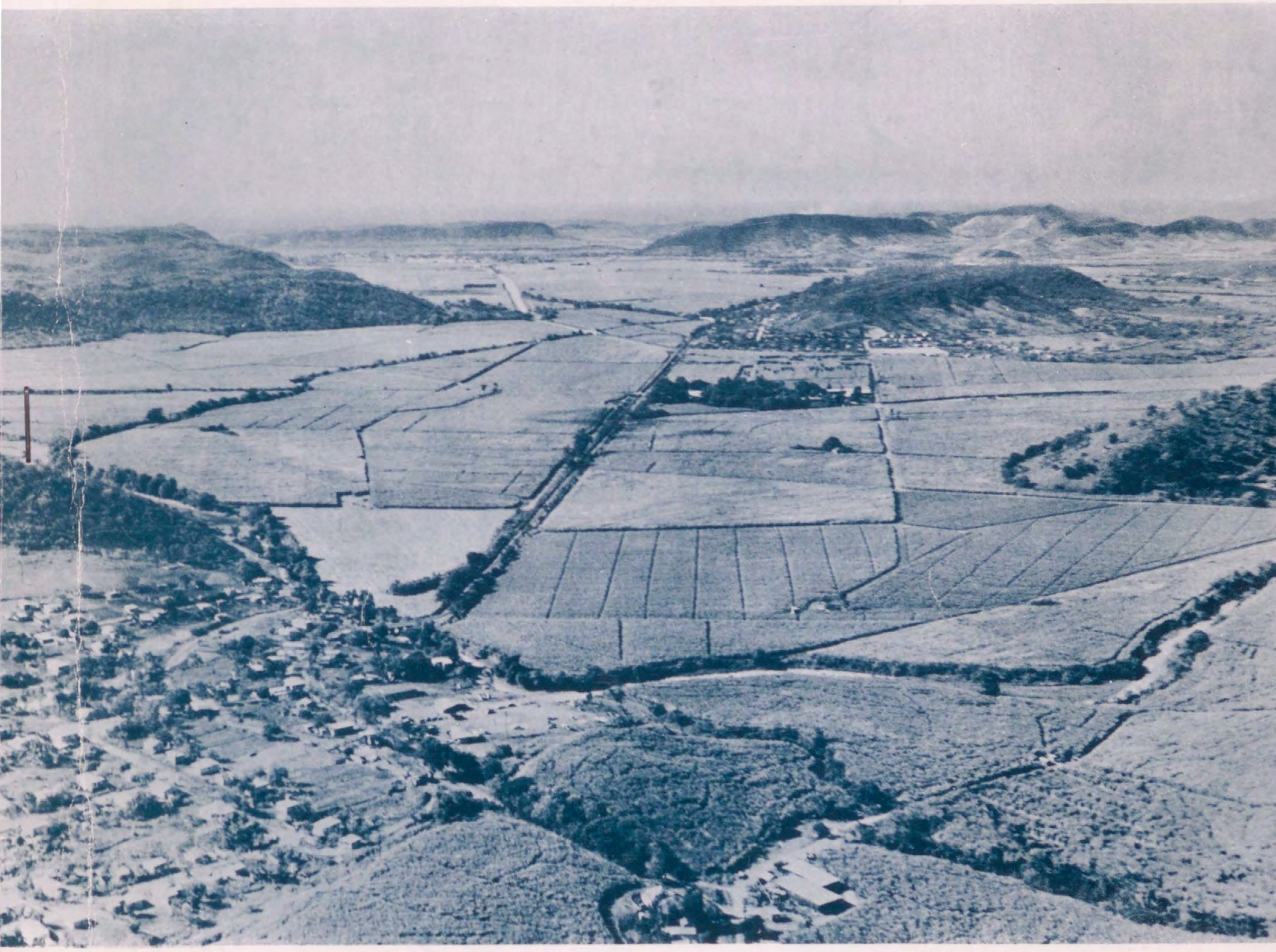
Water-Resources Bulletin No. 6

WATER RESOURCES OF THE GUANICA AREA, PUERTO RICO

A PRELIMINARY APPRAISAL, 1963



PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COOPERATION WITH THE

COMMONWEALTH OF PUERTO RICO

WATER RESOURCES BULLETINS

No. 1 WATER PROBLEMS OF PUERTO RICO AND A PROGRAM OF WATER-RESOURCES INVESTIGATIONS, by D. B. Bogart, T. Arnow, and J. W. Crooks, 1960.

No. 2 PUBLIC WATER SUPPLIES IN PUERTO RICO, by Ted Arnow and James W. Crooks, 1960.

No. 3 WATER WELLS IN PUERTO RICO, by P. E. Ward and L. S. Truxes, 1964.

No. 4 WATER RESOURCES OF PUERTO RICO, A Progress Report, by Dean B. Bogart, Ted Arnow, and James W. Crooks, 1964.

No. 5 WATER RESOURCES OF THE GUAYANILLA-YAUCO AREA, PUERTO RICO, A Preliminary Appraisal, by James W. Crooks, I. G. Grossman, and Dean B. Bogart, in press 1967.

No. 6 WATER RESOURCES OF THE GUANICA AREA, PUERTO RICO, A Preliminary Appraisal, 1963, by Neal E. McClymonds, 1967.

OTHER PUBLICATIONS OF THE WATER-RESOURCES INVESTIGATION

HYDROGEOLOGIC MAP OF PUERTO RICO AND ADJACENT ISLANDS, by Reginald P. Briggs and J. P. Akers, 1965, U. S. Geological Survey Hydrologic Investigations Atlas HA-197.

FLOODS OF SEPTEMBER 6, 1960, IN EASTERN PUERTO RICO, by Harry H. Barnes, Jr., and Dean B. Bogart, U. S. Geological Survey Circular 451.

FLOOD MAPS PREPARED IN COOPERATION WITH THE PUERTO RICO DEPARTMENT OF PUBLIC WORKS

FLOODS AT BAYAMON AND CATAÑO, PUERTO RICO, by Miguel A. López, 1962, U. S. Geological Survey Hydrologic Investigations Atlas HA-77.

FLOODS AT TOA ALTA, TOA BAJA, AND DORADO, PUERTO RICO, by Miguel A. López, 1964, U. S. Geological Survey Hydrologic Investigations Atlas HA-128.

COVER PICTURE.—Lower Río Loco valley, community of Palomas at left
Photo by Neal E. McClymonds.

Commonwealth of Puerto Rico

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WATER RESOURCES OF THE GUANICA AREA, PUERTO RICO

A Preliminary Appraisal, 1963

by

Neal E. McClymonds

Prepared by the United States Geological Survey

in cooperation with

Puerto Rico Legislative Assembly

Puerto Rico Water Resources Authority

Puerto Rico Aqueduct & Sewer Authority

Puerto Rico Industrial Development Company

1967

PREFACE

Guánica and the lower Río Loco valley lie between the extensive agricultural development in Lajas Valley to the west and the industrial development at Guayanilla to the east. Having a protected deep-water port, the Guánica area is particularly well suited to further development. The economic growth of the area depends, in important degree, on the amount of water available—water in the immediate area or water to be brought in from other areas.

Purpose and scope of study

The purpose of the study of the Guánica area was to evaluate the water supply in the immediate area. How much water is there? How much water moves through the area and what are the factors that control the movement? What is the composition of the water? And how much more water can be used?

The study itself took one year. Active data collection included measurements of streamflow, measurements of water levels in wells, measurements of well discharge, chemical analyses of surface and ground water, geologic reconnaissance, and considerable interviewing. Information for more than one year was obtained for rainfall and other weather data, well pumpage, water leaving Lago loco, and water used by the Southwestern Puerto Rico project.

Cooperation

The study was made possible by the continuing agreement between the Commonwealth of Puerto Rico and the United States Geological Survey to conduct water-resources investigations, based on essentially equal amounts of funds contributed by the two principal parties. Commonwealth contributions came from these agencies:

Puerto Rico Legislative Assembly
Puerto Rico Water Resources Authority (PRWRA)
Puerto Rico Aqueduct & Sewer Authority (PRASA)
Puerto Rico Industrial Development Company (PRIDCO)

Other official agencies, both Commonwealth and Federal, and numerous private concerns and individuals furnished information.

Additional information available

Although numerous data were used to arrive at the evaluations made in the report, the data were not included in the report. Those who need additional information should contact:

Water Resources Division
U. S. Geological Survey
San Juan, Puerto Rico

~~PUERTO RICO WATER RESOURCES AUTHORITY~~

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A Preliminary Appraisal 1963

by

Neal E. McClymonds

RESUME

1) Major change in water regimen

Before 1955, Río Loco flowed to the coastal plain essentially in its natural state. A major change occurred in 1955 when the first stage of the Southwestern Puerto Rico irrigation and power project was put into service. A dam was built in Río Loco, a relatively large amount of water from the Río Añasco and Río Yauco basins was brought into Lago Loco, and diversion of water to Lajas Valley was started.

2) Río Loco recharge to the alluvium

When water levels in the alluvial aquifer are below normal, flow from Lago Loco enters the alluvium along Río Loco. This recharge has been observed to be as high as 180 cfs (cubic feet per second) for a day, but commonly it is in the magnitude of 40 cfs, or 26 mgd (million gallons per day). Much of the recharge occurs when slugs of water (up to 400 cfs) spill over Loco Dam as a result of hydroelectric operations—this is an important factor in the water regimen of the lower valley.

3) The valley is a large reservoir

The Río Loco valley consists of a complex assortment of gravel, sand, silt, and clay. These materials exist as horizontal layers and lenses that overlap and interfinger in many combinations. The water capacity of this alluvium is large; the saturated part contains about 24,000 ac-ft (acre-feet) from the foothills to Bahía de Guánica. Less than one-half this capacity is above sea level To replace the 12,000 ac-ft of water per year pumped from wells requires replenishment of the upper part of the aquifer, either naturally or artificially.

The bedrock under the alluvial aquifer is a poor source of water because of its low permeability; but it provides a relatively tight container for the water in the aquifer above it.

4) Well pumpage 1924-63

Prior to 1955, water pumped from wells in the lower Río Loco valley averaged about 10,000 ac-ft per year, for all purposes. Pumpage increased to about 12,000 ac-ft by 1963, which is equivalent to a steady rate of 11 mgd. About 9,000 ac-ft of this was supplied for irrigation by 17 wells.

Several times during the 40-year period, ground-water levels dropped enough to result in a reduction of discharge from the wells. Part of the reduction was caused by limited capability of both pumps and wells. Water levels always returned to normal in the alluvial aquifer after every drouth. No persistent decline in the water table has occurred.

5) Characteristics of wells

Most of the large wells in the alluvium are 80 to 140 ft deep, with a yield ranging between 300 and 1,500 gpm (gallons per minutes), (694 gpm is equivalent to 1 mgd). The specific capacity may be as great as 140 gallons per minute per foot of drawdown, but this diminishes to as little as 15 near Bahía de Guánica. Drawdown in the better wells is small and recovery is rapid, reflecting the high transmissibility of the aquifer, which is in the magnitude of 300,000 to 600,000 gpd (gallons per day per foot).

6) Possible increase in pumpage with water regimen of 1963

With the water facilities and water management as they existed in 1963, it is estimated that another 10,000 ac-ft (9 mgd) can be pumped yearly from the lower Río Loco valley. It is desirable that this be accomplished gradually and in recognition of the situation mentioned in item 11.

7) Best area for more wells

The areas favorable for additional wells are shown in figure 1. Wells should not be located nearer than 600 feet to any other well. A line of wells across the valley or parallel with Río Loco probably would produce large amounts of water most readily.

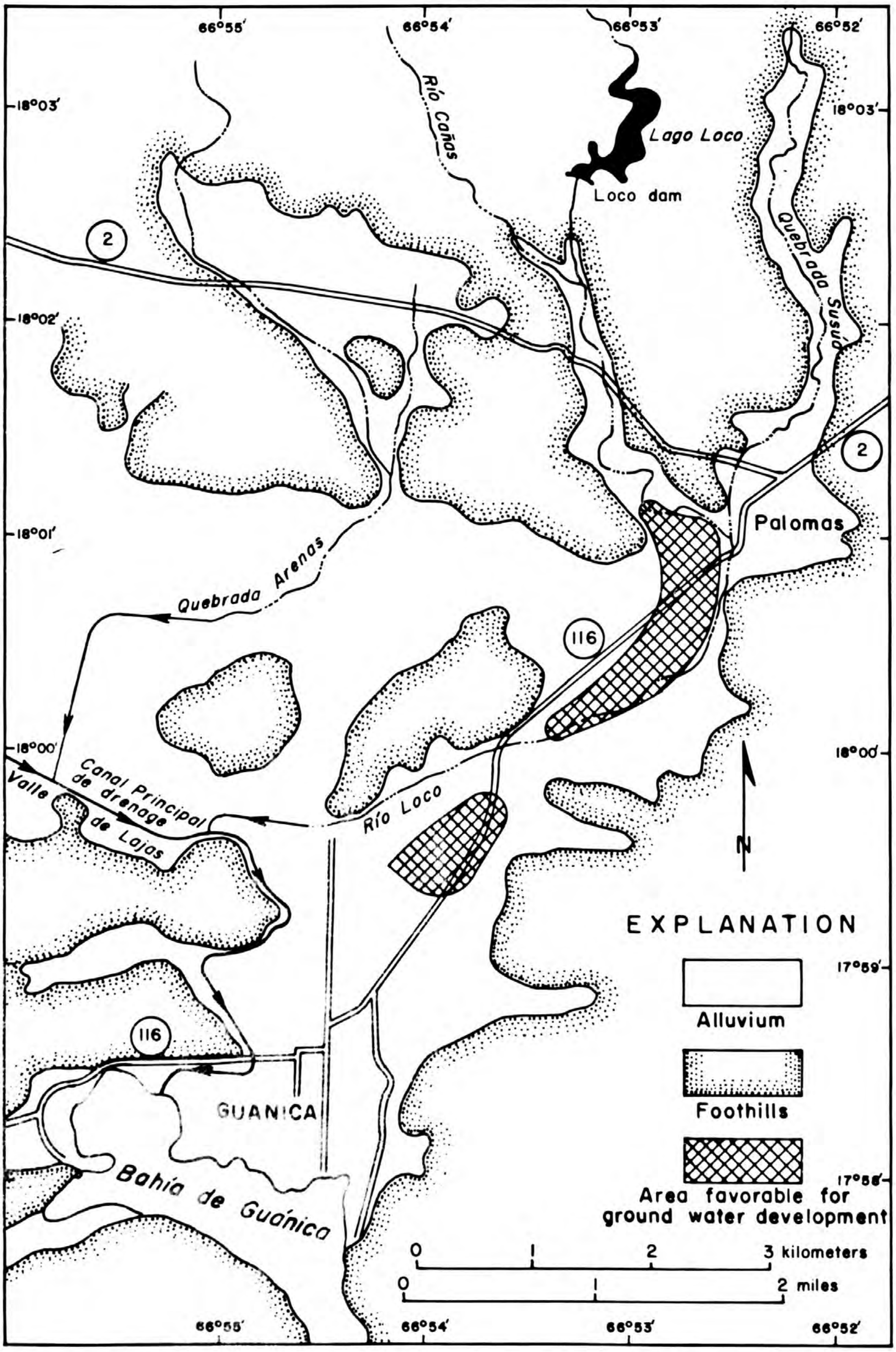


Figure 1.—Areas favorable for further ground water developments.

8) **Kind of water available**

The water in Lago Loco and in lower Río Loco is a calcium-bicarbonate type. With dissolved solids generally less than 200 ppm (parts per million), it is an excellent water for almost all purposes. During periods of very low flow, the quality may deteriorate in the vicinity of Palomas caused by inflow of poor water from Quebrada Susúa.

The ground water in the lower Río Loco valley is a magnesium-bicarbonate type, with dissolved solids ranging from 200 to 800 ppm, but mostly from 450 to 650 ppm. The water is satisfactory for most purposes. The quality deteriorates toward the sea, and near Bahía de Guánica a notable increase in chloride occurs in shallow wells (40 feet deep).

9) **Importance of Lago Loco to water regimen**

Impressive facts emerge from a study of 7 calendar years of available data from Lago Loco:

	Volume of water, acre-feet		
	Average 1956-62	Wet year 1956	Dry year 1962
Over spillway or thru controls in dam	56,100	95,300	20,600
Diversion to Lajas Canal	20,400	9,400	34,800
Total controlled by Lago Loco	76,500	104,700	55,400
Over spillway or thru controls in dam	56,100	95,300	20,000
From first three laterals of Lajas Canal	5,700	4,000	8,900
Total flowing into Guánica area	61,800	99,300	29,600
Estimated loss to Bahía de Guánica, percent	70	85	50

The total movement of water thru Lago Loco thus ranged between 55,000 and 105,000 ac-ft, of which 29,000 to 99,000 moved into the lower valley. Most of this available water passed through the area to Bahía de Guánica.

