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THE EXPLORATION AND EVALUATION OF GROUNDWATER UNITS IN THE  
VAN RYNEVELDS PASS DAM BASIN, NORTH OF GRAAFF-REINET,  
CAPE PROVINCE

VOLUME 1 : TEXT AND ENCLOSURES

by

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degree of Master of Science in the Department of Geography,  
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ABSTRACT

This thesis deals with a groundwater investigation conducted in the Van Rynvelds Pass Dam basin, north of Graaff-Reinet, in the Cape Province. The objective of the study was to assess the groundwater potential of the basin in terms of its development and exploitation as a municipal supply.

In order to achieve this objective, fieldwork was carried out involving a hydrocensus, geological/geophysical mapping, drilling, aquifer testing and hydrochemical sampling. The fieldwork was conducted during the period January 1983 to February 1984.

The investigation revealed that the most significant groundwater occurrence in the study area is an alluvial/weathered bedrock aquifer (Graaff-Reinet aquifer). The volume of groundwater stored in the Graaff-Reinet aquifer is in the order of  $27 \times 10^6 \text{ m}^3$ , while its exploitation potential is conservatively estimated at  $9\,300 \text{ m}^3/\text{day}$ . However, the quality of this water is poor and should be blended with dam water or better quality groundwater. Two minor fractured aquifer units were also identified.

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DURATION OF PROJECT

The fieldwork for the study commenced in January 1983 and was completed towards the end of 1984. The writing up of the thesis was only completed in 1988, due to military commitments of the author during 1985-1986.

## CHAPTER 1

### GRAAFF-REINET'S WATER SUPPLY PROBLEM AND INVESTIGATION OBJECTIVES

#### 1.1 INTRODUCTION

Since the establishment of Graaff-Reinet in 1786, there have been a number of occasions when water supply problems have been of concern to the town. During the period 1979 to 1983, the Van Rynevelds Pass Dam, the town's normal supply of water, was either dry or at a critically low level. Water supplies during this drought period were abstracted from boreholes. Abstraction from the wellfield was however stretched to the limit by 1982, and the Municipality approached the Department of Environment affairs to assess the groundwater resources and supply potential.

This study forms a part of the overall geohydrological investigation and specifically deals with the exploration and evaluation of the alluvial aquifers and other groundwater units, within and beyond the municipal boundary to the north of Graaff-Reinet.

In the remaining sections of this Chapter, Graaff-Reinet's water resources and requirements are discussed by way of an introduction to the town's water supply problem.

#### 1.2 HISTORICAL REVIEW OF GRAAFF-REINET'S WATER SUPPLY

Graaff-Reinet is situated in the eastern interior of the Cape Province, some 290 km inland from Port Elizabeth (Figure 1). From its establishment in 1786 up to 1924, the town's water supply was obtained from springs (Mackies Pits), and on a more sporadic basis from the Sundays River. The position of the Mackies Pits are indicated on Enclosure 1. In 1920, the springs yielded a continuous flow of approximately 10 l/s (Vegter, 1957). The water was of a moderate quality (TDS of 1080 mg/l) and was gravity fed to the town via a concrete-lined canal.

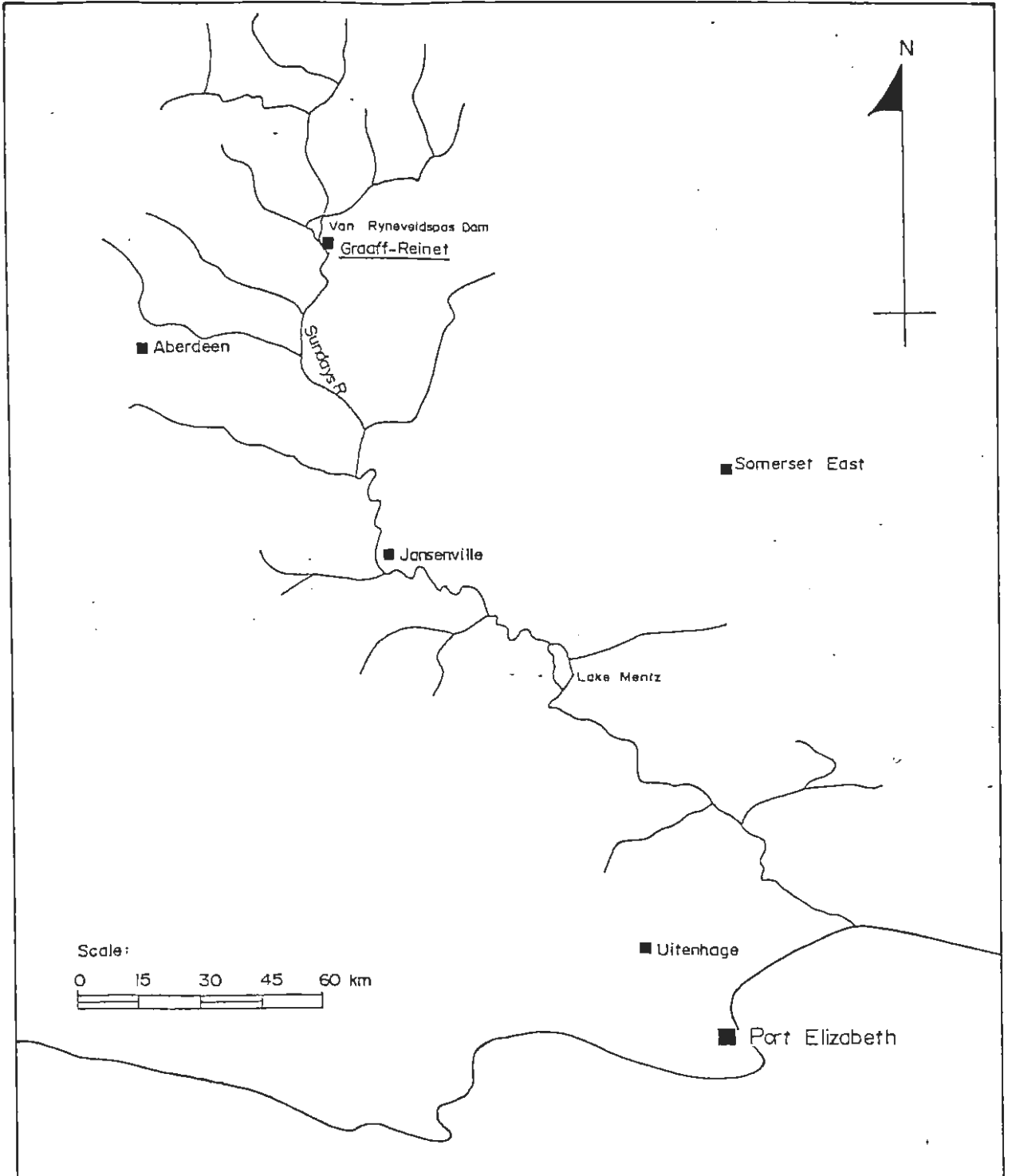


Figure : 1 Graaff - Reinet Regional Setting :

In 1920, the government decided to construct the Van Rynevelds Pass Dam. The main purpose of the dam was to provide irrigation water to the farmers in the plain of the Sundays River, south of Graaff-Reinet. The distribution of the water was administered by the Van Rynevelds Pass Dam Irrigation Board. An agreement was signed between the Irrigation Board and the Municipality concerning the allocation of water for urban use. The salient points of the agreement were:

- (a) The municipality was to maintain full rights to the Mackies Pit's water,
- (b) the municipality was entitled to draw a maximum of 9000 m<sup>3</sup> per day, and
- (c) if in the opinion of a qualified engineer, the water stored within the dam was only enough to supply the town at the above rate for the period of one year, withdrawal for irrigation purposes were to be halted.

In 1924, the Van Rynevelds Pass Dam was completed with a total capacity of approximately  $7.6 \times 10^7$  m<sup>3</sup>. To ensure the flow from the Mackies Pits, the wells and canal were sealed with concrete slabs. However, this precaution did not prevent a drastic deterioration in the water quality. In 1926, chemical analysis of the springwater revealed a TDS content of 3290 mg/l. This water could thus only be used for irrigation purposes.

Under the above circumstances, the Van Rynevelds Pass Dam was not the ultimate solution to Graaff-Reinet's water needs. The necessity arose to acquire an alternative source of water to supplement the dam during periods of drought.

During 1956 to 1958, the so-called "Emergency Borehole Scheme" was developed in the alluvial floodplain of the Sundays River, north of Graaff-Reinet (map, Enclosure 1). The scheme initially comprised two high-yielding boreholes, which was gradually expanded to six boreholes by the end of 1980.



Plate 1 : View of the proposed site of the Van Rynevelds Pass Dam wall on the Sundays River.



Plate 2 : Construction on the Van Rynevelds Pass Dam wall, and earth-lined canal from the "Mackies Pits" - July 1921.

### 1.3 EXISTING MUNICIPAL WATER RESOURCES

When not empty, the Van Rynevelds Pass Dam is Graaff-Reinet's major water source. The Municipality has a servitude for the withdrawal of 9000 m<sup>3</sup>/day from the dam (as discussed in Section 1.1). Prior to 1983, the municipal wellfield consisted of six fully equipped boreholes with an estimated maximum combined capacity of 5300 m<sup>3</sup>/day. The Mackies Pits water, because of its poor quality, is only used for the irrigation of gardens, recreation fields etc. The present flow of the springs is estimated at 10,5 l/s. Various privately owned boreholes in the town are used mainly for the watering of gardens. The average yield of these boreholes is less than 1 l/s.

### 1.4 MUNICIPAL WATER CONSUMPTION AND FUTURE REQUIREMENTS

Graaff-Reinet's present annual water consumption is estimated to be in the order of  $1.4 \times 10^6$  m<sup>3</sup> (3800 m<sup>3</sup>/day), with a peak demand of 6200 m<sup>3</sup>/day (Woodford, 1984).

The annual municipal water consumption is indicated on a histogram (Enclosure 3) for the period 1960 to 1983. The contribution of dam and groundwater to the annual totals are also indicated.

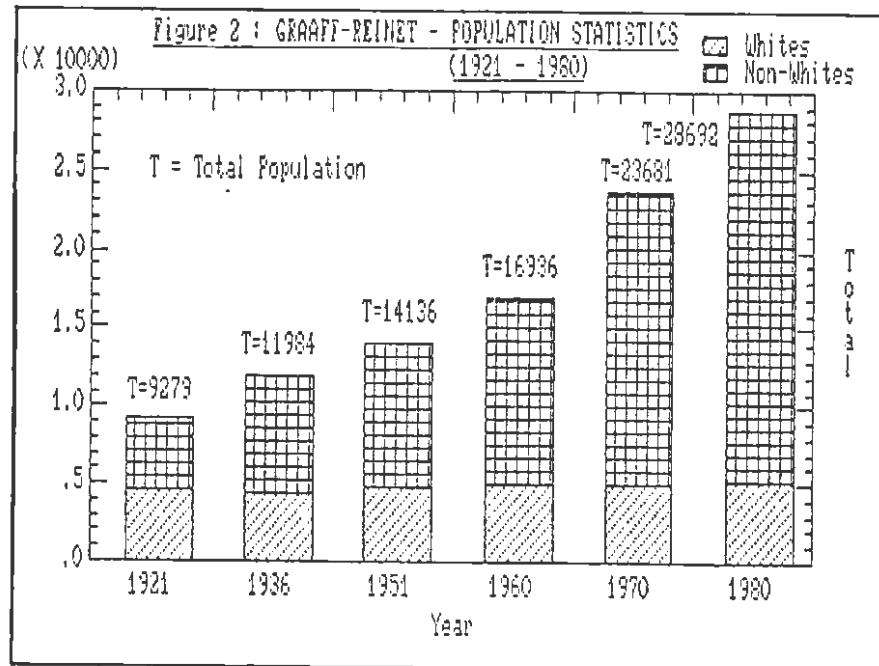
It is important to note that the apparent sudden steep rise in municipal water consumption after 1977 is related to the start of the official municipal record. Prior to 1977, consumption data was collated piecemeal from municipal documents and reports (de Bruin, 1972; Kok, 1974).

A histogram of the official population census figures for the period 1921 to 1980 is presented in Figure 2. The data are categorised into whites and non-whites in accordance with the official statistical records. It is evident that, from 1920 to 1980, the white population has shown a slight increase (14%), whilst the non-white population has increased over five fold. Based on these data, estimates of future population levels and municipal water consumption were calculated for the years 2003 and 2023 (Table 1).

TABLE 1: Expected Population and Water Consumption trends for Graaff-Reinet (Hoodford, 1984).

