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GEOPHYSICAL INVESTIGATION FOR GROUNDWATER RESOURCES AT THE SOTO CANO AIR BASE, HONDURAS

by

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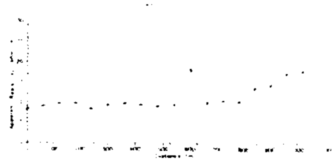

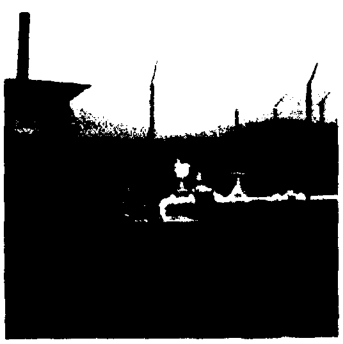

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Final Report

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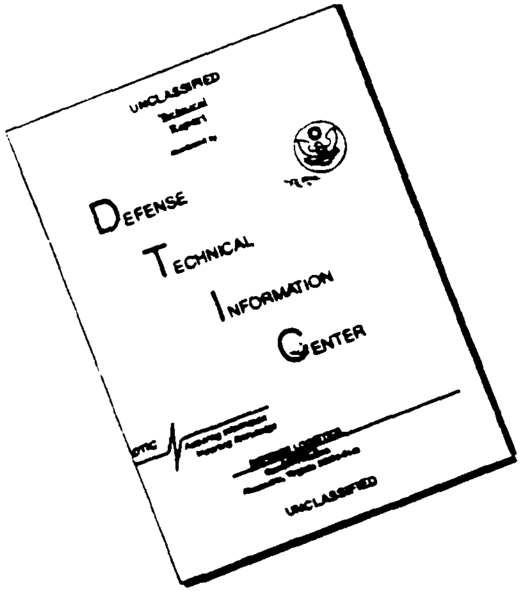

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13. ABSTRACT *(Maximum 200 words)*

A geophysical investigation was undertaken to explore the potential for further ground water development around the Soto Cano air base, Honduras. Electrical resistivity vertical sounding and horizontal profiling were utilized. The main ground-water aquifer in the area, a buried river channel now filled with gravel, was clearly defined. A tributary to this aquifer was also detected. Currently, the main ground-water aquifer has reached its capacity in the driest part of the year and additional water resources are needed at the current level of demand. A location southeast of the air base was determined for an exploratory water well which has possible yields of 20 to 60 gpm. Similar capacities may be achieved with a carefully located well in the tributary channel aquifer under the air base. Additional geophysical studies are recommended to determine the precise location of the tributary channel aquifer, locate another aquifer at the east edge of the Comayagua valley and Rio Canquigue, and investigate the feasibility of a deep (+1000 meters) well. It is also recommended that an aquifer management program be initiated where withdrawal flows are metered and charted, monitoring wells are installed, and the aquifer drawdown observed and projected.

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PREFACE

This investigation was conducted by personnel of the Earthquake Engineering and Geosciences Division (EEGD), Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES) during the period April to August 1992. This study was sponsored by the US Army Engineer District, Mobile, SAM.

Field data were collected by Drs. Janet E. Simms and Richard D. Lewis (EEGD), and Mr. Ivan Olivieri, Mobile Area Office, Soto Cano. Logistical assistance was provided by Messrs. Kevin Szydel and Jorge Zapata of the Mobile Area Office, Tegucigalpa. Information on the local area and previous investigations was provided by Messrs. John Baehr and Fred Mann, SAM, and by Mr. Charles Lopez, Military Hydrology Division, US Army Engineer Topographic Engineering Center. Thanks must be given for the support provided by MAJ. Anibal Caussade, Soto Cano Base Civil Engineer and CAPT. Tom Dover, Asst. Base Civil Engineer. Technical graphics support was provided by Mr. William M. Megehee, EEGD.

The project was conducted under the supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, Dr. Arley G. Franklin, Chief EEGD and general supervision of Dr. W. F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or Kelvin*
feet	0.3048	metres
gallons per minute	0.06309	liters per second
gallons per minute	5.541	cubic metres per day
miles (US statute)	1.609347	kilometres
ohm-feet	0.3048	ohm-metres

*To obtain Celsius (C) temprature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

GEOPHYSICAL INVESTIGATION FOR GROUNDWATER RESOURCES AT THE SOTO CANO AIR BASE, HONDURAS

PART I: INTRODUCTION

Background

1. Sufficient quantities of locally available potable water have been a recurring problem at the Soto Cano air base (formally called Palmerola air base) near Comayagua, Honduras. This is chiefly due to the local geology which underlies the air base. Down to at least 840 feet, and probably as deep as 3000 feet in places, the subsurface rock is a uniform volcanic unit which has a very low hydraulic conductivity. Due to the presence of these thick and low permeable volcanic units, many water wells, even those drilled hundreds of feet deep, yield less than 10 to 20 gpm (gallons per minute). Exceptions to this geology are present, especially in the first 200-250 feet of the subsurface. In the area around the air base at least one paleo-gravel channel has been located. This geologic feature allows a high quality, potable water aquifer to exist which has a good eletrical conductivity and a moderate to good water yield. Water wells in this aquifer typically produce from 50 to 150 gpm. This buried stream channel, now filled with gravel and sand, was located by a surface electrical resistivity survey conducted in 1986 (Borrock, 1987). The potable water situation at the air base was dramatically improved with the discovery of this channel. A well was developed in the channel, now termed well No. 5, which gave a sustained yield of 150 gpm. Due to additional use of this aquifer by commercial development adjacent to the Soto Cano air base, this source cannot sustain the potable water needs of all interested parties in the driest season of the year, February to April. This situation will become more acute as additional wells are located in the aquifer. Land adjacent to the air base is being commercially developed and the operators are searching for additional potable water assets. Other water sources must be found or provided in order to meet the needs of the military installation at the current consumption rate of nearby subsurface water resources.

2. The US Army Engineer District, Mobile (CESAM), requested that the Earthquake Engineering and Geosciences Division, USAE Waterways Experiment Station (WES) conduct geophysical surveys in the immediate area surrounding the Soto Cano air base in an effort to locate additional high yielding

aquifers. In addition, the area around a remote site west of the Soto Cano air base, TACAN, was examined to locate an acceptable place to drill for a water well. This activity was conducted during the time period 15 to 30 June, 1992.

Geography, Geology and Groundwater Resources

3. A large data base covering the geography and geology of the local area is maintained by the US Army Engineer District, Mobile. For an extensive review of information on the site consult Everett (1970), Fakundiny (1970) and Dupre (1970). The Soto Cano air base is situated in a physiographic region termed the Interior Volcanic Highlands. In general, the highlands are rugged topographic features with local elevations up to 2,200 meters. Most of the mountains and uplands are forested with open pine. The Interior valleys are predominantly covered with grass or scrub. A portion of the higher elevations and a significant fraction of the valleys are under agricultural production. The climate is tropical with the dry season from November through April and the wet season from May through October. At the peak of the wet season, in June-July, most streams have high discharge. During the dry season streams will have very low flows. Typical lowland temperatures are 80 to 100° F with high humidity. The upland temperature at the highest elevations are more moderate, ranging from 70 to 85° F with significantly lower humidity. Locally the Soto Cano air base is located within the Valle de Comayagua, just west of North Highway 1 and approximately 80 km by road north from Tegucigalpa, Figures 1 and 2.

4. The Soto Cano air base, aka Palmerola, is situated on a geological structure named the Comayagua Graben. This feature is part of the Depression of Honduras, a geologic tectonic feature which runs almost due north-south from the Golfo de Fonseca on the Pacific Ocean side to the Golfo de Honduras on the Atlantic Ocean side (Muehlberger, 1976, Weyl, 1980). This geologic structure was formed in the late Tertiary and is still active.
Faults bounding the Depression of Honduras display Quaternary displacements (Everett and Fakundiny, 1976). Part of this depression is the Comayagua graben which is a +50 km long feature, generally orientated south to north, and is a consequence of extensional or "pull apart" tectonics, Figure 3. As a

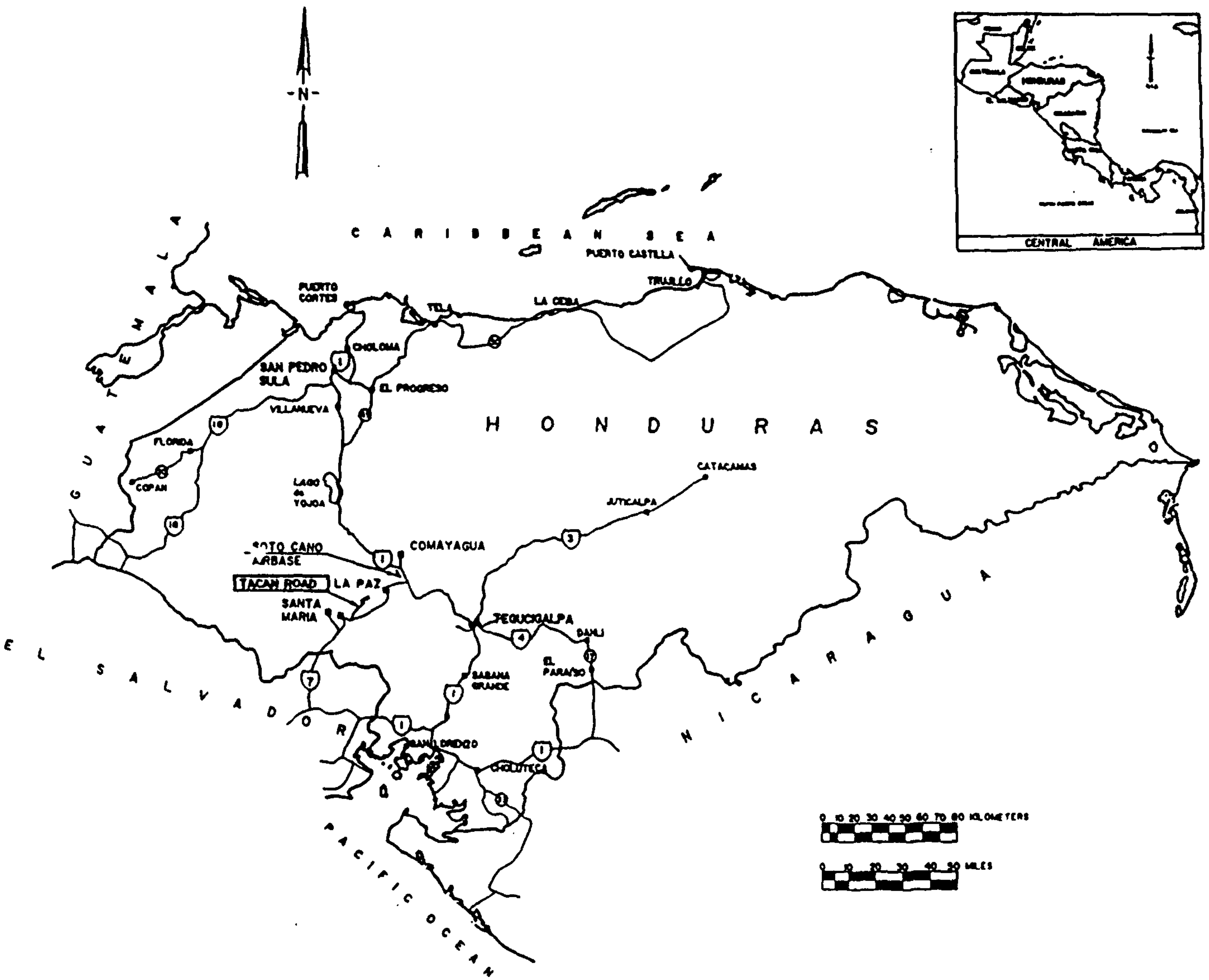


Figure 1. General location map for the Soto Cano air base.

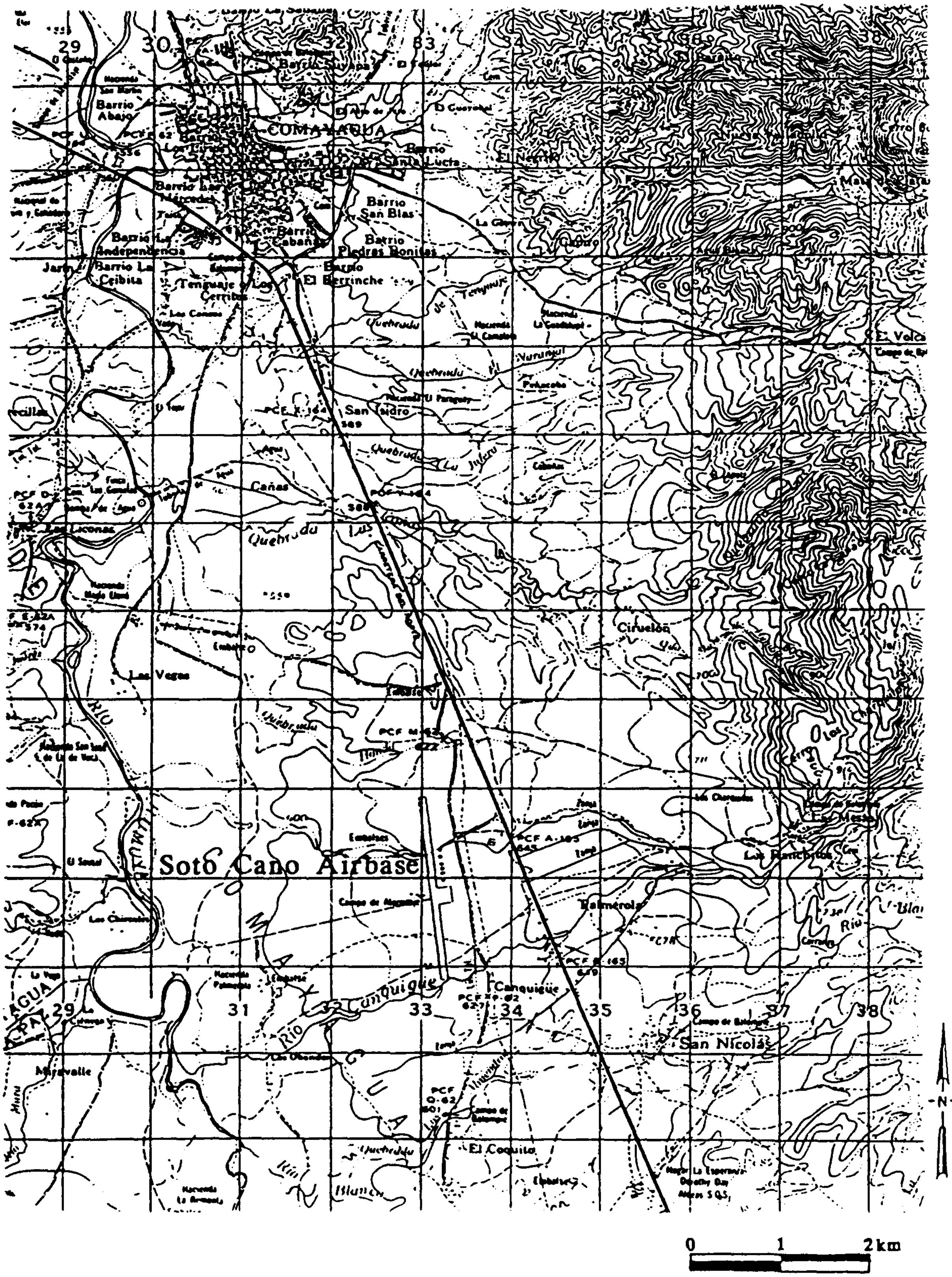


Figure 2. Topographic map showing the location of the city of Comayagua and the Soto Cano air base.