10) **How to increase water available in valley**

Lago Loco is the key to augmented water supplies in the valley. During the driest year of record, 29,000 ac-ft of water moved into the lower valley, most of it in Río Loco—and about half of this water probably was lost to Bahía de Guánica. In the average year, the input of water was about 60,000 ac-ft—and loss to Bahía de Guánica probably was around 70 percent or higher. Much of this loss can be converted to usable water:

1. By regulating release of water at Loco Dam so that more flow in Río Loco is absorbed by the alluvium.

2. By alteration of present water-management procedures of the Yauco hydroelectric complex. This may or may not require enlarging the capacity of Lago Loco.

These changes involve an irrigation and water-supply concept of the operation of the Southwestern Puerto Rico project that could result in an increase of usable water in the range of 10 to 30 mgd.

11) **Protecting water in the lower valley**

No significant amount of salt-water intrusion was known to have occured up to 1963, but development of additional water supplies should be undertaken only with the simultaneous establishment of a monitoring system to observe the possible changing position of the salt front.

12) **Other sources of water in Río Loco basin**

Quebrada Susúa, Río Cañas, and Quebrada Arenas are tributary to Río Loco downstream of Lago Loco. None of these streams is a reliable source of water unless storage is provided.

INTRODUCTION

Situation in Río Loco Basin

Pre-Loco Dam Set Up

Prior to 1954 and the construction of Loco Dam and the Yauco hydroelectric complex, Río Loco and its tributaries were the major sources of water for the Guánica area. To determine the quantity of water from these sources, flow of Río Loco at Cacique Dam (fig. 2) was measured in 1949, 1950, and 1951 by PRWRA. The annual rainfall during these three years was generally average on the plains and about 90 percent of average in the mountains. Based on these records, average flow in Río Loco basin above the confluence with Río Cañas is estimated to be about 10,000 ac-ft per year. Nearly all surface flow, except during floods, enters the ground water system near Palomas. Ground-water underflow and some surface-water runoff from Lajas Valley, as well as direct rainfall on the plains, also contributes water to the lower Río Loco valley.

The water supply in the lower Río Loco valley was sufficient for irrigation, industrial, and public supply requirements most of the time. However, an acute water shortage developed during a severe drouth culminating in 1923 and many wells in the lower valley decreased in production because of a drastically lower water table. Rainfall at Ensenada had been below the 30-inch annual average for 12 years and was less than 13 inches in 1922 and 1923. During the period from 1924 to 1954, about 10,000 ac-ft was pumped from wells annually without substantially changing the water level.

Present Set Up

Since the construction of the Yauco hydroelectric complex in 1955, water in the Guánica area may be divided into three separate but interrelated systems: 1) water coming into the area from Lago Lucchetti; 2) water from the Río Loco basin, as described previously; and 3) water leaving the Guánica area via the Lajas Valley irrigation system. The Yauco hydroelectric complex consists of a series of dams, tunnels, and hydroelectric power stations. It includes four reservoirs, connected by tunnels, north of the island divide, and a tunnel cutting under the divide to Lago Lucchetti on the south side. Electric power is generated at Yauco Hydroelectric Plant No. 1 where the transmountain diversion enters Lago Lucchetti. A large part of the water is diverted through another tunnel to Yauco Hydroelectric Plant No. 2 above Lago Loco. Exact measurements of the volume of water from Lago Lucchetti are not recorded; however, based on records of flow from Loco Dam, the annual average volume since 1955 is estimated to be 70,000 ac-ft. One-fourth to one-third of this volume is diverted to the Lajas Valley irrigation canal. The remainder, when Lago Loco is filled to capacity, flows over Loco Dam and down the lower Río Loco valley. This water is the major source for additional supply available to the Guánica area.

General Physical Setting

Location and Description

The Guánica area is on the south coast of Puerto Rico about 20 miles west of Ponce and about 20 miles east of the southwestern corner of the island (fig. 2). It includes Río Loco and tributary basins and a small coastal area with a combined drainage area of 50 square miles. The study area is 11 miles long, and varies in width from about 1½ miles in the mountainous section to 6 miles near the coast. The area is bounded on the west by the Río Guanajibo basin and by Lajas Valley, and on the east by the Río Yauco basin. In this report, the Guánica area has been divided into two principal sections: the mountains and the plains.

The mountain area includes the Río Loco drainage area north of Loco Dam and the entire Río Cañas basin. The area is characterized by steep sided peaks and ridges some of which reach altitudes greater than 2,000 feet above sea level. Pico Fraile, a triangular shaped landmark near the headwaters of Río Loco, is 2,506 feet above sea level. Defined surface drainage is in narrow, deeply incised valleys. There is little or no alluvial deposition except immediately above the entrance of Río Loco to Lago Loco. The ridges slope downward to about 1,000 feet above sea level in the foothills around Lago Loco and the lower Río Cañas valley.

The plains area encompasses the lower Río Loco valley below the lake, all of Quebrada Arenas and Susúa basins, and the hills and lowlands to Mar Caribe. The upper reaches of Quebrada Arenas drain a part of the foothills west of the Río Cañas basin. The stream then crosses the lowlying plains of the eastern edge of the Lajas Valley (75 feet to 15 feet above sea level) to where it joins the Lajas Valley drainage canal. The low hills of Quebrada Susúa basin are slightly more than 200 feet above sea level. The stream flows through a narrow valley about one-quarter mile wide and where it joins Río Loco the floodplain is about 160 feet above sea level.

The lower valley of Río Loco as used in this report includes the floodplain and alluvial lowlands from just below Cacique Dam to the Bahía de Guánica, a distance of about 6 miles. The valley from Cacique Dam to the junction of Quebrada Susúa ranges from 0.2 mile to 0.3 mile in width. Floodplain elevations are 160 feet above sea level and the surrounding hills are 550 feet above sea level. Near Santa Rita, the valley widens to about one mile and the plain elevation is 100 feet above sea level. The river gradient from the dam to this point is about 27 feet per mile.

South and east of Santa Rita an alluvial fan deposited by a small stream passing La Hoya has constricted the valley to one-quarter mile wide. As a result, the river gradient increases to about 33 feet per mile to Cañas.

The floodplain elevation is 50 feet above sea level. The valley broadens to one mile from Cañas to Guánica and the gradient is less than 20 feet per mile. Drainage of the valley from the constriction near Cañas to Guánica is toward the west where the canalized Río Loco directs excess irrigation water and floods to the Bahía de Guánica.

The entrance to Bahía de Guánica from the sea is about 500 yards wide, restricted by Punta Pescadores and Punta Meseta (fig. 2). A channel, dredged to a depth of 30 feet and a width of about 70 yards, facilitates access for ocean-going ships to the docks at Ensenada. Much of the undredged part of the harbor is about 20 feet deep and the bottom deepens rapidly from the shoreline, except along the north side where the Río Loco deltaic deposits extend from 200 to 400 yards from the shoreline. An offshore reef, outside the bay entrance, is developed extensively, but is broken at several places by channels from 20 to 50 feet deep between Punta Brea and Junta Jacinto.

Cultural Development

Towns and Populations

Guánica is the commercial center for the lower Río Loco valley area and had a population of 4,103 in 1960. Ensenada, mainly a residential town for the workers at Central Guánica, had 3,229 inhabitants in 1960. Small villages on the plains are populated by people working on the sugarcane farms and small enterprises (fig. 2).

Economy

Cultivating and processing sugarcane is the predominant industry in the Guánica area. The cane is raised on most of the cultivable lowlands and some of the lower hills. Since 1948, the Autoridad de Tierras of Puerto Rico has undertaken the task of planting, irrigating, and harvesting a large proportion of the sugarcane. Sugarcane also is grown on Hacienda Igualdad, between Hacienda María Antonia and Fraternidad, and on the farm north and west of Palomas. A large part of the crop is sold to the Southern Puerto Rico Sugar Company which owns and operates Central Guánica. Between 1903 and 1948, Russell and Company, now the Southern Puerto Rico Sugar Company, managed both the cultivation and processing of the cane in much of the area. Many wells and almost the entire irrigation system were constructed and maintained by Russell and Company. In 1954, the PRWRA built Loco Dam and started the Lajas Valley Irrigation system and the construction of the Yauco Hydroelectric Plants Nos. 1 and 2 to tie in with the island-wide electric power network.

The cattle and dairy industries are developed on land not suited for raising sugarcane, mostly in the hills north of Ensenada, on the drained land where Laguna de Guánica once was and the slopes to the north, and in the upper part of the Quebrada Arenas basin. Goats, now raised by only a few families on small plots of land, were once important to the economy of the Guánica area.

The González Chemical Industry, the second largest manufacturing firm in the area, produces ammonium nitrate and sulphuric acid for use in Puerto Rico and for shipment abroad.

INTRODUCTION TO THE HYDROLOGY OF THE AREA

General Hydrological Setting

Climate

The higher mountains of the Río Loco drainage area extend to the Rainy West Central Mountain region (Picó, 1950), where rainfall reaches 80 to 90 inches per year. Rainfall from 40 to 70 inches annually is typical of the Semi-arid Southern Foothills region. In the Guánica area this would include most of the mountain area and the Quebrada Susúa and Quebrada Arenas basins.

The largest part of the Guánica area, (the lower Río Loco valley and adjacent hills), is in the Dry Southern Coastal Lowland region, the most arid in Puerto Rico. The average annual rainfall over much of the coastal areas is less than 40 inches; at Ensenada it is only 30 inches. Evaporation rates are about the same as measured in the Lajas Valley to the west—70 to 80 inches per year.

The nearest weather station that records temperature is in Ponce, where conditions are comparable to the Guánica area. The mean annual temperature in Ponce, over a 25-year period of recording, is 78.8°F., with a mean low temperature of 75°F. in January and a mean high of nearly 82°F. in August.

Rainfall

The U. S. Weather Bureau has two stations in the Guánica area, one at Ensenada and one at Santa Rita. Other stations in the vicinity of, or of interest to, the area are south of Yauco in the lower foothills, at Salto Garzas near Peñuelas in the higher foothills, and at Maricao in the high rainy mountains (fig. 3). PRWRA has several raingaging stations cross the plains and northward to Lago Loco, for which four or five years of records were available in 1962.

Records at the Ensenada station show that rainfall from 1910 to 1927 was less than the 61-year average of 30 inches. During the years 1922 and 1923 less than 13 inches of rain fell. While the 17-year dry period was ending on the plains, a 3-year very wet period was occurring in the mountains.

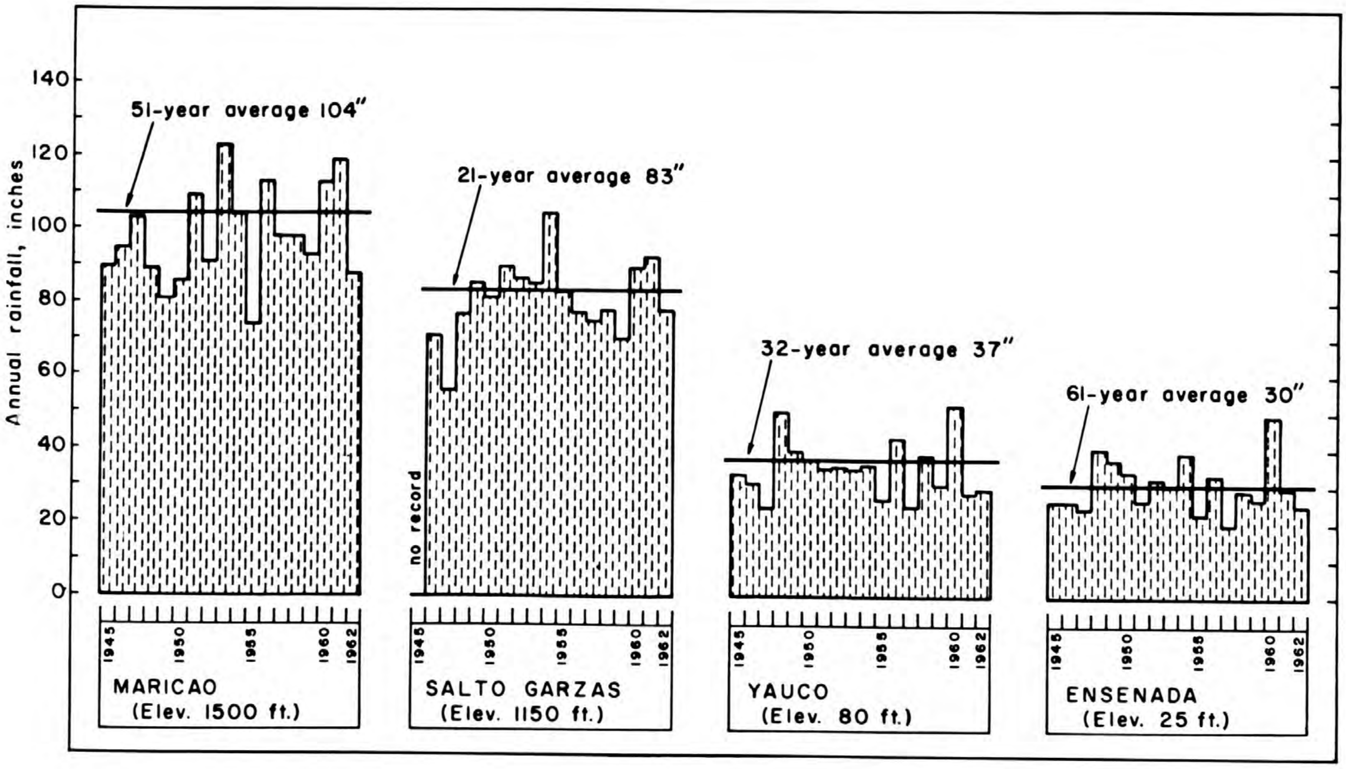


Figure 3.—Annual rainfall in and near Guánica area.

The seasonal trend of rainfall is well illustrated by the graph of monthly rainfall in figure 4. There is no difference between seasonal trends in the mountains and in the plains. Fifty percent of the annual precipitation falls in four months, August through November; the following four months, December through March, account for only 15 percent of the total rainfall. The short rainy season which usually begins and ends in May is important for recharging the ground water aquifers on the south coast of Puerto Rico.

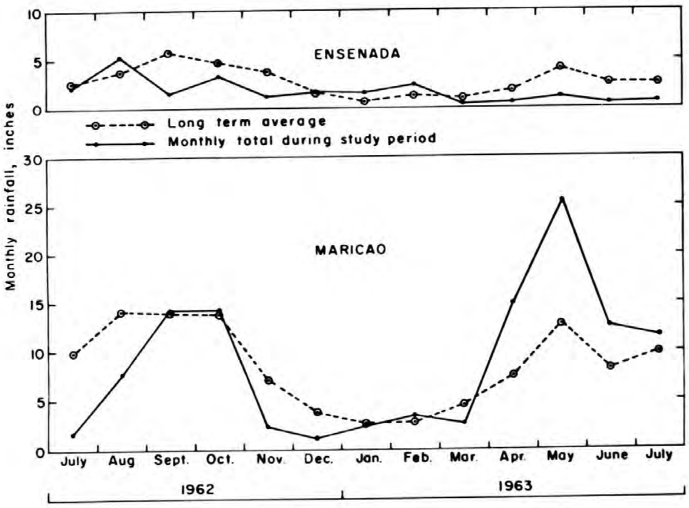


Figure 4.—Monthly rainfall at Ensenada and Maricao.

The Guánica area study was conducted during one of the driest years on record. The monthly rainfall during the last half of the study period (January through July 1963) was below average.

Evapotranspiration

When rain falls on the mountains and hills or irrigation water is spread over the cane fields, part of the water is immediately evaporated back into the atmosphere, part is taken in by the plants and later transpired, and part reaches the ground-water system or flows on the surface to streams or rivers. Light rains seldom produce any runoff in many areas along the south coast of the Island; most of the rain is evaporated or transpired. Evapotranspiration is an unknown—but significant quantity in the water budget at the present time.

Surface- Water Flow

Streams in the mountainous part of the Guánica area are perennial. Base flow is sustained by water released from temporary storage in the fractures of rocks and the pore spaces of more permeable rocks and soil. Rains in the mountains usually cause the rivers to rise above base flow, sometimes to flood proportions. Drainage from the mountains, via Río Loco and tributaries, flows into Lago Loco where it is supplemented by water diverted from Lago Lucchetti. Part of the water impounded in the lake is diverted out of the area via the Lajas irrigation canal, the remainder is released or spills over the dam and flows to the lower valley. Río Cañas and the other tributaries to Río Loco downstream from Lago Loco, have smaller drainage basins in lower rainfall zones, and contribute much less water to the Guánica area. Most of the time streamflow reaching the lower Río Loco valley, or the alluviated parts of the Quebrada Arenas and the Quebrada Susúa basins, is absorbed by the alluvium. Only during floods, or large releases from Loco Dam, does Río Loco flow all the way across the plains to Bahía de Guánica. At several places on the plains, even during the dry season, seeps from the ground-water system issue into the river channel, but usually this flow is reabsorbed by the alluvium a short distance downstream.

Ground-Water Environment

The major aquifer is the alluvium of the Río Loco valley, composed of gravel, sand, silt, and clay. Water is recharged into the alluvium from the stream channels, or percolates through the soil after rains or when the fields are irrigated. The water moves easily through the layers and lenses of sand and gravel because of their high permeability. It also moves through the alternate layers of silt and clay, but very slowly. The wells producing the largest quantity of water in the lower Río Loco valley are near the middle of the valley where the alluvium is thickest and where the greatest quantity of coarse material is found. A particularly thick layer of sand and gravel is near the narrow neck south and southwest of Cañas. Near Bahía de Guánica, the alluvium is finer grained and less permeable, therefore it yields less water to wells.