YEAR	1983					2003					2023				
	Popul- ation	Per Capita l/p/d	Consumption Yearly mill Kl	Daily Kl/day	Peak Kl/day	Popul- ation	Per Capita l/p/d	Consumption Yearly mill Kl	Daily Kl/day	Peak Kl/day	Popul- ation	Per Capita l/p/d	Consumption Yearly mill Kl	Daily Kl/day	Peak Kl/day
White	6 000	446	0.96			6 500	500	1.17			7 000	520	1.32		
Coloured	14 800	71	0.38			17 200	120	0.75			20 000	160	1.17		
Black	8 400	15	0.05			12 400	80	0.36			16 000	120	0.70		
TOTAL	29 200		1.39	3 808	6 093	36 100		2.32	6 356	10 170	43 000		3.19	8 740	13 984

- REMARKS - The 1983 figures have been adjusted to take into account the water restrictions.  
 - The per capita consumption for whites is unusually high because the S.A. Transport Services, industrial usage etc, is include under "white consumption".  
 - The 2003 and 2023 figures have been inflated to take into account improved living conditions amongst non-whites and possible industrial expansion in the case of the whites.  
 - The peak daily consumption calculated using a factor of 1.6 compares well with the peak rate of 6120 Kl/day on record.



#### 1.5 THE HYDROLOGICAL PROBLEM - MUNICIPAL WATER SUPPLY

Graaff-Reinet experiences water supply problems when the Van Rynevelds Pass Dam is dry. During such periods the town has to rely on its so-called "Emergency Borehole Scheme". By the year 2000, it is estimated that the town's average daily water requirements will be in the order of 6400 m<sup>3</sup>/day, with consumption rates of up to 10 200 m<sup>3</sup>/day during periods of peak consumption (Table 1).

From Section 1.2 it is evident that, when the Van Rynevelds Pass Dam contains water, the above requirements can be met from the dam. Although it may be necessary to utilise the municipal wellfield to augment supply during peak consumption periods.

In the long term, the Van Rynevelds Pass Dam is not a permanent water resource. According to the latest Silt Survey (1978), the dam has shown a 39% reduction in storage capacity. This represents an annual decline in storage capacity of 0.79% per year. It is therefore expected that by the year 2050 the dam's storage capacity will be practically nil.

When the Van Rynevelds Pass Dam is dry, the town is solely dependent on the municipal wellfield to meet its water requirements. The estimated maximum capacity of the wellfield is approximately 5300 m<sup>3</sup>/day. By the year 2000, this would result in an average daily shortfall of 1100 m<sup>3</sup>/day and a shortfall of about 4900 m<sup>3</sup>/day during peak consumption periods. This expected shortfall must be overcome by either:

- (a) expanding the existing municipal wellfield, or
- (b) acquiring alternative water resources.

Ninham Shand (1982) conducted a feasibility study into the various alternative water-sources available to the town. One of their major recommendations was that, prior to any of the other alternatives, the groundwater potential of the district be fully investigated.

Although it is known that large quantities of groundwater can be abstracted from the alluvial aquifer, as in the case of the municipal wellfield, no reliable estimates of the exploitation potential of the aquifer are available. It was therefore imperative that the aquifer's exploitation potential be quantitatively assessed prior to any further development of the aquifer.

#### 1.6 STUDY OBJECTIVES

The objective of this investigation is to provide a quantitative assessment of the groundwater potential of the study area, in terms of its development and exploitation as a municipal supply. The specific aims of the study are:

- (1) to identify and define the different aquifer units,
- (2) determination of the hydraulic and hydrochemical properties of the aquifer units, and
- (3) to assess the groundwater resource potential of the aquifers in terms of their exploitable yield and water quality.

Particular emphasis is placed on the quantitative assessment of the alluvial aquifer in terms of its further expansion and optimal utilisation.

The format and logical progression of the remaining chapters of this study are briefly outlined below:

- Chapter 2 - The study area is introduced and background information involving location and physiography are presented.
- Chapter 3 - The earlier hydrological research conducted in the study area is reviewed. A geohydrological model and the hypothesis of the investigation are formulated to provide a scientific approach to realisation of the objectives of the study.
- Chapter 4 - The broad methodology and work components of the investigation are outlined. The application and relevance of each of the components to the study are discussed.
- Chapter 5 - The theoretical aspects, data and results of the investigation are presented under the various geohydrological components of the study, outlined in chapter 4.
- Chapter 6 - The exploitation potential of the aquifer units are discussed.
- Chapter 7 - The hypotheses formulated in Chapter 3 are tested and the results are discussed.
- Chapter 8 - The conclusions and recommendations of the study are put forward.

## CHAPTER 2

### THE INVESTIGATION AREA

#### 2.1 LOCATION

The study area comprises the alluvial basin, north of Graaff-Reinet (Figure 3). The investigation covered an area of approximately 160 square kilometres, extending from the Van Rynevelds Pass Dam in the south to the Ouberg Pass in the north, and from the Pienaars River in the west to the Sundays River in the east (coordinates  $24^{\circ}15'$  to  $24^{\circ}37'E$  and  $32^{\circ}08'$  to  $32^{\circ}15'S$ ).

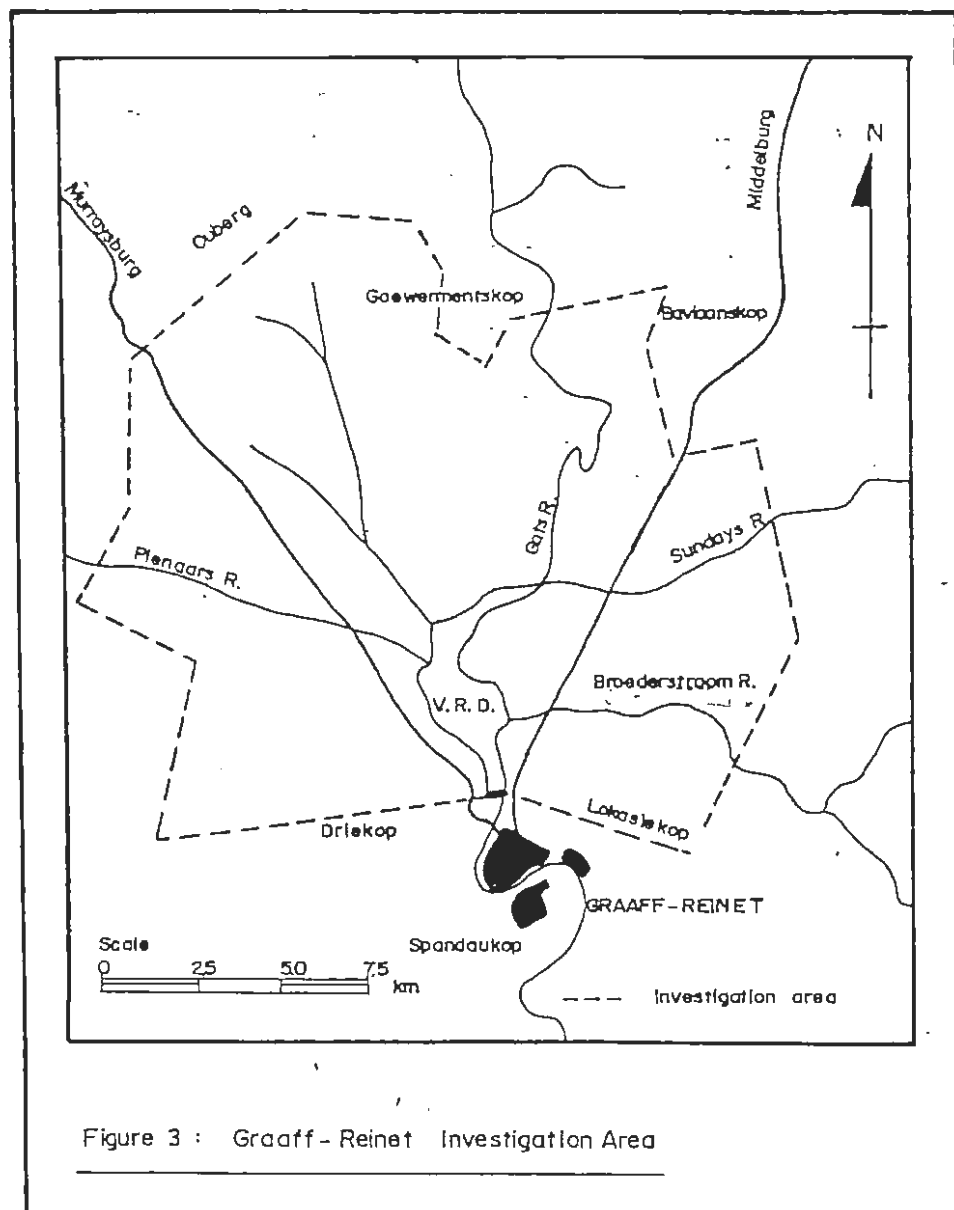




Plate 3 : The study area - view from Ouberg Pass (north) of the Van Rynevelds Pass and Graaff-Reinet.



Plate 4 : The study area - northerly view of the Van Rynevelds Pass Dam basin.

## 2.2 PHYSIOGRAPHY

### 2.2.1 RELIEF AND SURFACE DRAINAGE

The Sundays River originates to the north of the study area in the Sneeu Berg Mountains and flows southwards towards Graaff-Reinet. Here at its confluence with the Gats, Pienaars and Broederstroom Rivers it forms an extensive alluvial basin. The alluvial floodplain lies at an average elevation of 780 metres above mean sea level.

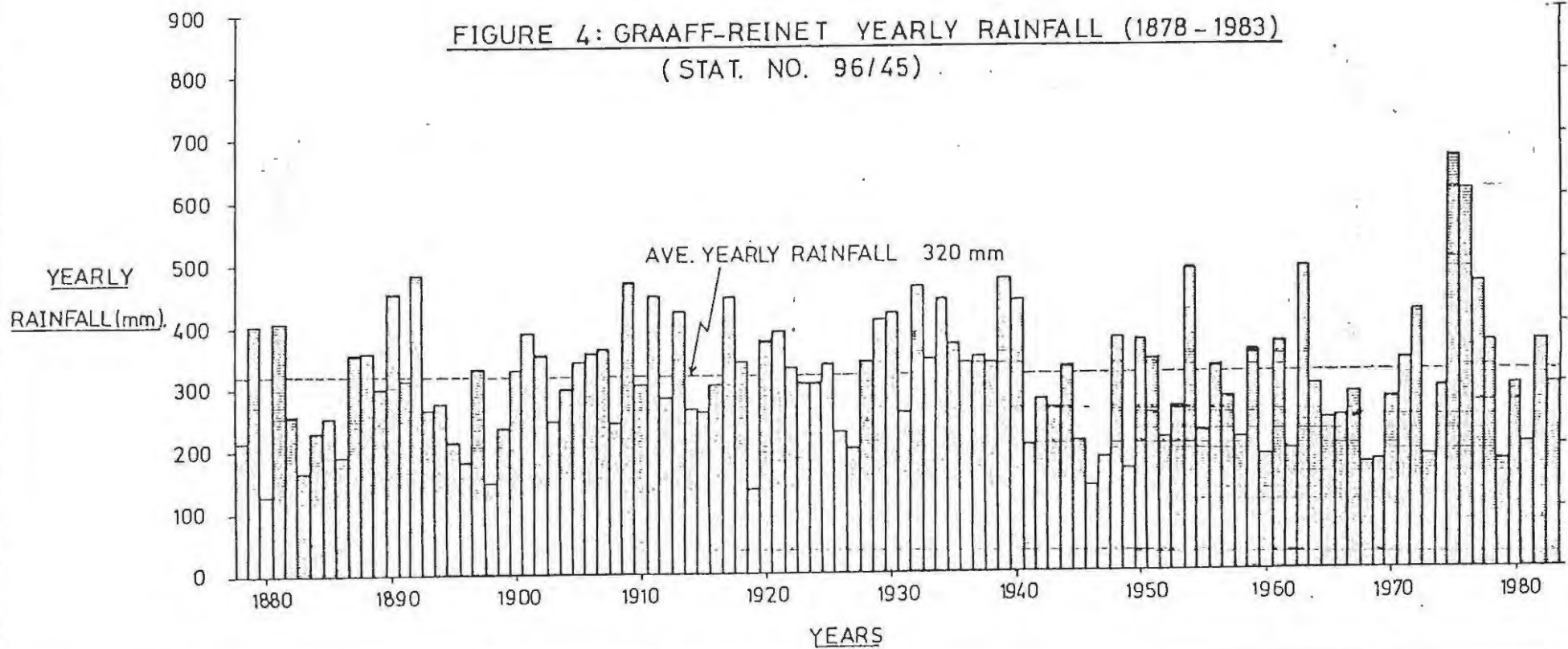
From the basin edges, the ground rises rapidly to heights of 1500 metres at Goewermentskop and 1600 metres at Ouberg. The mountains encircling the basin are capped with dolerite sheets. The Van Rynevelds Pass Dam wall is situated on a northward dipping dolerite sheet, which forms a ideal dam site, as well as a natural groundwater barrier. The Van Rynevelds Pass Dam has a catchment area of 3825 square kilometres.

