A-004

BULLETIN 208

# DRAINAGE AND GROUNDWATER RESEARCH IN LAJAS VALLEY, PUERTO RICO


A-004

# AGRICULTURAL EXPERIMENT STATION

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*(Continued on inside back cover)*

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*Bulletin 206*

*September 1967*

# DRAINAGE AND GROUND-WATER RESEARCH IN LAJAS VALLEY, PUERTO RICO

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## INTRODUCTION

Following the recommendations of Israelsen *(3)*,[2] Gardner *(2)*, and Reeve *(5)*, Willardson conducted research tending to solve some of the drainage problems present in Lajas Valley.

The research on drainage and ground-water in Lajas Valley was started by Mr. L. S. Willardson back in 1954. Many studies have been made since then. However, no publications have been issued since Willardson's report *(7)* in 1958 wherein he published the basic studies and preliminary results of the investigations underway at that time.

The authors made a comprehensive study and evaluation of the data so far collected since 1958, which are included in this Bulletin.[3] Details of experimental procedure are not included, because these were rather fully discussed by Mr. Willardson in his report *(7)*.

## PROCEDURE, MATERIALS, AND METHODS

### RAIN GAGES

In cooperation with the Water Resources Authority a network of rain gages was installed in the Lajas Valley (fig. 1). Because they were quite large, certain of the figures and illustrations had to be placed in a special Appendix. Attention will be called to these in text in parentheses as they appear. These gages were designed to measure the daily precipitation throughout. Wedge-shaped rain gages with an opening of 2.5 X 2.5-inch, and 12.5-inch long were installed at 3-mile intervals in the east-west direction. In the north-south direction the installation interval varied from 0.7 to 1.6 mile, depending on the width of the Valley. Some of them were relocated to nearby positions because of the inaccessibility of the original placement, or to permit the convenience of having them close to the observer's home, or because some of the existing old installations were used. Observations were made in a total of 31 units. Records are kept of the daily, monthly, and yearly precipitation at each rain gage.

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The authors wish to acknowledge the help of individuals and agencies who have in any way assisted with the work reported herein. Members of the Lajas Substation staff include Ferdinand Díaz Trizarry, J. García Albino, M. A. Negrón Weber, Carmen T. Ramírez, Julio A. Ramírez, and Guillermo Lluch Figueroa. Many of the leaders and subordinates of the Water Resources Authority, especially Edison Lluch Figueroa, have assisted with time, funds and good cooperation.

[2]Italic numbers in parentheses refer to Literature Cited, p. 37.

[3]From July 1965 to June 1966 work under this project was financially supported by the Water Resources Research Institute of the College of Engineering, Mayagüez, P.R.

## PIEZOMETERS

To measure the water pressure at different depths of the soil profile in Lajas Valley, piezometers were installed on a grid system a half-mile in each direction. The area covered by the grid system was that between the irrigation canals in the northern side and the southern fringe for the whole length of the Valley (fig. 2 — see Appendix).

The piezometers installed in Lajas Valley were of ⅜-inch standard galvanized water pipe. At each location, unless it was physically impossible, three piezometers were installed to 7-, 14-, and 28-foot depths, respectively. A 21-foot depth piezometer was installed where it was impossible to reach 28 feet.

The pipes were placed about 2 feet apart. They were flushed twice yearly to be sure that they were not plugged and inoperative.

Piezometers are read by measuring the distance from the top of the pipe to the water surface, and then subtracting the length of the pipe above the soil surface to get a reference of the water level below the soil surface. They were read once monthly.

Interpretation of piezometer readings can give the location, direction, and magnitude of vertical hydraulic gradients and depths to the water table in homogenous soils. The gradient was calculated by dividing the difference in water-level elevation in two adjacent piezometers by the vertical difference in elevation of the two pipe ends in the soil.

## WATER-TABLE WELLS

Small-diameter water-table wells were placed by each of the piezometer batteries to determine the water-table depth. These wells were installed by hand with a soil auger. They each consisted of ½ inch galvanized water pipe, 10 feet long, which has been perforated with two holes, ⅛-inch in diameter, at 6-inch intervals in the lower 6 feet.

At the sites selected for installation, a 1¼-inch auger hole was made in the soil to a depth of 9 feet. The pipe, with the perforations in the lower part, was placed in the center of the hole and the annular space outside the pipe filled with coarse sand to within 6 inches of the soil surface. The remaining 6 inches of the hole was filled with soil tightly tamped into place to prevent surface water from running into the more porous sand and filling the well. The water level was referenced to the soil surface by reading to the water surface from the top of the pipe, and then subtracting the length of pipe above the soil surface.

### DRAINAGE WELLS

Large areas in Lajas Valley are affected by artesian pressure, and it was thought best to pump 11 wells for drainage to see whether the artesian pressure could be eliminated, and reverse the gradient to the downward direction (fig. 3 — see Appendix). Radial lines of piezometers were installed centering on the well. For a detailed procedure on the well-drilling and installation of piezometers see Willardson's Bulletin *(7)*.

### FREE-FLOWING (PRESSURE-RELIEF) WELLS

Because of the limited effective area of deep wells in areas where artesian aquifers and high pressure exist, release of artesian pressure by the perforation or rehabilitation of free-flowing wells was intended. Figure 3 shows the distribution of relief wells in Lajas Valley. Discharge measurements and water samples for salt-content determinations were periodically taken.

## McDougal-Diez Area Seepage Problem

Two springs developed on land plots Nos. 173 and 174[4] in August 1961.

This problem area was studied in coordination with the Water Resources Authority. Well logs were made of two abandoned dug wells found in the area. Dug Well No. 2 was connected to a permeable water-bearing strata. Confined water was observed in some layers.

In September 1961, Well No. 2 was connected to Cristales Creek through a 6-inch-diameter iron pipe to work as a relief well. The inverse of the pipe was set at 8 feet below ground surface. Radial lines of observation points were established approximately perpendicular to each other, centering at a point 35 feet northwest, or half the distance between the two dug wells, and extending 1,000 feet north, 1,000 feet south, 900 feet west, and 250 feet east to Cristales Creek. The observation points were spaced at 100 feet, except where this was physically impossible.

## Delfín Rodríguez Relief Wells

The Delfín Rodríguez relief wells exist in an area of high artesian pressure on land plot No. 193. In general, the piezometric surface at the 28-foot piezometers in 1958 was about 2 inches above ground surface. A total of 14 relief wells, identified as RO-RW-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, were established in 1959 on this area (fig. 3). Most of them were abandoned deep wells that probably were used

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[4]List of land plots included in Lajas Valley Irrigation District, Water Resources Authority, Irrigation Division, Exhibit No. 707, San Juan, P.R., 1964.

for irrigation some time ago. These wells were cut from 0 to 4.5 feet below ground surface, depending on the depth of the available drainage canals. The casing depth ranges from 50.6 to 98.0 feet.

### Busigo Relief Wells

The Busigo Relief Wells are a series of seven in a high artesian-pressure area identified as BU-RW-1, 2, 3, 4, 5, 6, 7 in figure 3. They were a series of abandoned deep wells in land plot No. 248, owned by Escolástica Alvarez, that were cleaned and developed to drain spontaneously from 1.2 to 3.22 feet below ground surface in June 1960. These wells penetrate to depths of 32.7 to 42.5 feet below ground surface, with a 2.5-inch-diameter pipe.

### Encarnación Relief Wells

The Encarnación Relief Wells constitute a series of seven plus an intercepted spring, established in land plot No. 224 owned by Aurora Elisa Tió. These are presented in figure 3 as Enc. RW-1, 2, 3, 4, 5, 6, 7.

Most of them were abandoned deep wells that were cleaned, developed, and cut below ground surface at depths ranging from 2.2 to 2.7 feet. The original wells penetrated from 21- to 125-foot depths, the diameter of the casing ranging from 1.5 to 6.0 inches. They were put in operation as pressure-relief wells in July and August, 1960.

### Tea Relief Wells

These Tea Relief Wells consist of three abandoned deep wells known as Tea-RW-1, 2, 3, and cut about 4 feet from the ground surface to operate as free-flowing wells on land plot No. 396 owned by Sucesión Félix A. Tió (fig. 3). Two of them had a 3.5-inch-diameter casing and the other one had an 8-inch casing. They penetrated to depths ranging from 21 to 30 feet. Operation as relief wells started in January 1960.

### Mercedes del Toro Relief Wells

The Mercedes del Toro Relief Wells consist of four abandoned deep wells on land plot No. 194, which are identified as Car. RW-1, 2, 3, 4 in figure 3. They were cleaned, developed, and used to operate as relief wells in March 1961. They had a 4.0-inch diameter casing, 19.0-feet long.

### Other Relief Wells

There are some other relief wells like Cas. RW-1 and Fe RW-1 of minor importance for which there is not much information. They are installed in land plot No. 196 (fig. 3).

## WINDMILLS

There are 38 windmill installations well distributed north of the main drainage canal in Lajas Valley (fig. 4 — see Appendix). In general, they are shallow wells with a discharge of around 1 or 2 g.p.m. About 9 of them work rather continuously, most of them being used around 6 hours daily for watering livestock.

## INTERCEPTOR DRAINS

Based on ground-water and drainage investigations being conducted the Water Resources Authority, in cooperation with the Agricultural Experiment Station, established interceptor drains in the Lajas Valley to intercept ground-water flow, and to provide drainage in waterlogged areas. Six tile drain lines and some open ditches were made for that purpose (fig. 3).

### Drain Tile No. 1

Drain Tile No. 1 was located in land plot No. 173 owned by Ramón Diéz (fig. 3). The area was severely waterlogged and had become swampy and useless as result of irrigation of higher lands. A 6-inch-diameter, 85-foot-long tile drain line, at an 8 foot depth, with a gravel envelope, was established September 2, 1961 to provide drainage to this area. Water-discharge measurements were taken periodically, the effluent being sampled for salt determinations.

### Drain Tile No. 2

Drain Tile No. 2 was constructed November 7, 1961, on land plot No. 103, leased to David Antongiorgi (fig. 3). This line was established to intercept ground-water flow coming from higher lands. The tiles were 8 inches in diameter, installed in a 15-inch gravel envelope at a 5-foot depth and 750 feet long.

### Drain Tile No. 3

Drain Tile No. 3 was a concrete bell and spigot 6-inch-diameter drain-tile line installed in land plots Nos. 103 and 195-1, leased to David Antongiorgi and Sadí Antongiorgi, respectively (fig. 3). This 1,315-foot length tile line, 5 feet in depth, intercepted ground-water entering a waterlogged area. It was installed in a gravel envelope 24 inches wide and 18 inches deep. It was constructed in December 1963.

### Drain Tile No. 4

A concrete bell and spigot drain line, 6 inches in diameter, known as Drain Tile No. 4, was installed in a north-south direction on land plot No. 198 owned by Diez and McDougall (fig. 3). This line, 650 feet long, was constructed in March 1963 to intercept ground-water entering a waterlogged area.

### Drain Tile No. 5

Drain Tile No. 5 was similar to Line No. 4, established in the same area, but in an east-west direction (fig. 3). It was also constructed in March 1963.

### Drain Tile No. 6

A 6-inch-diameter drain tile line 1,650 feet long was established on land plot No. 703 owned by Frank Philippi. It is identified as Drain Tile No. 6 in figure 3. Its depth varies from 4 to 12 feet. Its construction was finished in August 1961. This drain was constructed to intercept ground-water entering a high water table-area.

### Anegado West Drain

An open channel, the Anegado West Drain, was built to provide an outlet to runoff of different farms in the area and to intercept springs in land Plot No. 423. It was constructed in April 1959.

## SUBSURFACE DRAINAGE

The type of drainage most vital to a permanently irrigated agriculture is subsurface drainage. Because of the drainage and salinity problems in Lajas Valley subsurface drainage is very important to keep the water-table low and promote a downward water movement to prevent salinization of the normal soils.

### Tile Drains

An experiment was designed to get information on the effectiveness of tile drains under the unusual conditions in Lajas Valley. Five tile lines were installed at 20-foot spacing and 3.5 feet in depth in the Fraternidad area. The experimental plot was flooded frequently for short periods of time, alternating with drying periods.

Additional tile lines were established in a nearby soil-reclamation experiment with organic matter. Tile lines were installed at a 6-foot depth with 60-foot spacing. The tile lines were 140 feet long. The experimental plots were flooded frequently, providing an excess of water application for leaching of salts.

In the same area tile lines were established to provide drainage in a soil reclamation experiment with sugarcane slops. Tile lines were placed at 20-foot spacing and 3.5-foot depth.

For the installation procedure of all these tile lines refer to Willardson's Bulletin *(7)*. Auger holes were bored in a regular pattern between plots and between drains. Periodic measurements were made of the water levels in these holes before, during, and after each flooding cycle.

### SEMISURFACE DRAINAGE METHODS

The soils of Lajas Valley have a better structural development in the surface 3 feet than in deeper layers where drains are normally installed. Keeping this in mind, two semisurface methods, mole drains and plastic tubing placed at shallow depths, were tried to investigate the possibility of using other methods of drainage which would be less expensive than tiles or deep open drains.

#### Mole-Plastic Tubing Trial

A small-scale trial was made to observe the functioning of plastic tubes laid with a cable-layer, and pulled into the soil behind a mole-ball, and of mole drains without plastic tubes. The drains were 20 feet long and 8 feet apart. There were three drains of each type.

Because of limitations of the equipment used to install the plastic tubes, they were placed at a shallow depth of 8 to 10 inches. Vertical movements of the installing devices during installation left the tubes undulated, the undulations in some instances being greater than the diameter of the tubing.

The day following the drain installation calcium chloride was applied to the plot at a rate sufficient to replace all exchangeable sodium in the soil to a depth of 15 inches. Periodic floodings were produced throughout the course of the experiment.

## EXPERIMENTAL RESULTS

### RAIN GAGES

The 6-year monthly average rainfall distribution in Lajas Valley is presented in table 1. As shown in this table there is a definite short rainy season corresponding to the period of August to November, and a long dry season during the remainder of the year, with the probable exception of April and May with a monthly average above 3 inches. About 54 percent of the expected 34.24 inches of normal annual precipitation in Lajas Valley fell in that rainy period, *i.e.*, from August to November.

Figure 1 shows the average rainfall pattern in Lajas Valley during the 6 years of record. As can be observed in this figure there is quite a variation in the amount of precipitation throughout the Valley. The highest rainfall was observed in the northern fringe of the Valley, the least amount at the east and west sides.

Table 1.–Six-Year Monthly Average Rainfall (Inches) in Lajas Valley, P.R., 1960-65

| Rain gage[1] station | Monthly average | | | | | | | | | | | | Total yearly average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | |
| R-0 | 0.99 | 1.64 | 0.50 | 2.14 | 2.33 | 2.66 | 1.64 | 6.39 | 4.46 | 3.41 | 2.79 | 1.69 | 30.64 |
| R-1 | 1.31 | 2.06 | .76 | 2.00 | 3.39 | 2.90 | 1.82 | 5.93 | 4.88 | 3.98 | 3.36 | 1.25 | 33.64 |
| R-2 | 1.14 | 2.23 | .76 | 2.31 | 2.40 | 1.92 | 1.95 | 5.63 | 5.46 | 3.53 | 2.64 | 1.03 | 31.00 |
| R-3 | 1.50 | 1.94 | .57 | 2.54 | 3.98 | 2.46 | 1.83 | 5.52 | 5.52 | 4.45 | 3.25 | 1.30 | 35.16 |
| R-4 | .98 | 1.27 | .59 | 2.20 | 2.22 | 2.01 | 1.52 | 5.65 | 4.68 | 3.37 | 2.50 | 1.67 | 28.66 |
| R-5 | .88 | 1.50 | .42 | 1.74 | 1.56 | 1.74 | 1.44 | 6.50 | 4.84 | 3.22 | 3.24 | 2.23 | 29.31 |
| R-6 | 1.71 | 1.22 | 1.21 | 4.39 | 3.62 | 2.21 | 2.76 | 6.02 | 5.12 | 4.42 | 4.16 | 1.05 | 37.89 |
| R-7 | 1.67 | .89 | .93 | 4.19 | 3.91 | 2.08 | 2.36 | 5.97 | 6.07 | 4.11 | 4.26 | .95 | 37.59 |
| R-8 | 1.36 | 1.18 | .93 | 3.23 | 3.16 | 1.90 | 2.02 | 5.61 | 6.95 | 3.45 | 4.13 | 1.13 | 35.05 |
| R-9 | 1.82 | 1.28 | 1.20 | 4.61 | 3.68 | 1.28 | 1.48 | 4.91 | 4.29 | 3.78 | 3.86 | 2.45 | 34.67 |
| R-10 | 1.28 | .61 | .56 | 2.84 | 2.91 | .87 | 1.28 | 4.28 | 5.47 | 3.26 | 3.46 | 2.33 | 29.15 |
| R-11 | 1.01 | .46 | .58 | 1.45 | 2.01 | 1.10 | 2.04 | 4.19 | 4.51 | 3.58 | 3.12 | 1.92 | 25.97 |
| R-12 | 2.10 | .76 | 1.78 | 4.31 | 3.72 | 2.27 | 2.96 | 7.00 | 6.47 | 4.37 | 3.57 | 3.06 | 42.37 |
| R-13 | 2.58 | 1.11 | 1.54 | 3.02 | 2.91 | 1.58 | 2.36 | 6.06 | 5.68 | 4.63 | 3.89 | 2.69 | 38.05 |
| R-14 | 2.04 | .81 | 1.37 | 3.18 | 2.91 | 1.55 | 1.98 | 5.05 | 6.39 | 4.02 | 3.38 | 2.31 | 34.99 |
| R-15 | 2.51 | .91 | .83 | 4.08 | 3.96 | 2.34 | 1.98 | 6.28 | 6.00 | 4.41 | 2.94 | 2.76 | 39.00 |
| R-16 | 1.64 | 1.00 | .94 | 2.64 | 3.65 | 2.23 | 2.76 | 5.87 | 5.77 | 4.79 | 3.54 | 3.46 | 38.29 |
| R-17 | 2.26 | .86 | 1.49 | 4.42 | 2.82 | 1.90 | 1.74 | 5.12 | 5.50 | 3.72 | 2.81 | 2.77 | 35.41 |
| R-18 | 2.04 | .84 | 1.10 | 4.55 | 3.32 | 2.18 | 2.70 | 7.07 | 5.26 | 4.03 | 3.60 | 1.66 | 38.35 |
| R-19 | 2.17 | .77 | 1.37 | 3.43 | 3.32 | 2.38 | 3.05 | 6.04 | 5.80 | 4.33 | 3.62 | 3.30 | 39.58 |
| R-20 | 1.42 | .68 | 1.12 | 2.66 | 2.98 | 2.04 | 1.21 | 5.13 | 4.96 | 3.42 | 2.89 | 2.28 | 30.79 |
| R-21 | 1.55 | .58 | .62 | 2.92 | 3.10 | 2.05 | 2.67 | 6.04 | 5.38 | 4.38 | 3.07 | 2.48 | 34.84 |
| R-22 | 1.67 | .59 | .79 | 1.39 | 2.70 | 2.02 | 1.17 | 4.94 | 4.80 | 3.25 | 2.32 | 1.80 | 27.44 |
| R-C | 1.07 | 1.48 | .60 | 1.45 | 1.59 | 1.89 | 1.59 | 6.04 | 5.05 | 3.08 | 3.05 | 2.10 | 28.99 |
| R-Lm | 1.16 | 1.19 | .46 | 2.78 | 4.39 | 1.67 | 1.85 | 5.67 | 5.79 | 4.59 | 3.60 | .81 | 33.96 |
| R-Ez | .93 | 1.24 | .39 | 2.74 | 2.64 | 2.17 | 1.47 | 4.92 | 5.71 | 3.96 | 3.67 | 2.14 | 31.98 |
| R-Ab | .70 | .69 | .50 | 1.90 | 2.00 | .66 | 1.10 | 4.99 | 5.97 | 4.23 | 2.97 | .85 | 26.56 |
| R-F | 2.21 | 1.07 | 1.34 | 4.30 | 3.35 | 1.77 | 2.95 | 5.74 | 5.64 | 3.98 | 3.85 | 2.71 | 38.91 |
| R-S | 2.91 | 1.05 | 1.58 | 4.84 | 3.92 | 2.36 | 3.18 | 6.90 | 6.55 | 4.35 | 3.63 | 3.38 | 44.65 |
| Average | 1.61 | 1.10 | 0.93 | 3.04 | 3.05 | 1.94 | 2.03 | 5.72 | 5.48 | 3.93 | 3.35 | 2.06 | 34.24 |

[1]For rain-gage station localization see figure 1.

## PIEZOMETERS

The permanent Valley-wide net of piezometers have given a permanent warning of the drainage situation in the Lajas Valley, especially in the area of upward hydraulic gradients.

A careful analysis was made of each piezometer hydrograph of 146 piezometer batteries installed throughout the Valley. Water-level fluctuations as presented by each piezometer hydrograph were observed since they were installed back in 1955, but special emphasis was given to the last 3 years.

Each hydrograph was classified according to its water-level variations, that is, whether the piezometric surface stood constant, rose, or dropped from its original level. These criteria were used to indicate the way the piezometric water surface has fluctuated since 1955 and especially in the period of 1963 to 1965 in each piezometer battery of the Lajas Valley network (fig. 5 – see Appendix). As can be observed in this map, in 60 of the piezometer batteries the piezometric water surface stood more or less constant, that is, with normal fluctuations within the same range. In 46 batteries the piezometric water surface steadily rose, in 19 batteries the water surface dropped from its original level, 9 batteries exhibited a rise and then a continuous drop in the water level, while 12 batteries behaved in the opposite way, that is, a drop in the water level was followed by a continuous rise.

The vertical hydraulic gradients in Lajas Valley as determined from the piezometers data of March 1958 and March 1965 are shown in figure 6 and 7, respectively (see Appendix). A comparison of these figures shows that the vertical hydraulic gradients have been increasing, both in the upward and downward direction. This is a bad sign, especially in the upward direction, since that means that the forces pushing the water upward are increasing with the possibility of bringing more water to the surface, and breaking through weak points that were not vulnerable to weak forces. The increase in downward hydraulic gradients suggests that the shallow water tables are closer to the ground surface.

The upward hydraulic gradients in the Lajas Valley are mostly caused by artesian aquifers in the gentle sloping land and the lowlands. The area affected with upward and downward hydraulic gradients in March 1958 and March 1965 are presented in figures 8 and 9, respectively (see Appendix). In March 1958 about 8,052 acres were affected with upward gradients, while 3,574 acres had downward gradients. In March 1965 the area with upward hydraulic gradients was 11,668 acres, and 4,142 acres had downward gradients. A comparison of these figures shows that more or less the original areas remain with the same problem, *i.e.*, in general, the areas that in 1965 had upward hydraulic gradients are the same as in 1958, except for some additional small areas. We want to point out that some areas included in 1965 were not under study in 1958.

Figure 10 (see Appendix) shows the water-level contours as shown by the deepest piezometers throughout the whole Valley in November 1965. It presents the possible direction of ground water movement at the depth of the deepest piezometer, indicating the natural outlets and sink in the bottom of the Valley. As Willardson (7) suggested, this is probably caused by the great loss of energy of water moving toward the low spot in the Valley as a result of the low permeability of the soil.

## WATER-TABLE WELLS

Like the piezometers, the water-table hydrographs since 1955 were carefully examined. Of 147 installations, 28 showed a rise in the water-table, 72 showed normal fluctuations, and 29 exhibited a lower water-table. In eight installations a rise in the water level followed by a continuous drop was observed, while in 10 installations, the reserve condition was noticed, that is, a drop in water level followed by a continuous rise (fig. 11 — see Appendix).

Maps were drawn to show the depth of the water-table from the ground surface in the soil profile throughout the whole Valley area. Typical maps are presented in figures 12 and 13 (see Appendix) showing areas of the Valley with water depth from 0 to 6 feet, in 2-foot increments, during the dry and wet seasons of the year 1965, respectively. In general, during the wet season approximately 3,627, 3,600, and 3,807 acres had the water-table from 0- to 2-, 2- to 4-, and 4- to 6-foot, respectively (fig. 13). During the dry season the number of acres with a water-table from 0 to a 2-foot depth dropped to 55 acres; acreage from 2 to 4 feet dropped to 2,706, while the area 4 to 6 feet rose to 5,406 acres (fig. 12). The monthly fluctuations of the area with the water-table depth from 0 to 6 feet in 2-foot increments throughout the years 1958 to 1965, the rainfall distribution, and irrigation-water deliveries are presented in figure 14 (see Appendix). This figure suggests that the water-table fluctuations are closely related to the rainfall pattern. No rainfall data were available for the years 1958 and 1959.

A water-table stage-recorder was installed in Land Plot No. 706 in a high water-table area to obtain a permanent record of the water's surface elevation (fig. 3). Some of the data taken are shown in figure 15 (see Appendix), showing continuous fluctuations when rain fell, or irrigation was applied in the area. The water surface varied from 2.4 to 4.8 feet below ground surface, the highest water level being observed from August to December, and the lowest from January to July, *i.e.*, in the rainy and dry seasons, respectively. During the dry season the water surface dropped continuously, except when irrigation was used in the area, and a rise in the water level was observed. The water table recession usually took a long time. For example, in May 1962 a rainfall of 2.75 inches raised the water table from 5.3 to 3.7 feet below ground surface, and it took 17 days to reach the original level.

Figure 16 (see Appendix) presents what have been identified as potential danger areas in Lajas Valley. It covers an area of approximately 8,123 acres. Those are the areas where the piezometric water surface and/or the water-table have been going up at a continuous fast rate, reaching a level close to the ground surface (within the top 2 feet, or above the ground surface), or where the watr table has always been high, or has dropped, but still is high. There are 60 piezometer batteries in the danger areas. Of these batteries 29 have shown a fast rise in the water surface, 27 maintained normal fluctuations, and 4 exhibited a drop in the water surface.

## WELL SURVEY

A detailed survey was made of all wells in Lajas Valley. It is not reported in this Bulletin since a similar study was recently published by Ward and Truxes *(6)*. Most of these wells had been abandoned or been used sparingly for irrigation under heavy drought conditions because of high salt content. Some of these wells had been used to water cattle.

## DRAINAGE WELLS

Some of the wells pumped for drainage studies were reported upon by Willardson *(7)*. Other wells were developed for drainage after Willardson's report in areas where the piezometers and water-table wells showed drainage problems, and where more permeable substrata were observed (fig. 3). The results are discussed for each individual well.

Willardson *(7)* reported the observations made on Wells Nos. 1, 2, 6, and 38. No more pumping trials were made in those wells after Willardson's report.

The average yields of W-1 and W-2 were 0.72 and 0.50 g.p.m. per foot of drawdown, respectively. As shown by Willardson *(7)*, in both wells the maximum distance where the water-pressure surface dropped significantly when pumped, was around 150 feet from the well. Once pumping was stopped the water level rose above the ground surface in Well No. 1 and about 2 feet from the ground surface in Well No. 2.

Both wells were left as ground-water observation points when pumping was discontinued. Well No. 1 had been overflowing since that time, while in Well No. 2 the water surface had fluctuated between 16 and 33 inches from the ground surface. As Willardson reported, both drainage wells functioning singly or together did relieve artesian pressure in their immediate area, but had no measurable effect on the area below them.

Well No. 6 was not pumped further after Willardson's report *(7)*. As Willardson concluded, pumping of W-6, known as the Antongiorgi Drainage Well, was considered to be successful, but not sufficient to eliminate all the artesian pressure in the area of influence of the well.

As Willardson *(7)* also pointed out, the effect of pumping Well No. 38 was not noticeable to any degree in the observation wells. The discharge was relatively low and apparently insufficient to affect the area away from the immediate surroundings of the well.

Once pumping was discontinued, readings were taken of the water level. The data show that the water level has been rising since pumping was stopped.

## Well No. 21

The site of Well 21 and its ground-water observation points and piezometer installations in the surrounding area, as well as its effective drainage area are presented in figure 17 (see Appendix). Initial pumping trials were reported by Willardson *(7)*. This well yielded an average of 20.4 and 3.7 g.p.m. per foot of drawdown at the beginning and end of the pumping trials, respectively.

The pumping effects of W-21 on the ground-water surface levels as shown by the ground-water observation points and piezometer batteries in the area, are presented in table 2 and figure 17. Definitely pumping W-21 had a marked effect on the ground-water surface level of the surrounding area. Although pumping of W-26, and the existing drought conditions, may have had some influence, the lowest water-surface levels were observed when W-21 was operating. Lowering of the water surface as far as 3,000 feet southeast of the well center was observed (fig. 17). In general we can say that its area of influence was around 1,117 acres (fig. 17). In this area the water-table dropped about 1 foot away from the well center, and about 19 feet close to the well. Unfortunately the pump did not work during the rainy season, so we cannot say certainly that lowering the water surface was caused by pumping alone, since pumping was done in a rather long dry period. However, during the dry period of January to March of 1958, the water levels continued to rise when pumping was stopped.

