THE NATION'S WATER RESOURCES 1975-2000

Volume 4: Caribbean Region

Second National Water Assessment by the U.S. Water Resources Council

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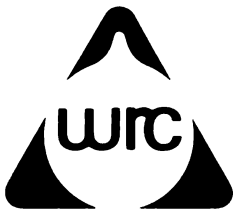

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Foreword

The Water Resources Planning Act of 1965 (Public Law 89-80) directs the U.S. Water Resources Council to maintain a continuing study of the Nation's water and related land resources and to prepare periodic assessments to determine the adequacy of these resources to meet present and future water requirements. In 1968, the Water Resources Council reported the results of its initial assessment. The Second National Water Assessment, a decade later, provides a comprehensive nationally consistent data base for the water resources of the United States. The results of the Second National Water Assessment were obtained by extensive coordination and collaboration in three phases.

Phase I: Nationwide Analysis

The Council member agencies researched, analyzed, and prepared estimates of current and projected water requirements and problems and the implications of the estimates for the future.

Phase II: Specific Problem Analysis

Regional sponsors, one for each of the 21 water resources regions, surveyed and analyzed State and regional viewpoints about (1) current and future water problems, (2) conflicts that may arise in meeting State and regional objectives, and (3) problems and conflicts needing resolution.

Phase III: National Problem Analysis

The Council conducted this final phase in three steps: (1) An evaluation of phases I and II, (2) an analysis that identified and evaluated the Nation's most serious water resources problems, and (3) the preparation of a final report entitled "The Nation's Water Resources--1975-2000."

The final report of the Second National Water Assessment consists of four separate volumes as described below. These volumes can assist Federal, State, local, and other program managers, the Administration, and the Congress in establishing and implementing water resources policies and programs.

Volume 1, Summary, gives an overview of the Nation's water supply, water use, and critical water problems for "1975," 1985, and 2000 and summarizes significant concerns.

Volume 2, Water Quantity, Quality, and Related Land Considerations, consists of one publication with five parts:

Part I, "Introduction," outlines the origin of the Second National Water Assessment, states its purpose and scope, explains the numerous documents that are part of the assessment, and identifies the individuals and agencies that contributed to the assessment.

Part II, "Water-Management Problem Profiles," identifies ten general water problem issues and their implications and potential consequences.

Part III, "Water Uses," focuses on the national perspectives regarding existing ("1975") and projected (1985 and 2000) requirements for water to meet offstream, instream, and flow-management needs. State-regional and Federal perspectives are compared.

Part IV, "Water Supply and Water Quality Considerations," analyzes the adequacy of fresh-water supplies (ground and surface) to meet existing and future requirements. It contains a national water budget; quantifies surface- and ground-water supplies, reservoir storage, and transfers of water within and between subregions; describes regional requirements and compares them to supplies; evaluates water quality conditions; and discusses the legal and institutional aspects of water allocation.

Part V, "Synopses of the Water Resources Regions," covers existing conditions and future requirements for each of the 21 water resources regions. Within each regional synopsis is a discussion of functional and location-specific water-related problems; regional recommendations regarding planning, research, data, and institutional aspects of solving regional water-related problems; a problem-issue matrix; and a comparative-analysis table.

Volume 3, Analytical Data, describes the methods and procedures used to collect, analyze, and describe the data used in the assessment. National summary data are included with explanatory notes. Volume 3 is supplemented by five separately published appendixes that contain data for the regions and subregions:

Appendix I, Social, Economic, and Environmental Data, contains the socioeconomic baseline ("1975") and growth projections (1985 and 2000) on which the water-supply and water-use projections are based. This appendix presents two sets of data. One set, the National Future, represents the Federal viewpoint; the other set, the State-Regional Future, represents the regional sponsor and/or State viewpoint.

Appendix II, Annual Water Supply and Use Analysis, contains baseline water-supply data and baseline and projected water withdrawal and water-consumption data used for the assessment. Also included are a water adequacy analysis, a natural flow analysis, and a critical-month analysis.

Appendix III, Monthly Water Supply and Use Analysis, contains monthly details of the water-supply, water-withdawal, and water-consumption data contained in Appendix II and includes an analysis of monthly water adequacy.

Appendix IV, Dry-Year Conditions Water Supply and Use Analysis, contains both annual and monthly baseline and projected water-withdrawal and water-consumption data for dry conditions. Also, a dry conditions water-adequacy analysis is included.

Appendix V, Streamflow Conditions, contains detailed background information on the derivation of the baseline streamflow information. A description of streamflow gages used, correction factors applied, periods of record, and extreme flows of record, are given for each subregion. Also included is the State-Regional Future estimate of average streamflow conditions.

Volume 4, Water Resources Regional Reports, consists of separately published reports for each of the 21 regions. Synopses of these reports are given in Volume 2, Part V.

For compiling and analyzing water resources data, the Nation has been divided into 21 major water resources regions and further subdivided into 106 subregions. Eighteen of the regions are within the conterminous United States; the other three are Alaska, Hawaii, and the Caribbean area.

The 21 water resources regions are hydrologic areas that have either the drainage area of a major river, such as the Missouri Region, or the combined drainage areas of a series of rivers, such as the South Atlantic-Gulf Region, which includes a number of southeastern States that have rivers draining directly into the Atlantic Ocean and the Gulf of Mexico.

The 106 subregions, which are smaller drainage areas, were used exclusively in the Second National Water Assessment as basic data-collection units. Subregion data point up problems that are primarily basinwide in nature. Data aggregated from the subregions portray both regional and national conditions, and also show the wide contrasts in both regional and national water sources and uses.

The Second National Water Assessment and its data base constitute a major step in the identification and definition of water resources problems by the many State, regional, and Federal institutions involved. However, much of the information in this assessment is general and broad in scope; thus, its application should be viewed in that context, particularly in the area of water quality. Further, the information reflects areas of deficiencies in availability and reliability of data. For these reasons, State, regional, and Federal planners should view the information as indicative, and not the only source to be considered. When policy decisions are to be made, the effects at State, regional, and local levels should be carefully considered.

In a national study it is difficult to reflect completely the regional variations within the national aggregation. For example, several regional reviewers did not agree with the national projections made for their regions. These disagreements can be largely attributed either to different assumptions by the regional reviewers or to lack of representation of the national data at the regional level. Therefore, any regional or State resources-

management planning effort should consider the State-regional reports developed during phase II and summarized in Volume 4 as well as the nationally consistent data base and the other information presented in this assessment.

Additional years of information and experience show that considerable change has occurred since the first assessment was prepared in 1968. The population has not grown at the rate anticipated, and the projections of future water requirements for this second assessment are considerably lower than those made for the first assessment. Also, greater awareness of environmental values, water quality, ground-water overdraft, limitations of available water supplies, and energy concerns are having a dramatic effect on water-resources management. Conservation, reuse, recycling, and weather modification are considerations toward making better use of, or expanding, available supplies.

CONTENTS

Illustrations

Physiography

The Caribbean Region consists of the Commonwealth of Puerto Rico and the U.S. Virgin Islands. The region is located approximately 900 miles southeast of Miami, Florida, and is bounded on the north by the Atlantic Ocean and on the south by the Caribbean Sea (Figure 21-1).

Puerto Rico

The Commonwealth of Puerto Rico forms part of the Greater Antilles island chain. It has a territorial extent of 3,434 square miles and consists of the main island plus the smaller islands of Culebra, Vieques, and Mona, and small offshore cays.

Notwithstanding its small size, Puerto Rico has environmental diversity, characterized by: (1) the variations in topography, climate, and the interaction of climate and topography; (2) the development of numerous small hydrologic units; and (3) diverse ecosystems. These ecosystems are small in territorial extent, but they have high productivity, sustaining a variety of living species.

The island of Puerto Rico was created by the combined effects of volcanism and tectonic stresses along a submarine fault line. Though there are seven distinct physiographic regions, it is simplest to think of Puerto Rico as a mass of volcanic and intrusive rock rising to a crest, with its less steep, sloped edges thickly overlain by sedimentary and clastic rocks, the whole mass of which is extensively eroded.

The most prominent physical and geological feature of the island is the central mountain range, the Cordillera Central. This highland region extends almost the entire length of the island. The crest averages more than 3,500 feet in elevation along its length, with the highest peak rising to 4,389 feet above sea level. Second in prominence in geologic and physiographic terms are the extensive karst regions formed by deep deposition of limestone during submergence of the island's margins between 40 and 50 million years ago. These limestone formations lie over the igneous parent material along the coastline over the western half of the island. This region is characterized by extremely rugged topography, very poor soils, and extensive sinkhole formations.

The coastal plain region of playas and alluvial deposits, formed by erosion of the volcanic and limestone formations in the interior of the island, is the most important to economic and agricultural development. These narrow plains and river valleys rarely exceed four miles in width, yet it is here that the greatest population concentration occurs.

A high proportion of the Puerto Rican landscape is very steeply sloped. Over 80 percent of the land in Puerto Rico is either hilly or mountainous, and 38 percent has a slope of 45 degrees or more. Much of Puerto Rico's territory is, therefore, unsuited to extensive agriculture, industry, or even domestic settlement. A generalized map of land use is presented in Figure 21-2.

Puerto Rico has a history of intensive land use. In the pre-World War II era essentially all but the most inaccessible sites and the poorest

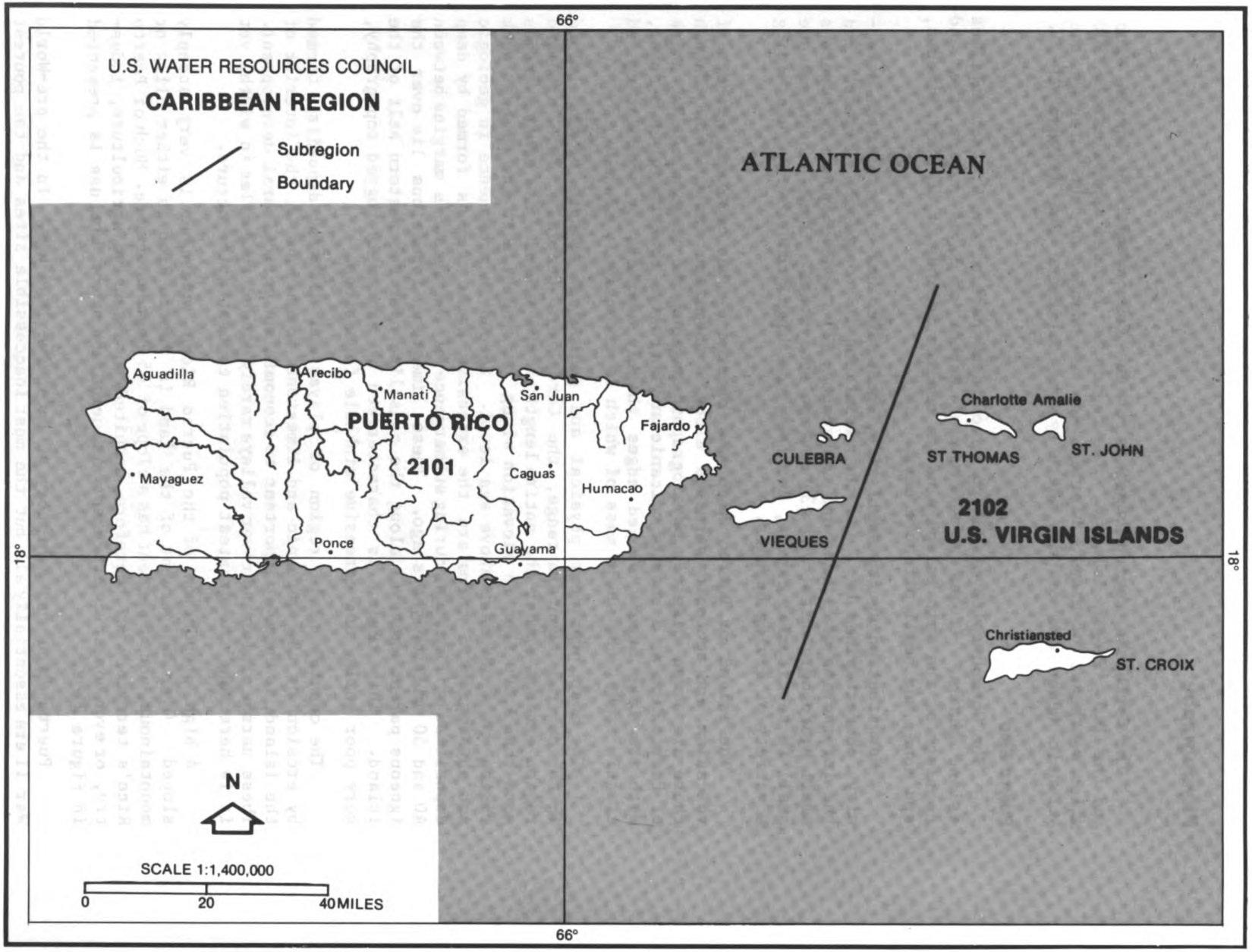


Figure 21-1. Region Map

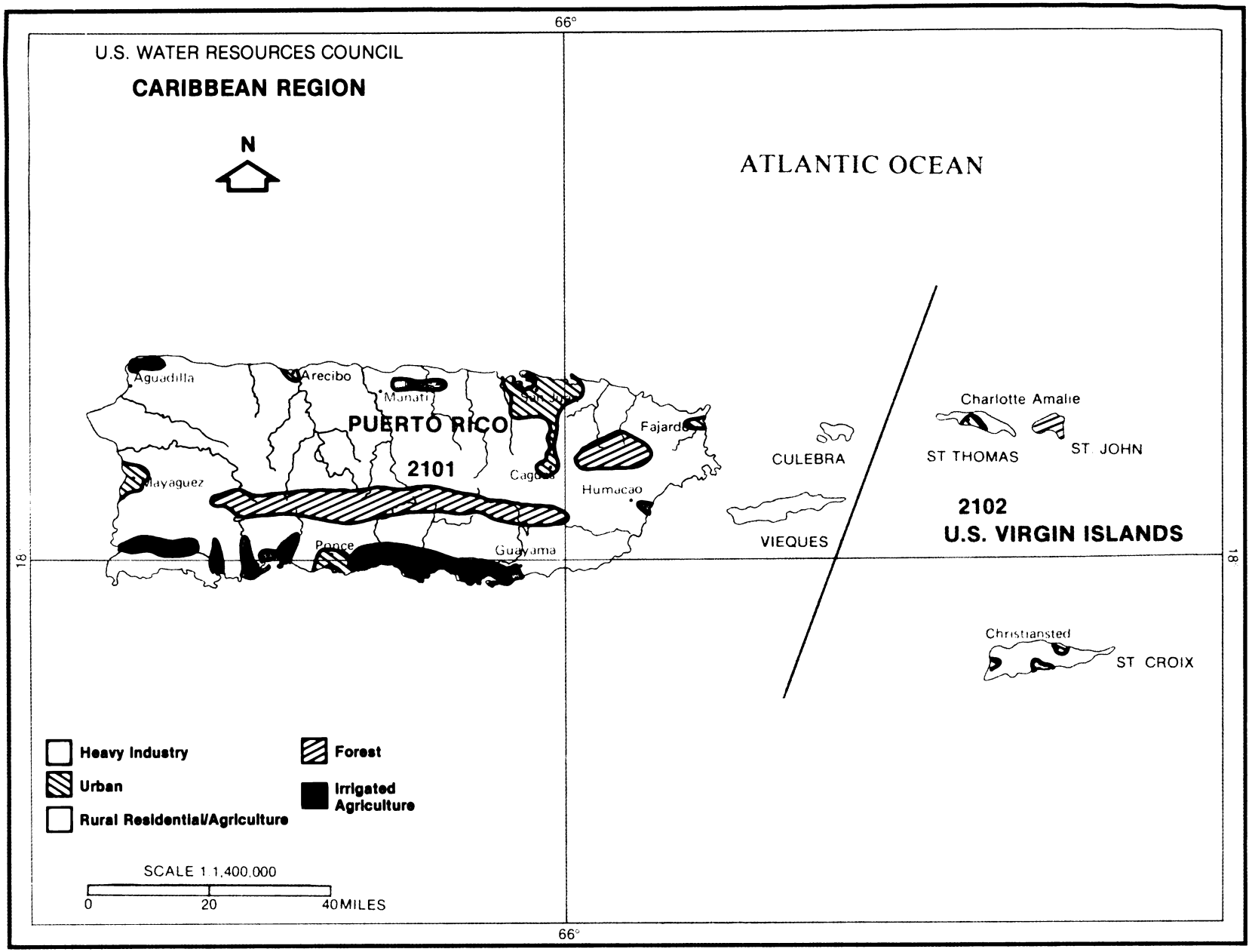


Figure 21-2. Present Land Use

soils were devoted to agriculture of some type. The interior of Puerto Rico is a patchwork of various small agricultural enterprises, many of which are so small and on such steep slopes that only manual cultivation can be practiced. The land use on the island today, outside of the industrial, urban and irrigated areas, reflects the gradual abandonment of the soils and steepest slopes over the past three decades. In the past, a large part of the interior was devoted to coffee plantations. Many of these were allowed to return to forest growth as the market for Puerto Rican coffee declined and the coffee plantation system became increasingly unable to compete for labor with the growing urban and industrial sector. As a result, the total forested acreage on the island has been increasing rapidly, with the attendant benefits of reduced sedimentation and soil erosion.