In the smaller stream basins, such as Quebrada Arenas and Quebrada Susúa, the alluvium is thinner, contains less coarse material, and wells produce smaller volumes of water.

Small amounts of ground water can be found in the mountainous part of the Guánica area, but unless in a highly fractured zone, wells drilled in the rock yield only very small quantities of water.

Water Distribution System

Lago Loco

Lago Loco provides temporary storage of water from Lago Lucchetti for diversion into the Lajas Valley irrigation canal and release to the lower Río Loco valley. The storage capacity of the lake is 1,950 ac-ft, but the design of the canal intake allows only the top half for irrigation. Throughout the year, 3 ac-ft per day (1 mgd) is released to Río Loco through the dam. Leakage under the dam nearly doubles the flow of the river downstream at Cacique Dam. This volume, which totals about 2,000 ac-ft annually, represents the base flow to lower Río Loco valley. When hydroelectric power is being generated at Yauco Plant No. 2 and Lago Loco is full, the excess water flows over the dam spillway in slugs, which may be as much as 800 cfs for several hours. The average annual flow from this type of release is 45,000 ac-ft; extremes ranged from 68,000 ac-ft in 1961 to 19,000 ac-ft in 1962. Other releases from Loco Dam, from a drain pipe and the sluice gates, range widely by seasons and year (table 1).

Lajas Valley Irrigation Canal

Since 1958 from 18,000 to 35,000 ac-ft of water was diverted annually from Lago Loco to the Lajas Valley irrigation canal. The demand for water has increased as more land was put under cultivation. For example, in 1958 18,000 ac-ft was diverted to the canal and in 1962 35,000 ac-ft was diverted. Annual volumes of 3,000 to 9,000 ac-ft of water were diverted from the Lajas canal to three canals supplying the Guánica area (fig. 2 and table 1).

General Geological Setting

Bedrock

Because of the low permeability of the indurated rocks in the Guánica area, they are grouped under the general heading of bedrock. However, the different composition of the various rock types influences the chemical constituents dissolved by water. Therefore, they are discussed by their formational name as outlined by Slodowsky (1956), and Mattson (1960) (figs. 5 and 6). Except for springs issuing from fracture zones and the possibility of small (10 gpm or less) domestic wells in these rocks, they are hydrologically important only as barriers to the movement of water. The barrier attribute is important in the mountainous part of the area in that the water is not absorbed quickly. On the plains, the barrier bedrock, which underlies and forms the sides of the valley alluvial fill, is most important in that it canalizes the flow of ground water in the lower Río Loco valley alluvium. The alluvium itself is formed from weathered and broken material derived from the bedrock in the mountains and along the sides of the lower valley.

Table 1.—Annual volume of water released from Loco Dam to Guánica area.
(Data from PRWRA records.)

Release source	1955 (6 mos.)	1956	1957	1958	1959	1960	1961	1962
					Ac-ft			
Loco Dam to Río Loco								
Drain pipe	—	26,502	5,542	10,198	2,653	140	0	0
Mueller Valve (daily disch.)	350	1,004	891	1,057	1,143	1,075	1,122	1,143
Sluice gate	5,086	4,472	5,019	7,449	7,790	0	446	112
Spillway	25,713	63,334	41,697	45,992	27,006	49,056	68,661	19,328
Subtotal I	31,149	95,312	53,149	64,696	38,592	50,271	70,229	20,583
Lajas Canal to CIL Diversion	1,188	2,553	3,323	2,324	2,511	1,413	2,421	3,452
Lajas Canal to M-5 Diversion	0	625	1,912	2,145	2,266	1,993	3,447	4,854
Lajas Canal de M-10 Diversion	222	796	728	677	520	315	541	643
Subtotal II	1,410	3,974	5,963	5,146	5,297	3,271	6,409	8,949
Total to Guánica area	32,559	99,286	59,112	69,842	43,889	53,992	76,638	29,532

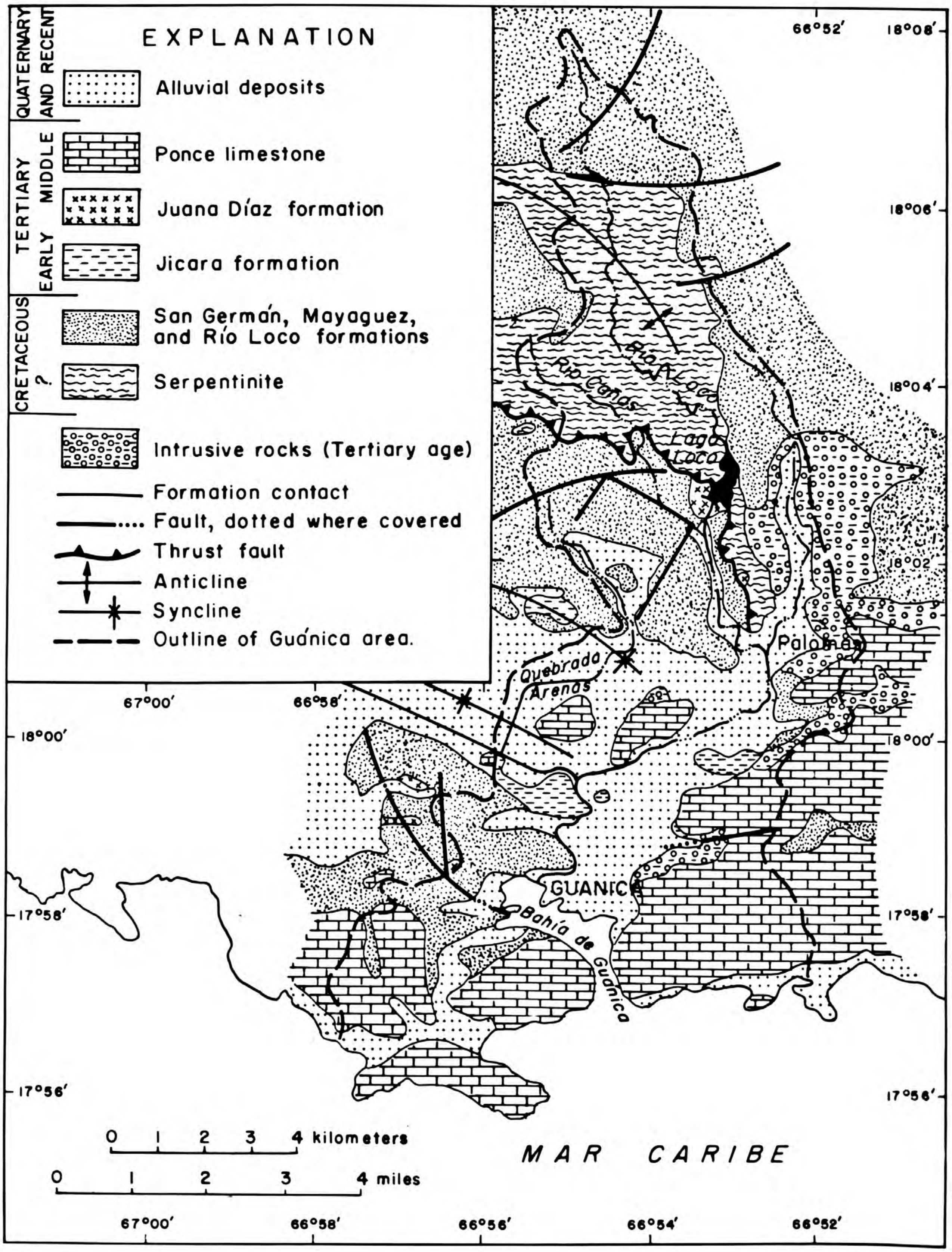


Figure 5.—Generalized geologic map. (After T. R. Slodowski, 1956).

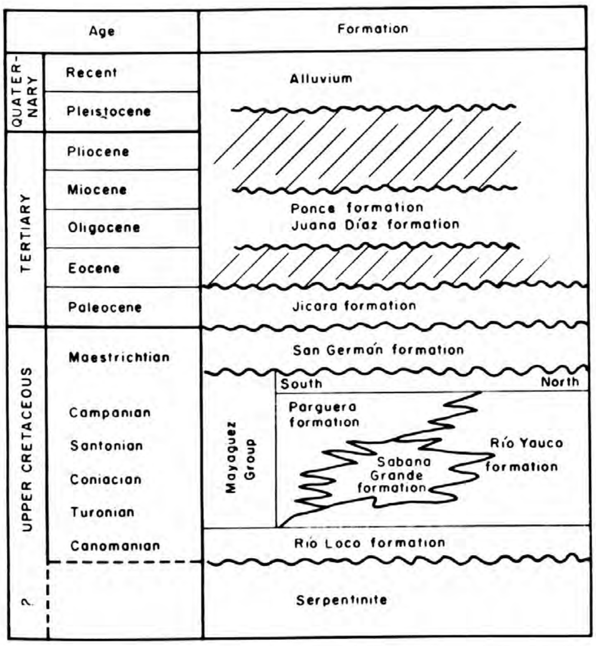


Figure 6.—Age and correlation chart of geologic formations. (After P. H. Mattson, 1960.)

Serpentinite, the oldest rock in Puerto Rico, crops out across most of the upper Río Loco valley and, is exposed as far south as the hills northwest of Palomas (fig. 5). Water passing over the serpentinite is characterized by a high silica and magnesium content. Andesite porphyry lavas and tuffaceous beds of the Río Loco Formation of Slodowski (1956) overlap the serpentinite basement northeast of Loco Dam, in the upper reaches of Río Cañas, and near Pico Fraile. These rocks are more resistant to weathering and erosion than the serpentinite; they form the higher ridges of the upper Río Loco basin. The Río Yauco Formation of Slodowski (1956), composed of gray calcareous mudstones and subordinate beds of tuff, volcanic wacke, and thin beds of limestone, overlies the Río Loco Formation to the northeast, mostly in the Río Yauco basin above Lago Lucchetti. The Río Yauco Formation is the northeastern facies of the Mayagüez Group. Toward the south and southwest the group includes the Parguera Limestone of Mattson (1960) and the Sabana Grande Formation of Slodowski (1956), a volcanic sequence, and has much thinner layers of mudstone. The hills north of Ensenada are largely made up of this facies of the Mayagüez Group. The San Germán Formation of Mattson (1960) is composed of andesitic volcanic rocks with a massive limestone at the top. Stratigraphically it lies over the Mayagüez Group and is restricted mainly to the upper Quebrada Arenas basin. Water passing over the San Germán Formation contains higher dissolved solids concentrations, particularly sulfate, than water in the lower Río Loco valley. The Jícara Formation of Slodowski (1956) is composed of the vari-colored volcanic and sedimentary beds overlying the San Germán Formation. These beds are exposed in the hills north of Fraternidad, around Fuí, under Hacienda María Antonia, and southwest of Cañas (figs. 2 and 5). The weathered exposures of the Jícara are very brittle, indicating they might be permeable in fracture zones. Several springs issue from these rocks near Fuí.

Juana Díaz Formation

Muds, silts, and conglomerates of the Juana Díaz Formation of Zapp, Bergquist, and Thomas (1948), filled a basin centered on the Quebrada Susúa valley. The accumulation, for the most part probably took place below sea level, for sodium chloride is prominent in the water from these deposits. A concentration of over 5,000 ppm dissolved solids is not uncommon in water from the Juana Díaz Formation east of Palomas. Although the Juana Díaz beds are generally similar to recent alluvial deposits, the pore spaces between gravel fragments are usually filled with finer grained and partially cemented material. Therefore, wells in the Juana Díaz Formation usually yield only small quantities of water.

Ponce Limestone

The Ponce Limestone of Zapp, Bergquist, and Thomas (1948), conformably overlies the Juana Díaz Formation and unconformably overlaps Slodowski's Jícara Formation and older formations. This limestone, about 400 feet thick in the Guánica area, forms the caprock on the hills east of the lower Río Loco valley, west of Cañas, and southwest of Guánica. The formation is above the water levels of the plains, but in some areas perched water, held up by lenses of clay or mud, occurs and may be tapped for small water supplies.

Alluvial Deposits

The pre-alluvium valley of the Río Loco cut in the bedrock is 10 feet above sea level northwest of Palomas, 60 feet below sea level south of Cañas, and about 150 feet below sea level beneath Guánica. The filling of the valley by alluvial materials, gravel, sand, silt, and clay, in a sequence of lenticular layers, created the aquifer from which all large-yield wells of the Guánica area obtain their water (fig. 7).

The alluvium in the lower Río Loco valley is 80 to 90 feet thick near Palomas, about 110 feet thick near Cañas, and about 160 feet thick near Guánica. The plains between Santa Rita and Fraternidad have a thin cover of alluvium probably less than 30 feet thick. In Quebrada Susúa valley the alluvium is much thinner than that in Río Loco valley. The exact depth to bedrock could not be determined from logs of wells near the stream because of the resemblance of the alluvium and Juana Díaz materials. The hills, made up of the Juana Díaz Formation, are covered by a thin veneer of soil and alluvial terrace deposits. Terrace deposits, 20 to 30 feet thick in places, extend for over a mile up the Río Cañas valley from its confluence with Río Loco. The bedrock in parts of the upper Quebrada Arenas basin has a thin alluvial cover. The alluvium is at least 50 feet thick along Quebrada Arenas in the southwest corner of the upper basin and probably retains this thickness as far north as Highway 2 along this stream and Quebrada Cipote (named for this report) (fig. 8). Near Fraternidad, where Quebrada Arenas is channelized to the Lajas Valley drainage ditch, test holes encountered bedrock at a depth of 50 feet. Between Fraternidad and Hacienda Igualdad, the alluvium is less than 30 feet thick. The thickness of the alluvium at the east end of the Lajas Valley at its junction with Río Loco valley is unknown.

Composition and Extent of Alluvial Aquifer

The sands and gravels of the alluvial aquifer in the Guánica area are coarse, and thickest along the lower Río Loco valley. Drillers' logs indicate that the ratio of silts and clays to coarser-grained material is about 4 to 1 in the area north and northeast of Santa Rita, but downstream, below the neck in the valley south of Cañas, the ratio decreases to about 2 to 1. The increased velocities and steeper gradient of the stream through the neck of the valley resulted in transport of coarse gravels to the downstream area. In the lower part of the valley between Hacienda Igualdad and Guánica the average ratio of fine to coarse-grained material is 4 to 1. The coarse-grained material probably would account for less than 20 percent of the total in the Guánica delta area (fig. 7).

Alluvial Fans

Several small alluvial fans extend onto the Río Loco plain. One which extends from the creek near La Hoya nearly to Highway 116 near Santa Rita, has several prominent terraces developed on its dissected surface. Another fan spreads out at the village of La Luna. Both of these, on the east side of the valley, contain thick deposits of alluvium mostly derived from the Juana Díaz Formation. A third fan spreads out from the narrow neck at the lower end of upper Quebrada Arenas basin and extends across the Fraternidad area toward Lajas Valley.

In other areas along the south coast of Puerto Rico the development of alluvial fans is of prime importance to the collection and availability of ground water. In the Guánica study area the fans are important only as sources of recharge to the alluvium of the main valley.

Guánica Delta

At the lower end of the Río Loco valley the gradient of the surface changes from about 30 to less than 15 feet per mile. The low gradient and the accumulation of finer material indicate the development of a delta formed by deposition of sediment at the ancestral mouth of Río Loco. The delta was built up in the sea, but throughout its history fresh water from the landward side probably was effectively cleaning out many of the salts. Test holes drilled 0.2 mile from the shore have slightly salty water, but these penetrated only 40 feet of the 160-foot thick deltaic deposits.

Quality of Water Relationships

Most rain water as it falls from the atmosphere is nearly pure chemically, except for small amounts of dissolved minerals and gases. After reaching the ground the water dissolves minerals from the rocks and vegetation over which it flows. In the Guánica area serpentinite and volcanic tuffs, breccias, and lava flows contain a variety of minerals, part of which are dissolved as surface and ground water passes over or through them. Sedimentary rocks, such as the mudstones of the Río Yauco Formation, the alluvial gravels and muds of the Juana Díaz Formation, and the calcareous beds of the Ponce Limestone, were accumulated mainly in marine environments in which sodium chloride, calcium and magnesium bicarbonates and sulphates precipitated along with the deposition of clastic material. Ground water passing through these beds dissolves the more soluble of the chemical constituents.

Water from several places along the rivers and from wells generally increases in mineral content from the mountains to the coast. Some areas, such as in the Quebrada Susúa valley and in the La Luna valley, have a marked increase of dissolved solids that can be attributed to the rocks from which the water is obtained—the Juana Díaz Formation. Water from wells penetrating volcanic rocks, or alluvium derived from volcanic rocks, contains comparatively small amounts of dissolved chemicals.

