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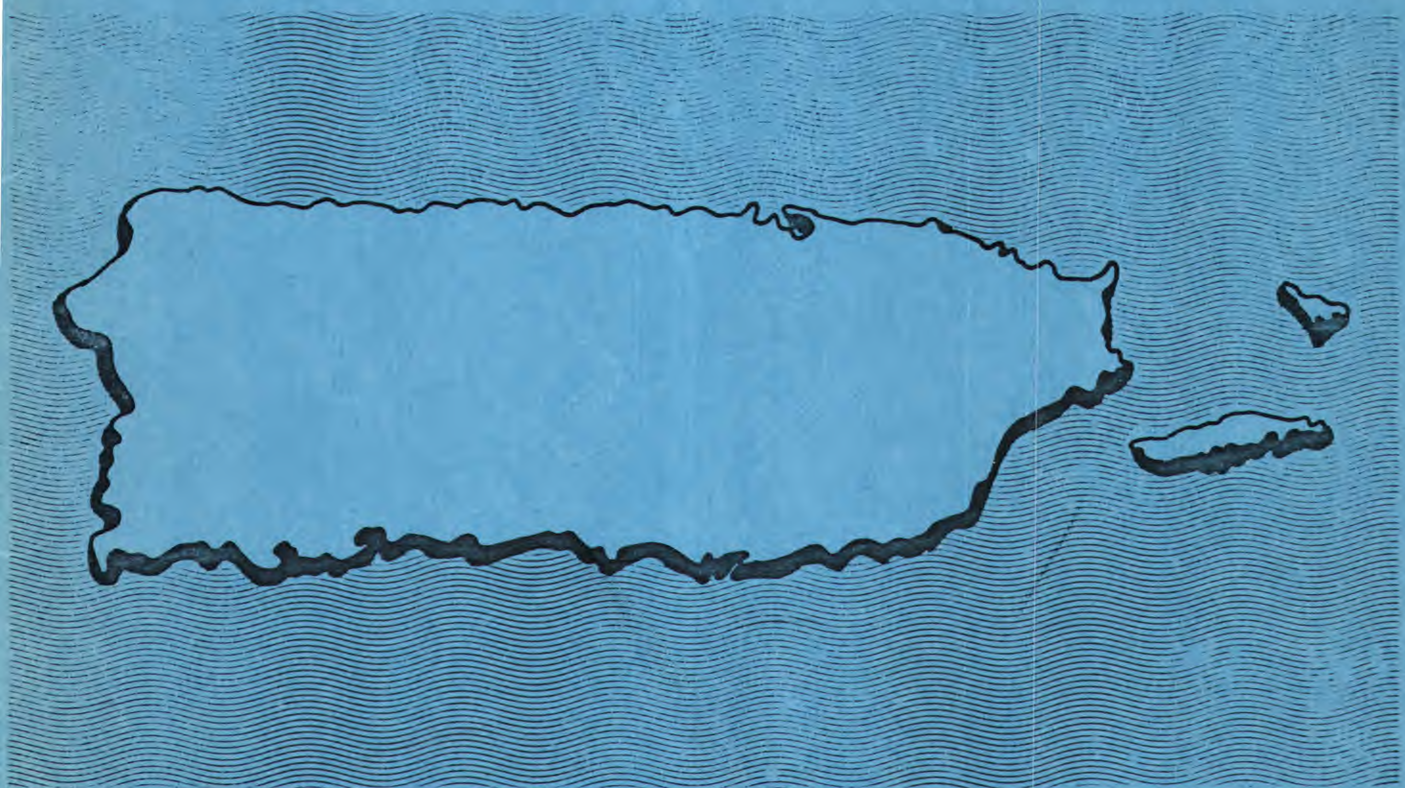
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SUMMARY OF THE WATER RESOURCES OF PUERTO RICO



Open-File Report 78-971

UNITED STATES
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SUMMARY OF THE WATER RESOURCES OF PUERTO RICO

By H. Jack McCoy

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San Juan, Puerto Rico

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SUMMARY OF THE WATER RESOURCES OF PUERTO RICO

by H. Jack McCoy

INTRODUCTION

Purpose of Report

The U.S. Department of Commerce (DOC) is the lead agency in the Federal Interagency Study of the Economy of Puerto Rico. At the request of DOC the U.S. Geological Survey is providing a discussion of the water resources of the island for inclusion in the study's section on macroeconomic assessment.

Explanation of Units

The International System (SI) of units is used in this report with inch-pound equivalents in parentheses. The conversion factors used are as follows:

Multiply SI unit	By	To obtain inch-pound units
kilometer (km)	0.6215	mile (mi)
square kilometer (km^2)	0.3861	square mile (mi^2)
millimeter (mm)	0.0394	inch (in)
cubic hectometer (hm^3)	264.2	million gallons (Mgal)
cubic hectometer per year (hm^3/year)	0.7238	million gallons per day (Mgal/d)
cubic meter (m^3)	35.31	cubic feet (ft^3)
cubic meter (m^3)	264.2	gallon (gal)

AVAILABILITY AND QUALITY OF WATER

Two of the most important aspects of a water appraisal of an area are how much water is available for use and how good is the water. "How much" is often difficult even to estimate because a considerable amount of data is necessary in order to define the quantity. However, the quality of water is much easier to assess in that variability in the quality of water is not as great as in the quantity of water, and less data are required for equal assessment.

Hydrogeologic Setting

Although only 177 by 56 km (110 by 35 mi) at the longest and widest points, Puerto Rico (fig. 1) has considerable diversity in topography, geology, and hydrology. The volcanic and orogenic development of the island produced igneous and metamorphic rocks which form the west-east mountainous axis (fig. 2). Limestone beds were deposited along the north and south coasts of the volcanic mass during periods of general subsidence.

