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PRELIMINARY GEOHYDROLOGIC STUDY OF THE RIO SINALOA GROUND WATER RESERVOIR

Submitted by

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CONTENTS

ILLUSTRATIONS

Tables

Figures

ABSTRACT

The present paper is based on fieldwork done during the summer of 1971. Together with information collected previously, this work constitutes a preliminary description of the Rio Sinaloa Ground Water Reservoir.

The study region is located in northwest Mexico on the Pacific Coast. It has the Rio Sinaloa as principal drainage. The climate is semiarid. The principal aquifer is quaternary alluvium, which consists of gravels, sands, clays and silts. There are two well fields one on each side of the river. About 300 wells on the left side pump approximately 149 x 10^6 m^3, and 240 wells on the right side pump 50 x 10^6 m^3. Water level information exists from 1968. On the basis of chemical analyses, a zone of high content of dissolved solids was located, that may be a clue to possible stagnant bodies of water. Apparently there is no danger of salt intrusion. From pumping test interpretation and water level information, a ground water budget was computed giving a regional storage coefficient of 0.004 for the Rio Sinaloa left side and of 0.01 for the Rio Sinaloa right side. Values of vertical infiltration were computed annually and bimonthly. The water levels are declining at the yearly rate of about 1m.

INTRODUCTION

Purpose and Scope of Investigation

The purpose of this study was to obtain a preliminary idea of the behavior of the Rio Sinaloa Ground Water Reservoir based on information collected before and to provide a starting point for future detailed geohydrologic studies.

Special attention was given to extractions by pumpage and formation constants. The study was hampered by the lack of usable data. Deficiencies in this respect are pointed out.

General Description

The area under study is part of a fertile agricultural valley which supports about 125,000 inhabitants. It is crossed by the Rio Sinaloa. Guasave City with about 25,000 inhabitants is the most important city. The right side of the Rio Sinaloa obtains its water supply for agriculture from the canal, Valle del Fuerte which comes from Miguel Hidalgo Dam situated near El Fuerte City. An area of higher topographic level to the north is supplied by a well field. On the left side of the Rio Sinaloa, almost all water is supplied by pumpage and to a lesser extent from the river directly.

Principal crops on the right river side are: cotton, wheat, saffron, sorghum and corn; on the left side: wheat, soybean, cotton, sorghum, and melon (see Table I).

Location, Topography and Drainage

The Rio Sinaloa Ground Water Reservoir is located in northern Sinaloa state in the Northwest of Mexico (Fig. 1). The area under study covers approximately 1200 km^2, just a narrow strip on the coastal plain of the Rio Sinaloa basin that covers an area of 12,300 km^2. The principal drainage of the zone is the Rio Sinaloa. Due to the fact that the river forms a dynamic barrier to ground water flow it was decided to divide the study zone in two parts: Rio Sinaloa left side (RSLF) and Rio Sinaloa right side (RSRS).

The RSRS has an area of about 400 km^2 and slopes in a southwesterly direction from 45 m above sea level to 20 m above sea level. The Arroyo Ocoroni is a very important drainage with the Arroyo Laguna de Piedra its tributary. The Arroyo Cabrera is another drainage of minor importance that joins with the Arroyo Ocoroni a few kilometers above Guasave City. There is only one important prominence, the Tetameche Hill about 60 m high just outside the area studied, to the west. The RSLS area is about 800 km^2 bounded by Rio Sinaloa to the west and Rio Mocorito to the east. Furthermore, there is a small drainage approximately through the center of this region, the Arroyo San Rafael. As in RSRS, the elevation of the terrain declines uniformly toward the southwest and descends from 65 m above sea level to sea level at the California Gulf Coast.

Climate

The climate of the study area is semiarid. The average annual precipitation for the valley is about 380 mm. It increases both to the northeast and in direction to the coast. July, August, September, and October are the rainy months. The rainy season sometimes can extend to January. During the remaining months the rain is scarce. The rainfall is greatly influenced by cyclones that flagellate the Pacific Coast of Mexico. There are many nonrecording rain gages in the area. The majority do not have good records. Table II summarizes the essential climatological information.

Hydrogeology

Sinaloa state is a prominently igneous region with two principal physiographic zones: the west front of the Sierra Madre Occidental and the elongated coastal plane which slopes gently toward the southwest, causing the Rio Sinaloa to be almost normal to the coast (13).

The Sonobari Complex is the oldest stratigraphic unit that crops out in the neighborhood of the study area. It is paleozoic and consists of metasediments that include quartzites, recrystallized limestones, schists, porphyritic rhyolite and deformed granites (2). It is the lower boundary or basement of any geologic formation containing water.

At the beginning of the paleozoic, the marine sedimentation was probably dominant in the region. It underwent metamorphism during middle paleozoic times. Toward the end of the cretaceous, the region was gradually rising and all later sediments were eroded. Volcanism started during early tertiary and diminished toward the end of the tertiary period. This was followed by an erosive cycle (2).

Non-metamorphized sedimentary and pyroclastic rocks only form small patches within the igneous bulk.(16). Three types of these rocks are distinguished: the oldest ones are continental origin, sandstones, lutites and limestones; tertiary (probably miocene-pliocene), pyroclastics, agglomerates, tuffs and volcanic ash; recent gravels, sands, clays and silts.

The study area is located in its totality on the coastal plane (Fig. 2). The geologic formations which form the principal aquifers in the basin are:

Alluvium. This formation is composed almost entirely of gravels, sands, clays and silts of quaternary age. It crops out in the whole study area with a minor exception on the RSRS (9). Due to its poor consolidation it is the best aquifer.

Vado Formation. This formation covers the high plains. It is younger than the tertiary volcanics but older than the alluvium. It consists of well rounded gravels mainly of volcanic origin (9). For this reason it is considered to be a relatively good aquifer; however, pumping tests carried out near its boundaries with the alluvium show a 40% decline of the transmissivity coefficient with respect to the alluvium.

Tertiary Formations. Many rocks of volcanic origin are included here such as rhyolite, rhyolitic tuffs, andesites and sandstones. Their aquifer properties are poor. It is probable that hydraulic conductivity values are very small. There are no pumping tests available from these formations, due to the lack of wells. Storage coefficient is also likely to be small.

For the alluvium and vado formation, which are the principal aquifers, there are some lithologic logs from several wells, but unfortunately all of them were taken by drillers without any geologic control. In the whole region studied no well appears to have reached the basement. There is one well with self potential-apparent resistivity log whose depth is 350 m, and even this well seems not to have reached the basement.

Because aquifer thicknesses are not known, transmissivity but not hydraulic conductivities could be calculated from the pumping tests to be discussed below.

No geophysical investigations have been carried out that might give information concerning the physical aquifer boundaries.

AVAILABLE DATA

Surface Hydrology

This is an outline of all those surface hydrology data available for the region which would be important for a more detailed study involving the management of surface water and ground water as a whole. The data have been collected by the Ministry of Hydraulic Resources.

Precipitation. These were mostly measured with non-recording gages, of which there is a large number. There is only one recording gage at Guasave City. Unfortunately, good records are lacking and most of them date from the last two years. In the area studied, there are four records that are very useful; two started in 1962 and the others in 1921. These data are published by the Ministry of Hydraulic Resources (Boletin Hydrologico). In the Rio Sinaloa as a whole there are 18 gages with good records.

Evaporation. These are evaporation pan data which give a rough estimate of the potential evapotranspiration. On account of the agricultural interest, many evaporation pans have been operated. But as in the precipitation case, there is not an adequate control of the measurements. There are only two evaporation pans with good records.

Hydrometry. This paragraph includes measurements of runoff with non-recording gages and recording gages. The only water-stage recorder in existence at Guasave City has been measuring runoff of the Rio Sinaloa for the last two years. There are hydrometric stations at Arroyo Ocoroni and Arroyo Cabrera with data since 1939 at the former and since 1959 at the latter.

Along the Rio Sinaloa there exist four hydrometric stations with daily discharge records. All of them are situated in the headwater region upstream from the area under study. There exists more or less adequate control of the flow in the main canals that supply surface water from creeks and from the river. Certain control structures are temporary, so called "barrajes" or earth dams built with sticks and mud. When the river stage is high or during floods, water spills over these temporary structures running without control. All these problems stem from the lack of a permanent dam on the Rio Sinaloa. There is a study of hydrographs, mainly of the recession curves, made by the author (unpublished) for the purpose of finding the connection of the Rio Sinaloa with the aquifer. All this information is based on data from the upstream hydrometric stations. The Rio Sinaloa is a river of big floods up to 12,000 m^3/s. In the season of low flow regime, the discharge decreases very much. In the study area this river is considered to be influent.

Geohydrology

Pumpage. It is one of the important elements of the ground water budget. Measurement of pumpage began in 1968 on RSRS and 1969 on RSLS. Attempts were later made to estimate water consumption on the basis of cultivated areas and consumptive use of the different crops. However, this did not produce good results due to a lack of trained personnel and poor reliability of supplied information. Therefore, the system of data collection was changed at the beginning of the crop season in September of 1969; henceforth, the following data were to be collected: measurement of the discharge for each well using an angle iron in order to find a horizontal distance on the discharge jet for a fixed vertical distance, and the pumping time. Thus, a graph of monthly pumpage for each river side was constructed (Fig. 3). As always in the beginning of a new system, there was a period of adjustment in which the data obtained were not reliable. The data on which confidence can be placed are those shown in Figure 3. They span the period from September of 1970 to July of 1971. The annual extraction thus computed for one crop year is 50 x 10^6 m^3 for RSRS and 149 x 10^6 m^3 for RSLS.

Water Levels. There are about 300 wells in the RSLS and 240 wells in the RSRS. New wells are being drilled at a fast rate. From available data, it was possible to determine the well depth distribution (Fig. 4). This shows a great number of shallow dug wells with large diameter, about 2 m, most of which are in the RSRS. By contrast in the RSLS the mean depth is between 26 m and 100 m. Here also increases the number of even deeper wells.

A large number of the cased wells are slotted along the whole depth except for a small length near the top. This information comes from owners or drillers. The majority of the wells are operated by means of diesel motors. From this arises the field problem of correct measurements of static water levels with the electric sounder because of oil spills produced by old equipment that consumes too much oil. These oil slides may have a thickness of several meters. The power supply of wells is gradually becoming electric. No numeric grid system exists for well identification. Wells began to be numbered in 1967 when a census was started. The numbering follows the order in which the wells are registered and now continues according to drilling date. In the future it will be necessary to establish a system of numeration based on a geographic grid for both sides of the river as a unit.

