THE HYDROGEOLOGY AND DEVELOPMENT OF THE GROUND WATER RESOURCES IN THE EL ASENTAMIENTO CAMPESINO EL CORTIJO, ESTADO ARAGUA, VENEZUELA

by

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ABSTRACT

This thesis pertains to the ground water resources of the El Asentamiento Campesino El Cortijo area, which is located within the mountain ranges of north-central Venezuela, South America. The area described in this thesis is an agricultural area of 400 hectares (1,000 acres) lying in a basin of 2,100 hectares (5,187 acres).

The sediments underlying the area consist of about 100 meters (328 feet) of gravel, sand and clay of Quaternary age and are bounded on the north and south by relatively impermeable metamorphic rocks.

The purpose of the investigation was to determine and to describe the ground water conditions in the mentioned area with special emphasis on the development of the ground water resources. The sources and movement of ground water, the recharge and discharge relations and the effects of pumping on the water levels are described.

Ground water occurs under water table conditions and precipitation and underflow represent the sources of recharge to the aquifer. The coefficients of transmissibility and storage were estimated to be 1,800 cubic meters per day (154,700 g./d./ft.), and 0.11 respectively. Water quality is satisfactory for irrigation use, but concentrations of turbidity, apparent color and dissolved-iron exceed the amount recommended by the United States Public Health Service for drinking purposes.

INTRODUCTION

Location and Extent of the Area

The area discussed in this thesis is called El Asentamiento Campesino El Cortijo and is located along the southern flank of the mountain range known as the La Serrania del Interior, Municipio Villa de Cura, Distrito Zamora, Estado Aragua, Venezuela, South America (Figure 1). The total basin area is about 2,100 hectares (5,187 acres) of which only 400 hectares (1,000 acres) are now used for agricultural purposes. This thesis considers only the agricultural area, which is bounded on the north by El Zamuro Hill, on the south by El Diablo Hill, on the east by El Ocumo Farm, and on the west by Los Aguacates Farm (Figure 2 - in pocket). The average width of the valley is about 1,725 meters (5,658 feet) and it is about 3,000 meters (9,840 feet) long.

Climate

Climatological data for the area were obtained from La Division de Hidrometeorologia, Ministerio de Obras Publicas, Caracas, Venezuela.

El Asentamiento Campesino El Cortijo has a topical climate, characterized by two seasons: one dry and the other humid. The dry season extends from November to April, during which it is necessary to use irrigation wells for agricultural purposes. The humid season extends from May to October. The mean annual temperature is 23°C., with the maximum of 35°C. occurring in May and the minimum of 18°C. occurring in December.

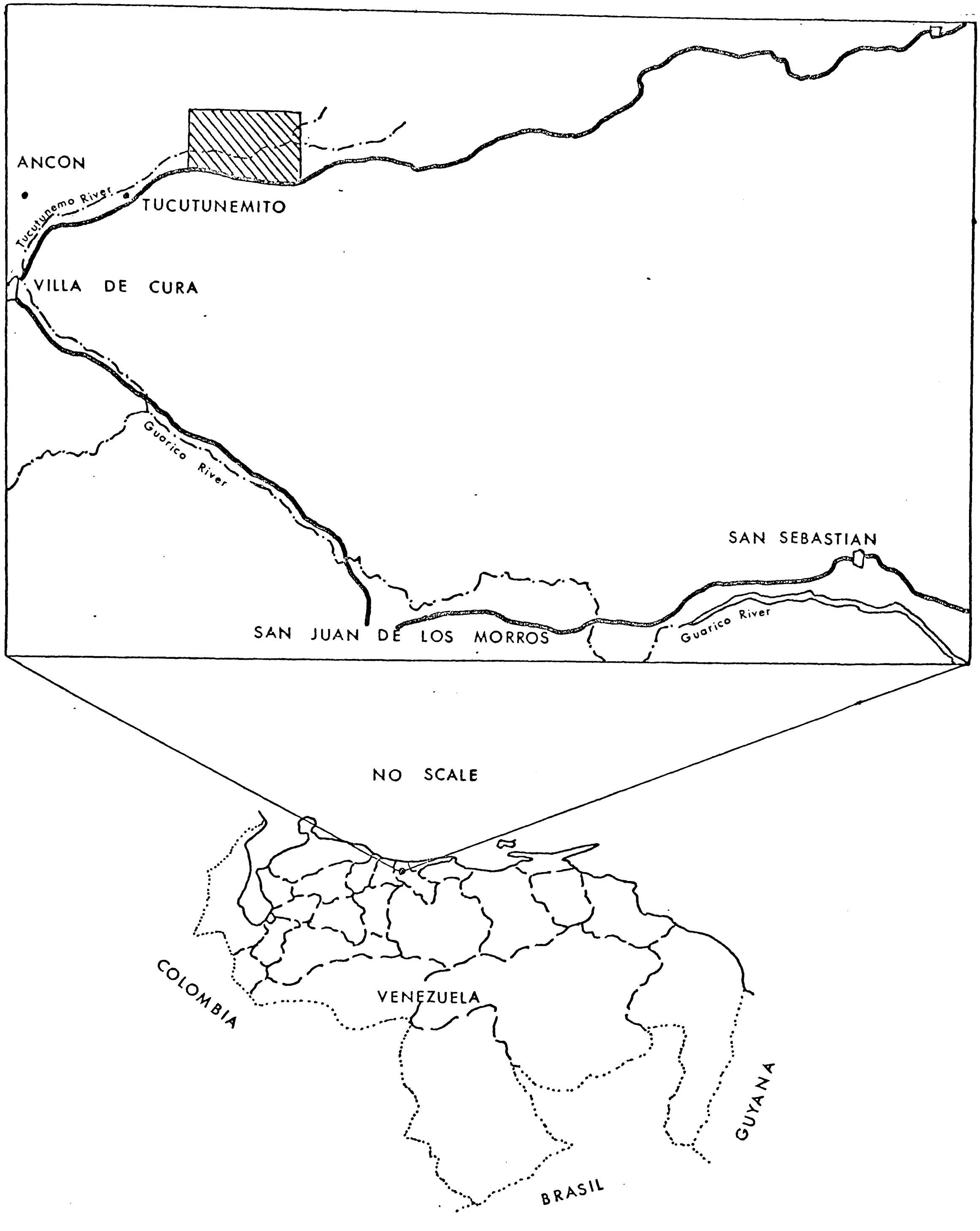

FIG. 1. MAP SHOWING THE LOCATION OF THE EL ASENTAMIENTO CAMPESINO EL CORTIJO

Precipitation

There are no climatological stations within the study area and, therefore, precipitation data were taken from the Ancon station which is situated 600 meters (1,969 feet) above mean sea level and located 6 kilometers (3.72 miles) west of the El Asentamiento Campesino El Cortijo (Figure 1). Based on data from this station, the mean annual precipitation is 870 mm. (34.25 inches), with the maximum average of 146.3 mm. (5.76 inches) occurring in June, and the minimum average of 2.7 mm. (0.11 inches) occurring in February. These averages were for the period 1951-1963, and are presented in Figure 3.

Runoff

Average monthly runoff data were obtained from the gaging station situated in Tucutunemito (on the Tucutunemo River), about 3 kilometers (1.86 miles) west of the area (Figure 1). The total runoff for the period 1956-1957 was about 3,422,000 cubic meters (120,831,000 feet^3) with a maximum average rate of 0.18 cubic meters per second (6.36 feet^3 per second) in October, and a minimum average rate of 0.04 cubic meters per second (1.21 feet^3 per second) in February and March. Since 1956-1957 the average runoff has been decreasing, the first recorded zero flow was in January, February and March of hydrologic year 1957-1958. The total runoff for the hydrologic year 1957-1958 was 2,500,000 cubic meters (88,000,000 feet^3 per year). For the period 1959-1962, runoff became nearly stable with an average of 1,043,000 cubic meters per year (36,828,000 feet^3 per year), and flowed equal to or near zero for the months of December through June, see Figure 3. These declines in

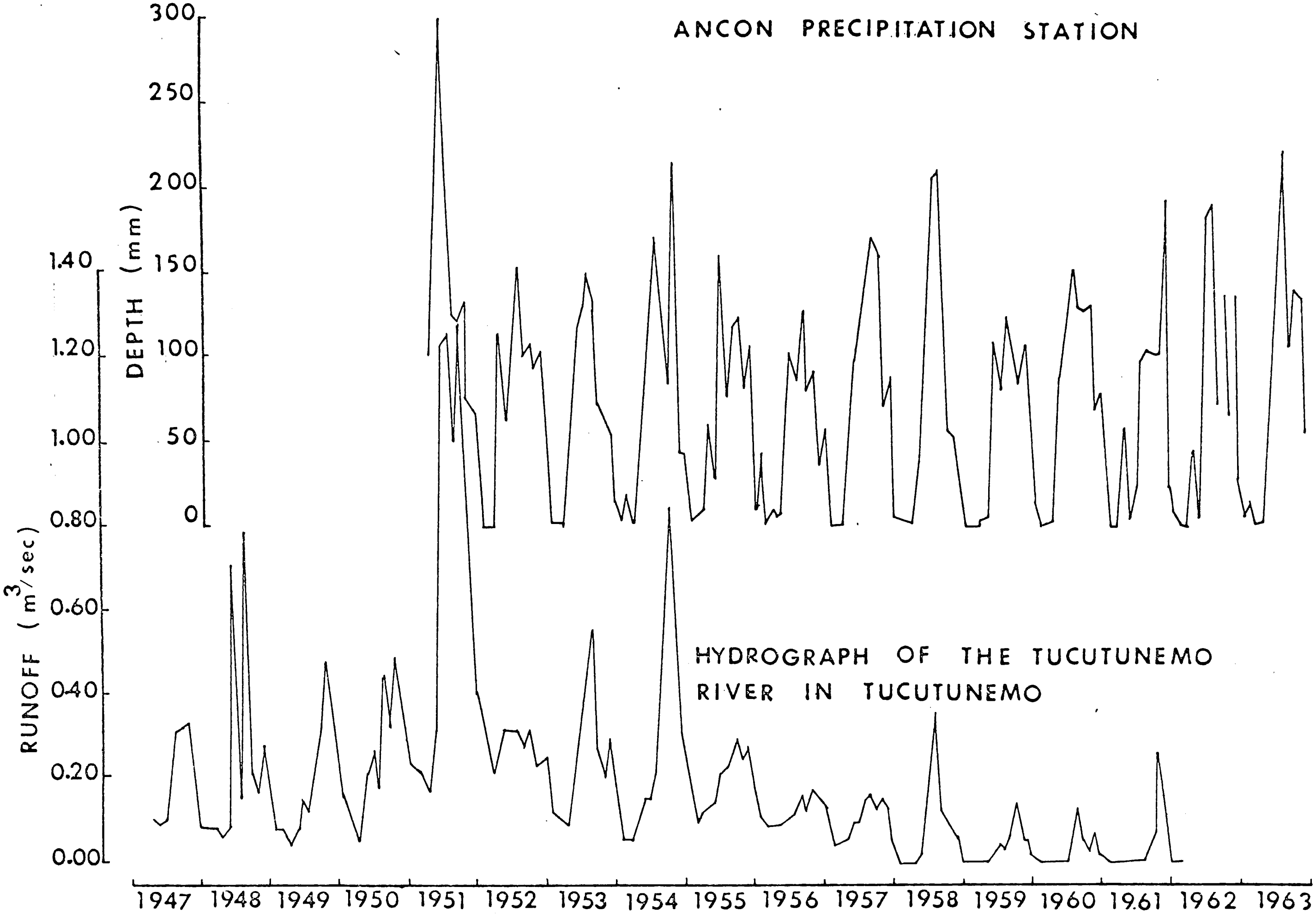

FIG. 3. MONTHLY VARIATION OF PRECIPITATION AND RUNOFF IN THE TUCUTUNEMO RIVER VALLEY

runoff coincide with the increase of ground water use for agricultural purposes.