## Delfín Rodríguez Carlo's Wells

Delfín Rodríguez Carlo's wells have been designated in the Lajas Well Survey[5] as W-10, W-13, W-14, W-15, and W-16 (fig. 3). They are

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[5]Unpublished well survey prepared by Lajas Substation

Table 2.—Ground-water Level Fluctuations (Feet from Ground Surface) at Observation Points During Pumping of Well No. 21, January 1957 to May 1958

| Date | Data from observation points indicated | | | | | | | | | General observations |
|---|---|---|---|---|---|---|---|---|---|---|
| | W-21 | W-23 | Intermittent pond Irizarry | Windmill Ramirez | Well Ramirez | W-25 | W-18 | W-69 | W-24-A | |
| Jan. 15 | 2.0 | ---[1] | 1.3 | 1.8 | 0.7 | 11.8 | ---[1] | 3.2 | 3.7 | Pump started |
| Jan. 16 | 19.4 | 0.2 | 1.3 | 1.8 | .8 | 12.2 | --- | 2.8 | 4.2 | |
| Jan. 31 | 31.2 | 3.4 | 1.7 | 3.8 | 1.5 | 12.6 | 0.1 | 2.8 | 4.2 | |
| Feb. 28 | 35.2 | 8.8 | 3.4 | 6.4 | 2.7 | 13.6 | 1.2 | 3.8 | 4.4 | |
| Mar. 18 | 26.7 | 10.9 | 5.7 | 6.6 | 3.2 | 13.8 | 2.5 | 3.6 | 4.6 | Pump stopped |
| April 3 | 38.9 | 11.1 | 4.8 | 7.3 | 3.5 | 14.2 | 2.6 | 5.1 | 4.8 | Pump started |
| May 2 | 60.8 | 14.4 | 10.0+[2] | 10.7 | 4.2 | 14.3 | 4.2 | 5.2 | 5.0 | |
| June 7 | 61.4 | 19.4 | 10.0+ | 11.6 | 4.7 | 15.7 | 6.4 | 5.7 | 5.1 | |
| June 27 | 32.7 | 21.1 | 10.0+ | 13.4 | 4.8 | 16.8 | 7.2 | 8.7 | 5.4 | Pump stopped |
| July 3 | 49.0 | 21.1 | 10.0+ | 13.9 | 5.1 | ---[3] | 7.3 | 9.6 | 5.4 | Pump started |
| Aug. 8 | 26.7 | 24.8 | 10.0+ | 14.1 | 5.3 | --- | 7.6 | 7.8 | 5.2 | Pump working few hours per day |
| Sept. 5 | 21.8 | 22.0 | 10.0+ | 12.9 | 4.2 | --- | 7.2 | 9.8 | 6.4 | Pump stopped |
| Oct. 3 | 16.0 | 15.1 | ---[3] | 9.7 | 2.6 | --- | --- | 8.2 | 6.4 | Do. |
| Nov. 1 | 10.2 | 8.8 | --- | 6.0 | 1.2 | --- | 2.0 | 5.2 | 6.3 | Do. |
| Dec. 5 | 6.8 | 4.0 | --- | 4.0 | 1.1 | --- | 1.3 | 5.4 | 6.5 | Do. |
| Jan. 2 | 4.8 | 1.5 | --- | 3.4 | .9 | --- | 2.2 | 4.2 | 6.5 | Pump stopped, W-18 was pumped |
| Feb. 6 | 4.2 | .1 | --- | 3.1 | 1.0 | --- | 3.8 | 2.8 | 6.4 | Pump working few hours per day |
| Mar. 13 | 5.8 | 1.8 | --- | 3.4 | 1.2 | --- | ---[3] | 3.8 | 6.2 | Do. |
| Apr. 10 | 3.8 | 1.5 | --- | 3.2 | 1.5 | --- | --- | 2.9 | 6.0 | Pump stopped |
| May 12 | 2.0 | ---[1] | --- | 2.6 | .7 | --- | --- | 3.2 | 5.7 | Pump removed |

[1]Water was flowing above top of well pipe.
[2]Reached maximum depth of well, water below 10 ft.
[3]Area flooded; impossible to take measurements.

close together in land plot No. 270, owned by Delfín Rodríguez Carlo. Most of them penetrated to depth of 80 to 90 feet, their casing diameter being around 12 inches, with a discharge pipe 4 to 6 inches in diameter. They are equipped with Pomona turbine pump driven by electric motors. They were used mostly for pumping irrigation waters to irrigate sugarcane fields.

Permission was kindly granted by Mr. Delfín Rodríguez Carlo for pumping these wells. Minor repairs only were required to return the pumps to working conditions. The pumped water was disposed of in the main drainage canal. Observation wells (fig. 18 — see Appendix) were selected at various distances from the wells.

Pumping began in May 1957. Mechanical difficulties with the pump and problems with earth disposal ditches made it impossible to start all pumps simultaneously.

Results of the simultaneous pumping of these wells are reported in tables 3 and 4. Figure 19 (see Appendix), as well as table 3, shows the discharge and drawdown of these battery of wells. As can be observed, these wells had a high discharge rate, with the exception of W-15. The average water yields for W-10, W-14, W-15 and W-16 were 5.2, 33.1, 1.5, and 2.7 g.p.m. per foot of drawdown, respectively. It was not possible to measure the water level in W-13.

The total combined discharge during pumping was 529.6 acre-feet. Hence a considerable amount of water was being pumped out, its effects being noticed in an area of about 716 acres where a decrease of about 12 inches or more in the water surface elevation was observed (table 4 and fig. 18). The water surface dropped as much as 46 feet close to the drainage wells.

Table 4 presents the water-level fluctuations at 23 observation points distributed in the area close to the battery of wells. As shown in this table the lowering of the water level in the surrounding area of the wells during pumping was of considerable magnitude. Once the pumping of these wells was stopped the water level rose rapidly, reaching its prepumping levels.

The average electrical conductivity of the pumped water was 1.79 millimho/cm. Although this is a high-salinity water, its sodium content is rather low. Approximately 692.7 tons of salt were pumped out during the pumping period.

## Well No. 50

Mr. Carmelo Mendoza's deep well at Hacienda Firmeza, Land Plot No. 689 was designated in the well survey as W-50 (fig. 3).

Long time piezometer and shallow water table pipe records revealed a persistent condition of upward hydraulic gradients at that

**Table 3.—Discharge, Drawdown, and Chemical Analysis of Water During Pumping Test for Drainage of Delfín Rodríguez Carlo's Wells, May to September, 1958**

| Well No. | Average draw-down | Average dis-charge | Time | Total dis-charge | Average elec-trical conduc-tivity | Ca + Mg. | Na | Total salt content |
|---|---|---|---|---|---|---|---|---|
| | *Feet* | *G.p.m.* | *Hours* | *Acre feet* | *Mmho./cm.* | *Meq./liter* | *Meq./liter* | *Tons* |
| W-10 | 54.4 | 286.0 | 2,386 | 125.6 | 1.84 | 11.3 | 7.2 | 200.9 |
| W-13 | [1] | 458.9 | 1,624 | 137.1 | 1.28 | 8.8 | 4.0 | 152.7 |
| W-14 | 22.2 | 735.9 | 1,616 | 218.8 | 1.25 | 8.7 | 3.8 | 237.9 |
| W-15 | 42.7 | 64.2 | 2,570 | 30.4 | 2.79 | 16.6 | 11.2 | 73.8 |
| W-16 | 50.6 | 135.6 | 708 | 17.7 | 1.78 | 9.7 | 7.5 | 27.4 |

[1]Not possible to measure the water level.

particular area. Salt-affected soils also exist in the area according to the salinity survey made by Bonnet and Brenes *(1)*.

Decision was made to pump this well to test its effectiveness in lowering the high water-table and creating a downward gradient of ground-water necessary to reclaim the salt-affected soils.

Permission was granted by Mr. Mendoza to pump this well and to perform minor repairs necessary to operate the unit. An earth ditch was dug along a safe course to divert all pumped water to Cartagena Lagoon.

Better to delineate the area of influence of the well, radial lines of shallow water-table pipes 9 feet deep were installed at distances of 10, 30, 70, 150, 310, 630, and 1,270 feet from the well center in northwest, northeast, southwest, and southeast directions.

Well No. 50 consisted of a well about 250 feet deep, with an 8-inch diameter casing, and an installation of a Pomona turbine pump driven by a 50 hp. electric motor. It has been used lately for providing water to farm animals.

This well was pumped for drainage purposes from October 20, 1958 to January 16, 1959. Some of the results are presented in table 5. The pump worked continuously, with minor stoppages, for 2,040 hours. During this period 382 acre-feet were pumped out. This water was high in total soluble salts and sodium. Its average electricity conductivity was 5.69 millimho/cm., with an average sodium content of 31.1 meq. per liter, (derived from table 5). Approximately 1,566 tons of

Table 4.—Ground-Water Level Fluctuations (Inches from Ground Surface) During Pumping of Delfín Rodríguez Carlo's Wells, May to September, 1958[1]

| Observation points[2] | Data for date indicated | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | May 8 | May 11 | May 20 | June 3 | June 18 | July 2 | Aug. 1 | Aug. 25 | Oct. 3 |
| 1. Land Authority dug well (La Plata) | 9 | ---[3] | 9 | 11 | 13 | 15 | 16 | 33[4] | 9 |
| 2. Land Authority abandoned well | --- | 18 | 22 | 24 | 28 | 29 | 32 | 34 | 7 |
| 3. José Rodríguez culinary well | --- | 28 | 38 | 46 | 51 | 54 | 55 | 57 | 35 |
| 4. Adolfo Mercado windmill | --- | +3[5] | 7 | 23 | 41 | 44 | 51 | 43 | 31 |
| 5. Pablo Soto hand-pump | +5 | --- | 2 | 2 | 2 | 66 | 86 | 98 | 41 |
| 6. José A. Torres hand-pump | +10 | --- | +10 | 2 | 13 | 19 | 23 | 27 | −10 |
| 7. Delfín Rodríguez Carlo dug well | 4 | --- | 13 | 14 | 32 | 10 | 36 | 53 | 5 |
| 8. Gualberto Busigó deep well | +6 | --- | +6 | +3 | +4 | −3 | 21[6] | +3 | −3 |
| 9. Estebania Rivera abandoned well | 0 | --- | 45 | 56−[7] | 56− | 56− | 56− | 56− | 0 |
| 10. Arcadio Torres hand-pump | 16 | --- | 128 | 155 | 144 | 196 | 215 | 234 | 52 |
| 11. María Antongiorgi culinary well | --- | 40 | 76 | 102 | 101 | 98 | 108 | 112 | 43 |
| 12. Elisa Weber hand-pump | --- | +31 | +31 | +31 | +31 | +31 | +31 | +31 | −31 |
| 13. Andres Belén culinary well | 201 | --- | 222 | 248+ | 248− | 248+ | 248+ | 248− | --- |
| 14. Josefa Ortiz culinary well | 32 | --- | 135 | 139 | 148 | 152 | 156 | 160 | 42 |
| 15. Delfín Rodríguez Carlo perforated protruding casing | 56 | --- | 237 | 349 | 475 | 680 | 529 | 510 | 180 |
| 16. Delfín Rodríguez Carlo Southwest of W-10 | 23 | --- | 23 | 24 | 25 | 24 | 25 | 24 | 21 |
| 17. Arturo Ríos culinary well | 68 | --- | 134 | 248 | 349 | 416 | 432 | 408 | 155 |
| 18. Andres Belén culinary well (along La Plata Creek) | 96 | --- | 137 | 218 | 249 | 292 | 317 | 317 | 180 |
| 19. Virgilio Alicea culinary well | 369 | --- | 420 | 453 | 487 | 520 | 553 | 555 | 480 |
| 20. Juan A. Tió abandoned well | 0 | --- | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21. Encarnación | +12 | --- | +14 | +14 | +13 | =+11 | +9 | +5 | +16 |
| 22. Adelaida Nazario windmill | +10 | --- | +6 | +12 | 68[6] | --- | --- | --- | --- |
| 23. Gloria Antongiorgi | 94 | --- | 112 | 124 | 135 | 145 | 132 | 145 | 114 |

[1]Battery of wells pumped for drainage purposes during the period May 8 to September 5, 1958.
[2]For observation-point locations see figure 18.
[3]No reading was taken.
[4]Water was taken from well for household purposes.
[5]Water level above ground surface; some of them were overflowing top of well pipe.
[6]Lowering of water level from pumping of windmill.
[7]Water level beyond that depth; not possible to take measurements as obstructions were present.

soluble salts, of which 328 tons were sodium, were removed with the pumped volume of water.

The average pump discharge was 1,015 g.p.m. with an average drawdown of 11.2 feet (fig. 20 – see Appendix, and table 5). This evidently shows that it was a high-yielding pump with an average discharge of 90. g.p.m. per foot of drawdown. However, as shown in figure 21 (see Appendix), the water-table fluctuations in the immediate vicinity of the well during pumping were insignificant; thus a high water-table was always maintained.

Figure 22 (see Appendix) shows the piezometric water-level fluctuations in a nearby piezometer installation during the pumping period, which, as in the case of the water-table, were insignificant. Nearly all the piezometer batteries of the area behaved in a similar way. Thus this condition emphasized that pumping of this well was not effective enough to relieve the high water-table conditions and the artesian pressure in the area. Apparently the high water-table conditions are caused by a perched water-table probably resulting from soil stratification. It is also possible that an artesian aquifer of low capacity exists at some depth above 45 feet, its pressure being revealed by the deeper piezometers, and which is hydraulically independent from the aquifer where the well draws.

### FREE-FLOWING (PRESSURE-RELIEF) WELLS

Some of the data taken in different pressure-relief wells are presented in table 6. Evidently these relief wells provide a cheap way to release some of the confined water present under the impermeable layers of the bottom of the Valley. Although the pressure release is not noticed in most of the nearby piezometers, it at least has prevented increase of the water pressure with additional irrigation water coming into the Valley, part of which is contributing the groundwater and confined water in the bottom lands.

In the McDougald-Diez seepage area (fig. 3) the pressure-relief wells established helped to drain the problem area fast. However, the continuous drawdown of the water level at the observation points, where the water surface dropped even below the well outlets, suggests that there might be other drainageways in the area, or that the water source creating the problem was stopped. Apparently the problem was created by additional irrigation water served by the Water Resources Authority Irrigation District to higher lands, or by an unlined irrigation pond built above the problem area.

Table 6 presents the water-discharge measurements of Delfín Rodríguez relief wells. As derived from table 6, a total yearly average discharge of 93.9 g.p.m., or 151.5 acre-feet per year, was observed in 1960. In 1961 the discharge dropped to an average of 71.7 g.p.m. In general this is a high-salt water, in some cases being high in sodium too.

Table 5.–Discharge, Drawdown, and Chemical Analysis of Water During Pumping Test for Drainage of Well No. 50, October 1958 to January 1959

| Period | Average draw-down | Average dis-charge | Time[1] | Total dis-charge | Average electrical conduc-tivity | Ca + Mg | Na | Total salt content | Na content |
|---|---|---|---|---|---|---|---|---|---|
| | *Feet* | *G.p.m.* | *Hours* | *Acre-feet* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* | *Tons* | *Tons* |
| Oct. 20 to Oct. 31 | 6.7 | 1,080 | 247 | 49.1 | 6.08 | 25.4 | 35.4 | 259.7 | 54.4 |
| Nov. 1 to Nov. 17 | 9.9 | 1,080 | 389 | 77.3 | 5.90 | 24.8 | 34.5 | 396.8 | 83.4 |
| Nov. 18 to Dec. 1 | 11.8 | 1,050 | 356 | 64.9 | 5.40 | 21.2 | 32.8 | 304.9 | 66.6 |
| Dec. 2 to Dec. 17 | 13.5 | 1,017 | 348 | 65.1 | [2] | | | | |
| Dec. 18 to Jan. 7 | 13.1 | 974 | 504 | 90.3 | 5.55 | 23.8 | 31.7 | 436.0 | 89.5 |
| Jan. 8 to Jan. 16 | 12.2 | 888 | 216 | 35.3 | 5.50 | 23.9 | 31.1 | 168.9 | 34.3 |

[1]Time which pump worked during period of time.
[2]No data taken.

Table 6.—Free-Flowing (Pressure-Relief) Wells Data in Lajas Valley, P.R.

| Relief well name and No. | Location land plot No.[1] | Pipe diameter | Depth of pipe below ground surface | | Average yearly water discharge | | | | Water chemical analysis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lower end | Upper end | 1960 | 1961 | 1962 | 1964 | Average electrical conductivity | Ca — Mg | Na |
| | | In | Feet | Feet | G.p.m. | G.p.m. | G.p.m. | G.p.m. | Mmho/cm. | Meq./liter | Meq./liter |
| Delfin Rodriguez | | | | | | | | | | | |
| 1 | 193 | 2.5 | ---[2] | --- | --- | 3.6 | 0.4 | 0.2 | 2.6 | 10.8 | 15.2 |
| 2 | 193 | 2.5 | --- | --- | 2.8 | -- | 3.9 | 3.4 | 2.4 | 13.3 | 10.7 |
| 3 | 193 | 2.5 | --- | --- | --- | 1.2 | 2.6 | 1.8 | 2.2 | 13.3 | 8.7 |
| 4 | 193 | 2.5 | --- | 1.4 | 3.0 | .5 | 3.9 | 2.8 | 2.2 | 14.0 | 8.9 |
| 5 | 193 | 3.5 | 69.5 | 2.6 | 10.8 | 11.0 | 10.0 | 11.8[3] | 1.6 | 12.1 | [illegible] |
| 6 | 193 | --- | 72.0 | 2.6 | 9.4 | 7.0 | 5.8 | --- | 1.6 | 12.3 | 4.2 |
| 7 | 193 | 4.0 | 69.2 | 4.5 | 20.0 | 14.6 | 10.5 | 7.4 | 1.8 | 12.9 | 5.1 |
| 8 | 193 | 3.5 | 64.0 | 3.6 | 24.3 | 19.6 | 29.4 | 22.2 | 2.2 | 14.7 | [illegible] |
| 9 | 193 | 3.0 | 92.0 | 1.0 | 10.9 | 10.4 | 5.6 | 8.2 | 2.3 | 14.4 | 8.6 |
| 10 | 193 | 2.5 | 98.0 | --- | --- | --- | 18.6[4] | 8.6[4] | 1.8 | 12.1 | 6.4 |
| 11 | 193 | 6.0 | 50.6 | 3.5 | 10.0 | --- | --- | --- | 1.8 | 12.3 | 5.7 |
| 12 | 193 | 3.0 | --- | 0 | 2.7 | 2.3 | 1.9 | 1.3 | 2.0 | 9.1 | 10.9 |
| 13 | 193 | --- | --- | --- | --- | 4.0 | 4.0 | 2.0 | 2.4 | 4.5 | 19.5 |
| 14 | 193 | --- | --- | --- | --- | 4.9 | 4.9 | 2.0 | 1.8 | 2.4 | 15.1 |
| Busigo | | | | | | | | | | | |
| 1 | 248 | 2.5 | 35.4 | 2.3 | .4 | 1.6[5] | --- | .8 | 2.8 | 3.5 | 24.7 |
| 2 | 248 | 2.5 | 36.3 | 3.1 | .4 | --- | --- | .6 | 2.7 | 3.5 | 23.5 |
| 3 | 248 | 2.5 | 34.8 | 2.6 | .1 | --- | --- | .8[6] | 2.8 | 3.5 | 24.5 |
| 4 | 248 | 2.5 | 36.5 | 2.9 | .7 | --- | --- | - | 2.8 | 4.5 | 23.5 |
| 5 | 248 | 2.5 | 32.7 | 3.2 | .9 | --- | --- | .7 | 2.6 | 3.7 | 22.3 |
| 6 | 248 | 2.5 | 32.7 | 3.2 | .1 | --- | --- | 0 | --- | --- | --- |
| 7 | 248 | 2.5 | 42.5 | 1.2 | 1.3 | 2.1 | 2.2 | 2.0 | 2.6 | 3.6 | 22.4 |
| Tea | | | | | | | | | | | |
| 1 | 396 | 8.0 | 30.0 | 4.0 | 5.1 | [illegible] | --- | 13.7[7] | 2.2 | 3.0 | 18.5 |
| 2 | 396 | 3.5 | --- | 3.8 | --- | 5.6 | --- | --- | --- | --- | --- |
| 3 | 396 | 3.5 | 21.0 | 3.8 | 1.2 | --- | --- | --- | --- | --- | --- |

Table 6.–(Continued)–Free-Flowing (Pressure-Relief) Wells Data in Lajas Valley, P.R.

| Relief well name and No. | Location land plot No.[1] | Pipe diameter | Depth of pipe below ground surface | | Average yearly water discharge | | | | Water chemical analysis | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lower end | Upper end | 1960 | 1961 | 1962 | 1964 | Average electrical conductivity | Ca — Mg | Na |
| | | *In.* | *Feet* | *Feet* | *G.p.m.* | *G.p.m.* | *G.p.m.* | *G.p.m.* | *Mmho/ cm.* | *Meq./ liter* | *Meq./ liter* |
| Encarnación | | | | | | | | | | | |
| 1 | 224 | --- | 125.0 | --- | 103.8 | 96.4 | 90.5 | 123.9[8] | 2.0 | 9.5 | 10.7 |
| 2 | 224 | 6.0 | --- | --- | 1.1 | 1.1 | --- | --- | 1.5 | 6.3 | 8.7 |
| 3 | 224 | 2.5 | 48.9 | 2.5 | 7.8 | 5.0 | --- | 4.8 | 2.0 | 9.5 | 10.2 |
| 4 | 224 | 2.5 | 44.9 | 2.7 | 3.9 | .8 | 1.1 | 1.4 | 2.1 | 10.5 | 10.5 |
| 5 | 224 | 2.5 | 34.0 | 2.2 | 4.0 | 6.8 | 6.2 | 4.8 | 2.0 | 10.7 | 9.3 |
| 6 | 224 | 6.0 | 70.0 | 2.3 | 8.9 | 8.2 | --- | 4.4 | 3.2 | 8.1 | 23.9 |
| 7 | 224 | 1.5 | 21.0 | 1.3 | 1.2 | 2.0 | 1.8 | 1.2 | 5.0 | 6.4 | 43.6 |
| Mercedes del Toro | | | | | | | | | | | |
| 1 | 194 | 4.0 | 19.4 | --- | --- | 2.1 | --- | 2.8[9] | 2.9 | 6.6 | 22.4 |
| 2 | 194 | 4.0 | 19.6 | 3.0 | --- | 2.3 | --- | --- | 3.2 | 3.8 | 28.2 |
| 3 | 194 | 4.0 | 19.5 | 2.0 | --- | 1.4 | --- | --- | --- | --- | --- |
| 4 | 194 | 4.0 | 19.1 | --- | --- | .6 | --- | .9 | 4.1 | 5.0 | 36.0 |

[1]Numeration of land plots included in Lajas Valley Irrigation District (see footnote 4).
[2]No data available.
[3]Combined discharge of relief wells 5 and 6.
[4]Combined discharge of relief wells 10 and 11.
[5]Combined discharge of relief wells Nos. 1, 2, 3, 4, 5, and 6 of Busigo area.
[6]Combined discharge of Busigo relief wells 3 and 4.
[7]Combined discharge of Tea relief wells 1, 2, and 3.
[8]Combined discharge of Encarnación relief wells 1, and 2, and intercepted spring in area.
[9]Combined discharge of Mercedes del Toro Irizarry relief wells 1, 2, 3, and 4.

Although their effectiveness in lowering the water surface was not shown in the nearby piezometer installations, the high volume of saline-water discharge spontaneously shows that it is an efficient method to get rid of some of the confined water in the lowland of the Valley where aquifers of low hydraulic conductivity exist, and where pumping of drainage wells is ineffective. Probably the spontaneous discharge of these wells diverted some spring such as occasionally develop in the area.

Rather low discharges were observed in three relief wells in operation in the Tea Area where high artesian pressures exist (fig. 3). A combined average discharge of 27.1 acre-feet per year of high saline-water was obtained from these wells in 1964 (derived from table 6).

The effects of the release of this volume of water were not noticed in the nearby piezometers. The piezometric water surface in some of the piezometers was going down before the relief wells were put in operation. Probably this was caused by the construction of several drainage canals in the area which intercepted some springs that were connected to the artesian aquifer.

A group of seven relief wells were operating in Busigo area (fig. 3). However, those were low-yielding wells, as shown in table 6. The total average yield was 7.9 acre-feet in the year 1964. This water was high in soluble salts, especially sodium. Nearby piezometers showed no change in water pressure.

In the Encarnación area seven relief wells and an intercepted spring were discharging in Barbara drain (fig. 3). These are high-yielding wells (table 6). The combined average discharge was 130.7 g.p.m., or 210.8 acre-feet per year in 1960. In 1964 the water discharged increased to 226.6 acre-feet. This water was high in both total salt and sodium.

As in the other relief-well installations, their effect on the release of water pressure is not clearly shown in the nearby piezometers.

Low discharges were observed in Mercedes del Toro Irizarry's relief-wells (fig. 3). This group includes four wells with a total discharge of 6.4 g.p.m. or 10.3 acre-feet per year in 1961, decreasing to 3.7 g.p.m. in 1964. The water had a high salt content, especially sodium. No effects were observed on the piezometric water-surface level.

Some of the data collected from the interceptor drains installed in Lajas Valley are presented in table 7. As shown, the water discharge was maintained fairly high for each one from its beginning to the year 1964, with the exception of tile lines 1 and 2 which dropped to 10.0 and 4.8 g.p.m., respectively. The combined total discharge for the tile lines and the Anegado west drain in 1964 was 448.2 acre-feet. The salt content was high with an average conductivity of 1.34 millimho/

Table 7.—Interceptor Drains Data in Lajas Valley, P.R.

| Drain No. or name | Type | Location land plot No.[1] | Size: Diameter | Size: Length | Depth of installation | Average yearly water discharge: 1961 | Average yearly water discharge: 1963 | Average yearly water discharge: 1964 | Water chemical analysis: Average electrical conductivity | Water chemical analysis: Ca / Mg | Water chemical analysis: Na |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Feet* | *Feet* | *Feet* | *G.p.m.* | *G.p.m.* | *G.p.m.* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* |
| 1 | Concrete tile | 173 | 0.5 | 85 | 8.0 | 16.9 | --- | 0 | --- | --- | --- |
| 2 | do. | 103 | .7 | 750 | 5.0 | 9.5 | 14.8 | 4.8 | 1.4 | 6.6 | 7.4 |
| 3 | do. | 103 & 195-1 | .5 | 1,314 | ---[2] | --- | 17.4 | 15.0 | --- | --- | --- |
| 4 | do. | 198 | .5 | 650 | --- | --- | 6.3 | 17.4 | 1.2 | 5.9 | 5.6 |
| 5 | do. | 198 | .5 | -- | --- | --- | 9.8 | 14.2 | 1.6 | 7.4 | 8.1 |
| 6 | do. | 703 | .5 | 1,650 | 4-12 | | --- | 47.5 | 1.4 | 10.1 | 4.1 |
| Anegado west drain | Open ditch | 423 | --- | --- | --- | 253.8[3] | --- | 170.0 | 1.1 | 7.1 | 3.9 |

[1]Identification of land plots included in Lajas Valley Irrigation District (see footnote 4).
[2]No available data.
[3]Data taken in 1959.

cm., however, it was low in Na with 5.8 meq./liter. The estimated total salt disposed with these waters in 1961 was 522.5 tons.

Although their influence on the water-table and piezometric water surface was not shown in the piezometers of the area (actual network of piezometers) it was shown in the immediate vicinity of the drain where springs and waterlogged areas were drained. Visual observations were made mainly in those areas.

The magnitude of the water disposed by the interceptor drains and their immediate drainage effect on the surrounding areas proved to be an efficient means of intercepting ground waters in the more permeable substrata that occur mostly at higher elevations in the Valley.

## SUBSURFACE DRAINAGE

Results derived from five tile lines 60 feet long at 20-foot spacing, and installed at 3.5 foot depth in a sodic soil in Fraternidad area of the Lajas Valley are presented in figures 23 through 25 (see Appendix) and tables 8 and 9.

Figure 23 shows the water discharge of two of the five tile lines at different flooding periods when the plot was maintained ponded with a nearly constant water level. Table 8 shows the average discharge of the five tile lines at two different stages, that is, at a nearly constant water level when flooded, and at a decreasing water level after the water entrance to the plot was stopped in order to be dried. Figure 23 as well as table 8 shows that the discharge was high initially and suddenly dropped to a more or less constant low rate.

The water-pressure distribution, as shown by piezometers installed at different depths throughout the soil profile in the 3.5-tile drains experiment, when flooded, is shown in figure 24. As shown, a great loss in energy was observed in the water moving from the soil surface down to the drains. A head loss of approximately 2.27 feet occurred in the water movement from the soil surface to a depth of 3.5 feet. The water-pressure distribution after a flooding period when no water was ponded in the soil surface is presented in figure 25. No water pressure was exhibited by the piezometers installed above the tile drains. The piezometric water surface stood 0.48 feet below the tile drains.

The electrical conductivity variations with time of the water coming off the tile lines are presented in table 8. It can be observed that the electrical conductivity and sodium content was maintained most of the time very high with an average of 33.9 millimho/cm. and 284.0 meq./liter, respectively.

