REPUBLIC OF KENYA




MINISTRY OF WATER DEVELOPMENT

# WATER RESOURCES RECONNAISSANCE STUDY

IN

# LAMU DISTRICT

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WATER RESOURCES ASSESSMENT DIVISION
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# 1. INTRODUCTION

## 1.1 Scope of the Survey

The present survey is the second of the water resources reconnaissance surveys to be executed within the scope of the Water Resources Assessment Project, Phase II, the first being the reconnaissance survey of Machakos District (see Figure 1.1).

The reconnaissance surveys of Machakos and Lamu Districts replace those originally proposed in the Plan of Operations 1984-1987 (see Interim Report Water Resources Assessment Project, October 1986).

Lamu District was chosen because of an urgent request by the Lamu District Development Committee concerning the water supply to Lamu Island. With Mokowe (on the mainland) to become the District Headquarters also there an increased need for water was foreseen and it was decided to execute a water resources reconnaissance survey of the entire district.

Because of the urgency of the water problems on Lamu Island and Mokowe, the survey was extended to include some geophysical field work in the above defined areas.

## 1.2 Description of the Survey Area

- General

The following paragraphs are mainly based on the District Development Plan 1984-1988 (MF & P, 1984), and the Preliminary Design Report, Lake Kenyatta Water Supply Project, by Cowi Consult, 1983.

Lamu District is situated in the northern-most part of the Kenya coast, between the Tana River Delta in the south and Ishakani town in the northeast, next to the Kenya/Somalia border. Besides the eastern boundary with the Indian Ocean, the district borders Tana River District to the west and south and Garissa District to the north (Figure 1.1).

The district extends 175 km from southwest to northeast with a widest northwest-southeast section of 70 km through Mpeketoni Division and has a surface area of 6,814 km$^2$. This area includes 308 km$^2$ of open water such as channels, lakes and other inland waters. Figure 1.2 shows the administrative boundaries of the district.

- Physiography

The survey area lies in the coastal region of the Tana River Plains. In general terms it is flat and featureless, rising from sea level to about 70 m above mean sea level in the northwestern part of the district.

The rise is very gradual, 1 m per kilometre, an exception being the dunes along the coast, the area southeast of Lake Kenyatta (70 m), Lamu Island (70-80 m), and the Mundane Range in the northeast with its highest point at 101 m, see Plate 1.

# WATER RESOURCES ASSESSMENT PROJECT

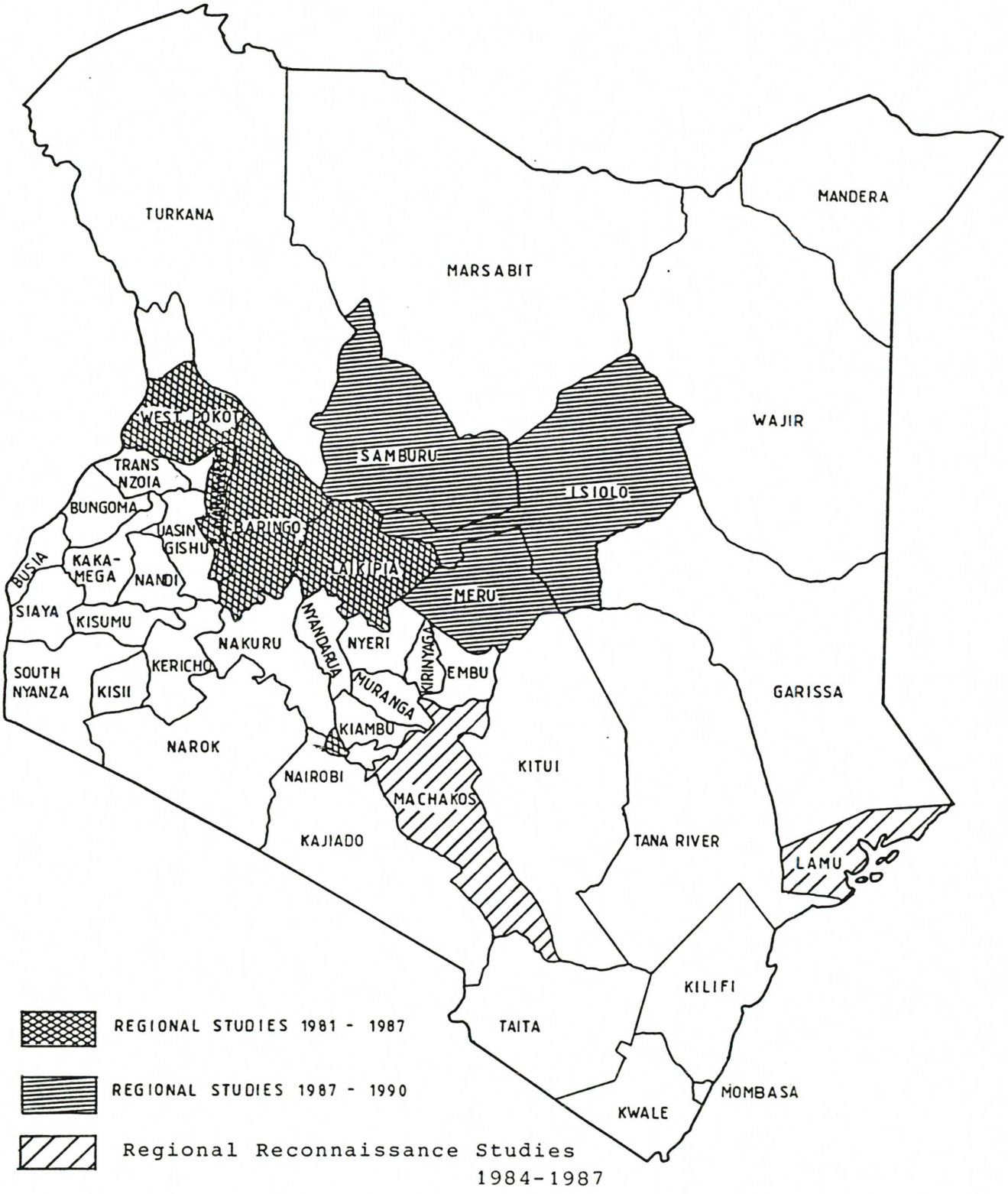



Fig. 1.1. Regional Assessment Studies under the WRAP Programme 1981-1990

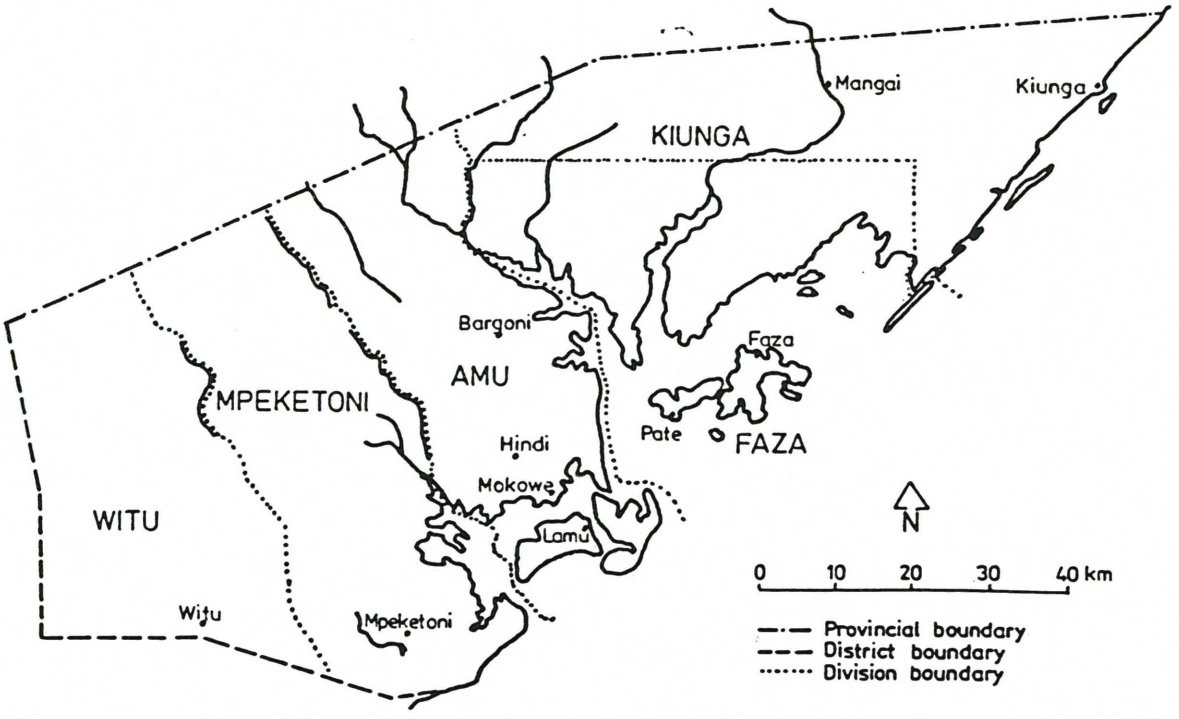



Figure 1.2 Administrative Boundaries of Lamu District

- Climate

The climate is "equatorial coastal" with such characteristics as slight temperature variation, high humidity, pronounced rainy season, high evaporation and monsoon winds. The temperature is usually high, ranging from 24°C to 30°C, with the minimum and maximum recordings at 19.5°C and 36.4° C respectively. The hottest months are December to April while the coldest are May to July. The mean humidity is 75 %.

Rainfall varies between 550 and 1,100 mm per year (see Figure 4.2 ). Much of the rain falls during April-June and is usually known as the long rains. May is the wettest month in the district. These rains are brought by the south-east monsoon or trade winds. The short rains are received in the months of November and December with the then prevailing north-east monsoon. January to March are usually dry months.

Evaporation is high and amounts to 2,327 mm per year for Lamu Met. Station with the maximum and minimum at only 5% from the average.

- Soils and Land Use

The district has dry woodland and bushland in the coastal strip changing into bush and scrubland further land inward. Most of the soils are moderately well drained sandy loams and sandy clay loams with a thick topsoil of friable loamy sand. Part of it is used for subsistence farming and shifting cultivation. The bush and scrublands are used for ranching. Along the creeks and some islands mangroves flourish while mainland forestry is found in Witu area.

- Population

At the time of the 1979 population census, Lamu District had a total population of 42,299. The official growth rate has been estimated at 5.15% per

annum (Source, Lamu District Development Plan 1984-1988), higher than the national growth rate, due to influx to the agricultural settlement schemes (Lake Kenyatta and Hindi). At this rate, a total population of 63,000 would be expected by 1987. Many ethnic groups are present with as largest the Bajuni (46%), followed by the Kikuyu (21%), Mijikenda (6%), Arab (6%) and Boni/Sanye (5%).

The Bajunis live mainly in the traditional villages and are cultivators and fishermen. The Kikuyus live in the Lake Kenyatta Settlement Scheme and are cultivators. The Arabs live mainly in Lamu Town and are traders. The Boni and Sanye are hunters but today also shifting cultivators.

80% of the population depends directly on agriculture and related activities and about 20% on fisheries.

- Livestock

Livestock in the district is difficult to assess as most cattle, goats and sheep are in transit. However, according to the Livestock Development Office in Lamu there was a total of 40,000 cattle and 20,000 goats and sheep in 1983. Additionally, over 110,000 units of poultry were estimated and some 1,500 donkeys.

## 2. GEOLOGY

### 2.1 Introduction

Due to the lack of geological reports on the area, much is quoted from the Cowi Consult Report.

### 2.2 Stratigraphy

All rocks in the area are sedimentary and can be divided into three stratigraphical groups.

. Tertiary sediments
. Quaternary marine sediments
. Quaternary soils

- Tertiary sediments

The Tertiary Sediments comprise deposits ranging in age from Miocene to Pliocene. They consist of alternating series of sands and sandy clays and clayey sands. Occasionally, and especially within the Miocene series, limestone occurs.

In the eastern part of the district a long dune ridge at some distance from the coast rises conspicuously (Mundane Range). This is probably a fossil dune ridge composed of terra rosa decomposition products of the Miocene limestones. More geological evidence is needed.

A small fossil dune is also found south east of Mpeketoni.

- Quaternary marine sediments

During the Pleistocene, sea level fluctuations were very complicated (regressions and transgressions), in which coral reefs were formed and decomposed. During the low sea levels the coastal rivers cut channels in the lagoons behind the coral reefs. These channels were later drowned when the sea levels rose again. The present creeks in the area are an example of these channels (Dodori Creek, Mto Wange).

The Quaternary marine sediments in the Witu-Lamu area are found to a depth of 40-50 m below surface and thus form the bulk of the Quaternary deposits. They consist of grey or yellow-grey sand and clayey sands. In the Witu-Lamu area coral reefs are found embedded in the deposits.

The raised Pleistocene coral reef which developed along the length of the coast forms the base of the islands in the area and remnants are also found inland at shallow depth.

- Quaternary soils

The Quaternary soils consist mainly of grey sandy loam to sandy clay. Where the drainage is improved, red sandy soils have formed. However, these sandy soils may also represent older (Tertiary) dunes.

The Quaternary soils may attain thicknesses of around 10 m. Of special interest within this series of deposits are the dune sand accumulations along the coast at Lamu Island and on the mainland, from Kiongwe southward.

## 2.3 Structure

The most prominent features from the aerial photographs are shown in Plate 1. The available photographs do not cover the whole district as can be seen in Figure 2.1.

The main direction of the lineaments is parallel and perpendicular to the present coastline. The seasonal rivers in the northeast seem to be controlled by features with the same directions.

The Mundane Range in the northeast runs parallel to the present coastline which is partly built up of coral reefs. This range may be a fossil reef or dune formed when the sea level was much higher then at present. It seems that at that time the reef was cut by a river of which the Mto Wange is the present remnant.

In the Lamu-Hindi area the lineaments are also parallel to the present coastline and perpendicular to it, whereas the coastline itself is at a more west-east direction.

The southwestern part of the district shows both of the aforementioned directions for the lineaments. Many of the lineaments are accompanied by sinkholes which can easily be recognised on small scale maps like Figure B.1 and C.1 (see Appendices B and C).

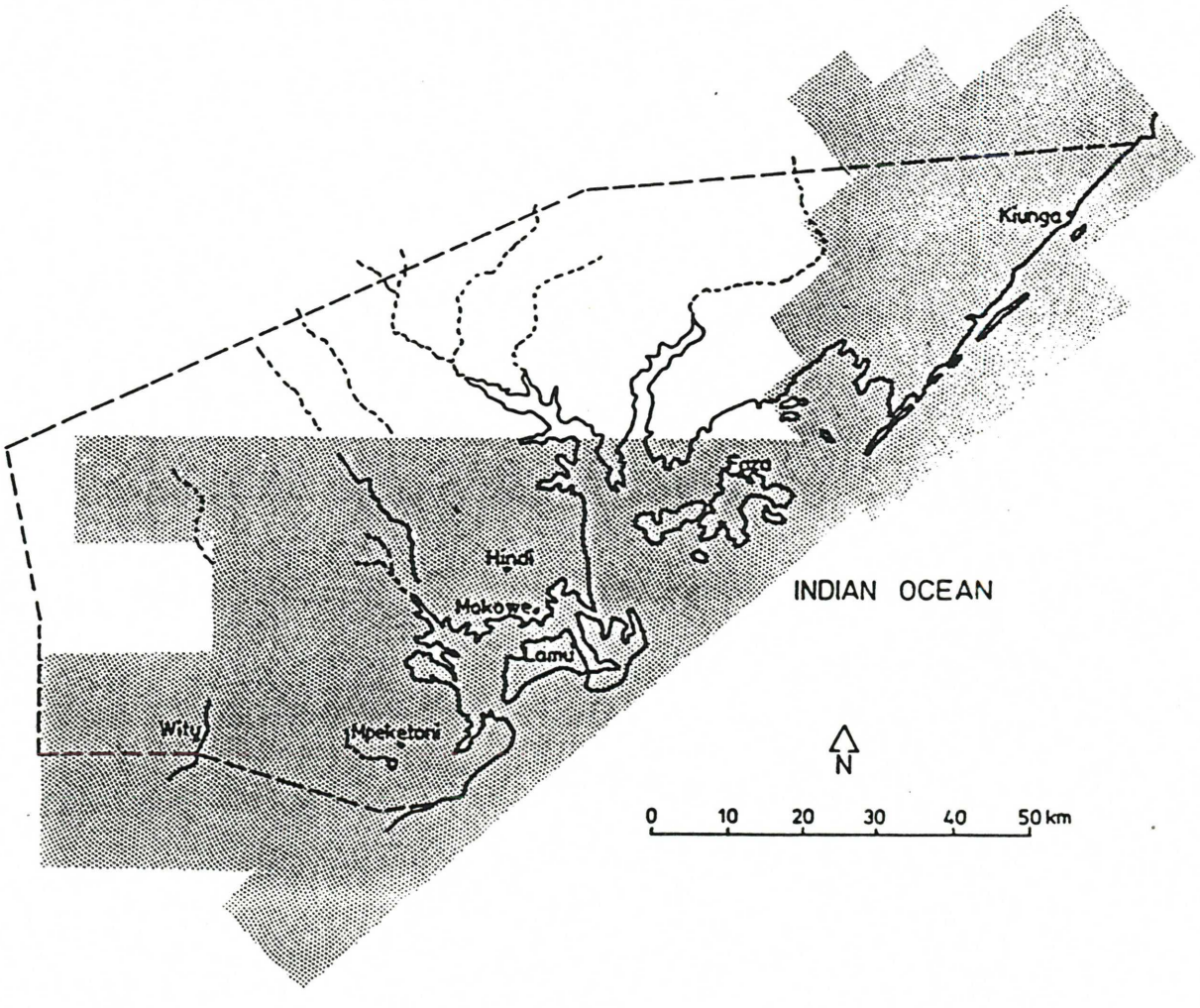



Figure 2.1 Airphoto Coverage, Scale 1 : 60,000

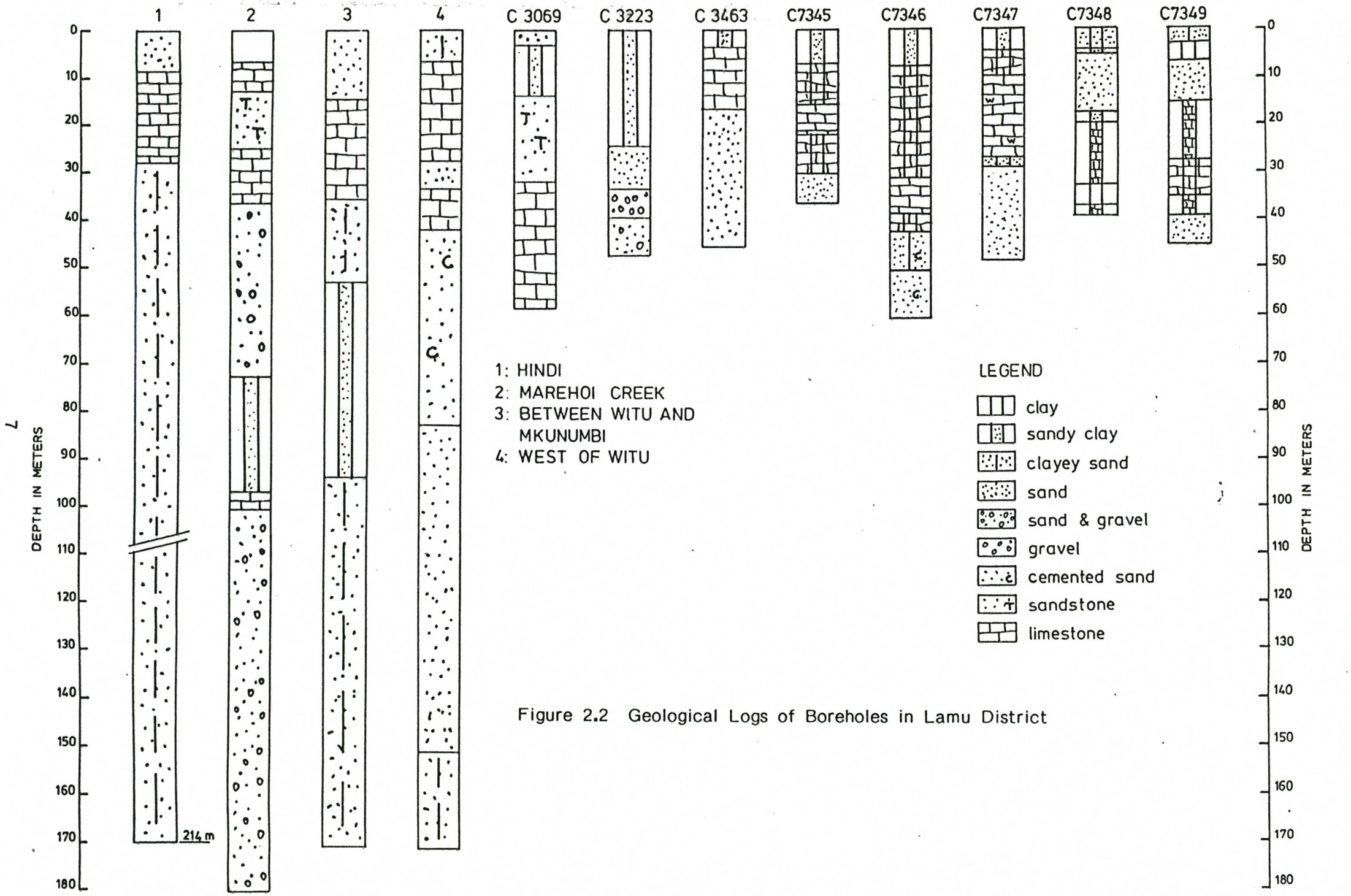



Figure 2.2 Geological Logs of Boreholes in Lamu District

In Figure 2.2, 14 geological logs are presented from boreholes in the area. The locations of the boreholes with C-numbers are indicated on Plate 1. The exact location of the others is not known.

## 3. GEOPHYSICS

### 3.1 Introduction

Lamu District was part of an extensive seismic survey carried out in the fifties. This survey was carried out by oil companies, in search of oil/gas reservoirs. They were not interested in the first few hundred metres and as such, the results have not much value for the purpose of water investigation.

A gravity survey was carried out in Kenya. The results are published by the Survey of Kenya and a copy from it for Lamu District is presented in Figure 3.1. From world-wide gravity measurements, it was found that the average Bouguer anomaly on land near sea level is approximately zero. In oceanic areas it is generally positive, while in regions of large elevation it is mainly negative.

From Figure 3.1 it can be deduced that no abnormal anomalies occur in the area and that the sediments continue to considerable depth.

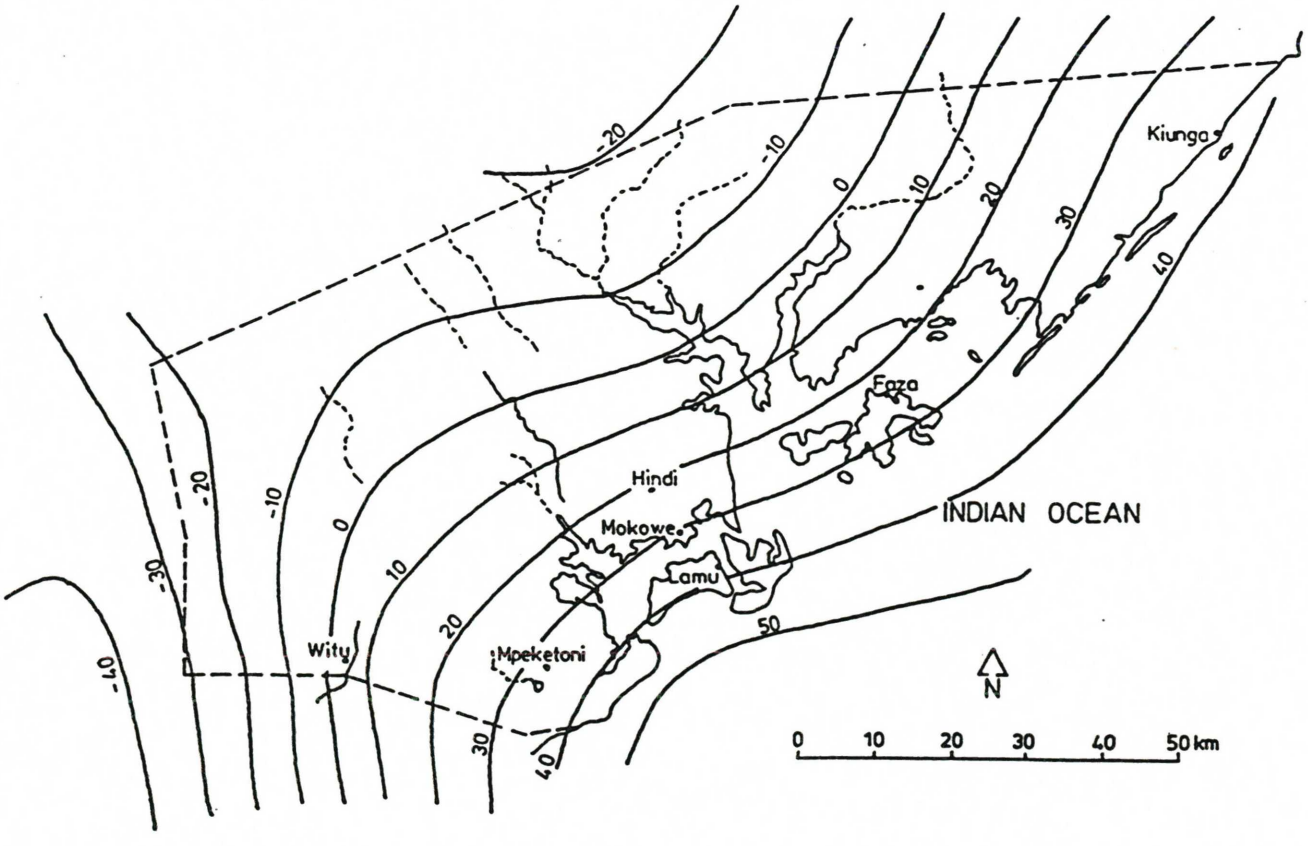



Figure 3.1 Bouguer Gravity Anomaly Contours in Lamu District

## 3.2 Geophysical Studies

In 1985, 1986 and 1988 three small scale geophysical surveys were carried out by WRAP. In 1987 Groundwater Survey Ltd. carried out a survey around Lake Kenyatta. The survey areas are discussed below.

- Lamu Island

To detect fresh water occurrence for possible extension of the existing well field in the Shela Dunes, WRAP carried out a resistivity survey in the dunes of Lamu island. The results of this study are positive so that extension of the wellfield is quite possible. A description and results are presented in Appendix A.

- Hindi Magogoni Settlement Scheme

As follow-up of the investigation on Lamu Island a resistivity survey was carried out in the area around Hindi, north of Mokowe. As Mokowe will be the future District Headquarters the water demand will increase considerably.

The main purpose of this survey was to check for possible fresh water resources to supply Mokowe and Hindi. The results show that fresh water occurs only in limited quantities as a thin lens on top of saline water. However, in some areas with permeable coral limestone and sufficient ground elevation, considerable quantities of fresh water can be stored when enough recharge takes place. This might be the case east and southeast of Hindi where a fresh water swamp might recharge the limestones southwest of it. A reconnaissance borehole is therefore necessary. To locate the exact position an electro-magnetic profile was run in November 1988.

A detailed description and the results of the surveys are presented in Appendix B.

- Lake Kenyatta Settlement Scheme

Some resistivity soundings were carried out by WRAP mainly to provide a reference for the surveys carried out in Hindi Magogoni and for future investigations.

In 1987 a more detailed survey was carried out by Groundwater Survey Ltd. for the German Assisted Settlement Project in Lake Kenyatta Settlement Scheme. The results of this survey are quite positive as a considerable underground storage reservoir was detected near lake Kenyatta. The lake water is recharging highly permeable fossil coral limestone which was encountered at depth.

The results of the soundings by WRAP are presented in Appendix C.

# 4. HYDROLOGY

## 4.1 Introduction

Hydrological information for Lamu District is very scant, due to the lack of an adequate hydrometeorological network. However, some data are available and these are discussed below. They are divided into three groups; rainfall, evaporation and surface runoff.

