (0.65)		APR 29	0.02 (0.01)
	AUG 03	1.0 (0.65)		AUG 10	0.02 (0.01)
	JAN 30	0.48 (0.31)	17	DEC 03	0.11 (0.07)
15	DEC 02	0.01 (0.01)		FEB 25	0.06 (0.04)
	FEB 23	0.00 (0.00)		APR 29	0.09 (0.06)
	APR 29	0.00 (0.00)		AUG 10	0.06 (0.04)
	AUG 10	DRY			

Appendix 2

Mean daily discharge at Ojo de Agua at Vega Baja, PR.

DAY	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	---	2.6	6.7	5.6	4.9	3.6	1.3	.97	.42	.14	.34	1.0
2	---	3.0	6.5	5.0	5.2	3.0	2.1	.95	.49	.13	.40	.90
3	---	3.2	6.6	5.5	6.3	2.5	2.2	.94	.46	.15	.47	.55
4	---	3.5	6.5	5.2	5.7	2.0	2.1	.90	.41	.16	.56	.88
5	---	3.5	6.6	5.0	4.9	3.0	1.3	.84	.37	.18	.67	1.0
6	---	4.0	5.6	5.0	5.9	2.9	1.7	.84	.28	.19	.74	1.1
7	---	3.8	6.5	4.9	4.7	2.8	1.9	.83	.21	.21	.55	1.1
8	---	3.1	6.5	4.4	5.1	2.9	1.9	.93	.21	.24	.43	1.5
9	---	3.3	6.2	4.6	4.3	2.9	1.7	.70	.20	.23	.42	1.6
10	---	5.5	5.9	4.6	4.8	2.9	1.7	.52	.28	.22	.48	1.4
11	---	5.0	6.9	4.5	5.0	2.8	1.7	.56	.40	.21	.46	1.7
12	---	6.4	5.4	4.4	4.9	2.9	1.7	.67	.32	[illegible]	.53	1.4
13	---	5.9	5.5	4.6	5.0	2.9	1.5	.73	.33	.20	.75	1.2
14	---	6.5	5.5	5.0	4.6	2.7	1.5	1.0	.34	.23	.79	1.2
15	---	6.9	5.5	5.3	3.6	2.3	1.5	1.1	.34	.31	.75	1.1
16	---	6.8	5.6	4.3	3.3	1.6	1.4	1.0	.32	.44	.75	1.0
17	---	7.3	5.7	4.2	4.0	2.2	1.4	1.0	.17	.56	.77	.93
18	---	7.3	6.2	5.5	3.0	2.2	1.3	.98	.22	.57	.82	1.2
19	---	7.3	6.3	4.5	2.9	2.4	1.3	.94	.30	.54	.82	1.2
20	---	6.7	6.6	4.5	3.9	2.4	1.2	.76	.29	.53	.88	1.2
21	.32	6.2	6.4	3.7	3.4	2.3	1.2	.56	.29	.47	.95	1.3
22	.36	5.6	6.6	4.4	2.3	2.4	1.1	.53	.23	.44	.96	---
23	.21	6.1	6.9	5.0	2.1	2.2	1.1	.50	.27	.42	1.0	---
24	.35	6.5	6.5	5.3	2.6	2.1	1.1	.43	.25	.45	.99	---
25	.59	5.9	6.2	6.7	2.9	2.2	1.1	.46	.24	.51	.94	---
26	.93	6.0	6.1	4.2	2.7	2.2	1.2	.46	.23	.60	.84	---
27	1.2	5.5	6.0	4.5	2.4	2.2	1.1	.47	.22	.69	.78	---
28	1.5	5.0	6.0	4.3	2.2	2.2	1.1	.43	.21	.71	1.1	---
29	1.7	5.2	5.2	3.2	2.0	2.4	1.1	.42	.19	.68	.85	---
30	2.1	5.4	5.2	4.5	2.3	1.7	1.1	---	.17	.53	.79	---
31	2.3	5.2	---	5.6	---	.94	1.0	---	.14	---	.94	---
TOTAL	---	167.2	185.5	146.4	116.6	75.74	44.9	21.32	8.55	10.91	22.66	---
MEAN	---	5.39	6.18	4.72	3.89	2.44	1.45	.74	.29	.36	.73	---
MAX	---	7.3	6.9	5.8	6.3	3.6	2.2	1.1	.49	.71	1.1	---
MIN	---	2.6	5.2	3.2	2.0	.94	1.0	.42	.14	.00	.34	---