The reclamation progress of the soil in the experimental plot is presented in table 9. As shown, the top 18 inches of the soil profile had

Table 8.—Flooding Periods, Discharge, and Chemical Analysis of Effluent in 3.5-Tile Drainage Experiment at Fraternidad, Lajas Valley, P.R., 1956-65

| Flooding period[1] | Discharge period at[2]— | | Average discharge at— | | Total discharge in flooding period | Effluent chemical analysis | | |
|---|---|---|---|---|---|---|---|---|
| | Constant water level | Drying conditions | Constant water level | Drying conditions | | Average electrical conductivity | Average Ca — Mg. | Average Na |
| | *Days* | *Days* | *G.p.m.* | *G.p.m.* | *Acre-feet* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* |
| 1956 | | | | | | | | |
| July 18 to Jan. 3 | 16 | 153 | 0.072 | 0.032 | 1.210 | 60.5 | 94.0 | 511.3 |
| 1957 | | | | | | | | |
| Jan. 4 to Mar. 11 | 57 | 9 | .059 | .040 | .745 | ---- | ---- | ---- |
| May 14 to May 28 | --[3] | --- | ---- | ---- | ---- | ---- | ---- | ---- |
| Aug. 14 to Aug. 28 | 0 | 7 | .000 | .011 | .015 | ---- | ---- | ---- |
| Dec. 17 to Jan. 21 | 14 | 22 | .011 | .005 | .053 | 42.2 | 69.3 | 352.4 |
| 1958 | | | | | | | | |
| Jan. 22 to Feb. 18 | 17 | 11 | .015 | .006 | .064 | 40.0 | 66.9 | 333.1 |
| Feb. 19 to Mar. 14 | 9 | 14 | .010 | .006 | .035 | 39.8 | 69.1 | 328.4 |
| Mar. 21 to May 5 | 11 | 34 | .008 | .003 | .038 | 34.2 | 56.2 | 285.5 |
| June 13 to July 29 | 13 | 33 | .035 | .007 | .055 | 40.1 | 63.8 | 337.0 |
| July 30 to Nov. 4 | 9 | 27 | .012 | .003 | .038 | 43.7 | 62.9 | 374.0 |
| 1959 | | | | | | | | |
| Oct. 5 to Oct. 23 | 11 | 4 | .003 | .001 | .008 | 5.6 | 5.1 | 51.2 |
| Nov. 4 to Nov. 27 | -- | 23 | --- | .001 | .005 | 8.8 | 9.4 | 78.5 |
| 1960 | | | | | | | | |
| Feb. 4 to Mar. 21 | 0 | 36 | .000 | .006 | .043 | 5.6 | 7.5 | 48.0 |
| Apr. 26 to June 3 | 24 | 14 | .011 | .003 | .061 | 13.7 | 14.3 | 122.9 |
| July 13 to Aug. 8 | 14 | 12 | .010 | .003 | .035 | 22.2 | 30.0 | 191.6 |
| Aug. 24 to Oct. 24[4] | 13 | 48 | .022 | .009 | .143 | 30.8 | 42.8 | 265.1 |
| 1961 | | | | | | | | |
| Mar. 2 to Mar. 20 | 7 | 11 | .010 | .001 | .016 | 12.6 | 17.5 | 108.4 |
| Apr. 20 to May 24 | 22 | 12 | .006 | .008 | .045 | 33.8 | 48.3 | 289.4 |
| | -- | 6 | --- | .004 | .005 | 33.2 | 46.8 | 285.0 |
| | -- | 20 | --- | .005 | .020 | 43.6 | 68.2 | 367.8 |

Table 8.—(Continued)—Flooding Periods, Discharge, and Chemical Analysis of Effluent in 3.5-Tile Drainage Experiment at Fraternidad, Lajas Valley, P.R., 1956-65

| Flooding period[1] | Discharge period at[2]— Constant water level | Discharge period at[2]— Drying conditions | Average discharge at— Constant water level | Average discharge at— Drying conditions | Total discharge in flooding period | Effluent chemical analysis: Average electrical conductivity | Effluent chemical analysis: Average Ca + Mg. | Effluent chemical analysis: Average Na |
|---|---|---|---|---|---|---|---|---|
| | *Days* | *Days* | *G.p.m.* | *G.p.m.* | *Acre-feet* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* |
| 1962 | | | | | | | | |
| Jan. 17 to Feb. 16 | 0 | 16 | 0 | 0.002 | 0.006 | 54.5 | 93.6 | 451.9 |
| Mar. 28 to Apr. 4 | 0 | 0 | 0 | .000 | 0 | --- | --- | ---- |
| July 9 to July 20 | 0 | 0 | 0 | .000 | 0 | --- | --- | ---- |
| July 24 to Aug. 17 | 0 | 16 | 0 | .001 | .003 | --- | --- | ---- |
| Dec. 11 to Dec. 13 | 0 | 0 | 0 | .000 | 0 | --- | --- | ---- |
| 1963 | | | | | | | | |
| Jan. 10 to Feb. 18 | 0 | 28 | 0 | .005 | .028 | 40.0 | 69.5 | 330.8 |
| Feb. 26 to Mar. 15 | -- | 9 | --- | .002 | .004 | 42.8 | 72.7 | 355.3 |
| Sept. 19 to Oct. 23 | 0 | 29 | 0 | .005 | .029 | 35.2 | 79.9 | 272.1 |
| Nov. 20 to Jan. 7 | 24 | 18 | .016 | .006 | .099 | 37.3 | 68.5 | 305.1 |
| 1964 | | | | | | | | |
| Mar. 17 to July 3 | 62 | 15 | .009 | .004 | .124 | 43.1 | 73.8 | 358.6 |
| July 22 to Aug. 19 | 0 | 0 | 0 | .000 | .000 | --- | --- | ---- |
| Oct. 21 to Dec. 23 | 31 | 24 | .009 | .006 | .085 | 43.5 | 74.0 | 360.6 |
| 1965 | | | | | | | | |
| Jan. 20 to May 3 | 33 | 34 | .008 | .006 | .094 | 35.6 | 63.0 | 292.8 |
| May 19 to May 28 | | 9 | -- | .002 | .004 | 38.9 | 64.5 | 324.3 |
| July 9 to Sept. 29 | 23 | 26 | .006 | .004 | .049 | 34.4 | 56.9 | 287.4 |
| Nov. 25 to Jan. 24 | 16 | 26 | .007 | .006 | .053 | 32.5 | 50.1 | 274.9 |

[1]Period of time that experimental plot was covered with water.
[2]Period of time that tile-lines were discharging under a constant water level or at an unsteady water level during the drying period after the water entrance to the plot was stopped.
[3]No available data.
[4]Heavy rainfall in the area.
[5]No flooding, heavy rainfall in the area.

**Table 9.—Soil Reclamation Progress in 3.5-Foot Tile Drainage Experiment at Fraternidad, Lajas Valley, 1956-65[1]**

| Depth (inches) | Saturation | Electrical conductivity | Ca + Mg | Na | Exchangeable sodium | Soil class[2] |
|---|---|---|---|---|---|---|
| | *Percent* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* | *Percent* | |
| | | | *July 8, 1956*[3] | | | |
| 0-6 | 74.8 | 10.66 | 15.6 | 91.0 | 32.3 | SA |
| 6-12 | 82.1 | 21.68 | 34.0 | 182.9 | 39.1 | SA |
| 12-18 | 81.1 | 32.00 | 54.8 | 265.2 | 42.3 | SA |
| 18-24 | 85.5 | 33.33 | 53.5 | 279.9 | 44.2 | SA |
| 24-36 | 96.9 | 27.56 | 36.0 | 239.6 | 46.1 | SA |
| 36-48 | 115.4 | 19.80 | 17.2 | 180.8 | 47.7 | SA |
| 48-60 | 125.7 | 15.51 | 11.3 | 143.8 | 47.4 | SA |
| | | | *July 26, 1957*[4] | | | |
| 0-6 | 73.1 | 1.57 | 5.3 | 10.4 | 8.1 | N |
| 6-12 | 83.9 | 3.86 | 13.2 | 25.4 | 14.3 | N |
| 12-18 | 92.9 | 5.42 | 16.9 | 37.3 | 17.0 | SA |
| 18-24 | 90.5 | 10.13 | 29.9 | 71.5 | 21.6 | SA |
| 24-36 | 138.5 | 11.63 | 23.2 | 93.2 | 30.8 | SA |
| 36-48 | 140.0 | 14.06 | 14.0 | 126.6 | 44.3 | SA |
| 48-60 | 128.9 | 16.97 | 15.7 | 154.0 | 45.5 | SA |
| | | | *November 20, 1958* | | | |
| 0-6 | 70.1 | 0.96 | 3.5 | 6.1 | 5.5 | N |
| 6-12 | 86.5 | 1.29 | 2.0 | 10.8 | 14.4 | N |
| 12-18 | 93.9 | 2.56 | 7.5 | 18.3 | 15.1 | NSA |
| 18-24 | 103.8 | 2.54 | 2.7 | 22.7 | 21.8 | NSA |
| 24-36 | 145.4 | 5.58 | 7.0 | 48.7 | 30.8 | SA |
| 36-48 | 168.4 | 8.15 | 5.9 | 75.6 | 39.9 | SA |
| 48-60 | 144.8 | 11.08 | 8.4 | 102.3 | 41.2 | SA |
| | | | *November 30, 1959* | | | |
| 0-6 | 82.0 | 0.82 | 3.9 | 4.4 | 3.9 | N |
| 6-12 | 87.0 | 1.03 | 2.3 | 7.9 | 7.5 | N |
| 12-18 | 90.0 | 2.51 | 9.6 | 15.5 | 11.1 | N |
| 18-24 | 94.0 | 3.81 | 10.8 | 27.4 | 16.7 | NSA |
| 24-36 | 116.0 | 6.48 | 7.6 | 57.3 | 29.6 | SA |
| 36-48 | 121.0 | 9.72 | 8.5 | 88.8 | 38.6 | SA |
| 48-60 | 121.0 | 11.75 | 9.2 | 108.3 | 42.1 | SA |

Table 9.—(Continued) Soil Reclamation Progress in 3.5 Foot Tile Drainage Experiment at Fraternidad, Lajas Valley, 1956-65[1]

| Depth (inches) | Saturation | Electrical conductivity | Ca + Mg | Na+ | Exchangeable sodium | Soil class[2] |
|---|---|---|---|---|---|---|
| | *Percent* | *Mmho/cm.* | *Meq./liter* | *Meq./liter* | *Percent* | |
| | | | *October 16, 1964* | | | |
| 0-6 | [5] | 0.9 | 4.2 | 4.8 | 3.3 | N |
| 6-12 | | 1.1 | 2.5 | 8.5 | 8.2 | N |
| 12-18 | | 1.4 | 1.9 | 12.1 | 12.3 | N |
| 18-24 | | 2.0 | 1.4 | 18.6 | 19.7 | NSA |
| 24-36 | | 5.3 | 10.9 | 42.1 | 25.6 | SA |
| 36-48 | | 6.6 | 9.0 | 57.0 | 33.0 | SA |
| | | | *November 5, 1965* | | | |
| 0-6 | 72.0 | 1.61 | 8.2 | 8.0 | 4.7 | N |
| 6-12 | 73.0 | 1.25 | 3.8 | 8.7 | 7.8 | N |
| 12-18 | 86.0 | 1.72 | 3.3 | 14.0 | 13.1 | N |
| 18-24 | 100.0 | 2.26 | 2.3 | 20.3 | 20.4 | NSA |
| 24-36 | 120.0 | 5.55 | 9.0 | 46.5 | 29.2 | SA |
| 36-48 | 135.0 | 6.96 | 5.2 | 64.5 | 39.1 | SA |

[1]Average electrical conductivity, calcium plus magnesium, sodium, and exchangeable sodium percentage of 8 soil samples taken midway between drains.

[2]Soil classification according to Handbook No. 60, USDA, 1954.

[3]Soil samples taken before drain-tile installation and flooding at experimental plot.

[4]After tile installations and experimental plot was flooded.

[5]Data lost.

After the experiment was discontinued the drains were uncovered to check their condition. The plastic drains were laid in an undulating form. Although they were in good physical condition, the tube was mostly full of soil and roots. The mole drains were closed, that is, only a small crack was observed where they were made.

Since those drains were placed at shallow depths it is obvious that the shallow placement of drains has limitations in providing drainage for soil reclamation.

## DISCUSSION

A careful analysis of the piezometer data from Lajas Valley since 1955 to 1965 shows that the piezometric water surface has been rising in 58 batteries. In other words, the area with upward pressures has increased, as well as the magnitude of the gradients. This is a bad sign since it means that the forces pushing the water upward are increasing, with the possibility of bringing more of this saline ground water to the surface and breaking through weak points that were not vulnerable to weak forces.

Similar conclusions were reached by Quiñones *et al.* *(4)* in their analysis and interpretation of these data which were submitted as a report to the Water Resources Authority.

Although the water-table observation-well data show that only 28 of the wells have exhibited a continuous rise, we want to point out that many of the remaining wells have maintained a high water table throughout those years. As can be observed in figure 14, there is a definite relation between the variations in monthly rainfall and an area with a high water-table; however, the water deliveries for irrigation purposes have been low.

As Quiñones *et al.* *(4)* pointed out, problems will become worse when the farmers use the full allotment of 3.0 acre-feet per acre per year.

Pumping of wells for drainage proved to be effective in the more permeable substrata of the northern Valley fringe, but not in the bottom-lands. The possibility of pumping those wells on a permanent basis must be studied. The possibility must also be studied of mixing these waters with the irrigation-system water in order to be used for irrigation purposes.

In the Valley bottom-lands where upward hydraulic gradients of great magnitude exist, spontaneous discharge of pressure-relief wells was of considerable magnitude. This method should be studied further to determine whether it is possible to relieve the present artesian pressure in the bottom-lands.

Apparently interceptor drains are effective in intercepting ground-water at higher elevations. This practice should be continued combined with research studies to get more information that could be used in similar areas.

As Willardson *(7)* pointed out, the amount of water passing through the soil of the 3.5-foot tile-drain experiment was very small, considering the narrow drain spacing and the length of time the water was ponded there. The soil reclamation was limited to 18 inches. This probably can be attributed to the limited depth of the drains, or to the high solubility of the calcium chloride that probably was washed out immediately after it was applied.

Apparently 3.5-foot tile drains at 20-foot spacing and/or 6-foot tile drains at 60-foot spacing are good enough to provide drainage in soil-reclamation experiments. The water table was mostly maintained at tile-depth.

Further research is needed with this type of drain in drainage-problem areas where the topsoil is underlined by a slowly permeable subsoil, and where the subsurface drainage must be provided on a farm basis. The effectiveness of shallow tile and/or plastic drains, and open drains at different depths and spacings must be studied.

Research studies must be continued in Lajas Valley in order to find answers to actual and future drainage problems that will develop. A soil-stratification study of the Valley must be made in order to delineate shallow and deep aquifers, so that appropriate measures can be taken to intercept these waters. The physical characteristics and the soil profiles of the major soil groups of the Valley must be determined to help the drainage research and practice. The areas delineated as potential danger areas must be studied carefully. The salinity status of the soil, especially in the areas with upward hydraulic gradients and high water tables, must be determined.

Management practices for irrigation and drainage will have to be developed, which will provide for uniform application and efficient use of irrigation water, and protect the soils from salinization and waterlogging.

## SUMMARY

A report is made in this Bulletin on drainage and ground-water research in Lajas Valley, Puerto Rico. It includes a comprehensive study and evaluation of the results obtained from previous work started by Willardson, as well as new investigations made after his report *(7)* in 1958.

Results of drainage investigations with piezometers, water-table observation wells, drainage wells, interceptor drains (tiles), pressure-relief-wells, mole drains, and plastic-tube drains are given. Results of drainage and soil reclamation with shallow, closely spaced tile drains are also included.

In general the data show the following:

1. In 58 of a total of 146 piezometer batteries under study, the piezometric water surface showed a continuous rise.

2. The areas with upward pressures have increased as well as the magnitude of the gradients.

3. Although only 28 of 147 water-table observation wells show a continuous rise, many of the remaining wells have exhibited a high water-table throughout the years under study.

4. There is a definite relation between the variations in monthly rainfall and the areas with high water-tables; however, the water deliveries for irrigation have been low.

5. Pumping of wells for drainage, as well as interceptor drains, proved to be effective in the more permeable substrata of the northern Valley fringe.

6. In the Valley bottom lands, where upward hydraulic gradients of great magnitude exist, the spontaneous discharge of pressure-relief wells was of considerable magnitude.

7. Apparently 3.5-foot tile-drains at 20-foot spacing and/or 6-foot tile-drains at 60-foot spacing are good enough to provide drainage in soil reclamation experiments.

8. Shallow placement of moles and plastic tube drains failed to provide drainage in a soil-reclamation experiment.

9. Management practices for irrigation and drainage will have to be developed which will provide for uniform application and efficient use of irrigation water, and protect the soils from salinization and waterlogging.

## RESUMEN

En este estudio se presenta un informe sobre los proyectos de investigación del desagüe y las aguas subterráneas en el Valle de Lajas, Puerto Rico. El informe incluye una cuidadosa evaluación de los resultados previos obtenidos por Willardson, así como también los estudios hechos después de rendido su informe *(7)* en 1958.

Se presentan los resultados obtenidos con piezómetros, pozos de observación del nivel freático, pozos de desagüe, desagüaderos interceptores de tejas, pozos de libre descarga, desagüaderos de tunel sin revestir (*mole-drains*) y desagüaderos de tubo plástico perforado.

En términos generales los datos demuestran lo siguiente:

1. El nivel del agua subió continuamente en 58 instalaciones de piezómetros, de un total de 146 que estaban bajo estudio.

2. Va en aumento el área que presenta presiones hacia arriba (artesianas), al igual que la magnitud de las gradientes hidráulicas.

3. Aunque solamente 28 de los 147 tubos de observación revelan un ascenso continuo del nivel freático, se ha observado que en un buen número de los restantes el nivel freático siempre se mantiene alto.

4. Existe una relación definida entre las fluctuaciones en las áreas con un alto nivel freático en el Valle de Lajas y las fluctuaciones de la lluvia. Sin embargo, hasta la fecha los despachos de agua de riego han sido bajos.

5. El bombeo de pozos de desagüe, así como los desagüaderos interceptores, prometen proveer un buen desagüe de las zonas más permeables que ahora se encuentran en la vertiente norte del Valle.

6. Se observaron descargas de gran magnitud en los pozos de libre descarga hincados en la parte baja del Valle, donde también existen presiones artesianas de gran magnitud.

7. Aparentemente, los desagües de tejas instalados a 3.5 pies de profundidad y a 20 pies de distancia, y/o a 6.0 pies de profundidad y 60 pies de distancia, son lo suficientemente adecuados como para proveer el necesario desagüe en los proyectos de reclamación de los suelos salinos.

8. Los desagüaderos de túnel sin revestir y los desagüaderos de tubo plástico perforado, instalados a poca profundidad, no proveyeron el necesario desagüe en los proyectos de reclamación de los suelos salino-sódicos.

9. Será necesario desarrollar e implantar aquellas prácticas de riego y desagüe que mejoren la eficiencia del riego, para así evitar los problemas de desagüe y, por consiguiente, los de la salinización y anegado de los suelos.

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# APPENDIX

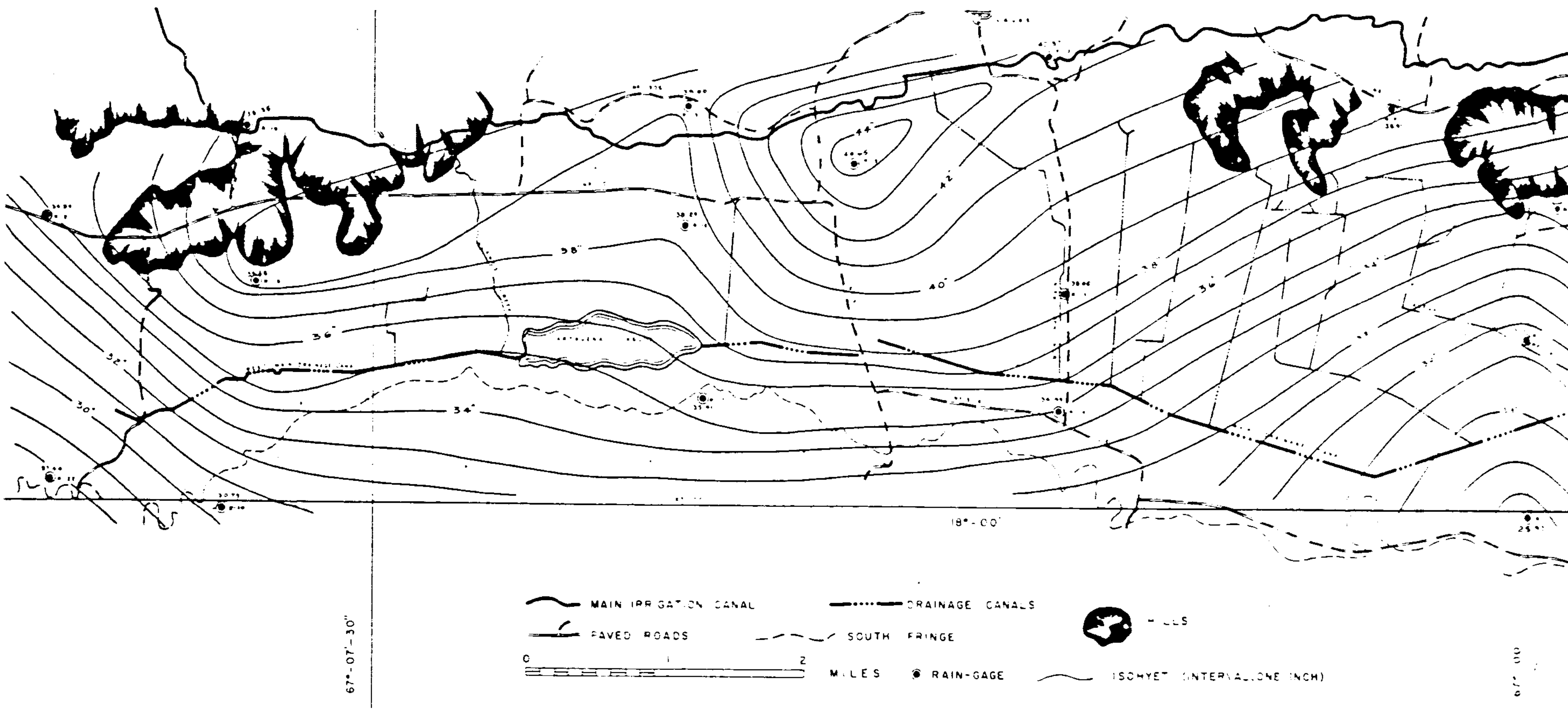
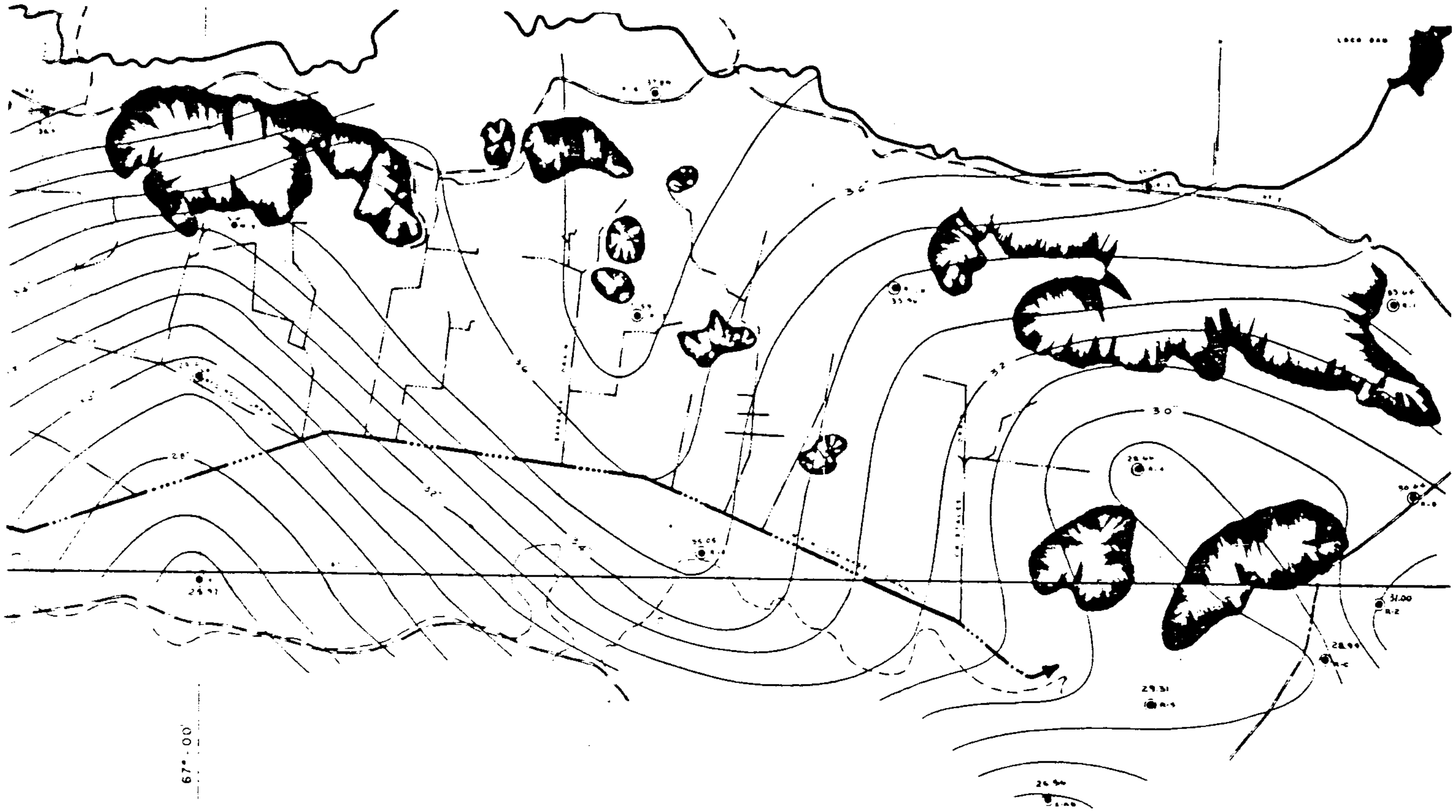



FIG. 1.—Network of rain gages and isohyetal map of 6-year average rainfall in Lajas Valley, P.R.




ap of 6-year average rain-

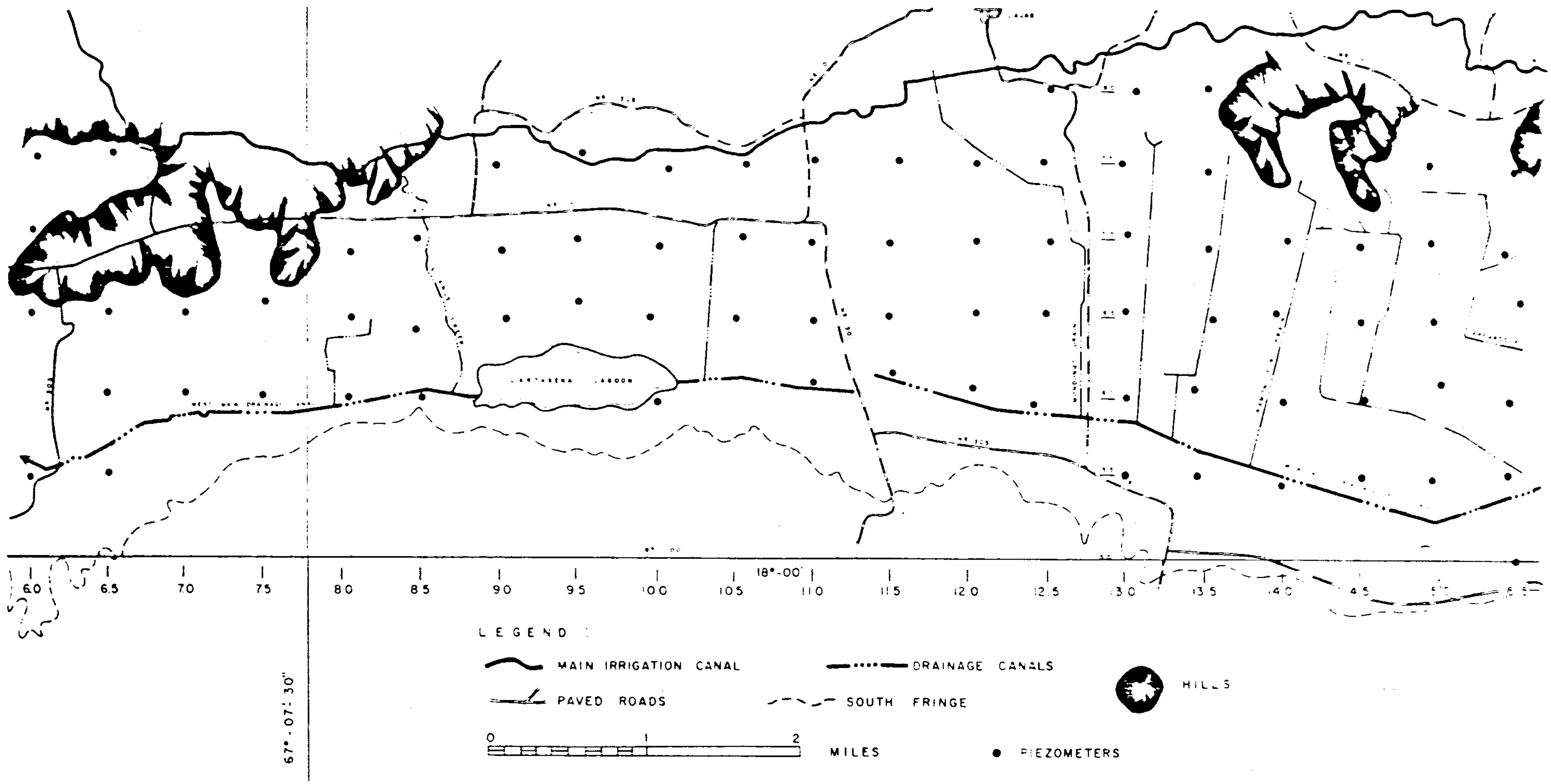
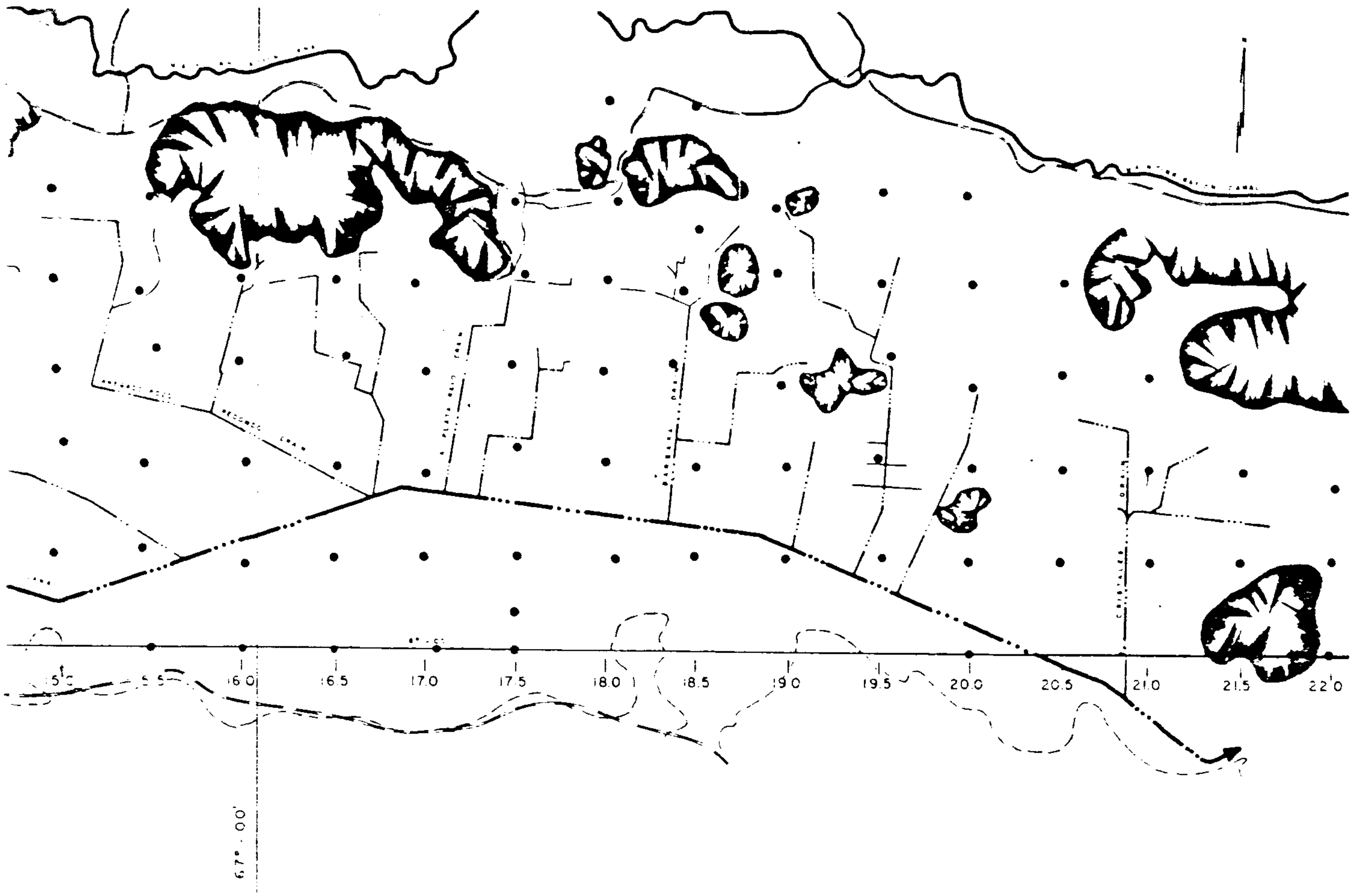



FIG. 2.—Network of piezometer batteries in La[illegible] Valley. F




Lajas Valley, P.R.