## 4.2 Rainfall

Figure 4.1 shows the location of the rainfall stations in Lamu District while Table 4.1 gives the number, name, location, period of record, and average yearly rainfall figures for the stations shown in Figure 4.1. The figures in Table 4.1. are from the ledger of MoWD, Hydrology Section, and are different from the ones shown in the Lamu District Development Plan, which could not be traced.

Table 4.1 Average Yearly Rainfall for Rainfall Stations in Lamu District

| Station Number | Name | Coordinates | UTM Grid | | Period of Record (years) | Average (mm) |
|---|---|---|---|---|---|---|
| | | | km N | km E | | |
| 1. 91.41.000 | Kiunga | 1° 44'S 41° 30'E | 9808.2 | 777.7 | 20 | 589 |
| 2. 92.40.001 | Lamu Met Station | 2° 16'S 40° 54'E | 9749.2 | 711.0 | 20 | 978 |
| 3. 92.40.014 | L.Kenyatta Cotton Proj. | 2° 24'S 40° 41'E | 9734.4 | 686.9 | 8 | 1142 |
| 4. 92.40.015 | Mkowe | 2° 14'S 40° 51'E | 9752.9 | 705.4 | 12 | 952 |
| 5. 92.40.018 | Magogoni | 2° 05'S 40° 52'E | 9769.5 | 707.3 | 4 | 959 |
| 6. 92.40.021 | Mambosasa Forest Post | 2° 23'S 40° 31'E | 9736.3 | 668.4 | 5 | 1250 |
| 7. 92.40.025 | Hindi NYS | 2° 07'S 40° 48'E | 9765.8 | 699.9 | 3 | 771 |
| 8. 92.41.000 | Rasini Island | 2° 03'S 41° 06'E | 9773.2 | 733.2 | 20 | 987 |

Much of the rain falls during April - June and is usually known as the long rains. May is the wettest month in the district. The short rains are received in the months of November and December while January to March are usually dry months.

Isohyets for the district are shown in Figure 4.2 and are derived from the East African Annual Rainfall Map which was based on data available in 1966. At some stations there is a slight deviation from this map but this can be ascribed to the short period of record for these stations.

Lamu Island has the only meteorological station of the district (Lamu Met. Station) and the longest period of record, starting in 1906. Figure 4.3 presents the annual rainfall for this station for a span of 80 years. The ten year moving average is plotted in the same figure which shows a significant inter-annual difference.

The average rainfall over this period is 962 mm with 322 mm for the driest year and 2,378 mm for the wettest year. The standard deviation is 37 % of the average.

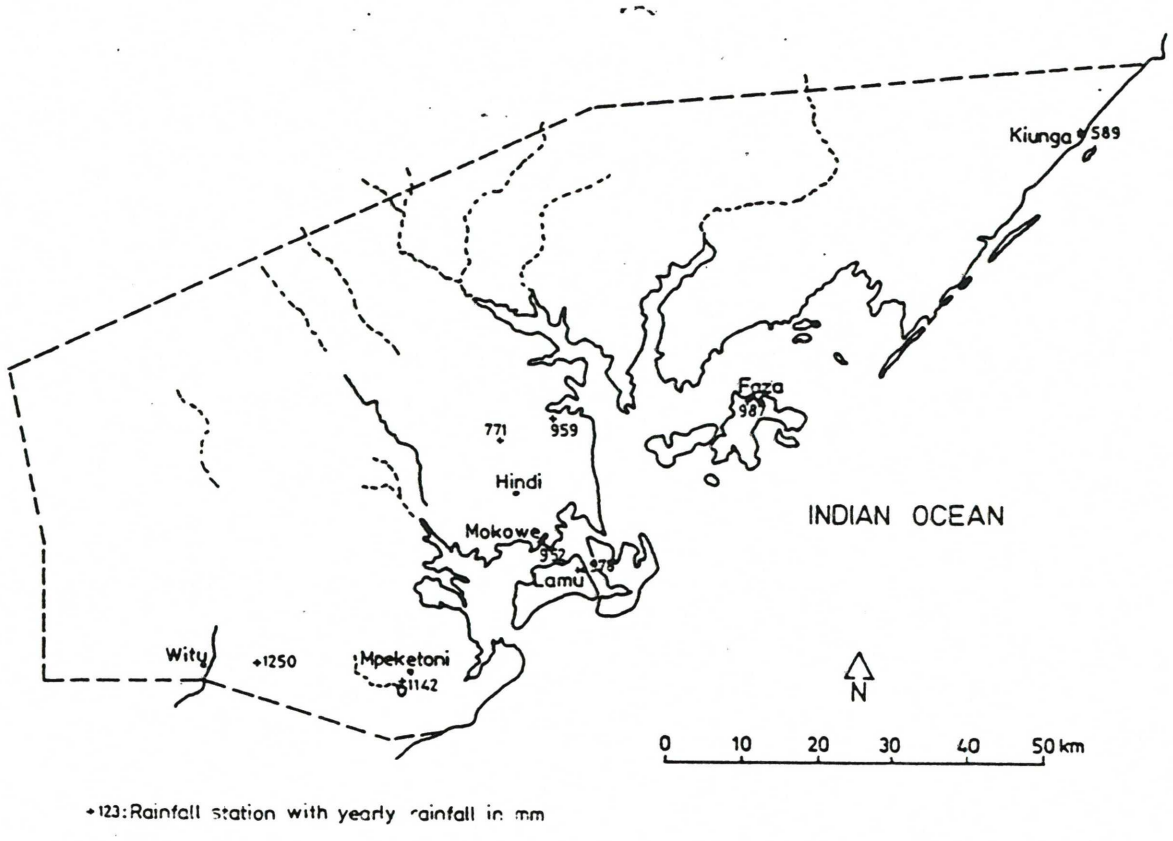



Figure 4.1. Location of Rainfall Stations in Lamu District

## 4.3 Evaporation

Potential Evaporation is fairly constant with an average varying between 220 mm (March) to 160 mm (June) and a total of 2,327 mm for an average year. The maximum is 245 mm (January) for dry years, while the minimum is 146 mm (July) for wet years. Except for the month of May the potential evaporation exceeds the monthly rainfall. These figures are for Lamu Met. station but can reasonably be applied to the whole district as the maximum potential evaporation will probably not exceed 2,400 mm per year.

## 4.4 Surface Runoff

There are no perennial rivers in Lamu District and no data exist concerning the volume of (flash) floods occurring in the major non perennial streams (the Mkondo wa Nainda, the Duldul and the Dodori river channels, see Plate 1). The general drainage pattern is from northwest to southeast while in the northern part the direction changes to northeast - southwest.

The floods can be considerable as shown in Figure 4.4, representing a photograph of the main road to Mokowe crossing the Mkondo wa Nainda River channel.

Figure 4.5 shows the areas of Lamu District classified according to drainage capacity. This map was derived from the Exploratory Soil Map of Kenya and illustrates what may be expected as regards surface runoff and recharge to groundwater.

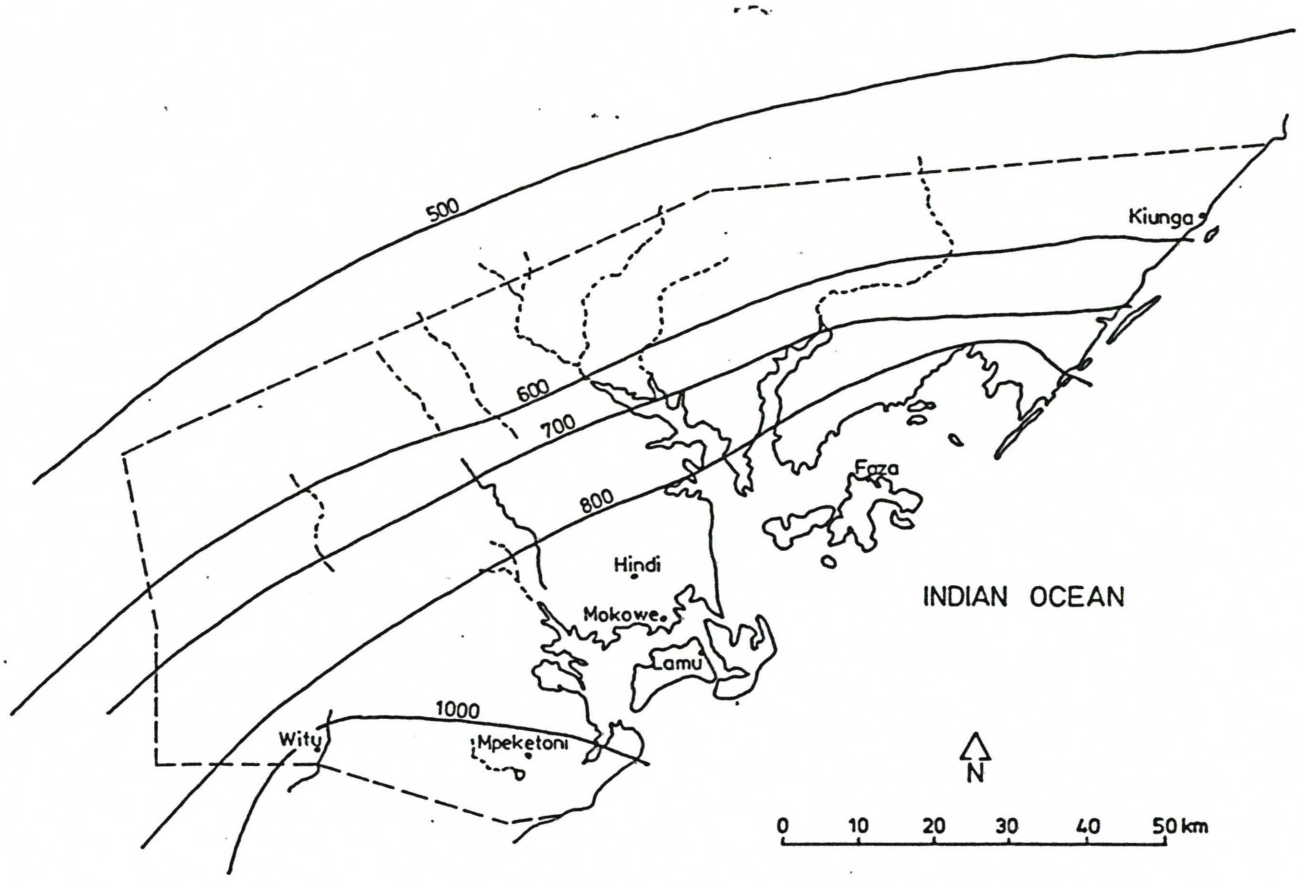



Figure 4.2. Isohyets for Lamu District

The imperfectly to very poorly drained areas are prone to flooding, with little recharge to the groundwater (an example is the lower reach of the Mkondo wa Nainda channel). Some poorly drained areas have internal drainage, such as Lake Kenyatta.

The moderately well drained area (greater part of the district) has some drainage channels; some channels arriving from the northwest terminate, which may indicate recharge to groundwater.

The well drained soils are located in the dune areas along the coast and are prominent inland in the Mundane Range. Recharge to groundwater may be considerable.

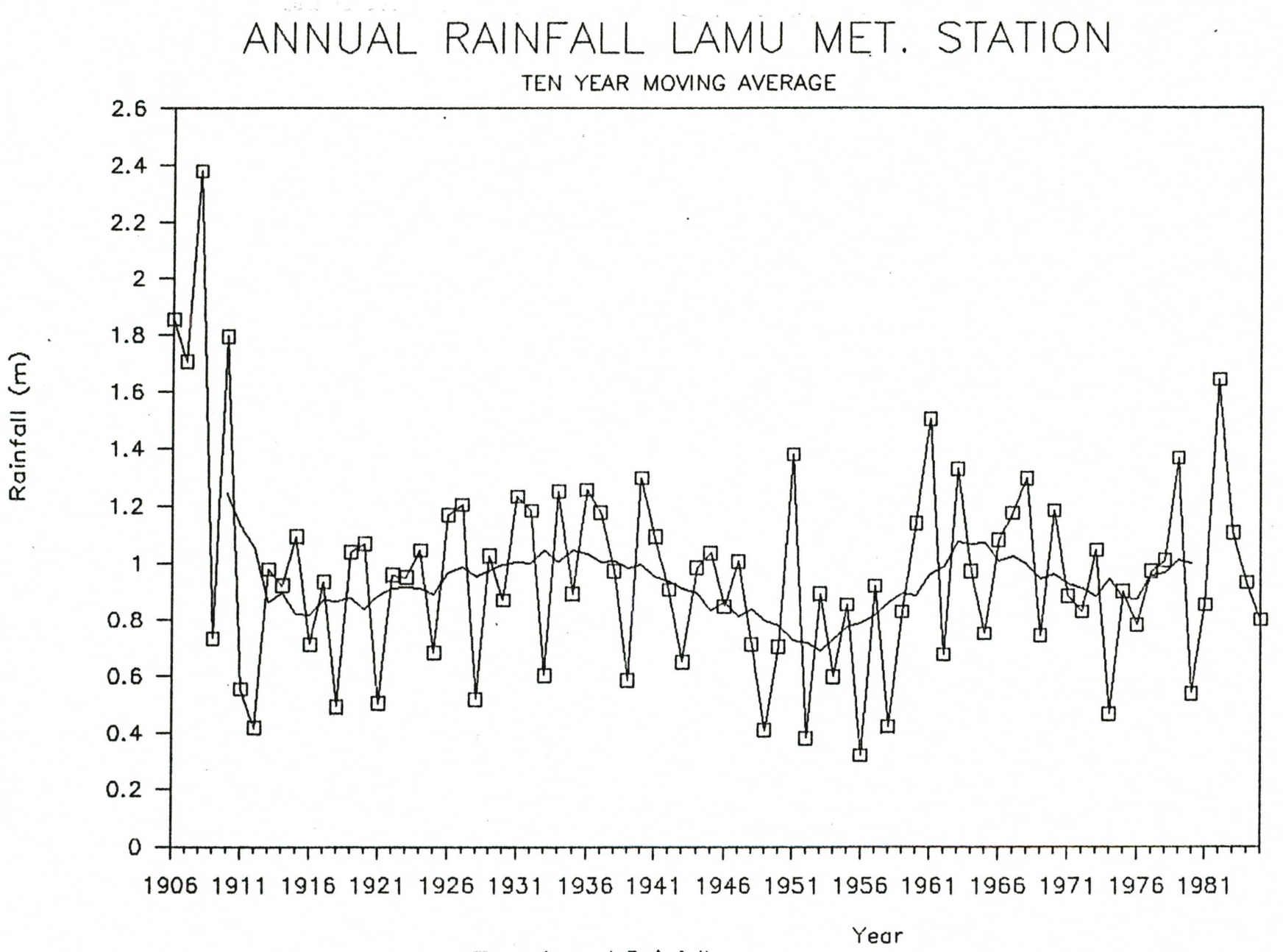
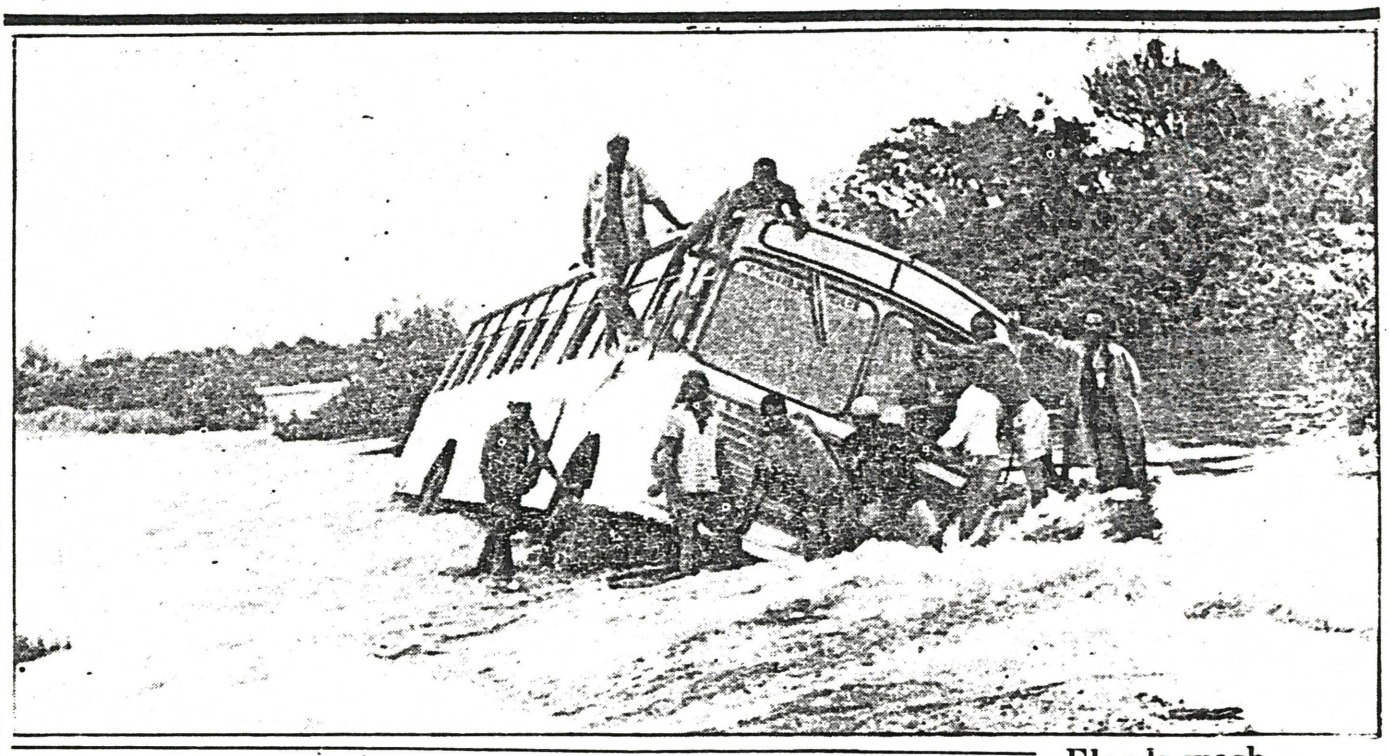



Figure 4.3 Annual Rainfall and 10-Year Moving Average for Lamu Met. Station



**Floods wash away bridge**

A bus belonging to the Tawakal Bus company lies on its side stranded at Milihoi bridge in Lamu. The bridge was washed away by floods. The Ministry of

Figure 4.4. Flood in the Mkondo Wa Nainda Channel at Milihoi Bridge

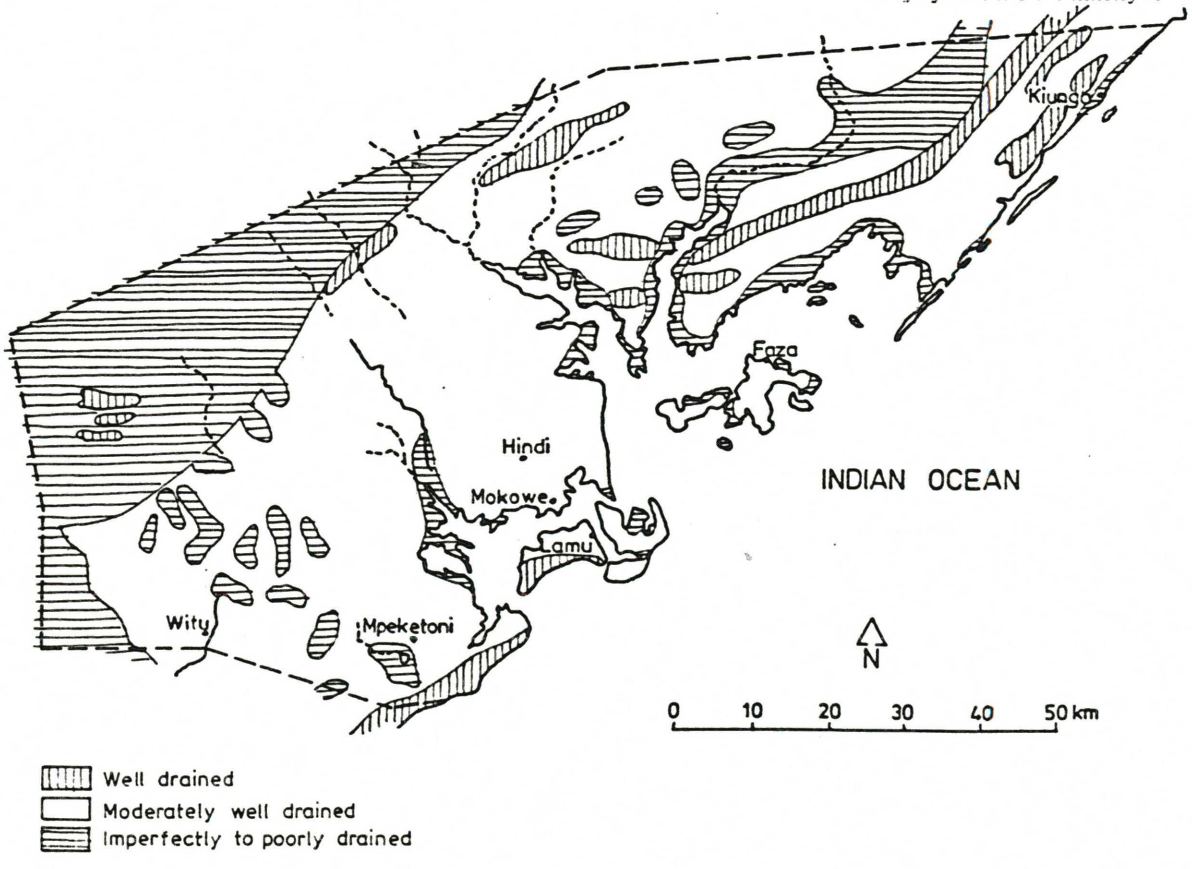



Figure 4.5. Soil Drainage in Lamu District

# 5. HYDROGEOLOGY

## 5.1 Available Data

Information on the hydrogeology of Lamu District is virtually non-existent in literature.

- Geology

The limestone deposits in the district are not very thick (20-30m) and rest on top of sand ranging from gravelly to clayey (see Figure 2.2.). The permeability of these limestones varies greatly from intercalations with clay layers to very porous coral deposits. Most of the recent sediments are clayey sands or sandy clays around the non-perennial streams and in the lagoons. Only the dune sands form recent deposits of high permeabilty.

- Aerial Photographs

From field observations and study of aerial photographs it is clear that most of the seasonal lakes (ziwa's) are sink holes. They form part of an internal drainage system. Many of these ziwa's are aligned in some way and not randomly distributed, see Figures B.1 and C.1. Not all lineaments are accompanied by ziwa's and can be ascribed to ridges and faulting.

- Lakes and Waterholes (Ziwa's)

The district has many waterholes which appear to be sinkholes. EC-measurements in many of them show that they have a very low content of Total Dissolved Solids (EC values are less than 20 mS/m). Also no salt deposits of any importance have been observed/reported after the surface water has disappeared at the end of the dry season. In February 1985 an EC of 35 mS/m was measured in a well situated 2 km south of Hindi right in the dry seasonal lake (water level 3m below surface, ZIWA LA SAFARISI).

From levels taken in Lake Kenyatta during January to March 1981, when rainfall was almost nil, a steady drop of 11 mm per day was observed (see Table 5.1). This is too much to be accounted for by evaporation alone which does not exceed 8 mm per day.

From the aforementioned it can be assumed that in the sinkhole areas (ziwa's) infiltration must take place, this infiltration may recharge the groundwater or is discharged as subsurface flow, depending on the underground permeability.

Recent investigations near Lake Kenyatta confirm this.

- Shallow Wells and Boreholes

Many shallow wells have been dug in the southwestern part of the district (Lake Kenyatta settlement scheme) and a lot yield fresh water for domestic purposes. On the other hand, many struck brackish water (in less permeable areas), while some wells have become brackish due to over-pumping.

Table 5.1 Relative Water Levels in Lake Kenyatta (Benchmark = 10.00 m)

| | 1979 | 1979 | 1980 | 1980 | 1980 | 1981 | 1981 | 1981 | 1981 | 1981 |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | November | December | February | March | April | January | February | March | April | May |
| 1 | 9.33 | 8.63 | | 7.29 | 7.05 | | 6.00 | 5.71 | 6.26 | 6.34 |
| 2 | 9.30 | 8.60 | | 7.31 | 7.07 | | 5.99 | 5.70 | 6.25 | 6.33 |
| 3 | 9.28 | 8.57 | | 7.31 | 7.09 | | 5.98 | 5.69 | 6.24 | 6.32 |
| 4 | 9.26 | 8.54 | | 7.29 | 7.08 | | 5.97 | 5.68 | 6.23 | 6.32 |
| 5 | 9.24 | 8.51 | | 7.27 | 7.07 | | 5.96 | 5.67 | 6.22 | 6.34 |
| 6 | 9.21 | | | 7.25 | 7.05 | | 5.95 | 5.66 | 6.21 | 6.35 |
| 7 | 9.18 | | | 7.24 | 7.04 | | 5.94 | 5.65 | 6.20 | 6.36 |
| 8 | 9.16 | | | 7.23 | 7.04 | | 5.93 | 5.64 | 6.19 | 6.37 |
| 9 | 9.13 | | | 7.21 | 7.02 | | 5.92 | 5.63 | 6.18 | 6.38 |
| 10 | 9.11 | | | 7.20 | 7.00 | | 5.91 | 5.62 | 6.17 | 6.37 |
| 11 | 9.08 | | | 7.19 | | | 5.90 | 5.61 | 6.16 | 6.35 |
| 12 | 9.06 | | 7.54 | 7.17 | | | 5.88 | 5.60 | 6.15 | 6.33 |
| 13 | 9.04 | | 7.52 | 7.16 | | | 5.87 | 5.58 | 6.14 | 6.31 |
| 14 | 9.01 | | 7.50 | 7.15 | | | 5.86 | 5.57 | 6.13 | 6.30 |
| 15 | 8.99 | | 7.48 | 7.14 | | | 5.85 | 5.62 | 6.14 | 6.28 |
| 16 | 8.95 | | 7.46 | 7.12 | | | 5.84 | 5.70 | 6.16 | 6.27 |
| 17 | 8.91 | | 7.44 | 7.11 | | 6.19 | 5.83 | 5.80 | 6.19 | 6.25 |
| 18 | 8.90 | | 7.42 | 7.10 | | 6.18 | 5.82 | 5.88 | 6.21 | 6.25 |
| 19 | 8.89 | | 7.41 | 7.09 | | 6.17 | 5.81 | 5.97 | 6.23 | 6.25 |
| 20 | 8.87 | | 7.40 | 7.08 | | 6.16 | 5.81 | 6.03 | 6.24 | 6.23 |
| 21 | 8.85 | | 7.40 | 7.07 | | 6.15 | 5.81 | 6.08 | 6.28 | 6.22 |
| 22 | 8.83 | | 7.38 | 7.06 | | 6.14 | 5.80 | 6.12 | 6.31 | 6.22 |
| 23 | 8.80 | | 7.37 | 7.07 | | 6.13 | 5.79 | 6.15 | 6.35 | 6.25 |
| 24 | 8.78 | | 7.36 | 7.09 | | 6.12 | 5.78 | 6.17 | 6.38 | 6.25 |
| 25 | 8.76 | | 7.35 | 7.09 | | 6.11 | 5.77 | 6.19 | 6.40 | 6.28 |
| 26 | 8.73 | | 7.33 | 7.11 | | 6.10 | 5.76 | 6.22 | 6.40 | 6.31 |
| 27 | 8.70 | | 7.32 | 7.13 | | 6.09 | 5.75 | 6.26 | 6.38 | 6.33 |
| 28 | 8.68 | | 7.31 | 7.12 | | 6.08 | 5.74 | 6.28 | 6.37 | 6.35 |
| 29 | 8.66 | | 7.29 | 7.09 | | 6.07 | | 6.30 | 6.36 | 6.38 |
| 30 | 8.64 | | | 7.07 | | 6.06 | | 6.29 | 6.35 | 6.43 |
| 31 | | | | 7.05 | | 6.03 | | 6.27 | | 6.46 |
| | monthly rainfall in Mpeketoni (mm) | | | | | | | | | |
| | -- | -- | -- | -- | -- | 1.5 | nil | 308.5 | 886.6 | 322.4 |

Table 5.2 is a list of boreholes in the district. The remarks that are made for the shallow wells also apply for the boreholes. However, from the recently drilled wells two out of five have a remarkable high yield while two are practically dry. This stresses the importance of proper siting for future boreholes.