Brief Description of the Area

The natural vegetation is mostly gramineous with some shrubs and tree species from Leguminacea. This vegetation has been replaced primarily by corn, although annual legumes and table grapes are also grown. The natural vegetation persists on the surrounding hills and can be used by livestock for light grazing.

The El Asentamiento Campesino El Cortijo area has been divided into individual land parcels. The size of each parcel is about 3.4 to 4.0 hectares (8.65 to 9.88 acres).

A sprinkler irrigation system is used for irrigation purposes, in such a system, a supply pipe line carries water from the wells to the main line, lateral pipe lines branch from the main line and carry water to the area to be irrigated (Figure 4).

Previous Work

In 1937-1938 Aguerrevere and Zuloaga (Shagan, 1960) made the first regional study of the metamorphic rocks in northern Venezuela. Later Reginald Shagan (1960) conducted a geological reconnaissance in the area outlined by the towns of Villa de Cura, San Juan de los Morros, San Sebastian and the Village of Tiara (Figure 1). This work included a detailed report on the geology of the mountains surrounding the El Asentamiento Campesino El Cortijo.

FIG. 4. SPRINKLER IRRIGATION SYSTEM USED IN THE EL ASENTAMIENTO CAMPESINO EL CORTIJO WITH THE METAMORPHIC ROCK BOUNDARY IN THE BACKGROUND.

PHYSIOGRAPHY

The land surface elevation varies from 528 meters (1,732 feet) above mean sea level in the western part of the area to 570 meters (1,870 feet) in the southern portion, with an average of 550 meters (1,804 feet) above mean sea level (Figure 2). The valley consists largely of piedmont slopes extending from the foot of the mountains to the center of the valley. These piedmont slopes consist of thick alluvial fill, except for the portion nearest the mountains at the southwest corner of the area where the alluvium becomes very thin (cross-section A-A', Figure 5).

Topography

The topographic relief of the valley is slight, especially in the northwestern part where the variation in elevation of land surface is less than 5 meters (16.40 feet) in a square kilometer. In a few places, such as the southcentral portion, the topographic relief varies as much as 15 meters (49.20 feet) in a square kilometer; the average slope perpendicular to the axis of the valley is about 10 meters (32.80 feet) per kilometer. To the north and south the valley is bounded by mountains which reach elevations of 900 and 1,000 meters (2,952 and 3,280 feet) above mean sea level respectively.

Drainage

All surface water drains into the Tucutunemo River which flows from east to west. Average annual runoff for 1959-1962 was 1,043,000 cubic meters (36,828,000 $feet^3$). Before 1957, the Tucutunemo River probably was a perennial stream, this means that the regional water table was above the stream bed throughout the year (effluent stream). After 1958, due to the increase in ground water use, the Tucutunemo River became an intermittent stream, which means that the regional water table rises above the stream bed during the rainy season and falls below the stream bed (influent stream) during the dry season.

GENERAL GEOLOGY

The El Asentamiento Campesino El Cortijo area is largely covered by alluvium of Quaternary age. These alluvial deposits are surrounded by rocks of the Caracas Group. Smith in 1953 (Shagan, 1960, p. 293) considered the formations of this group to have been deposited during Early Cretaceous time. The Caracas Group consists of metamorphic rocks which have been divided from the oldest to the youngest into Las Brisas, Las Mercedes and Tucutunemo Formations. As only the two uppermost formations of this group are found in the area, they alone are described herein.

Metamorphosed ultramafic rocks of post-Middle Cretaceous age and the metamorphic Paracotos Formation of Maestrichtian age (Upper Cretaceous), crop out in the southern and eastern parts of the area.

Rock Types

Caracas Group

Las Mercedes Formation. The Las Mercedes Formation consists chiefly of calcareous graphitic schists and phyllites and minor fine-grained graphitic limestone in its lower member, and quartz conglomerate in its upper member. The base of this formation is not exposed in the mapped area. Normally, Las Mercedes Formation overlies Las Brisas Formation and is transitional to it. Las Mercedes Formation is comfortably overlain by the Tucutenemo Formation or is covered by alluvium. The total thickness of the Las Mercedes Formation is estimated to be about 500 meters (1,640 feet), but only 150 meters (490 feet) of the upper part are exposed in the area. The age of the Las Mercedes Formation is considered to be Early Cretaceous.

Tucutunemo Formation. The Tucutunemo Formation consists largely of blue sandy carbonaceous phyllites which grade into feldspathic quartzose metasandstone and siltstone. According to Shagan (1960, p. 257), the presence of chemical limestone and a notable proportion of coarse-grained rocks points to a shallow-water shelf type of sedimentation. The Tucutunemo Formation lies transitionally on the Las Mercedes Formation and is in fault contact with the Paracotos Formation or is covered by alluvium. The exposed sequence of the Tucutunemo Formation is approximately 350 meters (1,150 feet) thick, and its age is considered to be Early Cretaceous.

Ultramafic Rocks

These intrusive rocks are commonly medium to dark green serpentines, which show a marked resinous luster, the dominant serpentine mineral is antigorite. In all cases the serpentinites and the country rocks are in fault contact. The thickness of these rocks is estimated to be about 30 meters (90 feet). The age of the ultramafic rocks is not certain but they are considered to be post-Middle Cretaceous (Shagan, 1960).

Paracotos Formation

The Paracotos Formation consists of phyllites, metatuffs and metagraywackes. The dominant rock type is a blue carbonaceous silty phyllitic shale which nowhere ranges to a sandy facies. The sandstones consist of angular and well sorted grains commonly less than 0.03 mm.

in diameter. According to Shagan (1960, p. 280), the phyllites and the sandstones are well sorted and imply a marine basin of deposition of shallow to moderate depth. The base of this formation is in fault contact with the Tucutunemo Formation and the top is covered by alluvial material. The thickness is estimated to be 400 meters (1,300 feet) and its age is considered to be Upper Cretaceous.

Alluvium

The alluvium consists of materials that range from clay to pebble size as recorded in the driller's logs of the wells. Appendix 1 and Figure 5 show the depth, thickness, distribution and general lithology of the alluvium penetrated during the drilling tests. The driller's logs used in this study were qualitative interpretations by individuals who may have had only limited formal geologic training. The maximum known thickness of the alluvium is about 100 meters (328 feet) in the eastern part of the area (Well PC-16); extending westward the alluvial fill appears to become thinner as shown on cross-section A-A' (Figure 5).

The predominant colors of the clay are yellow, grey and red, the thickness of the penetrated lenses of clay varies from 1 meter (3.28 feet) to 19 meters (62.32 feet). The thickness of the sand and gravel lenses varies from 1 meter (3.28 feet) to 13 meters (43.64 feet). Lenticular clay at various depths through the area indicated that several cycles of deposition occurred, but the alluvium is hydrologically interconnected and acts as a single aquifer.

The angular character of the gravel and sand suggests that these materials were transported a short distance and not subsequently reworked. This, in addition to the presence of fragments of the phyllites indicate that the source of sediments was the group of metamorphic rocks surrounding the area. The poorly sorted character of the gravel and sand implies a fluvial agency of transportation, this means that the alluvium was deposited largely by the Tucutunemo River and in part by the tributary streams within the drainage area of the valley.

Structure

The El Asentamiento Campesino El Cortijo area and the surrounding areas have been subjected to three periods of tectonic activity; these orogenies occurred during the Middle Cretaceous, the Upper Cretaceous and the Late Paleocene ages. According to Shagan (1960), the direction of application of the stresses appears to have been the same in all orogenies, so that re-emphasis of the earlier structural pattern was the only result. Following the third orogeny, the processes of weathering and erosion began and led to the present geomorphic character of the valley. As a result of these orogenies, several systems of folds and faults have been created.

Folding

Small open folds are common in the metamorphic formations, these folds generally strike N.75°E., parallel to the regional trend of the formations and plunge gently to the west. In the highly incompetent phyllites of the Tucutunemo and Paracotos Formations, folds may be of variable trend and character (Shagan, 1960). Folds do not play any important role in controlling ground water in the El Asentamiento Campesino El Cortijo area.

Faulting

Shagan (1960, p. 291) suggested a possible major strike-slip fault as the origin of the Tucutunemo Valley in the text of his report, but he did not show this fault on his map. He also reported that the ultramafic rocks were always associated with faults in the area. The presence of ultramafic rocks in the eastern and southern parts of the basin infer that the Tucutunemo Valley may have developed by erosion along that major strike-slip fault suggested by Shagan. A change in thickness of the alluvium between Wells PC-2 and PC-5 could also be related to that fault. In the areas surrounding the El Asentamiento Campesino El Cortijo basin, the principal faults are the eastwest trending Santa Rosa and Agua Fria faults, which strike parallel to the regional trend of the formations. Faulting controls the shape of the basin and possibly has developed secondary permeability in the metamorphic rocks, however faulting apparently does not play an important role in controlling ground water movement and in changing the degree of permeability of the alluvium.

GROUND WATER CONDITIONS

Occurrence and Movement of Ground Water

In the El Asentamiento Campesino El Cortijo area, ground water occurs under water table conditions (unconfined aquifer) and is found in the sands and gravels of the alluvial fill in the saturated zone. The saturated zone is the zone in which all pore spaces are filled with water. This zone includes all of the sediments between the basement rock (metamorphic rocks), and the water table which is about 3 meters (9.84 feet) below land surface.

Ground water movement is westward as shown by the water contour map for 1966 (Figure 2), and conforms to the gradient of the land surface. From east to west the ground water gradient is gentle as far west as Well PC-8, where due to a thinning of the alluvium the flow area decreases causing a steeper gradient.

Recharge

Precipitation and underflow are the major sources of recharge to the aquifer. Ground water recharge is greatest during the humid period, when evaporation is small and soil moisture is maintained at or above field capacity by frequent rains. During the dry periods evaporation is so great that little or no recharge occurs to the water table from precipitation.

Only a fraction of the annual precipitation is recharged to the water table. The remainder of the precipitation leaves the area as runoff or is returned to the atmosphere by evapotranspiration before it reaches the water table. The amount of precipitation that infiltrates to the saturated zone depends upon several factors. Among these factors are the character of the soil, the topography, vegetative cover, land use, soil moisture, the air temperature and the storm characteristics.

For an annual precipitation of about 870 mm. (34.25 inches) and a total drainage area of 400 hectares (1,000 acres), approximately 3,400,000 cubic meters (2,850 acre-feet) of precipitation per year are available. In addition, if the total amount of runoff for the whole basin is about 1,043,000 cubic meters per year (841.27 acre-foot per year), and the study area is only 19 per cent of this basin, the corresponding runoff for the agricultural area is about 198,170 cubic meters per year (160.22 acre-foot per year). The difference between the total precipitation and the runoff, gives us the amount of water that is evaporated plus the water that is recharged to the ground water reservoir. This amount is 3,281,830 cubic meters per year (2,660 acre-foot per year).