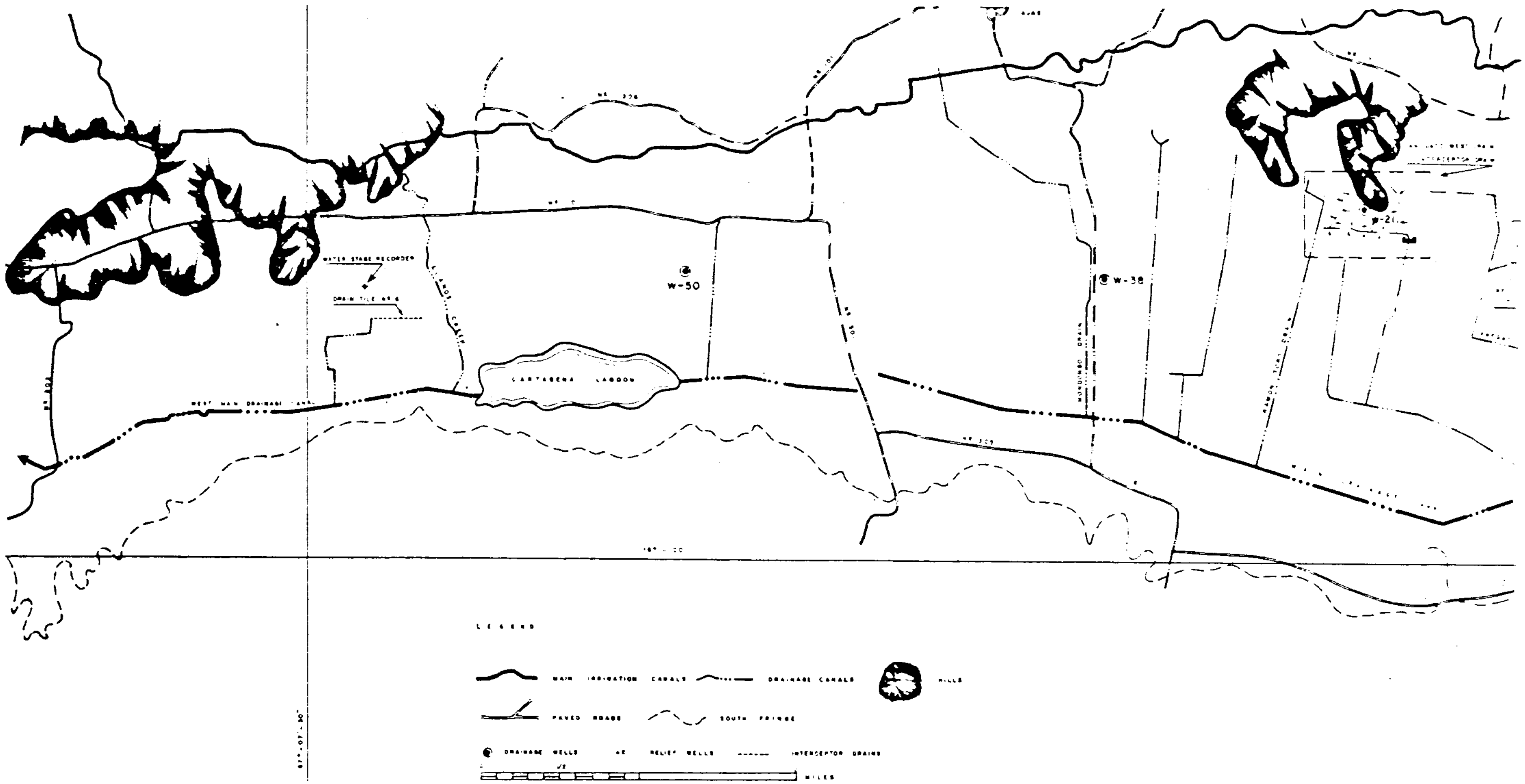
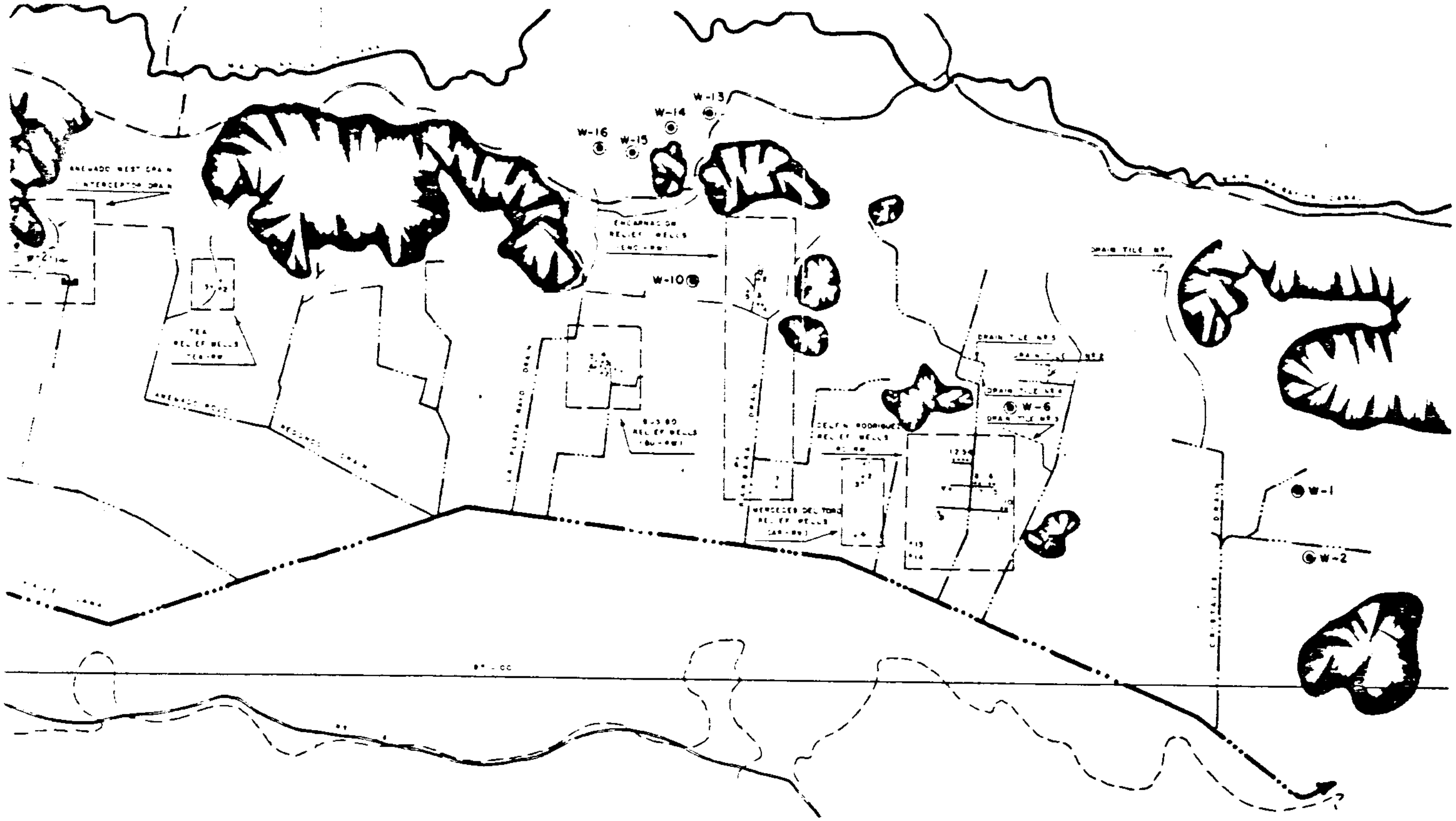
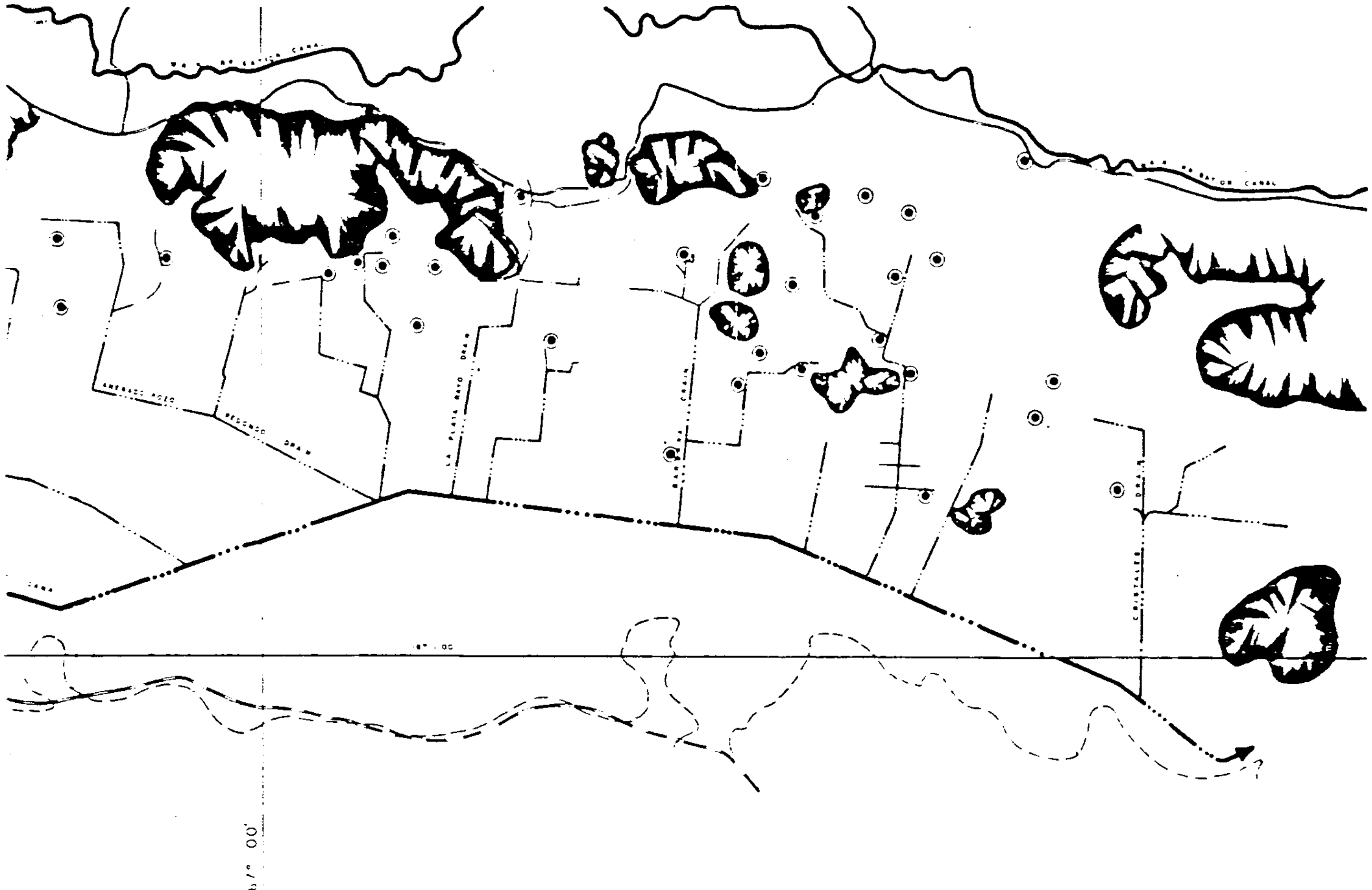



FIG. 3.—Water-table stage recorder and distribution of drainage flowing (pressure-relief) wells, and interceptor drains Valley, P.R.




n of drainage and free-
-ceptor drains in Lajas



ey. P.R.

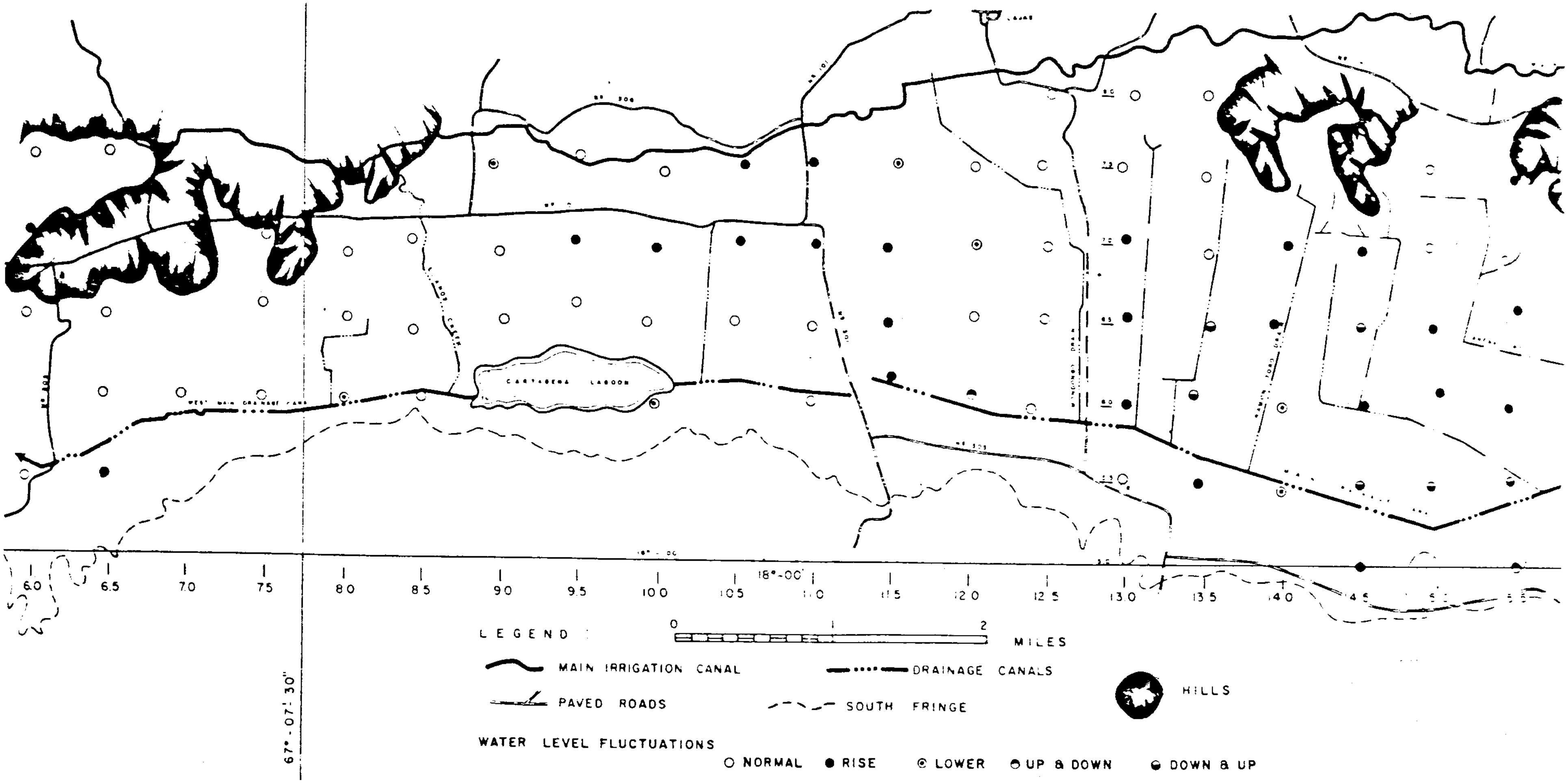
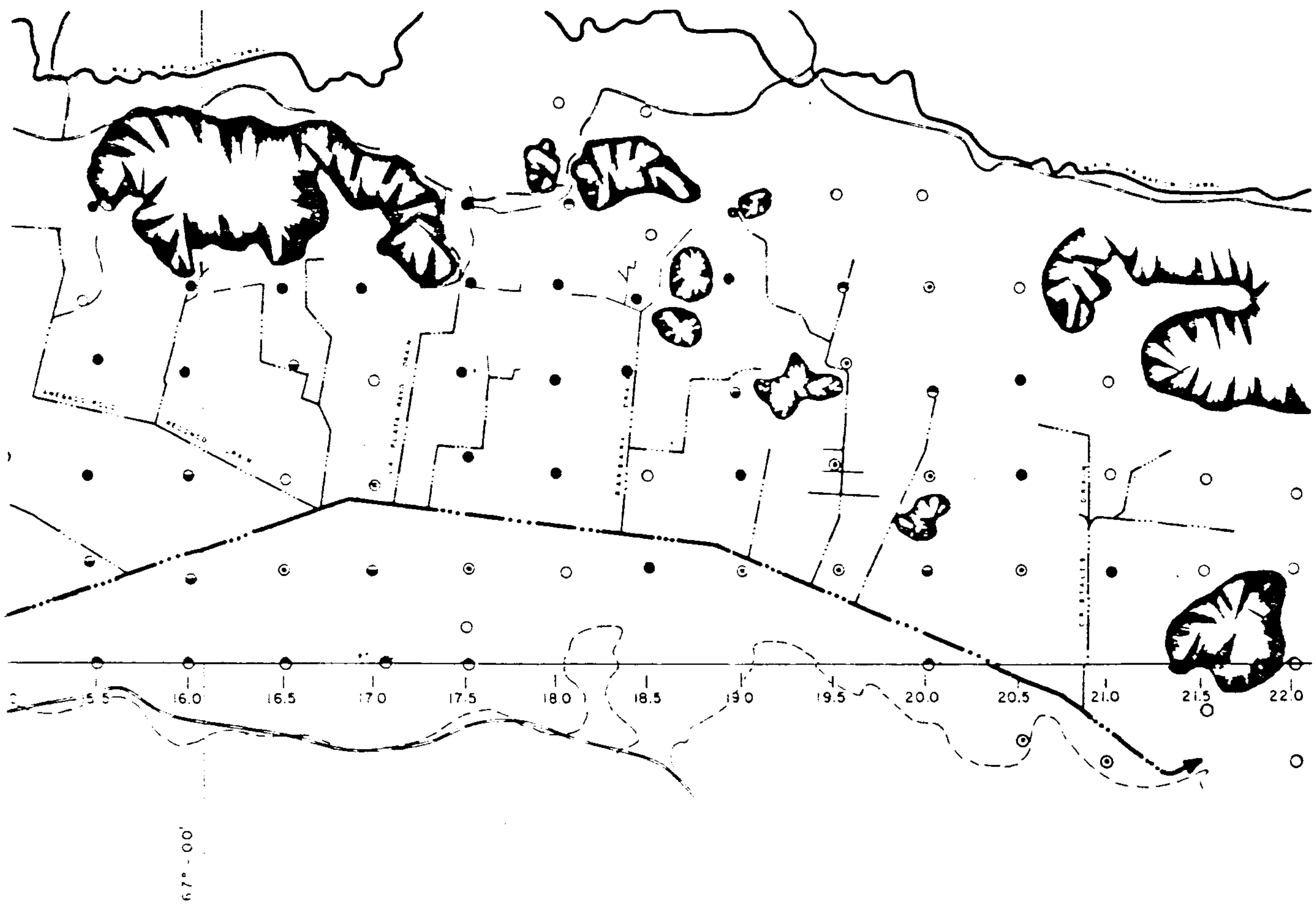



FIG. 5.—Water-level fluctuations as shown by hydrographs of network of piezometers in Lajas Valley, P.R., 1955-65.




network of

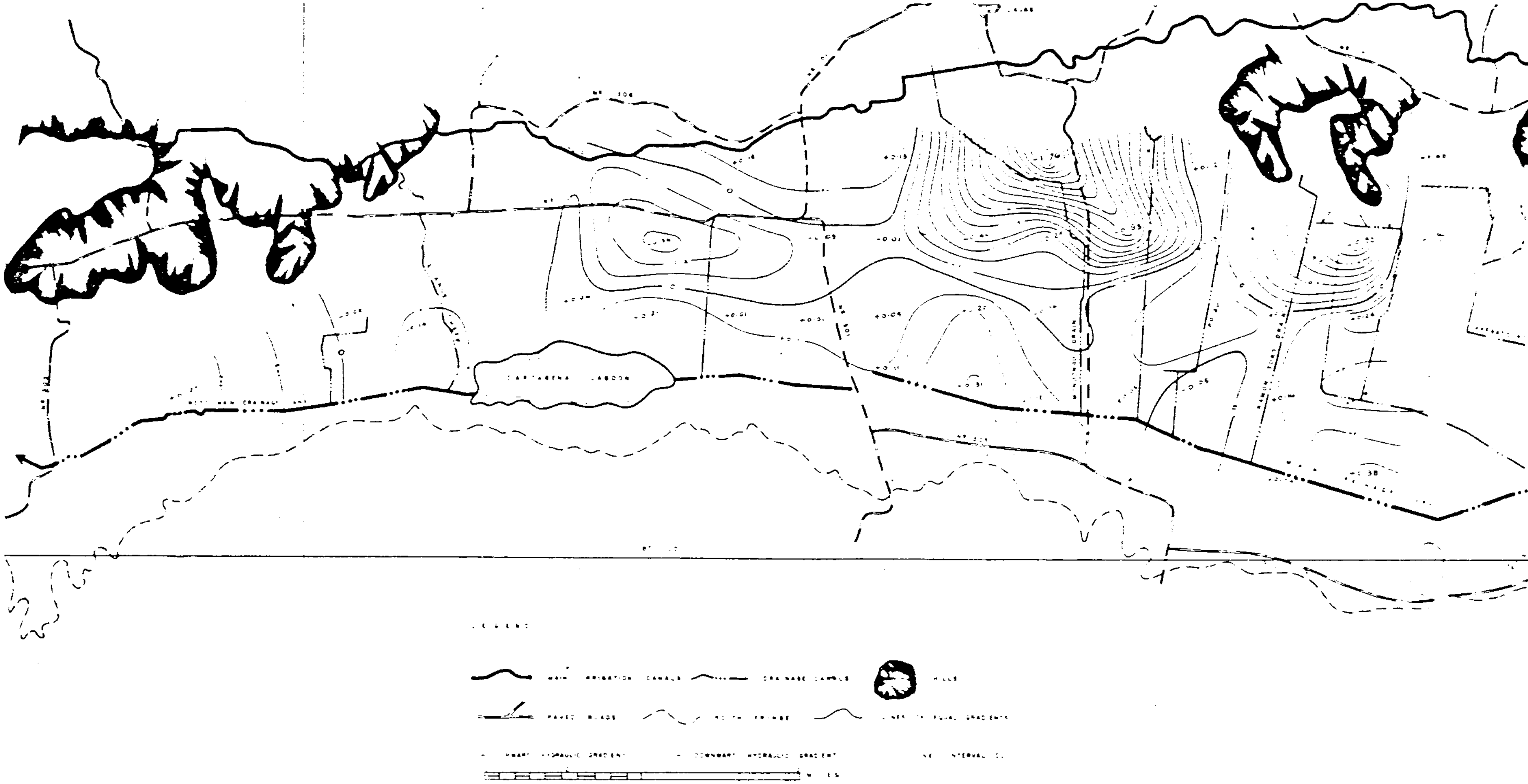
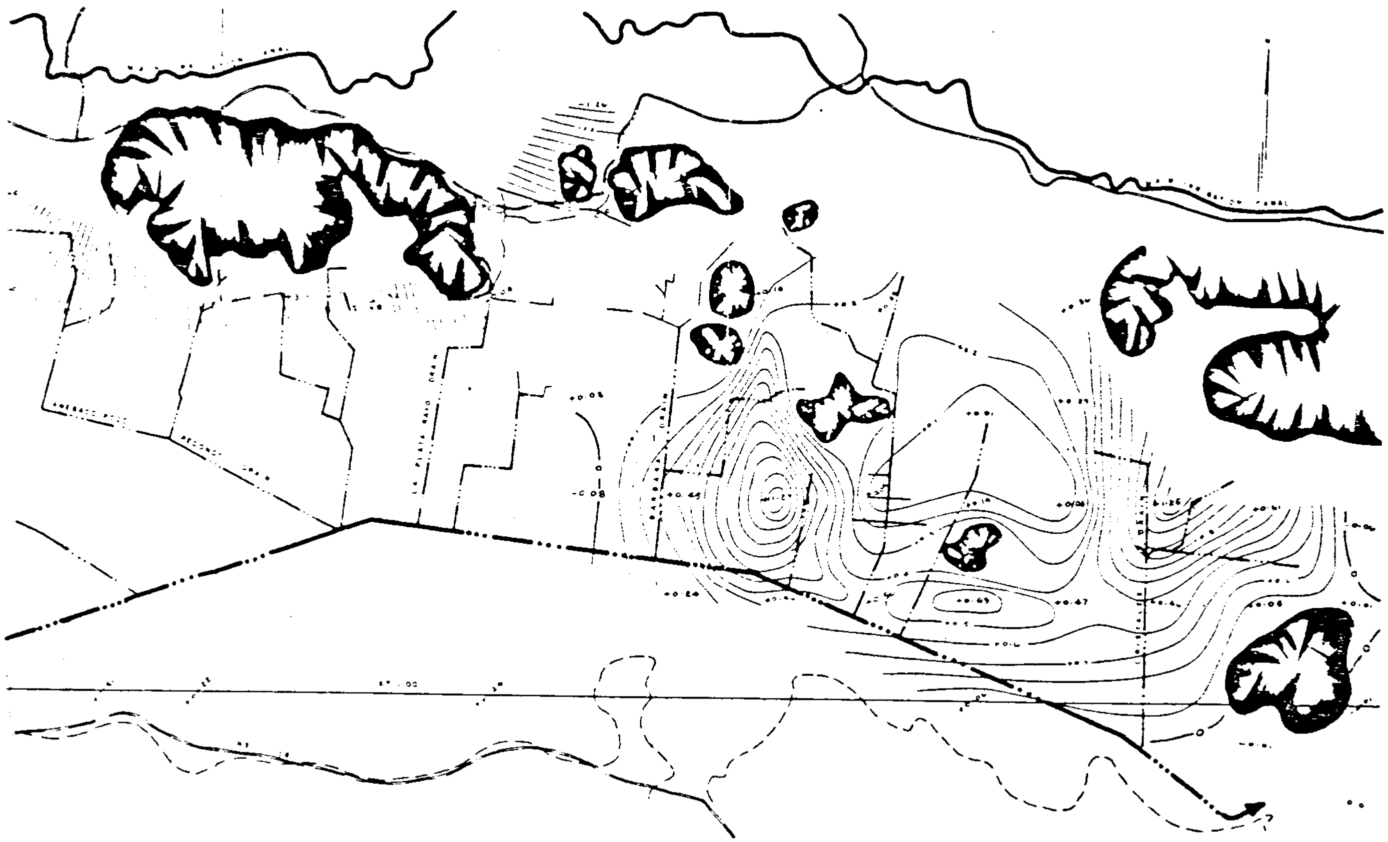


FIG. 6.—Vertical hydraulic gradients in Lajas Valley P.R. Mar



?.R., March 1958.