Puerto Rico possesses a typical tropical, ocean-island climate. Warm temperatures with little variation, steady breezes, and abundant rainfall result from constantly high levels of solar radiation, the presence of the marine trade winds and the mountainous nature of the island which induces rainfall. Temperatures on the island vary according to elevation and are essentially uniform at similar altitudes. In general, the average monthly temperature is 79°F. Island-wide rainfall averages 75 inches, humidity ranges between 69 and 86 percent, and mean wind speed is 12 mph from ENE.

Rainfall varies from 35 to 200 inches per year between the driest and the wettest sections of the island. The north slope receives most of the island's rainfall and has an annual average precipitation of 75 inches. Mountain peaks near the island center, which may receive as much as 200 inches, create a rain shadow on the south coast, which receives only 35 inches per year.

Virgin Islands

The U.S. Virgin Islands consist of the main islands of St. Croix, St. Thomas, and St. John plus approximately fifty uninhabited smaller cays. The largest island is St. Croix with an area of 84 square miles, followed in size by St. Thomas (28 square miles) and St. John (20 square miles).

The islands are mountainous in character, particularly St. Thomas and St. John. They were formed from a series of volcanic actions in the Atlantic Ocean and their basal rock has been altered by folding, faulting, up-lifting, erosion, and the formation of wave-cut terraces. St. Thomas and St. John are part of the Puerto Rican bank of the Greater Antilles, while St. Croix is geologically separate. The history of the Virgin Islands, as well as many of the other islands in the Lesser Antilles island chain, has been one of intensive agricultural production. Plantations worked by slaves produced sugar and spices for the European market and for smuggling to the American market. However, the end of slavery in the mid-1800's marked the end of the plantation system, and agricultural activity in the Virgin Islands has declined ever since. The last sugar mill in the U.S. Virgin Islands (on St. Croix) closed in 1968. Today land in the Virgin Islands which is not in urban or industrial use is devoted primarily to grazing. The steeper and more erodible slopes and the national parkland in St. John are reverting to tropical dry-forest vegetation.

The climate of the Virgin Islands is maritime tropical, characterized by generally fair weather, steady winds, and slight but regular seasonal and diurnal variations in temperature. The average annual total rainfall at the higher elevations (1500 feet) is between 50 and 60 inches, and approximately 35 inches at the driest sites, with an overall average of 44 inches per year. The temperature ranges between 70° and 90°F, and trade winds blow regularly from an easterly direction at a velocity of 5 to 15 miles per hour.

People and the Resources

In the Caribbean Region small islands of limited resources have been juxtaposed against a rapidly growing population and economy. Socially and economically, the Caribbean is one of the most volatile and uncertain areas of the United States. Puerto Rico and the Virgin Islands exist under special status categories as parts of the United States but not as States. Both areas have experienced post-war economic growth which has been possible because of this status, yet both face uncertain economic futures. Both are characterized by relatively large migrations in response to the ill-defined and relatively non-quantifiable variables mentioned below, making it difficult to assess the potential future population growth.

This section presents a summary of present demographic, economic, and environmental parameters and estimates of future change in the region. Estimates and projections of the population, economy, land and water resources, as well as other parameters, were made for the Water Resources Council by various Federal agencies, as explained elsewhere in the national assessment reports. These data were provided for three reference years, 1975, 1985, and 2000, according to national, regional, and subregional boundaries (see Figure 1-1 for subregional boundaries). This federally-developed data constitutes the Council's National Future (NF), one perspective on the most probable developments in population and economic growth and the resultant resource use over the next 25 years. State and regional representatives were encouraged to prepare alternative estimates for future growth and resource use in a corresponding perspective known as the State-Regional Future (SRF).

Population

Puerto Rico

Unlike Hawaii, where the indigenous population is greatly outnumbered by mainland immigrants, Puerto Rican residents of mainland origin are outnumbered approximately 30 to 1 by those of island descent. Spanish is the official language, and English is taught as a compulsory second language in grades 1 through 12.

Perhaps the most significant aspect of the Puerto Rican population is the fact that while there are about 2,960,000 people on the island, there are an additional 1.5 million Puerto Ricans in the northeastern United States, with the largest concentration in the New York City area. It is estimated that there are more Puerto Ricans in New York than in Ponce, the island's second largest city.

Massive migration of the island population to the mainland began following the Second World War and reached its peak in 1954. In that year alone over 4 percent of the total island population migrated to the mainland in search of improved economic conditions. By the early 1960's this migration slowed to a trickle, and by the early 1970's the net mi-

gratory movement reversed so that there is now a net inflow of persons to the island. Of the estimated total population growth rate of 3 percent for 1975, 1.7 percent was attributed to the natural rate of increase due to the excess of births over deaths, and the remaining 1.3 percent was attributed to migratory movement. Most of the island immigrants of the 1970's are arriving from other Caribbean areas, although there is also a significant net migratory movement from the mainland to the island.

The recent period of heavy immigration to the island occurred at a time when the island was experiencing its highest unemployment in the past 30 years. However, it was also a period of very high unemployment on the mainland as well as elsewhere in the Caribbean. This period also corresponded to the increasing availability of welfare benefits on the island, particularly with the implementation of the Federal food stamp program. These and many other factors undoubtedly influence this changing migratory pattern and make it difficult to make realistic population projections. The projection currently accepted by the Puerto Rico Planning Board assumes that net migration will continue, but at a reduced rate.

Although Puerto Rico's population structure is changing significantly due to the continuous reduction in birth rates, the population can still be characterized as predominantly young. Only 22.5 percent of the population is 45 years of age and over.

The past three decades have also seen a massive depopulation of the island's interior and the conversion from a rural to an urban society. The San Juan metropolitan area has absorbed most of the rural-urban migrants who did not leave the island and today has a population of approximately 1.5 million.

At the end of fiscal year 1975, the civilian labor force was estimated to be 872,000, of which 775,000 were employed. Some 68 percent of all persons employed were male, and 50.4 percent had less than high school education. Only 3 percent reported having no schooling. Puerto Rico has a very low labor participation rate. For 1975 this was estimated to be 43 percent, as compared to 60 percent for the United States and 72 percent for Japan. Unemployment is the most critical problem that Puerto Rico faces. At no time in the past three decades has island unemployment dropped below 10 percent of the labor force, and 1976 unemployment exceeded 20 percent.

Virgin Islands

The resident population of the Virgin Islands has been growing at an average annual rate of 5 percent, going from 26,655 in 1950 to 32,099 in 1960, 63,200 in 1970, and 92,000 in 1975.

There is a significant alien population in the Virgin Islands; 25,363 aliens registered in 1974. Tourist arrival figures for 1975 were estimated to total 1,154,362 for the year, with the peak season occurring in the winter and the April carnival week.

Future population growth in the Virgin Islands will depend largely

on the rate of economic growth since much of the recent rapid population increase is the result of immigration, particularly of other West Indian islanders seeking employment. In the foreseeable future the Virgin Islands will continue to rely on tourism as the major source of income and employment, which in turn is expected to continue to promote migration from the mainland and other Caribbean islands.

The foregoing population and employment data for Puerto Rico and the Virgin Islands are derived from SRF estimates. The NF estimated a population for Puerto Rico at mid-year 1975 of 2,960,000, with a density of 865 persons per square mile. For the Virgin Islands the estimate is 92,000 with a density of 701 persons per square mile. This is projected to increase to 4,030,000 persons in Puerto Rico and 204,000 persons for the Virgin Islands by the year 2000.

Economy

Puerto Rico

The key to understanding Puerto Rico's economy lies in the island's unique status. Puerto Rico was discovered by Columbus on his second voyage and was settled by Ponce de Leon in the first decade of the 1500's. Puerto Rico remained a Spanish colony until the conclusion of the Spanish American War in 1898, at which time it was ceded to the United States. Although there was a movement toward increasing autonomy in the latter 1800's, for both economic and political reasons, Puerto Rico did not launch a significant armed revolt against Spanish rule as did Cuba.

The island was administered as a U.S. territory until 1952, at which time it achieved commonwealth status. Under the provisions of this status Puerto Rico has its own income tax system and is not subject to Federal taxes, which is the basis for the island's program of corporate income tax exemption. The governor and bicameral legislature are locally elected, and the island is represented in Congress by a non-voting resident commissioner in the House of Representatives. Island residents cannot vote in presidential elections. Federal excise taxes collected on local products such as rum are remitted to the island treasury, and the island is eligible for most Federal aid programs.

The most salient features of the island's economy stem from the Puerto Rico government's efforts to promote increased employment at acceptable wage levels. Economic achievement was the key to the program of the Popular Democratic Party, which assumed power in the mid-1940's and which was responsible for the dramatic economic changes which were initiated during that era. The pattern and policies which were developed in the late 1950's have continued to the current time with the added factor of an increasing reliance on Federal funds in recent years.

Pre-war Puerto Rico was called "the poorhouse of the Caribbean." The island was densely populated and the limited area of fertile agricultural lands was characteristically held in large landholdings under a plantation

system. The three major crops were sugar, coffee and tobacco, all of which were produced primarily for export. Employment in the agricultural sector was seasonal, wages were at the subsistence level, and alternative employment was not available. The major island industry was native textiles.

The most extensively developed plantation system was in the sugar industry. American corporations purchased vast holdings on the fertile coastal plains soon after the American acquisition and converted these lands to the production of an export sugar crop. Sugar production became highly lucrative after Puerto Rico became a U.S. Territory because of its inclusion within U.S. tariff boundaries, and it soon became the primary crop grown on the island.

The concentration of wealth and land in the hands of a few individuals or corporations, while the majority of the population suffered extreme poverty, provided the impetus for the rise to power of the Popular Party. The program developed to combat this situation was industrialization. With the limited ability to develop local capital, and with local investment generally not aimed toward industrialization, a program of corporate income tax exemption was developed to attract mainland investments to the island. An important factor in attracting these investments was the temporary exemption of the island from Federal minimum wage criteria.

Another factor of crucial importance was the migration of a sizeable portion of the island's working age population to the mainland. This stabilized the size of the island labor force over a critical period of two decades, despite a natural population growth rate of nearly 3 percent per year.

Under the conditions which prevailed in the 1950's and 1960's the industrialization program was a marked success in its major aspects. However, the conditions in the 1970's are decidedly different, and the industrialization program is proving unable to resolve the island's unemployment problem in the face of a rapidly growing labor force.

Throughout the period of industrialization, the island's wage level steadily increased, and it became decreasingly attractive to highly labor intensive and low infrastructure industries. As wage levels increased, these labor intensive industries tended to move to other areas. In their place have come industries which are more capital than labor intensive, such as the chemical and petrochemical industries. Although capital intensive industries offered good opportunities for the growing trained labor force, they consumed an increasing portion of the island's limited resources such as water, and required an increasing level of both public and private investment per new job created. Although the flow of investment funds has increased, it is no longer able to keep pace with the growth in the labor force, particularly with the changed migration patterns the island is experiencing. Also, island petrochemical industries are heavily dependent on foreign oil, and the 1973 oil embargo seriously disrupted these industries, completely stalling new investment in this important sector.

Faced with the deteriorated global economic situation of the mid-

1970's, the decreasing effectiveness of the industrialization program, and a rapidly increasing population, the commonwealth government has implemented an extremely active program for the procurement of Federal aid as an answer to increasing unemployment. Federal assistance to Puerto Rico is higher on a per capita basis than to any State.

Puerto Rico's total earning for 1975 measured in 1975 dollars was 6,218 billion dollars (NF). Manufacturing activities accounted for 32 percent of total earnings. The largest single manufacturing sector was the chemical and allied products category, followed in importance by food and kindred products and by petroleum products. Although earnings from agriculture represented only 4 percent of total earnings, this activity remains important as a social welfare instrument for maintaining employment and rural income levels. Detailed projections of earnings are not available for the region.

Virgin Islands

The economy of the Virgin Islands has a centuries-long history of dependence on agriculture, principally sugarcane, except for St. Thomas which, during its early history as a Danish colony, developed as a regional center of mercantile activity. The islands were purchased from the Danes by the United States in 1917.

It was not until the early 1960's that tourism became the major income-producing activity, increasing from 176,100 visitors in 1960 to over one million in 1970. Tourist expenditures increased during this same period from $38 million to over $153 million (1975 dollars). Manufacturing earnings in 1975 were about $920 million, and agricultural earnings, about $2 million.

Although efforts have been made to diversify the island's economic base, manufacturing and other activities continue to be second to tourism. Two heavy industries have recently located in the Virgin Islands, a 700,000 barrels per day (bpd) refinery and an aluminum plant. In addition, there are some small, labor intensive industries such as watch assembly plants.

The last decades have been a period of extraordinary economic growth for the Virgin Islands, particularly in the areas of tourism, housing construction, and industrial development. This economic growth has broadened the tax base and provided more jobs. Even with the worldwide economic problems of the early 1970's, employment has remained relatively stable in the islands. Future economic growth is expected to be based on tourism, which will continue to be a major income-producing industry. The manufacturing and financial sectors are expected to continue to grow and to provide the basis for greater economic stability in the future. As in Puerto Rico, the role of Federal aid is large. The NF data for earnings in the Caribbean region in shown on Table 21-1.

