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THE MANAGEMENT AND CONTROL OF WATER IN PUERTO RICO

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All errors of commission or omission are, of course, the author's sole responsibility.

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INTRODUCTION

Probably no single factor has a more decisive influence on human beings than their relationships to the water that falls from the clouds. It has always bulked large in the consciousness of Man, altho usually he has not taken an intelligent attitude toward it. He has set up raingods and prayed for relief from drought and floods for which he himself has often been responsible. The Man's limited comprehension has wasted thousands of acres of land, caused drops in crop yields, raised the crests of floods, starved cattle, spread deserts over the face of the earth.

Man cannot live without water. Sixty percent of his body is composed of water, which must be constantly removed. His food consists largely of water: for example, three hundred tons of rainfall are required to grow one ton of corn. This is obvious, but what is not so obvious is the place of water in the total environment that determine Man's survival. Even less clear to most human beings if the way in which Man's habits influence the supplies of water available to him, in relation to storage in the accumulated trash of the forest floor, the soil, wells, springs, marshes, and lakes. Indeed many aspects of these relationships are still obscure even to scientific students of the subject.

There is a lot to be known about water. We see and feel rain. We use water for drinking and washing. We irrigate our lawns and fields. We talk about the weather, complain that it is too wet or too dry. Most of us are conscious nearly all the time of the importance of water in our lives, but actually our knowledge of it is very skimpy.

We know the symbol of water but little about its properties, which can make us confortable or uncomfortable, rich or poor, secure or insecure. We cannot live without water; we could live better if we knew more about it.

We have little need to remind that water has become one of our major public concerns.

Nearly everyone in Puerto Rico in the past few years has experienced some problem caused by too much water when we do not want it or too little water when we do want it. Farmers have had to haul water for stock in trucks from cities. City dwellers for a time have had to cut down their number of their baths, so low was the water in the reservoirs that serve the principal cities. Home owners in may places had to give up watering their lawns in order to husband municipal supplies. An ample amount of clean water has become a factor in the location of new factories. The intrusion of salt water into overused wells is making unusable the water in some underground reservoirs.

Farms know only too well the difficulties that attend getting enough water for irrigation, the need for supplemented irrigation, the worries of erosion, and the deficiencies of good water for house, stock, gardens, and crops. They have known the worries of dry wells, failing springs, and erratic surface supplies. We all have suffered the fury of floods and the hazards of pollution. Losses in life, security, productivity, and money have been great.

The development of Puerto Rico and its water resources followed the usual colonial patterns. Communities developed first on the coast where there were ports. Travel inland tended to follow the streams as being the most direct routes and the easiest to use. Inland communities thus developed where travel routes, land, and water were available.

Streams were the obvious source of water supply for people, originally on personal basis, followed by development of water supplies on a community basis by the construction of dug wells, dams, diversion works, and distribution facilties. Water was first diverted from streams for the irrigation of plantations at an early date, probably no later than the early 1800's.

Dug wells were used early in the colonial days, but drilling wells for the development of ground-water supplies apparently did not start until after 1900. The earliest records available are for a few wells drilled in 1906.

Development of supplies in Puerto Rico followed the natural sequence of use of the water closest at hand and easiest to obtain.

It then became necessary to go farther afield to meet the increasing demand of water. The expanding needs of the total community led to the development of larger supplies by public agencies, for domestic, irrigation, power, and industrial use, starting around 1907. About 1945 water development projects became more massive and multiple-purpose projects were favored. Use of the best available techniques was made for the development of large stream supplies.

It is axiomatic that the present-day development of a country is directly related to its water potential and to its water development. The rising economy, particularly the industrial segment of the economy, brought the realization that a comprehensive knowledge of the problems concerned with the management and control of water in Puerto Rico is essential.

The fundamental problem of water resources in Puerto Rico is not limited supply a fact experienced in other countries, but the way in which the resource is managed and controlled.

There was a time in Puerto Rico when the water from the rains soaked into the soil and only the surplus gradually worked its way into the streams and rivers which flowed crystal clear to the sea. But that was long ago, when the Island was covered by dense forests. Since then, under the pressure of a rapidly expanding population, much of this natural protective cover has given way before exploitation and reckless land used.

The great waste of natural resources that is now taking place in Puerto Rico thru improper use and management seriously endanger the future of the Island and the welfare of the people. Unless adequate measures are taken to halt the present trend, the productivity of the soil and the amount of land suitable for cultivation will be reduced further, and there also will be less water available for the continually increasing needs of the economy.

The future requirements of water in Puerto Rico are tied directly to the rate of population increase and the progress made in economic development. With population continuing to rise at a rate that is among the highest in the world, it is already apparent that present sources of water for household uses will be inadequate within a short span of years unless they are enlarged and adequately protected. Any further development of new irrigation areas will also place an additional demand on the present water resources. Likewise, the present program for industrialization, with continued increases in requirements for water and electric power, will prove increasingly costly and limited unless a sound policy for the management and conservation of the Island's water resources is put into effect.

On the basis of what is now taking place, it is clear that as population rises further and industry develops these will continue to be an incrasing strain on Puerto Rico's water resources. The need to conserve and use these water resources wisely so they will be permanently available for the greatest benefit to the people is a challenge that must be met if the Island's economy continue to progress.

The results of this study, we believe, will be of an invaluable contribution in the attempt to solve the problems encountered in the management and control of water in Puerto Rico. In Puerto Rico there is a diversity of agencies or organizations responsible for the management and control of our water resources. This diversity of agencies has contributed immensely to the improper and inefficient management and control of water.

The lack of a central water resources organization to deal with the different aspects of water management has given rise to a haphazard distribution of published information. All published water resources information are highly scattered. The scattering of information among these water related agencies, constituted a real impediment in the gathering of the information needed for this study. It was a difficult task to be acquainted and even to acquire the published information.

In our contacts with the institutions possessing publications on the water resources of Puerto Rico we found out that these people do not know a great deal of these problems, since when we intended to ask specific questions they concealed their answers among masses of disorganized statistics and other sorts of information. Most of the time these people were very much reluctant to give information of any kind. One of the serious handicaps facing research personnel in Puerto Rico is the need for more long-term water data. Other than rainfall records, relatively few data on water have been collected systematically on the Island.

One purpose of this research is to supply as much information as we can about water in a practical, useful way for those agencies and individuals concerned with the development and conservation of water resources. But not only that.

Another aim is to emphasize that more information, more wisdom are needed. The realization of ignorance is the beginning of wisdom. The statement of a problem is the first step in its solution.

As our population increases, more demands are being made on our water resources the effective use and conservation of water will come increasingly important, and conflicts over water use will have to be resolved.

Our primary aim is to explain the nature, use, behavior and conservation of water resources in its multiple uses. We address ourselves to urban and rural people and to all those interested in the water problems of Puerto Rico.

Some of the broad problems are forecast, but our main emphasis is on the facts and basic principles that will help people in reaching the best decisions.

To achieve these purposes we have presented a limited reference on hydrologic processes as observed in Puerto Rico, and the most significant problems concerning water use, pollution, flood control, sedimentation of reservoirs, and conservation of land and water.

The information this report contains is not just for today. All things, including weather and rainfall, change fast, and our memories are short. When it rains, we forget about drought; when it is dry, we forget about floods.

THE MANAGEMENT AND CONTROL OF WATER
IN PUERTO RICO

1. The Water Invironment [1]

Puerto Rico is the smallest and easternmost of the four islands which form the Greater Antilles [2] and is the northern extremety of a chain of smaller islands reaching to the northern coast of South America. Puerto Rico and the other Greater Antilles are formed by the high parts of a 1300-miles chain of mountains whose base and bulk are burried beneath the sea. Puerto Rico is, in fact, the top of what would be one of the highest mountains in the world, if it were entirely above rather than mostly below sea-level.

Puerto Rico is about 1000 miles southwest of Miami, about 1400 miles from New York, and slightly over 500 miles north of Caracas, Venezuela. Roughly rectangular in shape, the Island is about 100 miles long by 35 miles wide. Its area is approximately 3435 square miles including the adjacent islands of Vieques, Culebra, and Mona. It is bounded on the north by the Atlantic Ocean and the south by the Caribbean Sea. Situated

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[1] Much of the material of this section is drawn from "Water Resources of Puerto Rico," A Progress Report, By Dean B. Bogart, Ted Arnow, and James W. Crooks, 1964.

[2] Cuba, Jamaica, Dominican Republic and Haiti, and Puerto Rico.

at 18° north latitude, Puerto Rico is within the tropics.

The Land

The Island's central mountain chain, the Cordillera Central rises almost directly out of the sea on the west coast of the Island and extends eastward, finally terminating in the Sierra de Luquillo in the northeast and in the Sierra de Cayey in the southeast. While this rugged terrain covers about 70 percent of the Island's area, the fertile coastal plains extend like a fringe between the mountains and the Atlantic on the north and the Caribbean on the south. Geologists agree that while Puerto Rico cannot be considered a volcanic island, in the sense that some of the Lesser Antilles might be so classified, the land mass was formed by early volcanic activity during the upper Cretaceous. In general terms, the Cordillera Central is underlain by lavas and volcanically derived sediments resulting from this igneous activity. In the west a large body of serpentine occurs, and in the central and southeastern areas bodies of coarser plutonic rocks, quartz, diorites and granodiorities are found.

The coastal plain on the south side of the Island is not so wide nor so naturally fertile as the northern coastal plain. The north-south drainage divide runs parallel to the Caribbean coast about 10 miles from the shore line. As would be expected, thus, the southern side of the central mountain chain presents a more precipitous drop to the sea than that found on the north. To the north, most of the principal rivers, such as the Río Grande de Loíza, Río de la Plata or Río Grande de Arecibo, descend to the Atlantic thru foothills and slowly declining slopes. The flood plains formed by these rivers are extremely fertile.

Geographers have calculated that 27 percent of the Island's land can be classified as flat or gently rolling lowlands.[1] With one or two minor exceptions offered by small inland valleys, one near Caguas and the other near Cayey, this region is comprised primarily of land along the coastal fringe of the Island. Depending upon the availability of water, the flat or rolling coastal lands are the most fertile areas of Puerto Rico. The abundant rainfall on the north coast assures production, but on the south coast and particularly in the southwest corner, in the Lajas Valley sector, the flat rolling land needs irrigation.

For the most part the coastal plains produce the bulk of the Island's sugar-crop. This region produces more than 90 percent of the Island's sugar. More than 20 percent of this sugar is produced on the north coast and about 30 percent is produced on the irrigated plains on the south coast. Some coastal land lacking in rainfall or fertility is used as pasture.

1/ The Geographic Regions of Puerto Rico, by Rafael Picó, University of Puerto Rico Press, 1950.

In contrast to the coastal plains is the markedly mountainous terrain of the central part of the Island, which accounts for about 36 percent of the land area. This extensive area is marked by high local relief with little flat land. Most of the slopes range from 30 percent to over 60 percent grade. This region, comprised of the Cordillera Central, the Sierra de Cayey and the Sierra de Luquillo, includes the highest peaks of the Island drainage divide.

Heavy rainfall and fertile soil permit extensive cultivation of this region in spite of the sharp slopes. Coffee is the main crop in the area which extends from near the west coast to the centre of the Island.

The eastern mountainous section, with the exception of the Sierra de Luquillo, receives less rain than the western high-lands do, and the vegetation is less thick and the land unprotected by a covering forest. Tobacco is the principal commercial crop. Small farms produce subsistence crops, and extensive pasture areas can be found.

The area of the Island which lies between the two extremes of the flat coastal plains and the markedly mountain terrain can be described as rolling hill land; it comprises the remaining 37 percent of the land surface. Foothills adjacent to the central core of mountains are included in this area. In this region the unique limestone belts of the northeastern and north central section of Puerto Rico are found. This area is of a more recent geological age than the rest of the Island, having been formed during the Tertiary period. The limestone plateau, at one time under the sea, once lifted and exposed to rain and wind erosion, was slowly converted into striking karst topography. The area is characterized by precipitous cliffs, caves and large caverns, deep depressions or sinkholes and undissolved limestone remnants or "mogotes" which resemble conical haystacks. In this area rivers such as the Tanamá or Camuy disappear suddenly and, running underground, appear just as unexpectedly miles away. In spite of the rugged terrain, the irregular valleys among the "mogotes" and precipices are cultivated with some success by the small farmer. Subsistence crops, vegetables and fruit are the main products.

2. Elements of Water Situation [1/]

The fundamental movement of water on earth is the continuous circulation of water between the atmosphere, the land, and the sea, which is known as the "hydrologic cycle".

It is the intent in this topic, Elements of Water Situation, to present simple aspects of the cycle as it may to Puerto Rico.

1/ Dean B. Bogart, Ted Arnow, and James W. Crooks, cited, 1964.

Rainfall is the only source of fresh water in Puerto Rico, and it is considered to be the beginning point of the hydrologic cycle. A small part of the rainfall returns to the air by evaporation from foliage, from structures, and from the ground surface. Much of the rainfall infiltrates into the ground where it becomes soil moisture near the surface, and ground water farther down. This water absorbed by the ground may be taken up by the roots of vegetation and returned to the air by transpiration from the leaves, or it ultimately may contribute to stream-flow. The remainder of the rainfall runs off the surface of the ground as stream-flow.

Both ground water and streamflow of ground move down-slope toward the sea under the force of gravity. Large volumes of ground water seep into streams, and some emerges on the surface of the ground in springs. In some places and in some seasons, water from streams may seep into the ground to recharge ground-water systems. Thus the seaward routes of the water mingle and the water cannot be identified exactly as either ground water or surface water. For convenience, it is called surface water while it is in the stream, and ground water while it is underground; but in reality both are merely names applied to different phases of a single resource.

On a world-wide basis evaporation from the oceans, and to a lesser extent evaporation and transpiration from the land, return water to the atmosphere completing the water cycle. The atmospheric water once again is available for continuing the endless operation of the cycle.

The quantity of water flowing in a stream generally tends to increase as the ocean is approached because more and more land area contributes water to the stream system. The amount of ground-water flow may increase if the rocks and alluvium near the coast are water bearing and sufficiently permeable. On the other hand, both stream flow and ground water may decrease in coastal plains as the ocean is approached, particularly in the dry season. The decrease is caused by evaporation from the ground where the ground water is shallow and from water surfaces, and by transpiration from foliage.

In some parts of Puerto Rico, evaporation and transpiration exceed the rainfall, so that additional water is applied to comercially valuable crop by irrigation. Irrigation is practiced mostly in the southern coastal plains.

As water moves thru the hydrologic cycle, its chemical, physical, and biological characteristics are changed by various forces of the environment thru which it passes. As a vapor in the atmosphere, in the transitory state of evaporation, water attains its greatest natural purity. When it condenses into droplets, it loses this purity by contacting and absorbing gases, dust and smoke particles, and in some areas, wind-blown ocean spray. When it moves further, in river systems and the ground, water acquires new additives. Minerals from rocks and soils, organic material from vegetative matter, living plant and animal organisms, and wastes from Man's activities are added in various amounts at various intervals, and at various locations. Some materials are dissolved in the water and others are suspended. These materials become an integral part of the water and its identity.

The physical state of water and the type and amount of extraneous materials in water are the components that comprise the character of the water. Odor, taste, appearance, temperature, and chemical activity are some of the properties imparted by these components, and are features by which the character of the water is identified.

The suitability of a water for specific uses determined by comparing the properties of the water with established standards of acceptability, is expressed as water quality. The concentration of both mineral and organic materials dissolved in the water determines the chemical quality of the water. Factors that control the physical appearance or characteristics of the water, such as suspended materials, color, and temperature determine the physical quality of the water. Living organisms, especially pathogenic organisms, determine the biological quality of the water.

Storm water erodes the land surface and carries sediment into the streams. Flood waters become laden with suspended sediment, and in severe floods large particles, such as sand, gravel, and boulders, may roll along the streambed and ultimately be deposited in the channel, in the sea, or on the flood plains. Storm runoff usually does not dissolved much solid matter because the water is not in contact with the land long enough for much solution to take place. Water flowing thru the soil and rocks, however, usually moves slowly and has time for considerable solution. Thus ground water, and the low flows of streams, may acquire a considerable amount of dissolved solids. The nature of the dissolved solids depends mostly on the nature of the soils and rocks thru which the ground water percolates, and it varies in different parts of the Island.

The total volume of suspended sediment in streams generally tends to increase toward the sea because the streams become larger, but the volume may decrease as the streams cross the coastal plains. Water velocities decrease in streams that become wider and shallower in traversing the flat coastal plains, causing the suspended sediments to deposit. This deposition forms flood plains and deltas.

The dissolved solids also tend to increase in the seaward direction in both the stream systems and the ground-water systems. However, the increase is governed largely by the nature of the rocks, and the amount of dissolved solids may decrease in the seaward direction in some parts of the Island, depending upon the relative solubility of the rocks.

The works of Man often alter the general pattern of streamflow and ground water and their physical and chemical qualities. For examples, the deposition of sediment from highly turbid storm water passing thru a reservoir, results in somewhat clear water in the stream downstream of the reservoir. Also, when the moderately mineralized water stored in the reservoir is diverted for irrigation of fields in the coastal plain, some decrease of the mineral content of the ground water in the irrigated area may result. Excess irrigation water would percolate to the water table and dilute the ground water where concentration normally would be high because of the geology or proximity of salt water. On the other hand, streamflow below the reservoir would contain more strongly mineralized water derived from seepage of local ground water.

The quality of water in streams may be greatly altered locally by the works of Man. For example, the suspended sediment load of a stream may increase notably when the farm lands in the drainage basin are freshly plowed. Also, clearing and grading operations for new industrial areas, and shopping centers result in faster flooding and a great increase in sediment load. Municipal and industrial wastes introduce a variety of chemical constituents into the water and the use of water for cooling purposes raises the water temperature.

Other elements of the water situation must be considered. Ground waters often are great in volume, for instance, but because the rate of movement is slow ground-water flow may be limited. This means that the quantity of water that may be obtained continuosly from the ground depends on the rate of replenishment. To withdraw faster than it is replenished amounts to "mining" the ground-water system, and in time the supply may become seriously depleted or altered adversely in quality, and the cost of recovery may become prohibitive.

In general, ground waters tend to be relatively uniform over broad areas as to depth, flow conditions, and quality so that ground water may be surveyed and managed with relatively limited regard to changes that occur with time. The principal problems of evaluating ground-water resources are to locate the ground-water systems and to define their water characteristics, particularly the amount and location of recharge and discharge.

On the other hand, streamflow is highly variable not only with respect to place but also with respect to time. The location of a stream is readily seen, the area that it drains usually may be determined from maps, but the flow varies so much, literally from hour to hours, that a survey made at given time and place means little with respect to other places. Surveys of streamflow thus require continuing observations of streamflow over considerable periods of time. The total volume of water in the stream systems at any one time is small when compared to the volume of water in the ground, but streamflow usually is constantly replenished by water seeping out of the ground.

Water in a stream flows by many adjacent properties and desirably it should serve all properties equitably. Most uses of streamflow do not consume or withdraw the water, but merely delay its passage and sometimes alter its quality. One important exception is the use of water for irrigation, which frequently removes the water from the stream channel and returns little or none of it.

Water removed permanently from a stream or from a ground-water deposit, for example, that is used for irrigation, deprives the downstream properties of the use of the water and may involve property rights. This results in complicated water-management problems. The solution of such problems can never be considered final because new but associated problems constantly arise. However, water-management problems are less complex when the elements of the water situation are adequately defined and are understood.

A further complication of water events takes place along the coast where fresh water comes in contact with the sea water.

Larger flows in streams tend to flush salty sea water away from the stream mouths, but during periods of low flow the streams may have their flow reversed by incoming tides. Conditions vary locally, at times resulting in a mixture of fresh and salt water extending some distance inland.

Fresh ground water near the coast tends to lie on top of salt water deeper in the formations and to displace the salt water seaward. Consequently, there may be a considerable depth of fresh ground water adjacent to the sea coast. When ground water is pumped excessively in such places, salt water may be drawn toward the wells with serious consequences.

3. Surface-Water Characteristics [1]

The surface water of the Island flows from the Cordillera Central to the sea in 17 principal river systems and in many small streams. Practically all the streams are called rivers, even tho they may be only a few miles in length and may drain only a few square miles of area. In referring to the rivers in this report, the local name is used, as "Río Fajardo", and "Río Grande de Manatí", but the latter type may be called "Río Manatí" at some places for the sake of brevity. Simple physical characteristics of the 17 principal river systems are summarized in Table 1, in a clockwise order beginning with Río Guajataca.

1/ Dean B. Bogart, Ted Arnow, and James W. Crooks, cited, 1964.

The drainage areas shown in Table 1 are approximate, and for many of the rivers the drainage area may not be closely related to the flow. This is particularly true for the rivers that flow north. The length of the basin in Table 1 is the straight line distance from the mouth to the farthest drainage boundary. This usually is considerably less than the length of the principal stream.

Most of the north-flowing rivers cross the northern foothills area. These areas together coccupy a band about 10 miles wide along the northern coast. In that band, some of the river flow may seep into the ground at times, depending upon the height of the ground-water table along the river channel.

Three of the north-flowing river systems have more than half of their drainage basins in the interior uplands, where drainage areas are likely to be closely related to stream flows.

The principal river systems that flow to the east, south, and west also have part of their drainage basins in the coastal low-lands where some of the low flow discharged from the valleys of the mountains interior may seep out of the river channels.

Table 1. Dimensions of the Larger River Basins in Puerto Rico

River	Drainage Area Square Miles	Length of Basin Miles	Fall from Highest Point on Watershed Feet	Average Fall Feet per Mile
Rivers Flowing North:				
Río Guajataca	71	17	1740	102
Río Camuy	62	16	2300	144
Río Grande de Arecibo	289	24	4390	183
Río Grande de Manatí	224	25	4150	166
Río Cibuco	100	18	2200	122
Río de la Plata	239	30	3090	103
Río de Bayamón	105	21	2000	99
Río Grande de Loíza	308	26	3520	--
Total	1,398	22 Avg.	2920 Avg.	132 Avg.
Rivers Flowing East:	50	12	2130	178
Río Guayanés				
Rivers Flowing South:				
Río Nigua (Salinas)	53	13	2830	218
Río Coamo	78	17	2890	170
Río Jacaguas	94	16	3540	221
Río Tallaboa	35	10	3410	341
Río Yauco	47	15	3540	236
Total	307	14 Avg.	3242 Avg.	237 Avg.
Rivers Flowing West:				
Río Guanajibo	129	19	2950	155
Río Grande de Añasco	185	29	3950	136
Río Culebrinas	114	21	1680	80
Total	428	23 Avg.	2860 Avg.	124 Avg.
Summary for 17 rivers Total	2183	18 Avg.	2788 Avg.	168 Avg.

Data from the United States Geological Survey Records, 1964.

The upper portions of their drainage basins are well defined by the topography and the drainage areas should be related to streamflows.

Water developments such as reservoirs and diversions have complicated the low flow relationships of many of the principal rivers in the interior of the Island. Some of the flow from the headwaters of Ríos Arecibo, Manatí, La Plata, and Añasco is diverted to south-flowing rivers. Irrigation canals divert water from the main channels of Ríos Guajataca, Patillas, Guamaní, Jacaguas, Coamo, Yauco, and Loco; and the city of San Juan diverts municipal water from Ríos Bayamón and Loíza. Water also is diverted at many places on the lesser streams of the Islands.

Flows also are complicated by operation of hydroelectric plants or by diversions for power on Ríos Guajataca, Arecibo, Manatí, La Plata, Loiza, Blanco, Patillas, Guamaní, Jacaguas, Tallaboa, Yauco, Loco and Añasco.

The complications enumerated above make the determination and analysis of surface water resources very difficult. Reliable information for development and management requires streamflow records at a net-work of gaging stations having water-level recorders and other instruments at places on streams having hydrologic significance, at sites of potential projects, and at existing developments.

Gaging stations were operated in Puerto Rico by the predecessor agencies of Puerto Rico Water Resources Authority, as far back as 1907. These stations were relatively numerous and practically all were in the interior upland area. More particularly, there were operated for short periods on a reconnaissance basis to fill urgent needs for design data.

In 1945, the Puerto Rico Water Resources Authority started installing recording gaging stations in addition to reconnaissance-type stations. Periods of operation varied with the need, and at the end of 1961, seven PRWRA recording stations were being operated (four of them by the PRASA).

In 1958, the United States Geological Survey established the first gaging stations of a cooperative water-resources investigation. By the end of 1961, the USGS had 24 stations in operation - 17 continuous record, 7 partial record. Fifteen of the stations were for records of essentially natural flow; 9 were for records relating to special problems of availability and management. From the gaging station records, a number of examples were selected by the USGS to illustrate the variability of streamflow in Puerto Rico.

Variability of Streamflow

Streamflow in Puerto Rico varies widely with frequent change, because much of the rain falls in short scattered showers of varying intensity. This may be observed readily in any village. The day is bright and sunny, and the streets are dry. Suddenly a cloud appears, rain pelts down, the people take shelter, the roofs and streets are covered with water, the gutters run full. Then, just as suddenly, the rain stops, the sun appears. In a few minutes the streets are dry except for a few puddles and the water in the gutters goes away into a stream. On the next street, it may not have rained at all.

The flow of a stream at a gaging station is similar to that in the gutters of the streets, except that the streamflow from the rainstorm usually takes more time to accumulate and to dissipate. Often the runoff from successive showers overlaps, so that the stream rises again before it has finished receding from the previous shower. Then too, runoff from the showers that fall here and there on the drainage basin reach the gaging station at different times. Thus the direct relationship between the rain that falls and the storm runoff becomes very complex for even a small stream.

The continuos change in the quantity of water that flows and the associated change in the level of the water surface are not the only variables of stream-flow. The water likely will contain a greater proportion of dissolved materials when the flow is low and is derived from ground water. But the chemical concentration may be low if the flow is largely from storm runoff from the surface of the ground. Similarly, but in the opposite relation, the amount of sediment in the stream water likely will be negligible during periods of low flow, but the stream may have much sediment during a flow.

Temperature

Temperature is significant aspect of water quality to those who intend to use the water for public or industrial supplies. For public supplies, the temperature of the water should be within a palatable range for human consumption, generally lower than the body temperature of 98° F. Also, temperature is an important factor in chemical reactions involved in water treatment, in both chemical alteration of the water and germicidal treatment. Industries are concerned with the temperature of a water supply in respect to treatment, but they have greater interest in the temperature for cooling purposes.