Measurement of static water levels of all the wells began toward the end of 1967. They were carried out monthly until about the middle of 1970. At that time a grid of "pilot wells" was selected in order to get a good distribution over the entire area. Unfortunately, most of these measurements are of little value for several practical reasons: A substantial number of these pilot wells lack an opening through which an electric sounder may be introduced. During the growing season, it is often impossible to obtain a sufficient number of static level measurements since most wells are pumping for long periods without interruption. There are no regulations to obligate well owners to stop pumping for the purpose of allowing static level measurements. The overall result is a lack of sufficient data.

Chemical Analyses. Many water samples have been collected and analyzed but without control oriented toward hydrogeochemistry studies. This means that the samples have been tested according to agricultural standards. However, even these analyses are not complete and many ions are missing, for instance, potassium and nitrite as well as such important determinations like boron, iron, hardness and especially total dissolved solids. The collection of samples started in 1968. They were taken only from certain groups of wells. Thus the region was not covered systematically. Only in the period February - May of 1970 sampling was spread over the entire area. For a hydrogeochemistry study it is important to compare samples taken at the same time of the year, because the water gradually is altered with time by irrigation return flow or by mixture of ground water with additions from recent infiltration.

ANALYSIS OF DATA

Pumping Tests

The analysis of 11 pumping tests on RSLS and 20 on RSRS was carried out. The results are tabulated in Table 1. All pumping tests were of short duration (about 4 hours) without observation wells. The exception is one pumping test of 11 hours which was run by the author assisted by staff of the ministry of water resources. In this test the water level was measured at the pumping well itself and at one observation well 980 meters away from the pumping well. The purpose of this pumping test was to get a value of the storage coefficient. The value found was 0.001.

Due to the interbedding of discontinuous clay lenses, the alluvium locally behaves like a leaky confined aquifer, expecially in pumping tests of short duration. The preferred method for analyzing leaky aquifers is the Hantush method (11, 10). Another method used was Jacob's method (3). This method is useful as an approximation when the asymptotic part of the drawdown versus time curve on a logarithmic scale is not well defined. It was found that the discrepancy between Jacob's method and Hantush's method was not appreciable. Jacob's method is just a simplification of Theis' solution (18).

In the region studied there are many dug wells of large diameter. Because they store water in the well itself it is not possible to apply either of above methods which assume that the well can be idealized as a mathematical line sink without storage. For these wells the Papadopulos method (17) was used which takes into consideration the effect of water stored within the well. Although this method applies to confined aquifers it proved to be a good approach to the real case, because the aquifer behaves like a leaky aquifer. This method also assumes that well losses are negligible. Therefore it is possible to use type curves at the production well itself.

With the transmissivity values on both sides of the river, curves of equal transmissivity were constructed in order to obtain an overall view of the variation of transmissivity in space (Fig. 5). In the central portion of RSLS the curves show a decline of transmissivity likely because in this part the alluvium thickness decreases and some of the wells penetrate the vado formation. The RSRS shows greater transmissivity values than the RSLS. Surface drainage in this region and therefore coarse alluvial accummulations along the creeks are larger than on the left side. Two values were found that are appreciably lower than the majority. Well #170, in the NW, probably penetrates the Vado Formation. The other well, #46, located west of center, seems to indicate a thinning of the alluvium, since the decline in transmissivity coincides with an increased gradient in the groundwater profile (Fig. 6). Also, to the west from the well there is an outcrop of the basement at Tetrameche Hill (Fig. 2) confirming the decrease in thickness.

Hydrogeochemistry

Only a fragmentary picture has been assembled because of the deficiencies of the data mentioned earlier. The relationship between water composition and geologic environment is sometimes easy to demonstrate but to get a full evaluation presents many complications by the many factors involved (5).

Contours of equal electric conductivity (EC) in μ mhos/cm were drawn for the period February-May of 1970 (Fig. 7). A direct relationship between total dissolved solids and electric conductivity is assumed (12). As a first approach this ratio can be taken as 0.64 (23). On RSLS the water is of good quality (600 μ mhos/cm) in wells located in the northern part. It is likely that these are waters of recent infiltration through chemically resistant rocks (especially igneous rocks) (Fig. 2). As water flows to the south the content of dissolved solids increases. (See Ref. (1) for a study arriving at similar conclusions.) Close to the streams the water quality improves. The contours show an anomalous high toward the center of the zone where there is a concentration of wells with depths ranging between 26 and 75 meters. This anomalous zone presents values of EC up to 7000 μ mhos/cm, of the order of 4,500 ppm of dissolved solids (in this range of EC there is a departure from the 0.64 constant). It is interesting to note that in direction toward the coast the water again becomes good in quality. A possible explanation of this concentration of salts would be recirculation of water due to poor surface drainage and relatively shallow wells or evaporite layers. Another possible clue to the problem is the existence of a local flow system (20,21) with quasi stagnant bodies of water. Figure 6 shows that the potentiometric surface reflects the ground surface. There is a depression towards which the ground water flow converges from all directions like an artificial discharge zone. This convergence is enhanced by the great concentration of wells. At RSRS the curves of equal EC point out clearly the sources of recharge and low contents of dissolved solids, viz. Rio Sinaloa and Arroyo Ocoroni (Fig. 7). On this side of the river the water is of good quality (about 500μmhos/cm). Towards the west of the area the EC values increase. This may be related to a potentiometric depression clearly shown in Figure 6.

From curves of equal sulfate concentration in ppm it was inferrred that the occurrence of an evaporite lens at RSLS is not likely. Contours of equal chloride concentration were constructed in order to investigate the possibility of salt water intrusion on RSLS. The values found near the coast are of only 600 ppm; this would preclude salt water intrusion, but it must be remembered that the interface is a three-dimensional surface rather than a two-dimensional profile and furthermore there is a zone of mixing and diffusion (3). On both sides of Rio Sinaloa isochloride curves delineate recharge zones that coincide with those of small EC.

Hydraulic Properties

The ground water reservoir behaves on a local scale as a leaky aquifer due to the clay lens intercalation. On a regional scale it behaves like a water table aquifer because on a large scale it is homogeneous. As the time increases the cone of influence spreads encompassing a larger and larger volume. This yields by matching with a type curve the "equivalent transmissivity" from the last part of the logarithmic drawdown curve of a long duration pumping test (22). The values obtained from short pumping tests represent values of the transmissibility valid only in a small region around the well itself.

Almost all available values of water levels were used to construct the ground water contour maps. It was observed that certain wells close to each other but of different depths showed water level differences of the order of meters, hence it is possible to infer the possibility of different types of flow regimens due to the change of the fluid potential with depth. It is very important that these flows by studied in the future. According to Toth (20, 21, 22), a local system of ground water is a flow that has its recharge area at a topographic high and its discharge area at a topographic low that are located adjacent to each other. A system of ground water flow is considered to be regional if its recharge area occupies the water divide and its discharge area is at the bottom of the basin.

If the basin is very deep the regional flow pattern dominates. This tested aquifer, however, is relatively shallow. Therefore, local flow patterns may be expected to dominate. However; detailed studies should determine the slope of the water table and make a vertical division of local, intermediate, and regional flows based on numerical solutions (6, 7, 8) checked with measurements of static levels in wells of different depths. The great difficulty comes from lack of deep wells screened only at the bottom (15).

ESTIMATION OF NATURAL RECHARGE AND STORAGE COEFFIECIENT

Procedure

Ground water budget is a quantitative statement of the balance between the total water gains and losses of a ground water reservoir. In order to plan the ground water budget, the first step was to establish the boundary of the region where it would be computed (see Fig. 8). The equation representing the ground water balance is:

$$E + F = W + P \pm S\Delta V \qquad (1)$$

E: ground water inflow

F: any kind of vertical flow

W: ground water outflow

P: pumpage

ΔV: change in volume

S: storage coeffiecient

All terms of equation (1) are in units of volume for the period considered.

The above equation does not explicitly involve evapotranspiration and infiltration. Both are included in "F". Explicit computation of these terms is not possible at the present stage of the investigation.

The unknowns in equation (1) are the storage coefficients "S" and vertical flow "F". They were found statistically involving 3 equations (A) for each side of the river. Two consecutive periods of one year each (Sept. 1968 to Aug. 1969, and Sept. 1969 to Aug. 1970) were chose~~s~~n for analysis followed by one period of 10 months (Sept. 1970 to July 1971). All periods start in September when the pumping is minimum. A period of one year was selected because in a long period it is possible to get a constant "F", a requirement for solving the 3 equations. This assumption is quite good because in the periods chosen the hydrologic variables did not undergo notable changes; precipitation, and the area of crop remained almost constant so that pumping was almost constant through the 3 periods.

The computations of the different terms of equation (1) proceeded as follows:

Ground water inflow and ground water outflow were obtained from water level contour maps constructed for each period. Darcy's law was then applied to each channel (Fig. 8).

The change in storage was computed from maps of water level variation for each period.

The pumpage rate was considered to be the same for all three periods.

The values obtained for each side of Rio Sinaloa are shown below.

RSLS

	$E(m^3/s)$	$W(m^3/s)$	$E(10^6 m^3)$	$W(10^6 m^3)$	$B(10^6 m^3)$	$\Delta V(10^6 m^3)$
September 1968	3.685	0				
			101.0	0	148.7	-863.7
September 1969	2.724	0				
			106.0	0	148.7	-390.9
September 1970	3.982	0				
			97.8	0	142.1	-1322.5
July 1971	3.442	0				

RSRS

September 1968	0.737	0.311				
			23.7	10.9	53.6	-242.3
September 1969	0.764	0.370				
			26.6	10.8	53.6	-151.1
September 1970	0.919	0.301				
			23.0	7.8	51.0	-505.9
July 1971	0.836	0.284				

The values found when substituted into equation (1) produce:

RSLS

$$\begin{aligned} F + 863.7S &= 38.7 \\ F + 390.9S &= 42.7 \qquad (A) \\ \frac{5}{6}F + 1322.5S &= 44.3 \end{aligned}$$

RSRS

$$\begin{aligned} F + 242.3S &= 40.8 \\ F + 152.1S &= 37.8 \qquad (A) \\ \frac{5}{6}F + 505.9S &= 35.8 \end{aligned}$$

From least squares, if $XF + YS = Z$, $r = f(x,y) - Z$, and $S_1 = \sum_{i=1}^{3} r_i^2 = \sum_{i=1}^{3} (x_iF + y_iS - z_i)^2$

Then: $\frac{\partial S}{\partial F} = 0$ and $\frac{\partial S_1}{\partial S} = 0$.