Table 21-1.--Caribbean Region earnings--1975, 1985, 2000
(million 1975 dollars)

Earnings sector	1975	1985	2000
Manufacturing	2,908		
Agriculture	302	NA	
Mining	NA		
Other	NA		
Total	3,300		

Natural Resources

Puerto Rico

Puerto Rico has limited quantities of fertile alluvial soils. In addition, much of its land area is steeply sloped. Only 19 percent of the island is generally suited to cultivation, and the remaining 81 percent has severe restrictions on agricultural use. Most of the mechanizable soils stretch in a narrow band a few miles wide along the island's coastline. A large part of this alluvium is on the semi-arid south coast and requires irrigation for cultivation. Sugarcane continues to be the predominant crop on these mechanizable soils.

Though small in size, Puerto Rico is relatively rich in minerals. The island has exploitable deposits of copper and nickel, and there is geologic evidence of oil off the north coast, although this has yet to be confirmed by drilling. None of these minerals is currently being extracted, although plans are in various stages of negotiation. Limestone, construction aggregates, and glass-making silica are all extracted locally.

Puerto Rico has an abundance of terrestrial and submarine tropical flora. State and national forestland covers approximately 100,000 acres, mostly in the moist mountainous areas entirely unsuitable for agriculture. The island's interior, although rugged, is still rather intensively cultivated by hand on small farms. However, with industrialization and enhanced job opportunities much of this land is reverting to forest through natural regrowth.

Land use in the Caribbean region is shown in Table 21-2.

Table 21-2.--Caribbean Region surface area and 1975 land use

Surface area or land use type	1,000 acres	Percentage of total surface area
Surface area		
Total	2,283	100.0
Water	10	0.4
Land	2,273	99.6
Land use		
Cropland	514	22.5
Pasture and range	880	38.6
Forest and woodland	565	24.8
Other agriculture	49	2.1
Urban	126	5.5
Other	139	6.1

Virgin Islands

The primary natural resources of the Virgin Islands are its pleasant climate, clear marine waters, and beautiful beaches. These attract tourists, thereby supporting a major sector of the islands' economy while also providing unequaled recreational opportunities for residents.

Natural forest habitats in the Virgin Islands are small yet complex, responding to varying conditions of rainfall, sun and wind exposure, and soil. Most of the steep slopes are forested and are protected by local law to help prevent erosion. Approximately two-thirds of the land area on the island of St. John is protected as a national park.

The Virgin Islands have no commercially exploitable mineral deposits with the exception of limestone and aggregates. Agricultural potential is limited primarily by the lack of water.

Agriculture

Puerto Rico

Agriculture has traditionally played a central role in the Puerto Rican economy. However, beginning with the industrialization of the island in the late 1940's, the agricultural labor force as well as investors have been directed to the growing industrial and commercial sectors. Predictably, approximately 80 percent of all foodstuffs consumed in Puerto Rico today are imported. The agricultural sector continues to employ a significant portion of the rural labor force, and much of this agricultural activity is heavily subsidized by the commonwealth government. Approximately $350 million per year is budgeted for agricultural programs in Puerto Rico, yet the total on-farm value of production is less than $500 million.

Approximately 57 percent of the land currently dedicated to agriculture is in pasture, while the best mechanizable agricultural land continues to be used for sugarcane production. The sugar industry in Puerto Rico is managed by the government and suffers a loss of more than ten cents on every pound of raw sugar produced. Production in 1975 was 320,000 long tons.

In response to these problems the commonwealth government is implementing new agricultural policies which are designed to promote local production of non-sugar crops and greatly reduce the role of the sugar industry. Nevertheless, the area of cropland is projected to decline (Table 21-3).

Table 21-3.--Projected changes in cropland and irrigated farmland in the Caribbean Region--1975, 1985, 2000
(1,000 acres)

Land category	1975	1985	2000
Total cropland	514	453	399
Cropland harvested	353	304	256
Irrigated farmland	70	73	78

Virgin Islands

The settlement of the Virgin Islands historically depended on agriculture, but today this is an activity of relatively minor importance. Presently cattle, goats, and sheep utilize pastures, and some fruits and vegetables are grown locally, though generally for home consumption. Most food consumed in the Virgin Islands is imported. The largest agricultural acreages are located on St. Croix, with lesser amounts on mountainous St. Thomas. No land is zoned for agriculture on St. John. One of the greatest impediments to agricultural production in the Virgin Islands is the lack of water.

Energy

The Caribbean Region, with a total installed generating capacity of 3,293 megawatts, generated 9,937 gigawatt-hours of electricity in 1975. Of this total, 300 gigawatt-hours were generated in the Virgin Islands. On St. Thomas and St. Croix, power generation facilities are of the combined-cycle thermoelectric desalination type and have a 310 kilowatt-hour capacity.

Virtually all electric power generated in 1975 was by fossil fuel plants. Hydropower accounted for less than 1 percent of the total. Nuclear power is expected to generate approximately 50 percent of the Caribbean region's power in 1985 and over 60 percent by the year 2000 when the region's total combined power generation is expected to climb to 93,594 gigawatt hours.

All steam electric generating plants in the region utilize sea water for cooling.

Table 21-4.-- Caribbean Region electric power generation--1975, 1985, 2000
(gigawatt-hours)

Fuel Source	1975	1985	2000
Fossil	9,937	20,613	35,286
Nuclear	0	10,249	58,288
Conventional hydropower	0	0	0
Total generation	9,937	30,862	93,574

Environment

The natural environment of the Caribbean is diverse and beautiful. The tropical oceanic environment combined with diverse landforms and flora creates an esthetic environment of unique charm. Urban blight is limited to a few large cities. Figure 21-3 gives the location of some of the most outstanding natural and prehistoric features of the Caribbean Region.

Puerto Rico

Puerto Rico, a tropical island of varied topography, has many areas of natural beauty, notably its beaches and marine resources. The interior of the island with its rugged, mountainous terrain offers canyons, waterfalls, caves, forests, and vistas of immense beauty.

Besides representing an environmental resource of esthetic and recreational value to the population, natural beauty is also a basic resource for tourism. Some areas of natural beauty in Puerto Rico have already been developed into resorts with facilities to handle visitors, and many others remain as virgin areas. However, many areas suffer from misuse and are directly endangered by existing or proposed urban, industrial, and highway development.

The most important identified archeological site in Puerto Rico is the ceremonial ball park of the Taino Indians, located near Utuado. This site, which dates back to 1200 AD, has been restored as an archeological museum and recreational park.

Puerto Rico's karst (limestone) country along the north central region of the island is one of the few places in the world where limestone hills (haystack hills) are so extensively developed. The Arecibo radio telescope, the largest such facility in the world, has its dish located in a natural depression in this karst topography. Spectacular caves are also located in this area.

Among the unique natural areas of Puerto Rico is Mona, a semi-arid uninhabited island off the west of Mayaguez. In its 14,000 acres, Mona has many endemic species of fauna and flora adapted to its semi-arid conditions. Recreational and tourist development of this island has been limited in order to preserve its untouched quality. The island is wholly owned and administered by the Commonwealth of Puerto Rico.

Fresh-water recreation in Puerto Rico is limited primarily to swimming in the upper reaches of rivers at road crossings. There is only one significant natural body of fresh water in Puerto Rico. The sluggish lower reaches of rivers and the 26 island reservoirs are used very little for recreation, aside from limited fishing, since the presence of shistosomiasis makes body contact with these waters hazardous. The lower reaches of most rivers are heavily polluted with both municipal and industrial wastes and the biological quality of many streams is affected by the leachate from improperly constructed latrines and waste systems in the densely populated rural interior. Water-related recreation on the island is overwhelmingly ocean oriented.

Virgin Islands

As a result of lower rainfall, the Virgin Islands do not have the luxuriant tropical vegetation so typical of Puerto Rico. However, the island's coves have some of the finest white beaches in the world and azure tropical waters under which are found luxuriant tropical reef formations and their associated fauna. A major portion of the island of St. John is protected as a national park, and the coral reef formations of Buck Island off St. Croix are protected as a U.S. National Monument. Because of the lack of fresh-water resources, there is no fresh-water recreation in the Virgin Islands. Marine recreation includes public bathing, boating, and fishing.

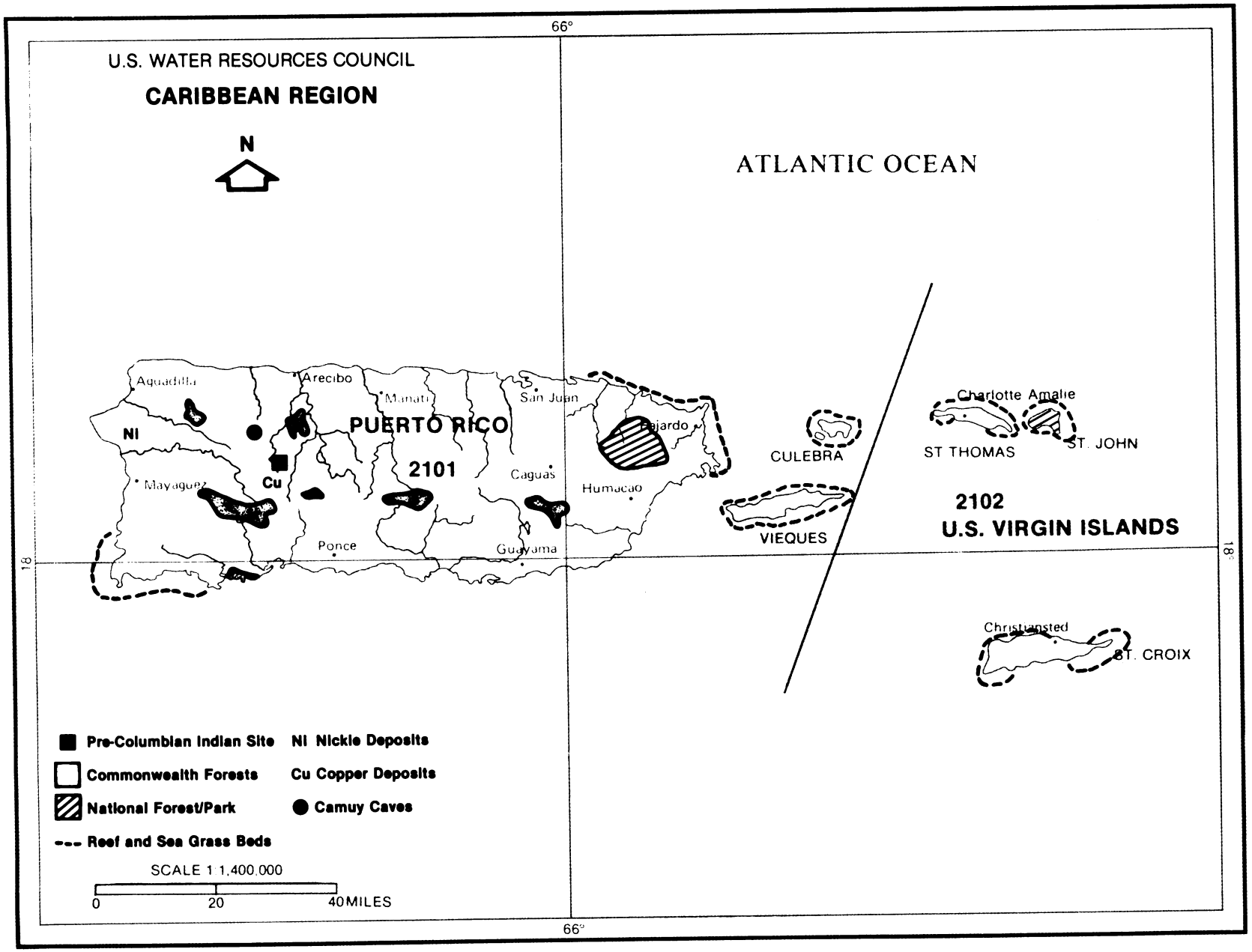


Figure 21-3. Environmental Resources

Surface Water

Puerto Rico

Most of the rivers in Puerto Rico are short in length and none are very large in terms of size or flow. The largest of these rivers is the Rio Grande de Loiza, draining an area of 310 square miles. There are only seven rivers on the island with drainage areas greater than 100 square miles, although more than 100 streams discharge into the ocean. The National Future estimates mean annual streamflow for Puerto Rico to be 4,850 mgd. (State-Regional Future estimates are shown in Figure 21-4.)

The principal factors influencing the surface hydrology of Puerto Rico are the relatively short length of stream reaches entering the sea, the steeply sloping and extensively dissected landforms, and the configuration of the Cordillera Central. This mountainous ridge which runs the length of the island is responsible for the abundant orographic rainfall on the island's northern exposure, and creates a rain shadow which is partly responsible for the semi-arid conditions on the south coast. While base flows of some northward flowing rivers are the highest on the island, on the order of 32 to 65 mgd, there are no perennial streams on the drier south coast.

Virgin Islands

Streamflow in the Virgin Islands is ephemeral and stream channels respond quickly to rainfall due to the extremely steep topography and small watershed areas. Tropical disturbances during the hurricane season and winter frontal activity provide most of the moisture, often producing intense rainfalls of long duration that result in flooding. The National Future estimate of average annual outflow is 1 mgd.

Ground Water

Puerto Rico

The aquifer system in Puerto Rico may be divided into five ground-water areas (Figure 21-5). The North Coast Aquifer is a limestone formation with a relative abundance of ground water which has a steady replenishment capacity. The total developable yield of this aquifer system is estimated to be approximately 45 mgd, if properly managed. The current pumping rate is approximately 20 mgd, which is near the safe yield capacity of the aquifer under the existing management conditions.

The east coast area is characterized by small coastal alluvial aquifers which, when undisturbed by pumping, contribute an aggregate average subsurface discharge of about 20 mgd to the sea and to the streams crossing them. These aquifer systems, extending from San Juan to Fajardo, have received little attention because of the lack of ground-water development in that area.