On the north coast where deposition was most widespread, the total thickness of limestone exceeds 1,220 m (4,000 ft). Overlying most of the north coastal area are alluvium and blanket sands. The alluvium, found chiefly in the valleys of major rivers, is as thick as 61 m (200 ft); the blanket sands, found in flat areas between limestone hills, are as much as 18 m (60 ft) thick. Inland of the blanket sands and alluvium are large outcrops of the limestone beds. In some areas of these outcrops intensive sinkhole development has produced a classic tropical karst topography.

On the south coast, limestone deposition was considerably less widespread. In the eastern half of the south coast, the limestone is almost completely blanketed by coalescing alluvial fans of rivers draining the inteior plutonic rocks. In the western half, limestone outcrops are separated by narrow alluvial valleys. On the extreme southwest coast, the diversity of geology is shown by an assortment of blanket sands, limestone, alluvium, serpentine, tuffaceous sandstone, siltstone, breccia, beach and dune deposits, conglomerate, lava, and tuff.

Limestone deposition was minimal on the west coast and almost absent on the east coast. The alluvial valleys on the west coast contain some limestone lenses and overlie limestone in some isolated areas. But the alluvial valleys of the east coast overlie plutonic and intrusive igneous rocks.

The interior of the island is underlain by sedimentary, volcanic, and intrusive rocks. Most of the rocks are fine grained or dense, and they will not yield large quantities of water to wells. Alluvial deposits are scattered throughout the stream valleys, and where they are thick, they yield moderate supplies of water to wells.

On the north coast, the deep limestone aquifer is confined and the contained ground water is under greater than atmospheric pressure (artesian). The artesian system contains high volumes of ground water and is recharged primarily from rainfall through sinkholes and on local outcrops. The water table or unconfined aquifer overlying the artesian system also contains copious supplies of ground water and is recharged mainly by local rainfall. Some recharge to the unconfined aquifer comes from streams cutting into the alluvium. But much of each year, the streams receive water from the ground-water system.

The south coast is covered by less permeable limestone and tight alluvial deposits. Moreover, average annual rainfall is less on the south coast than on the north coast and the amount of recharge varies correspondingly (fig. 3).

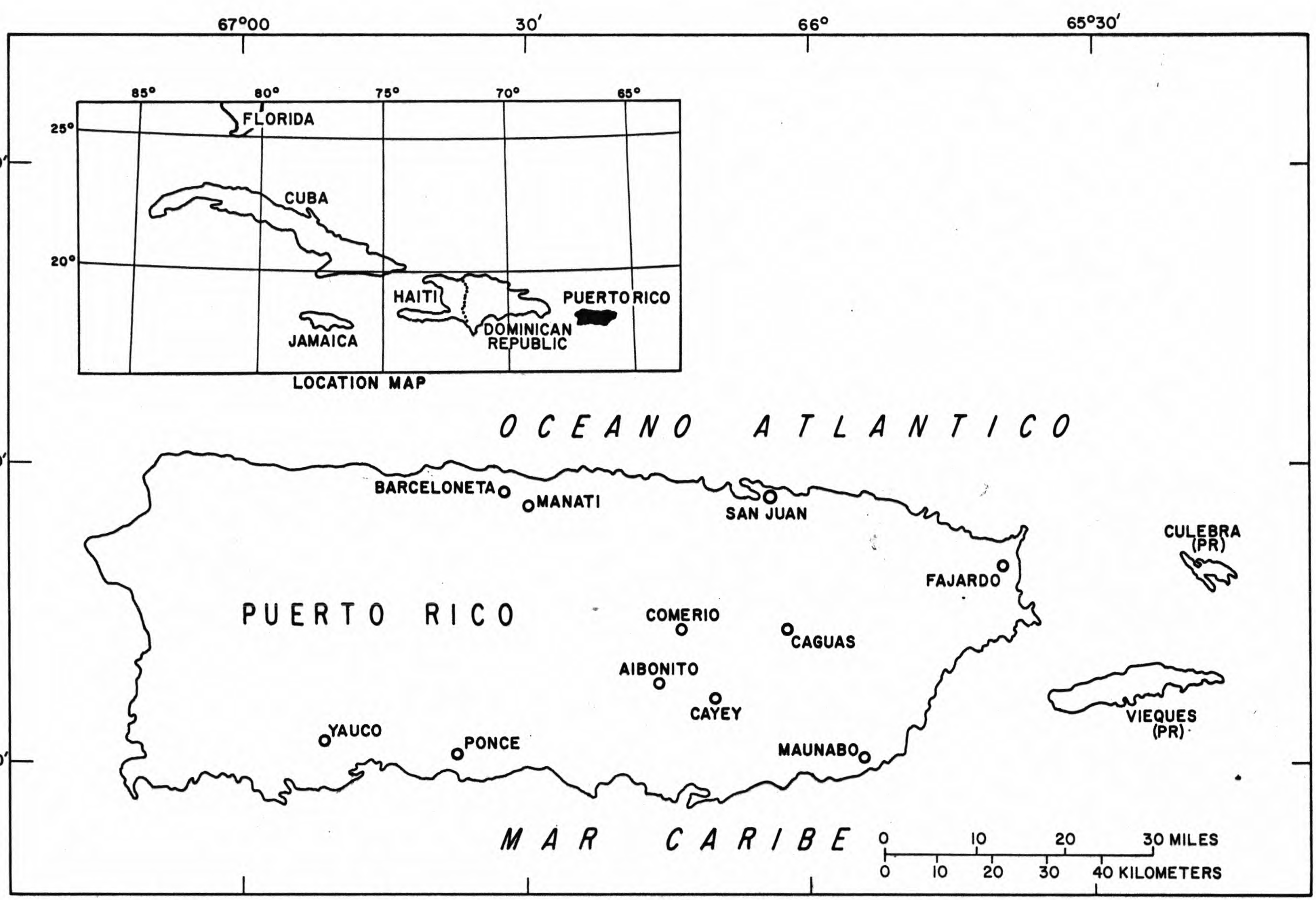


Figure 1.-- The principal islands of the Commonwealth of Puerto Rico, and location map.