From above equations it is possible to find:

$$F \sum_{i=1}^{3} x_i^2 + S \sum_{i=1}^{3} xy = \sum_{i=1}^{3} xz$$

$$F \sum_{i=1}^{3} x_iy_i + S \sum_{i=1}^{3} y^2 = \sum_{i=1}^{3} yz \qquad (B)$$

Where:

x: coefficients of "F" in equation (A)

y: coefficients of "S" in equation (A) (ΔV)

z: right hand side of equation (A) (W - E + B)

Combining (A) and (B) the following result is obtained:

RSLS	RSRS
$S = 0.004$	$S = 0.01$
$F = 36.5 \times 10^6 m^3$	$F = 37.5 \times 10^6 m^3$

The values of "S" here obtained are typical of the specific yield of water table aquifers.

Inorder to get an idea of the variation of "F" or vertical flow, piezometric contour maps were drawn for each two-months period from November of 1970 to July of 1971, and also maps of equal change of piezometric levels for each period. The computation proceeded as before. Finally, storage coefficient values were substituted into equation (1) giving the following results:

Period	RSLS F($10^6 m^3$)	RSRS F($10^6 m^3$)
November 1970 - January 1971	14.43	4.03
January 1971 - March 1971	15.33	8.54
March 1971 - May 1971	13.13	8.05
May 1971 - July 1971	4.02	4.05

It is interesting to appreciate how the values of "F" decrease in the period May-July. It is possible that they change to negative values in the following months when evapotranspiration increases and the pumping diminishes (see Fig. 3). The values found come from the budget data of the following table.

RSLS

	E(m^3/s)	W(m^3/s)	E($10^6 m^3$)	W($10^6 m^3$)	B($10^6 m^3$)	ΔV($10^6 m^3$)
November 1970	3.260	0				
			18.20	0	34.89	-524.3
January 1971	3.517	0				
			17.28	0	34.82	-512.7
March 1971	3.250	0				
			17.10	0	32.26	-495.5
May 1971	3.226	0				
			17.60	0	22.18	-130.0
July 1971	3.442	0				

RSRS

November 1970	1.165	0.387				
			5.97	2.11	9.96	-206.8
January 1971	1.067	0.401				
			5.48	2.04	12.58	-100.4
March 1971	1.077	0.401				
			4.94	1.90	12.50	-140.5
May 1971	0.796	0.320				
			4.31	1.60	8.94	-127.4
July 1971	0.836	0.284				

It must be remembered that all these results can be taken only as an approach to the problem and never as a final solution which will come in the future detailed studies. Nevertheless the foregoing figures give some guide for the management of the ground water reservoir. They also show how the water levels have been sinking year by year. According to the available information, the decline is of the order of 0.5 M/year on RSRS and 1 M/year on RSLS. As an illustrative idea of the storage capacity of the aquifers the following may be given: Each meter of drawdown for the RSLS aquifer produces just $3.2 \times 10^6 m^3$ and for the RSRS aquifer $4 \times 10^6 m^3$.

CONCLUSIONS

1. The Rio Sinaloa Reservoir behavior regionally tends toward a water table aquifer with a regional storage coefficient of 0.004 for RSLS and 0.01 for RSRS. One long pumping test for RSLS gave a local value of 0.001.

2. The values of annual vertical recharge were $36.5 \times 10^6 m^3$ for RSLS and $37.5 \times 10^6 m^3$ for RSRS.

3. Figures of bimonthly vertical recharge were obtained.

4. The values of pumping volume were computed for both river sides. The results are: $149 \times 10^6 m^3$ for RSLS and $50 \times 10^6 m^3$ for RSRS.

5. The monthly extraction by pumpage was computed.

6. An anomalous zone with high concentration of dissolved solids is present on RSLS. It is possibly caused by stagnant bodies of water or zones of lower water velocity.

7. There is not as yet an apparent hazard of salt water intrusion.

RECOMMENDATIONS

1. Establish a system of well numeration based on a geographic grid for both sides of the river as a unit.

2. It is necessary to have a better control of information and make a new selection of wells in which the water levels are taken (pilot wells).

3. When measuring water levels, the problem of oil leaking into the wells must be taken into account.

4. The methods and practices of chemical water analysis must be improved.

5. Pumping tests of deeper wells and pumping tests of longer duration are needed.

6. In future detailed studies the importance of regional and local flow systems should be established.

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23. Walton, W. C., Ground Water Evaluation, McGraw-Hill Book Company, 1970.

Table I Crop Cycles in the Irrigated Areas

	Spring Cycle		Summer Cycle		Winter Cycle	
Crop	Dates of sowing	consumptive use	Dates of sowing	consumptive use	Dates of sowing	consumptive use
squash	January 1 - February 28	35 cm				
soy beans*	February 1 - February 28	42	May 1 - June 15	85 cm	September 15 - October 20	38 cm
corn *	March 1 - March 15	67	July 15 - August 10	70	January 1 - February 28	45
melon*	February 1 - March 31	33			December 1 - January 31	31
water melon	February 1 - March 31	43			November 15 - December 15	42
sorghum*	January 15 - March 31	45	June 15 - August 10	78		
tomato	February 1 - April 30	47	June 1 - July 31	83	September 1 - December 31	54
bean	March 1 - April 20	53	June 15 - July 20	75		
rice			May 15 - July 20	83		
chili			August 1 - Sept. 31	89	October 1 - January 31	61
flowers			June 1 - August 31	65		
alfalfa					October 1 - November 30	120
cotton*					November 15 - January 10	68
oats, barley, wheat					December 1 -	57
onions					October 1 - November 31	36
pea					October 1 - December 31	22
garden produce					October 1 - December 31	34
lettuce					November 1 - December 31	50
potatoes					October 1 - November 15	52
pasture					October 1 -	170
cucumber					October 1 - January 31	37
wheat*					November 15 - December 31	58
kitchen garden					All season	125
saffron*						

*) **Principal crops raised in areas irrigated by wells**

Table II Climatological Table

ANNUM PRECIPITATION	
about 380 mm	
MONTHLY MEAN TEMPERATURE	
(Maximum)	(Minimum)
July - August - September	January
about 29°C	about 17°C
EXTREME MAXIMUM TEMPERATURE	
July - August - September	
about 40°C	
EXTREME MINIMUM TEMPERATURE	
January - February	
about 1 - 2°C	
ANNUAL MEAN EVAPORATION	
about 2300 mm	
SUNLIGHT MEASUREMENT	
(Maximum)	(Minimum)
May - June	December - January - February
about 350 hrs.	about 230 hrs.

Table III Transmissivity Values (m^2/s)

		Method		
RSRS Well	Papadopulus	Hantush (type curve)	Hantush (semi-log)	Jacob
7	0.021			
37	0.023			
46		0.005		
51	0.040			
62	0.025			
65	0.020			
76	0.039			
80	0.030			
81	0.025			
91	0.090			
97	0.047			
101	0.045			
108	0.011			
111	0.010			
121	0.018			
132	0.043			
144	0.037			
170	0.006			
175	0.054			
185	0.030			
RSLS Well				
11				0.001
12	0.014			
20	0.009			
81				0.022
100				0.033
163				0.022
226	0.030			
265	0.006			
269				0.001
273			0.019	
291*		0.051		