Appendix 3

Mean daily discharge at San Pedro Spring near Arecibo, PR, in cubic feet per second

DAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	---	14	8.5	7.1	6.5	15	7.4	6.3	5.3	5.1	3.4	4.2	4.3
2	---	16	8.5	6.8	6.3	14	7.6	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	29	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	---	16	7.6	6.8	5.9	20	7.6	6.5	5.1	4.0	3.5	4.6	35
7	---	13	7.5	6.6	6.8	19	7.6	6.5	5.1	3.9	3.4	4.6	33
8	---	13	7.4	6.2	20	17	7.5	6.5	5.0	3.7	3.5	4.5	19
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	19
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	3.9	4.9	9.5
13	---	9.0	7.4	6.0	13	9.1	7.6	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	---	8.3	7.9	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	7.9	5.9	6.0	3.5	4.0	4.9	11
19	---	8.2	7.0	13	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	5.9	6.0	3.6	4.1	16	7.3
23	---	8.2	7.0	6.0	19	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	5.9	5.5	3.2	4.0	13	6.3
25	16	8.3	6.8	6.8	24	7.6	6.5	5.9	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	6.2
28	15	8.2	7.2	11	15	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	5.9	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	---
TOTAL	---	311.4	231.2	227.3	453.2	345.0	221.0	187.9	158.3	112.9	115.0	193.2	299.6
MEAN	---	10.0	7.46	7.58	14.6	11.5	7.13	6.06	5.46	3.64	3.93	6.23	[illegible]
MAX	---	15	8.5	15	29	28	7.9	6.5	6.1	5.1	4.4	16	35
MIN	---	8.0	6.7	5.9	5.9	7.5	6.3	5.5	5.0	3.1	3.3	4.2	6.0

APPENDIX 4

Mean daily springflow at Banos de Coamo near Coamo, PR
in million gallons per day (Mgal/d)

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	.078	.057	.052	.056	.046	.046	.065	.046
18	.076	.062	.048	.057	.044	.043	.043	.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	.048	.050	.044
30	.065	.063	.049	-	.043	.047	.050	.043
31	-	.059	.047	-	.038	-	.050	

APPENDIX 5

Specific conductance and temperature at Banos de Coamo nr Coamo (1983)

(Specific conductance in micromhos per centimeter and temperature in degrees Celsius)