Collection and Analysis of Water Samples

In November 1962 and April and July 1963, water samples were collected from all large-yield wells from several points along all streams. Areas having water with a high concentration of minerals were sampled more often. The concentrations, expressed in parts per million (ppm), of ions of silica, iron, calcium, magnesium, sodium and potassium together, bicarbonate and carbonate together, sulfate, chloride, fluoride, and nitrate were determined. Specific conductance, a measure of the electrical conductivity of water which is an indication of the total ppm of ionized constituents in solution, also was determined. Although specific conductance does not indicate the concentration of particular ions, it is helpful in determining changes in total ion concentration with place or time; thus, a simple field measurement can provide a basis for the number of samples that may be needed for more detailed analysis. Hardness of water is a property attributed principally to calcium and magnesium ions. pH is a measure of the free hydrogen-ion concentration. Values of less than 7 indicate an acid condition in the water, more than 7 indicates an alkaline condition.

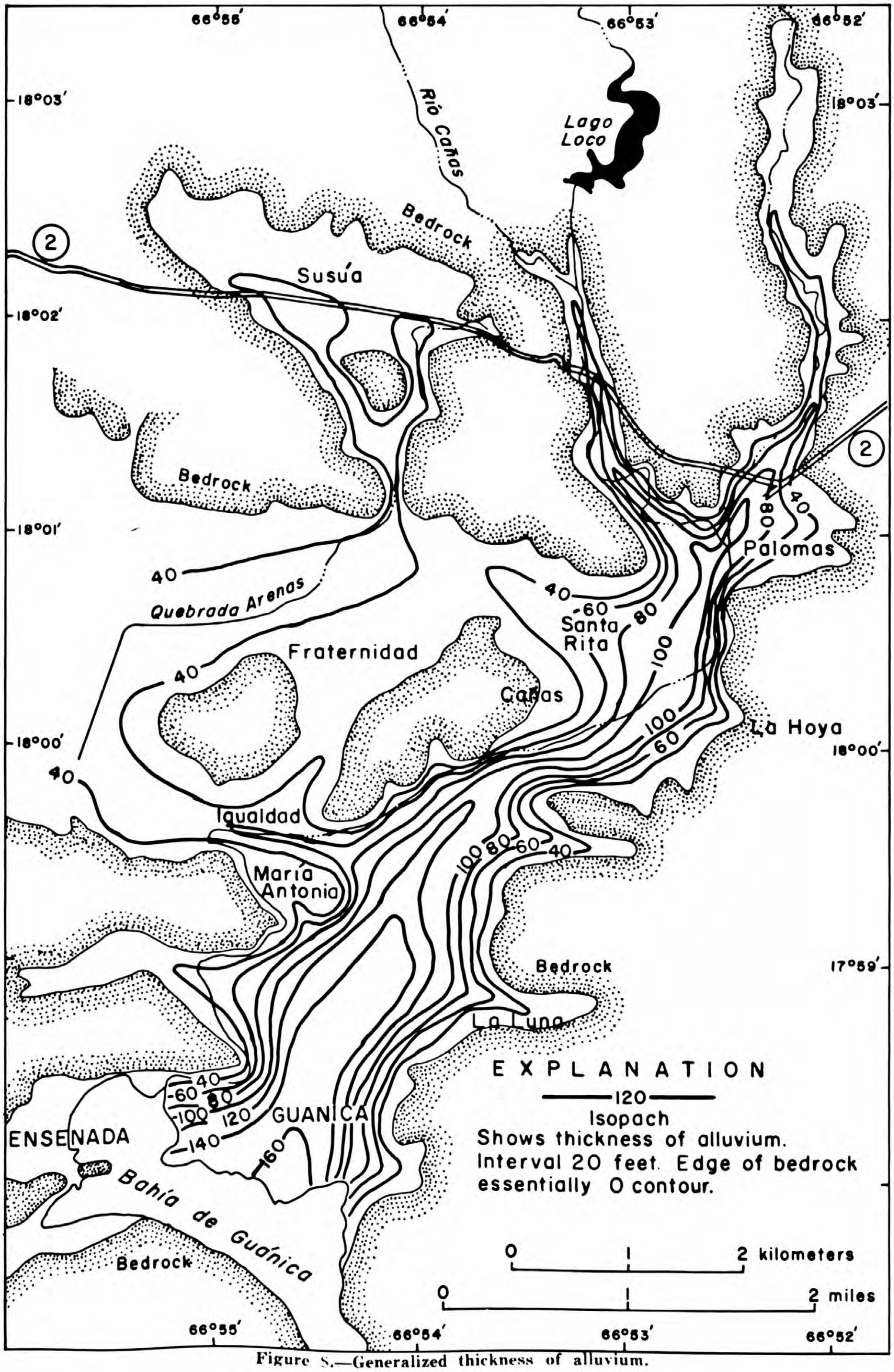


Figure 8.—Generalized thickness of alluvium.

WATER IN THE MOUNTAINS

Quantity

The mountainous part of the Guánica area, about 11.4 square miles, includes the drainage basins of upper Río Loco, Quebrada Grande, and Río Cañas. There are no rain gages in this section; however, based upon climatological maps of the U. S. Weather Bureau, rainfall ranges from 40 inches near Lago Loco to 90 inches in the higher areas (fig. 9). An estimated average of 37,000 acre-feet of rain falls annually on the mountains.

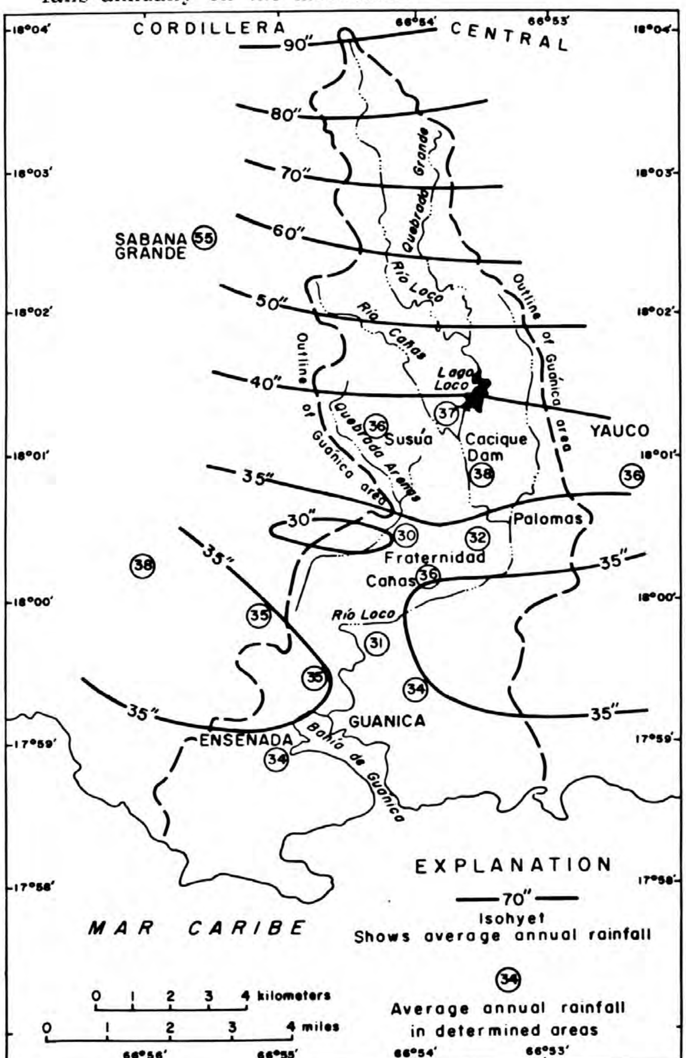


Figure 9.—Average annual rainfall in Guánica area.

Upper Río Loco Basin

Before Loco Dam was built, PRWRA measured Río Loco at Cacique Dam from April 1949 through December 1951. Records indicate that base flow from January through July is 3 cfs. During the period August through December storm runoff accounts for some 70-80 percent of the total annual flow. Table 2 shows some of the river characteristics during the period of record.

Records of the U. S. Weather Bureau indicate that rainfall in the upper basin 1945-51 was about 10 percent below the 50 year average. It was therefore estimated that average annual runoff from the upper basin would be in the magnitude of 10,000 ac-ft.

Since 1955 and the construction of Loco Dam, flow in Río Loco has been controlled. About 3 ac-ft per day is released from the dam and this plus seepage of 2 to 3 ac-ft per day constitute the daily minimum streamflow to the lower valley (2,000 ac-ft per year). High flows to the lower valley from Lago Loco comes from spills over the dam or through the sluice gates.

Ground water in the mountains occurs in fractures in the bedrock and in interstitial space in talus and weathered rock. Wells drilled into the bedrock would probably yield less than 10 gpm, although the yield may be as much as 50 gpm in severely fractured zones. Springs from these sources maintain flow in Río Loco during the dry season.

Río Cañas

The total annual discharge from the Río Cañas basin is estimated to be 1,000 ac-ft, of which about 75 percent occurs as storm runoff.

Quality

Río Loco basin above Lago Loco drains an area of serpentinite and volcanic rocks. The water at low flow contains about 240 ppm total dissolved solids, with relatively high concentration of silica and magnesium bicarbonate (table 3). The flow from the Río Loco basin represents only a small part of the total contribution to Lago Loco. About 90 percent of the water in the lake comes from Lago Lucchetti; consequently the quality of water in the lake is similar to water from Lago Lucchetti (compare B-1 and D, table 3). Lake water is a calcium bicarbonate type with about 160 ppm total dissolved solids.

Water in Río Cañas basin is similar to that of upper Río Loco, however, the dissolved solids content is about 1.5 times greater. As in Río Loco, the water is a magnesium bicarbonate type and contains high concentrations of silica (50 ppm). The increased mineralization is caused by the water leaching calcareous rocks of the Río Loco Formation and Parguera Limestone outcrops. The volume of water from Río Cañas basin is small compared to that coming from Lago Loco and it therefore has very little influence on the quality of water in the lower Río Loco valley.

Table 2.—Flow in Río Loco prior to 1955.

(Based on PRWRA records.)

Year	Total annual flow, ac-ft.	Total flood flow, ac-ft.	Flood flow, percentage	Month of greatest flow	Month of least flow
1949	8,350	4,480	54	Oct.	May
1950	10,950	9,070	83	Dec.	March
1951	7,110	4,430	62	Oct.	April
Averages	8,800	5,990			

Table 3.—Chemical analyses of surface water in mountains.

Fig. 2 map designation	Location	Date of Collection	PARTS PER MILLION													Temp °F
			SiO_2	Fe^{+3}	Ca	Mg	Na & K	HCO_3	SO_4	Cl	F	NO_3	Total Solids	Hardness	pH	
	Río Loco Basin															
(A)	Quebrada Grande	4-9 63	40	0.02	17	42	23	298	2.4	13	0 4	0.0	285	215	8.1	89
(B)	Río Loco	4 9-63	34	.00	13	37	19	246	2.0	15	0.8	.0	242	184	8.0	76
(B-1)	Lago Lucchetti	5-27 63	18	.00	23	3.5	16	100	8.8	8.5	.2	3.4	127	72	7.3	77
(D)	Lago Loco	4-10-63	20	.00	28	7.3	17	148	1.2	9.0	.7	.5	157	100	7.3	84
	Río Cañas Basin															
(K)	Upper Río Cañas	4-10-63	50	.00	18	61	30	406	1.2	19	.0	.0	379	296	8.0	77
(L)	Lower Río Cañas	4-10-63	50	.00	39	53	43	438	14	23	.2	1.8	440	316	7.7	76

WATER ON THE PLAINS

Most of the available water on the plains comes from Lago Loco which is the endline reservoir in the Yauco hydroelectric complex. In addition to low flow releases averaging 1.5 cfs, controlled releases often greater than 200 cfs, and floods comprise the streamflow to the lower Río Loco valley. All water of the low flow releases is lost as surface flow primarily being absorbed by the alluvium. Releases from the lake at rates exceeding 100 cfs and flood spills continue across the plains as surface flow in Río Loco. Depending upon antecedent climate conditions, as much as 90 percent of the higher streamflows reach the sea. Most of the apparent surface water loss between Lago Loco and the sea is recharged into the alluvial aquifer. This recharge occurs naturally because of the highly permeable alluvium or results from lowered water levels induced by pumping wells in the valley. Thus, there is almost continual recharging of the aquifer in the lower valley from Río Loco. This recharge is the major source of the water in the alluvium which is in turn the major source of ground water in the Guánica area.

The upper basin of Quebrada Arenas and its channel across the eastern end of Lajas Valley, the plains between Fraternidad and Santa Rita, and the Quebrada Susúa valley are sources of minor quantities of water to the Guánica area. In some cases the quality of water in these smaller basins has a temporary effect on water quality in part of the Río Loco alluvium.

Lower Río Loco Valley

Surface Water

Two recording gaging stations were in operation on Río Loco in December 1962; one at Cacique Dam, 0.15 mile below Loco Dam, and one about 0.2 mile above the Río Loco-Lajas drainage canal confluence (fig. 2). In addition, other sites on Río Loco, and its tributaries were measured three times during the study period (Table 4).

Table 4.—Flow measurements of streams on the plains.

Fig. 2 map designation	Location	November 1962				April 1963				July 1963			
		Day	Time	Flow, cfs	Temp. °F.	Day	Time	Flow, cfs	Temp. °F.	Day	Time	Flow, cfs	Temp. °F.
(D)	Río Loco below Loco Dam (recorder sta.	Dec. 6	0835	2.54	77	9	1613	3.14	78	30	1100	2.61	81
(E)	Río Loco at Hwy 116 bridge, Palomas	Nov. 28	1800	.37	76	8	1500	.00	—	30	1140	.64	89
(F)	Río Loco at Hwy 116 bridge, Cañas	28	1730	1.62	79	8	1550	.00	—	30	1345	2.01	86
(G)	Río Loco at Hwy 332 culvert, Igualdad	28	1110	.16	75	8	1630	.00	—	30	1420	.43	87
(H)	Río Loco at Piling Dam (recorder sta.)	28	1415	.00	—	11	1525	.00	—	30	1525	.27	83
(I)	Quebrada Susúa at Callejón Quiñones	27	1055	.05	77	9	1436	.01	91	29	1115	.00	—
(J)	Quebrada Susúa at Hwy 2 bridge	27	1140	.06	76	8	1430	.00	—	29	1145	.00	—
(M)	Quebrada Arenas at Hwy 2 bridge	28	0843	.04	73	10	1110	.04	—	29	1445	.00	—
(N)	Quebrada Arenas at Hwy 332 cruising near school	28	0915	.06	73	10	1137	.00	—	29	1510	.07	83
(O)	Quebrada Arenas below confluence with Quebrada Cipote	28	1140	.22	76	11	0920.	.7	79	29	1610	1.09	80
(P)	Quebrada Cipote at Hwy 332 culvert	28	0945	1.05	75	10	1612	.21	81	29	1540	.70	82

The influent and effluent conditions in Río Loco are indicated by the discharge values on November 28, 1962. About 2.5 cfs flowed past the gaging station at Cacique Dam. Downstream at Palomas, the flow in Río Loco was only 0.37 cfs; most of the water had entered the ground-water system. At Cañas the flow in the river was 1.6 cfs; the increase is attributed to effluence from the ground-water system. Further downstream at the Highway 332 bridge, the flow was only 0.16 cfs. Again the stream had lost water to the ground-water system; however, some of this loss was probably caused by a diversion to the Igualdad farm. In April 1963, there was no flow in Río Loco from a short distance below Highway 2 bridge to the Lajas drainage canal, except from a ground-water seep about 0.6 mile above the Highway 116 bridge at Cañas. The July 1963 base-flow measurements made between releases from Loco Dam show the same loss and gain of water as in November of the previous year.

Water from Lago Loco

When water is released from Loco Dam in May and June a large part of the flow is recharged to the ground water system. Figure 10 shows daily discharges at the upper and lower Río Loco gaging stations resulting from high discharge releases from Lago Loco during May, June, and July 1963. The difference in discharge between stations indicates recharge to the ground water is substantial during these months, even though the greater portion of the higher stream discharges (above 100 cfs) pass out to sea.

To determine where and how much water is recharged to the alluvium and how much is lost to the sea, it was arranged with PRWRA to measure a controlled release from Lago Loco on May 24, 1963.