Temperature data collected by the USGS from streams and ground-water supplies in Puerto Rico 1960-63 show that the range of temperature is rather small. Daytime temperatures of 15 streams measured at about monthly intervals ranged between about 70° F to 90° F as shown in Table 2. There appears to be little difference in the temperature of the stream in respect to altitude or location. The short length, and moderate velocity of the streams probably contribute to this condition.

Table 2. Ranges in Temperature of 15 Streams Observed During Daylights Hours at Monhly Intervals

(Data from de U. S. G. S. Records 1964)

Stream	Number of Observations	Period of Record	Temperature Range °F
Río Grande de Arecibo near Utuado	33	1959-61	70-89
Río Grande de Manatí near Morovis	22	1959-60	73-87
Río Toro Negro near Ciales	21	1959-60	76-90
Río Grande de Manatí near Ciales	28	1959-61	71-87
Río de la Plata At Proyecto La Plata	33	1959-61	72-89
Río de la Plata at Toa Alta	16	1960-61	76-85
Río de Bayamón at Bayamón	32	1959-61	71-91
Río Grande de Loíza at Caguas	32	1959-61	74-89
Río Gurabo at Gurabo	30	1959-61	76-89
Río Fajardo at Fajardo	19	1960-61	74-89
Río Humacao at Las Piedras	35	1959-61	71-87
Río Tallaboa at Peñuelas	33	1959-61	69-86
Río Tallaboa at Tallaboa	33	1959-61	75-88
Río Guayanilla near Guayanilla	10	1961	72-85
Río Yauco at Yauco	5	1961	76-89
Río Guanajibo near Hormigueros	31	1959-61	72-88
Río Grande de Añasco near Lares	33	1959-60	73-85
Río Grande de Añasco at El Espino	22	1960-61	73-86

4. Availability of Water [1]

The Water Budget

The source of all fresh water in Puerto Rico is the rainfall. The water cycle described in the section "Elements of the Water Situation", is a concept of the route taken by water in its endless travel between the atmosphere and the surface of Earth. When the elements of the cycle are viewed as from a specific area, and the factores of modification are added, the concept of the "water budget" is reached. The budget includes rainfall, evapotranspiration, streamflow, ground-water discharge and storage.

Rainfall, the Source of Water

Altho much could be said about the tropical marine climate of Puerto Rico, we are going to confine this discussion to a review of the major climatic features related to water.

Being in the belt of trade winds, the Island is exposed to a considerable air flow that is relatively persistent from the east-northest. The air comes from the broad reaches of the Atlantic Ocean and it contains much moisture. As a result of the effect of the mountains, a large amount of rainfall comes on the windward slopes of the mountains.

The average annual rainfall for Puerto Rico, based on rain gages operated over a long period, is 68.92 inches according to the

[1] Dean B. Bogart, Ted Arnow, and James W. Crooks, cited, 1964.

U.S. Weather Bureau. For the purposes of this report the average is reounded to 69 inches, which is equivalent to 13,000,000 acre-feet rainfall per year. Approximately 8,000,000 acre-feet constitute the runoff into streams discharging into the sea, and the balance of 5,000,000 acre-feet evaporates or percolates into the under-ground reservoirs.

The average annual rainfall ranges from about 60 inches along the north coast to about 100 inches at the divide of the Cordillera Central, and down to about 30 inches along the western portion of the south coast. The highest rainfall occurs in a small area near the northeast corner of the Island in the Sierra de Luquillo, where an average annual rainfall of about 210 inches has been reported.

The distribution shows that about half of the Island receives between 65 and 85 inches of rainfall annually, and about 80 percent of the Island receives between 45 and 95 inches of rainfall annually. The areas receiving less than 45 inches and more than 95 inches thus are relatively small parts of the Island.

The pattern of rainfall over the Island is a relatively uniform from the north and south coasts up to the Island divide. Somewhat less rain falls over the east-central portion of the principal mountains mass than over the portions at either end. Three small areas in the central part of the Island receive less than 60 inches of rainfall annually.

According to the Puerto Rico Water Resources Authority records, the annual rainfall is described in Table 3 below.

Table 3. Average Annual Rainfall in Puerto Rico

(Data from PRWRA Records, 1967)

Average Annual Rainfall, inches	Area Square Miles	Percent of Island Area
30	130	3.8
40	258	7.6
50	195	5.7
60	396	11.6
70	923	27.0
80	765	27.0
90	453	13.2
100	179	5.2
Over 100	121	3.5
	3420 Total	100.0

The areas now under irrigation are the naturally dry sections of the Island, and the water that is needed is drawn from the mountain regions. Since Puerto Rico is surrounded by tropical seas and lies well within the Torrid Zone, it enjoys abundant rainfall in the mountainous area of its interior. The rainfall, however, even tho it gives rise to numerous well watered streams, is not evenly distributed over the Island, varying from about 30 inches annually along the dry southern coast to more than 100 inches in the central mountainous regions and reaching over 180 inches in the El Yunque area in the northeastern section. This situation arises mainly from its topography and the prevailing winds.

The high mountains of the interior form a more or less continuous divide in east-west direction across the Island. When the moisture laden northeasterly trade winds are deflected upward by this barrier they are rarified and thus cooled. Their moisture condenses and falls as rain, largely on the northeasterly and easterly slopes. After the winds cross the divide to the southern side, they often retain insufficient water to continue precipitation, resulting in a comparatively dry southern coast. Similarly, the northern coast, lying almost at ocean level, also receives less rain than the mountain areas. This is particularly so on the plains of the northeastern corner of the Island.

Present methods of applying irrigation water in Puerto Rico are in the main costly, and need to be discarded in favor of other tested methods which will make more effective use of water at a much lower cost. The land under irrigation is used mostly to grow sugarcane. Practically no other use of real significance to the economy is made of irrigation water on farms that have it available.

Evapotranspiration or Water Loss

Evapotranspiration is the combined return of water to the atmosphere by evaporation from the wet surfaces of foliage, the land, and water bodies, and by transpiration from foliage. Neither evapotranspiration nor transpiration from large areas can be measured directly. Evapotranspiration, therefore, usually is estimated from records of rainfall and stream runoff. The average annual evapotranspiration for a period of several years is equal to the difference between average annual rainfall and average annual stream runoff; provided, a negligible quantity of ground water enters or leaves the specific area without reaching a stream channel; provided diversion into or out of the area can be evaluated; and provided, a negligible change takes place during the period in the quantity stored as surface water, ground water, or soil moisture. These provisions limit the reasonably accurate determination of evapotranspiration in Puerto Rico so far to the hilly and mountainous interior uplands. Because of the difficulty of determining movement of water in coastal lowlands and in the inland limestone area, the determination of evapotranspiration in those areas is approximate.

Because factors other than evapotranspiration are involved in the difference between rainfall and runoff, the term often used is "water loss". But water loss does not include surface-water and ground-water discharge into the sea, even tho that water is lost once it reaches the sea. Rainfall and runoff data for the determination of water loss presently are available for then areas in Puerto Rico. The ten areas are thought to be representative generally of the interior uplands of the Island. The data based on PRWRA records are presented in Table 4.

The average annual water loss in them ranges from 29 to 47 inches. This range is greater than should be expected from possible errors in the rainfall or runoff data, which suggests that some significant factor has not been evaluated. It could be altitude, exposure, wind movement, temperature, land use, soils, geology, or a combination of some of these. The cause of the differences in water loss should be a subject for hydrologic investigations.

Another way to study water loss, based on PRWRA data (representing about 9.4 percent of the total area of the Island), is to compare it with rainfall. Because rainfall in much of the interior uplands ranges from 65 to 85 inches, and averages 75 inches, the water loss in much of the interior uplands likely is in the magnitude of 46 inches.

Four years of water-budget computations made by the PRWRA, for the hill and mountain parts of the Río Tallaboa and Río Guayanilla basins, show a mean water loss of 48 inches. Their estimates about water loss in the lower hald (coastal and foothills) of the Island, indicate that in most of this half, mean annual temperature is higher than in the principal uplands area, which implies evapotranspiration should be greater. On the other hand, rainfall in the lower half generally is less. Along the south coastal plain in particular, the

Table 4. Average Annual Rainfall, Runoff, and Water Loss in Mountain Areas of Puerto Rico

(Data form PRWRA Records)

Stream	Place	Drainage Area Square Miles	Rainfall Inches	Runoff Inches	Water loss = Rainfall - Runoff	
					Inches	Percent of Rainfall
Río Vacas	Lago Garzas	6.2	92	63	29	32
Río Toro Negro	Lago Guineo	1.6	108	81	27	25
Río Matrullas	Lago Matrullas	4.4	95	61	34	36
Río Grande de Manatí	Ciales, gaging station	128.0	73	26	47	64
Río de la Plata	Lago Carite	7.9	83	53	30	36
Río de la Plata	Lago Comerío	135.0	69	24	45	65
Río Hicaco	Gaging Station	1.3	211	180	31	15
Río Grande de Patillas	Lago Patillas	25.2	75	45	30	40
Río Jacaguas	Lago Guayabal	43.4	80	34	46	56
Río Yahuecas	Gaging Station	15.5	81	45	45	--

rainfall probably is less than the potential water loss. Taking these partly offsetting factors into consideration, the water loss possibly is about 40 inches in the lower half of the Island, altho probably is much greater locally where sugarcane is irrigated.

The average annual water loss in Puerto Rico thus is in the magnitude of 45 inches. But refer to the later section, "Summary of Water Budget".

Average annual evaporation was measured at four places in Puerto Rico (United States Weather Bureau, 1956). Three of the stations had standard evaporation pans, selected data for which are as follows:

Station	Part of Island	Average Annual evaporation, inches
San Juan	North Coast	83.16
Aguirre	South Coast	81.40
Lajas Valley	Sothwest Coast	81.40
	Mean of three Stations	82.0

According to the United States Weather Bureau (USWB) records for the three evaporation gages show that the evaporation increases significantly with increases in wind movement. The total wind movement at San Juan, is two to three times that at Aguirre and Lajas, but the annual evaporation does not reflect this directly. Possibly the air at San Juan, coming off the sea most of the time, is more humid than that at Aguirre and Lajas, so that the higher wind movement is offset by the lower evaporation potential.

Information on evaporation in the mountainous interior of Puerto Rico may help to interpet the estimates of water loss. But evaporation from water surfaces apparently is not likely to be a serious problem as yet in the management of water resources in the interior, partly because of the relatively small surface area of the reservoirs. The annual rainfall exceeds the evaporation in the interior uplands and in the west, north, and east coastal lowlands In the dry southern coastal lowlands evaporation exceeds rainfall and is an important factor in water management.

Stream Runoff

Based on studies conducted by the PRWRA the annual stream runoff data for 10 drainage basins in the interior uplands are presented in the table below.

Table 5. Runoff from Mountain Areas

(Data based on PRWRA Records)

Area	Runoff for Entire Drainage Area (Inches)
Río Grande de Añasco	36
Río Grande de Arecibo	63
Río Grande de Manatí	61
Río Grande de Manatí	81

Area	Runoff for Entire Drainage Area (Inches)
Río Jacaguas	34
Río Cibuco	26
Río de Bayamón	24
Río de la Plata	53
Río Grande de Patillas	45
Río Fajardo	38

Rainfall runoff data for the 10 drainage basins were presented on Table 4.

A curve drawn by the PRWRA from the data provided useful estimates of annual runoff from other drainage basins in the interior uplands of the Island, when the annual rainfall is known. The runoff from drainage basins in the coastal lowlands and in the north-coast limestone area cannot be estimate accurately from the values of Table 5. Runoff data from those areas are not available. Moreover, according to PRWRA estimates, the limits of drainage basins in those areas seldom can be determined from topographic maps with desirable accuracy because the drainage boundaries seldom are defined by the topography.

In spite of the limited coverage of the available data on runoff, the figures in Table 5 can be used effectively. On the basis of a mean rainfall on the Island of 69 inches, the runoff is estimated to be 27 inches. This includes ground-water discharged directly to the sea, which has been computed as 4 inches by the PRWRA Engineers. The net stream runoff to the sea thus is about 23 inches, which is equivalent to 4,100,000 acre-feet of water. This quantity is used in the section "Summary of the Water Budget".

Ground-Water Discharge

Ground water discharges from the water-bearing formations into the streams constitutes the base flow of the streams.

The ground water discharge from the water-bearing formations directly into the ocean has been calculated by the U.S. Geological Survey on the basis of estimates made for the discharge from two areas: the alluvial deposits in the Ponce - Patillas section, and the belt of tertiary limestone in the Aguadilla - Arecibo and Arecibo - Bayamón sections.

The Ponce - Patillas Section is about 44 miles long. The hydraulic gradient toward the sea in the section averages about 15 feet per mile. Based on pumping tests in similar materials in the Tallaboa Valley in the Jobos area, the transmissibility of the alluvial deposits is estimated at 200,000 gpd per foot (gpd = gallons per day). On the basis of these figures, the underground discharge in the Ponce - Patillas section is calculated to be about 130 mgd (mgd = million gallons per day).

The sections between Aguadilla and Bayamón are about 68 miles long. The hydraulic gradient toward the sea, as calculated at two sites, averages about 7 feet per mile. Based on pumping tests in similar limestones in Florida (Parker, and other, 1955) the transmissibility of the limestones is estimated at 1 million gpd per foot. On the basis of these figures, the underground discharge in the area between Aguadilla and Bayamón is calculated to be about 480 mgd.

Assuming an additional 100 mgd for the remaining shoreline of the Island, the underground discharge then totals about 710 mgd, or about 1,100 cfs (cubic feet per second). If this estimated flow represents the average, the discharge of ground water into the sea is in magnitude of 800,000 acre-feet per year, the equivalent of 4 inches of rain on the entire Island. This quantity is used in the section "Summary of the Water Budget".

Storage

When more water is needed than a stream will produce during the low-flow season of a dry year, additional water may be available by the operation of a storage reservoir. Theoretically, a reservoir built anywhere on a stream system will yield any desired flow at a uniform rate up to the long-term average flow at the site of the reservoir, if sufficient storage is provided. Practically, however, such a reservoir probably would be uneconomical. An ideally, economical reservoir requires a site where a large volume of water may be impounded by a dam at a narrow place in the valley, where land values are low, where the sediment load is low, and where a minimum of developments such as highways, buildings, and cementeries will be inundated.

Before a reservoir is designed, a member of localities usually must be surveyed and studied to select the most economical site.

In the design of a reservoir the streamflow must be determined accurately and studied carefully for each site considered, because the reservoir is, in effect a device for controlling streamflow.

The effect of a reservoir on the flow of a river will vary depending on how the reservoir is operated and on what proportion of the natural stream flow in the river system is controlled by the reservoir. A reservoir that is a simple storage pond has relatively little effect on the streamflow below it probably increasing the flow slightly during wet seasons where rainfall exceeds evaporation, and decreasing it during dry seasons when evaporation exceeds rainfall. In most cases, reservoirs reduce maximum flood levels in a river, but they do so at the cost of prolonging the period of flooding at lower levels.

A reservoir that stores water for diversion to a hydroelectric power plant on another river or for irrigation, as many of the reservoirs in Puerto Rico do, probably leaves the channel dry downstream for long periods, to the point where seepage of ground water produces the only flow.

A reservoir that is operated for hydroelectric power probably will reduce the flood flows. However, the low flows may be highly variable during each day from the way the power plant is operated. Hydroelectric power usually is generated only during part of the day, and the water is released at high rates of flow, up to the capacity of the turbines. At other times during the day, no power will be generated and the flow may be very low.

Storage of streamflow in reservations has been widely practiced in Puerto Rico, and as of the end of 1966, 22 major reservoirs were in existence. The reservoirs are used for both single and multiple purpose, as follows:

Purposes	Number of reservoirs
Power	6
Power and irrigation	7
Irrigation	5
Water supply	2
Power and water supply	2

The statistical data of the 22 existing reservoirs are shown in Table 6 below with selected pertinent information.

Table 6. Principal Reservoirs in Puerto Rico

(Data furnished by PRWRA and PRASA)

Reservoir Name	Content, Acre-feet	River Basin
Guajataca	32,600	Guajataca
Garzas	4,700	Arecibo
Adjuntas	465	Arecibo
Pellejas	152	Arecibo
Viví	277	Arecibo
Caonillas	49,000	Arecibo
Dos Bocas	32,000	Arecibo
Guineo	1,860	Arecibo
Matrullas	3,000	Arecibo
Carite	11,300	Arecibo
Comerío (1)	600	La Plata
Cidra	5,220	Bayamón
Las Curías	1,100	Puerto Nuevo
Loíza	20,000	Loíza
Patillas	14,500	Patillas
Coamo (2)	200	Coamo
Guayabal	10,000	Jacaguas
Luchetti	16,500	Yauco
Loco	1,950	Loco
Yahuecas	1,800	Añasco
Guayo	17,400	Añasco
Prieto	700	Añasco

(1) Badly silted; original contents 4,920 acree-feet
(2) Badly silted; original contents 2,700 acre-feet

The capacity of the 22 reservoirs totals 225,000 acre-feet. This is equivalent to 1.2 inches of water over the entire Island, or about 1.8 percent of the average annual rainfall. Tho useful and important to Puerto Rico, the storage capacity of the principal reservoirs thus is only a small part of the total water economy. On the other hand, reservoirs regulate the flow of stream in an amount about four times their total storage capacity.

Studies conducted by the U.S. Geological Survey in 1964 indicate that the feasibility of a reservoir in the coastal lowlands and the north-coast limestone area is limited for several reasons. Land costs for the reservoir likely are very high in the coastal lowlands; a large part of the stored water leak out of the reservoir into the ground because of the high porosity of the underlying rocks; and little head is available for either hydroelectric power or gravity distribution by canals.

A reservoir in the interior uplands has many advantages. Foundations for a dam are better; the reservoir probably will not lose much water to the ground; the rainfall is greater than the evaporation; and altitude provides head for the development of hydroelectric power and the gravity distribution of water by canals and aqueducts. Also, the water is of better quality.

The reservoir system in Puerto Rico includes four developments where water is diverted from the north slopes and the central mountains to the south slopes. In two of these developments, water is collected from a number of reservoirs and points of diversion on the north slopes and is led to a single outlet on the south slope. The topography of the interior uplands area lends itself to this practice.

Storage, as an item of the water budget, includes not only water stored in reservoirs, but also the large quantity of ground water and the water in streams and ponds. The total amount of water stored in Puerto Rico varies continuously. If the water budget covered only a part of a year, or a year or two, the change in storage between the beginning and the end of the selected budget period would have to be evaluated. The water budget being developed in this report, however, is based on long-term data and considerations, such that the possible change in storage becomes a negligible factor (U.S. Geological Survey, 1964). In the summary of the water budget, change in storage is evaluated as zero.

Ground Water

The first comprehensive survey of ground-water conditions in Puerto Rico, was made by C. L. McGuinnes of the U.S. Geological Survey during the period september 1945 to March 1946. The results of the investigation were published in two reports, a descriptive text (McGuinness, 1948) and a tabulation of well records (McGuinness, 1946). The text includes a detailed description of ground-water conditions in all areas of Puerto Rico. The tabulation of well records includes descriptive data for 1045 wells and 4 springs formation logs for 467 wells and chemical analyses of water from 44 wells.

No general studies of ground-water were made from 1947 to 1957, but during this period it is estimated that approximately 800 wells were drilled in Puerto Rico. Further investigations of the ground-water supplies were began by the U.S. Geological Survey late in 1954. During the period 1958 to 1961 all wells and springs listed in McGuinness's tabulation of well records were visited and their status brought up to date, and records were obtained for about 1300 additional wells and springs. Records were available on June 30, 1961 of 2,342 wells and springs. These records show only the existence of data; they do not show the status of wells or springs at any given time. Many of the wells accounted for in these records have been abandoned or destroyed, but the information obtained during their construction and operation is of considerable value. Futhermore, during the collection of well data, emphasis was placed on obtaining information for large wells used for irrigation, industry, or public supply. Relatively few data were obtained for wells used for domestic supply, and unquestionably many wells exist in the Island that are not accounted in the tabulation.

The replenishment of the ground water resources of Puerto Rico is of vital importance not only as an aid in meeting municipal and industrial requirements but also in supplying the irrigation and hydroelectric needs.

The principal ground water recharge sources in Puerto Rico are: (1) Rainfall, (2) stream flow, and (3) irrigation. Most of the ground water reservoirs are recharged from rainfall, particularly in the interior of the Island; streams take care of ground water recharge in the alluvial areas of the eastern, southeastern, and western parts of the Island; and recharge from irrigation is important in the south coast area and to a lesser degree in the north west coast.

The largest ground water developments in Puerto Rico appear to be those found in the south coast, the Lajas, Guanajibo, and Mayaguez valleys, and the Arecibo-Bayamón and San Juan sections of the north coast. The total average pumpage of ground water on the Island has been estimated as at least 250 million gallons daily. Probably 200 to 250 million gallons per day are pumped from wells for irrigation, 15 to 20 million gallons for industrial purposes, and 7 to 8 million gallons for public supply. Several million gallons a day are also pumped for domestic and stock use in rural areas.

Small to moderate supplies of ground water for domestic used and small industries are also found in most parts of the Island. The only possible exceptions are the low rainfall areas of the southwest coast and those marshy areas where the ground water is salty.

Wide differences in the rates of ground water recharge and discharge accur on the Island, largely because of the great range in the amount and distribution of rainfall and the permeability of the soils and rocks. These variations may occur not only in different places but at different times in the same place.

One of the outstanding examples of artificial recharging in Puerto Rico is that which occurs from irrigation in the south coast. Similar recharge takes place in the Isabela Irrigation District, altho this is of lesser economic importance. Also of little economic importance is the reacharging that occurs as a result of the leakage in the Guajataca Reservoir.

Induced recharge is another practice of artificial recharge. An outstanding example is found in the south coast, where the water table has been drawn down by pumping from wells, so that some water from rainfall which formely ran off at the surface now enters the ground. Similarly, streams now lose more water to the ground during flood conditions than was lost when the water table was higher.

The principal use of ground water in Puerto Rico is for irrigation of sugarcane. Of approximately 950 wells, 300 are used for this purpose. Of these, 200 are located in the Patillas - Ponce section. It is estimated that the total pumpage of ground water for irrigation of sugarcane on the Island may exceed 250 million gallons a day. A relatively small number of wells, of rather small capacity, are used for irrigation of citrus fruits, pineapple, and miscellaneous fruits and vegetables, and for watering livestock.

The use of ground water for domestic supply depends chiefly on wells. These may be either drilled or dug. It is believed that a large proportion of the dug wells will yield contaminated water. Many drilled wells are also polluted. This is due largely to the location of the wells near buildings and other sources of pollution. Some wells have been dug principally for watering livestock. In some areas these yield water too salty for human consumption but tolerable for livestock.

Of the 76 municipalities on the Island, 17 were supplied from ground-water sources, and 8 received water from both surface and ground-water sources (U. S. G. S., records of 1964). There are also additional ground water systems in the suburds of the cities and in the rural areas. Most of these consist of a well and a storage tank to which the people come to obtain water; a few include distribution systems. Army and Navy installations also supply part of their needs from ground water sources. Sugar centrals such as Aguirre have installed wells for public supply in many of the surrounding settlements. Some hospitals, schools, resorts, etc., have provided their own wells.

The requirements of ground water for industrial purposes are certain to increase in future years. Thru to efforts of the

Economic Development Administration alone more than 600 new industries have been established during the past few years. In addition, sugarcane centrals, rum and alcohol distilleries, cement plants, paper, tile, and foot-wear factories require large quantities of ground water. Many of these plants obtain their water from wells. Most of the water required by sugarcane centrals is for general purposes, including domestic supply and washing. In addition some use is made for boiler feed, maceration of cane, and for cooling and condensing. Most of this water is needed only during the cane grinding season. It is estimated that as much as 25 million gallons of ground water are required each day during the grinding season, as compared with 2 to 3 million gallons daily during the remainder of the year. Industrial wells other than those of sugar centrals may produce as much as 4 to 5 million gallons of water daily.

To meet the increasing needs for water it will be necessary in many cases to top new sources of supply or extend existing sources. In many of the rural areas additional supplies of water may be developed thru the activities of the Soil Conservation Districts. This is already being done successfully in some communities. It has shown its possibilities in the wards of Maricao of Vega Alta and Pugnado of Vega Baja where the farmers have organized committees to raise funds and to allocate labor and responsabilities for carrying out their projects.

Under such an arrangement involving the Soil Conservation District, the communities may provide labor, casings, pipes, pumps, and other materials needed. Machinery and equipment for digging and drilling the wells may be obtained thru purchase, hire, loan, or grant. In this connection, it may be possible for such agencies as the Puerto Rican Department of Public Works or the Land Authority to make available to the Soil Conservation District, either on a rental or loan basis, any suitable machinery and equipment that may be temporarily idle. The Soil Conservation District would receive from the community in which the digging or drilling of the wells is done a small fee to pay for the cost of the fuel, maintenance, salary of the equipment operator, and a small amount to assist in paying for the costs of the equipment.

Public interest in ground water has increased greatly in recent years because of the rapidly increasing development and use of wells in many regions and the problems that have accompanied that development. The average citizen knows very little about ground water and even the hydrologist has less quantitative information than is available on other phases of the hydrologic cycle; this lack has been responsible for many controversies and difficulties in development of water resources.

Of the several phases of the hydrologic cycle, ground water thus is first in usable storage and is also of major interest, concern, and controversy among water users.

Approximately 1,075 mgd of fresh water was used in Puerto Rico for public supply, industry, irrigation, and power production during 1960 (U.S. Geological Survey, 1964). Of this quantity, 818 mgd was obtained from streams and 257 mgd was obtained from wells. Ground water is unimportant as a direct source for nonwithdrawal uses (hydroelectric power, waste disposal, recreation, and conservation of fish and wildlife), but it has considerable importance indirectly because the minimum flow of streams is sustained primarily by ground water. Also, the depletion of the ground water in some places has resulted in depletion of streamflow and thereby reduced the supply available for the nonwithdrawal uses.

The rural use of water, not including irrigation is an important item in the total amount of water consumption in Puerto Rico. Wells are widely distributed over the rural areas in many towns and cities of the Island, and they provide a sustantial bulk of the domestic and the stock-water requirements of farmers.

