Ground-Water Resources of the Lambayeque Valley, Department of Lambayeque, Northern Peru

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1663-F

Prepared in cooperation with
the Government of Peru
under the auspices of the
U.S. Agency for International Development

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By STUART L. SCHOFF *and* JUAN LUÍS SAYÁN M.

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO HYDROLOGY OF LATIN AMERICA AND THE ANTILLES

GROUND-WATER RESOURCES OF THE LAMBAYEQUE VALLEY, DEPARTMENT OF LAMBAYEQUE, NORTHERN PERU

By STUART L. SCHOFF [1] and JUAN LUÍS SAYÁN M.[2]

ABSTRACT

Ground water in the Lambayeque Valley has been developed mainly for irrigation of sugarcane and rice. The locality is on the coastal plain of northern Peru, about 650 km (kilometers) northwest of Lima, the national capital. The area considered in this study is about 1,670 sq km (square kilometers) and is mainly on the alluvial fan of Río Chancay and entirely in the Department of Lambayeque. Chiclayo, the departmental capital and largest city, has a population of about 46,000. The climate is hot and virtually rainless. Agriculture is dependent on irrigation. The available water, whether in streams or underground, is introduced from the Andean highlands by Río Chancay.

Rocks in the area range in age from Cretaceous, or possibly Jurassic, to Quaternary and in lithology from dense and hard igneous, sedimentary, and metamorphic rocks to unconsolidated sediments. The bedrock contains and yields water only in small quantities, if at all. The principal water-bearing strata are in the alluvium comprising the fan of Río Chancay. Where ground water in the alluvium has been most intensively developed, the productive zone is within 20 m (meters) of the land surface and is composed approximately as follows: (1) relatively impermeable soil, clay, and clayey sand, 5 to 10 m thick, (2) permeable sand and gravel, 6 to 10 m thick, at places including one or more layers of clay, so that several water-bearing beds are distinguishable, and (3) relatively impermeable mixtures of clay, sand, and gravel extending below the bottom of wells. Unit 3 in the deepest test continued to 102 m. Unit 2 is the principal source of water tapped by irrigation wells.

In the northern part of the area wells locally yield water rather freely from strata as deep as 73 m, but elsewhere in the area the strata deeper than 20 m are not very productive. Wells at and near Chiclayo yield only small amounts, and the deepest well disclosed, in 100 m of material, only 5.5 m of material that can be considered as possibly water bearing.

Water in the alluvium of the eastern part of the area occurs under water-table conditions at depths from 1 to 8 m below the land surface. The water table declines during pumping for irrigation and rises when pumping is stopped. Recharge comes mainly from infiltration on irrigated fields and from irrigation

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ditches and probably varies greatly from year to year at any given place. The ground-water reservoir is replenished when pumps are idle; therefore, it is concluded that the recharge is sufficient to offset withdrawal at a rate comparable to that of 1957, which was about 81 million cu m (cubic meters). A study of the effect of protracted pumping on yields of wells suggests that the rate of recharge locally, and for a short period, was more than 76,000 cu m per day. This recharge presumably declined rapidly to zero when irrigation was suspended in the locality.

A pumping test showed the transmissivity to be about 950 cu m per day per m and the storage coefficient to be about 0.07. Based on these coefficients, the drawdown caused by one well discharging 10 lps (liters per second) for 6 months would be only 0.066 m at points 4,000 m distant, but 50 wells at the same rate and distance would create 3.3 m of drawdown. As actual distances between wells range from 100 to 300 m where the wells are most numerous and as the average discharge rate is nearer to 20 than to 10 lps, the cumulative effect of the actual pumping is certain to be considerable. If it were not for the recharge resulting from infiltration of irrigation water, the pumping of so many wells probably could not be long sustained.

The waters from wells of the Lambayeque Valley compare favorably, in most respects, with the standards established by the U.S. Public Health Service for water for human consumption. Chemical analyses of 10 samples of ground water show that the dissolved solids, silica, bicarbonate, sulfate, and sodium increase in the downstream direction, whereas the amount of calcium, and concurrently the hardness, decrease. The ground water in the upper part of the valley is satisfactory for irrigation use, but the water at Chiclayo, represented by one mixed sample from two wells 110 m apart, is poor. Thus, deterioration in water quality from the apex of the fan toward the coast takes place.

Development of ground water has been carried out principally for irrigation and mainly by means of drilled wells. Most of the wells have been drilled by the percussion method. The average yield obtained from a meter of water-bearing stratum has been 6.7 lps in initial pumping tests but only 3.5 lps under steady pumping. The average yield per meter of installed well screen was 4.9 lps in initial tests but declined under steady pumping to 2.5 lps. About 83 percent of the water-bearing strata in a large group of wells had been screened, and about 84 percent of the screen was effectively placed.

Further development of the ground water will depend on finding large areas of water-bearing strata not already developed and on tapping them without detriment to previous users. The upper part of the valley already was intensively developed when fieldwork for this report ended, and further development there could advantageously have awaited analysis of the results and effects attained. Development in the lower part is likely to be limited by inferior chemical quality of the ground water. The area west of the Pan-American Highway may have only poor quality water.

INTRODUCTION

This report summarizes an investigation of the ground-water resources of the Lambayeque Valley, near Chiclayo in northwestern Peru. It deals principally, but not exclusively, with an area upstream from (east of) Chiclayo, because there many irrigation wells have been drilled and pumped on sugar haciendas. The purpose of the investigation was to collect the data resulting from drilling and pumping operations on the haciendas, to substantiate additional geologic

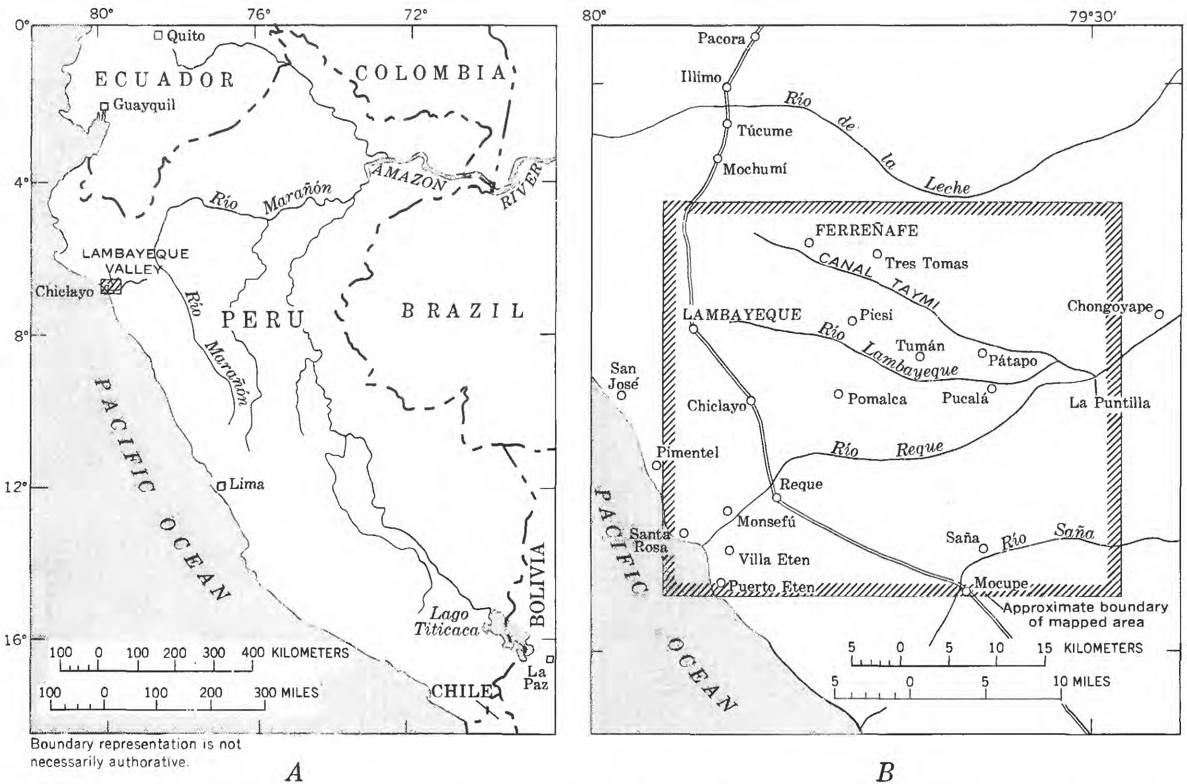

FIGURE 1.—Index maps. *A*, Location of Lambayeque Valley in Peru. *B*, Principal geographic features of the mapped area and vicinity.

and hydrologic facts by observation, to compare and correlate these facts, and to analyze all these facts and data. It was hoped that an understanding of the occurrence, movement, recharge, discharge, abundance, and chemical quality of the ground water might lead to more effective use of the water.

A pumping test, probably the first undertaken in Peru, was made in order to determine hydraulic characteristics of the principal aquifer. The results of this test may be of use to well owners, well drillers, and engineers concerned with ground-water development, even though the alluvial aquifers in other valleys along the Peruvian coast are certain to differ considerably from the one in the Lambayeque Valley.

AUSPICES

The International Cooperation Administration (later Agency for International Development) sponsored the investigation through its Mission to Peru. Messrs. John R. Neale and Vance Rogers were, successively, mission director. The Comisión de Colaboración, which represented the United States Geological Survey and the Instituto Nacional de Investigación y Fomento Mineros, planned and directed the investigation. Messrs. Frank S. Simons and W. W. Olive were, successively, chief of the party for the Geological Survey, and Augusto Cabrera La Rosa was director of the Instituto. The Servicio Cooperativo Interamericano de Irrigación, Vías de Comunicación, e Industrias, an agency operated jointly by the Peruvian and United States Governments, shared the conduct of the investigation with the Geological Survey. Mr. Charles R. Whipple was head of the Servicio.

LOCATION OF THE AREA

The area covered by this report comprises about 1,670 sq km (square kilometers) of northwestern coastal Peru, about 650 km (kilometers) northwest of Lima, the national capital (fig. 1). It is entirely within the Department of Lambayeque and includes parts of each of the three Provinces that make up the Department. It includes the provincial capitals, which bear the names of the Provinces and are Lambayeque, Ferreñafe, and Chiclayo. Chiclayo, the largest city, is also the capital of the Department. Its location is lat 6°46′ S and long 79°51′ W. The mapped area includes about 11 km of the Pacific shore and extends eastward for about 57 km. Northward it extends a maximum of 39 km. The cities, towns, and villages of the area are shown in figure 1 and on plate 1.

PREVIOUS INVESTIGATIONS

A detailed study of the bedrock geology of the Lambayeque Valley and vicinity had not been made up to the time of the investigation

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described here. The only geologic paper describing bedrock geology was Solar's report (1944) on limestone for industrial purposes; however, several hydrologic studies had been made, as follows:

Adams (1905, p. 93–101) described the Chancay basin and reported the flow of the Ríos Chancay, Reque, and Lambayeque. He also gave information on the distribution of the water and on the irrigated area.

García (1921, p. 38–41) reported the flow of Río Chancay for the years 1911–20, when discharge was being measured at La Puntilla. He included discharge of the main irrigation ditches for the year 1912.

San Martín (1929) concluded that wells would yield too little water for irrigation use, except near the town of Lambayeque. He regarded 100 liters per minute per meter of penetration of the aquifer as the practical minimum discharge for irrigation. This would require about 6 m (meters) of aquifer thickness for each 10 lps (liters per second) of water pumped.

Mercado (1929) summarized the factors that control seepage losses along irrigation canals. He stated that Taymi Canal was losing 20 percent of its volume in 40 km, that is, 0.5 percent per kilometer.

Leigh (1929, p. 883) estimated the amount of infiltration along segments of Río Chancay. He reported that Río Reque is fed from the ground-water reservoir, which in turn is replenished by infiltration from lands irrigated with water from Río Lambayeque.

Conkling (1939, p. 67–73) described the alluvial deposits of the Chiclayo area as a delta occupying a broad band that extends many kilometers from the toe of the mountains to the coast. In his opinion, the part of the valley most favorable for development of irrigation wells is upstream from the line of hills to which Cerro de Combo and Cerro Boró belong. Conditions west of the hills, he wrote, are not favorable, notwithstanding the existence of several shallow wells of small yield, as well as a deeper one from which 30 lps had been obtained.

Petersen (1956, p. 307–315) reported that by 1955 more than 125 wells had been drilled between Hacienda Cuculí and Chiclayo and near Ferreñafe and Mochumí (fig. 1). All but seven tapped water-bearing strata between 5 and 30 m below the land surface. He regarded the principal source of ground water in the alluvial fan to be infiltration from the Río Chancay channel above La Puntilla. Quoting previous estimates for Carhuaquero (the gaging station), he chose 1,100 to 1,500 lps as a reasonable order of magnitude for the underground flow, a part of which, he stated, enters the shallow aquifer in the alluvial fan. He considered the infiltration from irrigated fields to be negligible because the surface layer of clay, which had been found in many wells, should have prevented or greatly retarded it. He showed that sulfate, chloride, and sodium in the ground water increase westward gradually between Haciendas Pátapo and Pomalca and rapidly between Pomalca and Chiclayo.

In addition to the published reports cited above, several manuscript reports, or summaries of them, were available to the authors of this report, as follows:

I. H. Tafur A. in 1950 submitted "Informe Geológico Preliminar de la Napa Freática del Cono de Deyección del Río Chancay" to the Dirección de Aguas e Irrigación of the Ministerio de Fomento y Obras Públicas. He stated that the ground water in the alluvial fan of the Chancay was derived from the surface by infiltration, and he regarded the area between La Puntilla and Pátapo as the most favorable for ground-water development. He reported that the Taymi Canal was losing substantial quantities of water by infiltration.

Augusto Duffaut V. in 1950 wrote "Informe Preliminar Sobre la Captación de Agua Subterranea en el Valle del Río Lambayeque" for the Sub-Dirección de Obras Sanitárias of the Ministerio de Fomento y Obras Públicas. He recognized that, for practical purposes, all the water in the area is introduced by the Río Chancay. He concluded that it would be impractical to develop 1,200 lps of ground water, the quantity needed by Chiclayo, and to transport it to the city.

Bussel's report, also dated 1950, is summarized by Pons, Alfaro, and Arrisueño (see below) and is entitled "Informe Hidrológico de Chiclayo". This report called attention to a shallow sandy-clay aquifer 2.5 m thick and to a deep aquifer of alternating permeable and impermeable strata, both in the Chiclayo area. The author reported that some wells had been abandoned because of increasing hardness of the water.

Alfonso Pons M., Juan Alfaro S., and José Arrisueño A. in 1954 reported on "Ampliación y Mejoramiento del Servicio de Agua Potable de Chiclayo." They regarded the strata in the immediate vicinity of Chiclayo as too fine grained and too impermeable to yield enough water for the city. They reported undeveloped ground water at Hacienda Calupe, which, however, would cost the city too much to develop.

Pedro Verástegui M. in 1955 reported to the Empresa Petrolera Fiscal of the Ministerio de Fomento y Obras Públicas on "El Problema de las Aguas Subterráneas del Valle en Donde Se Ubica la Ciudad de Chiclayo en Relación con el Abastecimiento de Agua Potable." He mentioned two wells drilled in 1954 between Picsi and Ferreñafe, which yielded 60 to 70 lps from depths of about 70 m. He suggested that these wells might have tapped a hydraulic system independent of the shallow aquifer already developed, to some extent, by the haciendas.

PRESENT INVESTIGATION

Fieldwork was done intermittently between September 1955 and April 1958 in 13 trips most of which lasted 10 days to 2 weeks each. These trips were scheduled so that water levels would be measured just before and shortly after the main pumping season of the sugar haciendas and bimonthly during the nonpumping season. On each visit to the area, geologic, hydrologic, and geographic information was obtained in addition to the water-level mesurements. Much of the work of this investigation was the collection and analysis of data resulting from the test drilling and well development carried out by the agricultural enterprises in the area. Well drilling was still in progress and was observed as a means to understanding well-driller practices in both logging strata and well construction, but regular collection and description of the drill cuttings was not attempted. Drillers' logs, therefore, provide practically all the stratigraphic information.

The information from drillers' logs was supplemented with observations by the authors. Water-level measurements were made principally by the wetted-tape method and were made periodically in most of the wells of Negociación Tumán. Having been completed only recently, many of these wells lacked pumps and therefore afforded opportunity for a year or more of water-level record free of disturbances caused by pumping in the wells themselves. Measurements had to be omitted or discontinued when pumping was begun, but as pumping increased, the averages of the water levels suggested the extent to which the ground-water reservoir was being exhausted and also, during nonpumping periods, the extent of replenishment of the reservoir.

Measurements of water level in pumping wells were made in order to verify drawdowns. Where possible, these measurements were made by the wetted-tape method, but where obstructions prevented lowering a tape into a well, or where splashing or cascading water made tape readings inaccurate, air-pressure readings from gages at the wells were used ("air-line" method).

The altitudes of most of the irrigation wells of Negociación Tumán, referred to an assumed datum, were determined by Segundo Ortiz, topographer of the Servicio Cooperativo Interamericano de Irrigación, Vías de Communicación, e Industrias, by using a standard surveyor's level. The maximum error in closure was 0.025 m, which, although relatively large, has little effect on the position of a water-table contour line on the maps at the scale of those on plate 3.

The pumping test is described in detail elsewhere in this report. The samples of water collected during this test were analyzed in laboratories of both the Instituto Nacional de Investigación y Fomento

Mineros, Lima, and the U.S. Geological Survey, Washington, D.C. These analyses are supplemented by analyses, previously made in commercial laboratories, of waters which were obtained from wells of haciendas or business enterprises.

The base map (pl. 1) accompanying this report was compiled from several sources, beginning with the topographic sheets of the Carta Nacional del Peru. Most of the drainage and some of the roads were taken from the index sheet of aerial photographs by the Servicio Aerofotográfico Nacional. Other details, especially the well locations, are from hacienda maps or from maps of the Sub-Dirección de Obras Sanitarias del Ministerio de Fomento.

WELL-NUMBERING SYSTEM

The numbers assigned to wells and test holes in this report are referred to a grid of north-south and east-west lines superimposed arbitrarily on the map (pl. 1). These lines are 1 km apart and therefore enclose areas of 1 sq km each. The vertical rows of squares are numbered along the top and bottom of the map, beginning from the left (west). The numbers run from 1 to 53. The tiers are lettered along the sides by utilizing a full alphabet of capital letters (except O, which can be confused with zero) and about half an alphabet of lowercase letters (excluding l and o). A well in vertical row 15 and tier E is numbered 15E. A well symbol on a north-south grid line belongs to the square on the west; that is, to the square having the lower number. If a well symbol is on an east-west grid line, it belongs to the square on the north; that is, to the square nearer the beginning of the alphabet.

Where only one well or one test hole occurs within a square, no further differentiation is necessary, but where several wells are within the same square, serial numbers are added to distinguish them. For example, three test holes occur within square 27W and are numbered 27W–1, 27W–2, and 27W–3. The numbers 1, 2, and 3 appear on the map beside the corresponding well symbols.

Production wells and test holes at the same location have identical numbers, but can be distinguished by the terminology employed. Holes drilled only for exploration are called test holes; those drilled with the intention of pumping water to the surface are called wells.

ACKNOWLEDGMENTS

The authors of this report are indebted to many public and private organizations and individuals whose cooperation made this investigation possible. To name them all is impractical, but special thanks are due Sres. Felipe Pardo and José D'Ornellas, of Negociación Tumán, Lima, for free access to the properties of the Negociación and for arrangements that facilitated the work. Their generous cooperation was made effective in the field by Engineers Edgard Schindler, Jorge Reyes, and Enrique Garrido Lecca, whose kindnesses went far beyond bare cooperation. To have duplicated the test drilling and well data put at our disposal would have been costly beyond the means available.

Sres. Hernán Mercado, of Sociedad Agrícola Pucalá, Juan de la Piedra and Luciano Gonzales, of Sociedad Agrícola Pomalca, and Carlos Fraefel, manager for Compañía Peruana de Alimentos Lácteos, S.A. (Perulac), furnished well records, pumpage records, and water-quality information. Engineer Adolfo D. Zulueta Acuña, director of the Chiclayo office of the Dirección de Aguas e Irrigación, arranged for special gaging of the flows of Río Lambayeque and several irrigation ditches. Sres. Alfredo Muñoz C., of the regional office of the Ministerio de Agricultura, Lambayeque, and Roberto Carranza G., of the Servicio Cooperativo Interamericano de Producción de Alimentos, Chiclayo, provided information about haciendas and other named places appearing on old maps. Sr. Luís Heredia Castro and Engineer A. Delgado Revilla, of the Dirección de Caminos of the Ministerio de Fomento y Obras Públicas, provided information about roads.

GEOGRAPHY

The area described in this report is one of many rich valleys that interrupt the desolation of the Peruvian coastal desert. It is productive because a river, Río Chancay, brings water from the Andes Mountains and makes possible the irrigation of thousands of hectares. The prime importance of water is manifest along the margins of the valley, where a knife-edge line demarcates irrigated and nonirrigated land. Soil, climate, markets, and other factors play their part, but would be useless without the river water. Although part of the water used for irrigation is pumped from wells, the well water is also supplied, in the ultimate sense, by the river.

The productive part of the report area is the alluvial fan of Río Chancay, which lies between the foothills of the Andes Mountains and the Pacific Ocean. The alluviated plains are so extensive and their slopes are so uniform that the fan form is imperceptible. On these plains, the economic activity of the area takes place. Here sugarcane, rice, and other crops are grown. Here are the cities and towns.

TOPOGRAPHY

The mapped area comprises the alluvial fan of Río Chancay, a short segment of the canyon above the apex of the fan, and the Andean foothills that confine the canyon and partly mark the canyon and the boundaries of the fan. Altitudes within the mapped area range from sea level to more than 1,000 m above sea level.

The canyon ends and the alluvial fan begins approximately at La Puntilla (pl. 1, coordinates 48S). Bedrock ridges and hills south of the fan continue southwestward with interruptions to Morro Eten (altitude 195 m) on the coast at Puerto Eten. The highest peak on the south side of the valley is Cerro Pampa Grande, 1,060 m above sea level.

The bedrock hills north of the fan extend westward from La Puntilla about 17 km, and near Hacienda Pátapo their base swings northward, continuing this trend to the boundary of the mapped area. The highest peak on this side of the valley is Cerro Azul (or "Pátapo"), altitude 860 m. Some of the peaks, especially in the western part, are isolated by flat alluviated bottom lands from the main body of the foothills.

The north boundary, chosen arbitrarily to include the town of Ferreñafe, only approximates the north boundary of the Chancay alluvial fan. This fan in the area west of the foothills merges with the fan of Río de la Leche, and typical valley form is lacking.