### 2.2.2 CLIMATE AND VEGETATION

Graaff-Reinet has a semi-arid climate, characterised by warm summers and cold winters. The mean annual precipitation at Graaff-Reinet is 320 mm. Rainfall occurs mainly during the summer months in the form of high intensity storms. The yearly precipitation data, for the period 1878 to 1983, for Graaff-Reinet are presented in Figure 4. It is evident from Figure 4 that the rainfall is highly variable, with the lowest annual rainfall of 125 mm and the highest on record of 760mm. The longest period during which the annual rainfall was continually below the annual mean is 5 years. The mean annual potential evaporation is 1210 mm, while the highest evaporation losses occur during mid-summer.

The vegetation in the study area is sparse, and according to Acock's (1975) definition of veld types, is what he terms the False Karoid Broken Veld. The soils are generally saline, which is a common condition in areas where the evapotranspiration exceeds the mean annual rainfall.

FIGURE 4: GRAAFF-REINET YEARLY RAINFALL (1878 - 1983)  
(STAT. NO. 96/45)



### CHAPTER 3

#### PREVIOUS HYDROLOGICAL RESEARCH, GEOHYDROLOGICAL MODEL AND HYPOTHESES FORMULATION

##### 3.1 PREVIOUS HYDROLOGICAL INVESTIGATIONS

Hydrogeological investigations in the Graaff-Reinet district have been carried out since 1947 by geologists and hydrogeologists of the Geological Survey and the Department of Water Affairs, as well as various private consultant firms. The numerous geohydrological reports that have been produced are summarised below:

(a) GH 280 - J.R. Vegter (1947)

The report deals with a brief investigation of the groundwater potential of the Graaff-Reinet municipal area and includes the selection of drilling sites in an attempt to alleviate a municipal water shortage. It is concluded that the alluvial basin north of town has the greatest potential for high groundwater yields, but that the water quality would be poor.

(b) Ninham Shand (Eng.) (1947)

Ninham Shand compiled a report on an investigation aimed at augmenting the existing municipal water supply. The report includes a brief assessment of the existing water resources of the district. The conclusion reached is that the groundwater resources of the region are unsuitable and insufficient for long term municipal usage.

(c) GH 1001 - C.V. Joubert (1956)

A groundwater survey of the Graaff-Reinet district was carried out with the purpose of delineating areas for possible groundwater development for municipal use. An account is given of some of the boreholes drilled during January to July 1956 (GR2, -4, -5, -6 and GR22 in Appendix

1). It was recommended that the area encompassing the municipal wellfield be further developed.

(d) Ninham Shand (Eng.) (1956)

Ninham Shand present a scheme for the abstraction and transport of water from the municipal wellfield (boreholes GR5 and GR7) to the town's reticulation system. The boreholes GR5 and GR7 were tested individually for 72 hours at an average rate of 25,6 and 13,4 l/s, respectively. A "combined safe yield" of 39 l/s for a 24 hour period was put forward.

(e) GH 1018 - J.R. Vegter (1957)

Vegter reports on an attempt to assess the suitability of boreholes GR5 and GR7 as an auxiliary municipal water source. Geological mapping was performed in the vicinity of the municipal wellfield. A 72 hour pumping test was carried out on borehole GR5. Although it was admitted that insufficient data were available to assess the potential of the wellfield aquifer, the borehole scheme was recommended as a supplementary water supply until further data on recharge became available.

(f) GH 1761 - K.G. Buchanan (1970)

The occurrence of groundwater in the Graaff-Reinet area, more specifically the area immediately north of the town, is discussed. It was recommended that further work be conducted in the alluvial area about the airfield and that a watertable contour map be constructed to assist in the selection of drilling sites.

(g) GH 1803 - C.G. de Bruin (1972)

This report lists the data of an extensive borehole survey in the Graaff-Reinet district, within a radius of up to 35km from town. It also contains geological maps

produced from aerial-photograph study and delineates five major areas suitable for further groundwater exploration. The alluvial basin north of Graaff-Reinet is one of five areas recommended for further investigation.

(h) C.V. Joubert (1972)

This report followed a request by the municipality to re-evaluate the abstraction potential of the municipal wellfield. Based on pumping tests carried out in 1957, watertable observations, rainfall data, borehole and dam abstraction figures, some observations are made as to the "safe-yield" of the alluvial aquifer. It is estimated that the average daily abstraction of 394 m<sup>3</sup>/day could be increased by as much as six-fold.

(i) GH 1891 - T.S. Kok (1974)

Based on work carried out by de Bruin (1972), various areas for further investigation are pinpointed. Particular attention is given to the municipal wellfield and an abstraction potential of 6 million m<sup>3</sup>/year for the alluvial aquifer is put forward. The author does not give a clear indication as to how this value was derived. It is recommended that the area northwest of the existing wellfield, as well as the area north of the dam, be investigated.

(j) GW 1205 - C.V. Joubert (1980)

The Municipality commissioned Joubert to investigate the possibility of obtaining additional groundwater supplies from the municipal wellfield area. The feasibility of obtaining groundwater below the dolerite sheet in the area is discussed. Based on geological mapping and geo-electrical observations, boreholes GR17, GR18 and GR19 were selected (Appendix 1).

(k) Rp 753/3760 - Ninham Shand (Eng.) (1982)

The town's existing water resources, as well as the long and short term alternatives to providing a permanent water supply, are discussed at length. One of Ninham Shand's recommendations is that a comprehensive hydrogeological study of the region be made.

(l) C.V. Joubert (1982)

On request from the municipality, an estimation was made of the volume of groundwater stored within the alluvial aquifer. A volume of 120 million m<sup>3</sup> was arrived at, assuming an effective porosity for the alluvium of 10%.

It is evident from the above summary that over the years much thought was given to Graaff-Reinet's sources of water, particularly to its emergency or supplementary groundwater scheme. The general trend of recommendations was to expand the existing wellfield, to assess the potential of the alluvial aquifer and to explore the Graaff-Reinet district for additional groundwater resources. Not much action ever ensued and this investigation is intended to fulfill the research recommendations of the various preceding reports.

### 3.2 CONCEPTUAL GEOHYDROLOGICAL MODEL

Mandel et al (1981) lists the following important characteristics of groundwater occurrences in arid regions:

- (1) Recharge which is affected by seepage water from sporadic river flow.
- (2) Direct infiltration of rainwater plays a minor role in recharge.
- (3) The storage capacity of the aquifer is of special importance due to the irregularity of the rainfall.

- (4) Poor groundwater quality is a common constraint. This is because salts are accumulated by being continually recycled within the environment.
- (5) Large scale groundwater development almost always involves over exploitation.

These general characteristics are anticipated to be prevalent within the study area. A conceptual geohydrological model of the study area is proposed in Figure 5. The model is formulated upon the above generalisations and earlier hydrological investigations.

The basic geohydrological components of the model are:

- (1) Three, broadly defined, geological components:
  - (a) Extensive alluvial/colluvial cover, which includes the Van Rynevelds Pass Dam,
  - (b) sandstone, siltstone and mudstone of the Beaufort Group, and
  - (c) Karoo dolerite dykes and sheets.
- (2) Two basic aquifer units are recognised:
  - (a) Discrete-fractured (secondary), sedimentary aquifer(s) mostly associated with dolerite intrusions, and
  - (b) an alluvial/weathered bedrock aquifer, which comprises a two-media aquifer of porous alluvium (primary) and fractured/weathered bedrock (secondary). This aquifer will henceforth be referred to as the Graaff-Reinet aquifer.

Wilke (1962) states that the principal hydrological properties of a geological unit are its porosity, specific-yield and permeability.

It is postulated that the major transmissive zones within the Graaff-Reinet aquifer are the coarse basal horizon and fractured/weathered bedrock associated with dolerite intrusions.

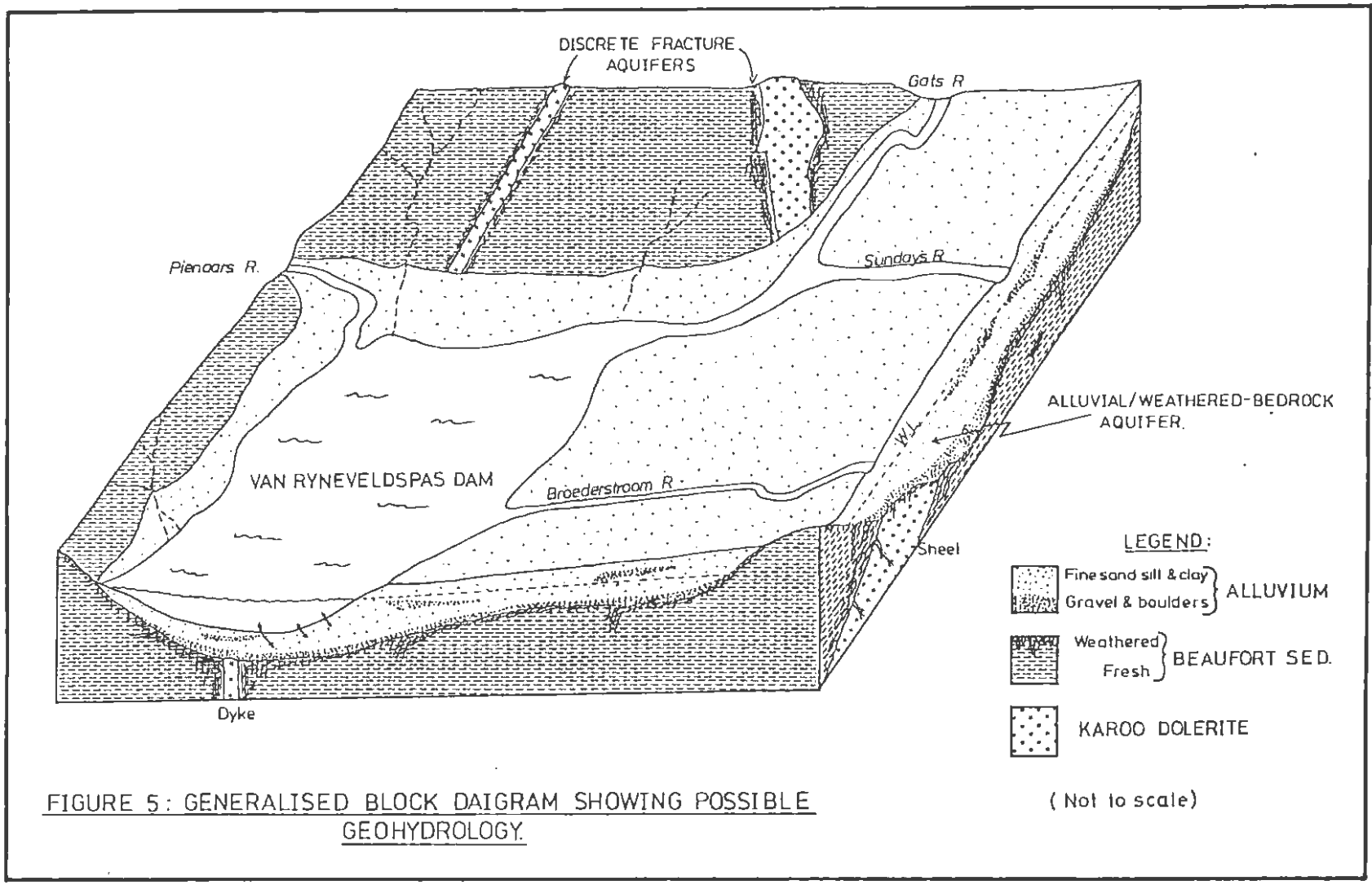


FIGURE 5: GENERALISED BLOCK DAIGRAM SHOWING POSSIBLE GEOHYDROLOGY.

According to Görgens et al (1981), groundwater flow will be concentrated in topographical channels and depressions scoured into the sub-alluvium erosional surface.

It is expected that weathering is confined to the near surface due to the nature of the lithologies and the semi-arid climate. Therefore weathered zone aquifers are not considered to be of any hydrological importance within the study area. Discrete aquifers are thus expected to occur in the hard-rock terrain, as a result of fracturing/weathering associated with dolerite structures.

Vandoolaeghe (1980) lists the following important characteristics of discrete-fractured aquifers associated with dolerite intrusives:

- (a) Linear, fissure type flow.
- (b) Semi- to confined nature.
- (c) Hydraulic properties that vary both vertically and laterally.
- (d) Variable, but limited extent of individual aquifers related to the shape of the intrusion.
- (e) Orientation of fractures exert<sup>an</sup> important control on the local pattern of groundwater flow.