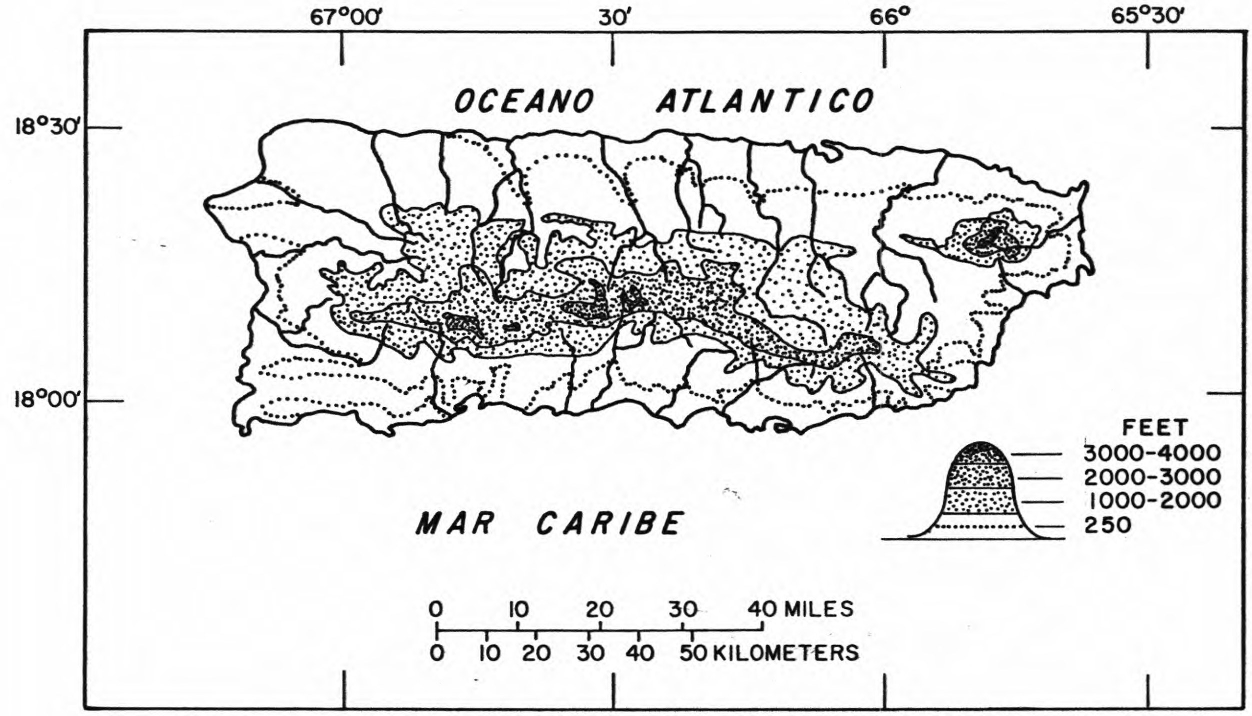


Figure 2.--Relief map of Puerto Rico.

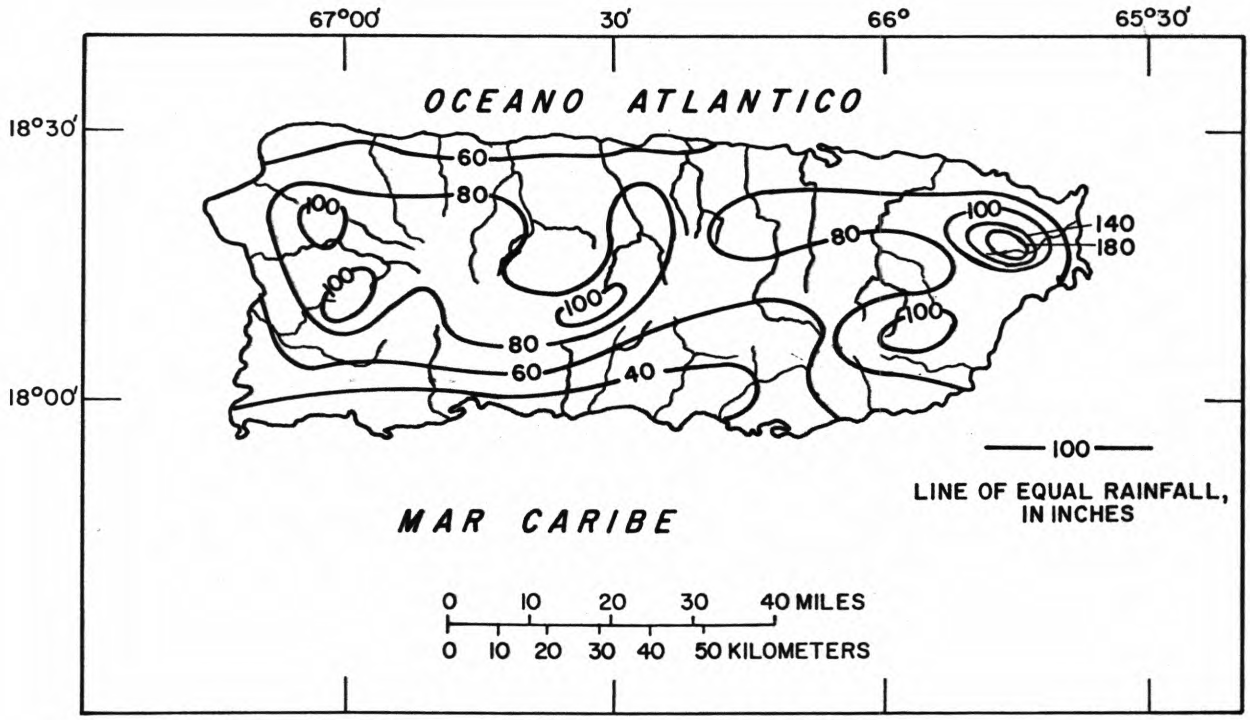


Figure 3.--Average annual precipitation.
(Modified from Calvesbert, 1970)

On the east coast, the alluvial aquifers receive about 2,080 mm (80 in) of average annual rainfall. The alluvium on the east coast is generally more permeable than on the south coast and recharge is considerably higher except in the Fajardo area.