The alluvial fan is not a plain of unrelieved monotony. Several bedrock hills project 100 to 150 m above the plain. Among them are Cerro San José, Cerro Morropío, Cerro de Combo (twin peak, altitude 211 m), and Cerro Boró, which form a chain of hills transverse to the valley axis. Independent of this chain is a pair of hills immediately west of Chiclayo, the larger of which is named Cerro Pimentel. In addition, other small unnamed hills project here and there, as at Hacienda Pátapo and half a dozen kilometers to the east of Pátapo.

The monotony of the plains is broken also by sand dunes, which rise above the general ground level at San Miguel (pl. 1, coordinates 19M), near Rinconazo (coordinates 28Z), and south of the town of Lambayeque (fig. 2). Other prominent features on the plains are mounds of adobes known as huacas, some of them many meters high, left by ancient inhabitants of the valley.

The alluvial plains slope gently away from the foothills. The slopes on the main part of the fan range from about 3 m per 1,000 m (near La Puntilla) to about 1 m per 1,000 m (near the coast). Slopes are steeper near the base of the foothills—4 m per 1,000 m between Luya and Picsi, for example. They are also steeper on the fans of tributaries, such as the Pampa de Burros just east of Pátapo, which even in its lower part slopes 5 m per 1,000 m.

DRAINAGE

Río Chancay, its tributaries, and its distributaries control the hydrology of the area covered by this report. The Chancay rises in the

FIGURE 2.—Sand dune beside Pan-American Highway a few kilometers south of Lambayeque.

Andes. Near the village of Lajas (east of the mapped area) it receives water diverted by canal and tunnel from the Chotano basin, which is on the Atlantic side of the Continental Divide. The maximum diversion, 35 cms (cubic meters per second), is governed by the capacity of the diversion works. The river emerges from the mountains onto its alluvial fan at La Puntilla. Here the distributaries begin.

Control works at La Puntilla divide the water between two main streams, Río Reque and Río Lambayeque (fig. 3). The Reque closely follows the southern margin of the alluvial fan and discharges into the Pacific Ocean north of Puerto Eten. Downstream from Villa Eten it is called Río Eten.

Río Lambayeque flows westward approximately along the axis of the fan. It passes between Haciendas Pátapo and Pucalá, south of Hacienda Tumán, and north of Hacienda Pomalca. Its flow generally ceases in the area north of Chiclayo, owing in large part to diversions of water for irrigation and for the public water supplies of Chiclayo and Lambayeque. The river channel becomes virtually unidentifiable west of Lambayeque.

Part of the flow of Río Lambayeque is directed into Taymi Canal at diversion works about 2 km downstream from the head of the river (La Puntilla). The canal rather closely follows the base of the mountains, extending beyond the town of Ferreñafe. The canal immediately east of Pátapo, entrenched about 5 m, is about 11 m wide (fig.

FIGURE 3.—Diversion works at La Puntilla. Río Reque flows diagonally toward upper right corner of photograph. Río Lambayeque flows horizontally to the right.

4). Although it loses considerable water by seepage to the alluvial sediments, large areas are irrigated by laterals leading from it.

The roles of the two distributaries were reversed in 1925 by flood scour. José D'Ornellas (oral commun., 1958) reported that the Lambayeque had been the main line of natural discharge. Its channel was deeply entrenched, and the flow discharged into the Pacific Ocean. Río Reque, on the other hand, had a channel which was only slightly entrenched and which, like that of the Lambayeque today, tended to fill with sediment.

Flood scour has made Río Reque the main distributary, and if it were not for the artificial control imposed at La Puntilla, the Reque today would carry most of the water. It has entrenched itself 10 m at the Rinconazo bridge and has a channel about 12 m wide (fig. 5). Downstream near the village of Reque, it is entrenched only 5 m and has a channel about 37 m wide. The Reque is a gaining stream which receives water from ground water as it flows seaward.

Río Lambayeque probably is a gaining stream, although segments of it, especially in downstream reaches, may lose water. Where it passes from the properties of Pucalá to those of Tumán (fig. 2, coordinates 33V), the river is several meters below the static water levels in nearby wells and hence is a gaining stream. The river probably gains less from ground water than does the Reque, because it is less deeply entrenched, and the adjacent water-table slopes are therefore less steep. The river

FIGURE 4.—Taymi Canal at highway bridge immediately east of Hacienda Pátapo's headquarters. Channel depth, about 5 m. Stream width, about 11.5 m.

FIGURE 5.—Río Reque near Rinconazo. Channel is entrenched about 10 m.

surface generally is only 1 to 3 m below the level of the plains (fig. 6). The width of the Lambayeque channel at Hacienda Tumán is about 15 m. The width at the railroad and highway bridges east of Cerro de Combo (plate 1, coordinates 23T) totals 29 m, divided in two channels.

FIGURE 6—Río Lambayeque at bridge immediately south of Tumán, in flood. The banks are low; entrenchment is slight.

The runoff of Río Chancay, based on the records from two gaging stations, has averaged somewhat more than 900 million cu m (cubic meters) annually, but it has ranged from about 460 million to more than 3,000 million cu m (table 1). The distribution of flow to water users is based on the discharge as gaged near Hacienda Carhauquero, about 35 km upstream fiom La Puntilla. The reported percentages differ slightly, but the distribution plan is approximately as follows: 10 percent is used along the canyon between the gaging station and La Puntilla, about 12 percent goes into Río Reque, 44 percent goes to Río Lambayeque, and 34 percent goes into Taymi canal.

TABLE 1.—*Summary of discharge of the Río Chancay, based on 44-year record of measurements at La Puntilla and Carhuaquero gaging stations*

[Data from the Servicio Hidrológico, Ministerio de Fomento y Obras Públicas]

Monthly averages			
Month	Millions of cubic meters	Month	Millions of cubic meters
January	67. 4	July	29. 8
February	110. 7	August	20. 1
March	185. 4	September	22. 9
April	185. 8	October	43. 5
May	104. 1	November	44. 3
June	53. 7	December	49. 8

TABLE 1.—*Summary of discharge of the Río Chancay*—Con.

Annual

	Millions of cubic meters
Minimum (1950)	459. 8
Maximum (1925)	3, 247. 1
Average of 44-year record	917. 1

CLIMATE

The climate of the Lambayeque Valley is hot and practically rainless (tables 2 and 3). The official climatic records kept by the regional office of the Ministerio de Agricultura at Lambayeque begin with 1950, and the data collected for this investigation end, necessarily, with March 1957. Although this record is short, it confirms the historical observation that coastal Peru is a desert—a desert since the Spanish conquest, at least.

TABLE 2.—*Mean maximum and mean minimum monthly and annual temperatures, and mean annual temperatures, in degrees centigrade, at Lambayeque and Tumán, 1950–56*

[Data from records of the regional office of the Ministerio de Agricultura and of Negociación Tumán]

	Mean maximum temperature		Mean minimum temperature	
	Lambayeque	Hacienda Tumán	Lambayeque	Hacienda Tumán
January	29. 5	30. 2	18. 4	19. 8
February	31. 0	31. 5	19. 3	20. 8
March	30. 4	31. 3	18. 9	20. 8
April	28. 5	29. 2	17. 6	19. 1
May	26. 5	27. 0	16. 7	17. 6
June	24. 0	24. 7	14. 8	16. 1
July	22. 6	23. 4	13. 5	15. 3
August	22. 4	23. 9	13. 5	14. 8
September	23. 4	24. 8	14. 0	15. 2
October	24. 0	25. 1	14. 3	15. 3
November	25. 6	26. 0	15. 7	16. 0
December	27. 1	27. 6	16. 8	17. 3
Annual	26. 2	27. 1	16. 1	17. 3

Mean annual temperature:	
Lambayeque	21. 1
Hacienda Tumán	22. 2

This record shows that, in the 7 years from 1950 to 1956, the mean annual temperature was about 21°C. The warmest month was February, with a mean daily temperature of approximately 25°C, and the coolest was August, with 18°C. July, however, was only a fraction of a degree warmer than August. The precipitation in the same 7 years ranged from 3 to 14 mm (millimeters) per year, and the maximum in

TABLE 3.—*Precipitation at Lambayeque, 1950–56, in millimeters*

[Data from records of the regional office of the Ministerio de Agricultura. Tr, trace; —, not recorded]

Month	1950	1951	1952	1953	1954	1955	1956
January	0. 4	0. 3	—	1. 75	0. 75	0. 35	2. 85
February	. 8	. 2	—	2. 15	—	. 4	—
March	3. 1	. 4	0. 9	1. 4	. 2	1. 2	—
April	—	1. 2	1. 4	3. 0	Tr	. 4	. 25
May	Tr	. 4	—	. 9	1. 4	—	. 3
June	Tr	. 43	—	Tr	Tr	. 2	. 2
July	Tr	—	—	1. 0	Tr	—	Tr
August	Tr	—	. 6	Tr	—	—	Tr
September	2. 6	—	Tr	2. 0	—	1. 3	Tr
October	Tr	1. 2	—	. 6	. 63	2. 1	. 85
November	—	2. 9	—	1. 2	Tr	2. 3	. 2
December	3. 65	1. 3	—	—	. 9	. 5	—
Total	10. 55	8. 33	2. 9	14. 0	3. 88	8 75	4. 65

any month was 3.65 mm. The erratic character of the precipitation is suggested by the fact that the precipitation for the single month of March 1957 was 14.4 mm, exceeding slightly the greatest annual precipitation in any one of the preceding 7 years.

Precipitation at Hacienda Tumán, recorded unofficially through 1956 and early 1957, was higher than at Lambayeque, but this comparison means little because the record is short. As at Lambayeque, the annual total was exceeded by the precipitation for the month of March 1957, which was 24.5 mm. The temperature record at Tumán from 1950 to 1956 was similar to that for Lambayeque: annual mean temperature, about 22°C; warmest month, February (mean daily, 26°C), but March nearly the same; coolest months, July and August (mean daily, 19.3°C). The maximum temperature recorded at Tumán was 35.5°C, in March 1950, and the minimum was 11°C, in July 1952.

Evaporation measured at Lambayeque for 34 months from June 1954 to March 1957 inclusive, averaged about 3 mm daily. The total evaporation for 1955 was about 985 mm and for 1956, about 1,170 mm. These totals are the amounts evaporated when water was continuously supplied. The amount supplied under natural conditions varies greatly and often approaches zero, so that the natural evaporation should have been less than indicated. The highest average daily rate recorded in the 34-month period was 5.5 mm (December 1956) and the lowest was 2.2 mm (July 1954 and June 1955).

POPULATION

The area considered in this report cuts across the geographic units for which statistics are usually reported, and for this reason the total population of the report area is not known. The city of Chiclayo in the 1940 census had a population of 31,539, which was estimated to have become 46,000 by 1953. Lambayeque in 1940 had 6,614, which by 1953 may have become 11,000. Ferreñafe in 1940 had 8,812; its 1953 population was not estimated. The towns, however, are only part of the total population, for many people live outside them. Some of the haciendas have large resident populations. Hacienda Tumán, for one, was said to have about 6,000.

COMMUNICATIONS

Chiclayo is linked with Lima and other coastal cities by air, highway, and sea. Communication within the area is facilitated by paved or graded roads and by railroad.

The Carretera Panamericana (Pan-American Highway) crosses the area from north to south and passes through Lambayeque, Chiclayo, and Reque. It is paved throughout, and from it connecting roads lead to Pimentel and Santa Rosa, to Monsefú, and to Puerto Eten. The highway leading eastward via Pomalca, Tumán, and Pátapo by 1958 had been paved as far as La Puntilla. Graded roads connect Chiclayo with Ferreñafe and with the fishing village of San José (on the coast just west of the mapped area). Private roads give access to practically all parts of the haciendas; only a few of the more important of these roads, being privately controlled, are shown on the map (pl. 1).

Rail connection between Puerto Eten and Ferreñafe via Chiclayo and Lambayeque is provided by the Empresa del Ferrocarril y Muelle de Eten. It has a branch line eastward from Chiclayo to Pátapo. Rail connection between Pimentel and Pucalá via Chiclayo and Pomalca is provided by the Compañía del Ferrocarril y Muelle de Pimentel. The Ferrocarril Eten-Hacienda Cayaltí extends eastward from Puerto Eten to serve a locality beyond the border of the map.

ECONOMIC DEVELOPMENT

The economy of the region is agricultural, and the greater part of the cultivated land is devoted to sugarcane and rice. In these crops the report area ranks first in Peru, but it also produces many other crops. The available agricultural statistics are for the region, of which the Lambayeque Valley is part. These show that the cultivated land in the region was 39,512 hectares in 1956, and the total production was nearly 1,700,000 tons (table 4).

The large haciendas have their own sugar mills and rice polishing plants. The industries of the towns are largely based on agricultural products, as table 5 suggests.

The large haciendas have grown by absorbing neighboring lands and now control thousands of hectares. They function as corporations, with corps of resident engineers managing complex and diversified

TABLE 4.—*Crops grown in the Lambayeque area in 1956*

[Data from the regional office of the Ministerio de Agricultura, Lambayeque, courtesy José Gutierrez]

Crop	Hectares	Metric tons	Crop	Hectares	Metric tons
Sugarcane	15,773	1,511,939	Wheat	103	91
Rice	15,727	53,466	Sorghum	97	778
Hay	2,602	82,854	Chickpeas	68	37
Corn	2,331	2,474	Grapes	15	66
Beans	735	507	Sesame	8	5
Yucca	557	4,247	Pallar	7	3
Sweet potatoes	480	3,321	Kenaf	6	156
Fruits	340	4,509	Coffee	3	1.5
Cotton	217	180	Olives	.4	.3
Vegetables	168	2,266			
Castor oil	168	194	Total	39,512.4	1,667,150.8
Peas	107	56			

TABLE 5.—*Principal industries in Chiclayo and Lambayeque, 1955*

[Data from Anonymous (1955)]

Industry	Number of plants in—		Number of employees in plants in Chiclayo
	Lambayeque	Chiclayo	
Evaporated milk		1	154
Carbonated beverages		2	90
Rice mills	2	4	50
Soap	1	3	45
Jute fabrics			135
Spaghetti	1		

operations for the company directors, who may reside elsewhere. Some of the formerly independent haciendas still have settlements, and old names continue in daily use. Confusion in some cases is possible because of dual meanings for the same name. The agricultural enterprise, Negociación Tumán, owns lands called Hacienda Tumán, which are north of Río Lambayeque, and also lands called Hacienda Calupe, which are south of the river. The name "Negociación Tumán" will be used in this report for the corporation, the name "Hacienda Tumán" will be used for the property north of the river, and the name "Tumán" will be used for the headquarters settlement. The authors of this report probably overlooked many locality names, but they noted that the Sociedad Agrícola Pomalca was operating Haciendas Pomalca, Saltur, and Pampa Grande and that the Sociedad Agrícola Pucalá was operating properties known as Pucalá, Pátapo, LaCría, Pedro Delgado, and Irrigación Juan Pardo y Miguel. Settlements bearing most of these names remain and will be found on the map with this report (pl. 1), but a few locality names—Pedro Delgado and Juan Pardo y Miquel, for example—are not shown because information on their location is indefinite.

GEOLOGY

The rocks at and near the land surface in the area of this report are in part igneous in origin, in part sedimentary, and in part metamorphic (table 6). They range in age from Cretaceous, or older, to Quaternary (Bellido and others, 1956). The major supplies of ground water are in alluvial deposits of Holocene age that make up the alluvial fan of the Río Chancay. This report, therefore, is concerned mainly with the alluvial deposits. The bedrock generally is dense and relatively impermeable.

TABLE 6.—*Rock units of the Lambayeque area and their water-bearing properties*

Era	System	Series	Formation	Description	Water-bearing properties
Cenozoic	Quaternary	Holocene	Dune sand	Wind-blown sand heaped into hills to a maximum height of 8 m.	Occurs only above water table; therefore not an aquifer.
Do	do	do	Alluvium	Stream-laid clay, sand, and gravel, and mixtures thereof; maximum thickness, 100 m or more.	Principal aquifer. Saturated sands and gravels yield up to 100 lps per well.
			Unconformity		
Mesozoic	Cretaceous(?) to Tertiary(?).		Bedrock	Undifferentiated granite, diorite, felsite, felsite porphyry, basalt, silicified limestone, sandstone, shale, and quartzite.	Not known to be water bearing and not likely to yield more than a few hundred liters per hour; water, where present, occurs principally in fractures.

BEDROCK

The Andean foothills, characterized by steep slopes nearly devoid of vegetation, contain much igneous rock of Cretaceous to Tertiary age (Bellido and others, 1956). This rock at the north end of La Puntilla diversion works is gray granite and diorite (pl. 1, coordinates 48S); in Cerro de Luya it is pink and gray granite and diroite (coordinates 31M); and about 8 km farther north, it is light gray felsite and felsite porphyry (coordinates 31E).

Banded silicified limestone crops out in an isolated hill about 7 km east of Pátapo (coordinates 40Q). The silicified bands in the lower part of the hill are regular and about 8 cm (centimeter) thick, and they alternate with bands of unsilicified (or less silicified) dark gray limestone about 15 cm thick (fig. 7). The unsilicified limestone contains fragments of ammonites. The silicified bands in the upper part of the hill are irregular, turning abruptly up or down, and therefore have not been controlled solely by the stratification. The rock is hard, dense, and fractured, but the fractures afford only a little permeability because they have largely been recemented or otherwise sealed.

Silicified limestone is reported to crop out also in a hill about 15 km east of the one described above on the opposite side of the valley at Hacienda Saltur. Solar (1944, p. 38–40) described these outcrops and suggested that the limestone is of Cretaceous age.

Quartzite and a little sandstone crop out in a ridge at Huacarajada (coordinates 37Y). Basalt, granite, and metamorphic rock occur in Cerro Morropío, which is about 4 km west-northwest of Tumán (coordinates 21R). Intersecting sets of parallel joints, exposed in a quarry in the north end of Morropío, produce large diamond-shaped blocks. Both granite and metamorphic rock occur also in the southern peak of Cerro de Combo, which is just across the Río Lambayeque from Morropío (coordinates 21T).

Quartzite is the principal rock type in Cerro de Pimentel, which is about 3 km west of Chiclayo (coordinates 7W). The quartzite in a roadcut at the base of the hill is gray to medium dark gray in layers 5 to 30 cm thick. Some of the thinner layers have been faulted. Included is a little vein quartz and some contorted, squeezed, and partly metamorphosed shale. The intensity of metamorphism decreases upward in the hill. The quartzite in the north peak is somewhat granular on broken surfaces. Both reddish-brown and white quartzite are present, and a layer of soft shale is included.

UNCONFORMITY

An unconformity separates the bedrock from overlying sedimentary rocks, but the time span represented by it is uncertain. The overlying rocks, so far as known, are alluvium of Holocene age, but if they include strata older than Holocene toward their base, the unconformity is older than Holocene. If Tertiary marine sediments should be present, the unconformable contact could possibly represent an interval between the Cretaceous Period and some part of the Tertiary Period. Around the margins of the valley and in the tributary canyons, however, the unconformable contact could represent a longer interval, extending into Holocene time; this is the situation suggested in table 6.

ALLUVIUM

The alluvium consists of sediments deposited from water in the channels, on the flood plains, and in the fans and deltas of streams, under varying conditions of volume and velocity of flow. These sediments are variable in both lithologic character and water-bearing properties, because of the widely varying conditions controlling their deposition. They range from gravel to clay and from highly to only slightly permeable. The arrangement of the strata in alluvium commonly seems to be highly irregular and unpredictable, yet a general statement on the occurrence of water-bearing strata in alluvium can have practical validity. For the Lambayeque Valley upstream from Pomalca as far as La Puntilla, it can be said that a good aquifer is generally found in the alluvium within the first 15 m below the land surface. Possible connections of the water-bearing strata from well to well are suggested on plate 2.

The alluvium described in this report makes up the fan of the Río Chancay, except locally where the fans of ephemeral tributaries protrude into the main valley. The sediments of the tributary fans interfinger around their margins with the sediments of the main fan.

The strata penetrated in the lower parts of some deep wells in the western part of the area may be of marine rather than fluvial origin. However, marine characteristics are not distinguishable from fluvial characteristics in the descriptions of the drillers' logs. All unconsolidated strata thus far penetrated in wells, therefore, are considered to be alluvium.

The character of the alluvium is best shown by logs of wells, because little can be seen at the land surface. The barren plain west of Chiclayo is liberally strewn with gravel. Silt and sand as much as 5 m thick is exposed at places in the river and ditch banks, but these are small exposures and do not fairly represent a deposit that is 100 m thick, or more. The kind and thickness of water-bearing material in the alluvium are ascertained from study of the well logs. For this investigation, 336 drillers' logs were examined; 36 of these have been published in duplicated form (Schoff and Sayán, 1963). A generalized log (table 7) suggests the sequence of strata to be expected in the first 20 m below the land surface between Tumán and the eastern boundary of the mapped area.

TABLE 7.—*Generalized log of strata in alluvium in first 20 m below land surface upstream from Tumán*

Description	Thickness (meters)
1. Relatively impermeable zone: Soil, clay, and some sand. The sand, where present, is generally fine grained and clayey	2. 5–15
2. Permeable zone: Gravel, coarse sand, and (locally) fine sand; clay layers at places	6 –10
3. Relatively impermeable zone: Clay and mixtures of clay with gravel and sand. Wells have not penetrated to bottom of this zone; hence, full thickness is not known	(?)