* Long Duration Pumping Test

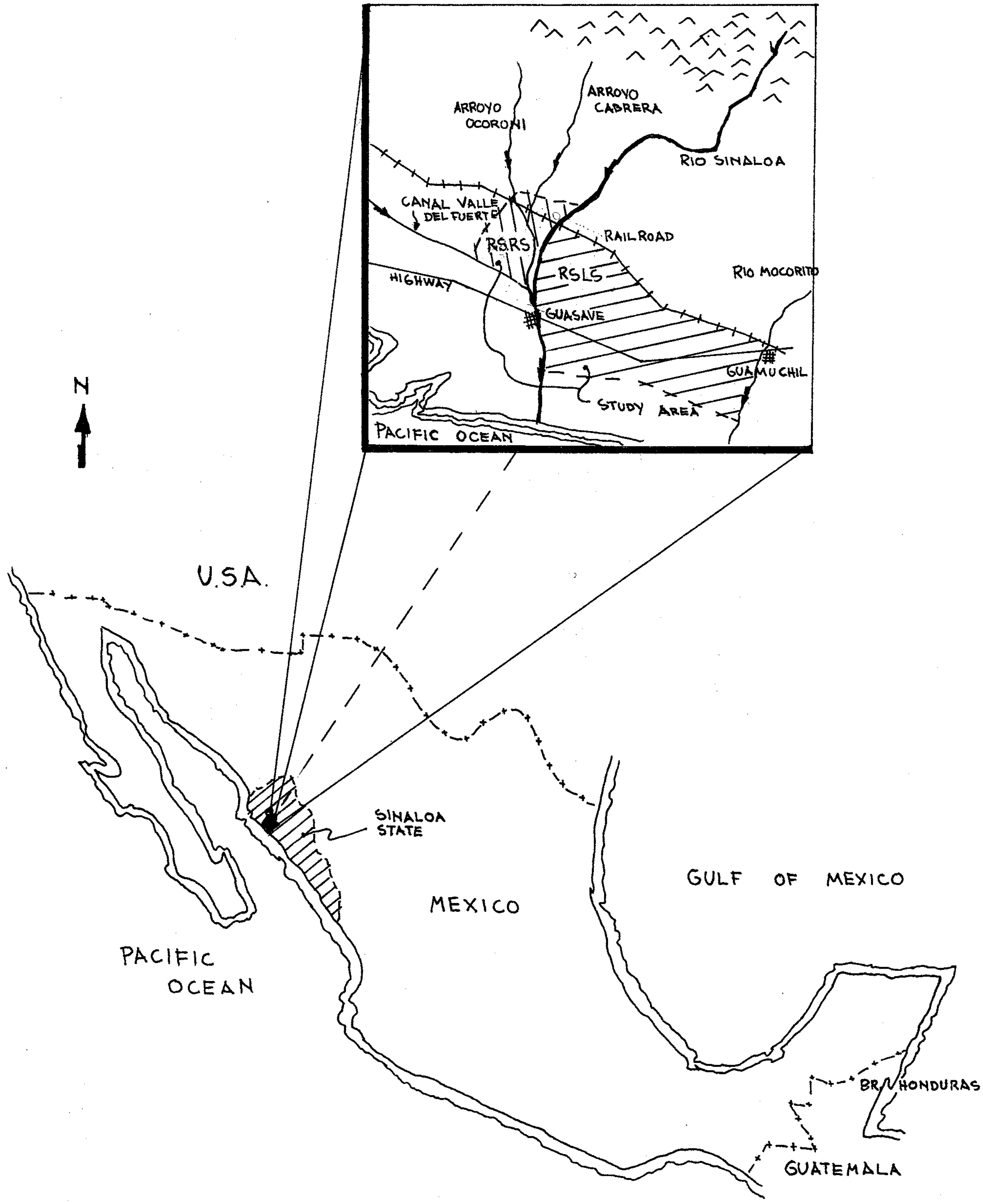


FIGURE 1. LOCATION MAP


A de Tohayana
TOHAYANA
②
A de San Jose de Gracia
A Potrerillos
A Ocoris
A Los Molinos
A Teranuito
A Bacirito
BACUBIRITO
EL FUERTE
AMOS
SONORA
SINALOA
DEL PACIFICO
CARRETERA INTERNACIONAL
①
⑤
④
③
⑨
SAN BLAS
RIO FUERTE
FERROCARRIL DEL PACIFICO
EST
EST BAMOA
BAMOA
LA TRINIDAD
M
N
Ⓛ
A Los Vacas
MOCORITO
RIO MOCORITO
A El Palmar
GUAMUCHIL
SAN MIGUEL
COMPUERTAS
AHOME
MOCHIS
CANAL VALLE DEL FUERTE
CARRETERA INTERNACIONAL
R. CORTINEZ
GUASAVE
ANGOSTURA
a Mexico
⑥
BAHIA DE OHUIRA
TOPOLOBAMPO
BAHIA
NAVACHISTE
MACAPULE
GOL
COLOR S
(YELLOW) ALLUVIUM
(ORANGE) VADO FOR
(BROWN) TERTIARY
(PURPLE) METAMOR
//// STUDY

