Pre-feasibility Geophysical Investigations

Garowe Town Water Supply
Puntland State, Somalia

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ADRA - Somalia

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November 1998

SUMMARY

This report describes the results of pre-feasibility geophysical investigations for the Garowe Town Water Supply, Nugal Region of the Puntland State, North East Somalia.

Garowe town is located on the southern bank of togga Garowe which has a permanent sub-surface base flow of water provided by a shallow perched aquifer. This aquifer is exploited by numerous shallow wells in the Garowe town area.

Physiography and geology
Garowe town lies within the Nugal valley. The togga Nugal basin covers an area of about 70,000 km^2 and is fed by numerous small toggas (rivers) which run from the Sool Plateau on the north, a semi-arid plain covered by limestone and worl, and from the Sool Haud Plateau similar to the Sool plateau to the south. These plateaux are characterized by a thick Karkar formation over the Taleex Formation and are superficially covered by more recent sedimentary deposits comprising sand dunes, detrital sands and limestone and marl deposits. Underlying the Taleex formation is the Auradu limestones.

The Perched Aquifer
This perched aquifer occurs as pockets embedded in the alluvial sedimentary deposits particularly in the area within the vicinity of togga Garowe and in the upper parts of sequences of Taleex formations exposed along the togga Garowe. The analysis of the water levels of wells penetrating the shallow aquifer indicate that the underground water flows towards the togga Garowe. In the shallow aquifer the water level vary between 6 to 12 meters below the surface. This aquifer lies on clay confining layer 12 to 16 m deep. This aquifer is recharged seasonally by the flow of the togga during the wet periods. Numerous hand dug wells tap this shallow aquifer with well depths varying between 5 and 10 meters and the water level about 5 to 6 meters. The storage in the perched aquifer has been estimated to be in the order of $2.5x10^6$ m^3.

The Deep Semi-confined Aquifer
From available borehole geological logs and the geophysical measurements carried out during this study, it is established that there exists a deep semi-confined aquifer located in limestone and anhydride of the Taleex formation. Available records of three drilled wells in the area show the existence of the two aquifers with a wide range in yields from 24 to 110 m^3/hr. This shows how variable the groundwater conditions are within this formation. It is thus concluded that the yields of boreholes in the area cannot be predicted accurately. However, it is expected that the yields will be in the order of 20 m^3/hr and may be expected within the limestone series and the Taleex formation. The higher yields are associated with the bottom semi-confined aquifers.

Groundwater Prospects
From the available data it is concluded that this area has good prospects of striking sufficient amount of water. The deeper aquifer appears to be quite extensive in the area. However, the relative productivity of specific locations will greatly depend on aquifer composition, grain size of material and aquifer matrix. Presence of gypsum and clays within the aquifer leads to poor hydraulic properties and hence low abstractable yields from the aquifer.

Overall, it can be concluded that the area is situated in a zone with a medium groundwater potential. An evaluation of the geological and hydrogeological information and the results of a geophysical field

survey indicate that the prospects for groundwater exploitation in the aquifers are good. However, further investigations are required to delineate the productive zones of the aquifer.

Water Quality
The water produced by the shallow aquifer is of poor chemical and bacteriological quality. The EC range usually from 3400 to 6000µS/cm with high sulphate, fluoride and iron contents. Water up to 5000µS/cm is used for all purposes including drinking while water of wells with higher mineralization is used only for washing. Generally the EC of water in the wells have been observed to decrease with distance from the Togga Garowe towards the catchment and fluctuates with seasons.

The EC analysis (GTZ, 1987) show that there is only a slight difference of water quality between the shallow well, GTZI and the two deep wells GTZII and WDA, which may be interpreted to imply that there is hydraulic connection between the two aquifers.

The EC of the water in the investigated area is expected to be comparable to that of the existing borehole, between 3000 and 5000 µS/cm and quality being fairly good for human consumption. Nevertheless the concentration of sulphate, iron and magnesium may be higher than the WHO limits for domestic use, as is the case observed in the wells and boreholes within the area. The pollution of the shallow aquifer by latrines have been reported to be the cause of the high salinity of the shallow wells. Recently, the Nugal Water Board has initiated sensitization of sanitation improvements, chlorination of wells and health education.

Recommendations
It is recommended that detailed geophysical investigations be carried out in the area south of Garowe town to determine in greater detail the prevailing hydrostratigraphy, aquifer extent and geometry; and to delineate the best site for the wellfield development. This should take into consideration the proximity to the town, location of other water supply facilities i.e. tanks, reticulation system etc.

Based on the geophysical investigation results, the best site for four boreholes would be in the area around Nasa Hablood and Laan Ali Firin hills within the area enclosed by VES locations VES 18, 6, 20 and 7 and 24. The proposed boreholes would have a maximum depth of about 250 m. Water struck level is expected at around 80 to 100 m but drilling should continue until sufficient yield is obtained. The chemical and bacteriological quality of the water will have to be determined.

During drilling the EC of the water should be monitored in order to identify saline water zones that may be encountered, and determine the water quality fluctuation with depth. If mud drilling is used, the EC and viscosity of the mud need to be monitored. Upon completion of the boreholes they should be developed and tested. In addition, water levels in nearby wells should be monitored during the tests.

It is recommended that the area delineated for wellfield development be restricted for human settlement, and proper sanitation practices implemented to safeguard against pollution of the aquifer.

The report recommends a detailed geophysical and hydrogeological investigation to delineate precisely, the aquifer geometry, storage, groundwater flow etc.

The report includes a VES location sketch map, data and geophysical interpretations.

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ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS: (NOTE: SI spellings used throughout).

EC	Electrical Conductivity (in micro Seimens/centimetre)
km	kilometres
m	metres
m amsl	metres above mean sea level
m bgl	metres below ground level
ppm	parts per million, equivalent to mg/l
swl	static water level (in m bgl) (the piezometric level or water table, see below)
TDS	Total Dissolved Solids (ppm)
wsl	water struck level (in m bgl)
NUWAB	Nugal Water Board

GLOSSARY OF TERMS: (> refers to another entry in this glossary)

Aquifer	A geological formation or structure which transmits water and which may supply water to wells, boreholes or springs.
Confined	Confined aquifers are those in which the piezometric level is higher (i.e., at a greater elevation relative to sea level) than the elevation at which the aquifer was encountered.
Recharge	The general term indicating the process of transport of water from surface sources (ie, from rivers or rainfall) to the groundwater.
Barkards	Concrete lined below ground surface reservoir, fed during the wet season by small catchments up slope. These have roofs of branches or thatch to limit evaporation and are comparatively efficient at retaining stored water.
Waroh	Large open dams, excavated from inside, with excavated material used to provide embankments. These are much larger than Barkads, but are unlined and not roofed.

1. INTRODUCTION

Earthwater Ltd was commissioned by by Adventist Development & Relief Agency (ADRA) Somalia to carry out pre-feasibility geophysical and hydrogeological investigations to determine the presence of an aquifer in the surroundings of Garowe town in the Nugal region of the Puntland State of North Eastern Somalia. The investigations were executed in a multi-step approach:

1) Desk study
2) Field reconnaissance study
3) Data acquisition
4) Data analysis and reporting

Garowe town is located approximately 700 km north of Mogadishu town in Somalia. It lies within the Nugal region, along the major Nugal valley on the rolling plains between Nasa Hablood and Laan Ali Firin hills to the south east and Legle and Dareyle hills to the west respectively. Togga Garowe is the most conspicuous feature near the town and it meanders along the Nugal valley.

The Client requires detailed information on the availability of groundwater resources to be used for the development of a central water supply for Garowe town. The projected water demand for domestic consumption is in the order of 800 m^3/day.

The objective of the present study is to assess the available groundwater, to recommend the best possible sites for further detailed investigations to develop a centralized wellfield for drilling of several boreholes, the required depth, expected yield and water quality.

For this purpose all the available hydrogeological information of the area has been analyzed and a geophysical survey carried out.

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2. BACKGROUND INFORMATION

The The town of Garowe is the capital of Nugal region and the newly created Puntland State of Somalia. It is situated on the banks of togga Garowe. It is located at longitude and latitude approximately 08° 23' 43" N and 48° 28' 15" E. The town is connected by a tarmacked road to Hargeysa, Galkayo and Muqdisho.

2.1 Physiography

The main physiographic feature of the Garowe region is the Nugal valley. This valley has a total length of about 600 km and is about 100 km wide at Garowe town area, narrowing progressively eastwards. The togga Nugal basin covers an area of 70,000 km^2 and is fed by numerous small toggas (rivers) which run from the Sool Plateau on the north, a semi-arid plain covered by limestone and worl, and from the Sool Haud Plateau similar to the Sool plateau to the south. These plateaux are characterized by a thick (up to 250 m) Karkar formation over the Taleex Formation and are superficially covered by more recent sedimentary deposits in the form of typical net sand dunes and alluvial deposits.

2.2 Climate

The climate of the area is the arid to semi-arid type, exhibiting a bi-modal rainfall distribution (April-May, and September-October) corresponding to 'GU', and 'DER' (or DAYR) respectively. Average annual rainfall ranges from 100 to 200 mm. The mean annual rainfall over a period of 22 years for Garowe was measured to be 110 mm. Temperatures are highest in the months of January to March. The annual average temperature is 28° C.

2.3 Water Supply and Demand

The present water supply in Garowe town comprises about 400 hand dug wells and one borehole drilled by GTZ in 1981. Water from all the shallow wells is unfit for human consumption due to high mineral content and faecal contamination. The borehole water is similarly mineralized.

Other sources of water include rain water catchments mainly barkads and warohs which greatly depend on surface water availability and rainfall intensity. This water supply last one to three months after the wet season. The dry seasons normally extend 5 to 9 months. Droughts in the area are known to occur once every 7 years in which time communities migrate to areas with perennial water supply sources or get water from truck vendors. Retail price of potable water for a single family of 8 amounts to about US$ 2.00/day.

With a population estimated at 40,000 people and assuming per capita consumption of 20 liters, the total projected daily demand for Garowe town is 800 m^3/day of water for domestic consumption. This does not include livestock requirements. It is projected that four boreholes yielding 200 m^3/day will adequately meet domestic water requirements for the town.