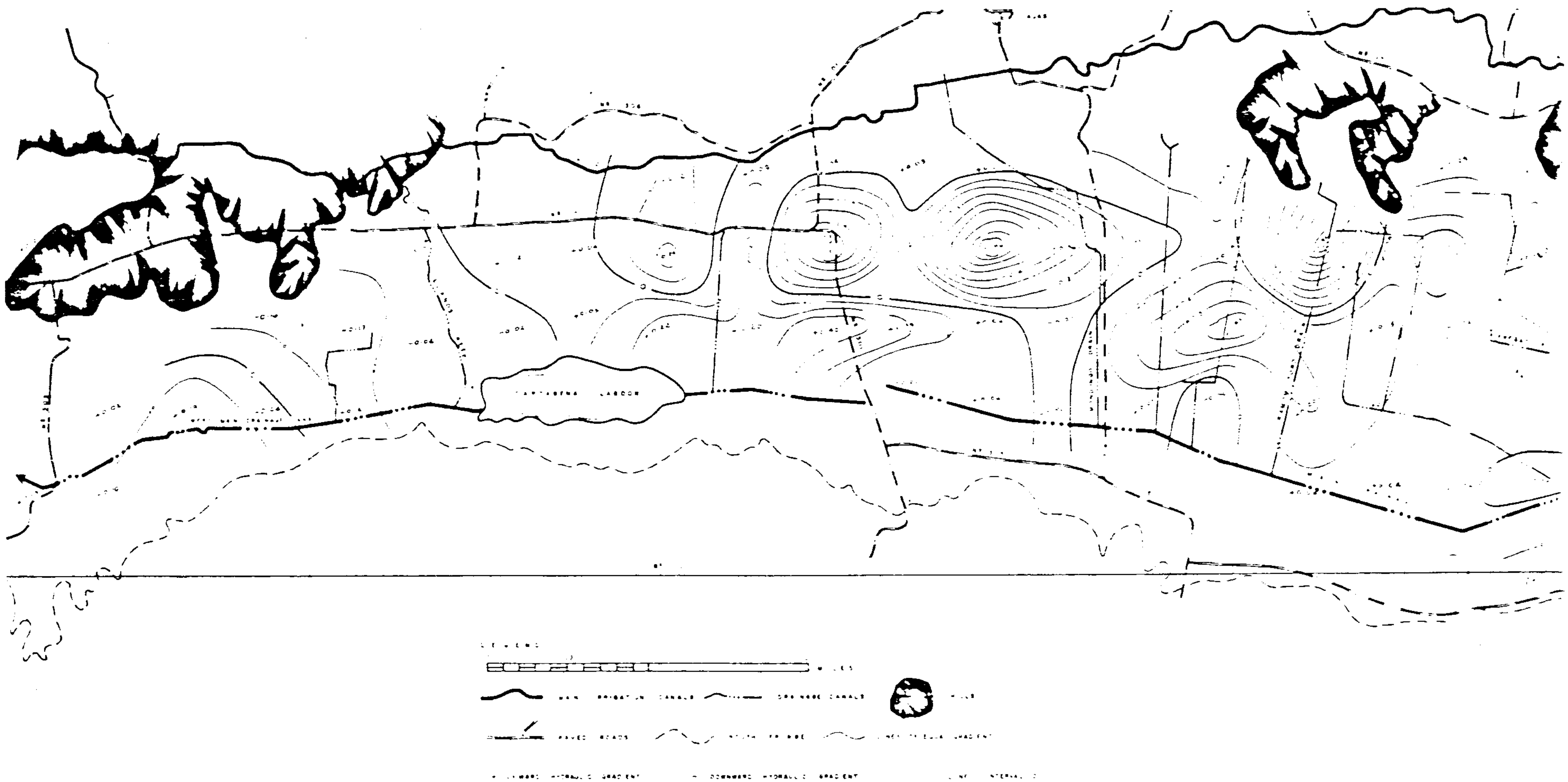
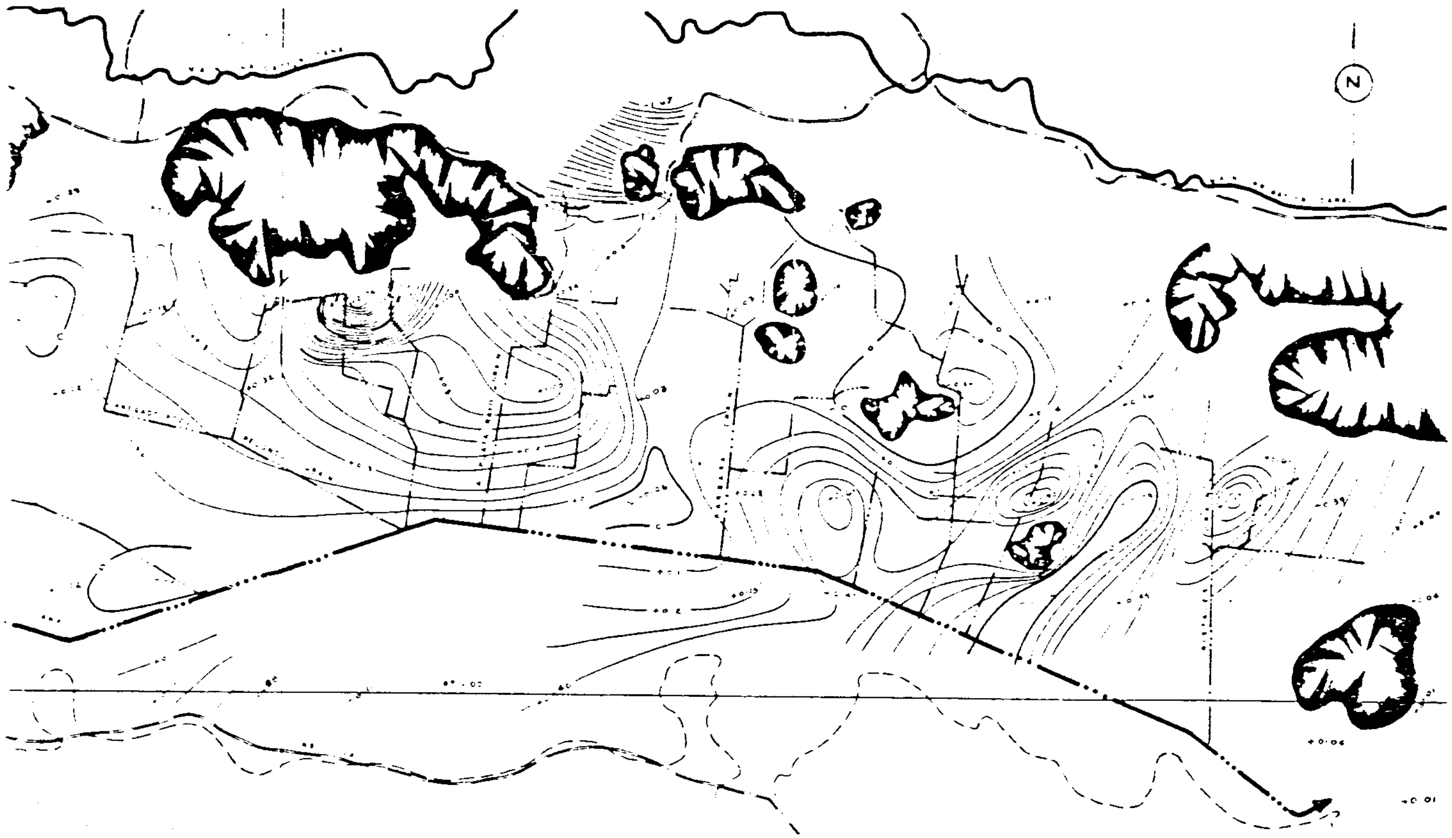


Fig. 7.—Vertical hydraulic gradients in Lajas Valley, P.R., Mar.




ey. P.R.. March . 85.

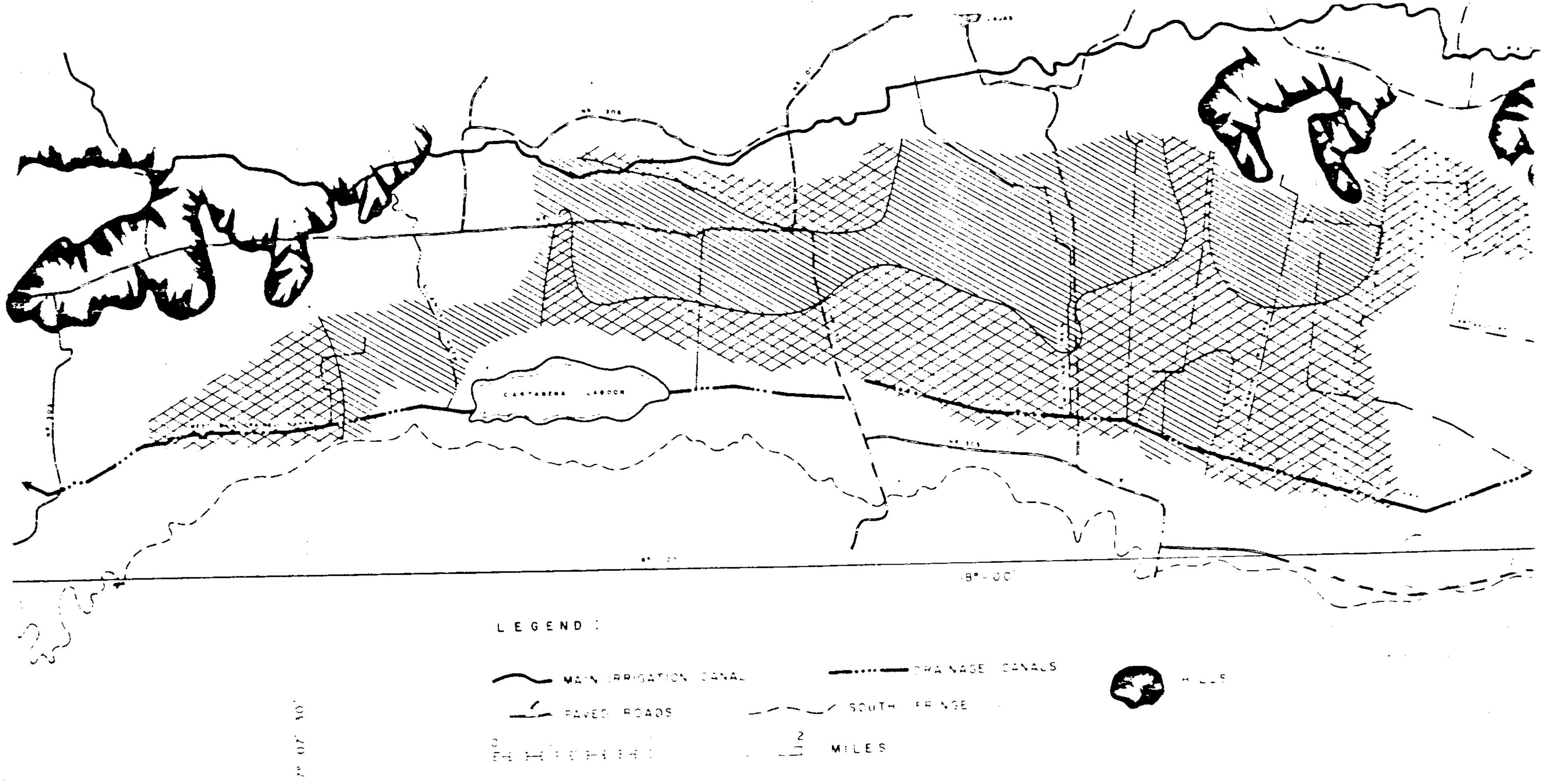
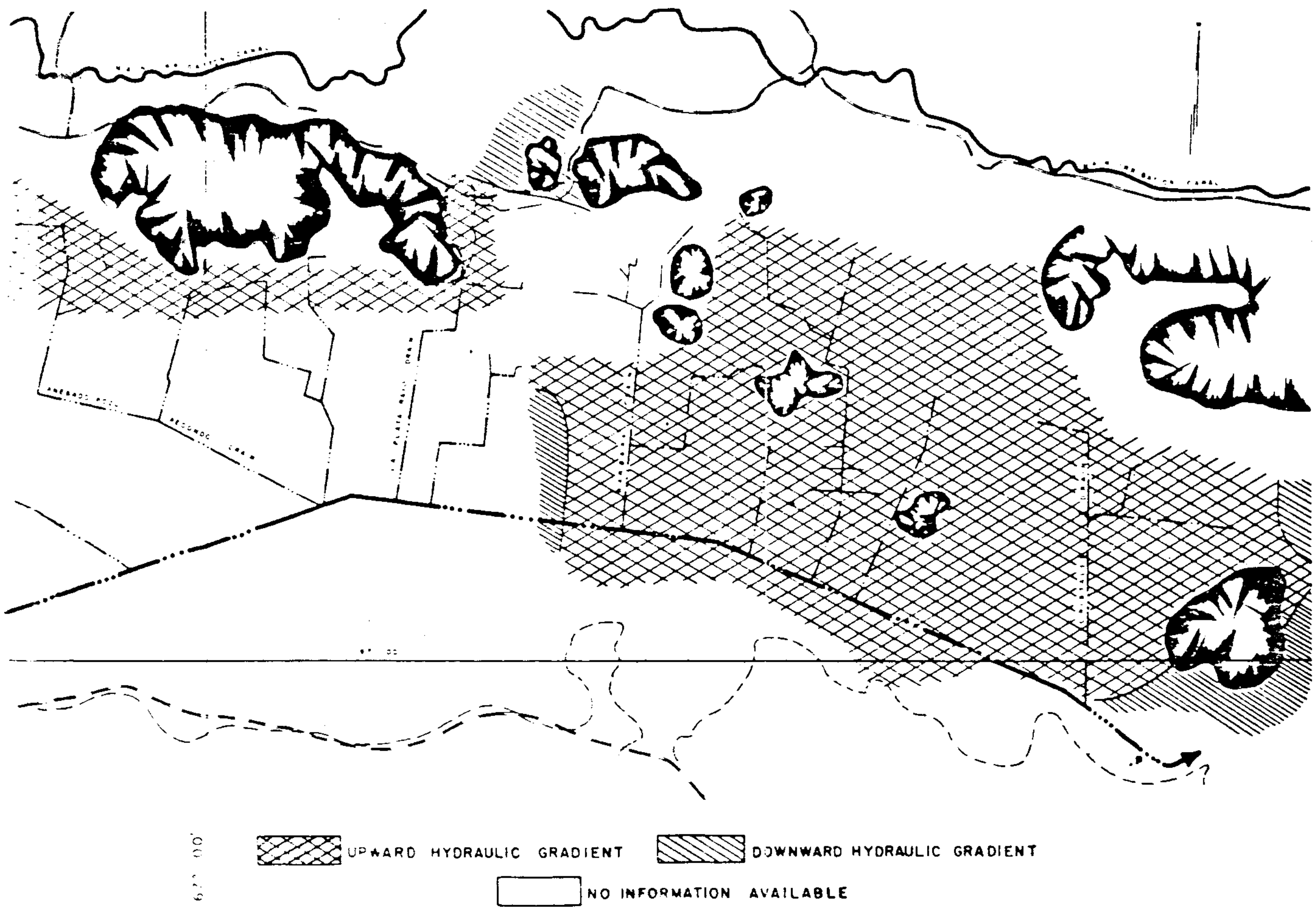



FIG. 8.—Areas affected with upward and downward hydraulic [illegible] in Lajas Valley, P.R., March 1958.




.raulic gradients

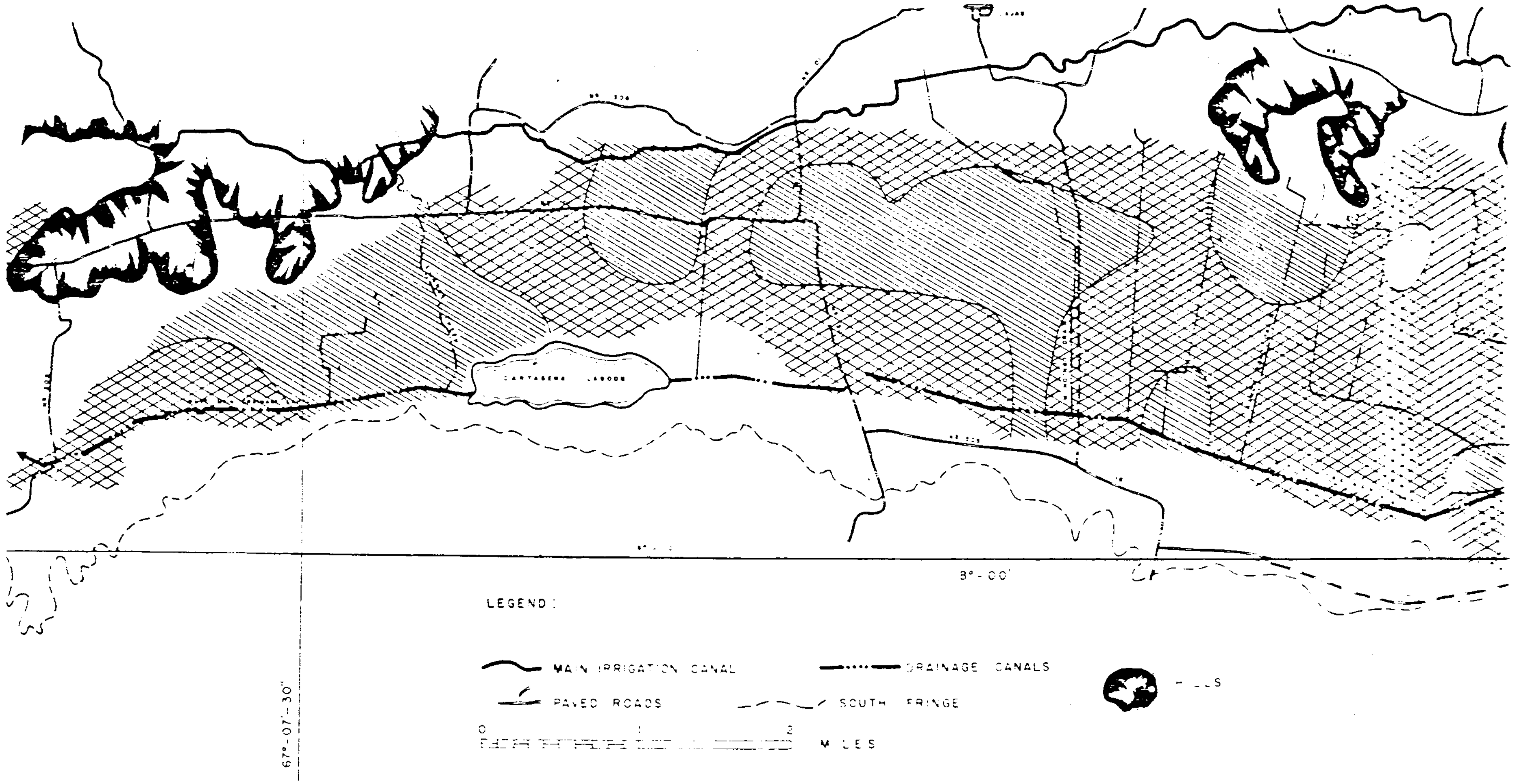
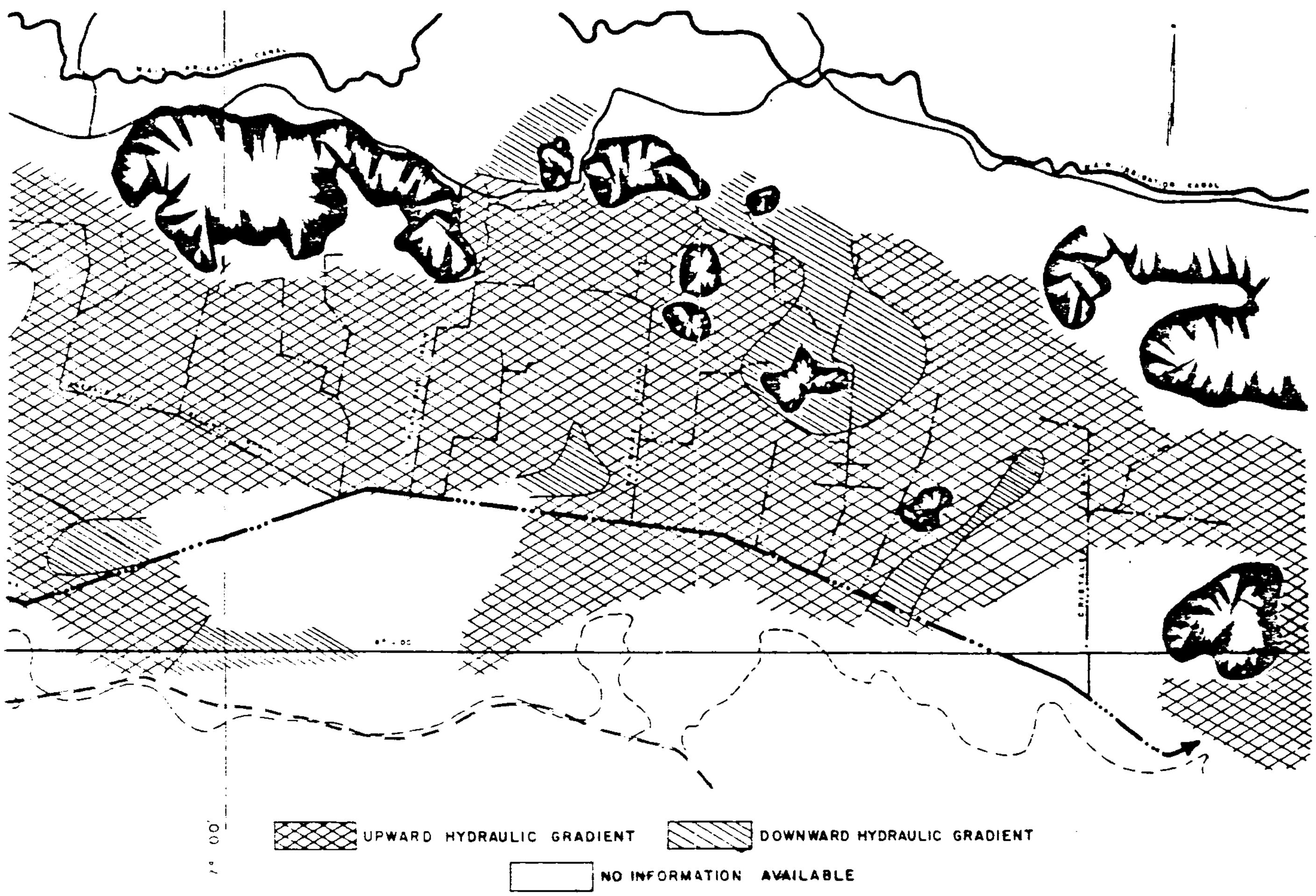



FIG. 9.—Areas affected with upward and downward hydraulic in Lajas Valley, P.R., March 1965.




hydraulic gradients

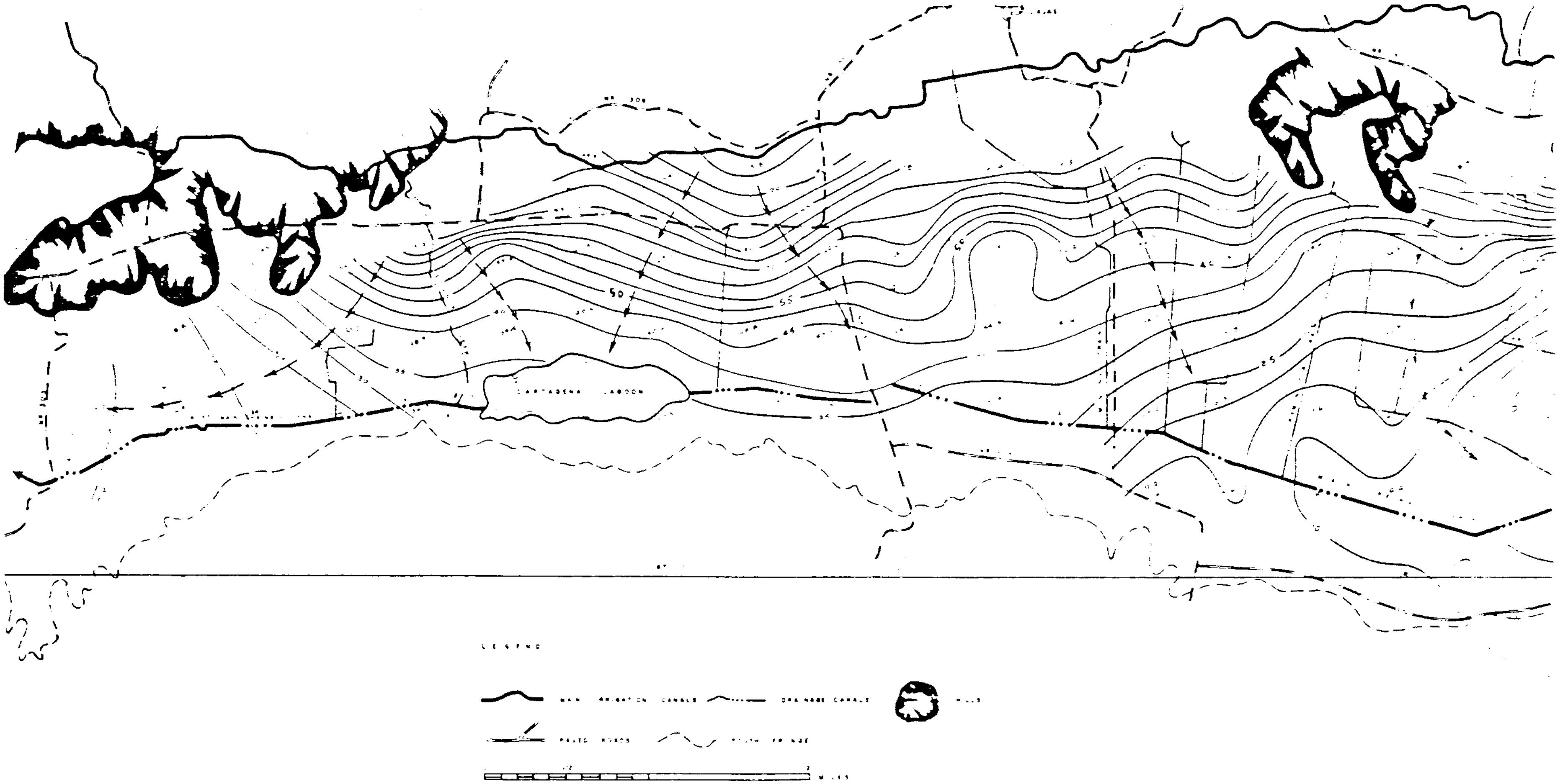
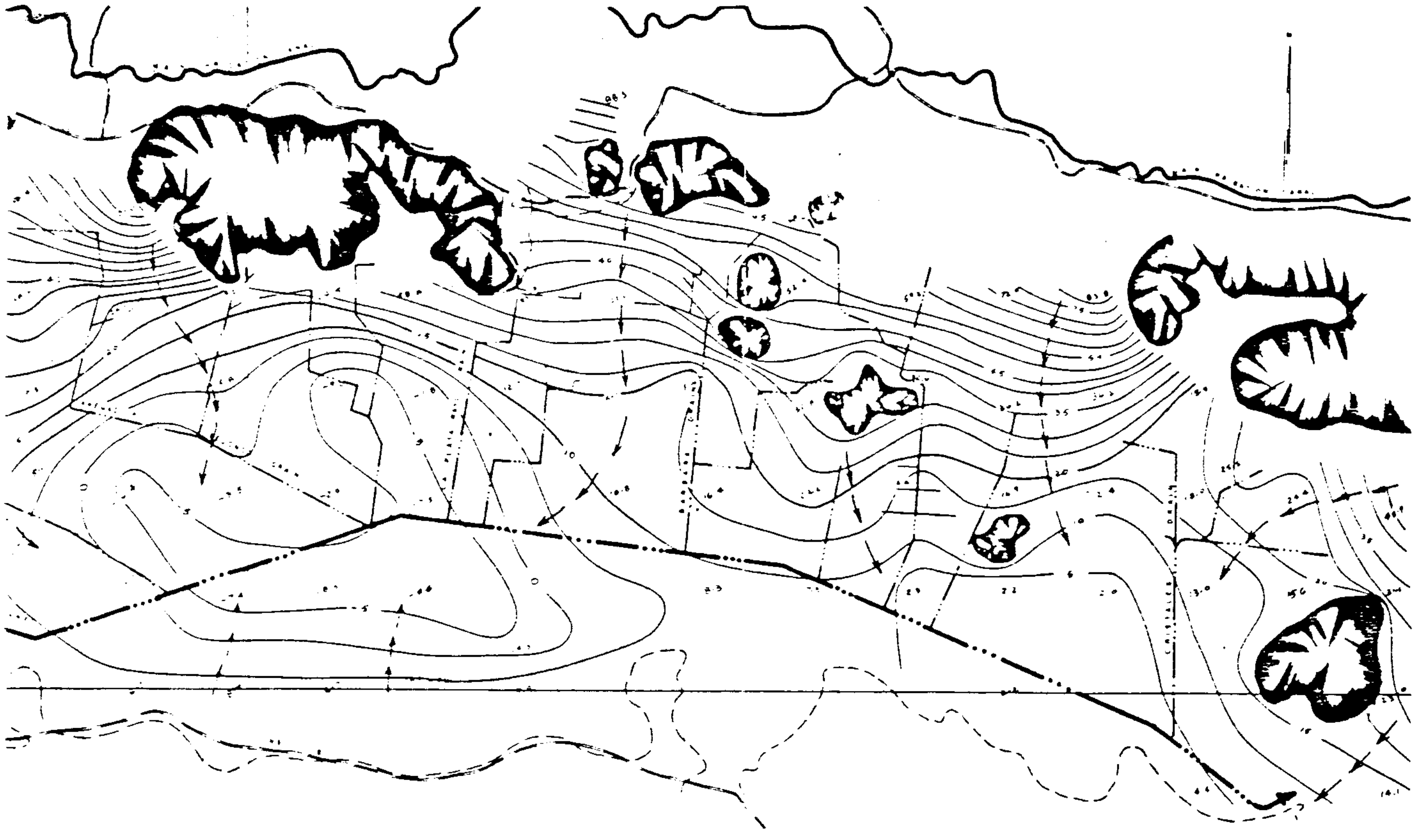



FIG. 10.—Water-level contours as shown by [illegible]
Valley, P.R., November 1965.