- Chemical data

From the production wells in the dunes on Lamu island EC-measurements are taken and these are presented in Table 5.3. From 22 samples taken in Lamu District chemical analyses are presented in Table 5.4. The location of the samples is indicated on Plate 1.

Table 5.2 Borehole Records of Lamu District (Source MoWD)

| Borehole | Location | WSL (m) | WRL (m) | Est. Yield ($m^3/h$) | Remarks | Total Depth | UTM grid Coordinates | | Completion date |
|---|---|---|---|---|---|---|---|---|---|
| C3069 | Pandanguo | - | 45.1 | 1.82 | brackish | 58.5 | | | |
| C3223 | Mokowe | 2.4 | | | saline | 47.2 | 704.8 E | 9754.3 N | 23/09/60 |
| C3463 | Witu | 23.8 | 22.0 | 1.70 | fresh | 45.7 | 660.7 E | 9736.8 N | 23/10/67 |
| C3593 | Mkunumbi | 7.9 | | 2.05 | fresh | 12.2 | 689.2 E | 9744.8 N | 3/68 |
| C3594 | Bargoni | 13.7(?) | 18.3(?) | | saline | 25.9 | 699.2 E | 9771.6 N | 5/68 |
| C3595 | Bodhei | 41.2 | | | saline | 42.7 | 688.4 E | 9796.1 N | 6/68 |
| C3596 | Majengo | | 5.5 | 2.05 | fresh | 7.9 | 693.6 E | 9788.2 N | 7/68 |
| C3597 | Mangai | 3.7 | | | saline | 11 | 742.0 E | 9807.0 N | 10/68 |
| C3598 | Mararani | 8.5 | | | saline | 10.7 | 755.8 E | 9811.9 N | 10/68 |
| C7345 | Mpeketoni | 11.0 | 8.8 | 22.1 | fresh | 37.3 | 686.2 E | 9734.5 N | 25/04/87 |
| C7346 | Mpeketoni | 11.5 | 10.0 | 59.9 | fresh | 62.5 | 687.9 E | 9733.5 N | 2/05/87 |
| C7347 | Mpeketoni | 7.5 | | | fresh/sal. | 50 | 686.3 E | 9734.6 N | 10/05/87 |
| C7348 | Mpeketoni | dry | | | | 40 | 685.3 E | 9740.2 N | 12/05/87 |
| C7349 | Mpeketoni | dry | | | | 46.6 | 683.6 E | 9742.7 N | 13/05/87 |

Table 5.3 EC-Measurements in Production Wells on Lamu Island (24/09/85)

| Well No. | EC (mS/m) | Well No. | EC (mS/m) |
|---|---|---|---|
| 1 | 38 | 11 | 40 |
| 2 | 43 | 12 | - |
| 3 | 43 | 13 | 34 |
| 4 | 50 | 14 | 40.5 |
| 5 | 43 | 15 | 41.5 |
| 6 | 50 | 16 | 49.5 |
| 7 | 42.5 | 17 | 49 |
| 8 | 53.5 | 18 | 57 |
| 9 | 49 | 19 | 37 |
| 10 | 43.5 | 20 | 45 |

For the location of the production wells on the island see Figure A.1.

## 5.2 Groundwater Occurrence

It is known that in the sand dunes on Lamu Island substantial fresh water storage takes place. This might also be the case in other dune areas in the district. However, investigations are necessary to establish the permeability, up to sufficient depth, to ensure that storage actually takes place.

Figure 4.5 shows that also the Mundane Range in the north east of the district may have potential for groundwater storage. Compare this with the elevated areas in Plate 1.

Near Lake Kenyatta a substantial groundwater reservoir has been tapped.

Table 5.4 Chemical Water Samples Taken in Lamu District

| | Place of Sampling & No.** | Date | Colour# | Turbidity | Deposit | pH | mg/l TDS | Hardness | Alkalinity | Ca | Fe | Mg | Mn | F | NO3 | SO4 | Cl | Zn* | SiO2 | Free CO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Lake Kenyatta | 25.2.80 | 50 | 12.0 | silt | 7.1 | 111 | 72 | 91 | 32.0 | 0.1 | 3.4 | 0.1 | nil | - | 0.7 | 18 | 0.70 | 20 | 7.0 |
| 2 | Mpeketoni Centre | 25.2.80 | <5 | 7.0 | silt | 7.4 | 470 | 288 | 236 | 73.2 | nil | 25.2 | nil | 0.14 | - | 2.3 | 86 | 0.01 | 20 | 19.5 |
| 5 | Witu Well | 25.2.80 | <5 | 0.1 | debris | 7.6 | 1100 | 370 | 340 | 120.0 | 0.1 | 16.8 | nil | 0.23 | - | 76.9 | 240 | <0.01 | 15 | 18.0 |
| 6 | Witu W.S. | 25.2.80 | <5 | 3.0 | nil | 8.7 | 610 | 286 | 378 | 81.6 | nil | 19.7 | nil | 0.34 | - | 20.0 | 68 | 0.10 | 40 | nil |
| 7 | Lamu Well No.7 | 25.2.80 | 5 | 0.8 | silt | 8.1 | 400 | 212 | 226 | 44.8 | 0.2 | 24.0 | nil | 0.81 | - | 11.9 | 70 | <0.01 | 30 | nil |
| 8 | Well At Uziwa L.E.S.S. | 25.2.80 | <5 | 0.1 | silt | 7.6 | 1000 | 260 | 180 | 88.0 | nil | 9.6 | nil | nil | - | 16.8 | 300 | <0.01 | 5 | 17.0 |
| 10 | Well Plot 1511 L.E.S.S. | 25.2.80 | 5 | 3.0 | debris | 8.1 | 2500 | 712 | 356 | 181.6 | 0.2 | 62.0 | nil | 0.12 | - | 116.0 | 1010 | <0.01 | 5 | nil |
| 11 | Baharini Pond | 25.2.80 | 60 | 0.2 | silt | 7.1 | 4000 | 874 | 80 | 163.2 | nil | 112.0 | nil | 0.42 | - | 42.0 | 2800 | <0.01 | 5 | 4.0 |
| 14 | Matondoni Inland | 6.11.80 | 40 | 2.0 | silt | 7.7 | 500 | 120 | 308 | 32.0 | 0.7 | 14.4 | nil | 0.40 | 0.6 | 4.7 | 84 | 0.20 | 30 | 6.0 |
| 15 | Matondoni Well in town | 6.11.80 | 10 | 2.0 | silt | 7.9 | 1550 | 600 | 320 | 136.0 | nil | 62.4 | nil | 0.40 | 70.9 | 37.5 | 350 | 0.12 | 60 | 5.0 |
| 16 | Mkunumbi Jarabu Well | 6.11.80 | <5 | 4.0 | silt | 7.5 | 6500 | 2410 | 220 | 532.0 | 1.5 | 259.2 | nil | 0.40 | 141.8 | nil | 6180 | 0.50 | 3 | 18.0 |
| 17 | Hongwe St. Mary's Church | 7.11.80 | <5 | nil | nil | 8.4 | 3300 | 1120 | 520 | 300.0 | nil | 88.8 | nil | 1.45 | 2.2 | 40.0 | 2950 | <0.01 | 110 | nil |
| 20 | Bargoni Hafir | 7.11.80 | 650 | 250.0 | silt | 7.5 | 80 | 34 | 46 | 7.2 | 12.0 | 3.8 | nil | 0.95 | 4.0 | nil | 4 | <0.01 | 10 | 7.0 |
| 21 | Hindi Prison Old Well | 7.11.80 | <5 | nil | debris | 8.1 | 245 | 136 | 146 | 4.8 | nil | 3.8 | 0.1 | 1.10 | 4.4 | nil | 18 | <0.01 | 5 | 2.0 |
| 22 | Hindi Prison W.S | 7.11.80 | <5 | nil | debris | 7.9 | 350 | 206 | 168 | 63.0 | nil | 11.5 | 1.3 | 1.20 | 6.2 | nil | 78 | <0.01 | 20 | 6.0 |
| 23 | Mapenya | 7.11.80 | 5 | 5.0 | silt | 7.8 | 3600 | 1400 | 380 | 380.0 | 0.1 | 1.8 | nil | 0.68 | 13.3 | 35.0 | 1430 | <0.01 | 30 | 8.0 |
| 24 | Manda Well | 7.11.80 | <5 | 6.0 | nil | 8.2 | 4500 | 900 | 302 | 136.0 | nil | 134.4 | nil | 0.94 | nil | 90.0 | 1635 | <0.01 | 20 | nil |
| 25 | Manda Jabir | 7.11.80 | 5 | 5.0 | silt | 8.1 | 220 | 70 | 84 | 16.8 | 0.1 | 6.7 | nil | 0.65 | nil | 1.0 | 38 | <0.01 | 10 | 3.0 |
| 26 | Shela Well Near Shore | 7.11.80 | <5 | 5.0 | debris | 8.4 | 1000 | 380 | 300 | 108.0 | 0.1 | 26.4 | 0.2 | 0.87 | 2.8 | 40.0 | 400 | <0.01 | 20 | nil |
| 27 | Shela Well | 7.11.80 | <5 | 5.0 | silt | 8.5 | 650 | 206 | 230 | 48.0 | nil | 20.6 | nil | 0.67 | 4.4 | 14.0 | 260 | <0.01 | 20 | nil |
| 28 | Kiongwe Well | 7.11.80 | <5 | 6.0 | silt | 7.5 | 11000 | 2350 | 426 | 440.0 | nil | 300.0 | nil | 0.90 | 106.3 | 175.0 | 5000 | <0.01 | 20 | 25.0 |
| 29 | Well at Baharini Dunes | 6.11.81 | 60 | 1.5 | debris | 6.8 | 350 | 118 | 174 | 35.2 | 0.7 | 7.2 | nil | 0.40 | 3.5 | 1.0 | 29 | <0.01 | 40 | 37.0 |

#Platinum-Cobalt scale
*The figures for the sources and treated water do not correspond
Both Cu and Pb are <0.001 mg/l in all samples
**Places are indicated with sample no. on Plate 1

Whether more deep aquifer systems exist is unknown.

Extensive shallow fresh water aquifer systems do not exist. Although the water table can be considered continuous in most places, the great variability in permeability of the sediments cause considerable differences in water quality with brackish water in the less permeable areas.

Figure 4.5 shows that more than half of the district has moderately well drained soils, therefore there must be considerable infiltration or subsurface outflow to the ocean.

## 6. WATER DEMAND, WATER SUPPLIES

### 6.1 Water Demand

- Population

According to the census of 1979 the district population was 42,300. The Lamu District Development Plan gives a growth rate of 5.15 % per annum with the following projections up to 1988 in Table 6.1.

Table 6.1 Lamu District: Population Distribution in 1979 and Projections for 1983/88

| Administrative Division | Area* (sq km) | Population | | | | Density |
|---|---|---|---|---|---|---|
| | | 1979 | 1983 | 1985 | 1988 | 1988 |
| Witu | 1,232 | 3,349 | 4,245 | 4,707 | 5,494 | 4.5 |
| Mpeketoni | 1,429 | 11,770 | 14,920 | 16,542 | 19,307 | 13.5 |
| Amu | 1,256 | 13,850 | 17,556 | 19,465 | 22,720 | 18.1 |
| Faza | 571 | 11,696 | 14,826 | 16,438 | 19,186 | 33.6 |
| Kiunga | 2,018 | 1,634 | 2,071 | 2,296 | 2,680 | 1.3 |
| Totals | 6,506 | 42,299 | 53,618 | 59,448 | 69,387 | 10.7 |

*Divisional boundaries have recently been changed. Therefore the figures for Faza and Kiunga do not correspond with the present reality.

From Table 6.1 a growth rate of 5.65 % results between 1979 and 1988. When using this figure the estimates for 1990 are shown in Table 6.2. The new division boundaries for Faza and Kiunga are taken into account.

Table 6.2 Lamu District: Population Distribution Projection for 1990

| Division | Area | Population | Density |
|---|---|---|---|
| Witu | 1,232 | 6,132 | 5.0 |
| Mpeketoni | 1,429 | 21,552 | 15.1 |
| Amu | 1,256 | 25,361 | 20.2 |
| Faza | 1,500 | 21,713 | 14.5 |
| Kiunga | 1,100 | 2,690 | 2.4 |
| Totals | 6,517 | 77,448 | 11.9 |

- Livestock

Table 6.3 presents the livestock numbers for the district. For the coastal area a livestock unit (LSU) is equivalent to 3 cattle, or 15 goats/sheep or 1.25 camel. One LSU represents 75 liters of water per day.

Table 6.3 Livestock Numbers by Division - 1983

| Division | Cattle | Sheep & Goats | LSU (cattle & sheep | POULTRY |
|---|---|---|---|---|
| Witu | 18,630 | 9,243 | 6,826 | 22,780 |
| Mpeketoni | 6,210 | 3,081 | 2,275 | 56,950 |
| Amu | 12,420 | 6,126 | 4,548 | 22,780 |
| Faza | 2,898 | 1,438 | 1,062 | 6,834 |
| Kiunga | 1,242 | 616 | 455 | 4,556 |
| Total | 41,400 | 20,504 | 15,166 | 113,900 |

(Source: District Livestock Development Office Lamu)

## 6.2 Water Supplies

There are seven existing water supplies in the district:

- **Lake Kenyatta Water Supply Scheme:** Run by Government Administration, supplies Mpeketoni, water not treated, supply 7 $m^3$/day.
- **Lamu Water Supply:** Run by MoWD, supplies Lamu Town, Mokowe on the mainland and Manda Island. The water is chlorinated, supply is 800 $m^3$/day (August 1986) of which 600 $m^3$/day supplies Lamu Town, the rest is exported.
- **Mokowe:** Supplied from Lamu Water Supply, supply 60 $m^3$/day (August 1986)
- **Manda Island:** (Ras Kitau Hotel), supplied from Lamu Water Supply, 40 $m^3$/day
- **Hindi G.K. Prison:** Run by prison, source: 5 m deep well, supply un-known, untreated.
- **Bargoni:** Run by Bargoni Livestock Marketing Holding Ground source: man-made dam (hafir), supply un-known diesel pump 6,5 H.P, untreated
- **Witu Water Supply:** Community owned, source: well, capacity pump 1.2 $m^3$/hr, not treated

Only three of these supplies; Lamu Water Supply, Lake Kenyatta Water Supply Scheme (Mpeketoni) and Witu have a reticulated system. Lamu Water Supply

delivers also to Mokowe and Manda and is the only system with treated water. Total population served by these systems in estimated to be 23,000 or 30 % of district population (see Section 6.1).

In the areas without water supply water is collected from ponds or lakes, from wells or by means of rainwater catchments (djabia). A survey in the Lake Kenyatta Project Area (Cowi Consult) shows the use of water sources in Table 6.4 as follows.

Table 6.4 Use of Water Sources in Lake Kenyatta Area

| | Well | Pond | Lake | Nearest Water supply |
|---|---|---|---|---|
| | % | % | % | % |
| Wet season | 61 | 32 | 7 | 0 |
| Dry season | 48 | 32 | 16 | 4 |

# 7. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

## 7.1 Conclusions

- Lamu Island

From the collected data and limited fieldwork the following may be concluded:

. Fresh water occurrence in the dune area is sufficient for the present needs of the Lamu Island population.

. Extension of the wellfield to double the present capacity is now under construction and will be expected to satisfy the present needs.

. The dune area west of the present well field and the one under construction is large and therefore may well be able to supply also the long term needs of the island. However, further investigations are necessary.

- Mainland

The situation on the mainland is more complicated. Generally, the low lying areas along the coast are unreliable as a source for large scale water supplies. There is little capacity for fresh water storage.

Some capacity exists but this has to be found in the (sometimes fossil) dunes and the elevated limestone areas. These areas generally have a higher transmissibility and therefore the presence of fresh water lenses is more likely:

. Near Lake Kenyatta an underground coral reef exists with high permeability which stores fresh water originating from the lake.

. This situation may also exist south-east of Hindi where a swamp may transmit water to coral limestone.

. On Pate Island some elevated areas exist. Dependent on the permeability they may contain fresh water.

. The northeastern coastal part of the district has dunes and ridges which may contain appreciable amounts of fresh water.

. An interesting possibility is the Mondane Range because of its large areal extent and elevation. Investigations are necessary.

Further inland, the area in general has a higher elevation but is also dryer. No data are available to give any conclusions, especially in the northwestern part of the district which is very sparsely populated.

## 7.2 Recommendations for Further Investigations

Lamu District has limited water resources. Development however is possible in certain areas but further investigations are necessary as follow-up to this reconnaissance survey.

- Lamu Island

It is recommended to further investigate the western dune area on the island. Important is to establish:

. The transmissibility of the dune area.

. The geological profile to establish any occurrence of clay layers beneath the sand which may limit fresh water storage.

. Effective recharge from precipitation.

Two exploratory boreholes are necessary to establish the depth to the saline interface. Also a programme for monitoring the existing boreholes should be initiated.

- Mainland

Investigations should be carried out in:

. Northeastern coastal area, in particular the Mundane Range, the dunes and ridges to investigate the possibilities to supply water to Kiunga, Mkokoni, Shakani. EM surveys supplemented by geo-electrical surveys and exploratory drilling are necessary.

. Pate Island, where the elevated parts of the island may be used for water supply. Geophysical surveys and exploratory drilling are necessary.

. Manda Island. Very limited potential exists but should be investigated in the manner described above.

. Hindi-Magogoni area for location of permeable limestone deposits. Geophysical surveys and exploratory drilling are necessary.

. North-western area: this area is very sparsely populated and arid. Only if developments are foreseen in the near future are investigations necessary. For now, the majority of the population lives on Lamu Island or in the coastal strip where investigations have higher priority.

REFERENCES


- Publications and Maps

. Cowi Consult, 1983, Lake Kenyatta Water Supply Project.

. Diettrich T.E.K., 1985, Rural Water Supply of Lake Kenyatta and Hindi Settlement Scheme.

. Groundwater Survey (Kenya) Ltd., 1987, Lake Kenyatta Settlement Scheme Groundwater Investigation.

. Grundy F., 1953, Lamu Water Supply Groundwater Investigation (Internal Document, Provincial Water Engineer,Mombasa).

. German Assisted Settlement Programme (GASP), 1984 Topographical maps scale 1:10,000 with 1m contours for Lake Kenyatta and Hindi Magogoni Settlement Scheme.

. Ministry of Agriculture, Kenya Soil Survey, 1980 Exploratory Soil Map and Agroclimatic Zone Map of Kenya, Scale 1:1,000,00.

. Ministry of Finance and Planning, Lamu District Development Plan 1984-1988.

. Ministry of Natural Resources, T.Woodhead,1968 Studies of Potential Evaporation.

. Ojany F.F. and Ogendo R.B, 1973, Kenya: A Study in Physical and Human Geography

. Selby J., 1969, Lamu Island Water Supply. Hydrogeological Report

. Survey of Kenya, 1982, Bouguer Gravity Anomaly Map of Kenya, Scale 1:1,000,000.

. Survey of Kenya, East Africa Mean Annual Rainfall Map, Scale 1:2,000,000.

. Survey of Kenya

Topographical Maps, Scale 1:50,000 series Y731

| | | | |
|---|---|---|---|
| 1981 | sheet | 179/2 | Pandanguo |
| 1981 | sheet | 179/4 | Witu |
| 1981 | sheet | 180/1 | Mkunumbi |
| 1981 | sheet | 180/2 | Lamu |
| 1981 | sheet | 180/3 | Milhoi |
| 1981 | sheet | 180/4 | Mokowe |
| 1981 | sheet | 180E/1 | Pate |

Scale 1:250,000 Series Y503

| | | | |
|---|---|---|---|
| 1970 | sheet | SA 37-8 | Kolbio |
| 1971 | sheet | SA 37-11/12 | Lamu |

- Aerial Photographs and Satellite Images

. Survey of Kenya

Aerial photographs, scale 1:12,500 Lamu Island
Aerial photographs, scale 1:60,000 part of Lamu District, see Figure 2.1 for coverage.

. Landsat, SPOT

Satellite images are available but due to the more than 25% cloud cover (increasingly over the land surface) they are not of the necessary quality.

# APPENDIX A

## DESCRIPTION OF GEOPHYSICAL SURVEY ON LAMU ISLAND

# LAMU ISLAND

## a.1 Introduction

In the beginning of 1985, at the request of the Chief Geologist in the Ministry of Water Development, WRAP carried out a geophysical investigation on Lamu Island.

The main purpose was to detect fresh water occurrence for the possible extension of the existing well field in the Shela dunes.

## a.2 Field Work

In the months of January and February 1985, 23 vertical electrical soundings (VES's) were carried out in and around the dunes on the south coast of the island.

The locations of the VES's are shown on the map in Figure A.1. Table A.1 gives a list of the VES's and their identifiers (L/2, X-coordinate and Y-coordinate in m; elevation in m + MSL and direction in degrees from the north). At the end of the field work period an electromagnetic (EM) profile was run over 850 m behind the dunes, to check the possibility of detecting clay layers.

The location of the profile is marked on the map in Figure A.1.

## a.3 Interpretation

Interpretation is basically done by matching the field curve (plotted measured values) with a calculated curve from a model. The resulting model can be regarded as a possible, non-unique, representation of the subsurface geohydrological situation.

In most cases equivalent models can be chosen which render the same calculated curve (principle of equivalence).

In the case of fresh water saturated dune sands with a dry top layer and a salt water saturated base layer, sufficient resistivity contrast exists to find a representative layer-model for a unique interpretation. However, when between layers with high contrast a relative thin, intermediate layer exists with intermediate resistivity, this layer will not show up in the curve (principle of suppression).

The use of additional data, such as known boundaries (depth to water table, clay layers, hard rock) and known resistivities (from resistivity well logs), can raise the reliability of the interpretation substantially. However, on Lamu Island very few additional data are available.

Some water levels and some electrical conductivities (EC) are known. From the EC of fresh dune water a resistivity of 20-25 Ωm can be calculated. Assuming a formation factor of around 2-3 for fine dune sands, the resistivity of fresh water bearing layers in the dunes, will be around 40-60 Ωm. This is according to the formula Rf=Rw*F, where Rf is the resistivity of the water bearing formation, Rw the resistivity of the water and F the formation factor. Similarly, a resistivity for seawater bearing layers can be calculated at around 1 Ωm.

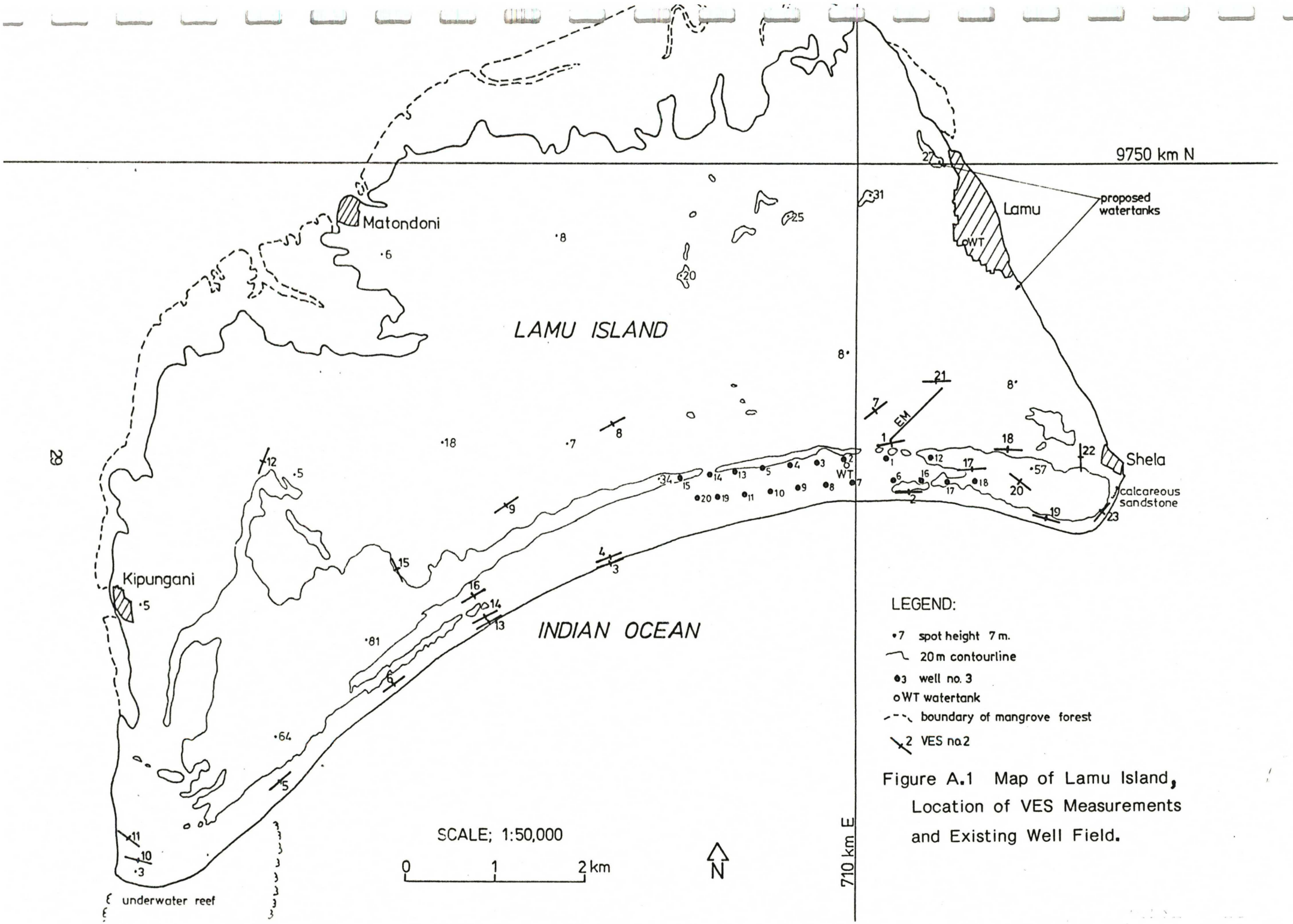



Figure A.1 Map of Lamu Island, Location of VES Measurements and Existing Well Field.

Table A.1 List of VES Data, Lamu Island

| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |
|---|---|---|---|---|---|---|
| LAMU 1 | 130.0 | 710360 | 9746880 | 300185 | ? | 93 |
| LAMU 2 | 80.0 | 710590 | 9746320 | 300185 | ? | 358 |
| LAMU 3 | 50.0 | 707290 | 9745550 | 310185 | ? | 67 |
| LAMU 4 | 100.0 | 707270 | 9745600 | 310185 | ? | 67 |
| LAMU 5 | 100.0 | 703610 | 9743190 | 310185 | ? | 75 |
| LAMU 6 | 100.0 | 704880 | 9744210 | 310185 | ? | 51 |
| LAMU 7 | 130.0 | 710220 | 9747260 | 010285 | ? | 76 |
| LAMU 8 | 130.0 | 707310 | 9747140 | 040285 | ? | 61 |
| LAMU 9 | 130.0 | 706110 | 9746230 | 040285 | ? | 69 |
| LAMU 10 | 20.0 | 702070 | 9742290 | 050285 | ? | 75 |
| LAMU 11 | 63.0 | 701970 | 9742530 | 050285 | ? | 95 |
| LAMU 12 | 80.0 | 703430 | 9746720 | 050285 | ? | 54 |
| LAMU 13 | 50.0 | 705950 | 9744890 | 060285 | ? | 57 |
| LAMU 14 | 100.0 | 705920 | 9744930 | 060285 | ? | 57 |
| LAMU 15 | 160.0 | 704930 | 9745460 | 070285 | ? | 165 |
| LAMU 16 | 160.0 | 705760 | 9745160 | 080285 | ? | 59 |
| LAMU 17 | 160.0 | 711260 | 9746610 | 110285 | ? | 87 |
| LAMU 18 | 160.0 | 711680 | 9746820 | 110285 | ? | 95 |
| LAMU 19 | 63.0 | 712110 | 9746060 | 120285 | ? | 108 |
| LAMU 20 | 130.0 | 711820 | 9746480 | 120285 | ? | 140 |
| LAMU 21 | 100.0 | 710890 | 9747630 | 120285 | ? | 90 |
| LAMU 22 | 200.0 | 712450 | 9746740 | 130285 | ? | 3 |
| LAMU 23 | 130.0 | 712610 | 9745960 | 130285 | ? | 85 |
| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |

Layers with brackish water are only put into a model when the sounding is made inland at some distance from the dunes and only when the presence of brackish groundwater has been established.