The public interest in ground water is paralleled by the interest in stream regulation and developments. This interest stems from the Island trend toward the increasing use of water for all purposes, a trend suggesting that in 25 years we shall be wanting twice as much water for industry, irrigation, and municipal use as we now use.

The selection of ground water as a supply, rather than the surface-water sources, has generally been on the basis of one or more of the following advantages:

1. Ground water may be reached within a few hundred feet of the place where it is to be used, and on the same property, whereas surface water may require pipelines and rights - of way over stretches of several miles.

2. Ground water may be available for use in areas where the water in streams has already been appropriated by other users.

3. Yield from wells and springs generally fluctuates less than streamflow in alternating wet and dry periods.

4. Ground water is more uniform in temperature and soluble mineral load than surface water, and is generally free of turbidity and bacterial pollution.

The development of water from surface sources has been a necessity in many places where ground water can be obtained only at excessive depth below the surface or where it cannot be obtained in sufficient quantity at any depth, where the ground water is deemed to be fully appropriated, or where it is of a quality that makes it unsuitable for the use intended. Even where good-quality ground water is available it may be at a disadvantage as an alternate to surface water in that its use generally requires expenditure of energy for pumping, whereas the surface water may produce energy besides supplying water for other uses.

The controversial features of ground water are numerous. Many disputes as to the effect of one well on another or on a spring have been decided in the courts. Many others have undoubtedly have avoided the courts only because of the high cost and the apparent hopelessness of obtaining proof in support of individual opinions. Many of the controversies reflect the general lack of understanding and uncertaintly in the public mind regarding ground water.

It can be said that controversies about ground water are a good omen. Altho they stem from incomplete knowledge of the resource, they show that we now have a little knowledge of it. And that is better for the Island's economy than our past failures to give any thought to ground-water aspects of water - development projects. We need to know much more, and we need especially the detailed knowledge of specific localities.

The ground water problems of one locality are rarely unique, for other localities have encountered similar problems and in many instances have found satisfactory solutions. Most of the problems of ground-water "shortage" are in areas where significant quantities of water are withdrawn from wells.

Ground-water storage has also been changed by other activities of Man, sometimes to his benefit, but more often to his disadvantage. Very commonly the changes have been unintentional and unforseen.

The difficulties created by pumping from wells are of several types. Some problems pertain to entire ground-water reservoirs, where the rate of replenishment is inadequate to meet the continuing demand. Pipeline problems (problems arising from inadequate capacity of ground-water reservoirs to transmit needed quantities of water to points of use) arise because of the inability of water to move rapidly enough thru earth materials to supply the demand of wells, even tho the ground-water reservoir as a whole may have an adequate supply of water. The third type occurs along watercourses, where an intimate relation exists between the water in the stream and that pumped from wells.

The serious problems of ground-water shortage occur in areas where water is pumped out faster than the entire ground-water reservoir is replenished. Under those conditions the reservoir is being emptied of water that may have taken decades or centuries to accumulate, and there is no possibility of a continuous perennial supply unless present conditions are changed. Even more serious is the condition where salty or otherwise unusable water flows into a ground-water reservoir as good water is pumped out, for those reservoirs may be ruined before they are emptied. Most of the excessively pumped reservoirs are in the arid regions, where precipitation is generally inadequate for the needs of man. Users of ground water generally are aware that they are using more than the perennial supply and that the supply will be exhausted unless action is taken. Corrective measures already applied in some areas include prevention of waste, a pro rata reduction of pumping from all wells, prohibitions of further development; reclaiming of used water, and artificial ground-water replenishment by surplus stream water.

Pumping from closely spaced wells has caused significant declines of water level in parts of the Island, chiefly in municipal or industrial areas that use large quantities of ground water. The water levels have reached approximate equilibrium in some of those areas, indicating that the pumped water is now being replaced by the water transmitted thru the ground-water deposit. In other areas the water levels are still declining each year. Concentrated draft has induced an inflow of ocean water or other unusable water to some wells.

The watercourse problems result from the pumping wells along rivers, where the ground water is so closely related to the water in the stream that pumping from wells depletes the streamflow. Diversions from the stream for various purposes may increase the amount of ground-water at one place and reduce it at another. The intimate relation between surface and ground water is also shown at some river where protection from floods requires not only protection from a rise in the river but also protection from the simultaneous rise of ground-water levels under the city.

Many activities unrelated to pumping of ground water have modified the storage of water below the land surface. Drainage projects and irrigation projects have proved that it is possible to manipulate the storage in ground-water reservoirs. Unfortunately ground-water storage has been increased by irrigation in some places until good agricultural lands have been water-logged and abandoned; and it has been decreased in other localities by drainage to the detriment of agricultural use of the land or municipal use of the water. Man has changed the quantity of water stored underground by his structures for storage of surface water or for protection against floods, and by providing cities with storm sewers. He has damaged some water supplies by discharging contaminated water into the ground or into streams from which it enters ground-water reservoirs, and also by puncturing protective layers, thus permitting entry of sea water or other mineralized water into ground-water reservoirs.

For the Island as a whole, the greatest change wrought by man has been the change from the original forest and grassland to cultivated or barren areas.

In the absence of actual records of ground-water levels in wells, there is a broad field for argument as to the effects of the changes in vegetative cover upon ground-water storage. It is certain, however, that where the earth materials were saturated to within a few feet of the surface, the cutting of deep gullies has lowered the water table as effectively as ditches have done for numerous drainage projects.

Summary of the Water Budget

From the principal parts of the water budget discussed in the preceding sections of this report, a budget is summarized as follows, using inches of water on the entire Island as the unit of measure:

	Input	Output
Rainfall	69 inches	
Water loss (evaporation)		42 inches
Stream runoff to the sea		23 "
Ground water discharge to the sea		4 "
Change in storage		0 "
Total	69 inches	69 inches

The water loss of 42 inches was obtained here by substraction. as the factor least liable to direct evaluation. It compares well with the independently arrived at figure of 45 inches presented in the section, "Evapotranspiration or Water Loss" of this report. It is suggested that 42 inches be used as the average annual water loss until better data become available.

The determination of the water budget for Puerto Rico as a whole is made difficult by the sparseness of information to date on the movement as losses of water in the north-coast limestone area and in the coastal plains around the Island. It is necessary to call the attention to the fact that the data summarized above are based in part on U.S. Geological Survey studies covering limited areas of the Island.

5. Water Use in Puerto Rico[1]

Water Rights and Concessions

Water is particularly subject to regulation because it is essential to human existence, because it is a changing resource that may bring good or evil to many people according to its use and management, and because some of it is subject to established public and private rights of use.

The more valuable water becomes, the more conflicts of interest arise over its use and management. The conflicts may lead to insecurity of investments and impeded or unbalanced economic growth if basic law is not provided to assure protection of rights and a fair apportionment of the supplies to satisfy the rights.

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[1] Data of this section are drawn from PRWRA and PRASA records, 1966 and 1967.

Water is a common denominator of human activity. To protect the interests of present and potential users of water, the Governments have to provide guides to encourage a fair division of the supply, the reduction of waste and damage, and the conservation of water.

All users of water depend in one way or another on the same sources of supply. Some users need surface or underground storage to help balance supply and demand-for hours, days, months, years. The supply in one area may be needed to balance the demand in another area. It is obvious, then, that cooperation among water users is an essential aspects of local development and use of water.

The practice of utilizing water from streams under government concessions in Puerto Rico dates back to Spanish Colonial Times. Until 1908 those franchises were obtained by grant as "Concessions" from the Spanish Crown. From then until 1917, they were obtained by application to the Public Service Commission. Such grants amount to a considerable proportion of the ordinary stream flow of most of the rivers in the south of the Island, and exceed the low flows of those rivers. Little official attention seems to have been given in the past to determine the actual quantities of water used, to the need for the water.

With concessions for the use of water now under the supervision of the Public Service Commission, all applications for permission to use water from streams are referred for approval to the Puerto Rico Water Resources Authority, the Aqueduct and Sewer Authority, and the Department of Health. The right granted is always a revocable permit, subject to cancellation at any time that a case of greater need for public use of the waters in question arises

Concessions for the use of waters granted by the Spanish Crown prior to the Treaty of Paris were recognized by Article VIII of this Treaty. These concessions were to be respected as vested rights, and unless their beneficiaries relinquished or surrendered them to the new government, these could not be impaired in any way. Further legislation and judicial interpretation reiterated this principle in authorizing the owner or owners of such water rights or concessions to negotiate with government officials.

The law relating to water rights in force in Puerto Rico dates back to June 13, 1879. This basic legislation was amended by Acts of March 12, 1903, and March 9, 1905. It is believed that in general, the law is adequate for regulating the use of surface waters, but difficulties arise out of the water rights themselves. In relation to ground water rights, the law recognizes some principles which are incompatible with ground water hydrology and with the fundamental of basin-wide management for optimum yield.

Irrigation

Rainfall is not always a reliable, and in places not a sufficient water supply for growing sugar cane and other crops. Altho the average rainfall is high in some sections of the Island, it is low in other sections. Also, rainfall occurs as short periods of high intensity, which, coupled with the steep topography and limited storage facilities, cause much of the water to be lost to the sea as runoff. To comensate for this deficiency in quantity and distribution, growers have sought additional sources of water to meet the high water demand of sugar cane and other crops particularly along the south coast.

Water systems for the irrigation of sugar cane have developed from simple diversions of streams in the days of Spanish rule, to extensive private and Government owned systems that provide water for much of the sugar cane grown on the Island. Simple systems still are used by some land owners, who may utilize remnants of Spanish structures. The more complex systems of larger land-owners include networks of canals and ditches that deliver water from privately-owned and Government-owned distribution systems. In some places, water is stored in small "charcos", or ponds, for later use.

There are three government irrigation districts in operation in Puerto Rico; the South Coast Irrigation District, the Isabela

Irrigation District in the northweastern corner of the Island, and the Lajas Valley Irrigation District. The systems are comprised of six major reservoirs, several smaller reservoirs and 623 kilometers of irrigation and drainage canals which provide water for irrigating about 46,000 acres. In addition, hydroelectric power plants provide flow in some rivers that is available for irrigation.

The average total amount of water utilized by the three districts is of the order of 330,000 acre-feet. Table 7 shows statistical data on the existing reservoirs the waters of which are utilized for irrigation. Most of the water for public irrigation systems is supplied by six main reservoirs as described below.

Table 7. Reservoirs Supplying Water for Irrigation, 1967

(Data furnished by PRWRA and PRASA)

Reservoir	Irrigation Only		Irrigation and Power	
	Storage Capacity Acre-feet	Average Annual Inflow Acre-feet	Storage Capacity Acre-feet	Average Annual Inflow Acre-feet
Patillas	14,500	60,700	-	-
Carite	-	-	11,300	30,000
Coamo (1)	-	23,300	-	-
Guayabal (2)	10,000	80,400	-	-
Southwestern P. R. Project (3)	-	-	38,350	120,000

Cont., Table 7

Reservoir	Irrigation Only		Irrigation and Power	
	Storage Capacity Acre-feet	Average Annual Inflow Acre-feet	Storage Capacity Acre-feet	Average Annual Inflow Acre-feet
Guajataca	-	-	32,600	70,000
Total	24,500	164,400	82,250	220,000

(1) Reservoir completely silted-in.
(2) Water from Matrullas and Guineo Reservoirs are discharged into Guayabal Reservoir by way of the Jacaguas River.
(3) This project comprises the reservoirs of Guayo, Yahuecas, Prieto, Luchetti and Loco.

Besides the Government owned irrigation districts, there are many farms that are irrigated by pumping underground water. Wells provide water for irrigation in areas where there are no available surface supplies or where the surface supplies become inadequate during dry periods. The wells, most of which are privately owned, are primarily on the south coast, altho a few are scattered on the north coast for intermittant irrigation during occasional dry periods. The annual use of water from wells for irrigation is estimated to be between 222,000 and 280,000 acre-feet.

The total known use of water for irrigation in Puerto Rico thus is in the order 580,000 acre-feet per year. Recently the use of overhead sprinklers has been adopted, and the flexibility of sprinklers may lead to the irrigation of land which previously was not practicable to irrigate. This coupled with the increasing appreciation of the value of supplemental irrigation for sugar and other crops will lead to an increased demand for water for irrigation in the Island. More water data will be needed for evaluation of present and future irrigation projects.

South Coast Irrigation District

A large proportion of the waters utilized by the South Coast and the Lajas Valley Irrigation Districts come from the northern part of the Island where they are stored and then conducted thru tunnels for use in the dry south plains. These waters are used for producing hydroelectric energy before being released for irrigation.

The development of irrigation in the southern coastal region of Puerto Rico goes back into many years of history. The scanty rainfall and rather frequent failure of the water supply prevailing in that area had long been an obstacle to agricultural development. The lay of the land and the character of the soil were found to be particularly suitable for growing sugarcane, but this plant could not develop without an adequate supply of water for its growth.

It was quite natural, then, that the practice of land irrigation in this part of the Island began with the early attempts to grow sugarcane. There were at first small isolated systems, some supplied by diverting by gravity the flow of streams and others by pumping from surface waters and from deep wells. By the middle of the last century water concessions for irrigation purposes began to be granted to landowners by the Crown of Spain, and in time there were many concessions.

These isolated systems, however, were inefficient since there were no impounding reservoirs, and when rainfall was deficient the water supply on which the systems depended soon became exhausted. Eventually, the idea of a general irrigation system for the area crystallized. This led to the enactment by the Legislative Assembly of Puerto Rico of the Public Irrigation Law, approved Sept. 18, 1908, which provided the initial authority for construction of a public irrigation system in the southern coastal region.

Engineering studies for the south coast project were begun in 1908, construction was started in 1910, and the system was completed in 1914. Thus, it already has been in successful operation many years.

Essentially the irrigation system of the South Coast Irrigation District is composed of four main storage reservoirs fed with the runoff from four different watersheds, about 98 miles of main canals and distribution laterals.

The system is formed by three separate systems of reservoirs and canals which receive their water supply from three different sources and which bear no physical relations among themselves. These are: The system which irrigates the lands situated between the Patillas and the Salinas Rivers and which consists of the Patilllas Reservoir and the Patillas Canal; the system formed by the Carite Reservoir and the Guamanſ Canal which irrigates the lands located above the Patillas Canal between Guayama and Salinas, and the system originally formed by the Toro Negro Diversion, Guayabal Reservoir, Coamo Reservoir, and the Juana Diaz Canal. This latter canal runs in an easterly direction from Juana Diaz toward Salinas and irrigates all the lands lying between the Jacaguas River and the Rio Jueyes near Salinas. The irrigation system of which it is a part was enlarged with the addition of the Guineo and the Matrullas Reservoirs in 1931, and 1934 respectively. Each of these three systems functions independently, that is, the irrigation waters, with the exception of the minor relation existing between the Guamanſ and the Melania Reservoir, do not meet at any place but flow thru separate canals located at different elevations and irrigate separate sections of the district.

The total acreage under irrigation in this south coast project amounts to apporiximately 53,630 acres, of which 35,130 acres receive water by gravity from the irrigation system and 18,500 are irrigated by pumps supplied from deep wells and operated with electricity served from the hydroelectric system. Of the 35,130 acres irrigated from the irrigation system, 14,160 acres receive water from the Patillas Canal. The Guamaní Canal serves 5,360 acres, and the Juana Díaz Canal takes care of 15,610 acres.

The amount of irrigation water fixed by the Public irrigation Law as appurtenant to the land is four acre-feet per acre per year, which is equivalent approximately to an application of four inches of water each month to the land under irrigation. This is the amount that was estimated as necessary to supply the deficiency in the rainfall.

The irrigation system has been delivering water at this rate of four acre-feet per year to each acre of land uniformly throughout the year. The methods and the sequence followed in the cultivation of sugar-cane in this district requires that irrigation be practiced continuously the year round and not only during a given season as it happens in some countries. Accordingly the project was planned and carried out subject to the requirement that it would have to function continuously and uniformly, and the method followed in its operation correspond with that requirement. Water flows thru the main canals continuously day and night and deliveries to the planters are also continuous during the time required to deliver to them all their appurtenant water for the month.

To enable the planters to use the water to best advantage it is the practice authorized by the Public Irrigation Law to allow each planter to group and use all the water he is entitled to, as appurtenant to all the land under his control under each of the three systems of canals, and to deliver this water in the amounts and thru the outlets as requested. This method of delivery, authorized by the Public Irrigation Law, permits the water to be applied to the fields economically. The planters are able to keep their labor costs down and also get the greatest benefit out of the water since they can apply it by rotation to their various tracts of land, using the water in quantities and in the number of times during the month best suited to their needs.

The Irrigation Service measures and deliveries the water to the planters thru outlets which have been conveniently located to irrigate by gravity all of the land served by those outlets. Each outlet consists of a gate and an orifice plate arranged as to space and elevation so as to secure an accurate measure and an uninterrupted flow of water into the field ditches prepared by the planters. The quantity of water delivered each month is one-twelfth of the amount appurtenant for the year. When owing to shortage in the water supply it becomes impracticable to deliver the full amount appurtenant for the month, then the planters are allowed a time extension of eleven months within which the shortage will be delivered to them, provided the supply becoming available is sufficient to cover first the regular monthly deliveries and then the shortgage.

In the case of lands which are receiving water from the Irrigation System under unrelinquished water concessions which were granted prior to the establishment of the Irrigation System, water deliveries are also made continuously even tho there may be a shortage in the reservoirs. In other words, deliveries to such concession lands are not subject to a reduction proportionate to the supply available as is the case with deliveries to other lands included in the Irrigation District when there is a shortage in the water supply.

When the supply available in storage is larger than that required to make full deliveries to the lands included in the Irrigation District, then this surplus water is sold to the planters who request it at a price which is fixed for each fiscal year at an amount approximately equal but never less than one-fourth of the water tax for the year.

The quantity of four acre-feet per year has proved sufficient for a good part of the land included in the Irrigation District but for porous sandy soils which abound in this zone, it falls short of meeting the irrigation requirement. To supply the deficiency the farmers avail themselves of underground water which they bring to the surface by means of tubular wells and pumps, this source of supply being constantly replenished by the same irrigation water supplied by the gravity system which is applied to the surface, a great part of which percolates into the lower strata.

There is a larger number of pumping installations scattered over this area and, with rare exceptions, they are all driven by electric motors. For this purpose electric power service is provided by the Hydroelectric System which came into existence as a by-product of the Irrigation System which has progressively developed to supply this need.

Considering the widespread use of pumps to make available the quantity of water in the irrigation of those lands which require more water than the gravity system can supply, as well as for increasing the area under cultivation, the South Coast Irrigation System may well be classified as a combined gravity and pumping system. The Puerto Rican Government has centered its activities on building of the gravity system and supplying at low rates the electric power required to operate the pumps, but it has left to private initiative the exploration of the underground water supply as well as the investment of capital required for the pumping installations.

The most serious problem, however, with which the South Coast Irrigation District confronts and which affects the economy of that region, is that of sedimentation of the supply lakes of Guayabal and Coamo. The Guayabal Lake had at is origin a reservoir capacity of 9,800 acre-feet and the Coamo Lake a capacity of 2,800 acre-feet. They both supply the distribution system of the Juana Díaz canal for the irrigation of 14,000 acre-feet. The auxilliary Coamo Lake has been losing capacity in such a way that, at present, the waters of the Coamo River which could be utilized are those of low water, so these are not disposed for reservoir. The Guayabal Lake began showing sings of sedimentation in 1919, when it was found necessary to empty the lake to get rid of the accumulated mud behind the portal of the water passageway. From that date on recurrent measures have had to be taken to avoid the interruption of water delivery due to the mud accumulation. The corrective measures which have been taken at the Guayabal Dam in different ocassions include:

1. The installation of a new tubing system to permit the diversion of water to a higher level to that of the accumulated mud behind the dam.
2. Dredging the lake between 1940 and 1947. The total mud removed amounted to about 500 acre-feet, equivalent to 800,000 cubic yards.
3. Enlargement of the dam in 1950 at a cost of $2,000,000 raising the crest sixteen feet to restore the dam to its original capacity of 9,800 acre-feet.

The problem of sedimentation of the Guayabal Lake consist in an annual entry into the lake of 160 acre-feet of mud. The accumulation up to date in the dam, reaches 7400 acre-feet or 12,000,000 cubic yards. If this volume of mud were extended uniformly over a farm of 1,000 acres, it would cover the land with a layer of mud 7.5 feet thick. Its removal constitutes a difficult problem.

Thirteen years have passed since the enlargement of the Guayabal Lake and during this time, 2,100 acre-feet of mud have accumulated in the dam. This means that, the available reservoir has been reduced to 7,700 acre-feet. The Water Resources Authority, together with technicians of the Bureau of Reclamation of the U.S. Department of the Interior, have been trying to find a solution to this difficult problems. Among the alternatives is the coastly and almost prohibitive operation of dredging the mud from the lake. This operation would also be of an almost continuous nature, since it would take between 30 to 40 years to be accomplished. The possibility of building a new dam up-river from the Guayabal Dam on the Toa Vaca River will be studied, and also that of obtaining new sources of water from the sub-soil to substitute the waters lost by the reduction in capacity of the dam. None of these measures would solve the problem of sedimentation of the Guayabal and Coamo Lakes. These would serve to prolong the life of the irrigation water supply system, but at the end we would be confronting with the reduction of agricultural productivity of the region, for lack of water.

The Engineers of the Bureau of Reclamation of the U.S. Department of the Interior, in their preliminary report, show that none of these mentioned measures should be taken unless they are accompanied by an immediate and intensive program of soil conservation of the Guayabal and Coamo basins.

Isabela Irrigation Service

The Isabela Irrigation Service was originally established to supply water for irrigating a projected area of 18,000 acres of land distributed among the municipalities of Isabela, Aguadilla, and Moca.

Water for irrigation is obtained from the Guajataca River, which is impounded in the Guajataca Reservoir. The capacity of the reservoir is 32,600 acre-feet. The annual runoff of the river ranges from 53,000 to 70,000 acre-feet. The diversion canal follows along the canyon of the river from its heading at the reservoir for a distance of 3.1 miles and then northwest for 1.2 miles to the irrigable lands.

This service was started about 1928, and after many modifications and revisions of the irrigation district, the area under irrigation has been reduced until now it is down to about 7,491 acres from the original 18,000 acres. The reservoir is being solely operated to cover the demands of Isabela Irrigation District, since the PRWRA, during the month of December 1965 ordered the close of the hydroelectric plant at Isabela, and since then have remained closed.

A significant feature of the agricultural lands in the Isabela is the larger number of small farms. Table 8 below indicates the way in which the lands actually under irrigation are divided:

Table 8. Significant Features of the Agricultural Lands in the Isabela Area

(Data furnished by the Isabela Irrigation Service, 1968)

	Number of Farms	Total Area Acres
Less than 10.00	657	2,189
From 10.01 to 20.00	85	1,126
From 20.01 to 30.00	30	754
From 30.01 to 50.00	15	584
From 50.01 to 100.00	7	427
Larger than 100.00	13	2,411
Total	807	7,491

At the present time the District is composed of 807 farms with a total area of 7,491 acres under irrigation. It should be noted that there are 657 farms with an area of less than 10 acres, which make a total of 2,189 acres. This situation has created serious problems in the irrigation service and for the agricultural development of the region.

The agricultural lands in the Isabela area are largely devoted to the cultivation of sugar cane which utilizes 6,415 acres. The area devoted to the cultivation of other crops amounts to 1,076 acres. According to the yearly crop census made by the personnel of the Isabela service in 1968, only 4890 acres are actually irrigated. Most of irrigation water is applied to sugarcane, and very few farmers use irrigation for any other crops in the area. On June 30, 1938 a Permanent District of irrigation was established with a total capacity of 9,694 acres. Later as a result of the construction of Ramey Base and the José de Jesús Esteves housing project, of the Housing Authority, this capacity was reduced to 8,815 acres by the Irrigation Commission by virtue of Law No. 201, which was approved May 11, 1942.

The failure of farmers to make full use of the irrigation system apparently stems from a lack of interest than from the cost of the water that would be used. Irrigation assessments are at the rate of $1.00 per acre per year without allotment for the first acres included. For all acres in excess of the first 10 included, the rate is $4.00 per acre per year, which includes $1.00 as a charge for readiness to serve and $3.00 as the value of 1.5

acre-feet allotments per year. Water may be sold to proprietors who have paid their assessment at the rate of $2.00 per acre-foot included, and at $2.50 per acre-foot to those who owe for two or less than 6-months periods.

Water is also supplied by the Isabela Irrigation Service to the aqueduct and sewage system to Aguadilla, Isabela, Moca, Aguada, Quebradillas and Ramey Air Force Base. The water served annually for these purposes totals approximately 8,700 acre-feet (1966-67).

Financing the operation of the Isabela Irrigation Service has been a continuing problem from the start. The system was established at a cost of more than $4,000,000 to irrigate the projected area of 18,000 acres. But since the area included in the permanent system has been reduced to about 7,491 acres, with only 4890 acres actually irrigated by farmers, the cost factor became an obvious burden.

After several years of operation, it was found necessary to find sufficient sources of a revenue thru the sales of water, water taxes, contributions from the PRWRA and the retention of 5% of electric revenues. Every year it is requested from the P. R. Government additional amounts to be retained from the 5% electric revenues to balance the budget of the Irrigation Service. But the course chose does not favor interest in expanding or trying to foster the efficient use of a maximum quantity of water for irrigation.

For several years most of the landowners in the Irrigation District have been heavily in debt, as a result of unpaid water taxes and yearly increases in rates of taxation. The P. R. Legislature, however, has passed numerous laws cancelling these debts and reducing to a minimum the irrigation taxes as well as the payment for water served. Even with these reductions no marked increase has taken place in the use of irrigation by individual farmers.

In the Isabela Irrigation District there is an average rainfall of 61 inches, which is in marked contrast to 40 inches in the South Coast Irrigation District, and 30 inches in the Irrigation District of the Lajas Valley. This, in part, explains the low consumption of water per acre, which a recent study revealed to be 0.7 acre-foot per acre.

One is struck with the problem of the land holdings. Notice the great number of small farms, (Table 7), which constitutes a serious problem for the efficient operation of an irrigation service, and, to our judgement, a challenge to the agricultural technicians to achieve an adequate development of this region.