On the west coast, alluvial deposits in the major stream valleys and the underlying limestone are sources of all ground water. Yields of wells vary from about 400 gallons per minute in the alluvium to about 1,100 gallons per minute in the limestone.

Quantity of Water Available

As indicated in figure 4, Puerto Rico and adjacent islands receive an estimated 16,000 hm^3 (11,600 Mgal/d) of water annually as rainfall (F. Gómez, U.S.Geological Survey, written commun., 1978). About 10,000 hm^3/year, (7,240 Mgal/d) is returned to the atmosphere by evapotranspiration; streamflow to the ocean amounted to more than 5,000 hm^3 (3,620 Mgal/d) in 1975; ground-water discharge to lowlands and the ocean was 260 hm^3 (188 Mgal/d); and municipal, industry, and agriculture accounted for about 580 hm^3 (420 Mgal/d) by means of consumptive use, discharges to the ocean, and evapotranspiration.

Of the more than 5,000 hm^3 of streamflow to sea, probably only about half could be retained in reservoirs. The same is probably true of ground-water discharges to the ocean--about half of the 260 hm^3 discharge to the ocean could be retained for use by pumping wells located near the coast. However, wells would have to be spaced and pumpage monitored to prevent the lowering of water levels to the extent that would induce seawater intrusion into the aquifer (Bogart, 1964, p. 80).

Of the 580 hm^3 used by numicipal, industry, and agriculture, 255 hm^3 (185 Mgal/d) is returned to the atmosphere as evapotranspiration by agriculture and is uncontrollable. Of the remaining 325 hm^3 (235 Mgal/d) probably half could be reused by recycling the effluent from proposed sewage treatment plants (U.S. Army Corps of Engineers, 1977).

The above analysis indicates that about 2,790 hm^3/yr (2,020 Mgal/d) of additional water is available for use. However, this is a potential amount; the actual amount is subject to technical and social as well as economic constraints. Moreover, the potential amount would not be distributed evenly throughout the island. For instance, although the south coast comprises about 16 percent of the island, 16 percent of 2,790 hm^3, or 445 hm^3 (323 Mgal/d), is not available for additional water supplies. Therefore, to increase the short-term water supply potential of the south coast will require improvements in present water-use practices and management. Long-term increases will require the importation of water from the water-rich areas of the north coast and the interior.