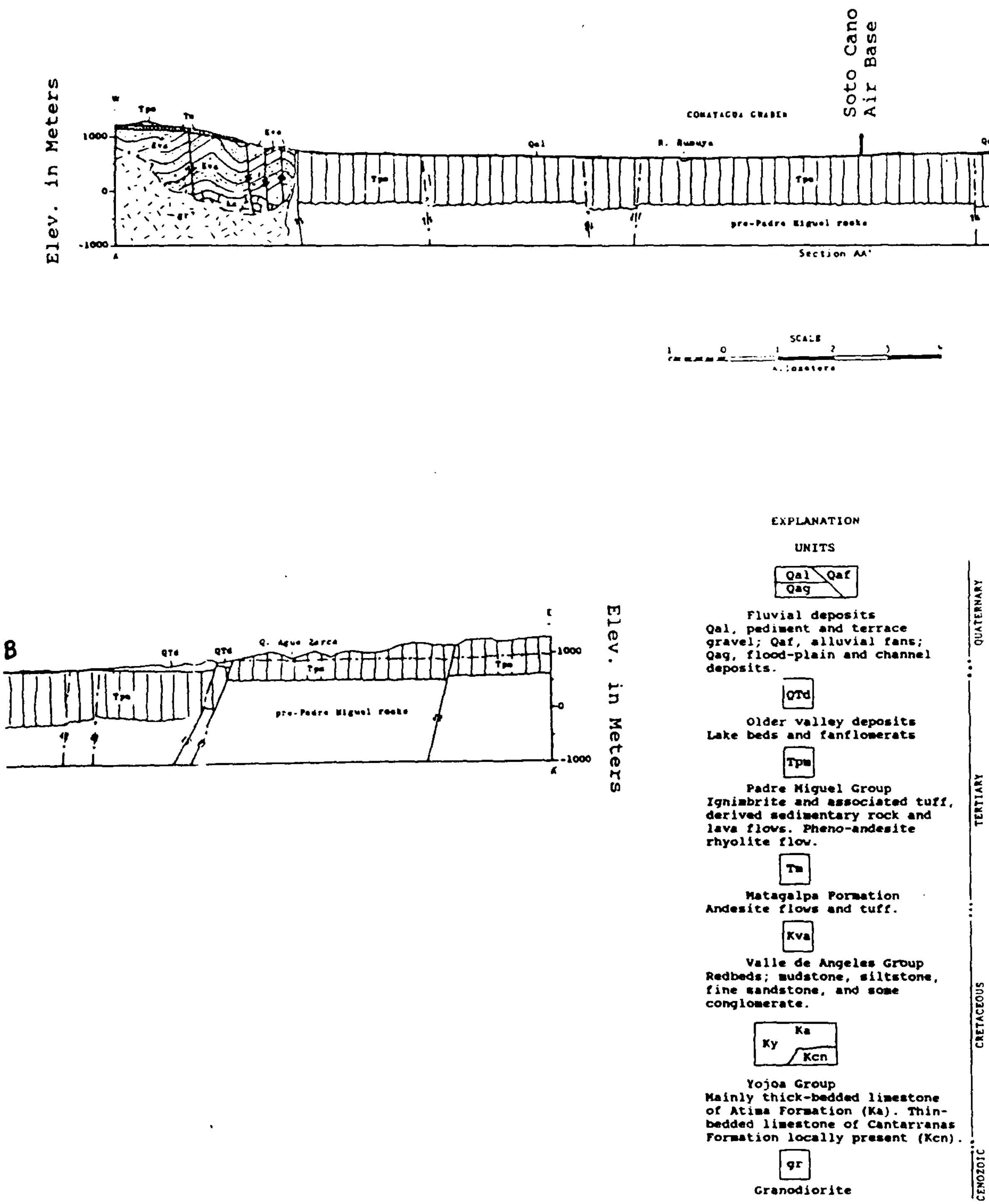


Figure 3. West to east geological cross section of the Comayagua Graben, (after Everett, 1970).

result of these earth forces, north-south orientated faults developed on each side of what is now the Comayagua valley. Flanked by these faults is a large down-dropped block, which has as much as 2000 meters vertical offset, that forms a graben (trench) which is 15 km wide (east to west) at Palmerola. The majority of this vertical movement has occurred within the last 9 million years (McDowell, 1974). This large, deep depression was later filled with late Tertiary volcanic ignimbrites (a type of volcanic ash with glass shards), associated lava tuffs and volcanic flows, the majority of which are collectively termed the Padre Miguel Group. This geologic group has a regionally estimated thickness of over 1000 meters; its depth at Soto Cano air base is not accurately known, but evidence suggests that its thickness should be of this magnitude. Most of the Padre Miguel volcanics in the Comayagua region appear to be weakly to moderately indurated ash-flow tuffs. This unit is typified by sand and smaller sized fragments of pumice and other pyroclastic debris in a finer matrix. These geological units are rather young age, having been produced by eruptions in the late Tertiary. Potassium-Argon age determinations for this group range from 19.1 to 5.2 Million years before present, which places it in the Miocene epoch of the Tertiary period (Duffield et al, 1986). The area is still volcanically active with the last eruption in the region occurring in the year 1845. Further evidence of relatively recent volcanic activity are represented by small fields of Quaternary volcanics occurring within or adjacent to the Honduras Depression. For additional information concerning the graben systems of central Honduras, see McBirney and Weill (1966), Williams and McBirney (1969), and Burkart and Self (1985).

5. Geological evidence is present that additional block subsidence from renewed tectonic activity followed the Padre Miguel volcanics. The Comayagua valley floor lowered in relation to the mountains surrounding it. The valley was then eroded and later capped with fluvial, flood plain, and channel Quaternary river deposits. At the Soto Cano air base these deposits are variable, but do not exceeded over 250 feet in thickness. The predominate source of this material originates from erosion of rocks termed the Valle de Angles Group which form the highlands east and west of the valley. This group is predominately Cretaceous Redbeds with some conglomerates. Redbeds are well known for their concentrations of fines (clays and silts), and generally the predominate Quaternary material encountered near the surface in drill holes in

and around Soto Cano are classified by well drillers as "clay". This material is soft and generally has very low permeability which does not allow a high rate of groundwater production (greater than 20 gpm). Material encountered in boreholes greater that 200 feet in the subsurface has generally been described as "green clay" in driller's reports. This material appears to be water and air laid volcanics which form the Padre Miguel Group. The encountered material is represented by rather soft and homogeneous impermeable clayey volcanics which have demonstrated low water yields in over 20 wells drilled in the area.

6. The Soto Cano air base is located in an area which is more favorable for good groundwater resources than other locations in the general region. This is due to the close proximity of the installation to the Rio Canquigue which flows from the highlands in the east. This river has been depositing stream load material in the Comayagua valley to form a partially developed alluvial fan. The Rio Canquigue has changed its course numerous times in the Quaternary leaving at least one large buried channel of stream gravel in the fan. These gravels generally prove to be good sources of ground water and typically have a high yield. One of these channels was earlier detected under the Soto Cano installation by the use of electrical resistivity surveys. This buried channel was drilled and a subsequently developed well (now termed well No. 5) placed into production for potable water. This single water well provides a high percentage of the necessary potable water for the Soto Cano installation. However, due to the very heavy demand for fresh water resources, the aquifer can no longer maintain such a large production volume at the end of the annual dry season. This problem occurs in many of the water systems of Honduran cities; only 60% of the country's systems can operate continuously, due to aquifer drawdown, in the driest portion of the annual seasons (Anonymous, 1982).

Past investigations

7. Past exploratory drilling to locate potable water sources in the area is summarized in "Field Water Operations No. 38-26-1355-87, Joint Task Force Bravo", Anonymous, 1986. This report documents some of the drilled wells on the Soto Cano air base, Figure 4. Typically, wells were drilled to 300 to

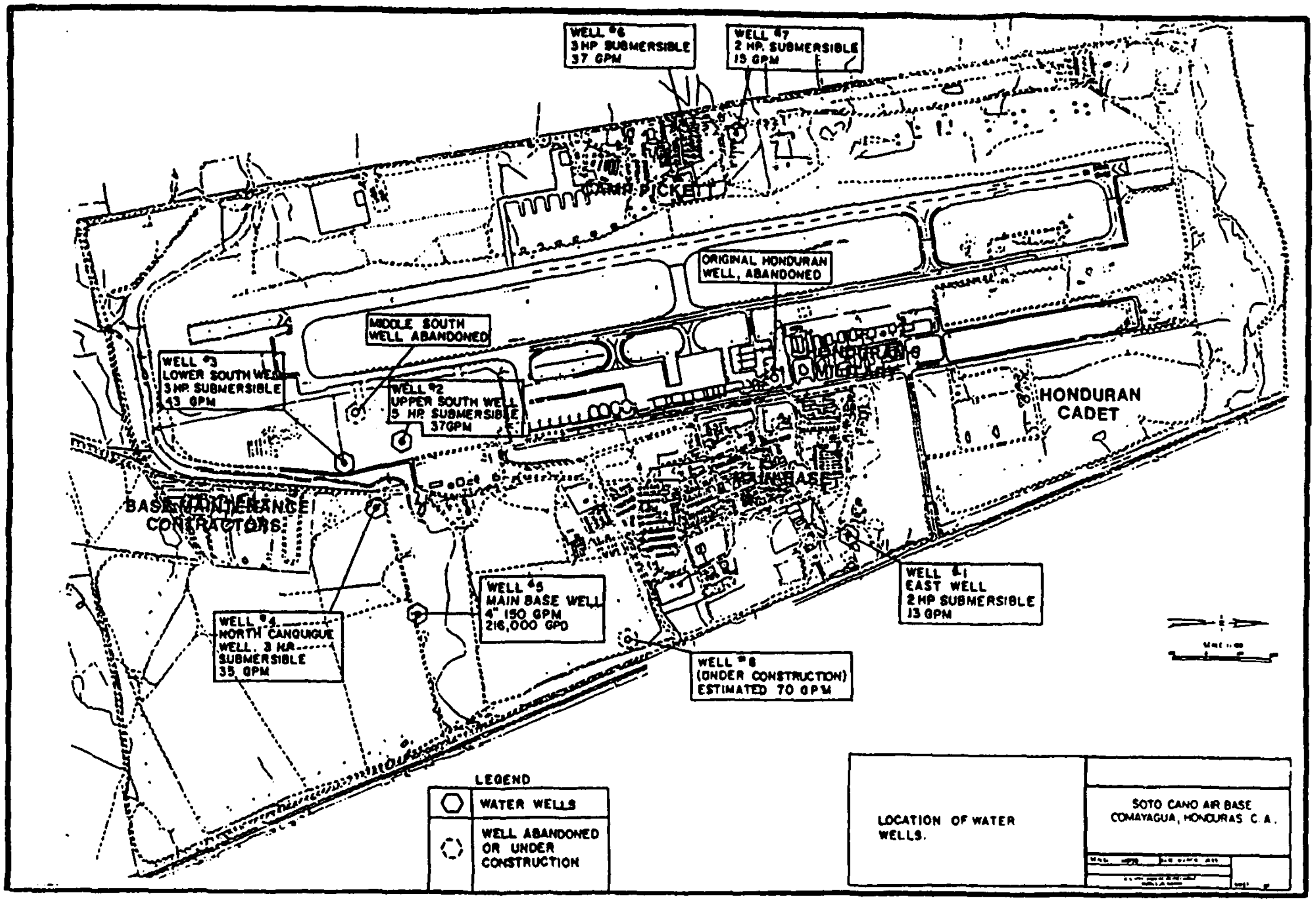


Figure 4. Location of primary water wells on the Soto Cano air base.

840 feet in the subsurface with mostly impermeable clays found below 250 feet. The static water levels were reported to be at 65 to 75 feet below ground surface. Lenses of sands and gravels were generally located at various depths in the first 250 feet of the well. The wells which displayed a larger water yield had significantly higher concentrations of sand and gravel present in the interval between the static water level and 200 to 250 feet in the subsurface.

8. A surface geophysical investigation was conducted in order to locate areas with potentially larger quantities of gravel in the subsurface, and hence be more favorable for water production. The results of this initial investigation are reported in Borrock (1987) and summarized in Figure 5. Multiple resistivity traverses using the Wenner array were performed within the confines of the air base at three different electrode spacings (see below for procedure explanation); "A" spacings of 25, 75 and 150 meters. Positive results were found using the 75 meter spacing, and a buried paleo channel, now filled with gravel, of the Rio Canquigue was located. Subsequent drilling into the buried channel resulted in an excellent and large yielding water well (No. 5) which yields in excess of 150 gpm.

Commercial Developments Effecting Water Supply

9. A large portion of the property surrounding the Soto Cano air base capable of sustaining commercial agriculture is in or will soon be placed in production. Local business interests have received permission from the central government to make a practice flight to air export produce from the air base. Currently a large international company is financing the planting and export of squash and cucumbers. Development of the canning industry is encouraged and two companies are producing canned juices, ketchup and tomato paste for local consumption and export. These activities are located adjacent to the Soto Cano air field and will require considerable quantities of fresh water for produce processing and canning.

10. One agri-business company adjacent to the air base requires a fresh water rate of 400 gpm for on-site processing of vegetables. Currently, drilled wells on the property are producing yields of 180 to 200 gpm. The company is attempting to recycle water where ever possible to cover

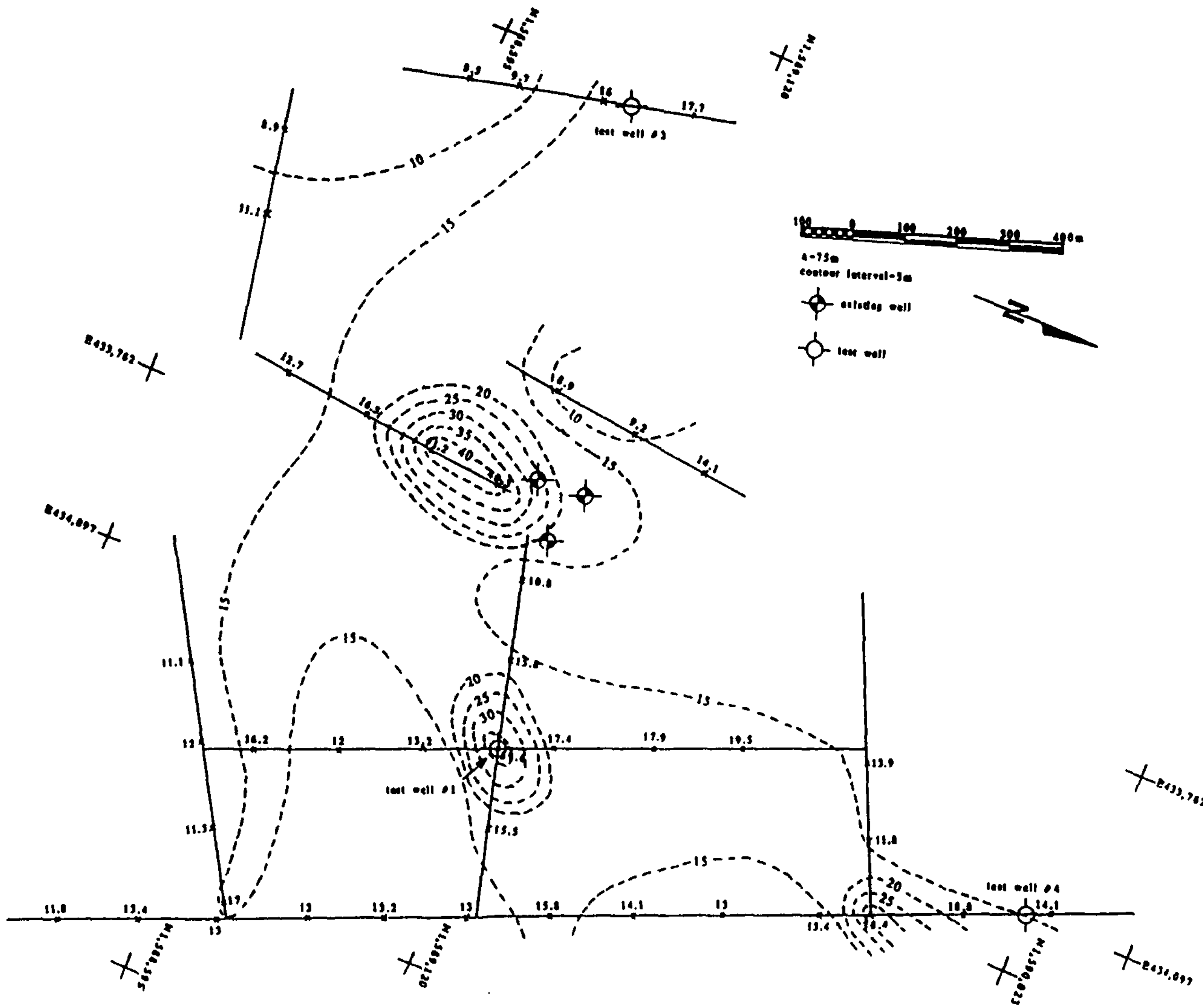


Figure 5. Results of previous resistivity investigation using a 75 meter Wenner "A" spacing. Redrawn from Borrock, 1987.

the deficiency, and is considering developing surface impoundments to provide additional water resources. The development of the groundwater resources on the property controlled by this company has paralleled the development of the groundwater resources on the Soto Cano air base. Within the last three years, nine wells were drilled. The first seven of these wells were drilled at random locations to depths of 400 feet. Of those wells with yields greater than 10 gpm, the production was from gravels found in the first 150 feet below the surface; below the depth of 200 feet only impervious clay was present. Four wells were drilled in locations where only a small quantity of permeable strata are present and the total yield was less than 10 gpm; these wells were abandoned. The wells now in production include three wells producing 10 to 20 gpm, one additional well producing 40 gpm, and another well producing 90 gpm. This later well was located by a geophysical survey late in the drilling program and is situated almost opposite the front gate of the Soto Cano air base. Pumping from this well was detected in well No. 5, proving that the two wells are in communication with each other. It is almost certain that both wells are situated in the same aquifer or in two connected aquifers, and this pumping well is reducing the water yield from the main aquifer beneath the air base.

PART II: GEOPHYSICAL INVESTIGATION

Background on Resistivity Method

11. The electrical resistivity method has proved successful for locating water wells at the Soto Cano air base. This geophysical method generally allows subsurface mapping of the underground gravel zones which are present within a few hundred feet of the surface. In addition, it is possible to determine the depths and thicknesses of these subsurface gravels. The resistivity method can be used conveniently to investigate to depths of about 200 to 250 feet, which has proven to be the location of all of the good near surface aquifers in the vicinity. For a review and case histories of the application of the resistivity method for groundwater exploration see Zohdy (1965), Aubert, Camus, and Fournier (1984), Frohlich (1974), and Lennox and Carlson (1967).

12. The resistivity method is used to obtain information on the resistivity structure of the subsurface. Measured resistivity values are generally reported in ohm-feet or ohm-meters, and the determined values for earth materials can range from a few ohm-meters to over several thousand ohm-meters. In the Soto Cano air base area, the major factor which effects the change in measured resistivity values is the change of geological material present; large concentrations of sand and gravel have significantly greater electrical resistivity values than the clays or volcanics. The contrast in measured resistivity allows the locations of these underground concentrations of sands and gravels to be determined. The much higher yielding aquifers are associated with these coarse grained geological materials.