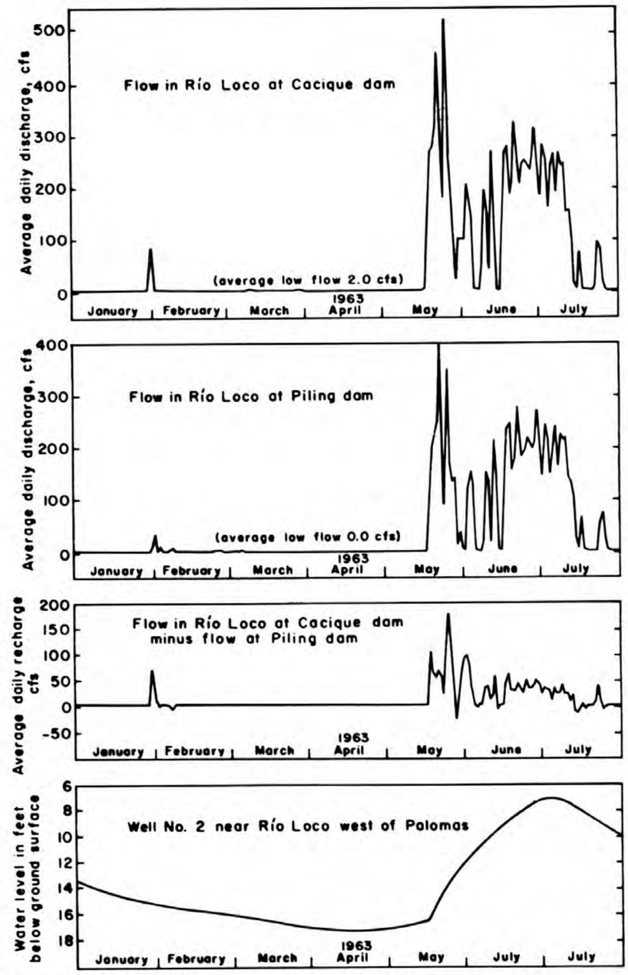


Figure 10—Difference in flow, and flow related to ground water level at two recording stations on Río Loco.

Release of May 24, 1963.—From May 18 to 23, the discharge through Loco Dam ranged from 200 to 450 cfs. On the evening of May 23 the gates were closed and the flow in the river decreased to about 2 cfs below Loco Dam and to about 5 cfs 50 yards downstream from the Highway 116 bridge at Cañas. This higher flow at Cañas is the result of water discharging from temporary storage in the banks of the river. The gate in Loco Dam was opened at 0905 hours, May 24, and the discharge was 270 cfs (fig. 11). By 0935 hours the leading edge of water reached the Highway 2 measuring point 1.0 mile downstream from the dam. Within 15 minutes 265 cfs was flowing by this point. At 1050 hours the water front had reached the Highway 116 bridge at Cañas, 4.6 miles downstream from the dam. Here the flow increased from 215 cfs at 1100 hours to nearly 230 cfs at 1200 hours. The water front reached the downstream gaging station, a distance of 6.3 miles from the dam, by 1130 hours, and within a half hour the flow had reached 200 cfs, and within an hour the crest was 215 cfs. The gates in the dam were closed at 1205 hours.

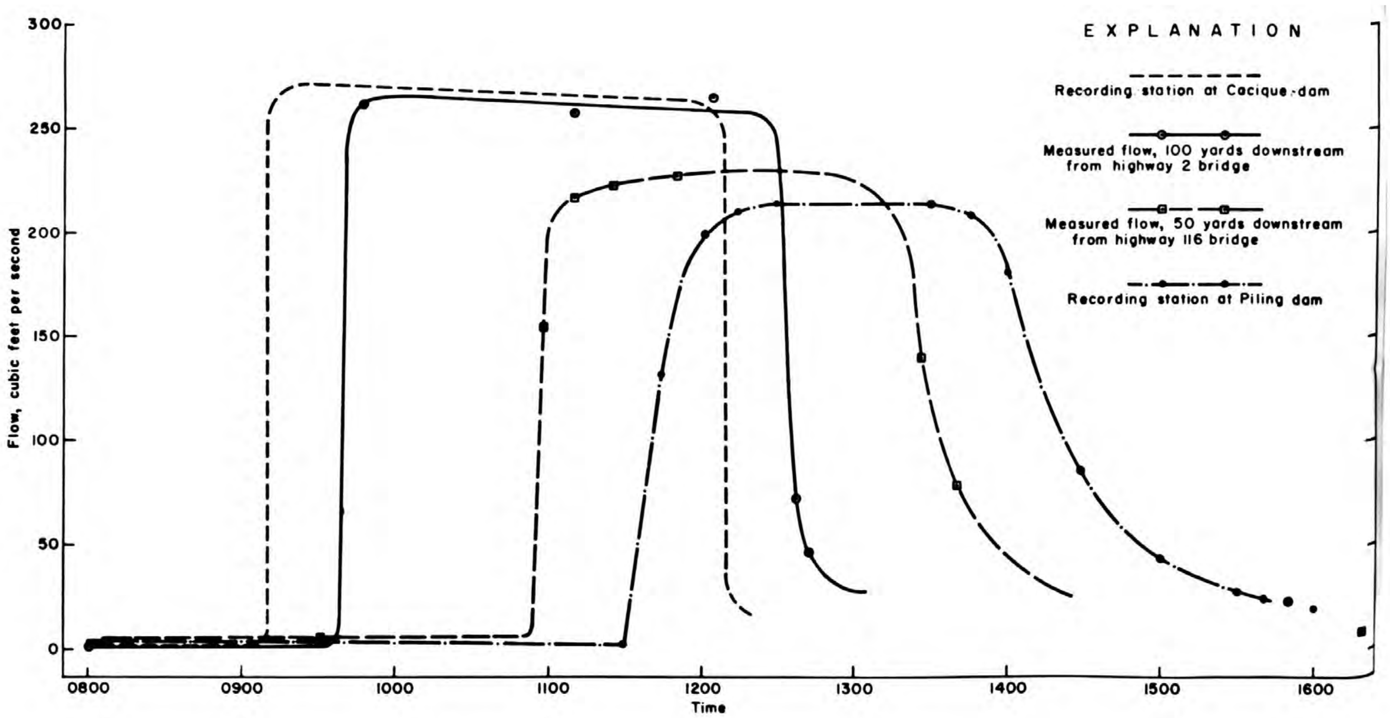


Figure 11.—Flow of Río Loco during controlled release from Lago Loco, May 24, 1963.

Calculations of discharge.—The total water released from Lago Loco for the 3- hour test period was 67 ac-ft. The amount discharged past the Highway 2 measuring point was 65 ac-ft, and at the Highway 116 bridge at Cañas it was 54 ac-ft. Thus, from the original 67 ac-ft, 13 ac-ft was lost along the 4.6-mile channel, or 2.8 ac-ft per mile in 3 hours. The loss in the 6.3-mile channel from Lago Loco to the lower gaging station is about 18 ac-ft. Since there is little loss of water to the ground water system along the Río Loco below this site, approximately 70 percent of the original release flowed out of the Guánica area to the sea. Therefore, if 75 cfs were released from the dam, all or nearly all would be absorbed into the alluvium.

Based on the May 24 release and the greater releases that occurred in the following two months (fig. 10), a considerable amount of water enters the ground-water system via Río Loco, although the larger part runs out to sea. For the period of record, about 60 percent of the stream discharge passed the lower gaging station. The data in figure 10 represents stream discharge conditions in Río Loco during the usual dry season from January to May, a very short rainy season in May followed by fairly dry conditions in June and July. Thus the ratio of streamflow to recharge is biased toward the latter event. During the annual wet season, August through December, when ground water levels are usually high and releases from Lago Loco at their peak, the ratio of streamflow to recharge is biased toward the former. A reasonable estimate of 70 percent runoff to the sea is projected for the annual water released through, or spilled over Loco Dam.

Surface flow and ground water recharge.—As indicated previously, water recharge to the alluvium from Río Loco occurs almost continually. The amount of recharge is dependent upon the amount of discharge in the stream, ground water levels, and the antecedent climatic conditions. This surface flow and recharge to ground water relationship is emphasized in figure 10 by the indicated rise in water levels in well 2 coincident with the increase in flow in Río Loco. Data in figure 12 further emphasizes this relationship by a breakdown of the streamflow at the upper and lower gaging stations into discharge and recharge components and relating these to average ground water levels in the valley.

During May, the recharge to the ground-water aquifer ranged from 100 percent to 8 percent and averaged about 40 percent of the released water from Lago Loco to Río Loco. As ground water levels rose and reached a peak in late June the amount of recharge to the alluvium decreased to an average of 18 percent of the released water. In July, most of the time the flow in Río Loco was absorbed by the alluvium before reaching the lower gaging station. During the months May through July the difference in discharge between the upper and lower gaging stations was about 4,600 ac-ft. and most of this represents recharge to the alluvium. This amount of water is equal to 30 percent of the average annual groundwater pumpage.

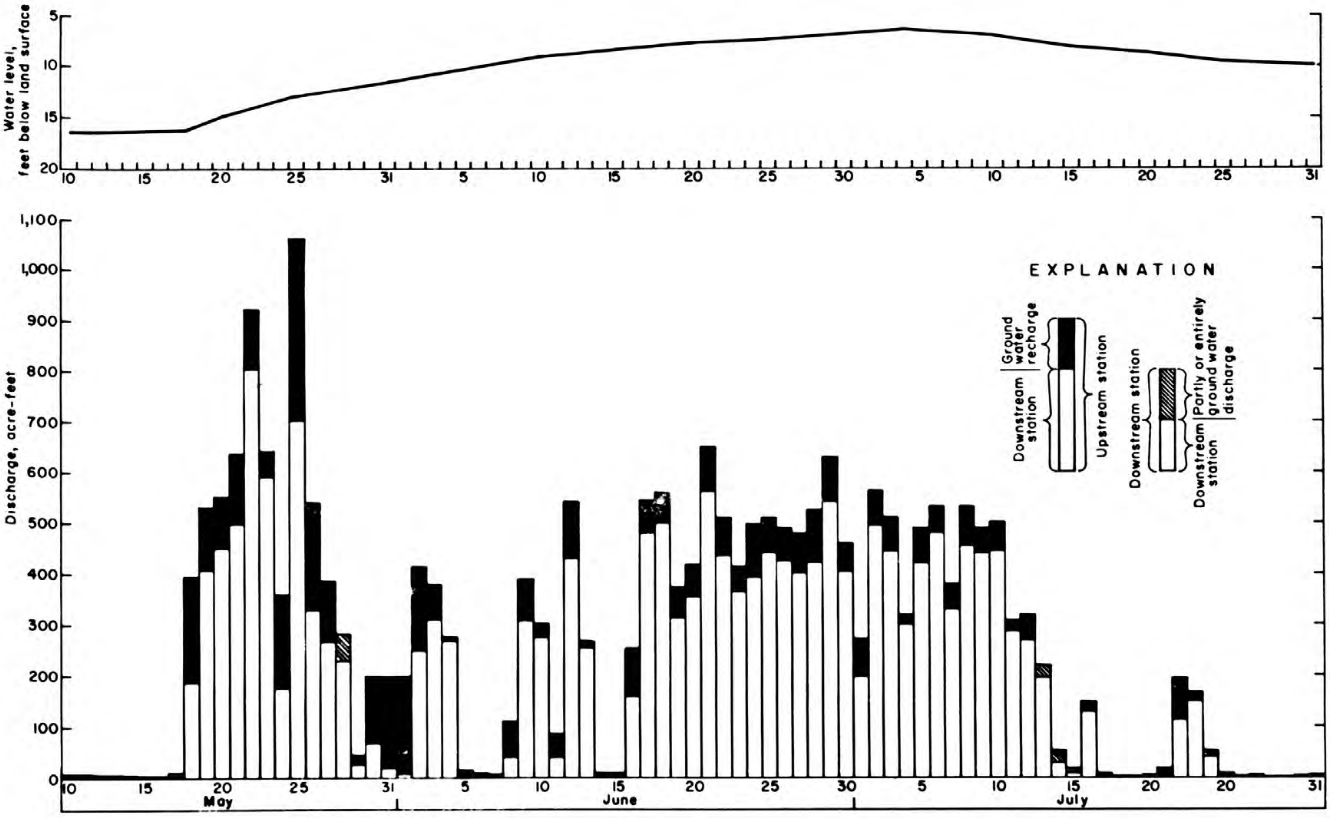


Figure 12.—Discharge and recharge components of flow in Río Loco with coincident ground water levels in lower valley.

Ground Water

Wells

Irrigation wells.—Scattered over the lower plains are 17 large-yield irrigation wells that are used about 8 hours a day five or six days a week throughout the year, and three wells that are used as needed. Most of these wells yield over 600 gpm; well 15 yields 3,200 gpm. Throughout the area the yield is restricted by the size and setting of the pumps rathen than by the capability of the aquifer. For example, in July 1963, well 5 yielded 650 gpm with only 6 feet of drawdown from a static water level of 11 feet. The pump is 25 horsepower, set at 70 feet. A larger pump at the well could double, possibly triple, the yield without excessive drawdown. The total yield from the irrigation wells is about 22,000 gpm, or about 32 ac-ft in an 8-hour day. For well locations see figure 2.

Public and industrial supply wells.—Other large-yield wells in the Guánica area supply public and industrial needs. Wells 28 and 32 serve the town of Guánica, and usually one at a time is pumped for 24 hours a day at nearly 300 gpm. Two others, wells 24 and 25, also are pumped alternately for 24 hours a day at about 650 gpm; these are used by the chemical plant east of Guánica. Three wells used by Central Guánica, wells 30, 31, and 34, together pump over 700 gpm for 24 hours a day from July to December, and pump nearly 1,000 gpm from January to June 1 when the sugar crop is being processed.

Two of these wells at Station M, wells 30 and 31, supply municipal water to Ensenada and the headland to the south as well as industrial water to Central Guánica. The battery at Station G, well 34, pumps about 200 gpm only when the sugar crop is being processed; the rest of the year this well flows about 10 gpm.

Small and abandoned wells.—Several wells supply water to local haciendas, and a large number of small domestic wells supply individual houses with drinking, washing, stock, and occasionally irrigation water for gardens. Most of the domestic wells have hand pumps and yield less than 10 gpm each. Abandoned and unused wells throughout the area furnished important geohydrologic information. Some of these wells were used for water-level observations and to determine water quality trends from area to area.

Withdrawals

The water withdrawals from major wells in the Guánica area are listed on table 5. The slight decline of pumping rates between November 1962 and April 1963 is a reflection of the decline in water level in most wells. The irrigation wells pump only five or six days a week. When an annual average is calculated, this must be taken into account. Thus the irrigation wells yield about 9,000 ac-ft of water annually. The industrial and public supply wells, pumping an average of about 9 ac-ft per day for 365 days a year, have an annual yield of over 3,000 ac-ft.

Aquifer tests

Specific capacity tests.—The specific capacity of a well is the discharge in gallons per minute for each foot of drawdown from static water level. Most of the specific capacities of wells in table 6 were obtained from pump tests during the present investigation or from test data in drillers' records.

Generally, wells having the highest specific capacity are in the part of the valley where the alluvium is thickest. This trend is reversed, however, near Guánica where the proportion of fine grained material is greater and the aquifer is less productive. The specific capacity of well 28 at Guánica is 35 gpm/ft of drawdown and that of well 31 near Guánica is 15 gpm/ft of drawdown; but wells 16 and 23 further up the valley yield 110 gpm/ft of drawdown or more.

The specific capacity of wells decrease with increasing yields and consequent deeper pumping levels (see original pump test of wells on fig. 13). This happens because at deeper pumping levels less of the aquifer is yielding water to the wells. As the pumping level is lowered in layers of gravels interbedded with less permeable silts and sands, only the lower layers maintain their yields. Most of the silt and clay layers in the alluvium of the Guánica area are slightly permeable, so near the well when these become depleted of water the overlying gravel layer contributes water to them rather than the well. This water eventually reaches the well through the silt and clay layers but it takes more time.

Step-down tests.—Step-down tests, which were conducted on some wells at the time they were drilled, indicate that they may be pumped at twice the yield reported during the study. A comparison of the specific capacities of the wells when drilled to those in 1962-63 indicate that the yield of all but well 28 has improved (fig. 13). The improvement probably resulted from removal of the fine grained material from between particles of coarse sand and gravel during the normal pumping of the wells.

Table 5.—Discharge of major wells in the Guánica area.