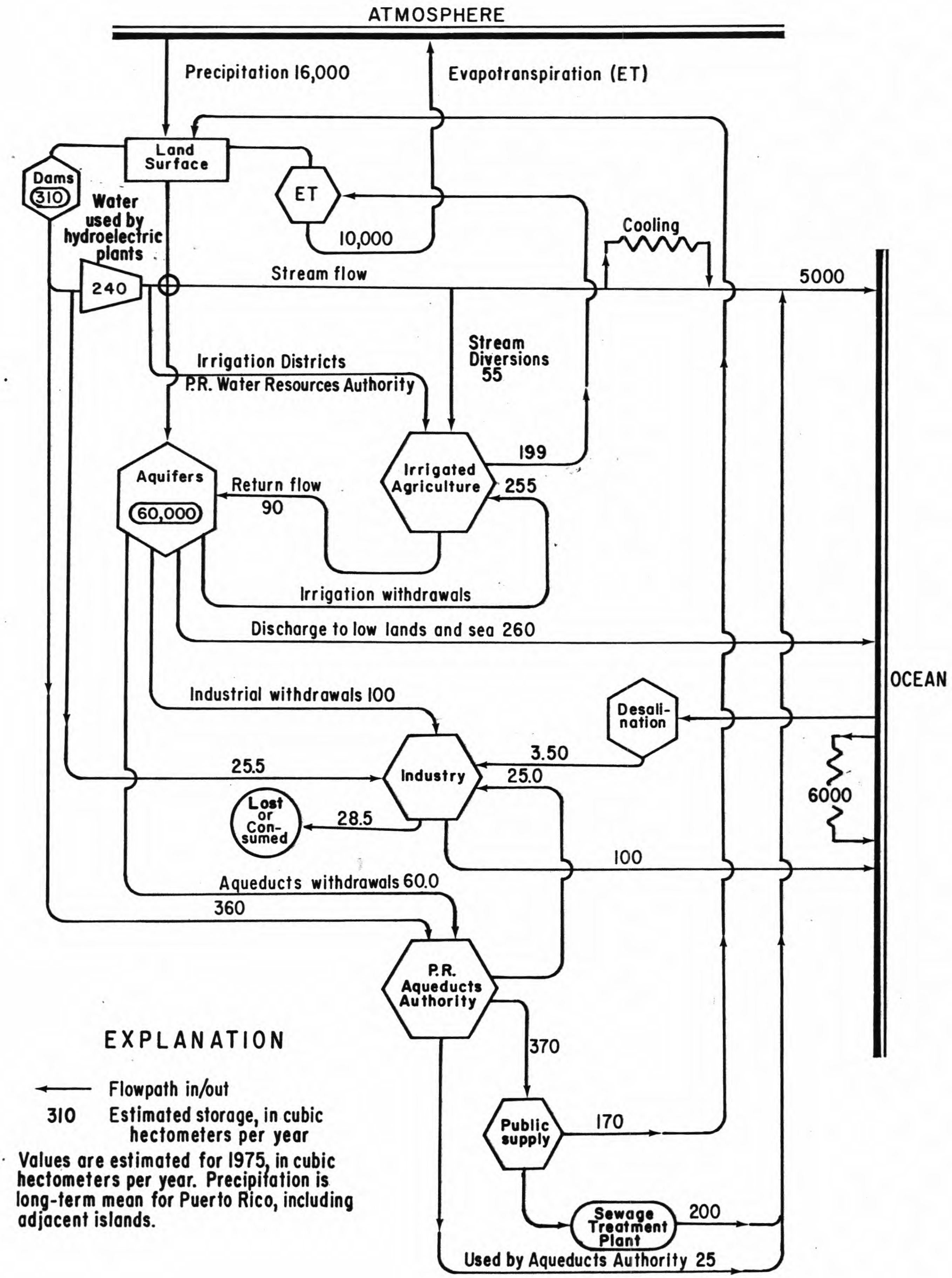


Figure 4.--Generalized water use and water budget for Puerto Rico and adjacent islands. (Modified from F. Gómez, U.S. Geological Survey written communication, 1978)

Quality of Water Available

Generally the chemical composition of nearly all surface waters in Puerto Rico is about the same (Bogart, 1964, p. 86). The waters are predominantly of the calcium bicarbonate type. However, characteristic differences do occur==especially in dissolved solids and in concentration of specific ions--as shown for the six areas delineated on figure 5.

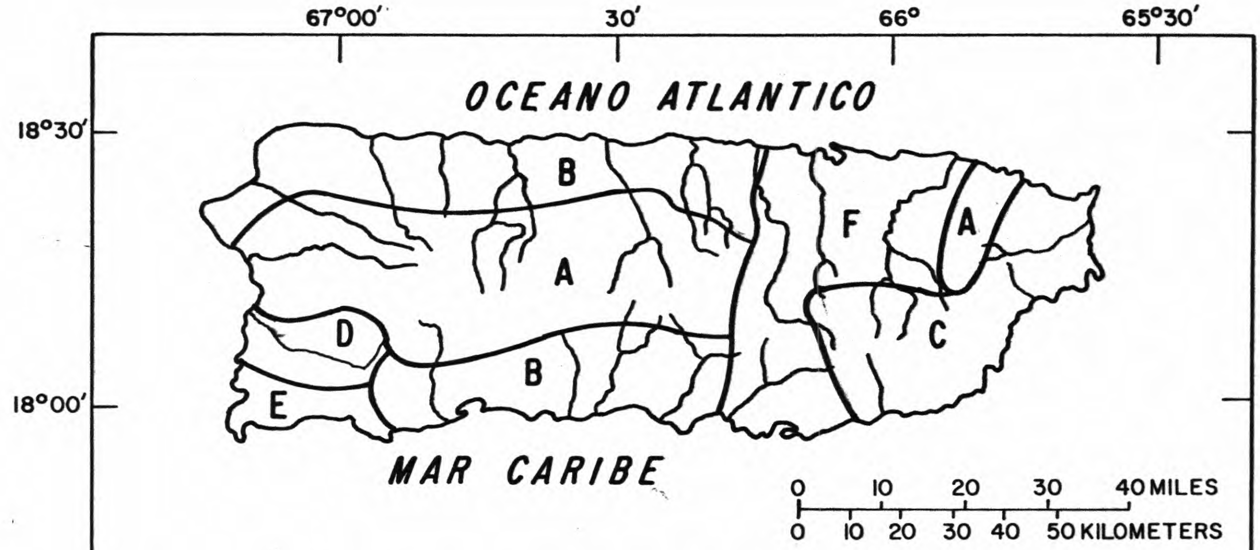
Most ground-water supplies in Puerto Rico are similar in chemical composition; calcium, magnesium, and bicarbonate are generally the principal ions. Calcium and chloride are the predominant ions in ground water in the Lajas Valley and other heavily pumped areas along the south coast, indicating the effect of seawater contamination or of salt buildup in the soils resulting from irrigation. Nitrates are also found in all ground water near the south coast, reportedly in concentrations as high as 149 mg/L (milligrams per liter) as nitrate. Origin of the nitrate is probably from fertilizers that are used extensively in sugarcane cultivation (Bogart, 1964, p. 89).

In general, most of the ground waters of Puerto Rico are hard (100-300 mg/L). Color is usually about 10 units and fluoride concentrations are seldom more than a few tenths of a milligram per liter (Bogart, 1964, p. 90). In the alluvium of the Maunabo Valley and adjacent valleys, high concentrations of manganese and iron are present in the water in some wells in the alluvium (Adolphson and others, 1977, p. 26, Puerto Rico Aqueduct and Sewer Authority, laboratory records).

The Puerto Rico Department of Health makes scheduled collections of samples from all public water supplies--surface water and ground water--on the island. These samples are analyzed to determine if the water quality meets Federal standards for drinking water. Industries perform chemical analyses of their water supplies to detect any constituents that might be harmful to machinery or manufactured products. Water quality is monitored at 55 surface-water sites throughout the island by the U.S. Geological Survey as part of various cooperative programs with other Federal and Commonwealth agencies. However, in areas where ground water is not a source of public or industrial supplies, few data on the quality of ground water have been collected.

Generally the physical properties of all ground water in Puerto Rico are within acceptable limits for most uses. Surface waters require considerable filtration during high flows for the removal of suspended sediment.

Few, if any, surface waters in Puerto Rico are free of coliform bacteria. Numerous streams throughout the island have coliform counts in the thousands of coliform per milliliter. Even the apparently pristine waters in the highest elevations of El Yunque (fig. 2) have to be chlorinated to reduce total coliform counts to acceptable levels for drinking water standards.