Day	Spe Cond	Temp	Spe Cond	Temp	Spe Cond	Temp	Spe Cond	Temp	Spe Cond	Temp	Spe Cond	Temp	Spe Cond	Temp
	umhos	degC	umhos	degC	umhos	degC	umhos	degC	umhos	degC	umhos	degC	umhos	degC
	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	2020	43.0
2	2210	42.7	2320	42.6	2270	42.8	2230	43.0	2220	42.9	2220	43.0	2020	43.0
3	2300	42.6	2300	42.6	2270	42.8	2230	43.0	2220	43.0	2220	43.0	2020	43.0
4	2310	42.7	2300	42.6	2270	42.8	2230	43.0	2220	43.0	2220	42.9	2020	43.0
5	2300	42.7	2310	42.6	2260	42.8	2230	43.0	2220	43.0	2220	42.9	2020	43.0
6	2300	42.6	2300	42.6	2260	42.8	2230	43.0	2220	42.9	2220	42.7	2020	43.0
7	2300	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.8	2020	43.0
8	2300	42.7	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.9	2020	43.0
9	2300	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	42.9	2020	43.0
10	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2020	43.0
11	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2020	43.0
12	2310	42.6	2300	42.6	2260	42.9	2230	43.0	2220	43.0	2220	43.0	2020	43.0
13	2310	42.6	2290	42.7	2250	42.8	2230	42.9	2220	43.0	2220	43.0	2020	43.0
14	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	43.0	2220	43.0	2020	43.0
15	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	43.0	2220	43.0	2020	43.0
16	2310	42.6	2290	42.7	2250	42.8	2220	43.0	2220	43.0	2220	42.9	2020	43.0
17	2320	42.6	2290	42.7	2250	42.8	2220	42.9	2220	42.9	2220	42.9	2020	43.0
18	2300	42.6	2290	42.7	2250	42.8	2220	43.0	2220	42.6	2220	43.0	2020	43.0
19	2300	42.6	2290	42.7	2250	42.8	2220	43.0	2220	42.7	2220	43.0	2020	43.0
20	2310	42.6	2290	42.7	2250	42.8	2220	42.9	2220	42.8	2220	43.0	2020	43.0
21	2320	42.5	2290	42.7	2240	42.8	2220	42.9	2220	42.9	2220	43.0	2020	42.8
22	2310	42.5	2280	42.7	2240	42.8	2230	42.8	2220	42.9	2220	43.0	2020	42.9
23	2300	42.6	2280	42.7	2240	42.9	2220	42.8	2220	43.0	2220	42.9	2020	42.7
24	2300	42.6	2280	42.7	2240	42.9	2220	43.0	2220	43.0	2220	42.9	2020	43.0
25	2320	42.6	2280	42.8	2240	42.8	2220	42.9	2220	43.0	2220	42.9	2020	42.9
26	2310	42.6	2280	42.8	2240	42.9	2220	43.0	2220	43.0	2220	42.9	2020	43.0
27	2320	42.6	2280	42.8	2230	42.9	2220	42.9	2220	43.0	2220	43.0	2020	43.0
28	2320	42.6	2280	42.8	2230	42.9	2220	42.9	2220	43.0	2220	43.0	2020	42.9
29	-	-	2280	42.8	2230	43.0	2220	42.9	2220	43.0	2220	43.0	2020	42.9
30	-	-	2280	42.8	2230	43.0	2220	42.9	2220	43.0	2220	43.0	2020	43.0
31	-	-	2270	42.8	-	-	2220	43.9	-	-	2220	43.0	2020	43.0

Specific conductance and temperature at Banos de Coamo nr Coamo (1983) --Continue

(Specific conductance in micromhos per centimeter and temperature in degrees Celsius)

Day	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC	Spe Cond umhos	Temp degC
	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	2020	42.5
19	2220	42.8	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	43.0	2020	42.5
20	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.9	2220	42.9	2020	42.9
21	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2020	42.9
22	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.5	2220	42.5	2020	42.9
23	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	42.5	2220	42.5	2020	42.5
24	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2020	42.5
25	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.9	2020	42.5
26	2220	42.8	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.9	2020	42.9
27	2220	42.9	2220	43.0	2220	43.0	2230	43.0	2230	43.0	2220	42.5	2020	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	-	-	-	-

APPENDIX 6

Physical, chemical and biological characteristics of the principal springs of Puerto Rico in comparison to sea water