In addition, the study area receives water as underflow from the basin to the east. This amount of water may be calculated by the following form of Darcy's equation (Ferris, et al. 1962):

$$Q = TIL$$

Where: Q = discharge in cubic meters per day (gallons per day)

T = coefficient of transmissibility in cubic meters per day per meter (gallons per day per foot

I = hydraulic gradient in meters per meter (feet per foot)

L = width of the cross-section through which the discharge occurs in meters (feet)

If: T = 1,800 m^3/d.m. (see section on the coefficient of transmissibility)

I = 0.0035 (at the east, Figure 5)

L = 1,500 meters (at the east, Figure 5)

Then: Q = 1,800 X 0.0035 X 1,500 = 9,450 m^3/d.

Q = 9,450 m^3/d. (333,700 $feet^3$ per day)

It means that about 3,450,000 cubic meters of water per year (122,000,000 $feet^3$ per year) was recharged to the agricultural area as underflow in 1966.

Because of the high irrigation efficiency of sprinklers, as well as the high rate of evaporation we may neglect infiltration due to excess irrigation water as a source of recharge to the aquifer.

Discharge

The main use of ground water in the El Asentamiento Campesino El Cortijo area is for irrigation with only minor amounts pumped for domestic use; essentially all irrigation occurs during the months of November, December and January. The irrigation wells were constructed of 6" to 12" diameter casing and to depths varying from 14.70 to 100 meters (48.22 to 328 feet), see Table 1. The yield of these wells varies from 14.30 to 58.00 liters per second (227 to 918.6 g.p.m.). For the hydrologic year 1957-1958 about 800,000 cubic meters (28,200,000 $feet^3$) of water were pumped, and for the period 1959-1962

TABLE 1

WELL INVENTORY OF THE EL ASENTAMIENTO CAMPESINO EL CORTIJO

Well	Year Drilled	Depth (meters)	Diameter (inches)	Discharge (liters per second)	Depth to water (meters)	Height above mean sea level (meters)	Use
PC-1	1962	60.00	8	8.00	9.06	544.07	Abandoned
PC-2	1962	73.00	8	2.80	11.06	563.81	Abandoned
PC-3	1962	42.00	-	-	-	556.25	Abandoned
PC-4	1962	76.00	8	22.00	10.63	547.69	Obstructed
PC-5	1962	76.00	8	20.00	19.26	558.56	Irrigation
PC-6	1962	71.00	8	25.00	10.80	551.61	Irrigation
PC-7	1962	75.00	8	25.00	12.15	553.87	Irrigation
PC-8	1962	44.00	8	19.00	3.11	536.18	Irrigation
PC-9	1962	38.00	-	-	-	538.80	Abandoned
PC-10	1962	55.00	8	20.00	3.00	537.49	Irrigation
PC-11	-	-	-	-	-	556.41	Obstructed
PC-12	-	-	-	-	-	538.83	Dug Well

TABLE 1, Continued

Well	Year Drilled	Depth (meters)	Diameter (inches)	Discharge (liters per second)	Depth to water (meters)	Height above mean sea level (meters)	Use
PC-13	1964	31.80	8	-	3.60	527.29	Abandoned
PC-14	1964	21.00	8	-	3.37	527.66	Abandoned
PC-15	1964	79.50	8	35.00	7.00	544.37	Irrigation
PC-16	1964	100.00	10	30.00	2.14	545.49	Irrigation
PC-17	-	-	-	-	-	538.49	Dug Well
PC-18	-	-	-	-	-	538.40	Dug Well
PC-19	-	-	-	-	-	541.20	Dug Well
PC-20	-	-	-	-	-	558.13	Dug Well
PC-21	-	-	-	-	-	551.00	Dug Well
PC-22	1966	56.00	12	58.80	2.60	542.78	Irrigation
PC-23	1966	58.00	12	26.60	15.00	555.60	Irrigation

TABLE 1, Continued

Well	Year Drilled	Depth (meters)	Diameter (inches)	Discharge (liters per second)	Depth to water (meters)	Height above mean sea level (meters)	Use
PC-24	1966	57.00	12	62.50	2.50	541.36	Irrigation
PC-25	1966	56.00	12	55.50	3.00	540.40	Irrigation
PC-26	1966	63.00	12	23.50	18.70	558.73	Irrigation
PC-27	1966	57.00	12	37.00	5.00	541.85	Irrigation
PC-28	1966	62.00	12	14.30	0.30	535.29	Irrigation
PC-29	1966	56.00	12	40.00	3.50	538.66	Irrigation
POC-1	1964	14.70	6	-	5.84	527.61	Observation
POC-2	1964	54.00	6	-	2.00	535.48	Observation
POC-3	1964	57.20	6	-	8.90	544.39	Observation

the total amount of water pumped was about 2,400,000 cubic meters per year (84,700,000 feet^3 per year).

Some water discharges as underflow westward from the agricultural area. Before the agricultural development that amount of water was probably equal to the amount of water recharged to the basin as underflow.

Possible losses of water due to evapotranspiration include transpiration by plants and the direct evaporation of water. Since there is no phreatophyte vegetation, loss of ground water through transpiration may be neglected. In addition, the agriculture crops are not capable of sending their roots to the water table, and trees are so scarce that their ground water consumption may be neglected. During the dry period, evaporation is possibly great enough to remove water from the relatively shallow water table.

Water Level Fluctuations

Water level fluctuations in the El Asentamiento Campesino El Cortijo area respond to variations in recharge and discharge. These fluctuations are reflected by water level changes in the wells. Figures 6 and 7 illustrate the fluctuations of the water table in Well POC-1. The water level rises in July and August; and declines in December, January and February. In general, these increases and decreases of water level coincide with the humid and dry periods respectively. From 1964 to 1966 the average water level rose, which indicates that the total recharge was higher than the total discharge during that period.

