Water—Resources Bulletin 9

WATER RESOURCES OF THE COAMO AREA, PUERTO RICO

UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
COMMONWEALTH OF PUERTO RICO

Cover picture.--Lago Coamo and southward across the coastal plain of the Coamo study area to Mar Caribe. The smoke is from planned burning of sugarcane prior to harvasting. Photo by Miguel A. López, U.S. Geological Survey.

Commonwealth of Puerto Rico
Water—Resources Bulletin 9

WATER RESOURCES OF THE COAMO AREA, PUERTO RICO

by

Ennio V. Giusti
U.S. Geological Survey

Prepared by the United States Geological Survey
in cooperation with
Puerto Rico Legislative Assembly
Puerto Rico Aqueduct & Sewer Authority
Puerto Rico Industrial Development Company

1971

RESUME OF PRINCIPAL FINDINGS

1. The water resources of the Coamo area, 100 square miles of land centered about the town of Coamo, were studied in 1967, a dry year which, on the basis of rainfall data, occurs once in 50 years on the average.

2. The flow in 1967 of Río Coamo, the only perennial stream, was 6,500 acre-feet into Lago Coamo, 1,200 acre-feet below the Lago Coamo dam, and 270 acre-feet into the sea. Correlation between rainfall and runoff indicates that the average flow of Río Coamo into Lago Coamo is about 35,000 acre-feet per year. Much of this is in floodflow that cannot be retained in the reservoir because of its small capacity.

3. Pumpage of ground water in the Coamo fan amounted to 52,000 acre-feet in 1967. This resulted in lowering the water table in the alluvium 5 to 12 feet, with an average of 8 feet.

4. The water table declined from heavy pumpage during the drought that began in 1964, to such an extent that the ground-water table in a large part of the Coamo fan was below mean sea level in 1967.

5. The water budget shows that 30 percent of the water used in furrow irrigation in 1967 was returned to the water table and recirculated. This prevented a more serious lowering of ground water, and may have retarded salt-water intrusion. The Coamo fan is naturally semiarid, and continuing drought and heavy pumpage would result in successively lower water levels and salt-water intrusion in wells near the coast.

6. Possible remedial measures worthy of investigation for improving the utilization of the water resources of the Coamo area are:

a) Artificial recharge of the Coamo fan. This is contingent on storing streamflow within the area or on importing water from outside the area.

b) Surface-water storage through restoration and increase of the storage capacity of Lago Coamo and possible flood water storage within entrenched channels of streams before they enter the coastal plain.

c) A better distribution of wells so as to minimize interference.

d) A program of ground-water quality monitoring leading to decreasing or stopping pumpage where the ground water approaches certain unacceptable levels of salinity.

NOTES ON THE REPORT

This study, like other similar studies, was made possible by a cooperative water-resources program between the U.S. Geological Survey and the Puerto Rico Water Resources Authority (at the time), representing also the Puerto Rico Aqueduct & Sewer Authority and the Puerto Rico Industrial Development Company.

This report covers the hydrologic investigation made in 1967 in the Coamo area, on the south coast of Puerto Rico. The purpose of the investigation was to make a preliminary, intensive reconnaissance of the water resources of the area. Emphasis was on the Coamo fan, which is essentially coextensive with the coastal plain.

The scope of the investigation covered the collection, analysis, and interpretation of hydrologic data so as to arrive at a linkage between how much, where, and what type of water is available in relation to the water needs of the area (largely for irrigation).

This report is based in good part on the field work of Ralph Gonzalez, hydrologic assistant for the project, who installed and maintained in working order most of the recording instruments and collected most of the field data. We acknowledge the cooperation of Luce & Company, owner or user of most of the water wells in the area. Its personnel guided us to their wells and provided invaluable records on well yield and rainfall.

Acknowledgements and thanks go to the many people who showed us obscurely located wells and provided many facts about the performance of the wells.

CONTENTS

ILLUSTRATIONS

TABLES

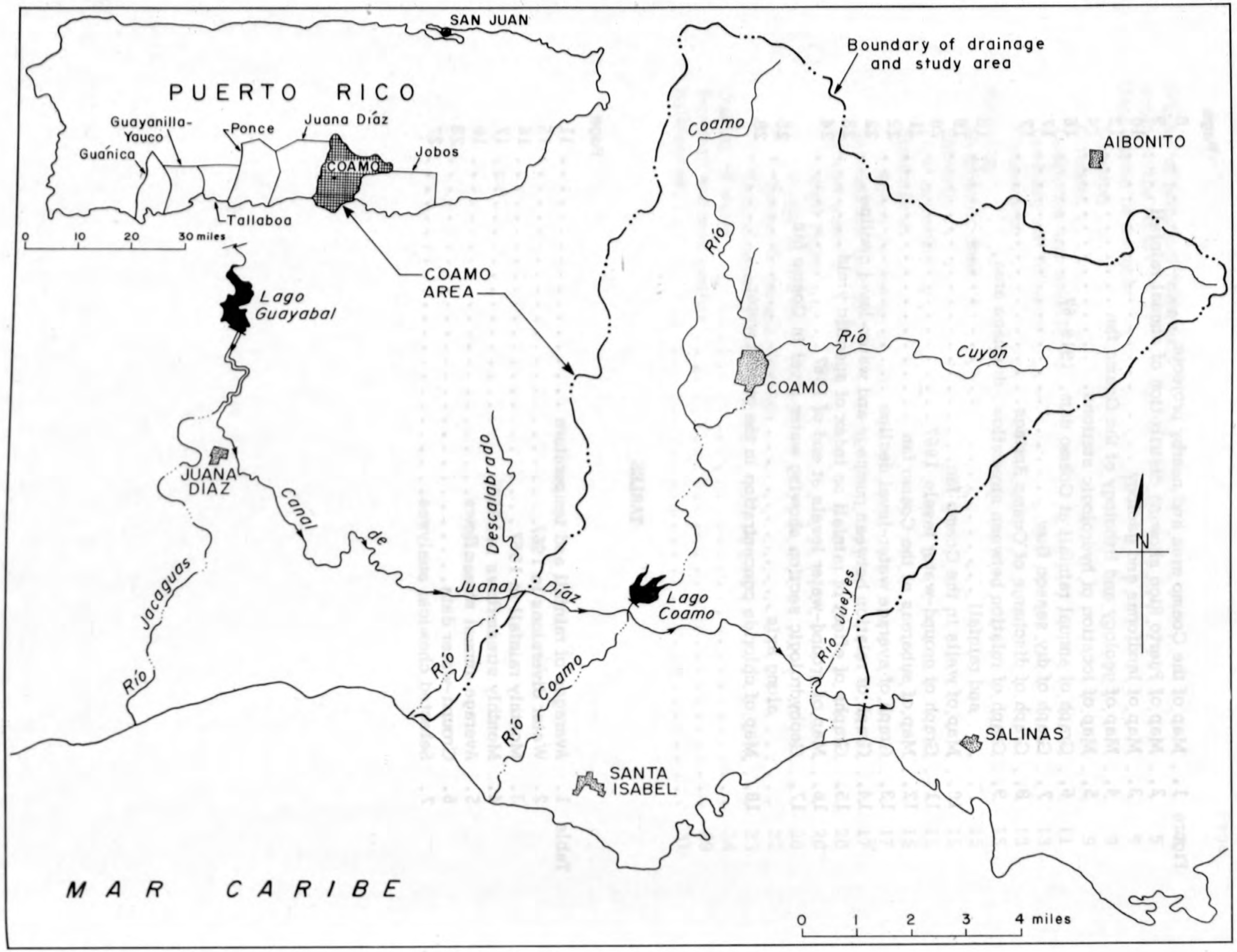

Figure 1.--The Coamo area and location of project areas on the south slope of Puerto Rico.

WATER RESOURCES OF THE COAMO AREA, PUERTO RICO

by Ennio V. Giusti
U.S. Geological Survey

DESCRIPTION OF THE AREA

Location

The Coamo area is about 100 square miles of land roughly centered around the town of Coamo on the southern slope of Puerto Rico--see figure 1. The area comprises the drainage basins of Río Coamo and Río Jueyes and includes that part of the coastal plain bounded by Río Descalabrado on the west and the divide between Río Jueyes and Río Nigua on the east. Figure 1 also shows other project areas on the south coast, whose hydrology has been investigated by the U.S. Geological Survey.

Climate

Most of the south coast of Puerto Rico lies in a rain shadow and is semiarid. The Coamo area, which lies in a broader part of the shadow, stands out as drier than the rest, as shown by figure 2. Not all the area is dry, however. There is, in fact, a marked difference in rainfall according to altitude. This is reflected in the natural vegetation, which is most dense in the mountains and thinnest--brush and cactus--in the few uncultivated areas within the coastal plain.