SPRING MAP NO	DATE	STREAM-FLOW, INSTANTANEOUS (FT3/SEC)	SPECIFIC CONDUCTANCE (UMHOS)	PH (STD UNITS)	TEMPERATURE (DEG C)	COLIFORM, FECAL, 0.7 UM/MF (COLS/100 ML)	STREPTOCOCCI FECAL KF AGAR (COLS/100 ML)	HARDNESS (MG/L AS CACO3)	HARDNESS NONCARBONATE (MG/L CACO3)	CALCIUM, DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)
1	DEC., 1982 06...	0.52	572	6.7	24.5	450	320	250	9	92	5.8	16
	AUG., 1983 05...	0.77	585	7.0	25.0	660	510	260	15	93	5.6	15
2	NOV., 1982 30...	0.63	860	6.8	24.5	41	58	310	57	110	9.5	48
	AUG., 1983 11...	3.90	820	7.1	25.0	4	1	320	60	110	11	47
3	DEC., 1982 09...	0.18	470	7.7	24.0	72	96	220	1	82	3.2	8.8
	AUG., 1983 05...	0.04	470	7.2	24.5	430	210	230	9	85	4.1	9.9
4	NOV., 1982 30...	0.54	390	7.8	23.0	20	50	190	4	70	1.9	6.0
	AUG., 1983 05...	0.16	388	7.5	23.5	95	310	180	12	69	2.2	6.7
5	DEC., 1982 16...	10	360	7.7	22.5	1800	830	160	0	61	2.0	6.4
	AUG., 1983 11...	6.10	384	7.3	23.0	340	360	190	10	72	2.5	6.7
6	NOV., 1982 30...	1.60	525	6.8	24.0	51	4	240	17	93	2.9	12
	AUG., 1983 04...	1.51	522	7.0	24.5	15	10	250	17	94	2.9	12
7	DEC., 1982 03...	9.20	5470	7.2	24.0	28	100	710	460	130	92	930
	AUG., 1983 04...	9.86	12100	7.1	24.0	22	72	1400	1100	190	220	2200
8	DEC., 1982 08...	10.0	1390	7.2	24.0	--	40	320	77	95	19	160
	AUG., 1983 04...	9.50	1420	7.4	25.5	78	670	330	92	100	20	150
9	DEC., 1982 01...	16.0	430	7.0	23.5	380	130	200	0	72	4.8	5.8
	AUG., 1983 03	8.40	470	7.4	24.0	42	52	230	19	83	5.1	5.6

SPRING MAP NO	DATE	POTASSIUM DIS-SOLVED (MG/L AS K)	SULFATE DIS-SOLVED (MG/L AS SO4)	ALKA-LINITY FIELD (MG/L AS CACO3)	CHLORIDE DIS-SOLVED (MG/L AS CL)	FLUORIDE 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., 1982 06...	1.6	9.0	220	32	< .1	7.8	303	312	0.42	--
	AUG., 1983 05...	1.8	8.5	240	28	< .1	7.5	333	303	0.69	--
2	NOV., 1982 30...	2.4	15	280	88	< .1	9.0	555	437	0.94	--
	AUG., 1983 11...	2.1	18	260	100	< .1	9.3	494	455	5.20	--
3	DEC., 1982 09...	0.9	13	240	13	.1	12	290	264	0.14	--
	AUG., 1983 05...	1.0	9.6	220	13	.2	17	281	274	0.03	--
4	NOV., 1982 30...	.2	7	180	9.9	.1	3.6	222	207	0.32	--
	AUG., 1983 05...	.4	6.1	170	12	< .1	4.0	253	205	0.11	1.0
5	DEC., 1982 16...	.5	3	160	10	.1	5.4	197	186	5.3	--
	AUG., 1983 11...	.4	3.5	180	10	< .1	3.7	214	208	3.52	2.4
6	NOV., 1982 30...	1.6	4	250	18	< .1	6.4	317	275	1.36	--
	AUG., 1983 04...	.9	4.8	230	19	< .1	6.5	348	282	1.42	3.4
7	DEC., 1982 08...	31	270	250	1900	.1	6.3	3360	3510	83.4	--
	AUG., 1983 04...	79	540	280	3800	.1	5.9	7550	7180	201	--
8	DEC., 1982 08...	4.9	41	240	280	< .1	6.8	788	751	21.3	--
	AUG., 1983 04...	5.1	38	240	280	< .1	6.7	881	746	22.6	--
9	DEC., 182 01...	1.5	9	200	8.8	< .1	8.3	216	231	9.33	--
	AUG., 1983 03...	1.0	7.7	210	10	.1	7.4	239	247	5.42	--