REPRESENTATIVE CHEMICAL ANALYSES OF SURFACE WATER

ZONE	MILLIGRAMS PER LITER					
	SILICA (SiO_2)	HARDNESS ($CaCO_3$)	ALKALINITY (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	DISSOLVED SOLIDS
A	26	83	99	7.2	10	145
B	24	170	194	4.8	8	212
C	37	39	66	4.4	12	117
D	26	190	208	15	12	221
E	24	260	360	78	100	582
F	28	104	121	10	18	165

Figure 5.--Chemical characteristics of surface water.

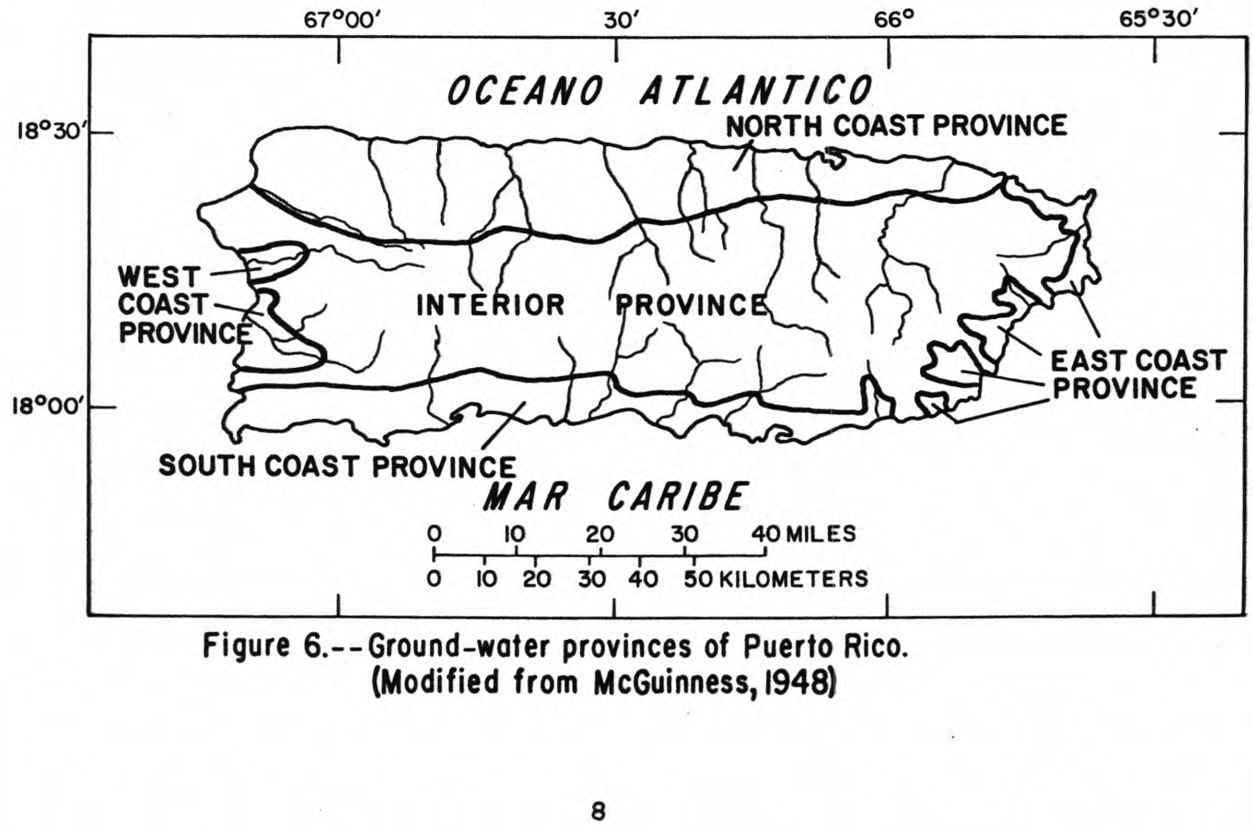


Figure 6.--Ground-water provinces of Puerto Rico.
(Modified from McGuinness, 1948)

WATER BUDGET

McGuinness (1948) divided Puerto Rico into five ground-water provinces (fig. 6). These areas were delineated by aquifer boundaries. In this discussion, McGuinness' provinces will be used for development of the water budgets, present (1975) water use, and future water needs and uses.

Puerto Rico and the outlying islands comprise about 9,000 square kilometers (3,475 square miles). The long-term mean annual rainfall is 1,850 mm (72.9 in) for Puerto Rico. The inclusion of the outlying islands reduces the rainfall value to about 1,780 mm (70.1 in). The following is a recent (1975) water budget for Puerto Rico and the outlying islands of Vieques, Culebra, and Mona and for each of the five provinces (F. Gómez, U.S. Geological Survey, written commun., 1978).

Islandwide

		hm^3/year	Mgal/d
INPUT	Precipitation	16,000	11,600
OUTPUT	Evapotranspiration	10,000	7,240
	Streamflow to ocean	5,000	3,620
	Ground-water discharge to wetlands and ocean	260	188
	Surface-water use		
	Agriculture	155	112
	Public supplies	360	260
	Ground-water withdrawals		
	Agriculture	100	72
	Industry	100	72
	Public supplies	60	43
	Total (rounded)	16,000	11,600

North Coast Province

		hm³/year	Mgal/d
INPUT	Precipitation	3,630	2,630
	Stream inflow (from Interior Province)	2,240	1,620
	Total (rounded)	5,870	4,250
OUTPUT	Evapotranspiration	2,510	1,820
	Streamflow to ocean	3,150	2,280
	Ground-water discharge to wetlands and ocean	121	88
	Ground-water withdrawal	90	65
	Total (rounded)	5,870	4,250