The years of operation of this District by the Puerto Rico Water Resources Authority, served the administrative personnel to think about the various land problems. The Authority, in its earnest desire to improve the water service to landowners, asked to help and cooperation of the P. R. Department of Agriculture. Estudies were conducted under the Department to determine the reasons for the low use of irrigation water and to evaluate the agricultural situation of the District. The study carried out by the office of the Development Program of the Lajas Valley, showed the necessity of establishing a more intimate contact with all the District landowners and to deepen in all of the phases of the District problems, not only in the agricultural aspect, but also in the irrigation system proper. To carry out this work, the P. R. Department of Agriculture established an office of Agricultural development in the Irrigation District of Isabela, similar to the one existing in the Lajas Valley. This office has been in operation since June 1961 and has the decided cooperation of all agricultural agencies and of the Water Resources Authority.

The agricultural development plan established in Isabela by the P. R. Department of Agriculture is guided toward the way by which the lands of the region could be developed, including those under the Irrigation District. Such plan will consider all the measures that would tend to improve and enrich the farm production which at the final account, will be the criteria by which the relative success of this program will be measured. The P. R. Department of Agriculture is carrying out studies and activities related to diversified farming, agricultural experimentation, the development of new farm industries, marketing, irrigation, and other phases of agricultural development.

Southwestern

Puerto Rico Project

For many years water power and irrigation engineers had been aware of the power and irrigation potentialities of the valuable water resources of western and southwestern Puerto Rico. The problem of irrigation for the Lajas Valley had confronted the farmers and engineers for perhaps 100 years.

The first positive approach was made in 1908 by a cooperative enterprise formed by landowners in the Lajas Valley to investigate the possibility of irrigating a portion of the valley area by gravity flow. The project was not considered to be economically feasible.

The Insular Department of the Interior was authorized by Act No. 72, of April 13, 1916 of the Legislature of Puerto Rico to make investigations of the Lajas Project. No data are available on the estimated cost of the plan involved but can be assumed that the project was not economically practical since it was never built.

Then, in 1917, irrigation possibilities were again studied by the Irrigation Service of Puerto Rico but nothing came out of these studies. It is probable that the lack of data on the amount of water available from the streams was an important factor in discouraging further study. The report, however, appears to have aided in stimulating a continued interest in the possibilities of irrigation in the Lajas Valley.

In 1934-35 the utilization of the Water Resources, predecessor of the Water Resources Authority, developed studies relating to power production and irrigation possibilities in this area. These early studies involved the hydrology of the region principally, but some preliminary surveys were included on the feasibility of irrigating the Lajas Valley.

As a result of a survey by Government Committee in 1945, the PRWRA was invested with power to build a combined project in the Southwestern part of Puerto Rico which would include the construction of an irrigation system at the Lajas Valley, development of potable water supply and electric power generation. Construction work started in 1948. The project comprises a network of 60 miles of main irrigation canals and 60 miles of drainage canals which will serve a net irregable area of about 23,000 acres of land planted with sugar cane and other various agricultural crops. It also includes two hydroelectric plants with a combined capacity of 28,000 kilowatts.

The irrigation system is supplied by the Guayo, Yahuecas, Toro and Prieto Rivers on the north side of the insular divide and from the Yauco and Loco rivers on the south side. The waters from north of the divide will be diverted thru about 46,660 feet of tunnels to the south, to develop electric power at Yauco Power Plants No. 1 and 2, before discharging into the Loco reservoir.

The headworks of the irrigation system are located at the Loco Dam, a concrete gravity-type dam about 600 feet long and 72 feet high on the Loco River, 2.4 miles west of the town of Yauco. The Loco reservoir with a capacity of 1950 acre-feet controls a drainage area of 8.4 square miles besides the water discharged from the tailrace of Yauco Power Plant No. 2. The outled works consist of seven-foot diameter conduit thru the dam, and a stilling basin controlled by an automatic self-centering disk valve, which maintains a constant level in the stilling basin. From the stilling basin the water is conducted to the main canal of the irrigation system by means of a seven-foot diameter closed conduit, an open canal, and a tunnel (Susua Tunnel) 1722 feet long.

The main canal is 21.5 miles long and runs along the base of the hills which form the northern boundary of the Lajas Valley. The point beginning at the east end is at elevation of 200 feet which is sufficiently high to serve by gravity all good arable lands in the valley, and extends to the western end of the valley toward Boquerón.

The distribution system consist of primary lateral heading at the main canal and discharging into secondary laterals. Most of the primary laterals are lined, and the secondary laterals consist largely of open and unlined ditches. A large lateral canal which runs in a north-west direction across the valley and along a divide near the center of the valley, feed a secondary main canal running west-east along the southern boundary of the valley. The original plans contemplated the construction of separate pumping systems for lands on the south coastal slopes.

It is expected, that the irrigation return water in the valley drainage system will be sufficient to permit the installation of pumping stations to raise it to the higher canal system required.

It is estimated that approximately 3,100 acres of arable lands may be irrigated by pumping. The construction of these pumping systems will be differed until actual operation of the main irrigation system indicates the availability of abundant return water. Further studies are being conducted to determine the economic feasibility of these pumping systems.

The total cost to branch the irrigation and drainage service amounted to $9,960,000 on June 30, 1963. This sum includes the cost of the establishment and organization of the Irrigation District. In addition, construction will continue on the required drainage and irrigation projects.

The irrigation system started to function partially with the first deliveries of water on August 12, 1955. Year after year a larger number of farm have been receiving the benefits from the irrigation system, creating a notable improvement in the economy of the region. On August 31, 1967, 259 farmers made use of the waters for irrigation with a total area of 19,975.50 acres. Of this total, 238 farms, representing a total area of 18,947.70 acres, were allowed to use 3 acre-feet of water per acre, to be apportioned during the 12 months of the year. The average water consumption is 1.85 acre-feet per acre per year. This low consumption of water for irrigation is an acute administrative problem for the proper operation of the Irrigation District. Since the sales of water do not provide enough income to cover the costs of operation the Commonwealth Government, since 1959, has been contributing with enough funds to balance the budget of operation as indicated in the following table:

Fiscal Year		Government Contributions
1959-60		$92,398.00
1960-61		49,578.00
1961-62		85,750.00
1962-63		48,532.00
1963-64		112,024.00
1964-65		183,800.00
1965-66		134,600.00
1966-67		159,300.00
	Total	$865,982.00

With the establishment of the Permanent Irrigation District in 1971, the water users will be required to pay construction, operation, and maintenance taxes on an average amount of $23.36 per acre per year. And these taxes are going to be increased with the increasing costs of operation and maintenance.

It is obvious, therefore, that the productive capacity of these lands in the Lajas Valley will never be able to pay such high costs. This means that farmers will be required to make the best and most efficient use of water for irrigation.

Water Use for Public Supply

During the year 1966-67 the Puerto Rico Aqueduct and Sewer Authority supplied 61.9 billion gallons of water for an average daily production of 169.8 million gallons. This amount exceeded that of the previous year by over 5.3 billion gallons, or 9.4 percent. It is interesting to note that daily water production for the year 1962-63 was only 117.3 million gallons for an increase of 45 percent in five years.

As usual, 56 percent of that water was produced by the San Juan Metropolitan Water System which supplies the capital city and six neighboring towns together with is sprawling suburbs and industrial parks. The daily average consumption for the Metropolitan system was 90.55 million gallons, the peak demand occured on June 21 when 103.41 million gallons were used.

Of the total water supplied, 85 percent received complete treatment in 45 filtration plants, four of which were expanded this year, and 12 percent came from deep wells, which required only a slight chlorine application. The remaining 3 percent, which received partial treatment, was supplied to the off-shore islet of Culebra and 91 independent small rural water systems.

All the water supplied by the Puerto Rico Aqueduct and Sewer Authority (PRASA), both in urban and rural regions, meets the rigid standards for drinking water of the U.S. Public Health Service.

At the end of 1967, all but two of the 76 towns were benefiting from flouridation program of the 61.9 billion gallons of water produced, 56.9 billion, 92 percent of total production, was fluoridated. Because the use of fluorides is a health program extraneous to water purification, the Government of Puerto Rico pays the Authority for its cost.

A tabulation of all water supplied by type of treatment received follows:

(Data furnished by PRASA)

Treatment	Number of Installations	Million Gallons (MG)	Daily Average (MG)
(a) Urban Systems			
Totally Treated	44	52,685	144.342
Partially Treated	2	808	2.214
Deep Wells (chlorinated)	97	5,913	16.200
(b) Rural System			
Totally Treated	1	30	.082
Partially Treated	90	880	2.414
Deep Wells (chlorinated)	64	1,662	4.556
Total	298	61,978	169.808

At the end of the fiscal year 1966-67 all our cities and towns, with the exception of the offshore islet of Culebra, had sewage disposal facilities. Twenty five towns were served by secondary and more by primary treatment plants; nineteen towns had Imhoff tanks; fourteen used septic tanks and the remaining eight towns discharged their wastes into the ocean. Al nineteen Imhoff and fourteen septic tanks will eventually be replaced with sewage treatments plants, preferably of the secondary type.

In addition, there are 21 secondary treatment plants which serve suburban developments, industrial parks and low-costs hausing projects.

As of June 30, 1967 water customers numbered 431,078, an increase of 24,970 over 1966, equivalent to 5.8 percent. The accelerated growth in the number of water customers may be better appreciated by at the following table.

Table 9. Number of Water Customers by Year

(Data furnished by PRASA)

June 30	Water Customers	Increase
1946	77,220	-----
1950	117,455	40,235
1954	161,529	44,074
1958	220,030	58,501
1962	300,482	80,452
1966	406,108	105,626
1967	431,078	24,970

The slight reduction of customer's growth in 1967 is no surprise in view of the slowdown in construction caused by the "tight money" situation which prevailed during most of 1966.

The temporary reduction in the rate of growth was more than offset by water sales. Revenues billed for water service amounted to $17,361,592, and increase of $1,598,545 over 1966, or 10 percent.

The classification of water customers and revenue received therefrom is presented in the following table:

Table 10. Breakdown of Water Customers and Revenue Received Therefrom

(Data furnished by PRASA)

Classification	1966 Number of Customers	1966 Revenue	1967 Number of Customers	1967 Revenue
Residential	367,503	$10,417,659	390,909	$11,605,792
Commercial	32,159	3,778,175	33,811	4,091,782
Industrial	1,962	1,058,121	2,041	1,153,767
Public Fountains	4,484	401,945	4,317	392,846
Temporary Service	-----	107,147	----	117,405
Totals	406,108	$15,763,047	431,078	$17,361,592

There was a moderate increase over 1966 in water use per customer as shown below:

(Data furnished by PRASA)

Class of Customer	Annual Income per Customer 1966	Annual Income per Customer 1967	Percent Increase
Residential	$ 29.64	$ 30.60	4.29
Commercial	120.50	124.05	2.94
Industrial	550.24	576.59	4.78

There is only one rate which applies to all customers. Since the price per cubic meter, equivalent to 264.2 gallons or 35.31 cubic feet, starts at 13.1 cents and is gradually reduced down to 4.4 cents, large users of water get a reasonable reduction in price shown in the following figures for the year 1966:

Classification	Water Sold In Million Cubic Meters	Average Price per Cubic Meter	Annual Income per Customer
Residential	87.71	0.1259	29.34
Commercial	140.22	.0939	120.50
Industrial	15.17	.0697	550.24

Public fountains, which has been growing in number year after year, decreased by 167. This is a loss that we should not regret. These fountains are installed for use by poorer families or by those who live far removed from water distribution mains. The Puerto Rican Government pays the Puerto Rico Aqueduct and Sewer Authority $90.00 per year for each public fountain in use. As family incomes go up and as water pipes reach farther and farther, more people in that group become regular customers and some of these public fountains are eliminated.

Water was metered in 1967 to 95 per cent of customers. The remaining 5 percent consisted mainly of residential customers living in slum areas and the public fountain installations.

There were obtained 17,622 new sewer customers during 1967 for a year end total of 216,072. For the first time in the Authority's history, more than half of its water customers are also sewer customers. The classification of the sewer customers and the revenue derived from them is shown below:

Classification	1966		1967	
	Number of Customers	Revenue	Number of Customers	Revenue
Residential	178,002	$1,964,281	194,080	$2,264,371
Commercial	19,450	789,552	20,878	875,990
Industrial	998	133,221	1,114	137,401
Temporary Service	------	7,000	------	6,156

The sewer revenue shown above surpassed that of last year (1966) by $389,864, or 12 percent. The sewer service charge is one-third of the charge for water and is collected in the same bill.

The rural water works program, which as shown below, is mostly financed with government appropriations, carried pure water to 129 rural areas which had been lacking such essential service and improved the facilities in 20 existing water systems. As of June 30, 1967 more than 178,000 families of the rural areas had potable water available either within their own homes or from a nearby public fountain.

To avoid the possibility that these rural projects, some of which are uneconomical, may become a drain on the Authority's resources, the Puerto Rican Government reimburses the Authority for their operation and maintenance cost.

As of June 30, 1967, over $48 million had been invested in this rural water program. Funds have come from the following sources:

Government Appropriations	$40,468,506
Authority's funds and Municipal Contributions	5,826,267
Federal grants-in-aid	1,106,873
Other Government Agencies	108,700
	$48,113,946

Water Use for Electric Power

The hydroelectric power potential of the Island has been estimated to be of the order of 700 million kilowatt-hours (Kwh) per year. However, the economically feasible potential has proven to be substantially smaller.

As of June 30, 1967, 104,840 Kw of dependable capacity have been installed in 15 hydroelectric stations, ranging from 640 to 20,000 Kw in capacity.

Table 11 below shows statitistical data on these stations including the estimated yearly inflows:

Table 11. Hydroelectric Plants, June 30, 1967

(Data furnished PRWRA)

Plant	Installed Capacity Kw	Reservoir Capacity Acre-feet	Water Discharged Acre-feet
Comerío No. 1, and 2	4,800	600	90,000
Carite No. 1, 2 and 3	4,640	11,300	17,000
Toro Negro No. 1 and 2	10,560	4,860	21,000
Garzas No. 1 and 2	12,240	4,700	19,000
Dos Bocas	18,000	32,000	250,000
Caonillas No. 1	17,600	49,000	-------
Caonillas No. 2	4,000	1,442	-------
Yauco No. 1	20,000	19,000	-------
Yauco No. 2	8,000	16,500	100,000
Río Blanco	5,000	8	21,500
Total	104,840	172,000	573,500

Discharges shown correspond to inflows less spillings.
Discharge of Dos Bocas includes the Waters of Caonillas No. 1 and 2.
Discharge of Yauco No. 2 includes the waters of Yauco No. 1.

The table indicates that a total of 573,500 acre-feet of water per year is discharged at the tailrace of the hydro plants. Of this total, 193,000 acre-feet are delivered to the irrigation districts, 11,000 acre-feet are utilized for water supply, and 369,500 acre-feet are discharged into streams that empty into the sea. This figure does not include water that was used more than one time for power generation, but does include water that was used afterwards for public supply and irrigation.

Ten systems that include reservoirs, tunnels, and penstocks provide water to these plants. In some parts of the systems, water from several reservoirs is combined before delivery to a plant and in some parts on the system, the same water is used, thru penstocks, to provide energy for more than one plant. Tunnels drilled thru mountains transport water from one area to another; from where it is to where it is needed.

Further development of water for hydroelectric power systems alone is not feasible. Increases in population and industrial development, however, have lead to the development of multipurpose systems that provide water for public supply and industry as well as for electric power.

The excessive cost of development of additional hydroelectric power has occasioned a shift from hydroelectric power to steam-electric generation during the last years, and the tremendous increase in the supply of electric energy to cope with rapidly increasing industrialization of the Island will have to depend on thermal generation for years to come.

As part of the integrated system, 6 steam plants are operated by PRWRA in different parts of the Island. Two of these are in the San Juan Area, one is located near Peñuelas on the south coast, two in the Mayaguez area on the west coast, and one is located in Vieques.

Water Used by Industry

An average of about 164 mgd of fresh water was used by industries in Puerto Rico during 1960 (U.S. Geological Survey, 1964). Of this quantity, about 120 mgd (Million gallon daily) was obtained from the ground. Eight mgd was treated water supplied by the Puerto Rico aqueduct and Sewer Authority from both ground and surface sources. Over 700 factories and industrial concerns were using water during 1960. Most of the industries have been established since the initiation of the Commonwealth's "Operation Bootstrap" in 1947. The majority of these are light industries for producing wearing apparel from cloth and leather and for assembling electronic equipment and similar products from component parts.

The emphasis during the past few years, however, has been to encourage the establishment and development of larger industries that will produce finished products from raw materials. The only industries of this type that existed earlier were sugar centrals (milla) that produced sugar from raw cane, distilleries that produced rum from sugar and cement manufacturing.

The establishment of petroleum, chemical, and paper industries in recent years, and the plans to establish other heavy industries in the near future, have created demands for new, larger water supplies of good quality in desirable locations. In the early phase of the industrial development of Puerto Rico, obtaining water supplies for industries was not a great problem. The small industries established during this period were small users of water and, for the most part, were adequately provided for by an improved public supply system. The existing and proposed large industries require greater amounts of water than can be provided by such facilities. The need to meet the requirements of these water users has been a major stimulus for evaluating the water resources of Puerto Rico.

The sugar industries still is by far the largest user of water for industrial purposes in Puerto Rico (U.S.G.S., 1964). During the "Zafra" or cane-cutting season from December thru May, about 295 mgd of water is used to wash cane and to process it into raw and refined sugar. This use amounts to 95 percent of the water used by all industries during this period (USGS, 1964). During the alternate season of June thru November, the sugar centrals are idle and they use no water for industrial purposes.

Weather may at times cause delays in starting and ending the cane-cutting season, but generally the season lasts six months. As the zafra occurs during the direct part of the year, the demand for water is greatest when streamflow is least and water tables are lowest. Drouth conditions have a serious impact on the efficient operation of the sugar centrals by decreasing the amount of water available for cooling and production may be decreased.

Altho the demand for water by the sugar industry is far greater than the combined demand for all other industries, the consumptive use by many centrals probably is relatively small. Most centrals discharge used, and some reused water into streams where it is available for down-stream needs. Other industries, in the metropolitan and coastal areas, discharge wastes into sewers or directly into the Caribbean Sea or Atlantic Ocean where it is lost as a fresh-water supply. In essence, this water is consumed.

Of the 16 mgd of water used by industries other than the sugar industry, about 7 mgd is used by chemical, petroleum, and cement factories. The remainder is used by manufacturers of clothing, food products, and assembly of electrical and electronic parts. Most of this water is provided by the Puerto Rico Aqueduct and Sewer Authority.

As industrial production and urban population grow, we can expect that our industries will intensify their efforts to economize in the use of water.

A survey by the National Association of manufacturers in 1964 has proposed 16 steps whereby an industry can reduce its water intake:

1. Install meters on all types of use.
2. Reduce pressure in the piping systems to the lowest practicable level.
3. Place thermostatic controls on cooling systems.
4. Use authomatic valves on controls.
5. Check all sanitary fixtures for waste.
6. Keep equipment clean.
7. Insulate hot and cooled water service pipes.
8. Make surveys of leaks frequently.
9. Use separate pipelines for various "grades" of water.
10. Recirculate cooling water as many times as possible.
11. Reuse water wherever conditions permit.
12. Adjust all processes to require less water.
13. Treat waste condensate for reuse.
14. Recondition waste and wash waters.
15. Look for substitutes for water, such as air for aspirating or siphoning.
16. Appoint a water-control Engineer to keep the waste-saving program in operation.

Just as cities face the problem of eliminating waste of water from their mains and waste of water by consumers, thru complete metering, so industry faces the need to conserve water by every possible method.

6. How Much and What Kind of Water is Available

The crux of any study on management and control of water is how much water is available for use and what is it like. The quantity of water in Puerto Rico can be stated approximately and in not much detail, because data are not yet available to define the quantity with any degree of precision.

Quantity of Water Available

It has been shown in the section "Summary of the Water Budget" that about 42 inches, or 61 percent, of the 69 inches of rainfall is lost by evapotranspiration. Altho much of the evapotranspiration really is water used in the growing crops and natural vegetation, "lost" indicates that this part of water budget essentially is uncontrollable. Reduction of evaporation from reservoirs by artificial means may be worth trying in the future, but the total gain will be relatively small because the total surface area of the reservoirs in Puerto Rico is small. Likewise, the destruction of water-wasting vegetation may have limited application.

The 23 inches of stream runoff and 4 inches of ground-water discharge constitute the water that is subject to control and use, in part. Flood runoff may be in the magnitude of 5 inches, and possibly up to 3 inches of this loss to the sea can be retained in reservoirs, but 2 inches will be lost. Perhaps 2 inches of the ground water lost to the sea can be intercepted by drilling wells near the coast, but the other 2 inches probably is not controllable. We are left then with about 23 inches (23 / 4-2-2 = 23) of the rainfall to work with, which is equivalent to 4,100,000 acre-feet per year (5,700 cubic feet per second (cfs), or 3,700 mgd). This can be called the controllable supply (U.S.G.S., 1964).

According to U.S. Geological Survey records for 1964, the total water use in Puerto Rico was in the magnitude of 1,075 mgd (1,660 cfs), which is equivalent to 1,200,000 acre-feet per year. The water was obtained from both surface-water and ground-water sources for public supply, for industry, for irrigation, and for hydroelectric power. Some of the water was used twice for these purposes, even three or more times.

Using the U.S.G.S. figures for 1964, the use of water in Puerto Rico can be summarized best in a table:

Source and Kind of Use	Use Acre - Feet Consumptive	Use Acre - Feet Non-Consumptive	Total
Ground Water:			
Public supply	11,000		
Industry-sugar centrals	20,000	11,000	
-other	11,000		
Irrigation (1)	235,000		
Total ground water			288,000

Surface Water:			
Public supply	99,000		
Industry-sugar centrals		134,000	
-other	8,000		
Irrigation-Government systems (1)	57,000		
-private systems (1)	139,000		
Hydroelectric power		479,000	
Total surface water			916,000
Total use	580,000	624,000	1,204,000
Total use, percent	48	52	100

(1) Possible excess irrigation disregarded.

The consumptive use of water in 1964 thus was only 14 percent of the estimated average controllable supply of 4,100,000 acre-feet. This does not imply, however, that all of the used non-consumptively can be salvaged for reuse.

Most of the water use for public supply and for irrigation can be considered consumptive use; that is, it is lost to further use by evapotranspiration or by being released near the coast in sewage lines or discharge lines from industrial plants. Most of the water used by industry is non-consumptive because the sugar centrals constitute by far the largest industrial use; the centrals take water directly from the streams, mostly in the lower reaches, and return it immediately. Similarly, much of the ground water used by the centrals is discharged into surface channels. Water use for hydroelectric power also is non-consumptive use; its natural movement usually has been slowed, perhaps its route of travel has been changed, but the water essentially is unchanged in quantity and quality. More particularly, the water used for hydroelectric power generally is available also for other kinds of use. This availability is recognized, of course, in multi-purpose development.

Of the 916,000 acre-feet of surface water used, about 643,000 acre-feet was stored in and passed thru the major reservoirs of the Island (See Table 6 in section "Storage" for description of major reservoirs of Puerto Rico). This compares with the total storage capacity of 225,000 acre-feet. But only 164,000 acre-feet of the water used from the reservoirs was used consumptively in planned projects. Some of the remainder, used by hydroelectric power only, was available for other use.

An examination of the development of surface water in Puerto Rico shows that the streamflow from practically all the areas between the Island divide and the inland edge of the south coastal plain from Río Yauco to Río Maunabo, has been allocated to private use by franchises. In addition, numerous smaller areas thruout the Island are developed for both public and private purposes.

It may appear that a large part of the surface water supply has been developed and that Puerto Rico already is past the half-way point in using the rivers in upland areas. This is not so. Studies conducted by the U.S. Geological Survey in 1964 have shown that much of the water from developed areas is available for further use. Río Grande de Loíza, the largest river of the Island, is used for water supply be means of Lago Loíza. The larger part of the water runs to the sea with relatively little other use and with almost no consumptive use. Similarly, much of the basin of Río Grande de Arecibo has been developed for power at Dos Bocas Dam and the developments farther upstream, but all of the water passing Lago Dos Bocas is available for other use.

Of still greater importance is the fact that most of the larger rivers of Puerto Rico remain virtually unused; except for the relatively small amount of diversion to south-coast areas. A great amount of water is available in the rivers along the west, north, and east coasts. Outstanding as additional water sources are Río Guanajibo, Río Grande de Añasco, Río Culebrinas, Río Grande de Manatí, Río de la Plata, and Río Grande de Loíza. Smaller streams have excellent possibilities: Río Camuy, Río Cibuco, Río Guayanés, and the streams on the northern slopes of the Sierra Luquillo.

Water can be obtained from some of these rivers in quantities in the magnitude of 10 to 30 mgd, by pumping stations in the coastal plain. The principal precautions for having dependable supplies at low coast are to not exceed the minimum flow of the river and place the pumping stations upstream of possible salt-water contamination.

It must not be supposed that the rivers can be developed all the way to the mouth. The coastal plain is not suitable for reservoirs other than small farm and industrial ponds. Nor do reservoirs seem to be very practical in the north-coast limestone area, because of the probability of large amounts of uncontrollable leakage. Best sites do exist for more reservoirs in Puerto Rico. In studying the opportunity for additional hydroelectric power developments, Puerto Rico Water Resources Authority (1963) listed possible reservoirs with a combined capacity of 318,000 acre-feet. One of these, on the Río Grande de Manatí, could have a capacity of 144,000 acre-feet, which is nearly three times the capacity of any reservoir existing in 1963. Other sides for reservoirs undoubtedly exist that were not considered for power projects.

The quantity of ground water available for future development appears to be considerable. In some areas additional, large supplies are available for irrigation and industrial purposes; whereas in other areas only small supplies are available such as for domestic, stock, and small municipalities. From the data furnished by the U.S. Geological Survey in 1964 it does not appear that the maximum ground-water potential has been realized in any of the ground-water areas as shown in their studies. At some localities within a few of the areas, however, further development may not be feasible at this time.