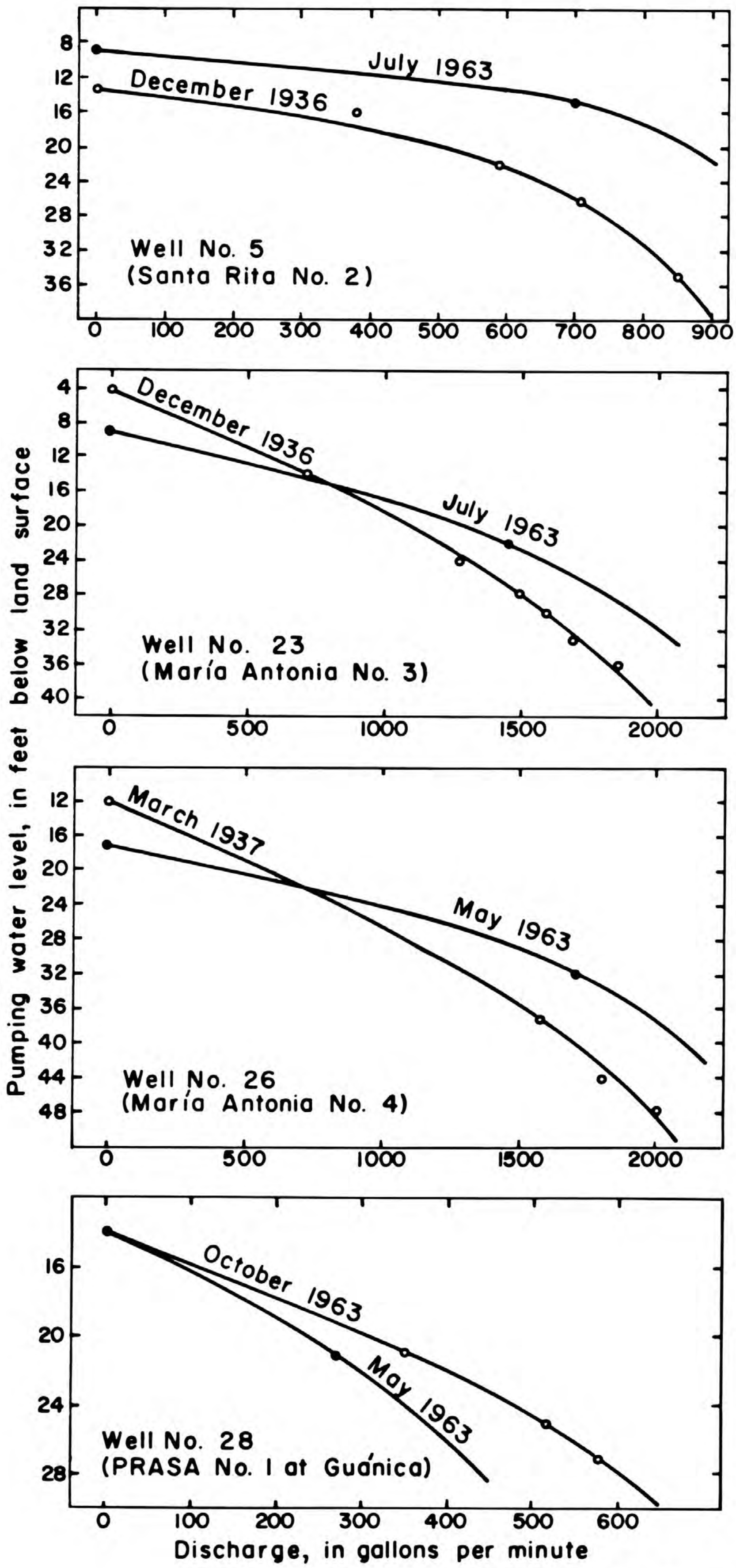
Well No.	November 1962			April 1963		
	Discharge, gpm	Hours pumped	Total yield, ac-ft/day	Discharge, gpm	Hours pumped	Total yield, ac-ft/day
2	250	2	0.09	250	2	0.09
5	650	8	.96	650	8	.96
6	1,530	8	2.25	1,860	8	2.73
9	1,260	8	1.86	1,200	8	1.77
13	1,300	8	1.92	1,250	8	1.85
14	1,440	8	2.12	1,400	6	1.55
15	3,200	8	4.72	3,100	8	4.57
16	1,100	8	1.62	1,200	8	1.77
17	630	8	.93	775	8	1.14
18	1,260	8	1.86	1,050	8	1.55
19	1,140	8	1.68	750	8	1.10
20	490	8	.72	450	8	.66
21	850	8	1.25	800	8	1.18
22	1,900	8	2.80	1,800	8	2.65
23	1,480	8	2.18	1,400	8	2.06
24&25	650	24	2.87	650	24	2.87
26	1,750	8	2.58	1,700	8	2.50
27	700	8	1.03	975	8	1.44
28	350	12	.77	350	12	.77
29	770	8	1.13	600	8	.88
30	1,000	24	4.42	1,000	24	4.42
32	300	12	.66	300	12	.60
33	800	4	.59	750	0	—
34	—	—	—	200	24	.88
70	30	16	.09	30	16	.09
Total			41.10 (12.6 mgd)			40.08 (12.3 mgd)

Table 6.—Specific capacity, transmissibility, and related information for selected wells in Guánica area.

Well number	Elevation, feet	Depth to bedrock, feet	Saturated thickness of aquifer, feet	Static water level below surface, feet	Pumping water level, feet	Yield, gpm	Specific capacity, gpm/ft of DD	Transmissibility, gpd/ft	Average permeability gpd/ft²
2	100	92	75	19	21	230	115	300,000	4,000
5	95	87	75	9	14	700	140	360,000	4,800
14	54	80	72	14	26	1,400	115	200,000	2,750
16	48	108	95	11	21	1,150	115	460,000	4,800
22	33	90	95	18	43	1,800	70	280,000	3,000
23	23	120	110	9	22	1,450	110	600,000	5,400
26	30	112	120	17	33	1,700	105	340,000	2,800
27	17	130	130	11	17	300	50	—	—
28	26	107	92	14	21	270	35	—	—
31	19	147	136	8	48	600	15	—	—
41	20	30	15	13	25	10	1	8,000	500
55	20	48	—	0	43	48	1	—	—
78	215	10	20?	41	77	5	0.14	—	—

Pump tests.—Figure 14 shows hydrographs of five wells during the regular pumping day. Theoretically the drawdown curve approaches some depth line asymptotically, but commonly the curve is affected by several outside factors so this line is not approached or it is crossed. Some of the factors are: daily or storm-caused barometric pressure changes; general water-level decline from lack of recharge or from excessive pumping; general water-level rise from greater-than-normal recharge; and local water-level rise or decline caused by starting or stopping pumps in nearby wells. The most effective of these factors during the tests in the Guánica area was the rise of water level caused by increased flow in Río Loco (see wells 5 and 26, fig. 14). During all tests other wells in the vicinity also were being pumped and water levels were declining. Nearby wells were turned off and water levels were recovering at nearly the same time as the tested well.

The sharp break in the drawdown and recovery curves (fig. 14) is indicative of an aquifer with high transmissability. In almost every well along the lower Río Loco valley, the recovery of the water level is within 2 feet of static water level one hour after the pump has been turned off.



December 1936

Discharge, in gpm	Drawdown, in feet	Specific Capacity in gpm/ft. of DD
380	3	125
590	9	65
850	22	38

July 1963

700	6	115

December 1936

730	9	81
1490	23½	64
1850	31½	60

July 1963

1450	13	110

March 1937

1580	25	63
1800	32	56
2000	35	57

May 1963

1700	16	105

October 1938

350	7	50
515	11	46
575	13	44

May 1963

270	7	38

Figure 13.—Changes in specific capacity of pumped wells with time.

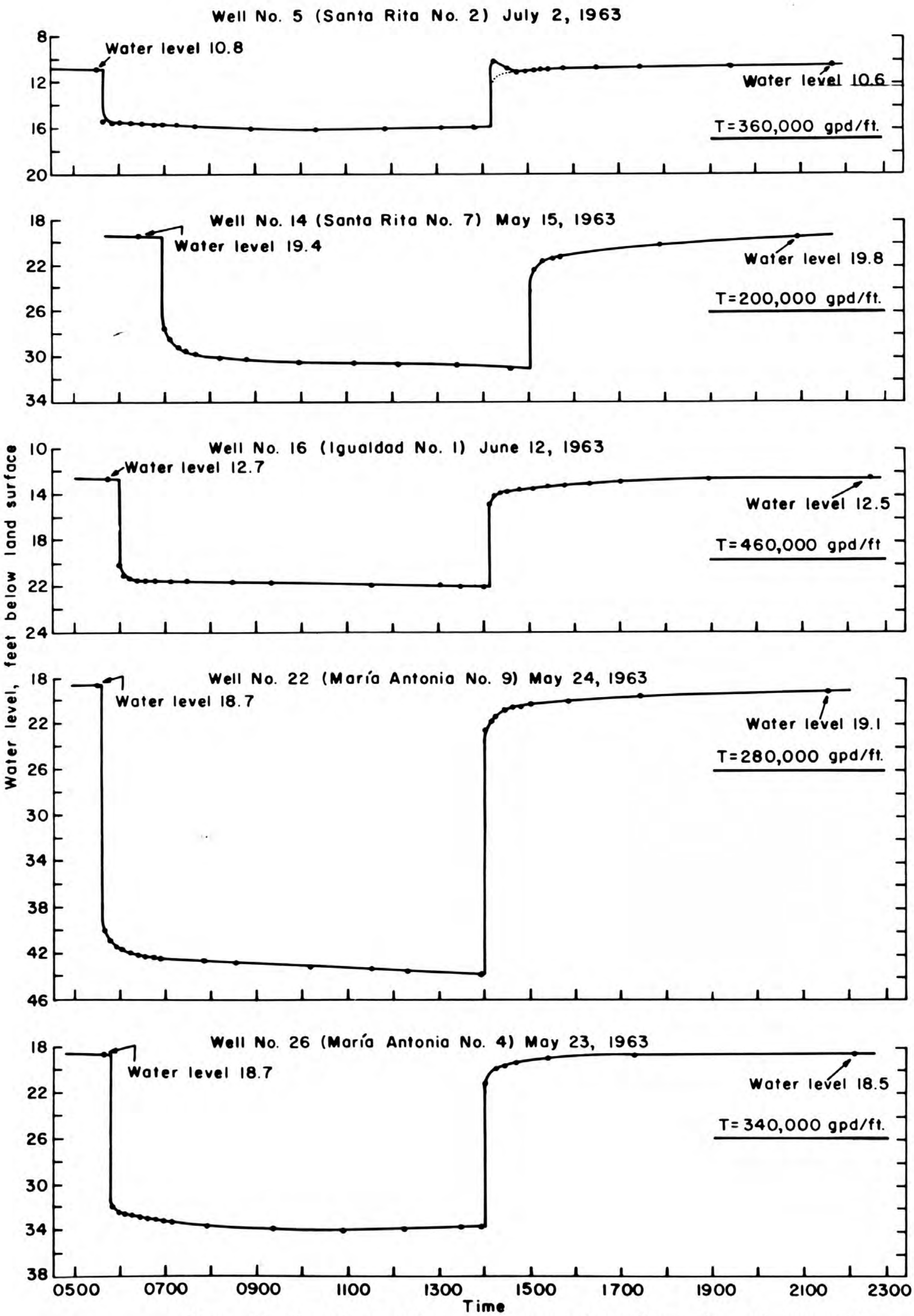


Figure 14.—Drawdown and recovery curves from five wells, and computed transmissibility.

Transmissibility.—Transmissibility is a coefficient indicating the amount of water, in gallons per day, which would pass through a vertical strip of aquifer one foot wide the height of the aquifer under a hydraulic gradient of 1 foot per foot. The transmissibility is calculated from measurements of the drawdown and recovery of water levels in a well. The aquifer transmissibility at well 16 is about 460,000 gpd/ft; this well is situated in the narrow neck south of Cañas. The aquifer at well 5, above the neck, and at well 26, below the neck, has a transmissibility of about 350,000 gpd/ft. Despite the constriction at the neck nearly the same amount of ground water passes through it as passes through the wider part of the valley at Santa Rita because of the higher transmissibility. The amount of water passing through various areas was calculated from the gradient of the water table, the transmissibility, and the average width of the alluvium. Approximately 4 mgd (1 mgd equals about 3 ac-ft. per day) passes between Palomas and the hill north of Santa Rita; 3.2 mgd passes through the neck south of Cañas, and 4.4 mgd passes between the hill on which Hacienda María Antonia is located and the hill north of la Luna. These figures would hold true only when there are no wells pumping and at the 1963 water levels. Approximately 4.4 mgd moves through an area of 440,000 square feet north of Guánica and part of this quantity moves on toward the area in Guánica delta pushing the salt water-fresh water interface seaward. It is believed that no salt-water encroachment has occurred at depths of 100 feet or more in the Guánica area. However, increased pumping of wells near Guánica could reverse the ground-water gradient and allow salt water from the bay to move inland. A careful study of the water gradients and transmissibility of material in the Guánica delta should be made before increases in pumping of any magnitude is attempted in the immediate vicinity of Guánica.

Water levels

Explanation of water levels.—The level of the ground-water surface fluctuates from wet to dry seasons and from wet to dry years. Occasionally, a decline in water level will withdraw water from a shallow sand or gravel layer and may reduce by a considerable amount the yield of wells, especially if no other good aquifers occur at greater depths. In most of the Guánica area, declines in water levels affect the efficiency of the pumps, because the pumps must withdraw water from deeper pumping levels which decreases the yield. The decrease in yield is less than 10 percent in most cases between the high water level wet season and lower water level dry season.

Figure 15 shows water levels during the course of the study as interpolated from monthly measurements. Records of water levels prior to the study are available only for the two wells shown on figure 16. Since large-yield wells were first constructed in the Guánica area around 1900 and the surge of well drilling in 1926 through 1930, the only water level records available are those made at the time the wells were completed.

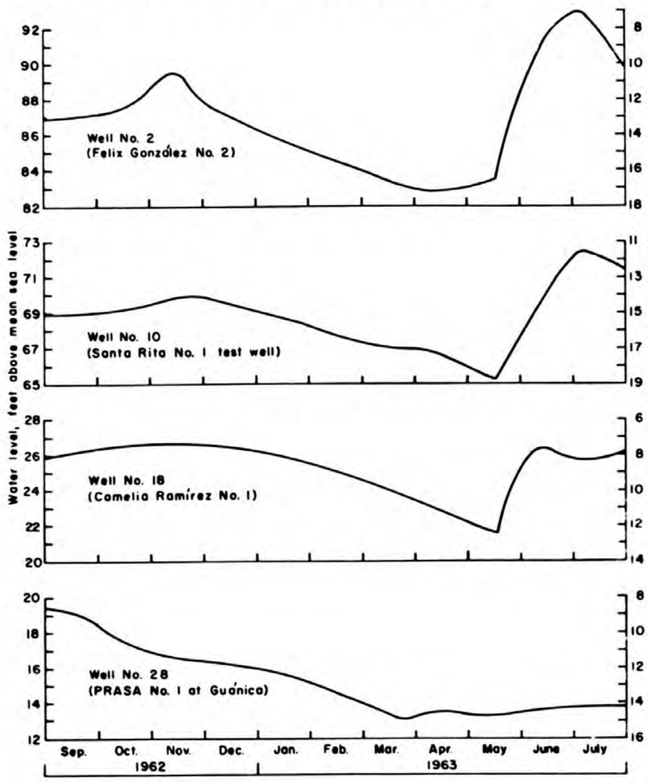


Figure 15.—Water levels in wells in lower Río Loco valley during study period.

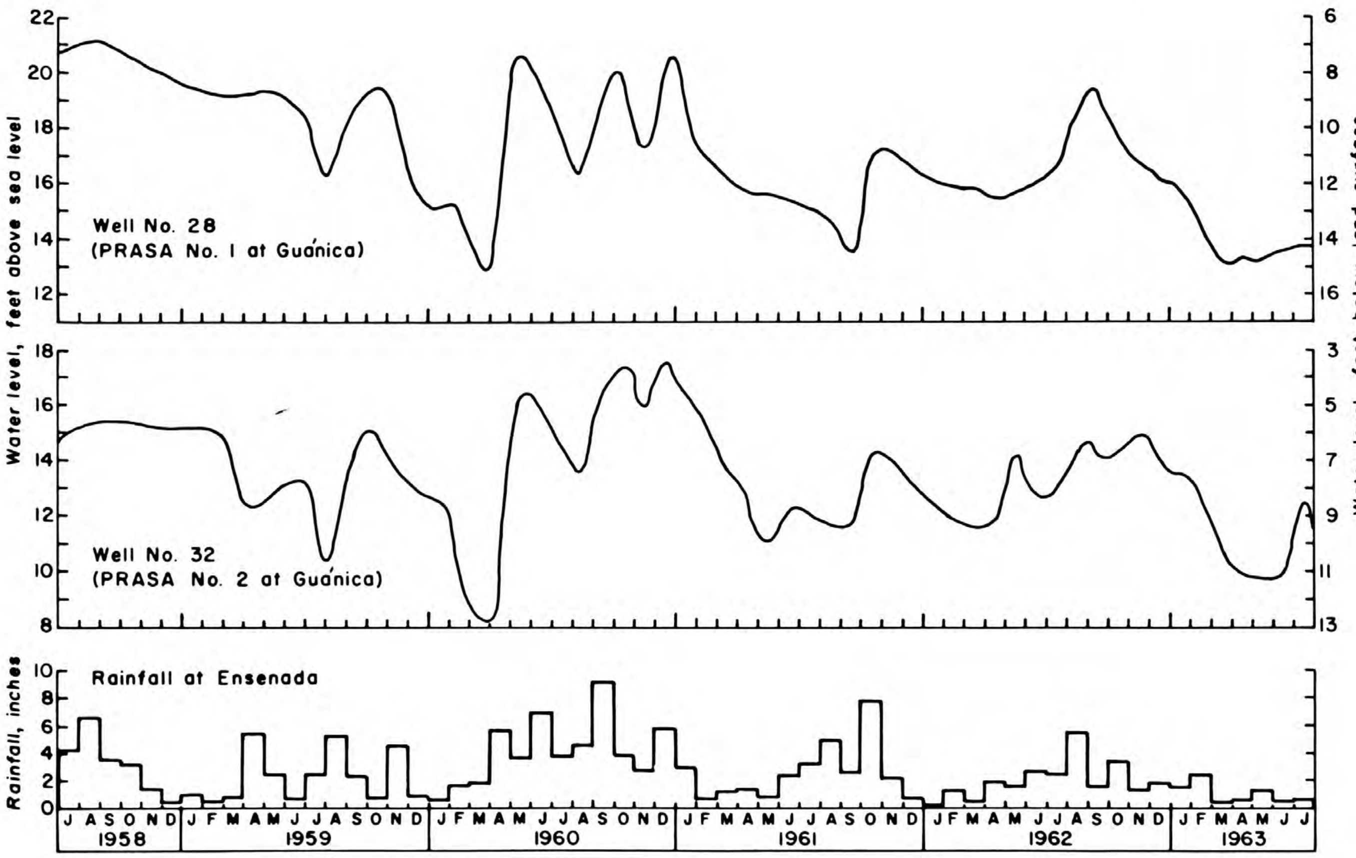


Figure 16.—Water levels in two wells near Guánica and monthly rainfall 1958-1963.