In many VES's the measured values near the end of the sounding are higher than expected. This might be explained by the fact that most resistivity equipment is not powerful enough to measure in circumstances where a combination is encountered of high contact resistance of the dry dune sand and the very low resistivity of salt water saturated layers.

For example, VES 13, Figure A.3, shows a very smooth field curve and tends to approach a resistivity value of 4 Ωm at more than 40 m depth. This seems quite unrealistic as the sounding is located very close to the ocean. The same holds for VES 6 where even higher values seem to reach even greater depths. Without additional data no plausible interpretation can be given.

Most calculated curves from the models show an "upsweep" in the lowermost part. This is due to the calculating programme which is unable to cope with the high contrast in the models. At the time of interpretation no better programme was available for microcomputers. However, this shortcoming does not affect the reliability of the other part of the curve.

The elevation of the soundings on Lamu Island is only known very roughly (± 5 m). It is therefore difficult to plot them in the cross sections. As the dunes are very close to ocean, the shape of the interface between fresh water and saline water may be approximated according to a principle stated by Badon, Ghyben and Herzberg.

This principle states that in a fresh water lens on top of saline water, the thickness of the lens above mean sea level will compare to the thickness below mean sea level with a ratio of 1 to 40, assuming a homoge- neous formation and a density of the saline water of 1.025. In this way it is possible to plot the fresh water bearing layer in the cross sections and to infer the elevation.

The EM profile was run with a coil separation of 50 m and a station interval of 10 m. At every station and with six frequencies (222, 444, 888, 1,777 and 3,555 Hz) the out-of-phase response (Quadrature, QP) and the in-phase (IP) response was measured. The values have been submitted to a weighted running average of five elements to smooth out geometrical effects. The plot is shown in Figure A.2.

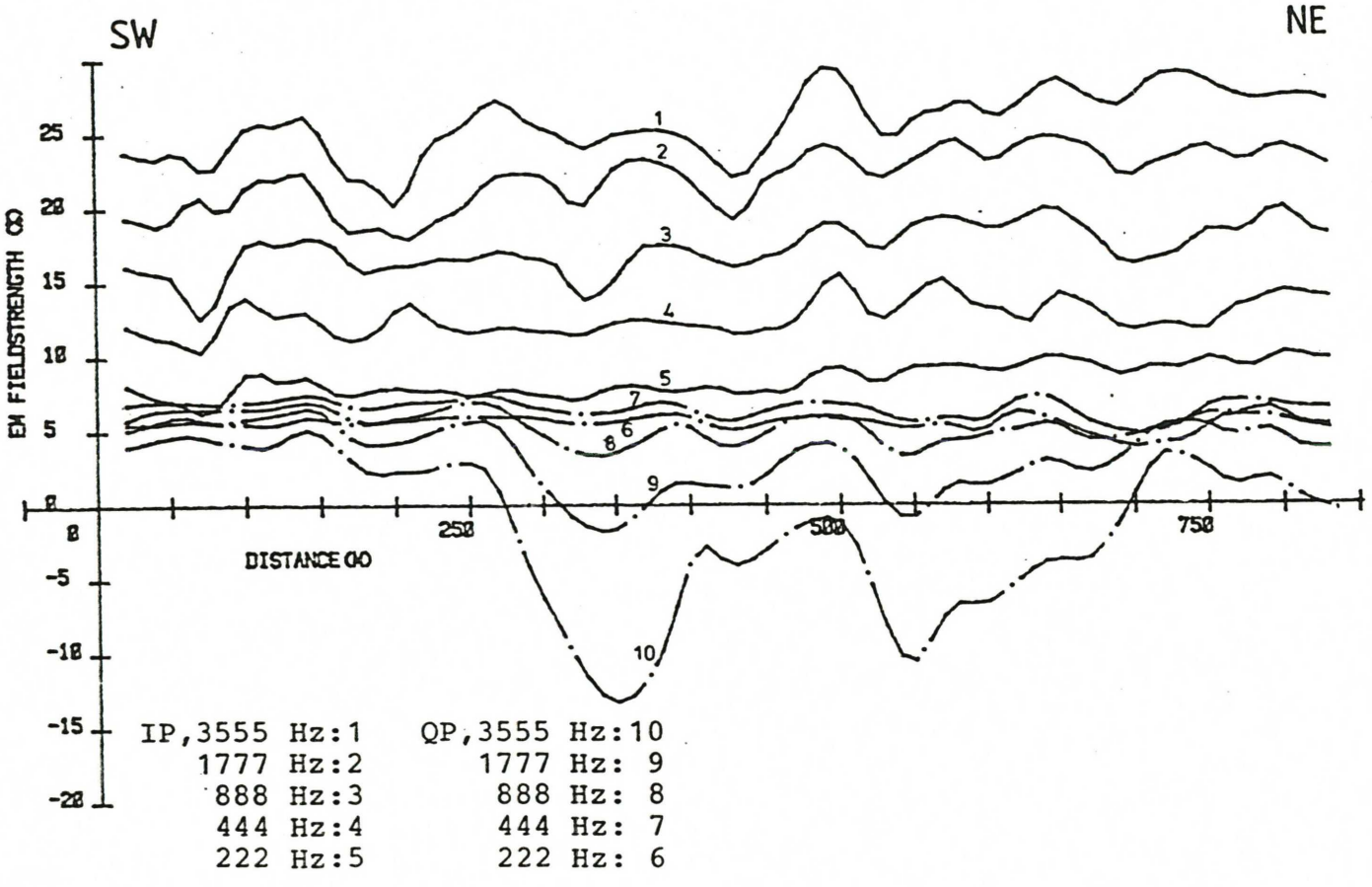



Figure A.2 EM-Profile Lamu Island

As the QP-response is lower than the IP response, it can be concluded that the resistivity is decreasing with increasing depth. The low response of the QP component at the high frequencies is indicative of a good conductor at relative shallow depth (clay).

However, the calculation of the depth and the resistivity of the layers, was not possible at the time of interpretation. In the near future a calculation programme might become available, which can be run on microcomputers.

## a.4 Summary of Results

Plots of the measured resistivities with the interpreted layer models and corresponding calculated curves are shown for every VES in Figures A.3-1 through A.3-22. Dots represent the measured values. The horizontal axis shows half the electrode distance and the vertical axis the apparent resistivity.

Four cross-sections through the dune area are drawn in Figures A.4-1 and A.4-2. These show the correlation between some of the interpreted VES and the topography.

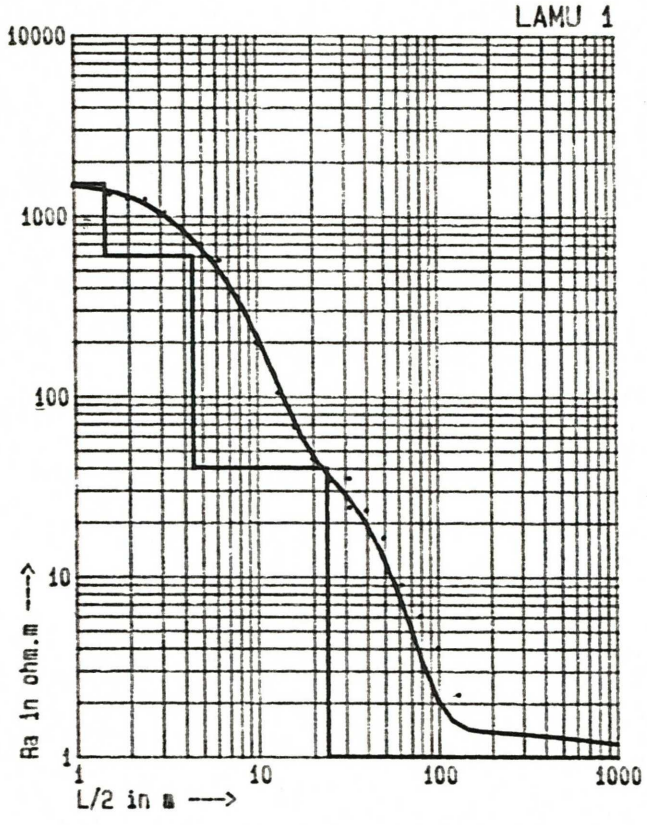
In all the sections fresh water pockets do occur and an extension of the production well field is possible.

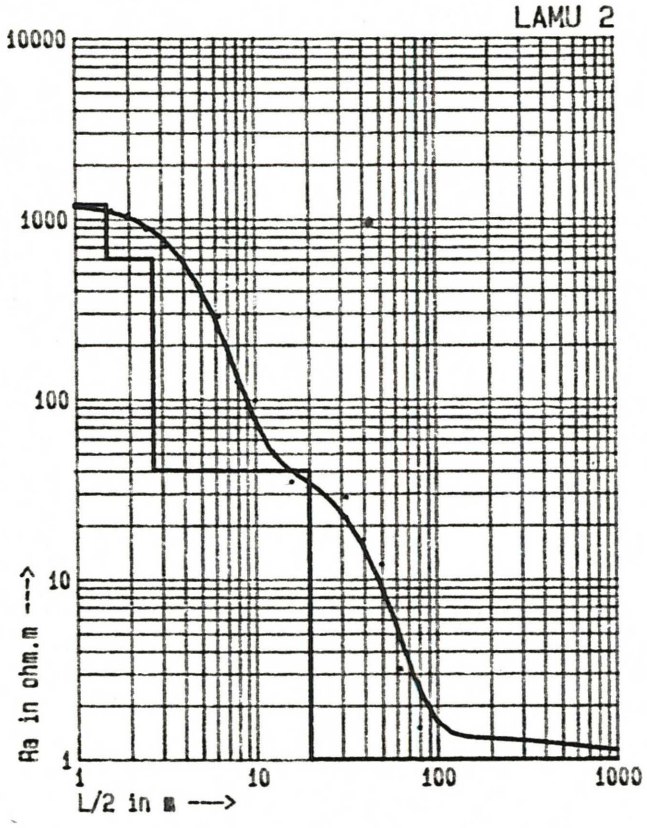
To monitor the behaviour of the fresh water pocket due to pumping it is necessary to have some monitoring wells in the production well field and some outside it, the last ones to monitor the natural behaviour of the aquifer during rainy seasons and dry spells and to estimate the effective recharge to the groundwater.

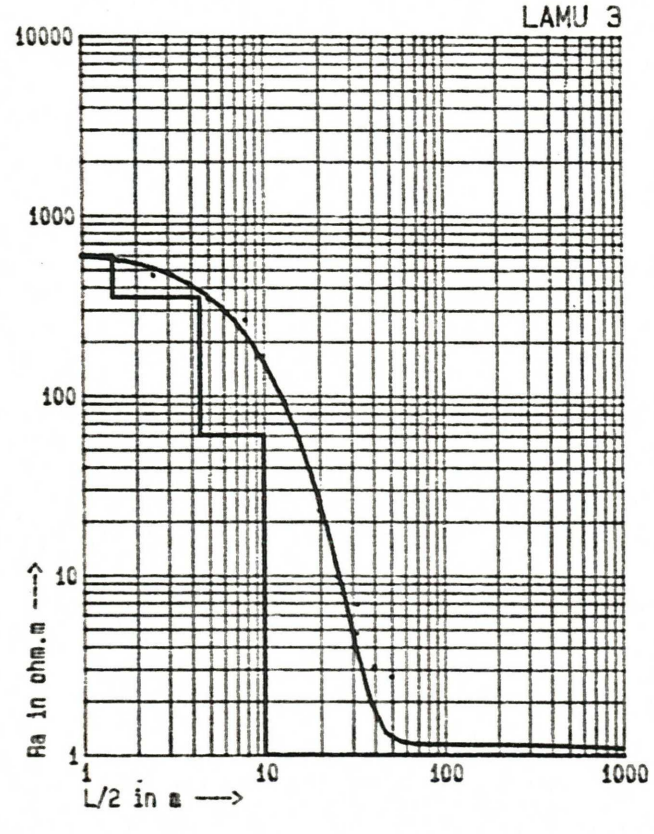
With the EM-profile it was possible to detect clay layers, however in a qualitative way only.

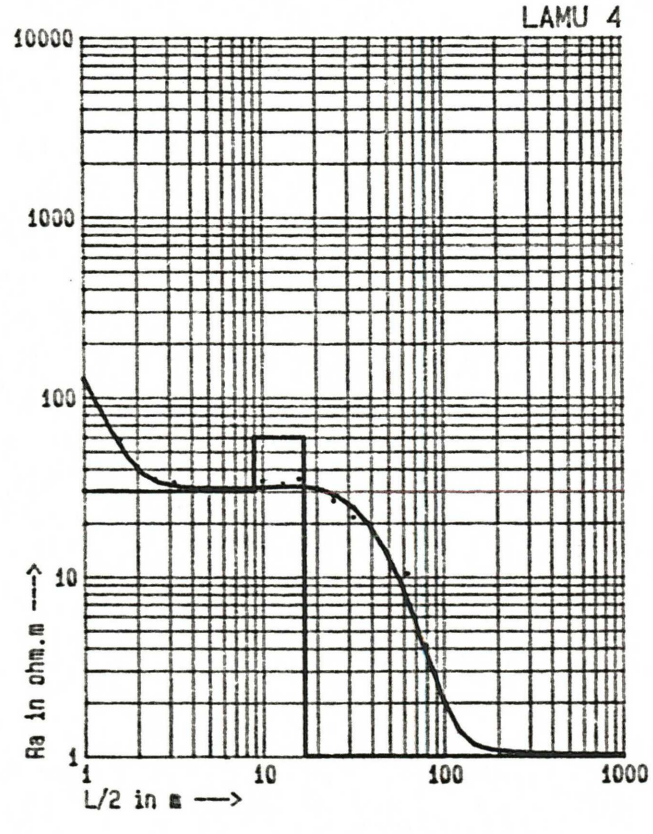
Figure A.3 VES PLots of Lamu Island

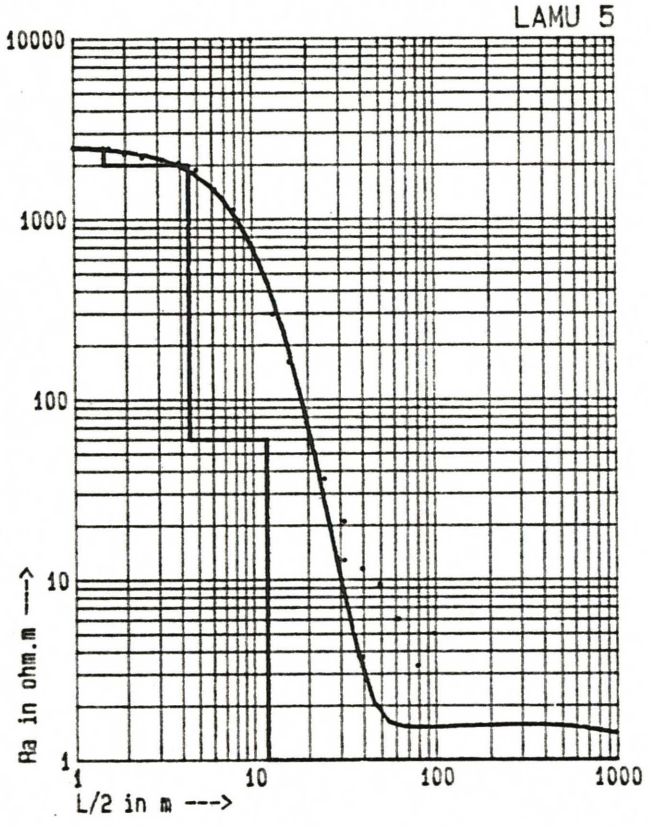
VES LAMU-1 through VES LAMU-22

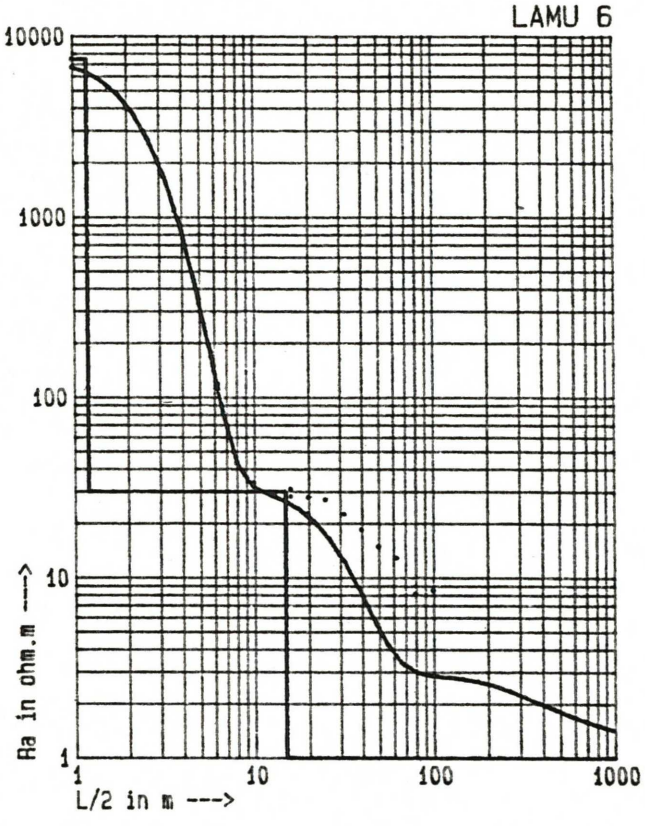

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100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->

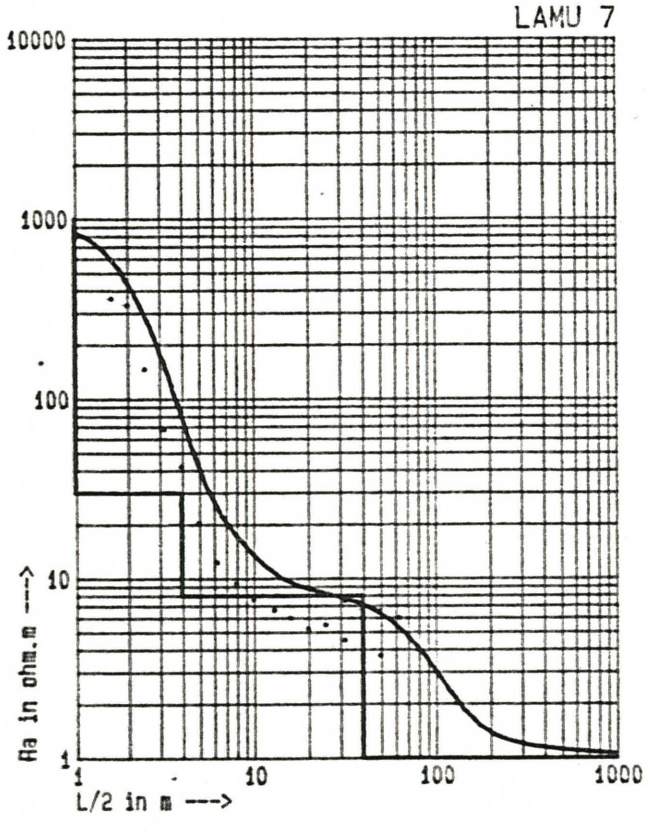

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1000
L/2 in m ---->

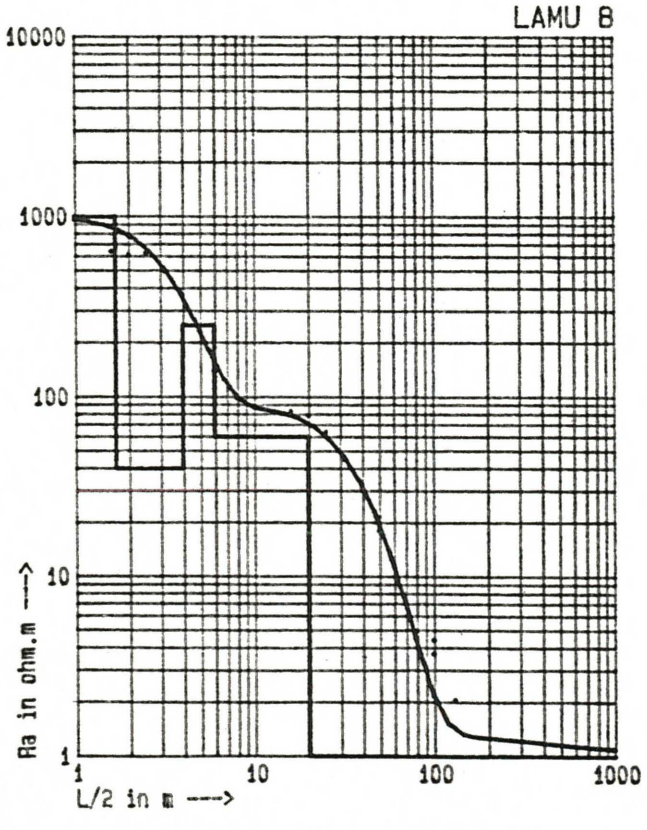

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100
1000
L/2 in m ---->

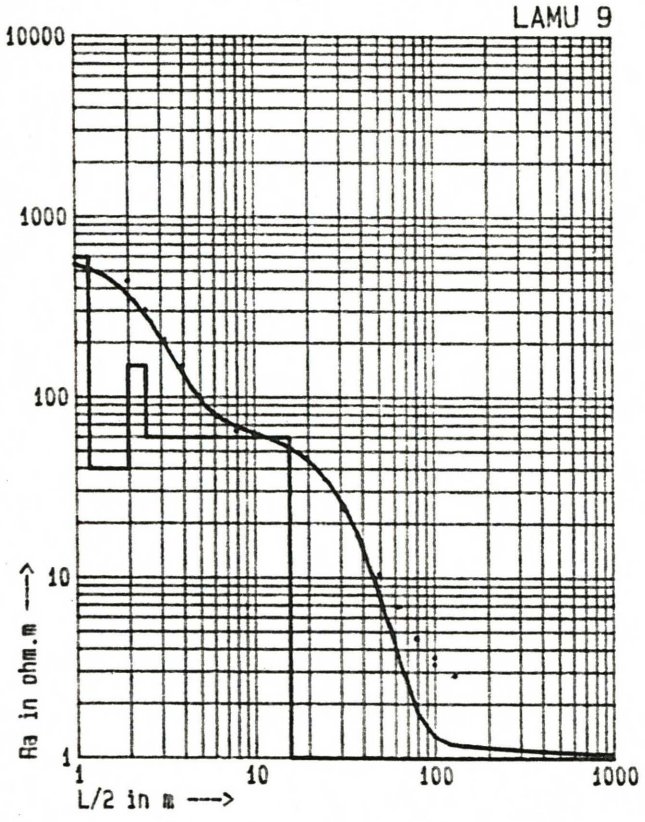

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L/2 in m ---->

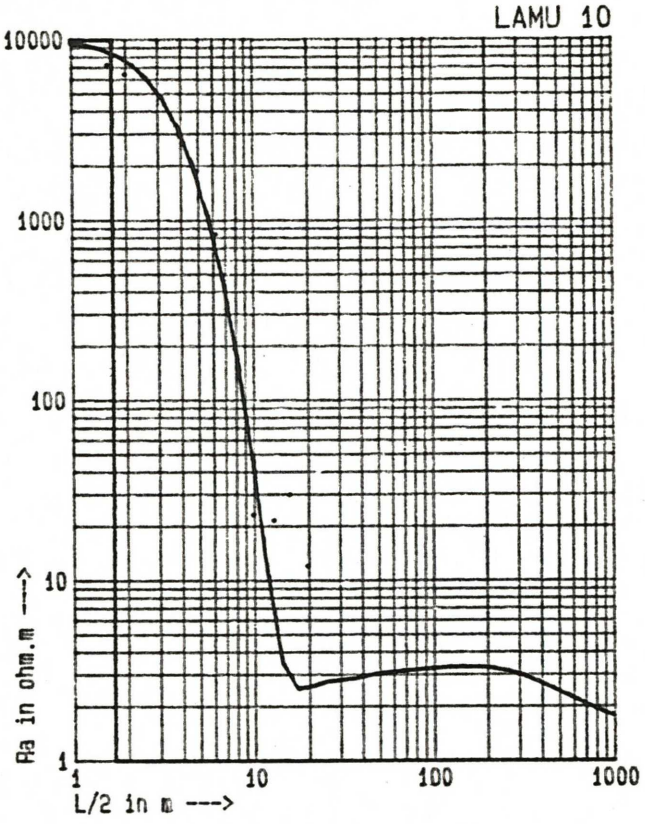

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100
1000
L/2 in m --->

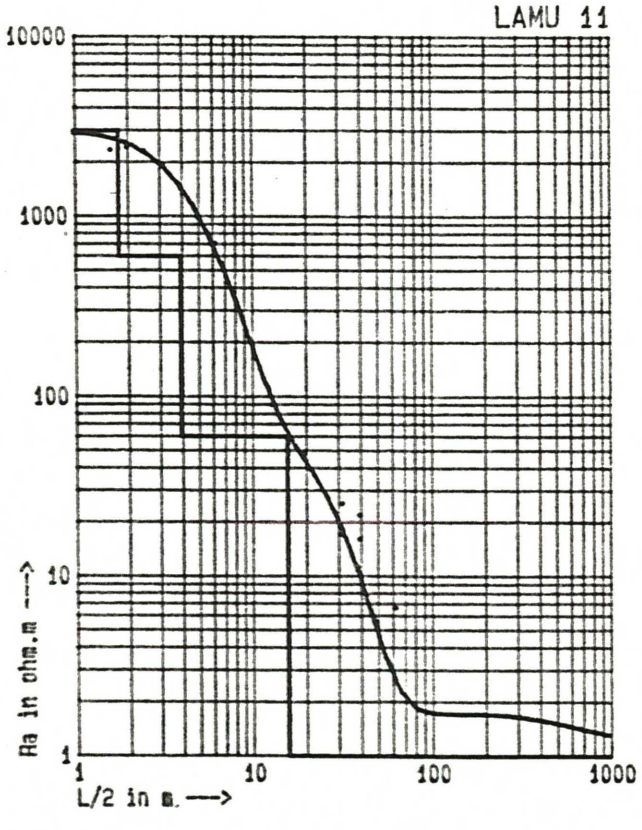

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100
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1
Ra in ohm.m --->
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100
1000
L/2 in m --->

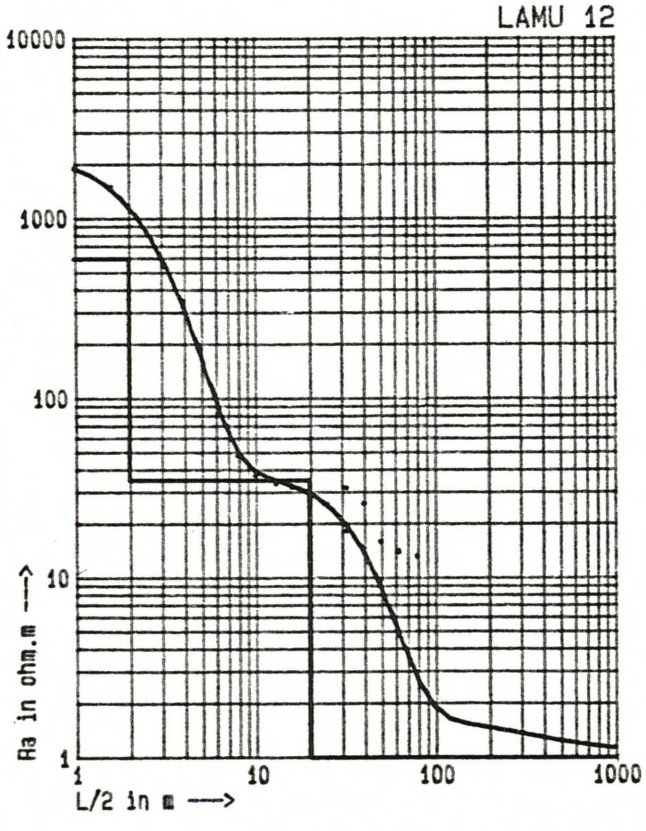

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1000
100
10
1
Ra in ohm.m --->
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10
100
1000
L/2 in m --->