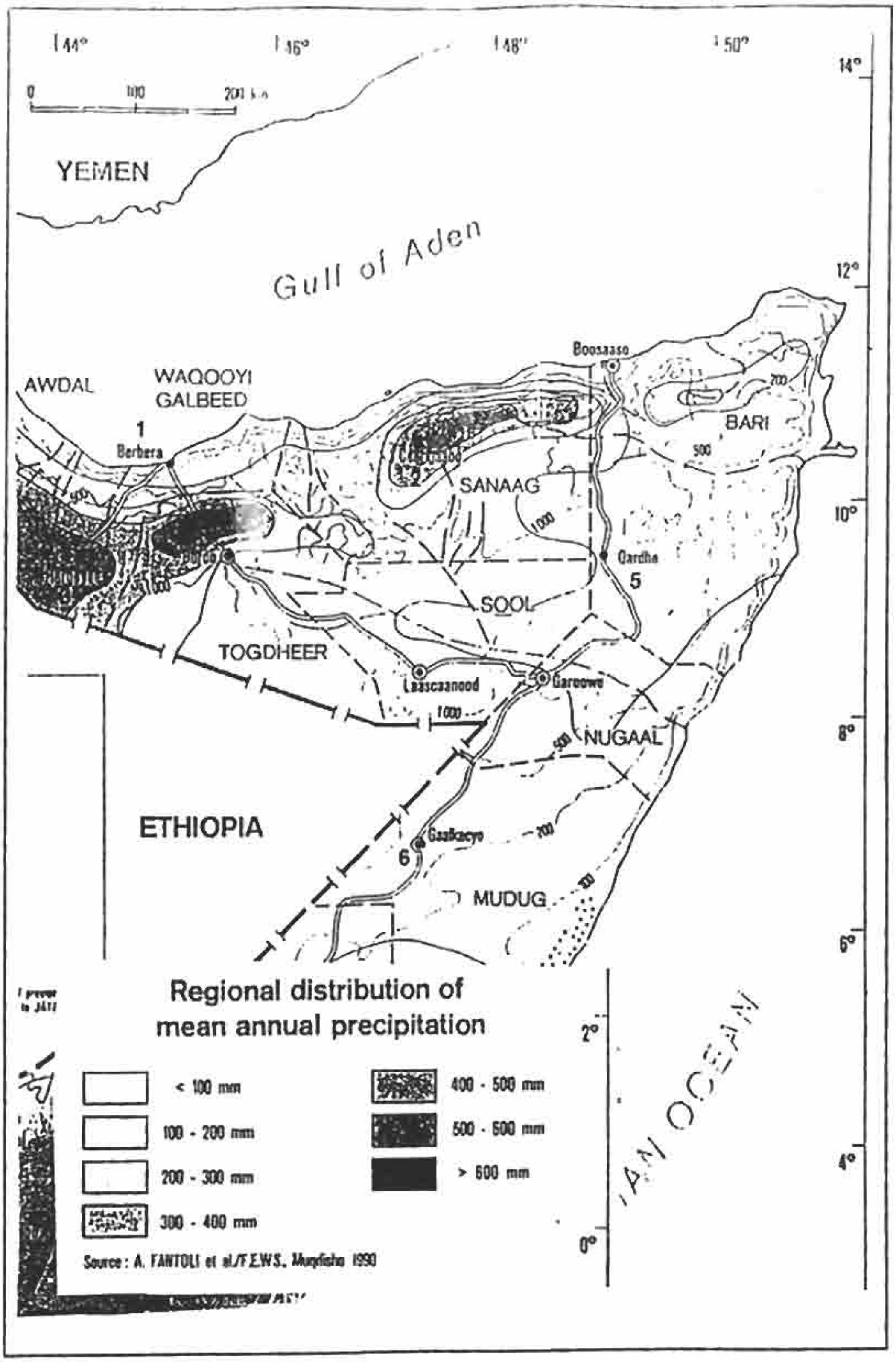


Figure 1 - Location Map of the Investigated Area.

3. GEOLOGY

3.1 Regional Geology

The investigated area falls within the Nugal valley which forms a large flat bottomed valley flanked by the Taleex, Sool Haud and Sool plateaus. The Nugal valley was formed following tectonic activities and erosion by togga Nugal and its tributaries extending for about 600 km total length. It is approximately 100 km wide at Garowe narrowing progressively in its eastern part. The togga Nugal basin covers an area of 70,000 km^2. The Nugal Region area in general is covered on the surface by a thin layer of dry brown Recent deposits comprising lateritic calcareous soils, calcareous limestone boulders, talus, alluvium and breccia. Silty clayey soils are observed on the valley bottoms. The plateaux are characterized by a thick (up to 250 m) Karkar formation over the Taleex Formation superficially covered by more recent sedimentary deposits and dune sands. The Taleex formation is covered by Auradu limestones.

The Auradu limestone is the oldest geological formation in the region. Although not outcropping in the investigated area, it is reported to outcrop further north towards the Gulf of Aden. It is overlain by the Taleex formation comprising gypsum, anhydrite, white marls, sand and gravel layers and gypsiferous limestones. The Karkar Formation comprising cherty limestone and marls, outcrops in some areas overlying the Taleex formation.

3.2 Geology of the Garowe Area

Most of the area is covered by gypsiferous and calcareous soils. These are underlain by stratified Karkar limestone formation. The Karkar formation has been deeply incised by togga Garowe. The areas covered by limestones are completely bare, with some pebble layers covering a few places. Alluvial deposits of up to 12 m cover the bottom of togga Garowe. Drainage is nearly absent in areas covered by gypsum; karstic depressions are common in these zones. Gypsiferous alluvial soil covers depressions and riparian togga belts. Outcrops of the Taleex evaporitic sequence occur further west. Limestone areas covered by red sand on the eastern part bordering the Jilab valley are dotted by giant termite mounds, carved and shaped by the wind.

These formations are underlain by the Taleex formation comprising gypsum, anhydrite, white marls, sand and gravel layers and gypsiferous limestones. The Karkar Formation comprising cherty limestone and marls, outcrops in some areas overlying the Taleex formation.

4. HYDROGEOLOGY

4.1 Regional Hydrogeology

The major drainage system in the Nugal Region is the Togga Nugal which flows during both wet seasons. A large number of smaller toggas drain across the region in the Sool and Sool-Haud Plateaus forming wide drainage valleys, in most cases tributaries of Togga Nagal. The area generally slopes towards the Indian Ocean. Drainage is generally poorly defined and an internal drainage in a closed basin is envisaged.

From information gathered from previous drilling for water supplies, aquifers in the general area occur at depths ranging between 100 m to over 200 m below ground level. The aquifers are encountered in the lower sections of the Karkar formations which are typified by marls and shales with intercalations of water bearing limestones, chert, marls and siltstones to depths of approximately 300 meters below ground level. Borehole yields are known to be very low despite the considerable drilled depths. Nevertheless, in the general area, yields of upto 30 m^3/hour have been reported in boreholes penetrating aquifers in these Karkar formations.

The Taleex formation outcrops typically below the water bearing zones. It is basically very poor in groundwater potential as reported from previous drilling. However, limestone beds intercalated within this formation are prospective for groundwater exploitation. It is concluded that the deep aquifer has a wide catchment.

Both the Karkar and Taleex formation aquifer zones are semi-confined to confined by the low yielding anhydride marly beds. Recharge is mainly through direct percolation from alluvium deposits along beds of the Toggas and shallow valleys. This can be further enhanced through structural discontinuities, fractures, and faults especially for the deep semi-confined aquifer.

The marly nature of the Karkar formations generally limits the rate of downward movement of water. Locally, most of the infiltrating water will be retained in the upper few meters and will be transpired by vegetation. Groundwater gradients in the deep aquifer is generally low in view of the poor rates of recharge.

4.2 Hydrogeology of the Study Area

There are two aquifers in Garowe: a shallow perched aquifer and a deep confined aquifer.

The Perched Aquifer

This perched aquifer is located in the alluvial deposits of togga Garowe and in the upper parts of sequences of the Taleex formations exposed along togga Garowe. From a qualitative analysis of the water tables of the shallow aquifer, it can be deduced that the underground water flows towards togga Garowe. During high flows in the river, the direction of flow is expected to reverse. The total storage in the perched aquifer in the area where hand dug wells are located, was estimated to be 28,000 m^3 by the former Water Development Agency of Nugal. But from the current study, the storage can be calculated as follows:

Assuming a conservative effective aquifer areal extent of about 5 km^2, a 5 m aquifer thickness and a 10% storage coefficient, the total storage of the shallow aquifer can be estimated as follows:

Storage = $5*10^6*5*0.1 = 2.5*10^6$ m^3 of water.

This groundwater storage constitute the major source of water at Garowe. However not all this water can be abstracted due to inhomogeneity of the aquifer, its geometry and presence of clayey and silty layers. The storage reduce significantly during dry seasons.

In this shallow aquifer the water level vary between 6 to 12 meters below the ground surface. This aquifer is confined by an impermeable clay layer 12 to 26 m deep. The aquifer is recharged periodically by the flow of the togga. Over 400 hand dug wells tap this shallow aquifer. The well depth usually vary between 5 and 10 meters and the water level is usually found at about 5 to 6 meters.

The Deep Semi-confined Aquifer

Below the shallow aquifer is a deeper semi-confined aquifer located in karstic limestone and anhydrite of the Taleex formation. Available records of three drilled wells by WDA and GTZ confirm the presence of this deeper aquifer underlying the perched shallow aquifer.

The yield of GTZII is much higher than for GTZI because it penetrates both aquifers.

TABLE I - Listing of Boreholes in the Vicinity of the Area

Borehole	Depth (m)	W.S.L (m)	W.R.L (m)	Yield (m^3/h)	Drawdown (m)	Spec. Cap. ($m^3/h/m$)	EC (uS/cm)
WDA(1976)	160		40	-			2900-3900
GTZI(1983)	36	12	9.04	24	20.5	1.17	2900-3900
GTZII(1984)	145	12,71	9.7	110	22.4	4.93	3200-4200

W.S.L Water struck level
W.R.L Water rest level

A summary of the lithologic log penetrated during drilling of GTZII is as follows:

0-12m alluvial deposits
12-66m clay and limestone layers
66-145m anhydrite interbedded with marls, clay, and limestone layers

The deeper aquifer was penetrated at 71 m bgl in limestone and anhydrite of the Taleex formation. This aquifer is under semi-confined conditions, where water rose from 71 to 26 m bgl. A heavy loss of mud circulation was encountered at 71 m bgl, depicting karstified limestone conditions with large cavities caused by dissolution of the limestones. It is these cavitied limestones that offer suitable aquifer properties including storage, hydraulic conductivity and transmissivity.

4.3 Groundwater Flow

The general groundwater flow is northwards towards togga Garowe. From water level data for the existing shallow wells and boreholes in the area, it is inferred that groundwater flows from the catchment towards the togga Garowe. This is probably one of the reason why boreholes drilled near the togga are high yielding as a result of groundwater flow towards the aquifer reinforced by the sub-surface base flow along the alluvial sediments on the togga.

4.4 Recharge

The mechanism of recharge (and the rate of replenishment) of the confined aquifers which underlie the Nugal area has not been studied in detail. However a broad pattern of recharge can be described. The two possible recharge mechanisms are direct recharge at the surface and indirect recharge via faults and/or other aquifers.

There are favourable conditions for direct recharge from rainfall through infiltration of precipitation into the ground through weathered and fault/fractured zones and cavitied limestone zones in the area. However, the aquifers are most likely to be recharged indirectly through lateral groundwater flow. The movement of water within the aquifers follows gravity, so water travels from the north and west and percolates through successive formations to south and east. Some of the rainwater is also conducted underground by local faults though, in the study area, no faults have been mapped on the surface. This mechanism is particularly important for recharge to the deep aquifers which provide more stable groundwater supplies.
Groundwater recharge by direct infiltration occurs mainly in the uppermost parts of togga Nugal catchment. Water infiltrates very rapidly in fractures, fissures, sinkholes, and karstic depressions in both the Auradu limestone, which constitutes the edge of the escarpment, and in the overlying Taleex formation. The amount of run-off increases with the increasing thickness of the soil cover towards the edge of the Nugal valley. Deposition of fine to medium sediments occurs in large flat areas where flood water spreads out and gets lost by infiltration and evaporation.