SPRING MAP NO	DATE	STREAM-FLOW, INSTANTANEOUS (FT3/SEC)	SPECIFIC CONDUCTANCE (UMHOS)	PH (STD UNITS)	TEMPERATURE (DEG C)	COLIFORM, FECAL, 0.7 UM/MF (COLS/100 ML)	STREPTOCOCCI FECAL KF AGAR (COLS/100 ML)	HARDNESS (MG/L AS CACO3)	HARDNESS NONCARBONATE (MG/L CACO3)	CALCIUM, DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)
10	DEC., 1982 14...	0.24	465	7.5	23.5	380	640	210	3	80	3.1	7.6
	AUG., 1983 09...	0.14	518	7.3	24.5	360	1000	230	16	85	3.2	7.9
11	DEC., 1982 07...	0.58	460	7.7	23.5	100	240	220	4	84	2.5	7.5
	AUG., 1983 09...	0.53	445	7.3	23.5	220	630	200	2	78	1.7	7.1
12	DEC., 1982 07...	0.58	465	7.4	23.5	580	220	220	35	86	1.4	7.0
	AUG., 1983 09...	0.38	517	7.4	24.0	400	550	250	7	96	1.7	7.9
13	DEC., 1982 01...	0.44	455	7.4	23.0	100	40	220	0	84	2.9	4.2
	AUG., 1983 03...	0.03	410	6.9	23.5	260	610	200	1	76	2.5	4.0
14	DEC., 1982 02...	2.10	540	6.9	25.0	74	4	250	0	94	4.5	8.6
	AUG., 1983 03...	1.00	555	7.2	25.0	270	2200	250	0	91	4.6	8.7
15	DEC., 1982 02...	0.01	825	6.8	24.5	1900	1000	460	19	30	93	15
	AUG., 1983 10...	DRY	---	--	--	---	---	---	---	--	---	---
16	DEC., 1982 15...	0.03	1520	9.3	31.0	480	850	170	150	69	0.05	270
	AUG., 1983 10...	0.02	1490	9.2	32.0	1500	410	170	150	68	0.08	230
17	DEC., 1982 03...	0.11	2250	8.3	43.0	4	--	550	530	220	0.15	340
	AUG., 1983 10...	0.06	2210	9.0	43.0	10	1	550	530	220	0.10	300
	SEA WATER	--	>35000	--	--	---	---	---	---	400	1350	10500

SPRING MAP NO	DATE	POTASSIUM DISSOLVED (MG/L AS K)	SULFATE DISSOLVED (MG/L AS SO4)	ALKALINITY FIELD (MG/L AS CACO3)	CHLORIDE DISSOLVED (MG/L AS CL)	SOLIDS, FLUORIDE DISSOLVED (MG/L AS F)	SOLIDS, SILICA, DISSOLVED (MG/L AS SIO2)	RESIDUE AT 180 DEG C DISSOLVED (MG/L)	SUM OF CONSTITUENTS DISSOLVED (MG/L)	SOLIDS DISSOLVED (TONS PER DAY)	NITROGEN, NITRATE TOTAL (MG/L AS N)
10	DEC., 1982 14...	1.1	11	210	13	< .1	5.1	224	251	0.17	--
	AUG., 1983 09...	1.6	17	210	18	< .1	5.8	304	268	0.11	2.2
11	DEC., 1982 07...	.6	8	220	13	< .1	5.1	224	251	0.35	--
	AUG., 1983 09...	.7	6.4	200	14	< .1	4.6	261	236	0.37	.964
12	DEC., 1982 07...	.2	8	220	11	< .1	4.9	246	231	0.39	--
	AUG., 1983 09...	.7	6.9	240	15	.1	5.4	309	281	0.32	1.2
13	DEC., 1982 01...	.5	6	230	6.7	< .1	4.6	237	244	0.28	--
	AUG., 1983 03...	.5	9.1	200	7.8	.2	4.1	225	222	0.02	--
14	DEC., 1982 02...	.5	7	250	15	< .1	6.2	300	244	1.70	--
	AUG., 1983 03...	.6	6.4	260	16	< .1	6.4	305	287	0.82	--
15	DEC., 1982 02...	.6	12	430	26	1.0	49	478	491	0.01	--
	AUG., 1983 10...	DRY	---	---	--	--	--	---	---	---	--
16	DEC., 1982 15...	1.2	300	24	250	.4	26	874	---	0.07	--
	AUG., 1983 10...	1.3	300	23	260	.4	26	970	901	0.05	--
17	DEC., 1982 03...	2.2	1000	17	130	1.1	30	1860	---	0.30	--
	AUG., 1983 10...	2.2	1000	20	140	1.1	30	1880	1710	0.30	< .010
	SEA WATER	380	2700	116	19000	1.3	6.4	---	---	---	--