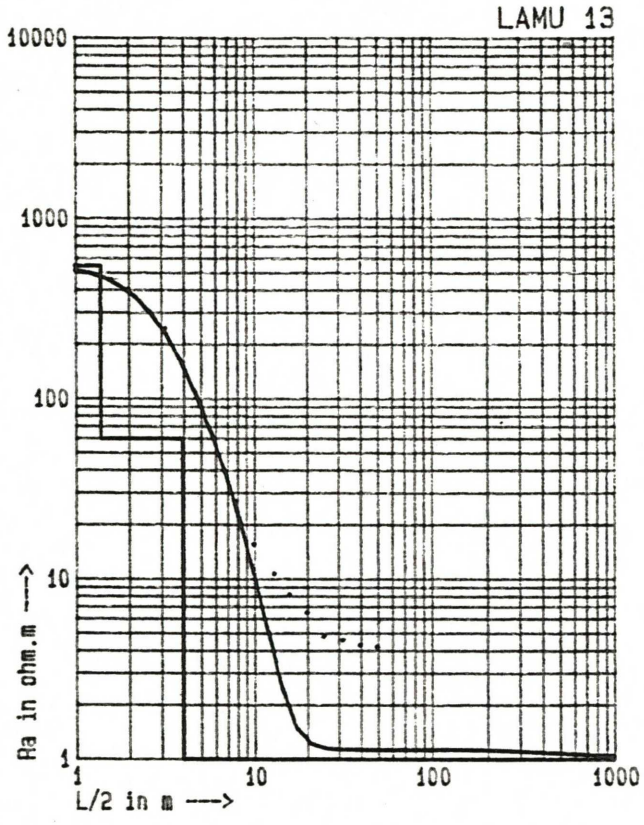

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100
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1
Ra in ohm.m --->
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100
1000
L/2 in m --->

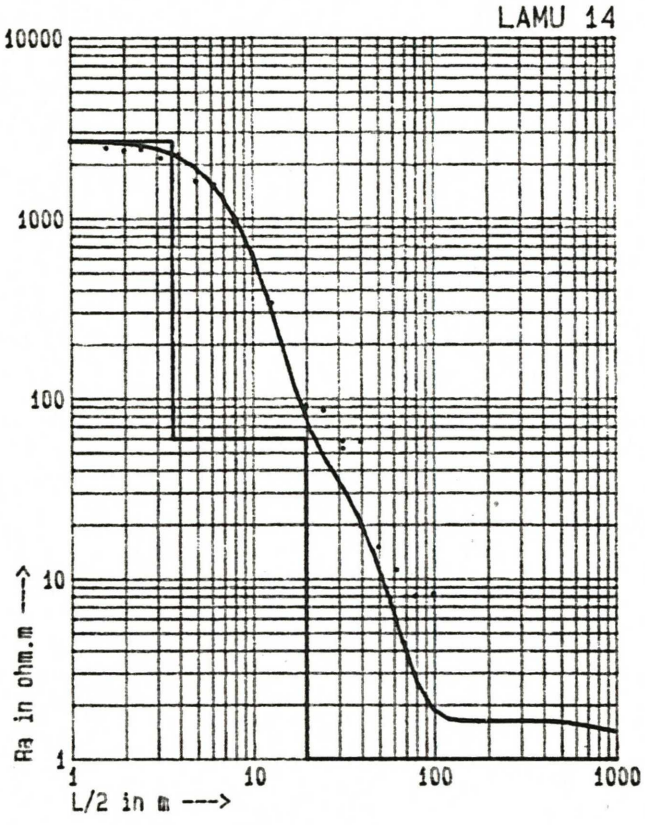

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1
Ra in ohm.m ---->
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100
1000
L/2 in m ---->

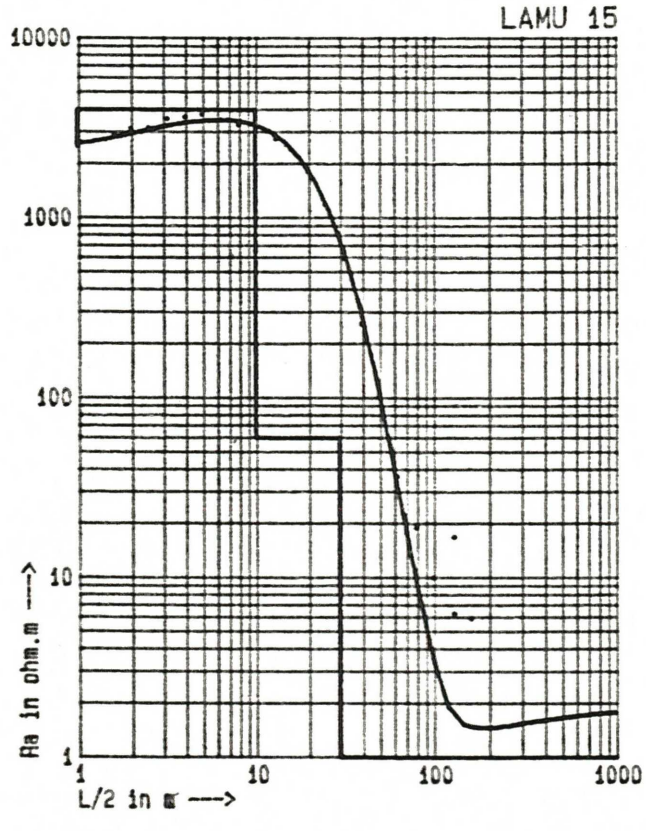

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100
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Ra in ohm.m ---->
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100
1000
L/2 in m ---->

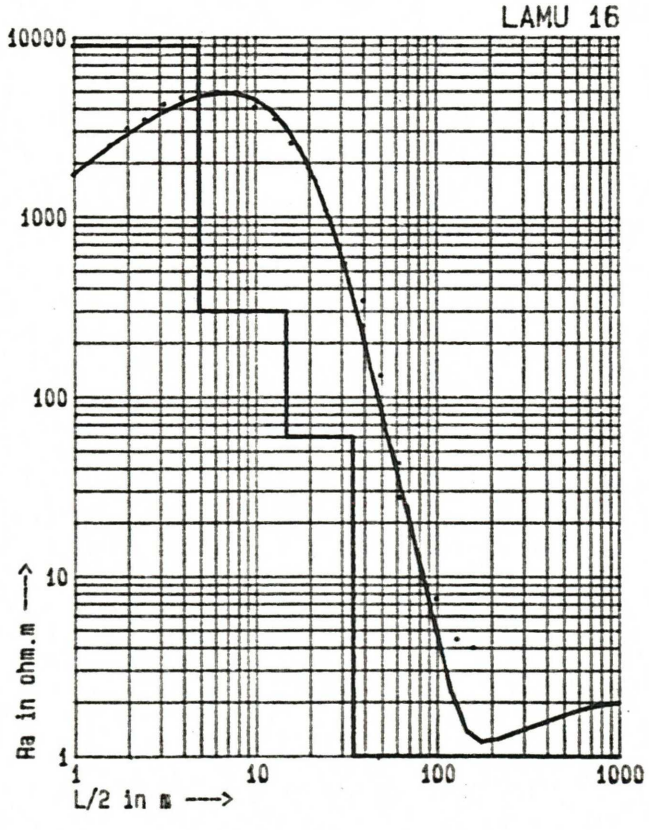

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100
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Ra in ohm.m ---->
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1000
L/2 in m ---->

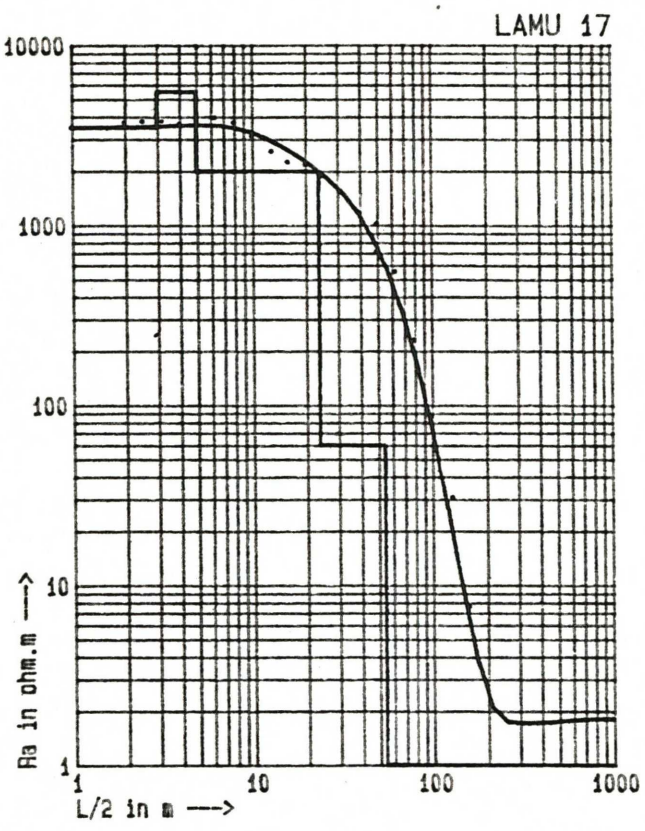

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1000
L/2 in m ---->

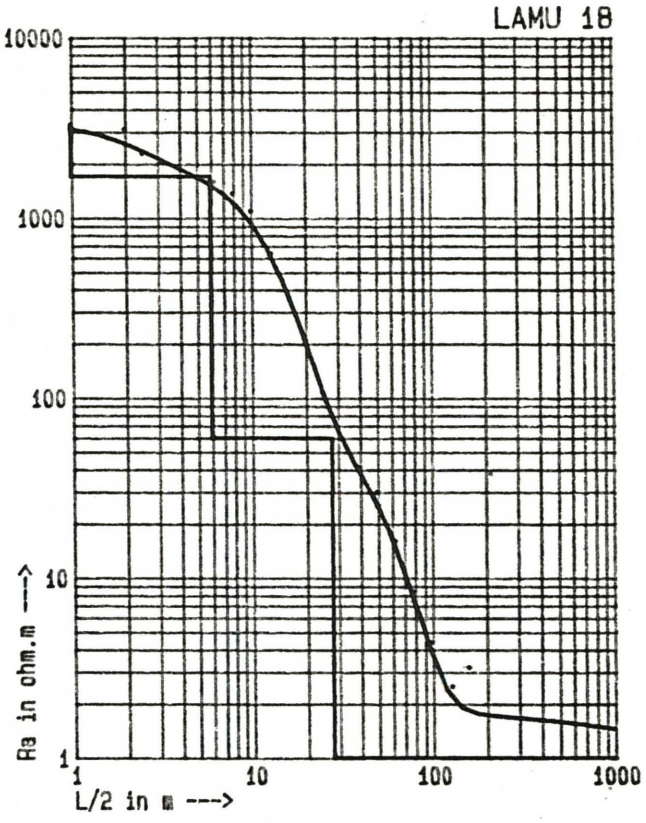

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1
Ra in ohm.m ---->
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100
1000
L/2 in m --->

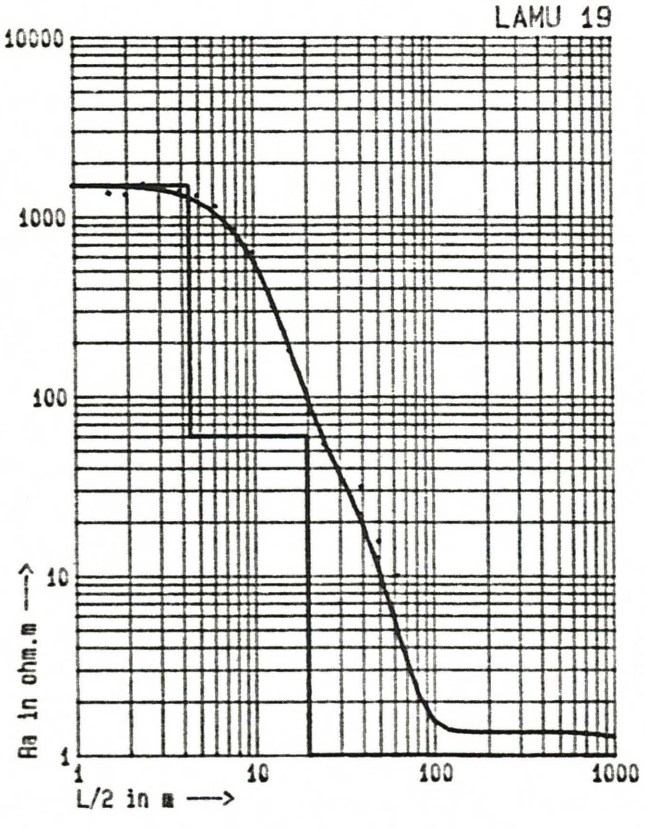

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1
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100
1000
L/2 in m ---->

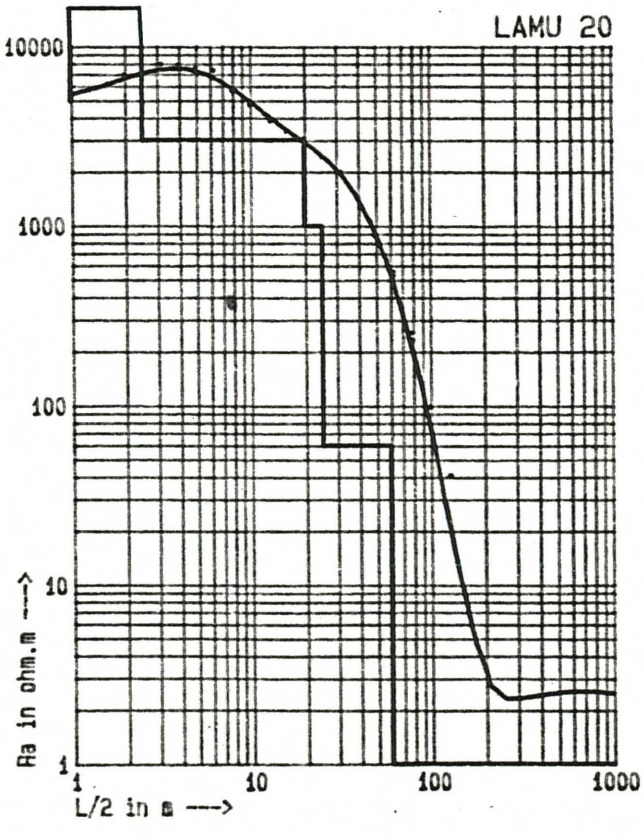

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1
Ra in ohm.m ---->
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100
1000
L/2 in m ---->

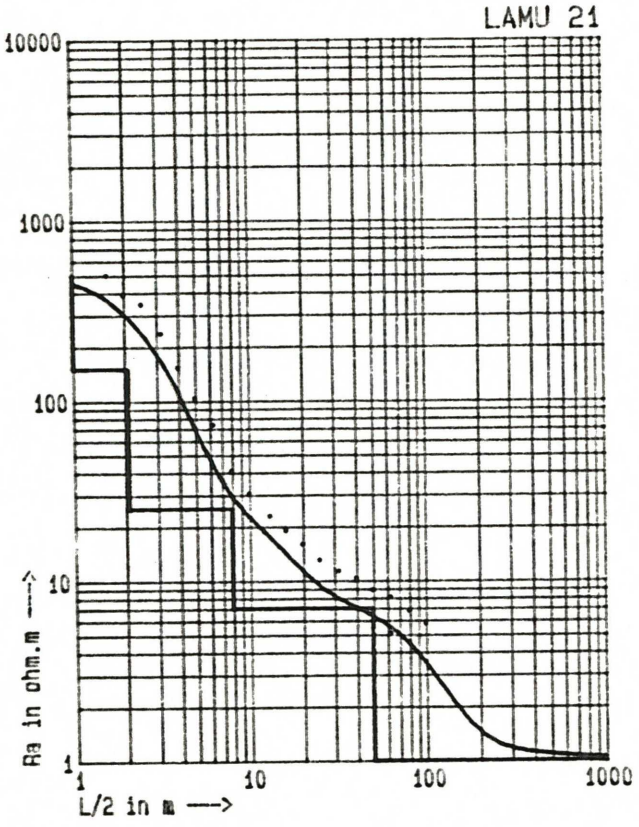

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1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->

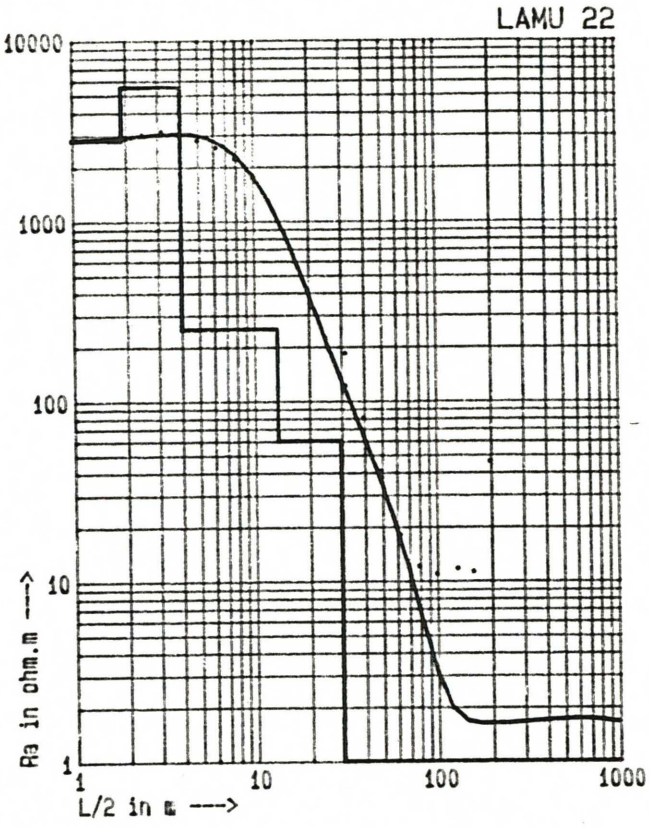

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100
10
1
Ra in ohm.m ---->
1
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1000
L/2 in m --->

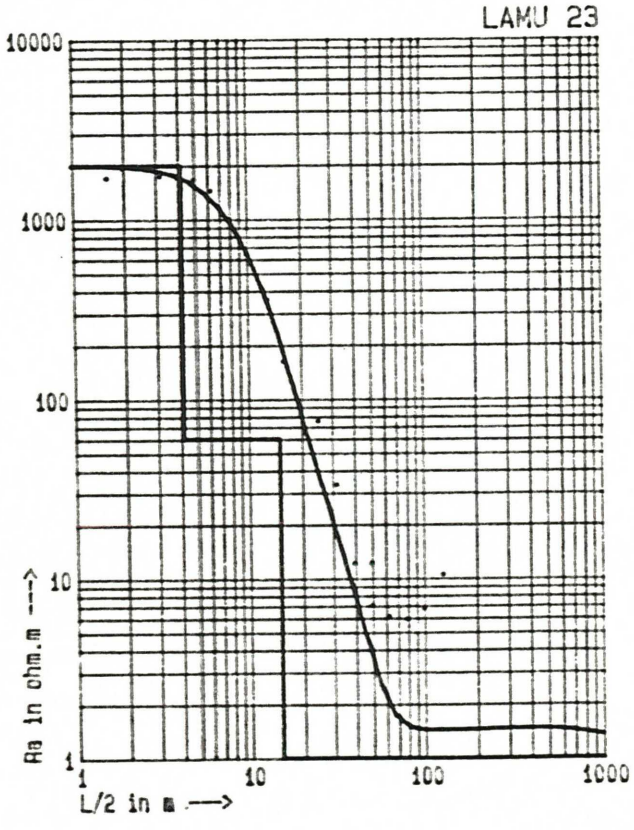

LAMU 18
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1000
100
10
1
Ra in ohm.m ---->
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10
100
1000
L/2 in m ---->


LAMU 19
10000
1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->


LAMU 20
10000
1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->


LAMU 21
10000
1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m --->


LAMU 22
10000
1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->


LAMU 23
10000
1000
100
10
1
Ra in ohm.m ---->
1
10
100
1000
L/2 in m ---->

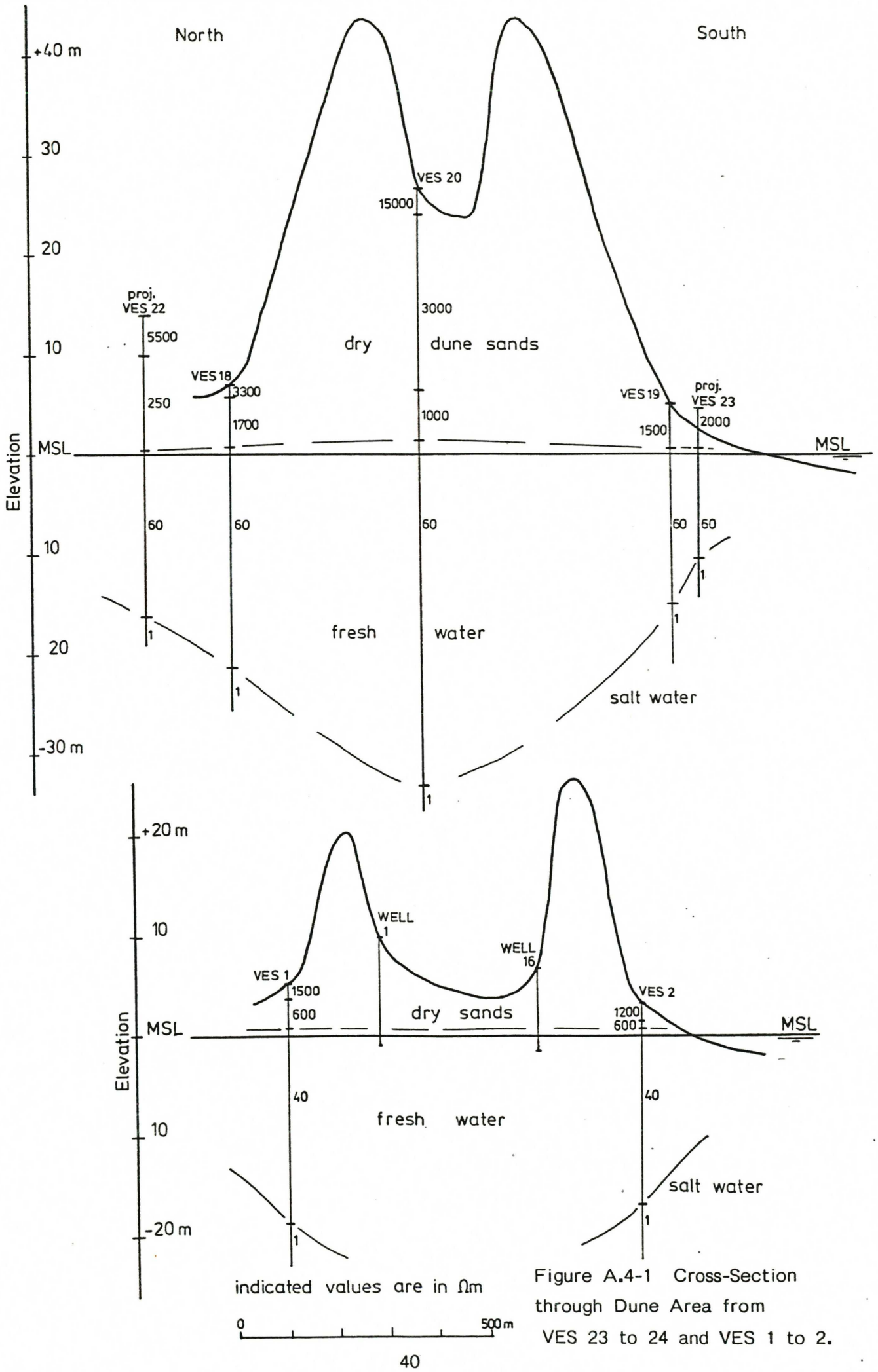



Figure A.4-1 Cross-Section through Dune Area from VES 23 to 24 and VES 1 to 2.

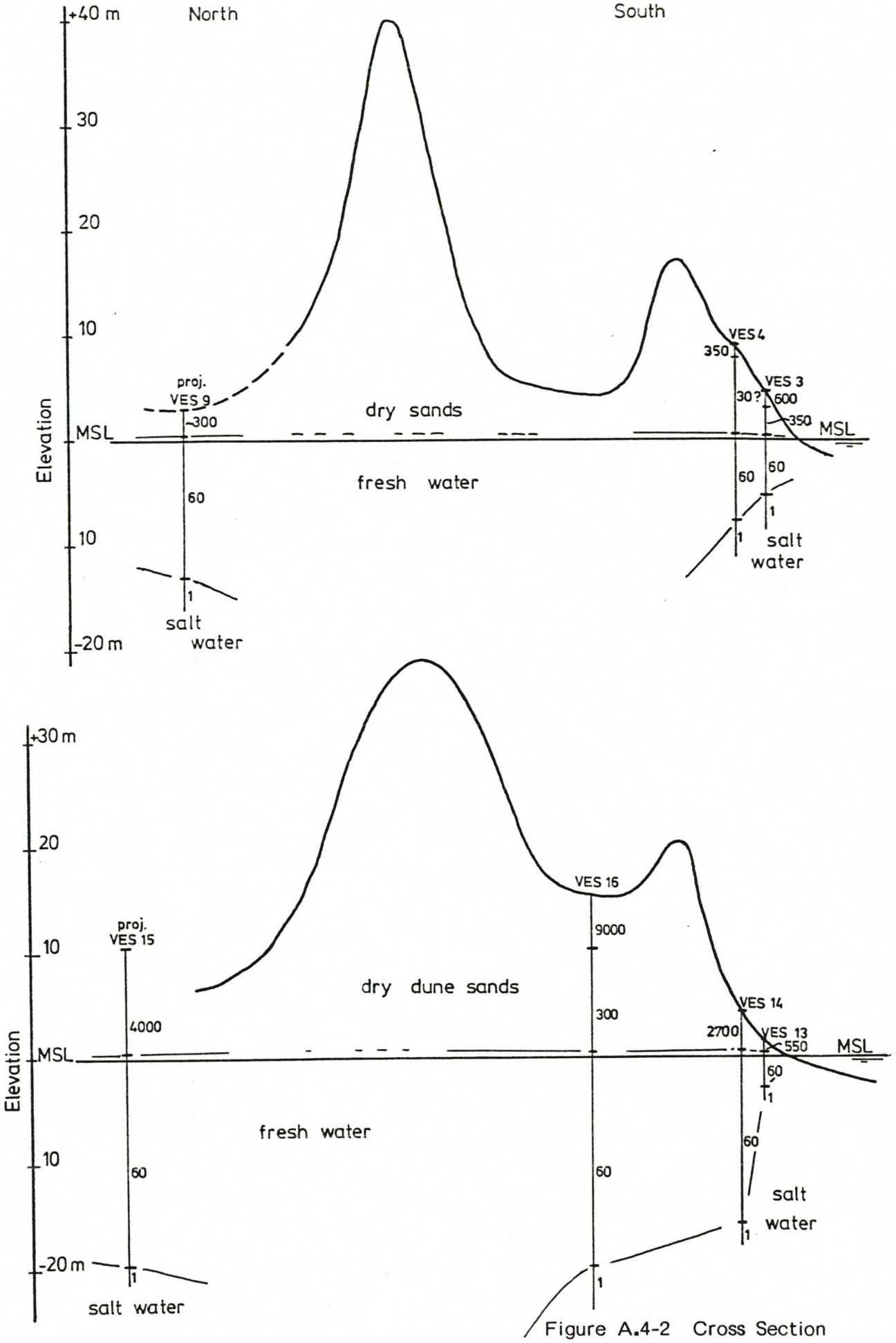



Figure A.4-2 Cross Section through Dune Area from VES 9 to 3 and VES 15 to 16.

# APPENDIX B

## DESCRIPTION OF GEOPHYSICAL SURVEY IN HINDI-MAGOGONI SETTLEMENT SCHEME

## HINDI-MAGOGONI SETTLEMENT SCHEME

### b.1 Introduction

As follow-up of the investigation on Lamu Island a geophysical survey was carried out around Hindi on the mainland, 7 km north of Mokowe. The future water demand for Mokowe will be far greater than it is at present and a settlement scheme, started in the Hindi-Magogoni area, is also in need of fresh water.