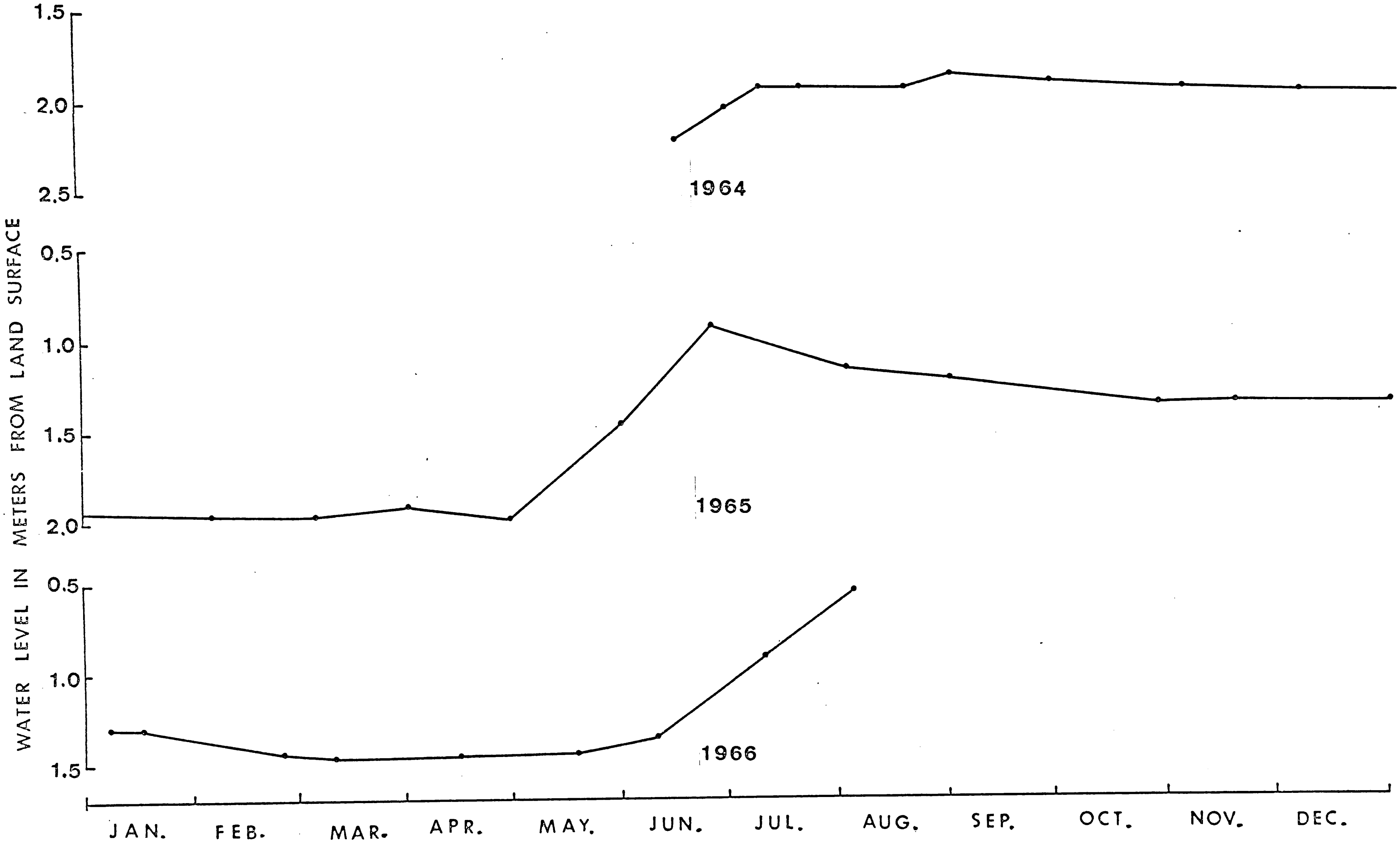

FIG. 6. SEASONAL FLUCTUATIONS OF THE WATER LEVEL IN WELL POC-1

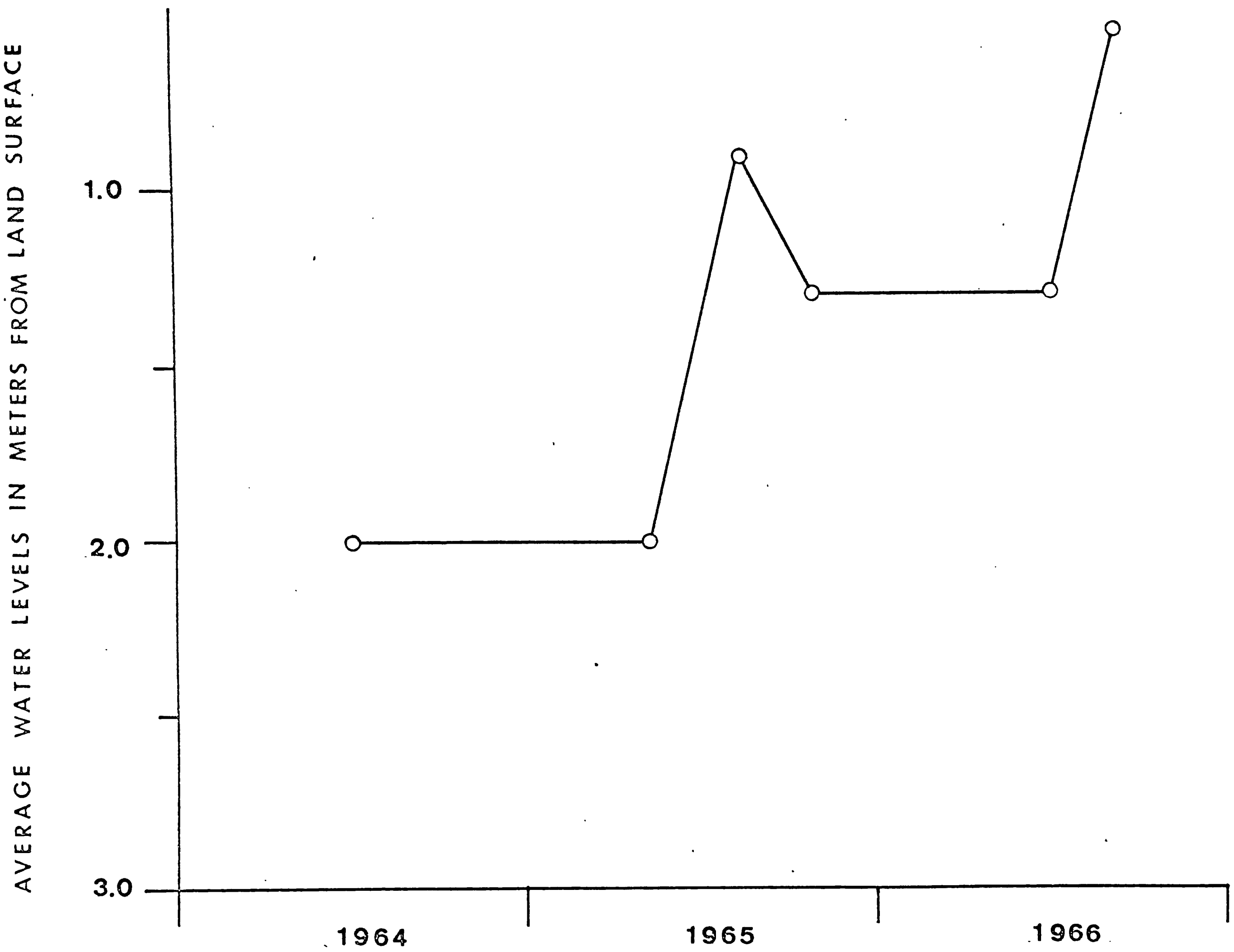

FIG. 7. WATER LEVEL FLUCTUATIONS FOR THREE YEARS IN WELL POC-1

Water Quality

Chemical analyses of water were available only for Wells PC-7, PC-8 and PC-15; and one for the Tucutunemo River, which was taken near the vertical control station BM-A-82 (Figure 2). These analyses indicate that, in general, the water is suitable for irrigation use according to the standards of the United States Department of Agriculture (Wilcox, 1948), although the water contains turbidity, apparent color and dissolved-iron in excess of the amount recommended by the United States Public Health Service for drinking purposes. Only three analyses are insufficient to define any water quality trends or patterns in the area (Table 2).

TABLE 2

CHEMICAL ANALYSIS OF WATER SAMPLES

(RESULTS IN PARTS PER MILLION, EXCEPT AS INDICATED)

Source	PC-7	PC-8	PC-15	Tucutunemo River
Date of Collection	11-4-64	11-10-64	5-22-64	11-19-64
Specific conductance (micromhos)	323	286	344	441
P.H.	7.5	7.6	7.1	7.6
Apparent color (PT-Co)	30	20	2	35
Real Color (PT-Co)	0	2	5	10
Turbidity (units)	96	50	2	32
Chloride (Cl)	4	4	7	6
Sulphate (SO_4)	11	15	11	31
Nitrate (NO_3)	3.6	3	0.5	19
Nitrite (NO_2)	0	0.02	0	0.12
Fluoride (F)	0.15	0.15	0.10	0.15
Calcium (Ca)	33	31	44	59

TABLE 2, Continued

Source	PC-7	PC-8	PC-15	Tucutunemo River
Magnesium (Mg)	12	14	14	15
Sodium + Potassium (Na + K)	16	9	7	17
Dissolved-iron (Fe)	0.20	0.07	0	0
Dissolved-iron (extractable)	2.30	1.20	0	1
Dissolved Manganese (Mn)	0	0	0	0
Dissolved Manganese (extractable)	0	0	0	0.10
Silica (SiO_2)	29	32	24	25
Free carbon dioxide (CO_2)	9	6	25	10
Total Hardness ($CaCO_3$)	130	134	168	210
Carbonate hardness ($CaCO_3$)	130	132	160	190
Noncarbonate hardness ($CaCO_3$)	0	2	8	20
Dissolved Solids (TDS)	196	186	203	286
Langelier index (Ph-PHs)	-0.2	-0.2	-0.5	+0.2

HYDRAULIC PROPERTIES OF AQUIFER

For proper management of the aquifer it is important to ascertain the hydrologic characteristics that control the storage capacity of the aquifer and the transmission of water through the aquifer. The principal hydraulic properties of an aquifer influencing water level decline are transmissibility, T, permeability, P, and the coefficient of storage, S.

The capacity of a formation to transmit ground water is expressed by the coefficient of transmissibility, which was defined by Theis in 1935 (in Ferris et al. 1962) as the rate of flow of water in cubic meters per day (gallons per day), through a vertical strip of the aquifer of 1 meter (1 foot) wide and extending the full saturated thickness under a hydraulic gradient of 100 per cent at the prevailing temperature of water (20°C.). The coefficient of transmissibility is the product of the saturated thickness of the aquifer, and the coefficient of permeability, which is defined as the rate of flow of water in cubic meters per day (gallons per day), through a cross-sectional area of 1 square meter (1 $foot^2$) of the aquifer under a hydraulic gradient of 100 per cent at the prevailing temperature of the water (20°C.).

The storage properties of an aquifer are expressed by the coefficient of storage, which is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit changes in the water level. For water table conditions, the coefficient of storage is virtually equivalent to the specific yield, which is defined as the ratio of the volume of water that a saturated rock or soil will yield by gravity to the total volume of the rock or soil.

A determination of all these characteristics makes possible an understanding of the physics of the ground water system and helps to evaluate the ground water resources of an area in relation to the development of these resources.

Cone of Depression

The manner in which the coefficients of transmissibility and storage are related to water level decline and yields of wells can best be illustrated by a discussion of the cone of depression. When a well is pumped, water levels decline and a low area develops which is called a cone of depression which has the lowest point at the pumped well. Water moves from surrounding areas down the gradient of the cone toward the pumped well. The shape of the cone is controlled in part by the coefficient of transmissibility. With other factors remaining constant, the lower the coefficient of transmissibility, the steeper will be the gradient of the cone of depression and the greater will be the drawdown in a well.

During the initial period of pumping, discharge is balanced by water taken from storage within the aquifer closest to the well. As pumping continues, the cone of depression expands taking water from storage at greater distances from the well. With continuous pumping the cone of depression grows in size and depth at a diminishing rate until (1) the lowering of water levels results in increased recharge to, and/or decreased natural discharge from the aquifer and (2) hydraulic gradients are established sufficient to bring from recharge or natural discharge areas the amount of water pumped. Provided the aquifer is infinite in areal extent, the dimensions of the cone of depression depend upon the hydraulic properties of an aquifer, the pumping rate and the total elapsed time after pumping started. Water level decline is directly proportional to the pumping rate and diminishes in a logarithmic manner outward from the well. The greater the coefficient of storage, the less water level decline is required to obtain from storage the amount of water being pumped.

Under natural conditions, precipitation reaching the water table percolates towards streams to become ground water runoff or is discharged into the atmosphere by the process of evapotranspiration. The cone of depression intercepts part of this water which otherwise would become ground water runoff or ground water evapotranspiration.

Thus far the cone of depression created by pumping a single well has been considered. In a multiple well system the cones of individual wells overlap and water levels lower more rapidly and to greater depths as the result of mutual interference between wells. The amount of the interference is directly proportional to pumping rates and inversely proportional to the logarithm of the distances between wells. Under a given spacing of wells and pumping regimen, a quantitative evaluation of interference is largely dependent on the determination of the hydraulic properties of the aquifer.

Storage

The storage capacity of an aquifer is the volume available to contain water; in other words: it is the volume of saturated sediments multiplied by their porosity. The porosity of a rock is its property of containing interstices and is expressed as the percentage of the aggregate volume of its interstices to its total volume.

A method has been devised for computing the average specific yield (coefficient of storage) and the amount of water than can be withdrawn from storage. This method consists of assigning values of specific yield to the several categories of material penetrated during drilling. The values of specific yield used in this thesis were based on the results obtained by Johnson (1967) from test drilling and laboratory analyses. The procedure was as follows:

(I) The total volume of available sediments was calculated based on Well PC-16; the saturated thickness of the alluvium is about 100 meters (328 feet), and the surface area is about 1,000 meters (3,280 feet) by 3,000 meters (9,840 feet), giving a total volume of 300,000,000 cubic meters (243,048 acre-feet) of sediments.

(II) The materials described in the wells were grouped into categories and the specific yields were assigned as follows:

(A) Sand and gravel, 20 per cent

(B) Sand and gravel with clay, 10 percent

(C) Clay, 2 per cent

(D) Bedrock, 0 per cent

(III) The computation of the volume of recoverable water for the area included the following steps: (1) Each well log was examined and the material described was classified into one of the four categories (Appendix 1). (2) The thickness of each of the categories of material was added, tabulation of the total thickness is shown on Table 3. (3) The percentage of the total thickness contained in each category was calculated. (4) By use of the specific yield assigned to each category of material, the average specific yield was calculated. (5) By use of the total volume of sediments multiplied by the average specific yield, the volume of water available for use was calculated (Table 3).

Coefficient of Transmissibility

The coefficient of transmissibility was calculated in two ways:

(1) Well-data analyses. This computation consisted of estimating the coefficient of transmissibility from the specific capacity of individual wells and the specific yield (coefficient of storage) of the aquifer. The specific capacity of a well is the relation of drawdown to discharge; that is, its yield in liters per second (gallons per minute) per meter (per foot) of drawdown caused by the pumping. The specific capacity is dependent not only on the hydrologic characteristics of the aquifer penetrated by the well but also on the construction of the well itself, the condition of the perforations in the casing and their distribution within the saturated zone.