### 3.3 HYPOTHESES

In order to provide a scientific framework for the investigation a number of hypotheses have been formulated. The hypotheses are based on the findings of earlier investigations and the conceptual geohydrological model postulated in Section 3.2:

#### AQUIFER LITHOLOGY AND GEOMETRY:

- (1) The major groundwater unit is a laterally extensive alluvial/weathered bedrock aquifer (Graaff-Reinet aquifer).

- (b) Well developed fractured aquifer(s) in consolidated sediments represent discrete groundwater units and are directly related to dolerite intrusions.
- (3) Dolerite intrusions, themselves, do not contain large amounts of groundwater.

#### HYDRAULIC PROPERTIES OF THE AQUIFERS:

- (4) The alluvial/weathered bedrock aquifer is unconfined to semi-confined with the principal zone of transmission represented by a basal gravel/boulder layer.
- (5) The fractured aquifers are confined and anisotropic.

#### HYDRAULIC CONNECTION BETWEEN THE VAN RYNEVELDS PASS DAM AND THE GRAAFF-REINET AQUIFER:

- (6) A discharge/recharge relationship exists between the Van Rynevelds Pass Dam and the Graaff-Reinet aquifer.

#### HYDROCHEMISTRY OF THE GROUNDWATER:

- (7) The quality of groundwater associated with the Graaff - Reinet aquifer is of a poorer chemical quality than with that associated with fractured aquifers in hardrock terrain.
- (8) In the Graaff-Reinet aquifer the mineralisation increases in the direction of groundwater flow.
- (9) During periods of drought the decrease in quality of the groundwater in the vicinity of the wellfield is as a result of induced inflow of poor quality water from beneath the Van Rynevelds Pass Dam.

In this Chapter the earlier groundwater research conducted in the study area was reviewed and a conceptual geohydrological model postulated. This provided the basis whereupon the hypotheses of the investigation were formulated. The methodology whereby the investigation will be conducted in order to achieve the study objectives are discussed in Chapter 4.

## CHAPTER 4

INVESTIGATION APPROACH

Lloyd (1981) defines a typical regional hydrogeological investigation as encompassing the following:

- (a) Location and definition of the aquifer(s).
- (b) Determination of the hydraulic characteristics of the aquifer(s).
- (c) Evaluation of the hydrochemistry of the aquifer(s) and possible relationship to groundwater flow.
- (d) Assessment of recharge/discharge characteristics of the aquifer system(s).

The overall objective of a regional groundwater investigation should be the collection of data from which decisions can be made as to the optimal exploitation of the resource.

Walton (1970), Mandel et al (1981) and Lloyd (1981) present a broad outline of the various phases of work involved in such a regional groundwater investigation. In accordance with the aims and objectives of this investigation, the following components of the study are outlined in their logical sequence of execution:

- (1) Desk study and review of available information.
- (2) Hydrocensus of all waterpoints.
- (3) Geohydrological mapping.
- (4) Geophysical mapping.
- (5) Exploration drilling.
- (6) Aquifer testing.

It must be stressed that, although the above study components are presented under separate headings, they are inevitably linked and interrelated to such an extent that progression from one component to another may be gradational or even proceed concurrently.

In the following sections each of the above outlined components is discussed in terms of fulfilling the overall objectives of this study.

#### 4.1 DESK STUDY AND REVIEW OF INFORMATION AVAILABLE

The usefulness of a desk study in developing a programme for effective field operation is often underestimated in its value (Gray, 1975). During the initial stages of the investigation the desk study involved the following:

- (a) A map and photogeological appreciation of the area. The advantage of high viewpoint and sensing characteristics of air photographs is that in areas with few rock exposures an interpreter can often more easily detect structures than a ground observer (Norman et al, 1978).
- (b) Appraisal and integration of research already completed in similar hydrogeological investigations, and
- (c) The collection and study of literature relevant to the investigation.

The scientific framework of the investigation was then formulated in the light of the above review.

At a later stage, the desk study involved the interpretation of the various field techniques employed, as well as data synthesis and report compilation.

#### 4.2 HYDROCENSUS OF ALL WATERPOINTS

Due to the high cost of drilling it is essential that the greatest possible use be made of existing borehole information. The borehole inventory usually marks the first field

phase of a regional groundwater investigation and generally serves a dual purpose, namely:

- (1) enables formulation of a field understanding of the geo-hydrological system, and
- (2) serves to expand the basic data base of the investigation and may reveal areas requiring detailed study.

A borehole survey was conducted to include all waterpoints, both private and municipal, within the study area. Although complete data for each waterpoint was seldom available, the borehole inventory involved the obtaining of the following particulars:

- (a) depth to waterlevel below collar elevation,
- (b) depth of borehole,
- (c) yield and annual rates of abstraction,
- (d) quality and use of groundwater, and
- (e) any geological information available.

#### 4.3 MAPPING

##### 4.3.1 GEOHYDROLOGICAL

Geology is the single most important factor controlling the occurrence, magnitude and quality of groundwater and hence its significance in a regional groundwater investigation cannot be over-emphasized (Gray, 1975).

Lahee (1961) and Crompton (1962) state that geological mapping requires the following three procedures:

- (1) location and definition of lithologies,
- (2) structural and stratigraphic study of the lithologies, and

(3) plotting of field data on a map.

However, geohydrological mapping is more concerned with mapping of geologic zones in terms of their water-bearing and yielding capacities (Freeze et al, 1979). In many cases the distribution of water-bearing zones or aquifers are not restricted to stratigraphic or lithological boundaries, but more to the distribution of permeability and porosity within formations.

Geohydrological mapping was carried out with the aim of defining the following three major lithological units:

- (a) Alluvium/colluvium.
- (b) Beaufort Group sediments.
- (c) Karoo dolerite intrusives.

Special attention was given to the mapping of the alluvial deposits and dolerite occurrences, as the water-bearing potential of these units had been previously recognised (Joubert, 1956, 1952, Vegter, 1957 and Buchanan, 1970).

#### 4.3.2 GEOPHYSICAL

Geophysical methods provide indirect evidence on the subsurface geohydrological conditions. Shiftan (in Morley, 1970) points out that although geophysics forms an integral part of a regional groundwater investigation, it must be conducted in close co-ordination with mapping and exploration drilling procedures. Successful application of surface geophysical methods relies largely upon the correct choice of technique or combination thereof, quality of instrumentation, competence of fieldwork and correct interpretation of the field data (Telford et al, 1976).

With strong indications for the presence of an important alluvial/weathered bedrock aquifer, the electrical resistivity method was incorporated to:

- (1) establish the geometry of the aquifer (in the process save on costly drilling),
- (2) attempt to locate and trace dolerite bodies underlying the alluvium, and
- (3) site exploration boreholes within the aquifer.

Electrical resistivity methods are the most widely used geophysical method in groundwater investigations (Keller et al, 1966). The application of electrical resistivity surveys in the study of alluvial aquifers is well documented in South Africa (Worthington, 1975, 1977; Vandoolaeghe, 1977; van Zijl et al, 1979, 1981 and Meyer et al, 1982) and elsewhere (Singh et al, 1982 and Stewart et al, 1983).

The magnetic method was employed to locate and delineate intrusive bodies occurring in the study area. The magnetic method is probably the most rapid, uncomplicated and least expensive of the geophysical measurement techniques (Bouwer, 1978). Magnetometric methods are based on the observation of anomalies in the magnetic field of the earth, that are caused by the different magnetic susceptibility of rocks (Koulomzine et al, 1970).

During the investigation this technique was mainly utilised to trace dolerite dykes covered by overburden, and to a lesser extent, dolerite sheets. Digital computer analysis of certain dyke anomalies were performed to aid with accurate siting of exploration boreholes in dyke contact zones.

#### 4.4 EXPLORATION DRILLING

The drilling programme is of great value in a groundwater study, as it provides the only means of direct access to the water-bearing formations. Mandel et al (1981) states that a scientifically planned drilling campaign must be based on working hypotheses regarding prospective aquifers, their extent and distribution within the hydrologic regime.

In general, the exploration drilling programme was formulated to:

- (a) Provide information on the hydrogeological and hydro-chemical nature of the formations.
- (b) Provide a geological control for the calibration and interpretation of the resistivity survey data.
- (c) Enable the determination of the hydraulic properties of the aquifers by way of aquifer-tests and semi- or permanent waterlevel monitoring stations.

#### 4.5 AQUIFER TESTING

One of the primary goals of groundwater resource evaluation is the prediction of hydraulic-head drawdowns in an aquifer under proposed abstraction schemes (Freeze et al, 1979). To accomplish this, it is necessary that the hydraulic characteristics of the aquifer system be quantified, which according to the Johnson Division (1980), can only be reliably assessed by means of aquifer testing.

Depending on the requirements of the investigation, a well designed aquifer testing programme will allow the determination of some, if not all, of the following:

- (a) Yield characteristics and potential of the borehole.
- (b) Efficiency of the borehole performance as an indication of it's hydraulic condition.
- (c) Confirmation of the hydrogeological nature of the aquifer.
- (d) Determination of the hydraulic properties of the aquifer.
- (e) Prediction of the effect(s) of present and/or future abstraction from the borehole on groundwater conditions in the aquifer (Rushton et al, 1979).

In order to obtain information on the above specified aspects, it was necessary to combine into the aquifer testing schedule two types of pumping:

- (1) Short duration, multiple rate or step-drawdown tests.
- (2) Relatively long duration, constant discharge tests.

#### 4.6 HYDROCHEMICAL SAMPLING AND PERIODIC MEASUREMENTS

In many regions, especially in semi- and arid areas, the quality of the groundwater is as limiting, if not more of a limitation than the quantity (Edmunds in Lloyd, 1981). As a result, hydrochemical studies in these areas form a major portion of the investigation effort. This was expected to be the case in the Graaff-Reinet aquifer. The hydrochemical survey therefore had two major objectives, namely:

- (1) to determine the suitability of the groundwater supply for domestic and industrial use, and
- (2) to provide an understanding of the geochemical and hydrogeological flow relationships in the aquifer(s).

Groundwater samples were collected during the exploration drilling, aquifer testing and borehole inventory. Samples collected were analysed for pH, TDS, major cations and anions.

Waterlevel measurements obtained during the study from boreholes situated in the Graaff-Reinet aquifer were used to compile a groundwater contour map. A number of important hydrogeological inferences could be made from such maps, relating to groundwater flow direction, recharge/discharge areas and aquifer response to pumping.

Waterlevel measurements from the wellfield boreholes (Graaff-Reinet aquifer) and the Van Rynevelds Pass Dam are available on a monthly basis from 1958 and 1930, respectively. These data are essential in assessing the presumed recharge/discharge relationship that is thought to exist between the aquifer and the dam.

The theoretical background and field application of the various exploration phases of the study will be elaborated upon in Chapter 5. The interpretation and results of the various components of the study are discussed.

CHAPTER 5

DISCUSSION OF GEOHYDROLOGY

5.1 HYDROCENSUS

The inventory covered the following cadastral farms: Winterhoek, Ganna Leegte, Thornlands, Buffelshoek, Brakfontein, Welgevonden, Good Hope, Boschkraal, Roodebloem, Bloemskraal, Waterloo and the Graaff-Reinet Allotment Area.

A full inventory of the hydrocensus results are contained in Appendix 1, while the position of water-points are indicated on Enclosure 1. The borehole survey data are arranged in alphabetical order of cadastral units. A summary of the hydrocensus results are presented in Table 2.

TABLE 2 : SUMMARY STATISTICS OF THE BOREHOLE INVENTORY

Number of farms :	12
Total number of water-points:	197
Total number boreholes in use:	108 (56% of total)
(a) domestic	26%
(b) stock	60%
(c) irrigation	14%
Average depth of borehole (m):	48 (max - 108m) (min - 6m)
Number boreholes reliably tested/or being pumped at:	
Yield(l/s)	No. boreholes
> 5	15
> 10	6

It must be remembered that some of the information collected during the inventory may be unreliable and that for several boreholes little or no information was available. The following general conclusions were drawn from the survey:

- (1) High yielding boreholes (greater 10 l/s) are located in either the Graaff-Reinet aquifer (GR5, GR7, GR11 and BK16) or the contact zones of dolerite intrusives (GR19

and BF1). Boreholes GR19 and BF1 are located in the contact zones of the Dalham and Piensaars dolerite sheets, respectively (Enclosure 1). This would suggest that similar yields might be intercepted in similar geohydrological conditions located elsewhere in the study area.

- (2) Boreholes tapping the Graaff-Reinet aquifer in the vicinity of the municipal wellfield yield water with a TDS in excess of the South African Bureau of Standards (1971) recommended limits of 2000 mg/l. The boreholes concerned are GR5, GR6, GR7, and GR11.
- (3) The quality of groundwater in the Graaff-Reinet aquifer is of a poorer quality than aquifers located in hard-rock terrain.
- (4) A large density of operational boreholes tap the Graaff-Reinet aquifer.