The survey was aimed at mapping fresh water occurrence in the area to assist the planning of water supply schemes.

### b.2 Field Work

In the month of August 1986, 26 Vertical Electrical Soundings were carried out around Hindi. The locations of the VES's are shown on the map in Figure B.1, and Table B.1 gives a list of the VES's (L/2, X-coordinate and Y-coordinate in m; elevation in m above mean sea level (MSL) and direction in degrees from the north).

In addition, resistivity profiles were run, covering a distance of 1,800 m.

During the second working day the power booster broke down and the team was left with a small power instrument only.

As the water table in the area is rather shallow (less than 10 m) is was decided to continue, keeping in mind that resistivity values could still be derived while the instrument worked beyond its limit.

The lower power capacity mainly effects the lower end of the field curve, resulting in measured values that are too high. Therefore, the VES's were interpreted using the first part of the field curve only.

In November 1988 an EM-profile was run along the road from Hindi to Mokowe to establish the exact location for an exploratory borehole. The profiles are marked on the map in Figure B.1.

### b.3 Interpretation

The same principles for interpretation apply as mentioned under Section a.3.

When high contrast exists, relative thin, intermediate layers with intermediate resistivities will not show up in the curves (principle of suppression). Where additional data were available, such as water levels, geological boundaries, water quality (water resistivity), these were used to raise the reliability of the interpretation.

The surface elevations of all but four VES's (3, 9, 10 and 21) were taken from maps at scale 1:10,000, with 1 m contour intervals. For VES 3,9,10 and 21 they were estimated.

Water levels and resistivities from the water were taken in several wells and from surface water. They are listed in Table B.2.

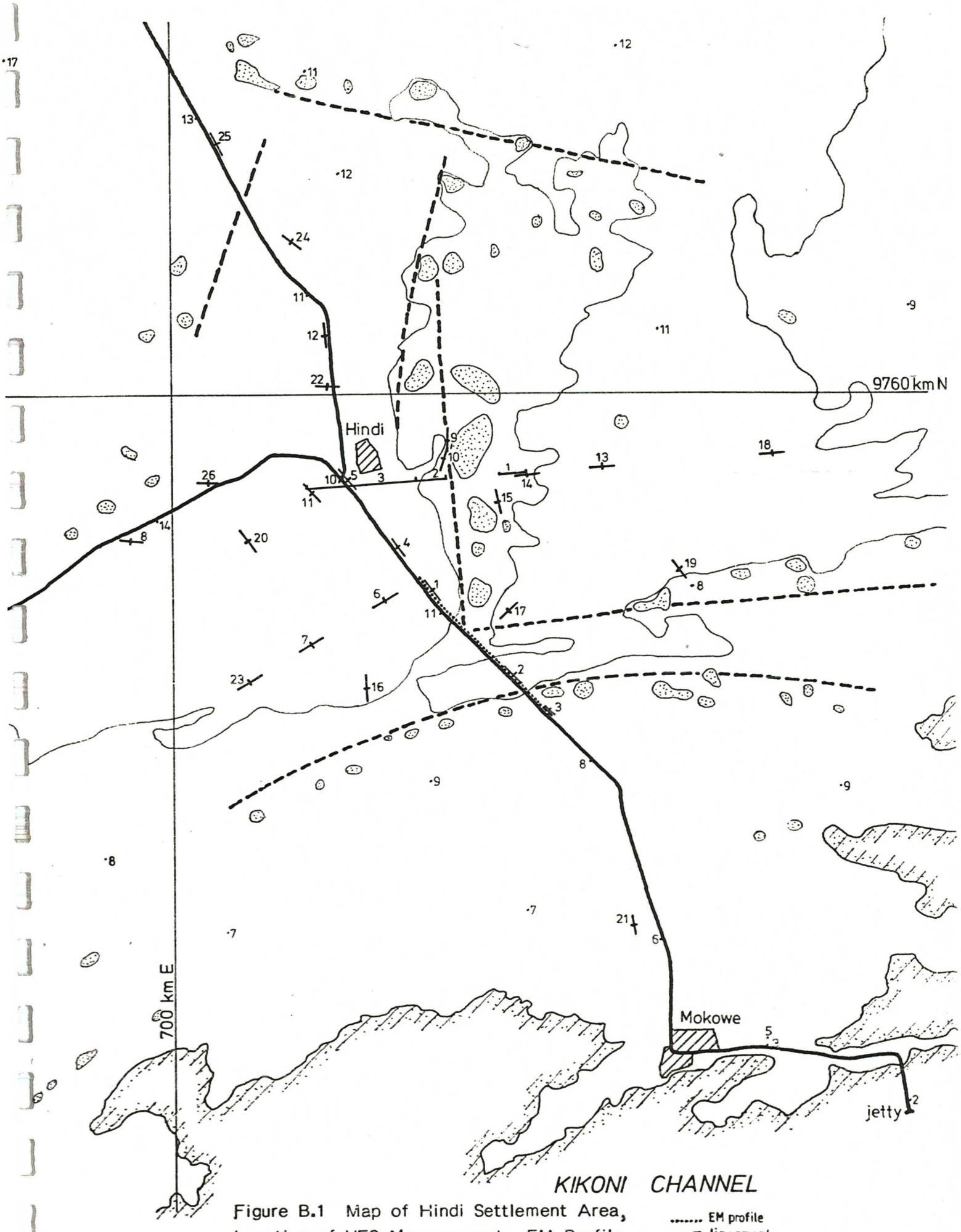



Figure B.1 Map of Hindi Settlement Area, Location of VES Measurements, EM Profile and Hydrogeological Features.

Table B.1 List of VES Data of Hindi - Magogoni Settlement Scheme

| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |
|---|---|---|---|---|---|---|
| HMSS 1 | 130.0 | 702790 | 9757800 | 050886 | 11 | 327 |
| HMSS 2 | 160.0 | 703620 | 9756950 | 050886 | 9 | 134 |
| HMSS 3 | 32.0 | 704050 | 9756540 | 050886 | 4 | 134 |
| HMSS 4 | 80.0 | 702420 | 9758300 | 060886 | 11.5 | 145 |
| HMSS 5 | 160.0 | 701900 | 9759030 | 070886 | 10.2 | 340 |
| HMSS 6 | 160.0 | 702320 | 9757750 | 070886 | 10.5 | 240 |
| HMSS 7 | 160.0 | 701520 | 9757280 | 070886 | 10.5 | 240 |
| HMSS 8 | 130.0 | 699520 | 9758410 | 080886 | 13 | 105 |
| HMSS 9 | 160.0 | 702870 | 9759480 | 080886 | 6.5 | 0 |
| HMSS 10 | 200.0 | 702850 | 9759320 | 110886 | 6.5 | 17 |
| HMSS 11 | 100.0 | 701590 | 9758950 | 110886 | 10.8 | 145 |
| HMSS 12 | 160.0 | 701710 | 9760630 | 110886 | 10.5 | 173 |
| HMSS 13 | 100.0 | 704620 | 9759210 | 120886 | 10.5 | 85 |
| HMSS 14 | 160.0 | 703830 | 9759150 | 120886 | 8 | 86 |
| HMSS 15 | 50.0 | 703520 | 9758830 | 120886 | 6.5 | 339 |
| HMSS 16 | 80.0 | 702090 | 9756790 | 130886 | 13 | 340 |
| HMSS 17 | 130.0 | 703600 | 9757630 | 130886 | 10 | 42 |
| HMSS 18 | 200.0 | 706410 | 9759340 | 140886 | 12.1 | 85 |
| HMSS 19 | 200.0 | 705430 | 9758110 | 140886 | 10 | 144 |
| HMSS 20 | 130.0 | 700770 | 9758430 | 150886 | 12 | 143 |
| HMSS 21 | 100.0 | 704950 | 9754900 | 150886 | 6 | 170 |
| HMSS 22 | 100.0 | 701700 | 9760070 | 180886 | 11 | 265 |
| HMSS 23 | 130.0 | 700840 | 9756870 | 180886 | 10.5 | 240 |
| HMSS 24 | 80.0 | 701270 | 9761620 | 250886 | 11 | 310 |
| HMSS 25 | 50.0 | 700460 | 9762710 | 250886 | 13 | 151 |
| HMSS 26 | 160.0 | 700400 | 9759030 | 250886 | 11.4 | 260 |
| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |

Table B.2 Water Levels and Resistivity Data in Hindi-Magogoni Settlement Scheme

| Well | Elevation (m + MSL) | Water level (m below surface) | Resistivity (Ωm) |
|---|---|---|---|
| Hindi Prison, main supply appr. | 9.5 | 6.30 | 6.5 |
| 110 m N from VES 5 | 10.5 | 7.50 | 5.2 |
| 40 m SW from VES 9 | | 9.90 | 18.4 |
| W of VES 10 | | | 11.2 |
| at VES 11 | 10.8 | 8.50 | 5.6 |
| at VES 22 | 11.0 | 7.80 | 2.6 |
| Surface water at VES 3 | | | 64 |
| Surface water at VES 9 | | | 118 |
| Perched water at VES 8 | | 0.60 | 46.5 |

At VES 26 it is known that limestone exists at 4.3 m below surface. From the water levels in the wells and the differences in water quality it can be

concluded that there does not exist an extensive homogeneous aquifer in the area, but that (more or less) local pockets of water exist of varying quality.

The water levels between wells at short distances sometimes differ considerably which may be an indication of perched water tables and different transmissivities.

As the survey area is close to the ocean, a "base" layer with saline water can be expected and a resistivity of 2 Ωm has been assumed for it. The "base" layer may consist of clay layers which also have low resistivity values but can be as high as 6 Ωm when saturated with fresh water. Exploratory boreholes will eventually show the true geological strata in the area.

To check whether the differences in the VES's west and east of the swamp (East of Hindi) were due to a geological fault, three resistivity profiles, along a cut-line that crosses the swamp, were run. The area itself is quite flat and from the surface a fault could not be inferred.

To gather a better insight in subsurface resistivity changes a so called tri-potential array* was used, where at each set of four electrode positions three measurements were made.

These are the apparent $\alpha$,$\beta$ and $\tau$ resistivities ($R\alpha$, $R\beta$, $R\tau$), where $R\alpha$ is the normal apparent resistivity. The measured values were submitted to a weighted, running average procedure (filter) to smooth out for array-geometrical effects.

A pseudo-resistivity section results (resistivity-contours) when the three apparent resistivity values are plotted at three corresponding normalized depths.

The plots are shown in Figure B.2.

b.4 Summary of Results

Plots of the measured resistivities with the interpreted layer models and corresponding calculated curves are shown for every VES in Figure B.3-1 through B.3-26. Dots represent the measured values. The horizontal axis shows half the electrode distance and the vertical axis the apparent resistivity.

From the interpretation it can be concluded that fresh water bearing layers of any importance for large scale water supply, do not occur north and east of the swamp at Hindi. In the area south west of Hindi fresh groundwater does occur in limited quantities. Thicknesses of around 5 to 6 m for the fresh water layers can be expected here from the interpreted models. Especially around VES 7 and 16 thicker layers might be encountered (see cross section, Figure B.4) which may be suitable for exploitation.

The area apparently most suitable for medium scale water supply is the swamp at Hindi. VES 9 and 10 are made almost in the swamp and show high resistivities up to 20-25 m depth. They also show layers with lower resistivities on

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* R.I.Acworth & D.H. Griffiths
Simple Data Processing of Tripotential Apparent Resistivity Measurements as an Aid to the Interpretation of Subsurface Structure.
Geoph. Prosp. 1985, 33, 861-887.

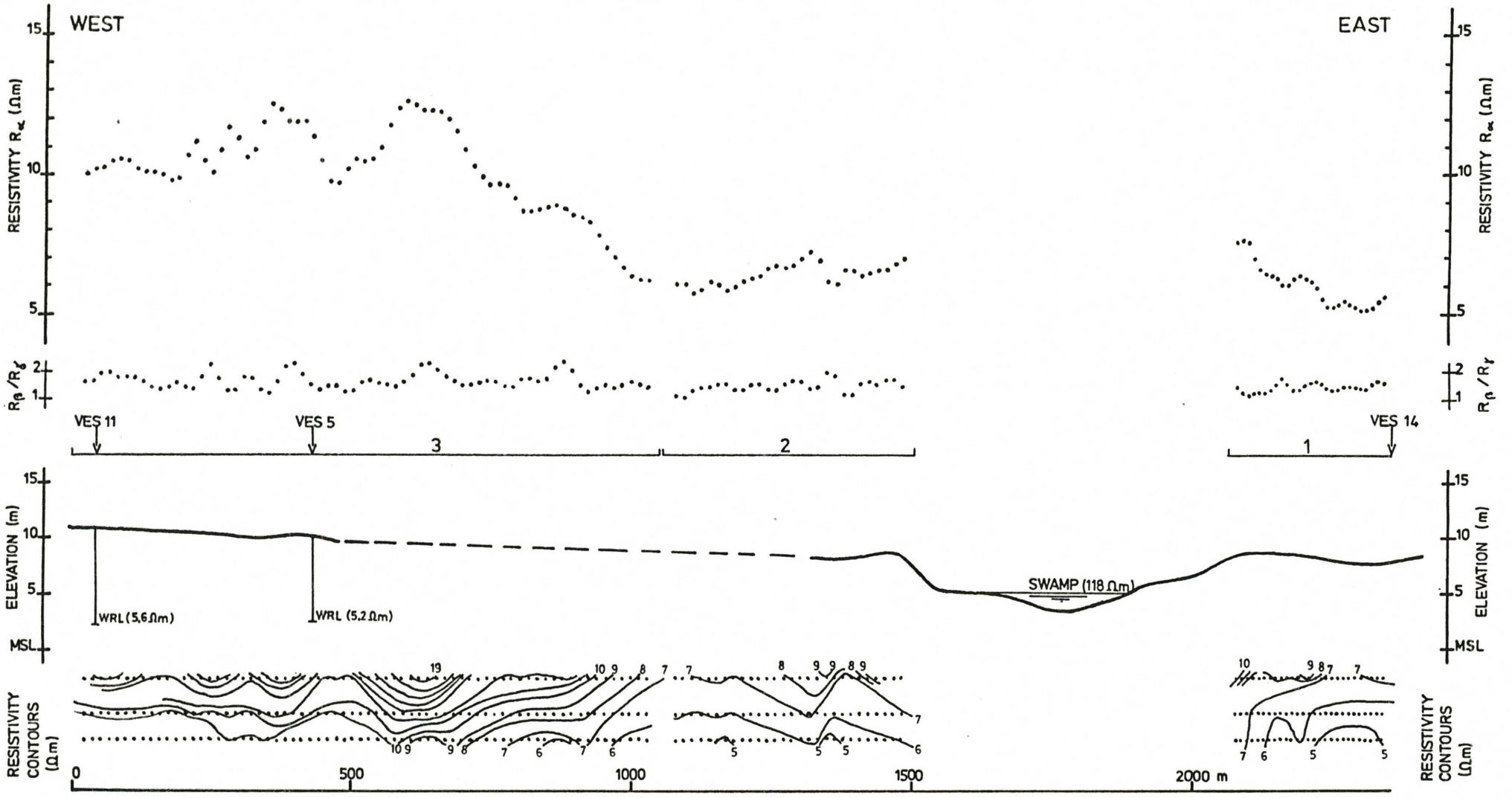



Figure B.2 East-West Resistivity Profile in Hindi Area

top which indicates the presence of loam and clay. This confirms with the nature of a swamp and the possible recharge of the groundwater. In order to check the effect of the lineament running through the swamp, (submerged at the time of investigation, see Figure B.1), it might be useful to drill a borehole in it to establish the possible effect of draining groundwater to the sea. A suitable location may be east of the road from Mokowe to Hindi between VES 1 and 2. An EM-profile has been run in order to establish the best location. From Figure B.5 the best location seems to be 740 m northwest from the Jamhuri Mosque at the location marked "junction". Another cross section, in Figure B.4, runs west-east over the swamp, and shows the difference in the soundings west and east of it.

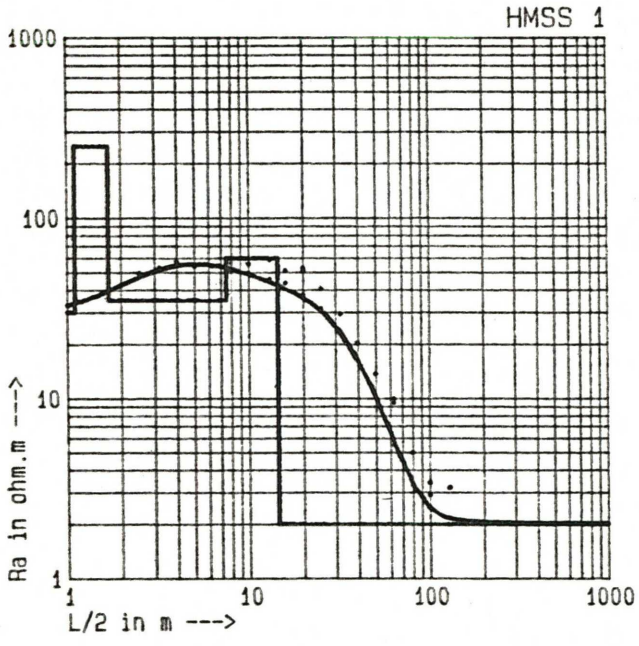
From the pseudo-resistivity section (Figure B.2) a clear boundary shows at around 950 m, whereas in the resistivity profile ($R\alpha$ - plot) a transition zone exist of more than 200 m width.

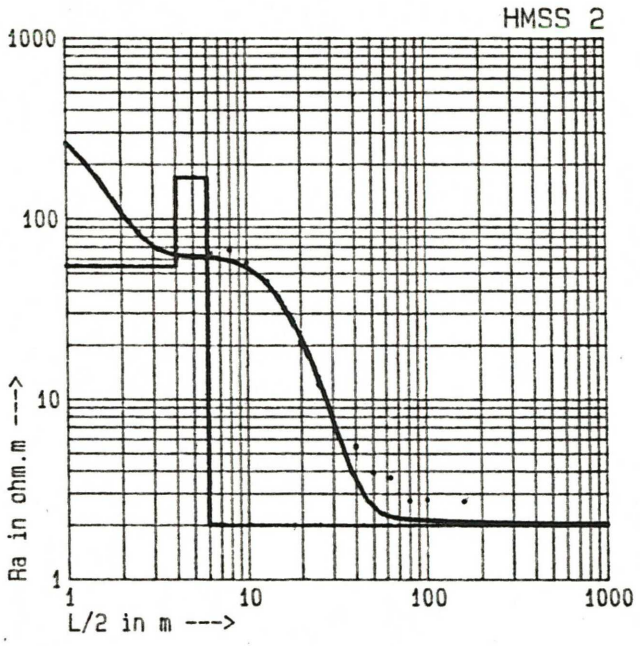
From the resistivity contours it can also be seen that the lower resistivities are dropping steeply when nearing the swamp, which indicates fresh water infiltration. The boundary at around 950 m is probably due to a higher clay content and makes it reasonable that the swamp is not recharging the ground water at VES 5 and 11, as this boundary acts as a vertical barrier.

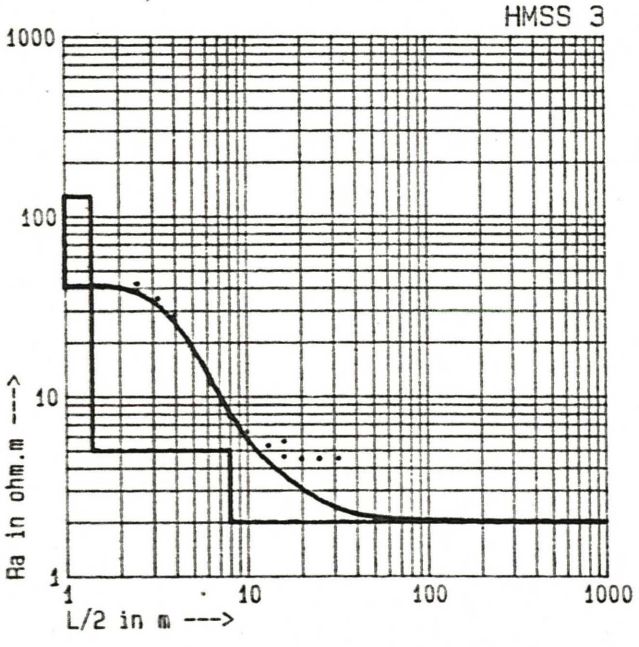
The recharge at VES 5 and 11 must therefore be local as it is in most places in this area.

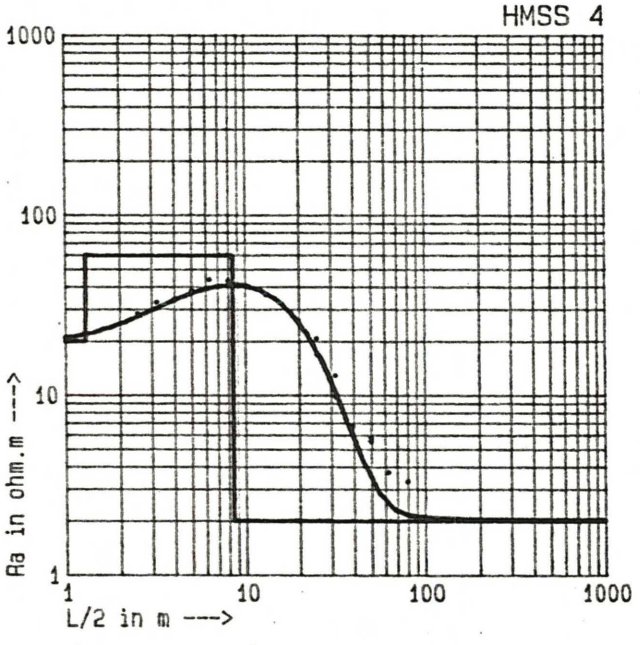
Figure B.3 Ves Plots Hindi - Magogoni Settlement Scheme