It is believed that large to moderate supplies of water of good quality can be developed in many areas from the limestone and alluvium of northern Puerto Rico. Wells very near the coast, especially if drilled to or below sea level, and in topographic lows, are subject to salt-water intrusion. Small to moderate supplies of ground water can be developed in many places in the valleys along the west coast and larger supplies may be obtained in a few places. Salt water may present a quality problem in wells located near the coast especially if drilled below sea level or if they are pumped heavily. In the southwest corner of the Island only small supplies of water can be developed and even these may be of poor chemical quality. Altho there has been extensive ground-water development locally in valleys along the south coast, additional large supplies are available in many places. Small to large supplies of good quality water may be obtained in the valleys along the east coast by properly constructing carefully located wells. Small to moderate supplies may be developed locally in the mountainous interior of Puerto Rico especially in the valleys and lowlands. (As used in the U.S. Geological Survey records a small ground-water supply means less than 50 gallons per minute, moderate means between 50 and 250 gallons per minute, and large means more than 250 gallons per minute per well).

The total quantity of water available for additional development cannot be separated neatly into surface water and ground water. It is true that surface-water reservoirs can be developed in the volcanic uplands. Such projects, however, affect the ground water in the alluvium of the coastal plains. If the reservoir feeds water to the lower reaches of the stream in a more regular pattern that the natural stream-flow, the groundwater in the coastal alluvium is recharged more consistently and more wells can be developed. If the water in the reservoir is diverted to another basin, the recharge of ground water may be less, and the opportunity for development of wells may be diminished.

Wells can be developed close to a stream in the alluvium, such that streamflow will be diminished or will cease, except during floods. This may be undersirable if interests farther downstream are entilled to the unaffected flow of the stream. On the other hand, the reduced streamflow and the increase of ground water used may be an efficient use of water that otherwise would have been wasted to the sea.

When it becomes economically feasible, probably half of the ground-water discharge to the sea can be intercepted and used. This would have little effect on streamflow near the coast. Developing this water supply would mean careful attention of rates of pumping to avoid contamination by salt water, and a system of observation wells would be inherent in the development scheme.

With respect to most areas of ground-water development, it often is practical to overpump ground-water deposits. This means seasonal increased pumping just prior to and during periods of recharge by rainfall, in order to take advantage of the great storage capacity of the ground-water deposits. Once again, a system of controls would have to be used.

Development of streamflow and ground water has proceeded in Puerto Rico so far with relatively little attention to their high interdependence. This a natural sequence, as water was fairly easy to find. Wells were drilled in a trial and error basis, which generally has been a successful procedure because the limits of ground-water development have been exceeded very seldom. Water still is easy to find, but the utilization of Puerto Rico's water requires that the close relationship of all aspects of water must be recognized. Much detailed information will be required to do the job properly for the needs of the future. Each area of possible further development must be studied individually in order to obtain the maximum amount of water, consistent with the extent of the supply.

Quality of the Water Available

Water quality is affected in several ways by Man's activities in Puerto Rico. The major influence that results in changes in quality of the water is the storage and controlled release of water for hydroelectric power and irrigation. These changes generally are beneficial. Considerable quantities of the water stored in reservoirs are dilute waters from storm runoff. When the water is released water, stream flow is greater in volume and more dilute in concentrations of dissolved solids than would be normal. This condition occurs in the Río Grande de Arecibo basin, in the Río Grande de Loíza basin, and to some extent in other basins. Data are insufficient at present to determine the significance that these activities have on the water.

Water diverted to the Tallaboa Valley for hydroelectric power is the major source of water to the valley and is considerably lower in concentration than the natural limestone type water of Río Tallaboa. Studies conducted by the U.S. Geological Survey in 1964 show the effect that releases of water from the hydroelectric plant above Peñuelas has on the water of Río Tallaboa at Peñuelas. As indicated by the conductance records, dissolved solids decreased to about half that of the normal river water. Discharge, at the same time, increased several times.

Several areas receive water from the other areas thru diversion tunnels and penstocks of hydroelectric plants. In three areas, the diverted water is a different type than normally is found in the receiving area: the Lajas Valley, the Tallaboa Valley, and the Jobos area. The diverted water is more dilute than water normally found in these areas. The saline waters of the Lajas Valley are diluted by water that originates in areas of rocks of Cretaceous age, causing a slow improvement in the quality of ground-water supplies in the valley. Water from Río Guamaní and from Lago Patillas is diverted by irrigation canals to the alluvial plains of the Jobos area. Areas of saline and alkali soils are being flushed by the diverted water with the result of improving the quality of the ground water.

Other alterations of the quality of surface waters in Puerto Rico that occur as a result of Man's activities are of not great significance at present, but there are elements to be observed and controlled if the present quality of the water is to be safeguard. Complete chemical analyses of streams above and below discharge outlets of several industries, have disclosed continuous conditions of significant stream pollution by industrial waste. This subject is treated at length in the section "Pollution Control" of this report.

7. Projections of Future Demands for Waters 1/ and Water Related Activities

Population Projections

For the purpose of estimating future domestic, commercial and industrial water supply requirements, the population has been conservatively estimated at 3,600,000 for the year 1980, equally

1/ Data from PRWRA Records, 1965

distributed between the urban and rural zones. It is further estimated that out of this population, 2,800,000 can and will be served by public water supplies.

Municipal Water Use

For residential and commercial use in urban areas, an average future per capita production of about 100 gallons daily has been estimated against a present production of 75 gallons. Slum clearance projects, more housing projects, and a high standard of living seem to justify the higher future rate for urban areas. For rural areas, experience shows that 30 gallons per capita is ample.

Based on the future water production on these rates, the following figures are obtained for the year 1980:

Population to be Served (For Residential and Commercial Use Only)		Daily Water Rate	Production Required MGD
Urban ----------	1,800,000	100 gallons	180
Rural ----------	1,000,000	30 gallons	30
Total	2,800,000		210

Agricultural Use of Water

In addition of the lands now irrigated by the present three irrigation districts, there are about 25,000 acres scattered along the southern and northern coastal plains that are in need of irrigation for the support of year round crops. Some of these irrigation systems were studied in preliminary form years ago. On the basis of present costs, their development appears prohibitive.

Possibility of Adding New Supplies

The Puerto Rico Aqueduct and Sewer Authority (PRASA) has performed studies for determining the additional quantities of water that can be obtained from present or new sources and the approximate cost of the works required for catchment, purification, and transmission. These studies are outlined and summarized in Table 12 below:

Table 12. Summary of Present and Future Water Demand For Domestic, Commercial and Industrial Uses

Municipality or Zone	Present Capacity (MGD)	Additional Future Demand (MGD)	Preliminary Cost Estimate of Providing Additional Supply (Dollars)
San Juan Metropolitan Zone Covering			
11 Municipalities	68	108	$41,000,000
Ponce City	17	10	12,000,000
Mayaguez City	8	3	5,500,000
15 Additional Cities and Towns	11	23	2,500,000
Special Industrial Zone of Guayanilla and Guánica	10	35	35,000,000
Total (For 31 Cities and Towns)	121	189	108,250,000

San Juan Metropolitan Area

The water supply system of the Metropolitan area at present produces about 68.4 mgd, of which 30 mgd are derived from Loíza River and 26 mgd from the Bayamón and Guaynabo Rivers, 5 mgd from Río Piedras and the rest from deep wells. An extension to the Loíza filter plant up to 45 mgd rated capacity, has been completed.

The estimated future demand for 1980 for a population of over one million for residential commercial, and industrial use amounts to 144 mgd. The future industrial demand alone has been estimated at 40 mgd.

In order to meet the future demand, the following additional sources may be developed:

Source or River Basin	Unregulated Flow That May be Used	Estimated Cost of the Works
Loíza River (1)	55 M G D	$ 11,000,000
La Plata River (1)	15 "	5,000,000
Canovanillas River	3 "	1,200,000
Canóvanas River	5 "	2,000,000
Espíritu Santo and Río Grande Rivers	7 "	3,600,000
Mameyes River	10 "	6,000,000
Total	95 M G D	$ 29,000,000

(1) Flow of these rivers is regulated by impounding dams.

The yield of Canóvanas, Espíritu Santo, Río Grande and Mameyes Rivers may be further increased from 22 mgd to about 35 mgd by regulating their flows thru impounding dams, at a combined estimated cost of $12,000,000.

In accordance with the above, the Metropolitan Zone of San Juan may be supplied with an additional flow of about 108 mgd over present supply at an estimated cost of $41,000,000. The possible 50 mgd of treated effluent from the Puerto Nuevo Treatment plant are not included in this figure.

Ponce City

Ponce is the second largest city in Puerto Rico. Its urban population in 1960 was around 114,286 and the estimate for 1980 is about 200,000. The future rural population which may be served from the city system is estimated at 30,000. The expected future water demand is a shown in the following table:

Population to be Served		Use	Daily Rate (Gals. per cap)	Total Demand (MGD)
Urban	200,000	Residential and Commercial	1000	20.0
Rural	30,000	Residential and Commercial	30	0.9
		Industrial	--	14.0
Total	230,000			34.9

In Ponce additional sources which may be developed are the Portugués River (by an impounding dam) and Chiquito, Cañas and Castillo Rivers. An additional daily flow of 13 mgd may be obtained from these rivers. The total cost of these works including additional deep wells is about $6,000,000. About 6 mgd may be obtained from Toa Vaca River.

Mayaguez City

Mayaguez is the third important city in the Island. Its urban population in 1960 was 58,887. It is estimated that for [illegible] this population will be about 90,000. Of its future rural population, about 20,000 will be supplied from the city aqueduct. The estimated future water demand is as follows:

Population to be Served	Use	Daily Rate (Gals. per Cap)	Total Demand (MGD)
Urban 90,000	Residential and Commercial	100	9.0
Rural 20,000	Residential and Commercial	30	0.6
	Industrial	--	18.0
Total 110,000			17.6

At present the city of Mayaguez is supplied from Cañas and Yaguez Rivers. The city system has two filter plants, an old one of 3 mgd capacity, and a new one of 5 mgd under partial operation. The combined minimum flow of both rivers is 5.4 mgd.

Construction of an intake structure and pumping station at Añasco River was started in 1964 to supply the new filter plant, completing its total capacity of 9 mgd. Añasco River is one of the largest in the Island, so that the future water demand of Mayaguez can be supplied by pumping from the river. Besides, a gravity system may be completed from Cañas River, by the construction of an impounding dam to regulate its flow to yield from 6 to 8 mgd at a cost of around $2,500,000.

Caguas City

The 1960 population of Caguas was about 34,000 and the estimate for 1980 is 52,000. Its water supply system also serves the town of Gurabo, with a future estimated population of 7,000. The rural residents that may be served in the future are about 18,000 for Caguas, and 6,000 for Gurabo. The future industrial demand is estimated at 4 mgd. The following table shows the future demand:

Population to be Served		Use	Daily Rate (Gals. per Cap.)	Total Demand (MGD)
Urban	59,000	Residential and Commercial	100	5.90
Rural	24,000	Residential and Commercial	30	0.72
		Industrial		4.00
Total	83,000			10.62

At present the city of Caguas is supplied from Quebradillas Creek with a minimum dry weather flow of 2 mgd and from Turabo River by pumping to a 5 mgd filter plant.

In the future, waters from the Loíza River will be used to supply the additional flow to complete the plant capacity. The estimated cost for these works is approximately $2,500,000.

Special Industrial Zones

Several petrochemical industries have been established adjacent to the Commonwealth Oil Refinery at Tallaboa, near the towns of Guayanilla and Peñuelas. All these industries are contemplating future expansions. The future water requirements, including a fertilizer plant at Guánica, are estimated at 45 mgd. Their present consumption is about 10 mgd which is supplied from deep wells drilled and owned by the different firms. The sources are the Rosario and Guanajibo Rivers, both located on the Western side of the Island.

The Puerto Rico Water Resources Authority is carrying out preliminary studies and investigations, for the Government of Puerto Rico, for the development of the Guanajibo River Basin, to supply water to the industrial areas of Guánica and Guayanilla. The inmediate plans envisage diverting approximately 25 mgd from the Guanajibo River to the Lajas Valley Irrigation System. An even amount of water will then be diverted from the Loco Reservoir, headwaters of the irrigation system, thru pipe lines to the Guánica and Guayanilla industrial areas. The ultimate project includes a high dam across the Rosario tributary and tapping various other streams with small diversions dams, installation of a 48-inch concrete pipe line approximately 30 kilometers long, construction of about 13,000 feet of tunnel with a 7-6" horseshoe section, a water treatment plant and a complete distribution system. The total cost of the project is estimated at $25,000,000.

Towns of the Central, South, and Southwestern Zones of Puerto Rico

The small towns along the Central, South and Southwestern zones are mostly supplied from deep wells, but generally the yield of these wells is small.

A water - resources investigation conducted by U.S. Geological Survey in 1964 with the Puerto Rico Water Resources Authority, has provided working information that will yield a better understanding of the hydrology and will be useful in planning for water development of these areas.

Towns Along the Central Highlands

Most of the towns located along the central highlands are small and the capacity of their water supply systems is just enough for their domestic and commercial use.

Other Small Towns

The following table shows the estimated of future demand for 15 other towns:

Towns	Capacity of Present Works	1980 Population Urban	Rural	Domestic	- Industrial	Total	River Source Additional Demand	Cost Estimate Million Dollars
Arecibo	2.50	50,000	20,000	4.10	4.00	8.10	Tanamá	2.3
Aguadilla Aguada and Moca	3.0	50,000	42,000	4.77	1.88	6.65	Irrigation Canal	1.2
Humacao and Las Piedras	1.0	25,000	20,000	2.35	1.34	3.69	Mariana Creek	1.3
Fajardo and Ceiba	1.6	27,000	12,000	2.25	2.40	4.65	Fajardo	1.4
Guayama and Arroyo	1.5	39,000	16,000	3.21	3.70	6.91	Chiquito	3.0
Luquillo	0.5	3,000	6,000	0.36	0.50	0.86	Sabana	0.1
Quebradillas	0.2	3,300	10,000	0.50	0.10	0.60	Guajataca	0.35
San Germán and Lajas	1.0	18,500	29,000	1.98	0.52	2.50	Rosario	1.0
Vieques Is.	0.15	5,000	5,000	0.40	0.10	0.50	Blanco	1.6
Total for 15 Towns	11.45	221,000	160,000	19.92	14.54	34.46		12.25

Water Supply Systems Being Improved

The water supply systems of the towns of San Sebastián, San Lorenzo, Vega Baja, Adjuntas, and Peñuelas are being improved and will have facilities to supply the future demands. The improved water workds for these 5 towns will have a combined capacity of 3.5 mgd.

Water Needs for Industry

In 1946, Puerto Rico started "Operation Bootstrap", and intensive program of development of its potential as an industrial center. From 1947 to 1960 over 700 factories were established with the assistance of the Economic Development Administration and this agency anticipates a continued increase. During the early part of the program most of the factories established were small, making light consumer goods and assembling electrical, electronic, and similar equipment. More recently the trend has been toward developing more complete manufacturing and introducing heavier industry. The light industries generally use little water, their use being confined largely to domestic and sanitary purposes. The heavy industries, however, may have a large demand for water.

The existing municipal systems operated by the Puerto Rico Aqueduct and Sewer Authority were designed to supply potable water mostly for domestic, public commercial, and light industrial use. None of the systems, except that of San Juan, was planned to meet specific industrial demand, especially if such demand was that of heavy industry or of a type that had large requirements for process water. Thus, except at San Juan, almost all future demands for water for industrial use will have to be filled from sources other than existing systems.

According to present projections, between the years 1963 to 1980 there will be established thruout the Island about 1700 new factories of which 10 percent will be heavy industries, 20% semi-heavy 70 percent of the light type.

The total future industrial demand for 1980 has been estimated at 100 mgd of which the heavy industries will consume 60%, the semi-heavy 10%, and the light type industries 30%.

Based on these estimates, the total water production for 1980 for domestic, commercial, and industrial purposes, will therefore, amount to 310 mgd.

Water Needs for the Production of Electric Energy

The Puerto Rico Water Resources Authority is the government agency responsible for the supply of electric energy in Puerto Rico. The present total thermo and hydroelectric installed capacity amounts to 988,340 K W (PRWRA Annual Report of 1967), of which 104,840 K W is hydroelectric power as shown in Table II of this report.

In order to be able to provide the required energy for the rapidly expanding industrialization, the possible population increase, and the continous increase in the use of electric appliances and facilities which follow the raising of the standard of living, it is necessary to periodically install additional steam electric generating units in the existing stations and perhaps to construct additional stations.

As indicated in the Puerto Rico Water Resources Authority records the yearly peak load increased from 55,000 K W in the year 1944 when the total installed capacity of the system was 71,000 K W to 988,340 K W in 1967, or an increase of 817,340 K W in 23 years.

On the basis of present trends, it is estimated that an average of about 50,000 K W capacity will have to be added every year. The fresh water requirements, for this capacity are of the order of 121 acre-feet per year, so that the total additional requirements for the year 1980 will be about 2 mgd. The above figures do not consider the large quantities of condenser circulating water required by the future units because sea water is utilized for this purpose.

The location and order of addition of the new units will depend on the results of load studies; however, there are only two stations where these additions would be installed, the Palo Seco Station near San Juan and the South Coast Station near Ponce.

Salt Water Conversion for Industrial Use

The Government of Puerto Rico faces an increasingly serious water problem due to the growth in population with a high standard of living and the need of industries for more water. As stated previously, resent studies made by Aqueduct and Sewer Authority indicate that by 1980 the requirements will be of the order if 310 million gallons per day. The very low dry season flow of the main streams in the Island preclude the construction of relatively low cost diversions. The construction of other storage reservoirs to insure adequate water supply during the year is, therefore, necessary.

The lack of additional adequate reservoir sites in the north watershed where rainfall is more abundant, makes this problem still more critical.

In a report on water resources jointly published six years ago by the U.S. Geological Survey and several Government agencies we read: "There is sufficient water in Puerto Rico to meet the greatest anticipated demands of population, agriculture and industry". Between then and now, in this short time, the situation has changed drastically. A report recently prepared by the Aqueduct and Sewer Authority sounded a different note: "Water demands have grown to the point where conflicts now exist between different uses. Before long, water resources will be insufficient to supply the demands of our growing population and economic activity"

The scarcity of water may be further accentuated by the degradation of the existing supplies, by more pollution from the additional population in watersheds and from increasing industrial wastes being dumped in the river channels. The seriousness of this situation requires prompt and agressive action for the solution of the problem. Among the courses of action recommended, the following merit special considerations:

1. Conservation of the existing supplies by adequate maintenance and preservation of storage capacity of the reservoirs by remedial actions to reduce silting.
2. Development of new storage reservoirs for the conservation of as much as possible of the present runoff that is wasted into the ocean.
3. The use of sewage water after it has subjected to adequate treatment, is a promising possibility.
4. Conversion of salt or brackish water into fresh water supply.

The conversion of salt water offers attractive possibilities in the immediate future. Intensive studies conducted by the Saline Water Department of the Federal Government indicate that fresh water can be obtained by desal'ing processes, using techniques and equipment which have been now developed to the point where commercial size installations are made.

Saline water conversion has advanced to include a number of different processes.

Major groups are:

1) Distillation by using fuel.

2) Solar heat distillation.

3) Membrane process.

4) Separation by freezing and

5) Other chemical, electrical and physical conversion methods.

All of these processes involve the use of large amounts of heat. According to the Aqueduct and Sewer Authority studies the cost of water produced by other means was around $1.00 per 1,000 gallons in 1965. Reduction in the cost depends entirely on the availability of low cost sources of heat energy and improvement in devices and operational techniques. Distillation processes are the most advanced to date. Multiple flash distillation being the preferred process for conversion of sea water.

On the basis of present experience, it is expected that a price of between $0.30 and $0.40 per 1,000 gallons can be obtained in the near future.

The Atomic Energy Commission has been studying the construction of large size breeder type reactors for the production of electricity and low cost heat for water conversion. Preliminary figures indicate that electricity at 5 mills per K W - hr and water at 5¢ to 8¢ per 1,000 gallons can be produced in breeder type nuclear stations of large size. The cost of fresh water thus obtained would be well below that of waters from surface streams and underground sources, which normally require additional treatment and purification.

According to Puerto Rico Water Resources Authority studies there are two sources of heat in the operation of thermal stations. These are the residual heat in the hot gasses leaving the chimneys and in the water used for cooling the condensers. The Authority has been studying the possibility of utilizing this heat for the production of enough water for boiler make - up.

A pilot plant capable of producing 10 gallons of fresh water per minute using the 10° to 15° F differential in the circulating sea water used for cooling the condensers in the South Coast Station, is now under way. A diffusion evaporation process developed by Burns and Roe, Inc. of New York will be used.

A similar study is also under way for the design of a 1,000,000 gallons per day plant using the same process but in a larger scale utilizing the cooling water from the condenser of a 40,000 K W unit of this same station. Preliminary construction cost figures indicate a capital investment of the order of $350,000 to $400,000 for this bigger installation. If a conversion cost of the order of 25¢ per 1,000 gallons as claimed by the plant designer can be obtained, the possibilities are that the size of the conversion plant be increased for the production of water for industrial purposes in the Guánica - Guayanilla area.

While water with dissolved solids up to 350 parts per million would be acceptable for domestic use, certain industries including modern power plants require water with less than 0.5 parts per million of total dissolved solids. These requirements are not so strict when water is intended for irrigation and for such industrial use as cooling and flushing. In the latter cases natural water of all types including sea water and treated sewage are now being used for these purposes.

Due to the increasing demands for higher quality water, salt and brackish water conversion will grow in use, specially in industry and in towns now using highly mineralized water.

8. Fundamental Water Problems 1/

Pollution Control

Due to the high density of population of the Island, with practically no unpopulated areas, only the water in the uppermost reaches of a few of the streams in Puerto Rico is fit for human consumption without treatment. Pollution studies of 15 rivers and

1/ Data from Puerto Rico Dept. of Health Annual Reports and PRWRA and PRASA records.

2 lagoons have been made by the Puerto Rico Health Department, the major sources of pollution to the streams of Puerto Rico being waste products of the sugar industry and human wastes. The sugar industry produces waste products only during the grinding season (about 5 months long) and these wastes evidently are not sufficiently concentrated to prevent downstream use of the water from the streams into which the wastes are dumped. Human wastes have contributed to the spreading of the parasite Schistosoma Mansoni which causes schistosomiasis (bilharzia), a debilitating disease which may eventually result in death.

One by product of the industrialization of Puerto Rico, particularly by heavy industry, will be large quantities of wastes.

As far as we could find with the available data, problems of the chemical quality of water from the streams and the ground for industrial use have been minor to date. There is no doubt, however, that the expected increased demand will create many problems. New Industry in general has tended to become more demanding about water quality, but at the same time this new industry creates problems of contamination that affect maximum use of water.

Island-wide water pollution control programs are relatively new to Puerto Rico altho various measures have been applied in the past to meet particular problems in local situation. Such programs are necessary to maintain water quality or to restore its condition so that the water may be suitable for the various uses to which it may be put. The bodies of water in Puerto Rico are mostly low-flow streams with very little capacity to recover from the continuous intake of sewage and industrial wastes to which most of them are subjected. This has given rise to acute problems of water pollution. One of the most critical on the Island is that of the San José Lake and the Martín Peña Channel, both within the Metropolitan Area of San Juan. Industrial wastes from distilleries, soft-water bottling plants, pharmaceutical products factories, and other sources are discharged directly, or thru the sewerage system of San Juan, into the lake and channel. Moreover, thousands of people are discharging their domestic sewage into these bodies of water. Such uncontrolled pollution has been a menace to public health and has been the cause of the death of thousands of fish and the production of boul-smelling gases which are a real nuisance to the large population area and its surroundings.

Another problem of great importance is that of the excessive pollution of the Yaguez River, at Mayaguez. This river has a very low-flow capacity. In addition, because of tidal effects, the mouth of the river is filled with sand most of the time, thus preventing free flow of the river water into the ocean. From the discharge of wastes from one brewery and other plants as well as from many other sources in the area, the water of the river, which is stagnant, becomes highly septic at certain seasons. Generation by hydrogen sulphide from the anaerobic decomposition that takes place causes a foul odor and destroys the oil paint on houses located in the area surrounding the main stem of the river.

There are many other similar problems in various parts of the Island. If nothing is done to control the pollution of the different bodies of water, conditions will grow worse with increasing damage to the economy.

The community responsibility for building needed treatment works can best be fulfilled thru the informed action of local citizens. Facts on pollution problems and needs must be brought to the attention of the public.

Obtaining the best treatment for the least cost requires the professional guidance of Engineers, Lawyers, and experts in municipal finance. Engineers design the treatment works to meet specific local needs, supervise the letting of contracts and the construction, and train the plant operators. Legal aid is necessary to insure clear property titles, compliance with state laws, and legal financing procedures.

Faster progress is needed with respect to some phases of the problem, despite the accomplishments of State, and Federal Programs.

Construction of pollution-abatement works, municipal and industrial, is lagging behind the increasing volumes of waste. Much of the State and Federal effort of the past few years has been directed toward producing the foundation material necessary to a good construction program. Efforts must now be marshaled for a sustained drive to raise construction levels to meet the needs.

Research has failed to keep up with the new problems created by advancing technology and changing water patterns. Greater emphasis is required in many areas of research in order to permit more rapid and effective control measures. Some of the problems urgently needing special attention are:

1) The impact of public health of increased bacterial, virus, and chemical pollution, and the ability of present processes to cope with increased volumes and new types of pollution.

2) A redefinition of the natural purification phenomena of streams in the light of the new composition of wastes including chemical loadings.

3) The development of more economical waste treatment methods; success in this area would save millions of dollars of treatment plant construction cost.

4) Adjustment of laboratory techniques for measuring pollution levels in streams and for determining efficiency of water treatment.

5) The effect of impoundments on pollution behavior in streams.

More effective integration of comprehensive plans to control pollution with overall programs to develop water resources is essential in order to assure full consideration of the effects on public health of stream regulation thru construction of projects for flood control, power, and irrigation, or combinations of them. Pollution - abatement works are designed with consideration to the streamflow conditions that exist in the water-courses into which they drain. The governing standard as to the type of treatment to be constructed is the low-flow record of the water-course. The change in characteristics of stream-flow resulting from the construction and operations of stream-regulating devices can seriously alter the effectiveness of waste treatment facilities, thus negating the public health benefits to be derived as well as the beneficial effect that adequate dilution water provides for all water uses.