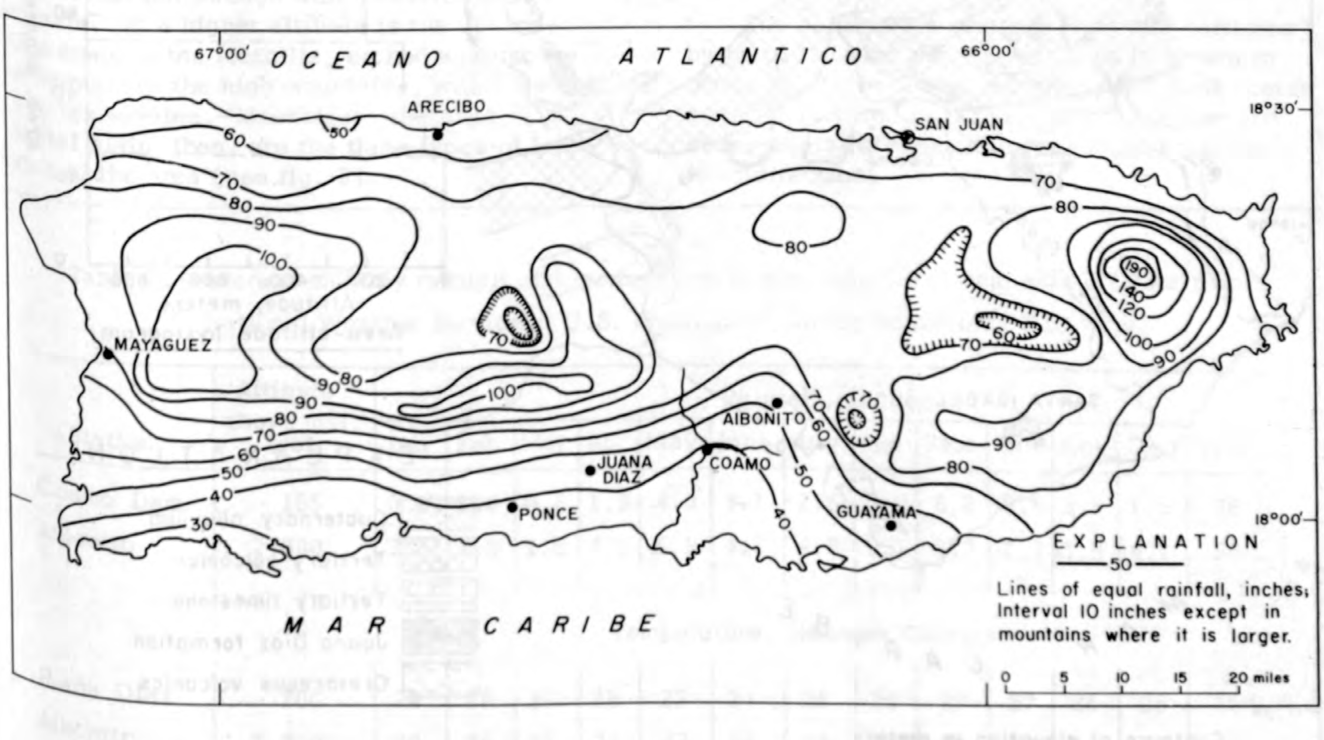

Figure 2.--Distribution of average annual rainfall in Puerto Rico (adapted from Bogart, 1964).

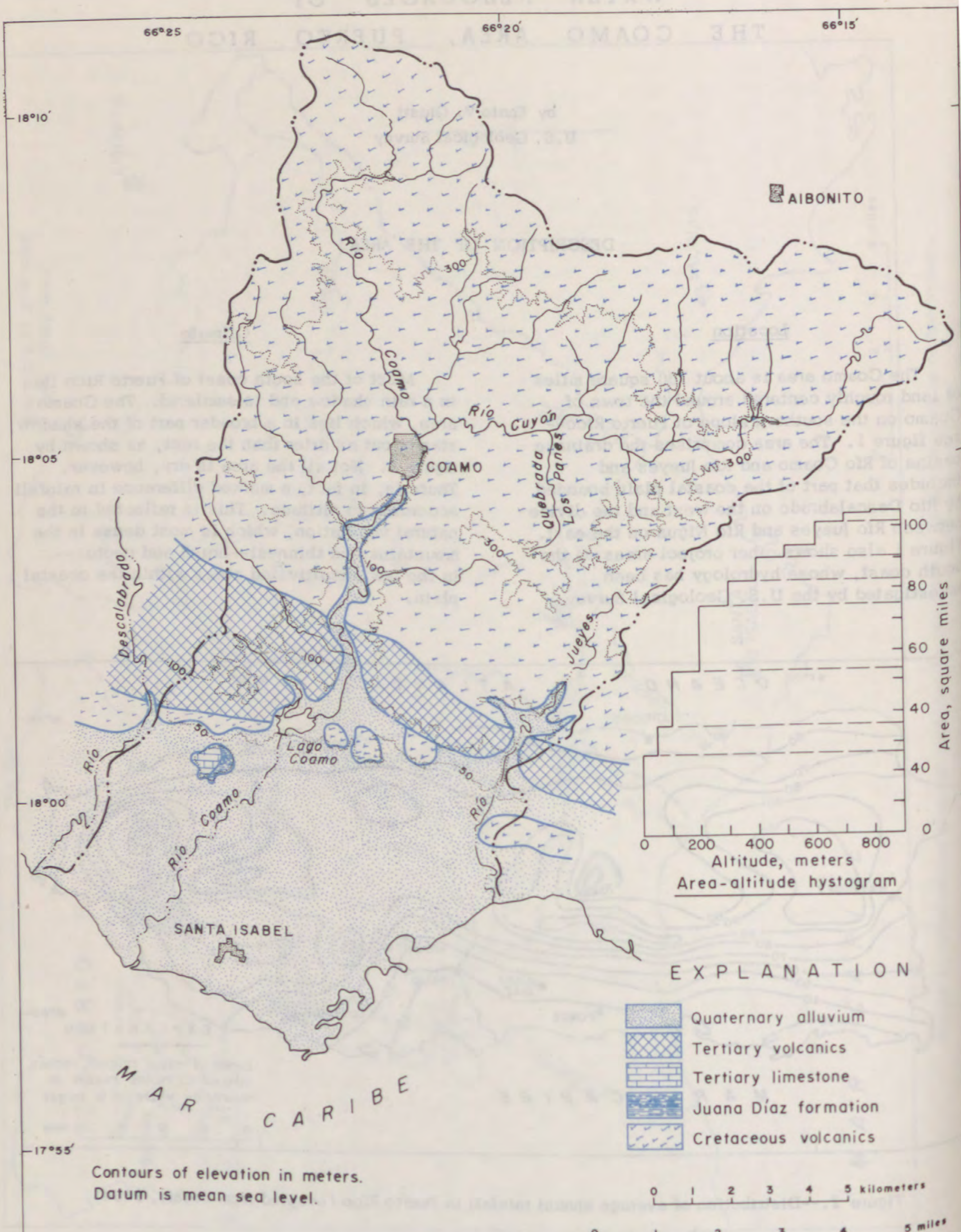

Figure 3.--Land forms and geology of the Coamo area.

Variation of temperature with altitude accounts for the fact that the mountains are about 7° F cooler than the coastal plain.

Within the year there is a seasonal variation of both temperature and rainfall. The variation of temperature is cyclically uniform; it increases from a minimum in February, reaches a maximum in July-August, and decreases thereafter. The seasonal variation of rainfall, though cyclical, is not so uniform as the variation of temperature and there are large differences of rainfall from year to year. In general, however, the wet months are April-May and August-November.

Table 1 shows some climatic data in and near the Coamo area.

Landforms and Geology

To look northward from the shore of Mar Caribe on a clear day is to see a succession of horizons that reflect the landforms of the Coamo area. At the lowest level one notices the almost horizontal trace of the upper boundary of the alluvial fan through which several hills protrude. At a higher altitude is the up-and-down trace of the foothills, etched against the background of the high mountains, which hazily trace the skyline. Mountains, foothills, and coastal plain then, are the three types of landforms of the area (see fig. 3).

Rivers have established their paths through the landforms, and near the foothills they flow in entrenched valleys or small canyons before debauching onto the alluvial fan. Along these entrenched valleys are found alluvial terraces 500 to 1,000 feet wide. Where the terraces merge with gently sloping surfaces at the base of the foothills, they give rise to large stretches of nearly flat land, which, on first impression, resembles a plateau.

The geology of the Coamo area, closely related to the landforms, consists of volcanic rocks of Cretaceous age in the mountains, volcanic rocks of Tertiary age in the foothills, and Quaternary clay, sand, and gravel in the coastal plain (fig. 3). One small limestone hill projects from the alluvial fan. A detailed map of the geology and lithology of the alluvial fan is presented in figure 4. This figure was prepared from well drillers' logs, and only for the upper part of the Coamo fan was it possible to indicate the depth to bedrock. Near the coast the thickness of the fan is unknown.

The general distribution of coarse particles by percent (sand and gravel) also is shown in figure 4. As would be expected, the most coarse material is found near the apex of the fan, and sucessively finer particles are found in a seaward direction.

Table 1.--Average monthly rainfall and temperature in and near the Coamo area. (Data from National Weather Service. U.S. Geological Survey converted °F to °C.)

Station	Altitude above msl, feet	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
		Rainfall, inches												
Coamo Dam	165	0.9	1.0	0.6	1.9	4.0	3.1	2.6	4.9	6.2	5.6	3.6	1.6	36
Aibonito	2,300	3.5	3.0	2.8	4.0	5.9	4.2	4.8	6.1	6.7	7.2	5.9	4.1	58
		Temperature, degrees Celsius												
Juana Díaz	200	24	25	25	26	27	27	28	28	27	27	26	26	26
Aibonito	2,300	20	20	21	22	23	23	23	24	23	23	22	21	22