The already highly developed south coast area presents a very complex

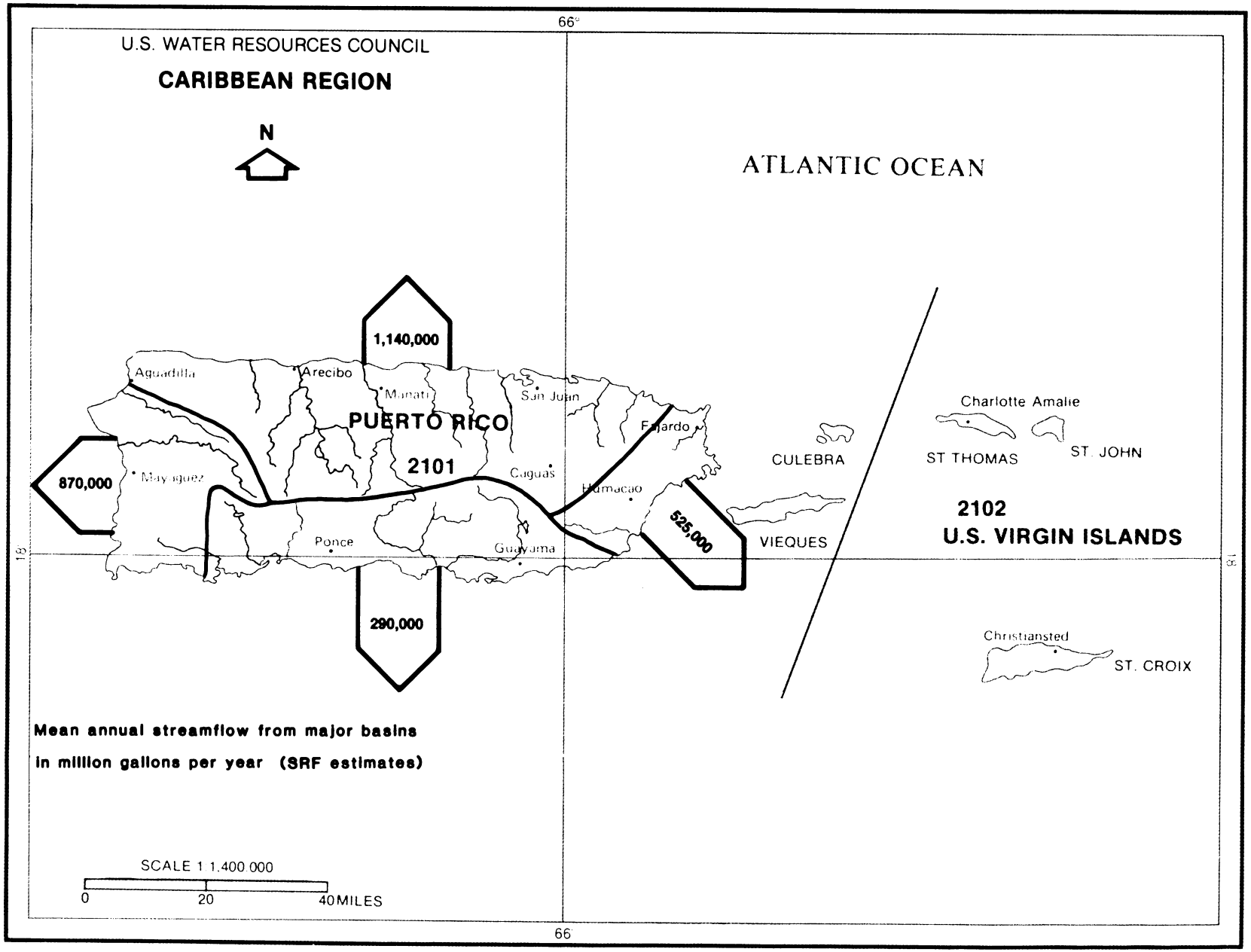


Figure 21-4. Streamflow

hydrologic picture. Excluding the Lajas area, mean annual recharge for the aquifers in this province currently approaches 320 mgd. However, more than one-third of this recharge can be attributed to basin imports and to irrigation return flows from current pumpage. There are signs of overdrafting in many areas, although saline intrusion is not yet a serious problem. Anticipated increases in irrigation efficiency are expected to greatly reduce return flow from irrigation, reducing recharge by as much as 25 percent and creating severe overdraft problems.

Alluvial aquifers on the west coast presently contribute an average subsurface discharge of about 22 mgd to the sea and to the streams which cross them. This yield can be expected to fall to less than half of this amount during sustained drought conditions. Some ground-water shortages are foreseen for this area as a result of increasing resource development.

The alluvial aquifer in the vicinity of Caguas-Jancos is the principal aquifer in the interior. The yield of this aquifer based on local discharge, exclusive of deliberate efforts to induce streamflow, is thought to range from 2 to 8 mgd.

Virgin Islands

The availability of ground water varies from island to island. Ground-water supplies on St. Thomas and St. John are relatively small and do not constitute major supplies of fresh water. St. Croix has a larger supply of ground water than the other islands, although it satisfies only a small portion of that island's fresh-water demand. On St. Croix, municipal waste water is being used for aquifer recharge after it has undergone advanced treatment. Ground-water supplies on all three islands are of poor quality.

Withdrawals

As estimated by the National Future, total withdrawals (1975) were 907 mgd, with irrigation accounting for about 57 percent of withdrawals followed by domestic and commercial withdrawals, which together comprised about 39 percent of total withdrawals. Mining and other uses made up the remainder of withdrawals, but it should be noted that manufacturing withdrawals have not been estimated. (See Figure 21-6.)

Total withdrawals by NF estimates are expected to decrease to 890 mgd by the year 2000. A decline of 36 percent is expected in agricultural withdrawals while domestic and commercial withdrawals are expected to rise by 45 percent to 514 mgd.

Consumptive Use

According to NF estimates, total 1975 consumption was 343 mgd, of which 276 mgd, or 80 percent, was consumed by irrigation. Domestic and commercial consumption for 1975 was estimated at 58 mgd. This is expected to increase to only 88 mgd by the year 2000. Consumption for manufacturing purposes has not been estimated (see Figure 21-6).

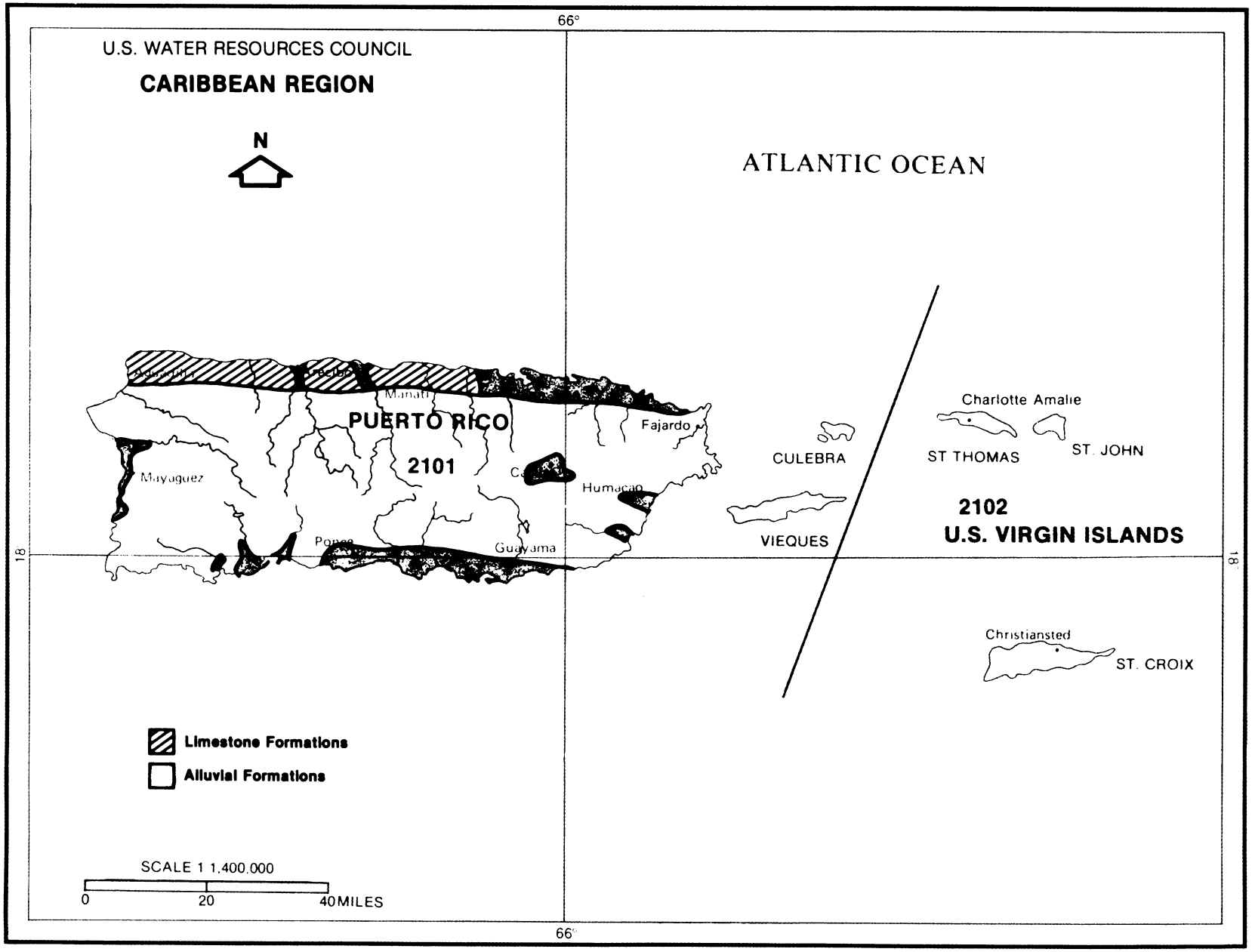


Figure 21-5. Major Aquifers

Instream Use

This section will only consider instream use in Puerto Rico since all streams in the Virgin Islands have intermittent flows. The NF instream flow approximation for total outflows for fish and wildlife in the region is 3,706 mgd or 76 percent of present average outflows. The streams in Puerto Rico are typically very small, with base flow characteristically less than 100 cfs. Many of the streams, particularly on the south coast, are intermittently dry through their lower reach, partly due to upstream diversions and to ground-water lowering which enhances aquifer recharge from the river. The Rio Loiza and Rio La Plata, respectively the island's largest watershed and longest river, are both impounded for supplying the San Juan metropolitan area, thus reducing base flows to essentially zero.

Beneficial instream uses include recreational and non-recreational bathing, fishing for both fresh-water shrimps and fish, the dilution and conveyance of waste inflows, and aquifer recharge. To date, no effort has been made to systematically determine the existing instream flow benefits on the island; instream flow benefits are accorded relatively little importance, with the exception of aquifer recharge.

Water Supply and Demand

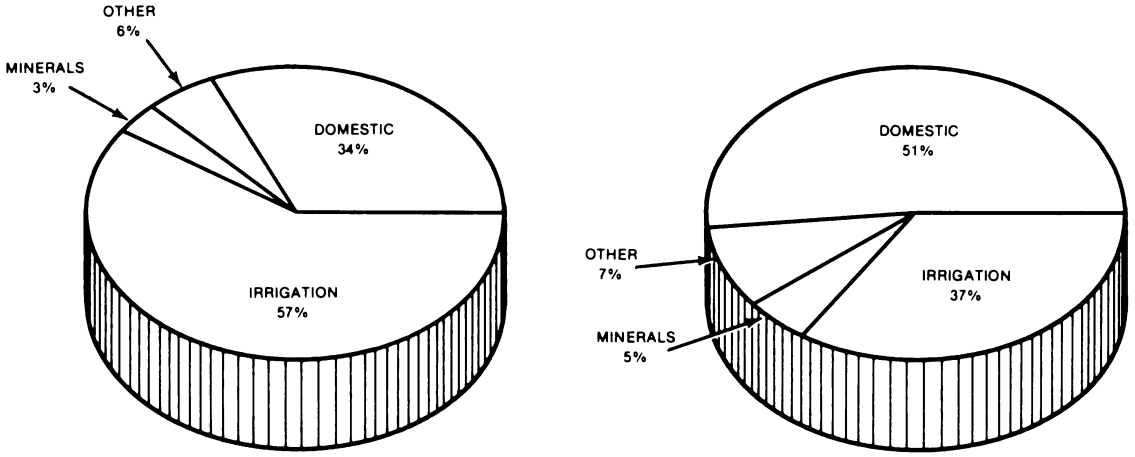
Puerto Rico

If supplies are compared to total demand, it appears that there is more than sufficient water in Puerto Rico to meet projected future demand levels with the present level of resource development. However, such a comparison of the island-wide supplies and demand is misleading due to the lack of island-wide distribution systems. For this reason, the good water supplies which are available in some regions cannot serve heavy demand areas in San Juan or on the south coast. Many reservoirs are regulated for electric power production which adversely affects their use for water supply, although a demand for that water supply exists. Accordingly, both structural and institutional problems adversely affect the availability of water on the island in areas of high demand, a factor which is not explicitly considered in a simple comparison of demand versus total supplies.

In addition to reservoirs, a small amount of water is supplied from unregulated stream diversions for both municipal and irrigation uses. Irrigation use from this source is estimated, but no estimate is made of the municipal diversions due to lack of data. The general opinion is that the amount diverted for municipal purposes is relatively small. Non-regulated streams which are not yet developed for water supply purposes are not counted as water supplies.

If managed wisely, Puerto Rico's water resources can support significantly increased levels of population and economic activity. However, the island's limited resources will not permit a blind continuation of many development trends which have occurred without consideration of serious long-term consequences.

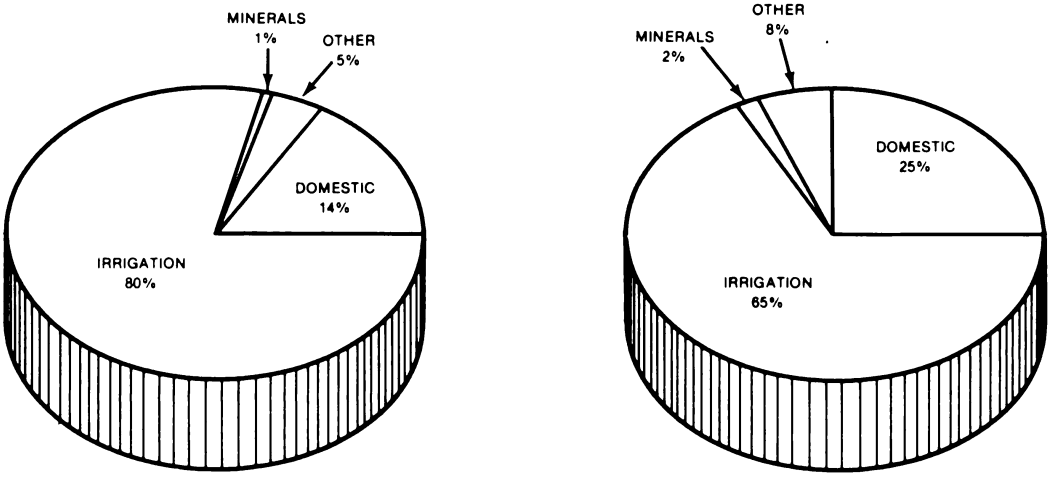
ANNUAL FRESHWATER WITHDRAWALS



1975
Total Withdrawals — 907 MGD

2000
Total Withdrawals — 890 MGD

ANNUAL FRESHWATER CONSUMPTION



1975
Total Consumption — 343 MGD

2000
Total Consumption — 300 MGD

Figure 21-6. Withdrawals and Consumption

Virgin Islands

Unlike Puerto Rico, there are no "unused" water supplies in the Virgin Islands. Sources of water supplies consist of both raw and desalinated sea water-rainwater collection in cisterns, dams, wells, waste-water recycling, and barging. Municipal fresh water comes primarily from desalination plants but is supplemented by well supplies (this water is sold by private water haulers), and individual rooftop catchments. The Virgin Islands building code requires catchments and cisterns on all housing. In some areas there is a dual municipal water system which utilizes sea water for sanitary flushing.

Approximately 50 percent of the population is not connected to a distribution system, but augments cistern supplies by purchases from water haulers (water trucks), as necessary. Haulers obtain their water from a standpipe at the desalination plant or from wells. Approximately 5 percent of the total production of desalinated water is sold to water haulers.

During periods of water emergencies when the desalination plants are unable to produce sufficient water due to mechanical failure, it is customary to ship water in from Puerto Rico by barge. The feasibility of an undersea pipeline to transport water from the eastern coast of Puerto Rico to the Virgin Islands is presently being studied.

In the Virgin Islands, water for livestock and agricultural uses comes from two major sources: wells and reservoirs created by dams. There are approximately 280 small impoundments with a combined storage capacity of 500 million gallons. Irrigation uses are negligible, but these wells and small impoundments supply an estimated 100,000 gallons per day (gpd) for livestock water demand.

Comparative Analysis

Table 21-5 compares the National Future (NF) and State-Regional Future (SRF) estimates of streamflows and water needs in the Caribbean Region. National Future estimates of total withdrawals and consumption in 1975 are greater than those of the State-Regional Future. By the year 2000, this situation is reversed, with the SRF exceeding NF projections. Differences between NF and SRF values are significant in the agricultural and domestic use categories. Both commercial and minerals withdrawal and consumption show good agreement.