4.5 Discharge

Discharge occurs from springs, evaporation from the shallow aquifer, groundwater flow, evapotranspiration, abstraction from shallow wells and boreholes. Discharge from aquifers is either through natural processes as baseflow to streams and springs or artificial discharge through the human activities. A number of boreholes have been drilled in the study area which contribute to the discharge process. The total effective discharge from the Garowe aquifers via either of the above means is not known.

4.6 Water Quality

Several shallow wells have been dug and a few boreholes drilled in the area within the Taleex formation. Water from the hand dug wells is polluted by pit latrines dug close within close proximity to the wells, penetrating the shallow perched aquifer zone. The poor quality of the water renders it unfit for human consumption due to high mineral content and faecal contamination.

Water from the existing borehole and the hand dug wells is of the sodium sulphate type, with SO4>Cl>HCO3/ca>Mg>Na+K. The fluoride and sulphate content from samples analyzed has 3 and 6 times higher than the maximum allowable limits respectively.

The electrical conductivity (EC) of hand dug wells within the Garowe area is in most cases more than 5000 uS/cm. The EC range from 3400 to 6000uS/cm with high sulphate, fluoride and iron contents. EC of 8000US/cm has been measured in some wells. Generally the EC of water in the wells have been observed to decrease with distance from the Togga Garowe towards the catchment and fluctuates with seasons. It has been suspected that the high mineral content of the water is the cause of the many kidney problems prevalent in the local community.

From the EC measurements by GTZ, there is only a slight difference of chemical water quality between the shallow wells , GTZI and the two deep wells GTZII and WDA

Water with EC up to 5000uS/cm is used for all purposes including drinking while water of wells with higher mineralization is used only for washing. Temperature of the water ranges between 28 and 31 degrees celsius.

5. GEOPHYSICAL INVESTIGATION METHODS

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey resistivity (also known as the geoelectrical method) has been used.

5.1 Resistivity Method

Vertical electrical soundings (VES) were carried out to probe the condition of the sub-surface and to confirm the existence of deep groundwater. The VES investigates the resistivity layering below the site of measurement. This technique is described below.

5.2 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of the saturated rock, the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

The resistance R of a certain material is directly proportional to its length L and cross-sectional area A, expressed as:

$$R = Rs * L/A \qquad \text{(Ohm)} \qquad (1)$$

where Rs is known as the specific resistivity, characteristic of the material and independent of its shape or size. With Ohm's Law,

$$R = dV/I \qquad \text{(Ohm)} \qquad (2)$$

where dV is the potential difference across the resistor and I is the electric current through the resistor, the specific resistivity may be determined by:

$$Rs = (A/L) * (dV/I) \qquad \text{(Ohm.m)} \qquad (3)$$

5.3 Vertical Electrical Soundings (VES).

When carrying out a resistivity sounding, current is led into the ground by means of two electrodes. With two other electrodes, situated near the centre of the array, the potential field generated by the current is measured. From the observations of the current strength and the potential difference, and taking into account the electrode separations, the ground resistivity can be determined.

While carrying out the resistivity sounding the separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

This graph can be interpreted with the aid of a computer program and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

6. FIELD WORK AND RESULTS

Fieldwork was done between 18th and 28th November, 1998. Vertical Electrical Soundings (VES) were conducted in the area south of Garowe town at selected points. Selection of VES locations was done in such a way that a large area is covered and was based on preliminary interpretation of VES carried out in the field. In addition the VES were executed at a distance sufficiently far from human settlement area to avoid the area contaminated by pit latrines.

One VES was carried out north of the togga Garowe. A total of 25 soundings were executed in the area. In most cases the distance between the VES was approximately 1 km. The location of the soundings are shown in the VES location map. The approximate locations of the VES were determined using a Global Positioning System (GPS) and plotted on a 1:62,500 base map provided by NUWAB. Some discrepancies were observed from the plotted points with respect to the actual position. Bench marks were also pegged in the ground at these locations using steel pins and concrete. The interpretation graphs and their respective models are given in Appendix 1.

6.1 Interpretation and Results

Preliminary interpretations were done in the field on which basis locations for further VES were determined. The interpretation of the VES measurements executed south of Garowe town indicate presence of deep highly weathered Karkar limestones, anhydrite, marls and sediments of the Taleex formation to depths of up to approximately 250 m in the area. The contemporaneous sedimentary layers have different resistivity values at varying depths.

The results of interpretation of VES 1 and 6 are briefly discussed below and their respective interpretation curves presented.

VES 1 was executed next to the existing Garowe borehole close to togga Garowe in order to offer calibration of the geophysical measurements. Interpretation results of VES 1 indicate presence of a 10 Ohm-m layer to a depth of approximately 1.2 m bgl. This is interpreted to be composed of red gypsiferous alluvial soils. This layer is underlain by a 130 Ohm-m layer to a depth of approximately 3.8 m bgl corresponding to alluvial sands and gravels. Underlying this layer is a 12 Ohm-m layer to a depth of 9.5 meters, interpreted to represent clayey alluvial sands. It is within this layer that the alluvial perched aquifer is to be found. This is underlain by a 7 Ohm-m layer to a depth of 59 meters interpreted to be clays and highly weathered limestone layer. It is underlain by a 12 Ohm-m layer to a depth of 75 meters, corresponding to sandy clays.

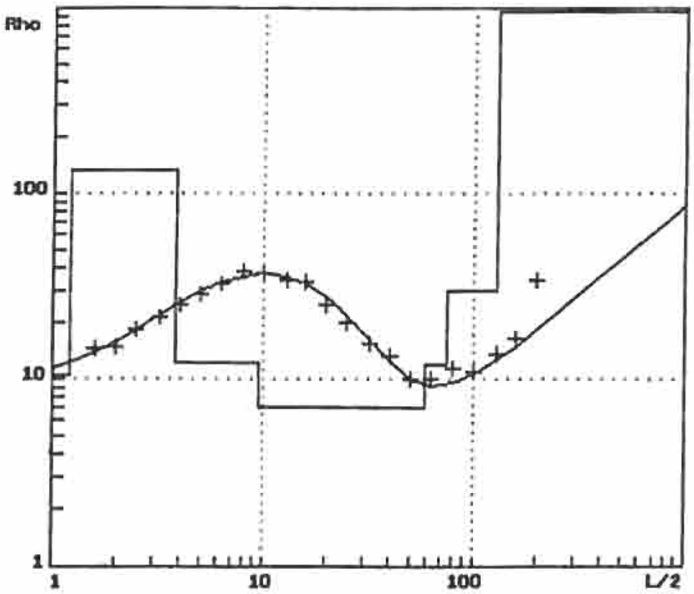
Underlying this layer is a 30 ohm-m layer to a depth of 130 meters. It is interpreted to comprise water bearing anhydrite interbedded with marls, clay and limestone layers of the Taleex formation. This layer is underlain by a 960 Ohm-m layer interpreted to be composed of dry anhydrite of the Taleex formation. The following table summarizes the interpreted results. The interpreted results coincide with the geological logs of the borehole.

Table 2: Interpreted results of VES 1:

VES 1

Resistivity (Ohm-m)	Depth (m)	Formation
10	0-1.2	Dry calcareous/gypsifeorus silty alluvial soils
130	1.2-3.8	Alluvial sands and gravels
12	3.8-9.5	Clayey alluvial sands
7	9.5-59	Clays
12	59-75	Sandy clays and marls
30	75-130	Anhydrite/marls/limestones: Taleex formation (water-bearing)
960	>130	Dry Taleex formation: Anhydrite, gypsum, marls, conglomerates and sands

VES 1



Res.(Ωm)	Depth (m)
10	0 - 1.2
130	1.2 - 3.8
12	3.8 - 9.5
7	9.5 - 59
12	59 - 75
30	75 - 130
960	> 130

Remarks: GTZ II borehole

Figure 2 Interpretation Graph for VES 1

VES 6 was executed next to the Nasa Hablood and Laan Ali Firin hills approximately 5 km south of Garowe town. Interpretation results of VES 6 indicate presence of a 384 Ohm-m layer to a depth of approximately 0.1 m bgl interpreted to be composed of dry sands. This layer is underlain by a 55 Ohm-m layer to a depth of approximately 7.7 m bgl corresponding to limestone gravels. Underlying this layer is a 13 Ohm-m layer to a depth of 51 meters, interpreted to represent gypsyriferous sandy clays and highly weathered limestone layer.

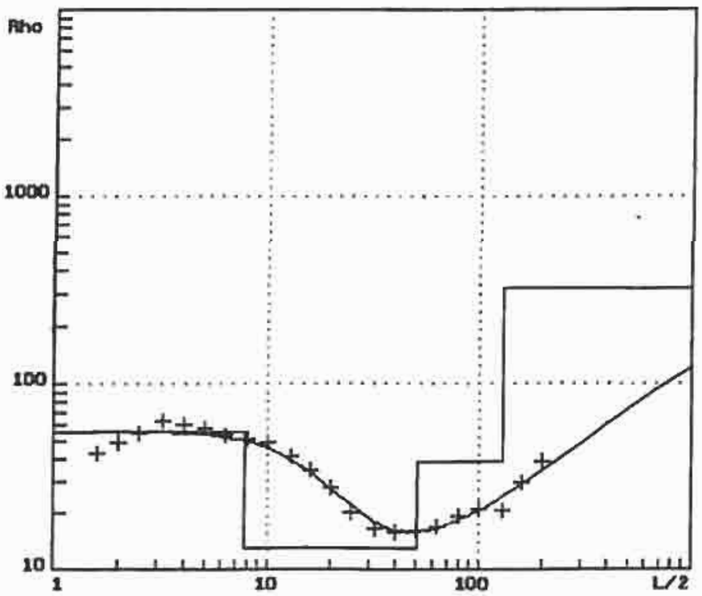
Underlying this layer is a 38 ohm-m layer to a depth of 130 meters. It is interpreted to comprise water bearing anhydrite interbedded with marls, clay and limestone layers of the Taleex formation. This layer is underlain by a 316 Ohm-m layer interpreted to be composed of dry anhydrite of the Taleex formation. The following table summarizes the interpreted results.

Table 3: Interpreted results of VES 6:

VES 6

Resistivity (Ohm-m)	Depth (m)	Formation
384	0-0.1	Dry sands
55	0.1-7.7	Limestone gravels
13	7.7-51	Gypsiferous sandy clays and highly weathered limestones
38	51-130	Anhydrite/marls/limestones: Taleex formation. (water-bearing)
316	>130	Dry Taleex formation: Anhydrite, gypsum, marls, conglomerates and sands

VES 6



Res.(Ωm)	Depth (m)		
384	0	-	0.1
55	0.1	-	7.7
13	7.7	-	51
38	51	-	130
316	> 130		

Figure 3 Interpretation Graph for VES 6

In order to show the vertical resistivity layering and to enable the hydrostratigraphy of the area to be discerned, two geo-electric cross-sections were drawn showing the resistivity variation with depth. The results of interpretation are presented and described below.