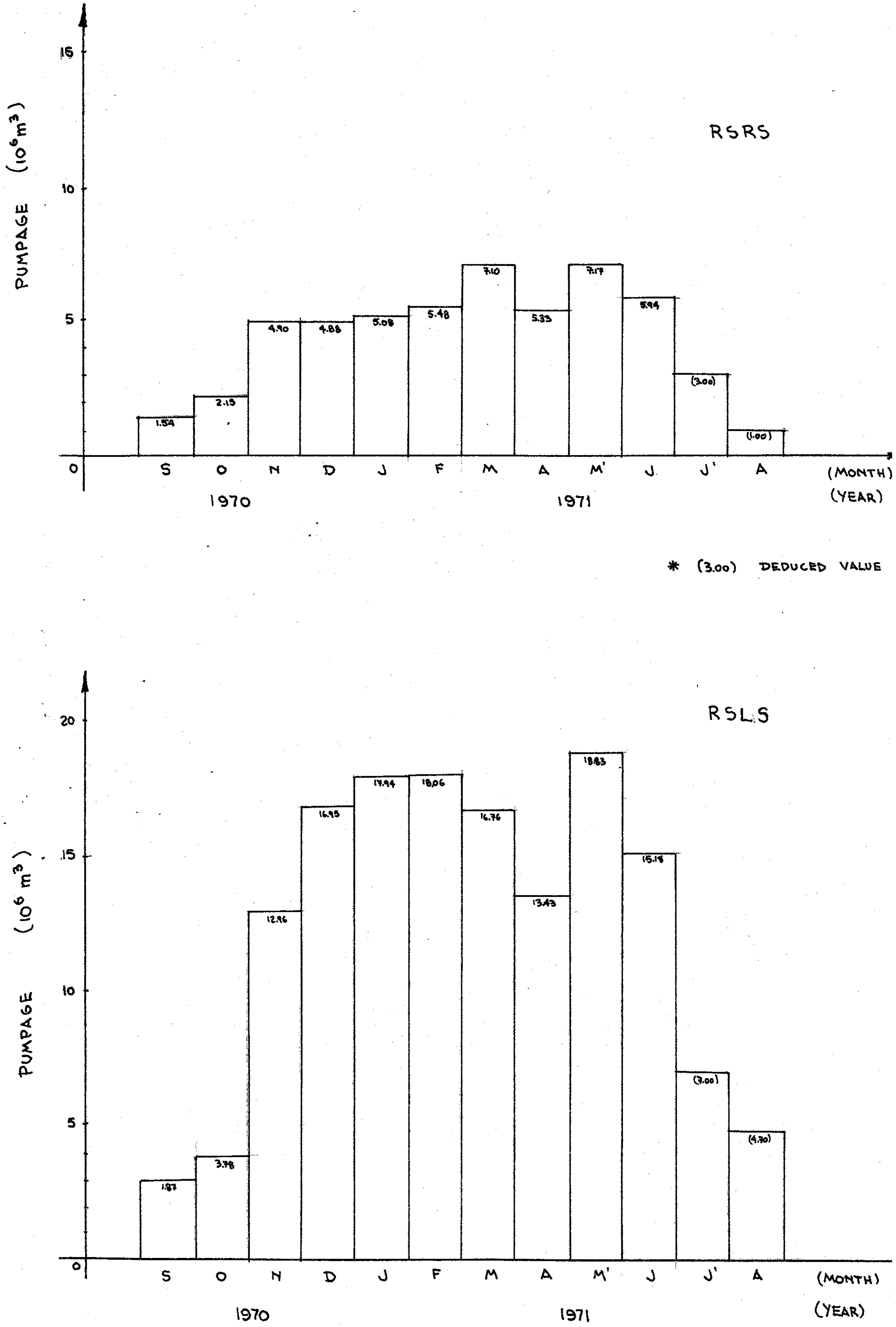


FIGURE 3. MONTHLY PUMPAGE

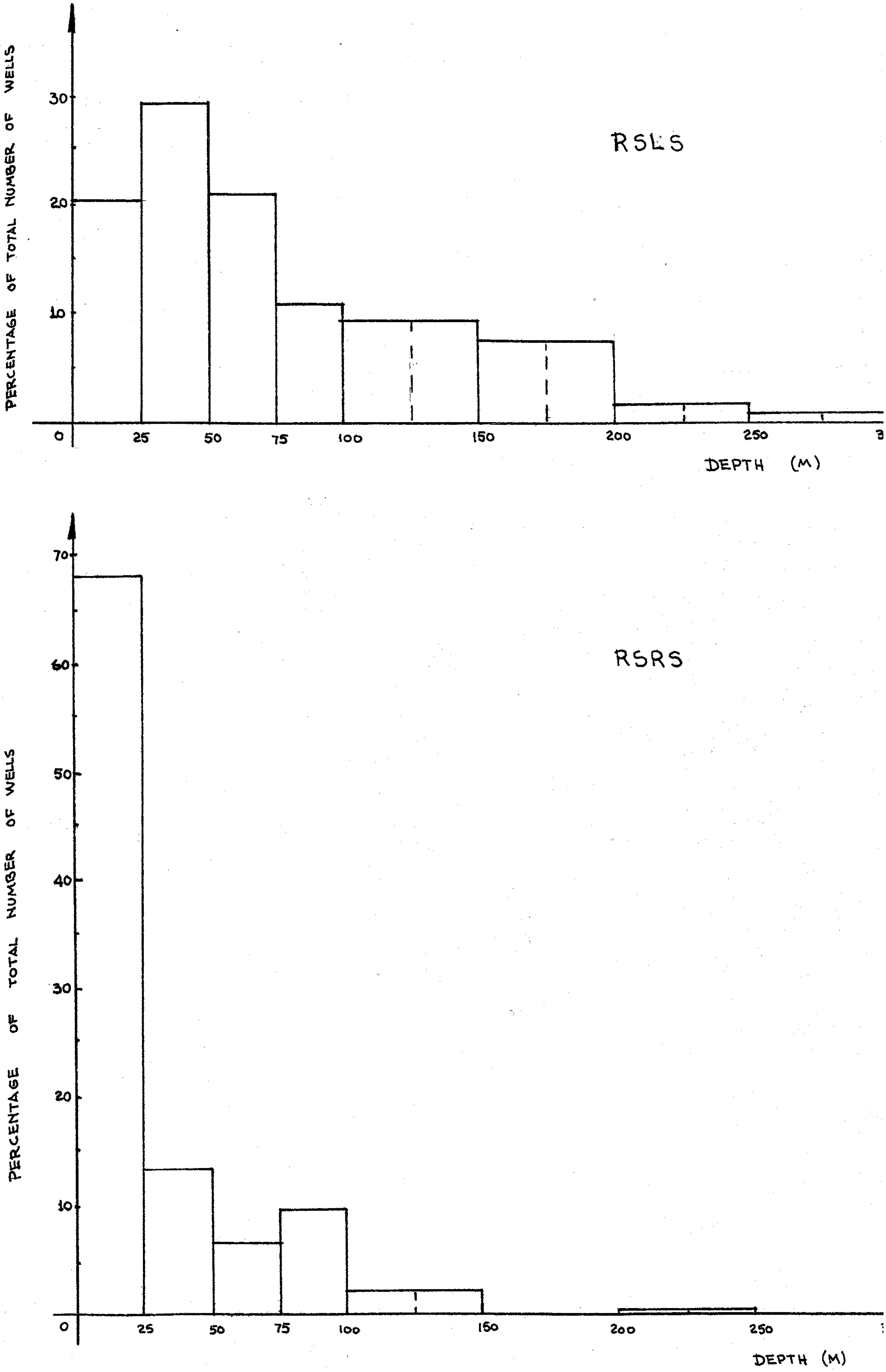


FIGURE 4. WELL DEPTH DISTRIBUTION

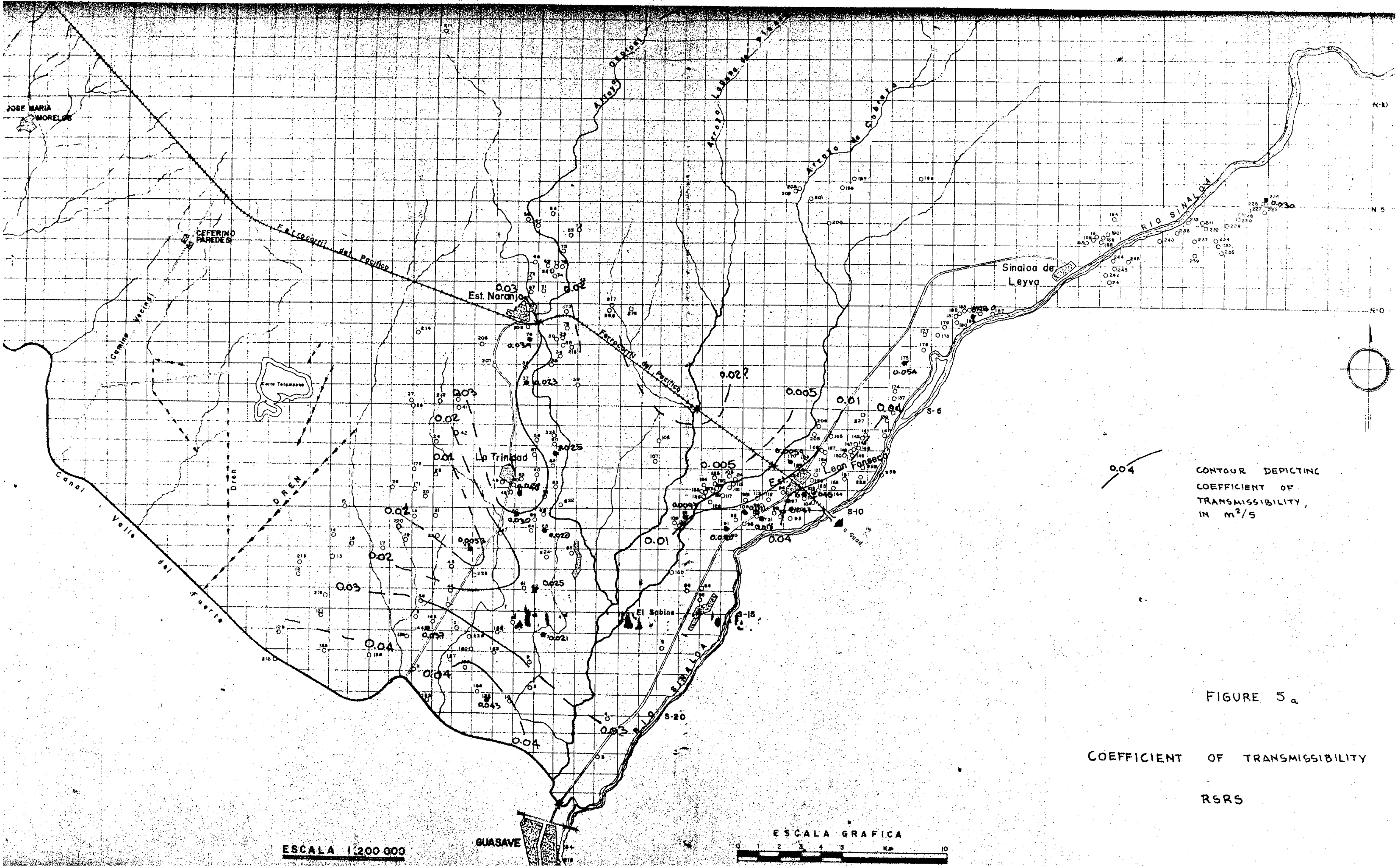


FIGURE 5a

COEFFICIENT OF TRANSMISSIBILITY

RSRS