13. The field technique for collecting resistivity data involves inserting four metal rods or electrodes into the ground which are generally orientated in a linear fashion, Figure 6a. A direct current (DC) is then passed between the outer electrodes. The subsurface earth material acts as a natural resistor and thus an electrical potential difference is present between the inner electrodes. The apparent resistivity of the subsurface material can be computed from the known values of the electrode position and separation, the current (in Amperes) between the outer electrodes, and the electrical potential (in Volts) between the inner electrodes. The greater the

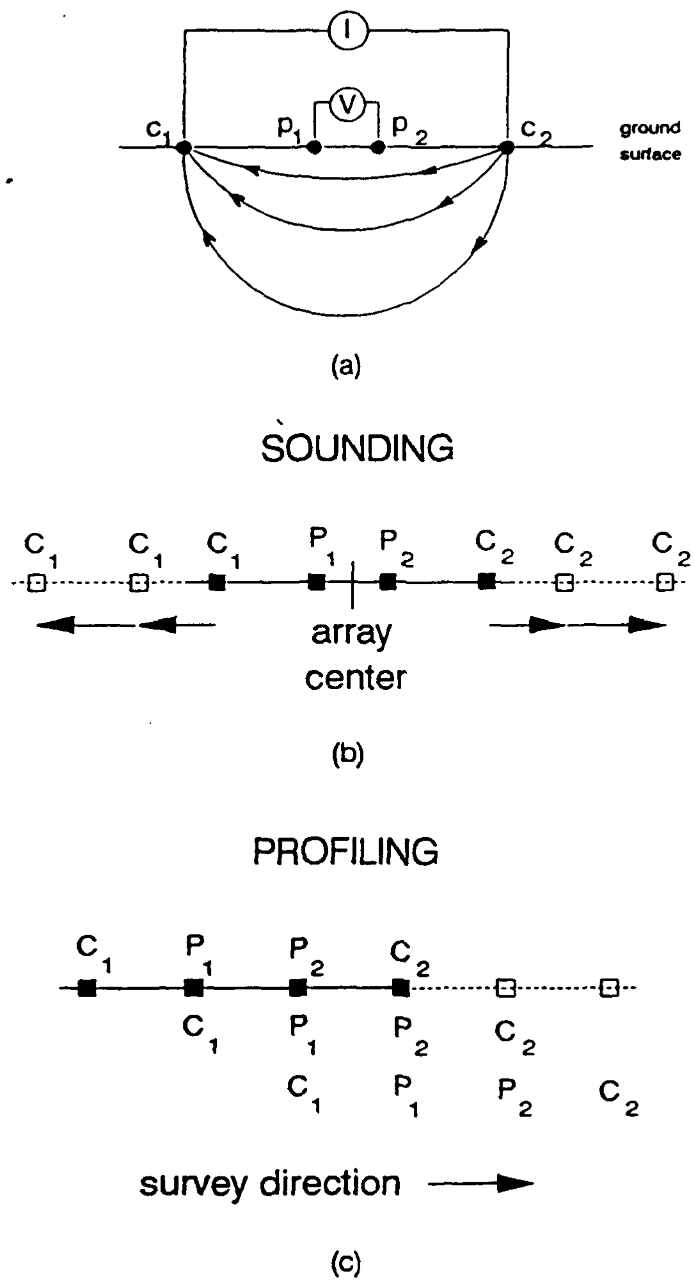


Figure 6. Electrode configurations for resistivity sounding and profiling.

separation of the electrodes the deeper the depth of investigation, hence the larger the volume of material influencing the resistivity measurement.

14. Field resistivity surveys are typically one of two types, vertical sounding or horizontal profiling. Resistivity sounding is used to obtain variations in resistivity with depth at a particular location. When performing a sounding, the center of the electrode array remains fixed and measurements are taken in sequence as the electrodes (metal rods) are moved to increasingly greater distances apart, Figure 6b; the greater the electrode spacing, the greater the depth of investigation. In this study the electrical sounding data were collected using an electrode configuration termed the Schlumberger electrode array, where the distance between the current electrodes is approximately five times the spacing of the potential electrodes (inner electrodes). The profiling technique is used to identify lateral variations in resistivity at a given depth of investigation. The spacing between the electrodes remains constant and for each new measurement all four electrodes are shifted laterally the same distance, Figure 6c. Location of gravel deposits within the depth of investigation can be inferred beneath a predetermined traverse. In this investigation, the Wenner electrode array, which has an equal distance between all electrodes, was used to collect the resistivity profile data.

15. The resistivity data, as collected by either sounding or profiling techniques, are displayed in different manners. Sounding data are plotted on a log-log scale where the apparent resistivity is plotted versus the electrode spacing. The plot forms an "apparent resistivity sounding curve" which can be visually or numerically interpreted. When this data is reduced or processed by numerical means, a best fit solution is typically computed for two to four subsurface layers. The generated best fit solution produces values for the thickness and electrical resistivity of each layer. The resistivity value is used to characterize the subsurface material type, i.e in this case sand and gravel or clay. These computed subsurface boundaries and resistivites are generally used as estimates rather than as absolute values. Data collected by resistivity profiling is plotted on linear axes with apparent resistivity versus traverse distance. Lateral changes in the material at a particular zone in the subsurface are then readily visible. Generally, profiling data do not receive a rigorous numerical inversion but are interpreted by visual

inspection.

Resistivity Soundings

16. Three resistivity soundings were performed during this investigation. Two were accomplished in order to verify the previous results from past surveys and to confirm information obtained from well logs. An additional sounding was sited at a location which was judged to be the most favorable new well site as determined by preliminary investigation of the resistivity profiling results. The data were processed using the computer program RESIX Plus (Interpex Ltd., 1988) to give a layered model of resistivity versus depth.

17. The first resistivity sounding was orientated in an approximate east-west direction and was situated with well No. 5 very close to the center of the electrode array, (Well No. 5 sounding). Another east-west sounding was positioned in the southeastern corner of the air base where no permeable gravel aquifers were believed to be present, (South sounding). The third sounding was aligned generally east-west and was parallel to profile Line 13, (Line 13 sounding). This sounding is believed to represent the best new well location as a result of this investigation. The mathematical inversions of these soundings are listed in Table 1. Figures 7, 8, 9, 10 and 11 exhibit the resistivity sounding curves for these locations along with the depth verses material resistivity profile. These curves document the viability of the resistivity method in the type of geologic framework found in the Soto Cano air base area. Well No. 5 sounding (Figures 7 and 9) clearly shows the presence of the higher resistivity and permeable gravels (about 22 ohm-meters) from about 5 to 50 meters below the surface. Figure 10 directly compares the information from well No. 5 driller's log, resistivity sounding inversion, and the borehole resistivity log. Presently well No. 5 is the best yielding well on the alluvial fan. Compare this curve to the South sounding where no evidence of significant gravel zones at depth are observed in the data; only impermeable volcanic clay with an 8 ohm-meter resistivity is indicated from 5 to +200 meters in the subsurface, Figure 9. The data from these two soundings indicate that a Wenner "A" spacing of 60 meters should be sufficient

Table 1

Resistivity Soundings for the Soto Cano Air Base Groundwater Investigation

Well No. 5 Sounding

	Resistivity in Ohm-Meters	Depth to Top of Layer in Meters	Thickness of Layer in Meters	Material
Layer 1	64.5	0.0	1.7	soil profile
2	142.9	1.7	3.5	near surface clays & gravels
3	22.6	5.2	44.0	river channel gravels
4	9.0	49.2	very large	volcanic clays

South Sounding

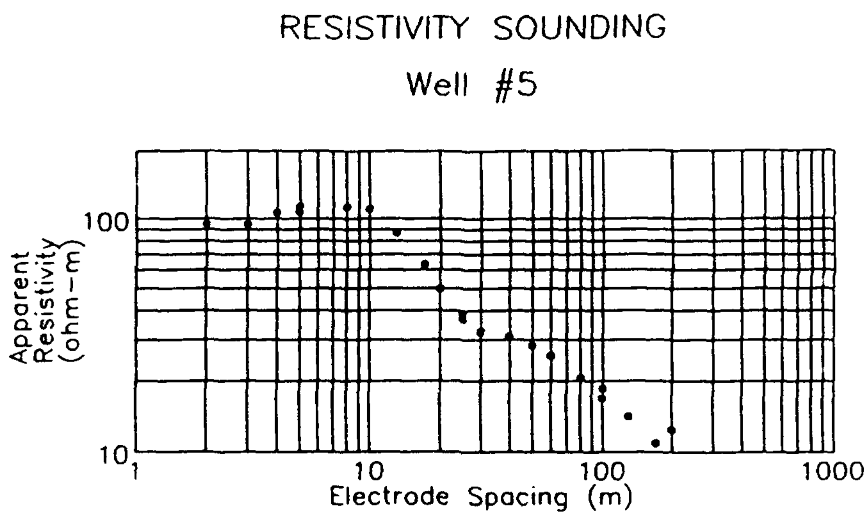
	Resistivity in Ohm-Meters	Depth to Top of Layer in Meters	Thickness of Layer in Meters	Material
Layer 1	15.1	0.0	2.6	soil profile
2	34.8	2.6	4.2	near surface clays & gravels
3	7.9	6.8	very large	volcanic clays

Table 1, Continued

Resistivity Soundings for the Soto Cano Air Base Groundwater Investigation

Line No. 13
Sounding

	Resistivity in Ohm-Meters	Depth to Top of Layer in Meters	Thickness of Layer in Meters	Material
Layer 1	20.5	0.0	1.1	soil profile
2	32.7	1.1	11.3	near surface gravels
3	17.0	12.4	106.7	clays & gravels
4	9.0	118.7	very large	volcanic clays



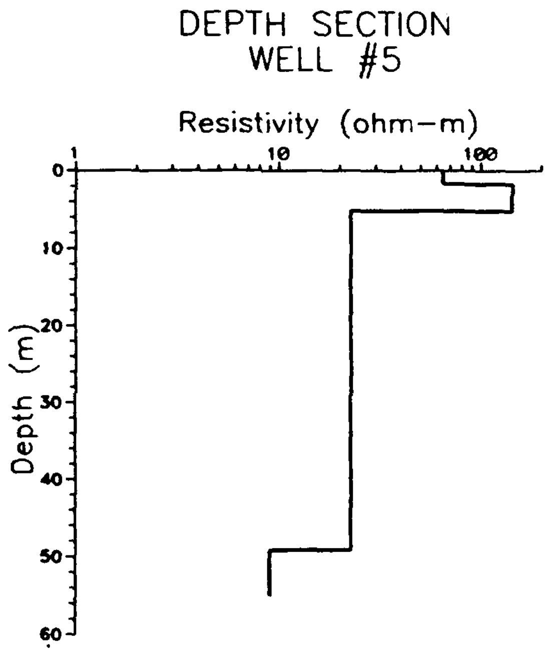
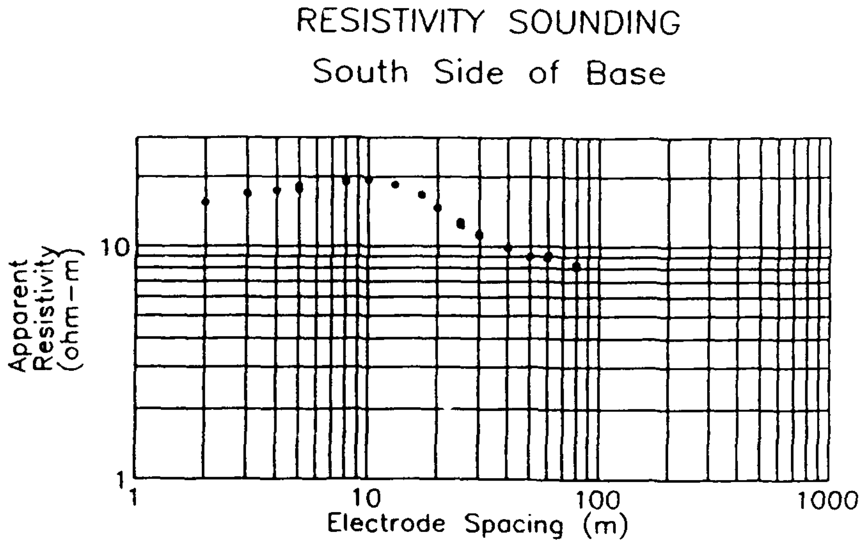


Figure 7. Resistivity sounding and interpreted depth section adjacent to well No. 5.



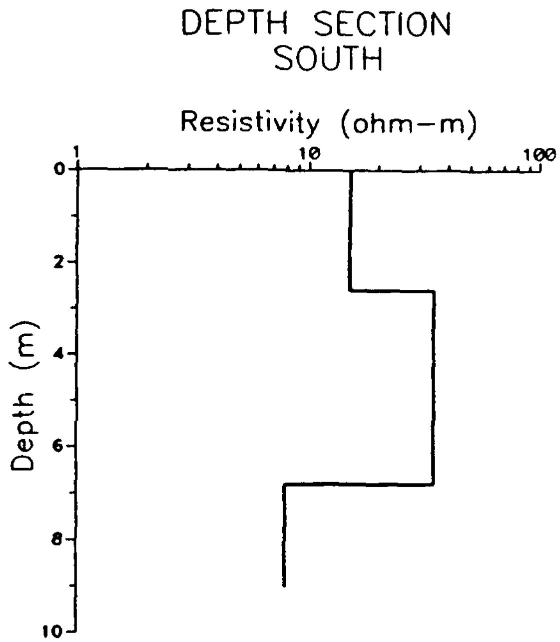
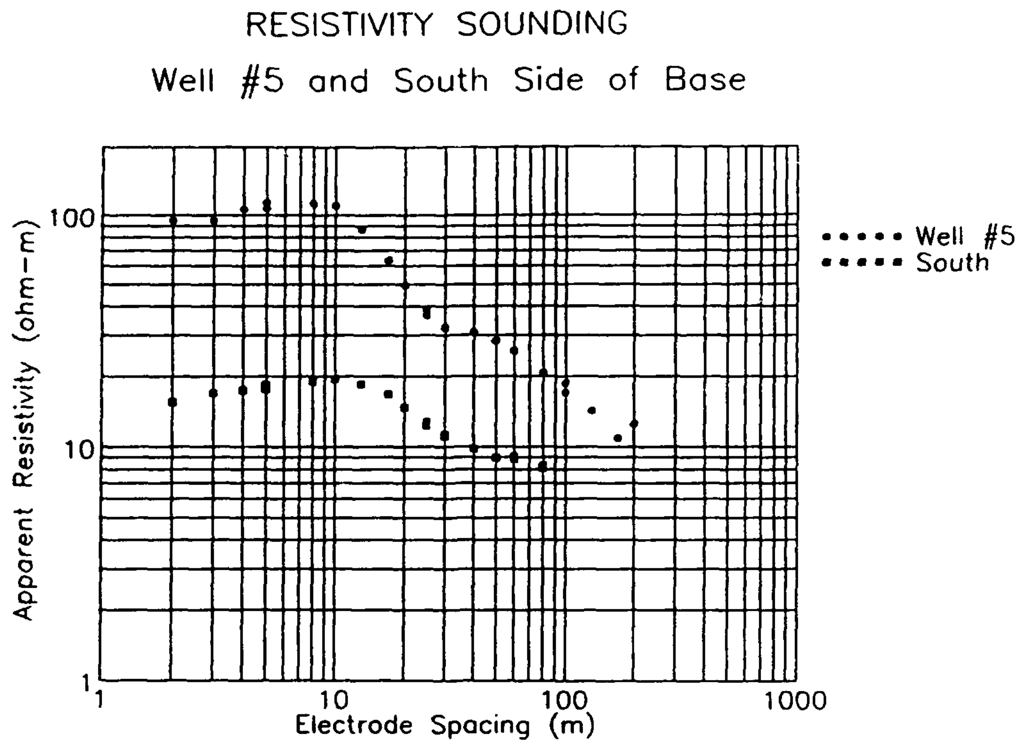


Figure 8. Resistivity sounding and interpreted depth section on the south end of the Soto Cano air base.



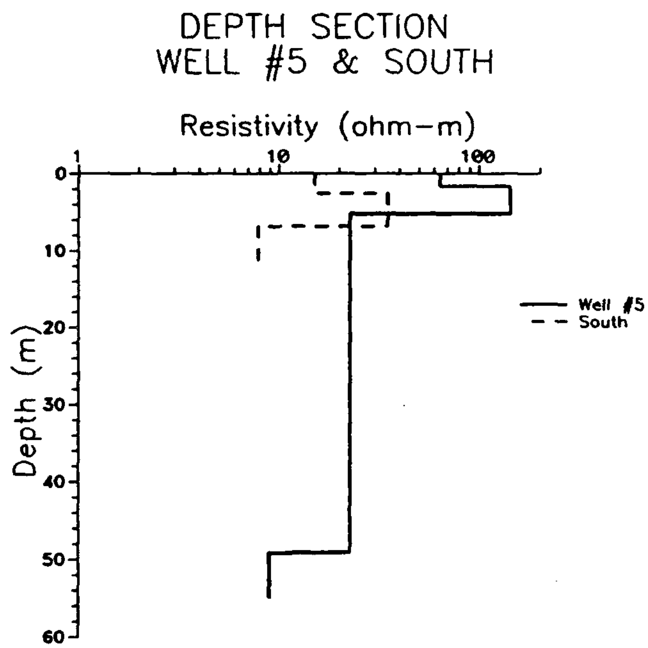


Figure 9. Direct comparison of resistivity soundings and interpreted depth sections at well No. 5 and at the south end of the Soto Cano air base.