6.2 Cross-section A-A'

Cross-section A-A' runs NNW-SSE between VES 1 and 23. It shows the geo-electrical layering of the investigated sites along the profile.

The resistivity profile shows that the top geo-electrical layer has resistivities varying between 1 and 1160 Ohm-m and extends to a depth of up to 40 meters. The wide range of resistivity values depicts the variation in the geological composition of the top layer. It comprises sediments including alluvial deposits, soils, gypsiferous sands and silts and highly weathered limestones. Underlying this layer is a 4.6 to 17 Ohm-m layer to depths varying between 15 and 80 metres. This layer comprises clay and limestone layers. These are underlain by a 6.5 to 36 Ohm-m resistivity layer to depths ranging between 120 and 180 meters. This geo-electrical layer is interpreted to be comprised of anhydrite interbedded with marls, clay, and limestone layers. It is within the lower part of this layer that aquifers are to be expected. The wide range of resistivity values within this layer depicts the inhomogeneity of the composition. The bottom layer has a resistivity of 49 to 1232 ohm-m and is interpreted to be comprised of the dry anhydrite of the Taleex formation.
The following tables summarizes the interpretation results:

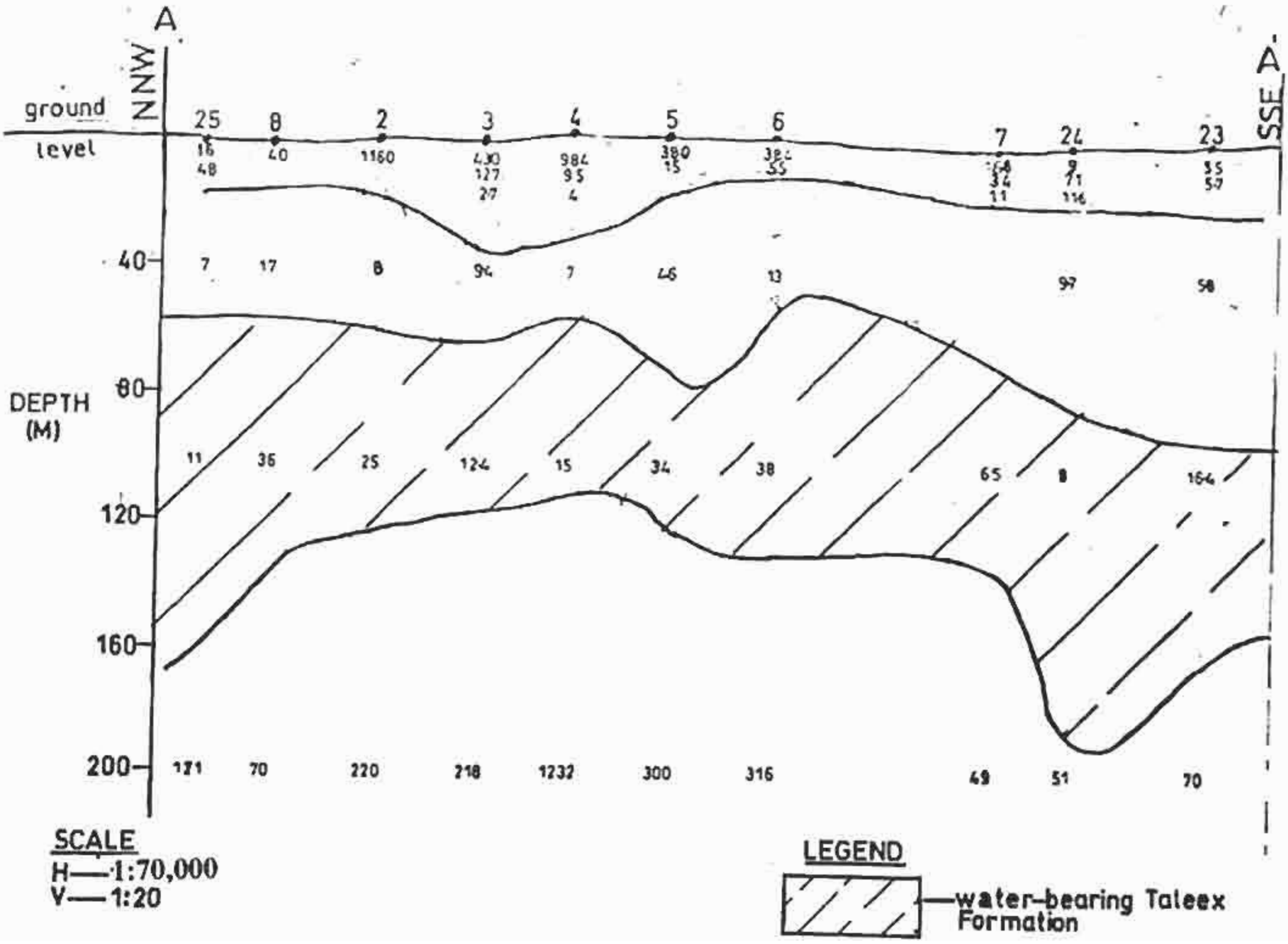


Figure 4: Geo-electrical Resistivity Profile A-A"

6.3 Cross-section B-B'

Cross-section B-B' runs W-E between VES 12 and 21 and depicts the geo-electrical layering of the investigated sites along the profile.

The resistivity profile shows that the top geo-electrical layer has resistivities varying between 22 and 384 Ohm-m and extends to a depth of up to 20 meters. The wide range of resistivity values depicts the wide variation in the geological composition of the top sub-surface layers. It comprises sediments including alluvial deposits, soils, gypsiferous sands and silts and highly weathered limestones. Underlying this layer is a 5 to 13 Ohm-m layer to depths varying between 55 and 65 meters. This layer comprises clay and limestone layers. These are underlain by a 10 to 38 Ohm-m resistivity layer to depths ranging between 120 and 210 meters. This geo-electrical layer is interpreted to be comprised of anhydrite interbedded with marls, clay, and limestone layers. It is at the bottom of this layer that aquifers are to be expected. The wide resistivity layer depicts the inhomogeneity of the composition. The bottom layer has a resistivity of 74 to 316 ohm-m and is comprised of the dry anhydrite of the Taleex formation.

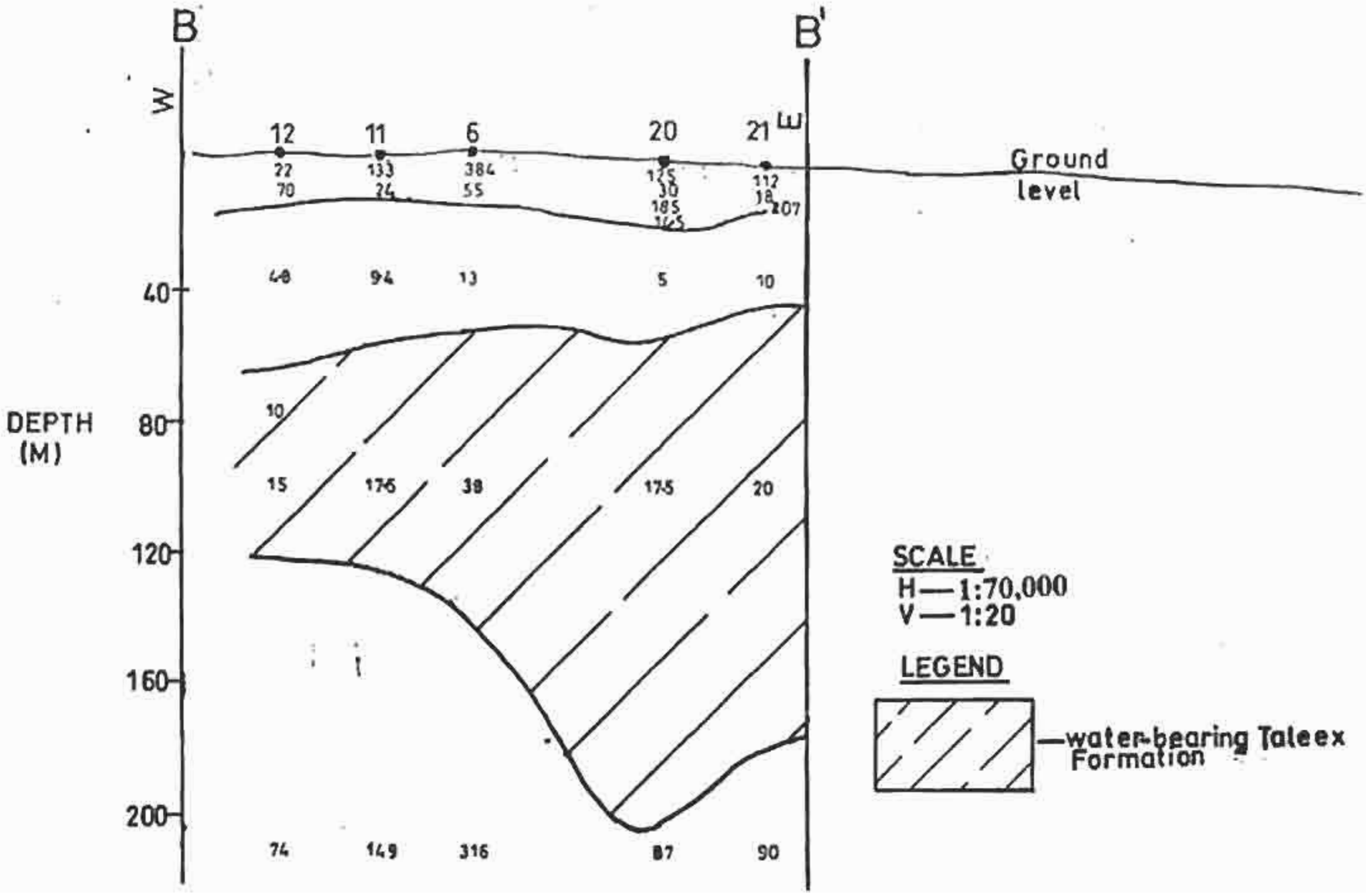


Figure 5: Geo-electrical Resistivity Profile B-B"

It can be deduced from the geo-electric sections that the water bearing zones have very variable composition as exhibited by the variable resistivities within the aquiferous layer. The low resistivities depict marly and clayey matrix while the higher resistivities represent the coarser sediments with better permeability and transmissivity. The low resistivity values also depict high salinity of the water. This means that the hydraulic properties of the aquifer zone are variable.

The detailed investigations should target establishment and delineation of the areal and vertical extent of this layer with good physical properties in respect to groundwater occurrence and their potential as aquifers and their respective quality.

The detailed interpretation graphs of all the VES are presented in Appendix 1 and the location of the VES is shown on the VES location map in the back pocket.

7. CONCLUSIONS AND RECOMMENDATIONS

From the study of the hydrogeology of the area, it is concluded that the groundwater prospects are good. However, it should be noted that suitable aquifers in the area occur in specific places depending on the texture and structure of the aquifer formation.