Of paramount importance is the prevention and correction of pollution of the present and future supplies from wastes originating in densely populated areas or from industrial wastes. It is a well known fact that pollution, which, in addition to its obvious menace to health, severely limits our supply of water for many uses. The sheer amount of waste materials dumped into our rivers and streams by the activities of people and industries is increasing rapidly. Our waters and lands must absorb, dilute, carry away and otherwise take care of much of the refuse that is the product of our progress and growth. In fact, this task has come to be one of the principal uses we are making of our natural environment.

Long established industries like sugar and rum are major sources of wastes, many of which are presently untreatable. Other factories established year ago, when we were unaware of pollution problems, must now be dealt with under new regulations, or when they choose to expand and thus return to us from approvals. The new industries being established are being required to provide adequate pollution controls because we now have the technical knowledge and sufficient awareness to insist on such measures.

One particular aspect of pollution deserves special mention. The people and process that cause pollution are frequently not those who suffer from it. The industrial plant upstream may be inflicting damages on users of water further downstream. But as our society functions, those who make the decisions that cause pollution do not usually take much account of the damages outside their immediate surroundings. They are concerned only with their own operations. The rest of us can complain about an apparent lack of community spirit, but the reality is that industry wants to retain its competitive position, and thus tries to keep its costs down.

The only recourse is obviously public action in the form of incentives and penalties, and within a framework that can effectively resolve such privately-caused and publicly-felt problems. Only government seems to be in a position to take remedial actions. And the government is taking effective measures to deal with this problem.

The Puerto Rico Department of Health has greatly concerned with water pollution problem, and has given attention to various abatement measures. In 1947 the Puerto Rican Legislature enacted Law 444 which created a Commission for the Control of the Bodies of Water in Puerto Rico. The Commission was charged with the responsibility of dealing with all problems related to water pollution.

A section was created within the Bureau of Sanitation of the Department of Health, whose chief, a Sanitary Engineer, served as the advisor on technical matters to the Commission.

Immediately after the section was organized, the work on abatement of pollution was started. Problems reported by local health units on the Island were considered and different surveys were made to establish the fact that uncontrolled pollution was causing damage. There was, however, no program of organized action.

In 1950, the Legislature passed Law 142, which repealed Law 444 and all others which were in conflict with the new act. This new act designated the Department of Health as the Puerto Rican agency to intervene in everything related to pollution of the Island and vested in the Secretary of Health authority to prevent and abate water pollution in Puerto Rico, as well as to establish rules and regulations for the purpose. It also fixed penalties for violation of any of its dispositions and established the administrative and judicial procedures to be followed in handling violations. Also created was the water Pollution Control Advisory Board, which advises and consults with the Secretary in connection with the administration of the act.

After Law 142 was enacted, the Department of Health developed plans for a water pollution abatement program. This is a responsibility of the Department of Health of Puerto Rico, but it is administered and operated by the Puerto Rico Aqueduct and Sewer Authority. In 1945, the year this agency was created, only 41 of the Islands 76 municipalities had sewerage facilities and these were limited to a sewer collection system and an old, inadequate septic or Imhoff tank which overtaxed, with its effluent, the oxygen resources of the limited - flow rivers and streams.

It is obvious that, because of the limited flow of surface waters, good purification of the sewage effluents was a necessity for the Island municipalities, as the down-stream river waters were used for several purpose, including raw feed to the water filtration plants. Also, in some coastal towns it was necessary to protect the beaches, tourist resorts and recreational areas. To that effect, some old systems were improved, and both primary and secondary treatment plants were constructed.

Several Imhoff tanks of circular design were built to serve the small communities. It is interesting to observe that the Puerto Rico Aqueduct and Sewer Authority experience with these tanks has been very good, and it appears that their efficiency for suspended solids removal is very seldom below 45 percent. This is an excess of that obtained in Imhoff tanks of conventional design.

The primary plants usually consisted of sedimentation, sludge drying beds and digestors. An improved design of circular Imhoff tank was also developed.

The largest of the primary treatment plants is the Puerto Nuevo plant, which serves Metropolitan San Juan. This plant was inaugurated in 1957. It has a nominal design capacity of 24 mgd. The plant, when needed, can be converted to a secondary treatment plant. Its effluent is discharged thru a 66 inch main into the San Juan bay.

Both activiated sludge and trickling filter plants have been constructed. The early experience proved that, altho the activated sludge plants produce a cleaner effluent than the trickling filter plants, their cost of operation and maintenance was far in excess of those encountered with the filters. Operating difficulties were also greater. Four activated sludge plants were constructed at the municipalities of Luquillo, Gurabo, Lajas, and Aibonito. It is not expected that any more activated sludge plants will be used because of the above mentioned reasons. The exception will be for small plants at private or public housing projects.

The Puerto Rico Aqueduct and Sewer Authority experience with the trickling filters has been excellent. Altho this type of plant requires a greater area than the activated sludge plant, its operation is simple and demands a relatively low amount of electric power for its operation. Furthermore, they operate with a good efficiency. Suspended solids removals with the filters have varied from 74 to as high as 96 percent, depending on the rate of recirculation and the nature of the efluent. On the average, filter efficiency is about 85 percent. In 1964, 16 municipalities were served by 28 trickling filtration plants, and there were some municipalities, like San Juan, with several installations.

Since Puerto Rico is surrounded by water, it was logical for the Puerto Rico Aqueduct and Sewer Authority to look to the nearby ocean as its ally for the disposal and final oxidation of sewage effluents. Several coastal cities discharge their raw sewage into the ocean.

Before considering the ocean location where the sewage will be discharged, extensive oceanographic studies are performed to assure that the shoreline waters will not be polluted. Float studies are conducted to ascertain the pattern of ocean currents. Wind, tidal action, current density, ocean topography, and chemical, physical, and biological considerations are taken into account to determine the probable dispersion of the sewage effluents once they are discharged.

All new suburban housing projects must construct a secondary sewage treatment plant for the disposal of their wastes. These plants are constructed by the developers and transferred to the Aqueduct and Sewer Authority for operation and maintenance. Altho, as a general rule, the developer uses a trickling filter plant, there is a growing tendency toward the construction of extended aeration plants because they take less land for their installation and have lower initial cost.

The year 1966-67 was quite active and fruitful in the area of water pollution control.

To comply with the Clean Water Act of 1966 the Puerto Rico Aqueduct and Sewer Authority helped the Department of Health in preparing the water quality criteria for Puerto Rico together with an implementation plan for a reasonable number of years.

After a rigorous inspection, the Puerto Rico Aqueduct and Sewer Authority central laboratories were approved by the U.S. Public Health Service for investigation and control work on pollution control programs.

The report on sanitary conditions of San Juan bay, where efluent of Puerto Nuevo's primary wastewater treatment plant is discharged, was practically finished at year end.

A constant watch was kept on the quality of sugar mill's industrial wastes discharged into streams used as sources of water for San Juan and other communities.

At year end all our cities and towns, with the exception of the off-shore islet of Culebra, had sewage disposal facilities. Twenty-five towns were served by secondary and nine more by primary treatment plants; nineteen towns had Imhoff tanks; fourteen used septic tanks and the remaining eight towns discharged their wastes into the ocean. All nineteen Imhoff and fourteen septic tanks will eventually be replaced with sewage treatment plants, preferably of the secondary type. As a matter of fact, at the end of the year 1967, three of these plants were under construction and four more on the first stages of design.

In addition, there were 21 secondary treatment plants which served suburban developments, industrial parks and low-cost housing projects.

The rural areas, however, are severely handicapped by lack of sanitary facilities and the lack of knowledge concerning sanitation and health. The situation is deplorable in many respects since it involves the health and welfare of such a large segment of the population of the Island. More sanitation work needs to be done in the rural sections with greater emphasis on the proper disposal of human feces, and other wastes such as garbage. The great deficiency in health education that exists among rural people will have to be met head on by positive action to overcome widespread ignorance which now results in a tremendous waste of human, as well of economic resources.

All of the agencies functioning in the rural areas can contribute to the improvement of health conditions, provided the Health Department assumes its proper role of leadership in this situation. For example, the Extension Service, which reaches in the remote corners of the Island, could cooperate more effectively with the Health Department in a unified rural health program, as could many other agencies, including the rural schools. Local civic organizations and business groups could cooperate also in conducting cleanup campaigns and other activities designed to boost interest and pride in sanitation and good health by means of encouraging self-help.

But these programs, we believe, are far from enough. Municipal and domestic waste control is a serious problem, hampered more by a lack of adequate funds than by a lack of knowledge to deal with the problem. Many existing sewer systems around the Island are still inadequate, and will remain so until resources are made available to improve and expand them. New material wastes will continously be introduced by new industrial processes before it is learned how to treat or control them. The people of Puerto Rico will be constantly facing the dilema of trying to balance the need for conserving their natural resources with the economic and social benefits of further industrial growth and development.

The continued usefulness of our streams will depend on our desire and ability to control pollution. There will be an ever-increasing demand for clean water. We cannot escape the fact that unless pollution is controlled, the country's health and economy will suffer greatly.

Sedimentation of Reservoirs

Sediment, which is soil and rock transported by surface water, is a problem of water management and control in Puerto Rico. It is a result of steep topography, heavy rainfall, erodable soils, and Man's activities on the land. It muddies the streams, despoiling their beauty; it alters river channels and the hydraulic characteristics of streams; it is deposited as unwanted materials in some locations, decreasing the efficiency of reservoirs, bridge spans and tailraces of hydroelectric plants; and it is lost if carried to the sea. On the other hand, it provides new soil for agricultural use in alluvial areas; river deltas, flood plains, and costal plains provide large areas for sugar-cane production. It provides raw material for sand and gravel plants thruout the island, and it may support the formation of sand-bars at river mouths which prevent salt water from intruding inland during periods of low flow.

Sediment may exist in particle sizes so fine that when it is combined with water, near-colloidal mixtures are formed that require several days to clarify on standing. Or, the particles may be several feet in diameter and become destructive agents of the flows that move them. In all sizes, sediment presents problems to the water user. Silty waters require treatment before they can be used for domestic consumption and for most industrial purposes. Suspended matter cuts down the penetration of the light on which plants depend for photosynthesis and the stimulation of growth and release of oxygen. The entire ecological balance--the natural beneficial interrelationship--is upset for the plant and animal life that live in or on the silty waters. Afterward, additional work and costs are involved in removing sediments from settling basins and tanks. Removal of boulders from unwanted locations and repairs of damaged bridges and waterworks are additional costs to agencies concerned with bridges and hydroelectric plants.

Thru its use for irrigation and power purposes, water plays an important role in the economy of Puerto Rico. But the natural supply of water on the Island fluctuates markedly from one time of the year to another on account of the seasonal distribution of rainfall. Thus, in order to have ample supplies of water available at all times, it is necessary to provide reservoirs which collect and conserve runoff during the wet seasons so that requirements for water during the dry season may be met.

The sites available for reservoirs are definitely limited in Puerto Rico. Once a reservoir is built, it immediately assumes the importance of an irreplaceable facility. Its value to the economy depends on how long it will maintain enough storage capacity to impound water for power, irrigation, and other public needs. In this connection, the amount of sedimentation that takes place as the streams and rivers empty their waters into the reservoir becomes immediately and specially significant.

Detailed information on reservoir sedimentation in Puerto Rico is rather meager. Nevertheless, it is clear that the rate of sedimentation ranges from an almost negligible amount for the reservoirs high in the mountains to very severe silting for reservoirs in the lower regions. Geological conditions on the Island are such as to be favorable to a rapid rate of erosion. But the balance between natural forces has largely been overcome by the destruction of forests and the cultivation of steep slopes with the result that the rate of erosion has been greatly increased. When this has taken place, the streams and rivers are usually loaded with soil that is carried from the land by the runoff after each heavy rain. When these arteries empty into a reservoir, they deposit the sediment that has been carried down from the ravished hillsides. As this sediment piles up in the storage area, it reduces the amount of water that may be impounded and lowers the value of the reservoir. Thus the accelerated erosion that has been induced by man poses a really serious problem and endangers the future usefulness of the Island's fresh water resources for power, irrigation, and other needs.

What actually has been taking place in some parts of the Island is shown by estimates of sedimentation in the Guayabal, Comerío, and Coamo Reservoirs (Table 13). The Guayabal and Coamo Reservoir were built to supply water for irrigation while the Comerío Reservoir was constructed to furnish water for the production of electric power.

Table 13. Sedimentation in Six Reservoirs of Puerto Rico

(Data from PRWRA Records, 1958)

Name of Reservoir	Original Water Storage Capacity	Area of Watershed	Age	Estimated Sedimentation Volume	Estimated Sedimentation Percentage	Average annual rate loss in capacity
	Acre-feet	Square miles	Years	Acre-feet	Percent	Percent
Guayabal	9,544	43.4	45	5,307	49.7	1.34
Comerío	4,918	135.0	45	2,221	95.9	2.59
Coamo	2,687	58.0	45	4,318	79.0	1.89
Patillas	14,500	25.0	45	1,000	7.0	.20
Caonillas	50,149	50.0	10	266	.5	.10
Loíza	20,000	206.0	7	440	2.2	.20

Since they were completed in 1913, the amount of sediment deposited in these reservoirs over a period of 45 years has reduced their storage capacity at rates estimated as ranging from 1.34 to 2.59 percent a year.

The accumulation of sediment in the Guayabal Reservoir between 1913 and 1958 reduced storage capacity by about 50 percent. This brought on a shortage of irrigation water in the western section of the South Coast Irrigation District which was detrimental to agriculture. In order to restore the initial capacity of this reservoir, the crest of the dam was raised an additional 16 feet in 1950 at a cost of about 2 million dollars. But nothing has as yet been done to reduce the rapid rate of sedimentation which made raising of the dam a costly necessity. And reduction of capacity inexorably continues.

Siltation in the Comerío Reservoir has been very severe. It is located in an intensely cultivated hilly agricultural area with about 75 inches of rainfall annually. The altitude of the watershed that drains into this reservoir varies from a little more than 350 feet above sea level to slightly over 2,900 feet. The amount of sediment flowing into this reservoir has almost completely destroyed its usefulness for the production of electric power. The Coamo Reservoir is similarly located, the altitude of its drainage area varying from about 330 feet to 2,950 feet above sea level. Within a 45 year period sedimentation reduced its original capacity to store water by an estimated 79 percent.

Several other reservoirs are located considerably below their watersheds. As indicated in Table 12, it is apparent that they too hace their sedimentation problems in varying degrees. The Caonillas Reservoir, the largest on the Island, was completed in 1948, and already a considerable amount of sedimentation has taken place. Also, a long delta is already forming in the upper end of the Dos Bocas Reservoir which was completed in 1942.

Some studies have been made to determine sediment accretion of several reservoirs in Puerto Rico. The earliest known report (Nolla and Crawford, 1941) presents information on capacity losses of five reservoirs and emphasizes the need for soil conservation. A detailed study of Lago Caonillas (Noll, 1953) provides information on land cover, land use, and topography, and a description of sediment in the reservoir.

The most resent report on reservoir sedimentation was on Lago Loíza (Cepero Brewer, 1958). The investigator found the sediment accretion to be small because of early depositing of sediments above the head of the long narrow reservoir. Also, by using discharge gates at a low level in the dam during storm runoff, much of the heavy-density, sediment-laden water was permitted to pass thru the reservoir. This latter situation at Lago

Loíza well illustrates one of the characteristics of sediment discharge. Storm flow of the river, highly concentrated with sediment, was observed entering the headwaters of the reservoir. The reservoir remained clear at the surface and apparently was free of suspended sediment. At the dam, however, at a low-level outlet, water was being discharged that the same murky appearance as that which entered the head of the reservoir a few miles upstream.

Studies of other areas, not above reservoirs, have been made as part of an evaluation of soil use by the U.S. Soil Conservation Service. It was estimated that Río Humacao transported 60,000 tons of sediment during the devastating floods of September 1960. This amounts to about 6,000 tons of sediment per square mile in a day.

Initial rainfall loosens and transports topsoil quickly to the river system, but once wetted, the soils are more resistant to erosion by subsequent rains. Additional sediment is moved from the stream bed and stream banks while water is lost to bank storage. Altho water moves faster than a water-sediment mixture, the length of streams in Puerto Rico is too short to cause any noticeable delay of sediment movement. Determination of the time interval between peaks of sediment and water discharge can benefit water users who store flood flows in reservoirs. By allowing the initial portion of a flood to pass before storage is begun, water at peak flow with lower amounts of sediment could be stored. Loss of storage capacity could be reduced considerably by such operations.

Flood flows and sediment content were measured over portions of flood cycles at four locations during 1960, as shown in Table 14. Complete flood cycles were not measure in any of the floods, but the sediment discharge shown for four hours or more probably is more than 90 percent of that transported during the complete flood cycle.

Table 14. Suspended Sediment Discharge of Several Streams in Puerto Rico

Observed During Minor Floods in 1960

Location	Date	Time hours	Tons	Tons per hour	Tons per square mile of drainage area	Number of times sediment discharge probably was equalled or exceeded during 1960
Río Gurabo at Gurabo	8-2-60	5.75	1970	343	33	12
	8-13-60	1.50	953	635	16	--
Río de la Plata at Toa Alta	7-19-60	2.50	599	240	10	--
	8-14-60	5.50	18500	3364	324	2
Río de Bayamón at Bayamón	4-29-60	6.50	13000	200	202	--
Río Tallaboa at Peñuelas	6-17-60	4.00	894	224	36	24

(Data from U.S. Geological Survey)

As aspect of sediment that has not been studied but is planned, is the movement of bed material of streams. Río Arecibo, Río Guayama and Río Humacao, for instance, are essentially sand-bed streams. Depth of water during low flow is less than a foot in most places and velocities often exceed one foot per second. Even tho the water is clear, these streams are transporting sediment close to the bed which may be a significant factor in the sedimentation of reservoirs on the Island.

Before adequate sediment-control measures can be developed, it is necessary to determine the source, amount and nature of damaging sediment. Thus, if damage is caused mainly by fine materials resulting from sheet erosion in a watershed, we have to put into use the types of land treatments recommended for the reduction of sheet erosion. If the damaging sediment consists primarily of coarse materials and the sediment is derived from channels, measures to stabilize the channel are needed.

Measures needed to control sheet erosion are designed primarily to provide protection of the soil against the impact of raindrops and reduction of rapid runoff. The most effective and important means of reducing sheet erosion is by using the land properly and improving the cover of vegetation. Land too steep for cultivation should be put into pasture or woodland. Land not suitable for continuous row crops should be placed in rotation with other crops such as small grains and meadow to maintain productivity of the soil and to provide protective cover for a good part of the time.

The protective cover of range and forest lands can be improved by revegetation and by proper use and management. Erosion losses from sloping land may be further reduced by decreasing the effective length of slope. That can be done by contour cultivation and terraces, which intercept the runoff at regular intervals down the slope and prevent it from building up to erosive flow.

Methods for reducing channel erosion are designed on a basis of altering the discharge, the cross section, depth of flow, gradient, or other conditions that cause erosion or by accepting unaltered flow and protecting the channel against it. Not all problems of channel erosion are solved easily. For example, the shaping and seeding of a waterway may be all that is needed to halt erosion of a small gully, but an expensive drop inlet structure may be required to stop erosion of a large gully. Economics obviously may determine the limits of control that can be justified.

One of the measures for reducing channel erosion is by regulating flow. That is done by retarding reservoirs, which impound excess runoff water and release it slowly to downstream channels. The realinement, shaping, and revetment of channels may be done if the discharge cannot be controlled and if the damages justify the cost. Sills are a good way to stabilize the grade of a channel and reduce bed degradation. Bank erosion may be controlled by using revetments or altering the direction of flow. Finally, channels may be downed out and erosion reduced by strategically placed reservoirs and drop inlet structures.

If it is not possible physically or economically to control sediment at its source, the construction of sedimentation basins may be required to reduce the damages from sedimentation. The basins may be designed to trap silt, sand, gravel, and even large boulders. Basins often are built to provide temporary relief from sedimentation damages until control can be installed and become established at the source. Periodic excavation of sedimentation basins is required in many instances, or new basins must be built to provide long-term protection.

One way to reduce excessive deposition of sediment loads in channels is to design channels that maintain sediment in transit. Changes of channel alinement, which involve modification meanders, have been made in may parts in the United States in an attempt to avoid excessive deposition; channels have been straightened in hundreds of valleys of all sizes, but most of the results have been undesirable. The excavation and straightening of meandering channels (many of which contain large sediment deposits) usually have resulted in a great increase in erosion by the stream. That, in turn, has meant a great increase in downward incision, new areas of bank cutting, and excessive subsidence of the water table. Artificial ways of making a channel narrower can increase the velocity of flow, but they involve complex engineering structures. Other mechanical means of controlling stream and current involve the use of vanes and deflectores, chiefly at bends.

To reduce sedimentation, which can lower the storage capacity of a reservoir, it is advisable to select reservoir sites within watersheds protected by vegetation and containing a minimum of cultivated areas. If that is not possible, good conservation practices should be established within the watershed before the reservoir is constructed.

Flood Control[1/]

A flood is a condition that occurs when more water is flowing in a stream channel than the channel can carry. Consequently, water escapes over the banks of the channel and spreads out the flood plain. During a small flood the water covers only low places on the flood plain and recedes without cousing much harm. During a large flood the water may cover extensive areas of the flood plain deeply, and the velocity of the water may be very high.

[1/] Data from Quiñones, M.A., High Intensity Rainfall and Major Floods in Puerto Rico: Am. Soc. Civil Engineers, 1953.

Records of past floods in Puerto Rico are very scanty. The most damaging floods in Puerto Rico are usually the result of the heavy precipitation which accompanies tropical hurricanes. Miguel A. Quiñones, former Chief Enginner, of the Puerto Rico Water Resources Authority, suggests in a study of major floods in Puerto Rico that the "absence of record" may be partly due to the fact that during hurricanes when most of the people are too busy looking for protection of their own lives, and partly to lack of curiosity in determining afterwards the magnitude of the floods.

Hydrologic information indicates that the floods of September 6, 1960, were the greatest known over much of eastern Puerto Rico. The only previous flood in the area with which they may be compared occurred September 13-14, 1928, during the San Felipe hurricane. Quiñones study of the 1928 flood at Comerio Falls Dam indicates that the peak discharge was slightly higher than total of the 1960 flood.

Studies on flood control were conducted by the U.S.D.A. Soil Conservation Service and Miguel A. Quiñones on the Añasco River Watershed, Bayamón River, and Guayanés River from 1961 to 1964.

These studies indicate that a great deal of the damage from floods can be reduced by the use of the land according to its capability and the application of soil conservation measures. Much of the flood damages is due to soil erosion caused by the lack of forest or other protective cover and by clean cultivation, particularly of tabacco and other crops grown on extensive hillside areas which are too steep for cultivation and located near the headwater of the streams.

Losses from floods in these areas are of several kinds - damge to crops and pastures; land damage in the form of flood plain scour, streambank erosion, gullying, and valley trenching, infertile overwash or deposition of sediment and swamping; damage to residential areas and farm buildings, fences, roads, and bridges; stored crops, and livestock; and indirect losses, such as delays in field work and disruption or delays in marketing of farm products.

According to these studies, several factors determine the part that land treatment has in preventing floods. First are the factors that cause floods; the factors than Man cannot control or change - climate, rainfall, geology, topography, the size and shape of watershed - and those he can control.

The factors Man can change are few, but important. They comprise his own use of the land-what he does to the soil and vegetation it produces- or, simply, the treatment of the land, which means the vegetative and simple mechanical measures that converse soil and water, increase the rate at which soil absorbs water, and improve the storage capacity of the soil. Such measures include contour - tillage, crop rotations, contour furrowing and listing, stripcropping, green manures, cover crops, level terracing, reseeding, proper management of range and pasture, reforestation, forest and woodland protection and management practices and such minor structural measures as gully plugs, diversions, and grade stabilizers.

For more complete watershed protection, however, those measures must be supplemented by, or combined with, water - retarding and disposal structures in farm drainage ways, along roads, and in the smaller streams.

The second category of measures is planned primarily for the management of water-flow after it has left the fields and farm waterways and reached the small branches and creeks. They included floodwater - retarding structures, stream - channel improvements to increase carrying capacity and stabilize beds and banks, minor flood-ways, sediment - detention basins, and similar measures. The distinguishing characteristic of this group of measures of flood control is that their primary benefits are off-site or down-stream, not at the places where they are installed. In a sense the primary benefits are public, because they accrue to other farmers, towns, roads, and so on, downstream from where the measures are installed.

Some of the measures, which are needed for stabilization of watershed lands, are too complex for landowners to install, or the benefits will be so long deferred that it is unreasonable to expect very many farmers to do these jobs without assistance. For example, rainforced concrete structures needed to stabilize large gullies require all the elements of planning, design, and supervision of construction that go into a major flood-control dam. The benefits from this type of gully control are primarily to watershed lands that would be destroyed by the headward growth and enlargement of the gullies. And those lands may be on other farms above the present gully head. If economically justified in the public interest, it becomes more efficient and economical for the installations to be made by agencies of Government under binding maintenance agreements.

The measures that are primarily for flood control, such as retarding structures and channel improvement, can rarely be installed by individual - landowners. They require group action, skilled technical planning, and corporate or governmental financing.

One of the most important recommendations that needs to be carried out is the development of sound coordinated flood-control plans for every watershed in Puerto Rico in order to assure a well balanced and truly effective program for the prevention of flood damage. Piecemeal flood control, where only a part of the watershed is considered, will not be effective. A coordinated plan should be prepared by the Federal and Puerto Rican agencies concerned. These should include the Soil Conservation Service, Forest Service, Aqueduct and Sewer Authority, Water Resources Authority, the Puerto Rican Department of Agriculture, and the Experiment Station.

Flood control must begin where the rain first hits the land. It is first necessary to get the land to absorb as much of this water as possible. The excess that cannot be absorbed should be held or retarded on the fields by means of soil conservation measures applied to the land as needed. Adequate control must be exercised for every acre, from the top of the watershed down to the place where the river empties into the ocean.

In addition to the need for a coordinated program, group action on the part of farm owners and operators should be encouraged to facilitate dealing with problems of watershed extent. This may be done thru the Soil Conservation Districts or thru the formation of watershed associations where the areas overlap into different districts.

Greater emphasis should be placed on creating public understanding of the soil and water resources problem in Puerto Rico and the importance of corrective measures which will also contribute to flood control. This is important in both rural and urban areas.

Drainage

Where excess water accumulates in and on the soil, the land is rendered unfit for production of many crops. Even where th[illegible] condition is of fairly short duration, cultural operations required for crop production may be delayed past the optimum planting date or crops already planted may be drowned out.