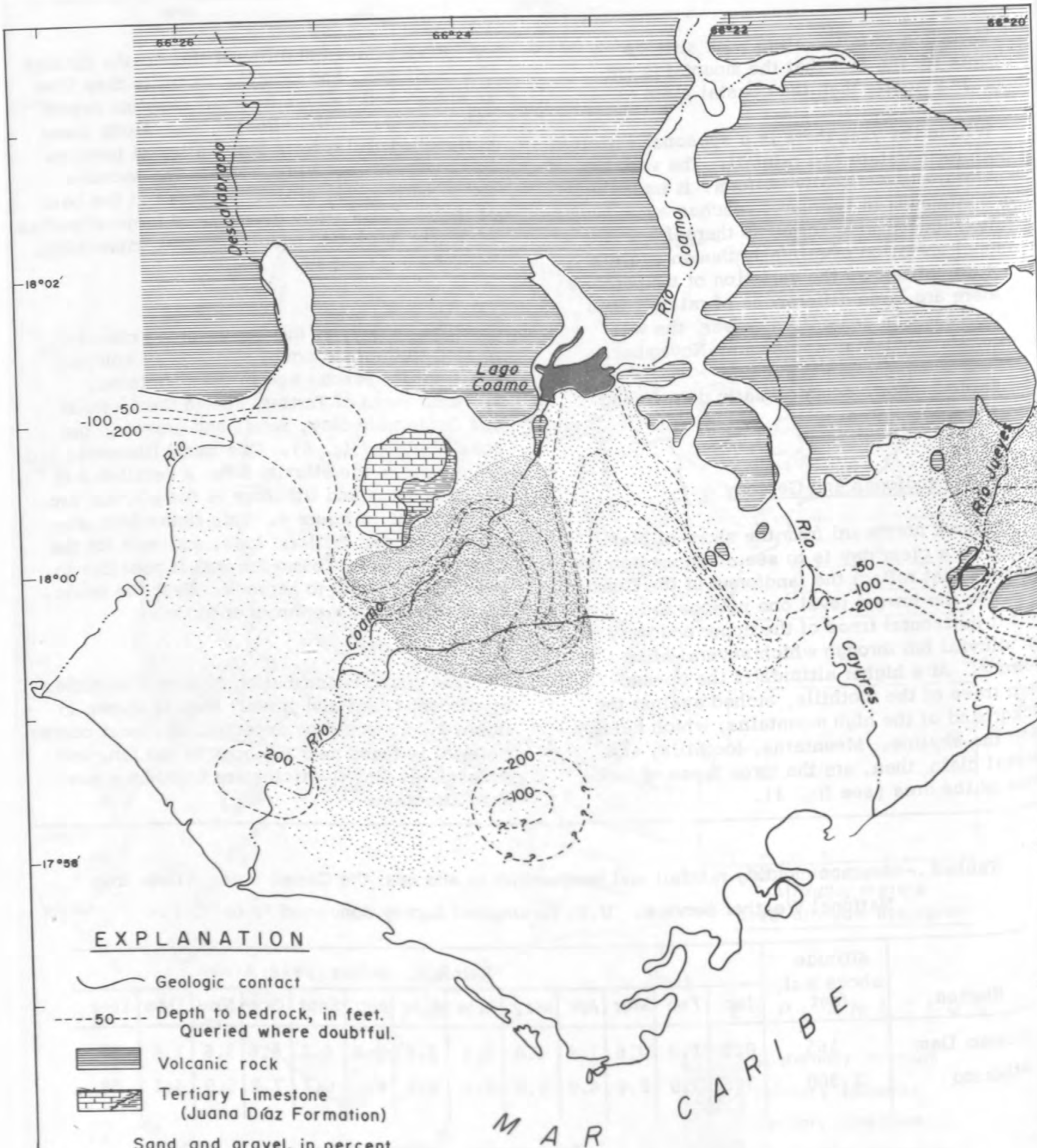

Figure 4.--Geology of the Coamo fan.

Land Use and Industry

The original forest in the mountains has been cut, and now only patches of land are covered with trees. Most of the denuded mountain land is grazed by a hardy breed of cattle who have developed the ability to snatch a sustenance from the steep slopes. Mountain farms, where bananas, coffee, and citrus fruits are grown, are scattered here and there. Dairy farms dot the foothills and the river valleys.

Below Lago Coamo (fig. 4) and within the alluvial fan of the coastal plain, lies the main agricultural district of the area. Here most of the land is used to grow sugarcane, though tomatoes are grown on several hundreds of acres.

The industry of the area is mainly geared to the processing of sugarcane and tomatoes, but sand and gravel for the building industry is extracted from the bed of Río Coamo both above and below Lago Coamo.

Waterworks

The principal waterworks of the Coamo area are: Lago Coamo and the Canal de Juana Díaz (see fig. 1).

Lago Coamo is the major water facility. It was built in 1914 to store about 3,000 acre-feet of water for irrigation. Since that time, sediment in the reservoir has reduced its storage capacity to about 300 acre-feet, and, at present (1967), the Lago Coamo dam holds the less prestigious rank of a diversion dam.

Canal de Juana Díaz, which begins at Lago Guayabal on Río Jacaguas to the west, crosses the Coamo fan along its upper edge and comes to an end just east of Río Jueyes. Many diversion outlets of the canal are in the Coamo fan, and most of the water release comes from Lago Guayabal. Most of the water contributed by Lago Coamo is released through sluice gates to another canal below the dam. This canal runs directly south along the axis of the Coamo fan to a distribution lake.

A diversion dam for the public water supply of Coamo is located on Río Coamo about 3 miles above the town. The villages in the coastal plain are served by wells.

Irrigation is carried out with water diverted from the Canal de Juana Díaz, with water release from Lago Coamo, and with ground water from about 70 wells scattered throughout the coastal plain.

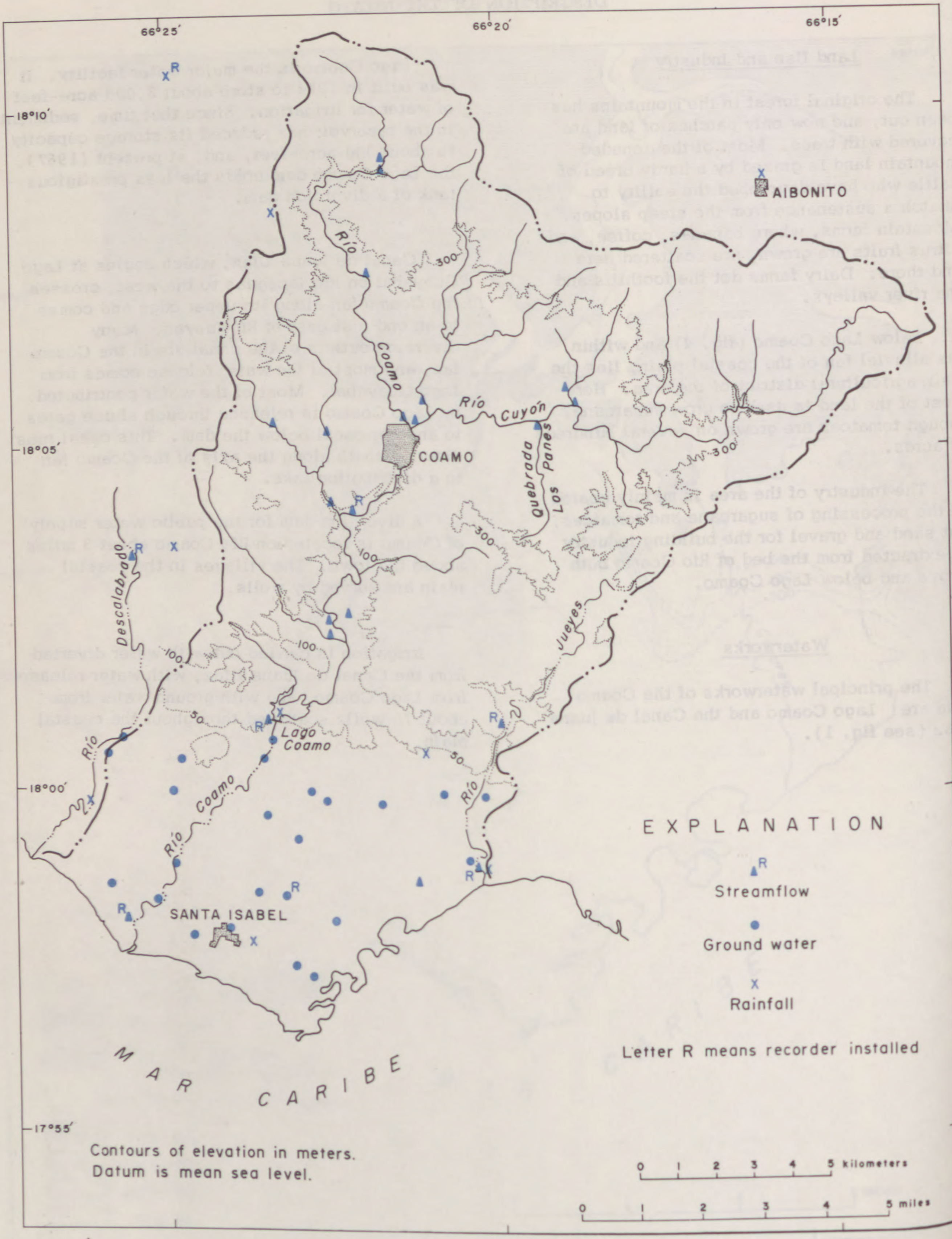

Figure 5.--Hydrologic stations.

Hydrologic Data

The investigation of the hydrology of an area requires the collection of rainfall, canal flow, stream runoff, and ground-water data on a time basis. Because the only data available at the beginning of the study were rainfall records and the inflow into Lago Coamo, several hydrologic stations were installed by the Geological Survey. Figure 5 shows the location and the type of data collected for this study, which covers the hydrologic events of 1967.

Rainfall

The amount of rain that fell each month of 1967 in and near the Coamo area is shown in table 2.

A comparison between the rainfall in 1967 and the average, as shown by Aibonito (table 1), reveals that in 1967 the rainfall was less than half the average. In fact, the rainfall at the Río Jueyes station was the lowest in 23 years of record (oral commun. from National Weather Service). To pursue this matter further, we shall try to find out the statistical probability of occurrence of the rainfall of 1967. We shall use the data from the rainfall station at the Coamo dam (Lago Coamo).

Figure 6 shows the sequence of annual rainfall from 1919 to 1967. By comparison it is apparent that 1967 was the driest year of record. Its probability of occurrence is once in 50 years. This does not mean that another 50 years will go by before a drought so severe as that of 1967 occurs again. Quite unfortunately, it could occur again in any year. The meaning attached to the concept of return period is a statistical one. It means that in a very long period of time (order of thousands of years) during which climatic fluctuations may be considered randomly distributed in intensity and in time, the average time span between annual rainfall as low or lower than that of 1967 will be 50 years.

Flow in Canals

Canal de Juana Díaz brings water to the Coamo fan from Lago Guayabal. Table 3 shows the amount of water that was diverted from the canal and distributed within the Coamo area during 1967.

Streamflow

The less-than-average rainfall in 1967 resulted in low runoff. The streamflow was derived in large part from ground-water storage. Those streams not fed from a large reservoir of

Table 2.--Monthly and annual rainfall at three stations in and near the Coamo area, 1967. (Data from National Weather Service.)