From the borehole inventory it is evident that the most prolific producers of groundwater were associated with either:

- (a) Dolerite intrusives and associated fractured sediments, or
- (b) the Graaff-Reinet aquifer.

As a result, these two areas were singled out for detailed geological and geophysical mapping.

## 5.2. GEOLOGICAL AND GEOPHYSICAL MAPPING

### 5.2.1 GEOLOGY

#### 5.2.1.1 GENERAL

An understanding of the geology of an area is essential, as lithology exerts a major influence on variations between aquifers (Davies and de Wiest, 1966). As no detailed geological map of the study area existed a large portion of the total investigation effort was spent compiling a geological map of a standard generally required for a geohydrological investigation.

From earlier investigations and information gathered during the hydrocensus (Section 5.1), it was apparent that the most important water-bearing zones were either directly or indirectly associated with the occurrence of dolerite intrusives and alluvial deposits (Graaff-Reinet aquifer). As a result, particular attention was paid to the mapping of these formations.

The geology of the study area comprises Beaufort Group sediments, unconsolidated alluvial/colluvial deposits and Karoo dolerite intrusives (Enclosure 2). The map was synthesized from air-photogrammetry, field mapping, geophysical mapping and exploration drilling.

#### 5.2.1.2 BEAUFORT GROUP SEDIMENTS

The deposition of the Beaufort Group of sediments can be regarded as a mere continuation of the infilling of the Karoo Basin, a process which began with the deposition of the Dwyka Tillite. The environment, however, changed from marine during the Dwyka to fluvial during the Beaufort (Truswell, 1977). The stratigraphy of the Beaufort Group is illustrated in Table 3.

The consolidated sediments in the study area are confined to the Middleton and Balfour Formations (Ouberg Sandstone Member) of the Adelaide Subgroup. These two formations will therefore be elaborated upon.

##### 5.2.1.2.1 MIDDLETON FORMATION

The Middleton formation consists of a fining upward, fluvial sequence of sandstones, siltstones and mudstones. This sequence correspond well with deposition of recent fluvial environments, as described by Allen (1970) and Reineck et al (1973). A fluvial cycle commences with the deposition of sandstone, mostly deposited as lenticular bodies. The sandstone lithosomes consist mainly of fine to medium grained, grey/green to light grey, feldspathic rocks.

TABLE 3 : STRATIGRAPHY OF THE BEAUFORT GROUP

PERIOD	SEQUENCE	GROUP	SUBGROUP	FORMATION (E of 24°E)
T r i a s s				Burgersdorp
			Tarkastad	
		K		Katberg
		a		
-225Ma-	r	Beaufort		
P e r m i a n				Balfour
			Adelaide	Middleton
				Koonap
		o		

(After S.A.C.S., 1980)

The sandstones grade upwards into grey/green to grey/blue siltstones, followed by grey/blue mudstones. Maroon staining of the mudstones is common. This type of discolouration is attributed by Reineck and Singh (1973) to the presence of haematite and iron pigment as a matrix or coating on detrital grains. Such staining is indicative of an oxidising depositional environment. Occasionally a dark grey/black, carbonaceous mudstone is encountered, which is often associated with sulphurous groundwater.

Within the study area, the arenaceous component of the succession is by far subordinate to the total argillaceous lithology. Tordiffe (1978) estimates that sandstone constitutes generally about 30% of the Middleton Formation, which increases to approximately 40% near the top of the formation. Johnson (1976) estimates the thickness of the Middleton Formation, north of Graaff-Reinet, at approximately 1500m.



Plate 5 : Maroon/grey mudstones and sandstones of the Middleton Formation, overlain by calcified alluvial deposits.



Plate 6 : Type section of the Ouberg Sandstone Member (Balfour Formation) in the Ouberg Pass, north of Graaff-Reinet.

#### 5.2.1.2.2 BALFOUR FORMATION (OUBERG SANDSTONE MEMBER)

The Ouberg Sandstone Member forms the base of the Balfour Formation, which directly overlies the Middleton Formation. Tordiffe (1978) states that the boundary between the Middleton and the overlying Balfour Formation is taken as the first occurrence of an arenaceous sandstone, which possesses a lateral extent of a few kilometres and above which maroon mudstones are absent.

The Ouberg Sandstone Member is encountered in the more elevated sections of the study area, generally above 1000m a.m.s.l., and therefore is of little geohydrological significance. The type-section of the Ouberg Sandstone Member can be observed in the Ouberg Pass, north of Graaff-Reinet. Tordiffe (1978) estimates that approximately 70% of the member is made up of sandstone units. The sandstones are usually fine to medium grained, light grey/blue, while mottling is common in lower lithosomes (Johnson, 1976). According to S.A.C.S. (1980) the Ouberg Sandstone Member has an average thickness of 180m in the Graaff-Reinet area.

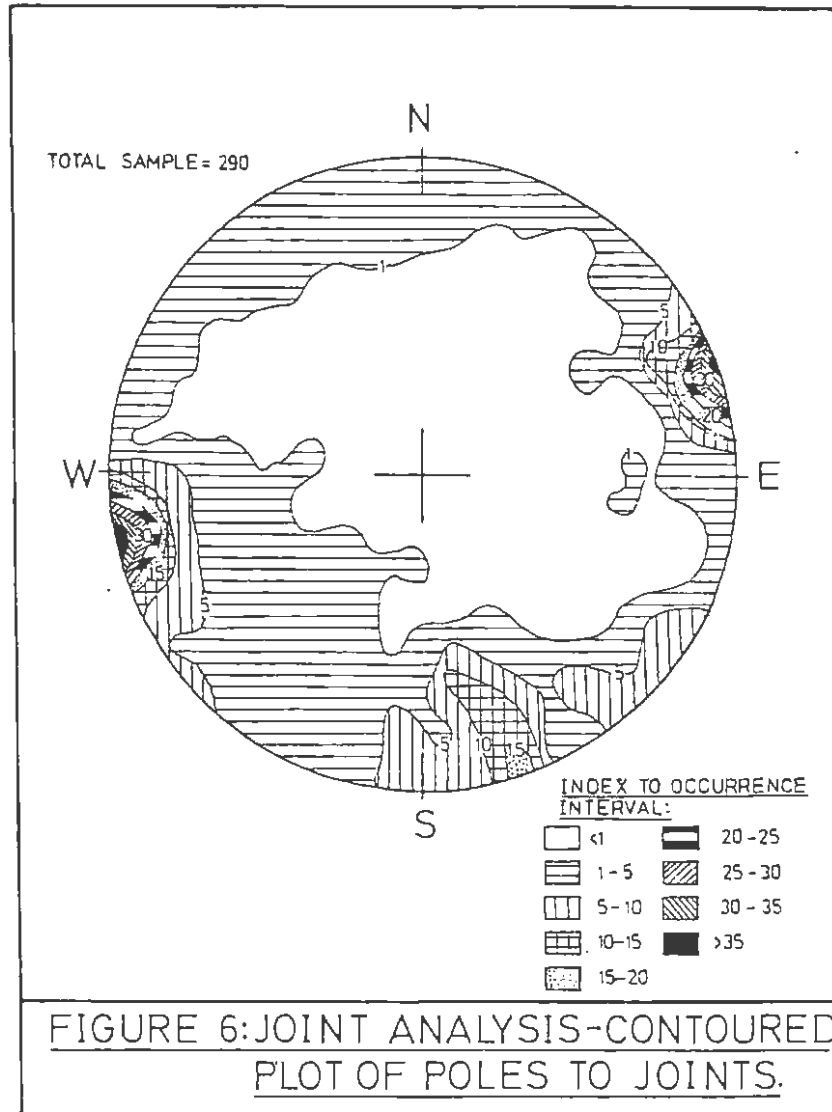
#### 5.2.1.2.3 STRUCTURE

The dip of sedimentary formations in the investigation area is virtually zero, although exceptional tilting of strata occurs locally near dolerite intrusions. The regional dip of the strata in the Graaff-Reinet area varies between 0 to 5 degrees towards the northeast (Tordiffe, 1978). Joint and fracture analysis within the study area indicated a dominant north-south alignment, with a subordinate east-west trend (Figure 6).

#### 5.2.1.3 SUPERFICIAL DEPOSITS

##### 5.2.1.3.1 ALLUVIUM/COLLUVIUM

The amount and nature of unconsolidated deposits within an area may play an important role as far as the infiltration of meteoric water, and therefore groundwater recharge, is concerned (Bond, 1946). Two major types of unconsolidated depo-



sits occur in the study area, namely, the alluvial and paleo-fluvial deposits of the floodplains and the in-situ colluvial deposits of the more elevated ground.

The colluvial deposits are mainly derived from the weathering and erosion of the country rocks. These deposits predominate on the more elevated areas of the investigation area. At the edges of the Van Rynevelds Pass Dam basin they merge indistinguishably with the alluvium.

Alluvial deposits cover an extensive area about the confluence of the Sundays, Pienaars, Broederstroom and Gats Rivers, as well as the floor of the Van Rynevelds Pass Dam. In general, the alluvium represents a typical progradational, fining-upward channel-fill sequence, typical of that described by Miall (1978), Grannemann et al (1979), Meyer et al (1982) and Singh et al (1982).

According to Foreman et al (1981), a typical alluvial sequence can be subdivided into three, more or less, distinct vertical facies based on the lithological character of the sediment. They are:

- (1) Lower cobble or boulder facies,
- (2) Middle gravel/sand facies, and
- (3) Upper sand/silt/clay facies.

This sequence of deposition was found to be generally present in the study area:

(a) Upper Facies

Generally, the upper facies is loamy in nature, except in the riverbeds and adjoining areas, as well as the upper reaches of the Van Rynevelds Pass Dam. The thickness of this zone varied considerably (1 to 6m). A thin calcrete layer was often present. Due to the lack of sufficient rainfall and high rates of evapotranspiration salt accumulations are common in this facies (Van der Rys, 1981).

## (b) Middle Facies

This facies is characterised by a sequence of poorly sorted silt, sand and gravel with minor intercalations of pebbles. Both the extent and lithology of this zone was found to be highly variable.

## (c) Lower Facies

Commonly this facies consisted of moderately sorted gravel or boulder horizons, with minor finer material. This facies appears to be fairly extensive, but shows marked lateral variations in thickness over short distances (0.5 to 8m). This horizon is considered to be the principal zone of transmission in the Graaff-Reinet aquifer and thus is of prime geohydrological importance.

In general, the alluvium varies in thickness between 1 and 17 metres. Exceptional thickness of 23 metres are attained in the vicinity of the municipal wellfield and airfield, which is probably related to a deep river-scour immediately upstream of the Dalham dolerite sheet.

On a broader scale, the alluvial deposits represent a complex hydrogeological system, of more or less lens shaped, elongated bodies or discontinuous layers of boulders, pebbles, gravel, sand, silt and clay, including various mixtures of these components.

5.2.1.3.2 CALCRETE

The lack of leaching results in the precipitation of calcrete or caliche' layers at or near to the surface of soils (Tordiffe, 1978). A surface calcrete layer with a thickness of between 0.2 to 3m is common. The calcrete layers occur in association with dolerite intrusions and alluvial/colluvial boulder deposits, giving rise to honeycomb- and calcified gravel-type deposits, respectively (Nettenburg, 1980).

Calcretes are formed by the cementation and/or replacement of pre-existing regolith host material by carbonate (usually calcite) precipitated from the soilwater or groundwater (Nettenburg, 1980). Hawkes and Webb (1962) point out that the lower limit of calcrete formation usually indicates the maximum

depth to which rainwater percolates before being dissipated by evaporation and transpiration by plants.

#### 5.2.1.4 KAROO DOLERITE INTRUSIONS

The close of the Beaufort depositional cycle (150 to 180 Ma), was marked by the injection of basaltic magma into the sedimentary rocks in the form of sills and dykes, and eruptions of vast flows of basaltic lava - Drakensberg Lavas (Meyboom et al, 1978).

During the Jurassic the Cape Fold Belt and adjacent areas to the north were still subjected to compressive forces, resulting in the absence of dolerite intrusives south of latitude 33° south (S.A.C.S. 1980).

In this investigation two types of intrusives were recognised:

- (1) Dolerite dykes - vertical to subvertical bodies, with a large length/width ratio, and
- (2) Dolerite sheets - horizontal to subhorizontal intrusions, and bodies of varying dip which are intimately related to the horizontal intrusion. The term dolerite sheet therefore corresponds to the widely used term sill.

##### 5.2.1.4.1 DOLERITE DYKES

The following four prominent dolerite dykes were located in the study area:

- (1) Welgevonden dyke.
- (2) Perries dyke.
- (3) Dalham dyke.
- (4) Roodebloem dyke (Enclosure 2).