The actual depth to, and thickness of, the water-bearing zone differ considerably from well to well (table 8 and plate 2). The top of the zone is practically at the land surface in a well at Cuculí, but

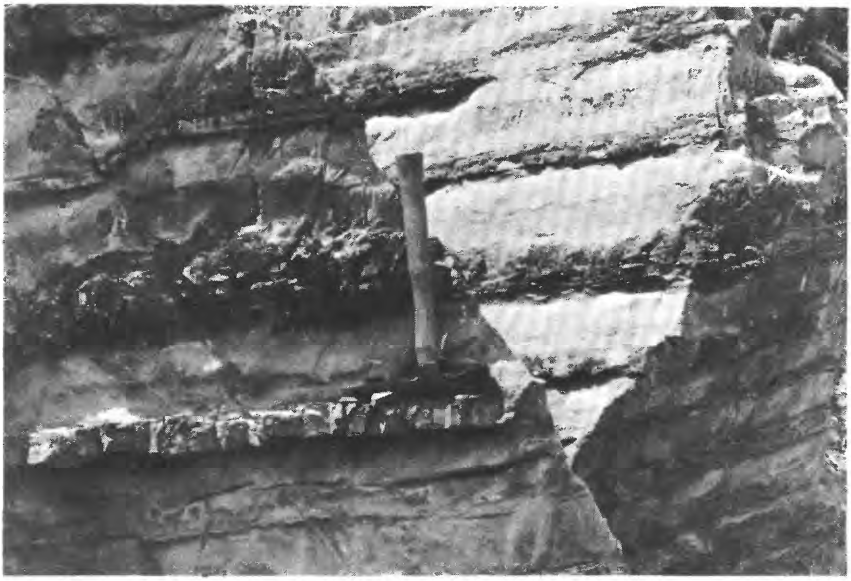

FIGURE 7.—Banded and faulted siliceous limestone in a hill about 7 km east of Pátapo headquarters; limestone probably of Cretaceous age.

it is 24 m below the land surface in a well near coordinates 38Q. The bottom of the zone is as little as 9 m below the land surface in a well at Cuculí and as much as 68 m near coordinates 38Q. The thickness of the water-bearing material ranges from 1 m in a well at Hacienda Calupe to 28 m in one near coordinates 38Q

TABLE 8.—*Range in and average of depth and thickness (impermeable interbeds excluded) of principal water-bearing zone in Lambayeque Valley, by localities in approximate downstream order*

Locality	Depth in meters to—						Thickness in meters		
	Top of zone			Bottom of zone					
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Hacienda Pampa Grande	9	10	9.7	17	18	17.8	7	9	7.9
Hacienda Cuculí	0	4	2.6	9	21	13.4	8	13	9.8
Hacienda La Cría	4	8	6.5	11.7	14.2	12.9	5	9.4	6.4
Hacienda Pucalá	2	17	7.7	12	23	18.5	3	16	10.1
Hacienda Pátapo	4	13	9.7	16.5	24.5	16.5	7	12.5	9.4
Approximate coordinate 38Q	9	24	15.2	17	68	26.6	3	28	8.4
Hacienda Tumán	2.1	15	9.9	14	20	17.4	2.5	12.5	7.2
Hacienda Calupe	4.5	16.8	11.3	12.9	22.5	18	1	15	6.3

Even in averages for small areas the variations are large. The average depth to the top of the water-bearing zone at Cuculí is only 2 m, whereas the averages for wells near coordinates 38Q is about 15 m. The average depth to the bottom of the zone is least at Hacienda La Cría (12.9 m) and greatest near coordinates 38Q (26.6 m). The thickness of water-bearing material is least at Hacienda Calupe (6.3 m) and greatest at Hacienda Pucalá (10.1 m).

The averages given in table 8 are comparable for the different localities, so far as possible. They are based on the data from production wells only. A wealth of information also is available from the test holes drilled for Negociación Tumán, but this has been excluded in order to make the averages for Tumán comparable to the other localities. Inclusion of the test-hole data probably would increase the accuracy of the averages for Tumán, but they would not compare fairly with others. Among the test-hole data are the records of many poor producers and dry holes, whereas the records of unsuccessful wells in other localities had not been preserved and, therefore, could not be included. Hence, the averages probably suggest subsurface conditions that are more favorable than actual conditions because favorable data have been overemphasized.

Well logs at best provide only limited clues to the ground-water potential of localities, and the averages fail to indicate what can be expected from individual wells. Table 8 shows a somewhat greater thickness of water-bearing material for Hacienda Tumán than for Hacienda Calupe, yet more poor producers and dry holes were drilled at Tumán than at Calupe. Possibly the drillers logged the strata more optimistically at Tumán than at Calupe. Perhaps the authors of this report have interpreted the Tumán well logs too optimistically. Or, perhaps the sand and gravel samples at Tumán looked more permeable than they really were but actually contained admixed silt and clay that disappeared into the drilling fluid and thus escaped detection by the drillers.

As of 1958, strata below a depth of about 15 m had been productive only in the area between Pomalca and Ferreñafe. The depths to the top of the uppermost water-bearing stratum in seven irrigation wells in that part of the valley are 5 to 18 m, or about the same as at Tumán, but the depths to the bottom are 41 to 73.5 m, or greater than at Tumán. Thicknesses, consequently, are greater: 15 to 27 m. As elsewhere, however, lithologic character and thickness as reported in drillers' logs may be deceptive. Nearly 16 m of apparently promising sand and gravel were penetrated in well 21G (Schoff and Sayán, 1963, p. 32), yet the well yielded only a small quantity of water. Probably clay or silt, mixed with the gravel and sand but not observed, led to the erroneous conclusion that good water-bearing material was present. The deep test holes drilled at and upstream from Tumán penetrated impermeable materials below the depth of 15 m almost exclusively. No water-bearing stratum was reported below that depth in 73 of the Tumán test holes. In the deepest test hole (No. 24R, pl. 2, cross section *H–H'*; Schoff and Sayán, 1963, p. 33), there was only a tight mixture of clay and gravel between 8 and 102 m in depth. Altogether, a total of 351 linear meters of drilling was done in the various test holes below the 20-m depth, and of this only 1 m can be regarded as probably water bearing.

The alluvium probably becomes progressively finer textured downstream, but only a few well logs are available to suggest its character in the downstream area. The wells farthest downstream are at and near Chiclayo, where less sand and gravel was penetrated than in wells in the area upstream from Pomalca. The water-bearing strata reported in wells at Chiclayo range from 1.5 to 12 m thick, but this wide range may be due as much to different drillers as to the strata themselves. The maximum and the minimum are from wells only 230 m apart, which makes the wide range questionable. Only 5.5 m of possible water-bearing material was penetrated in the deepest well in the Chiclayo area, which was 100 m deep (well 12X, Schoff and Sayán 1963, p. 28). Although individual strata may be relatively coarse, the preponderance of silt and clay suggests that, when considered as a whole, the alluvium of the Chiclayo area is finer grained than that upstream.

Subsurface information for the vicinity of the town of Lambayeque is limited to a report that an irrigation well 2 or 3 km west of the town and 45 m deep had yielded 40 to 45 lps. This is one of the deeper and more productive wells of the Lambayeque Valley. The driller's log of it was not available.

Although the results obtained from deep wells in the alluvium of the Lambayeque Valley have been rather unsatisfactory, they do not mean that all deep testing is futile. The good results obtained from wells as much as 75 m deep in the area between Pomalca and Ferreñafe, together with the reported good yield of the well near Lambayeque, suggest that adequate exploratory drilling will disclose the presence of good aquifers at other places. The deep test holes are few with respect to the size of the area.

Alluvium still is being deposited at places along the distributaries of the Río Chancay, and it is, therefore, not very old geologically. It is assigned to the Holocene Epoch of the Quaternary Period.

DUNE SAND

Wind-blown sand occurs in dunes at San Miguel, between Pomalca and Rinconazo, and south of Lambayeque. Some of the dunes near Lambayeque are 6 to 8 m high and are steep sided (fig. 2). The dune at San Miguel, on the other hand, has gentle slopes, as if modified by time and weather. Hence, this dune may be older than those near Lambayeque and older, too, than relatively steep-sided dunes that are only a kilometer or two east of San Miguel.

The dune sand is the youngest geologic deposit in the area and is considered to be of Holocene age. It lies on top of the alluvial plain and is younger, on the whole, than the alluvium. Yet, some of the sand in the base of a dune may have been deposited before the upper strata in the alluvium at some localities. The dunes may still be growing at places, or they may be shifting about, and the alluvium doubtless is accumulating at places along the rivers. There is contemporaneity to a degree, yet most of the dune sand is younger than most of the alluvium.

The dune sand is unimportant in the hydrology of the Lambayeque Valley. Its base generally is above the water table, and it therefore contains no significant amount of water that can be developed by wells. Moreover, it cannot facilitate the recharge of ground-water supplies in this area. The ability of dune sand to soak up water received as precipitation plays an important part in the replenishment of aquifers in many places, but this is of little benefit in the Lambayeque Valley because the precipitation is negligible. All the rain is ordinarily returned to the atmosphere by evaporation before it can soak far into the ground.

OCCURRENCE OF GROUND WATER

The ground water in the alluvium of at least the upper part of the Lambayeque Valley is essentially unconfined; that is, the principal aquifer does not contain water under artesian pressure. This statement seems not to agree with the geological generalization that the principal aquifer is between two impermeable strata (table 7). At places, however, the upper impermeable stratum is missing (pl. 2), so that the upper seal is not complete. Furthermore, the difference in altitude between intake and discharge areas seems to be insufficient to create much pressure. The water does not rise in wells much above the level at which it is first found. Although artesian conditions can occur locally in alluvium, large areas of substantial artesian pressure are unlikely to exist. No such areas were found in the Lambayeque Valley.

The upper surface (water table) of the saturated zone slopes seaward, that is, westward. Altitudes on the water table are too sparse and too unevenly distributed to permit drawing a water-table map for the entire area, but maps for selected dates for Hacienda Calupe are shown on plate 3. These maps show the general westward slope of the water table and suggest local slopes toward the rivers. The rivers, therefore, were receiving water from the saturated zone. A shallow trough in the water table trends westward in the northern part of the area covered by the maps. This trough did not diasppear, even when pumps had been idle for several months, and therefore was not due solely to withdrawal of water. A low ridge along the Casa Blanca ditch indicates seepage from the ditch to the saturated zone.

Water in substantial quantity is unlikely to occur in the bedrock underlying the alluvium. The deepest wells (to 1958) have not entered the bedrock, which presumably is similar to rock in the nearby Andean foothills. That rock is mainly hard dense instrusive igneous rock having only low permeability. The bedrock at best would be no more than a poor aquifer with poor connections to water sources.

FLUCTUATIONS OF GROUND-WATER LEVEL

The water levels in wells in the Lambayeque Valley fluctuate in response to the addition of water to the aquifer or its removal (fig. 8). They fluctuate also in response to changes in the load on the aquifer

The water levels decline during protracted pumping of ground water for irrigation, and they rise when pumping is stopped. They decline when and where the fields are not being irrigated. They rise when water is applied. The fact that much of the irrigation water comes from the rivers rather than the wells makes it possible for the ground-water levels to recover fully after pumping ceases. Seepage of river water, which is used in irrigating the fields while pumps are idle, refills the

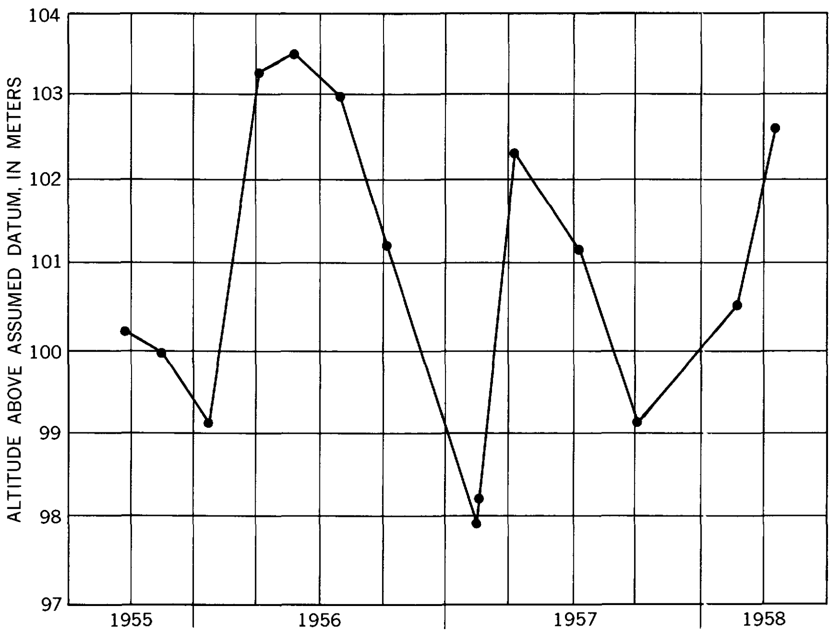

FIGURE 8.—Hydrograph showing average of water levels in wells of Negociación Tumán, September 1955–April 1958. The effect of pumping for irrigation, which ordinarily begins in August and lasts until February, is apparent, as is also the recovery of water level after pumping is stopped.

ground-water reservoir and makes up the deficit that otherwise would be created by the pumping.

Figure 9*A* shows a decline that probably was due to cutting off the flow in Combo ditch, and one that probably was due to the initiation of irrigation pumping. Figure 10*A* shows a rise of water level followed by a decline, which seems to be related to stopping and then resuming the pumping. However, another decline occurred about a week later, when all pumps had been stopped for several days; this decline cannot be related to any known cause. Figure 11 shows that the effect of withdrawal by pumping extends to a considerable distance around a discharging well, although at a distance of 310 m the drawdown amounted to only a few centimeters.

Semidiurnal water-level fluctuations probably are due to changes in load on the aquifer caused by changes in barometric pressure. Such fluctuations occur in wells tapping aquifers that are to some degree confined. They are illustrated by figures 11 and 12 which were traced from the hydrograph made by an automatic recorder on well 32W–2. Compared to the hydrograph in figure 12 is the record of barometric pressure at Lambayeque, 30 km away. The barometric peaks and valleys are only approximate in both height and time because the vertical scale of the barograph was small, making precise identification of maxima and minima impossible, but the general agreement between the two curves is apparent. Barometric-induced water-level fluctuations are superimposed on a rising water level in figure 9*B* and on a declining water level in figure 10*B*.

Water levels in the Lambayeque Valley probably decline where phreatophytes take and transpire water from the saturated zone and where the water table is so near the land surface that ground water can be evaporated, but fluctuations of water level due solely and unequivocably to transpiration and evaporation have not been recognized in the hydrographs collected in this investigation.

Tides may cause frequent regular small fluctuations of water levels in wells near a sea coast, but the wells in which water levels were recorded in this investigation apparently are too far from the Pacific shore for this effect. Fluctuations due to tidal loading are not recognizable in the wells where continuous records were obtained. Tidal fluctuations are caused by the alternate loading and unloading of the tidal zone as the tide rises and falls, but the semidiurnal water-level fluctuations in well 32W–2 have no consistent relation to the occurrence of high tide (fig. 11*A*). Hence, the semidiurnal fluctuations are due principally, if not entirely, to changes in barometric pressure.

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RECHARGE AND DISCHARGE OF GROUND WATER

Recharge, the replenishment of water in ground-water reservoirs, may be derived by infiltration from precipitation on the outcrops of permeable rocks or from the streams that cross those outcrops and by underflow through other permeable strata.

Recharge to the aquifers in the Lambayeque Valley depends principally on the water brought down from the Andes by the Río Chancay, because virtually none can be derived from precipitation within the area. The precipitation at the town of Lambayeque over a 7-year period averaged only 7.6 mm per year, and all or most of it was evaporated or transpired. The locality has been a desert, except where irrigated with river water, since the days of the Incas.

The river water seeps into the channel sands at some places, and it seeps downward from irrigation ditches and irrigated fields. Light loose sandy soils will take in more water than will heavy clay soils, but even clay and sandy clay, which commonly are found not far below the surface of the Chancay fan, do not entirely prevent infiltration. The infiltration generally is greater on gentle than on steep slopes and should be relatively great on the Chancay fan because the areas receiving irrigation water are, on the whole, rather gently sloping. The vegetation may help to promote infiltration by loosening the soil and retarding runoff, but it may at the same time reduce or prevent infiltration by using all or part of the water.

AMOUNT OF RECHARGE

The amount of the annual recharge in the Lambayeque Valley probably varies because of differences from year to year in the quantity of water applied for irrigation and, hence, in the amount of infiltration from irrigated fields. The following estimate of recharge is based on a rather short record and therefore should be regarded only as an order of magnitude.

The magnitude of the recharge can be estimated from the fact that during the period covered by this investigation the ground-water reservoir filled up when wells were not being pumped. Figure 8 shows that the average of the water levels in April 1958 was slightly higher than the highest level recorded in 1957, despite the withdrawals of the 1957–58 pumping season. That withdrawal was not summed up, but it probably was about the same as, or was somewhat higher than, the estimated pumpage for the calendar year 1957, that is, 81 million cu m. (See section on "Annual pumpage.") This approximates the quantity of water that was pumped from the ground-water reservoir and had to be replaced in order to restore the water levels to their former positions.

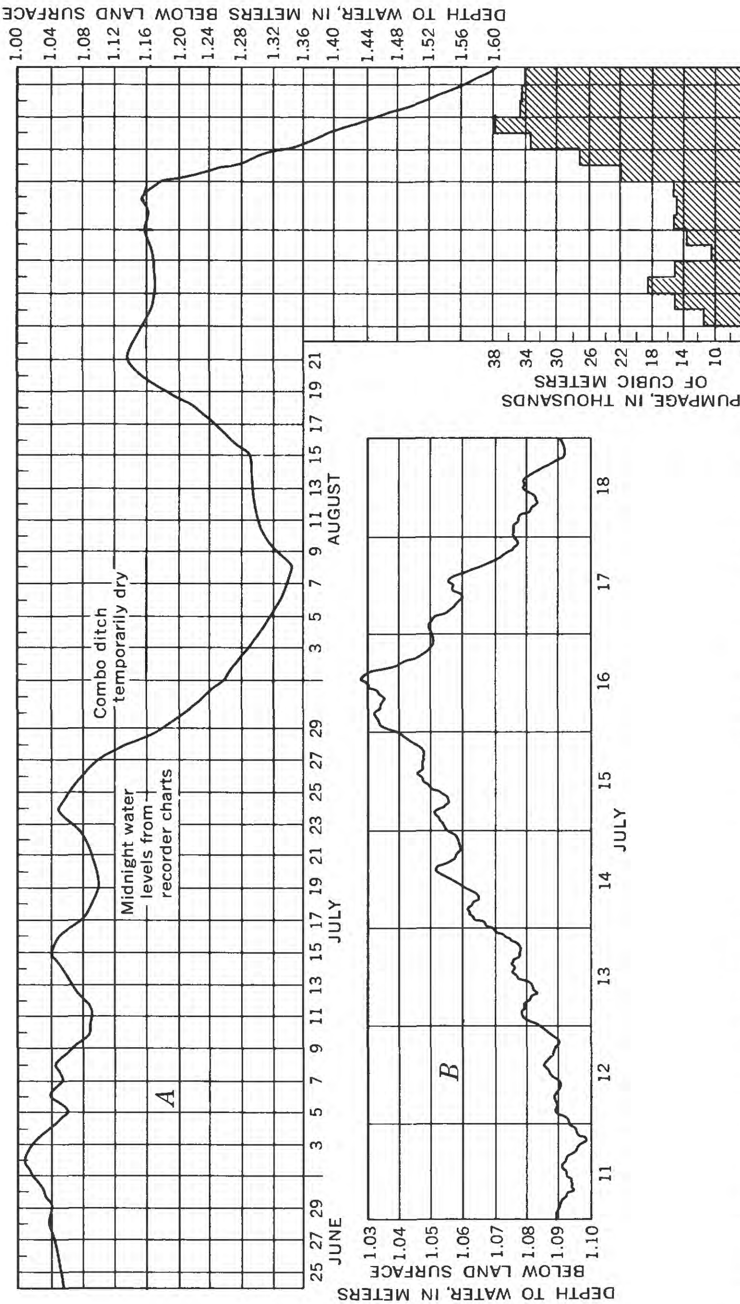

FIGURE 9.—Hydrographs from well 32V–4. *A*, Daily water levels at midnight showing effect of cutting off flow in adjacent ditch and effect of pumping. *B*, Semidiurnal fluctuations due to changes in barometric pressure superimposed on a seasonal rise. Vertical scale in *A* is one-fourth that in *B*.

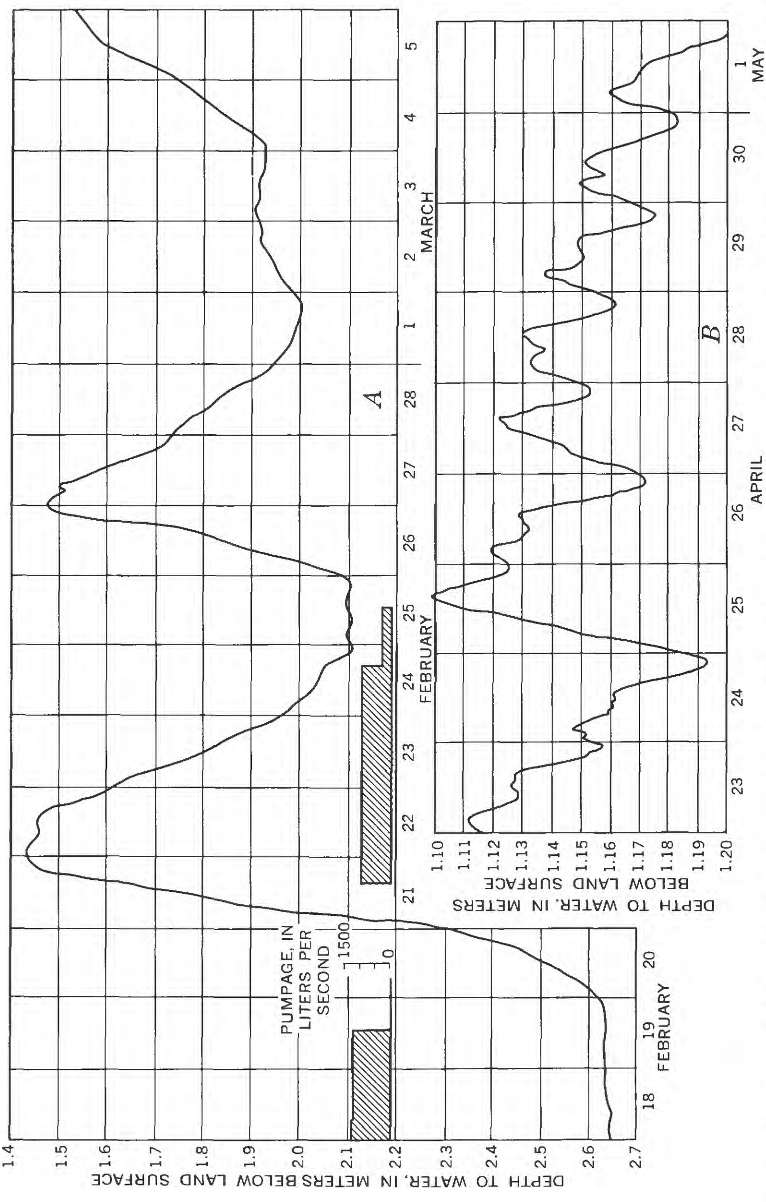

FIGURE 10.—Hydrographs from well 30W-4. *A*, Rise and decline of water level might be attributed to stopping and then resuming the pumping, except that another decline occurred when there was no pumping. *B*, Fluctuations of water level due to changes in barometric pressure superimposed on a general decline of water level.