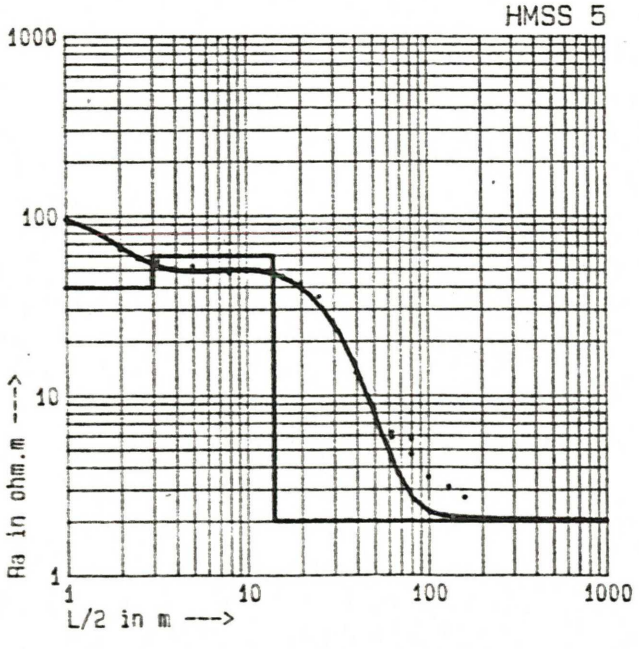
VES HMSS-1 through VES HMSS-26

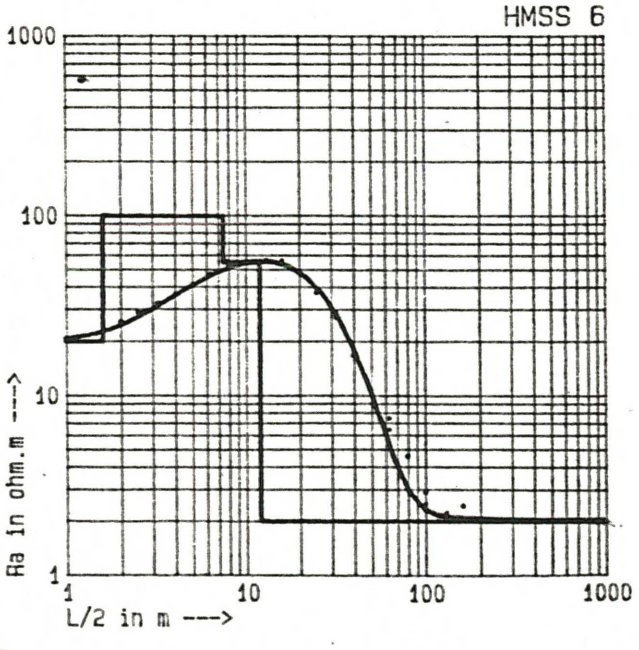

HMSS 1
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

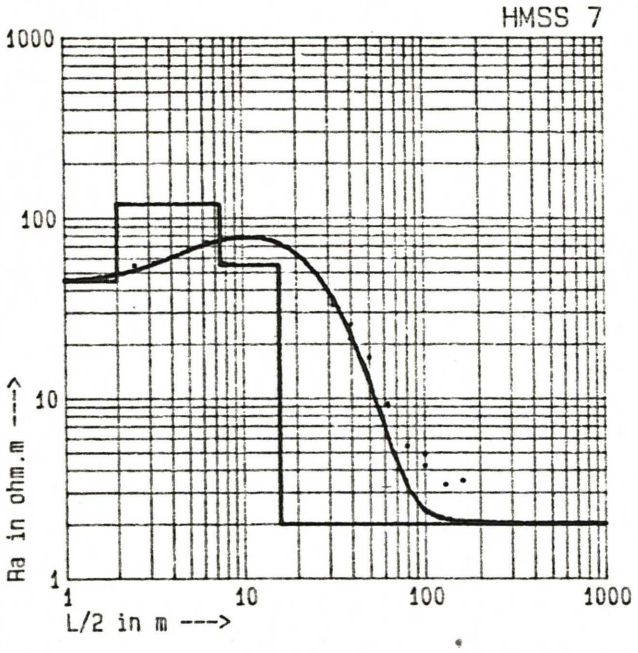

HMSS 2
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

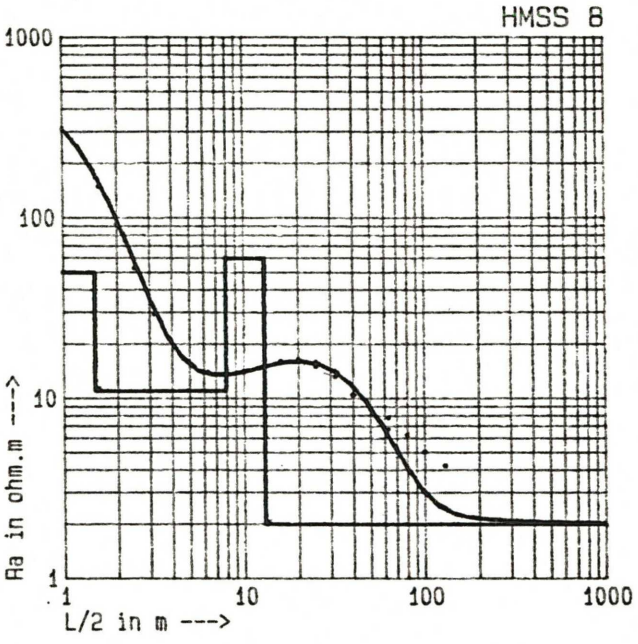

HMSS 3
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

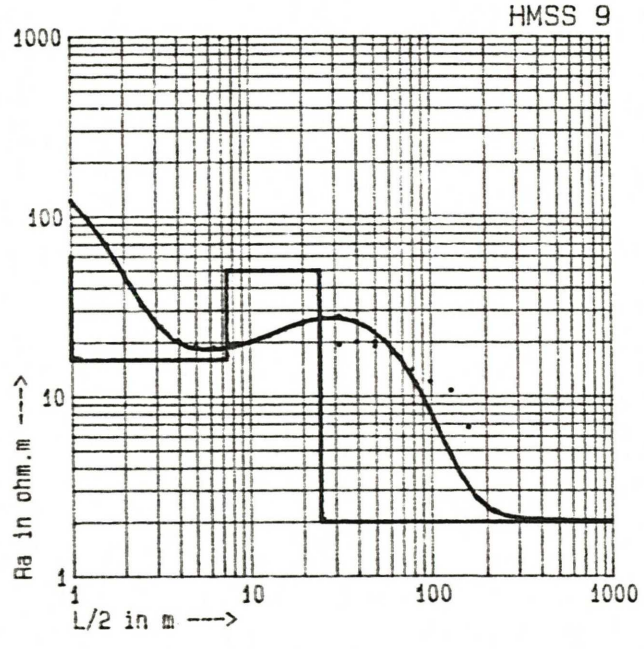

HMSS 4
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

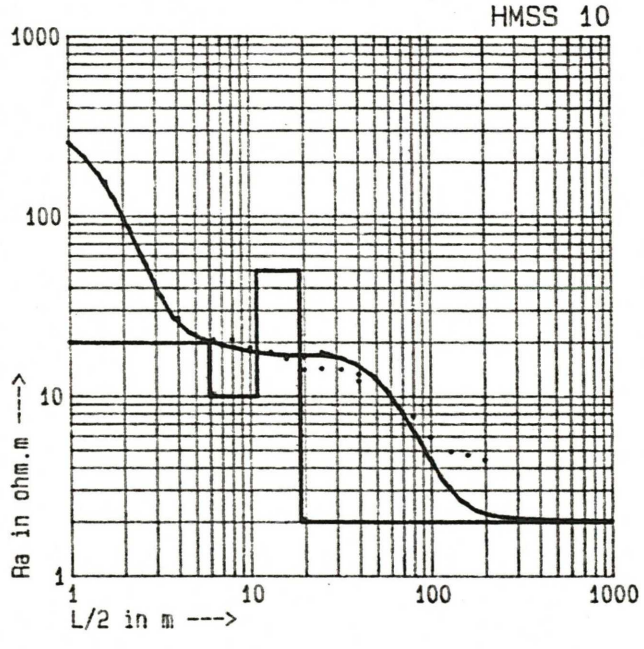

HMSS 5
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

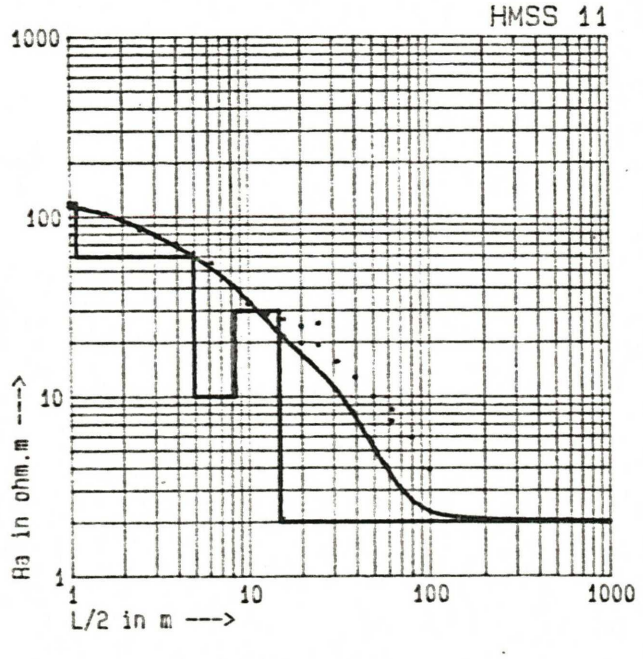

HMSS 6
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

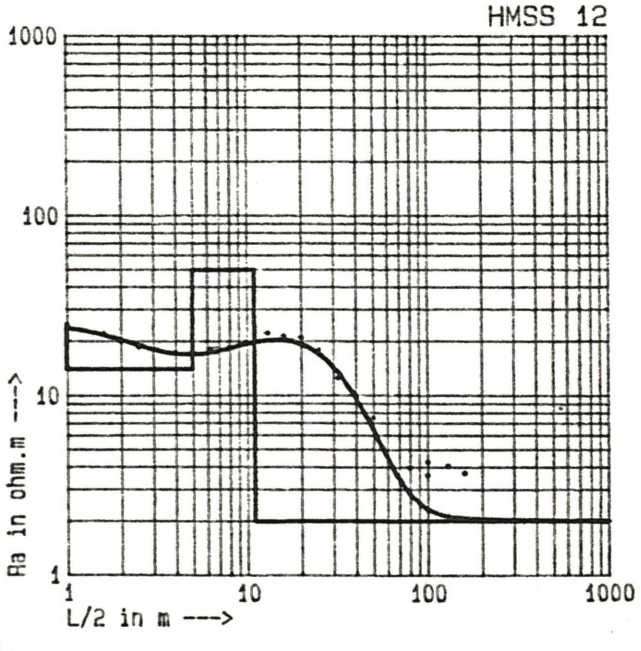

HMSS 7
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

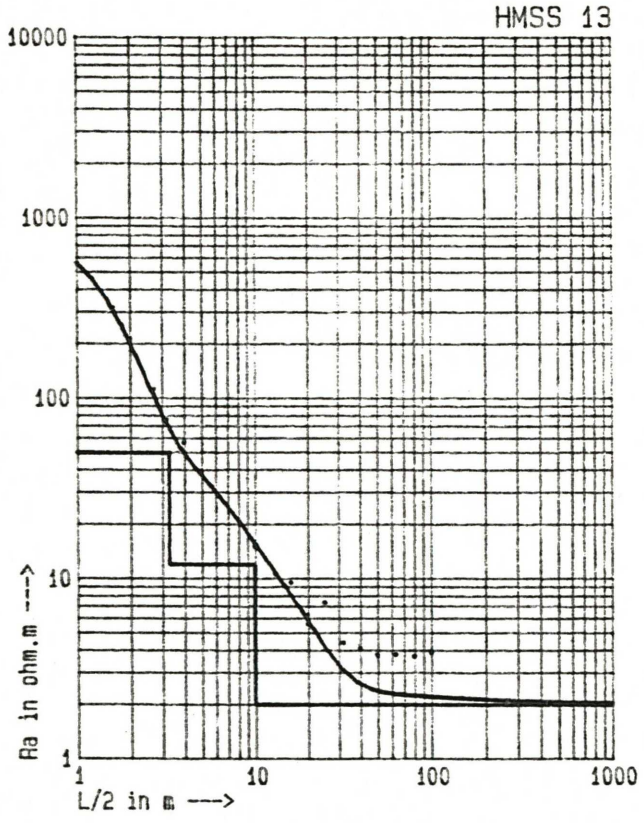

HMSS 8
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

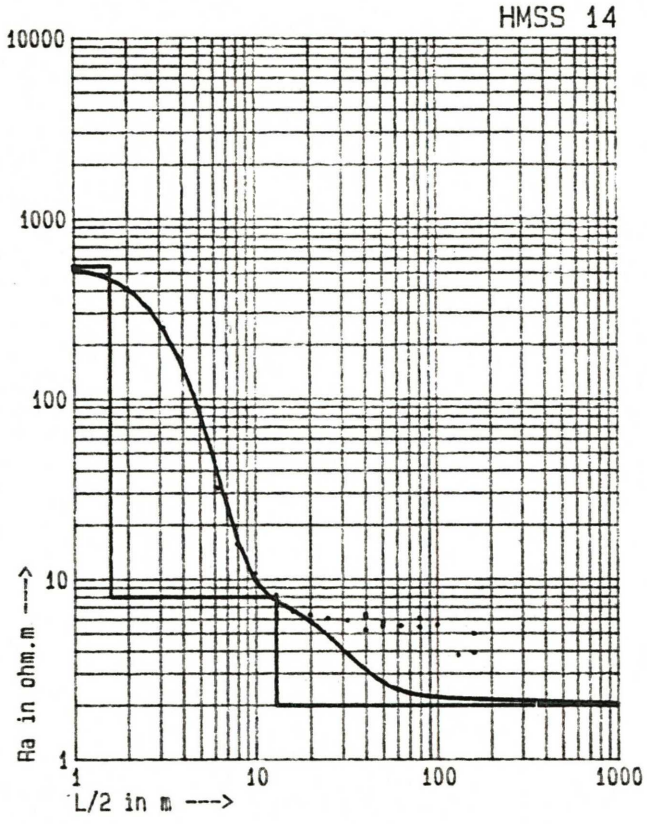

HMSS 9
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

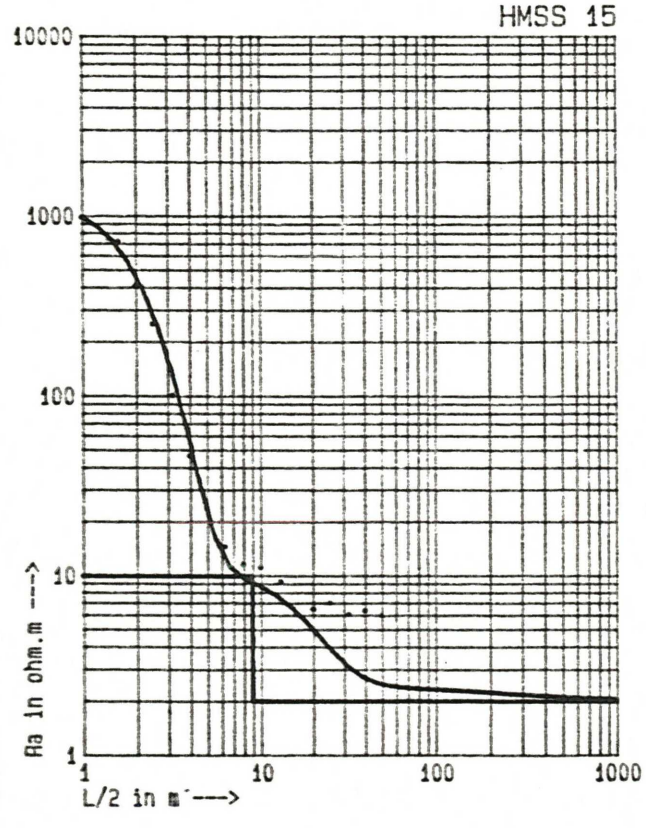

HMSS 10
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

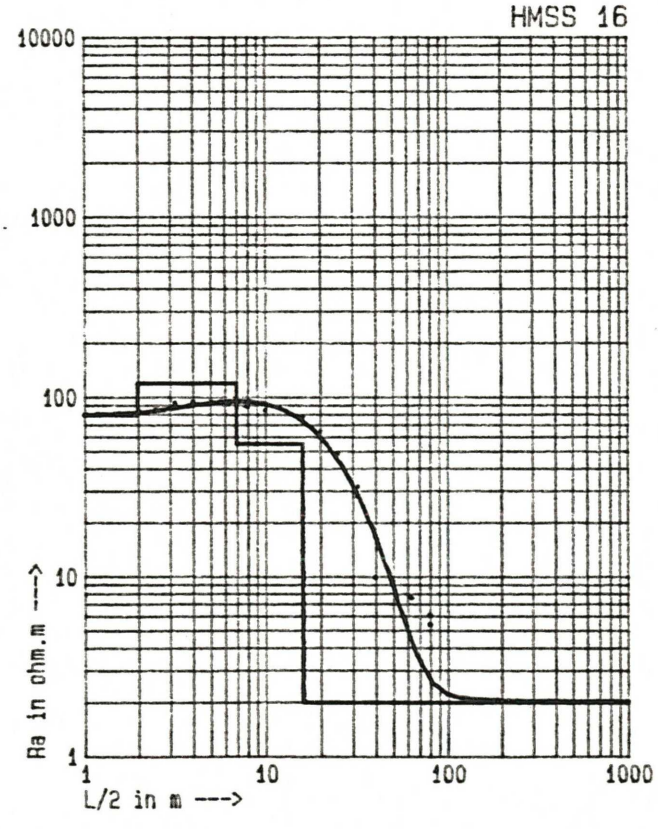

HMSS 11
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

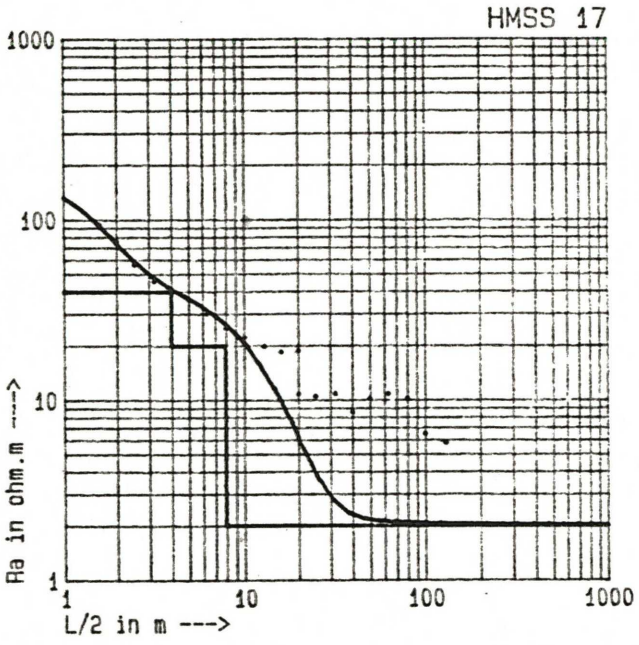

HMSS 12
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

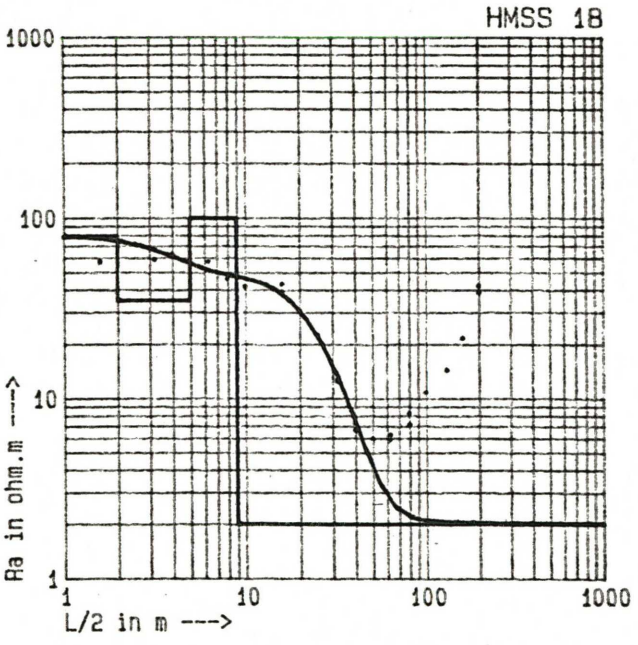

HMSS 13
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

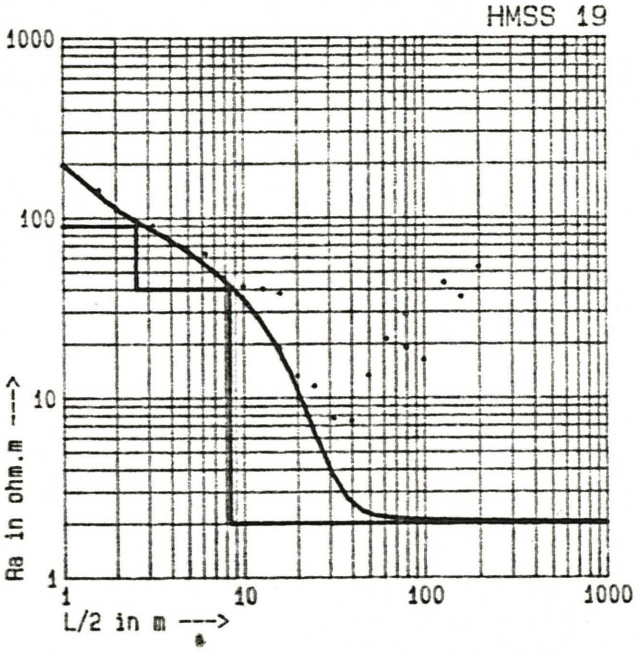

HMSS 14
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

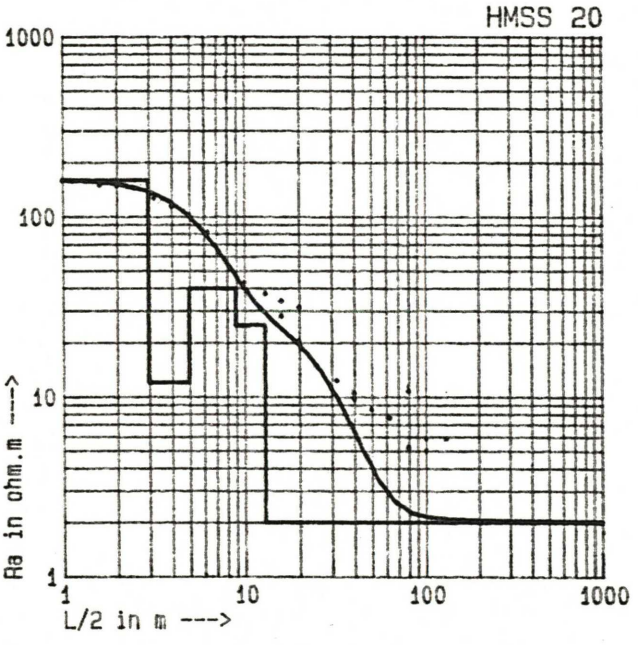

HMSS 15
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1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

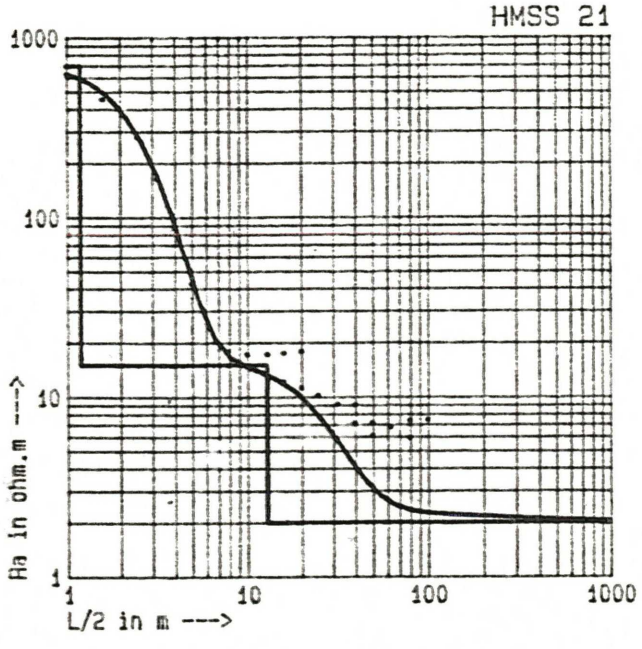

HMSS 16
10000
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

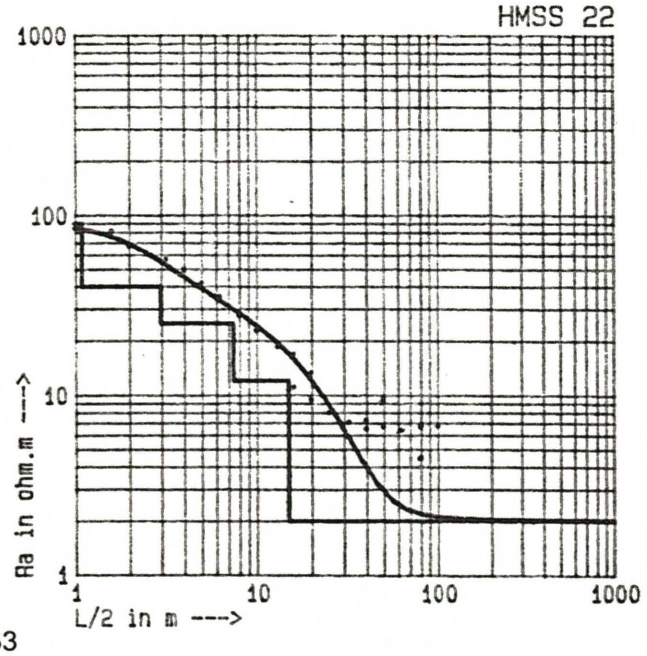

HMSS 17
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

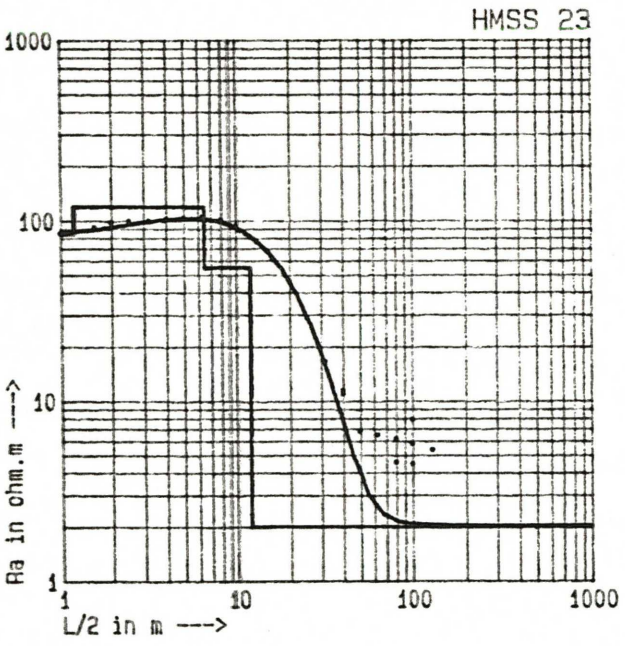

HMSS 18
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

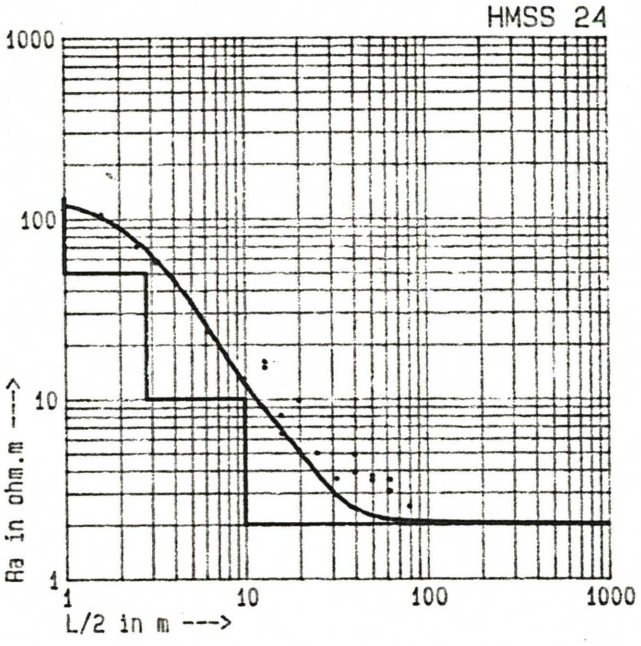

HMSS 19
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

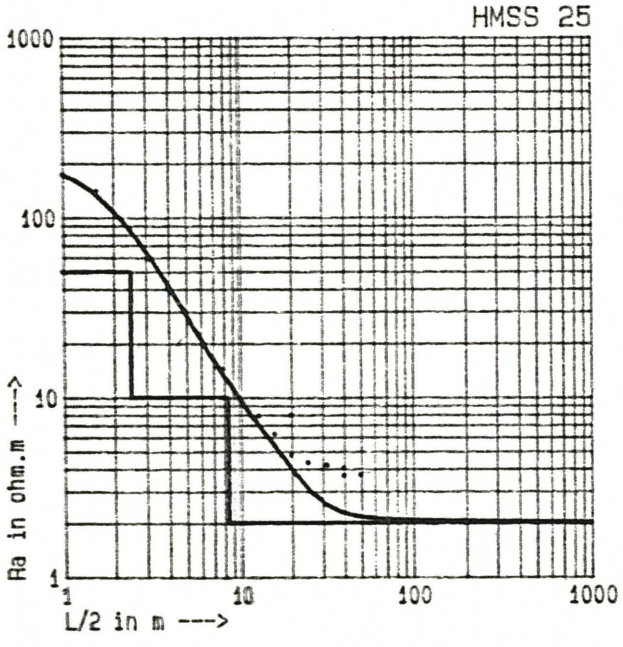

HMSS 20
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

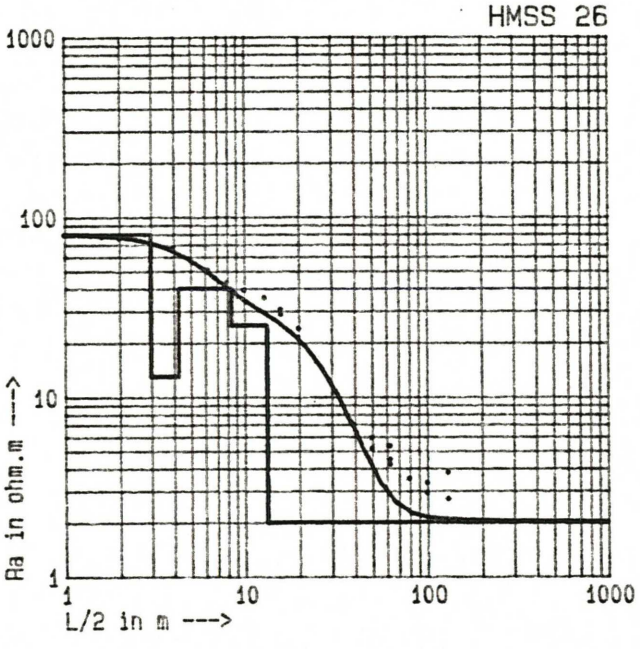

HMSS 21
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


HMSS 22
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


HMSS 23
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


HMSS 24
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


HMSS 25
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


HMSS 26
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

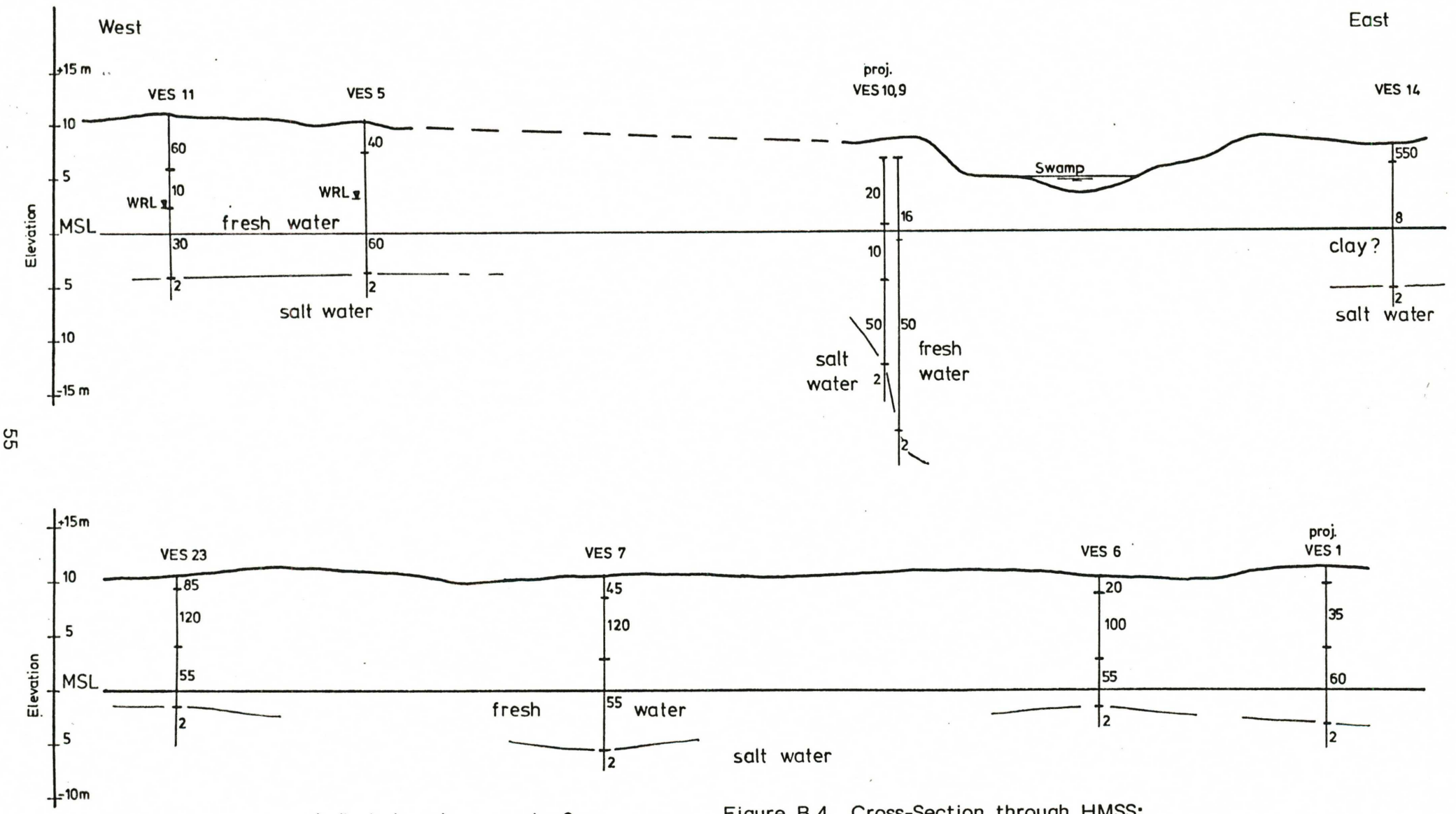



Figure B.4 Cross-Section through HMSS;
VES 11 - 14 and VES 23 - 1.