: piezometer in Lajas

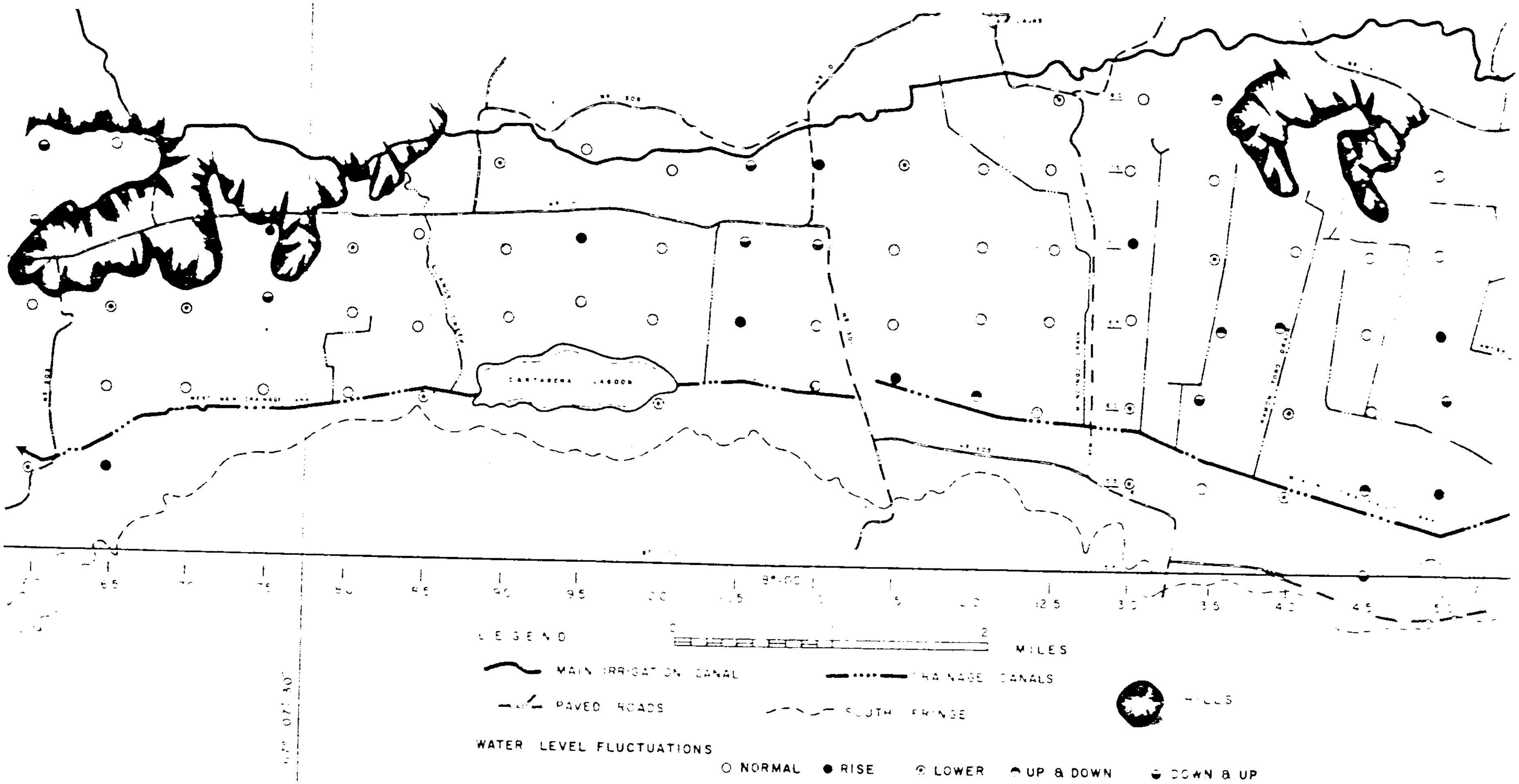
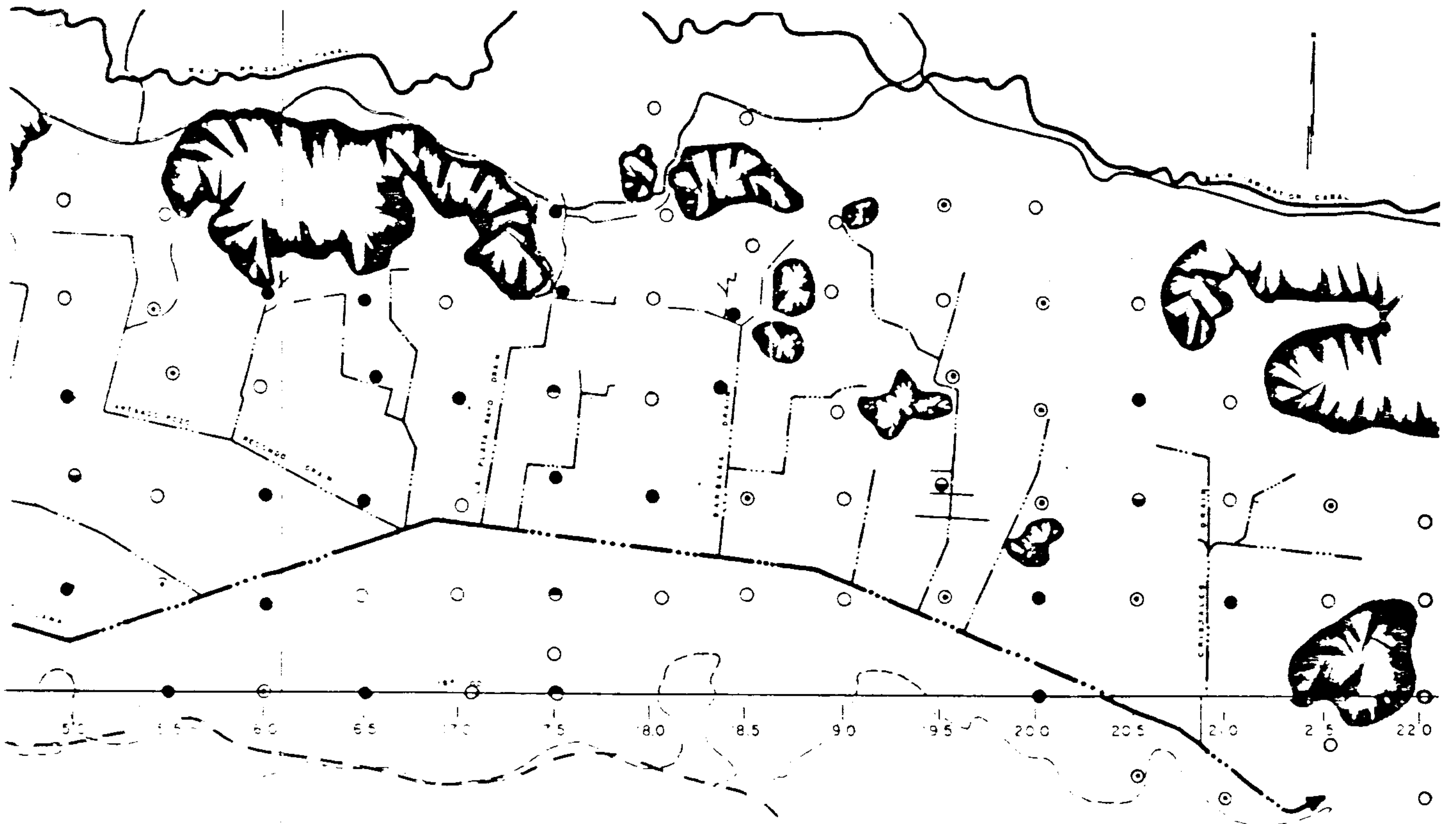



FIG. 11.—Water-level fluctuations as shown by hydrographs of [illegible] water-table observation wells in Lajas Valley, P.R. [illegible]




...ographs of network of
...lley, P.R., 1955-65.

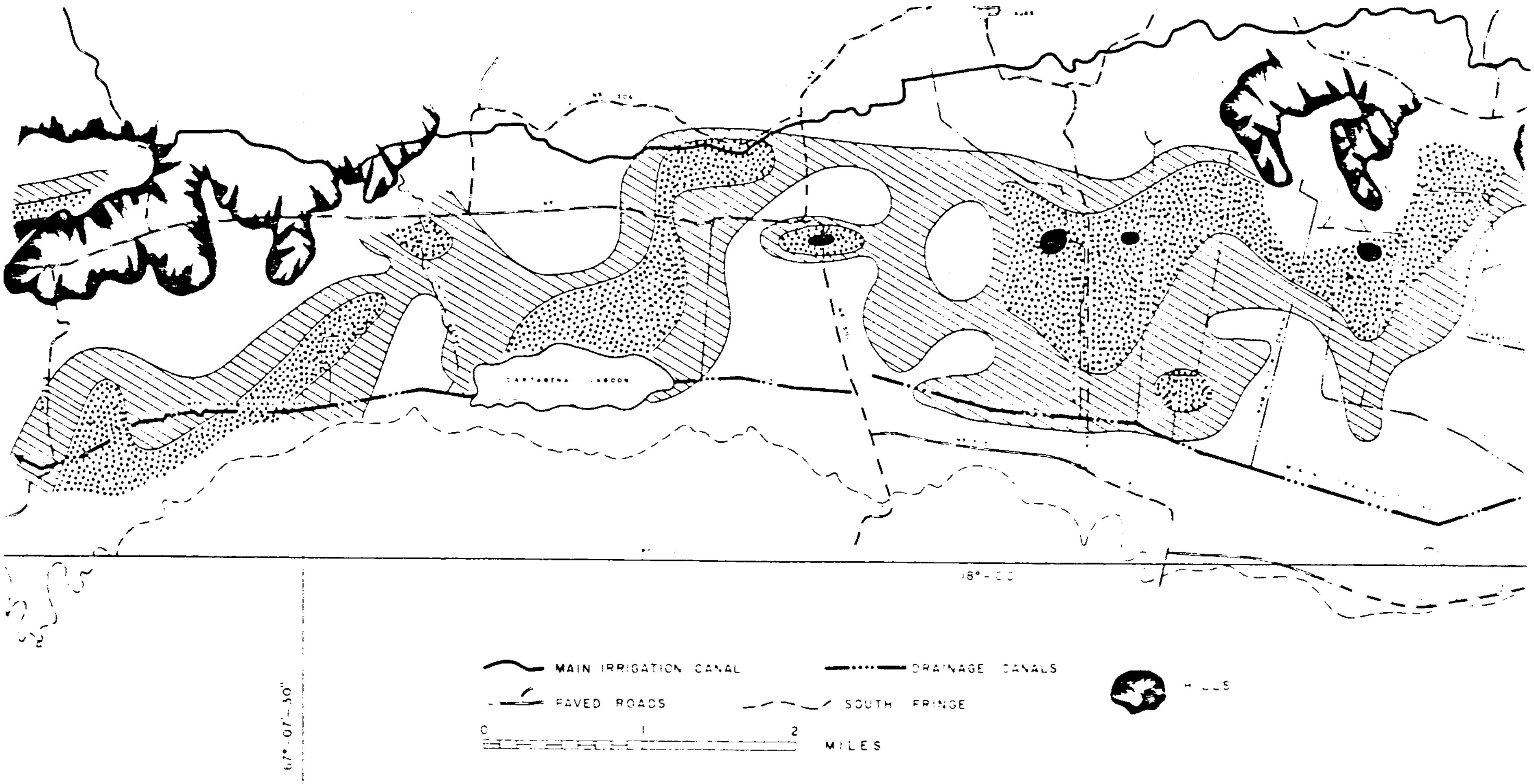
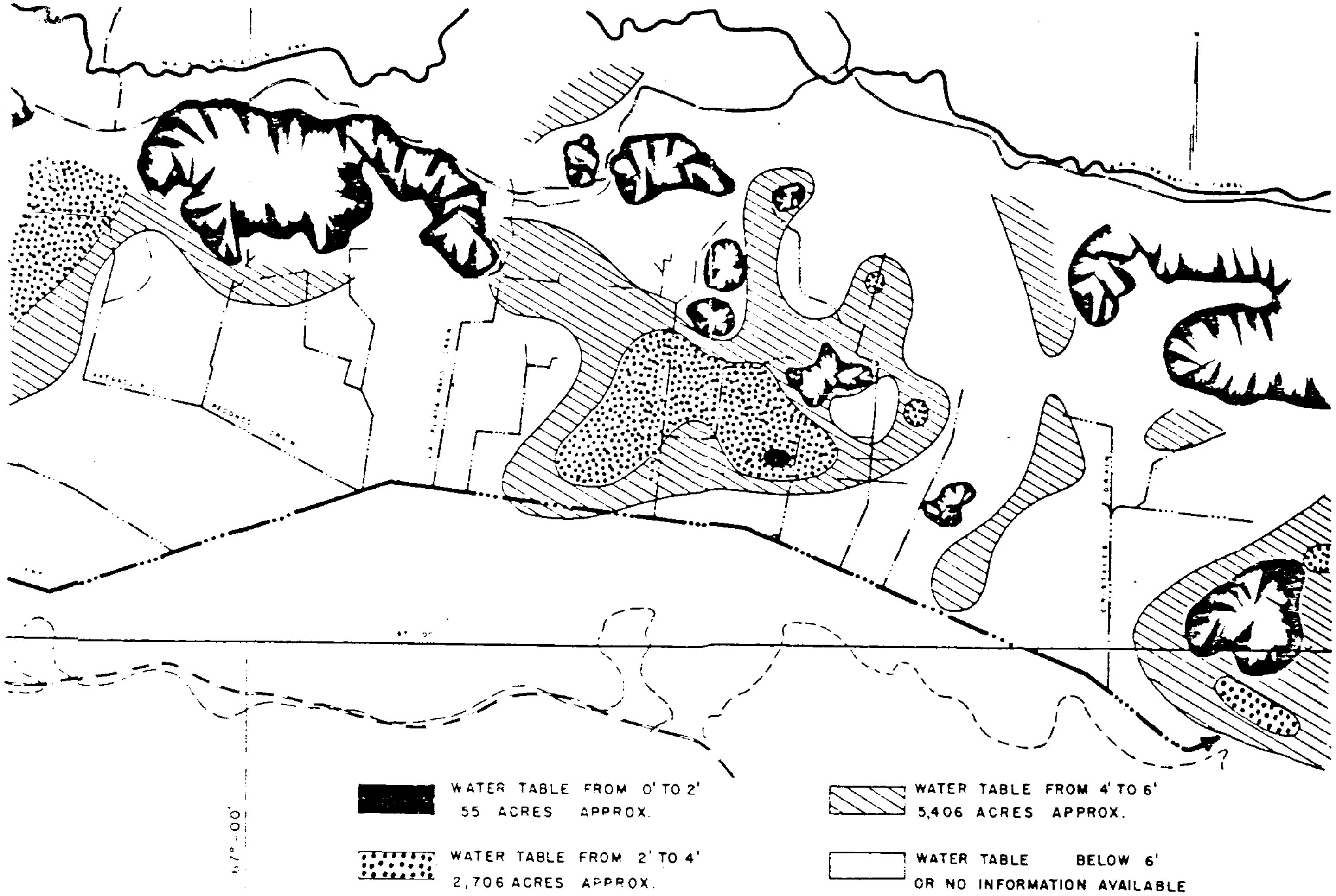



FIG. 12.—Areas with water-table depth from 0 to 6 feet in 2-ft increments. Lajas Valley, P.R., March 1965.




6 feet, in 2-foot incre-

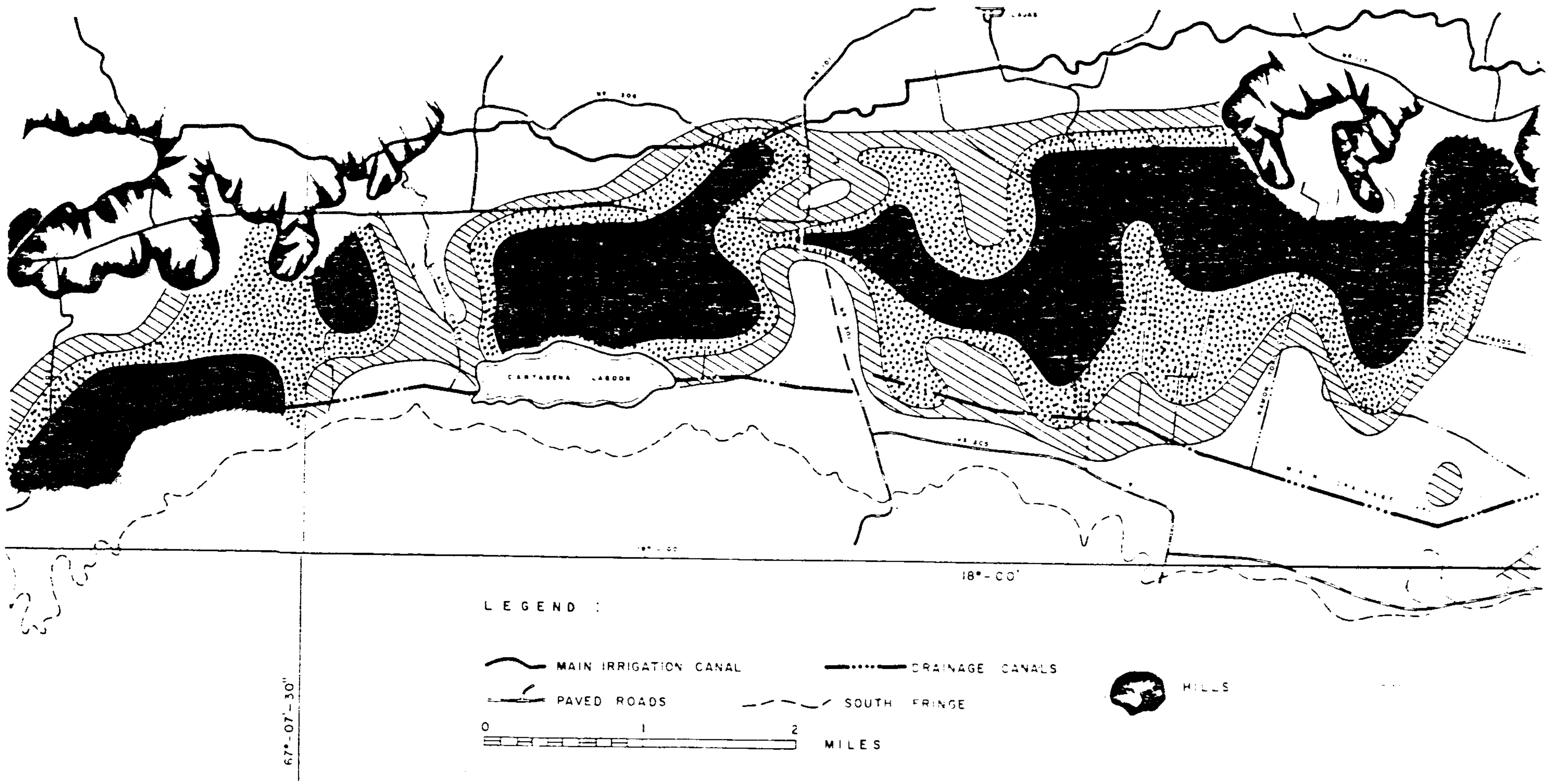
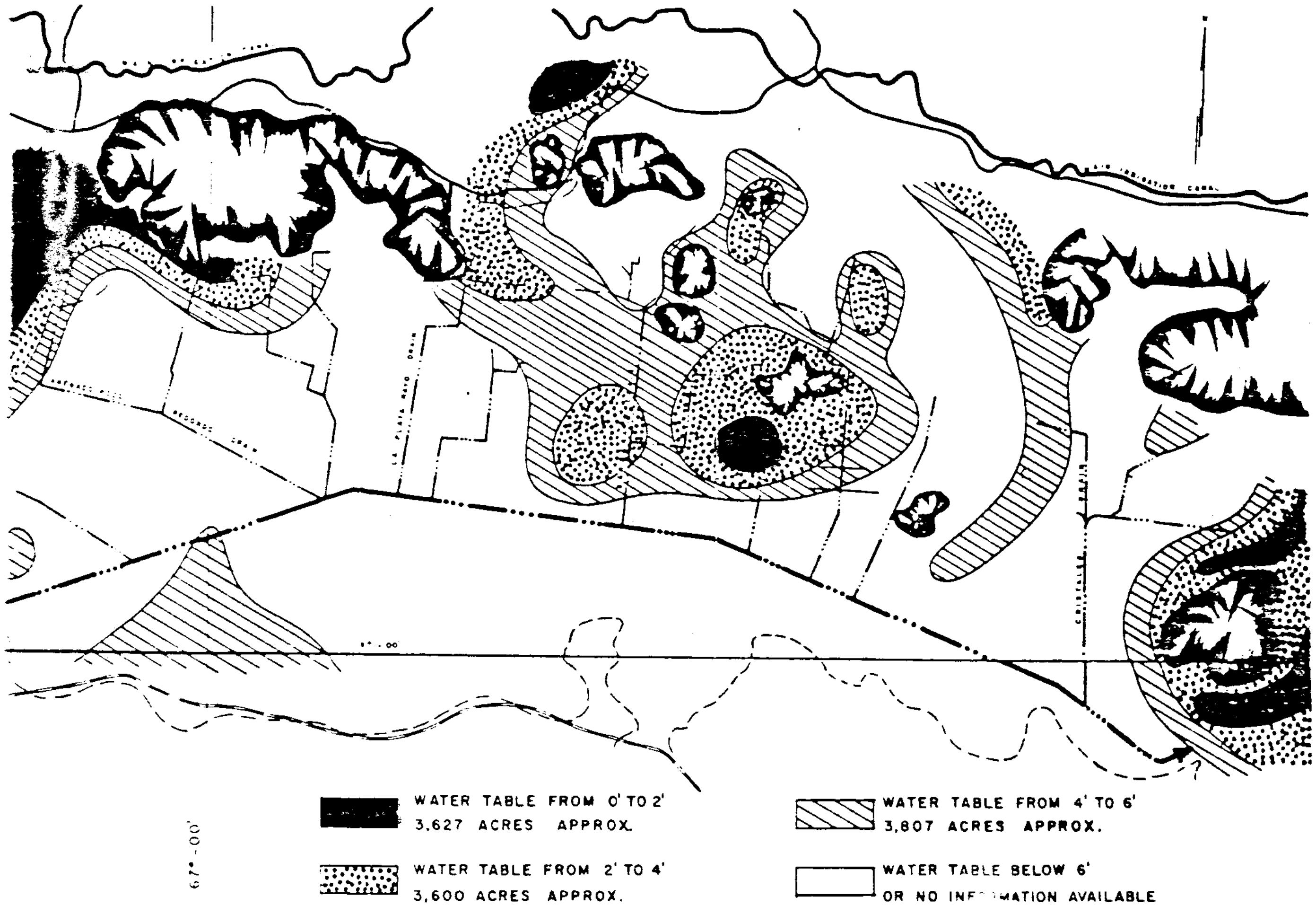



FIG. 13.—Areas with water-table depth from 0 to 6 feet, in 2-foot ments, Lajas Valley, P.R., November 1965.




t in 2-foot incre-

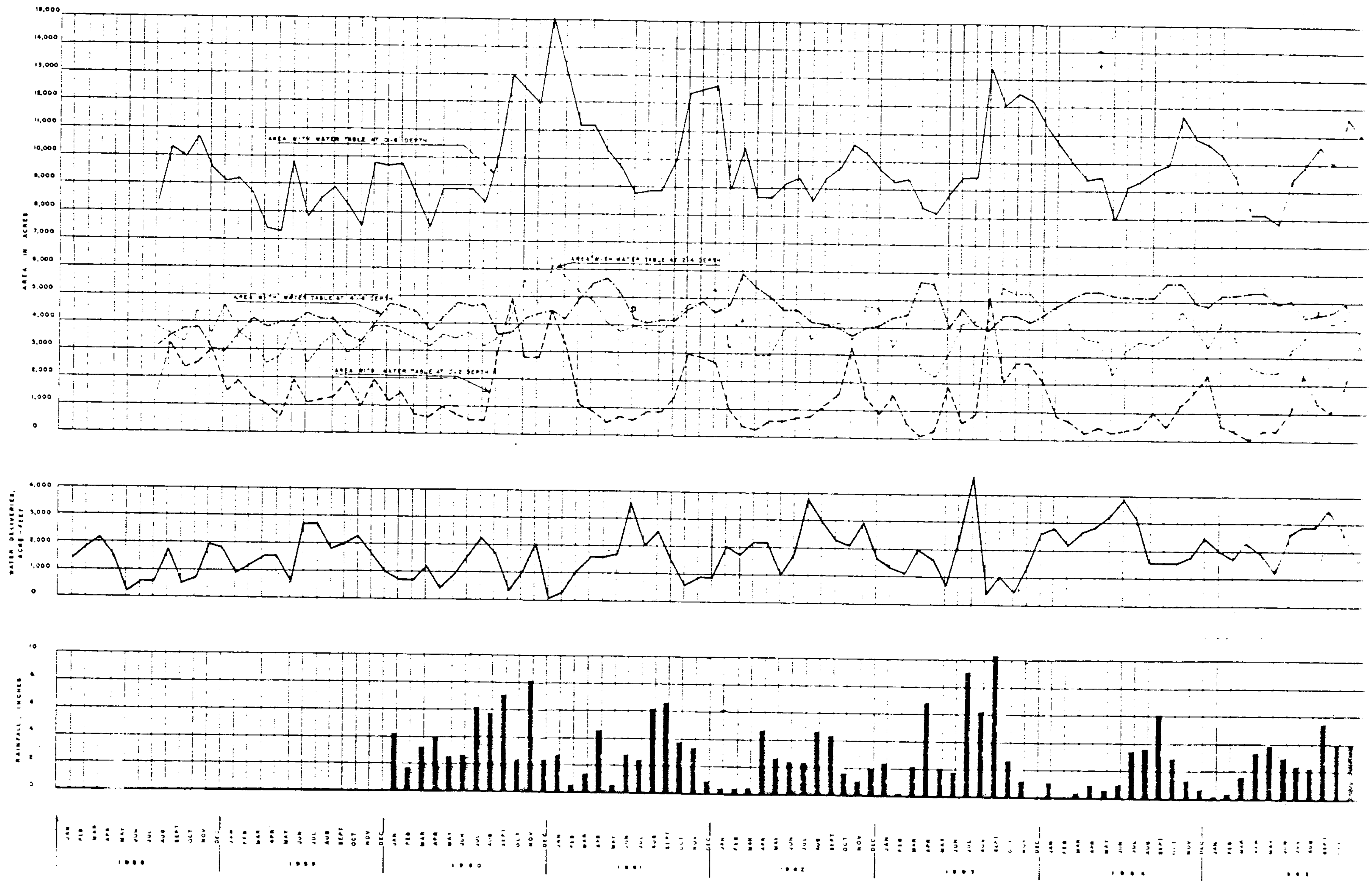



FIG. 14.—Monthly rainfall, water deliveries, and land areas with water-table depth from 0 to 6 feet in 2-foot increments, Lajas Valley, P.R., 1962-63.