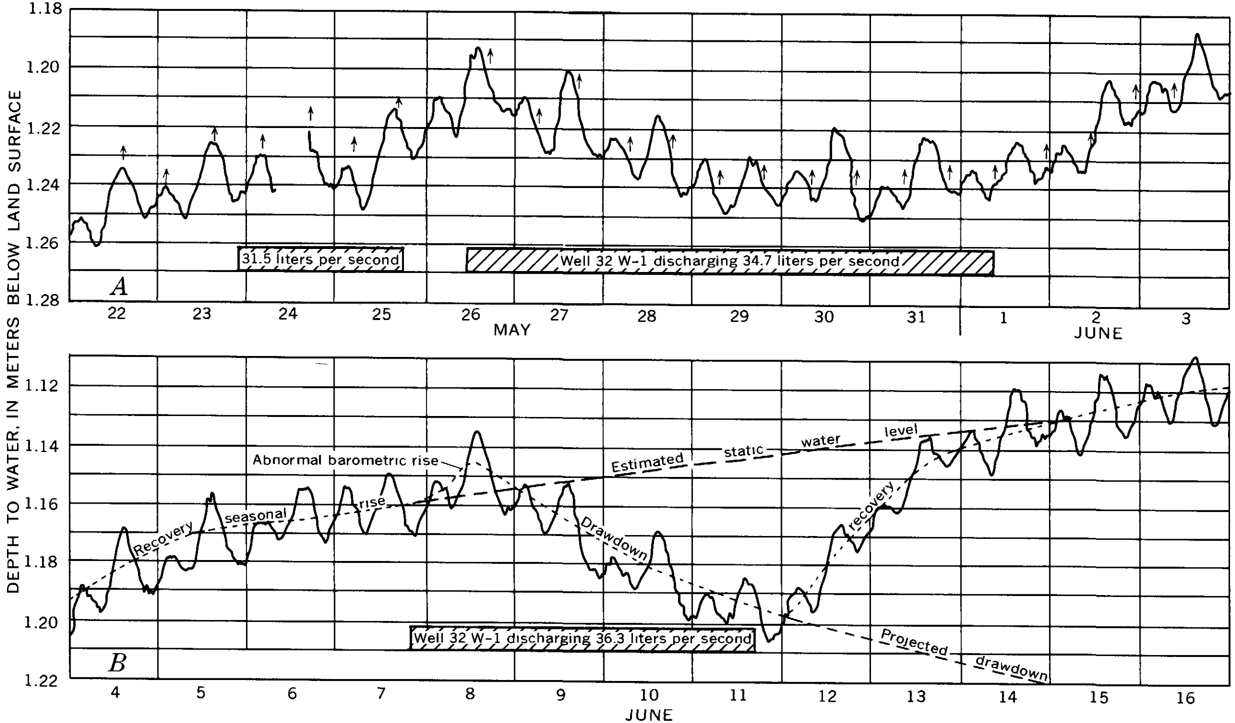

FIGURE 11.—Hydrograph from well 32W-2. Pumping in well 32W-1, 310 m away, caused only a few centimeters of drawdown. *A*, High tides at Puerto Eten (represented by arrows) had no consistent relation to semidiurnal water-level fluctuations. *B*, Dotted line shows how water level might have changed if barometric fluctuations had been absent.

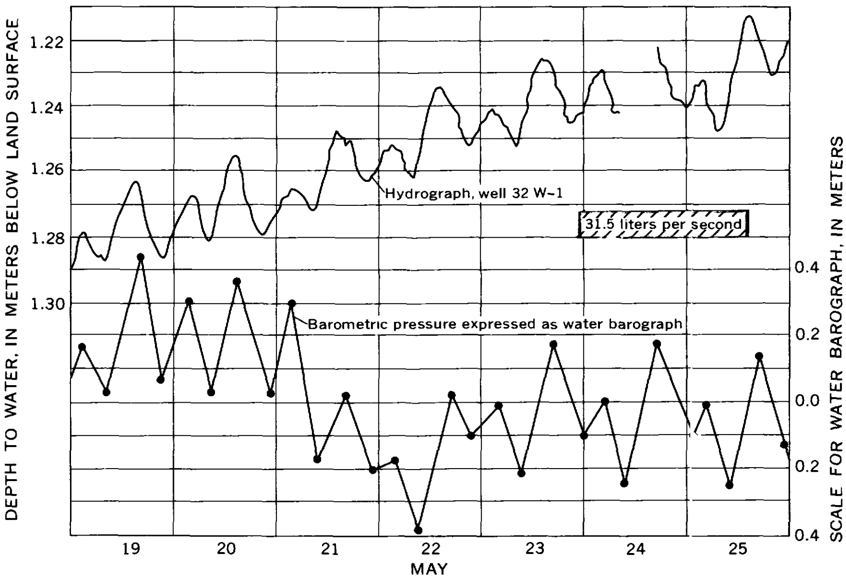

FIGURE 12.—Water-level fluctuations caused by variations in barometric pressure. Upper curve is traced from hydrograph made by automatic water-stage recorder on well 32W-2. Lower curve shows barometric pressure at town of Lambayeque (30 km west of well 32W-2) inverted and amplified as if registered by a water barograph.

Recharging of the aquifer may take place rapidly under favorable conditions. The rate of recharge on part of the Turrán property early in 1958 is shown on another page to have been more than 76,000 cu m per day. (See section on "Effect of protracted pumping on aquifer yield.") The recharge doubtless dropped nearly to zero in that locality when irrigation was stopped.

EFFECT OF PUMPING

Pumping water from a well in an unconfined aquifer lowers the water level both in the well and in the aquifer adjacent to it and creates a cone of depression in the water table. This cone enlarges as pumping continues. The depth, diameter, and rate of expansion of the cone of depression depend on the rate and duration of the pumping and also on the hydraulic properties of the aquifer. The cone will reach a condition of apparent stability if the pumping rate is constant and is less than the ability of the aquifer to deliver water to the well. Actually, however, the cone will continue to expand very slowly until it reaches the limits of the aquifer, both horizontally and vertically, unless there is recharge to arrest its growth.

If the aquifer is artesian, pumping from it reduces the artesian pressure in the vicinity of the well and creates a cone of pressure relief observable as lowered water levels in nearby wells in the same aquifer. The cone will deepen and will expand more rapidly than one in an unconfined aquifer, other conditions being equal (Wenzel, 1942, p. 99). It was the failure of the cone of depression to expand rapidly, in the one pumping test made in the Lambayeque Valley, that demonstrated the ground water to be unconfined, not artesian. This pumping test is described later in this report.

EFFECT OF PROTRACTED PUMPING ON INDIVIDUAL WELLS

Steady pumping may lead to a gradual increase in the yield of wells that have not been fully developed, or it may lead to a decrease in yield. The pumping in 1957–58 caused a decrease in discharge rate at many of the wells of Hacienda Calupe. The decrease at some wells was as much as 75 percent and was just cause for dismay, especially if initial tests had promised a large yield. Decreases in discharge generally cannot be explained without investigation. The causes are hidden in the well, in the pump, or in the aquifer. Among the causes are the obstruction of the screen openings by encrustation or by clogging with silt or fine sand or the loss of pump efficiency because of abrasion where much sand is pumped with the water. Reconditioning of well or pump, or both, might in some cases restore part of the lost discharge.

EFFECT OF PROTRACTED PUMPING ON AQUIFER YIELD

The effect of protracted pumping on the ability of an aquifer to deliver water appears in the average discharge rate of a group of irrigation wells. The pumping on Hacienda Calupe, although suspended several times, was nearly continuous from early June 1957 to early March 1958. Most of the interruptions lasted only a few days. The longest was 16 days, and the total of the stoppages was only a small percentage of the 8-month period being considered. The dominant trend in average discharge rate during the first 6 months was downward.

The average daily discharge rate per well, in liters per second, is shown in figure 13, together with the number of wells being pumped each day. The average discharge was obtained from summaries prepared by hacienda engineers from the daily reports of their field men. Their summaries showed for each day the number of wells being pumped and the total pumping rate; that is, the sum of the individual rates. Dividing the total rate by the number of wells yields the average rate per well, which seems to be a useful index but is an approximation for the following reasons:

1. Most discharge rates were estimates, because most of the wells lacked measuring devices. However, the estimates were made by

men experienced in estimating the flow of water. Several men and many wells were involved, so that the overestimates presumably offset the underestimates satisfactorily.

2. A large change in the number of wells being pumped could cause a change in average discharge that would be meaningless with respect to the aquifer. At times all but a dozen pumps were stopped. When this happened, the average discharge rate could rise abruptly if all the wells still being pumped were among the better producers, or it could decline if they were among the poorer producers. For this reason, the sharp fluctuations in figure 13 may not be especially significant.
3. The method of reporting fractional days of pumping tended to make the average discharge unrealistically low on some days. If a pump was operated less than 24 hours in a day, the observed pumping rate was adjusted to the 24-hour basis. Thus, a well pumped for 12 hours at an observed rate of 30 lps was included in the summaries at 15 lps. Enough adjustments of this sort could make the average discharge appreciably lower than a true average of actual pumping rates would have been. As the adjustments would always lower the average, never raise it, the low points of the diagram probably are less significant than the peaks.

The peaks in figure 13 show a gradual decline in average discharge that occurred between July 15, 1957, and January 5, 1958. This was a decline from 26 lps to about 18 lps, or a decline of nearly 31 percent. It probably was due to lowering of the water table throughout the area as the cones of depression enlarged and presumably overlapped, thus reducing the thickness of saturated material.

RECHARGE ESTIMATED FROM DISCHARGE RATE

If declining well discharge is due to general lowering of the water table, as the foregoing section indicates, an increase in discharge could be due to a rise in the water table. A water table rising in spite of heavy pumping could mean replenishment (recharge) greater than the withdrawal. This reasoning suggests a method of estimating the rate of recharge.

The average discharge rate at Hacienda Calupe increased between January 21 and March 9, 1958, somewhat faster than it previously had been decreasing (fig. 13). The total increase was 3 lps or about 13 percent. The increase may have been due initially to the suspension of pumping for 16 days (January 5–21). This suspension permitted partial filling of cones of depression and a general rise of the water table due to the arrival of water from other parts of the aquifer. However, the suspension would have caused only an immediate, shortlived increase in discharge unless sustained by recharge at a rate

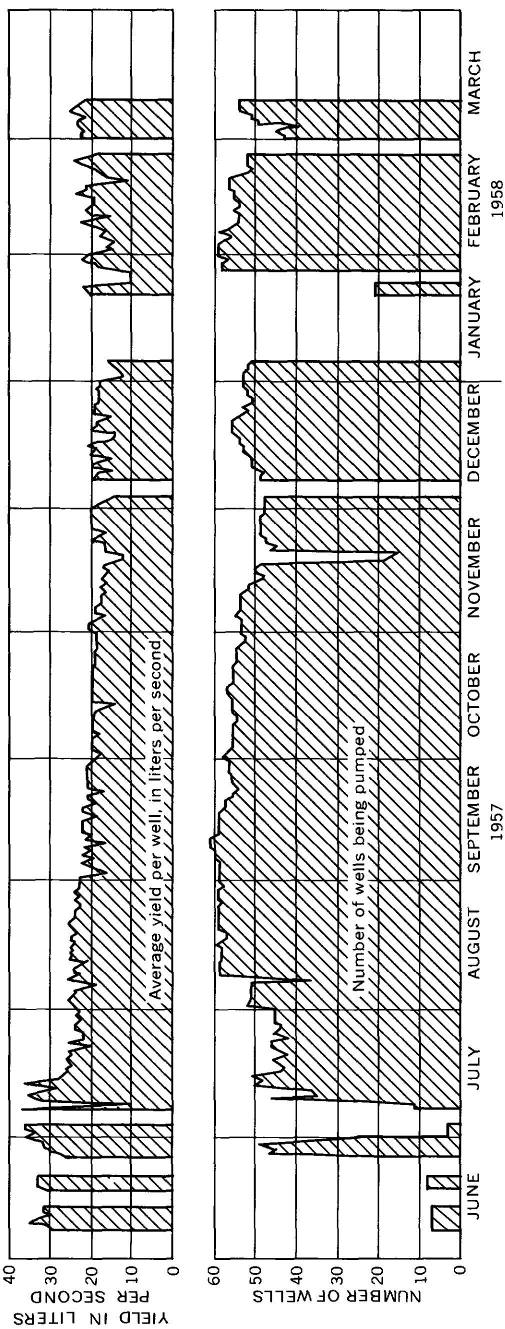

FIGURE 13.—Effect of protracted pumping on average well yield, Hacienda Calupe, 1957–58. The number of wells being pumped does not directly govern the average well yield but roughly measures the magnitude of pumpage, which in the long run affects the average yield.

greater than the rate of withdrawal. This recharge could have been due to infiltration from the irrigated fields. The withdrawal, then, partially measures the recharge that was being effected. The withdrawal was nearly 77,000 cu m per day.

Possibly the increase in average discharge was due to some other cause, such as an increase in well efficiency resulting from progressive development at new wells or an increase in the efficiency of pumps and motors. But pumps and motors are likely to lose efficiency, not gain it, and wells that improve are likely to be offset by those that deteriorate. These possible causes, therefore, seem to be less likely than recharge by infiltration, and the estimate of 77,000 cu m, or more, per day as the amount of recharge seems to be valid.

CALUPE AQUIFER TEST

One aquifer test was made in the Lambayeque Valley. It is here called the Calupe aquifer test because it was made by pumping a well on Hacienda Calupe. Its purpose was to provide a measure of the hydraulic properties of the principal aquifer of the locality, so far as this could be accomplished by a single test.

The hydraulic properties measured in the test were the transmissivity and storage coefficient. The transmissivity is related to the hydraulic conductivity, which for field use in metric units may be expressed as the number of cubic meters of water per day that can percolate through each kilometer of the water-bearing bed (measured at right angles to the direction of flow) for each meter of thickness of the bed and for each meter per kilometer of gradient, at the prevailing temperature of the ground water. The hydraulic conductivity multiplied by the thickness of the water-bearing bed gives the transmissivity (T).

The storage coefficient (S) of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. When the water level in a water-table aquifer declines, either naturally or as a result of pumping, water is released from storage. This water is derived partly by gravity drainage and partly by compression of the water and of the aquifer material in the saturated zone. But as the quantity of water attributable to compressibility is generally negligible, the water comes almost entirely from gravity drainage, and the storage coefficient is essentially a measure of this drainage. The coefficient may range from 0.05 to 0.30 (Wenzel, 1942, p. 87; Ferris and others, 1962, p. 78).

When an aquifer refills—after being pumped, for example—the process is reversed but the hydraulic properties of the aquifer are the same. Determinations of the transmissivity and storage coefficient, therefore, should be identical whether based on the drawdown of water level during pumping or on the recovery of water level afterward, but in practice they differ for various reasons. These differences may be summed up as failure of the conditions of the test to match the conditions basic to the formula used in analyzing the results (Wenzel, 1942, p. 87–88; Ferris and others, 1962, p. 91–92). The conditions applicable to the Calupe aquifer test are described below.

LOCATION, TOPOGRAPHY, AND LOCAL CROP

The site of the Calupe aquifer test is near the eastern boundary of Hacienda Calupe, about 980 m south of Río Lambayeque and 2,320 m north of Río Reque (pl. 3). The land is flat and slopes evenly westward. The fields surrounding the discharge well were being plowed and levelled for a new planting of sugarcane at the time of the test; therefore, no crop was transpiring ground water, and no irrigation pumping was in progress in the immediate vicinity.

GEOLOGY AT TEST SITE

The driller's log of the discharge well shows the principal aquifer to be 11 m of gravel and coarse sand in the depth interval from 7 to 18 m (pl. 2, cross section *D–D′*, well 32W–1). Over the aquifer are clay and sand that doubtless contribute small quantities of water by slow drainage. Under the aquifer are clay and gravel, presumably so mixed together as to be relatively impermeable, although these materials also may contribute a little water. As judged from drillers' logs of nearby wells, the clay content of the aquifer increases westward. For example, the log of a well only 310 m distant to the west shows no stratum without included clay.

The logs of most wells and test holes near the discharge well show a layer of soil and clay extending from the land surface to a depth of 5 or 10 m, but this layer probably is not so impermeable as the logs imply. It probably is composed of alternating thin layers of clay and fine sand, which the drillers were unable to distinguish as layers, together with silty or sandy clay. Logs of hand-auger holes (holes D25 and D50) 25 and 50 m from the discharge well suggest the probable stratification (table 9).

The upper clay layer, although found in a majority of the wells in the area, is not continuous. Even the drillers' logs record considerable sand in the first 10 m at some wells. At well 32V–6, which is 284 m north-northwest of the discharge well, the first 8.7 m below the land surface is about half sand and half clay (pl. 2, cross section *D–D′*; Schoff and Sayán 1963, p. 39). At well 33W–2, 276 m northeast of the discharge well, the first 6 m is sand, and the clay below it is

TABLE 9.—*Logs of auger holes 25 and 50 m from discharge well, Calupe aquifer test*

Description of material	Thickness (meters)	Depth (meters)
Hole D25		
Clay, dark-grayish-brown, including a thin sand in first 30 cm; clay, nearly plastic	1.8	1.8
Clay, sandy, brownish-gray	.2	2.0
Sand, clayey, and sandy clay, the sand increasing with depth; clay made compact ball in the auger, the ball preventing the auger from picking up a full load	3.6	5.6
Sand, brown, coarse, a few pebbles, not much clay; sample not retained and hole not maintained below 5.7 m	.1	5.7
Hole D50		
Clay; water at 0.5 m	3.0	3.0
Sand, fine, brown, clayey	.5	3.5
Clay, sandy	2.0	5.5
Sand, clayey, the sand increasing with depth; pebble or pebbles at 5.70–5.76 m; sample not retained below 5.8 m	.3	5.8

only 2 m thick. The upper clay, therefore, is only an imperfect confining layer at best.

HYDROLOGY AT TEST SITE

Static water levels in wells near the discharge well are 1 or 2 m below the land surface when there is no pumping. They are above the top of the principal water-bearing stratum, opposite the upper clay, except where the clay is absent.

The auger holes 25 and 50 m from the discharge well were started in the bottom of a ditch. They were not dry during the penetration of the clay layer but instead contained water almost from the start of boring.

The ditch itself contained small pools of water, which were thought to be only puddles left when another well had been discharged into the same ditch several days earlier. These pools, however, dried up when the discharge well was pumped for the aquifer test. Afterward, they reappeared. Hence, they represented the water table.

The water levels, therefore, represent a water table, not a potentiometric surface. The water table at the site of the test is a plateau in relation to the adjacent rivers, and the cone of depression probably was no more than a dimple in its surface. The water table slopes westward about 3.75 m per kilometer (pl. 3). Near the discharge well at the time of the test, it was about 4 m above the water level in Río Lambayeque. Ground water, therefore, should have been discharging into the river, not river water into the aquifer. Ground water should also have been discharging into Río Reque, which is lower in altitude than Río Lambayeque, as well as farther away. The water table somewhere between the test site and the Reque slopes steeply toward that river, but this slope begins many hundreds of meters south of the discharge well and far beyond the edge of the cone of depression that was created.

The cone of depression hardly extended to the nearest irrigation wells, as will be shown in the section on "Preliminary observations." Nor could it have extended to Río Lambayeque and induced recharge there.

The chief possibilities for recharge to the aquifer near the discharge well during the aquifer test were at the irrigation canals, which bound the site on the north, east, and south (pl. 3). These probably are not as water tight as had been assumed. When the one on the north was cut off and became dry, the water level in adjacent well 32V–4 abruptly declined (fig. 9). This canal probably is too far from the discharge well for the seepage from it to have affected the test. The cone of depression may have reached only halfway to it. The other canals are nearer the discharge well, and seepage from them, therefore, may have been diverted into the cone of depression. This may be especially true of the canal south of the discharge well. The ditch that carried away the pumped water, although dug in clay, probably leaked more than had been anticipated.

DISCHARGE WELL

The discharge well (32W–1) is about 20 m deep and passes entirely through the sand and gravel that constitute the principal water-bearing stratum but not through all the alluvium to end in the bedrock (pl. 2, cross section *D–D′*). The driller's log of this well follows.

Description	Thickness (meters)	Depth (meters)
Clay	3.6	3.6
Clay and sand	3.4	7.0
Gravel and coarse sand	11.0	18.0
Clay and gravel	2.2	20.2

The screen in the well is a 10.5 m section of the well casing in which 286 slots were cut. Its length closely approximates the thickness of the water-bearing stratum, and its placement is neither too high nor too low. The well doubtless had been fully developed at the time of the test, as a result of 10 years of pumping for irrigation. Indeed, the gravel and sand immediately adjacent to the screen could have become considerably more permeable than the natural aquifer. On the other hand, encrustation accumulated on the screen and in the interstices of the sand and gravel could have obstructed the entrance of water to the well. The magnitude and net effect of these opposing effects were not measurable, but they may not have been important. The well was regarded nearly as good as when new.

The well is cased from the land surface to 18.8 m with 17-inch casing and from 18.4 to 20.2 m with 15-inch casing. The pump used in the aquifer test was a turbine driven by a V-8 gasoline engine and delivered about 36 lps through an 8-inch discharge pipe that was 3.7 m long.

MEASUREMENT OF WATER LEVEL AND DISCHARGE

Observations of water level in the discharge well were made by 300-foot steel tape and by air line and pressure gage. The tape gave good results to a depth of about 12.2 m, where the sounding weight caught and often was difficult to withdraw. Below that depth, therefore, the water levels are based on the readings of the air line and pressure gage. Measurements by both methods were made where possible, and these showed that the gage depths were 2.16 m too great. This amount, therefore, was subtracted from the gage readings.

Water levels in the auger holes and in the irrigation wells were measured with a steel tape. A continuous record of water level in well 32W–2, which is 310 m west of and down the water-table slope from the discharge well, was obtained with a water-stage recorder.

The discharge was measured by means of a manometer attached to the discharge pipe about 39.5 cm from its free end. This distance is less than ideal, but changing it was impractical.

PRELIMINARY OBSERVATIONS

Pumping the discharge well had little effect on water levels in surrounding irrigation wells, as shown by preliminary observations. The well was pumped and water levels were measured for about 19 hours; then, after a rest of more than a day, the well was pumped again for nearly 6 days. The fluctuations of water level caused by changes in barometric pressure, as revealed by the hydrograph of the water-level recorder, were nearly as large as the drawdown in a well 310 m from the point of discharge. However, the hydrograph did show, in both pumping periods, declines that probably were drawdown. These declines can be demonstrated by comparing the peaks and valleys of the hydrograph. The early morning peak water level occurred about the time pumping stopped in the first (19-hour) test. This peak was lower than the comparable peak for the preceding (prepumping) day. Especially, it was below the level that could have been attained, if the seasonal upward trend had prevailed. The succeeding (mid-morning) valley also was lower than could have been expected. By the next morning the drawdown had shrunk to a few millimeters.

Pumping for 6 days caused greater drawdown at well 32W–2 than pumping for 19 hours did, but even this was not large. The seasonal upward trend of water level was reversed for 3 or 4 days, but the drawdown, measured from a projection of this trend, was only 0.035 m. The seasonal trend even reasserted itself about 2 days before the pumping ended, and the water level began to rise again (fig. 11).