Boreholes drilled in the Garowe town area show a wide range in yields from 24 to 110 m^3/hr. This shows how variable the groundwater conditions are within this formation. It is therefore difficult to predict accurately the yields of boreholes in the area. However, it is expected that the yields will be in the order of 20 m^3/hr and may be expected within the limestone series and the Taleex formation.

The perched aquifer occurs as pockets embedded in the sedimentary succession within the vicinity of togga Garowe. The deeper aquifer appears to be quite extensive in the area. However, the relative productivity of specific locations will greatly depend on aquifer composition, grain size of material and aquifer matrix. Presence of gypsum and clays within the aquifer leads to poor hydraulic properties and hence the abstractable yields from the aquifer.

The EC of the water is expected to be comparable to that of the existing borehole with EC varying between 3000 and 5000 µS/cm and quality being fairly good for human consumption except high sulphate, iron and magnesium content as is the case observed in the wells and boreholes within the area.

Based on the geophysical investigation results, the best site for four boreholes would be in the area around the location of VES 18, 6, 20 and 7 and 24. The proposed boreholes would have a maximum depth of about 250 m. Water struck level is expected at around 80 to 100 m but drilling should continue until sufficient amount is obtained.

It is recommended that a detailed geophysical investigations be carried out in the area south of Garowe town to determine in greater detail the prevailing hydrostratigraphy, aquifer dimensions and geometry; and to delineate in detail the best site for the wellfield development. This should take into consideration the proximity to the town, location of other water supply facilities i.e. tanks, reticulation system etc. Therefore further detailed investigations are required to delineate the productive zones of the aquifer.

During drilling the EC of the water and the water levels should be monitored in order to seal off saline water zones that may be encountered.

Although the area of investigation is generally sparsely populated it can be observed that sanitary conditions of the available wells are generally poor and unprotected against pollution. For long term groundwater management, it is recommended that the area delineated for wellfield development be restricted for human settlement, and proper sanitation practices implemented to safeguard against pollution of the aquifer.

8. REFERENCES

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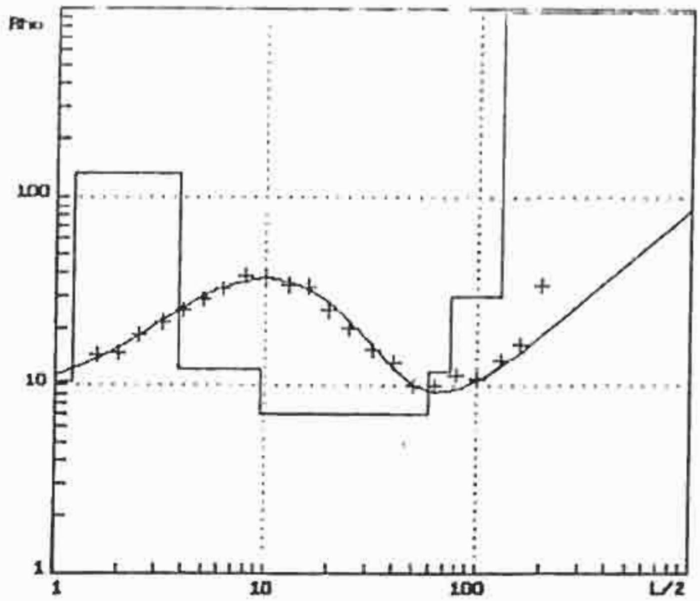
PELLETEY J, HILLMANN M, 1994. Mission Report. Water Supply Working Group. Nugal Technical Mission, United Nations Development Office for Somalia.

APPENDICES

APPENDIX 1 - VES Interpretation Graphs and Results

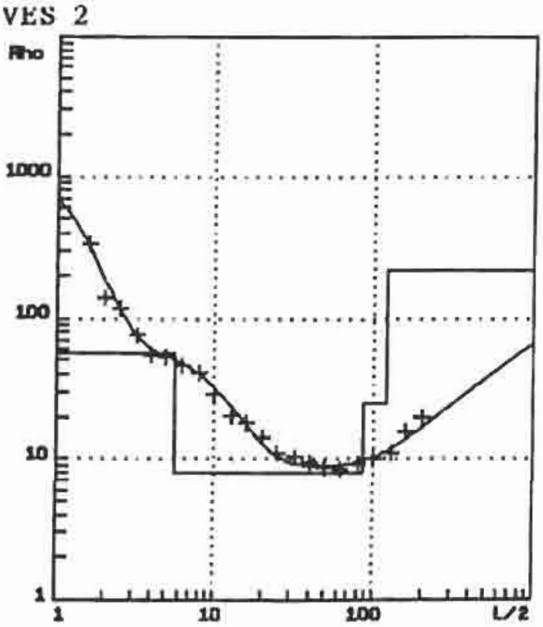
VES 1



Res.(Ωm)	Depth (m)		
10	0	-	1.2
130	1.2	-	3.8
12	3.8	-	9.5
7	9.5	-	59
12	59	-	75
30	75	-	130
960	> 130		

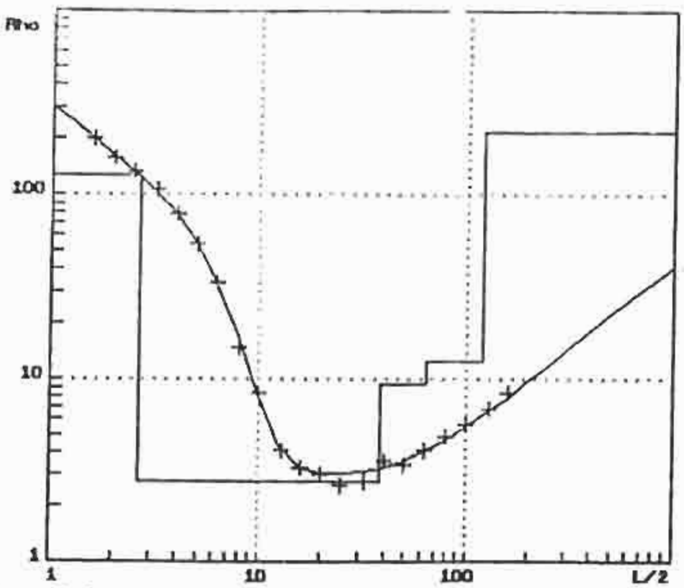
Remarks: GTZ II borehole

VES 2



Res.(Ωm)	Depth (m)		
1160	0	-	0.6
57	0.6	-	5.6
8	5.6	-	86
25	86	-	120
220	>120		

VES 3



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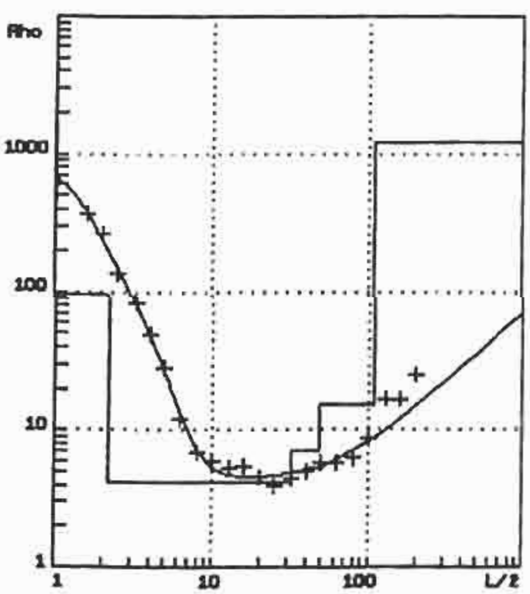
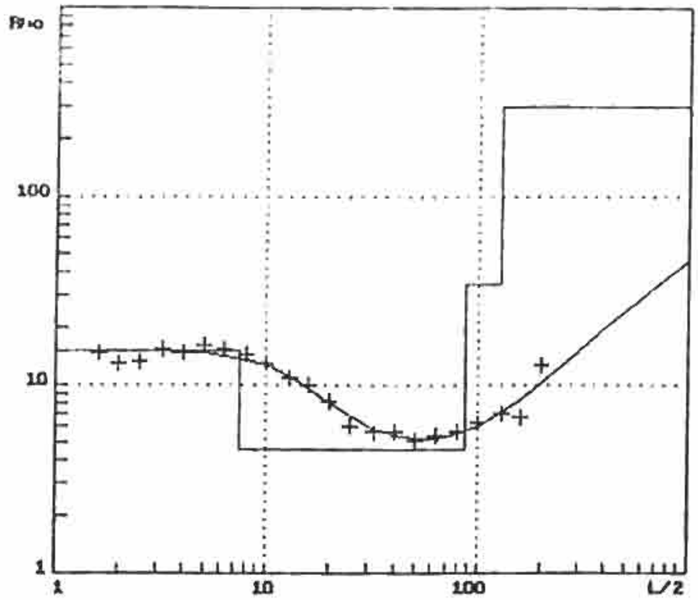
Res.(Ωm)	Depth (m)		
430	0	-	0.5
127	0.5	-	2.7
2.7	2.7	-	38
9.4	38	-	64
12.4	64	-	120
218	>120		

VES 4



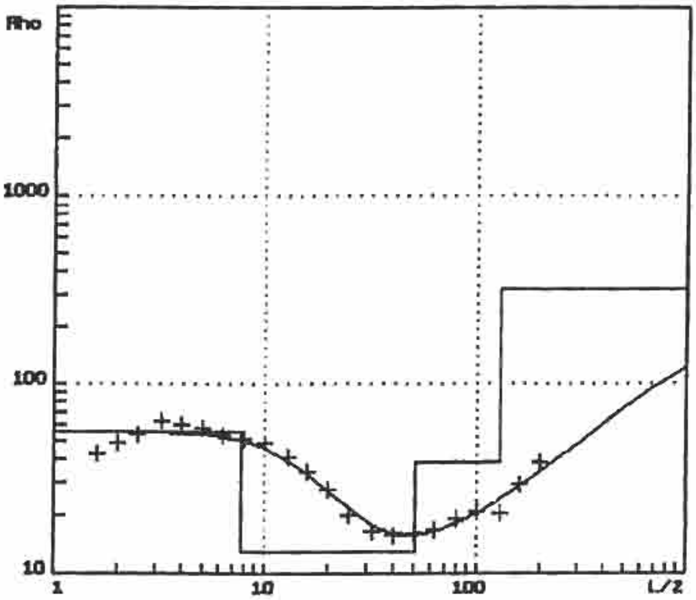
Res.(Ωm)	Depth (m)		
984	0	-	0.7
95	0	-	2.2
4	2.2	-	32
7	32	-	49
15	49	-	110
1232	>110		

VES 5



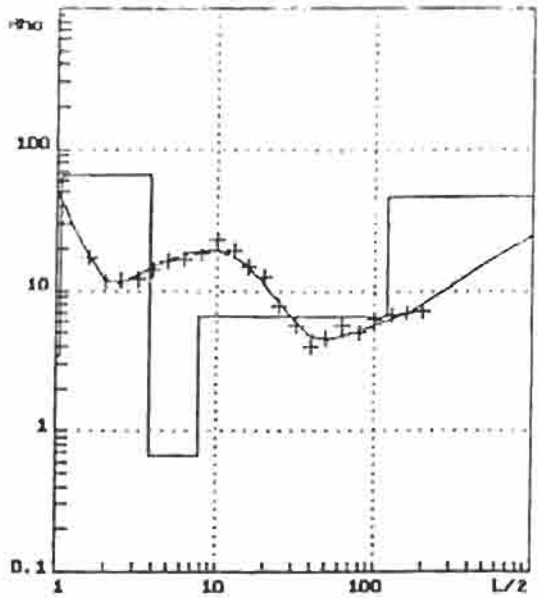
Res.(Ωm)	Depth (m)		
380	0	-	0.1
15	0.1	-	7.5
7.5	0.1	-	87
34	87	-	127
300	>127		