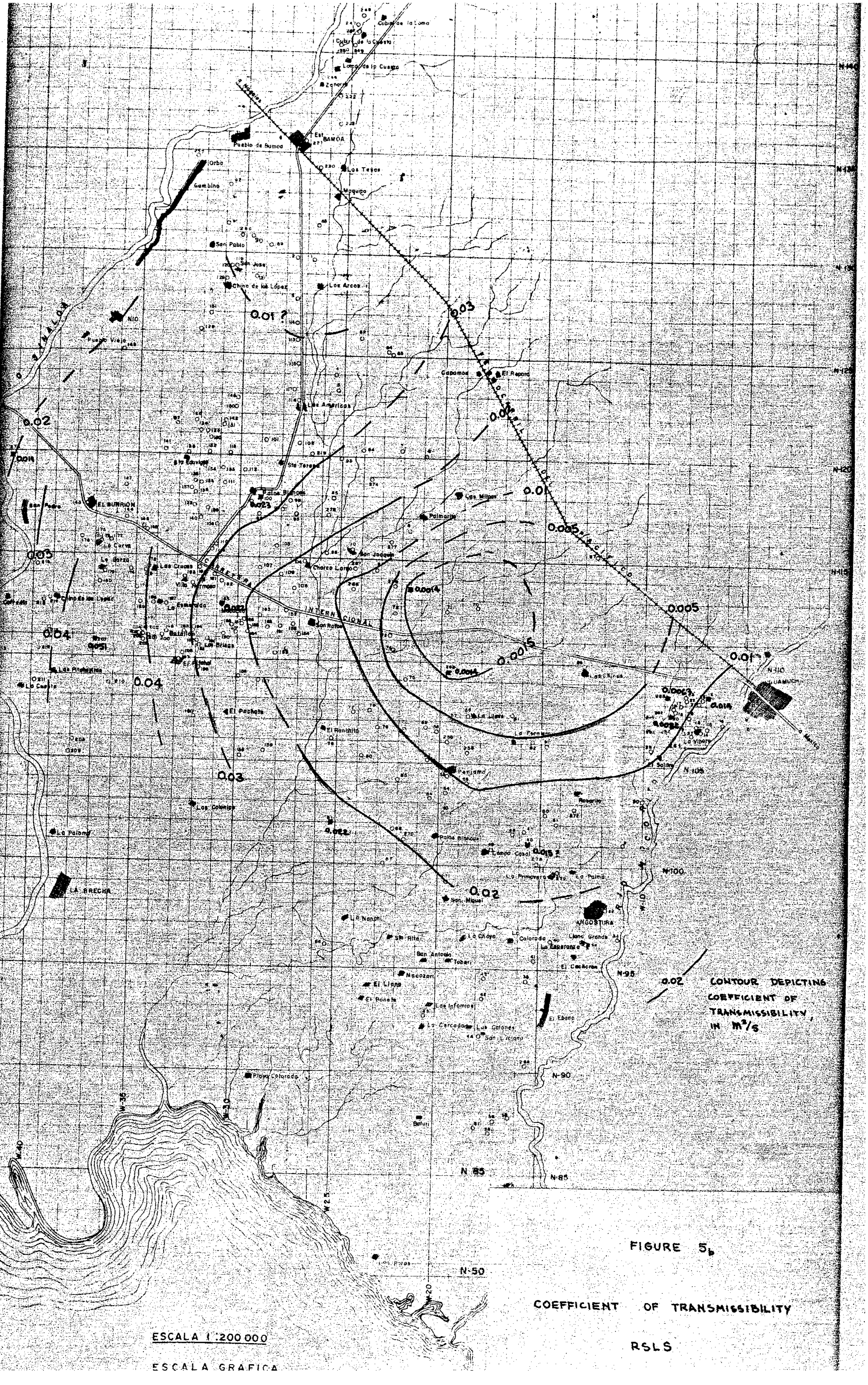


FIGURE 5_b

COEFFICIENT OF TRANSMISSIBILITY

RSLS

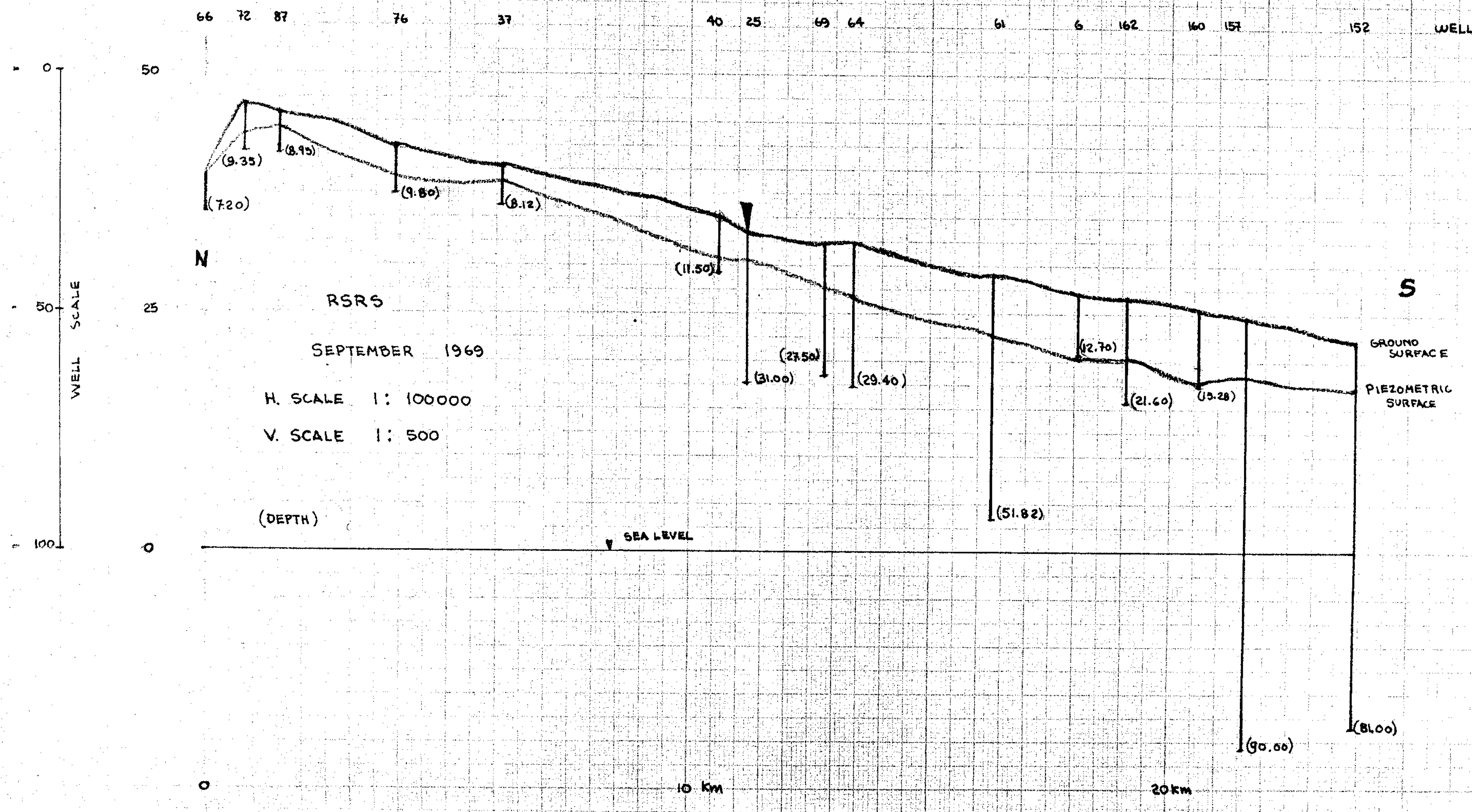


FIGURE 6a. GROUND WATER PROFILE

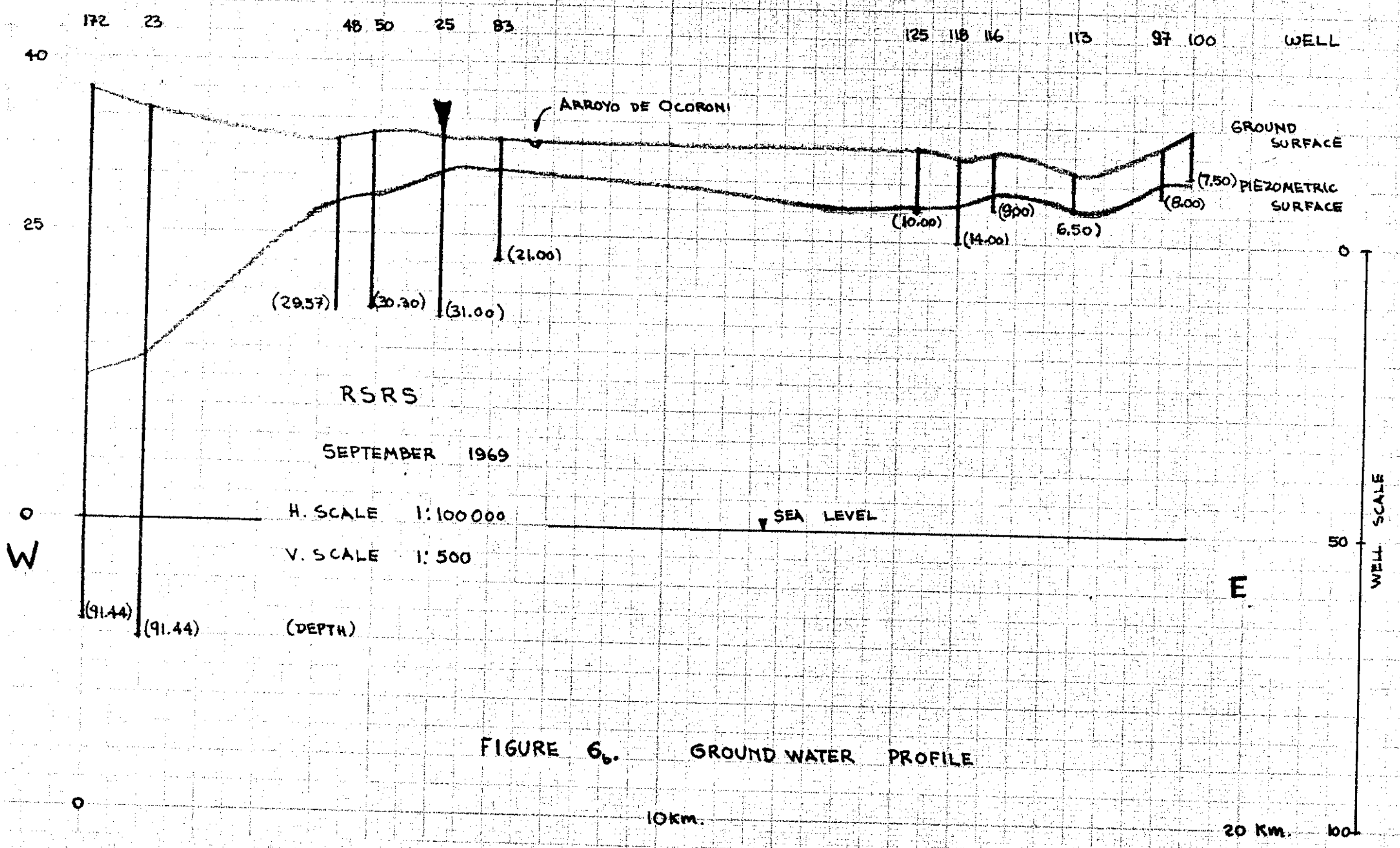
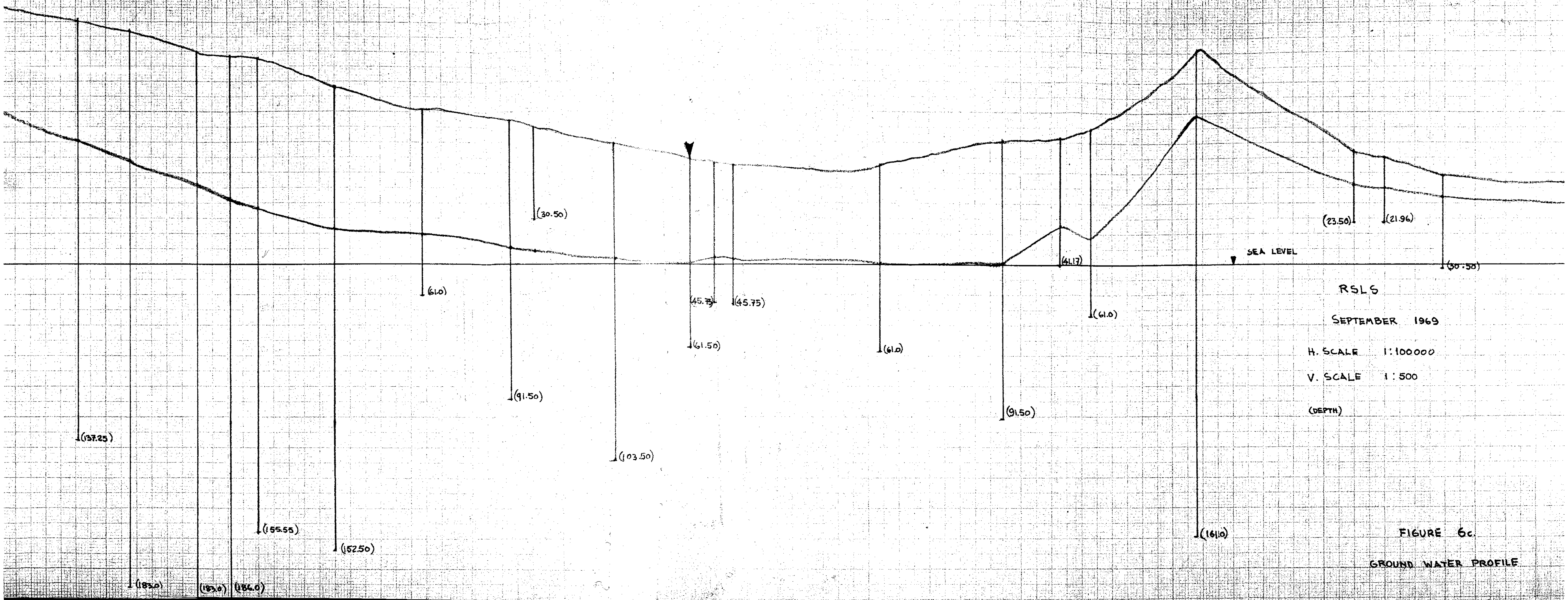