Data were available with which to compute the specific capacity for only one well in the area (Table 4). The method used

TABLE 3

COMPUTATION OF AVERAGE SPECIFIC YIELD AND VOLUME OF RECOVERABLE WATER IN THE EL ASENTAMIENTO CAMPESINO EL CORTIJO

(CATEGORY OF MATERIAL: A, HIGH WATER-YIELDING MATERIAL, WHERE SATURATED; B, MEDIUM WATER-YIELDING MATERIAL, WHERE SATURATED; C, LOW WATER-YIELDING MATERIAL, WHERE SATURATED)

Wells examined	Category of material	Estimated specific yield[1] (percent)	Total thickness of logs examined[2] (meters)	Percent of total thickness	Average specific yield[3] (percent)	Average thickness of alluvial deposits[4] (meters)	Area (square meters)	Total volume of sediments[5] (cubic meters)	Volume of recoverable water[6] (cubic meters)
	A	20	291	31.8	6.36				
19	B	10	358	39.2	3.92				
	C	2	265	29.0	0.58				
			914	100.0	10.86	100	3×10^6	3×10^8	3.26×10^7

1. From A. I. Johnson. Computation of specific yield for various material. U.S.G.S. Water Supply Paper 1662-D, 1967
2. Total thickness in each of the categories of material for all logs examined
3. Multiply column 3 by column 5
4. Based on well PC-16
5. Multiply column 7 by column 8
6. Multiply column 6 by column 9

TABLE 4

COEFFICIENT OF TRANSMISSIBILITY ESTIMATED FROM WELL DATA IN THE EL ASENTAMIENTO CAMPESINO EL CORTIJO

Well	Total depth (meters)	Static water level (meters)	Discharge (liters per second)	Specific capacity at the end of one day (liters per second per meter)	Average specific yield (percent)	Transmissibility (square meter per day)	Permeability (meters per day)
PC-16	98.50*	2.14	30	14	10.8	1,900	20
	(322.86)**	(7.19)	(475.56)	(67.0)	(10.8)	(150,000)	(484)

* Amount without parenthesis in Metric System

** Amount in parenthesis in English System (U.S.G.S. Units)

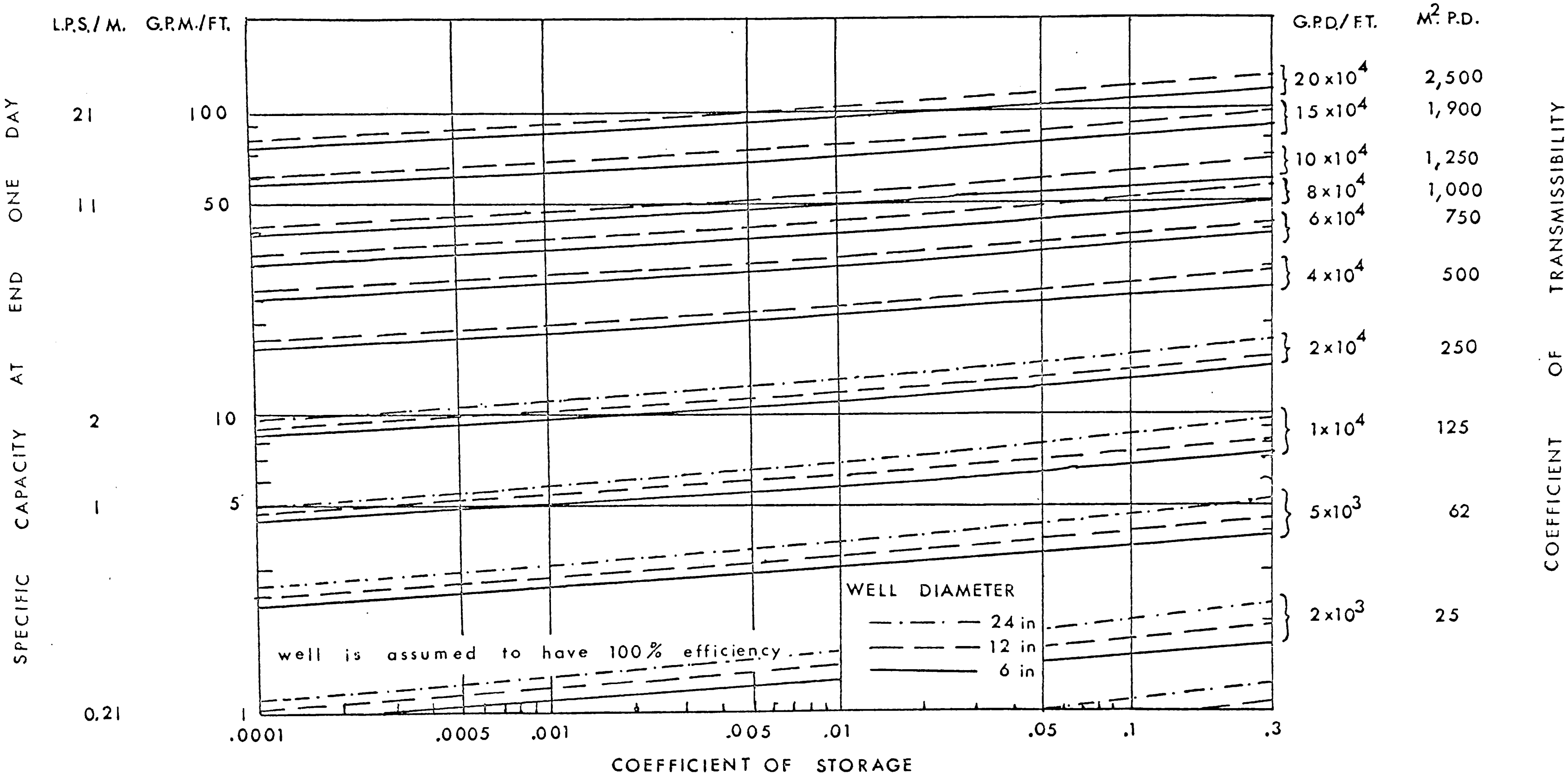

FIG. 8. GRAPH SHOWING RELATION OF WELL DIAMETER, SPECIFIC CAPACITY, AND COEFFICIENTS OF STORAGE AND TRANSMISSIBILITY (THEIS et al. 1954)

to compute the coefficient of transmissibility was described by Meyer (Theis, Brown and Meyer, 1954). When the specific capacity and the coefficient of storage are known the transmissibility may be read from a graph based on the Theis (1935) non-equilibrium formula (Figure 8). The coefficient of storage (specific yield) was computed to be about 11 per cent, and the specific capacity for well PC-16 (Table 4) is about 14 liters per second per meter (67 g./min./ft.). The average value for the coefficient of transmissibility derived by this method is about 1,900 cubic meters per day per meter (150,000 g./d./ft.), and the coefficient of permeability is about 20 cubic meters per day per square meter (484 g./d./ft.^{2}), see Table 4.

(11) Aquifer test. Only one pumping test was made to determine the coefficient of transmissibility of the aquifer. No observation wells were used to measure drawdown during the pump test. The data (Table 5) corresponded to the pumped well and were analyzed by the method described by Cooper and Jacob in 1946 and by Ferris in 1959 (in Walton 1962). The equation and method used to analyze data for the pumping test and its result are given in Figure 7. Determination of the coefficient of transmissibility by this method is based on the slope of the straight line (Figure 9), this slope is not greatly affected by well losses in the pumped well which remain almost constant during pumpage. But well losses do affect the position of the straight line and in consequence it is not possible to find the true value of the coefficient of storage by this method.

TABLE 5

PUMPING TEST DATA FOR PUMPED WELL PC-16

Date: from 2-2-65 at 11:30 a.m. to 2-4-65 at 8:35 a.m.

Duration of the test: 45 hours 6 minutes

Discharge: 30 lt./sec. (475.56 g.p.m.)

Well casting: 10''

Depth of the well: 98.50 meters (323 feet)

Static water level: 3.62 meters (11.87 feet)

Temperature of water: 25°C.

Time after pumping started (in min.)	Drawdown (in meters)	Time after pumping started (in min.)	Drawdown (in meters)
0	0	54	1.800
1	1.370	60	1.814
1.5	1.410	70	1.827
2	1.435	80	1.836
3	1.455	90	1.850
4	1.490	96	1.853
5	1.510	120	1.870
6	1.548	150	1.910
7	1.562	200	1.947
8	1.577	250	1.985
9	1.597	330	1.993
10	1.610	400	2.037
12	1.634	500	2.050
15	1.660	600	2.080

TABLE 5, Continued

Time after pumping started (in min.)	Drawdown (in meters)	Time after pumping started (in min.)	Drawdown (in meters)
18	1.684	720	2.090
22	1.710	860	2.130
25	1.721	1100	2.130
30	1.739	1400	2.170
35	1.754	1800	2.200
40	1.768	2300	2.240
46	1.797	2706	2.270

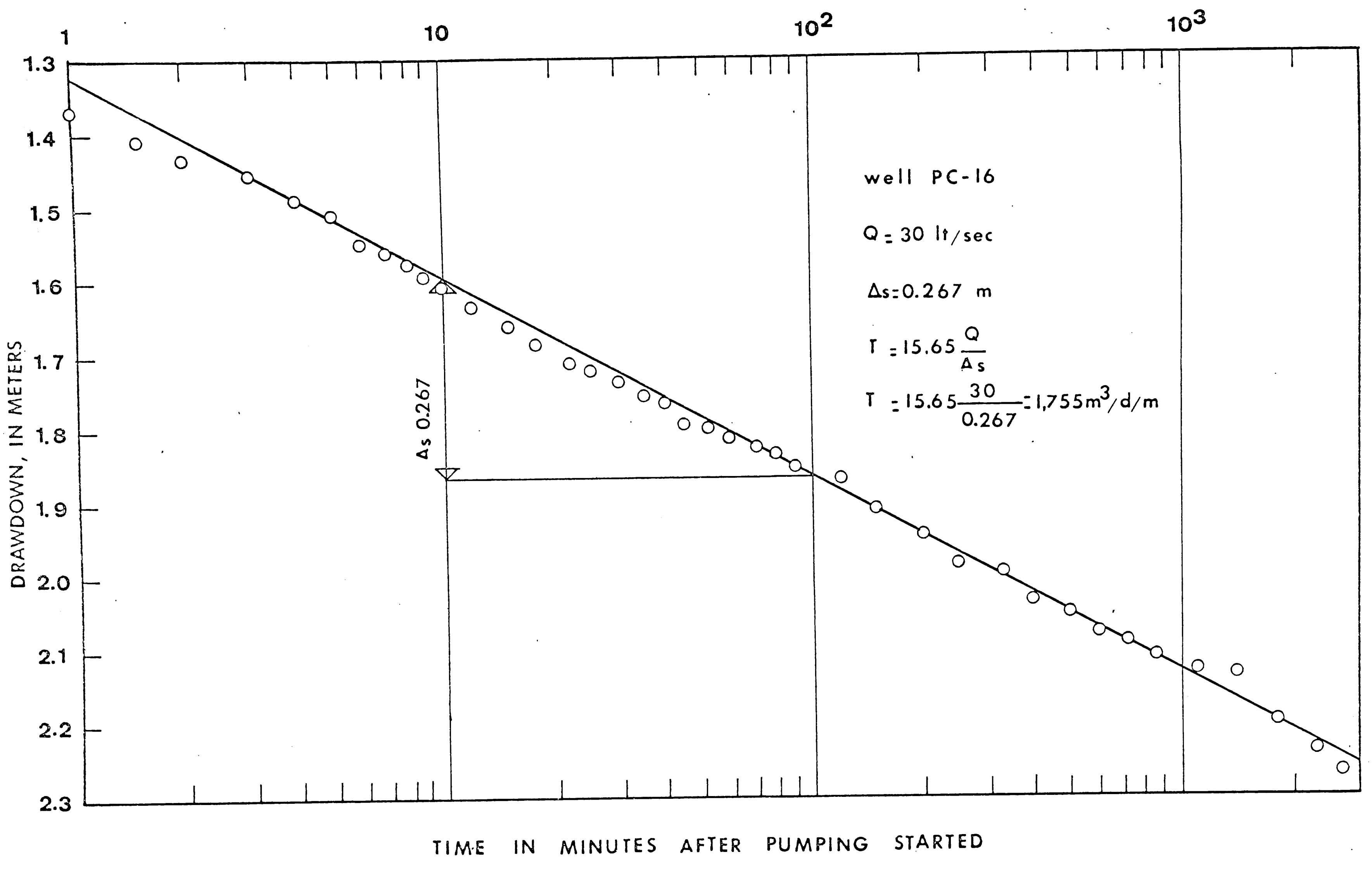

FIG. 9. GRAPH OF RESULTS OBTAINED FROM PUMPING TEST OF WELL PC-16 (FERRIS, 1962)

From the preceding methods, it is concluded that the average coefficient of transmissibility of the aquifer is about 1,800 cubic meters per day per meter (154,700 g./d./ft.), and the coefficient of permeability is about 20 cubic meters per day per square meter (484 g./d./ft.^{2}).