South Coast Province

		hm³/year	Mgal/d
INPUT	Precipitation	470	340
	Stream inflow (from Interior Province)	495	358
	Irrigation imports	80	58
	Total (rounded)	1,040	756
OUTPUT	Evapotranspiration	490	355
	Streamflow to sea	350	253
	Ground-water discharge to wetlands and ocean	50	36
	Ground-water withdrawal		
	Agriculture	100	72
	Industry	40	29
	Public supplies	10	7
	Total (rounded)	1,040	753

West Coast Province

		hm^3/year	Mgal/d
INPUT	Precipitation	360	261
	Stream inflow (from Interior Province)	880	673
	Total (rounded)	1,240	898
OUTPUT	Evapotranspiration	270	195
	Streamflow to sea	920	666
	Ground-water discharge to wetlands and ocean	40	29
	Ground-water withdrawals	10	7
	Total (rounded)	1,240	897

East Coast Province

		hm^3/year	Mgal/d
INPUT	Precipitation	390	282
	Stream inflow (from Interior Province)	510	369
	Total (rounded)	900	651
OUTPUT	Evapotranspiration	278	201
	Streamflow to sea	580	420
	Ground-water discharge to wetlands and ocean	30	22
	Ground-water withdrawals		
	Agriculture	0	0
	Industry	10	7
	Public supplies	2	1
	Total (rounded)	900	651

Interior Province

Because data are sparse in the Interior Province the following table was obtained by subtracting the total water budgets of the four provinces from the islandwide water budget (excluding outlying islands):

		hm^3/year	Mgal/d
INPUT	Precipitation	11,100	8,030
OUTPUT	Evapotranspiration	6,490	4,700
	Streamflow to other provinces	4,200	3,040
	Ground-water discharge and withdrawals	376	272
	Total (rounded)	11,100	8,010

WATER SOURCES AND USE

Islandwide

Islandwide, about 60 percent of man's water requirements are served by surface water and 40 percent by ground water. Figure 4 (F. Gómez, U.S. Geological Survey, written commun., 1978) provides a breakdown of 1975 water requirements for Puerto Rico, including the islands of Vieques, Culebra, and Mona.

Surface-water sources account for about 86 percent of public supplies but only about 17 percent of industrial supplies; agriculture uses almost equal amounts of ground water and surface water.

Water for municipal and industrial supplies is treated and distributed by the Puerto Rico Aqueduct and Sewer Authority. Charges for treated water (1978) are as follows:

0-10 m^3 (0-2,640 gal)	\$1.60 per month (61¢ per 1,000 gal)
10-50 m^3 (2,640-13,200 gal)	22¢ per m^3 per month (83¢ per 1,000 gal)
50-1,000 m^3 (13,200-264,000 gal)	26¢ per m^3 per month (98¢ per 1,000 gal)
1,000-10,000 m^3 (35,300-353,000 ft^3)	21¢ per m^3 per month (79¢ per 1,000 gal)
more than 10,000 m^3 (more than 2,640,000 gal)	16¢ per m^3 per month (61¢ per 1,000 gal)

North Coast Province

Public supplies and agricultural demands are furnished almost exclusively by surface water. However, industry receives more than half its water needs from ground water.

South Coast Province

Ground water is the primary source of supply on the south coast. Of the 190 hm^3/year (137 Mgal/d) of ground water used islandwide by agriculture, 180 hm^3/year (130 Mgal/d) is used on the south coast. And of the 100 hm^3/year (72 Mgal/d) used islandwide by industry, 40 hm^3/year (29 Mgal/d) is used on the south coast. Almost 500 hm^3/year (360 Mgal/d) of streamflow enters or is diverted to the south coast but a large amount of this inflow recharges the ground-water system. Most municipalities on the south coast use ground water for public supplies but the largest city on the south coast, Ponce, uses surface water. Therefore, surface water is the major source of public supplies on the south coast.

West and East Coast Provinces

Surface water is much more plentiful on the west and east coasts than on the south coast. Consequently, major water users obtain supplies from surface-water sources rather than from aquifers. Ground-water withdrawals account for only about one or two percent of the water used on the east and west coasts.

Interior Province

The major water source in the interior is surface water. However, at one time (1960), Aibonito obtained all of its public supplies from four wells; Comerío from a spring and a well; Cayey obtained 27 percent of its supply from wells; and Caguas obtained almost 10 percent from wells.

Industry and public supplies account for almost all of the water used in the interior.

FUTURE WATER DEMANDS

Public supply accounted for 420 hm^3 (304 Mgal/d) of water used in Puerto Rico in 1975 and is estimated to reach almost 600 hm^3 in 1985. Water used for agriculture was 345 hm^3 (250 Mgal/d) in 1975 and is estimated to remain the same through 1985 as more efficient irrigation measures and water reuse practices are being implemented. Water used by industry in 1975 was 154 hm^3 (112 Mgal/d) which includes about 25 hm^3 (18 Mgal/d) from public supplies. An additional 50 hm^3 (36 Mgal/d) was obtained from surface waters for cooling by sugar mills. Industrial use is estimated to increase only slightly through 1985 because stringent environmental laws imposed on the quality of effluents will persuade industry to use water more efficiently and judiciously (F. Gómez, U.S. Geological Survey, written commun., 1978).

WATER PROBLEMS

A number of water problems exist or can be anticipated which may have significant impacts on the economic development of Puerto Rico. Some of these problems are natural, others are man produced or are worsened by man's activities.

The most obvious problem is a natural one and one which is not unique to Puerto Rico: variability of rainfall within a year, from year to year, and with location. Precipitation records from 1941-70 (U.S. National Oceanic and Atmospheric Administration, 1973) show that San Juan, on the north coast, had a monthly high average precipitation of 177 mm (6.97 in) in August and a monthly low average of 51.8 mm (2.04 in) in March. Ponce, on the south coast, had a monthly high average precipitation of 147 mm (5.79 in) in October and a monthly low average of 18.3 mm (0.72 in) in February.