Station	Rainfall, inches												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Aibonito (Mountains)	2.2	3.4	1.2	1.6	3.0	1.1	0.6	1.2	2.5	3.4	3.8	1.2	25.2
Los Llanos (Foothills)	0	.5	4.8	.8	0	0	0	.3	1.0	3.3	4.4	.2	15.3
Río Jueyes (Coastal plain)	1.4	.9	.4	0	0	1.2	.1	.6	1.6	1.5	1.9	0	9.6

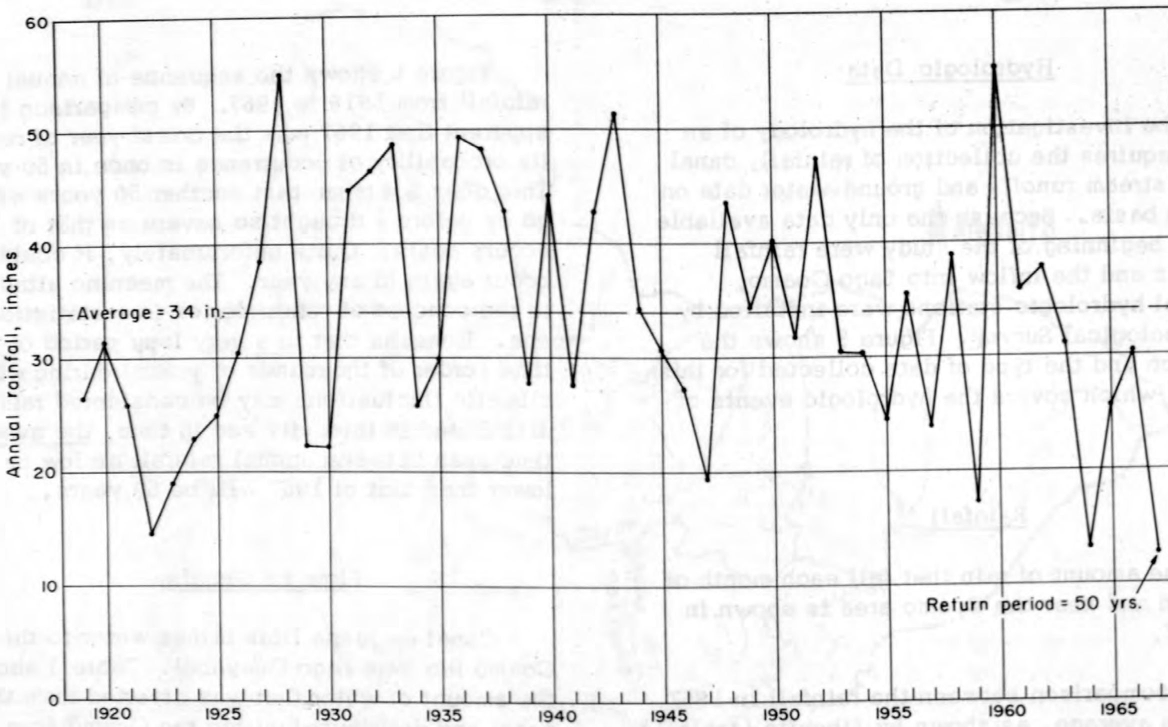

Figure 6.--Annual rainfall at Coamo dam, 1919-67. (Data from P.R. Water Resources Authority.)

ground water became dry. Those streams in the zone of less rainfall near the coastal plain remained dry most of the time--they flowed only two or three times in 1967, during and after the larger storms. Table 4 shows the total monthly flow at the continuously gaged sites in the Coamo area. The difference between the inflow and the outflow of Lago Coamo is about 5,000 acre-feet. This amount is taken to have been diverted for irrigation. The difference between the flow of Río Coamo below Lago Coamo and at the mouth, about 1,000 acre-feet, is assumed to have infiltrated and recharged the Coamo fan.

Table 3.--Water delivered to the Coamo area by Canal de Juana Díaz and from Lago Coamo in 1967. (Data from Puerto Rico Water Resources Authority.)

Area irrigated in coastal plain	Acre - feet												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Between Río Descalabrado and Río Coamo	443	321	281	295	135	127	55	67	54	111	274	416	2,579
Within Río Coamo drainage basin	821	485	421	536	210	256	119	136	106	254	757	698	4,799*
Within Río Jueyes drainage basin	318	182	218	210	76	76	30	68	38	136	221	284	1,857
													9,235

* Includes 27 acre-feet contributed by Lago Coamo to Canal de Juana Díaz.

Table 4.--Monthly runoff of main streams of Coamo area, 1967.

Stream name	Acre - feet												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Río Coamo above Lago Coamo	580	410	360	460	240	220	180	310	330	1,500	1,600	210	6,400
Río Coamo below Lago Coamo.	5	2	6	17	24	44	28	28	64	740	260	15	1,230
Río Coamo at mouth	6	6	5	0	0	0	1	15	200*	21	13	5	270
Río Jueyes above alluvium	0	0	0	0	0	2	0	0	0	20	1	0	23
Río Jueyes at mouth	0	0	0	2*	0	0	0	0	0	27	1	0	30
**Río Descalabrado above alluvium	90	60	13	7	3	0	0	27	4	120	450	12	790

* Spillage from irrigation canals.

** This stream forms the western boundary of the Coamo fan. Half of its flow is assumed to be potential recharge for the Coamo fan.

During the dry season, streamflow was measured several times at several sites. A plot of some of these measurements is shown in figure 7. The rate of decrease of streamflow during periods of no rain is shown by straight lines. The slope of each line is indicative of both the storage capacity of the basin and of its climate: the steeper the slope, the drier the basin. Most of the small streams in the foothills and coastal plain are almost always dry and their only flow is storm runoff. Except for Río Coamo, streams in the area offer little water for a run-of-the-river supply.

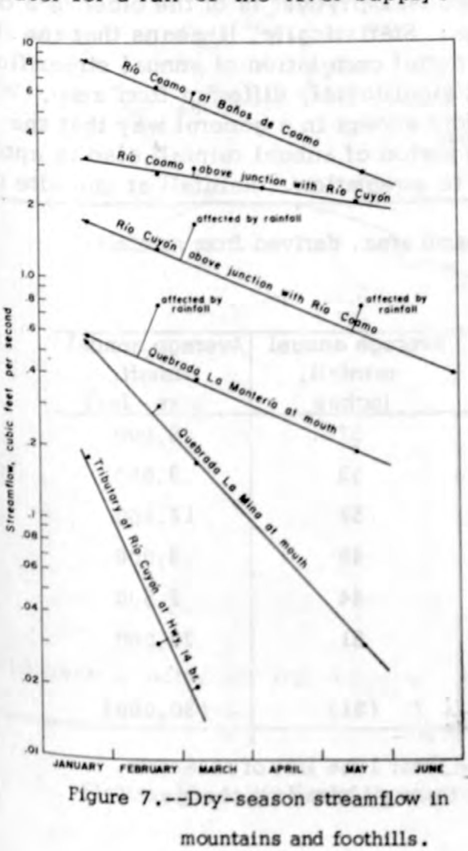

Figure 7.--Dry-season streamflow in mountains and foothills.

Baños de Coamo

The thermal springs of Baños de Coamo, located about 5 miles south of the town of Coamo, are a unique feature of Puerto Rico. The water issues from fissures in a hill next to Río Coamo. Years ago this was a popular spa, as witnessed by the remains of a hotel where the 19th century seems to have stood still. The springs are small--note the discharge shown in figure 8. The apparent cyclical fluctuation follows that of rainfall, which indicates the influence of nearby recharge. The temperature of the water is about 38° C. The quality of the water is shown by the chemical analysis in table 7.

Rainfall and Runoff

As we have seen, 1967 was an extremely dry year. And, in order to estimate streamflow in the Coamo area for more nearly normal climatic conditions, one must seek a means of relating rainfall to streamflow.

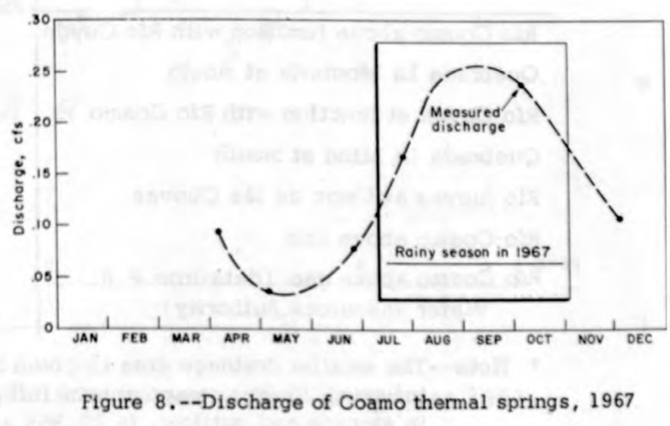

Figure 8.--Discharge of Coamo thermal springs, 1967

This relation is shown on figure 9, a plot of annual streamflow versus drainage area. Various other streams in Puerto Rico are used in addition to those in the Coamo area (points in solid black), in order to increase the range of the data. An average line (heavy line) drawn through the array of points, separates wet years from dry years--the numbers written next to the points are the inches of rain that fell that year. The other parallel lines or family of curves provide a graphical means of estimating streamflow, given the drainage area of the basin and the amount of rainfall. The range of rainfall extends to about 100 inches, which for the Coamo area is extremely high (notice in fig. 6 that the maximum rainfall is less than 60 inches).

The graph of figure 9 is expressed mathematically by

$$Q = 0.004\, A\, P^3 \text{ for } P \leq 100$$

where
Q = annual runoff in acre-feet
A = drainage area in square miles
P = annual rainfall in inches

The graph and the average rainfall of figure 2 were used to compute the average annual runoff of the principal streams of the Coamo area. The results are shown in table 5.

The correlation between rainfall and runoff on a monthly basis is more complicated than that on an annual basis because of seasonal variation and carryover from one month to the next. In any event, we need more rainfall data than is now available.

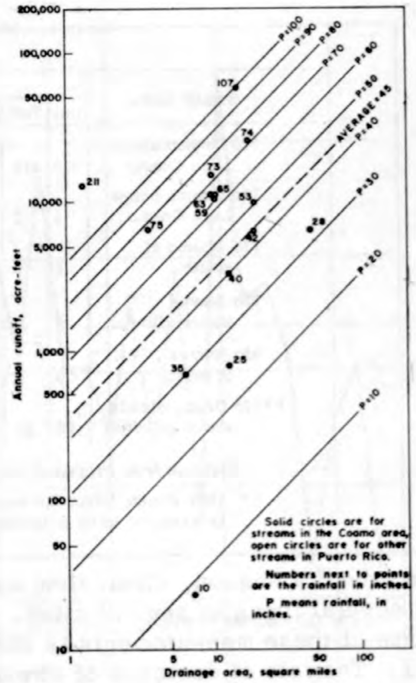

Figure 9.--Relation between annual streamflow, drainage area, and rainfall.