The reclamation of such wet areas is centred on means of removing the water from these areas more rapidly than it is removed in their natural condition. This process is termed drainage.

Excess water becomes a problem when it interferes with tillage, land preparation, the development of plants, and harvest operations.

Much of the excess water is removed naturally by surface runoff, deep seepage, evaporation, and transpiration, but those processes often are to slow to prevent damage to the crop, and farmers must resort to drainage to remove the water faster. This water may be in the soil voids or may come as runoff from the surrounding places at higher elevations.

Proper drainage is the removal by artificial means of excess water from the soil profile to enhance agricultural production - more specifically, the removal of excess gravitational water from the soil. The word excess implies that drainage water cannot be considered as water lost, for it never was available for plant growth. The word gravitational indicates that drainage water is not held in the soil by any forces except gravity.

For Puerto Rico where land is so scarce, the reclamation thru drainage of swamps and other low areas subject to frequent overflows is important, but effective drainage of lands already under cultivation is probably still more important.

It is estimated that in Puerto Rico there are about 59,000 acres of swampy land which need provision for drainage if crops are to be produced successfully. Poorly and imperfectly drained soils of Puerto Rico include the alluvial soils of the inner plains and river flood plains, the terraces and alluvial fans, and the coastal plains and lowlands. About 40 percent of them are fertile soils of the river flood plains which are mostly devoted to sugarcane cultivation.

Infiltration tests conducted by the Experiment Station of the University of Puerto Rico have indicated a slow infiltration rate of 0.09 inch per hour for representative soils of this group. The values range from 0.03 for Aguirre Clay to 0.19 inch of water per hour for Vayas Clay. Laboratory percolation determinations on subsoils have indicated rates of less than 0.01 inch per hour for Caguas Clay, for Vega Baja Clay, and a poorly drained phase of Lares Clay. Any rate below 0.05 inch per hour is considered likely to limit the growth of the most crops. These soils are confined to level topography where percolation is impeded by some unfavorable soil condition, or where the distance to the drainageway prevents the effective movement of water at enough speed before more water is added by rainfall. Most of these lands are under cultivation.

Surface drainage systems are designed primarily to remove water that is on the surface and has not entered the soil profile.

That is done by developing the slope of the land so that the excess water will flow by gravity to a system of shallow field ditches, which empty into larger mains and extend to a satisfactory point for disposing of the water.

The removal of water that has already entered the soil profile is considered subsurface drainage. Thus open - ditch drainage removes surface water but is classified as subsurface drainage because the ditches affect the movement of ground water to the same degree as mole or tile drains placed at the same depth.

Essentially any one drainage problem must be considered as a combination of surface and subsurface water removal. They are interdependent; planning for one without concern for the other will result in systems that are inefficient and ineffective. Solution of a drainage problem also depends on the application of modern soil and crop management principles that will maintain soil structure and high fertility.

Drainage requirements, as they affect plant growth and response, are determined by the effects of the excess moisture on aeration (the amount of air in the soil), soil temperature, biological activity, structural stability of the soil, soil chemistry, and the overall problems of land and crop management.

In localities where drainage is a problem, one often sees stunted crops with yellowing leaves in low areas of a field when the soil has become saturated. If the excess water remains for some time, the plants usually die. Such conditions are primarily the result of root damage caused by reduced supplies of oxygen and accumulations of carbon dioxide with the related effects on the soil - plant relations. The adverse effects are not necessarily from the direct presence of the excess water, for crops will not suffer even in total water culture if they can get air.

Soil aeration is a function of the sizes of the soil particles and their arrangement and the degree of saturation, or the soil moisture content. If the larger pores are free of water, so that the moisture level is below field capacity, gas diffusion can be proceed satisfactorily. When the profile becomes saturated, however, the rate of diffusion declines.

Open ditches are used as a rule for removing excess water in cultivated fields. If well constructed, they usually have ample capacity and are able to dispose of the water quickly at a low grade. On the other hand, open ditches waste considerable land, (sometimes as much as 10 or 15 percent of the area) and demand a yearly expenditure for upkeep. If not well constructed, they sometimes are ineffective, inconvenient, and may encourage erosion.

The flatland areas of organic soils planted to sugarcane require more complex drainage patterns than do mineral soils; in many cases pumps must be installed and dikes built in addition to all other ditches needed for mineral soils.

Drainage problems on many hillsides and on rolling land are limited to the disposal of runoff during excessive rainfalls. The removal of runoff must be effected with a minimum of soil losses, which under improper management may be large. Rather than a removal of water, the problem with soils of the uplands is mainly one of soil and moisture conservation. The term "drainage" under such conditions must only imply the disposal of excess runoff at a nonerosive speed.

In the case of tabacco plantations, which are often on fields with slopes of more than 40 percent in Puerto Rico, shallow ditches are dug around every plot (each plot enclose about 900 to 1200 square feet) giving the field the appearance of a gridiron. In that way, the water travels only very short distances before entering the ditches and therefore its erosive power may be decrease.

In coffee plantations, holes may be dug one by one foot and about 8 to 12 inches deep near most of the coffee trees. During rains these holes catch runoff water and sediment and check the speed of the flow. In addition, deep long pits are dug along drainageways and hillside roads which also receive sediment and check the velocity of the runoff.

With shallow soils on the uplands there are often seepage spots where slowly permeable rock layers force percolating water to the surface. These areas may interfere with farming operation and they must be considered when hillside ditches, bench terraces, or other conservation practices are being applied.

Land not under cultivation in Puerto Rico, but which could be cultivated if properly drained, totals around 58,800 acres. Land already reclaimed by gravity, tiles, and pumping approximates 7,500 acres.

Law number 254 of May 14, 1945 commended the Land Authority with the reclamation of the swampy or improductive lands. Among these, was included the area known as the Caño Tiburones, comprised in the municipalities of Arecibo and Barceloneta. By virtue of law number 42 of 1948, an appropriation of $1,500,000 for the construction of the drainage system which provides the reclamation of 6,600, acres of land, was made.

Already about 8,768 acres of land in Caño Tiburones, Plazuela, Matamba-Regadera, Loíza and Toa farms have been reclaimed by the Land Authority.

In the following table, is summarized the work accomplished by the Land Authority in the drainage of these swampy lands.

Proyect	Location	Number of Acres Reclaimed	Invested Resources
Caño-Tiburones	Arecibo and Barceloneta	6,578	$2,118,000
Plazuela	Barceloneta	800	63,511
Matabamba-Regadera	Vega Baja, Vega Alta, Dorado	540	212,254
Loíza	Loíza	450	142,245
Toa	Toa Baja and Dorado	400	46,215
		8,768	$2,572,225

Other poorly drained soils which could be reclaimed for agricultural uses total more than 40,000 acres. These are located in various sections of the Island.

Drainage requirements are different on each group of soils and for each crop. There is need for improved drainage in the lowlands and this ordinarily calls for the establishment of properly spaced laterals, or "cruceros", and main channels of adequate capacity. The spacing, depth, and capacity of the ditches will vary with the amount of water to be disposed of, and this in turn varies with the rainfall and soil properties.

Also, drainage is an essential part of the improvement of salty soils. Deep ditches or tiles are needed to hold the permanent water table below about 4 feet or deeper, so that salts may be carried down far enough to keep them from returning by capillary action to the crop-root zone. Until adequate drainage is provided, it is usually impossible to improve or reclaim salty soils.

Improved drainage in the upland areas is necessary. This calls for the use of hillside ditches, bench terraces, graded contour planting, and grassed waterways as the particular piece of land and the crop grown may require. Properly located hillside interception ditches will usually eliminate hillside seepage zones as well as provide runoff control. The Soil Conservation Service has done considerable work on drainage problems in Puerto Rico, and the advice of this agency should be utilized for best results.

Drainage costs vary widely from area to area according to the volume of water to be disposed, soil characteristics, and other factors. Under present conditions the cost of establishing drainage projects averages $604.84 per acre in Puerto Rico (Land Authority, 1966).

Since providing proper drainage tends to be rather costly, there is need for developing improved methods and techniques for removing excess water. Proper planning should produce a drainage system that will permit maximum effective water intake and storage in the soil and will remove excess rain without excessive erosion. Studies should be made of the possibilities of subsoiling to break compact soil layers and allow quicker percolation of water. Also, studies should be made of the possibilities of tile and mole drainage systems. Use of chemicals and other materials that may improve soil structure should be examined to determine their practicality from the standpoint of effectiveness and cost. In view of the common use of ditches, there is need to determine the proper spacing and depth of open ditches under varying conditions. In connection with all the work on drainage, there is need for intensifying research relating to water movement in soils and other physical properties of soils.

Of no less importance is the need to take into consideration such items as soil fertility, cost of developing farm units after drainage is completed, cost of maintaining drainage improvements, and markets for the farm products to be grown. Sometimes plans for drainage are incomplete in some sections or improvements are designed with insufficient capacity. Large areas sometimes remain poorly drained and cannot be made to produce profitable crops without extensive additional work. Difficulties in most cases are due to poor planning and piecemeal methods of drainage. Some projects do not employ competent drainage Engineers. Many of the projects are unsound from the beginning because the soils are unsuitable for tillage or not sufficiently fertile to warrant development or because lack of control or erosion from surrounding hill lands made it impracticable to maintain the drainage improvements.

To avoid such difficulties enough investigations should be made by those interested to determine the desirability of drainage enterprises from the soil and land - use view points, to develop sound engineering plans, and to finance the work on a reimbursable basis.

In the development of drainage enterprises many mistakes have been made. Some land of little value to agriculture has been drained. It has also been damaged for wildlife. In other areas the plan of drainage proved to be unsatisfactory and too costly. In some places no provisions are made to control sediment or to maintain ditches and other works, and within a few years the drainage improvements are destroyed.

Salt-Water Intrusion

Problems related to the water table are many and varied and often are acute in the irrigated areas of the south and southwest. The use of surface waters for irrigation usually is accompanied by a rising water table, altho in some conditions the percolating waters actually assist in the recharge of underground water deposits in adjoining areas or move downslope and interfere with the use of lower lying lands. When the water table rises too near the surface, it can produce drainage, salinity, and alkali problems, which must be corrected if cropping is not to be limited.

Pollution of the ground waters occurs as a result of overdraft. Salt water has intruded into the underground water supply in parts of the south and along the southwestern coast. In these areas, overdraft of wells have brought an increasing percentage of minerals in the waters. The water in some wells is now adjudged injurious to unsatisfactory for irrigation.

The anticipated construction of extensive industrial facilities at the port areas or the draining of marine sloughs for agricultural use may involve the construction of additional wells, drainage ditches, or canals close to the sea. Intrusion of sea water in fresh-water supplies can occur and will occur unless careful control is exercised over the location of wells and intakes and the amount of water withdrawn. Excessive lowering of ground-water levels can induce intrusion directly from the sea or from the lower reaches of streams. The streams themselves can become the spearheads of intrusions. A comprehensive observation and sampling network will be necessary to warn of the event of salt - water intrusion, thereby providing the opportunity for remedial action before extensive damage results to streams or ground-water deposits.

A special intrusion threat may exist where sandbars form at the mouths of streams, a common phenomenon in Puerto Rico. Salt water moves up a stream channel during periods of medium to low discharge. As the sandbars form, inflow of salt water is retarded or even stopped; but saline water is impounded and may contaminate the ground-water deposit in which channel is cut.

Concurrent with the impoundment of saline water, fresh water coming down the stream also is impounded. If the resultant stream level is higher than the level of the adjoining ground-water, water from the stream will flow into the ground and may waterlog the soils.

Often we could save ourselves toil and trouble if, in planning public water works, we made a thorough study of water supply and of other points that pertain to the proper functioning of projected works. But too often we neglect the water-resources factors of which salt-water encroachment is one. Thus, because of inadequate planning, irrigation projects and other public works may fail because the fields become waterlogged with too highly mineralized water.

Salt-water intrusion thus looms as a big problem in some sections of the Island. Fortunately, even in the parts that are seriously threatened, there generally still exist plentiful ground - and surface - water that need only intelligent development and management to make them serve long-term human needs.

Salt-water encroachment, both from the ocean water and from residual saline bodies, is more serious in the coastal sections.

In places where the factors involved in salt-water encroachment are known, public agencies generally can formulate operational plans for the effective, continued, and satisfactory use of water. If, thru, ignorance, apathy, or carelessness, the proper management of this precious resources is neglected, salt-water intrusion could become disastrous.

9. Summary and Recommendations

Six developments since 1940 have made us realize that we must take immediate steps to increase the conservation, improve utilization, and expand the administration of our water resources. They are (1) the Second World War, (2) increases in population, (3) industrial and agricultural development, (4) droughts, (5) pollution of streams and lakes, and (6) erosion and sedimentation.

The outbreak of World War II marked the beginning of a new era in the economic and social affairs of the Island. First, there was the Federal Government change's in approach to the problems of Puerto Rico which gave greater recognition to the underlying problems of the Island and, by shifting away from the emphasis previously given to the relief aspects, concerned itself with building the foundations for a sounder economy and a more potent and capable local government. Secondly, for the first time, the government was able to evolve a program consistent in its objective of ending to planless drift which had been so characteristic of the Island's economy. From the very start, this program directed at basic problems affecting the welfare of the people, gave expression to new development and the improvement of living conditions for the people. The industries recently developed in Puerto Rico have added to employment and buying power with benefit to all the people. The drive for further industrial expansion is being pushed vigorously. This is as it should be. In addition to increasing employment for more people, greater industrialization enables the people living in urban areas to become better customers, not only for local businesses but also for the farmers. It improves the economic balance between agriculture and industry while at the same time providing greater opportunities in both rural and urban areas. While doing everything possible to contribute fully to the war effort, the Puerto Rican Government moved forward with its program for land reform, economic development, and social improvement.

Our population has grown far above normal expectations and so has the amount of water needed for production and to fill the countless other needs people have for water. We estimated in 1965 that the Island's population in 1980 would be 3,600,000. Since then we have had to revise that estimate to 4,100,000 (Unpublished Report, Planning Board 1967). If the present high rate of population continues, Puerto Rico will double its population in twenty five years.

Industrial expansion (and with it a heavy demand for water) is moving from the Metropolitan area of San Juan to other sections of the Island. Planning Board studies have shown that, to continue the rate of industrial growth our population requires, we shall have to place more industrial plants per square mile in Puerto Rico than the United States. The total future industrial water need for 1980 has been estimated at 100 mgd besides the brackish and salt water for cooling. Samples of industrial requirements are: 18 barrels of water to refine a barrel of oil; 300 gallons of water to make a barrel of beer; 10 gallons of water to refine a gallon of gasoline; 250 tons of water for a ton of sulfate wood pulp; and 600 to 1,000 tons of water for each ton of coal burned in a stream powerplant.

A large paper mill uses more water each day than does a city of 50,000 inhabitants.

Recurring droughts are a normal feature of climate in Puerto Rico. Critical periods of drought have existed practically in every section of the Island. The severest drought on record of 1944 was followed by droughts of varying intensity during the years of 1945 thru 1967 causing great losses to agriculture particularly to sugar growers. Losses to this sector of our agricultural industry brought by these drought periods amounted to over 5 million dollars. Municipalities had to find new sources of water to supplement or replace their supplies. Industries had to develop more of their own water supplies. Satisfying the needs of human beings and livestock for water became a serious problem in many sections of the Island.

To farmers everywhere drought is a serious matter. Drought is hard to measure because we are not yet able to determine the water needs of plants very accurately. We do not know when to expect droughts or how intense they may be. Therefore we cannot be sure which moisture conservation measures may be best at a given time and place. Drought deserve study. Not until we have conquered drought by scientific irrigation will we achieve the maximum from the soil.

Large increases in the acreage under irrigation and the rapid introduction of supplemental irrigation thruout the south and southwest will contribute to the much heavier consumption of water.

The changing Puerto Rican diet now includes more animal products, fruits, vegetables, and sugar, and fewer grain products. The cropland requirements for food production because of the inclusion of more livestock products in our diet would make a total of 2.5 acres of cropland needed to support each person. Because the land available for new production is limited (less than one-half acre of arable land per capita), the increase in food requirements will be associated directly with use of water thru irrigation and with the planned increase in production on lands now being farmed.

The application of water in irrigation is relatively inefficient, and the annual delivery to farm may range from less than an acre - foot (325,850 gallons) up to more than 7 acre - feet (2,280,950 gallons) an acre.

The efficiencies with which farmers apply their irrigation water to their crops may range from 15 percent to 90 percent - that is, from 15 to 90 percent of the water they turn onto a field will be made available to the plant roots, the remainder will be lost as runoff, deep percolation, and evaporation.

Efficiency in the use of water is an important phase of water resources management. Irrigation is costly in Puerto Rico because of the large amount of labor required by the prevailing methods of water distribution. The cost of the water itself to farmers is reasonable where supplied by the Government, but water from some private development is much more costly. The loss of water thru inefficient methods of application adds greatly to the overall cost. As an average, approximately 70 cents out of every dollar paid for water is lost because of water leaches away. With improved methods only 25 percent or less would be lost in this way. If all irrigation water were distributed efficiently, there might be no lack of water for maximum yields on land now under irrigation. Moreover, certain adjoining lands which are not now irrigated could receive water they need.

A continuing problem in the Isabela irrigation district, for example, is the great loss of water that takes place thru seepage and other causes. When the irrigation system started operation, it was found that from 50 to 60 percent of the water was lost thru seepage and occasional sink holes that appeared in the main irrigation canals and in the distribution laterals. In the network of canals owned by the service this has been corrected by lining the canals with concrete. The losses of water thru cracks and other causes in the diversion canal have now been reduced to 4.6 percent. The losses in the Moca Canal, which has been lined with precast concrete slabs, have been cut down to 20 percent. This latter method of lining canals does not appear satisfactory since there always will be numerous cracks between the slabs where water may escape in considerable quantities. The craks of the main canal and several other important laterals have been lined with concrete, using a mixture of cement, sand, and "polvillo" from local stone quarries.

In spite of all these improvements that have been made to save water, the overall losses thru seepage, craks, evaporation and other causes are still considerable. In 1964-65 they amounted to 29.2 percent. The water losses suffered by the farmers are above 50 percent.

Water applied in excess of needs is not only lost, it also leaches away needed plant nutrients, especially nitrogen. This increases fertilizer costs and reduces yields per acre.

If all of the land in Puerto Rico received adequate water at all time it is estimated that total agricultural production would be icreased by one third or more, but very little effort has been made by the Puerto Rican Government to demonstrate to farmers the benefits from irrigation under normal weather conditions and under dry conditions. With the exception of a single irrigation experiment performed with sugarcane, no research has so far been carried out with other crops to indicate the influence of irrigation water in increasing yields.

Observations made at Aguirre Central show sugarcane can utilize from 100 to 160 inches of water a year, including water lost by deep percolation during irrigation. The amount of such loss depends on the soil properties, porous sandy soils needing the most water and clayey soils needing the least. Rainfall on the lands where these experiments were conducted averages about 45 inches a year. These lands receive the equivalent of some 45 inches more of rainfall from the South Coast Irrigation Service. This total of 90 inches has been found inadequate and is profitably supplemented by more than 50 inches of water obtained by pumping from the subsoil.

Rainfall in the north coast area averages from 60 to 80 inches per year. This is less than the amount of water received from rainfall and gravity irrigation by Aguirre Central lands, with the further inconvenience that rainfall water is unevenly distributed during the year while irrigation water can be served when it is most needed.

During years of normal rainfall, supplemental irrigation on the north coast lands may not show a particularly high gain in yield over non-irrigated lands. However, irrigation presents an insurance against damage to crops as a result of possible dry spells, prolonged or short, which could readily cause millions of dollars in losses. Viewed in this way, the margin of profit from irrigation is high compared to the cost. The fact that the north coast area is favored with an adequate supply of surface water which is now wasted to the sea, adds to the attractiveness of supplemental irrigation for this area.

Of the total number of acres now under irrigation in Puerto Rico, at least 90 percent of the irrigated land is used for growing sugarcane. A very small acreage is irrigated by sprinkling, the remainder by furrow methods. The so-called "McLane" system with minor variation is used on an estimated 90 percent of the irrigated area. This is a short furrow, or essentially a modified basin method. Each furrow is filled individually from closely spaced supply ditches, or "McLanes", which most commonly are spaced from 20 to 40 feet apart. Recently, some "McLanes" have been spaced as much as 72 feet apart. Long furrow are graded for about 0.5 percent of fall, and the shorter furrows are often level. In essentially all systems, sugarcane is planted and grows in the bottom of the furrow. With time and cultivation the furrow tends to fill so that during the second or later years, the capacity for water is much reduced. The canes also retard and interfere with water movement in the furrows.

In 1953 numerous tests were conducted on the lands of Luce & Co. in the Santa Isabel area, to determine the efficiency of various methods for applying irrigation water. These tests showed that, on the average, about 40 percent of the water applied is held in the root zone for plant use. Highest losses occur when the land is poorly prepared, and when excess quantities of water are applied at times when the soil has only a small capacity to store available water. More limited tests have been made thruout other parts of the Island.

As an overall average, it is estimated that only 30 percent of the water applied as irrigation is held in the soil for plant use. In certain cases only 20 percent is retained, 80 percent being lost by deep percolation or by runoff to the sea. From this it is apparent that any considerable improvement in the efficiency of applying water would obviously result in a substantial saving of water. Also, the prevailing methods of furrow irrigation have a high labor requirement making distribution more costly. The average irrigator probably irrigates about one acre per day. Careful planning, training, and supervision have increased the average per man-day to two acres or more in some cases.

Properly designed sprinkler irrigation is an efficient method of water application. Further tests conducted by Luce & Co. have indicated that with properly spaced application of about one inch per irrigation, an average of 75 percent of the water is held in the root zone. Most of the remainder probably blows away as spray or is evaporated. Sprinkling also has a low labor requirement. But the initial costs of equipment and the upkeep tend to be high, altho these costs are being reduced as various improvements are made. The feasibility of wide spread sprinkler irrigation appears to be primarily an economic problem for which there is as yet no stock answer. Its efficiency in saving water and labor is unquestioned. On the other hand carefully laid out and properly used furrows can provide at least 50 percent efficiency; average practices with planted cane are about 40 percent efficient; poor practices which are common thru Puerto Rico give only 25 percent or less efficiency in the distribution of water.

Once the advantages of surface irrigation and the greater advantages of overhead irrigation are more widely known thruout the Island, it should be possible to overcome the apathy toward irrigation that now exists among many farmers. This would, perhaps, lead farmers to organize cooperative or government - sponsored portable sprinkler system.

The need to educate farmers to the value of irrigation and the methods to be employed for effective results is not confined to any one area. Most of the farmers in Puerto Rico think of irrigation in terms of irrigating sugarcane. The general tendency is to overlook the possibilities of irrigating other crops profitably. Few other crops are irrigated on a substantial scale, even tho irrigation water may be available.

One of the drawbacks has been the lack of information concerning the irrigation of crops other than sugarcane. Experiment work is needed to demostrate the value and methods of irrigating a wide range of crops under the different conditions found in the various parts of Puerto Rico.

In considering the irrigation needs of Puerto Rico, it must be recognize that despite many shortcomings the Island has made notable progress in the use of water for irrigation. The Island has had very little outside help and most of what has been accomplished in developing the various projects in the last half centry has been thru local governmental effort and enterprise.

Irrigation has contributed greatly to agricultural productivity and has made it possible to bring into use lands which otherwise would remain far less productive. This has been of vital importance to economy, and it can become far more significant for the future.

The experience that has been gained both good and bad offers a sound basis on which further development of irrigation in Puerto Rico may advance, provided full advantage is taken of the lessons taught by experience with existing projects. The fact that a large part of the water resources of Puerto Rico are still unused and are being wasted when the economy could profit so greatly if they were fully and wisely employed, stands out as a prime motivating force for prompt and determined action.

But action cannot effectively accomplish a set purpose without organized planning and follow - thru, adequate education and information, and research sufficient to provide the basis for the work that is scheduled. The one main weakness in the development and operation of irrigation projects in Puerto Rico is that various agencies in position to help either have not been fully utilized or else they have not been directly tied in with the work soon enough. Projects for irrigation (or for any other purpose involving the broad interest of agriculture) should be considered and planned jointly by all agencies concerned. In this way the single agency charged with the basic responsibility will have the benefit of technical assistance and advice which will enable it to avoid or anticipate possible pitfalls.

Use of conservation must go hand in hand in overall management of water resources. Altho the manner of use is important from the standpoint of the economic benefits to be derived, proper conservation is necessary to insure prolonged use. For example, where a dam is built to impound water, the life span of the reservoir is largely dependent on how much sedimentation takes place from the waters that run into it for storage.

The importance of conserving and thereby prolonging the usefulness of the irreplaceable water - storage capacity of every reservoir on the Island must be stressed again and again. This dependency is increasing year by year, but the land sources from which water may be drawn and the natural areas for storage are limited. Yet, despite this situation, there is no complete program operating for the conservation of the water supply and storage resources which are so vital to the economy.

The typical dam in Puerto Rico has been built largely on the basis of whether it would amortize its cost within an estimated period of usefulness determined by such factors as prevailing conditions affecting erosion and possible sedimentation. Once it was reasonably certain that the expenditure would be returned within the estimated period before siltation destroyed the water storage area, construction of the dam was ready to start. Whether any thought was given to measures that might initially be taken to prolong the estimated life span of the reservoir is academic, since nothing of the sort that would provide adequate watershed protection or treatment has actually been carried out as an integral part of such a project.

The ample experience with reservoirs in Puerto Rico makes it clear that under the conditions that prevail, the building of a dam in the lower regions ahead of watershed protection work in the upstream areas is like putting the cart before the horse. Of course, a certain amount of sedimentation caused by geological erosion cannot stopped, but the big problem awaiting attack in most of the watersheds above reservoir locations is the accelerated erosion caused by man. To provide the necessary watershed protection, work must be started even before construction of a dam begins. It must be carried thru continuously after the reservoir is in operation and adjustments made in the methods employed as changing conditions may require. Soil, plants, and water are so interdependent that all three must be considered in managing a watershed for the greatest public benefit.

The agency of the Puerto Rican Government that is primarily responsible for the various aspects of water and energy resources conservation, development, and utilization is the Puerto Rico Water Resources Authority, a public corporation established by the Legislature. This agency has done an excellent job in developing the water and power resources of the Island. But the various activities have not been properly balanced so as to make adequate provision for watershed protection in the planning and maintenance of water development and reservoir projects.