Water levels during study.—Water levels were relatively high in September 1962, because of the heavy rains in August (figs. 4 and 15). From November 1962 to May 1963 the water levels throughout the area declined. Temporary reverses to this decline or sudden increases in the rate of decline can be accounted for by irregular pumping during the harvest and replanting of sugarcane. Rainfall was less than average in April and May 1963 on the coastal area, but in the mountains (see Maricao station, fig. 4), it was far above average, especially during May. The reservoirs connected to the Yauco hydroelectric and Lajas Valley irrigation systems were filled and a large quantity of water was released through the system to the Río Loco valley from May 18 to the middle of July. Approximately 30 ac-ft of water per mile entered the ground water system from Río Loco and this water moved laterally from the river raising the ground-water levels. The water level in test well 89, situated about 50 feet from Río Loco west of Hacienda Igualdad, rose 0.2 foot 1 hour after a release on May 24 raised the stage of the river 3 feet. Only slightly permeable silts and muddy sands were encountered in this hole. Gravel aquifers near Río Loco would show greater rises in water levels.

Water levels in wells farther from Río Loco were not as quickly affected by these large releases of water, but were influenced by the slightly greater amount of rainfall in April, May, and June. This is shown best by comparing well 28, which is far from the river northeast of Guánica, with wells 2 and 10, which are close to the river (fig. 15). The water levels of the wells in the lower part of the Río Loco valley, including well 28, had not recovered to the elevation of the previous September by the end of July 1963. This does not indicate, necessarily, that the general water level in the Guánica area is declining year by year, but merely that the first part of 1963 was drier than the first part of 1962. Many years of record are needed to develop trends of water-level decline.

Water levels of wells - 5-year record.—The water levels in the two PRASA public supply wells at Guánica (fig. 16) are closely related to rainfall. The high water levels in the wells usually follow about one month after the heavy rainfall in the area. These wells also are influenced by high water in Río Loco, as in May 1960, but the influence takes longer to reach the aquifer near Guánica.

Water level map.—Ground water levels in the Guánica area, in April 1963, are shown on figure 17. The contours show the decrease in gradient from 55 feet per mile below Loco Dam to 25 feet per mile near Santa Rita. The gradient south of Hacienda María Antonia to Bahía

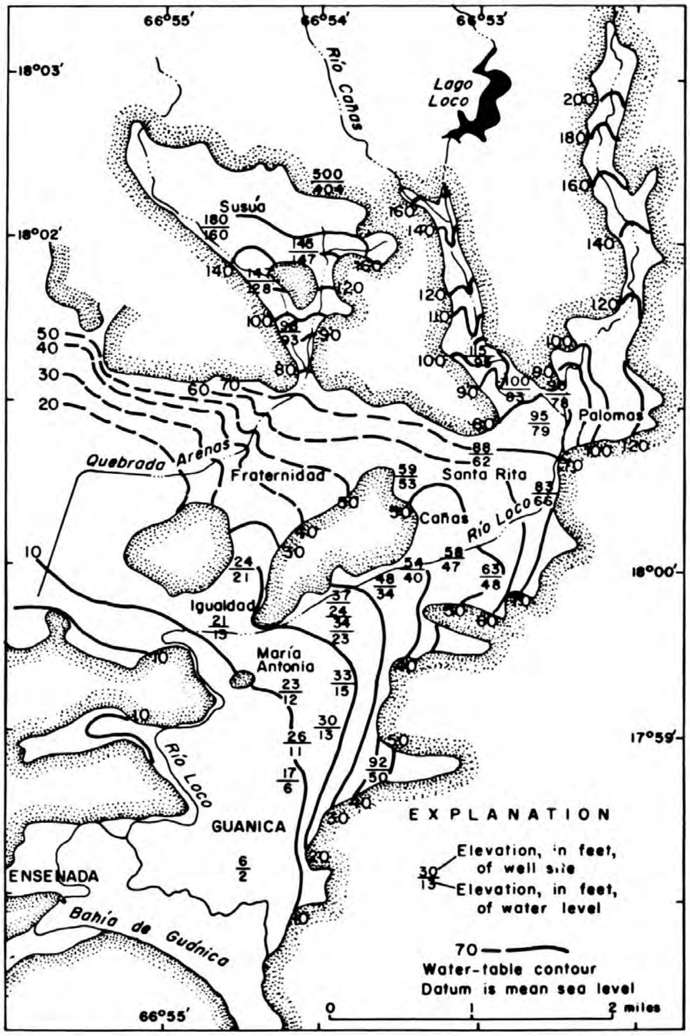


Figure 17.—Generalized water table contours, April 1963.

de Guánica is only about 7 feet per mile. The water level declined about 5 feet west of Palomas and about 3 feet near Guánica between the wet season in November and the dry season in April.

The water-level gradient in the Quebrada Susúa valley, of about 75 feet per mile, reflects the ground surface gradients. The contours in Lajas Valley and in the area between Santa Rita and Fraternidad are hypothetical, for no control wells exist there.

Water movement and storage

Water entering the ground from flood flow of streams and sheet wash after rains on the lowland area is evaporated or absorbed by the plant roots and transpired, or it percolates to the ground-water system. The movement of the water in the ground-water system is like that of water everywhere; that is, down gradient. In the aquifer, however, the movement is slow, from tens of feet a day in a sand and gravel aquifer to inches per month in finer silts and clays. The water in the ground-water system moves down the lower Río Loco valley to the vicinity of the Guánica delta. How far fresh water moves seaward depends on the hydraulic head and the nature of the material. Somewhere under Bahía de Guánica the fresh water merges with salt water from the sea. Because the sea water is more dense it usually underlies the fresh water; however, if a layer of fairly impermeable materials, muds or clays, is at the surface and directly under the floor of the bay, it is possible for fresh water to reach beyond the shoreline in a seaward direction.

The amount of water stored in the alluvium of the lower Río Loco valley is directly related to the porosity of the material. Effective storage would be the water between the water table and the alluvium-bedrock contact. To accurately estimate this storage it would be necessary to have information on the configuration of the bedrock valley under the alluvium and on the porosity and permeability of the alluvial material. All the information needed is not available, but approximate calculation can be made from available information—water levels, pump test data, and driller's logs. Of a total of about 200,000 ac-ft of alluvium in the lower Río Loco valley, about 80 percent, or 160,000 ac-ft, is below the water table. The alluvium has an approximate effective porosity of about 15 percent; thus 24,000 ac-ft of water is in transient storage. These figures are calculated from the dry-season (April) water levels. During the wet season the water levels are 4 to 8 feet higher and there is an increase in storage of about 1,200 ac-ft, or about 300 ac-ft per foot of rise of water level throughout the area.

Quality of Water

Surface Water

Streamflow in Río Loco at discharges high enough to persist from Lago Loco to the downstream gaging station has chemical characteristics similar to that of the lake water (table 3). The available water quality data indicates dissolved solids would rarely, if ever, exceed 200 ppm and silica concentrations would be less than 30 ppm.

Base flow chemical characteristics in Río Loco from Lago Loco to Palomas are similar to those in the lake. Below the confluence of Quebrada Susúa, base flow chemical characteristics in Río Loco are at times influenced by ground water discharge from the Juana Díaz Formation. This ground water discharge may be entering the main stem of the river either from Quebrada Susúa, or from a small tributary that runs through Palomas, or both. When this occurs in sufficient quantity, base flow in Río Loco in the reach near the Highway 116 bridge has dissolved solids contents raging from 800 to 1,200 ppm, silica concentrations from 45 to 50 ppm and chloride concentrations from 140 to 250 ppm. This situation is sporadic and dependent upon ground-water levels in the lower Quebrada Susúa basin being sufficiently high to allow discharge to the stream. The water quality degradation in Río Loco is localized in the immediate vicinity of Palomas. Ground-water discharge from the alluvium in the main valley is sufficient to markedly improve the water quality within a short distance downstream.

From the Highway 116 bridge to the confluence of Río Loco with the Lajas Drainage Canal, base flow is effluent ground water and as such is of similar chemical character. Table 7 indicates the similarities in the chemical characteristics of the ground water and base flow in Río Loco.

Río Loco Estuary.—The water of the Río Loco, below the confluence with the Lajas drainage canal, is greatly influenced by surface salt-water encroachment in the river estuary. A salt water retaining dam with flap gates was built at Abra to allow water to pass downstream, but not upstream. Debris has caught in the gates and rendered this structure completely ineffective. Water of near sea-water composition reaches at least one-half a mile above the dam. The effect of this salt water on the ground water quality is not known; the closest wells, wells 30 and 31 (fig. 2)do not appear to be affected. Well 34, at the edge of the estuary west of Guánica, gets most of its water from fresh water alluvial sources; sea water is in the estuary less than 30 yards away, but water, which flows naturally from the well, contains a total of only about 650 ppm dissolved solids and a chloride content of about 100 ppm. When the well is pumped the chloride content increases to about 300 ppm. The pumping water level is about 10 feet below the level of the estuary, which is essentially sea level.

Ground water

The ground water in the lower Río Loco valley alluvium is a magnesium-calcium bicarbonate type ranging from 200 to 800 ppm total dissolved solids with a modal range from 450 to 650 ppm. In certain areas and near the outer edges of valley, the general chemical characteristics are altered by ground water seepage to the alluvium from adjacent aquifers. Usually this results in a temporary and/or localized water quality degradation. Table 8 shows the results of chemical analyses of selected wells in the lower valley and indicates the gradual increase in mineral content and effects of drainage from adjacent aquifers.

The chemical analysis of well 2 is representative of the ground water in the alluvium between Lago Loco and Palomas. The alluvium in this section is influenced mainly by recharge from Río Loco. Releases from Lago Loco of 3 to 5 cfs are readily absorbed by the alluvium along this reach of the river. The ground water in wells near the river therefore varies from time to time from about 250 to 350 ppm total dissolved solids. The magnesium-calcium bicarbonate type is maintained however.

The chemical analysis of well 4 near Palomas indicates the effect of ground water seepage from the Juana Díaz Formation into the alluvium. In the area of this well, further ground water development would increase the contribution of water from the Juana Díaz Formation with resultant water quality degradation. Just how far downstream in the alluvium this quality

Table 7.—Chemical analyses of base flow in Río Loco and adjacent well water.

Reference, fig 2, Date of Collection	Discharge (cfs)	Parts per million Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness $CaCO_3$ Calcium magnesium	Hardness $CaCO_3$ Non-carbonate	Specific conductance (micromhos at 25° C)	pH	Color	Temperature °F
(F) Río Loco at Cañas																			
		54		24	46	50		368	22	16	—	1.0	404	249			7.8		78
Well No. 15																			
		46		29	55	41		400	24	18	0.1	10	417	298			7.7		79
(G) Río Loco at Highway 332																			
		57		39	49	65		432	33	32	0.3	8.0	515	299			8.3		78
Well No. 19																			
		53		33	60	63		462	36	31	0'0	9.1	511	329			7.9		78

degradation extends is unknown. However, chemical analyses of base flow in Río Loco would indicate it to be localized to the area immediately upstream of the Highway 116 bridge.

The data in table 8 for wells 9 to 32 indicate the gradual increase in total mineral content in the ground water downstream to the junction of Highways 116 and 332. The increases in sulfate, chloride, and nitrate concentrations are the most significant. The increase in sulfate and chloride content is the result of leaching of the rocks in the alluvium as the ground water moves down valley. The rise in nitrate concentration results from the application of liquid nitrogen and nitrogenous fertilizers to the sugarcane fields. Some of the water used in the extensive ditch irrigation process carries this nitrogenous material with it and recharges the aquifer. The analysis given for well 32 indicates that the nitrate can reach very significant concentrations. A nitrate concentration exceeding 44 ppm is not usually recommended for drinking water.

Chemical analysis of well 33 indicates another example of seepage from the Juana Díaz Formation that outcrops in a small valley near La Luna. Well 33 is a battery well and was pumped at about 1,000 gpm, and very probably induced seepage from the Juana Díaz Formation before it was taken out of production. Chemical quality data collected in November 1962 as well as April 1963 indicate constant seepage of poor quality of water to this well. The very high nitrate concentration in this well results from direct seepage of irrigation water from the fertilized sugarcane fields. Because the well is not pumped regularly there is probably some concentration of constituents within the well casing and the chemical analyses are not truly representative of aquifer water.

In Guánica, four test holes were augered in the deltaic deposits to a depth of about 40 feet. The chemical analysis of test well 92 is representative of the shallow ground water quality of this area. The data indicate definite saline water. This is the result of intrusion of salt water from the Bahía de Guánica at shallow depths. No data are available for water quality below 40 feet in this section of the study area.

Water in Quebrada Susúa Valley

Surface Water

Streamflow in Quebrada Susúa is ephemeral, depending upon sporadic rainfall that averages about 6,500 acft annually. Occasionally, when ground water levels are high, base flows of about 0.05 cfs may persist from the upper to the lower basin. Most of the time low streamflow in the upper basin, resulting from spring discharge or light rain, will travel short distances in the channel before being absorbed into the ground. Only after intense rainfall on the basin is there any substantial surface discharge to the lower Río Loco valley.

Table 8.—Chemical analyses of ground water from selected wells in lower Río Loco valley.

Well Number	Depth of well (feet)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25° C)	pH	Temperature °F
			Parts per million															
2			39		21	34	32	268	19	10	0.1	11	335	192			7.6	--
2			38		21	28	22	238	3.2	10	.0	2.2	240	168			7.8	78
4			57		38	68	539	728	385	385	.5	5.0	1,810	374			8.0	79
9			49		22	41	42	318	21	18	.0	9.5	345	224			8.0	79
15			46		29	55	41	400	24	18	.1	10	417	298			7.7	79
18			56		36	73	53	510	37	32	.0	5.8	557	390			7.9	78
22			53		45	83	29	514	42	33	.0	8.5	585	454			7.9	79
23			52		36	71	55	504	40	27	.0	9.7	524	382			7.7	78
28			52		47	70	84	568	54	40	.1	11	646	406			7.8	79
30			48		47	82	66	586	52	35	.0	19	651	454			8.2	—
32			48		47	69	152	586	100	75	.1	52	820	401			7.8	80
33			49		49	57	434	696	287	220	.0	149	1,590	357			7.9	79
92			27		45	154	293	798	190	375	.2	.4	1,450	745			8.0	—

Ground Water

Most of the water not lost to the atmosphere by evapotranspiration enters the alluvium in the Quebrada Susúa valley. None of the few wells that have been drilled in the valley has large yields and most have water of poor quality. Well 77, drilled in 1963, is 125 feet deep, yields about 100 gpm from a pumping level of 65 feet, and has a 13-foot static water level. This well has the largest yield in the valley; the driller reported that gravel was encountered from 10 to 35 feet. Other wells are less than 40 feet deep and have yields less than 10 gpm. The amount of water used from all wells was not measured, but the total is estimated to be less than 10 ac-ft per year. Therefore, nearly all of the water in the ground-water system or in the streams passes from the Quebrada Susúa valley to the lower Río Loco valley.

Quality of Water

Surface water

During base flow the available data indicate that dissolved solids content in the stream increases in a downstream direction. In the upper basin, streamflow drainage from volcanic rocks contains less than 500 ppm total dissolved solids. Downstream, drainage from serpentinite rocks and the Juana Díaz Formation contribute more highly mineralized water and the stream water has a dissolved solids concentration slightly more than 1,000 ppm. The downstream surface flow is characterized by substantial increases in the concentration of silica, sulfate, and chloride ions. Table 9 lists the results of chemical analyses of water from Quebrada Susúa.

Ground water

The only available data on water quality in the alluvium in Quebrada Susúa valley is from well 76, located at about the midpoint of the basin. Chemical analyses indicate very hard water, high silica, and dissolved solids content of about 700 ppm. Other wells, located lower in the valley, penetrate a thin alluvial layer and draw water from the Juana Díaz Formation or are influenced by the ground water from the serpentinite rock on the west side of the valley. The principal quality characteristics of water from the Juana Díaz are high sulfate and chloride concentrations (well 77). Water from the serpentinite rocks are characterized by extremely high silica content (well 81). Table 10 lists the chemical characteristics of ground water in the Quebrada Susúa basin.

Water in Quebrada Arenas Basin

Surface Water

The upper part of Quebrada Arenas basin is roughly circular in outline, almost closed at its lower end by limestone hills, and it has an area of about 2.8 square miles. Flow in Quebrada Arenas and its principal tributary, Quebrada Cipote, is from excess irrigation water and ground-water seeps, except for sporadic storm runoff Streamflow measured in November, April, and July, during the study period, ranged from 0.2 cfs to 1.10 cfs. Most of this runoff came from Quebrada Cipote and was a combination of irrigation overflow and ground water seepage. The irrigation water used in the basin is diverted from the Lajas Canal.