Table 21-5.--Socioeconomic and volumetric data summary: the Caribbean Region

Category	1975		1985		2000	
	NF	SRF	NF	SRF	NF	SRF
SOCIOECONOMIC DATA (1000)						
Total population	3,052	3,052	3,614	3,614	4,234	4,234
Total employment	809	809	1,010	1,010	1,190	1,190
VOLUMETRIC DATA (mgd)						
-Base conditions-						
Total streamflow	5,181	NE	5,181	NE	5,181	NE
Streamflow at outflow point(s)	4,851	667	4,807	NE	4,881	NE
Fresh-water withdrawals	907	725	963	901	890	1,086
Agriculture	521	239	498	229	330	232
Steam electric	0	0	0	0	0	0
Manufacturing	0	101	0	124	0	133
Domestic	311	311	376	461	454	618
Commercial	44	44	52	52	60	60
Minerals	31	30	37	35	46	44
Public lands	0	0	0	0	0	0
Fish hatcheries	0	0	0	0	0	0
Other	0	0	0	0	0	0
Fresh-water consumption	343	299	374	368	300	427
Agriculture	281	147	297	154	206	163
Steam electric	0	0	0	0	0	0
Manufacturing	0	25	0	31	0	33
Domestic	49	114	61	167	75	212
Commercial	9	9	11	11	13	13
Minerals	4	4	5	5	6	6
Public lands	0	0	0	0	0	0
Fish hatcheries	0	0	0	0	0	0
Other	0	0	0	0	0	0
Ground-water withdrawals	254	254	NE	221	NE	241
Evaporation	0	0	0	0	0	0
Instream approximation						
Fish and wildlife	3,706	3,706	3,706	3,706	3,706	3,706

NE - Not estimated.

Problems

Institutional

Puerto Rico

Institutional problems have been identified as the most severe impediment to the resolution of water and related land resource problems in Puerto Rico. The assessment analysis concluded that the legal and administratiave organization for undertaking planning and management activities, including construction, are fully adequate for conducting this work. However, there has been a lack of progress in resolving many of these issues at policy-making levels of the government.

Institutional shortcomings result from a severe lack of coordination among agencies and from a low level of efficiency in key agencies. The latter is due to insufficient staffing and a lack of qualified staff personnel. The lack of innovative or action-oriented programs is notable.

The commonwealth government is experiencing a very tight fiscal situation, partly due to the global recession of the early 1970's. This fiscal austerity, however, cannot be identified as the major reason for instititutional problems and program inadequacies, but rather as an associated problem which has exacerbated an already difficult situation.

Virgin Islands

Institutional difficulties in the Virgin Islands are responsible for poor maintenance of desalination plants and distribution systems. These difficulties arise from the status of the water supply utilities which are operated as a tax-subsidized service. A policy directed to make utilities self-supporting could provide the means to generate the income necessary to properly maintain the utility.

Water quality in the public distribution system is monitored by the Department of Conservation and Cultural Affairs as is the quality of public water supplies from wells. There has been some difficulty in maintaining an efficient metering system, and over 50 percent of all desalted water produced disappears as unmetered losses. The cost for producing this water is estimated to run from $4 to $6 per 1,000 gallons. The lack of adequate chemical feed facilities on St. Thomas and the failure to chemically stabilize desalted water delivered to the distribution system has resulted in severe corrosion of pipes, thereby creating leakage from the system.

Water Quality

Puerto Rico

Puerto Rico faces water quality problems from the upper reaches of

most watersheds to the ocean. Surface waters are heavily used as depositories for all types of wastes throughout the island, and are also used as a source of water for multiple domestic and agricultural uses. Fecal contamination of water supplies in 1976 led to 7,800 cases of gastroenteritis in the town of Comerio as a result of improper chlorination of the public water supply. Many rural families still rely on small community or private surface-water systems which do not have chlorination facilities. Stations on 24 rivers at inland locations show that 75 percent of all surface-water stations had dissolved oxygen violations, 64 percent had BOD (biochemical oxygen demand) violations, and 96 percent had violations of the total coliforms standard.

The significance of pollution in surface waters is further intensified by its role in the transmission of schistosomiasis (also known as Bilharzia), a debilitating disease caused by parasitic flatworms which quickly penetrate human skin during contact with infested waters. The worm's eggs are transmitted to water via fecal contamination from infected persons. The worm passes through a period using a fresh-water snail as a host, and then releases larvae from the snail which may then reinfect humans. It is estimated that between 1 and 10 percent of the island's population is infected. Symptomatic expression of this disease has lessened considerably over the years, apparently due to dietary improvements. However, its symptoms are easily confused or masked by other diseases, and health authorities feel that as a result schistosomiasis frequently goes unreported.

Waste effluents from coastal urban-industrial areas have created severe water quality degradation in the island's coastal waters adjoining the most populated areas. San Juan harbor and its associated lagoon system is grossly polluted from domestic and industrial effluents as well as from leachate from the San Juan municipal dump. Coliform standards for recreation use are exceeded along some of the San Juan beachfront. This problem is being addressed, and notable progress has been made in reducing this pollution.

Virgin Islands

Streams in the Virgin Islands flow only intermittently, and usually only immediately following rains. This runoff is generally high in sediments, street wastes, etc., and may have a deleterious effect on downstream marine ecosystems. However, this does not appear to be a major problem.

Although the Virgin Islands are well known for their clear waters, there are some areas which receive runoff and effluents from sewage and boat traffic. Among the several bays which suffer from turbidity and siltation are the St. Thomas and Christiansted harbors.

Flooding

With torrential rains, steeply sloping watersheds, and a large population concentrated in low lying areas, the potential for flood damage and loss of life in Puerto Rico is great. Although records are not considered reliable, it is estimated that the average annual flood damages on the

island amount to $2,638,000, and an estimated 100,000 persons live in flood prone areas. The most recent serious flooding occurred in September 1975 when Hurricane Eloise passed offshore. Although high winds were not experienced, the southwest portion of Puerto Rico recorded over 20 inches of rain in a 24 hour period, producing flash flooding in which over 30 persons lost their lives and millions of dollars in property were lost.

Flooding problems also occur as a result of storm waves and storm tides associated with major hurricanes. In St. Thomas, for example, storm waves can raise water levels five to twelve feet above normal, and a six foot storm tide will flood lower parts of Charlotte Amalie up to 800 feet inland. Besides flooding, damage to waterfront facilities and erosion of shores by storm waves can be heavy. In both Puerto Rico and the Virgin Islands many low income families have constructed homes at the water's edge or in low-lying coastal areas which are prone to inundation by storm waves. Although reliable estimates are not available, it is estimated that on the order of 500 homes in the Caribbean have been destroyed by storm waves in the past decade, a decade in which no hurricane struck the islands. A major hurricane could create heavy damage and loss of life due to both torrential rains and flash flooding, as well as storm wave action.

Irrigation

Irrigation is practiced only in Puerto Rico. It is estimated that as many as 70,000 acres are irrigated, including over 50,000 acres on the south coast alluvium and in the Lajas Valley which receive irrigation regularly. Approximately 95 percent of this irrigated land is currently in sugarcane. Irrigation techniques are in most cases antiquated, employing an irrigator with a shovel to turn the flow of water into field furrows, and most irrigated land has not been leveled. This same system has been in use since the early 1900's and results in high labor costs and low water use efficiency. The labor cost of water application is approximately $20 an acre-foot, and only an average of 53 percent of the water applied is consumed.

Despite the scarcity of water for agriculture, not even the most fundamental water management techniques for increased water use efficiency have been implemented. Irrigations are not scheduled based on crop needs and the quantity of irrigation water applied to fields is not measured. Canal losses both on and off the farm are large, yet no programs have been implemented to increase the efficiency of water deliveries. As a result of these and other problems, the private sugar industry has sustained heavy losses, and the commonwealth government now owns or manages the largest portion of the island's sugar industry, providing annual subsidies of approximately $60 million (about $500/acre) to maintain this labor intensive system as a social welfare instrument.

Under the new administration, the Puerto Rico Department of Agriculture is formulating a plan for agricultural development and diversification which greatly reduces the emphasis on sugarcane and encourages the production of irrigated rice and produce for the local market. To implement this plan it will be necessary to bring large acreages on the north coast under irriga-

tion and to improve water management practices on currently irrigated lands. The development of additional irrigation supplies from waste-water recycling and new surface-water developments may become economically feasible if high earnings in new non-sugar crops are achieved. Limited supplies of recycled waste-water may be available at approximately $20 acre-foot (AF), and large new surface-water supplies may be developed for approximately $50 AF. Without new development the availability of irrigation water will continue to decrease due to the sedimentation of existing reservoirs.

Erosion and Sedimentation

Puerto Rico

The range of measured sedimentation rates in Puerto Rico is from 0.6 to 3.5 AF/square mile/year. On the average, sedimentation rates are in the vicinity of 2 AF/square mile/year, corresponding to the loss of one inch of soil every 25 years.

For 25 years the 17 soil conservation districts in Puerto Rico have cooperated with landowners in the voluntary planning and application of soil and water conservation measures. As a result, approximately 35 percent of the island's agricultural land area is adequately treated for conservation. However, as land is developed for urban and transportation uses, erosion and runoff increase. Public agencies and private developers who construct roads, industrial developments, and urban development are now required to consider the soil and water conservation aspects of their projects.

Virgin Islands

Steep slopes, dry conditions, heavy storm rainfalls during the hurricane season, and the high density of population and development all contribute to the island's susceptibility to erosion. The islands have implemented an earth-moving regulation which effectively controls erosion. This step protects the clear waters surrounding the islands as well as marine organisms from damage due to excessive turbidity, and prevents the the loss of the highly erodible soils on the island's steep slopes.

Individual Problem Areas

The following problem areas have been identified and are discussed in the following pages:

1. Institutional Problems (Puerto Rico)
2. San Juan Area
3. Barceloneta Area
4. South Coast Area
5. Flooding
6. Waterborne Pathogens
7. Sedimentation and Eutrophication
8. Institutional Problems (Virgin Islands)
9. St. Croix
10. St. Thomas
11. St. John

The location of these problem areas is shown in Figure 21-7a. Figure 21-7b shows a tabulation of problem issues by problem areas.

1. Institutional Problems (Puerto Rico)

The primary institutional problems in Puerto Rico appear to be: (1) fragmentation of agency responsibilities for water resources planning and management; and (2) lack of priority, foresight and initiative characteristic of other Commonwealth planning programs. This condition is exacerbated by the dual problems of (3) poor interagency communication and technical reliance on outside consultants. The relative severity of these problems may change from one year or one administration to another, reflecting the reliance of local government operation on personalities rather than on established administrative procedures.

2. San Juan Area

The San Juan area is the most heavily polluted area in Puerto Rico. With an estimated 1975 population of 1.1 million, water resource problems in this area affect the largest single group of people in the region. Because of the high population of the metropolitan area and the inadequacy of the water quality management program, the most severe resource problems in this area are related to water quality.

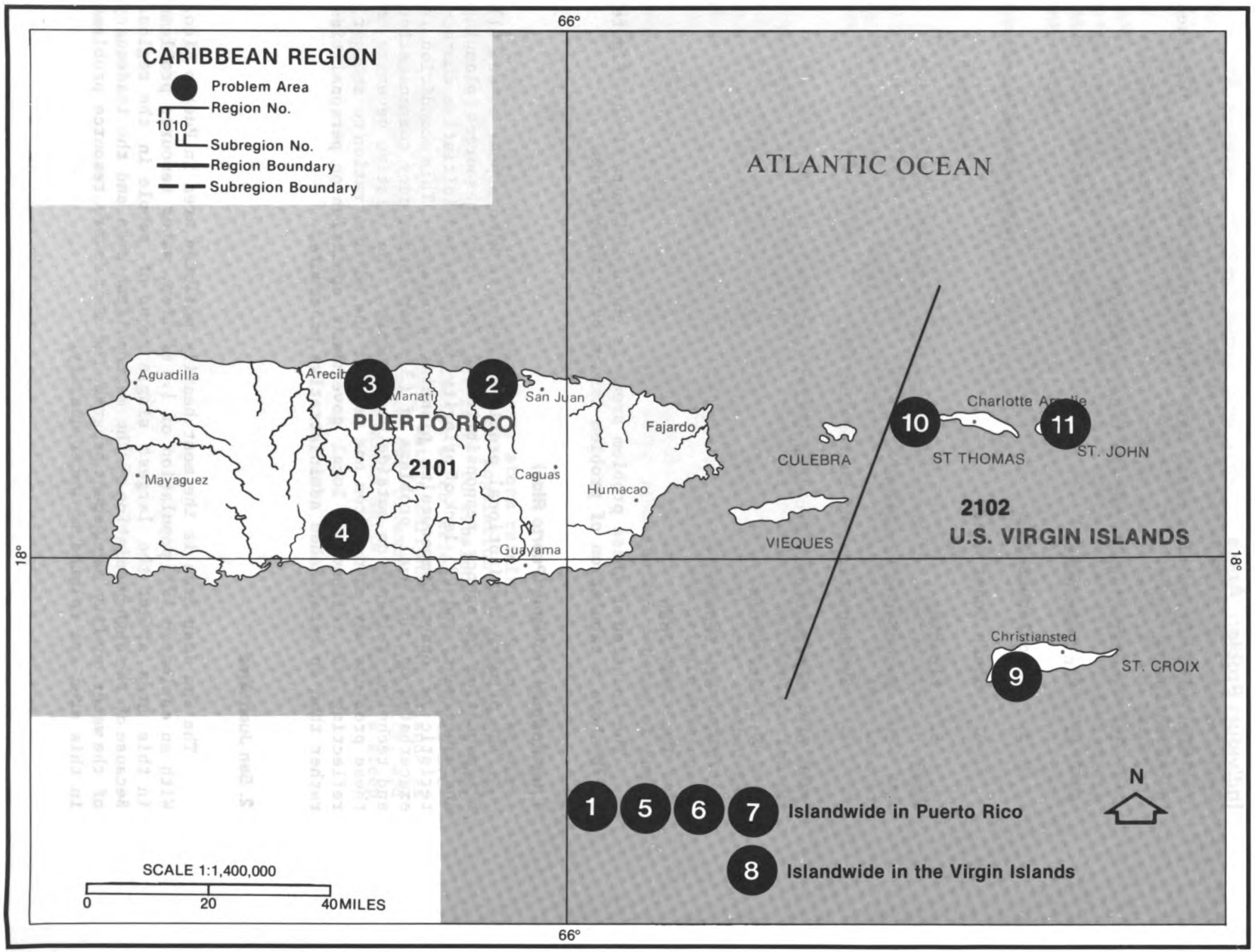


Figure 21-7a. Problem Map

CARIBBEAN REGION (21)

PROBLEM MATRIX

Problem area		Problem issues O= Identified by Federal Agency Representatives X= Identified by State-Regional Representative													
		Water quantity				Water quality				Related lands					
No. on map	Name	Fresh surface	Ground	Marine and estuarine	Surface/depth	Fresh surface	Ground	Marine and estuarine	Surface/depth	Flooding	Drainage	Erosion and sedimentation	Dredge and fill	Water related use conflicts	Other
Subregion 2101	Puerto Rico	O	O			O	O	O		O					O
Area 1	Puerto Rico														X
2	San Juan Area, Puerto Rico	X				X	X	X		X	X	X	X	X	
3	Barceloneta Area, Puerto Rico		X			X	X	X		X	X		X	X	
4	South Coast Area, Puerto Rico	X	X			X	X	X		X	X	X	X	X	
5	Islandwide Puerto Rico: Flooding									X					
6	Islandwide Puerto Rico: Waterborne Pathogens					X	X	X							
7	Islandwide P.R.: Sedimentation & Eutrophication					X						X			
Subregion 2102	Virgin Islands	O	O				O	O							
Area 8	Virgin Islands														X
9	St. Croix, Virgin Islands	X	X			X	X	X		X		X	X		
10	St. Thomas, Virgin Islands	X	X			X	X	X		X		X	X		
11	St. John, Virgin Islands	X	X			X		X		X					

Figure 21-7b. Problem Matrix

Three droughts requiring rationing of water deliveries have occurred in the San Juan area within the past ten years. The ongoing program of system interconnections to the recently completed La Plata reservoir is expected to resolve this problem. Pricing is not used as a device to manage water demand and bears consideration as a future management tool.