Because of the small area of the drainage basins in the Coamo area, which implies low storage capacity, streamflow in any one year is independent of the flow of the previous year. That is, the recharge effect of the rainy season is dissipated in the dry season, and the longest carryover is of the order of 2 or 3 months. Statistically, it means that the first order serial correlation of annual streamflow is not significantly different from zero. We therefore accept in a general way that the return period of annual rainfall also is applicable to streamflow. Rainfall at one site does

Table 5.--Average annual runoff of streams in the Coamo area, derived from rainfall-runoff correlation (refer to figure 9).

Stream	Drainage area, square miles	Average annual rainfall, inches	Average annual runoff, acre - feet
Río Coamo above junction with Río Cuyón	12.4	57	9,000
Quebrada La Montería at mouth	5.00	53	3,000
Río Cuyón at junction with Río Coamo	31.00	52	17,500
Quebrada La Mina at mouth	6.60	48	3,000
Río Jueyes at Cerro de las Cuevas	7.35	44	2,500
Río Coamo above dam	65.4*	51	35,000
Río Coamo above dam (data from P.R. Water Resources Authority)	(58.0*)	(51)	(30,000)

* Note--The smaller drainage area is given by PRWRA in their 1966 list of reservoir inflows. Their average annual inflow for Lago Coamo, based on change in storage and outflow, is 29,955 acre-feet.

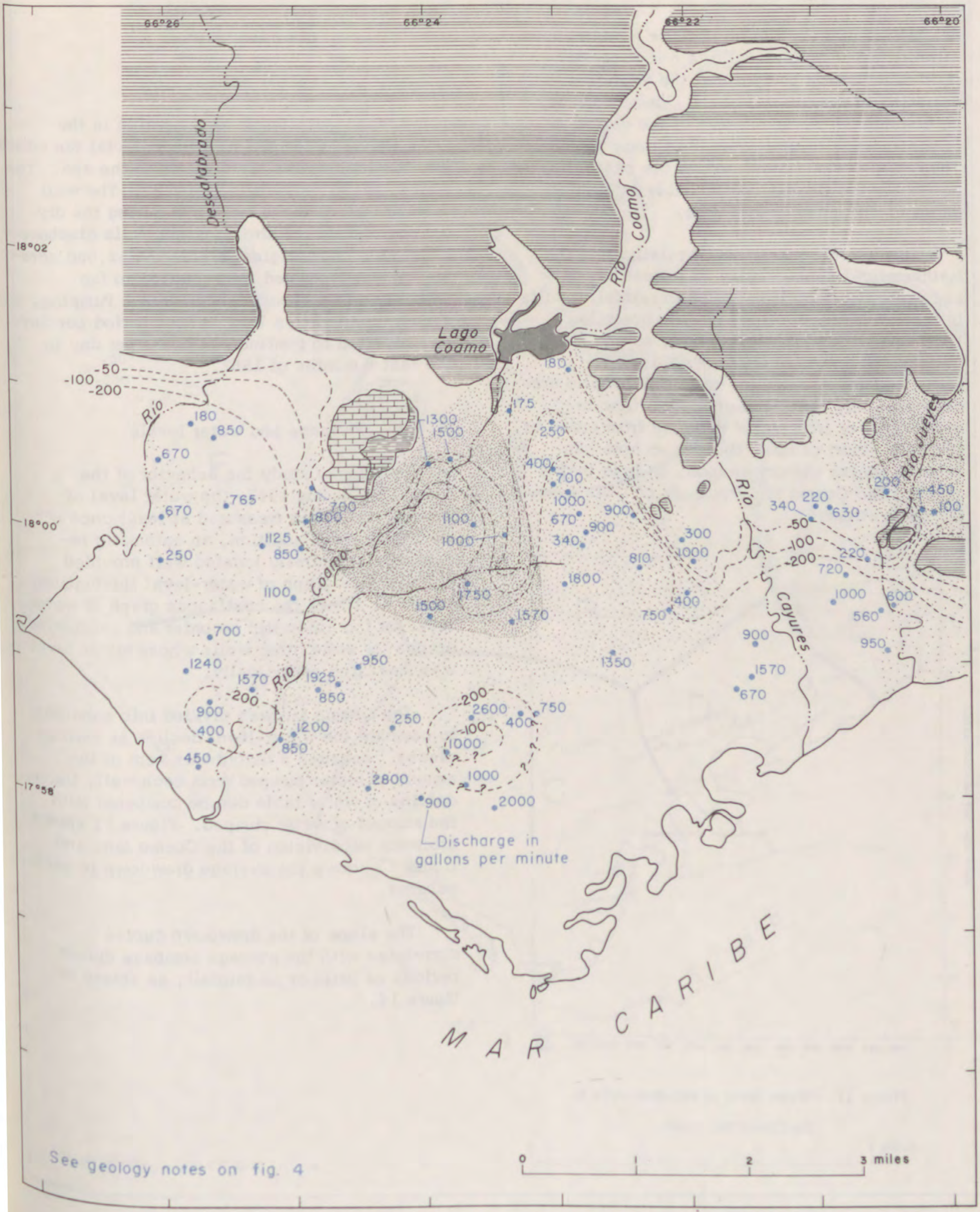

Figure 10.--Wells in the Coamo fan, and discharge measured in dry season 1967.

not reflect entirely the rainfall for a basin, but rainfall in Puerto Rico follows a sufficiently rigid distribution pattern that the year-to-year variation in the rainfall at the Coamo dam may be considered representative of the variation of the average rainfall over the Coamo area. The return period calculated on the basis of the record for the Coamo dam probably is applicable to all of the Coamo area.

Because there is a power relation (in the mathematical sense) between annual riverflow and rainfall, a small increase in rainfall results in a relatively large increase in streamflow. Lago Coamo cannot store floods, so any large increase in riverflow will run off to sea. Additional fresh water for use in the Coamo area can come only from storage of riverflow in reservoirs, or from water imported from areas of surplus. Short of this, the Coamo area can depend, during the dry season, on less than 4 cfs from Río Coamo and fractions of 1 cfs from the other streams.

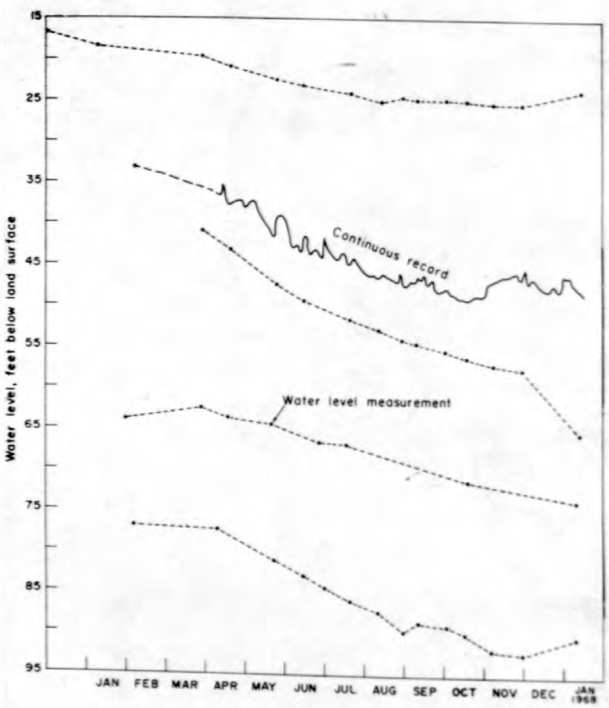

Figure 11.--Water level in selected wells in the Coamo fan, 1967.

Ground Water

Well fields

Ground water used for irrigation in the Coamo area is pumped from the alluvial fan which extends from below Lago Coamo to the sea. The well fields are shown in figure 10. The well discharges are those measured during the dry season of 1967. Although some wells discharged about half their original yield, the 52,000 acre-feet of water pumped from the Coamo fan probably was a record for the area. Pumping, usually limited to a 7 to 10-hour period per day, was reported to continue 24 hours per day in the last 8 months of 1967.

Pumpage and water levels

In order to study the behavior of the Coamo fan during 1967, the water level of several wells was measured at least once each month. In addition, an automatic recorder at a centrally located well provided a continuous graph of water-level fluctuation. Figure 11 shows the continuous graph of water level for the automatic recorder and segmented graphs for some other wells whose water level was measured periodically.

The Coamo fan was divided into subareas to compare the water-level decline at various places. Because a record was kept of the amount of water pumped from each well, the decline of water table can be compared with the amount of water pumped. Figure 12 shows arbitrary subdivision of the Coamo fan, and figure 13 shows the average drawdown in each subarea.

The slope of the drawdown curves correlates with the average pumpage during periods of little or no rainfall, as shown in figure 14.