Plate 7 : Baked/jointed dolerite dyke/sediment contact.

Each dyke has been allocated a name for ease of reference in later discussions.

(1) WELGEVONDEN DYKE

The Welgevonden dyke extends from Goewermentskop in the north to Spandaukop, south of Graaff-Reinet. It is possible that the Mackies Pits lie in close proximity to the dyke. Its thickness varies from 6 to 9m, while it dips towards the west. Drilling indicated a dip of  $85^{\circ}$  west (Figure 7).

(2) PERRIES DYKE

The Perries dyke exhibits a general north-northwest to south-southeast trend and extends from the farms Boschkraal in the north to Broederstroom in the south. The dyke has an average thickness of 9m and dips towards the west. Drilling indicated a dip of  $70^{\circ}$  west (Figure 7). The dyke is extensively weathered at its intersection with the Roodebloem dyke.

(3) DALHAM DYKE

The Dalham dyke extends from the Gats River in the east to the Murraysburg national road in the west, where it splits into two separate dykes. The dip of the body varies between  $45^{\circ}$  and  $60^{\circ}$  to the south, while its thickness averages about 2.5m. The dyke exhibits numerous lateral displacements or breaks along its length.

(4) ROODEBLOEM DYKE

The Roodebloem dyke is limited in extent and varies in thickness between 3 to 6m. The dyke dips towards the southwest.

#### 5.2.1.4.2 DOLERITE SHEETS

Dolerite sheets cover a substantial portion of the investigation area. For reasons of convenience three main sheets have been identified and allocated names:

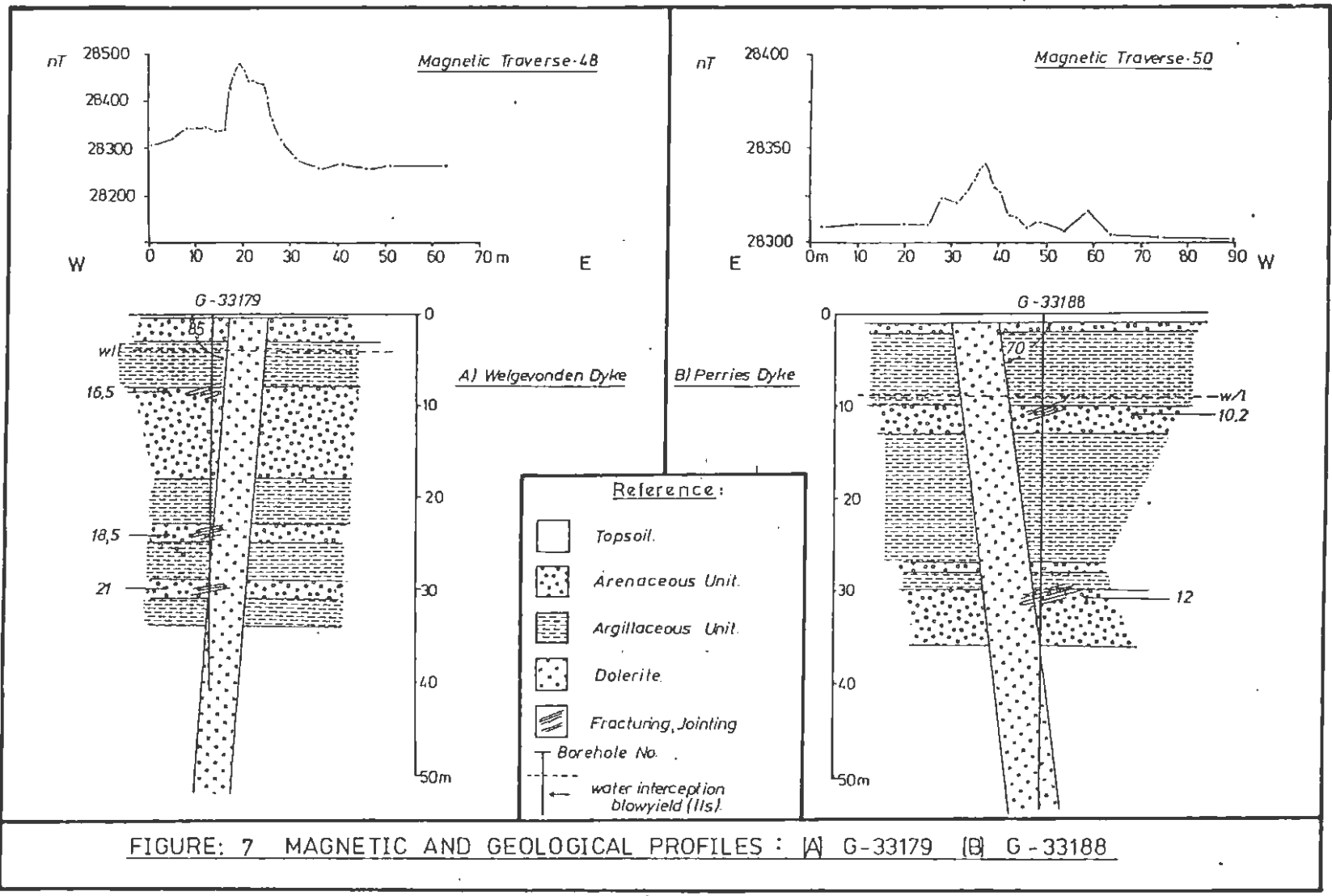


FIGURE: 7 MAGNETIC AND GEOLOGICAL PROFILES : [A] G-33179 [B] G-33188

- (1) Dalham sheet.
- (2) Welgevonden sheet.
- (3) Thornlands sheet (Enclosure 2).

These sheets would, however, appear to be linked in some way or another, as is clearly the case with the Welgevonden and Thornlands sheets. Furthermore, local lateral branching of the main sheets into two or more sheets does occur, as for instance in the case of the Dalham sheet.

#### (1) DALHAM SHEET

The sheet extends from just south of Lokasiekop to the foothills of Goewermentskop. It is overlain by a large thickness of alluvium in the vicinity of the municipal wellfield and airfield. The sheet appears to change its dip from  $14^{\circ}$  east in the south to between  $8^{\circ}$  and  $15^{\circ}$  east in the north, while in the municipal wellfield area it is relatively flat lying (Figure 8).

Drilling in the vicinity of the municipal wellfield indicated that the thickness of the sheet is in the order of 40 to 50m. It thins rapidly towards the north, and at Goewermentskop it is only a few metres thick. At the confluence of the Gats and Sundays River the sheet is extensively weathered (Geological borehole logs G33233 and G33234 in Appendix 2).

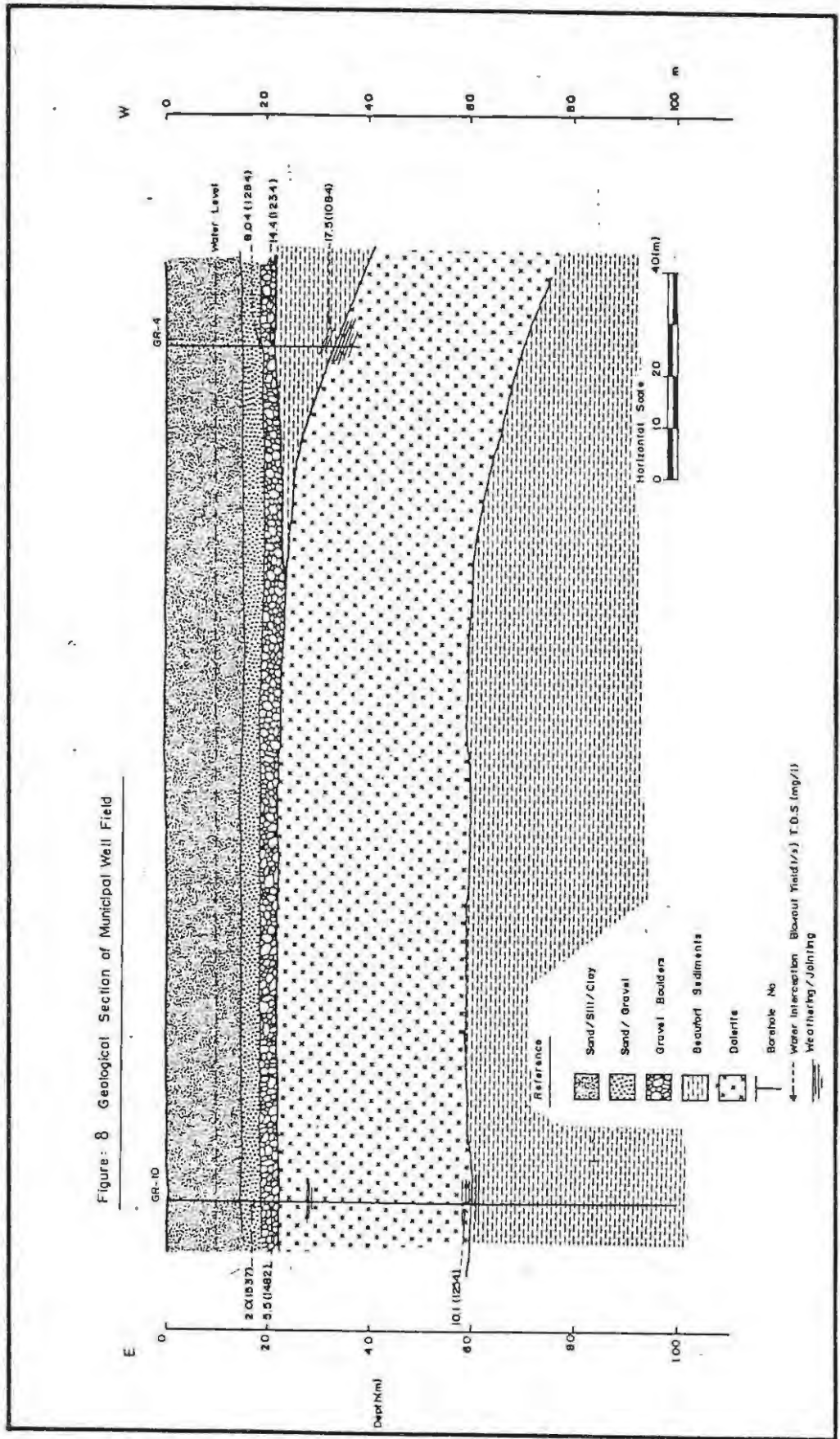
#### (2) WELGEVONDEN SHEET

The Welgevonden sheet outcrops over a large portion of the upland area to the north of the Van Rynevelds Pass Dam and merges with the Thornlands sheet in the west. The central portion of the sheet has an approximate thickness of 55m and dips at towards the north at approximately  $10^{\circ}$ .

#### (3) THORNLANDS SHEET

This sheet forms a portion of a typical ring-structure (described by Meyboom et al, 1978), which can be traced

Figure 8 Geological Section of Municipal Well Field



from the Moordenaars Valley in the south to the Ouberg Pass in the north. In the Pienaars River valley the sheet is approximately 30m thick and dips at about  $13^{\circ}$  towards the east.

Two thin sheets, the Pienaars and Brakfontein sheets, have estimated thicknesses of between 25 to 35m and 15 to 20m, respectively. Further sheets, not considered of any hydrogeological significance, cap many of the surrounding mountains. In most cases, the dolerite sheets are dissected by the dykes.

It must be noted that the dolerite intrusives do not constitute any lithostratigraphic formation or group, and are not considered to be part of the Karoo Supergroup (S.A.C.S; 1980).

## 5.2.2 GEOPHYSICAL EXPLORATION

### 5.2.2.1 ELECTRICAL RESISTIVITY SURVEY

With strong indications for the presence of an important alluvial/weathered bedrock aquifer (Graaff-Reinet aquifer), the electrical resistivity method was incorporated to:

- (a) principally to define the geometry of the aquifer, as well as
- (b) attempt to locate and trace the Dalham dolerite sheet underlying the alluvium, and
- (c) site exploration boreholes in the alluvial aquifer.

Vertical electrical-sounding (V.E.S.) techniques are commonly employed in alluvial environments to solve similar problems (Worthington, 1975, 1977; van Zijl et al, 1979; de Beer et al, 1981 and Singh et al, 1982). The Schlumberger (1939) technique was employed in this investigation.

#### 5.2.2.1.1 PRINCIPLES OF SCHLUMBERGER SOUNDING

The Schlumberger resistivity method is based on the concept that different lithologies have different resistivities, which

can be determined by passing a direct current between two current electrodes (A and B) and measuring the resultant potential difference between two potential electrodes (M and N) (Figure 9).