Water resource problems in the San Juan metropolitan area are being studied under the Federal 208 Water Quality Planning Program. The Environmental Quality Board found water quality in the surface-water system of the San Juan area generally poor with respect to coliform levels and BOD. Sewage, industrial and agricultural wastes at various stages of treatment, urban runoff, and sediments are all sources of pollution. Leachate from sanitary landfill is a major source of pollution for San Juan Bay and the Martin Pena Channel.

Domestic sewage, collected from less than 70 percent of all the metropolitan area population, is discharged with or without treatment into the surface-water system. This discharge is the primary contributor to the organic content and oxygen demand of receiving waters and the related health hazards of gastrointestinal diseases and schistosomiasis.

The principal water-using industries in the San Juan area, such as the petroleum refinery, rum and beer industries, gravel plants, and the cement, clay, and metals industries, generate a variety of toxic or oxygen demanding wastes. In most cases these wastes are dumped directly into the receiving streams with no pre-treatment.

In the San Juan metropolitan area population is heavily concentrated around the lagoons and bays. The resultant demands and stresses placed on these water bodies include discharge of sewage, urban runoff, landfill for housing and highways, fishing, and recreation.

San Juan's interconnected lagoon system is one of the largest estuaries and bird havens in Puerto Rico and has remained surprisingly functional despite the devastation it has suffered. Protection and development of these water bodies require the understanding of their interrelationships, since changes in one lagoon may, in time, affect the others.

Industrial and domestic effluents have affected the recreational value of one of the most used contact recreation areas of the island. Coliform criteria are violated at many sampling points along the beachfront from Punta del Morro to Punta Miquillo, which includes the most important contact recreation area of the region.

The heavily trafficked industrial port of San Juan has been subjected to progressively greater abuse since water quality observations began. Here coliform concentrations are the highest of any of Puerto Rico's waters, with violations noted at all sampling points. The worst BOD violations occur near the mouths of Rio Puerto Nuevo and Cano Martin Pena. The rest of San Juan Bay has relatively low BOD counts. The drastic increase in coliform bacteria in San Juan Bay outside the channel is due to leachate released by the municipal dump into the Martin Pena Channel and the deficiencies in operation of the Puerto Nuevo treatment plant.

Garbage dumping, industrial and domestic discharges, dumping from ships, and general environmental abuse have turned San Juan Bay into a disaster area. The bay's bottom itself constitutes a serious in-place source of pollution, and soundings with poles found no bottom through accumulated sludge and slime at probe depths of 12 feet.

Laguna del Condado represents a happy exception to the generally poor condition of the San Juan area's coastal and estuarine waters. In 1971, coliform standards were universally violated and dissolved oxygen (DO) depletion was noted at the eastern end of the lagoon. However, later readings have shown DO violations only at the bottom, and only in the eastern half of the lagoon are coliform counts excessive. Cleanup operations involving the identification and closing of raw sewage discharges have greatly improved the lagoon's water quality. Fish life is returning and offensive smells have disappeared, and the lagoon, which is ringed by high-rise apartments and hotels, is used for boating and fishing. Water quality in the lagoon is, in fact, superior to that of many nearshore stretches in the region, and high hopes exist for complete reclamation of this body of water. Investigations of slow oil spills in the lagoon are underway, and water quality monitoring operations are continuing.

3. Barceloneta Area

The primary water resource problem in the Barceloneta area is the rapid depletion of ground-water resources from the underlying limestone aquifer caused by the growth in water intensive industries, primarily chemicals and pharmaceuticals. Other water resource problems have emerged as a result of this industrial growth, among them changing land use and changes in surface-water quality due to the disposal of treated and untreated effluents into rivers and coastal waters. There is also concern over the current practice of waste discharges into the sinkholes which form a part of the upper limestone aquifer. Flooding problems occur here also.

The Barceloneta area, which consists of the five municipalities of Arecibo, Barceloneta, Florida, Manati, and Vega Baja, is located on the north central coast of the island. It has a total area of about 254 square miles, approximately 7 percent of Puerto Rico's total land area.

In 1950 the Barcelonata area had a population of 155 thousand, of which 32 percent was urban and 68 percent rural. The 1970 census indicated that the population had not grown appreciably over two decades but that its composition had changed to 46 pecent urban and 54 percent rural. This stability in population, despite a high birth rate, is attributable to the large scale migration of rural Puerto Ricans to San Juan.

Of the total area of 159,894 acres, urban and rural residential land uses occupy 8 percent of the land, with a continuous sprouting of commercial and residential nuclei along Highway 2. Commercial, industrial, and extractive activities accounted for 49 percent of land use in the area. Forest covered 24 percent, and the remaining 18 percent falls into other categories.

The Barceloneta area is the center of the recent influx of the pharmaceutical and chemical industries in Puerto Rico. The siting of so many pharmaceutical companies in one area is unique. Sixteen facilities have already been constructed in the Cruce Davila area alone; one chemical plant is currently under construction, and others are proposed.

A dramatic change in income structure has occurred in the Barceloneta area as a result of the influx of industries. The relative importance of agriculture as a source of income has decreased dramatically. The internal adjusted income in the agricultural sector has increased at an average annual rate of 2.24 percent year over the past 24 years, while manufacturing income increased at an average rate of 10 percent per year from 1960 to 1974.

The following rivers cross the Barceloneta area: Rio Tanama, Rio Grande de Arecibo, Rio Grande de Manati, Rio Indio and Rio Cibuco. Parallel to the shoreline lies Cano de Tiburones swamp, with an area of approximately 12 square miles. This swamp, a portion of which lies below sea level, has been drained by the Puerto Rico Land Authority and converted to agricultural use. It was originally planted in sugarcane, but the majority has now been converted to pasture. Due to the continuing drainage of fresh water plus saline intrusion into Cano de Tiburones, the Land Authority pumps approximately 130 mgd to the ocean. Approximately 60 to 70 percent of this discharge (i.e., around 80 mgd) is estimated to be fresh water (USGS).

East of Cano de Tiburones is Laguna Tortuguero, the largest natural fresh-water body on the island. Laguna Tortuguero is considered an environmentally critical area which should be protected from water quality and other environmental degradation and preserved for recreational uses.

The Barceloneta area is underlain by copious limestone aquifers. However, rapid water development of water intensive industries has caused local overdrafting. The current water balance for the aquifer system appears to be negative, yet no management program exists at this date to improve water management in this area. This problem will be complicated by proposals to plant large acreages in rice, thereby bringing thousands of acres into irrigation.

Industrial facilities in the Cruce Davila area use an estimated 11 mgd daily and discharge waste water at a rate of 8.6 mgd. Because the treatment plant scheduled to process this waste water has experienced construction and operation delays, some of these industrial effluents are discharged directly into the Rio Grande de Manati without treatment. Chemical discharges from pharmaceutical plants are the primary contributors to degradation of water quality in Rio Manati. Several industries discharge wastes into sinkholes which drain into the upper limestone aquifer. Several injection wells which discharge industrial wastes into the saline portion of the artesian aquifer are also in operation. Other sinkholes in the region are probably receiving urban wastes, particularly storm-water runoff, but this is not documented.

It is unknown to what extent the aquifers are being affected by

the disposal of these effluents, and no comprehensive study of this problem has been made to date.

4. South Coast Area (Puerto Rico)

In contrast to the moist north coast of Puerto Rico, the south coast is semi-arid and its coastal plains receive as little as 35 inches of mean annual rainfall. Approximately 50,000 acres in this area are under irrigation, most of which are dedicated to sugarcane cultivation. The sugarcane industry in Puerto Rico is operated at a loss by the Commonwealth government and is maintained as a social welfare instrument for maintaining employment opportunities. The sugar industry required approximately $60 million in subsidies in 1976.

Water management practices in the irrigated agricultural sector of Puerto Rico are archaic and highly inefficient both in the utilization of water and labor. Irrigation efficiencies have been estimated to be on the order of 30 percent, based on the difference between water withdrawal and the transpiration requirements of the sugarcane actually produced. Approximately 28,000 acres are served by government irrigation projects which date from before the First World War, and most stretches of the irrigation canals can be reached only by foot or on horseback. Although designed to deliver over 120,000 acre-feet of water per year, the South Coast Irrigation District has delivered an average of approximately 55,000 acre-feet per year over the past ten years. This is due largely to reservoir sedimentation, but deterioration of canals and the current cycle of drier years are also contributing factors.

Heavy industrial growth has occurred on the south coast, and there has been competition between the traditional agricultural sector and the newer industrial sector for the use of limited ground-water supplies. Large scale development of new supplies has been postponed due to uncertainty as to the magnitude and timing of future industrial demand in the area. Smaller development projects and management alternatives which could increase the utilization efficiency of the existing water resources and structures have not been pursued. Serious conflicts over ground-water use have occurred between industrial and agricultural users in the Yauco Valley and remain unresolved.

Income levels on the south coast are lower than in the San Juan area, and the level of infrastructure development to serve many of the smaller communities has lagged. According to the 1970 census approximately 75,000 persons on the south coast were living in dwellings without running water. However, the overall quantity of water available for municipal uses is expected to be adequate through the year 2000.

The south coast is currently being studied by the U.S. Army Corps of Engineers, and the final results of this study will be forthcoming in 1977. This study, along with the Island-Wide Supply Study, has delineated a range of water management alternatives which could be pursued on the south coast. However, it will be up to the Commonwealth to make more detailed analyses to select from the alternative presented, to generate short term plans, and to undertake implementation.

5. Flooding (Puerto Rico)

With an extent of only 3,434 square miles, river basins in Puerto Rico are small, the largest being that of Rio Grande de Loiza which has a total watershed area of 310 square miles. Steep topography and heavy rainfalls make flash flooding a common and dangerous phenomenon, particularly since flooding can occur at points relatively distant from rainfall. The Puerto Rico Planning Board estimates that approximately 300,000 acres are affected by flooding, most of which lie in the coastal plains.

The extreme scarcity of level land, the high population density (915 per square mile), and increasing development pressures have augmented flood damages in recent years. In spite of existing zoning regulations designed to control construction in flood prone areas, many residential developments have encroached on flood plains. More stringent flood-plain zoning is presently being implemented by the planning board in an effort to curtail damage levels, but the success of this program is not yet assured.

The average annual damage level is on the order of $3 million island-wide. Approximately 100,000 persons on this island live in flood prone areas according to the U.S. Army Corps of Engineers (Framework Study for Puerto Rico, 1974). The estimate of persons affected by flooding made by the Department of Natural Resources (DNR) in 1974 is approximately 13 times greater than the Corps of Engineers estimate. The DNR estimate was arrived at by counting the entire population of barrios (neighborhoods) where a large portion of the area was subject to flooding. In this manner the population which was directly affected as well as indirectly affected was counted. If only a small portion of any particular barrio was floodable, none of the population was counted.

The DNR estimate appears to be heavily inflated, but it is uncertain whether or not the Corps methodology was itself accurate. Personnel who compiled the DNR estimates could not provide an estimate of the percentage of a barrio which was subject to flooding for the entire population to be counted as "affected" although they were quick to point out that the "affected" population was clearly substantially greater than those persons actually living in dwellings subjected to flood damages. The personnel responsible for preparing the Corps of Engineers estimates are no longer in Puerto Rico, and a description of their methodology could not be obtained.

The assessment staff made efforts to obtain records of population affected and damage caused by recorded historic floods but met with little success. No agency in Puerto Rico could be found which had good records of historic flood damage.

6. Waterborne Pathogens (Puerto Rico)

Waterborne disease agents pose a serious problem in Puerto Rico from the uppermost reaches of many watersheds to the ocean itself. The significance of the fecal contamination of these waters is intensified by the role of fecal contamination in the transmission of schistosomiasis, a debilitating disease caused by parasitic flatworms which live in the human

bloodstream. The microscopic waterborne larvae can rapidly penetrate human skin when contact is made with infested waters. During the aquatic portion of the parasite's life cycle the parasite's host is a fresh-water snail whose habitat is the muddy banks and bottoms of sluggish rivers and ditches. The snail is infected as a result of contact with water exposed to fecal contamination from infected persons. Larvae are later released from the snail. Repeated human exposure to infested water leads to an increase in worms within the body and gradual physical disability. There is no effective cure for this disease.

Between 1 and 10 percent of the island population is estimated to be infected, but the symptomatic expression of the disease has lessened considerably over the years. Although there were formerly numerous illnesses and deaths attributed to schistosomiasis, only three deaths were attributed to this disease in 1973. Because of the gradual, debilitating nature of the disease, its symptons are easily masked by other ailments and consequently may go unreported.

Water quality problems in the island interior are usually associated with fecal contamination. In 1976, 7,800 cases of gastroenteritis in the town of Comerio resulted from improper chlorination of the public water supply. Many rural families still rely on small community or private surface-water systems which do not have chlorination facilities. Samplings of inland stations on 24 streams revealed that 23 of these violated the total coliform standard for island water established by the Puerto Rico Environmental Quality Board.

Waste effluents from urban and industrial concentrations have created water quality degradation along the island's coastline.

In the Barceloneta area, the practice of discharging wastes from chemical and pharmaceutical plants directly into sinkholes in the upper aquifer has created health problems. Fecal discharges from illegal connections to storm sewers have contaminated popular swimming beaches in San Juan which are used by both residents and tourists.

7. Sedimentation and Eutrophication (Puerto Rico)

Puerto Rico has small watersheds and a pronounced wet and dry season, which has heightened the necessity for construction of reservoirs for water supply expansion. There are now on the island 26 manmade lakes and two natural fresh-water bodies. Both natural fresh-water bodies are coastal lagoons; Laguna Tortuguero is approximately 600 acres in size, and Laguna Cartagena is less than 50 acres. Serious sedimentation and eutrophication problems occur primarily in the island's reservoirs, many of which, due to age, have experienced considerable changes from decades of sedimentation and aquatic plant loading.

The aquatic plant problem in Puerto Rico is heightened by the tropical climate and the lack of natural herbivores. The most troublesome aquatic weed on the island is the water hyacinth, which is a source of organic sediments deleteriously affecting the development of desirable fisheries as well as degrading the quality of potable water. Aquatic weeds do not

interfere with recreation since the schistosomiasis threat and ease of access to marine recreation have retarded the development of fresh-water related recreation.

Sedimentation and eutrophication problems are particularly severe due to the steep slopes of watersheds, frequency of extremely heavy rains, and the intensive level of land use. Small-scale agriculture is conducted on sloping land throughout the island interior with the exception of the rugged karst region with its poor soils. Agriculture is the primary contributor of sediment and nutrients. Highway and housing construction also contributes significantly to sedimentation.