The fact that a dam will amortize its cost by the time sedimentation destroys its usefulness is important from the standpoint of investors who may finance the project. It also appears to the public. But by merely reaching this point the project does not serve the public interest in full measure. It does not deal with the question of what can and should be done to prolong the life span of a reservoir so that it may continue to render good service for a period far greater than the number of years estimated for amortization purposes. This should be of paramount public concern in Puerto Rico in view of the scarcity of natural damsites and the great need that exists for prolonging the useful life of those that are available.

Of course, the cost of applying adequate watershed protective measures must be taken into consideration and weighed against the benefits that would accrue. However, a great deal of what needs to be done can be accomplished with a relatively small expenditure of funds on some things and without spending any money on others. All of the possibilities need to be explored.

The full burden of the watershed work does not necessarily have to be borne by the Water Resources Authority. It should, however, provide the leadership that will permit and adequate job to be done in the watershed and reservoir areas. Various other governmental agencies in Puerto Rico deal directly with soil and water conservation and forestry problems, and they also work with farmers. Those agencies are in position to contribute materially to the success of a well - rounded watershed program. The help that is available from them should be more effectively utilized by the Water Resources Authority both in planning and executing watershed treatment and protection measures. As a basis for cooperative action, the Water Resources Authority might find it desirable to enter into a working agreement with all the agencies that would be involved so as to arrive at a definite understanding of the responsibilities that would be shared by each in moving forward with a watershed program.

In some instances, it may be necessary to resort to regulatory measures in order to stop destruction arising out of unconscionable waste and misuse of limited natural resources. For example, tilling of steeply sloping land right up to the very edge of a reservoir certainly hastens the time when this water storage facility will be ruined by sedimentation. On the other hand, the growing of grass, trees, or some other permanent cover over a fixed area starting away from the water line would afford protection from silting and at the same time not deprive the owner of the use of this land. Help could be provided to farmers to make the necessary adjustments in land use practices. In some of the more important watershed, it might be desirable for extremely critical areas to be publicly owned, with perhaps a form of zoning to permit proper management and use of such lands by the people who live on them. Such a zoning system might also be desirable for critical areas under private ownership, so as to prevent seriously destructive land use and cropping practices.

No matter what course is followed, the fact is that is must be suited to the needs of the particular area and the problems that must be met. With the proper approach it should be possible to develop the understanding that is necessary for the support and cooperation required in the successful operation of any program.

In considering the problems associated with conservation of land and water, the problems of sedimentation of reservoirs and the resulting damage, are of paramount importance. The fact stands out that the movement of certain quantity of soil and rock particles by running water from higher to lower parts of a stream drainage area is a natural and continuous phenomenon that cannot be stopped by Man. In planning and designing reservoirs in Puerto Rico, this basic fact should be recognized and included in estimating the economic feasibility and the life span of projects. But, even when the quantity of sediment transported by a stream does not prove to be a critical factor, interest in the rate of erosion should not diminish.

By reducing erosion, a low rate of silting may be maintained so as to prolong the useful life of storage reservoirs many years after the cost of their construction has been amortized. Since desirable sites for storage reservoirs are limited in Puerto Rico, this factor alone demands that they be made to serve as long as is practically possible.

The silting of storage reservoirs in Puerto Rico has specially significant objectionable results because of the seasonal distribution of rainfall, which necessitates ample storage to conserve runoff during the wet season for use during the dry season. Most of the water stored in reservoirs on the Island is used for the development of power, irrigation, and domestic and industrial water supply, all requiring continuous delivery. Reservoirs are subject to gradual filling by sediment which must be considered carefully in the planning of a project. To some extent, sedimentation may be controlled by land use practices deliberately planned and maintained to reduce sediment loads in the streams. Also, it may be feasible to operate group of reservoirs so as to bypass the sediment laden flood water during the early part of a flood, and to store relatively clear water during the latter part of a flood.

The value of a dam depends, in varying degrees, on the amount of reservoir storage the dam creates. Dams on larger rivers that have relatively uniform flow may created little or no storage (altho usually some pondage) value. On the other hand, dams on streams of variable flow may be value in large measure by their creation of storage capacity for equalizing the flow.

Variable stream flow is the rule in Puerto Rico, and accelerated sedimentation of reservoirs results in the loss of power, irrigation, and other water use values, that, under a lower rate of sedimentation, would be available for a longer period.

In addition, a water management and conservation policy for Puerto Rico must concern itself with the problem of pollution, which is already serious in many respects. As population density increases and industrialization expands, this problem grows more acute and dangerous. The pollution of most streams in Puerto Rico, many of which are used for domestic purposes, constitutes a menace to public health, recreation, agricultural and industrial production, and wildlife. Corrective measures and proper controls are urgently needed to cope with this situation.

The principal forms of pollution are domestic wastes (sanitary sewage), industrial wastes, and silt.

Sanitary sewage includes everything that goes down the drains of a city and into its sewer system - the used water from toilets, bathtubs, and sinks and washings from restaurants, laundries, hospitals, hotels, mortuaries, and many more.

Industrial wastes are the acids, chemicals, oils, greases, and animal and vegetable matter discharged by factories, sometimes

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Municipal water purification systems have remained a remarkably effective protection against the health hazards of water pollution. But the growth and concentration of population and the increase in the volume of pollution make more complicated and costly the job of producing safe and acceptable drinking water. The dangers increase. A human error or a mechanical failure that permits even a small breack in the protective wall can bring disaster.

Serious as are the dangers from the wastes discharged by municipal sewers, they are only part - and in point of complexity only a small part - of the total pollution problem that the Island faces today. The sevenfold increase in industrial production since 1947 has added tremendous volumes of wastes to the streams. The new products that advancing technology is turning out have created complex problems of water pollution. The possible effects of some of the wastes stemming from production and widespread use of the new chemical products are not yet known. The effectiveness of present water-treatment processes in removing them is not fully assured.

Most uses of water are affected by pollution. We all believe that water for drinking and related domestic purposes has highest priority and that those uses must be safeguarded from the effects of pollution.

Water is the most used raw material in our factories. Most of it is taken from rivers. For many industrial processes, the into city sewer systems and sometimes thru separate outlets directly to the watercourses.

Silt is the soil that washes into the streams, muddies to waters, and fills up reservoirs.

In Puerto Rico, until comparatively recent times, the disposal of rubbish, garbage, and human wastes was a haphazard undertaking, left entirely to each household. Usually wastes were dumped in alleys, streets, or ditches for eventual destruction by time and the elements. The growth of towns and cities with concentration of population in metropolitan areas brought the development of inside plumbing, and the general use of cesspools as repositories for human wastes. Disease epidemics, traced to pollution of wells by seepage from the early cesspools, provided the impetus for the systematic construction of our sewer systems.

With the widespread adoption of modern sewer systems, which collected the wastes of whole cities and discharged them at a few concentrated outlets, human wastes and other filth no longer accumulated in the streets to make pestholes of our towns and cities. But the problem had only moved its location. The many communities taking their water supplies from streams are still menaced by the wastes reaching those surface waters thru sewer outlets. Science provided a solution by developing purification processes for removing bacteria and other pollutants from water.

fewer fish. Substantial economic loss is suffered by the tourism industry, which is an important sources of income in Puerto Rico.

Pollution can be controlled. Pollution is not something that must be endured as an inevitable consequence of our urban and industrial growth. Remedies already available will prevent much of it. Some difficult problems remain, but they can be solved. All these harmful effects can be prevented by maintaining a sound program for abatement of water pollution.

The Puerto Rican Government should rate sewage disposal as important in the modern community as is the supply of drinking water. Still more funds will have to be appropriated for supplying sewage-treatment plants to all existing sewerage systems which do not have adequate disposal facilities. To reduce pollution dangers, everytown on the Island would have to have a sewerage system and sewage-treatment plant.

Also, more funds for the pollution abatement are needed by the Department of Health. This program is now being carried on almost completely with Federal funds granted to Puerto Rico by virtue of Public Law 845. The money now available is wholly inadequate. More funds are necessary to increase personnel and facilities in order to achieve pollution abatement more efficiently and in a shorter period of time. The time factor is a very important one in view of the serious nature of the pollution problem that exists in Puerto Rico.

water must be relatively pure. Our fastgrowing chemical industries require tremendous amounts of good water. Production costs rise if the water must be treated before it is used. The availability of good-quality water therefore is an important matter in the location of new industrial plants. Its lack discourages new industry and the expansion of existing plants and adversely affects the overall economy of the Island.

Crops irrigated by waters containing sewage pollution may transmit disease. Waters carrying industrial pollution, such as chemical wastes, can damage the crops they irrigate. Many natural streams formerly relied on to provide water for livestock have become so polluted that their continued use is unsafe.

Desirable fish do not thrive in heavily polluted waters. On different occasions, as a result of excessive pollution, thousand of dead fish have appeared in many bodies of water on the Island. The destruction of animal and vegetable life in these waters represents a great loss of income for the many people who make their living from fishing.

Outdoor recreation suffers from pollution's damaging effects. Beaches have been closed to swimmers because of health hazards. Boating not only loses its esthetic appeal when waters are loaded with pollution; it becomes actually dangerous. The joys of waterside picnicking are destroyed. Sport fishing produces few pleasures and

The different agricultural agencies concerned with research, education, and operational programs could help solve many of the difficulties if their technical resources were focused on them. Altho a great deal of information is available about the use, the management and control of water for irrigation and other purposes, this is of a disorganized nature. However, there is much that remains to be developed to meet the special conditions of soil and other factors found in Puerto Rico.

For example, there is a need to determine the economical methods and the cost of improving present irrigation canals and laterals in order to reduce water losses to a practical minimum. Once this has been determined, it should provide the basis for making available for the necessary improvements. At the same time, provision should be made for furnishing to farmers the technical and other assitance that will be required to enable them to cooperate in this work.

Also, there is an urgent need to encourage farmers to improve efficiency in their use of irrigation water. This could be accomplished thru educational activities, demostrations, and suitable information, but certain incentives may also be required. Perhaps a system of rate differentials might be employed as an incentive that would favor users who make and maintain certain approved permanent improvements. Consideration should also be given to the

Focal Points of Action

It is apparent that there is a need to centralize the responsibility for establishing policies, standards and procedures, for uniform use in the formulation, appraisal and review of plans for the development of water resources, to provide the best use of water to meet all foreseeable short and long term needs.

The kind of water management and conservation policy that is needed in Puerto Rico involves far more than merely incrasing the capacity of reservoirs by raising the height of the dams where sedimentation already is serious, or by constructing expensive retaining walls to protect a city from floods.

Such a policy suggests cooperative efforts of the different government agencies concerned with the range of workable programs for the Island - wide conservation, treatment, distribution and use of water.

The participating agencies will be in position to evaluate the needs they may have to meet in servicing any project and to prepare in advance for meeting the load when the project is completed. This sort of teamwork and cooperation can contribute much to insure the successful operation of any project that serves a community. This is a problem that demand constant attention so that the healthy relationships basic to good teamwork may be fostered and responsibilities to the public recognized an discharged without stint.

possibility of making incentive payments on a soil conservation basis for lining with concrete irrigation laterals and ditches running thru individual farms. Some form of incentive may be desirable to encourage farmers to construct watertight irrigation reservoirs on their farms.

A well planned research and educational program directed at the water supply and utilization problems would fill a big gap in the present situation. With possible exception of the individual investigations carried out by some of the sugar centrals in Puerto Rico, research and education on the use and conservation of water have been rather limited. During the last 5 years some valuable information on conditions along the south coast has been obtained thru research work by the Soil Conservation Service and the Bureau of Plant Industry, Soils, and Agricultural Engineering of the U.S. Department of Agriculture, cooperating with the Puerto Rican Experiment Station. These results clearly indicate the need to develop additional information not only for the south coast but also for other sections.

In moving forward with such a program, closer and more direct technical linkage should be established among the various agencies such as the Extension Service, Puerto Rican and Soil Conservation and Forest Services, Water Resources Authority, Production and Marketing Administration of the U.S. Department of

Agriculture, Experiment Station, and any other agencies or groups which may be concerned with water use and conservation. Direct liaison and close cooperation among all agencies are essential to insure that fundamental information obtained thru research is promptly put to practical use.

There is an immediate need for a wide range of experimental and research work to produce the information required for use in overcoming existing problems as well as for making improvements in irrigation on the Island. Early attention should be given to the following:

New methods of furrow irrigation should be devised and adapted to local conditions and their efficiency tested in terms of water held in the root zone as well as in terms of crop yields.

More information is required concerning the plant use of water under irrigated conditions by important crops other than sugarcane, by sugarcane at higher levels of production that result from increased fertilization and other improved practices, and by fall planted (gran cultura) crops of sugarcane.

Determination should be made of the use of water by upland crops in areas not now irrigated, in relation to weather, soil moisture, and runoff from small watersheds. Such information would be very helpful in measures taken to increase crop production, in calculating total water supplies, and in developing soil and water conservation practices, and in designing conservation structures. For the northern and western sections especially, sprinkler irrigation as compared with furrow methods should be more accurately evaluated, in terms of water savings, yields of various crops, and costs to irrigate.

The need for supplemental irrigation should be determined for areas where rainfall is considered adequate during most of the year. Also, work should be done in these areas to find out whether crop adjustments and small reservoirs or other devices could be used to increase the total per acre crop returns.

The relation of evaporation and transpiration to weather should be developed in more detail. Additional information about the influence of hours and intensity of sunshine and wind is especially needed. Also, the effect of wind barriers or windbreaks on evaporation and transpiration should be investigated.

There is need for determining the benefits to be derived from irrigation of farms located in the agricultural areas of the six north coast rivers. This is necessary before any development project is undertaken.

Work should be done to find out what are the best methods of land preparation and irrigation ditching, of lining secondary canals with concrete, and of flume and reservoir construction. The proper spacing and depth of open ditches and the possibilities of tile and mole drainage systems should also be explored.

Research relating to water movement in soils and physical properties of soils should be intensified. Also, research is needed to determine the possibilities of increasing the capacity and efficiency of underground storage of water which is now being lost to the sea. This should include consideration of the possibilities of water spreading and other devices as a means of increasing the input into appropriated underground reservoirs.

The heavy pumping of ground water that is now taking place and the need for increasing supplies calls for various measures that will provide the basis for intelligent action in safeguarding the total supply. There is need for some intensive investigations to determine the effect that pumping is having on ground water in such areas as the south coast, and determine what control measures should be put into effect to maintain the supplies of water. Also, ground water investigations are needed to determine the quantities available and the location of the sources thruout the Island. This is particularly needed for the Bayamón - Arecibo section, for such valleys of the west and east coasts as the Añasco, Guanajibo, and Yabucoa as well as for some sections of the interior of the Island.

Of great help in developing information that would reveal what is happening to the ground water resources would be the establishment of observation wells. By periodic measurements of water level in these wells, it would be possible to determine the fluctuations taking place in the ground water levels. This work should be in the form of a permanent network of observation wells established in the major underground water deposits thruout the Island. Some of the wells would be used in planning by recording long and short-term natural trends to the water level. Other would be installed in areas of heavy pumpage to forewarn of overdevelopment. Also, observation wells would help greatly to evaluate changes in the hydrologic setting as a consequence of future water development projects. Many of these should be close to the coast to evaluate and warn of salt-water intrusion.

The recharging of underground reservoirs is important to maintaining the supply of water. Investigations are needed to determine the feasibility and means of recharging underground reservoirs, particularly in areas where excessive pumpage is taking place. Some of the methods that may be considered are: Spreading water over alluvial fans or other porous areas; using natural streams channels, ditches, basins, wells, or pits; and flooding.

The major effort of data collection on the quality of water in Puerto Rico has been to determine the general characteristics of water in relation to environment, climate, and water use.

Evaluation of the water for specific uses is needed for potential consumers. Of equally great value is the determination of frequency of certain conditions; and how many days of the year the hardness and other characteristics of a stream exceeds desirable limits. What minor elements such as cooper, manganese, lithium, are in the waters of Puerto Rico; what organic compounds such as synthetic detergents, fertilizers, and insecticides exist in the waters; and in what concentrations and under what conditions do they occur? Better definition also is needed of fresh water-salt water relationships, and of the effect that use has on water resources of the Island.

Current and future studies must be directed to meet these needs for water-quality data. Correlations between conductance and chemical properties of water could provide a continuous records of water quality on the basis of water - level records for many streams. Extrapolation of data could provide continuous description of quality of other streams in the same or in other basins. Such data will be of considerable value to potential users, especialy to industries.

Because of the chemical characteristics of the geologic formations and the water in Puerto Rico, it is presumed that large concentration of minor elements do not exist in the water (U.S.G.S., Report 1964). Small deposits of copper, manganese, and other metal are known to exist, which indicates that the determination of the amount of these elements is desirable. Findings from such investigations may be the determining factor in the selection of one water supply over another for some industrial processes. Altho it is presumed that synthetic detergents and other organic compounds are not present in significant amounts in the Island's waters, investigations to determine the amount are needed.

Emphasis on studies of sediment so far has been to determine the general characteristics of sediment yield of the Island. More information in specific areas is needed in greater detail. A few areas have been selected for the necessary studies; many more areas should be selected as the need for data arises.

More attention and research should be devoted to the problem of watershed management. The need for providing more specific attention to the watershed aspects of water management to some extent has grown out of our experiences that have shown how watersheds function and how their orderly function may be changed by use.

It has been found that watersheds convert large amounts of rain to streamflow. For example, in places where 24 inches of precipitation annually reaches the soil, a plot only 10 feet square receives and disposes of about 6.25 tons of water each year. One acre receives 2,718 tons; and 10,000 acres, a rather large watershed, receives and disposes of more than 27,180,000 tons.

In the orderly disposition of those huge amounts of water, every piece of ground - a square foot, an acre, a square mile, a complete drainage basin - performs a vitally important hydrologic function. That that function can be changed by Man's use of the land has been demonstrated in recent times by many experiences.

Altho the total precipitation which falls in most of Puerto Rico is ample to meet all water needs, critical shortages arise in certain parts of the Island, particularly along the south coast, and there are seasonal shortage thruout most of the Island. These deficiencies together with the increasing requirements emphasize the need for more effective use of the total supplies of water available and the importance of putting into effect adequate measures for the improvement, expansion, and conservation of water resources. This requires dealing with the problem of each watershed and determining the protective measures needed on the basis of such factors as geological conditions, vegetative cover, rainfall, and runoff, so that damage from runoff, floods and sedimentation is held at the lowest point practical.

Oustanding watershed needs for Puerto Rico can be summarized to include:

An Island wide inventory of areas that are sources of water, with special reference to the amount, rates, and qualities of water-flow and the types, extent, and values of water use.

Classification of watershed forests in terms of their requirements and values for the highest water production, erosion prevention, and flood and sediment damage abatement.

Application of measures to protect and manage forests, designed to maximize the contributions for a given set of conditions, with regard to the requirements for recreation and any other forest services.

Intensified and more widespread application of measures to improve soil and waterflow to forested and other parts of damaged watersheds.

Practically all flowing surface waters of the south watershed of the Island have already been committed to use by law. They are used principally for irrigation of sugarcane lands along the coastal plains. These legal rights introduce serious problems in the development of a water supply in this area. In fact, unless a major part of such supply is diverted from nonconcession streams of the north watershed, no rivers of the south slopes appear feasible of development because of the existing water rights.

The laws affecting ground water of Puerto Rico date back to the Spanish Colonial times. Water now plays a far more important role in the economy of Puerto Rico than it did when these laws were enacted. For this reason it is important that the law be brought more nearly in line with present needs so that provision may be made for greater protection of the water resource in the public interest. The provisions of law governing water rights should, in the light of present advanced knowledge, be revised so that they are more compatible with ground water hydrology and with the fundamentals of basin - wide management for optimum yield.

In view of the essentiality of ground water to the economy and widespread use on the Island, the law governing water rights might well declare that all ground waters are public waters and subject to appropriation when in the public interest.

Provision might well be made in the law so that any change in the location of a well or in the use of the water is prohibited unless application is made to the agency administering the law. Such agency should be responsible for determining whether any such change will impair existing rights before granting a permit to make the change. In granting the permit, the agency should require the proper plugging or repair of the well that is involved.

Wells for domestic and stock water purposes should be exempt from the operation of the law. Wells used for these purposes make a relatively insignificant demand upon the water supply, and such an exemption would prevent possible hardship. It would be advisable, however, to require owners of such wells to furnish such information with respect to them as may be needed by the agency administering the law.

The law could also provide that all determinations of the agency administering it, in granting or refusing permits, determining vested rights, designating areas or subareas of ground water supplies, or forfeiting rights for a nonuser, should be subject to appeal to the courts within a specified time by any aggrieved party. Otherwise, such determinations of the agency should be final.

Over all, wherever water rights or concessions are involved, it is important for the protection of the resource that a good measure of scrutiny be given to the actual amounts of water used, the efficiency of utilization, and the necessity of the use that is being made of the supply. Technical and other assistance should be readily available to water users so that they may be in position to cooperate effectively in the wise use and conservation of the Island's water resources.

Our expanding economy calls for a firm, positive policy of expanding beneficial use and conservation of surface waters.

Revision of the existing water law may be necessary in order to meet the requirements of changing times and to provide a design for the future orderly development of all water resources. The following adjustments in our existing water law might well be considered as one means of encouraging better management of water:

1. Develop and incorporate into our legislation, new basic water policies that contribute to beneficial use, conservation, and the prevention of waste; security of an encouragement for investments; wise administrative guidance in water development and use and fair and equitable division of water supplies among present and potential water users under quantitative rules of guidance known to every one.

2. Legislation implementing those basic policies, including definition of terms to clarify existing and new laws, limitations on

or exemptions from the application of new laws, and definition of agency administrative responsibility and provision for administrative and other procedures.

3. Programs of research, education, and technical guidance that seek to encourage full development and use of the water resources of the Island according to their capabilities and the needs of all the people.

The drafting of legislation itself will be only one of the many tasks involved in a modernization of our water law. The major problem is obtaining understanding and acceptance of principles of law, which tend to limit what a landowner or group of owners may do with waters occurring upon or flowing over their properties. The corollary of this problem is determining the most practical manner in which authority to limit use of these waters is vested in and exercised by Government agencies.

As the economy of water use becomes more complex in Puerto Rico, regulations must be resorted to so as to protect both private and public interests. This regulation amounts to a degree of transfer of power from individuals to agencies of Government. It is perfectly natural for property owners to resist such transfer until they are sure as to how a new or improved system is going to work. The key to success in bringing about this transfer lies in keeping control of broad operating policies in the hands of the people who give up some of their powers over water.

In these circumstances a great deal of cooperative study, factual information, and planning is required to achieve understanding and acceptance of water problems and provisions of law required to solve them. The solution of these problems should be the responsibility of all water users - municipalities, farmers, households, the industries, recreation groups, and organizations indirectly involved. Those users must be given equal opportunities to participate if sound and equitable legislation is to pass and receive public acceptance.

Modernizing water legislation is only part of the total job. There must be well planned, organized, and supported programs of research, education, and technical and other services provided by private and public organizations and agencies.

The total of what is suggested by this study constitutes an account that charts a possible course of action in the many problems that concerns the management and control of water in Puerto Rico. Thru this research we have come to know only too well the problems associated with the demand for water, sedimentation of reservoirs, flood control, salt-water intrusion, pollution control, ground-water and drainage.

Manufacturing has now supplanted agriculture as the main source of income in Puerto Rico and a continuously accelerating trend toward industrialization is expected in the future. Thus a conflict is to be expected between the traditional use of water by agriculture which is backed by the existing water law, and the growing need for water by industries which are being attracted to Puerto Rico by the Commonwealth Government, and the steadily increasing municipal use.

A large increase in the proportionate use of our presently developed supplies of water can well be made thru conservation and wise management. The present supplies can be extended thru:

1. Adoption of laws for controlling the conservation and distribution of surface and ground-water resources for beneficial use. Water conservation generally results from the establishment of new, or the improvement of old, water laws. Good water laws establish a control of use among competitive needs, protect the water rights of the users, maintain a control over the amount of available water, and reduce misuse and wastage.

2. Planning on a river-basin basis for natural resource developments where all interrelated water users are included.

3. Reclamation of what today is called waste water.

4. More efficient reuse of industrial waters.

5. Beter land - use practices to conserve natural precipitation and reduce the movement of sediment.

6. More efficient handling and use of irrigation water to reduce the losses in transportation and increase the efficiency of application.

The water saved can usually be used locally.

7. Intensified drainage, irrigation, and flood-control activities.

8. Reduction of evaporation from water surfaces. This opens a new field of investigation that may develop into a way to conserve water.

Those problems and many more like them we know. What have we done about them? What more can we do to solve them?

We have to know where water comes from and what happens to it. We have to know how much can be used and when, and how our land practices influence its behavior.

We have to stop wasting water. We have to use it more efficiently in industry, in towns and cities, in general farming, and in irrigation, which is destined to be adopted in most parts of the Island.

We have to learn more about the control of floods and their sources as well as in the rivers. That will take a great deal of governmental planning much more for the future than we have ever done.

We have to look to the fields, the forests, and the hills that make up our watersheds, for the way we manage them affects the abundance and purity of the water farmers and city people need in increasing quantities.

We need to explore all possibilities that the science now offer - "cloud seeding", forecasting water supplies, converting saline waters.

treating waste water, reducing erosion and floods, cutting down evaporation, finding out more about how plants use water, and many more.

We need an increased awareness among all citizens of the oneness of our physical resources. Water, land, and people are inseparable components of one thing, our welfare. The subject of management and control of water can be viewed from the various aspects of soil conservation, agronomy, forestry, irrigation, wildlife, recreation, business, industry, law, and so on - but never alone.

Planning for the maximum development and better management of our water resources for the longtime benefit of all of our people, when properly conceived, can bind together individual and the community, farmer and urbanite, as few other conservation activities can do. Our dealings with soil, forests, wildlife, recreation, community betterment, and industrial development can be viewed in terms of their interrelationships with water. More and more people must become informed and interested in all these fields because our water troubles and our attempts to resolve them have a direct impact upon their personal, economic, and social affairs.

A greater effort must be made to educate the general public as to the need for proper use and protection of our water resources. Thus, all water users who are now indifferent to our water problems

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