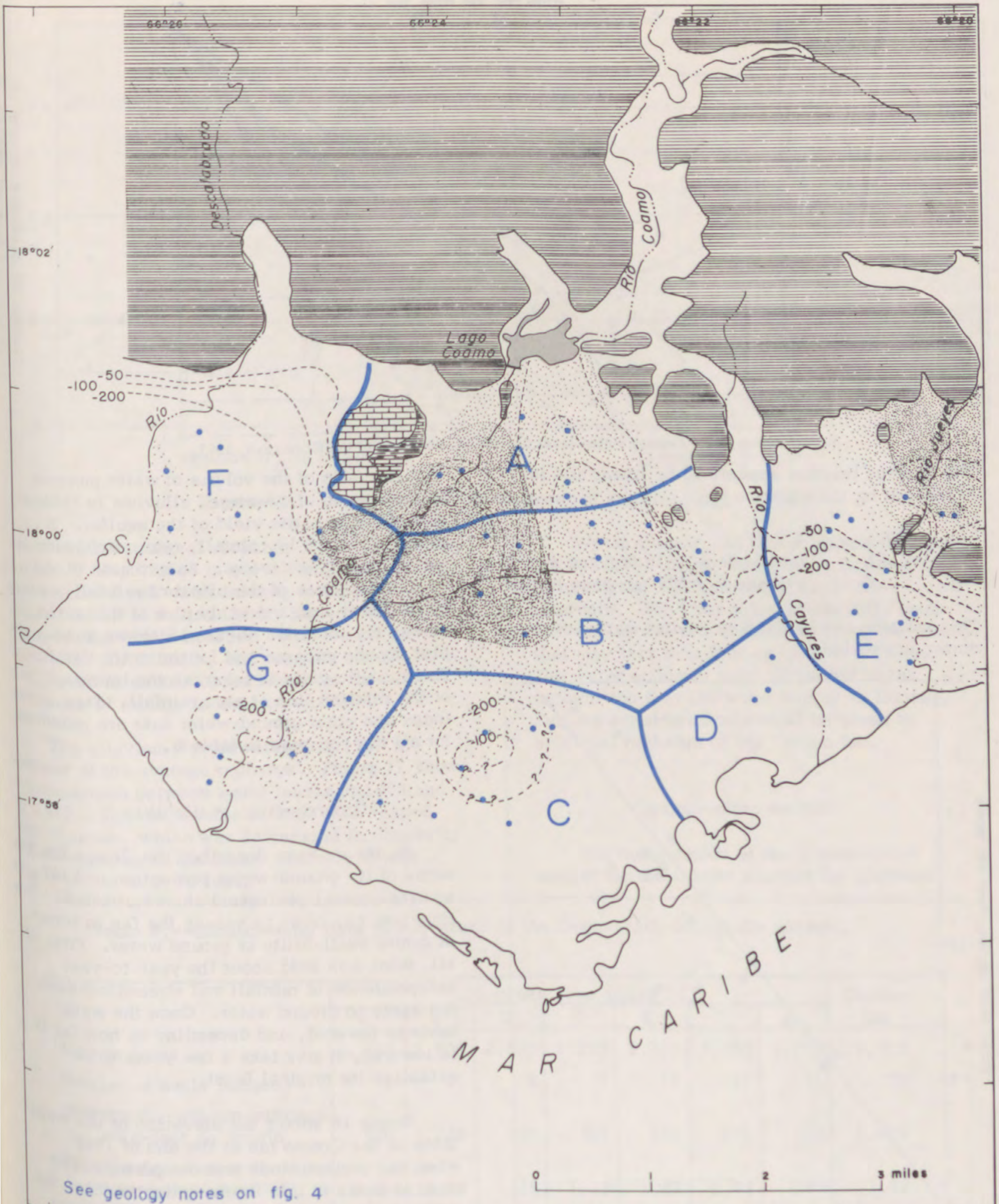

Figure 12.--Sub-areas of the Coamo fan.

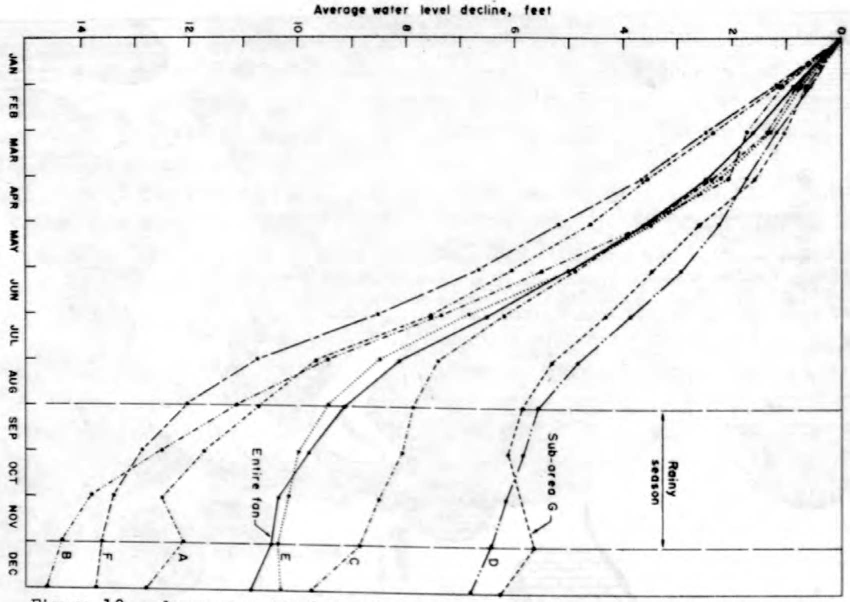

Figure 13.--Average water-level decline in sub-areas of the Coamo fan, 1967.

The average relation appears to be linear and is expressed by the equation:

$$\Delta h = 4.3\ Q$$

where Δh = rate of decline in feet per month

Q = average monthly pumpage in feet

This relation can be used to predict water levels during dry periods.

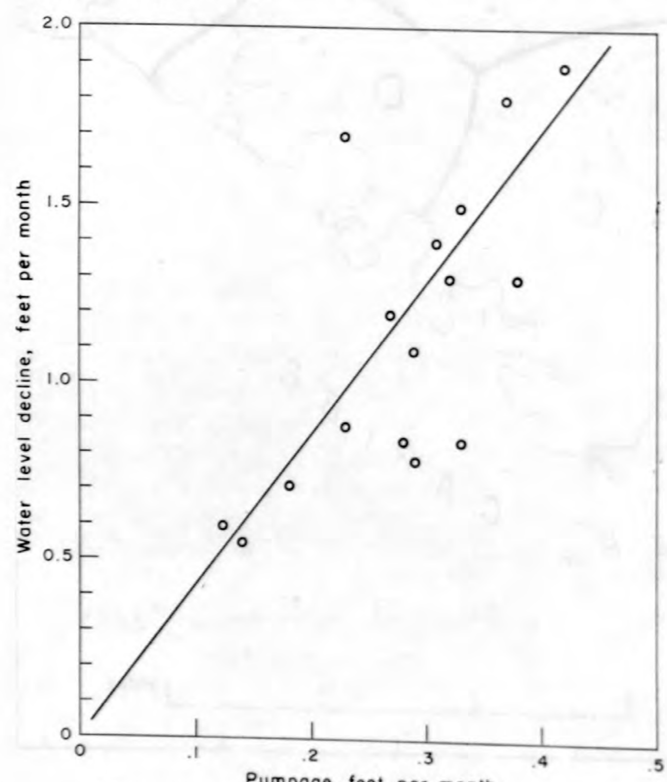

Figure 14.--Relation between pumpage and water-level decline.

The ratio of the volume of water pumped to the volume of dewatered alluvium is indicative of the specific yield of the aquifer. It may be affected by rainfall, return irrigation water, and other factors. An estimate of the coefficient, free of the effect of rainfall, can be obtained from a monthly plot of this ratio versus the rainfall. Figure 15 shows such a plot for one subarea and for the entire fan. The specific yield is taken as the intercept of the relation line at zero rainfall. This index and other ground-water data are recorded for all the subareas in table 6.

Ground-water availability

So far we have described the Coamo fan in terms of its ground-water production in 1967 and its general geological characteristics. The time now has come to assess the fan in terms of future availability of ground water. First of all, what was said about the year-to-year independence of rainfall and streamflow does not apply to ground water. Once the water table is lowered, and depending on how far it is lowered, it may take a few years to re-establish its original level.

Figure 16 shows the elevation of the water table in the Coamo fan at the end of 1967, when the project study was completed. The shaded areas in this figure indicate where the water table was below sea level. The three arrows at the coastline indicate possible sea-water intrusion--also see figure 18. It is clear that continuous high pumpage in these

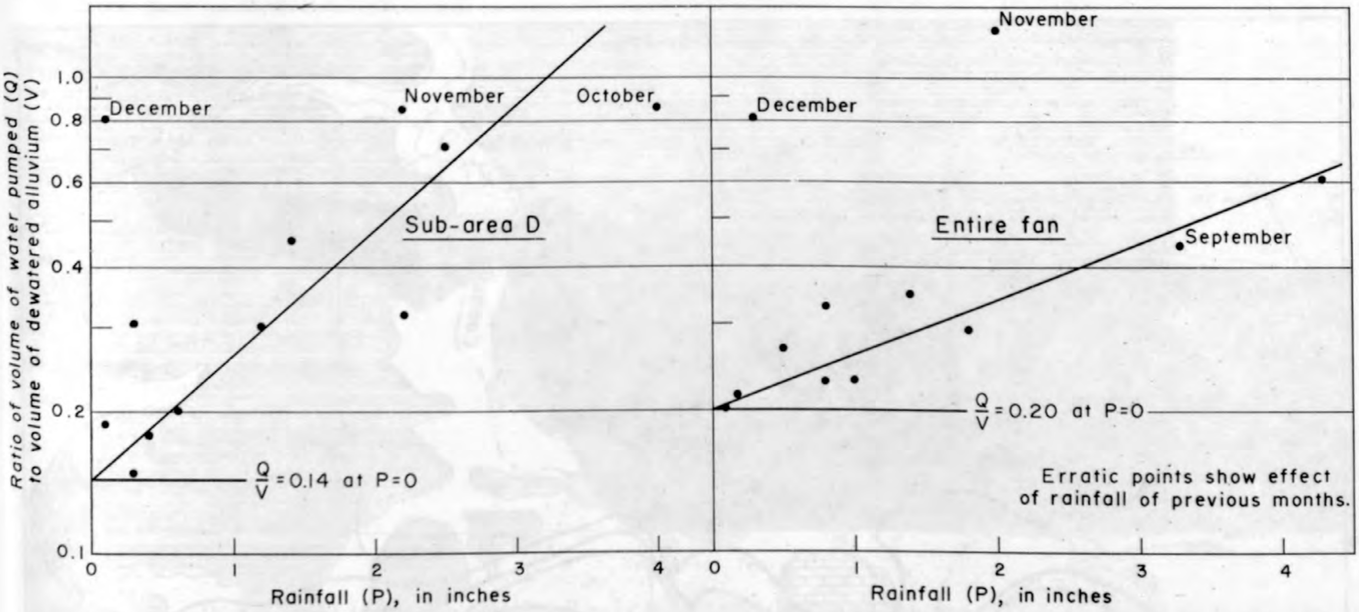

Figure 15.--Effect of rainfall on the index of specific yield.

areas without general recharge of the Coamo fan, as could be provided in a wet year, can lead to movement of sea water inland, forcing the abondonment of wells. In dry periods the water pumped from wells near the coast should be monitored for salinity, and pumping should be decreased or even stopped wherever there is evidence of rapidly increasing salinity.