Precipitation and consequent streamflow can vary considerably from year to year. For example, annual precipitation at San Juan was 940 mm (37.0 in) in 1966 and 1,910 mm (75.2 in) in 1965. Annual precipitation at Ponce was 380 mm (15.0 in) in 1967 and 1,600 mm (63.0 in) in 1970.

Precipitation is also quite variable with location. In the area of El Yunque (near the east coast) the average precipitation is more than 4,570 mm (180 in), whereas about 97 km (60 mi) to the southwest (west of Ponce) the average annual precipitation is about 890 mm (35 in)(Calvesbert, 1970).

The distribution of rainfall in time and space is a natural problem. The major problem resulting from man's activities is the lack of formal coordination between the 23 Commonwealth and Federal agencies concerned with water management (U.S. Army Corps of Engineers, 1977, Summary, p. 30). The Water Law of Puerto Rico (PL 136), approved in June 1976, empowers the Department of Natural Resources to develop plans and regulate the use, conservation. and development of water resources. Development and implementation of an islandwide water plan would be an aid in the solution of the following problems:

1. Quantity and quality of ground water.--The U.S. Geological Survey's monitoring network is insufficient to provide a reliable estimate of ground-water storage or quality for the entire island.

2. Longevity of streamflow gages.--The U.S. Geological Survey's islandwide streamflow network needs to be stabilized in order to permit the long-term collection of data at key locations. Few stations in Puerto Rico have record of sufficient length to generate reliable flood frequencies and duration data.

3. Contamination of resources.--Some of the forces affecting the quality of the island's water resources are natural: the quality of the precipitation, the character of the host rock in the aquifers, and wastes from wild animal populations. But by far the greatest impact on water quality is from the activities of man:

a. Seawater encroachment.--Pumpage from wells in several areas along the south coast has lowered ground-water levels sufficiently to cause seawater encroachment at depth in the alluvial aquifer.

b. Landfills.--In the past, the locations of landfills have been determined more by a concern for economics than for the protection of the water resources. Many landfills are located on permeable materials which offer ready access of toxic leachates to the ground-water and surface-water system (F. Gómez, U.S. Geological Survey, written commun., 1978).

c. Sewage treatement plants.--Many public sewage and industrial-waste treatment plants operate at much greater than design capacities. This allows for poorly treated effluents to enter rivers and streams.

d. Nonpoint sources.--The quality of water resources is affected to a large degree by factors whose sources are difficult to pinpoint and, therefore, difficult to control. These sources are agricultural operations, urban runoff, and mining and construction activities. These problems are presently (1978) being evaluated by the Islandwide 208 Program of the Puerto Rico Environmental Quality Board.

4. Distribution of users.--Some of the problems of adequate water resources are the result of the distribution of the water users:

a. Barceloneta-Manatí area.--The foregoing presentation of water budgets throughout the island shows the North Coast Province to have, by far, the largest potential of water supplies. Yet in the Barceloneta-Manatí area, water levels in the artesian system have declined steadily since 1972. Many wells that flowed in the past must now be pumped. This condition has resulted from many users (mostly industrial) being located in a relatively small area and the combined withdrawals of the users being larger than the capacity of the aquifer to transmit water. This problem can be relieved by several methods including:

(1) Enlargement of withdrawal area.--Drawdowns in wells would be significantly reduced if current demands were met by supply wells being spread over a larger area and the water brought to the user via pipelines.

(2) Use of water-table aquifer.--A more practical alternative than (1) above, would be to augment current water needs by utilizing the shallower water-table aquifer (ground water under atmospheric pressure).

b. Yauco area.--The Yauco area on the south coast is similar to the Barceloneta-Manatí area in that well fields are concentrated in a small area. However, the Yauco area has considerably less water than the north coast and has but one ground-water system available for most uses--the shallow water-table aquifer in the alluvial deposits.

c. Conflicts of users.--On the south coast, varying needs of water users create water-management problems. Hydroelectric plans need large volumes of water for the generation of electricity; agriculture needs large supplies for irrigation; PRASA requires certain amounts of water for public supplies; and sugar mills and oil refineries require large amounts for the manufacture of products. Allocation of water to meet these concurrent needs would be a formidable task even in a water-rich area, but on the south coast it becomes a monumental one. The task of water allocation is compounded by the areal discontinuity of the alluvial aquifers: some water users are unable to meet their water needs from supplies within the area where they are located and must obtain additional supplies from adjacent areas.

6. Storage of water.--In the discussion on availability of additional supplies it was pointed out that probably half of the streamflow discharge to the ocean, or about 2,500 hm^3/year (1,800 Mgal/d), could be salvaged and retained for later use. It was also pointed out that this figure was probably unrealistic because of economic and technical constraints. One of these constraints is storage. The capacities of reservoirs in 1975 were such that

about 5,000 hm^3 (3,620 Mgal/d) of stream discharge flowed to the sea. In addition, capacities of most existing reservoirs are decreasing each year as a result of sedimentation. To salvage any of this amount would require additional reservoirs. The U.S. Army Corps of Engineers is currently (1978) designing reservoirs on the south coast to salvage some of this runoff.

7. Flooding.--Floods have always had a serious impact on the economy of Puerto Rico. However, the U.S. Geological Survey has documented numerous historical floods on the island and has delineated hypothetical floodway boundaries in several basins as part of the U.S. Department of Housing and Urban Development's flood insurance studies. The U.S. Army Corps of Engineers and other agencies have prepared similar maps for other basins. These documents should be of assistance to water managers and planners and also to land-use and industrial planners.

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