FIGURE 6b. GROUND WATER PROFILE



RSLS

SEPTEMBER 1969

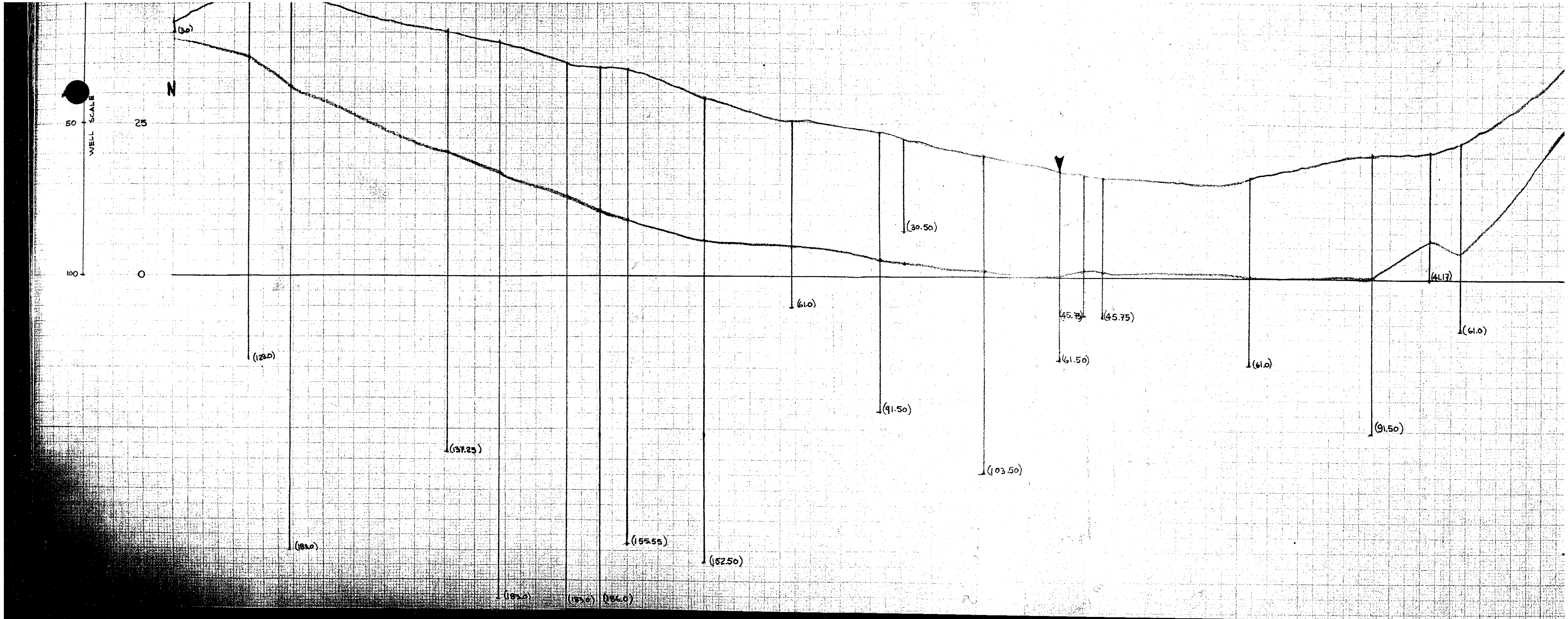
H. SCALE 1:100000

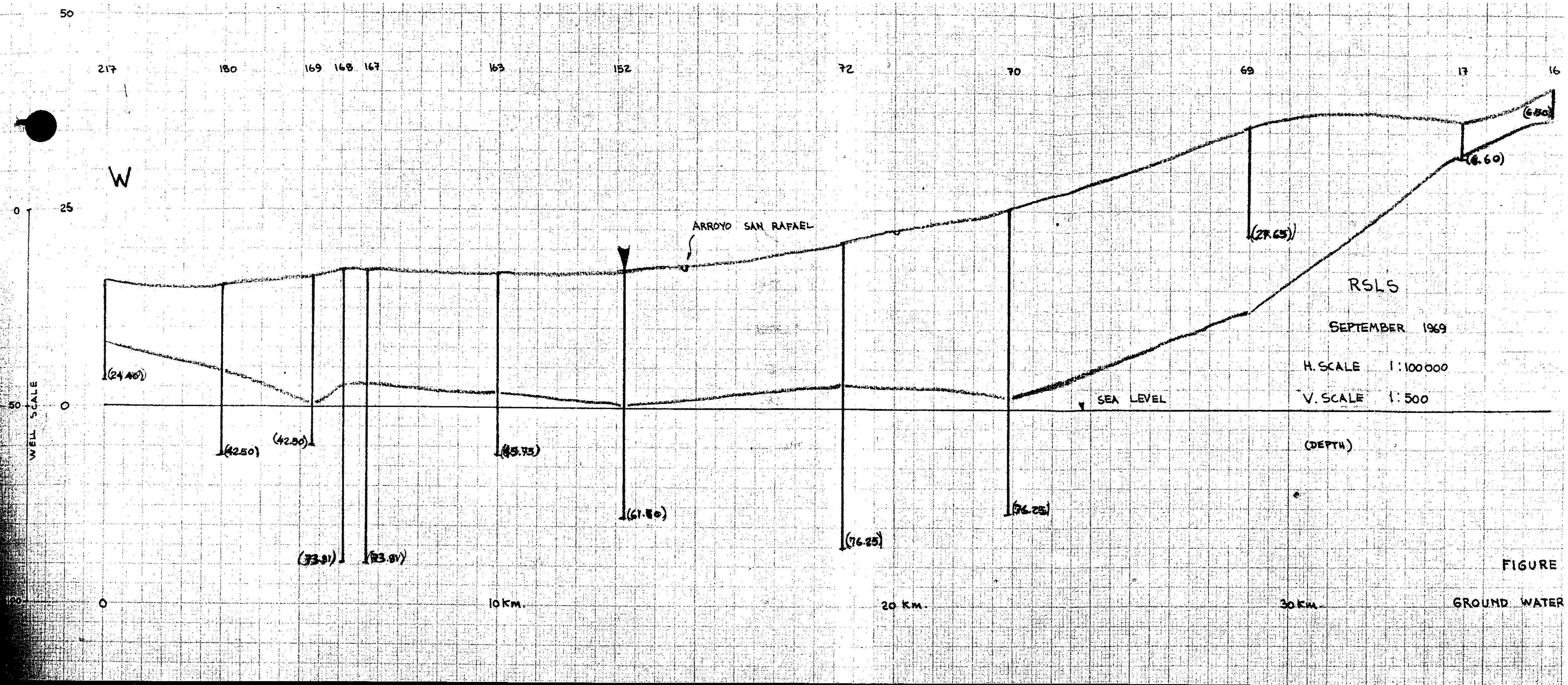
V. SCALE 1:500

(DEPTH)

FIGURE 6c.

GROUND WATER PROFILE


WELL SCALE
50
100
25
0
N
(3.0)
(123.0)
(183.0)
(137.25)
(183.0)
(183.0)
(184.0)
(155.55)
(152.50)
(61.0)
(91.50)
(30.50)
(103.50)
(45.75)
(45.75)
(61.50)
(61.0)
(91.50)
(41.17)
(61.0)



FIGURE

GROUND WATER

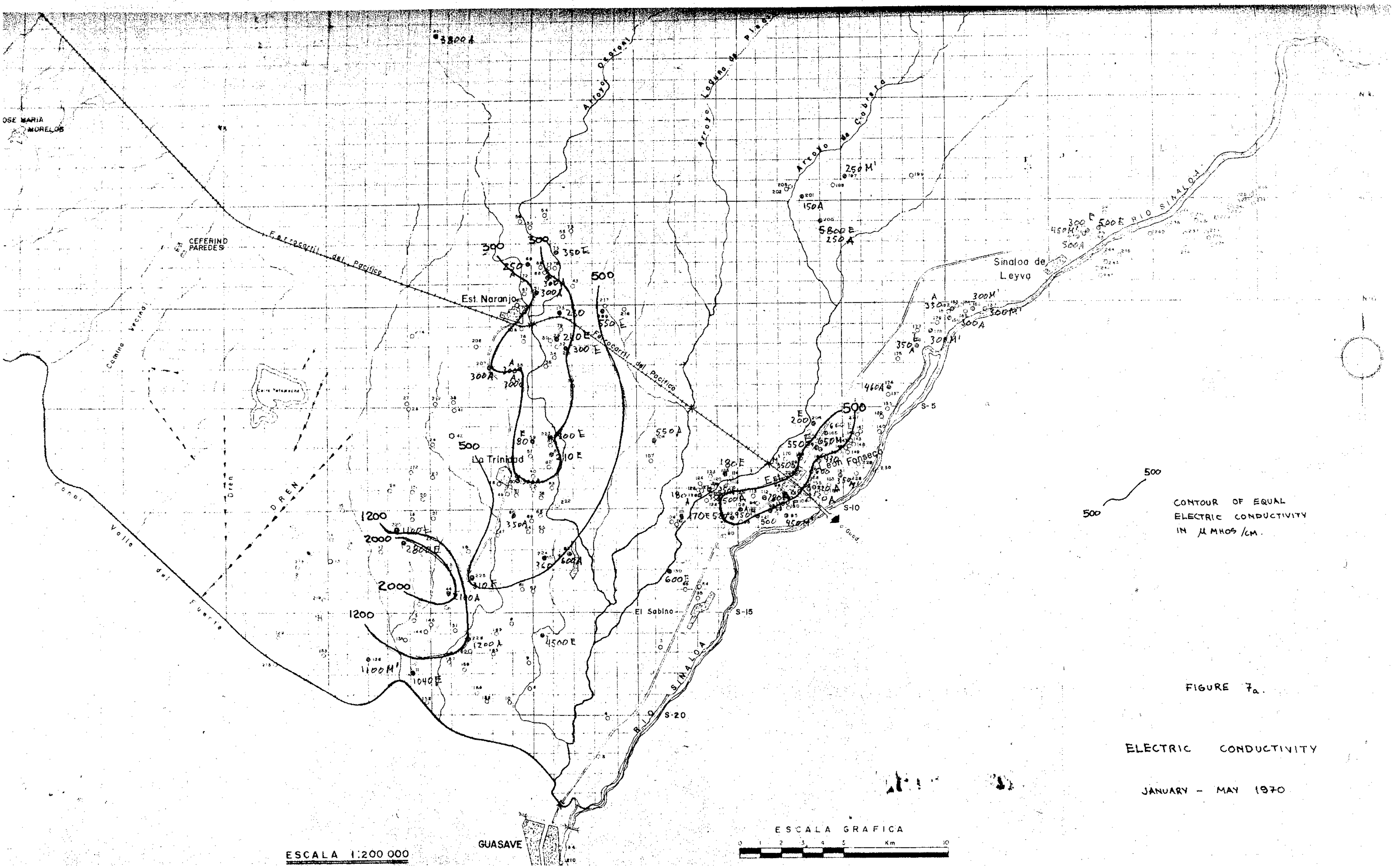


FIGURE 7a.