Theoretical Effects of Pumping

The hydraulic properties of the aquifer and the nonequilibrium formula were used to evaluate the magnitude of drawdown and to compute the theoretical decline in the water table at any distance from a pumped well and at any length of time after pumping started (Figure 10).

We know that the average annual amount of water pumped for the period 1959-1962 was about 2,400,000 cubic meters (84,700,000 feet^3), which corresponds to an average pumping rate of 6,660 cubic meters per day (1,220 g.p.m.). Figure 8 shows the amount of drawdown that will occur at distances of 10 meters (32.8 feet) to 10,000 meters (32,800 feet) from one well pumping continuously at 6,660 cubic meters per day (1,220 g.p.m.) for periods of 30 days, 1 year, 30 years and 100 years. Assuming that the aquifer is homogeneous and of infinite area extent, the drawdown pattern will be similar in all directions from the pumped well. The graph assumes that all the water pumped is withdrawn from storage (there is no recharge). The drawdown is not appreciable at short distances from the pumped well indicating that even closely spaced wells in the alluvial deposit will interfere very little with one another. For example, the drawdown at a distance of 10 meters (32.8 feet) is about 3.42 meters (11.22 feet) for a pumping period

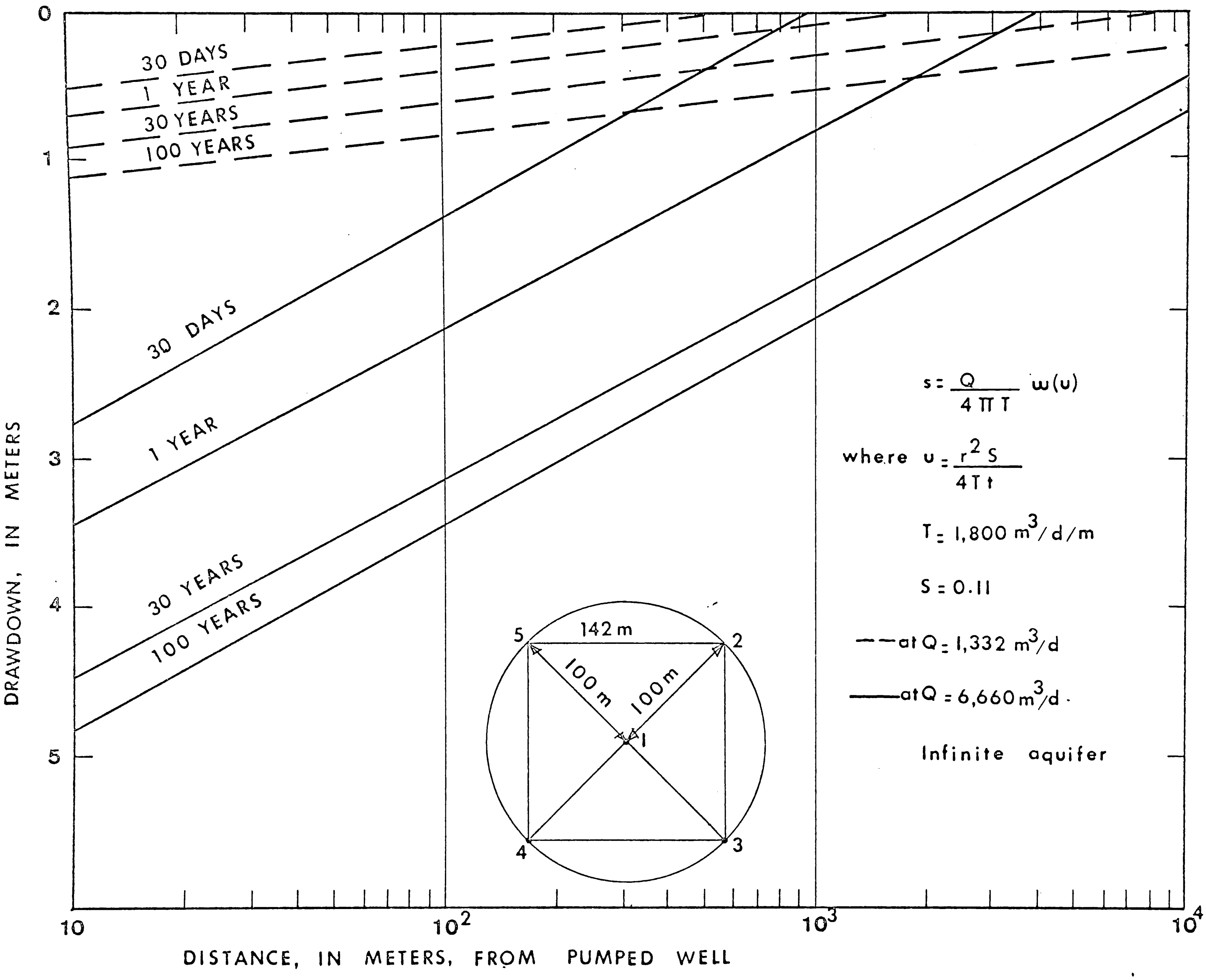

FIG. 10. GRAPH OF THEORETICAL DISTANCE - DRAWDOWN, AND DISTRIBUTION OF 5 WELLS

of 1 year. The theoretical drawdown is directly proportional to the pumping rate.

If we assume that five wells are used, each pumping at a rate of 1,332 cubic meters per day (224 g.p.m.) and a distribution of these wells as shown on Figure 10, Well 1 will be the most affected by pumpage because it is the nearest well to all of the others. Figure 10 also shows the drawdown for only one of these wells neglecting interference among them, after 30 days, 1 year, 30 years and 100 years of continuous pumpage. Assuming that the diameter of Well 1 in Figure 10 is 1 meter (3.28 feet), for the same periods of time, and with the five wells pumping simultaneously, the drawdown in Well 1 will be 1.88 meters (6.14 feet), 2.78 meters (9.11 feet), 3.76 meters (12.33 feet) and 4.80 meters (15.74 feet) respectively.

Geologic Boundaries of Aquifer

The graphs in Figure 10 were constructed assuming an aquifer of infinite areal extent. However, geologic conditions limit the extent of the alluvial deposits. As shown in Figure 2, the alluvial deposits are bounded on the north and south by relatively impervious metamorphized rocks, which limit the aquifer and act as boundaries. The boundaries distort cones of depression and increase drawdown in Wells. By treating the boundaries as straight line demarcations, the image-well theory described by Ferris (1959) can be used to evaluate the effects of the boundaries on regional pumping.

The image-well theory as applied to boundaries may be stated as follows (Walton, 1962, p. 15): "the effect of a barrier boundary on the drawdown in a well as a result of pumping from another well, is the same as though the aquifer were infinite and a like discharging well were located across the real boundary, on a line at right angles thereto, and at the same distance from the boundary as the real pumping well."

Thus, an imaginary hydraulic system of a well and its image counterpart in an infinite aquifer satisfies the actual barrier boundary conditions. The two barrier boundaries (north and south) are for all practical purposes parallel. The arrangement of the boundaries is such that analysis by the image-well theory is required. Figure 11 shows the effects of the barrier boundaries on drawdown in an observation well located 100 meters (328 feet) either east or west of the pumping well for 80 years of continuous pumpage at a rate of 6,660 cubic meters per day (1,220 g.p.m.). In constructing the graph of Figure 11, the barriers were considered to be 1,000 meters (3,280 feet) apart with both pumping well and observation well midway between the barriers.

Well Spacing

Accurate information about the hydraulic characteristics of an aquifer is essential for estimating the most efficient spacing of two or more wells to be constructed in the same area. As previously discussed, when wells are spaced closely together their cones of depression may overlap, where overlap occurs, drawdown is additive. The drawdown half-way between two wells spaced 100 meters (328 feet) apart, and pumped a rate of 6,660 cubic meters per day (1,220 g.p.m.) each well for 30 days would be about 2.76 meters (9.06 feet) or double

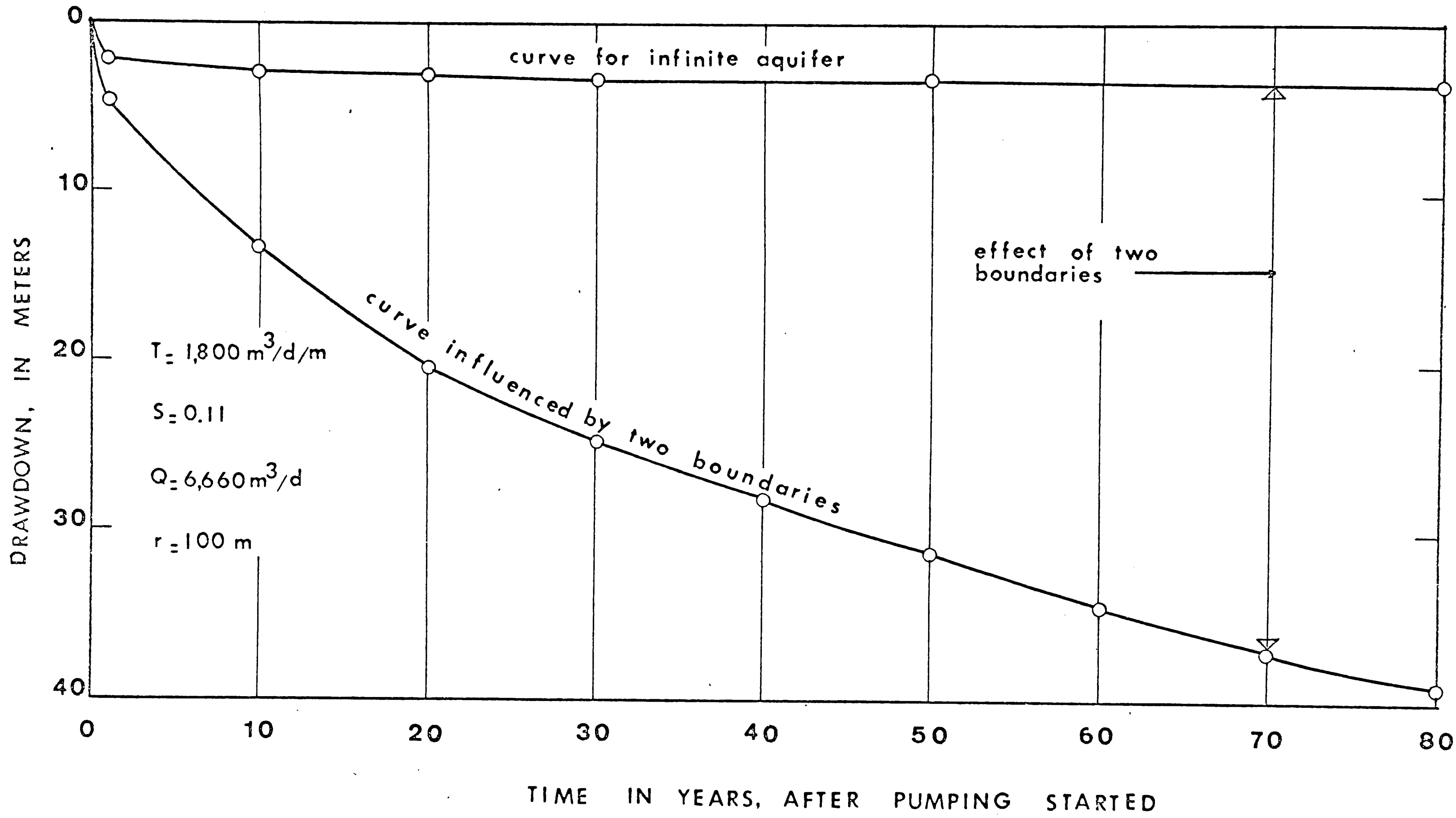

FIG. 11. GRAPH SHOWING THE EFFECTS OF TWO BOUNDARIES ON DRAWDOWN

the drawdown that would occur 50 meters (164 feet) from one well pumped at a rate of 6,660 cubic meters per day (1,220 g.p.m.) for 30 days (Figure 10).