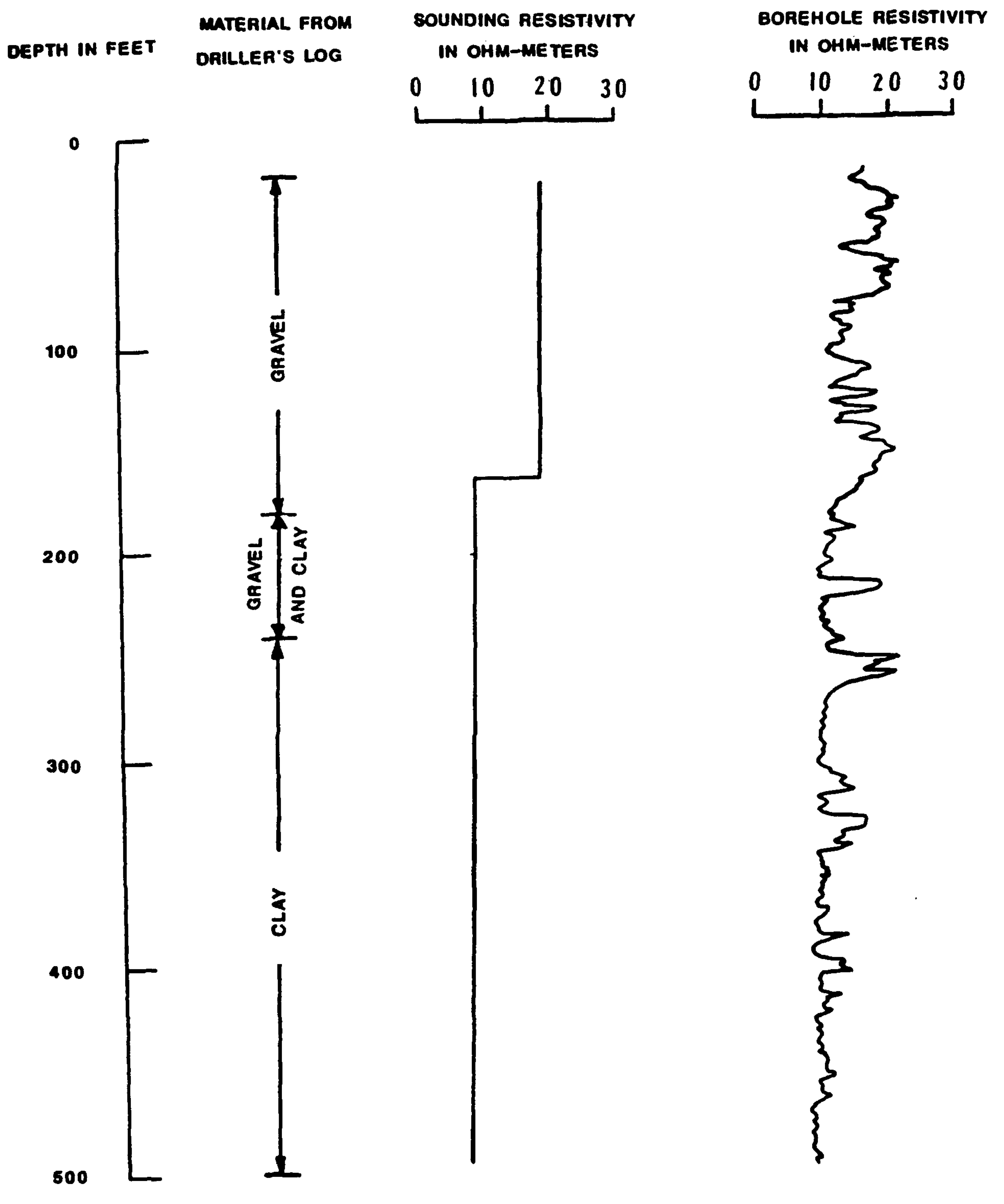
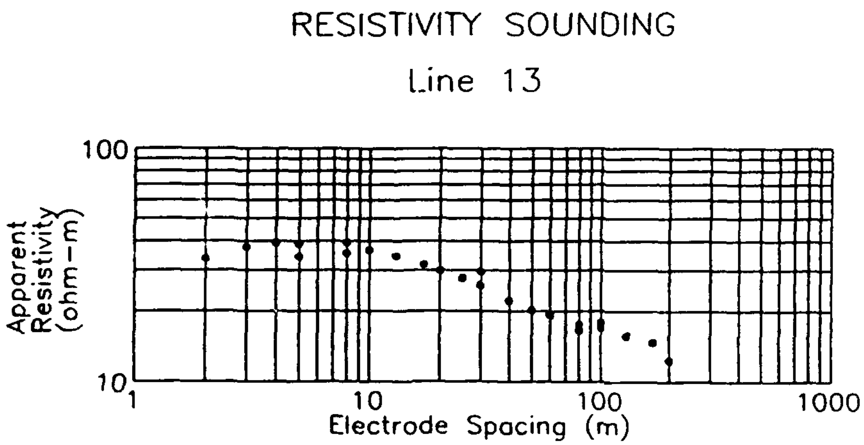


Figure 10. Comparison of data from well No. 5. Note the higher resistivity for the gravels in the 15 to 180 foot interval.



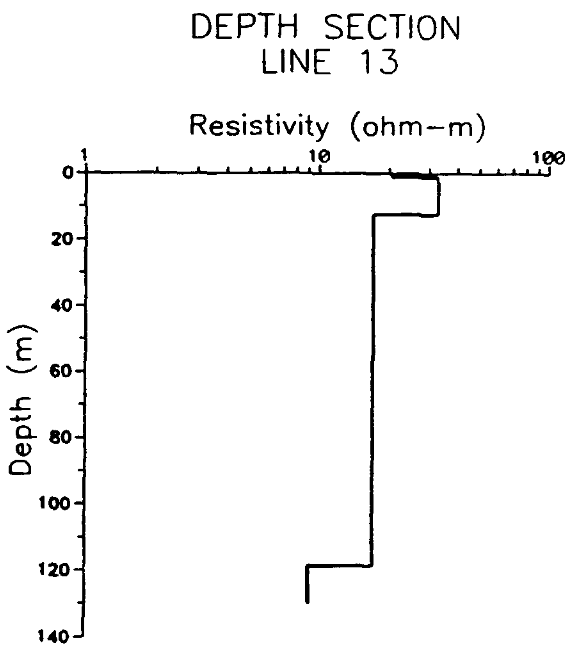


Figure 11. Resistivity sounding and interpreted depth section centered at the highest apparent resistivity value along profile Line 13.

to detect and resolve the subsurface gravel channel aquifers. The sounding conducted at profile Line 13 (Figure 11) indicates that intermixed layers of clay and gravels prevail from 10 to 120 meters in the subsurface, as documented with the computed material resistivity of 17 ohm-meters. This compares to an electrical resistivity of 22 ohm-meters for the gravel aquifer at well No. 5, and 8 ohm-meters material resistivity for the impermeable clays. A well at this location should produce useable quantities of potable water. A cooperative Honduran-Japanese government rural development well was drilled approximately 1 kilometer to the northeast of this site in similar subsurface geological conditions; this well has a rated capacity of 20 gpm.

Resistivity Profiles

18. A large percentage of the property on the air base was tested for subsurface gravel channel aquifers in the 1987 resistivity investigation. In addition, numerous additional wells have been drilled and then abandoned in the search for additional water resources. Due to the probability that all good shallow water aquifers within the confines of the Soto Cano air base property have been located and that deep aquifers, if present, have been estimated to be in the neighborhood of +1000 meters in the subsurface, it was judged imperative to extend the exploration for good aquifers off base. Two proposed survey lines were initially recommended: (1) A north to south electrical resistivity traverse west of the airfield, and (2) If no favorable gravels were detected on the first traverse, an additional, generally north to south traverse was to be executed just east of the main highway. Before the survey was completed however, the entire boundary of the Soto Cano air base was surveyed and additional areas were investigated east and southeast of the installation. All data from the resistivity traverses are reported in Appendix A.

19. The locations of the previous resistivity profiles and test wells are indicated on Figures 5 and 12. The portion of the investigation reviewed here is the resistivity profiles where the data were collected with a Wenner array "A" spacing of 75 meters. Lines I,D,B, and A indicate a buried gravel channel

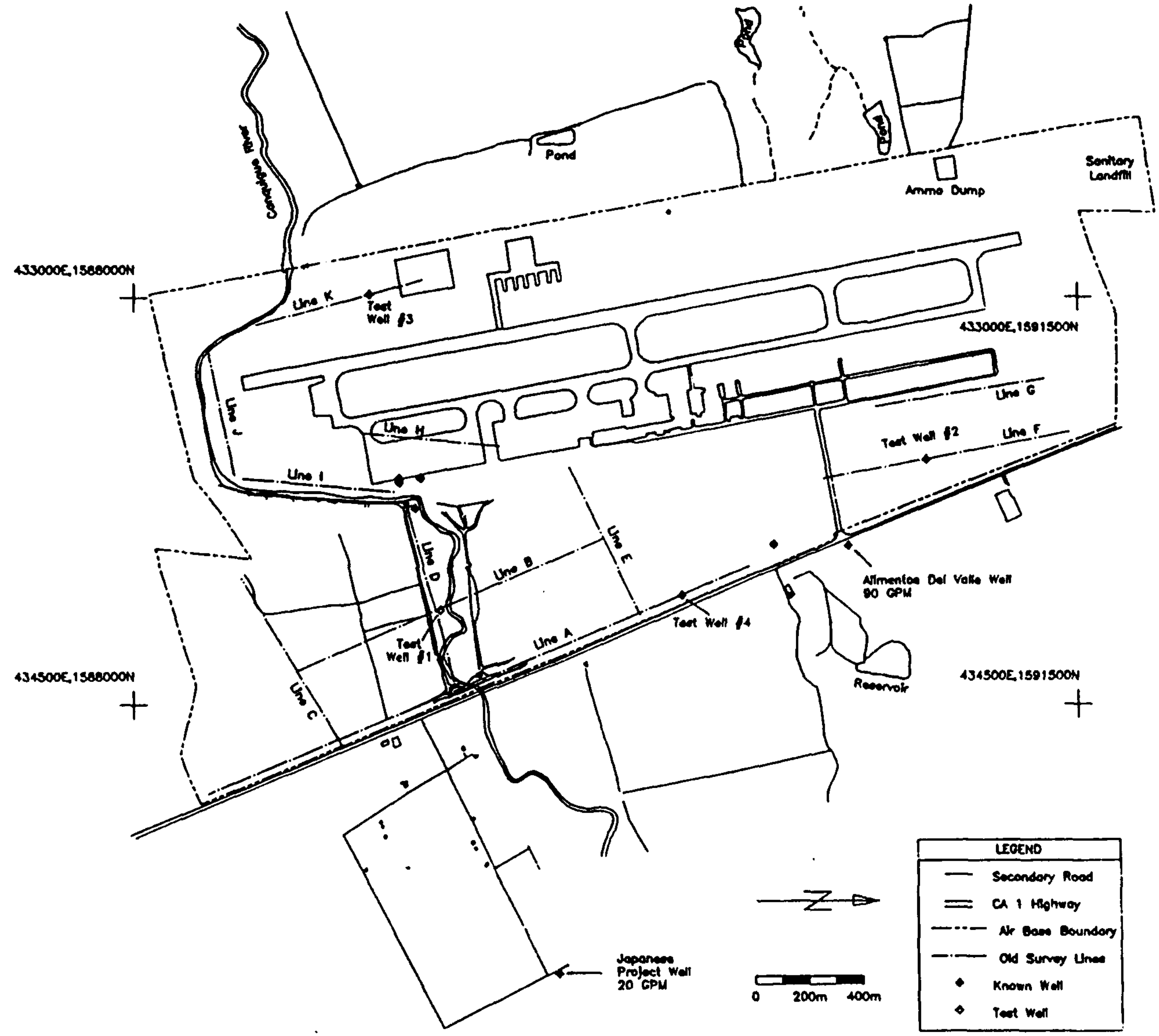


Figure 12. Location of resistivity profile lines and test wells from a previous geophysical investigation at the Soto Cano air base, (after Borrock, 1987).

approximately 40 to 80 meters wide meanders in the subsurface from a location close to the south end of the eastern runway to the eastern side of the air base property just north of well No. 8. Lines A through G and I through K and test wells No.1 through No.4, and other wells demonstrated that areas with measured subsurface apparent resistivites in excess of 33 ohm-meters contained sufficient alluvial gravel in the subsurface to enable water wells to be drilled with capacities greater than 35 gpm. The largest water production came from test well No. 1 (now termed well No. 5) with a subsurface apparent resistivity of 39.6 ohm-meters and a water well production of 150 gpm. Figure 13 displays the current production wells and their rated capacity as identified at the time of that investigation. Wells No. 2, 3, and 4 have rated capacities of 37, 43, and 35 gpm respectively. They are also located approximately 100 meters north of the greatest thickness of subsurface channel gravels as indicated by the resistivity traverses. As a group, these wells are adequately communicating with the main subsurface gravel channel and an additional well centered on the predominate subsurface gravel body would not significantly increase water production. Well No. 8 is located approximately 80 meters south of the subsurface gravel channel where it exits from the Soto Cano air base property, and has a rated capacity of 70 gpm. It is apparent from the dry season drawdown that these wells, Nos. 2,3,4,5, and 8, have reached this channel aquifer's delivery capacity and additional wells drilled on the Soto Cano air base into this subsurface gravel channel will not produce substantial increases in water production.

20. The results of the resistivity traverses performed in this investigation outside the Soto Cano air base are reported in graphical and numerical form in Appendix A. The section covered by the west portion of the air base are from south to north represented by traverse Lines 6, A, B, C, 1, and 2, Figure 14. The apparent resistivities along these traverses ranged from 3 to 16 ohm-meters (the 16 ohm-meter measurement is considered to be a spurious measurement), Figure 15. No favorable locations for large capacity water wells were detected along these traverses. The North side of the Soto Cano air base was investigated from west to east by traverse Lines 3, 4, and 5. Along these traverses the apparent resistivities range from 4 to 6 ohm-meters. The data indicate that the area under the northwestern portion of the air base contains the least permeable material of any locale in this

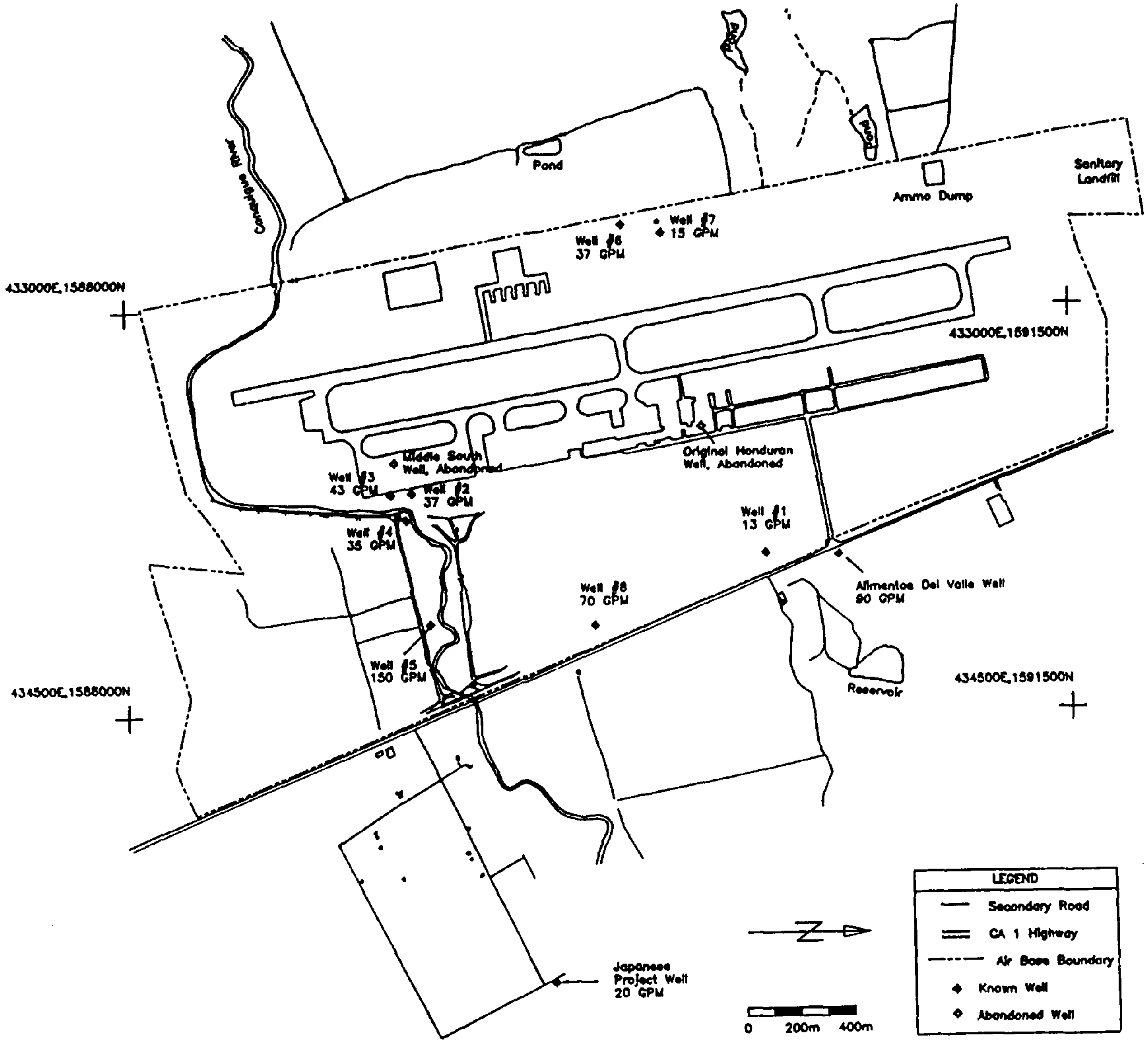


Figure 13. Location of water wells in the vicinity of the Soto Cano air base.