The alluvium was dewatered in 1967 in excess of the average recharge. Figure 17 shows a comparison between water levels in 1960 and in 1967. The water table in 1967 was shaped like a spoon, which was increasing in concavity; the dewatering in the center since 1960 was of the order of 40 to 50 feet.

Water demand and pump capacity exceeds the available supply at times, which results in extensive dewatering and less water for all interests. The Coamo fan is naturally semi-arid and is subject to frequent droughts, some that may last from 2 to as long as 6 years. The water economy must be geared to the recognition that the water supply is limited. Serious consideration should be given to artificial recharge of the Coamo fan.

Ground-water budget

The computation of the ground-water budget for the Coamo alluvial fan provides

Table 6.--Ground-water data in sub-areas of the Coamo fan, during dry season.

	Sub-areas (see figure 12)							Coamo fan
	A	B	C	D	E	F	G	
Area in acres	1,450	2,900	2,500	1,200	2,300	2,200	2,100	14,600
Number of wells pumping	8	15	9	4	12	11	11	70
Average dry-season pumpage, acre-feet per month	500	1,200	900	350	550	800	700	5,000
Average dry-season decline, feet per month	1.50	1.88	1.29	1.10	1.67	1.79	.83	1.38
Average water level, feet below land surface	42	62	26	20	39	39	26	36
Specific yield	.19	.20	.25	.15	.13	.19	.20	.19

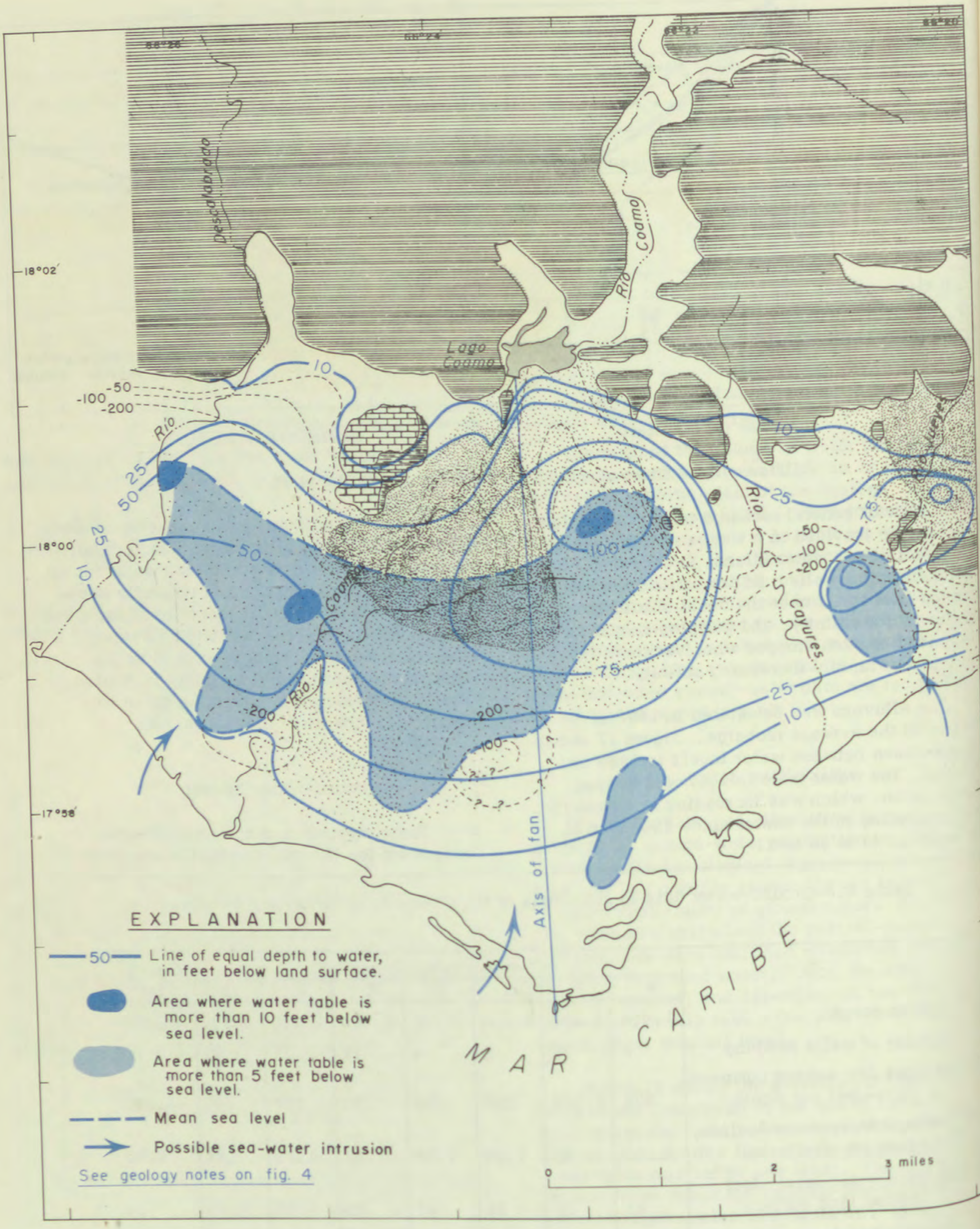

Figure 16.--Ground-water levels at end of 1967.

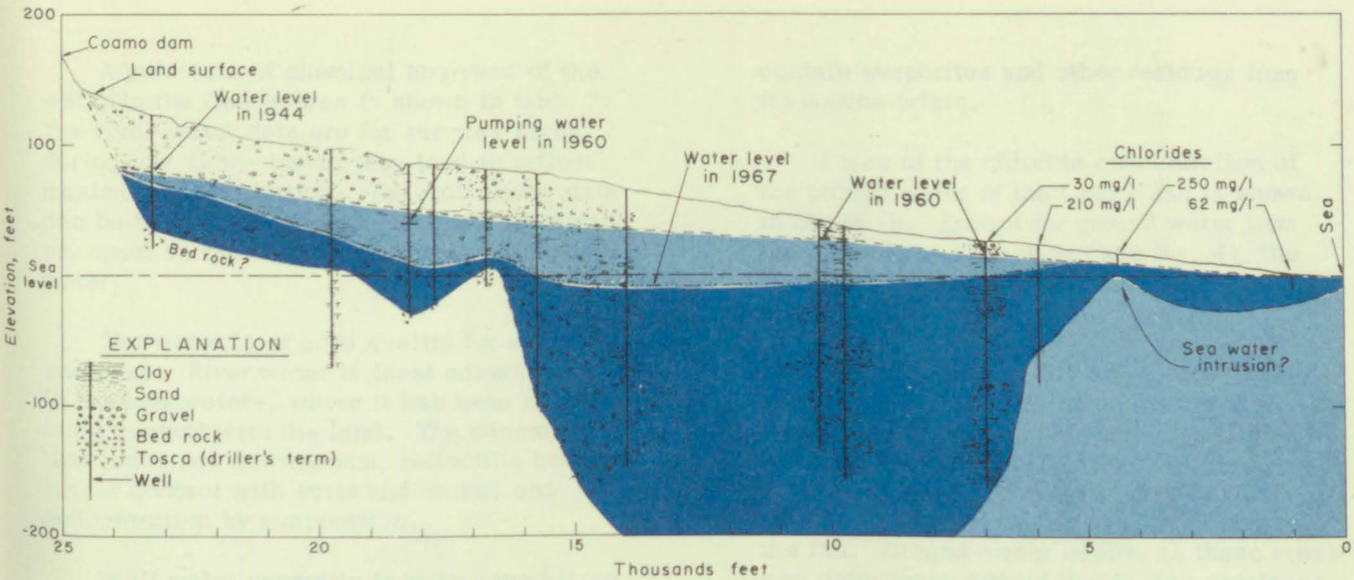

Figure 17.--Water level in Coamo fan along axis from Lago Coamo to the sea. Line is shown in figure 16.

interesting and useful information on the recirculation of irrigation water. The items in the budget are the inflow, the outflow, and the change in storage. These items are related by the basic equation:

$$I - 0 = \pm\Delta S$$
$$\text{or, } I = 0 \pm \Delta S$$

where 0 = outflow (pumpage)
I = inflow (recharge)
S = change in storage

The main outflow from the fan in 1967 was the ground water pumped out, 52,000 acre-feet. The change (decrease) in storage was 28,000 acre-feet, computed by integrating the monthly decline of water levels over the area and multiplying the result by the specific yield. So far, we have:

$$I = 52{,}000 - 28{,}000$$
$$= 24{,}000$$

Therefore, we must account for an indicated inflow of 24,000 acre-feet. This inflow into the ground-water body was recharge from rainfall, streamflow, and water applied for irrigation.

The total rainfall in 1967 was about 20,000 acre-feet. Assuming that about 10 percent infiltrated into the ground and reached the water table, we obtain recharge of 2,000 acre-feet from rainfall. This reduces the inflow to be identified to 22,000 acre-feet ($I_1 = I - 2{,}000 = 24{,}000 - 2{,}000 = 22{,}000$ ac-ft).

The recharge from streamflow, obtained by the difference between the flow at the head of the fan and the flow at the mouth of the fan, amounted to about 2,000 acre-feet. This reduces the inflow to be identified to 20,000 acre-feet ($I_2 = I_1 - 2{,}000 = 22{,}000 - 2{,}000 = 20{,}000$ ac-ft).

The only possible source of this 20,000 acre-feet of inflow is irrigation water that infiltrated into the ground and reached the ground-water body.

The water applied as irrigation amounted to:

Ground-water pumpage	52,000 ac-ft
Diversion from Canal de Juana Díaz	9,000
Diversion from Lago Coamo	5,000
Total	66,000 ac-ft

The ratio of recharge from irrigation to the total applied thus was

$$\frac{20{,}000}{66{,}000} = 0.30.$$

This means that 30 percent of the irrigation was excess to the demand by sugarcane and evapotranspiration and, in effect, was recirculated by means of ground-water pumpage. Circulated irrigation is an important factor of the water economy of the south coast.