Excessive drawdown due to close well spacing will lower the specific capacity of the wells and may serve to reduce the ultimate yield of the wells. From this standpoint it is desirable to minimize overlap of the cones of depression, but this infers greater costs in constructing interconnecting pipelines and subsidiary pumping plants as well as in supplying electrical power to the pumps at the wells. The best solution is a balance between the economic cost of equipping the wells as opposed to the hydrologic-hydraulic factors entailed in well spacing.

Practical Sustained Yield of Aquifer

The rate at which water can be continuously pumped without eventually dewatering the aquifer is called the practical sustained yield of the aquifer. In the El Asentamiento Campesino El Cortijo area, the practical sustained yield of the aquifer is largely dependent on the following conditions: the rate and distribution of recharge, the hydraulic properties of the aquifer, the thickness of the aquifer, the geologic boundaries and the spacing of wells. As previously discussed, large quantities of water enter the aquifer as underflow and precipitation. It has been estimated that the total recharge is greater than 3,450,000 cubic meters of water per year (122,000,000 feet^3 per year) or 9,450 cubic meters of water per day (331,000 g.p.m.). Since the present pumping rate of about 2,400,000 cubic meters of water per year

(84,700,000 feet^3 per year) or 6,660 cubic meters of water per day (1,220 g.p.m.) has not caused a net decline in water levels, the practical sustained yield of the aquifer is greater than the present rate of pumping. But the exact amount of the practical sustained yield of the aquifer is unknown largely because of the following reasons: (1) the average coefficient of transmissibility, 1,800 cubic meters per day per meter (154,700 g./d./ft.) is great; (2) the aquifer is limited by geologic boundaries; and (3) the distribution of pumpage and thickness of the aquifer is not uniform.

CONCLUSIONS

The study has shown that the data available are sufficient only for a rough quantitative analysis of the ground water resources of the area. The quantitative estimates that have been given are as good as can be made with the information available and probably are in the correct order of magnitude.

Conclusions drawn from this investigation are:

1. Quaternary alluvium deposits were derived from the metamorphic rocks surrounding the basin and mainly transported into the area by the Tucutunemo River. Additional deep test holes or geophysical exploration would be necessary in order to better define the thickness of the alluvium and determine the depth of the bedrocks (metamorphic rocks).
2. Pumping lowers the water levels during the dry season, although no significant net declines in water levels occurred due to the high rate of recharge to the aquifer.
3. In the El Asentamiento Campesino El Cortijo basin, only 19 per cent of the total land has been cultivated; from the ground water standpoint further development of the basin appears possible.
4. In general the water quality is suitable for irrigation use.

APPENDIX 1

SELECTED DRILLERS' LOGS WITH WATER-YIELDING CATEGORIES INDICATED

(WATER-YIELDING CATEGORIES: A, HIGH WATER-YIELDING WHERE SATURATED; B, MEDIUM WATER-YIELDING, WHERE SATURATED; C, LOW WATER-YIELDING, WHERE SATURATED; D, IMPERMEABLE).

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
PC-1			
Soil	0.30	0.30	
Clay	3.70	4.00	C
Gravel	6.00	10.00	A
Clay	20.00	30.00	C
Clay, grey	5.00	35.00	C
Phyllites	25.00	60.00	D
PC-2			
Soil	0.20	0.20	
Gravel	5.80	6.00	A
Clay	6.00	12.00	C
Clay, grey	18.00	30.00	C
Phyllites	43.00	73.00	D
PC-3			
Soil	0.20	0.20	
Sand	1.80	2.00	A
Pebbles and Clay	4.00	6.00	B

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Clay	12.00	18.00	C
Pebbles and Clay	22.00	40.00	B
Phyllites	2.00	42.00	D
PC-5			
Soil	0.20	0.20	
Clay	2.80	3.00	C
Sand	5.00	8.00	A
Clay	10.00	18.00	C
Gravel	2.00	20.00	A
Clay and Gravel	56.00	76.00	B
PC-6			
Soil	0.20	0.20	
Gravel	3.80	4.00	A
Clay	6.00	10.00	C
Clay and Gravel	61.00	71.00	B
PC-7			
Soil	0.30	0.30	
Clay	3.70	4.00	C
Gravel with traces of clay	36.00	40.00	B
Pebbles	7.00	47.00	A
Clay and Gravel	28.00	75.00	B

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
PC-9			
Soil	0.30	0.30	
Clay	2.70	3.00	C
Sand	5.00	8.00	A
Clay	12.00	20.00	C
Phyllites, blue	18.00	38.00	D
PC-10			
Soil	0.30	0.30	
Clay	7.70	8.00	C
Sand	4.00	12.00	A
Pebbles	13.00	25.00	A
Gravel	5.00	30.00	A
Clay	25.00	55.00	C
PC-13			
Soil	0.50	0.50	
Clay, plastic, grey-blue	5.10	5.60	C
Sandy gravel, angular poorly sorted, dark-grey	1.30	6.90	A
Sand, angular, yellow	2.75	9.65	A
Sand, poorly sorted, dark-grey	1.95	11.60	A
Sand, yellow, and thin streaks of clay	3.00	14.60	B

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Clay, grey, and angular-grained streaks of sand	2.40	17.00	B
Clay, plastic, and thin streaks of sand	1.70	18.70	B
Phyllites, blue	13.10	31.80	D
PC-16			
Soil	0.50	0.50	
Clay, plastic, grey-blue	5.00	5.50	C
Sand, angular, grey	1.20	6.70	A
Clay, plastic, grey	4.30	11.00	C
Sand, dark-grey; and clay	1.90	12.90	B
Clay, grey	0.60	13.50	C
Sand, dark-grey	0.50	14.00	A
Clay, plastic, grey	4.00	18.00	C
Clay, plastic, grey; with gravel, phyllites and schist	5.30	23.30	B
Clay, plastic, grey	5.13	28.43	C
Gravel, grey	0.87	29.30	A
Clay, red	2.70	32.00	C
Gravel, angular; with grains of phyllites as large as 20 cm.	2.20	34.00	A
Clay, dark-grey	1.80	36.00	C
Gravel and sand, angular, dark-grey	3.00	39.00	A

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Clay, grey	4.75	43.75	C
Gravel, angular, dark-grey	4.75	48.50	A
Clay and thin streaks of sand	33.20	81.70	B
Gravel, angular	1.40	83.10	A
Clay, grey	15.40	98.50	C
Phyllites, blue	1.50	100.00	D
PC-22			
Clay, grey	5.00	5.00	C
Gravel and sand, angular	7.00	12.00	A
Clay, yellow	9.00	21.00	C
Gravel, angular	3.00	24.00	A
Clay, yellow	5.00	29.00	C
Gravel, angular	9.00	38.00	A
Clay, yellow	3.00	41.00	C
Gravel, angular	3.00	44.00	A
Clay, white	1.00	45.00	C
Gravel, angular	8.00	53.00	A
Clay, yellow	3.00	56.00	C
Gravel and sand	5.00	5.00	A
Gravel, sand and clay	8.00	13.00	B
Gravel, angular	11.00	24.00	A

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Gravel, angular with clay	6.00	30.00	B
Gravel, angular	6.00	36.00	A
Gravel and clay	5.00	41.00	B
Sand	3.00	44.00	A
Clay	1.00	45.00	C
Gravel, angular	4.00	49.00	A
Clay	1.00	50.00	C
Sand	2.00	52.00	A
Gravel	5.00	57.00	A
Gravel and clay	1.00	58.00	B
PC-24			
Clay, yellow	9.00	9.00	C
Sand and gravel	5.00	14.00	A
Clay	3.00	17.00	C
Gravel, angular	2.00	19.00	A
Clay	1.00	20.00	C
Gravel, angular	5.00	25.00	A
Clay	1.00	26.00	C
Gravel, angular	7.00	33.00	A
Gravel	6.00	39.00	A
Clay	1.00	40.00	C
Sand	6.00	46.00	A

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Clay	2.00	48.00	C
Sand and gravel	5.00	53.00	A
Clay	1.00	54.00	C
Gravel	1.50	55.50	A
Clay	1.50	57.00	C
PC-25			
Sandy clay	2.00	2.00	B
Sand and gravel	5.00	7.00	A
Clay, black	2.00	9.00	C
Sand and gravel	3.00	12.00	A
Clay, red	2.00	14.00	C
Clay and gravel	6.00	20.00	B
Gravel	5.00	25.00	A
Sandy clay, yellow	2.00	27.00	B
Gravel	2.00	29.00	A
Sandy clay, yellow	6.00	35.00	B
Gravel	7.00	42.00	A
Clay, yellow	2.00	44.00	C
Clay, yellow with gravel	6.00	50.00	B
Gravel	2.00	52.00	A
Clay, yellow with gravel	4.00	56.00	B

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
PC-26			
Gravel, angular	1.00	1.00	A
Sand	5.00	6.00	A
Gravel	10.00	16.00	A
Clay	5.50	21.50	C
Gravel	3.50	25.00	A
Clay	1.00	26.00	C
Gravel	7.00	33.00	A
Gravel and clay	9.00	42.00	B
Clay	3.00	45.00	C
Gravel	1.50	46.50	A
Gravel and clay	10.50	57.00	B
Sand	5.00	62.00	A
Clay, grey	1.00	63.00	C
PC-28			
Sandy clay	2.00	2.00	B
Gravel and sand	2.00	4.00	A
Clay, yellow	19.00	23.00	C
Gravel and sand	7.00	30.00	A
Clay and angular gravel	6.00	36.00	B
Clay	5.00	41.00	C
Clay and gravel	3.00	44.00	B