Average sedimentation rates on the island are about two AF/square mile/year, or approximately one inch of soil every 25 years. The range in measured sedimentation rates on the island is from 0.64 to 3.52 AF/square mile/year. The reservoirs most seriously affected by sedimentation problems are the Loiza reservoir which supplies water to San Juan, and the Coamo and Guayabal reservoirs of the South Coast Irrigation District. The small Coamo reservoir has been completely sedimented for many years and is no longer in use. The Loiza reservoir suffers in addition from serious aquatic weed problems.

8. Institutional Problems (Virgin Islands)

Poor maintenance of the fresh-water production and distribution system and the operation of the water supply utilities as a subsidized service are the primary institutional difficulties in the Virgin Islands. These two problems are closely related. If the utilities were switched from a subsidized to a self-supporting status, their income could increase sufficiently to support maintenance of the utility. Under current conditions the operating deficit is recovered by payments from the government's fiscally constrained general fund, and essential maintenance services are postponed as an "economy" measure.

The failure to monitor water quality in the public distribution system and to maintain an efficient metering system (over 50 percent of all water produced appears as unmetered losses) are additional problems. On St. Thomas, the lack of adequate chemical feed facilities and failure to chemically stabilize desalted water delivered to the distribution system results in severe corrosion and leakage from the distribution pipes.

9. St. Croix (Virgin Islands)

St. Croix is the largest of the 50 islands and cays that make up the territory of the U.S. Virgin Islands. It is roughly 84 square miles in area, 18 miles long, and 6 miles wide at its broadest point. A low mountain range forms a spine along its length and there is a large coastal plain on its south shore, and numerous smaller level areas around the island. This relatively level land lent itself historically to more extensive agricultural development than the rugged topography of St. Thomas and St. John.

Historically, St. Croix's principal crops have been cotton and sugar-

cane. During the nineteenth and twentieth centuries, sugar was predominant, but the island's last crop of sugarcane was produced in 1968 when the viability of a sugar-based economy became marginal.

During the 1960's, the island moved from agriculture to tourism and industrial development. In the mid-1960's, Martin Marietta Alumina Company established an alumina processing plant and Hess Oil Virgin Islands Corp. established an oil refinery on St. Croix's southern coast. The Martin Marietta Alumina Company converts about 2,450 tons of bauxite into alumina daily using the Bayer process. There are also two rum distilleries on the island and some smaller industries, such as textile processing and watch assembly. Tourism is a significant industry, although it is not as large as tourism on St. Thomas and St. John. As a result of this development, St. Croix's population has increased considerably as people from the mainland United States and the other Caribbean islands came to the territory to work. This rapid overall growth pattern has been leveling out since 1973. The present population of St. Croix is approximately 46,700; however, it is expected to climb to an estimated 73,820 by 1986.

The lifting of warm moist air over hilly, steep terrain produces most localized rainfall. Generalized rainfall is a result of intertropical convergence zones, easterly waves, polar air, and hurricanes. On the easternmost point of St. Croix the average annual rainfall is 25 to 30 inches, while the average annual rainfall on the northwestern shore is 50 to 55 inches.

Surface water is collected in small reservoirs throughout the island for agricultural purposes. There are 22 impoundments on St. Croix with about 390 million gallons of storage capacity. Fresh surface water collected in guts (stream channels) is usually poor because of siltation and other debris, and in addition, sewage leachates adversely influence the quality of surface water. The limited supply of fresh surface water is also a result of the absence of year-round flowing streams.

Consumption for agricultural purposes is divided between livestock watering and crop irrigation. The total average daily consumption of water for livestock is about 100,000 gallons. Half of this water comes from wells and half comes from surface-water impoundments. The use of ground water for stock watering and crop irrigation is practiced without major problems. There are only limited sites with adequate and dependable quantities which produce ground water for agricultual uses. It is anticipated that the demand for water will show an increase to 500,000 gallons per day by the year 2000 from both wells and dams.

The major source of desalinated water for domestic use is limited because of the high cost of production. The daily capacity for production is 3.2 million gallons per day. The cost of producing desalinized water is $4.00 to $7.00 per thousand gallons for 1976. In situations of extreme emergencies water is barged from Puerto Rico for domestic use.

The estimated cost of rainwater collection for domestic use was $18 per thousand gallons for 1976. The estimated storage capacity of the

existing cisterns on St. Croix is 55 million gallons with the annual amount of water produced on the island by roof runoff at about 110 million gallons (0.3 mgd).

There is currently an experiment funded by the U.S. Environmental Protection Agency (EPA) to supplement existing natural ground-water supplies by recharging the aquifers with tertiary-treated effluent from the St. Croix sewage treatment plant. The designed capacity of this water reclamation is 0.5 mgd. St. Croix has two public salt-water flushing systems, one in Christiansted and one in Frederiksted. The mixing of this saline waste water with fresh waste water in the waste water reclamation plant increases the chloride content of the effluent. For this reason the reclaimed waste water cannot be recycled directly.

Because of the limited and unreliable supply of fresh surface water, it is not used for manufacturing purposes. The manfacturing industries either require low water consumption or are self-sufficient in water by desalinating the quantities desired.

Major storms during the hurricane season (July-November) and winter frontal activity often produce intense rainfall of long duration that results in occasional floodings. Tidal flooding, created by major hurricanes having an average frequency of once in 33 years, raises water levels from 5 to 12 feet above normal. Guts, areas of little relief, and coastal zones are most subject to flooding during continued periods of rainfall.

10. St. Thomas (Virgin Islands)

St. Thomas is the second largest island in the U.S. Virgin Islands with an area of 28 square miles. The island's topography is very steep with 70 percent of the land having slopes exceeding 20 percent. The highest peak, Crown Mountain, is 1,550 feet above sea level. Throughout the island, soils are generally thin and classified as having severe limitations.

The lifting of warm moist easterly winds over hilly, steep terrain is the most common cause of rainfall, and precipitation is localized. Elevation and exposure to the windward or leeward side of the slope are significant factors in the amount of rainfall received. Average annual rainfall varies from less than 35 inches on the east end of the island to over 50 inches near Crown Mountain, 14 miles westward. Tropical depressions and winter frontal activity moving through the area can often produce intense generalized rainfall of long duration that can result in serious flooding.

The isolated location of the island, its small land area, and its limited resources have resulted in a natural scarcity of wildlife. Clearing land for agriculture and development plus the introduction of exotic species have threatened much of the native wildlife. Mangroves and reefs on offshore islands and cays are the only areas not significantly altered.

Historically, St. Thomas was settled by people who depended on agriculture, hunting, fishing, and trade. Charlotte Amalie, the urban center of St. Thomas, became a major port and mercantile city in the West Indies.

Today, it is the center of the government for the territory. A multitude of cruise ships now visit Charlotte Amalie harbor. Tourists seeking the sun, beach, freeport shopping, and scenery provide the major industry for St. Thomas.

St. Thomas had an estimated population of 43,910 in 1975 and is projected to reach 66,000 by 1985. Charlotte Amalie contains most of the financial, legal, and governmental offices; commercial port facilities; and many of the hotels, restaurants, and tourist-oriented shops. It is the most important city in the Virgin Islands.

Most areas outside of Charlotte Amalie do not presently have municipal water systems and must rely on cistern storage of rainwater catchment for water supply and septic systems for waste water disposal. The hotel water supply is often hauled in from the Charlotte Amalie system by truck.

Charlotte Amalie has a dual municipal water supply system. A fresh-water system is supplied by a desalination plant located in Krum Bay. Desalinized water from this plant is transported by truck throughout the island and barged to St. John. A salt water system is used for sanitary flushing and fire fighting. Both systems are in poor condition and the fresh-water system is totally inadequate for the demands placed on it. Intercepting sanitary sewers collect waste water in Charlotte Amalie. A primary waste-water treatment plant is located near Truman Airport and the treatment effluent outfalls offshore into the Caribbean Sea. Projects underway will extend the water supply system and a new waste-water collection and secondary treatment system will be constructed to service the outlying communities. Ground-water supplies are very limited and of poor quality on St. Thomas. The ground-water aquifer in the island's center is now being heavily pumped, probably beyond the long-term yield capacity. An adequate system for the collection and disposal of solid wastes is a pervasive problem on St. Thomas. Studies are now underway for methods which will improve the present methods of collection and disposal of solid waste.

There are no fresh-water lakes on St. Thomas and streamflow is ephemeral. However, there are 40 earthen farm ponds on St. Thomas with a total capacity of about 90 million gallons. Historically the island has relied mainly on the collection of rainwater in cisterns for its source of fresh water. Cisterns are still a major source of supply, and building codes require cistern capacity in proportion to the roof size. Collection of rainfall for domestic use is estimated to average 5 gallons a day per person.

Rainfall records show wide ranges in both the monthly and annual amounts of rainfall. Maximum rates of rainfall have been recorded during the passing of hurricanes and lesser tropical storms which generally occur during the months of August, September, and October. A study of the records indicates that extremely dry periods of from three to four months duration may be expected to occur every few years. During these dry periods, individual daily rainfalls are usually of such small magnitude that most of the water evaporates immediately.

The tremendous increase in the demand for water on St. Thomas in the 1960's necessitated the construction of desalination plants. In 1975 some 719,000,000 gallons of desalinated water were sold and 209,600,000 kWh of electrical energy were generated simultaneously. In fiscal year 1975 the desalinated water was sold at $4.34 per thousand gallons. During a water crisis such as a total breakdown of the desalination plants or an extreme drought, water is barged to St. Thomas from Puerto Rico, as it was before construction of the desalination plants.

Localized flooding is a serious problem in many areas, and is correlated with the intense rainfalls associated with tropical depressions and hurricanes. Except for the last three years, St. Thomas has experienced a decade of very high growth rates. The amount of residential, commercial and industrial construction has resulted in significant changes in the hydrology of many areas, despite the fact that most of the land possesses limitations to developments. Guts have been encroached upon thereby increasing the flood hazard to people and property. Higher percentages of paved land areas and drainage patterns are modified with the installation of storm drainage systems. The result is that storm water runoff is delivered to guts at faster rates and in greater quantities, and the flood hazard has increased for downstream land and property immediately adjacent to the guts.

11. St. John (Virgin Islands)

St. John is the smallest island in the U.S. Virgin Islands with an area of 20 square miles. The topography of the island is extremely steep with 86 percent of the land having slopes exceeding 20 percent. Soils are very thin with severe limitations. The most common cause of rainfall is the lifting of warm, moist air over hilly, steep terrain. Elevation and exposure to windward or leeward sides of a slope are significant factors in the amount of rainfall received. Tropical depressions and winter frontal activity can often produce intense rainfall of long duration that can result in serious flooding. The average annual rainfall varies from 35 to 55 inches.

Historically, St. John was settled by people who depended on agriculture, hunting, fishing, and trade. Today few agricultural enterprises exist on St. John and no land is zoned for agriculture. Tourism associated with visitors to the 6,000-acre Virgin Islands National Park is the major industry. St. John had an estimated population of 2,185 in 1975. Approximately 85 percent of the population lives in the main urban area, Cruz Bay.

Presently, the main source of domestic water supply for St. John is cistern catchments. The supplemental quantity of water barged for fiscal year 1976 was approximately 12,827 gallons per day. There is also a system of wells being provided by the HUD's Community Development Block Grant Program. The quantity of water withdrawn from wells is expected to be an estimated 110,000 gallons per day. Although water supplies on St. John are highly limited, they are generaly sufficient for the level of development on the island and the lifestyle of the residents which has evolved in a water-short environment.

Summary

Physiography

The Caribbean Region is located approximately 900 miles southeast of Miami, Florida, and is bounded on the north by the Atlantic Ocean and on the south by the Caribbean Sea. The Commonwealth of Puerto Rico, which forms part of the Greater Antilles island chain, is the largest of the two subregions of this region and has a territorial extent of 3,434 square miles and an estimated 1975 population of 2,960,000. The U.S. Virgin Islands is the other subregion, consisting of the islands of St. Croix, St. John, St. Thomas, and approximately 50 uninhabited smaller islands and cays. The total land area of 133 square miles consists of 84 square miles in St. Croix, 20 square miles in St. John, and 28 square miles in St. Thomas. The estimated 1975 resident population was 92,000.

The region is mountainous in character and possesses a maritime tropical climate of warm temperatures with little variation, steady breezes, and slight but regular seasonal and diurnal ranges of temperature. Annual rainfall averages 44 inches in the Virgin Islands and 75 inches in Puerto Rico. The increased rainfall in Puerto Rico is due to the orographic effects of the island's larger mountains. The northern portion of Puerto Rico receives most of the island's rainfall while the southern slope lies in the rain shadow of the central mountain range.

Natural Resources

The Caribbean has many areas of natural beauty, which, combined with a mild climate, create the basic resources that attract tourists. The Virgin Islands have no mineral deposits of economic importance, but in Puerto Rico exploitable deposits of copper and nickel have been discovered and there is geological evidence of oil off the north coast. This has yet to be confirmed by drilling.

Puerto Rico has extremely rugged topography and a severely limited supply of mechanizable agricultural soils. Yet the cultivation of these soils is of great importance to the island for providing fresh food needs, since the nearest mainland supply is over 900 miles away. Although of small extent by mainland standards, the island's prime agricultural lands and year-round growing season are extremely valuable resources.

Population and Economy

The Caribbean Region is composed of small islands of limited resources and growing population. Socioeconomically, the Caribbean is one of the most volatile and uncertain areas of the United States. Both areas are characterized by relatively large migrations in response to ill-defined and relatively nonquantifiable variables, making it difficult to assess the future population growth potential.

Although there was a very heavy migration of Puerto Ricans to the New York City area in the 1950's, this net migration pattern has changed and Puerto Rico is now facing its highest population growth rate in the past three decades, despite a steadily decreasing birth rate. Most island immigrants are from other Caribbean areas, although the return migration from New York is also significant. The population of the U.S. Virgin Islands has grown at an average annual rate of 5 percent since 1950, with a large portion of this increase due to the influx of aliens in search of improved economic conditions. Over 25 percent of the 1975 population of the Virgin Islands is alien, mostly from other Caribbean islands.

Puerto Rico and the Virgin Islands exist under special status categories, as parts of the United States but not States. Both areas have experienced rapid economic change which has been possible because of this status. Both areas face uncertain economic futures and the issue of the political status of Puerto Rico is again being seriously debated.

Both Puerto Rico and the Virgin Islands have undergone significant industrial development and have worked with increasing diligence to attract heavy industry, particularly chemicals and petroleum. The sudden change in the relative prices of imported and domestic crude petroleum following the Arab oil embargo has greatly reduced the earning potential of the Caribbean petrochemical industry and has virtually stopped new investment in this active sector.

Tourism is the major source of income in the Virgin Islands but is much less significant in Puerto Rico. Although the vicissitudes of the tourist industry are unpredictable, the outlook for the Virgin Islands appears favorable and the predominance of a strong tourist industry is projected to continue.