A selection of chemical analyses of the water in the Coamo area is shown in table 7. The river-water data are for samples taken during low flow--hence they tend to reflect maximum concentration. The well-water data can be taken as average because of the small seasonal variation in the quality of ground water.

The water is of good quality for most purposes. River water is least mineralized in the headwaters, where it has been in the least contact with the land. The mineralization increases downstream, reflecting both longer contact with soils and rocks, and concentration by evaporation.

Well water generally is more mineralized than surface water, and it too increases in mineralization toward the coast.

Ground water is of poor quality in the Juana Díaz Formation (fig. 4), which may contain evaporites and other residues from its marine origin.

A map of the chloride concentration of the ground water of the Coamo fan is shown in figure 18. Except for ground water from the Juana Díaz Formation (see fig. 4), the quality of the water is good.

Three areas near the coast show higher chloride content of the ground water than the regional average. Though the salinity level still is acceptable, there is the possibility that sea water may be moving inland, especially in the eastern portion of the fan. Ground-water quality in these areas may deteriorate further if pumpage continues at the high rate of 1967 without recharge of the aquifer. (Because of delay in publishing this report, it can be reported that the high amount of recharge in the fall of 1969 alliviated the threat of continued intrusion for the time being.)

Table 7.--Selected chemical analyses of water of the Coamo area, 1967.

	Milligrams per liter											Hardness as $CaCO_3$		
	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	pH	Temperature, °C
Streams														
Río Coamo at Coamo Arriba	31	0.00	34	12	22	180	11	13	0.4	2.0	225	134	7.4	22
Río Coamo above junction with Río Cuyón	30	.01	46	19	19	230	19	18	.0	1.4	260	190	7.6	22
Río Cuyón at Hwy 14 bridge	31	.01	40	22	36	250	26	28	.2	.1	325	190	7.7	22
Quebrada La Montería at mouth	30	.00	68	27	35	320	27	46	.0	4.6	410	280	8.3	18
Coamo Springs	28	.00	232	5.1	312	28	1,020	135	1.0	.1	1,840	600	8.7	35
Wells														
Well in upper part of Coamo fan	41	.05	98	41	36	484	43	32	.2	8.2	553	415	7.9	27
Well in lower part of Coamo fan	43	.00	84	38	121	480	134	65	.1	7.0	745	365	8.1	28
Well in Juana Díaz Formation	37	.00	80	41	240	540	156	190	.3	18	1,050	370	8.0	22

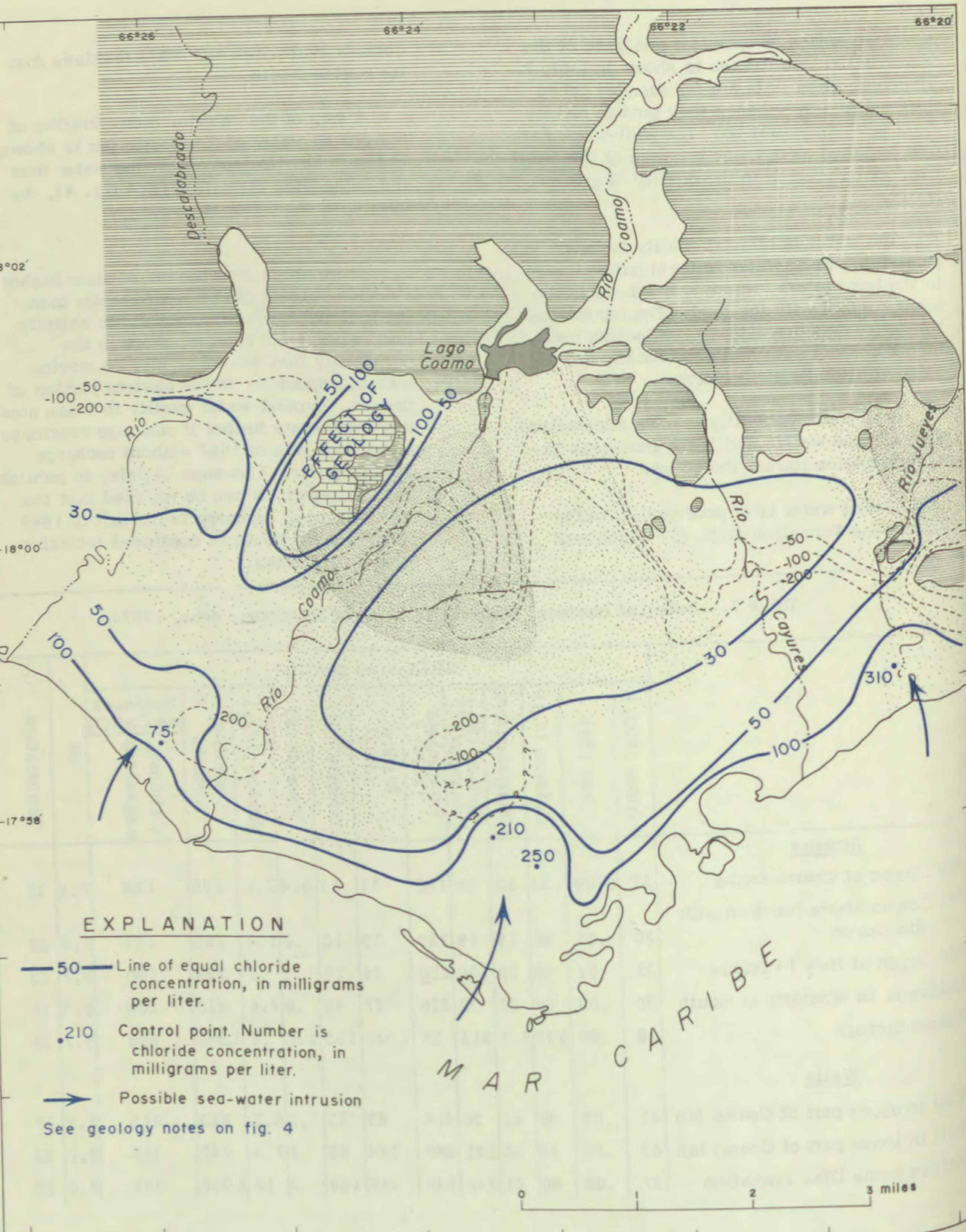

Figure 18.--Chloride concentration in the ground water of the Coamo area.

SUMMARY AND CONCLUSIONS

The water resources of the Coamo fan were investigated in 1967, a dry year that occurs on the average of once in 50 years. Río Coamo, the only sizable stream in the area, flowed a total of 6,500 acre-feet into Lago Coamo; whereas in normal years its flow is in the order of 30,000 acre-feet. Because the drought extended to the entire south coast, the delivery of water via Canal de Juana Díaz was severely curtailed, and far more irrigation water than usual had to be provided from wells. This led to almost continuous pumping for the first two-thirds of the year, resulting in extensive dewatering of the alluvial fan.

In spite of the heavy pumping, the demand for irrigation exceeded the supply, and many acres of sugarcane was abandoned for lack of water.

In the south coast it commonly is assumed (Munson, 1964) that 99 inches of water is needed for optimum growth of sugarcane. Given that rainfall on the alluvial fan in 1967 was about 16 inches, an additional 83 inches of irrigation water would have been needed. Instead, only 55 inches could be provided, about 28 inches short of what is considered to be the normal water requirement.

The 55 inches of water provided in 1967 would have been adequate, however, with rainfall of about 44 inches, which is nearly the average for the area. From this it can be inferred that in about half the years ground-water pumpage and other irrigation water in the amount provided in 1967 would be insufficient to meet the water demand for optimum growth.

Clearly, under present irrigation practice in the Coamo fan and under the present development of well fields, a drought even less severe than that of 1967 can cause insufficiency of irrigation water. As 30 percent or more of applied furrow-irrigation water infiltrates rapidly, pumpage of ground water is greater than would otherwise be necessary.

Yet, in the Coamo fan, the return flow helps to retard sea-water intrusion by providing a fresh-water mound along the coast. This mound, however, is formed at the expense of the ground water farther inland, where the water table was lowered 40 to 50 feet between 1960 and 1967 (but it recovered in the several subsequent years).

A more efficient method of irrigation with overhead sprinklers was being tried experimentally in 1967 by one agricultural company in the Coamo area. Should it prove to be economically feasible, this method could result in a considerable saving of water. To meet irrigation demands during droughts, however, it seems that storage of surface water is needed.

Among the possible sites within the Coamo area for storing excess stream runoff is Lago Coamo itself. Its original storage capacity of 3,000 acre-feet would have to be restored by removing the accumulated sediment and possibly increasing its capacity, because the high sediment content of Río Coamo (Bogart, 1964) soon would fill it. To decrease the sedimentation problem it would be worthwhile to establish a program of land management in the upland area.

Other sites for small reservoirs are where streams flow in entrenched channels--up to 100 feet below the general land surface--before they enter the coastal plain. It may be desirable to build numerous small dams within these entrenched channels. The advantages to be derived from such a scheme would be:

1. Small land acquisition as compared with large reservoirs.

2. Reduced evaporation because of the smaller surface area exposure as compared with the usual reservoir, which fills an entire valley.

3. Irrigation of the upper terraces adjacent to the entrenched channels.

In any event, any scheme of reservoirs must take into account the ground-water and irrigation practices in the coastal plain. It makes a lot of sense, hydrologically, to retain streamflow and to release it later to the alluvial fan--for the Coamo fan itself is an effective reservoir for storing excess streamflow, by means of artificial recharge. A detailed hydroeconomic analysis of the various alternatives is needed, however, to arrive at an efficient scheme--a systems analysis.

REFERENCES

Bogart, D. B., Arnow, Ted, and Crooks, J. W., 1964, Water resources of Puerto Rico, a progress report: P.R. Water Resources Bull. No. 4, 102 p.

Munson, W. C., 1964, Hydrologic study, western division, south coast irrigation district: U.S. Bur. of Reclamation open-file report for Puerto Rico Water Resources Authority, 93 p.