The preliminary pumping seemed to cause small drawdowns of water level in some of the 12 irrigation wells where water levels were measured by steel tape but not in others. The records for these wells are sketchy because the measurements were to be infrequent until definite drawdown appeared, and as the drawdowns were questionable to the end, the frequency was not increased. The maximum range of water-level fluctuation in these wells is summarized in table 10.

The pumping rather definitely caused drawdown in wells 33W–2 (fig. 14) and 32V–6, which are 276 and 284 m, respectively, from the pumped well and which are remote from canals. The hydrographs for these two wells parallel rather closely the one made by the recording gage at well 32W–2, at a distance of 310 m. Small though the drawdowns were, they suggest that the radius of the cone of depression was greater than 310 m.

TABLE 10.—*Amplitude of water-level fluctuation shown by tape measurements in irrigation wells during preliminary pumping, May 23–June 5, 1956*

Well	Distance (meters) and direction from discharge well	Proximity to irrigation canal	Amplitude of fluctuation (meter)
32W–7	268 S	Adjacent	0.196
33W–2	276 NE	Remote	.094
4	278 SE	Adjacent	.126
32V–6	284 N	Remote	.094
5	458 NW	do	.042
33W–1	472 ENE	Adjacent	.057
3	490 SE	do	.049
32W–6	559 SW	do	.265
3	624 W	Remote	.043
33V–1	656 NE	Adjacent	.053
2	672 NE	do	.165
32V–4	736 NNW	do	.056

The pumping apparently caused no drawdown at the other two wells that are remote from canals, that is, wells 32V–5 (fig. 14) and 32W–3, at 458 and 624 m, respectively, from the pumped well. In these wells there were nearly equal rises in water level amounting

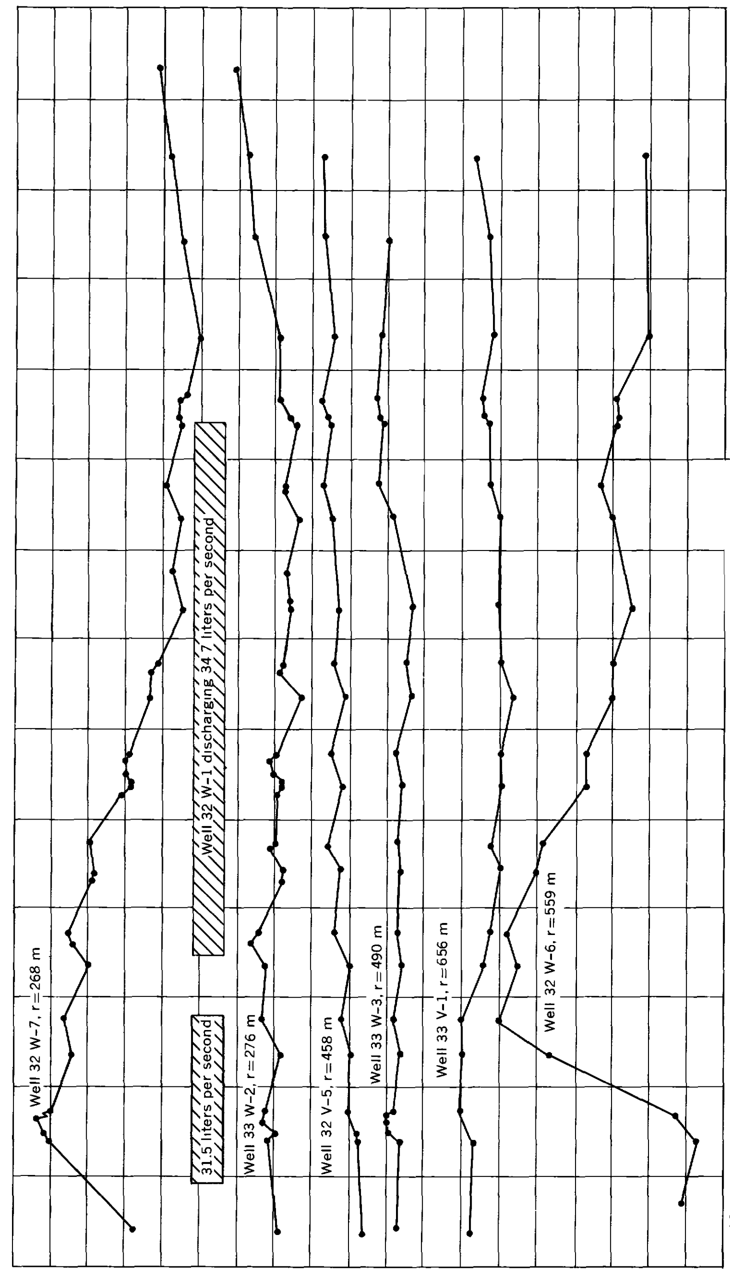

Figure 14.—Typical hydrographs based on tape measurements made in irrigation wells surrounding the discharge well before, during, and after the preliminary pumping that preceded the Calupe aquifer test. Distances (r) from the discharge well and the pumping periods are shown.

to slightly more than 4 cm. The conclusion here is that the radius of the cone of depression was less than 458 m.

The hydrographs for the wells near canals probably show mixed effects of variations in the amount of seepage from the canals, changes in load due to variations in the volume of water in the canals, and perhaps some drawdown due to the pumping. If the radius of the cone of depression was between 310 and 458 m, as indicated above, the cone should have extended to wells 32W–7 (fig. 14) and 33W–4, at distances of 268 and 278 m. Indeed, it seems to have done so. The water levels declined somewhat during the pumping and began to rise 1 day after the pumping was stopped. They also went over a peak in the 2 days just before the end of the pumping. The peak itself is no cause for suspicion, but the whole pattern, including the peak, appeared at well 32W–6, 559 m from the pumped well, and with greater amplitude. This observation raises the questions (1) Whether any of these three wells were affected by the pumping, (2) whether the cone, contrary to evidence presented above, reached more than 559 m, and (3) whether all the evidence was valid and the cone was very asymmetrical. These questions seem not to be answerable, but it seems safe to say that the amount of drawdown in these wells cannot be determined from the hydrographs.

Water levels at three other wells, which also are adjacent to canals, apparently were not affected by the pumping. These water levels declined somewhat at first, but they began to rise 2 days before the pumping was stopped (well 33V–1, fig. 14). The wells are from 656 to 736 m distant from the discharge well and are probably beyond the edge of the cone of depression.

The observations of water level in the irrigation wells produced no data useful in appraising the hydraulic properties of the aquifer, and a way to measure drawdown closer to the discharge well was sought. The auger holes were bored for this purpose, although it was recognized that they could not be sunk as deeply into the water-bearing stratum as they should have for best results.

ADJUSTMENT OF FIELD OBSERVATIONS

The water levels in auger holes D25 and D50 were affected by changes in barometric pressure to some extent. An abrupt rise in water level that occurred just before the pumping probably was due to this cause, as were also some of the irregularities that appeared later. The water levels were affected, also, by the seasonal upward trend that was in progress. Adjustments were made to correct the observed water levels for these effects, but they changed the curves for drawdown and recovery only slightly (figs. 15, 16).

The water levels measured by air-pressure gage in the discharge well (fig. 17) were corrected for inaccuracy of the gage as previously

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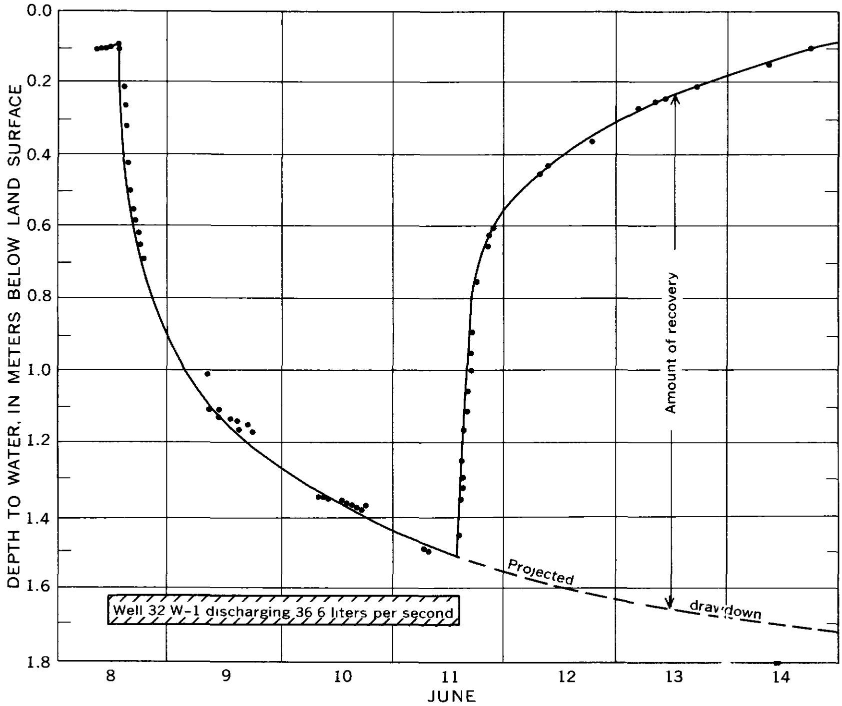

FIGURE 15.—Drawdown and recovery of water level in auger hole D25, Calupe aquifer test, June 8–14, 1956. Recovery is measured from the position the water level would have had if pumping had continued.

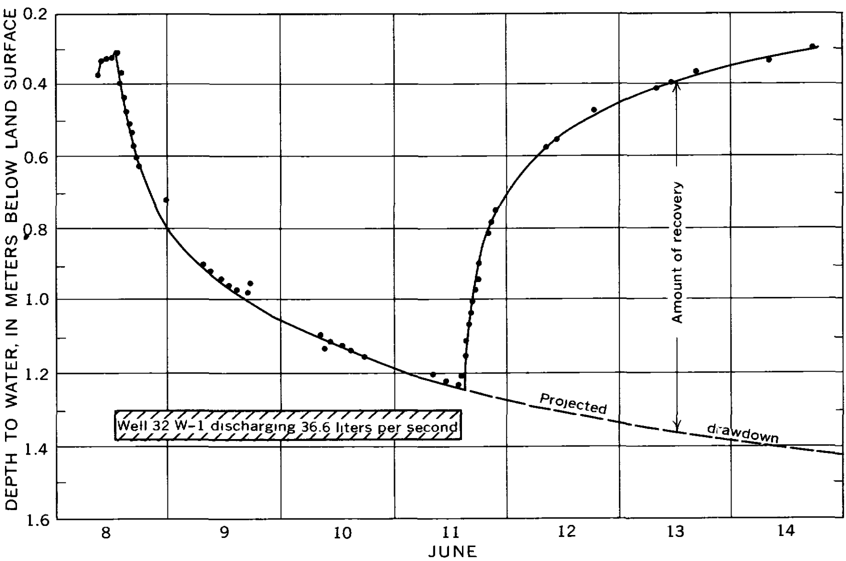

FIGURE 16.—Drawdown and recovery of water level in auger hole D50, Calupe aquifer test, June 8–14, 1956. Recovery is measured from the position the water level would have had if pumping had continued.

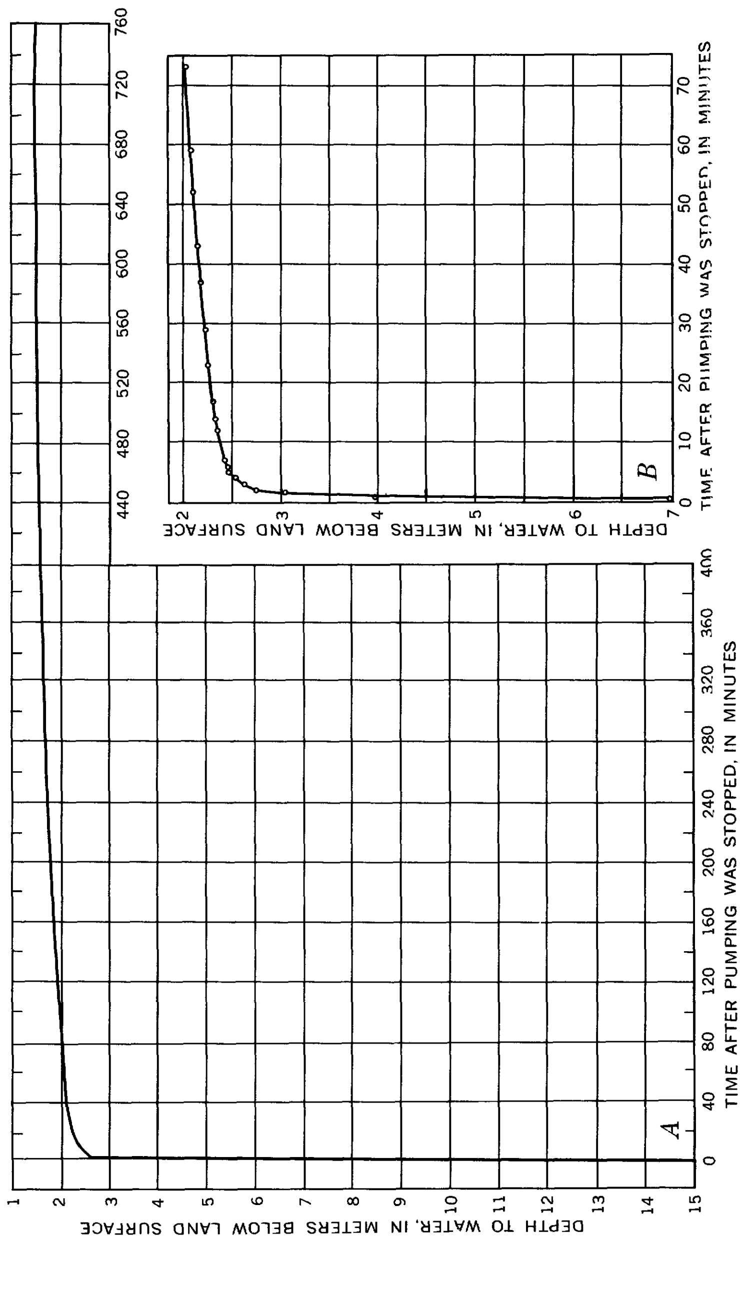

FIGURE 17.—Recovery of water level in discharge well, Calupe aquifer test. *A*, Recovery during the first half day after pumping was stopped. *B*, The first 73 minutes of the recovery on an enlarged scale (omitting an initial, almost instantaneous, rise of water from the 15-m level to the 7-m level).

explained. The drawdown in this well was large in relation to other possible errors, which therefore shrank to insignificance.

INTERPRETATION OF TEST

Using the graphical method described by Wenzel (1942, p. 87–89) as well as others, observations obtained in the Calupe aquifer test were analyzed by means of the nonequilibrium formula of Theis (1935, p. 519–524).

The formula is:

$$s=\frac{Q}{4\pi T}W(u). \quad (1)$$

In metric units,

$$s=\frac{0.0795Q}{T}W(u), \quad (2)$$

where s is the drawdown in meters,

Q is the rate of discharge of the pumped well in cubic meters per day, and

T is the transmissivity in cubic meters per day per meter.

$W(u)$ is the well function of u, an exponential integral.

The value of u is found by the equation,

$$u=\frac{r^2S}{4Tt}=\frac{0.25r^2S}{Tt}, \quad (3)$$

where r is the distance from the discharge well to the point of observation in meters,

t is time in days,

S is the storage coefficient,

and other units are as defined above.

Five usable sets of data from the test were available. These were the drawdown and the recovery of water level in each of the auger holes and the recovery in the discharge well. The drawdown in the discharge well was useless because variations in engine speed in the first part of the test caused irregularities in discharge and drawdown.

The results from the five sets of data (table 11) provide a useful index, but not a precise determination, of the hydraulic properties of the aquifer. They differ sufficiently among themselves to make it probable that the conditions of the test deviated, in one respect or another, from those basic to the Theis formula. Furthermore, the Theis formula itself has been shown by Stallman (oral commun., 1963) not to fit the water-table condition ideally. The results, then, suggest an order of magnitude. If their limitations are kept in mind, they are useful for estimating what might result from continuous pumping.

TABLE 11.—*Results of Calupe aquifer test. Transmissivity, in cubic meters per day per meter, and storage coefficient*

Coefficient	Based on— Drawdown	Based on— Recovery	Average
Transmissivity (*T*)			
Auger hole D25	841	695	768
Auger hole D50	1, 093	882	987
Discharge well 32W-1		1, 068	1, 068
Approximate average			941
Storage (*S*)			
Auger hole D25	0. 092	0. 048	0. 07
Auger hole D50	. 054	. 048	. 05
Average			. 06

The transmissivity, for purposes of estimating, is taken to be 950 cmd/m (cubic meters per day per meter). This is not the average given in table 11, but is close to it. The storage coefficient is taken as 0.07, which is the average of the results obtained from the drawdown and the recovery of water level in hole D25. The results from this hole are probably better than those from hole D50 because this hole was nearer to the discharge well, and less pumping should have been required to achieve satisfactory drawdown and drainage. Possibly the highest figure shown for storage coefficient (0.09) is too low.

ESTIMATED DRAWDOWN

The coefficients derived from the Calupe aquifer test cannot be extended blindly to all the alluvium of the Lambayeque Valley. One aquifer test does not constitute a quantitative study of an aquifer unless the aquifer is unusually uniform; one test is merely a guidepost or indicator. Nevertheless, the Calupe test—first of its kind in the Lambayeque Valley and possibly in Peru—can be a useful preliminary measure of the order of magnitude of the hydraulic properties of the alluvial aquifer. Accordingly, the following discussion suggests what might result from pumping ground water steadily where the transmissivity and storage coefficient are as determined in the Calupe test; that is, 950 cmd/m and 0.07, respectively.

The drawdown for any time and any point on the cone of depression can be estimated by substituting appropriate coefficients in the nonequilibrium formula. Figure 18 shows by means of curves how the drawdown at locations between 100 and 1,000 m from a pumped well would increase during a 6-month period if the discharge were 30 lps,

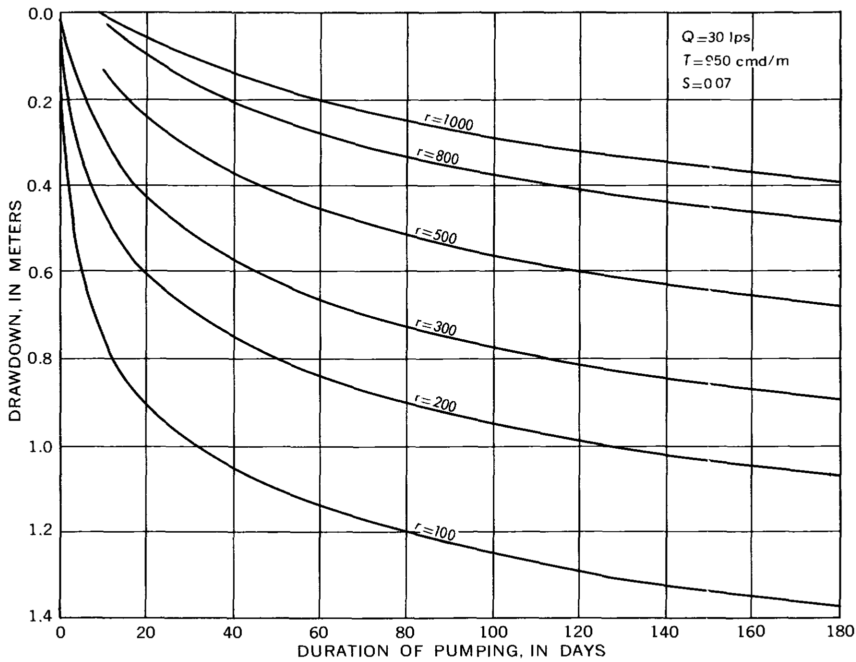

Figure 18.—Estimated progress of drawdown during 180 days of discharge at 30 lps from one well tapping an aquifer having the transmissivity and storage coefficient determined in the Calupe aquifer test. Distances (r) from the pumped well.

if the aquifer constants were those of the Calupe aquifer test, and if there were no recharge. The curves make it plain that the decline of water level is most rapid during the early stages of pumping.

Figure 19 shows the drawdown at distances between 100 and 4,000 m after 6 months of pumping one well at 10 lps and 30 lps, provided that no recharge or natural discharge were to occur meanwhile and that no nearby wells were being pumped. As the drawdown at any given point within the cone of depression is directly proportional to the rate of discharge, figure 19 can be applied also to other discharge rates. Thus, the drawdown at any place will be twice as great for a discharge of 20 lps as it is for 10 lps.

The effect of pumping a group of wells can also be predicted, although the more wells there are and the more unequal the distances between them, the more complicated the computation becomes. Consider a central well surrounded by other wells arranged in two concentric circles. All wells tap the same aquifer, which has the coefficients determined in the Calupe test. All but the central well are to be pumped steadily at 30 lps for 6 months. The inner circle consists of 6 wells that are 300 m from the central well and are spaced

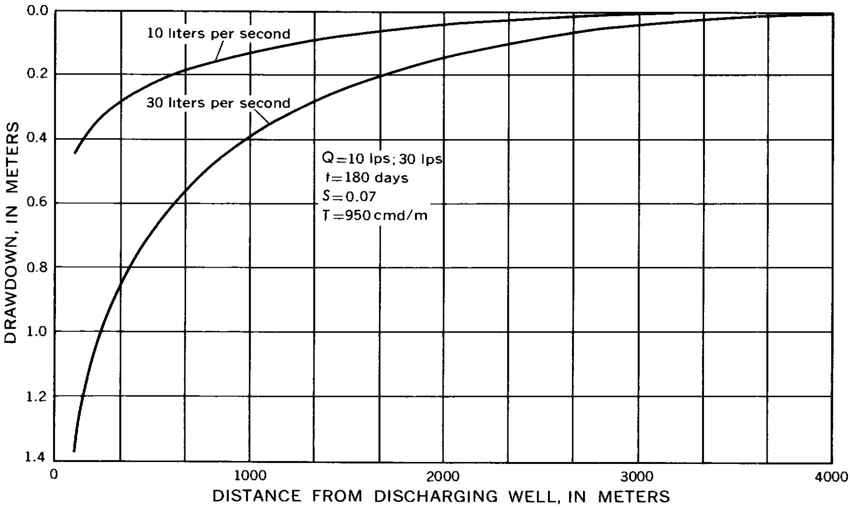

FIGURE 19.—Estimated drawdown at the end of 180 days of continuous discharge at 10 lps and 30 lps, at locations between 100 and 4,000 m distant from the discharging well.

about 300 m apart along the circumference. (This distance, 300 m, is approximately the average distance between wells in the eastern part of Hacienda Calupe.) Figure 19 shows that, for each pumped well, 6 months of pumping will cause 0.9 m of drawdown at a distance of 300 m. At the central well, therefore, the combined drawdown of these six wells will be $6\times0.9=5.4$ m.