APPENDIX 7

Trace metals at the principal springs of Puerto Rico

SPRING MAP NO	DATE	ALUMINUM, DISSOLVED (UG/L AS AL)	ARSENIC DISSOLVED (UG/L AS AS)	BARIUM DISSOLVED (UG/L AS NA)	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., 1982 06...	10	1	28	<1	20	1	<1	<3	<10	< 7
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	< 3
2	NOV., 1982 30...	10	1	41	<1	30	<1	<1	<3	<10	< 3
	AUG., 1983 11...	--	--	--	--	--	--	--	--	--	4
3	DEC., 1982 09...	10	<1	24	<1	70	<1	<1	<3	<10	8
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	4
4	NOV., 1982 30...	10	1	9	<1	30	<1	<1	<3	<10	5
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	6
5	DEC., 1982 16...	50	1	16	<1	70	<1	<1	<3	<10	< 3
	AUG., 1983 11...	--	--	--	--	--	--	--	--	--	3
6	NOV., 1982 30...	< 10	3	19	<1	30	<1	<1	<3	<10	< 3
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	6
7	DEC., 1982 0d...	10	<1	24	<1	370	1	<1	<3	<10	9
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	50
8	DEC., 1982 08...	20	1	16	<1	90	<1	<1	<3	<10	8
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	< 3
9	DEC., 1982 01...	30	1	21	<1	10	2	3	<3	<10	19
	AUG., 1983 03...	--	--	--	--	--	--	--	--	--	10

SPRING MAP NO	DATE	LEAD DIS-SOLVED (UG/L AS PB)	LITHIUM DIS-SOLVED (UG/L AS LI)	MANGA-NESE DIS-SOLVED (UG/L AS MN)	MERCURY DIS-SOLVED (UG/L AS HG)	MOLYB-DENUM DIS-SOLVED (UG/L AS MO)	SELE-NIUM DIS-SOLVED (UG/L AS SE)	STRON-TIUM DIS-SOLVED (UG/L AS SR)	VANA-DIUM DIS-SOLVED (UG/L AS V)	ZINC DIS-SOLVED (UG/L AS ZN)
1	DEC., 1982 06...	< 10	< 4	3	< .1	< 10	< 1	120	< 6	< 4
	AUG., 1983 05...	--	--	--	--	--	--	120	--	--
2	NOV., 1982 30...	< 10	< 4	1	.1	< 10	< 1	170	< 6	5
	AUG., 1983 11...	--	--	--	--	--	--	--	--	--
3	DEC., 1982 09...	< 10	5	< 1	.1	< 10	< 1	200	< 6	5
	AUG., 1983 05...	--	--	--	--	--	--	210	--	--
4	NOV., 1982 30...	< 10	4	< 1	.1	< 10	< 1	150	< 6	< 4
	AUG., 1983 05...	--	--	--	--	--	--	150	--	--
5	DEC., 1982 16...	< 10	< 4	< 1	.4	< 10	< 1	140	< 6	5
	AUG., 1983 11...	--	--	--	--	--	--	170	--	--
6	NOV., 1982 30...	< 10	< 4	14	.1	< 10	< 1	110	9	< 4
	AUG., 1983 04...	--	--	--	--	--	--	120	--	--
7	DEC., 1982 08...	< 10	17	1	.3	< 10	< 1	860	< 6	< 4
	AUG., 1983 04...	--	--	--	--	--	--	1700	--	--
8	DEC., 1982 08...	< 10	7	1	.2	< 10	< 1	210	< 6	4
	AUG., 1983 04...	--	--	--	--	--	--	220	--	--
9	DEC., 1982 01...	20	< 4	1	.1	< 10	< 1	330	< 6	< 4
	AUG., 1983 03...	--	--	--	--	--	--	470	--	--