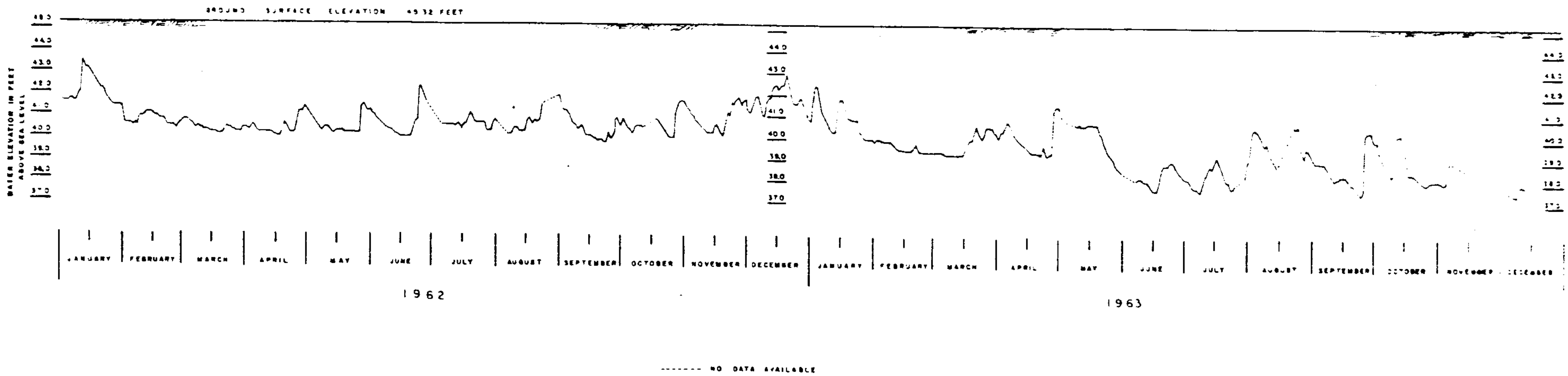



Fig. 15.—Water-table fluctuations as shown by water-table stage-recorder in Lajas Valley, P.R., 1962-63.

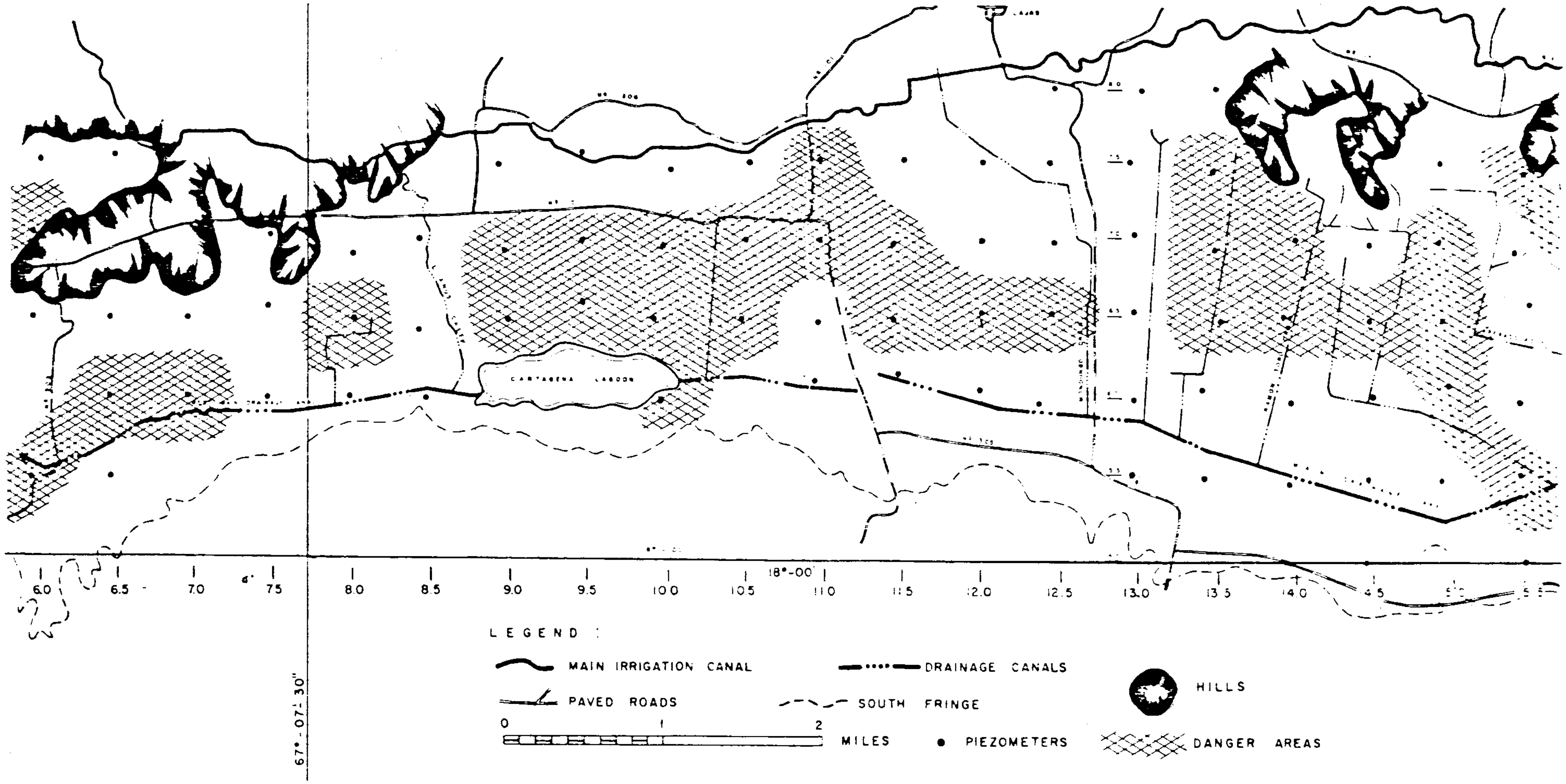
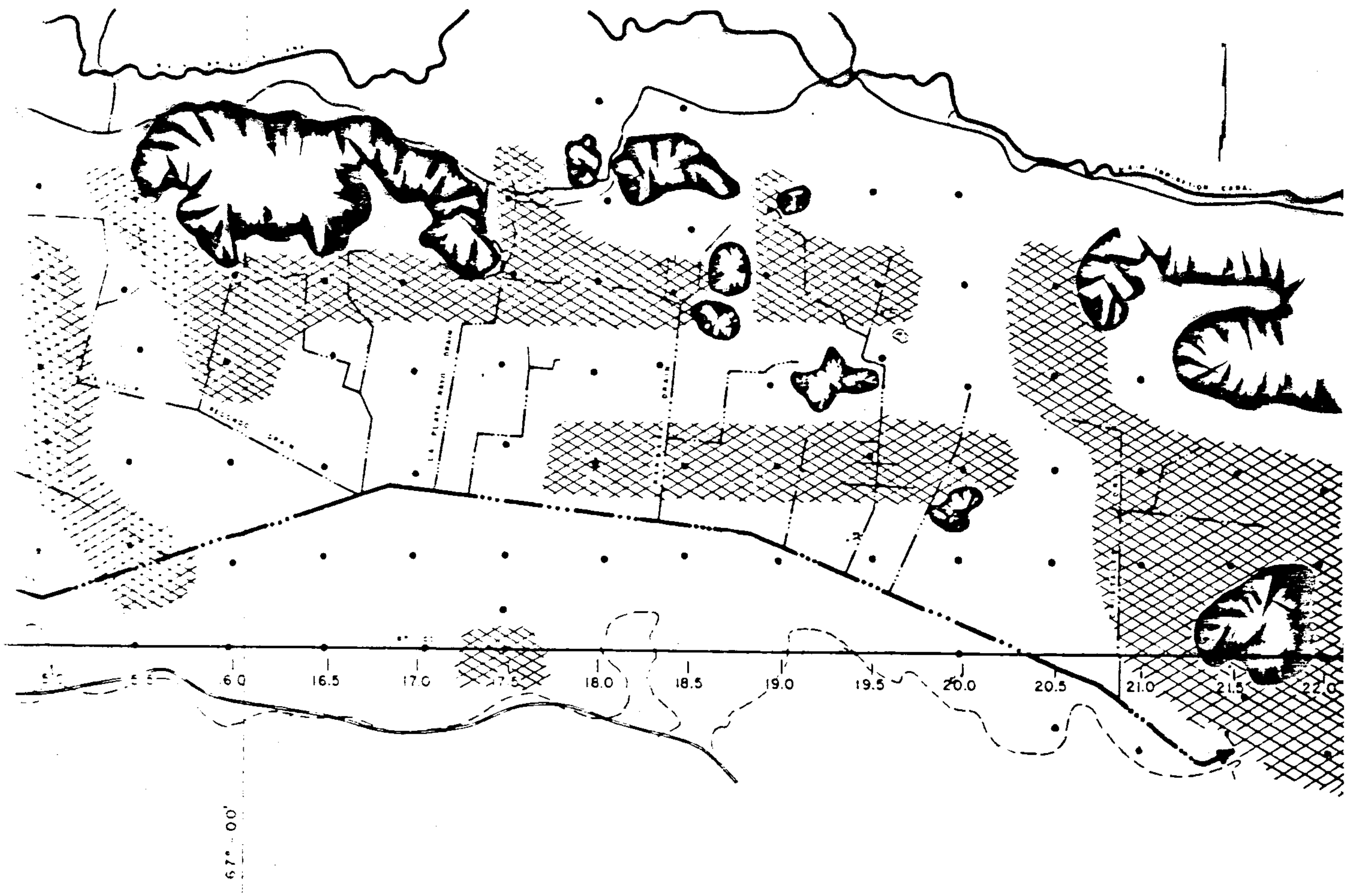



FIG. 16.—Potential danger areas in Lajas Valley, P.R.




Valley, P.R.

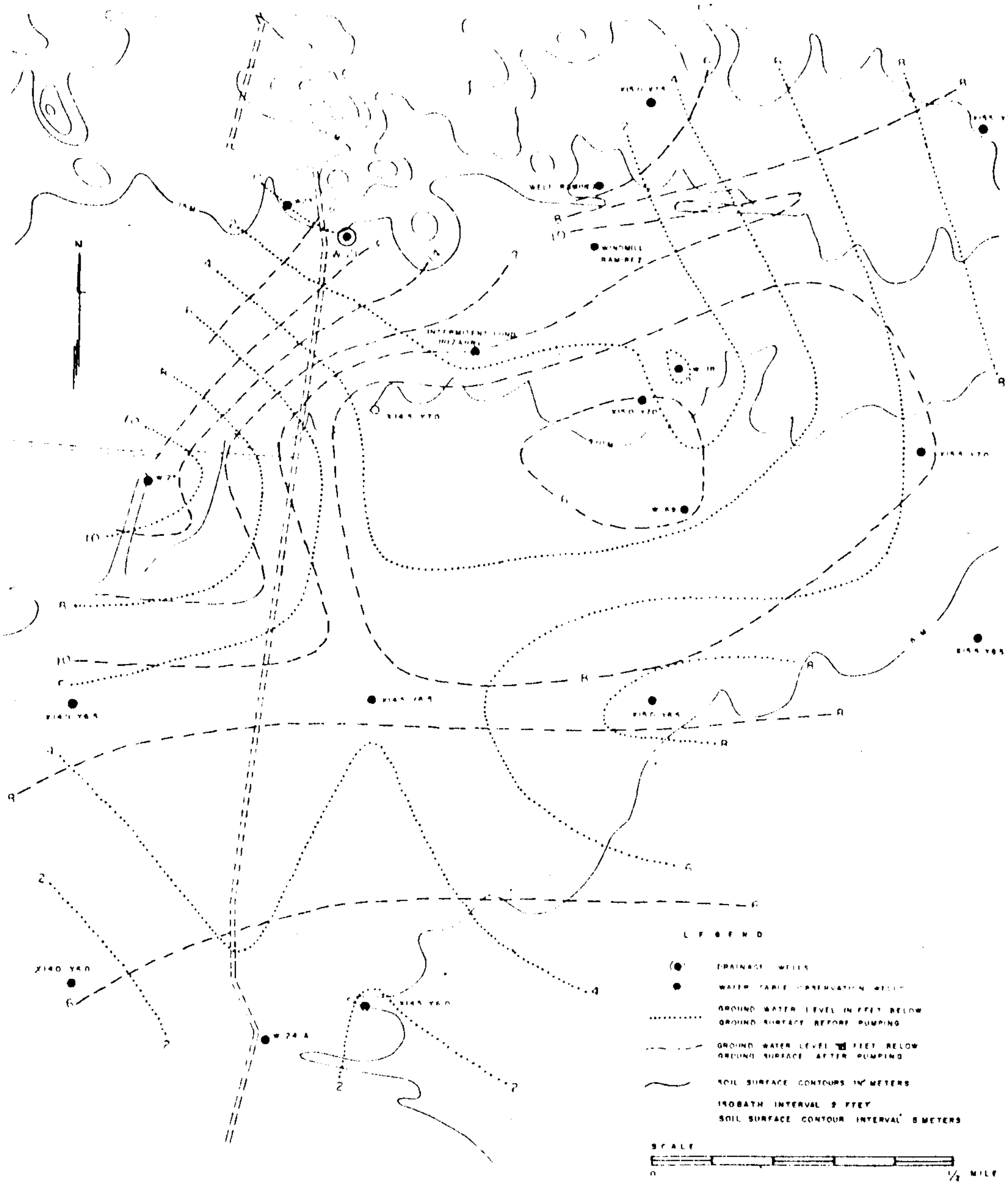



FIG. 17.—Drainage Well No. 21 with water-table observation wells, piezometer batteries, and water levels in surrounding area, before and after pumping test, January 1957 to May 1958.

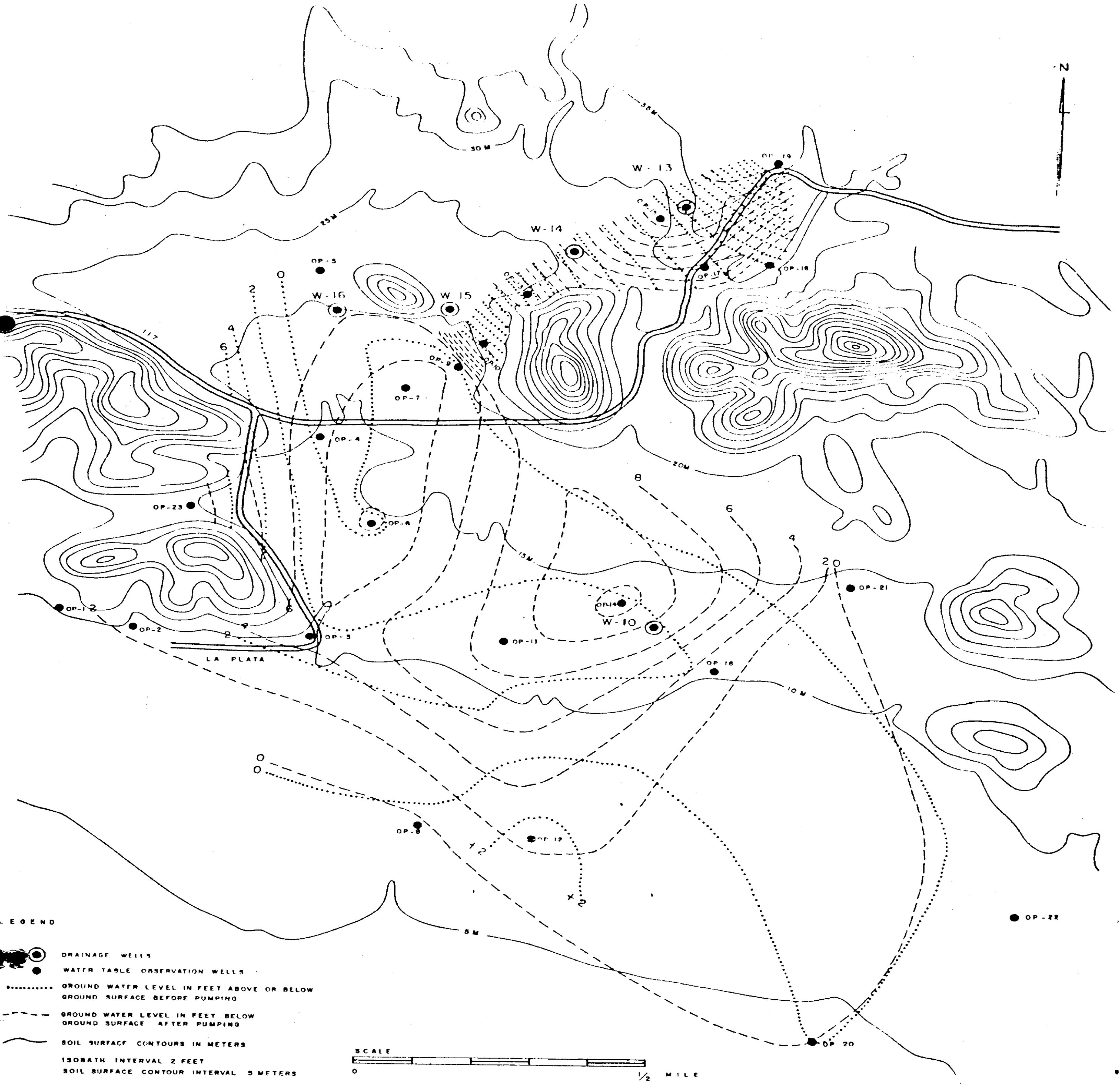



FIG. 18.—Delfín Rodríguez Carlo's drainage wells with water-table observation wells and water levels in surrounding area before and after pumping test, May to September, 1958.

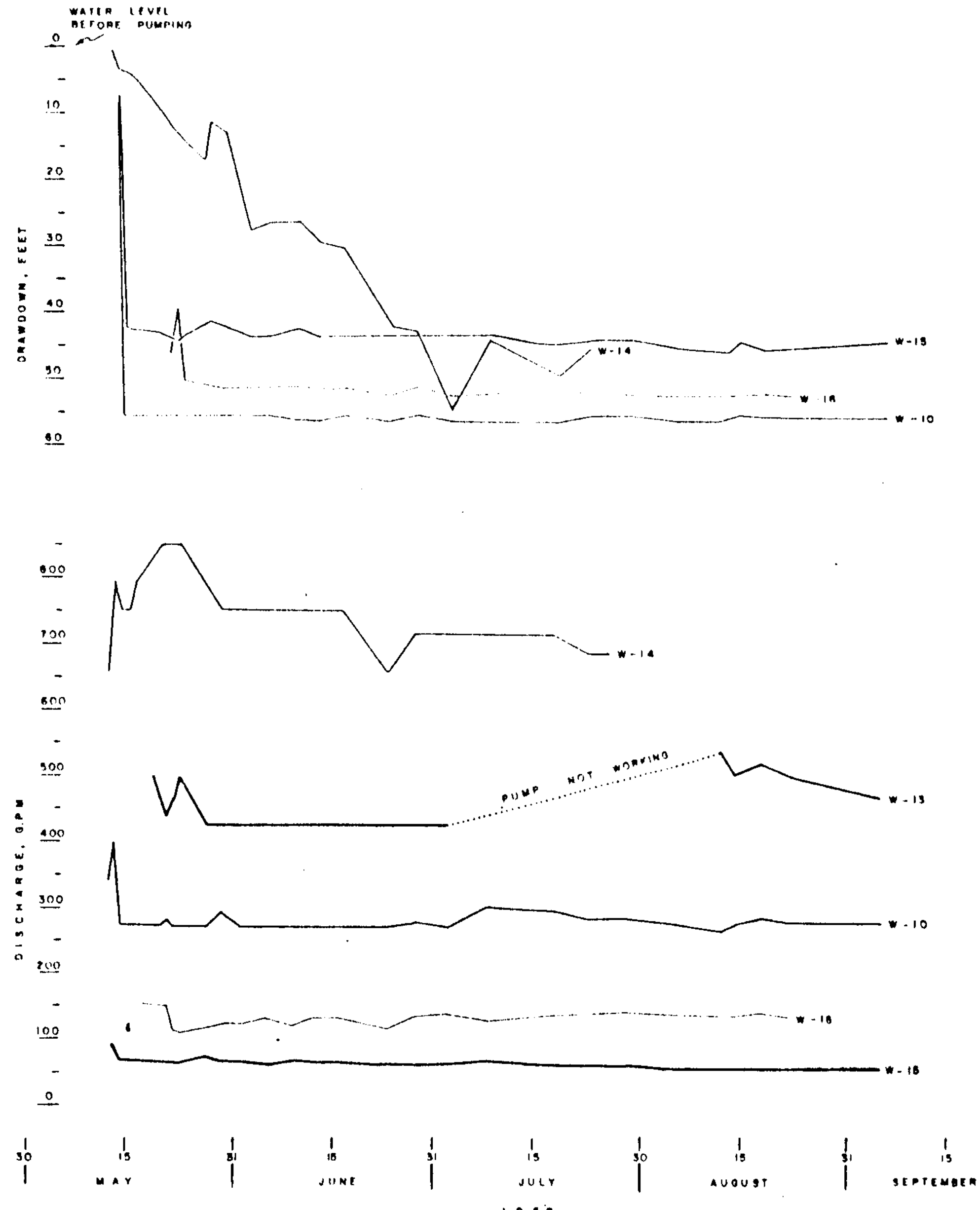



FIG. 19.—Water levels and discharge of Delfín Rodríguez Carlo's drainage wells during pumping test, May to September, 1958.

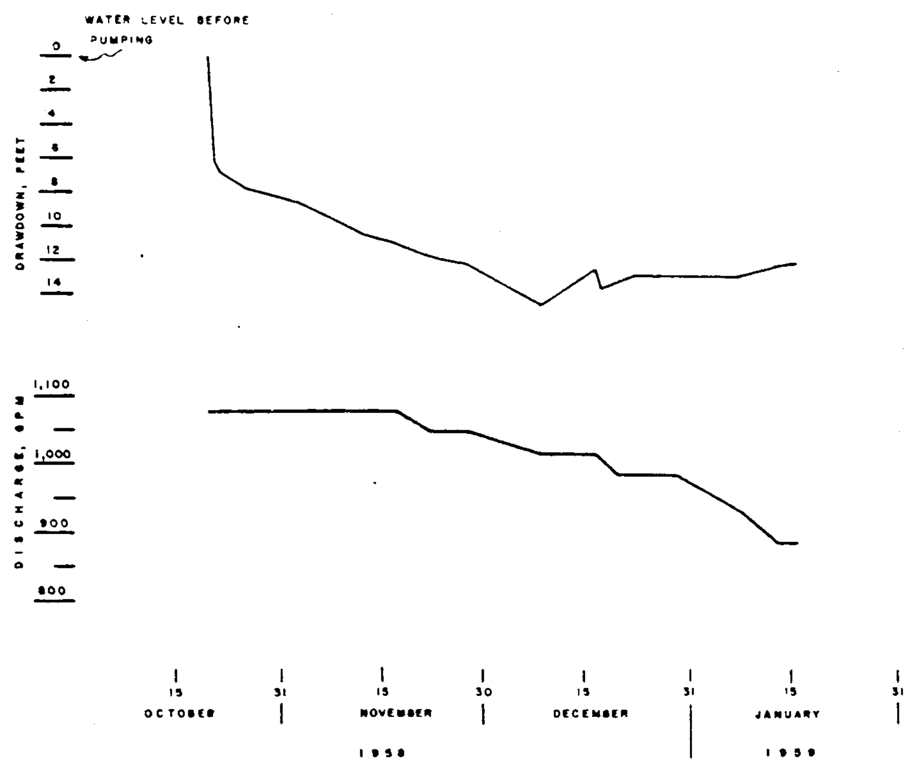



FIG. 20.—Water-levels and discharge of Drainage Well No. 50 during pumping test, October 1958 to January 1959.

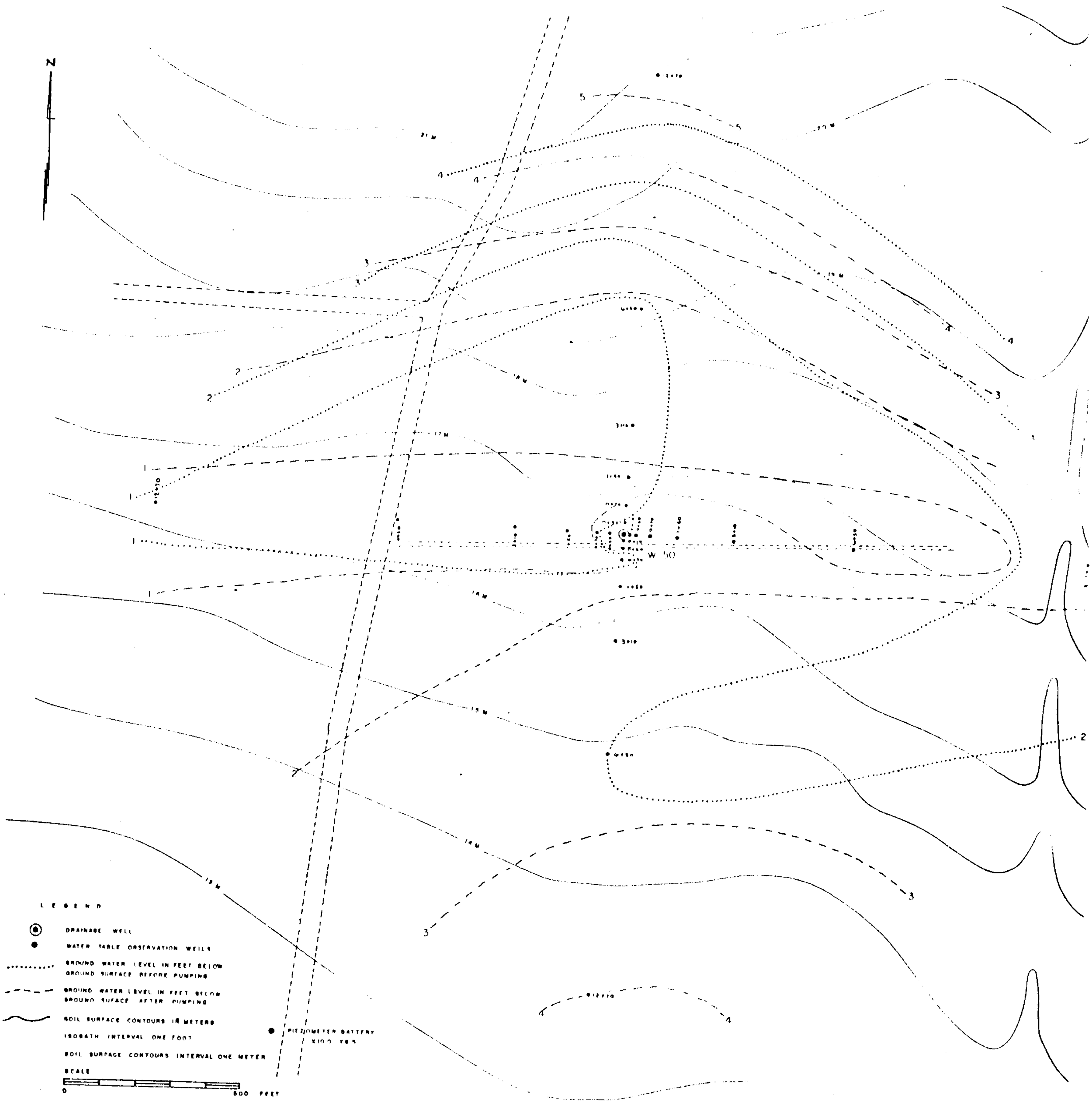



FIG. 21.—Drainage Well No. 50 with water table observation wells, piezometer battery, and water levels in surrounding area, before and after pumping test, October 1958 to January 1959.