A Schlumberger sounding is performed by progressively increasing the current electrode (A and B) spacing, while keeping the potential electrode (M and N) spacing at less than  $AB/5$  (Dobrin, 1976). The current electrodes are expanded about the centre of the array, with an approximate progression coefficient of 2 (Keller, 1970). As the distance between the current electrodes is increased, the total volume of earth included in the measurement becomes larger, both vertically and laterally (Figure 9). However, for a given centre position of the array the increasing volumes overlap and unless lateral variations in resistivity are severe, successive results will strictly be related to depth.

At each current electrode spacing an apparent resistivity ( $\rho_a$ ) is calculated, according to the following formula:

$$\rho_a \text{ (ohm. metres or } \mu\text{.m.)} = k \times \frac{\Delta V}{I}$$

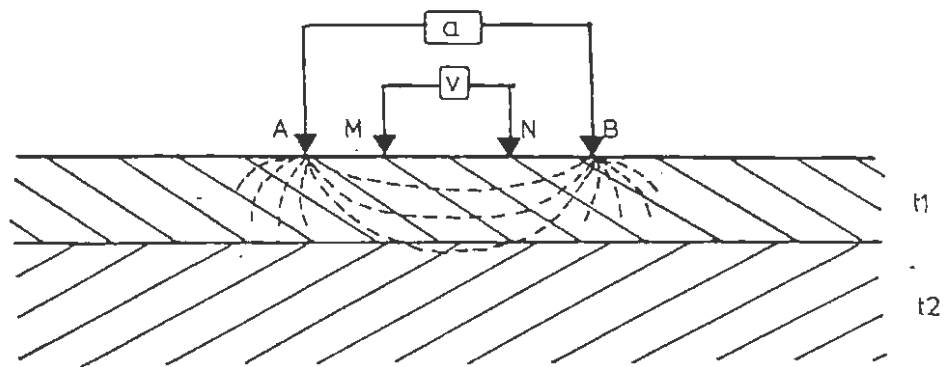
$$\text{where } k = \pi \times \frac{AM \times AN}{MN}$$

$\Delta V$  is the voltage difference between the inner M and N electrodes.

I is the applied current between the outer A and B electrodes (van Zijl, 1977).

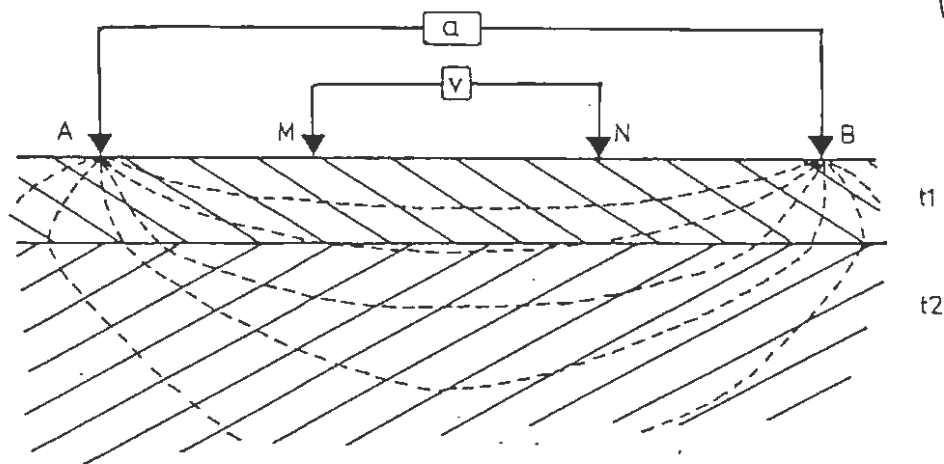
Apparent resistivity is a measure of the resistivity (not the true nor the average resistivity) of a specific volume of earth, dictated by:

- (1) the electrode spacing, and
- (2) local geological conditions (Flathe, 1967).

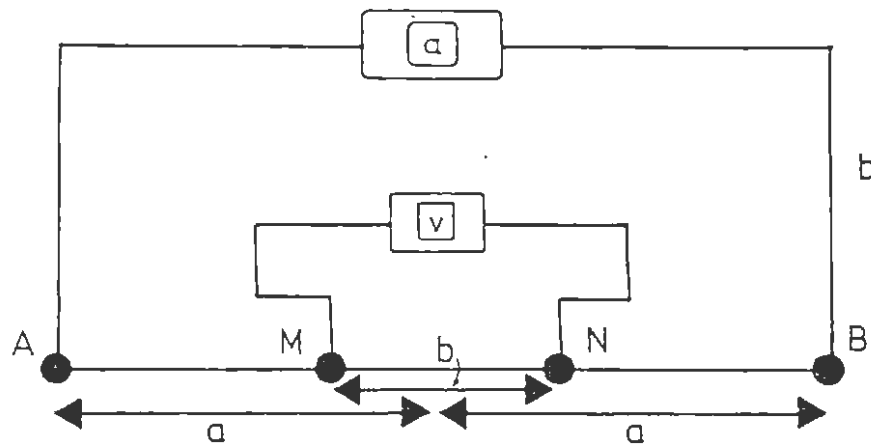


t1  
t2

(A)



t1  
t2



$b < 0.2 a$

(B)

$\square a$  ampmeter + generator

$\square v$  voltmeter

FIGURE 9: (A) PRINCIPLE OF ELECTRICAL SOUNDING  
(B) SCHEMATIC ARRANGEMENT FOR THE SCHLUMBERGER METHOD

The true resistivity would only be obtained if the media being measured were homogeneous.

The effective probing depth of the Schlumberger array is difficult to define. The depth of penetration is generally taken as approximately equal to the distance  $AB/2$  (van Zijl, 1977; Ballukraya et al, 1983).

#### 5.2.2.1.2 RESISTIVITY OF EARTH MATERIALS

Although all earth materials are able to conduct electricity, their conductivity varies greatly. For example, dense granite has an average resistivity of a million ohm.m; whereas clay saturated in saline water is about 1 ohm.m. Not only does resistivity vary from one formation to another, but it varies both laterally and vertically within a particular horizon. As a result, no set correlation between lithology and resistivity exists, although broad generalisations can be made. Table 4 represents a synthesis of typical earth-resistivities obtained from various sources.

TABLE 4 : TYPICAL RESISTIVITIES OF EARTH MATERIALS

Material	Resistivity (ohm.m)
Pure sand and gravels (saline)	1 - 50
Pure sand and gravels (fresh)	100 - 200
Pure sand and gravels (dry)	1000 - 5000
Marls and clays (dry)	1 - 25
Loamy soil	10 - 100
Clayey soil and topsoil	100 - 1000
Sandy soil	1000 - 10 000
Sandstones	10 - 10 000
Mudstones	10 - 100
Weathered mudstones	30 - 200
Igneous intrusives	100 - 10 mill.

(After Flathe, 1967; Mcneill, 1980; Barker et al, in Lloyd, 1981)

The actual minerals within the soils and rocks are electrical insulators of a high resistance, except in the case of metallic minerals. Hence, the conductivity takes place through the moisture-filled pores and passages which are contained within the insulating matrix. The conductivity of both consolidated and unconsolidated materials are determined by:

- (a) Porosity and permeability - the shape and size of pores, the number, size and shape of the interconnecting passages.
- (b) Moisture content - the extent to which pores are filled with water.
- (c) Degree of mineralisation of the pore-water.
- (d) The amount and composition of colloids.
- (e) The temperature and phase state of colloids. (McNeill, 1980).

As a result, most of the earth materials conduct electricity because of the mineralised water contained within them. This is known as electrolytic conduction. In general, the greater the degree of mineralisation of the fluid, the lower its resistivity. Therefore it can be stated that a material which is saturated with mineralised water will have a lower resistivity than the same material saturated with freshwater (Table 5). Other minor types of conduction exist, such as solid and metallic conduction.

**TABLE 5 : RESISTIVITY OF COMMON PORE FLUIDS**

Fluid	Resistivity (ohm.m)
Seawater	0.2 - 0.5
Brack water (3%)	0.15
Saline water (20%)	0.05
Fresh soil water	50 - 150

(After Telford et al, 1976)

### 5.2.2.1.3 FIELD PROCEDURE AND INTERPRETATION OF RESULTS

The resistivity survey was conducted using Chemtron sounding apparatus. The Chemtron apparatus consists of two physically separate and independent circuits, namely:

- (1) The current or AB circuit, whereby a direct current is injected into the ground. This circuit consists of essentially a current source (12V car-battery), a control unit, ampmeter, cables and two electrodes.
- (2) The potential or MN circuit, which measures the potential difference due to the primary current. The circuit consists of essentially a direct current voltmeter coupled to a recorder, a compensator and two electrodes.

One hundred and eighty Schlumberger vertical electrical soundings were carried out in the alluvial basin, including the floor of the Van Rynevelds Pass Dam. The survey was conducted along east-west stretching traverse lines. The sounding positions and spread directions are indicated on Enclosure 4. The spread lines were, as far as possible, orientated parallel to the axis of the alluvial valley. In general, successive soundings were spaced at intervals of approximately 150 to 300 metres.

Current electrode distances were increased until the resistive maximum was well defined or, if no maximum was present, until the curve rose sufficiently to allow the total longitudinal conductance to be calculated. This distance was on average 200 metres, with a maximum of 400 metres and a minimum of 150 metres.

On the whole, the terrain covered in the survey met fairly well with the ideal conditions required for vertical electrical-soundings, that is, a relatively flat terrain, with lithologies being horizontal to sub-horizontal.

The field data for each sounding were plotted on transparent, bilogarithmic graph-paper as a sounding curve, with the distance  $AB/2$  plotted on the abscissa and the corresponding resistivity value plotted on the ordinate. Interpretation of the sounding curves involved the following three steps:

- (1) Interpretation of the field V.E.S. curves using master-curves (Orellana and Mooney, 1966; Joubert, 1977).
- (2) Correlation of the interpreted curve with actual geological conditions.
- (3) Verification and calibration of the curves by means of a computer simulation program (Ghosh, 1971; Zohdy, 1973).

The process of curve-matching and interpretation is a fairly tedious one. Reliable interpretation demands sound knowledge of and considerable experience in the resistivity method. As a result, a brief and general overview of the procedures involved will suffice.

Initially the sounding curves were classified according to the variation and number of geo-electrical layers encountered. Kalenove's method (Smith, 1982) of classifying sounding curves was utilised in this study:

- (a) Two-layer curves: with  $p_1 < p_2$  (ascending type)  
 $p_1 > p_2$  (descending type)
- (b) Three-layer curves: with  $p_1 > p_2 < p_3$  (H-type curve)  
 $p_1 < p_2 > p_3$  (K-type curve)  
 $p_1 > p_2 > p_3$  (Q-type curve)  
 $p_1 < p_2 < p_3$  (A-type curve)
- (c) Multi-layer curves: with four or more layers are expressed in terms of three-layer type curve combinations, for example:

(1) KH Curve  $p_1 < p_2 > p_3 < p_4$



(2) KQ Curve  $p_1 < p_2 > p_3 > p_4$



The various layered curve types and examples are illustrated in Figure 10.