Table 9.—Chemical analyses of Quebrada Susúa.

Date of collection	Discharge (cfs)	Parts Per million														Specific conductance (micromhos at 25° C)	pH	Color	Temperature °F
		Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate				
At Callejón																			
		33	0.02	52	35	61		406	23	34	0.3	0.5	482	274			8.3		77
At Highway 2																			
		67	0.02	43	83	202		600	117	185	0.3	16	1,050	449			8.1		76

Table 10. — Chemical analyses of ground water in Quebrada Susúa valley.

Well number	Depth of well (feet)	Date of collection	Parts per million													Specific conductance (micromhos at 25°C)	pH	Temperature °F
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardenss as $CaCO_3$				
														Calcium, magnesium	Non-carbonate			
76		4-2-63	46	0.04	45	58	138	644	37	60	0.4	0.0	691	351			7.7	78
76		7-29-63	48	—	47	76	115	680	34	60	.3	.8	694	430			7.8	79
77		7-4-63	44	.00	36	81	379	818	239	235	.3	8.0	1,400	423			8.3	78
81		11-28-62	145	.00	18	94	117	526	14	152	.7	30	650	432			7.7	—
81		4-8-63	100	.00	20	89	48	476	8.8	65	.0	36	601	416			8.0	82

Two small springs are located in the upper basin. Spring 72 contributes less than 0.5 cfs to Quebrada Cipote and Spring 69 contributes about the same to Quebrada Arenas. These springs are directly related to ground water levels in their immediate areas and probably go dry during extended drouths.

The lower Quebrada Arenas basin, at the east end of Lajas Valley, is very narrow, limited to a short distance on either side of the canalized streambed. There is little or no defined surface drainage to the stream channel. Much of the time during the study period there was ground water seepage to the channel. Upstream from Fraternidad there is irrigation overflow to the stream channel and this plus ground water seepage maintains about 1 cfs as base flow in the quebrada to its confluence with Lajas drainage canal.

Ground Water

The alluvium south of Highway 2 in the upper Quebrada Arenas basin is at most 50 feet thick and apparently is no thicker at the lower end. The wells in lower topographic areas have water levels close to the surface. Well 71 has a static water level above the ground level most of the year. Presently, wells are pumped at a rate of about 10 gpm, a yield restricted by the size of the pump rather than the transmissibility of the aquifer. Well 70, owned by PRASA, yields 30 gpm for 16 to 22 hours a day with a drawdown of 4 to 6 feet from a static water level of about 20 feet, and supplies most of the western half of the basin with domestic water. Well 74, on the side of the hill northeast of Susúa, is 100 feet deep and has a water level more than 90 feet below the surface. When the well was drilled in 1958 it yielded 75 gpm and had a static water level of 58 feet. Evidently, in 1958 the well obtained its water from a perched water body, because in 1963 it yielded less than 5 gpm, pumping from about 95 feet. Wells in the Quebrada Arenas basin are used for domestic and stock supplies, or to irrigate garden-sized plots.

Quality of Water

The only available water quality data that represents runoff in the upper Quebrada Arenas basin was obtained from a sample collected from the stream near Highway 2. The chemical analysis indicates a calcium-bicarbonate type water, low in dissolved solids (184 ppm) and hardness of 100 ppm. This analysis is probably representative of residual storm runoff in the stream; base flow has total dissolved solids concentrations ranging from 500 to 730 ppm. Chemical analyses of water discharged from springs 69 and 72 and that flowing in Quebrada Arenas at the Highway 332 crossing and near Fraternidad represent base-flow water quality. Table 11 gives the results of chemical analyses of water from springs and low flow in the basin.

Springs

Few springs were found in the lower hills north of the lower Río Loco valley, even though the ground water level in the hills is much higher than in the valleys. Evidently, most of the water passes from the higher elevations to the alluvium without emerging at the surface.

Vargas spring (Spring 80), in the hills north of Palomas, is improved by a stone-walled catchment basin and was used by the local people for many years before installation of the Yauco city distribution system. Water from this spring has passed exclusively through serpentinite rocks, and as a result is very hard (310 ppm) and has a high silica content (84 ppm).

Another spring (Spring 63), on the east side of the valley neck where Quebrada Arenas and Quebrada Cipote flow onto the plains north of Fraternidad, issues from a limestone of the Mayagüez Group and flows about 20 gpm (about 0.05 cfs.) The water is a calcium bicarbonate type, with about 600 ppm dissolved solids content and hardness of 260 ppm.

Table 11. — Chemical analyses of streamflow and springs in Quebrada Arenas basin.

Reference, fig. 2	Date of collection	Discharge (cfs)	Parts per million												Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	Temperature °F
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Calcium, magnesium	Non-carbonate				
(M) Quebrada Arenas at Highway 2																				
			20		28	7.8	20		148	10	8.0	0.3	2.1	184	102			7.8		75
(N) Quebrada Arenas at Highway 332																				
			40		72	17	151		596	56	51	0.6	—	600	250			8.2		73
(O) Quebrada Arenas near Fraternidad																				
			50		65	30	143		510	55	80	0.6	7.8	531	286			8.3		76
Spring 69																				
			47		70	34	159		632	44	65	1.5	0.1	732	314			8.0		—
Spring 72																				
			30		83	19	152		590	64	43	1.5	2.3	686	285			7.6		76

Manantial Fuí (Spring 44) is one of the prominent points of ground water discharge in the lower Río Loco valley. This spring is on the east side of the Río Loco canal upstream from the foot bridge at Fuí. The rate of flow is about 0.15 cfs and, according to the local people, it never has gone dry. The spring serves as a domestic water source and was in use even before the channel of Río Loco was canalized. The quality of the water is like that of water from wells on the plains to the east. Several other points of ground water effuence occur along the east side of the Río Loco canal, and other springs having very small discharges issue from the Jícara Formation on the west side of the canal.

CONCLUSIONS

Sources of Water

Most of the surface water in the Guánica area has been controlled since the construction of the Yauco hydroelectric system and Loco Dam in 1955. There are no data available for determining the amounts of water transferred annually from Lago Lucchetti to Lago Loco. However, based upon releases from Lago Loco during the period 1956-1962 an average of 76,000 ac-ft of surface water was controlled by this reservoir. The majority of this water represents diversion to the Guánica area through the Yauco hydroelectric system. Water sources not controlled are surface- and ground-water flow in the Río Cañas, Quebrada Arenas, and Quebrada Susúa basins, rainfall on the plains and coastal hills, and drainage from the Lajas Valley. The volume of non-controlled water from these sources, exclusive of the Lajas drainage, is approximately 20,000 ac-ft per year. Therefore, an average of about 96,000 ac-ft of water was available to the area annually.

Of the 76,000 ac-ft annually released from Lago Loco, about 20,000 ac-ft is diverted to the Lajas Valley. The remainder, plus the non-controlled surface flow, is absorbed by the ground-water system or passes as flood flow through the lower valley and is wasted to Bahía de Guánica.

The alluvial aquifer in the lower Río Loco valley contains about 24,000 ac-ft of water in transient storage. As the ground water is pumped, it is almost continuously replaced by recharge from streams, rainfall, and a small part of the irrigation water. Annually, there is little or no change in ground water levels. In the southernmost sections of the alluvium there is almost constant seepage to surface drainage for periods of 3 to 5 months.

Water Use

The main use of water in the Guánica area is to irrigate sugarcane; this water comes from 17 wells on the plains and from the Lajas Valley irrigation canal. Municipal and industrial water is obtained from seven wells located on the plains.

About 6,000 ac-ft of water for irrigation is diverted each year from the Lajas Valley irrigation canal to the Guánica area. About 12,000 ac-ft of water annually is pumped for irrigation, municipal, and industrial supplies from the alluvial aquifer in the lower Río Loco valley.

Water Quality

Most water in the Guánica area is suitable for irrigation, municipal, and industrial uses. The water in the upper Río Loco basin contains 240 ppm dissolved solids; that diverted from the Río Yauco basin contains about 130 ppm. The mixed water released from Lago Loco is a calcium bicarbonate type and has about 160 ppm total dissolved solids. As the water flows down Río Loco and enters the ground-water system, more minerals are dissolved. The ground water near Palomas contains about 300 ppm dissolved solids, whereas downstream near Guánica it contains 800 ppm. Flood flows are essentially unchanged in chemical content from Lago Loco to Bahía de Guánica. Surface and ground water in the Río Cañas basin is a magnesium bicarbonate type and dissolved solids range from 250 ppm to 700 ppm. Surface and ground water in Quebrada Arenas basin is usually a sodium bicarbonate type and dissolved solids range from 250 ppm to 700 ppm. Surface and ground water in Quebrada Arenas basin is usually a sodium bicarbonate type and dissolved solids range from 250 ppm to 700 ppm. Surface and ground water in Quebrada Susúa basin varies in chemical composition and increase in dissolved solids downstream. Water in some wells in the lower Susúa valley contains more than 7,000 ppm dissolved solids. Except in Lago Loco, silica is a major constituent in the ground and surface water in the area.

Unused Water

Thirty-nine thousand ac-ft of water was about the average annual surface flow to the sea from the Guánica area from 1955 to 1963. The excess water ranged from a minimum of 10,000 ac-ft in 1962 to a maximum of 80,000 ac-ft in 1956. By far, most of this unused water comes from Lago Lucchetti to operate the hydroelectric plant above Lago Loco. The largest part of this water spills or is released from Lago Loco to the lower Río Loco valley during the months of August through December at rates far greater than the recharge capacity of the alluvium.

About 10,000 ac-ft of water could be pumped annually from the alluvium in the lower Río Loco valley in addition to the amount now being withdrawn.

DEVELOPMENT OF THE WATER POTENTIAL

The amount of water available annually in the Guánica area in excess of that presently being used ranges from 10,000 to 40,000 ac-ft. The means by which this water may be obtained for future use and the necessary changes in water management follow.

A. **Minimal changes in water management.**—Under the present water regimen an additional 10,000 ac-ft (9 mgd) can be pumped from the alluvium in the lower Río Loco valley. This water can be obtained from about 6 large-diameter wells (20 inch) which would yield 1,200 to 1,400 gpm each. A lines of wells parallel to the river or across the valley would be the most effective method of obtaining this amount of water. Each well should be no less than 200 yards from another well, and none should be close enough to the valley edge to induce seepage from adjacent aquifers, especially the Juana Díaz Formation (fig. 5). Figure 1 (in resumé) shows the areas that are most favorable for development of these wells. The resultant lowered water levels and increased withdrawals should not adversely affect the aquifer even during drouth periods. Actually the combination of the lowered water levels and aquifer permeability will:

1. Increase the amount of recharge to the ground water supply by water released from Lago Loco.

2. Increase recharge to the ground water supply from medium to high flows in the small streams in the area.

3. Minimize or eliminate ground-water discharge to the main stem of Río Loco from Santa Rita to the Lajas drainage canal.

B. **Substantial changes in water management.**—To provide water in amounts ranging from an additional 10,000 to 40,000 ac-ft per year (9 to 35 mgd) would require definite changes in present water management techniques. The present water distribution system via which certain amounts of water are diverted to the Guánica area consists of 4 interconnected reservoirs located in or near the Cordillera Central. The amount of water diverted varies annually and in general is based upon hydroelectric power production and irrigation water demand. All four of these reservoirs (Lagos Lucchetti, Prieto, Guayo, and Yahuecas) are located in an area where rainfall averages 90 inches per year and rarely is less than 70 inches per year. Combined storage capacity of the four reservoirs plus Lago Loco is 38,000 ac-ft. Storage capacity of the four reservoirs in the Cordillera is about 0.3 the total annual runoff and in Lago Loco is about 0.2 the annual runoff. This information indicates that the capabilities are present to provide the Guánica area with substantial amounts of water upon demand. To control, and thereby intercept for use, the diverted water involves implementation of the following water management techniques:

1. Diverting from the system to Lago Loco, quantities of water on a daily or weekly basis, based on definite water consumption requirements in the Guánica area, and relegating other requirements to a secondary position. This may or may not, depending upon water demand and management techniques, require increasing the storage capacity of Lago Loco.

2. Initiation of:

a. A system for distributing water via pipe or open canals from Lago Loco to the user; or

b. Release from Lago Loco to Río Loco of definite amounts of water to recharge the alluvial aquifer. This would necessitate construction and operation of strategically located wells to intercept this recharge from the river.

Table 12 shows storage requirement for Lago Loco to provide varying daily water demands to the Guánica area. The annually available amounts of water are based upon the excess water in the Guánica area from 1955 to 1962. Filling and maintaining Lago Loco at near present capacity would provide 14 days storage for a 13 mgd water demand and daily diversions of 41 ac-ft from the system. Any lesser or greater daily demand for water would of course change the time-storage relationship in Lago Loco or the system. Note that storage requirements in Lago Loco include amounts of water for daily release to Lajas Valley Irrigation District based upon an annual demand of 30,000 ac-ft.

Maximum storage in the reservoirs in the mountains would have the advantage of allowing power generation from daily deliveries of water to the Guánica area. This would entail maintaining higher lake levels in the region of highest annual rainfall and runoff, and thereby increase the chance of spillage from the lakes. Conversely, maintaining Lago Loco at near capacity levels may result in spillage of storm runoff from the upper Río Loco basin. However, capacity levels in Lago Loco would provide a certain minimum storage of water near the vicinity of the water demand and in an area of low rainfall and annually variable storm runoff.

The details to provide the most efficient water management practices are beyond the scope of this report.

Precautions

Coincident with any changes in the present water regimen resulting from increased development of the water resources of the area, a ground water level and water quality monitoring program must be set up in the

Table 12.—Available water, daily release, and storage requirement in Lago Loco for Guánica area.

Annually available, ac-ft	Daily release, cfs	Available as ground water 80% recovery		Available via canal or pipeline		Storage requirement* ac-ft	
		ac-ft	mgd	ac-ft	mgd	7-day	14-day
10,000	14	22	7	27	9	764	1,529
15,000	21	33	12	41	13	862	1,725
30,000	42	67	24	82	27	1,149	2,299
40,000	56	88	29	110	36	1,345	2,690
50,000	69	109	40	137	50	1,534	3,069
65,000	90	143	52	178	54	1,821	3,643

* Includes Lajas Valley allocation 30,000 acre-feet per year.

vicinity of Guánica. The presence of saline water at shallow depths 1 kilometer inland orfm the Bahía de Guánica was indicated in this study. The absence of deep wells precluded obtaining water quality data from the lower section of the aquifer in this area.

It is recommended that 3 deep test holes be drilled at intervals across the valley at or near the suggested sites in figure 18. These wells should be drilled to bedrock. If no salt water is encountered, one of the wells should be drilled into the bedrock to a depth sufficient to encounter salt water or 100 feet, whichever is less.

Water levels and chemical quality characteristics should be measured immediately upon completion of the wells.

Depending upon such factors as:

1) results of initial testing,
2) immediate and long range water development,
3) climatic conditions past and present,

a water level and water quality monitoring program set for definite time intervals should be initiated. The data should be incorporated into a water development and management program to allow maximum utilization of water resources of the area with minimal degradation of water quality caused by saline intrusion from the bay

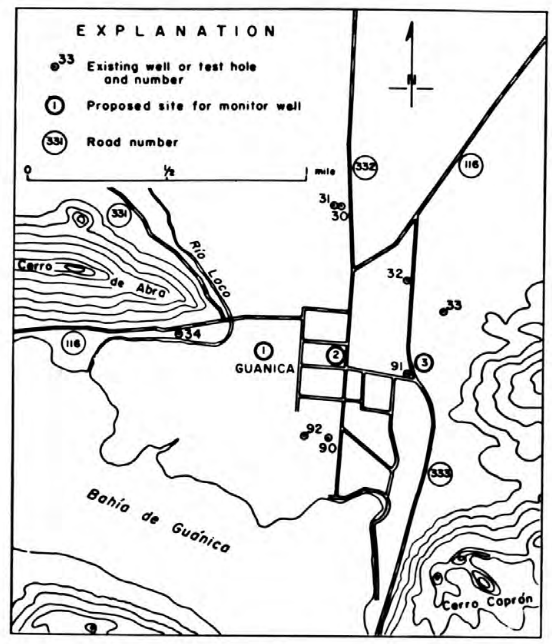


Figure 18.—Suggested location for ground water monitoring wells.

REFERENCES

Mattson, P. H., 1960, Geology of the Mayagüez Area, Puerto Rico: Bull. Geol. Soc. of America, Vol. 71, pp. 319-362.

McGuinness, C. L., 1948, Ground water resources of Puerto Rico: San Juan, Puerto Rico Aqueduct and Sewer Service dupl. rept., 617 p.

Slodowski, T. R. 1956, Geology of the Yauco area, Puerto Rico: unpublished Ph.D. thesis, Princeton Univ.

Zapp, A. D., Bergquist, H. R., and Thomas, C. R., 1948, Tertiary Geology of the Coastal Plains of Puerto Rico: U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map 85.

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