VES 6



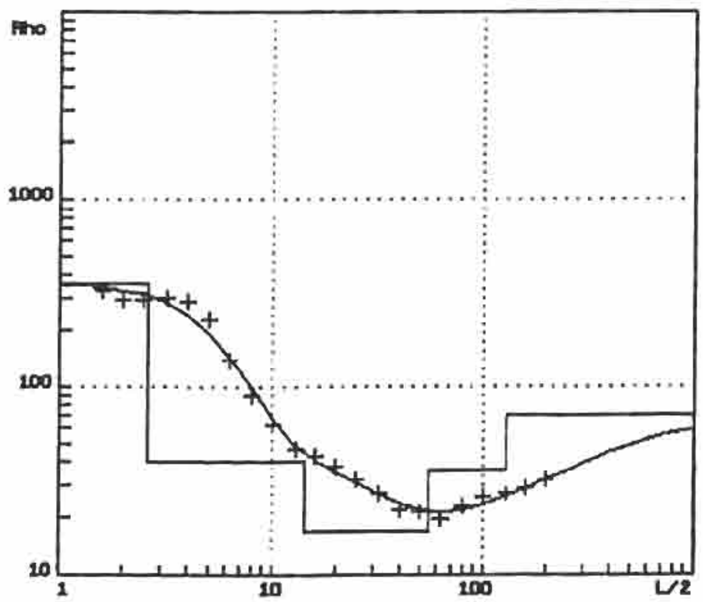
Res.(Ωm)	Depth (m)		
384	0	-	0.1
55	0.1	-	7.7
13	7.7	-	51
38	51	-	130
316	> 130		

VES 7



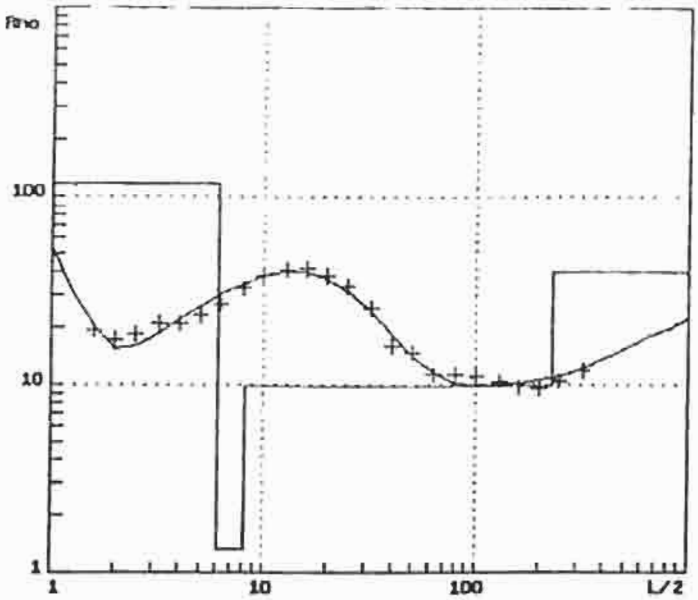
Res.(Ωm)	Depth (m)		
168	0	-	0.4
3.4	0.4	-	1.1
65	1.1	-	3.8
1	3.8	-	8.2
6.5	8.2	-	130
49	> 130		

VES 8



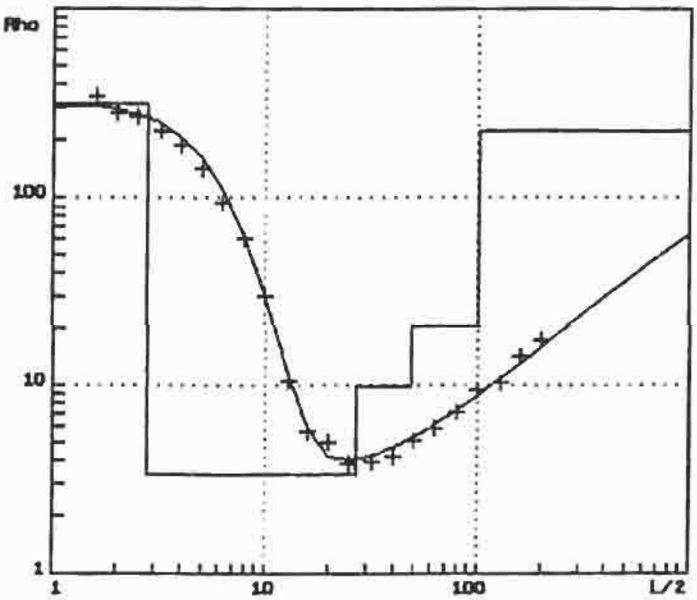
Res.(Ωm)	Depth (m)		
355	0	-	2.6
40	2.6	-	14
17	14	-	56
36	56	-	130
70	>130		

VES 9



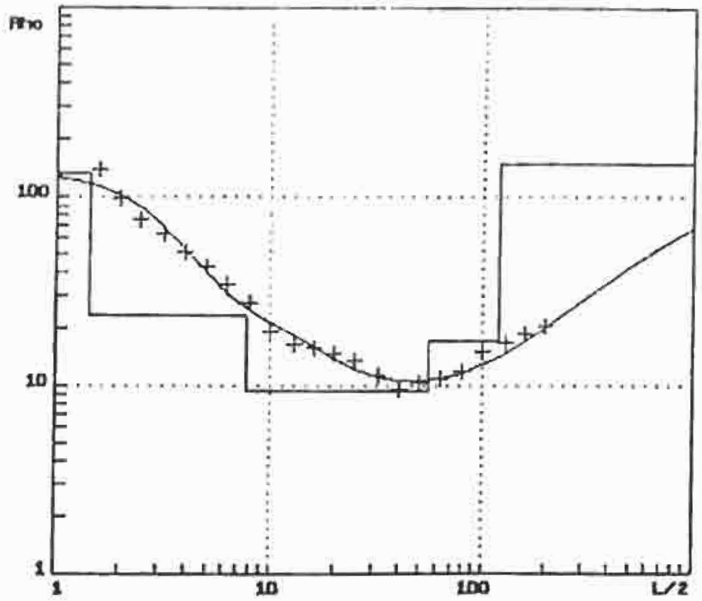
Res.(Ωm)	Depth (m)		
155	0	-	0.4
4	0.4	-	1
116	1	-	6.1
1.3	6.1	-	8.1
10	8.1	-	230
40	>230		

VES 10



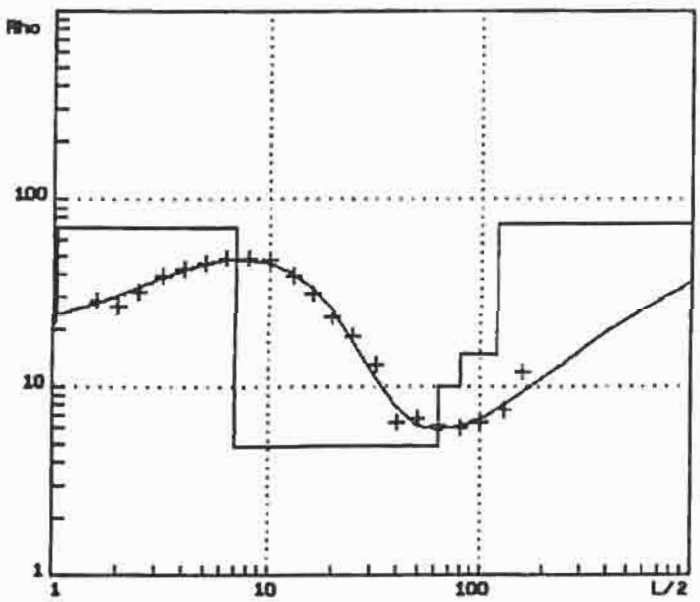
Res.(Ωm)	Depth (m)		
315	0	-	2.8
3.3	2.8	-	27
10	27	-	49
21	49	-	101
226	>101		

VES 11



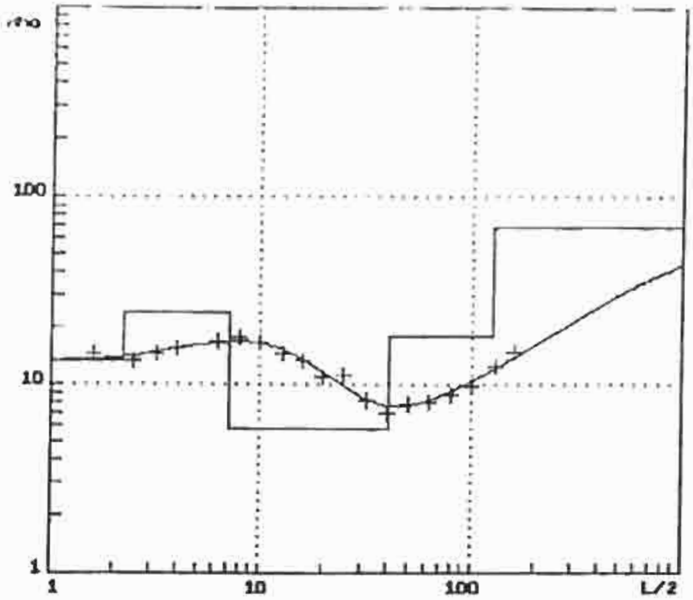
Res.(Ωm)	Depth (m)		
133	0	-	1.5
24	1.5	-	7.8
9.4	7.8	-	55
17.5	55	-	120
149	> 120		

VES 12



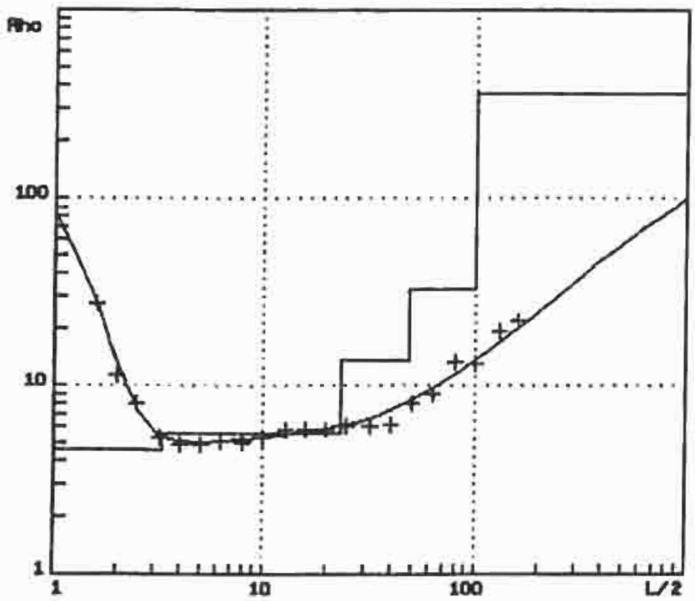
Res.(Ωm)	Depth (m)		
22	0	-	1.0
70	1	-	7.1
4.8	7.1	-	63
10	63	-	80
15	80	-	120
74	>120		