ELECTRIC CONDUCTIVITY

JANUARY - MAY 1970

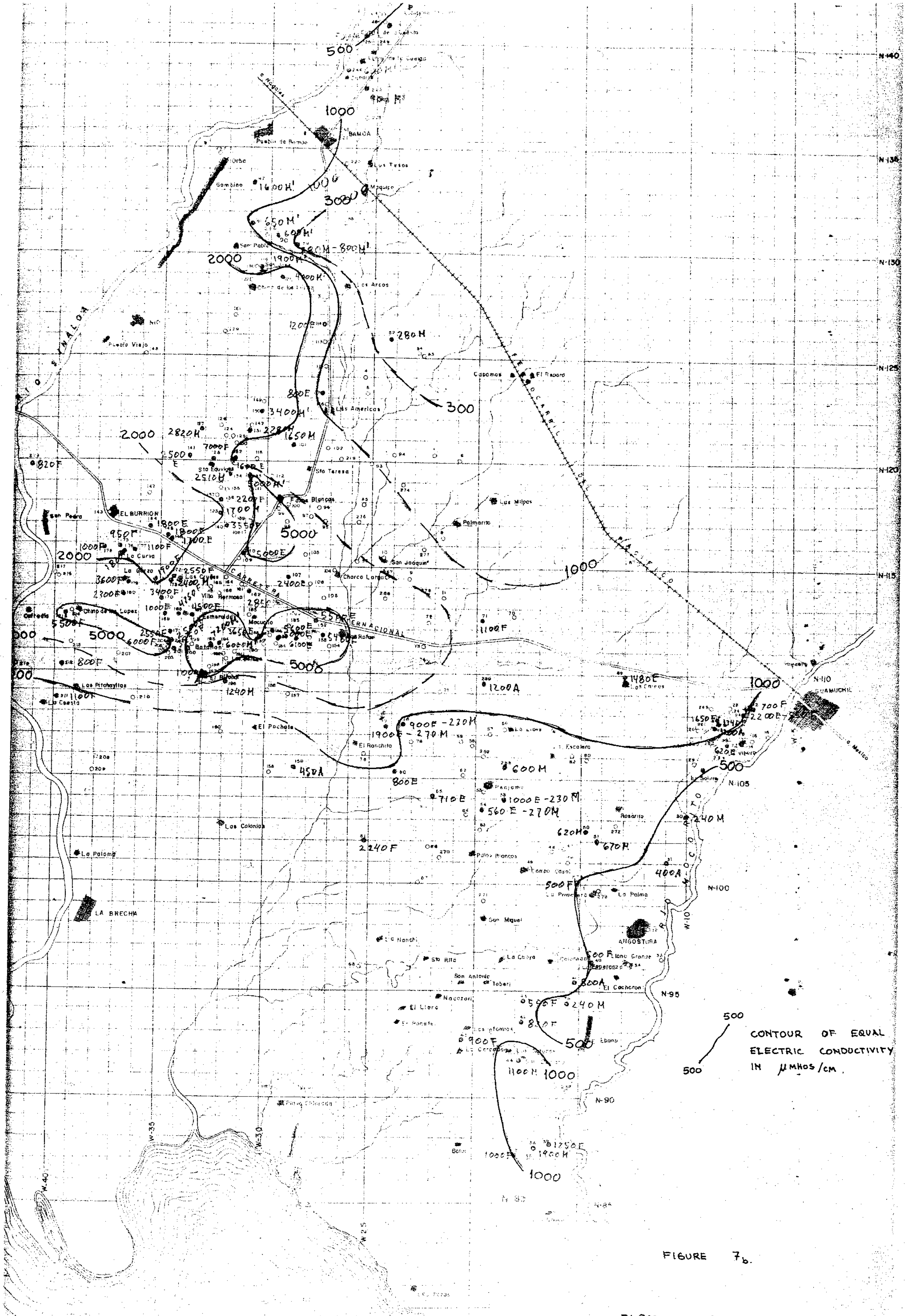


FIGURE 7b.

ELECTRIC CONDUCTIVITY

JANUARY - MAY 1970

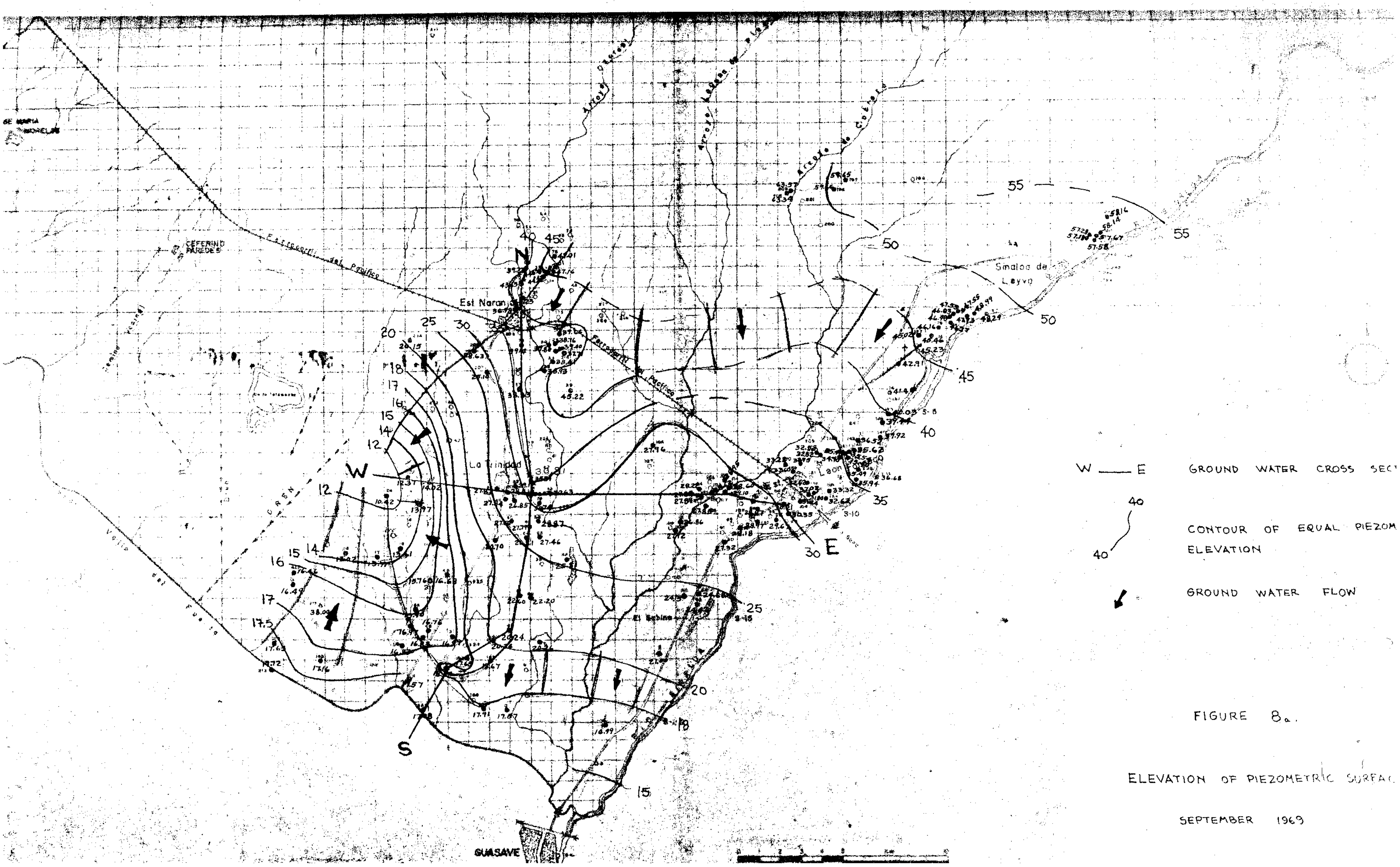


FIGURE 8a.

ELEVATION OF PIEZOMETRIC SURFAC

SEPTEMBER 1969

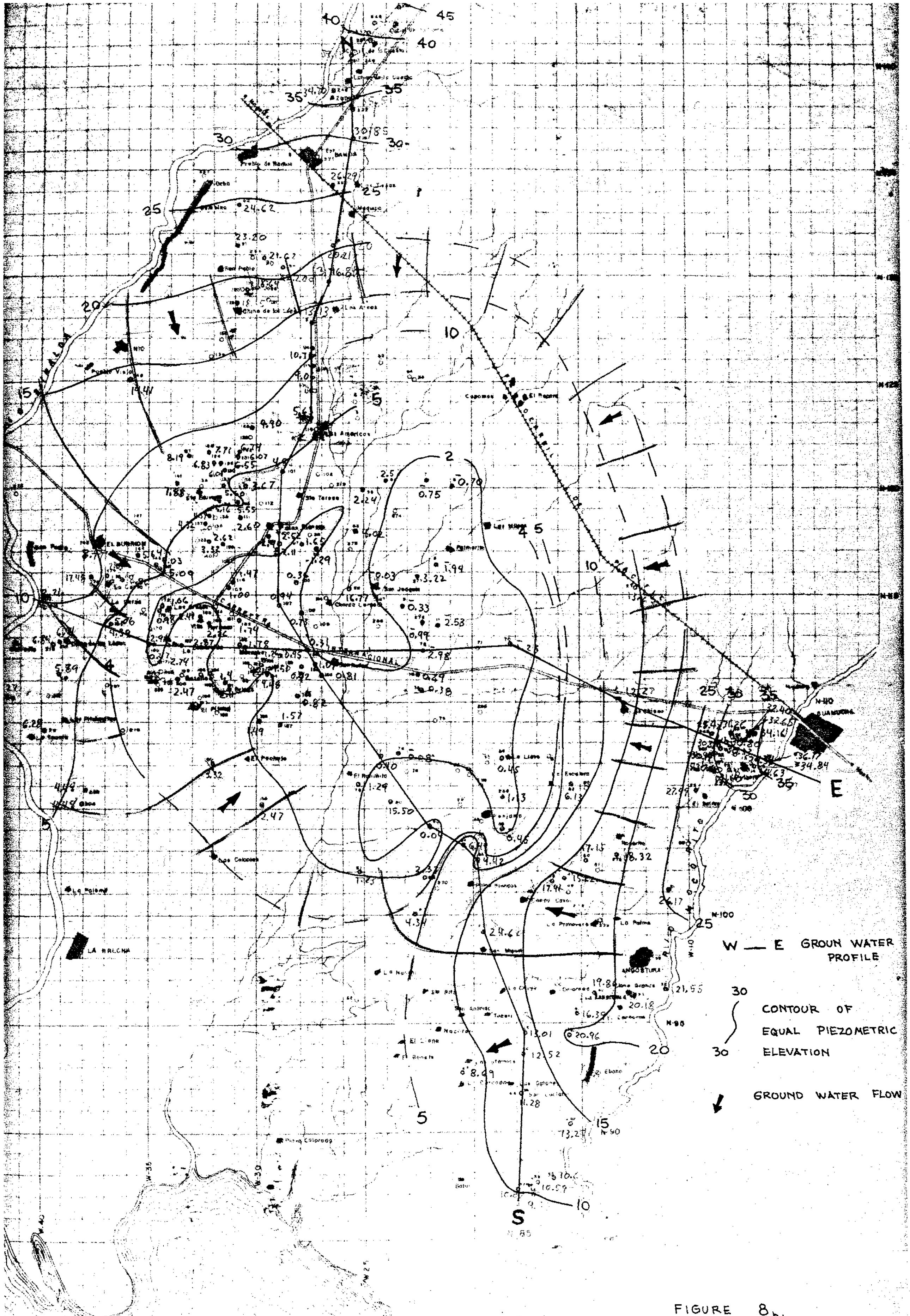


FIGURE 8b.

ELEVATION OF PIEZOMETRIC SURFACE

SEPTEMBER 1969