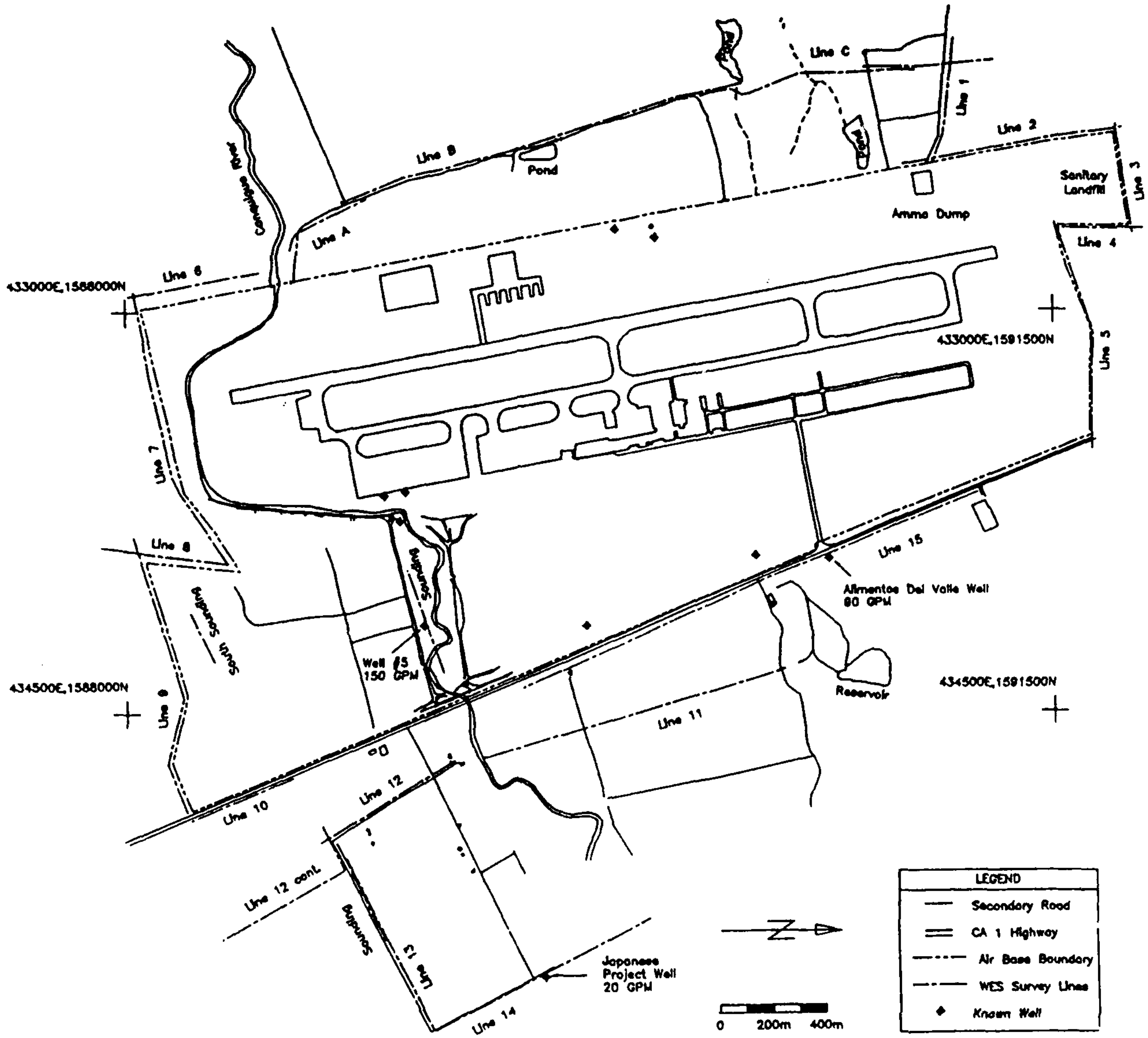


Figure 14. Resistivity profile and sounding locations in the vicinity of the Soto Cano air base.

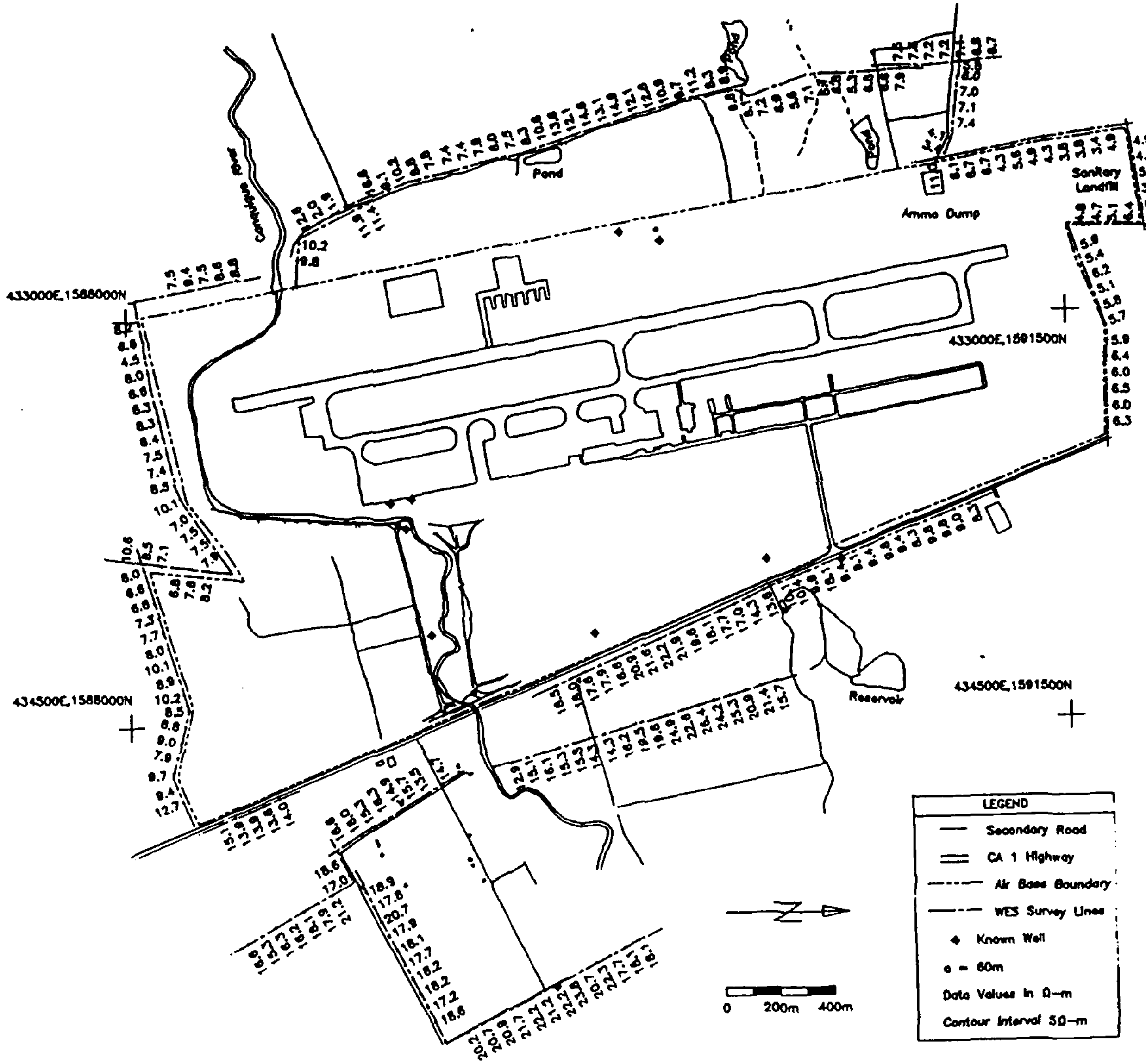


Figure 15. Apparent resistivity values along profile lines ("A" spacing equal to 60 meters) near the Soto Cano air base.

investigation. Although its permeability is the least favorable in the area for the development of water wells, it is the most advantageous for the site location of sanitary landfills. The area on the south perimeter of the air base was investigated from west to east by traverse Lines 7, 8 and 9. Along this periphery of the base resistivity values of 6 to 12 ohm-meters were obtained. These low values indicate that sufficient quantities of high permeable gravels are not present in the subsurface for a significantly productiing water well.

21. More favorable results were obtained from the resistivity traverses east of the air base. Traverse Line 15 exhibited a maximum apparent resistivity of 18 ohm-meters, very close to a commercially developed 90 gpm production well. This anomalous measurement was verified as representative of higher resistance material in the subsurface. This well is by far the most prolific producer of all 10 wells drilled adjacent to the air base. The location of this well was selected by a geophysical survey after numerous wells were drilled which did not produce significant water yields. According to reports, this well also encountered vastly greater amounts of gravel from 50 to 200 feet in the subsurface when compared to other wells in the immediate vicinity. Almost immediately after this well was placed into production, drawdown effects were noted in well No. 5 on the Soto Cano air base. Due to the narrow shape of the gravels indicated in the subsurface by the resistivity traverse and the communication between this well and well No. 5, it is interpreted that this well has encountered a tributary of the buried gravel channel which is currently the main aquifer of the Soto Cano air base. This smaller gravel channel has not been detected by any previous geophysical surveys on the Soto Cano air base or in any drilling. Most likely it crosses into the air base near the front gate, turns to the south somewhat west of well No. 1, and connects with the main gravel channel aquifer between wells No. 8 and 5 (refer to Figure 17 for a possible location of the tributary channel).

22. Traverse Line 15 also crossed the main channel aquifer approximately 200 meters north of well No. 8 where a maximum value of 22 ohm-meters was noted. The center location of the channel aquifer was again determined on traverse Line 11 where a peak apparent resistivity value of 26 ohm-meters was measured. If a well is drilled into this hydraulically up gradient area

of the channel aquifer where it crosses beneath Line No. 15 or 11, the water yields of wells No. 8, 5, 4, 2, and 3 could be diminished.

23. Three traverses, Lines 12, 13, and 14, were performed south of the Rio Canquigue and east of the Soto Cano air base. This area is dominated by small farmers. As a result of the generally higher apparent resistivity values in this locale, the subsurface geology is interpreted to generally contain a higher concentration of gravel lenses than the other surveyed areas, however, no channel gravel aquifers were detected. Traverse Line 14 displayed a maximum subsurface apparent resistivity of nearly 24 ohm-meters almost adjacent to the Japanese project well. This site is certainly the most favorable location to drill a well as predicted by these three resistivity traverse lines. It is not known if geophysical surveys were conducted to determine this well point. The yield of this well is reported to be 20 gpm, somewhat lower than would be expected from the measured apparent resistivity value. Another potential well site location was determined on traverse Line 13, where a maximum apparent resistivity value of approximately 21 ohm-meters was determined using the 60 meter Wenner "A" spacing. The results of the resistivity sounding are shown in Table 1. A generally favorable material resistivity of 17 ohm-meters was found between 10 and 110 meters in the subsurface, Table 1.

PART III: DISCUSSION OF CHANNEL AQUIFER AND LOCATION OF ADDITIONAL WATER RESOURCES

24. The collected traverse data demonstrates that the apparent resistivity of the subsurface geologic material generally increases from the northwest portion of the air base to the area to the southeast, Figure 16. This is interpreted to represent a general increase in the amounts of subsurface gravel concentration as the apex of the alluvial fan is approached. The area immediately below where the Rio Canquigue river emerges from the highlands into the valley should have the greatest gravel concentration in the nearer surface alluvial deposits. The vicinity immediately south of the villages of Los Ranchitos and Los Mesas, approximately 3 kilometers due east of the Soto Cano air base, would be the most favorable general target location for nearer surface gravel aquifers. Resistivity traverses in this locality would determine the most promising location for groundwater development in this target area.

25. Some additional water resources could be developed on the Soto Cano air base by establishing a well in the tributary channel aquifer which enters near the main gate. This aquifer is relatively narrow, perhaps only 10's of meters wide, and would require a resistivity survey to locate its course from its location near the main gate to where it connects to the main channel aquifer. As a new well in this aquifer might have communication with the production well near the main gate, it is anticipated that the yields from this later well would be diminished.

26. Additional water resources could be achieved by drilling a well near the highest apparent resistivity value along traverse Line 13. This location would require approximately 1400 meters of pipeline to connect into the present well system, and the line could easily cross highway CA 1 at the bridge over the Rio Canquigue. It is estimated that the yield of a well located here might be in the 20 to 60 gpm range. This proposed well location is 800 meters from the Japanese development project well and overlapping cones of depression should not be a significant problem.

27. This investigation suggests that the majority of the potable water for the Soto Cano air base is originating from one channel aquifer, Figure 16. This aquifer may have at least one significant tributary which has been

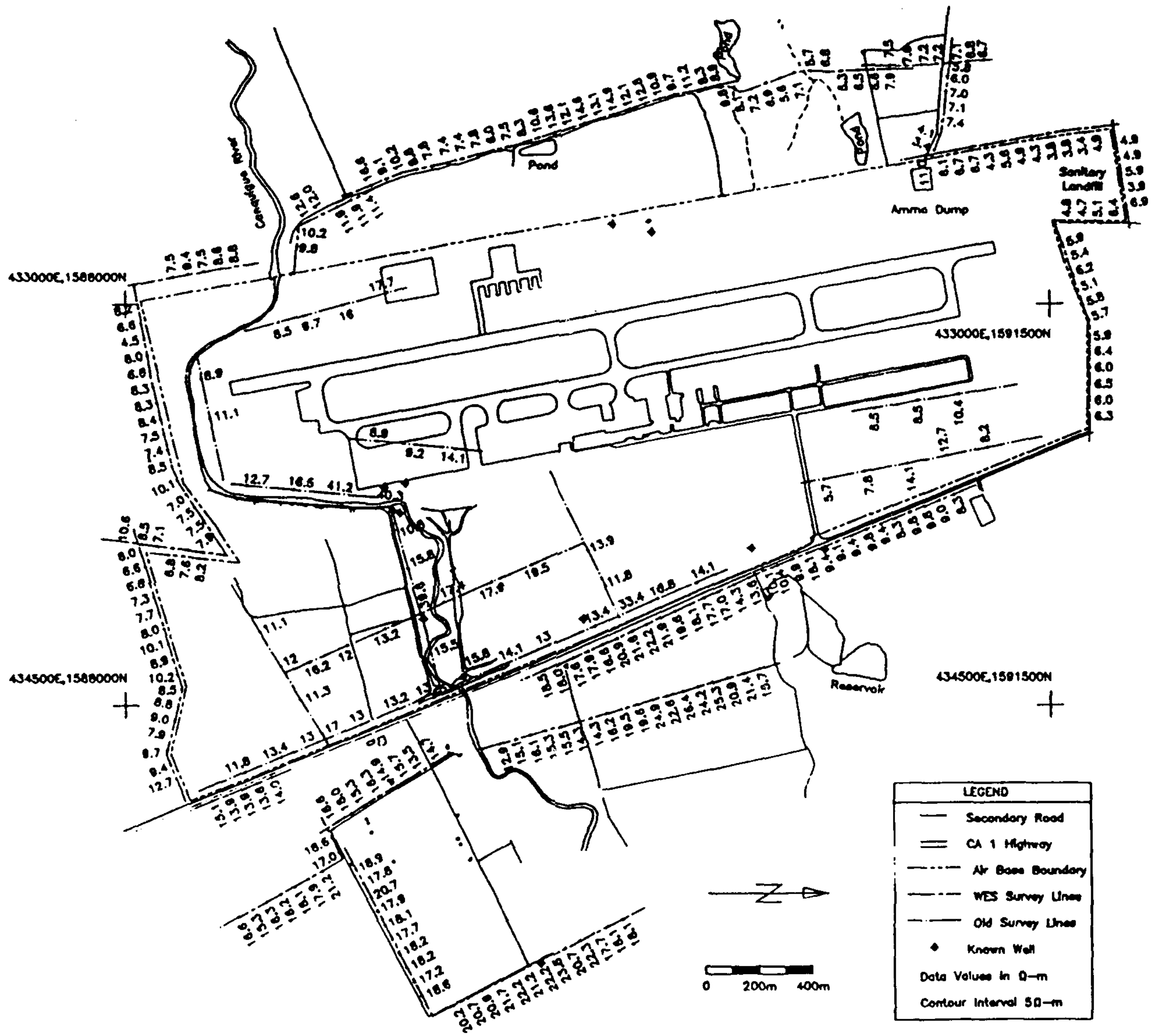


Figure 16. Compiled drawing of all 75 and 60 meter Wenner "A" spacing apparent resistivity measurements.

located by an agri-business adjacent to the Soto Cano air base. The heavy dashed lines in Figure 17 shows the interpreted locations of the buried gravel channel and the tributary aquifer. This same business controls the hydraulic up gradient portion of the only known large aquifer in the vicinity, but at the present time has not drilled into it, in spite of needing an additional 200 gpm of potable water resources. From historical performance, if the present rate of depletion is maintained, the main channel aquifer cannot provide all demands for fresh water needs during the driest portion of the year. Consequently, this water resource needs to be managed with some due prudence. The water flow from the wells tapped into this aquifer need to be metered and monitored on a regular basis, especially in the dry season. Additional wells instrumented with piezometers and located within the gravel channel at systematic intervals would provide much needed data to predict when the aquifer draw down will reach a critical level. This type of instrumentation may also be used to determine the sustained water withdrawal from the aquifer during various seasons of the year. Data such as this and aquifer analysis can be used to institute conservation measures before a critical water depletion occurs.

28. The Padre Miguel Group is the dominant geological material around the Soto Cano air base and it has not proven to be a good aquifer in the immediate region. From 250 to at least 840 feet in the subsurface it has demonstrated to have low fluid permeabilites and small water yields (less than 20 gpm). Deeper drilling into the Valle de Angles Group, which is believed to lie unconformably below the Padre Miguel Group may prove productive. It is uncertain how much cover this deeper target has at Soto Cano air base, but estimates in the order of +1000 meters have been stated in the literature and elsewhere. One author places the estimated thickness at around 2000 meters, but this seems rather high. A deep well, drilled through the Padre Miguel Group in the search for good aquifer resources is feasible if this Group is not excessively thick. The thickness of the Padre Miguel Group could be determined with seismic refraction techniques. It is recommended that this type of geophysical investigation be undertaken before drilling a deep water well.