The outer circle has a radius of 600 m and consists of 12 wells about 300 m apart along the circumference. Figure 19 shows that a discharge of 30 lps will cause, at a distance of 600 m, a drawdown of 0.6 m. The total drawdown at the central well caused by pumping the wells of the outer circle will be $12\times0.6=7.2$ m. Adding the drawdown effect of the inner circle of wells brings the total to 12.6 m. If the central well also is pumped, its own discharge will easily send its water level to the 15- to 17-m levels common in the Calupe irrigation wells during protracted pumping.

The preceding assumed conditions are simpler than those that prevail when 50 or 60 wells are being pumped simultaneously. To the drawdown created in any given well by pumping from it must be added the drawdown caused by all other wells discharging in the vicinity. Although one well discharging 10 lps for 6 months will cause only 0.066 m of drawdown at a point 4,000 m distant (fig. 19), 50 wells at the same distance and rate of pumping would cause 3.3 m of drawdown. As the wells of Hacienda Calupe where most numerous are not 4,000 m apart but about 300 m and as their average discharge rate is not 10 lps but nearly 20 lps, the cumulative effect of pumping all of them at once is obviously great. If it were not that substantial recharge results from infiltration of the irrigation water, the pumping of 50 wells probably could not be sustained, as it has been, for 6 months.

COMPOSITION OF GROUND WATER

All natural waters contain dissolved mineral matter in quantities that depend on the type of rock or soil through which the waters have passed, the length of time of contact, and the pressure and temperature conditions. In addition, human activities, such as the diversion and use of water for irrigation of croplands and for many other purposes and the disposal of sewage and industrial waste into streams and wells, alter the composition of water.

The chemical character of ground water from wells in the Lambayeque Valley is suggested by 10 analyses presented in table 12. Two analyses by the U.S. Geological Survey, Washington, D.C., represent samples collected 30 minutes after the beginning, and just before the end, of the Calupe aquifer test. Analyses by other laboratories have been restated in ionic form.

The analyses represent the area from Huaca Blanca, which is a few kilometers upstream from the eastern boundary of the mapped area, downstream to Chiclayo. From left to right in the table, they are in downstream order, an arrangement that reveals a crude pattern of increasing mineralization in the downstream direction. This is shown also in figure 20. The pattern is imperfect, partly because wells at Chiclayo probably do not tap strata that are strictly equivalent to those in wells upstream, but a trend is apparent. The dissolved solids, silica, bicarbonate, sulfate, and sodium increase downstream. On the other hand, the amount of calcium and the hardness decrease downstream, although irregularly because the water from well 39Q–2 is less mineralized than its location in the valley calls for. The increase in sodium probably is due to ion exchange at the expense of calcium.

SUITABILITY OF WATER FOR IRRIGATION

Several factors in addition to mineral content determine whether water is suitable for irrigation use. Among them are the amount of water applied to the soil, the amount and distribution of rain, the drainage, and the physical and chemical character of the soil. If the concentration is not excessive, some dissolved salts favor plant growth, but others are harmful to plants or to soils. The total concentrations of dissolved salts in water range from a few to many thousand milligrams per liter, but in most irrigation waters are in the range of 100 to 1,500 mg/l (milligrams per liter).

The U.S. Salinity Laboratory Staff (1954, p. 69–81) stated that the most important characteristics of water for irrigation are: (1) total

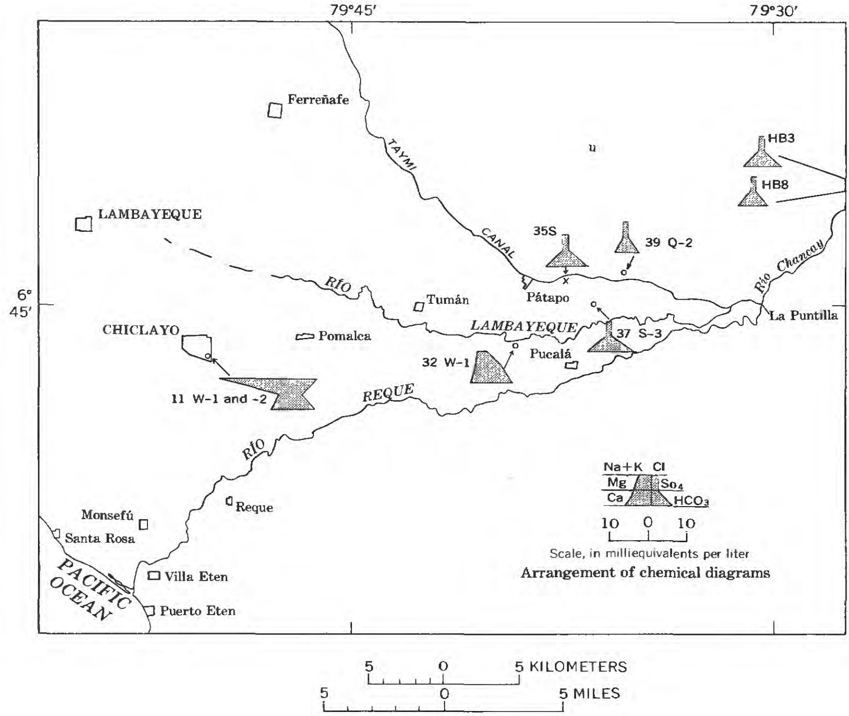

Figure 20.—Map showing by means of diagrams the changes in concentration of the principal ions in ground water in Lambayeque Valley.

concentration of soluble salts, (2) relative proportion of sodium to other cations, (3) concentration of boron or other elements that may be toxic, and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium. Their system for classifying irrigation water on the basis of electrical conductivity and sodium content is explained in the following paragraphs.

The total concentration of soluble salts can be adequately expressed for purposes of diagnosis and classification in terms of electrical conductivity, which is useful because it can be readily and precisely determined.

Waters with conductivity below 750 micromhos per centimeter generally are satisfactory for irrigation insofar as salt content is concerned, although salt-sensitive crops may be adversely affected by use of waters having conductivity in the range of 250 to 750 micromhos per centimeter. Waters in the range of 750 to 2,250 micromhos per centimeter are widely used, and satisfactory crops are obtained under good management and favorable drainage conditions, but saline conditions will develop if leaching and drainage are not

TABLE 12.—*Chemical analyses, in milligrams per liter except as indicated, of ground water from wells in the Lambayeque Valley, Departmento de Lambayeque, Peru*

Well number: See p. 888 for description of well-numbering system. HB (Huaca Blanca)-3 and HB-8 are outside mapped area.
Owner: Perulac, Compañía Peruana de Alimentos Lácteos, S.A.; Tumán, Negociación Tumán; Pucalá, Sociedad Agrícola Pucalá.
Location: Hda, hacienda; J. Pardo, Irrigación Juan Pardo y Miguel; H. Blanca, Hacienda Huaca Blanca.
Date: USGS analyses, date of sample collection; others, date of analysis.
Analyses: FCC, Ferrocarril Central; Perm, Permutit Co., New York; SAPL, Servicio de Agua Potable de Lima; USGS, U.S. Geological Survey, Washington, D.C.

Well number	HB8	HB3	39Q-2	37S-3	35S	[1] 32W-1	[2] 32W-1	11W-2	11W-1	[3] 11W-1, 11W-2
Owner	Pucalá	Pucalá	Pucalá	Pucalá	Pucalá	Tumán	Tumán	Perulac	Perulac	Perulac
Location	H. Blanca	H. Blanca	J. Pardo	Hda Pátapo	Hda Pátapo	Hda Calupe	Hda Calupe	Chiclayo	Chiclayo	Chiclayo
Depth (m)	15.0	18.3	24.5			20.2	20.2	30	27.5	27.5, 30
Date	10-22-57	9-10-57	2-2-57	2-2-57	2-2-57	6-11-56	5-24-56	2-9-52	2-9-52	July 1948
Analysis Number	FCC-108234	FCC-108232	FCC-(JP9)	FCC-(Pa-5)	FCC(Pa-14)	USGS-52848	USGS-52851	Perm-5062-1	Perm-5062	SAPL
Silica (SiO_2)	8.0	19				30	30			41
Aluminum (Al) } Iron [4] (Fe)	9.6	{4.0								
Iron [4] (Fe):						.0	.0			.2
Dissolved						.01	.01	0.1	0.1	.2
Total						.04	.12			
Manganese [4] (Mn):										
Dissolved						.63	.06			
Total						.83	.95			
Copper [4] (Cu)						.0	.0			
Zinc [4] (Zn)						.0	.0			
Calcium (Ca)	75	93	57	118	98	98	77	} 2.40	2.40	{65
Magnesium [4] (Mg)	5.6	10	7.8	9.3	7.7	15	28			{13
Sodium (Na)	11	} 10	14	8.0	18	{29	33	386	} 396	375
Potassium (K)						.4	.8			
Lithium (Li)						.1	.2			
Bicarbonate [6] (HCO_3)	233	310	173	378	321	409	411	517	522	486
Carbonate (CO_3)		0				0	0		0	0
Sulfate [4] (SO_4)	23	24	31	27	25	16	24	240	250	205
Chloride [4] (Cl)	11	11	18	7.2	15	12	11	190	191	299

Fluoride [4] (F)						.2	.2			
Nitrate [5] (NO_3)	3.1	8.1	6.2	1.4	5.2	.0	.1			Trace
Phosphate (PO_4)						.1	.0			
Boron (B)						.16	.16			
Dissolved solids [4]:										
Residue on evaporation			259	400	367					
Calculated	261	331				402	406			1,240
Hardness as $CaCO_3$:										
Calcium, magnesium	209	273	142	310	263	306	307	120	120	192
Noncarbonate	18	19	32	22	12	0	0	0	0	0
Alkalinity as $CaCO_3$						335	337			
Sodium adsorption ratio (SAR)	.3	.3	.5	.2	.5	.7	.8	15	16	11
Specific conductance micromhos/cm						733	739			
pH	8.6	7.2	7.5	8.0	7.0	7.6	7.5	7.5	7.4	

[1] Sample collected at end of aquifer test.
[2] Sample collected 30 minutes after beginning of aquifer test.
[3] Composite sample, two wells.
[4] Desirable standards for domestic use are from U.S. Public Health Service (1962):

Chloride	250
Copper	1.0
Dissolved iron	0.3
Dissolved solids	500
Fluoride	1.7
Iron	0.3
Magnesium	125
Manganese	0.05
Sulfate	250
Zinc	5.0

[5] Limit for domestic use: 44; from Maxcy, K. F. (1950).
[6] Includes carbonate equivalents.

adequate. Successful use of waters with conductivity above 2,250 micromhos per centimeter is exceptional. Only the more salt-tolerant crops can be grown with such waters, and then only if the water is used copiously and if the subsoil drainage is good.

The relative proportion of sodium is best expressed by the sodium-adsorption ratio (SAR). The soluble inorganic constituents of irrigation waters react with soils as ions rather than as molecules, and the alkali hazard is determined by the absolute and relative concentrations of the cations. If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is low.

The SAR of a soil solution has advantages as an index of the sodium or alkali hazard because it is simply related to the adsorption of sodium by the soil. This ratio is defined by the equation:

$$SAR = Na^{+}/\sqrt{\frac{(Ca^{++}+Mg^{++})}{2}},$$

where Na^{+}, Ca^{++}, and Mg^{++} represent concentrations in milliequivalents per liter.

Four classes of water are recognized on the basis of the SAR:

S1. Water with a low content of sodium is usable for irrigation on almost all soils with little danger of accumulating harmful quantities of exchangeable sodium. However, sodium-sensitive crops may accumulate injurious concentrations.

S2. Water with a medium content of sodium involves an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially where leaching is inadequate, unless the soil contains gypsum. This class of water may be used on coarse-textured or organic soils having good permeability.

S3. Water with a high content of sodium may lead to harmful quantities of exchangeable sodium in most soils but may be controlled by good drainage, liberal leaching, and the addition of organic matter. Gypsiferous soils, however, may accumulate harmful quantities of exchangeable sodium from such waters.

S4. Water with a very high content of sodium is generally unsatisfactory for irrigation except at low and perhaps medium salinity, where the solution of calcium from the soil or the use of gypsum or other additives may make these waters usable.

Four classes of water also are recognized on the basis of electrical conductivity (salinity):

C1. Water of low salinity is usable for irrigation with most crops on most soils. Some leaching is required, but the leaching incidental to normal irrigation is sufficient, except in soils of extemely low permeability.

C2. Water of medium salinity can be used if there is moderate leaching. Plants having a moderate salt tolerance generally can be grown without special salinity control.

C3. Water of high salinity cannot be used on soils having poor drainage. Special management for salinity control may be required, even with adequate drainage, and the plants should have good salt tolerance.

C4. Water of very high salinity ordinarily is not suitable for irrigation, but may be used occasionally if the soils are permeable, the drainage is adequate, the irrigation water is applied in excess to provide considerable leaching, and very salt-tolerant crops are grown.

Combining the four SAR classes with the four conductivity (salinity) classes makes a total of 16 possible classes, as shown in figure 21. From the SAR and electrical-conductivity values used as coordinates, a point showing the quality classification of a water is found on the diagram. The first water sample from well 32W–1 had an electrical conductivity of 739 micromhos per centimeter and an SAR of 0.8 and accordingly is in class C2–S1.

The electrical conductivity was not reported in the analyses of water from other wells, but it may be estimated from the total dissolved solids (U.S. Salinity Laboratory Staff, 1954, fig. 21, p. 21). The estimated conductivities for water from wells HB5 and HB8 are about 400 micromhos per centimeter and 500 micromhos per centimeter, respectively, and their SAR values are less than 1, so that they fall in class C2–S1. But the estimated conductivity for the mixed sample from wells 11W–1 and 11W–2 is about 2,300 micromhos per centimeter and the SAR is 11—values that make the class C4–S3.

Boron is essential to the normal growth of all plants, but the quantity required is small. A deficiency of boron produces striking symptoms in many plants. On the other hand, boron is toxic to sensitive plants, and the concentration that will kill them may approximate the concentration required for normal growth of the very tolerant plants. Lemons show definite, and at times, economically important injury when irrigated with water containing 1 mg/l of boron, whereas alfalfa will make a maximum growth with 1 to 2 mg/l of boron. Scofield (1936) proposed the limits for boron shown in table 13.

TEMPERATURE OF GROUND WATER

The temperature of a ground-water supply is important if the water is to be used for industrial cooling processes or for air conditioning, but

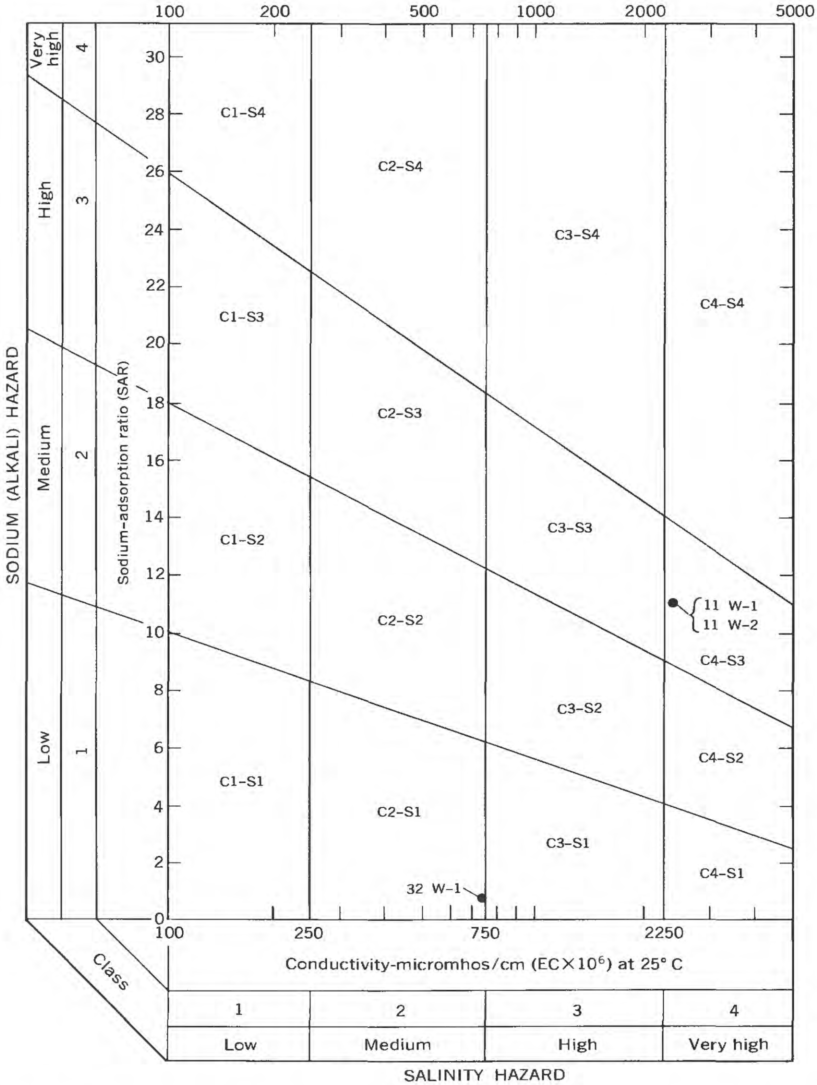

FIGURE 21.—Diagram for classifying irrigation waters (from U.S. Salinity Laboratory Staff, 1954), showing classification of waters from several wells in the Lambayeque Valley.

within the ordinary natural range it is not especially important in irrigation use. Temperatures about 24°C are the most common in the ground water of the Lambayeque Valley (table 14). The lowest and highest observed by the authors of this report were 23.9°C and 28.3° C, respectively.

TABLE 13.—*Permissible limits, in milligrams per liter, for boron in several classes of irrigation water*

Classes of water	Sensitive crops	Semitolerant crops	Tolerant crops
Excellent	<0.33	<0.67	<1.00
Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.50	>3.75

TABLE 14.—*Temperature of ground water from wells in the Lambayeque Valley, 1956–57*

Well	Temperature (°C)	Date	Well	Temperature (°C)	Date
16K	28.3	1–25–56	32W–4	24.2	1–20–56
17N	27.2	1–25–56	32W–5	24.4	2–14–57
19K	28.1	1–25–56	32W–6	24.4	2–14–57
25V–4	23.9	1–26–56	32X–1	24.4	2–13–57
25W–1	24.4	1–26–56	32X–4	24.4	2–13–57
25W–3	23.9	1–26–56	32X–5	24.2	2–13–57
30V–6	23.9	2–14–57	32X–10	24.4	2–13–57
30W–1	24.4	1–18–56	33V–1	24.4	2–14–57
30X–5	24.2	1–19–56	33V–2	23.9	2–14–57
31V–2	23.9	2–14–57	33W–1	24.4	1–18–56
31V–4	24.2	2–14–57	33W–2	24.4	1–18–56
31W–1	24.4	2–14–57	33W–3	24.4	2–14–57
31W–5	23.9	2–14–57	33X	24.4	2–13–57
31W–8	24.2	2–14–57	37R	25	1–26–56
31W–9	23.9	2–14–57	38Q–2	27	----------
32V–2	23.9	2–14–57	38Q–3	27	----------
32V–5	24.4	2–14–57	38R	25	----------
32W–1	24.4	2–14–57	40R	27.2	----------
32W–3	24.4	2–14–57			

WATER DEVELOPMENT

The development of ground water in the Lambayeque Valley, as of 1958, had been accomplished principally for irrigation and mainly by means of drilled wells, although the early irrigation wells were hand dug. Some of the dug wells were highly successful. The Tulipe well (37R), dug in 1915 for Sociedad Pucalá, was still being used in 1956, although it no longer was a big producer. Dug well 35S, on Hacienda Pátapo, was equipped with two turbine pumps that were reported to discharge 235 lps (fig. 22). But despite such successes, the new wells in the 1950's were being put down by machine.

Few wells and only small quantities of ground water are used for purposes other than irrigation. The Hospital del Seguro Social del Empleado and the Compañía Peruana de Alimentos Lácteos, S.A., both in Chiclayo, are the principal nonirrigation users of ground water.

FIGURE 22.—Dug well 35S, Hacienda Pátapo. Two turbine pumps were discharging 235 lps.

Most other water needs in the area are met with surface water. Water for domestic use, including the water from public water systems and water for stock use, comes mainly from rivers. Some rural residents use well water, but many depend on water from the nearest irrigation ditch, most of which is surface water.

PUBLIC WATER SUPPLIES

The major public supplies of water in the Lambayeque Valley are obtained from surface sources, but a few of the smaller ones are drawn from ground water. The supplies for Chiclayo and Lambayeque are taken from Río Lambayeque. Each city has its own treatment plant. Pimentel gets water from Chiclayo through a pipeline, and Santa Rosa gets water from Pimentel by truck. Reque and Monsefú depend on water transported in cans from Río Reque. Ferreñafe gets water from a filtration gallery that passes under a canal carrying water from Taymi canal, which is fed from Río Chancay. But Puerto Eten and Villa Eten rely on a well 30 m deep in Villa Eten. The rather large populations of some of the haciendas, among them Pátapo, Tumán, and Mamape, are in part supplied with well water.

WELL-DRILLING METHODS

Wells have been drilled in the Lambayeque Valley by both the percussion and the hydraulic-rotary methods, but the majority have been put down by percussion. Most wells are cased to the bottom and have screens made by slotting the casing after installation. Some wells have been gravel packed.

WELL DRILLING BY NEGOCIACIÓN TUMÁN

Well-drilling operations were in progress in the valley, chiefly by or for the sugar enterprises, Tumán, Pomalca, and Pucalá, throughout the fieldwork for this investigation. The operations of Tumán were the most elaborate, because they included preliminary test drilling. These operations are described below.

Negociación Tumán contracted with the Servicio Cooperativo Interamericano de Producción de Alimentos (SCIPA) for the drilling of the test holes. The Servicio was an agricultural service agency operated jointly by the Peruvian and United States governments under the program of international cooperation. Well drilling was one of its functions.

The drilling was done by the hydraulic-rotary method between July 1, 1953, and August 1, 1955, all under the same crew chief. A total of 155 test holes, aggregating 3,401 linear meters, was drilled. Fifty-three test holes were drilled north of Río Lambayeque (Hacienda

Tumán) and 98 were drilled between the Ríos Lambayeque and Reque (Hacienda Calupe). The remaining four test holes were drilled to test areas outside the Lambayeque Valley.

Many of the test sites proved to be favorable, especially on Hacienda Calupe, and the Negociación made a contract with a commercial drilling company, Agrícola-Comercial-Industrial, S.A. (ACISA), for the drilling of production wells. This company between February 1954 and November 1956 drilled 91 wells by the percussion method (fig. 23). The Negociación then contracted with SCIPA for six more bringing the total to 97.