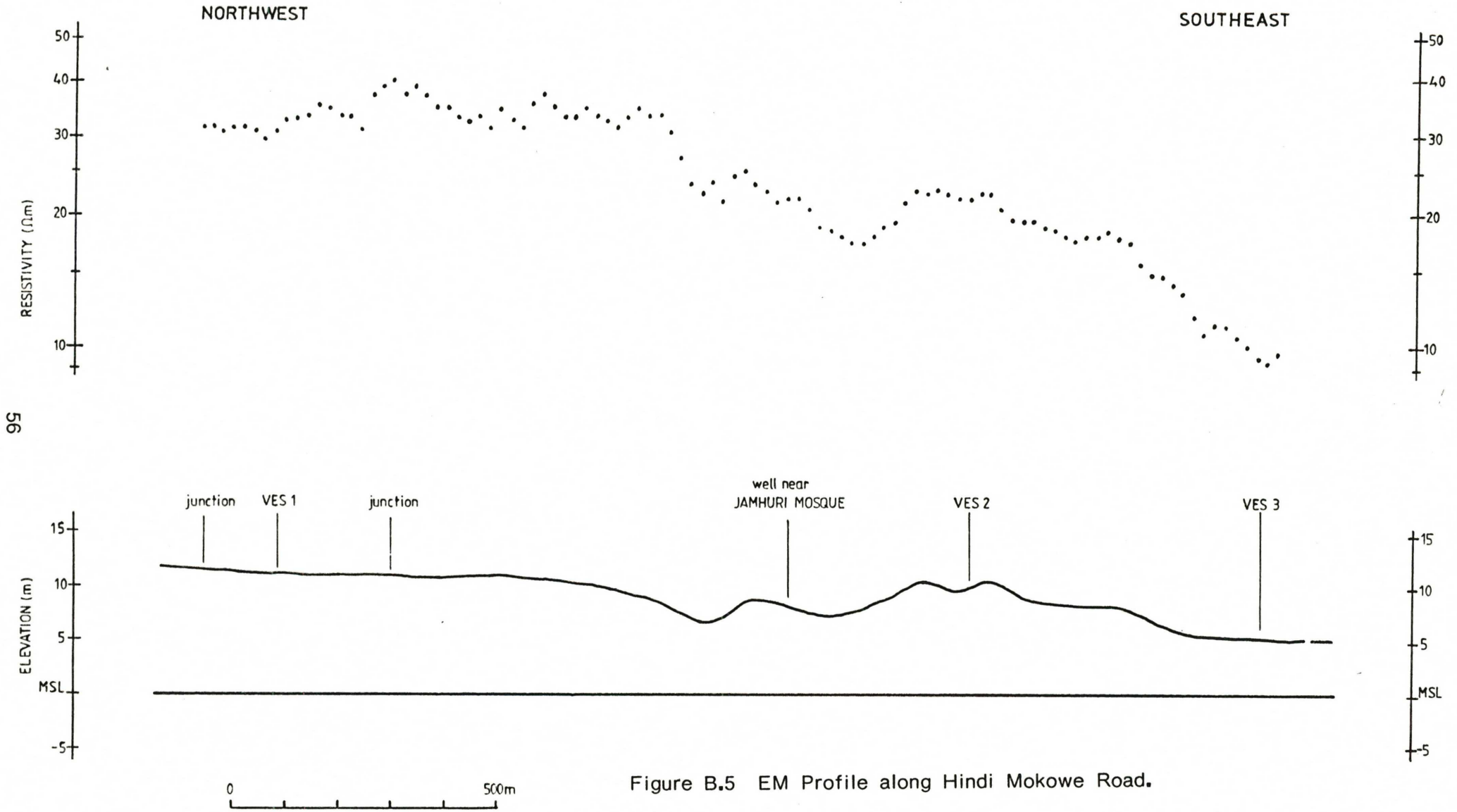



Figure B.5 EM Profile along Hindi Mokowe Road.

# APPENDIX C

## DESCRIPTION OF GEOPHYSICAL SURVEY IN LAKE KENYATTA SETTLEMENT SCHEME

## LAKE KENYATTA SETTLEMENT SCHEME

### c.1 Introduction

Some resistivity soundings were carried out around Lake Kenyatta in the same period as in the Hindi-Magogoni area, mainly to compare the results with those in the Hindi Magogoni area and to have a reference for future investigations.

### c.2 Field Work

In the month of August 1986, 11 vertical electrical soundings were carried out around Lake Kenyatta. The locations of the VES's are shown on the map in Figure C.1. In Table C.1 a list of the VES's is given (L/2, X-coordinate and Y-coordinate in m; elevation in m + MSL and direction in degrees from the north).

Table C.1 List of VES Data Lake Kenyatta Settlement Scheme

| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |
|---|---|---|---|---|---|---|
| LKSS 1 | 200.0 | 687300 | 9734110 | 190886 | 8 | 350 |
| LKSS 2 | 160.0 | 687540 | 9735110 | 190886 | 13 | 55 |
| LKSS 3 | 160.0 | 688380 | 9735880 | 190886 | 9.2 | 332 |
| LKSS 4 | 130.0 | 685630 | 9734650 | 200886 | 7.3 | 345 |
| LKSS 5 | 160.0 | 686840 | 9735540 | 200886 | 13.2 | 53 |
| LKSS 6 | 100.0 | 687340 | 9737130 | 200886 | 10.5 | 55 |
| LKSS 7 | 100.0 | 681970 | 9730910 | 210886 | 11.5 | 145 |
| LKSS 8 | 100.0 | 681370 | 9731760 | 210886 | 11 | 145 |
| LKSS 9 | 130.0 | 690770 | 9732790 | 210886 | 7.5 | 63 |
| LKSS 10 | 250.0 | 685790 | 9734780 | 220886 | 13 | 53 |
| LKSS 11 | 160.0 | 687310 | 9735920 | 220886 | 12 | 53 |
| Measurement | Max L/2 | X-coord. | Y-coord. | Date | Elevation | Direction |

As far as the instrument is concerned, the remarks under Section b.2 also apply for this area.

### c.3 Interpretation

The same observations concerning interpretation hold as stated under Sections a.3 and b.3.

The surface elevations of all the VES's are taken from maps at scale 1:10,000, with 1 m contour intervals.

Water levels and resistivities from the water have been taken in some wells and from surface water and are listed in Table C.2.

In a well dug near VES 8, porous cemented clayey sand was encountered at 3 m below surface.

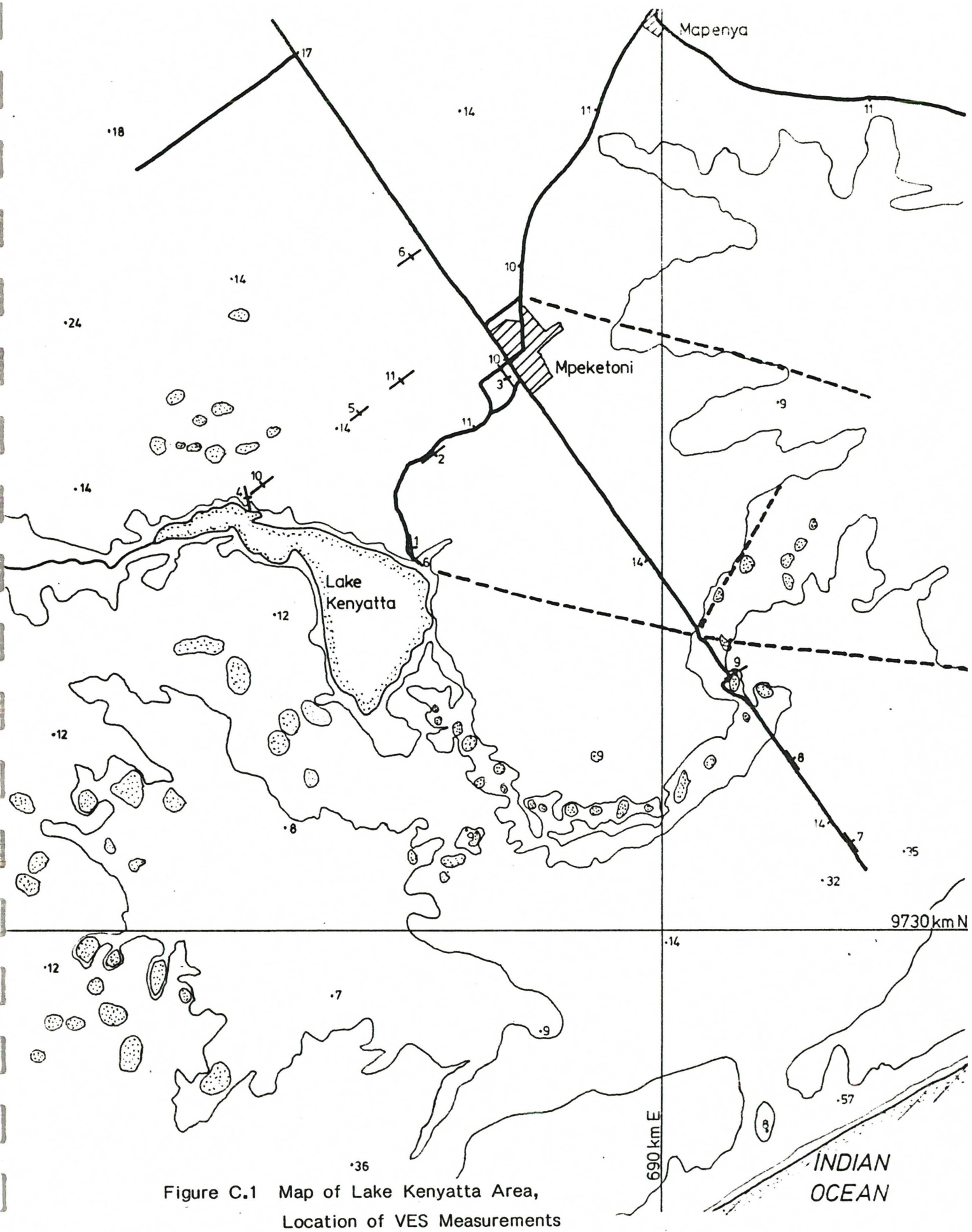



Figure C.1 Map of Lake Kenyatta Area, Location of VES Measurements and Hydrogeological Features.

Table C.2 Water Level and Resistivity Data Lake Kenyatta Settlement Scheme

| Well | Elevation (m + MSL) | Water level (m below surface) | Resistivity (Ωm) |
|---|---|---|---|
| 175 m SW of VES 3 | 9.3 | 5.40 | 8.3 |
| 260 m NE of VES 6 | 10.5 | 6.78 | 6.9 |
| 230 m N of VES 10 | Appr. 13 | 7.65 | 6.7 |
| Surface water at VES 1 | | | 85.6 |
| Surface water at VES 4 | | | 84.4 |
| Surface water at VES 9 | | | 62.0 |

From the water resistivity and the level below surface, it seems that fresh water bearing layers in this area have a resistivity of 30 to 50 Ωm.

With lower resistivities a higher clay content may be expected or a lower water quality.

As the survey area is close to the ocean, a "base" layer with saline water can be expected and a resistivity of 2 Ωm has been assumed for it in all the models.

## c.4 Summary of Results

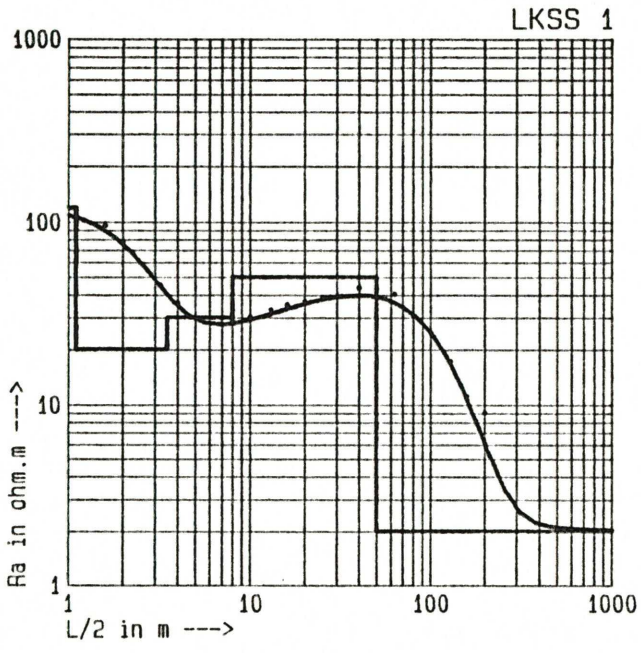
Plots of the measured resistivities with the interpreted layer models and corresponding calculated curves are shown for every VES in Figures C.2-1 through C.2-11. Dots represent the field values. The horizontal axis shows half the electrode distance and the vertical axis shows the apparent resistivity.

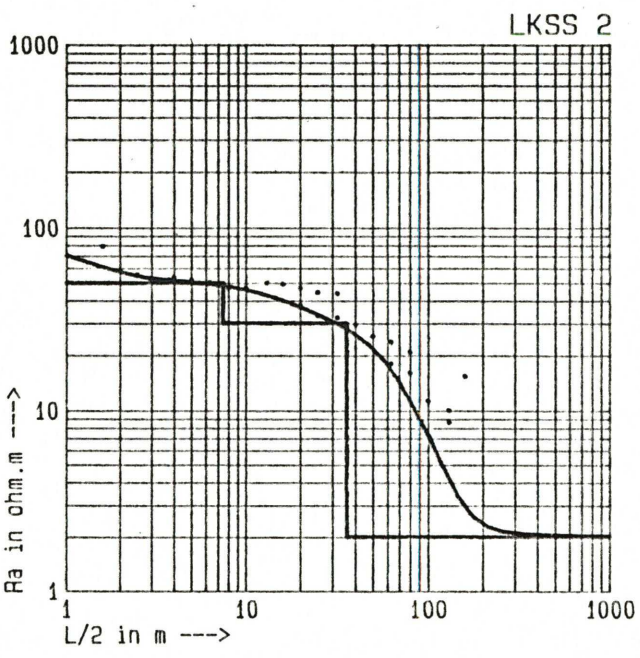
Like in Hindi-Magogoni Settlement Scheme no extensive aquifer system seems to exist in this area. Near the lake there is some underground storage up to considerable depth (VES 1). However clayey layers can be expected, especially in the area of VES 4 and 10.

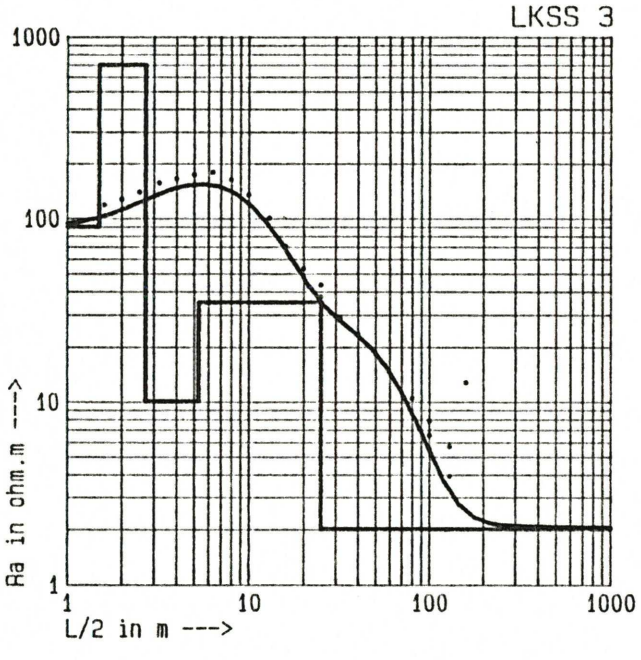
At VES 9 a relative low resistivity layer (20 Ωm) exists which might indicate only low underground drainage towards the ocean (see map in Figure C.1). The wells at VES 3 and 6 seem to have only local recharge while at VES 5 and 11 the prospects for fresh water are poor, as they are for VES 7 and 8.

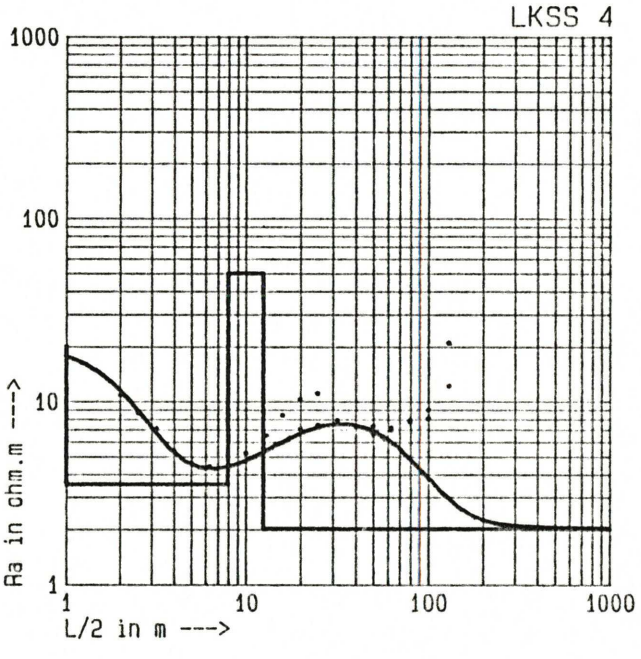
Figure C.2 List of VES Plots Lake Kenyatta Settlement Scheme

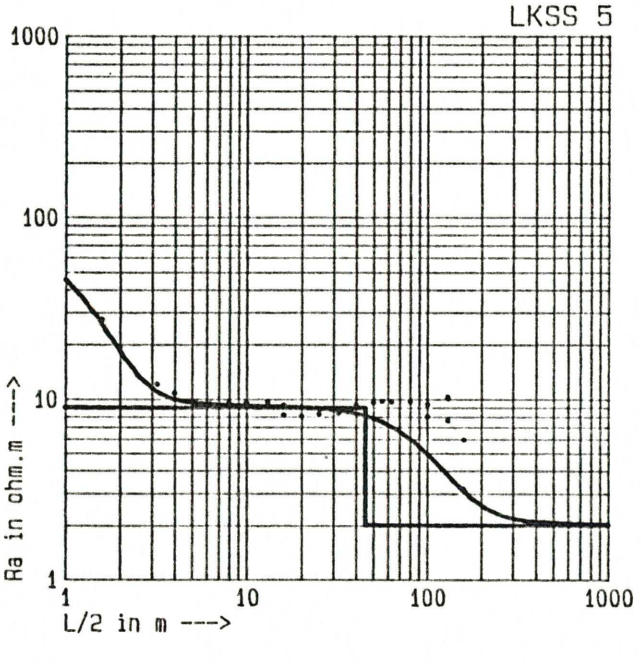
VES LKSS-1 through VES LKSS-11

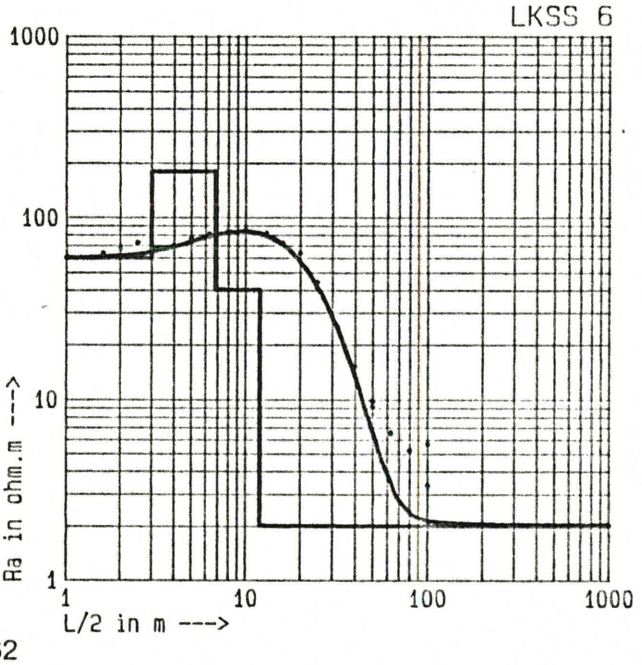

LKSS 1
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

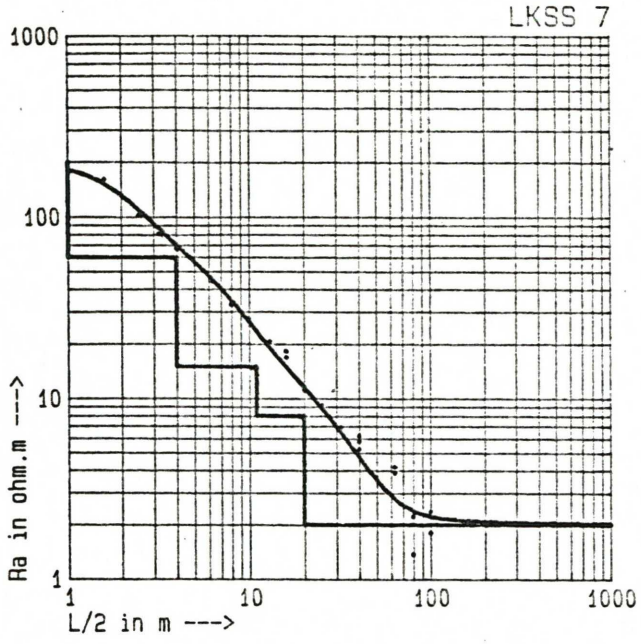

LKSS 2
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

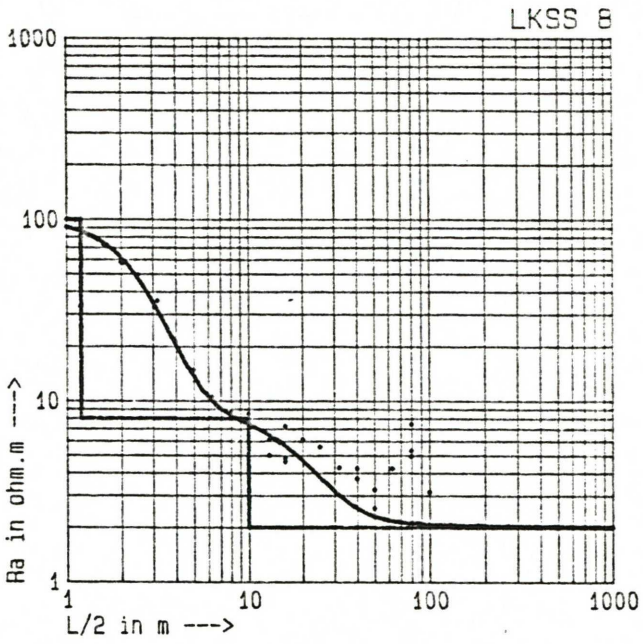

LKSS 3
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

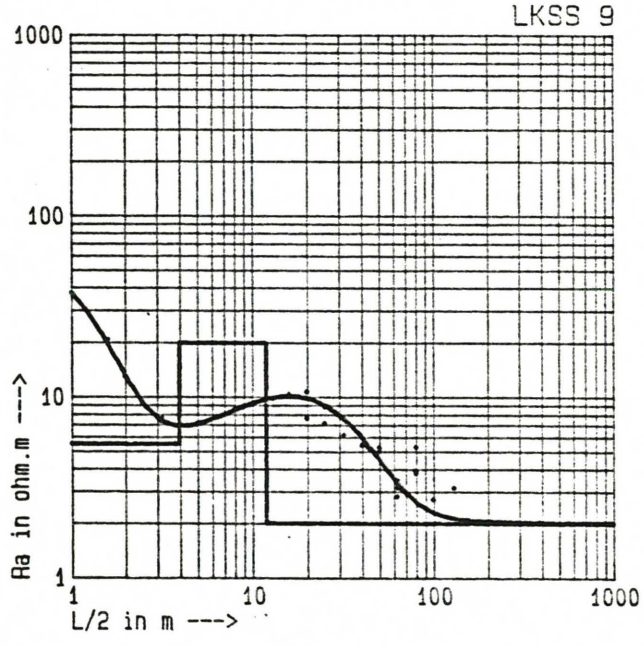

LKSS 4
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

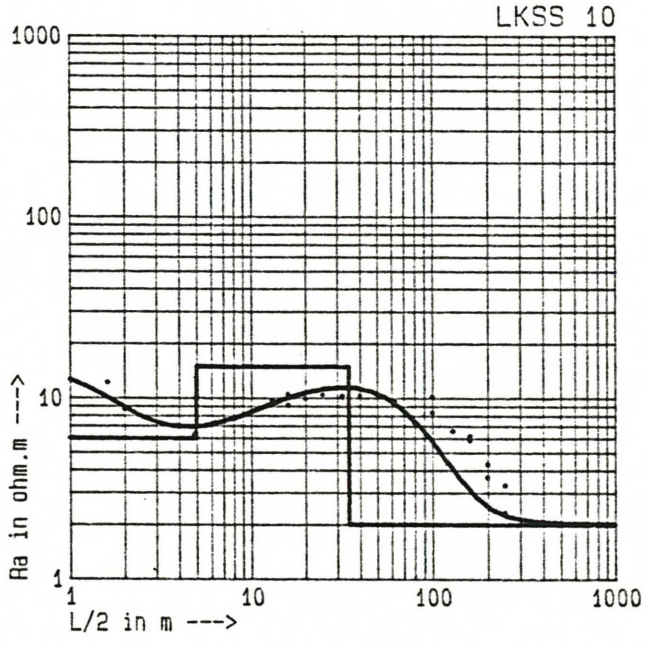

LKSS 5
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->

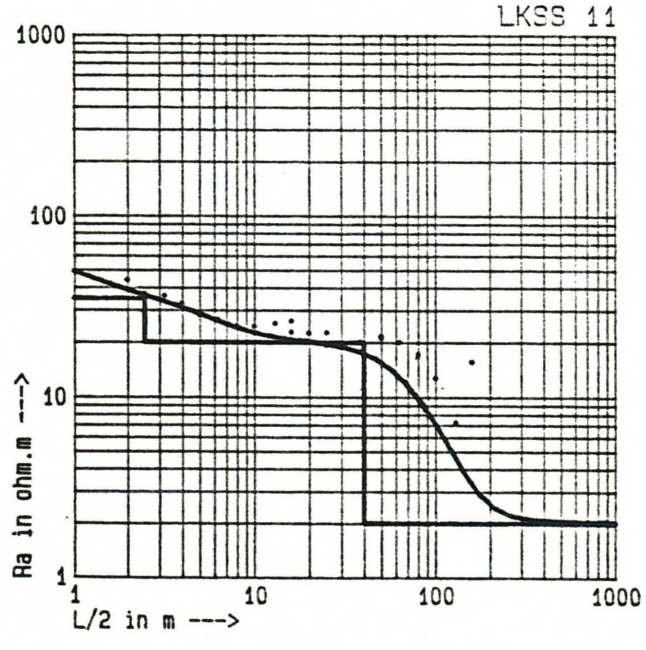

LKSS 6
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


LKSS 7
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


LKSS 8
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


LKSS 9
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


LKSS 10
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->


LKSS 11
1000
100
10
1
Ra in ohm.m --->
1
10
100
1000
L/2 in m --->