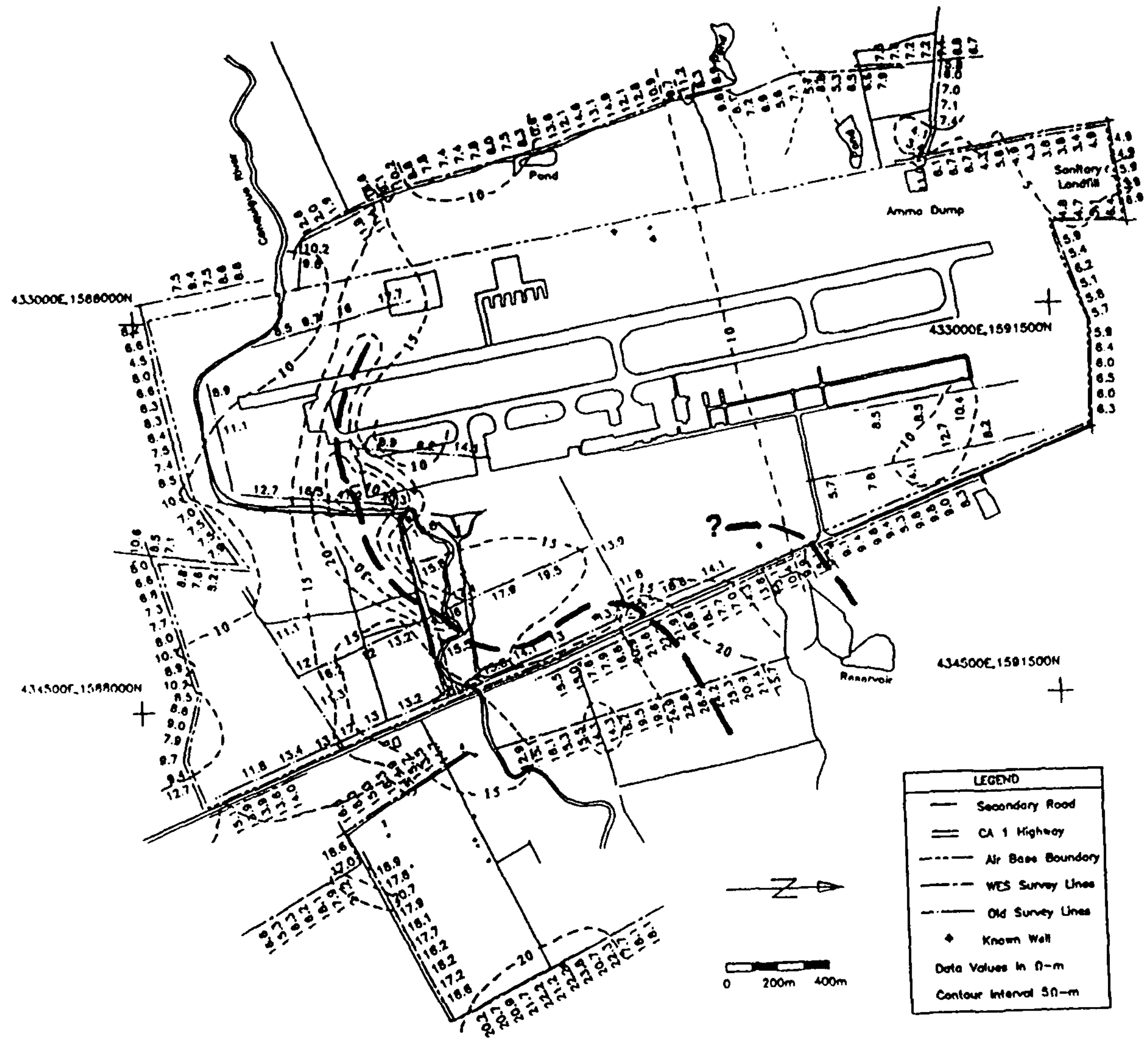


Figure 17. Contoured apparent resistivity values showing center line of buried gravel channels (heavy dark dashed line).

PART IV: TACAN WATER WELL SITES

29. A remote site called TACAN, located approximately 8 kilometers east of La Paz, was examined for the suitability for a water well, Figure 18. Currently potable water is being hauled to this facility from Soto Cano air base which is approximately a 2 to 3 hour one - way haul by truck. This location is situated on a mountain top at about 2,200 meters in elevation on a thick 600 meter sequence of the Padre Miguel Group. Generally, such geography and geology do not favor well sites. Several sites located off the mountain summit area were selected which may have a reasonable water yield. These places are not at locations currently leased for the TACAN site, and it would not be advisable to attempt to drill a water well near the very top of the mountain.

30. The three potential well sites are indicated on Figure 19 as sites A, B, and C. The sites are at elevations of 1740, 1820, and 2020 meters respectively. The elevation of TACAN is at 2120 meters. These potential well sites were selected in the most favorable local geologic conditions, yet be close enough to current roads and utilities so as not to generate a large construction expense. Several springs were investigated. Two springs near site C are reported to trickle year round and provide the water source for Hacienda Los Reyes. A spring approximately 50 meters north west of site B is also reported to have an annual flow. No spring was reported at site A, but at this low elevation no problem should be present in establishing a reasonable well. All of these wells are located in a geologic shear zone(s) which should increase the permeability of the aquifer. Each site represents the most favorable location for that elevation, however a greater elevation represents a greater risk that the well will be a seasonal well with low or no flow present in the dry season.

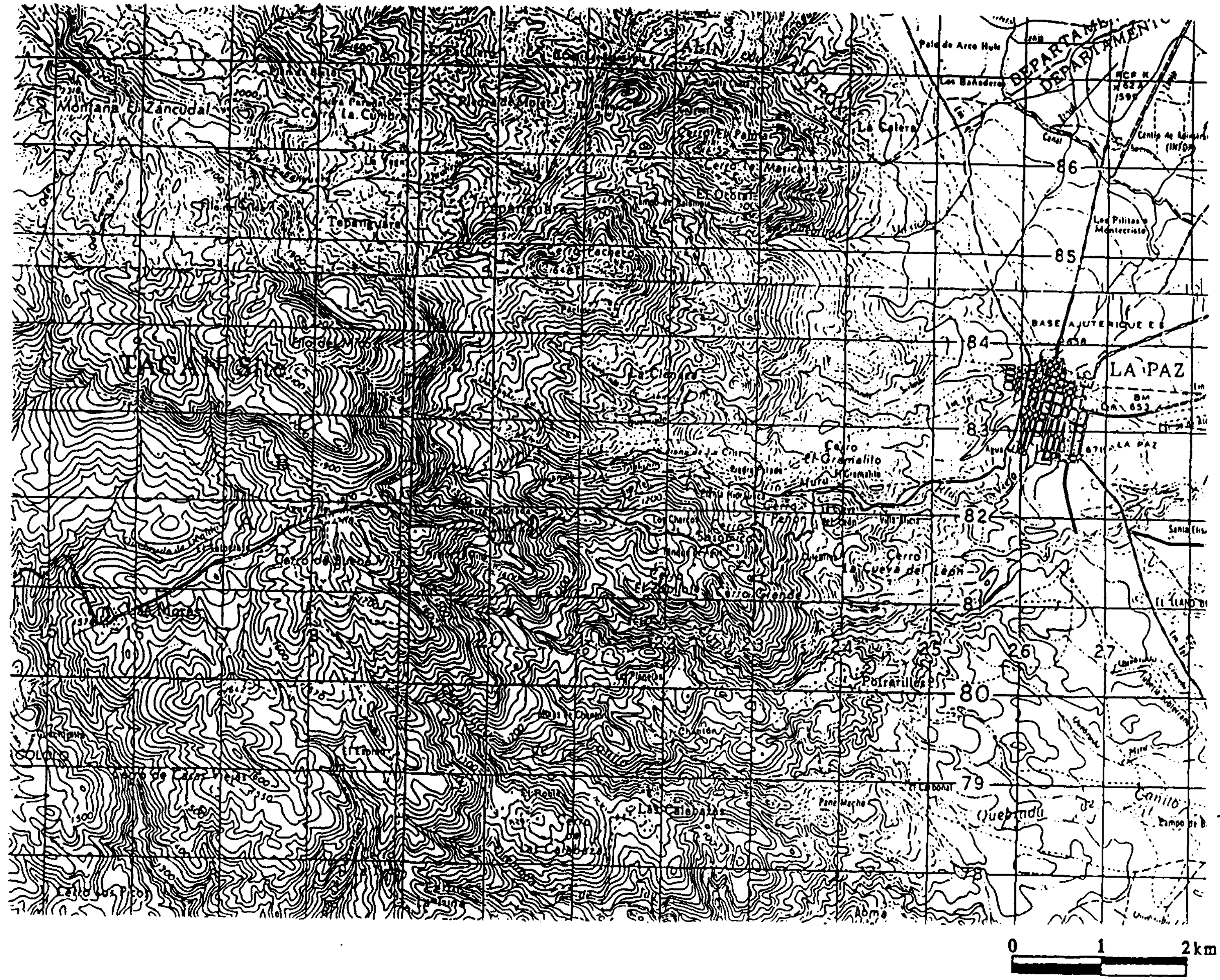


Figure 18. Topographic map showing the general location of the TACAN site.

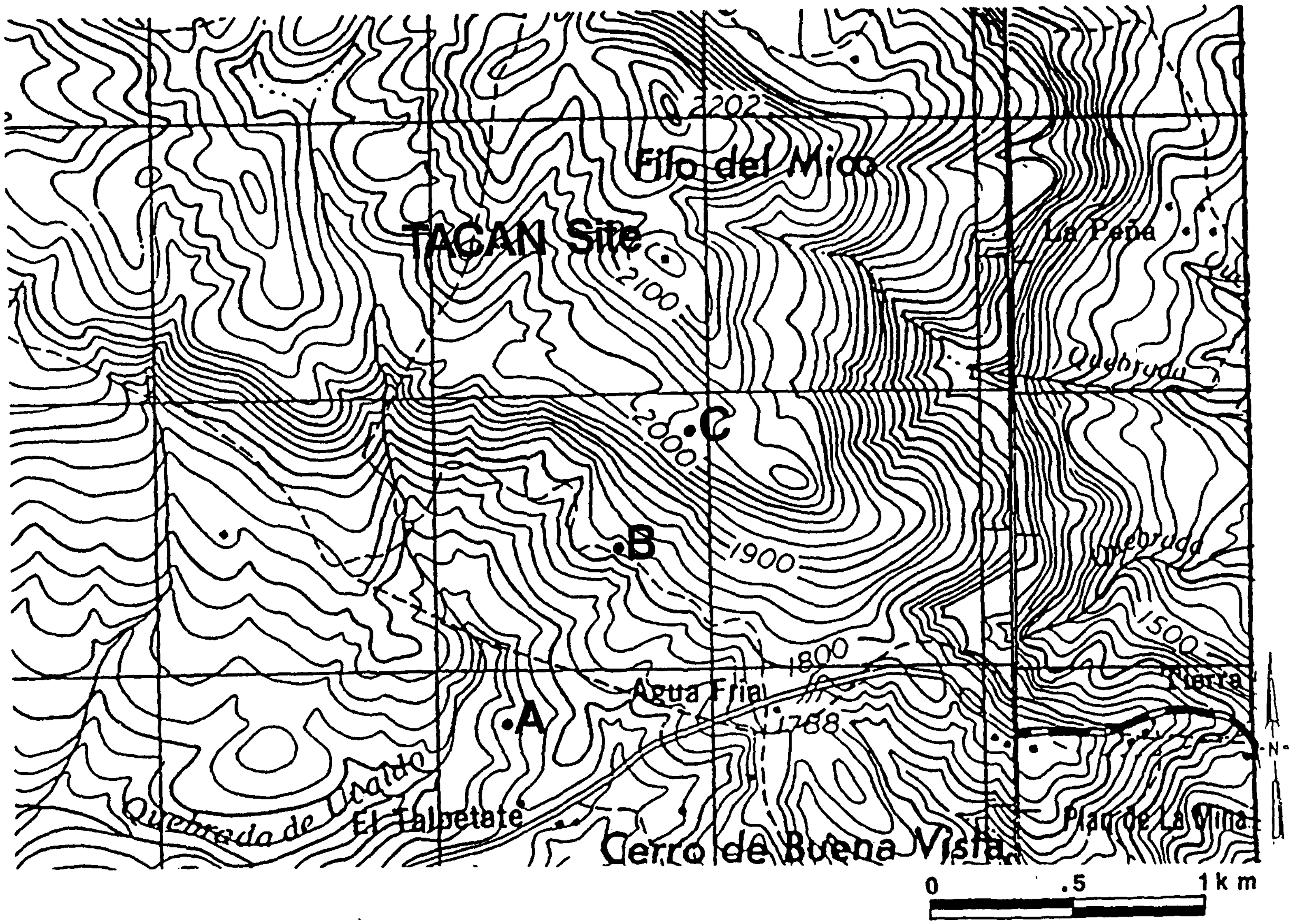


Figure 19. Potential water well sites A, B, and C near the TACAN site.

PART V: SUMMARY AND CONCLUSIONS

31. The main potable water aquifer which extends under the Soto Cano air base, Honduras cannot provide all the fresh water demands for the air base and commercial activities in the area during the driest portion of the year. A well opposite the main gate of the air base may intersect a tributary of the main aquifer under the installation. Withdrawal from this well has decreased yields from the air base wells in the gravel channel aquifer. This aquifer extends east of the air base and the hydraulic up gradient portion lies beneath property which is being commercially developed by a company in need of additional potable water resources. If wells are developed in this aquifer on the adjacent property, a substantial decrease in the large yielding water wells on the air base may occur.

32. Additional water resources may potentially be located from several sources.

a. The smaller tributary channel aquifer under the air base may be developed for water supply. This narrow aquifer extends from the main gate area and intersects the main channel aquifer somewhere near well No. 5. An additional resistivity investigation could define the exact location of this smaller aquifer under the air base.

b. Additional near surface aquifers may be found close to the river-valley throat or where the Rio Canquigue enters the Comayagua valley. An additional resistivity investigation could locate these potential aquifers.

c. A deep water well, in excess of 1000 meters, could be drilled through the Padre Miguel volcanic group into the underlying formations. It is recommended that a seismic refraction investigation be conducted to determine if this approach is feasible.

d. A potential well location has been found south and east of the air base. A well drilled in the determined location should produce water yields in the neighborhood of 20 to 60 gpm. Approximately 1400 meters of pipeline will be necessary to connect this well site to the existing air base water collection system.

33. The existing aquifer needs to be monitored and managed in a more extensive manner. Weekly well withdrawals should be metered and charted. Additional monitoring wells should be drilled and multiple piezometers

installed so that the aquifer draw down in the dry season may be carefully regulated.

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APPENDIX A: DATA FROM RESISTIVITY PROFILES

PROFILING DATA

Line 1

distance (m)	ρ_a (Ω-m)
0	5.8
60	6.0
120	7.0
180	7.1
240	7.4
300	4.1
360	3.4

Line 2

distance (m)	ρ_a (Ω-m)
0	11.0
60	6.1
120	6.7
180	6.7
240	4.3
300	5.6
360	4.9
420	4.3
480	3.8
540	3.8
600	3.4
660	4.9

Line 3

distance (m)	ρ_a (Ω-m)
0	4.9
60	4.9
120	5.9
180	3.9
240	6.9

Line 4

distance (m)	ρ_a (Ω-m)
0	6.4
60	5.1
120	4.7
180	4.8

Line 5

distance (m)	ρ_a (Ω-m)
0	5.9
60	5.4
120	6.2
180	5.1
240	5.8
300	5.7
360	5.9
420	6.4
480	6.0
540	6.5
600	6.0
660	6.3

Line 6

distance (m)	ρ_a (Ω-m)
0	8.8
60	8.6
120	7.5
180	9.4
240	7.5

Line 7

distance (m)	ρ_a (Ω-m)
0	8.2
60	6.6
120	4.5
180	8.0
240	6.6
300	8.3
360	8.3
420	8.4
480	7.5
540	7.4
600	8.5
660	10.1
720	7.0
780	7.5
840	7.5
900	7.9

PROFILING DATA

Line 8

distance (m)	ρ_a (Ω-m)
0	8.2
60	7.6
120	6.8
180	7.1
240	8.5
300	10.6

Line 9

distance (m)	ρ_a (Ω-m)
0	8.0
60	6.6
120	6.8
180	7.3
240	7.7
300	8.0
360	10.1
420	8.9
480	10.2
540	8.5
600	8.8
660	9.0
720	7.9
780	9.7
840	9.4
900	12.7

Line 10

distance (m)	ρ_a (Ω-m)
0	15.1
60	13.9
120	13.9
180	13.6
240	14.0

Line 11

distance (m)	ρ_a (Ω-m)
0	15.7
60	21.4
120	20.9
180	25.3
240	24.2
300	26.4
360	22.6
420	24.9
480	19.6
540	19.5
600	16.2
660	14.3
720	14.3
780	15.5
840	15.3
900	16.1
960	15.1
1020	12.9

Line 12

distance (m)	ρ_a (Ω-m)
0	14.7
60	13.5
120	15.7
180	14.9
240	16.3
300	15.3
360	18.0
420	16.6
480	18.6
540	17.0
600	21.2
660	17.9
720	18.1
780	16.2
840	16.3
900	15.3
960	16.6

PROFILING DATA

Line 13

distance (m)	ρ_a (Ω-m)
0	18.9
60	17.8
120	20.7
180	17.9
240	18.1
300	17.7
360	18.2
420	18.2
480	17.2
540	18.6

Line 14

distance (m)	ρ_a (Ω-m)
0	20.2
60	20.7
120	20.9
180	21.7
240	22.2
300	21.2
360	22.2
420	23.8
480	20.7
540	22.3
600	17.7
660	18.1
720	18.1

Line 15

distance (m)	ρ_a (Ω-m)
0	8.3
60	9.0
120	9.8
180	9.8
240	8.3
300	9.4
360	9.8
420	9.4
480	9.1
540	9.4
600	18.1
660	9.9
720	10.4
780	10.1
840	13.6
900	14.3
960	17.0
1020	17.7
1080	18.1
1140	19.6
1200	21.9
1260	22.2
1320	21.6
1380	20.9
1440	16.6
1500	17.9
1560	17.6
1620	18.0
1680	18.5

Line A

distance (m)	ρ_a (Ω-m)
0	9.8
60	10.2
120	12.6
180	12.0
240	11.9
300	11.9
360	11.4