Of the 97 production wells, 81 were to be used in irrigation, two were for potable water supplies, and 14 were abandoned as dry holes. All were cased with 15-inch casing, which was perforated at appropriate depths after installation.

The drillers submitted logs of the strata penetrated in each test hole and each production well. The engineering department of the Negociación then prepared graphic logs showing not only the strata but also the position of the perforated section of casing and the number of openings in it. Many of these logs carried notations on the yield and drawdown obtained in the initial and subsequent pumping tests of the well.

COMPARISON OF DRILLERS' LOGS

Comparison of test-hole logs with the logs of production wells drilled at the same sites for Negociación Tumán reveals many discrepancies and suggests that test drilling, even when conscientiously done, may be misleading. It is not a sure guarantee that a well will produce.

Two holes—first a test hole and then a production well—were drilled at 69 sites, 61 of which were on Hacienda Calupe and eight were on Hacienda Tumán. The logs of the 61 Calupe test holes indicated that, on the average, the water-bearing strata would be found in the depth interval from 8.7 to 15 m below the land surface. The logs of the production wells, however, indicated the depth interval to be from 11.3 to 18 m. The test holes indicated the average thickness of water-bearing materials to be 5.5 m, but the production wells indicated 6.3 m. The difference in thickness is 0.8 m (15 percent). At some sites the discrepancies were very great; for example, only 1 m of water-bearing material was recorded in the test hole, but 12 m were recorded in the production well. An extreme case of contradictory drillers' logs is illustrated in figure 24.

The logs of the eight test holes on Hacienda Tumán showed, on the average, that water-bearing strata would be found in the depth interval from 8 to 14.2 m, but the logs of the production wells indicated the depth interval to be 9.9 to 17.4 m. The test holes indicated an

FIGURE 23.—One of the irrigation wells drilled for Negociación Tunâm in the mid-1950's. Electric cable for submersible turbine pump is at left. Steel tape used in measuring water level has been lowered in nipple through which an air line was to be installed.

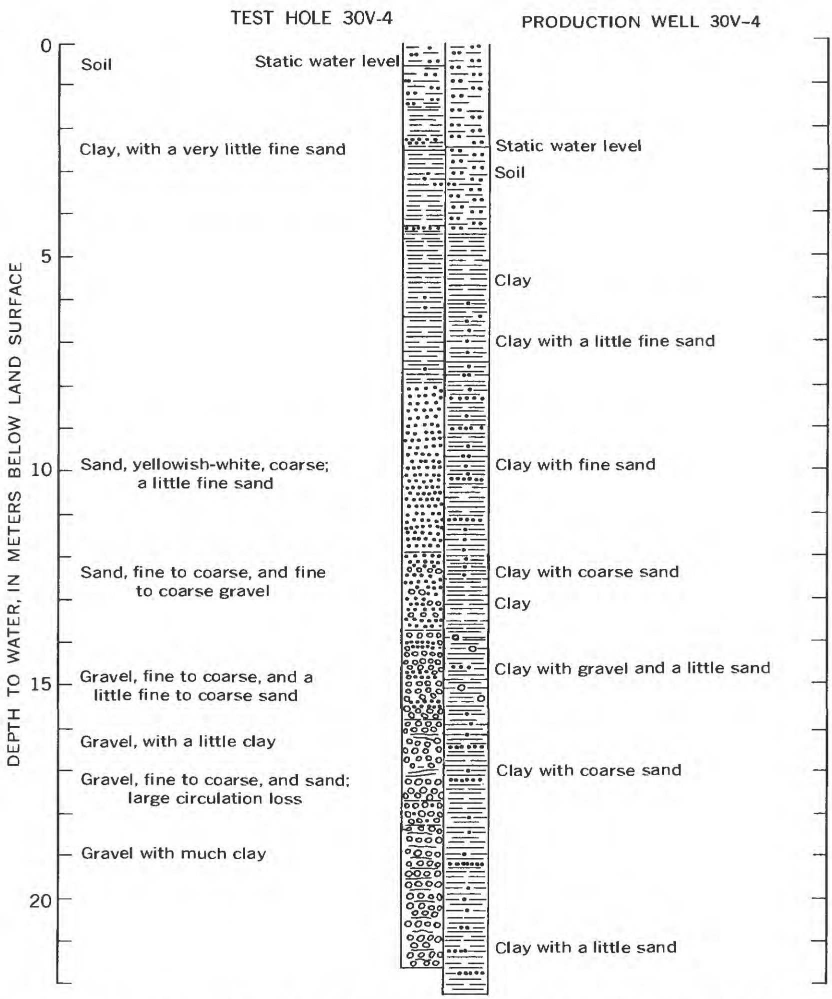

FIGURE 24.—Contradictory drillers' logs for the same location. Test hole 30V-4 (left), drilled by the hydraulic-rotary method, suggests the presence of about 10 m of water-bearing sand and gravel, promising a high yield. Production well 30V-4 (right), drilled by the percussion method, suggests almost complete lack of water-bearing strata.

average of 5.1 m of water-bearing material, but the production wells indicated 7.2 m. The difference is 2.1 m (40 percent).

The proportion of water-bearing material reported in the first 20 m below the land surface on Hacienda Tumán was 26 percent in the test holes, but it was 36 percent in the production wells.

The discrepancies described above are due to many causes, some of which are:

1. Different drilling methods yield drill cuttings of different appearance and physical character from the same strata.

2. When muddy or clayey sand is penetrated in hydraulic-rotary drilling, the clay will disappear into the drill fluid, and the driller may describe the cuttings as "sand," thus implying greater permeability than is actually the case.
3. Some mixed samples can be described as well by one set of terms as another. A mixture of sand and clay may be described either as clayey sand, suggesting a degree of permeability, or as sandy clay, suggesting relative impermeability.
4. Different drillers will describe the same strata in different ways, according to their knowledge of rock materials and their experience.
5. The same driller may describe similar strata in rather different terms because of accidental differences in sample collection and sometimes because of subtle, subconscious factors.
6. In percussion drilling, all the strata penetrated in a depth of 1 or 2 m will become mixed together by the bit, pending cleaning of the well by bailing. The mixed materials will be described as one, unless the driller has distinguished changes in strata from the action of the drill.

The discrepancies in drillers' logs make interpretation of the logs uncertain and probably uneven. No one can determine from the log alone how much permeable material is included in a stratum described as sand and clay—translatable as permeable and impermeable—but often this is the best description a driller can give for the samples taken from alternating thin layers. The authors of this report, when summing up the amounts of permeable and impermeable strata, necessarily have made assumptions and adopted arbitrary procedures. To them, therefore, may be attributed some part of the apparent differences between test-hole and production-well logs.

EFFECTIVENESS OF TEST DRILLING

The effectiveness of test drilling is not readily appraised. It depends on planning and management as much as on the skill and experience of drill crews. The test drilling is intended to locate the aquifer or aquifers so that production wells may be constructed where the strata will yield water most freely. It is intended to eliminate the drilling of dry holes at unfavorable sites and to promote efficient well-field operation through good spacing of production wells. Enough test holes should be drilled to develop the essential hydrologic facts in each situation, but not so many should be drilled that their cost absorbs or exceeds the potential savings. Whether testing in specific situations attains the foregoing objectives is often clouded by inability to demonstrate how much the efficiency of the well or well field has been increased or even to demonstrate that it has been increased at all. The efficiency that might have been achieved without testing cannot be known. Whether the cost of test drilling is less than the probable cost of dry holes not drilled also is hard to demonstrate convincingly. Results in two different locations that presumably are similar geologically and hydrologically, one of them test drilled and the other not, may be compared, but there usually are enough differences between the areas or the procedures to create doubts about the validity of the comparison. Although the results attained by Negociación Tumán might be compared with those of Pomalca and Pucalá, where test drilling was not done, the comparison lacks conviction because full information on the failures at Pomalca and Pucalá is lacking. Hence, the effectiveness of the Tumán testing cannot really be gaged, though the following observations are suggestive.

Many sites were abandoned after test drilling. No production well followed the test hole at 82 sites. This is 54 percent of the 151 tested sites in the Lambayeque Valley, and it implies that subsurface conditions proved to be unsatisfactory at more than half the locations considered. Potentially, 82 dry holes or poor producers were never drilled, although admittedly a few good sites may have been passed up because of considerations not related to subsurface strata. If it is assumed that the test drilling reliably disclosed the information that was sought, the plausible conclusion is that the testing saved money because test holes cost less than production wells.

But the test drilling did not eliminate dry holes. Sixteen percent of the production wells that were preceded at the same site by test holes were ultimately abandoned. If the test-hole information really controlled management's decision to proceed with a production well, the conclusion is that, at these sites, the testing missed its objective.

The results seem to have been better, at least superficially, where no test holes were drilled. Only seven percent of the production wells drilled without benefit of previous testing were failures. And in them, the average thickness of permeable strata was 1 m greater than in wells preceded by test holes, although for no obvious reason the average maximum yield on test was 3.3 lps less (table 15). But the apparent success of these wells is not all accident. Most of them are at locations intermediate between, and only a few hundred meters from, successful production wells, or they were between favorable test holes. Actually, therefore, normal testing procedure had been followed, and the percentage of failures among these wells perhaps should be regarded as high, not low.

The concentration of test holes in the eastern part of Hacienda Calupe logically raises the question, Were so many test holes necessary? The test holes, where most concentrated, were only 260 to 360 m apart. Elsewhere, they were as much as 400 m apart, not counting

TABLE 15.—*Comparison of production wells drilled on sites of test holes with production wells drilled at untested sites, Negociación Tumán*

	Production wells	
	Not preceded by test hole	Preceded by test hole
Failures percent	7	16
Average thickness of permeable strata m	7.1	6.1
Average maximum yield on test lps	28.7	32

some large gaps between groups of wells, which may purposely have been left untested. It would be easy to assert that fewer test holes would have produced nearly equivalent information, but not easy to prove this assertion in the face of the well known general variability of alluvium, and the demonstrated variations, in the fields of Tumán, between some adjacent locations. Probably many of the test holes were needed and worth while, although here and there savings might have been made by eliminating some test holes and rearranging others.

WELL DRILLING BY OTHERS

In addition to the drilling operations of Negociación Tumán, there was in the period 1956–58 considerable well drilling by others. Sociedad Agrícola Pomalca and Sociedad Agrícola Pucalá both owned two percussion well-drilling machines and operated them with their own crews. A commercial well-drilling company based in Chiclayo, the Empresa Perforadora, Sociedad Anónima (EPSA), also was operating a percussion drill. These operators followed procedures normal to percussion drilling. They generally did not make a test hole, but drilled, cased, and tested a production well, which was put to use if results were satisfactory. Gravel packing of such wells was a standard practice, and one operator, at least, routinely had each well surged before the initial testing.

WELL SCREENS

A well screen is a section of the well casing that has holes through which water may enter the well. The selection and installation of well screen is not a simple matter. A well screen, to be efficient, should have openings appropriate to the size of the mineral grains of the water-bearing strata, should have enough area in openings to admit the desired quantity of water without excessive turbulence, and should be placed in the well opposite the water-bearing stratum or strata.

Some well screens consist only of well casing in which holes have been cut, often at the well site. In very light casing, such as galvanized iron, the holes may be cut by hacksaw. In heavier iron or steel casing, they may be cut by oxyacetylene torch before installation of the casing in the well. They may also be cut after installation by means of a knife that is lowered inside the casing to the desired depth. The knife has been used in many of the wells in the Lambayeque Valley. It has the disadvantage that the operator, being unable to see the opening he has made, cannot know how large it is and sometimes cannot even be sure that he has made one. All these methods make openings that cannot easily be varied in size and, therefore, that may be inappropriate to the size of the mineral grains. They are generally too large, unless the water-bearing strata happen to consist of gravel.

A factory-made well screen has uniform openings, which in one screen may be small, for use in sand, and in another screen may be large, for use in gravel. The screen may be constructed of metals especially selected to minimize corrosion. Such screens are more efficient, and are likely to last longer, than the screens described in the preceding paragraph, but their initial cost is greater.

A well screen should be opposite (exposed to) the water-bearing stratum or strata, if it is to let the water into the well efficiently, but the length of screen need not equal the thickness of the strata (Johnson Drillers' Journal, 1956). Where the water is under pressure, screen should generally be placed opposite the lower 70 to 80 percent of the strata, if maximum yield with minimum drawdown is to be obtained. Where the water is not under pressure, less screen is necessary. The water is drained from the upper part of the water-bearing stratum, and screen opposite this part would do no good. No more than the lower half need be screened in strata ranging in thickness from 3 to 15 m.

The effectiveness with which screen was placed in the wells of Negociación Tumán is suggested by table 16, which compares screen placement to the position of the water-bearing strata as identified by the authors from the drillers' logs of the production wells. Comparison to the test-hole logs is not made because a well driller is not likely to install screen in a well on the basis of a previous driller's log. He will install it according to his own observations of the well under construction. Part *A* of the table shows that, on the average, 83 percent of the thickness of water-bearing material was screened. It shows also that, on the average, 84 percent of the screen was placed opposite water-bearing material. Part *B* shows that, although only 10 percent of the wells have all the screen effectively placed, 38 percent of them have between 75 and 100 percent of the screen so placed.

Table 16 suggests how effectively the screens were being installed in wells under the conditions that prevailed in the late 1950's in the

TABLE 16.—*Screen effectiveness. Placement of well screen compared to position of water-bearing strata as identified in drillers' logs of production wells, Negociación Tumán*

A. Water-bearing strata in relation to screens

	Minimum	Maximum	Average
Percent of strata screened	21	100	83
Percent of screen opposite strata	14	100	84

B. Screen effectiveness, by wells

Effectiveness of screen (percent)	Production wells (percent)
100	10
75–100	28
50–75	27
0–50	35

Lambayeque Valley. Those were the ordinary conditions of well drilling under contract. Screen effectiveness in the table means only that more or less of the screen is opposite water-bearing materials, the details of restricting the screen to the lower part of that zone having been neglected. The table suggests that, despite a rather considerable expenditure for test drilling and the logging of the production wells, not all the screen achieved its purpose.

The practical effectiveness of the well screens is measured approximately by the quantity of water obtained per unit of screen length; that is, well discharge divided by meters of installed screen. This quantity, here called screen unit yield, is a clue to the length of screen required to obtain a desired discharge, but it is not precise because it depends on several variables, some of which are usually unmeasurable. Comparison with an "ideal" screen unit yield is impossible because the permeability of the water-bearing stratum—one of the controlling factors—differs from well to well and usually is not known, or at least its share in controlling the discharge of a well is not known. Except in a truly uniform aquifer, the "ideal" screen unit yield will differ from well to well. It is probably safe to say that the screen unit yield in most wells is less than the ideal. The screen that is too long will have a unit yield lower than it should be, because the obtainable yield will have to be distributed to more length than is necessary. The screen that is too short, or has openings too small, or is misplaced in the well, will have a unit yield lower than it should be, because the screen cannot admit all the available water. Likewise, if the pump is incapable of lifting all the water, the unit yield will be lower than it could be.

The screen unit yield, determined in the initial pumping tests of the wells, ranged from about 2 to about 16 lps/m (liters per second per meter) of screen, but declined about half (0.8 to 7.1 lps/m) under regular irrigation pumping. The average screen unit yield, based on the pumping tests, was 4.9 lps/m, and in regular use, it was 2.5 lps/m. The number of wells having screen unit yields of eight different magnitudes is shown in table 17.

TABLE 17.—*Screen unit yield of 31 irrigation wells of Negociación Tumán*

Screen unit yield (lps/m)	Number of wells	
	On initial test	In regular use
<1		1
1–2	1	14
2–3	5	7
3–4	8	5
4–5	5	3
5–6	5	--------
6–7	5	--------
>7	2	1

AQUIFER UNIT YIELD

The probable yield of a well in a water-bearing stratum of given thickness is a matter of prime interest to both well owner and well driller. The yield cannot be predicted with much confidence when only the thickness is known, but an estimate can be made where information from other wells is available. If the average well discharge per meter of thickness of water-bearing stratum—here called aquifer unit yield—is known, this average need only be multiplied by the thickness of water-bearing stratum in a newly drilled well to obtain an approximate, but useful, estimate of the probable discharge of the well. The estimate assumes, of course, that the well being completed is to be similar in construction and in the type of pump to the wells included in the average.

The aquifer unit yield—measured in liters per second per meter of thickness—depends directly on the permeability of the aquifer, but it depends also on well construction and pump capacity and efficiency. A well badly screened or a screen partly obstructed may admit much less water than the aquifer is capable of delivering. Likewise, a pump that is too small does no justice to either the well or the aquifer. The less permeable the aquifer, the more likely it is that well and pump can take all the water delivered to them; but the better the aquifer, the more likely it is that less water is brought to the surface than might be. The aquifer unit yield, therefore, is likely to be too low rather than too high, provided of course that the aquifer has been accurately logged and identified and that the discharge has been accurately measured.

The aquifer unit yield should decrease under protracted pumping from an unconfined aquifer because the water table is lowered by the pumping, reducing the thickness of saturated materials. An adjustment might be made by taking into account the amount of water-table decline, as determined from water-level measurements, but this would be tedious, uncertain, and perhaps not worth while. The magnitude of the decline is itself worth knowing. The aquifer unit yield of 31 irrigation wells ranged widely: from 1.4 to 31.3 lps/m of thickness, as calculated from initial pumping tests, and from 0.9 to 14 lps/m at the end of the pumping season. The averages were 6.7 lps/m on test and 3.5 lps/m after protracted pumping. Hence, an average well drawing water from 6 m of water-bearing stratum can be expected to yield, under ordinary operating conditions, about 21 lps. The number of wells having unit yields of eight different magnitudes is shown in table 18.

TABLE 18.—*Aquifer unit yield of 31 irrigation wells of Negociación Tumán*

Aquifer unit yield (lps/m)	Number of wells	
	On initial test	In regular use
<1		2
1–2	1	6
2–3	2	8
3–4	4	9
4–5	5	--------
5–6	5	4
6–7	6	--------
>7	8	2

PUMPING PRACTICE

Pumping practices are a clue to the probable total pumpage in the Lambayeque Valley. Pumping for irrigation is seasonal and varies inversely with the availability of river water. It probably varies with the growth of crops, but not markedly so because sugarcane, the principal irrigated crop, is both planted and harvested in every month. At any time, some cane needs abundant water, some cane is beyond needing much, some cane is being harvested, and some cane fields are barren, awaiting new planting. The water need of the area, therefore, is about the same the year around, although the application of the water is continually shifting from place to place. With rice, the demand for water is seasonal, and the principal cause for drawing on the underground reservoir is declining availability of surface water. The pumping practices of the users of ground water naturally differ somewhat according to their needs, and the practices of any one user will differ from one year to the next. A study of the pumping regimen of two major irrigators in 1956–57 suggests that the average well used for irrigating sugarcane in the Lambayeque Valley is pumped about 112 days during a 6-month season of heavy pumping, or an average of about 18 days per month.

ANNUAL PUMPAGE

The annual ground-water pumpage in the Lambayeque Valley was fast approaching 100 million cu m at the time fieldwork for this report was completed. The quantities pumped by two major users in 1956 and 1957 were nearly 32 million cu m and about 62 million cu m, respectively (table 19). The pumpage of others was estimated on the basis of the number of wells probably in use, their known or probable discharge rate, and normal pumping practice as analyzed above. Other irrigators are estimated to have pumped about 18 million cu m in 1957. The industrial users and the Hospital del Seguro Social del Empleado in Chiclayo probably pumped only 200,000 cu m. Adding something for the pumping of ground water for public supplies in a few towns brings the total to 81 million cu m. There was additional pumping capacity, represented by wells completed but not equipped with pump and power by mid-1957, and some old wells were being abandoned. After allowance for these uncertain plus and minus factors, it appears that the total annual pumpage in the area was soon to become 85 or 90 million cu m, with 100 million cu m in sight.

TABLE 19.—*Pumpage, in cubic meters, of ground water by Negociación Tumán and Sociedad Agrícola Pucalá, 1956–57*

Month	Pumpage 1956	Pumpage 1957	Month	Pumpage 1956	Pumpage 1957
January	4,511,927	7,994,126	August	3,514,359	7,897,302
February	720,328	6,695,031	September	5,026,365	8,010,953
March	236,775	1,037,934	October	1,443,858	7,760,334
April	518,850	499,867	November	3,686,019	6,430,702
May	1,731,299	654,475	December	7,380,381	7,543,964
June	975,013	1,821,374			
July	2,074,582	5,748,891	Total	31,819,756	62,094,953

FURTHER DEVELOPMENT OF GROUND WATER

The data presented in this report indicate that ground water in the Lambayeque Valley was probably susceptible to further development without serious danger of adverse results, provided that water-bearing strata are present in unexploited localities. The upper part of the valley already had been rather intensively developed by 1958, but not much had been done in the lower part. The upper and lower parts are here considered to be separated by an imaginary line extending from Reque to Pomalca and thence through Picsi and Ferreñafe to the Pan-American Highway at the north boundary of the mapped area.

The full effect of existing wells in the upper part of the valley was not apparent in 1958, because not all the wells had pumps, but the effects of protracted (through seasonal) pumping at Hacienda Calupe suggest that total well capacity at that place approached reservoir capacity. Substantial recharge derived from river water used in irrigation made heavy drafts possible. Further development of ground water was not necessarily to be avoided, but concentrations of new wells, located incautiously in relation to older wells, could invite disaster.

Not all the upper valley is blessed with good water-bearing strata, notwithstanding the many successful wells already completed there. The drilling in a rather large area on Hacienda Tumán disclosed unfavorable geologic conditions to a maximum depth (in one well) of 102 m. On the other hand, good results had been obtained to the northwest, beyond Tumán, thus affording an example of the irregularity of alluvial deposits and the uncertainty connected with drilling wells in them.

The possibilities for development in the lower part of the valley are poorly indicated because only 11 wells were found there, and most of these were concentrated in and near Chiclayo. But lack of wells means room for exploration and development. Large withdrawals of ground water in the lower part of the valley probably would not adversely affect the established well fields, unless the new pumping were concentrated immediately adjacent to those fields. The adverse effects would be more likely to work the other way: wells in the upper part of the valley, by getting the water first, might deprive wells in the lower part of the valley of water at critical times.

All the successful irrigation wells in the lower part of the valley were near the eastern boundary, at Capote (17N), Mocopú (16K and 19K), Las Lomas (9B), and Los Cocos (11A). Some of the other wells in the lower valley were small producers, but wells at Villa Eten (8k) and Chacra Vieja were reported to yield 16 and 40 lps, respectively. The Chacra Vieja well had been only recently completed when the authors of this report were last in the area, and even though it is "near" Lambayeque, it could not be visited because heavy rain had made the road impassable.