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Sand	1.00	45.00	A
Clay	3.00	48.00	C
Gravel	6.00	54.00	A
Gravel and clay	8.00	62.00	B
PC-29			
Soil	0.20	0.20	
Gravel and sand	12.80	13.00	A
Gravel	2.00	15.00	A
Clay	1.00	16.00	C
Gravel and sand	13.00	29.00	A
Clay	1.00	30.00	C
Gravel and sand	9.00	39.00	A
Clay	5.00	44.00	C
Gravel	8.00	52.00	A
Sandy clay	4.00	56.00	B
POC-2			
Soil	0.50	0.50	
Clay, grey and angular gravel	1.50	2.00	B
Sand and gravel, poorly sorted with grains of schist and phyllites	3.00	5.00	A
Gravel, angular, poorly sorted, grey	4.26	9.26	C

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Clay, sandy	9.04	18.30	B
Sand and clay	2.72	21.02	B
Clay	1.83	22.85	A
Sand and gravel, angular poorly sorted	0.90	23.75	A
Clay, grey and streaks of sand and gravel	19.25	43.00	B
Sand well sorted	0.60	43.60	A
Clay, red	10.40	54.00	C
POC-3			
Soil	0.50	0.50	
Gravel, angular, grey with grains of schist and phyllites	2.50	3.00	A
Sand and gravel, brown	5.90	8.90	A
Gravel, angular, dark-grey with grains of schist and phyllites	1.30	11.20	A
Clay, grey	3.80	15.00	C
Clay, dark-grey	1.70	16.70	C
Clay, yellow, and gravel	1.50	18.20	B
Clay, grey, and thin streaks of clay	6.80	25.00	B
Gravel and sand with grains of schist and phyllites as large as 2 cm.	3.50	28.50	A

Description of material	Thickness (meters)	Depth (meters)	Water-Yielding Category
Gravel, angular with grains of phyllites as large as 10 cm.	2.10	30.60	A
Gravel, angular with streaks of clay	11.80	42.40	B
Clay, dark-grey with streaks of sand	6.90	49.30	B
Clay, grey	4.90	54.20	C
Gravel, angular with grains of phyllites and schist	3.00	57.20	B

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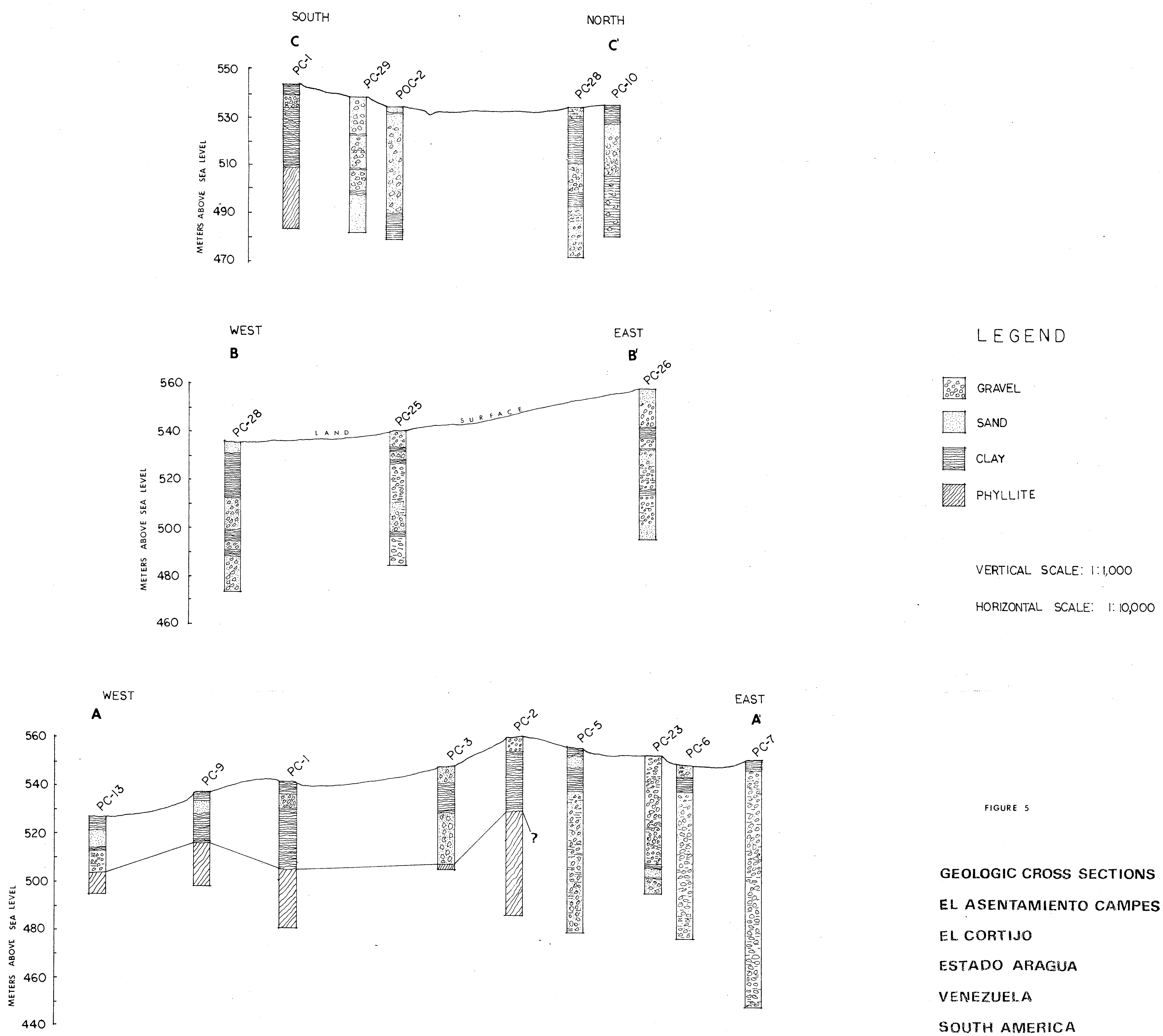
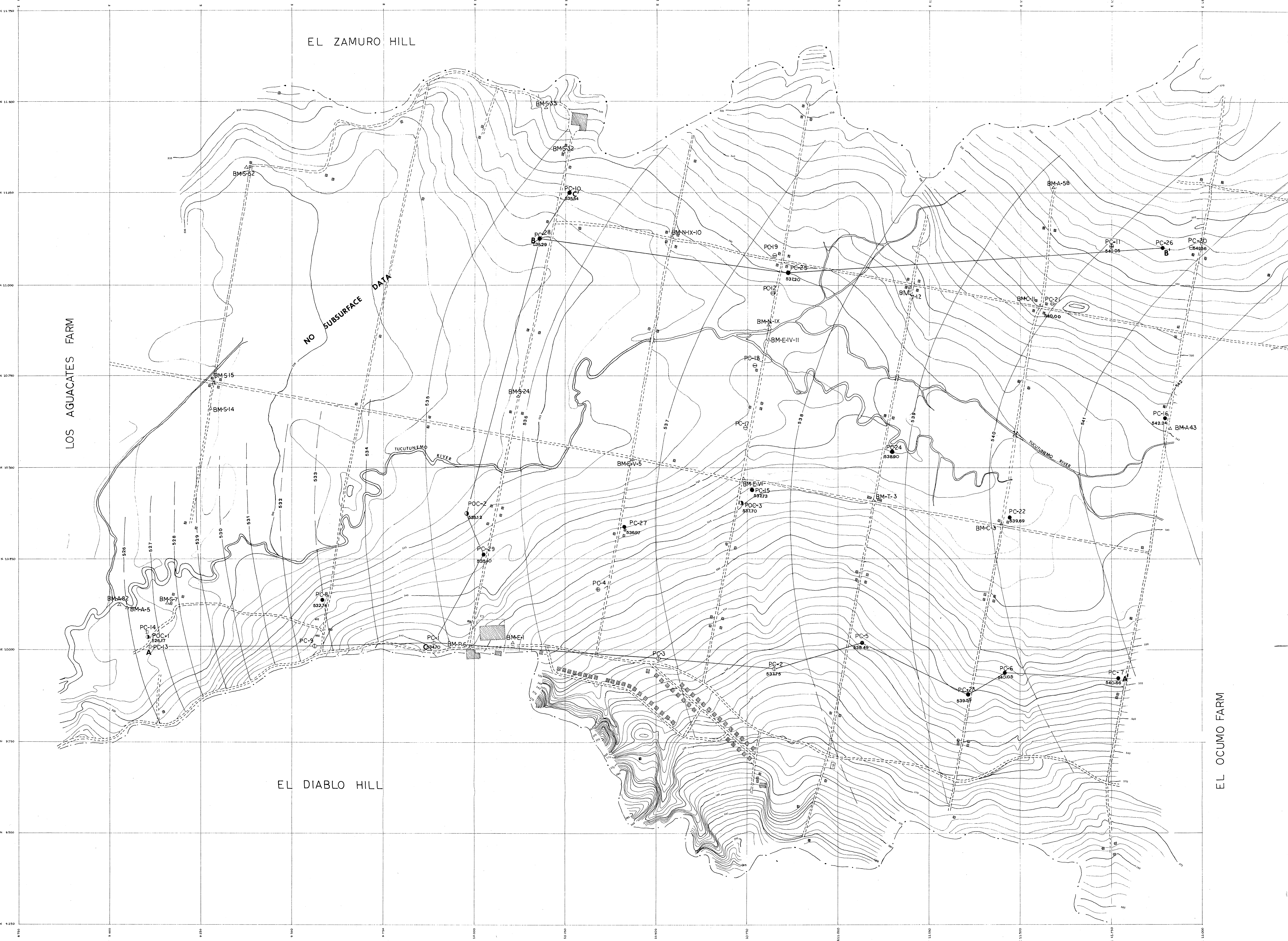


FIGURE 5

GEOLOGIC CROSS SECTIONS
EL ASENTAMIENTO CAMPESINO
EL CORTIJO
ESTADO ARAGUA
VENEZUELA
SOUTH AMERICA

GEOLOGY 1970 THESIS

ROMULO MARQUEZ OROPEZA



LEGEND

- 550 — Topographic Contour Lines
- BM-S-22 △ — Vertical control station (Bench Mark)
- Unimproved dirt road
- –x–x–x– — Fence line
- Bridge
- Buildings (barn, warehouse, rural house, etc.)
- Chapel
- River
- Washes
- ● PC-16 — Irrigation well in good condition and water level in meters.
- ⦶ PC-1 — Abandoned water well (uneconomical yield) and water level in meters
- ⊕ PC-4 — Abandoned water well (obstructed)
- Geological boundaries (limit of alluvial fill)
- ⊖ PC-12 — Dug well
- —540— — Water level contour (based on 1966 water level data)
- ◑ POC-2 — Observation water well and water level in meters
- A——A′ — Line of cross section

NOTE This map is based on information furnished by the Division de Geotecnia Ministerio de Obras Publicas, Caracas, Venezuela

Datum is M.S.L. (Meters)

SCALE:

Meters

0 100 200 250

$1:33\frac{1}{3}$

FIGURE 2

MAP OF THE

EL ASENTAMIENTO CAMPESINO

EL CORTIJO

ESTADO ARAGUA

VENEZUELA

SOUTH AMERICA

GEOLOGY 1970 THESIS

RUMULO MARQUEZ OROPEZA