PROFILING DATA

Line B

distance (m)	ρ_a (Ω-m)
0	16.6
60	9.1
120	10.2
180	8.8
240	7.8
300	7.4
360	7.4
420	7.8
480	6.0
540	7.5
600	8.3
660	10.6
720	13.6
780	12.1
840	14.6
900	13.1
960	14.9
1020	12.1
1080	12.8
1140	10.9
1[illegible]00	9.7
1260	11.2
1320	8.3
1380	8.9

Line C

distance (m)	ρ_a (Ω-m)
0	9.8
60	8.1
120	7.2
180	6.9
240	5.6
300	7.1
360	5.7
420	6.8
480	5.3
540	6.5
600	6.6
660	7.9
720	7.5
780	7.6
840	7.2
900	7.2
960	7.1
1020	6.8
1080	6.7

SOUNDING DATA

Well #5

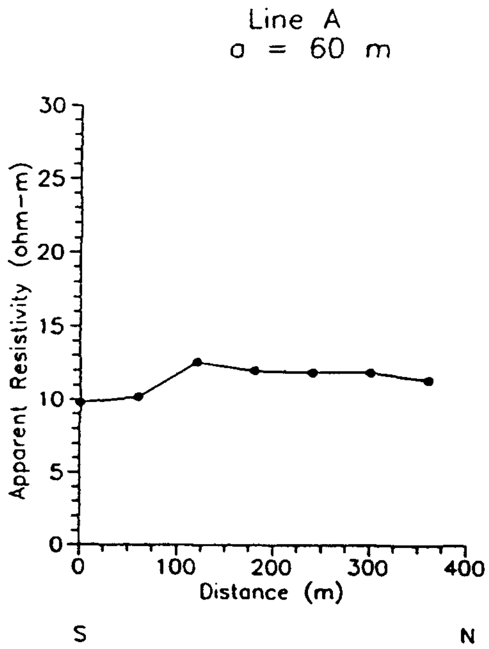
electrode spacing (m)	ρ_a (Ω-m)
2	94.8
3	94.7
4	106.2
5	113.9
5	106.8
8	112.6
10	110.5
13	86.6
17	63.4
20	49.6
25	38.9
25	36.8
30	32.4
30	32.7
40	31.1
50	28.5
60	25.7
80	20.7
100	3.7
100	17.0
130	14.2
170	10.9
200	12.5
200	11.6

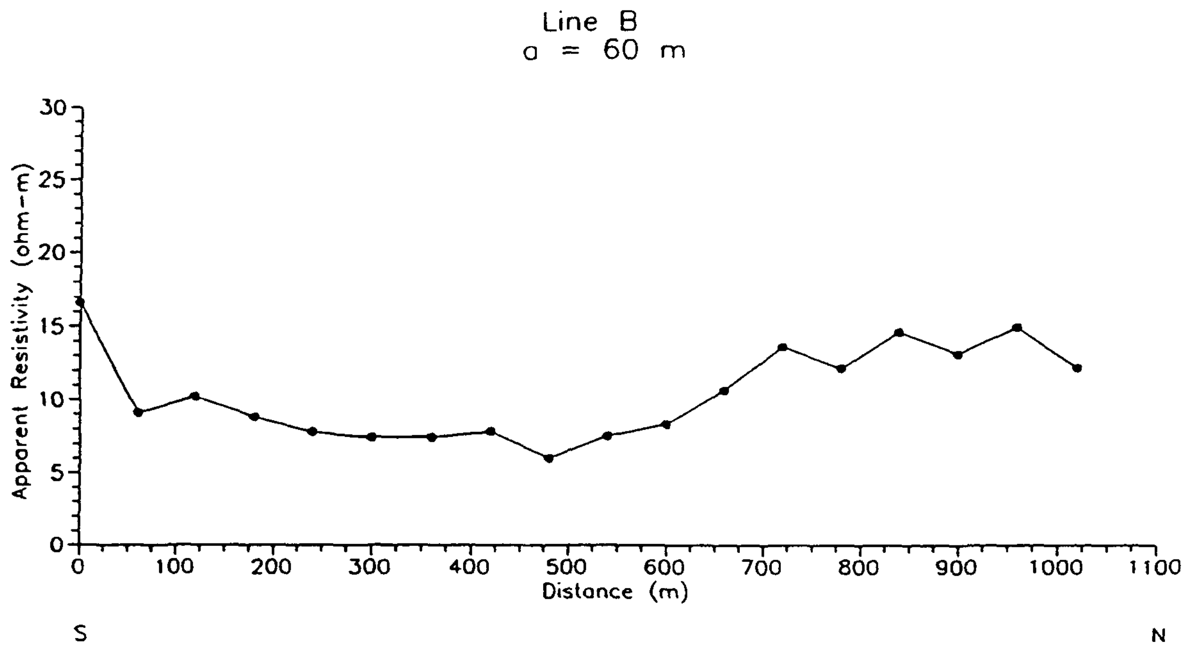
South

electrode spacing (m)	ρ_a (Ω-m)
2	15.5
3	16.9
4	17.4
5	18.3
5	17.6
8	19.4
8	19.0
10	19.5
13	18.5
27	16.7
20	14.7
25	12.3
25	12.8
30	11.1
30	11.3
40	9.8
50	9.0
60	8.9
60	9.1
80	8.3
80	8.1
100	7.7

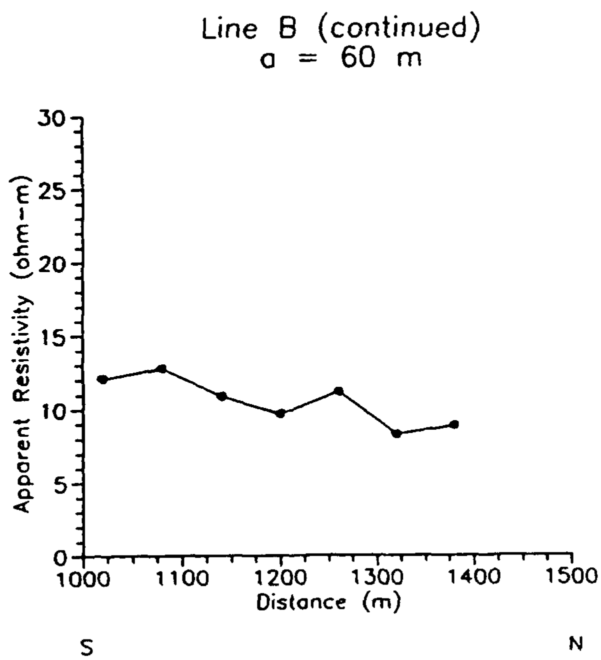
SOUNDING DATA

Line 13 electrode spacing (m)	ρ_a (Ω-m)
2	33.7
3	37.8
4	39.4
5	38.9
5	34.3
8	39.4
8	35.5
10	36.7
13	34.6
17	31.8
20	29.9
25	27.8
25	27.9
30	29.6
30	25.9
40	22.3
50	20.3
60	19.3
80	16.6
80	17.6
100	18.0
100	17.0
130	15.8
170	14.8
200	12.4


Line A
a = 60 m
Apparent Resistivity (ohm-m)
30
25
20
15
10
5
0
0
100
200
300
400
Distance (m)
S
N

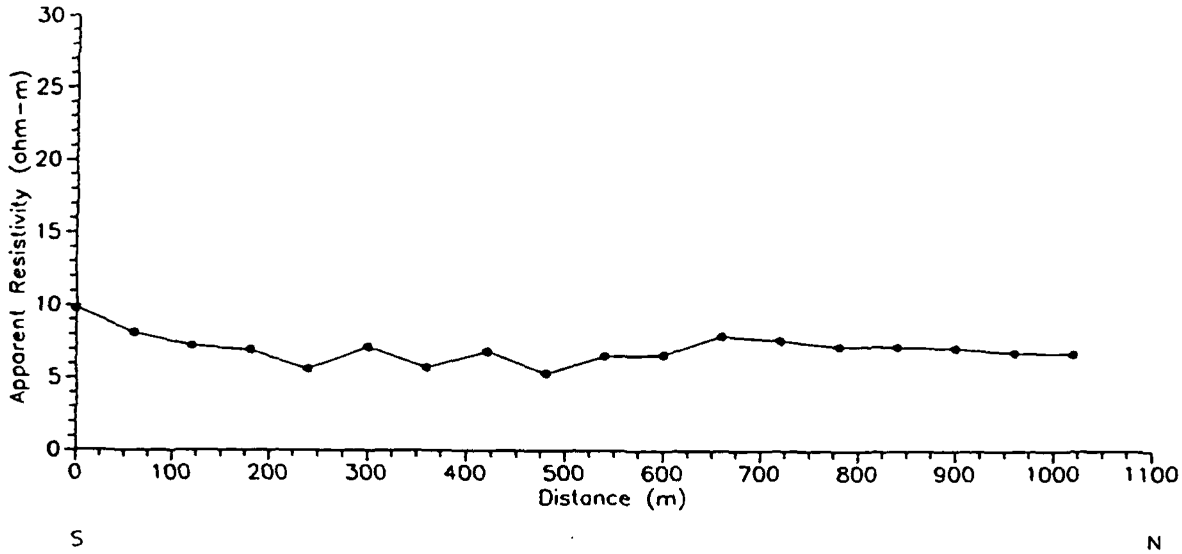


Line B
a = 60 m
Apparent Resistivity (ohm-m)
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
1100
Distance (m)
S
N

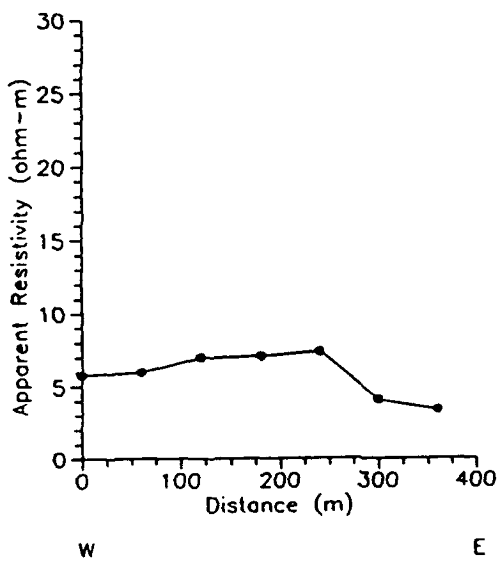


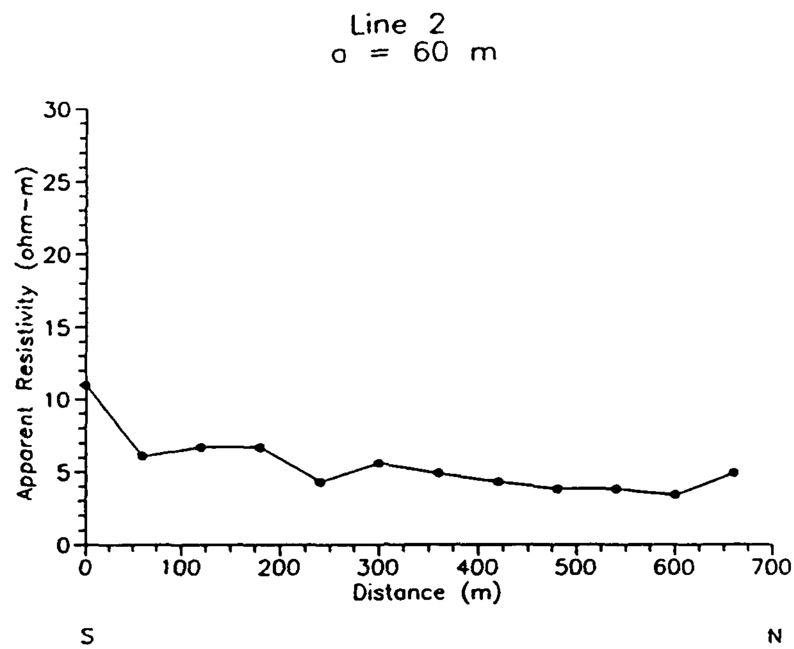
Line B (continued)
a = 60 m
Apparent Resistivity (ohm-m)
30
25
20
15
10
5
0
1000
1100
1200
1300
1400
1500
Distance (m)
S
N

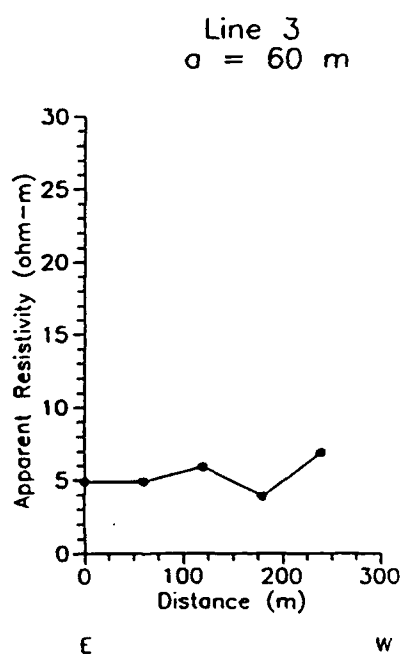
Line C
a = 60 m

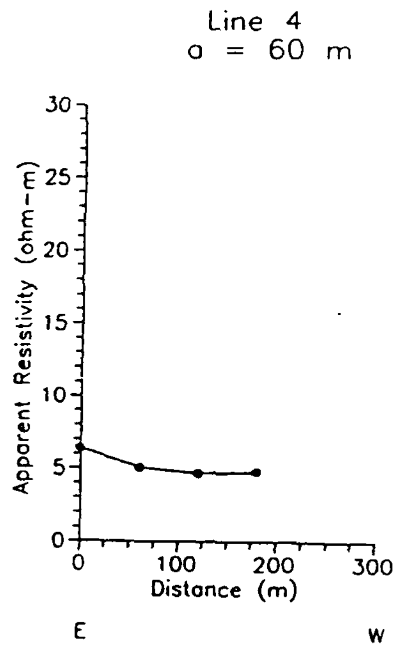


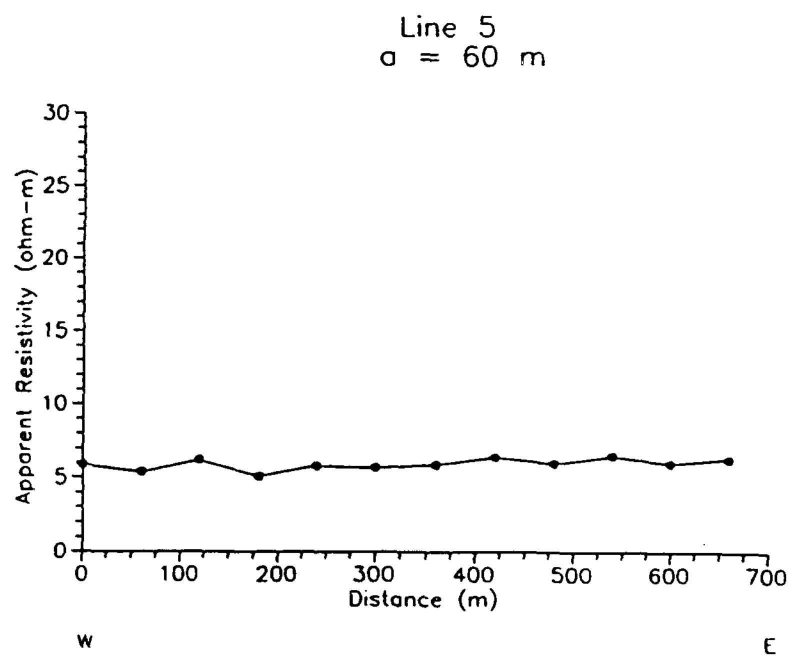
Line 1
a = 60 m

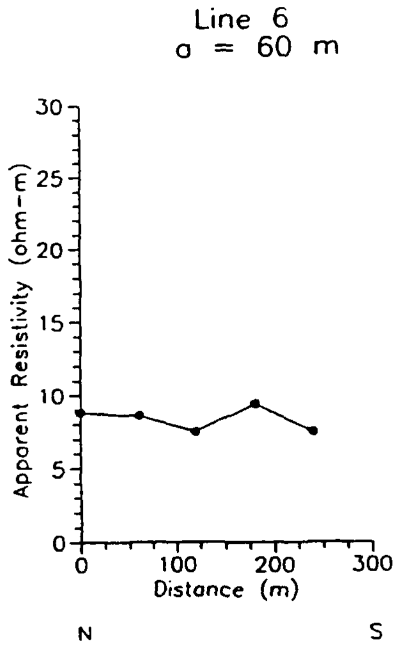



Line 2
a = 60 m
Apparent Resistivity (ohm-m)
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
Distance (m)
S
N

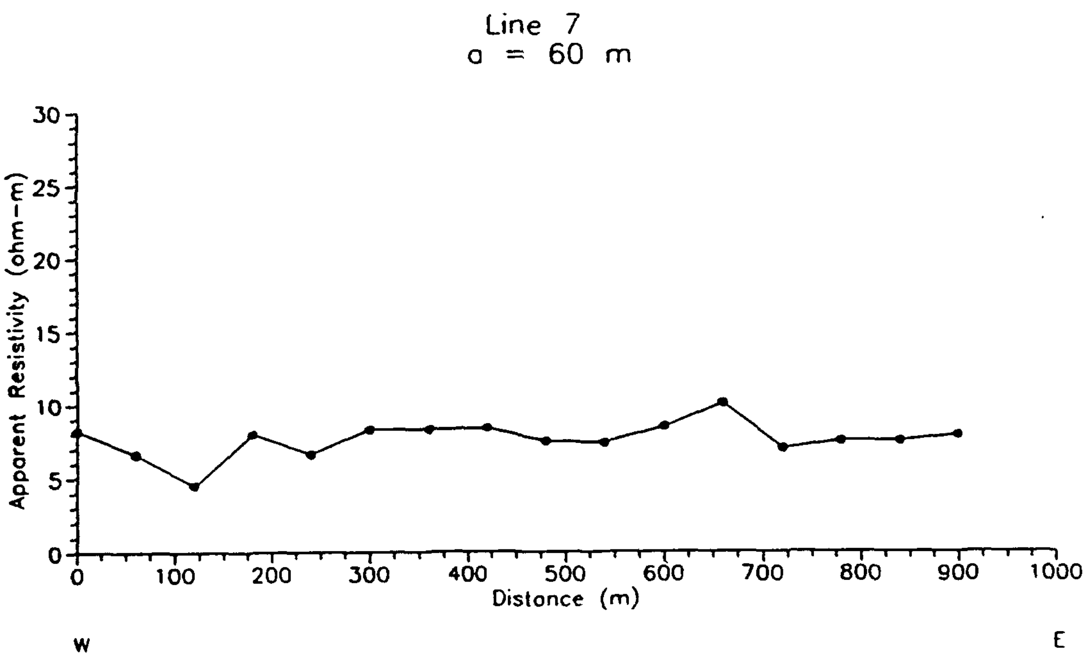

Line 3
a = 60 m
Apparent Resistivity (ohm-m)
0
5
10
15
20
25
30
0
100
200
300
Distance (m)
E
W