VES 13



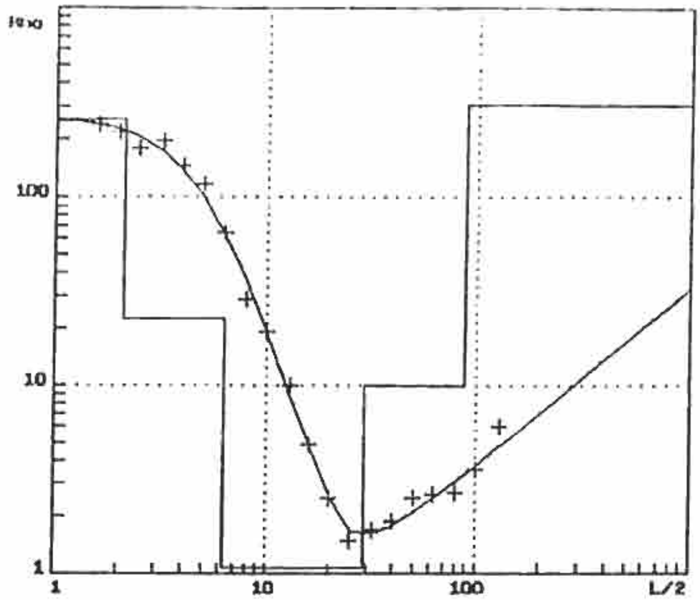
Res.(Ωm)	Depth (m)		
13.3	0	-	2.2
24	2.2	-	7.1
5.8	7.1	-	41
18	41	-	125
69	> 125		

VES 14



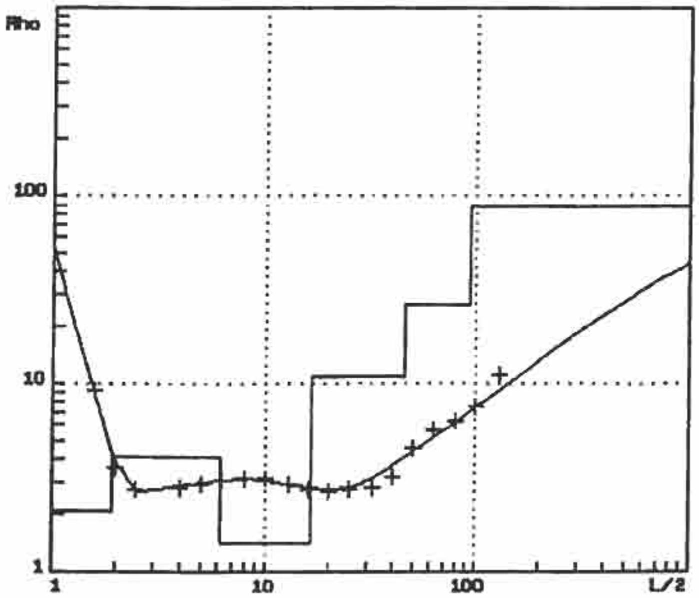
Res.(Ωm)	Depth (m)		
210	0	-	0.5
4.6	0.5	-	3.3
5.6	3.3	-	23.4
14	23.4	-	49
33	49	-	100
357	> 100		

VES 15



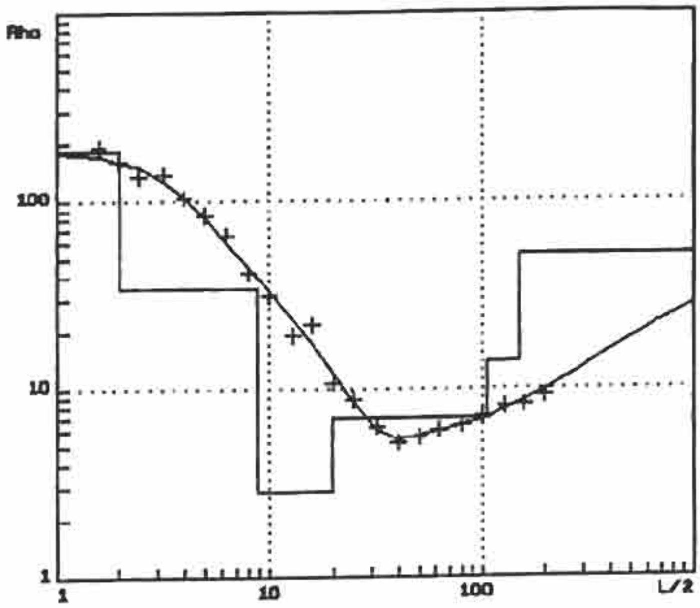
Res.(Ωm)	Depth (m)		
258	0	-	2.1
22.5	2.1	-	6.3
1	6.3	-	29.3
10	29.3	-	89
306	> 89		

VES 16



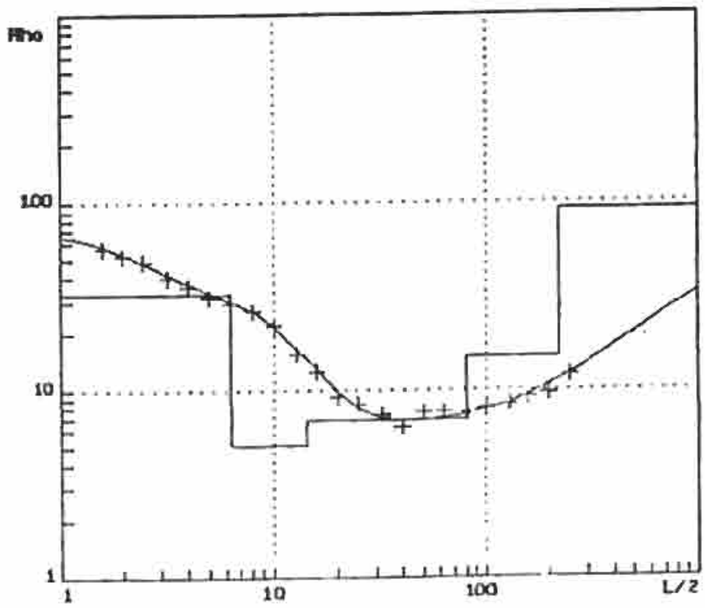
Res.(Ωm)	Depth (m)		
377	0	-	0.3
2.1	0.3	-	1.9
4	1.9	-	6.2
1.4	6.2	-	16.4
11	16.4	-	46
26	46	-	95
89	>95		

VES 17



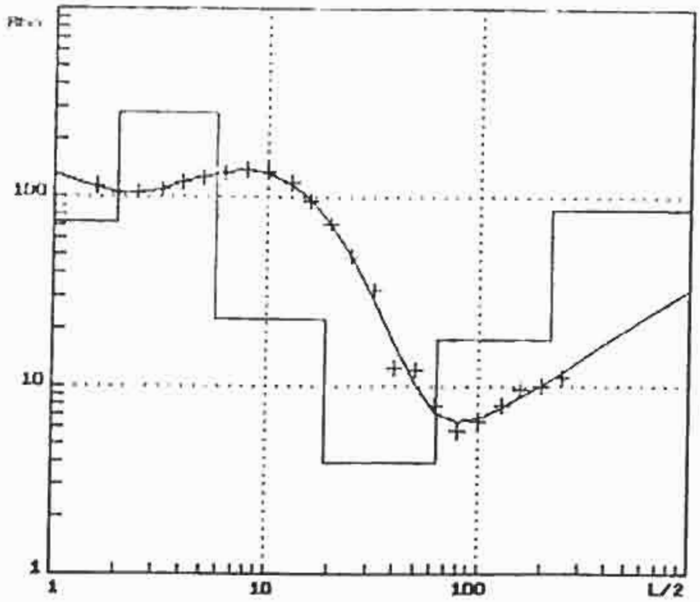
Res.(Ωm)	Depth (m)		
184	0	-	2.0
34	2	-	8.8
2.9	8.8	-	19.6
7	19.6	-	105
14	105	-	151
52	>151		

VES 18



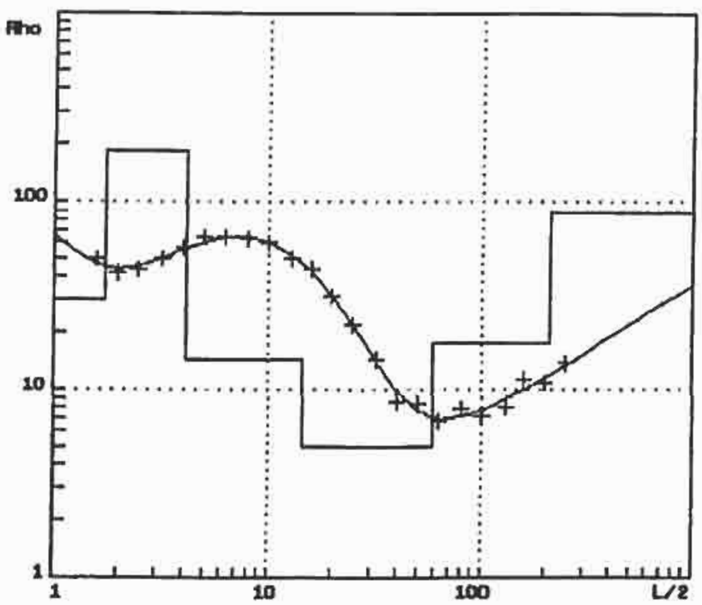
Res.(Ωm)	Depth (m)		
70	0	-	6.3
32	6.3	-	14
5	14	-	80
7	80	-	224
92	>224		

VES 19



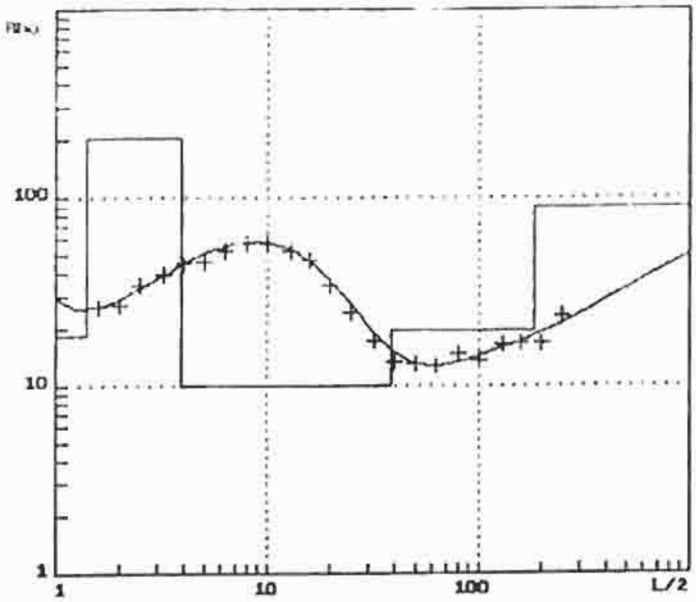
Res.(Ωm)	Depth (m)		
160	0	-	0.6
74	0.6	-	2
282	2	-	5.8
23	5.8	-	18.8
4	18.8	-	64
18	64	-	220
86	>220		