The possibilities of finding ground water in the immediate vicinity of Chiclayo, as judged by the records of wells drilled before 1958, seem to be limited by scarcity of water-bearing strata. The records of existing wells disclose a few meters of sand and gravel, although a maximum depth of 100 m had been attained by drilling. Yet, good aquifers not uncommonly are found where sparse data initially imply that well drilling would not be justified.

Poor chemical quality of the ground water in the lower part of the valley could prove to be an important deterrent to development. The quality of a mixed water sample from two wells at Chiclayo is not good; the water could be used for irrigation only if soils and crops are especially suitable. The water from the Chacra Vieja well (Lambayeque) was reported to be partly salty because of the occurrence of a stratum containing salty water, separated by clay beds from strata above and below that contain fresh water. This scanty evidence suggests that the ground water in a belt of unknown width parallel to the Pacific coast may be too mineralized for most ordinary uses. It is inferred that salty ground water is present at most locations west of the Pan-American Highway.

Repeated use of water for irrigation inevitably will cause an increase in the mineral content of the water. Each time the water is spread over the fields, a part of it is evaporated and transpired, increasing the concentration of mineral matter in the part remaining. The number of times that the ground water can be pumped to the surface, spread on the land, and partially returned to the underground reservoir before it becomes excessively mineralized is not known. Clearly, however, the mineralization will increase in the downstream direction unless dilution with fresh water is effected.

It would be appropriate in the lower Lambayeque Valley to analyze the water from selected wells periodically, possibly in the area between Pomalca and Chiclayo. The process of mineralization will take place slowly. Analyses at 5-year intervals probably will suffice.

CONCLUSIONS

As this investigation was brought to a close, it appeared that further large-scale development of ground water in the upper part of the Lambayeque Valley would be inadvisable until the effects of the existing development could be appraised. Limited additional development, however, appeared to be feasible.

Further development in the lower part of the valley, east of the Pan-American Highway and west of Pomalca, Picsi, and Ferreñafe, seemed to present no serious problems. The development probably will be limited on the west by poor chemical quality of the water. Tentatively, the Pan-American Highway seems to mark the western limit of chemically acceptable ground water.

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INDEX

[Italic page numbers indicate major references]

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
GOVERNMENT OF PERU
UNDER THE AUSPICES OF THE
U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT

WATER-SUPPLY PAPER 1663-F
PLATE 1

EXPLANATION

Qds
Dune sand
Windblown sand, at places 10 meters thick. Lies above regional water table

Qa | Qf
Alluvium
Stream-laid gravel, sand, and clay. Principal aquifer. Qa, alluvium deposited mainly by the Río Chancay and distributaries; Qf, fan alluvium of tributary canyons, less well sorted and less permeable

QUATERNARY

TKb
Bedrock
Mainly intrusive rocks, but including a little quartzite and limestone. Not water-bearing because of low porosity and lack of recharge

CRETACEOUS AND TERTIARY

Geologic contact

Well

Test hole

Well and test hole at same site

Abandoned well
Wells are only numbered where more than one occur in the same square kilometer. See text

Paved highway

Road
Good gravel or dirt

Road
Private or poor

Monsefú
City, town, or hacienda having many residents

Hacienda, caserío, or ranchería

DIVERSION POINT
Diversion point

211 Cerro del Combo
Mountain peak number, where shown, is altitude in meters above mean sea level

Base from various sources listed in the text

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MAGNETIC DECLINATION, 1969

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1969—W69053

MAP SHOWING THE GEOLOGY AND HYDROLOGY OF LAMBAYEQUE VALLEY DEPARTMENT OF LAMBAYEQUE, NORTHERN PERU

SCALE 1:100 000

5 0 5 KILOMETERS

5 0 5 MILES

Geology and hydrology by S. L. Schoff and J. L. Sayán M., 1955–58

UNITED STATES DEPARTMENT OF THE INTERIOR
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WATER-SUPPLY PAPER 1663-F
PLATE 2

INDEX MAP SHOWING LOCATION OF HYDROLOGIC SECTIONS

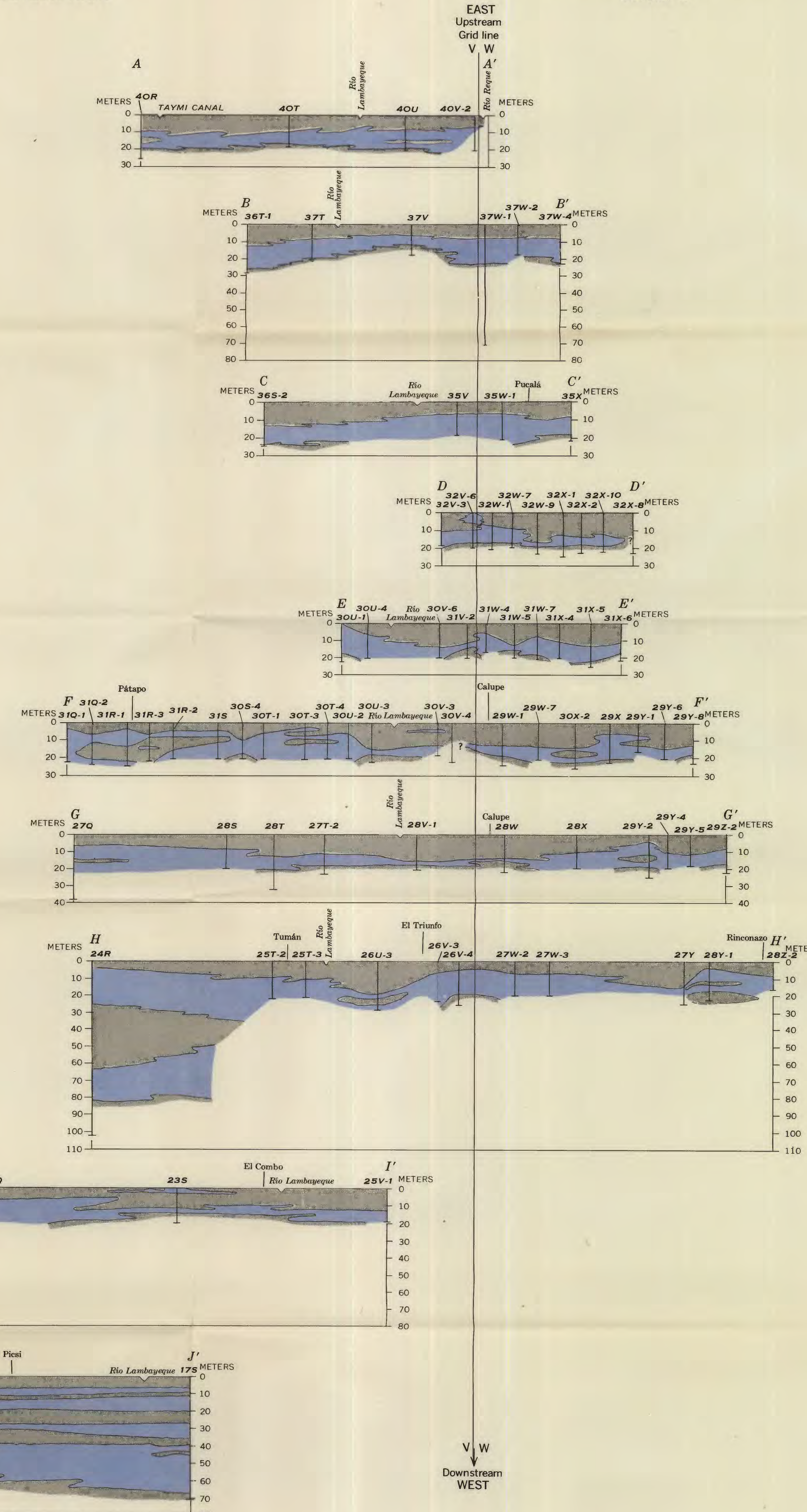
EXPLANATION

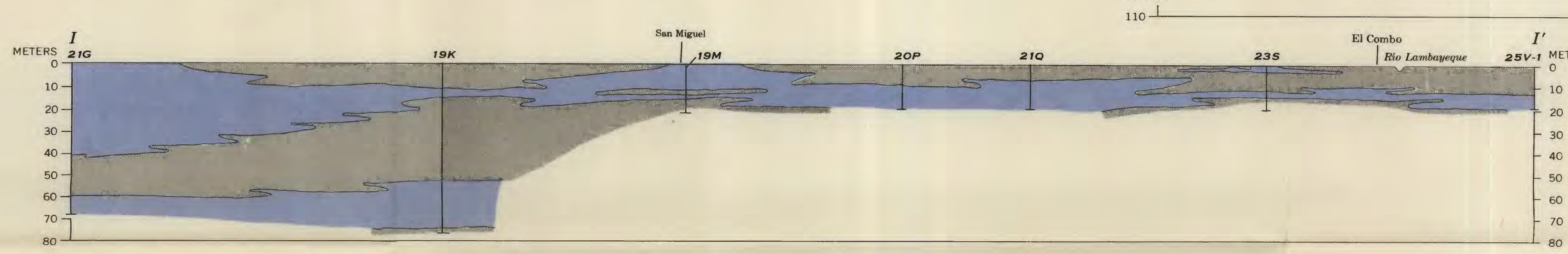
Water-bearing zone

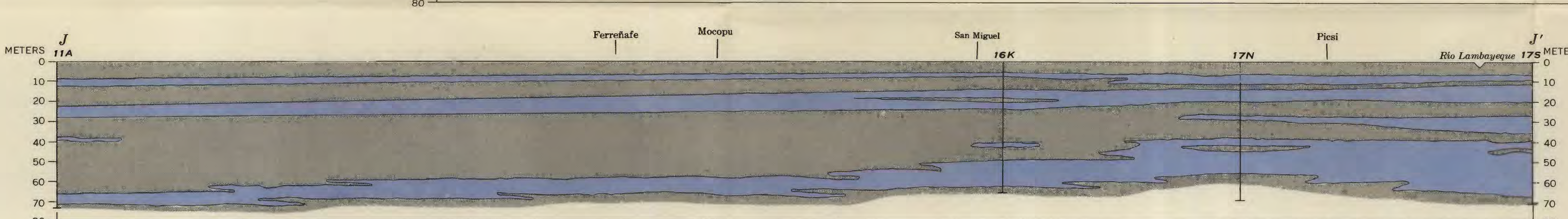
Impermeable strata

Approximate contact between water-bearing zone and non water-bearing strata
Dashed where inferred

40R
Well or test hole
Number refers to assignment in report. Well-numbering system referred to in text







INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1969—W69053

HYDROLOGIC SECTIONS, BASED ON DRILLERS' LOGS, SUGGESTING CORRELATIONS OF THE PERMEABLE ZONES IN LAMBAYEQUE VALLEY, DEPARTMENT OF LAMBAYQUE, NORTHERN PERU

SCALE 1:50 000

1 .5 0 1 2 3 4 5 KILOMETERS

1 ½ 0 1 2 3 4 5 MILES

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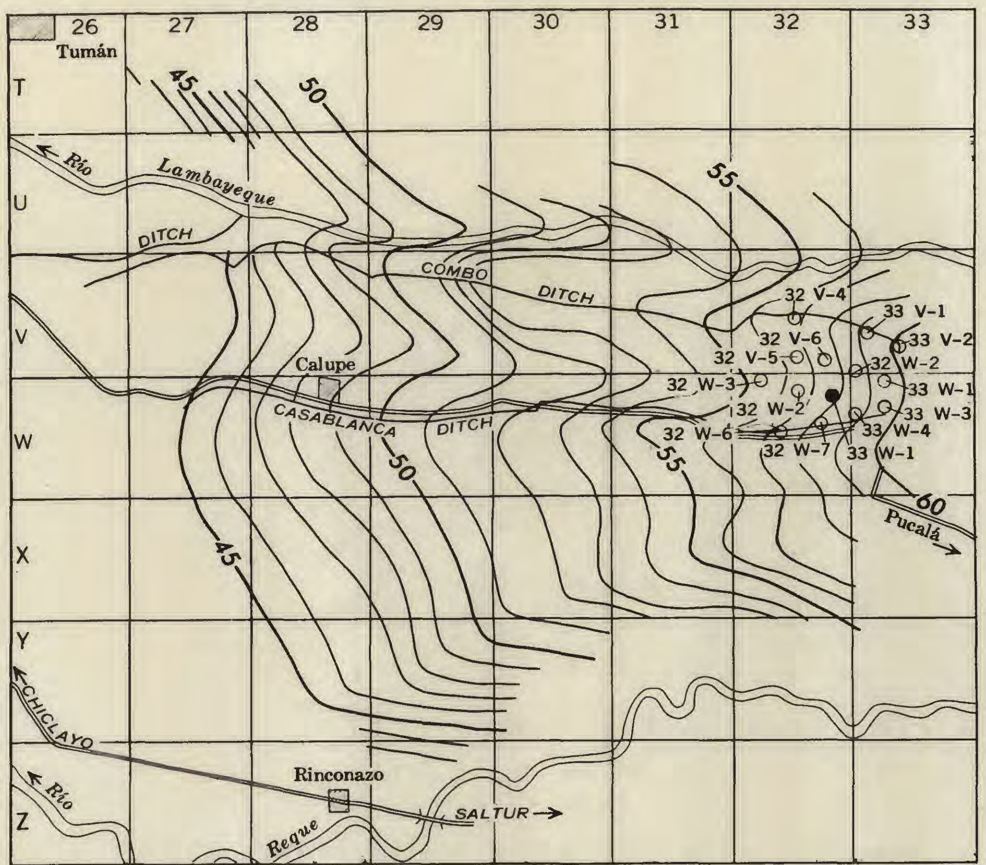
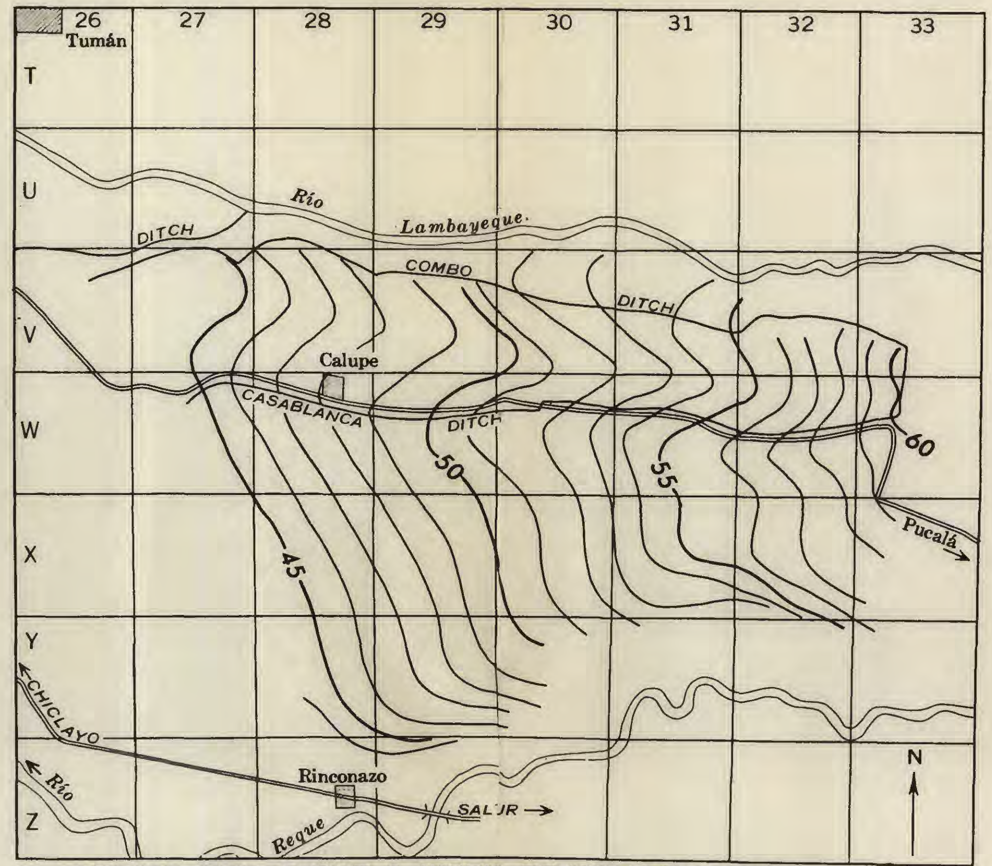


MAY–JUNE 1956. WELLS MEASURED DURING PRELIMINARY TEST PUMPING FOR CALUPE AQUIFER TEST ARE SHOWN



AUGUST 1956. ABOUT 3 WEEKS BEFORE THE BEGINNING OF IRRIGATION PUMPING FOR THE 1956–57 SEASON

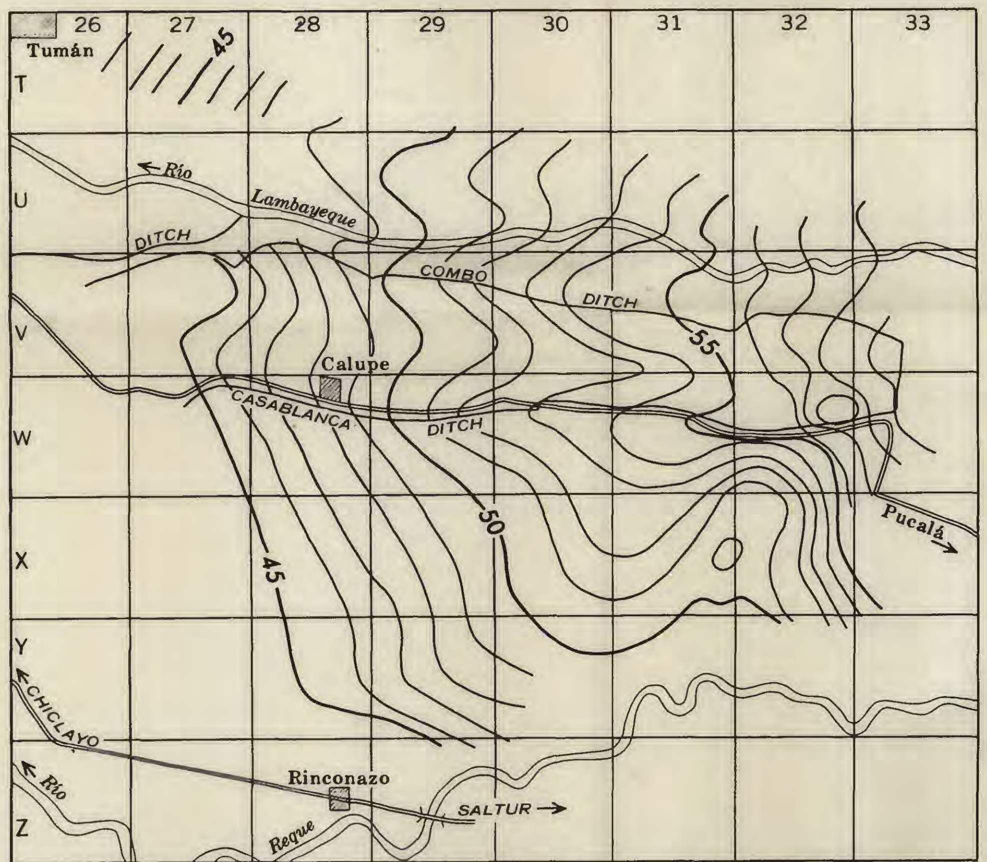
EXPLANATION

● Discharge well

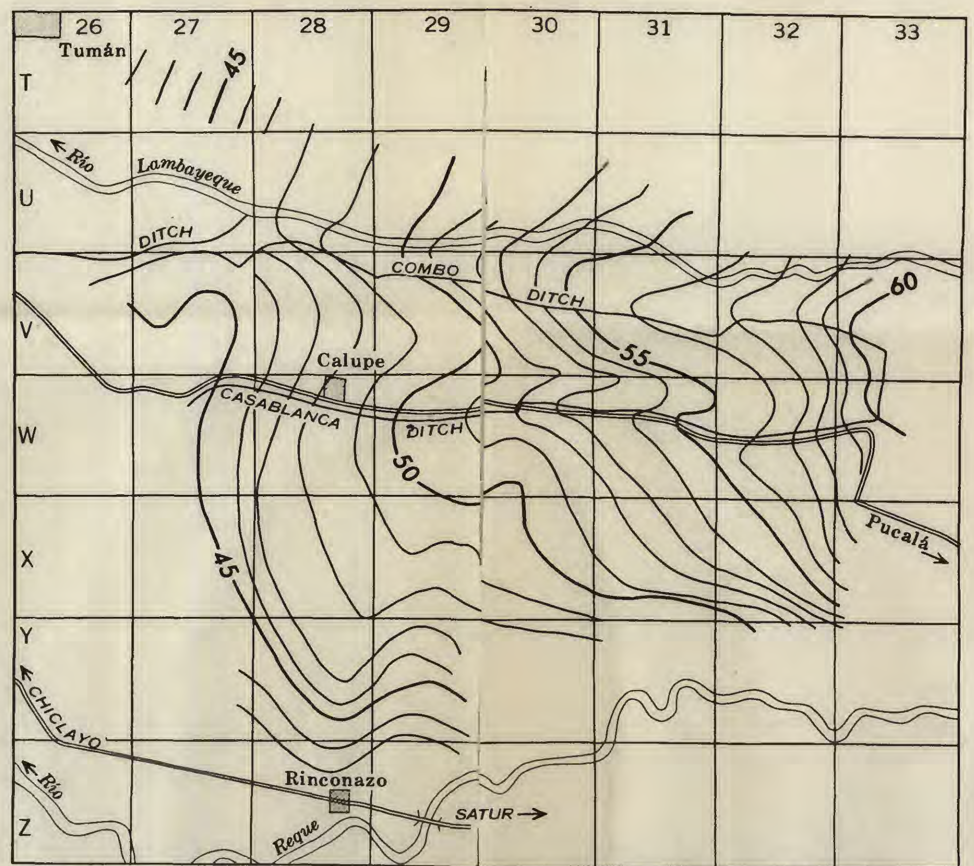
○ Observation well

—45— Water-table contour
Interval 1 meter
Datum is assumed

COMBO DITCH
Main irrigation ditch



APRIL 1957. ABOUT 6 WEEKS AFTER THE END OF IRRIGATION PUMPING FOR THE 1956–57 SEASON



APRIL 1958. ABOUT 40 DAYS AFTER THE END OF IRRIGATION PUMPING FOR THE 1957–58 SEASON

MAPS OF WATER TABLE FOR SELECTED DATES AT HACIENDA CALUPE, LAMBAYEQUE VALLEY, DEPARTMENT OF LAMBAYEQUE, NORTHERN PERU

1 0 1 2 3 KILOMETERS

1 0 1 2 MILES

349-824 O - 69 (In pocket)