Line 4
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
0
5
10
15
20
25
30
100
200
300
E
W


Line 5
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
0
5
10
15
20
25
30
100
200
300
400
500
600
700
W
E

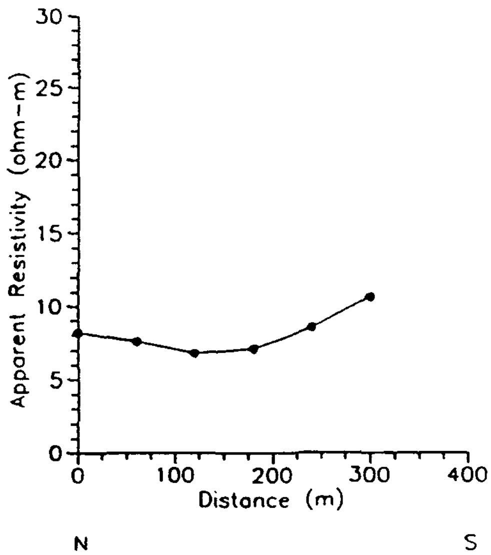


Line 6
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
N
S

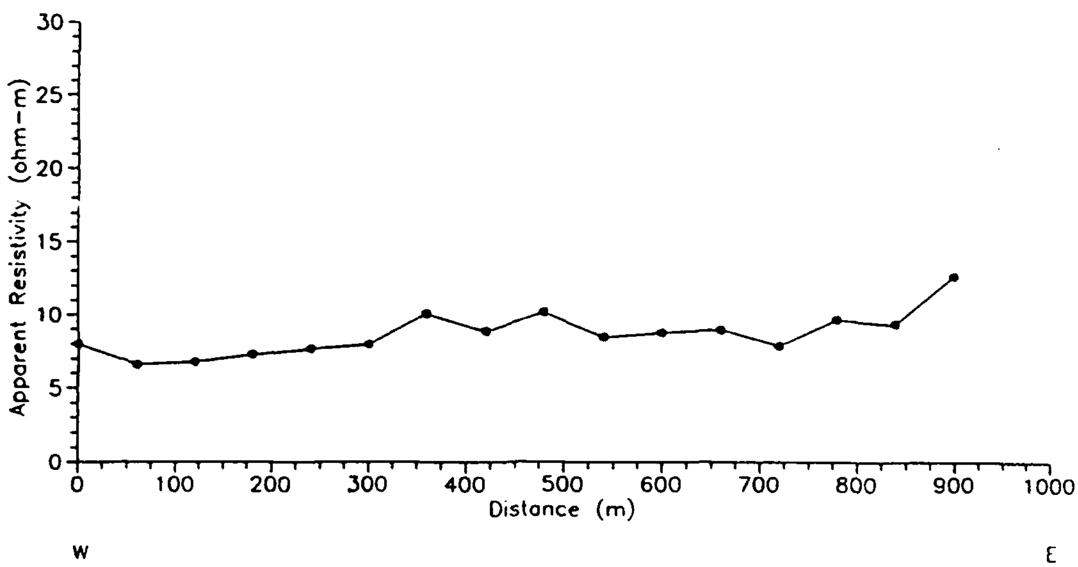


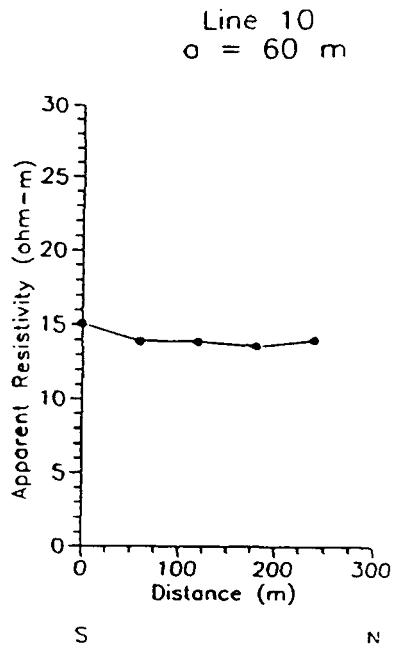
Line 7
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
W
E

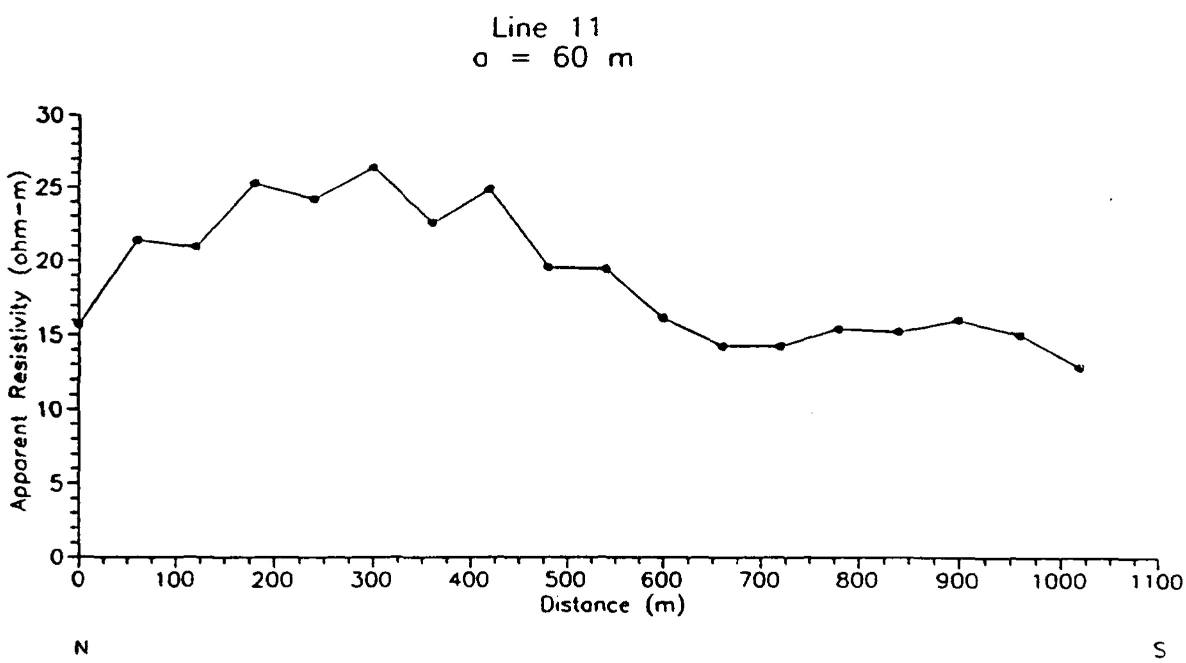
Line 8
a = 60 m



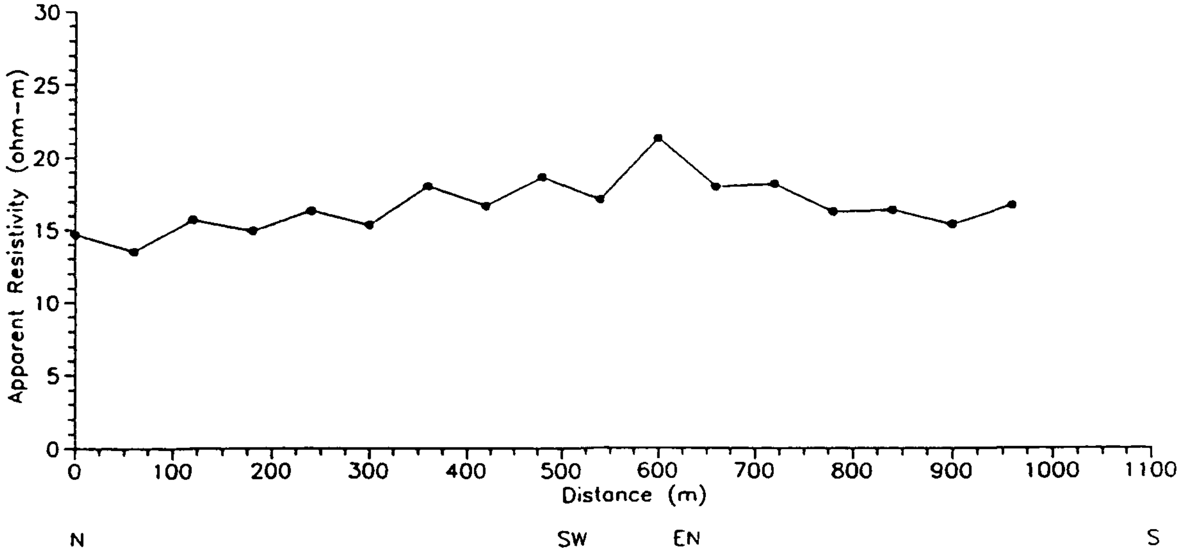
Line 9
a = 60 m



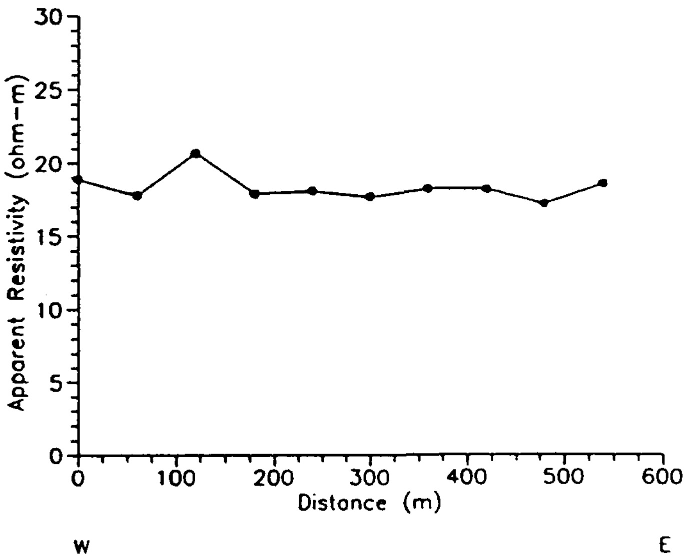

Line 10
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
S
N

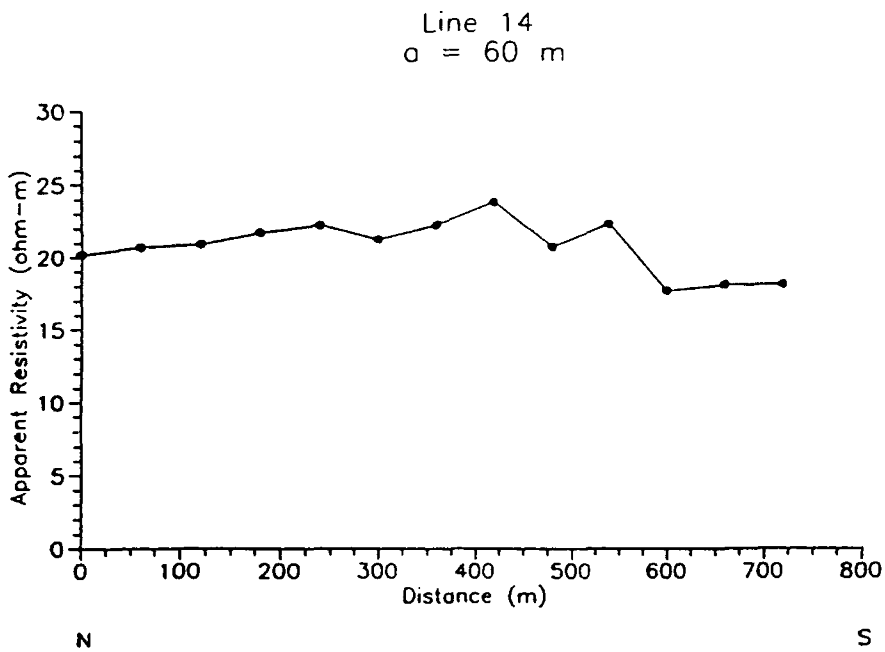

Line 11
a = 60 m
Apparent Resistivity (ohm-m)
Distance (m)
N
S

Line 12
a = 60 m

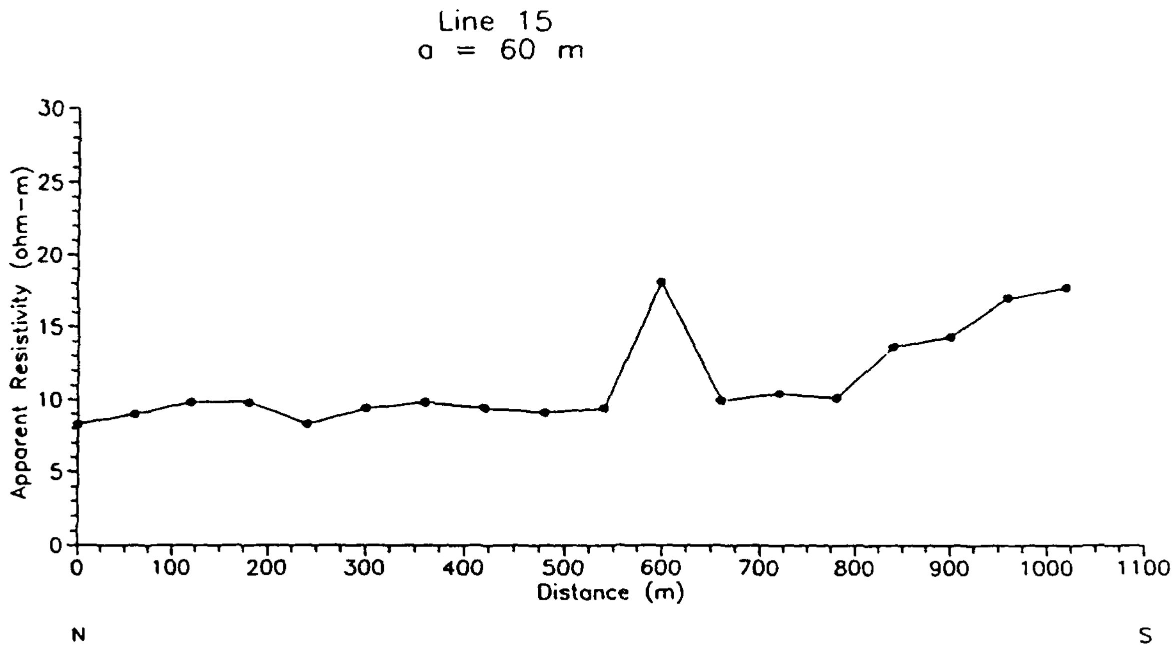


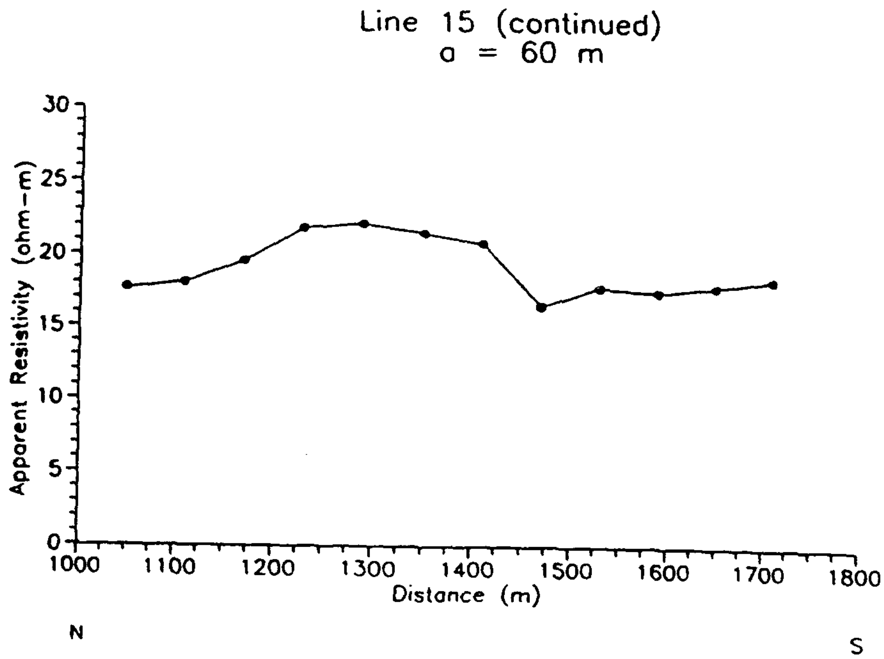
Line 13
a = 60 m





Line 14
a = 60 m
Apparent Resistivity (ohm-m)
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Distance (m)
N
S


Line 15
a = 60 m
Apparent Resistivity (ohm-m)
0
5
10
15
20
25
30
0
100
200
300
400
500
600
700
800
900
1000
1100
Distance (m)
N
S


Line 15 (continued)
a = 60 m
Apparent Resistivity (ohm-m)
0
5
10
15
20
25
30
1000
1100
1200
1300
1400
1500
1600
1700
1800
Distance (m)
N
S

Waterways Experiment Station Cataloging-in-Publication Data

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