VES 20



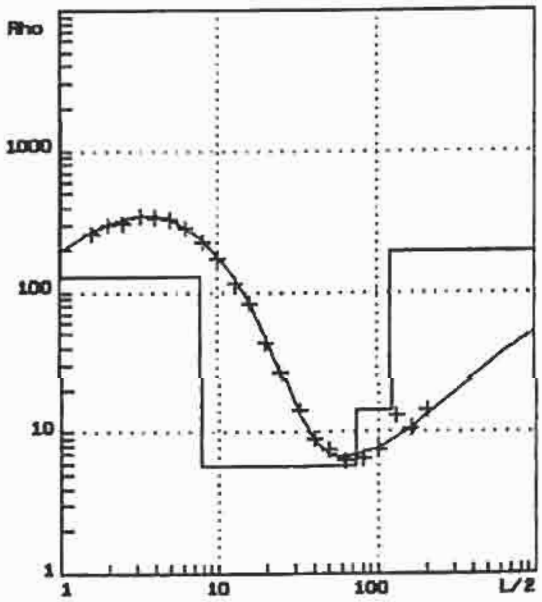
Res.(Ωm)	Depth (m)		
125	0	-	0.4
30	0.4	-	1.7
185	1.7	-	4.1
14.5	4.1	-	14.4
5	14.4	-	59
17.5	59	-	210
87	> 210		

VES 21



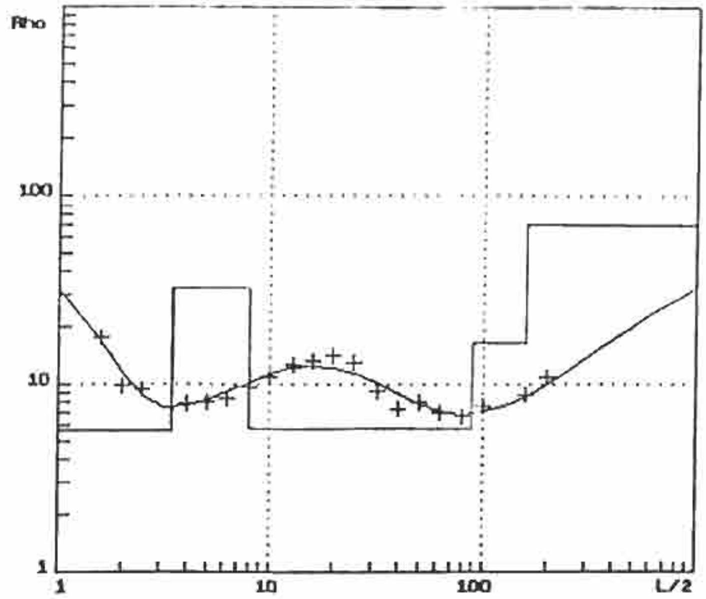
Res.(Ωm)	Depth (m)		
112	0	-	0.3
18	0.3	-	1.4
207	1.4	-	4
10	4	-	39
20	39	-	183
90	> 183		

VES 22



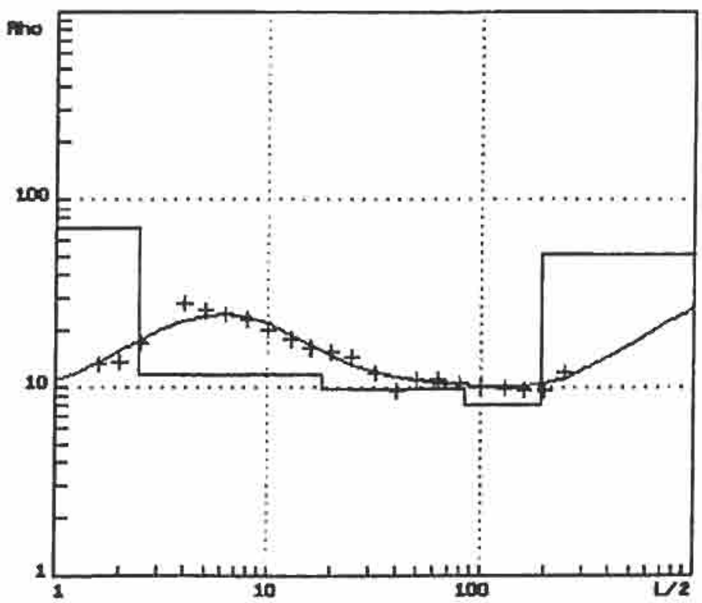
Res.(Ωm)	Depth (m)		
89	0	-	0.4
1660	0.4	-	1
126	1	-	7.7
5.7	7.7	-	72
14.4	72	-	120
193	>120		

VES 23



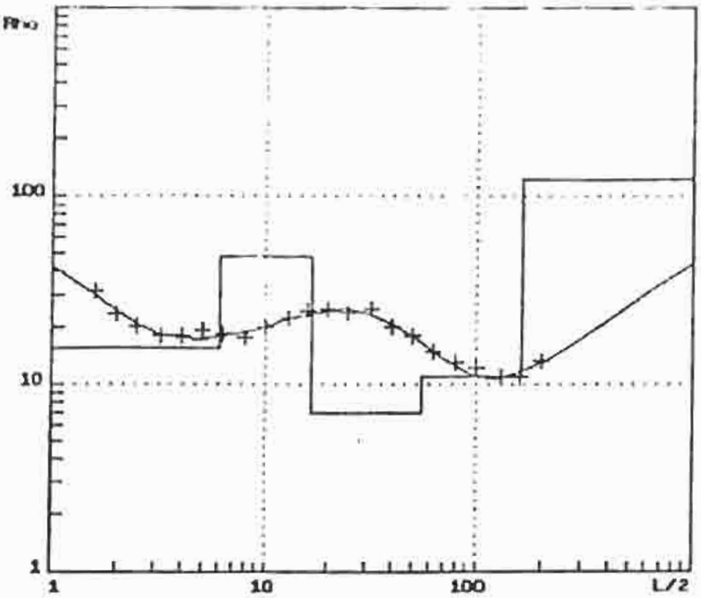
Res.(Ωm)	Depth (m)		
55	0	-	0.6
5.7	0.6	-	3.4
32	3.4	-	8
5.8	8	-	89
16.4	89	-	160
70.3	>160		

VES 24



Res.(Ωm)	Depth (m)		
9	0	-	0.9
71	0.9	-	2.4
11.6	2.4	-	18
9.7	18	-	84
8	84	-	182
51	>182		

VES 25



Res.(Ωm)	Depth (m)		
57	0	-	0.6
16	0.6	-	6
48	6	-	17
7	17	-	56
11	56	-	162
121	> 162		

APPENDIX 2 Acceptable Ionic Concentration - Various Authorities

Substance or Characteristic	World Health Organisation: 1983 Guidelines: Value (GV	1971 Int Standards: Guideline (HL)	European Community: EC Directive 1980 relating to the quality of water intended for human consumption: Upper limit (tentative)	GuideLevel (GL)	Max Admissible Concentration (MAC)	
Inorganic Constituents of health significance,						
Antimony Sb				0.01		
Arsenic As	0.05	0.05		0.05		
Cadmium Cd	0.005	0.01		0.005		
Chromium Cr	0.05	0.05				
Cyanide CN	0.10	0.05		0.05		
Fluoride F	1.5	1.7		1.5		
Lead Pb	0.05	0.10		0.05		
Mercury Hg	0.001	0.001		0.001		
Nickel Ni				0.05		
Nitrates	10 (as N)	45 (as NO_3)	25 (as NO_3)	50 (as NO_3)		
Selenium Se		0.01		0.01		
Other Substances	Desirable Level:	GV: Permissible Level:	Highest	Maximum	GV:	MAC:
Aluminum Al	0.20			0.05	0.20	
Ammonium	NH_4				0.05	0.50
Barium Ba				0.10		
Boron B				1.0		
Calcium Ca		75	50	100		
Chloride Cl	250	200	600	25		
Copper Cu		0.05		0.10		
Hydrogen Sulphide H_2S	ND				ND	
Iron Fe	0.30	0.10	1.0	0.05	0.20	
Magnesium	Mg	0.10	30	150	30	50
Manganese Mn	0.10	0.05	0.50	0.02	0.05	
Nitrite NO_2					0.10	
Potassium K				10	12	
Silver Ag					0.01	
Sodium Na	200			20	175	
Sulphate, SO_4	400	200	400	25	250	
Zinc Zn		5.0	15	0.10		
Total Dissolved Solids	1000	500	1500		1500	
Total Hardness as $CaCO_3$	500	100	500			
Colour °Hazen	15	5	50	1	20	
Odour	Inoffensive	Unobjectionable			2 or 3 TON	
Taste	Inoffensive	Unobjectionable			2 or 3 TON	
Turbidity (JTU)	5	5	25	0.4	4	
pH	6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	6.5 - 8.5	9.5 (max)	
Temperature	°C				12	25
EC uS/cm				400		

Notes ND - Not Detectable IO - Inoffensive
GL - Guide Level UO - Unobjectionable

(Based on Table 6.1, in Twort, Law & Crowley, 1985).

APPENDIX 3. Geographical Locations of the VES Soundings.

VES	LATITUDE	LONGITUDE
1	08° 23' 43.2" N	48° 28' 11.6" E.
2	08° 23' 30.8" N	48° 28' 55.2" E.
3	08° 23' 01.8" N	48° 29' 08.2" E.
4	08° 22' 34.8" N	48° 29' 21.2" E.
5	08° 22' 05.9" N	48° 29' 32.4" E.
6	08° 21' 37.0" N	48° 29' 47.9" E.
7	08° 20' 35.2" N	48° 30' 21.8" E.
8	08° 23' 58.3" N	48° 28' 33.7" E.
9	08° 19' 22.5" N	48° 30' 32.4" E.
10	08° 18' 30.3" N	48° 30' 27.7" E.
11	08° 21' 43.7" N	48° 29' 17.8" E.
12	08° 21' 32.1" N	48° 28' 50.8" E.
13	08° 20' 52.0" N	48° 28' 56.3" E.
14	08° 22' 47.5" N	48° 28' 39.9" E.
15	08° 22' 15.4" N	48° 28' 42.9" E.
16	08° 23' 06.8" N	48° 28' 37.2" E.
17	08° 23' 46.3" N	48° 29' 41.4" E.
18	08° 23' 07.1" N	48° 30' 04.1" E.
19	08° 22' 25.1" N	48° 30' 22.5" E.
20	08° 21' 50.0" N	48° 30' 44.9" E.
21	08° 21' 58.2" N	48° 31' 13.1" E.
22	08° 23' 25.5" N	48° 32' 28.4" E.
23	08° 19' 37.7" N	48° 30' 57.5" E.
24	08° 20' 12.2" N	48° 30' 31.8" E.
25	08° 24' 17.8" N	48° 28' 25.5" E.