SPRING MAP NO	DATE	ALUMINUM, DIS-SOLVED (UG/L AS AL)	ARSENIC DIS-SOLVED (UG/L AS AS)	BARIUM DIS-SOLVED (UG/L AS BA)	BERYLLIUM DIS-SOLVED (UG/L AS BE)	BORON DIS-SOLVED (UG/L AS B)	CADMIUM DIS-SOLVED (UG/L AS CD)	CHROMIUM, DIS-SOLVED (UG/L AS CR)	COBALT DIS-SOLVED (UG/L AS CO)	COPPER DIS-SOLVED (UG/L AS CU)	IRON DIS-SOLVED (UG/L AS FE)
10	DEC., 1982 06...	20	1	12	<1	30	<1	<1	<3	<10	<3
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	< 3
11	NOV., 1982 30...	10	1	12	<1	10	<1	<1	<3	<10	9
	AUG., 1983 11...	--	--	--	--	--	--	--	--	--	15
12	DEC., 1982 09...	<10	1	12	<1	10	<1	<1	<3	10	6
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	8
13	NOV., 1982 30...	30	1	19	<1	<10	3	3	<3	<10	21
	AUG., 1983 05...	--	--	--	--	--	--	--	--	--	< 3
14	DEC., 1982 16...	20	1	15	<1	10	<1	3	<3	<10	7
	AUG., 1983 11...	--	--	--	--	--	--	--	--	--	5
15	NOV., 1982 30...	10	3	79	<1	40	2	3	<3	<10	16
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	--
16	DEC., 1982 08...	50	<1	19	<1	1300	<1	1	<3	<10	4
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	4
17	DEC., 1982 03...	20	5	32	<1	2500	1	3	<3	<10	24
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--	20

SPRING MAP NO	DATE	LEAD DIS-SOLVED (UG/L AS PB)	LITHIUM DIS-SOLVED (UG/L AS LI)	MANGA-NESE DIS-SOLVED (UG/L AS MN)	MERCURY DIS-SOLVED (UG/L AS HG)	MOLYB-DENUM DIS-SOLVED (UG/L AS MO)	SELE-NIUM DIS-SOLVED (UG/L AS SE)	STRON-TIUM DIS-SOLVED (UG/L AS SR)	VANA-DIUM DIS-SOLVED (UG/L AS V)	ZINC DIS-SOLVED (UG/L AS ZN)
10	DEC., 1982 06...	< 10	< 4	1	< .1	< 10	< 1	170	< 6	< 4
	AUG., 1983 05...	--	--	--	--	--	--	160	--	--
11	NOV., 1982 30...	< 10	< 4	1	.1	< 10	< 1	110	< 6	< 4
	AUG., 1983 11...	--	--	--	--	--	--	90	--	--
12	DEC., 1982 09...	10	4	1	< .1	10	< 1	110	< 6	< 4
	AUG., 1983 05...	--	--	--	--	--	--	120	--	--
13	NOV., 1982 30...	10	< 4	1	.1	< 10	< 1	700	< 6	< 4
	AUG., 1983 05...	--	--	--	--	--	--	790	--	--
14	DEC., 1982 16...	< 10	< 4	< 1	.2	< 10	< 1	230	< 6	< 4
	AUG., 1983 11...	--	--	--	--	--	--	220	--	--
15	NOV., 1982 30...	< 10	< 4	16	.1	10	< 1	160	< 6	< 4
	AUG., 1983 04...	--	--	--	--	--	--	--	--	--
16	DEC., 1982 08...	< 10	23	< 1	.4	< 10	< 1	1000	< 6	26
	AUG., 1983 04...	--	--	--	--	--	--	1000	--	--
17	DEC., 1982 08...	< 10	63	2	.3	< 10	.1	1600	< 6	< 4
	AUG., 1983 04...	--	--	--	--	--	--	1800	--	--