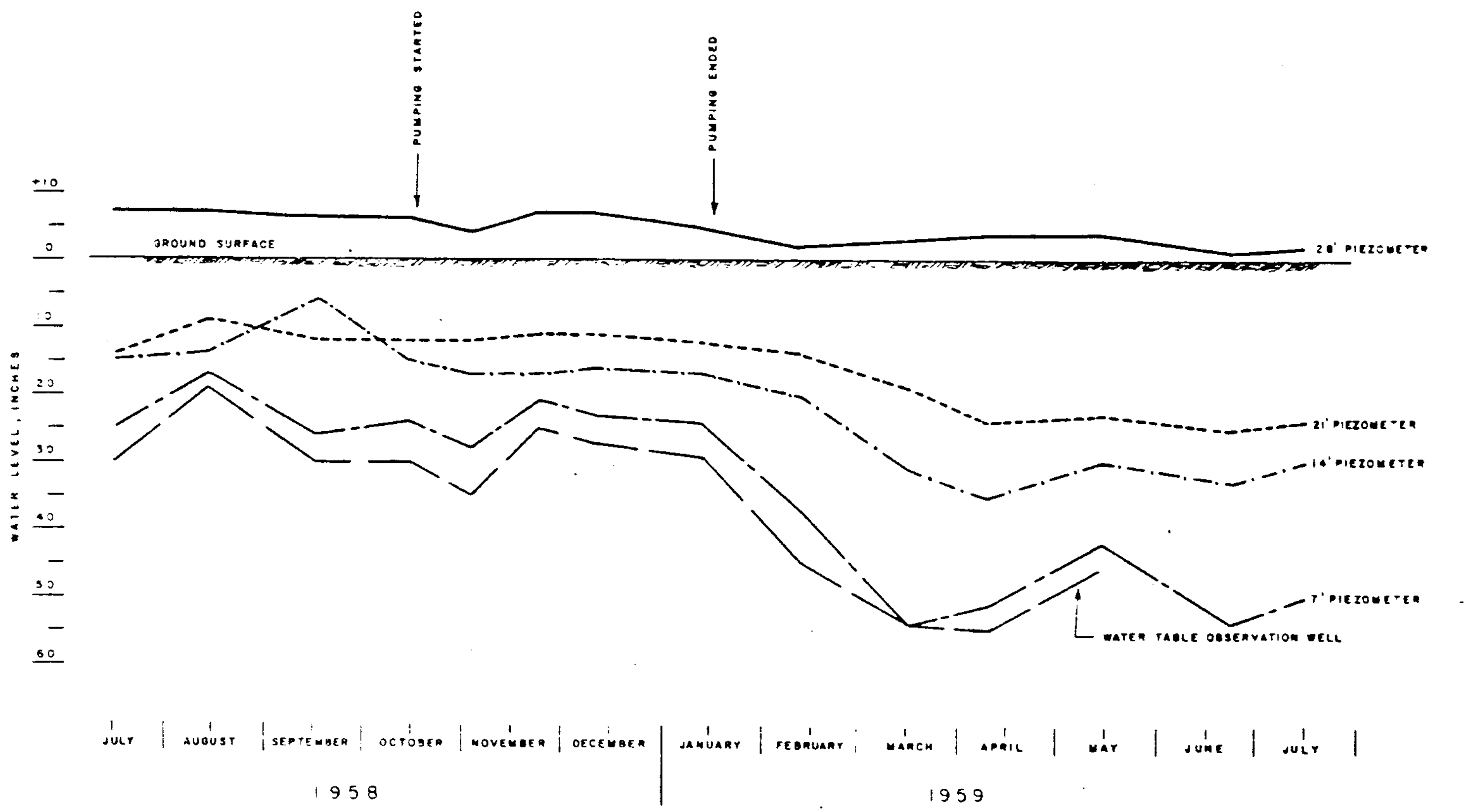



FIG. 22.—Ground-water-level fluctuations in surrounding area of Drainage Well No. 50 as shown by piezometer battery X 10.0 – Y 6.5 during period July 1958 to July 1959.

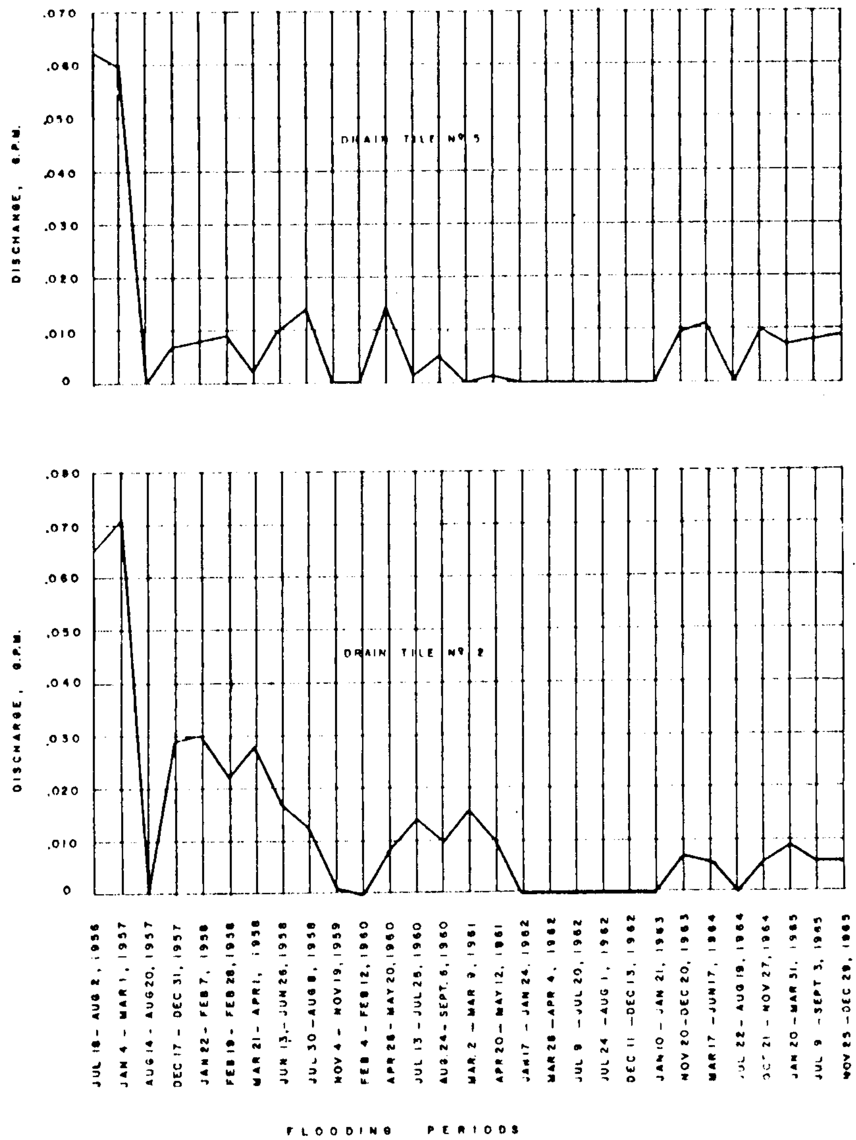



FIG. 23.—Tile-line discharge during flooding periods of 3.5-foot tile-drain experiment at Fraternidad, Lajas Valley, P.R., 1956-65.

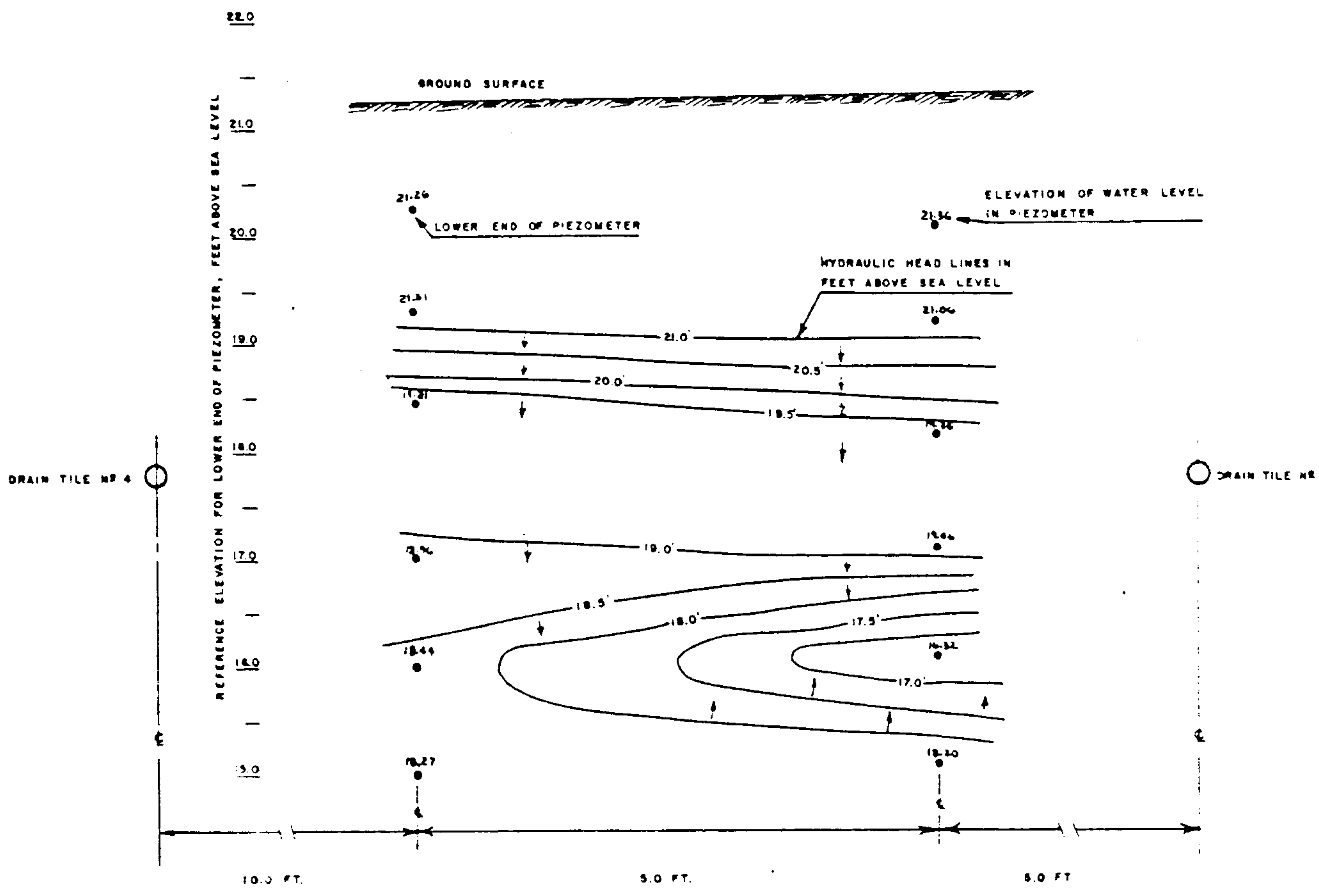



FIG. 24.—Water-pressure distribution throughout the soil profile of 3.5-foot tile-drain experiment at Fraternidad, Lajas Valley, P.R., when flooded on Mar. 31, 1965.

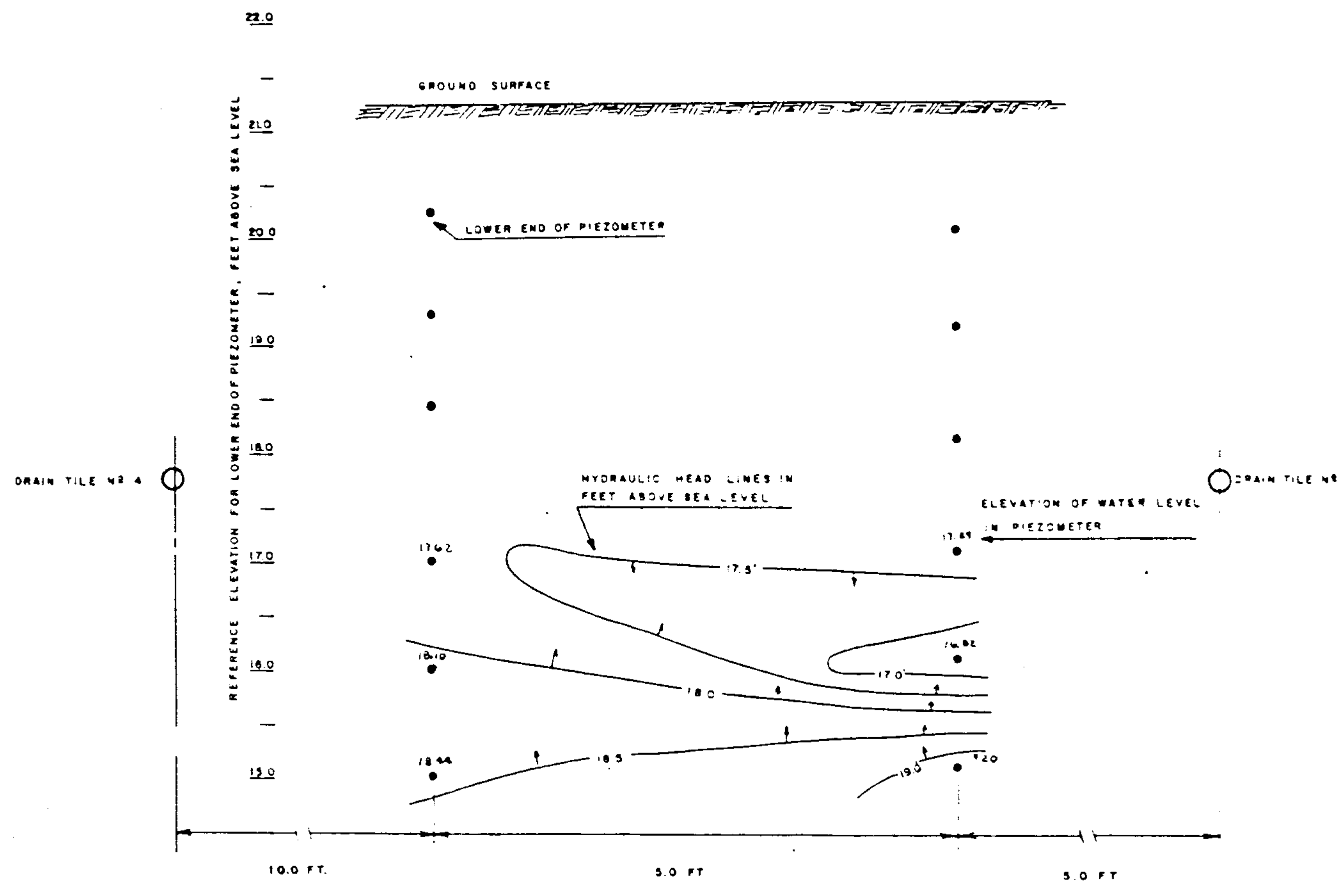



FIG. 25.—Water-pressure distribution throughout the soil profile of 3.5-foot tile-drain experiment at Fraternidad, Lajas Valley, P.R., after being flooded, June 14, 1965.

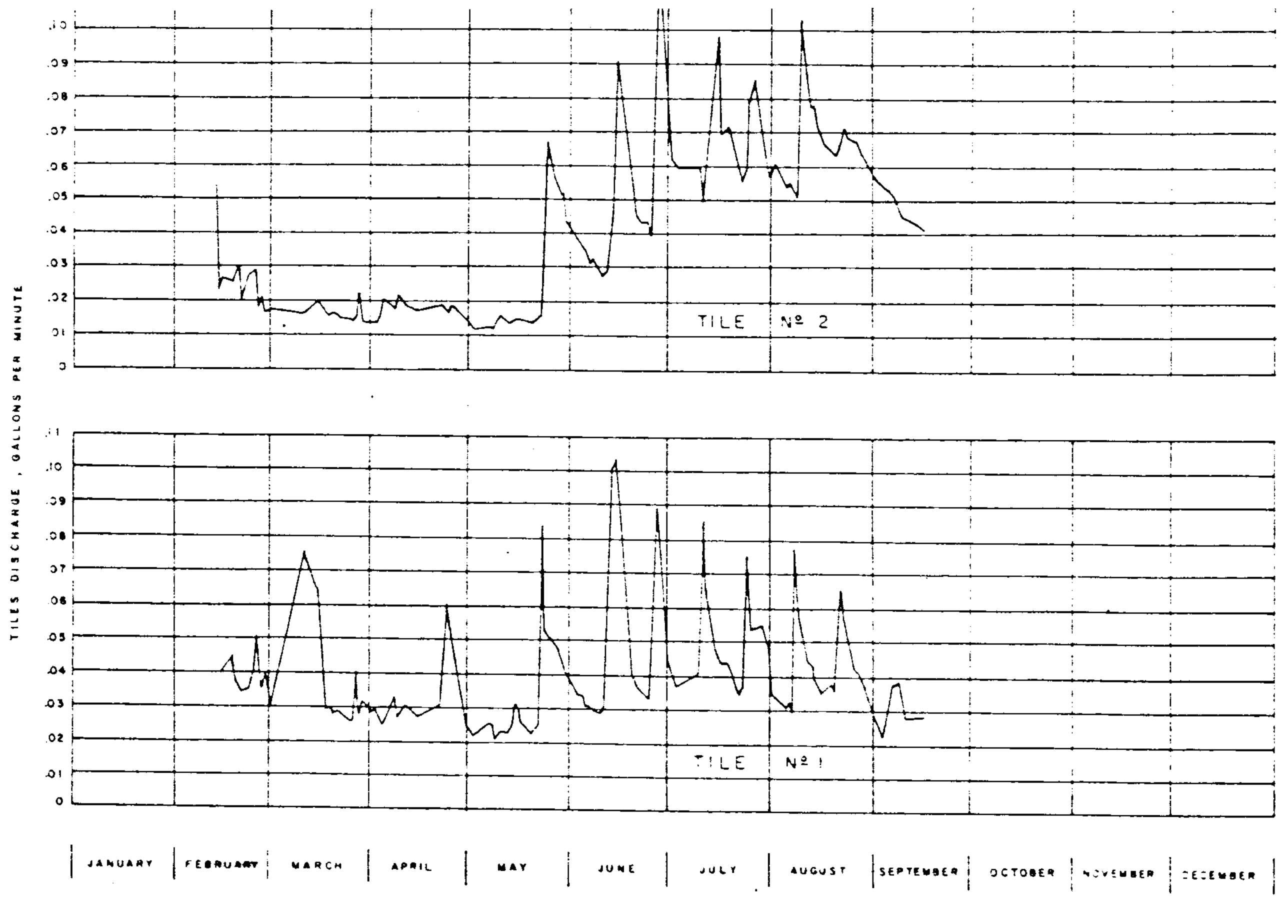



**Fig. 26.**—Tile-line discharge in soil-reclamation experiment with organic matter at Fraternidad, Lajas Valley, P.R., February to September, 1957.

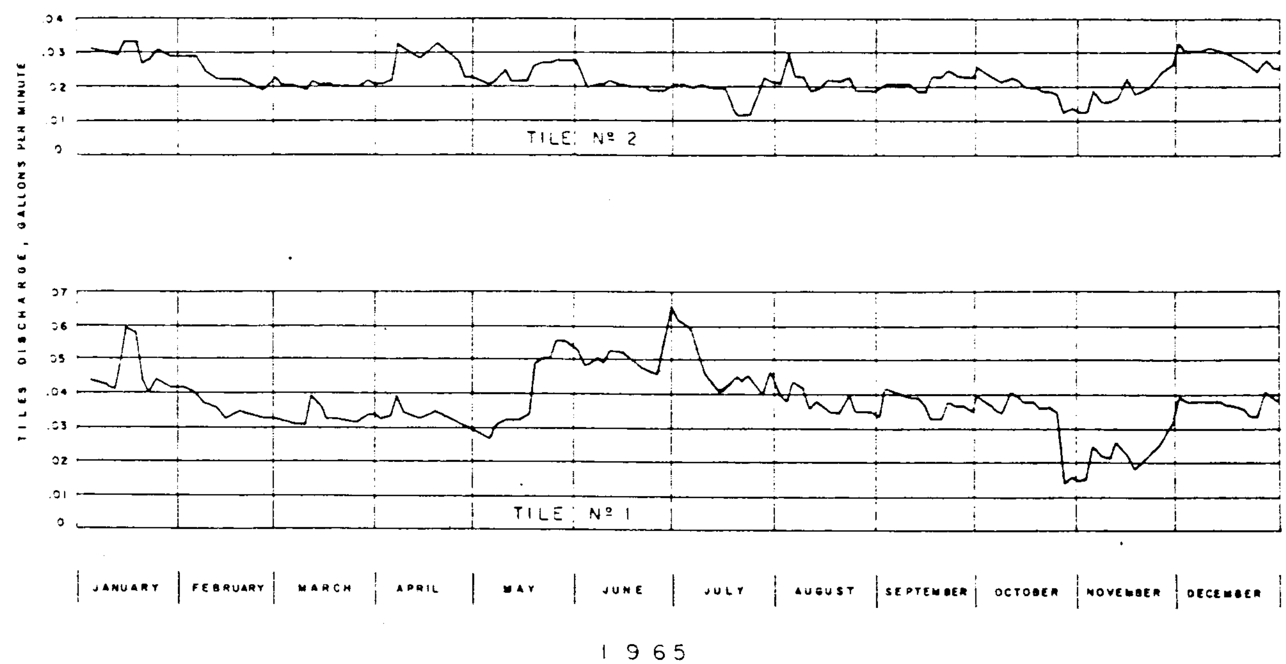



FIG. 27.—Tile-line discharge in soil-reclamation experiment with organic matter at Fraternidad, Lajas Valley, P.R., January to December, 1965.

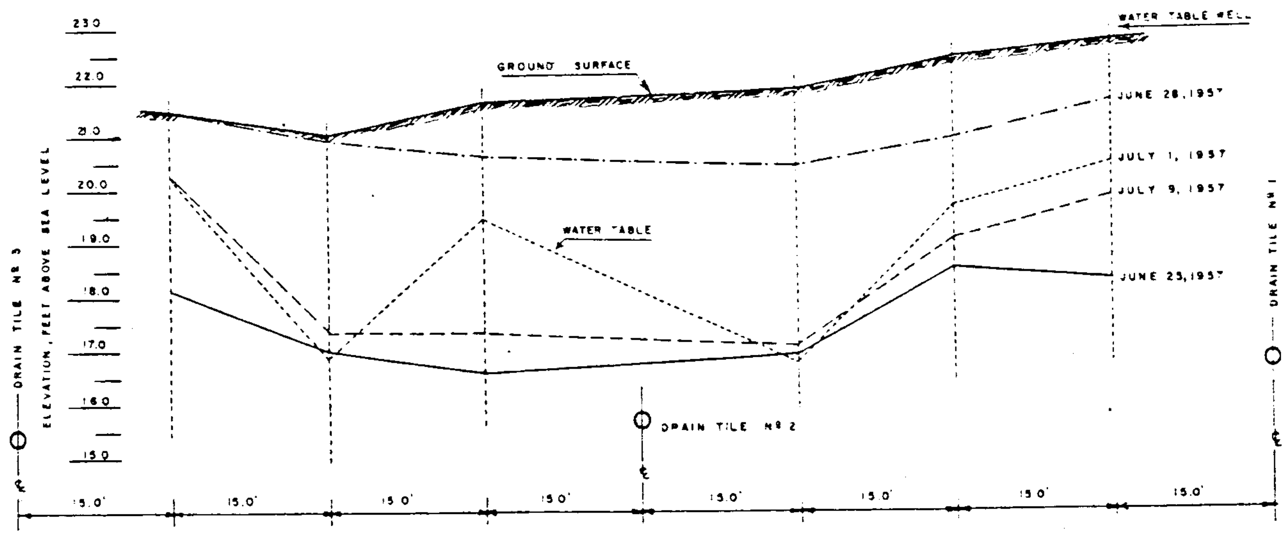



FIG. 28.—Water-table levels in soil-reclamation experiment with organic matter at Fraternidad, Lajas Valley, P.R., before and after being flooded, June to July, 1957.

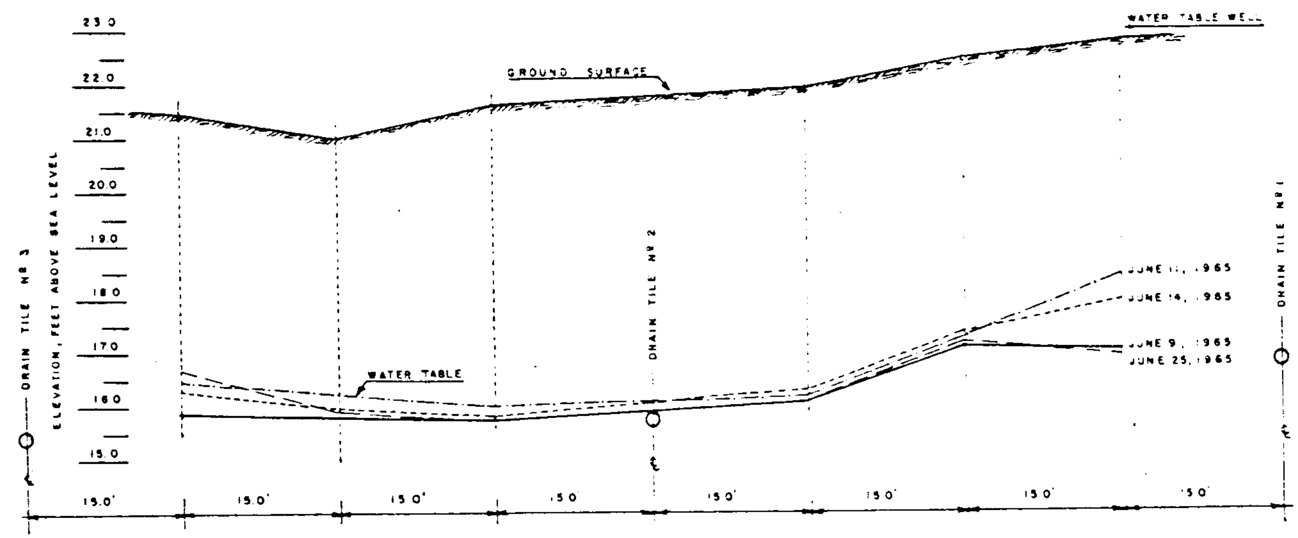



FIG. 29.—Water-table levels in soil-reclamation experiment with organic matter at Fraternidad, Lajas Valley, P.R., before and after being flooded, June 1965.

# AGRICULTURAL EXPERIMENT STATION

*(Continued from inside front cover)*

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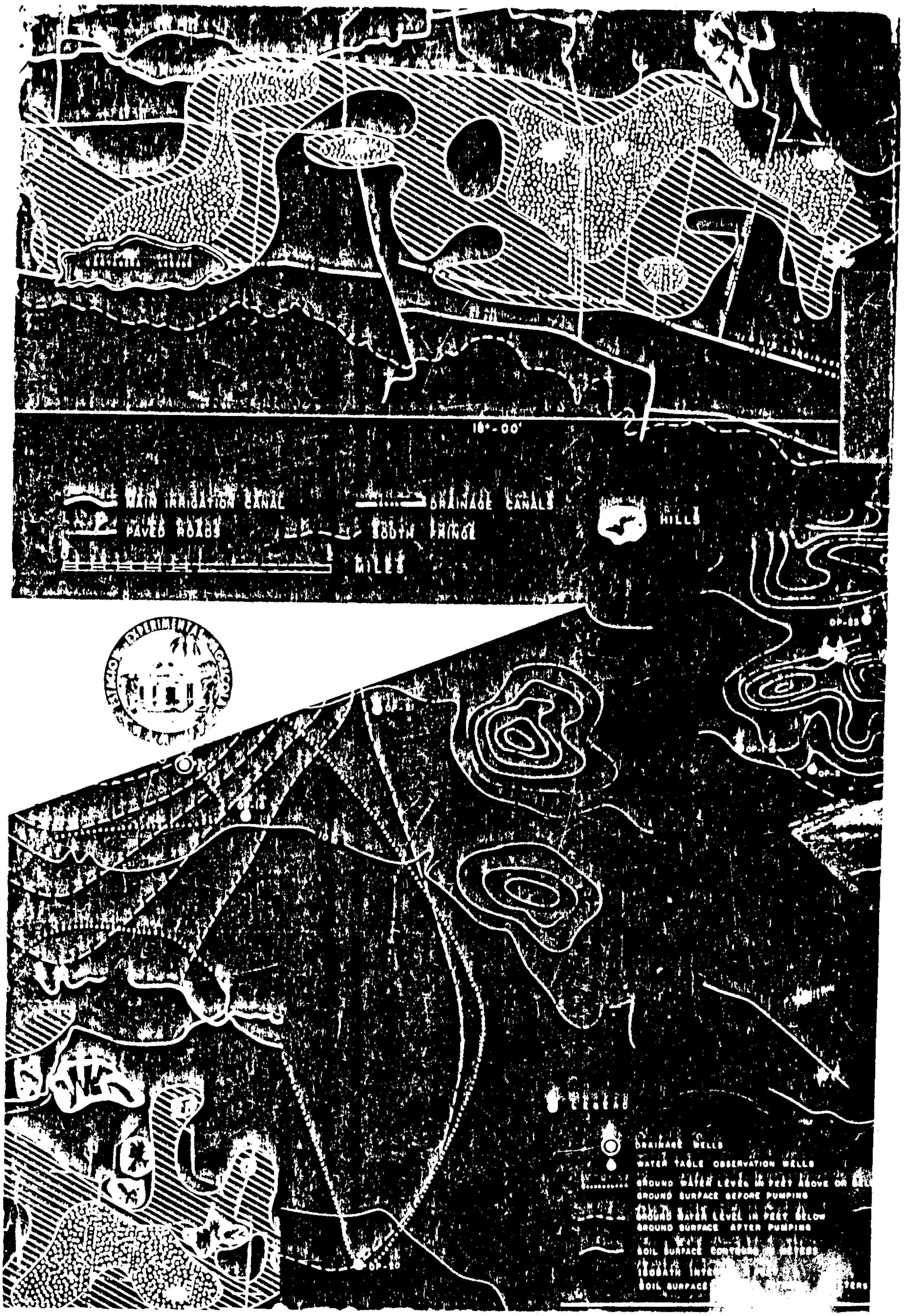
[1]August 1, 1967.
[2]Other types of leave.
[3]On leave to pursue studies.
[4]Part time.
[5]Staff, College of Agriculture and Mechanic Arts, Mayagüez.
[6]Collaborators.



10°-00'
MAIN IRRIGATION CANAL
DRAINAGE CANALS
PAVED ROADS
TOOTH FRINGE
HILLS
MILES
DRAINAGE WELLS
WATER TABLE OBSERVATION WELLS
GROUND SURFACE BEFORE PUMPING
GROUND WATER LEVEL IN FEET BELOW
GROUND SURFACE AFTER PUMPING