Agriculture has been dwindling in importance in the Caribbean and most agricultural products consumed are imported from the United States. Agricultural acitivity in the Virgin Islands is limited primarily to grazing due to the lack of natural rainfall and irrigation water. In Puerto Rico, agricultural activity is undertaken in all but the poorest soils with large acreages dedicated to grazing and labor intensive crops, usually in small family farms. Approximately 50,000 acres of the island's best soils are under regular irrigation on the south coast. The predominant crop is sugarcane, occupying 95 percent of all land under irrigation. Sugar production in Puerto Rico is operated as a social welfare instrument by the Commonwealth government, and suffers a loss in excess of $500 for every acre in cane. With losses increasing, the government is beginning to lease irrigated lands to the private sector for the production of nonsugar crops, most of which are now imported.

High unemployment and low labor participation rates are characteristic of the labor pool in the Caribbean Region. In Puerto Rico unemployment is one of the most serious problems that confront the island's economy, where between fiscal year 1973-74 and 1974-75 a net total of 37,000 jobs were lost. A crisis of the first magnitude has been averted by masssive injec-

tions of Federal funds. The largest and most conspicuous program is Federal food stamps, which is estimated to reach approximately 60 percent of the Puerto Rican population.

Hydrology

The two subregions of the Caribbean have markedly dissimilar hydrology. Streamflow in the Virgin Islands is ephemeral and watersheds are tiny and steep. The availability of ground water varies from island to island, but all have a very limited supply, with ground water constituting about 10 percent of total withdrawals.

The principal factor influencing the surface hydrology in Puerto Rico is the relatively short length of stream reaches prior to entering the sea, the steeply sloping and extensively dissected landforms, and the configuration of the central mountain range, the Cordillera Central. The largest watershed in Puerto Rico, that of the Rio Loiza, is only 310 square miles. Although this is small by mainland standards, it is approximately four times the size of the largest of the U.S. Virgin Islands. Puerto Rico's northeastern coast is dominated by limestone formations which are particularly rich in ground water and are currently exploited for industrial and agricultural purposes. The south coast has an alluvial aquifer system which provides water for irrigation, municipal, and industrial uses. Overdrafting is becoming a problem in both these aquifers. Approximately 253 mgd are withdrawn from ground-water sources in Puerto Rico, of which about 13 mgd are from ground-water mining. If managed wisely, Puerto Rico's water resources are sufficient to sustain levels of economic activity and population projected to the year 2000.

Fresh-Water Withdrawals

Total fresh water withdrawn from rivers and ground-water aquifers in the Caribbean Region during 1975 averaged 907 mgd, of which 6 mgd represent withdrawals in the Virgin Islands. Withdrawals are projected to decrease to 890 mgd by the end of this century.

Sources of fresh water appear abundant in Puerto Rico when compared to total demand. However, such a comparison is misleading due to the lack of island-wide distribution systems. For this reason the water supplies which are available in some regions cannot serve heavy-demand areas in the San Juan or south coast areas, and the favorable comparison of existing supplies with demand cannot be taken as a sign of water adequacy. Many of the existing supplies are used for hydropower development, located some distance from demand centers.

Sources of water supplies in the Virgin Islands consist of both raw and desalinated sea water, rainwater collection in cisterns, dams, wells, waste-water recycling, and barging from Puerto Rico. Potable municipal water comes from desalination plants while water for agricultural uses (livestock watering) comes from dams and wells. During emergencies, when

the desalination plants are broken down, it is customary to ship water from Puerto Rico in barges.

Water Resource Problems

The fundamental impediment to the resolution of water resource problems in Puerto Rico is the lack of responsiveness of the island's government institutions, despite the fact that Puerto Rico has exceptionally strong legislation which grants the Commonwealth broad resource planning and management powers. The primary institutional problems appear to be dispersal and dilution of agency responsibilities for water resources and the the lack of priority, foresight and initiative characteristic of Commonwealth planning programs. These problems are exacerbated by the problems of poor interagency communication and technical review procedures, and inadequate development of agency staffs.

In the Virgin Islands, the most crucial water resource problems are related to the poor condition of the water supply and distribution system, which is currently operated in a financially nonaccountable manner with dependence on subsidies from the government's financially constrained general fund for the payment of operating deficits. Continued operation under such financially constrained conditions has contributed to the lack of priority given to regular maintenance, and the desalination plants as well as the distribution system have deteriorated rapidly. The desalination plants are poorly maintained, and mechanical failures often leave the islands with insufficient fresh water for municipal usage.

Although desalted water costs $4 to $6 per 1,000 gallons to produce, only 50 percent of the total production on St. Thomas is accounted for as metered deliveries. The other 50 percent is either delivered to clandestine users or is lost from the badly corroded distribution system. Lack of water quality control and the failure to properly stabilize the highly corrosive desalted water has led to the severe corrosion of pipes.

Conclusions and Recommendations

Role of the Federal Government

The role of the Federal Government in planning and data collection programs in the Caribbean is well developed. The region has already come to depend heavily on Federal programs such as those of the Water Resources Division of the U.S. Geological Survey as well as those of the Army Corps of Engineers. A substantial reduction of these programs would clearly be deleterious to the interest of the local community.

On the other hand, if Federal programs and money are always available for the resolution of local problems, then the need never arises for the local government to exercise its responsibility for local resource management. In many areas of the country, Federal involvement may be necessary because of the interstate nature of water resource problems, but water problems in the Caribbean do not cross the equivalence of interstate boundaries, with the single exception of a proposed pipeline from Puerto Rico to St. Thomas. However, the sale of Puerto Rican water to the Virgin Islands is a prerogative that may be exercised at the pleasure of the Puerto Rican government, and Federal participation is not foreseen.

In view of the local nature of water resource problems in the Caribbean and the already well developed Federal programs, a significant enlargement of the Federal role is considered inappropriate and potentially prejudicial to the development and exercise of local responsibility in water resources management.

The Need for Level B or Other Planning Studies

Puerto Rico

Under the auspices of the Puerto Rico Environmental Quality Board, a Level B proposal for Puerto Rico was submitted to the Water Resources Council (WRC) in 1974. This proposal was not funded. Subsequent work on the 1975 assessment has reinforced the need for a comprehensive resource planning program in Puerto Rico. A Level B proposal was again submitted to the council in mid-1977, and action on this proposal is still pending.

Although the 1974 Level B proposal was not funded, there have been a variety of other Federal programs which have been implemented in the interim. Work on the Army Corps of Engineers Ponce Regional Water Resources Management Study has provided a substantial quantity of technical information and synthesis. The federally-funded 1975 water resource assessment has further focused on the island's most severe water resource problems, and Title III funds from the WRC have continued at the level of approximately $50,000 per year. Water quality problems in the San Juan metropolitan area are being addressed by the ongoing Metro 208 Study, and the island-wide problems in the Isla 208 Study. Flood plain mapping and Federal flood

insurance programs are being funded by HUD, in addition to the activities of the Corps of Engineers and Geological Survey in this same area. Programs such as those carried out by the U.S. Geological Survey, the Water Resources Research Institute in Mayaquez, and the National Oceanographic and Atmospheric Administration are continuously adding to the availability of water resources information in the Commonwealth.

Unfortunately, to date, these and other water related programs have not been welded into a comprehensive water resources plan for Puerto Rico. The development of this water plan could be addressed within the framework of a Level B Study. However, it must be realized that it will also be necessary to develop co-equal emphasis in the area of implementation.

Virgin Islands

The water resource problems in the U.S. Virgin Islands are severe due to the scarcity of that resource there, but the nature of that subregion's problems are not interdisciplinary in nature. There is neither irrigation nor hydropower generation in the islands, and there are no perennial streams. Water development for both domestic and commercial uses comes from individual rainfall catchments and desalinated water. Water for heavy industry is derived from individual desalting plants owned and operated by those industries. Major problems with the reliability and distribution of desalted water are due primarily to poor maintenance and management of the system, as was previously mentioned. Because water resource problems in the U.S. Virgin Islands are not interdisciplinary in character, that subregion is not recommended for a Level B Study.

Research and Data Collection

Puerto Rico

A substantial quantity of water resource data and technical information is being or has been collected in Puerto Rico but is not fully utilized. The most urgent need in many areas is not to collect additional data, but rather to place emphasis on actually utilizing the data and studies which have been compiled to date.

There are several areas which need additional information-gathering and analytical work. For instance, one of the most severe water resource problems in Puerto Rico is the inefficient management of irrigation water. Yet, in the first 55 years of publication (up through 1971) only 10 of 1,619 titles (0.6 percent of the published research) in the Journal of Agriculture of the University of Puerto Rico dealt with any facet of agricultural water management.

Primary areas in which research and data collection activities are deficient in Puerto Rico include:

- o irrigation technology and applications
- o analysis of multiple-use potential of existing reservoirs
- o support of the establishment of a ground-water monitoring and management system
- o inventory of wells
- o response of marine ecosystems to pollutant loading and presentation of this information in a format usable by local agencies.

Virgin Islands

The primary research needs in the Virgin Islands relate to water conservation methods, aquifer development and management, and the potential for increased water recycling. A waste-water recycling plant is already in service on St. Croix, and studies of the potential for direct recycling are being planned now. Fruitful studies which could be undertaken at this point might include infiltration studies, an assessment of the potential for additional aquifer development, and an assessment of the potential for additional waste-water recycling.

The most glaring data collection problem is the deficiency of the program for monitoring the biological and chemical quality of the water in the public distribution system. A major problem is the extreme corrosion of distribution pipes by highly active desalinated water, which is not properly stabilized by chemical post-treatment. Because the distribution system pressure is turned on and off daily due to a lack of water, there is also particular concern about the potential for biological contamination from underground sewage lines. This is another problem which warrants investigation.

Institutional Arrangements

The major shortcoming of water resources programs both in Puerto Rico and the U.S. Virgin Islands is the failure to implement the mandate of existing legislation. The technologies required to resolve problems already exist and the legislative structure necessary to achieve implementation is already present. However, implementation has not occurred, and agencies having primary responsibilities have failed to exercise initiative in either preventing or resolving problems.

Puerto Rico

The most fundamental impediment to the resolution of water resource problems in Puerto Rico is the lack of responsiveness of the island's government institutions to emerging problems. Compared to other regions of the United States, Puerto Rico has exceptionally strong legislation which provides the Commonwealth with broad resource planning and manage-

ment powers, including the centralized public ownership and administrative control over all water resources within the island's territorial limits.

Puerto Rico has the advantage of an island-wide approach to resource management as a result of the considerable strength of the Commonwealth government in relation to the authority of the individual municipalities. This minimizes jurisdictional problems. Yet, despite more than ample legal authority and prerogative to undertake strong and innovative resource management activities, the record has shown that Commonwealth agencies experience serious difficulties in implementing meaningful programs.

The primary institutional problems appear to be: (1) dispersal and dilution of agency responsibilities for water resources, coupled with (2) the lack of priority, foresight, and initiative characteristic of Commonwealth planning programs. This problem is exacerbated by the dual problems of (3) poor interagency communication and technical review procedures, and (4) inadequate agency staffing with excessive reliance on outside consultants. The relative severity of these problems may change from one year or one administration to another, reflecting the reliance of local government operation on personalities rather than on established administrative procedures.

Of these problems the greatest institutional impediment to the conduct of a comprehensive water planning and management program in Puerto Rico is the fragmentation of water resource responsibility and decisionmaking power among many Commonwealth and Federal agencies and public corporations. This arrangement assures that everyone can play the game but that nobody is accountable for the outcome. Although water resource issues on the island are of sufficient importance to constitute the primary responsibility of a cabinet level department, by spreading the responsibility among so many agencies the importance of water resource responsibility is reduced to a secondary level in each agency, thereby assuring that no agency has primary accountability.

There is great need for a single Commonwealth agency to step forward and to undertake enhanced responsibility in the water resource field. The new water law has designated the Department of Natural Resources (DNR) as the lead agency for water resource planning and management in Puerto Rico. However, DNR has not exercised this responsibility to date, and Puerto Rico is without an effective water resource planning and management program. The funds which are needed to implement this program have not been forthcoming since the department's creation in 1973, and most of the department's limited water resource planning funds have come from Federal programs (U.S. Water Resources Council Title III and National Assessment funds).

Under the provisions of the new water law the Department of Natural Resources may make changes against the issuance of water use permits. It is recommended that water prices be assigned on the basis of generating the revenue necessary to maintain a water resource planning and management program. In areas where the water scarcity is more acute it would be expected that the charge against its use would be linked to supply availability, thereby utilizing a market mechanism to encourage water conser-

vation in water-short areas. Furthermore, agricultural uses should not be summarily exempted from water charges inasmuch as on the semi-arid south coast agriculture is the largest as well as most inefficient user.

Virgin Islands

The primary use of water in the U.S. Virgin Islands is for municipal supply servicing both residential and commercial customers. The primary problem facing the Virgin Islands is the unreliability of this supply and the inefficiency of the current system in meeting customer demands.

Water supply has always been a problem on St. Thomas, but it has become particularly acute since November 1976, and the problem is still unresolved. Water supply rationing has been more or less regular over this time, and the reserve storage of water for public distribution has fallen below the four-day level on several occasions. A 12-day supply is considered "adequate," and public storage facilities have been constructed with a 24-day capacity. This problem has two basic causes: (1) the poor maintenance and subsequent unreliability of the four desalination plants on St. Thomas, and (2) the extremely leaky distribution system. The ability to resolve these physical problems is severely constrained by the financial condition of the water supply and production utilities which results from their status as government-subsidized rather than self-sustaining utilities.

No accurate figures are available for the population served by the distribution system or the number of connections. Metered deliveries account for less than half of the water produced by the desalination plants. However, assuming that this system delivers to 50 percent of the residents in St. Thomas, the population served would be on the order of 22,000. When the desalting plants are functioning properly on St. Thomas, approximately 2.5 mgd is produced and pumped into the distribution system for a per capita consumption rate of approximately 115 gpd. This is a high consumption rate for an island which has such a restricted water supply, particularly when the low income of the population which is served plus the lack of industry are considered.

A per capita consumption of 115 gpd on the public system appears very far out of line when compared to the estimated use rate of dwellings not on the public system. The remaining 50 percent of the island residents obtain water only from rainfall roof catchments and water haulers and are estimated to use approximately 22.5 gallons per person per day (gcd) of fresh water, compared to 115 gcd for users on the distribution system. This high per capita consumption rate appears to be attributable more to a high rate of leakage from the distribution system than to lack of water conservation.

The water supply system is currently operated as if it were a government-supplied service which is operated in a nonaccountable and financially dependent manner. It is strongly recommended that a policy be designated and implemented under which the water supply utilities on

each island would have separate budgets, revolving accounts, accounting systems, and rates set separately. In support of this attempt to increase the revenue from the system's operation, it will be essential to undertake a complete inventory of the distribution system for the purpose of insuring that all connections are properly metered and to locate and repair leaks. A separate and lower price would be appropriate for standpipe water since it does not use the service of the public distribution system.

The implementation of a greatly improved maintenance program will be required to resolve the reliability problems which are being experienced with the four desalination plants on St. Thomas. This problem is considerably less severe on St. Croix, but still exists because of the lack of funds for an adequate spare parts inventory.

Existing chemical feed facilities should be moved to the desalination plant sites so that chemical stabilization can be undertaken upstream of the storage facilities, thereby helping to protect these facilities from corrosion. It is essential that a basic water quality laboratory and a continuous monitoring program be established so that the quality of the treated water can be assured. On-site inspection of the chemical feed system in St. Thomas showed it to be entirely inadequate, and showed that the actual chemical dosage entering the distribution system line is inadequate to render proper water treatment. The use of a gas chlorinator instead of the current dry powder might also be considered.

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with the cooperation of all
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States, local government, individual
corporations, business enterprises,
and others concerned.

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