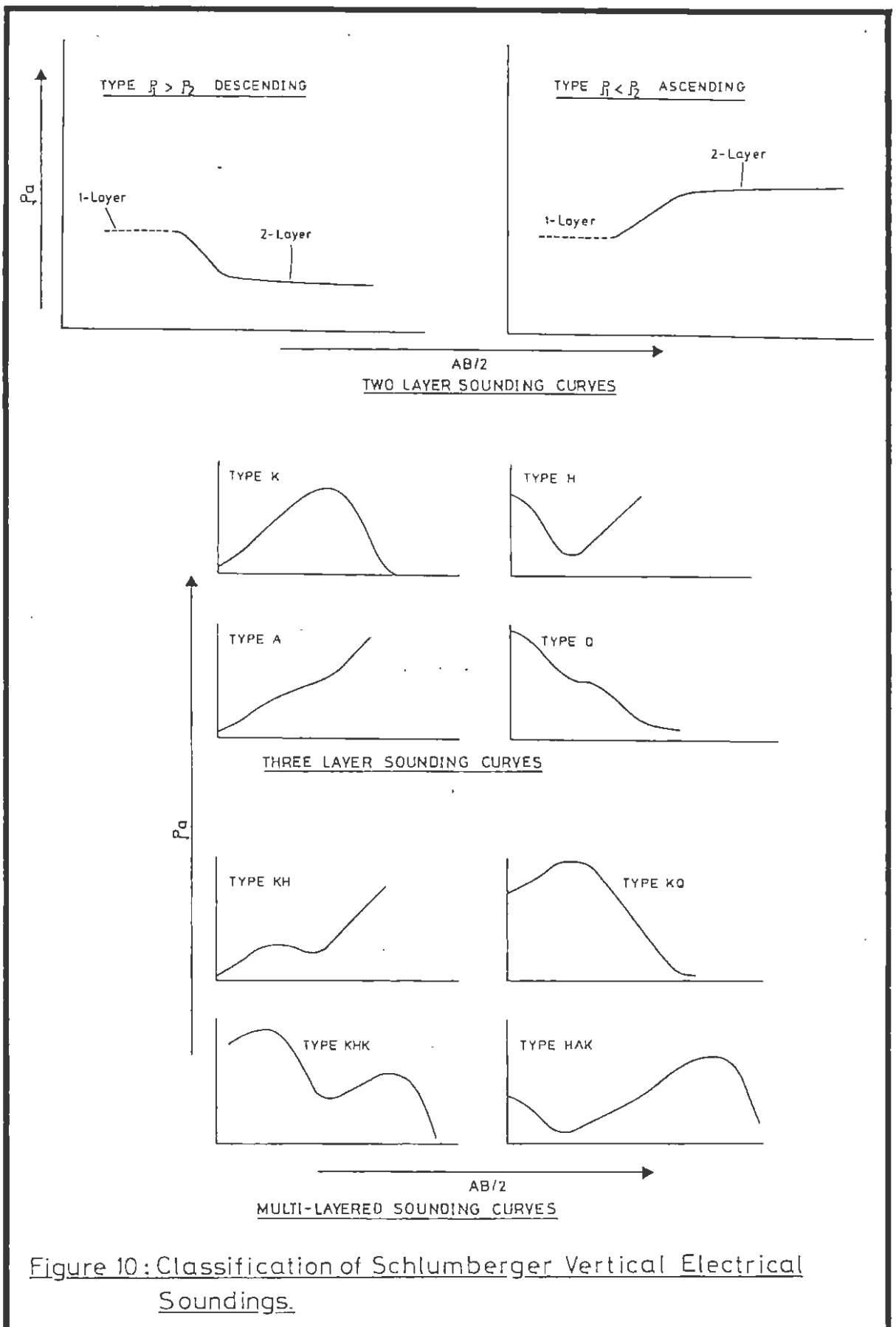


Figure 10: Classification of Schlumberger Vertical Electrical Soundings.

After classifying the field sounding curves they were matched to various master-curves. Master-curves are theoretical curves, constructed by assuming an infinitesimal potential electrode spacing and a horizontally stratified media (Worthington, 1978). Two volumes of master-curves have been published by the Geophysics Division of the C.S.I.R. (Joubert, 1977), for two-,three- and multi-layered sounding curves.

The field sounding curves were plotted on transparent, bilogarithmic graphpaper of the same modulus as the master-curves, thereby allowing the field curves to be superimposed on the master-curves for matching purposes. Hence by keeping the respective axis of <sup>the</sup> graphs parallel, the field curves can be slid over various master-curves in succession, until a satisfactory match is obtained with a particular master-curve.

In practice, the process of curve-matching is reduced to the determination of an appropriate Dar Zarrouk parameter for each subsurface layer on the sounding curve. The Dar Zarrouk parameters are:

(a) Total longitudinal conductance (S).

(b) Transverse resistance (T) (Zohdy, 1973).

In a resistive bed between two or more conductive beds, electrical current will tend to flow perpendicular to the bedding so that such a bed will be characterised by:

$$T = h \times \rho_a \text{ (ohm.m )}$$

where  $h$  is the vertical thickness, and  
 $\rho_a$  is the apparent resistivity of the layer.

If a sounding curve contains either a K- or a Q-type section, the transverse resistance of the maximum point of inflection (the more resistive of the layers) is calculated.

In a conductive bed between two or more resistive beds, electrical current will tend to flow along the conductive bed, parallel to the bedding so that such a bed is characterised by:

$$S = h / \rho_a \text{ (Siemens)}$$

Where S is the longitudinal conductance (Smith, 1982).

Sounding curves containing either an A- or H-type sections are solved for S. In general, if the transverse resistance of a resistive layer is high, then it's longitudinal conductance is low and vice versa.

Calculation of S and T values for each section of the field-curve represents the basis whereby sounding curves are interpreted, involving the ultimate calculation of thickness and resistivity of each of the geo-electrical layers.

Sounding curves were interpreted in groups from a specific locality, rather than isolated studies of the individual curves. This enabled common characteristics and progressive changes in curve forms to be located and interpreted. Interpretation usually commenced at a sounding where some form of geological control, ie borehole or rock outcrop, was present.

Having manually determined the thickness and resistivity of the various geo-electrical layers on a sounding curve, using the Dar Zarrouk parameters, the sounding data were verified and calibrated by computer simulation. In this study all sounding curves were checked using a resistivity curve-matching program, developed after Ghosh (1971), on a Hewlett-Packard 85 microcomputer. However, it must be realised that computer simulation of a particular sounding-curve is often not unique and the results may only represent one of many solutions (Kelly, 1977). It is therefore necessary that all geological information available be used to constrain the solution.

#### 5.2.2.1.4 DISCUSSION OF RESISTIVITY RESULTS

The following boreholes were drilled to aid in the calibration and interpretation of the resistivity work:

Borehole No.	Resistivity Station No.
G33172	40
G33173	10
G33174	15
G33175	33

The resistivity models and geological logs of the above calibration boreholes are presented in Figures 11 to 14. The computer verified sounding curves are contained in Appendix 5, while the station localities are indicated on Enclosure 4.

Although the V.E.S method is ideally suited to two-layer problems, (eg. alluvium overlying bedrock), the presence of clay, calcrete, sand and gravels, all with various states of saturation and mineralisation resulted in difficulties in matching of geo-electric layers to geologic layers.

In general, the field curves were of the KH- and HA-type. Based on the resistivity models (Appendix 5), the substrata could be subdivided into geo-electric categories (Table 6). They correspond more to the degree of saturation and mineralisation of the pore water within the lithological units than to geo-electrical differences between grain size or mineral composition.

These values compare favourably with those sited in Table 4 and studies carried out by Vandoolaeghe (1977) under similar geohydrological conditions.

**TABLE 6 : GEO-ELECTRIC CLASSIFICATION OF SUBSTRATA**

Category (geo-electric)	resistivity (pa) (ohm.m)
Dry loamy topsoil	40 - 150
Moist loamy topsoil	5 - 20
Dry sandy topsoil	100 - 1000
Saturated clay/sand/gravel	30 - 50
Saturated sand/gravel/boulders	10 - 150
Weathered/jointed sediment	30 - 250
Unweathered bedrock: sediment	80 - 800
dolerite	150 - 100 000

Theoretical and Field Curves :

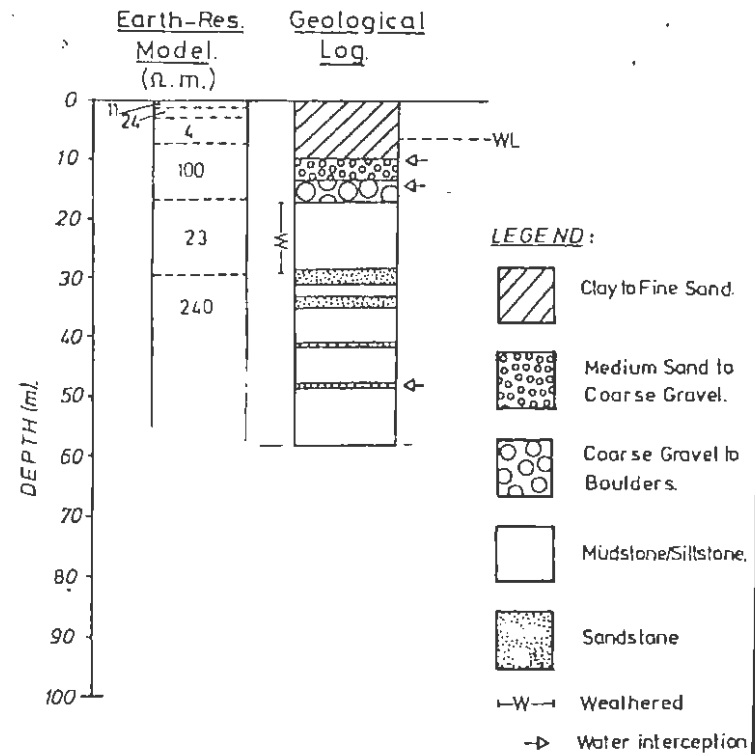
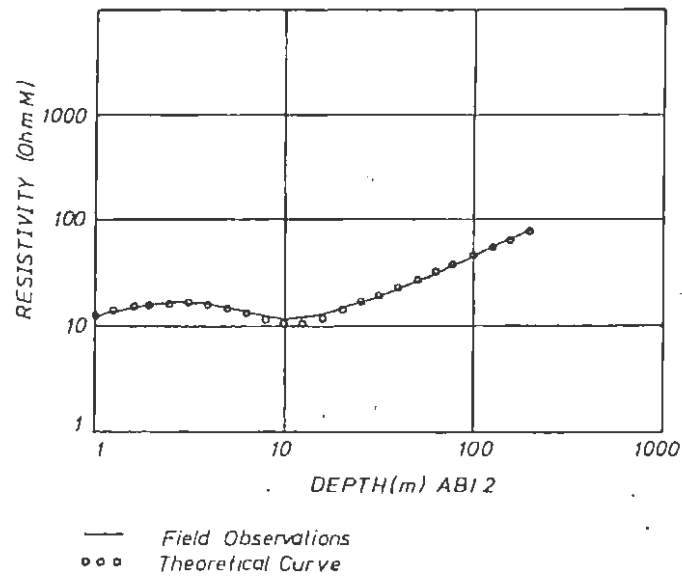


Figure: 11 Calibration Borehole No:33172 Resistivity Sounding No:40

Theoretical and Field Curves :

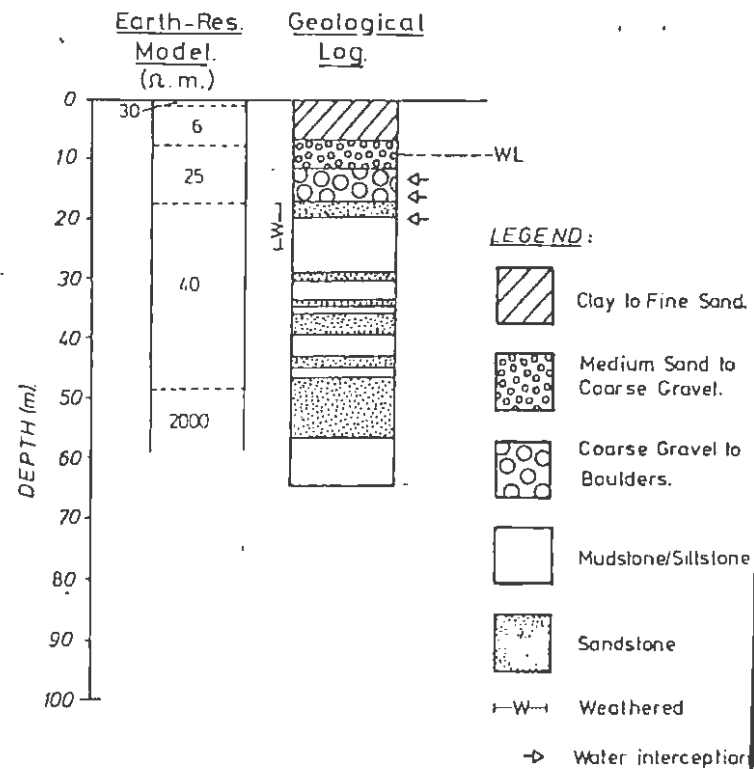
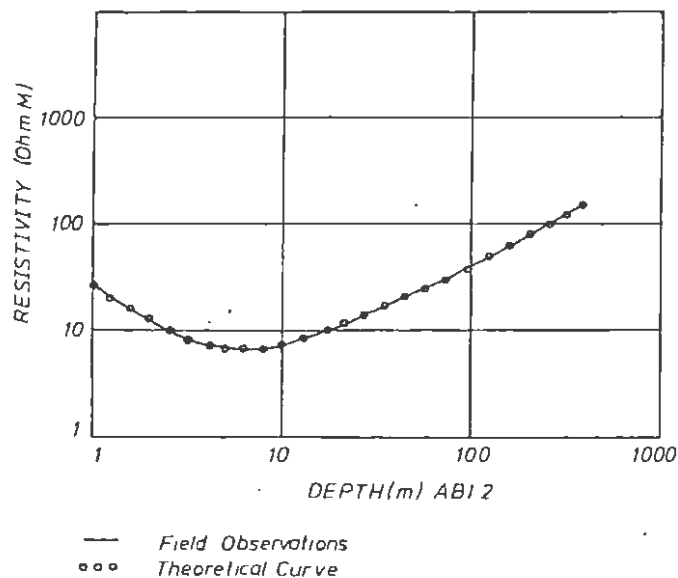


Figure: 12 Calibration Borehole No:33173 Resistivity Sounding No:10

Theoretical and Field Curves :

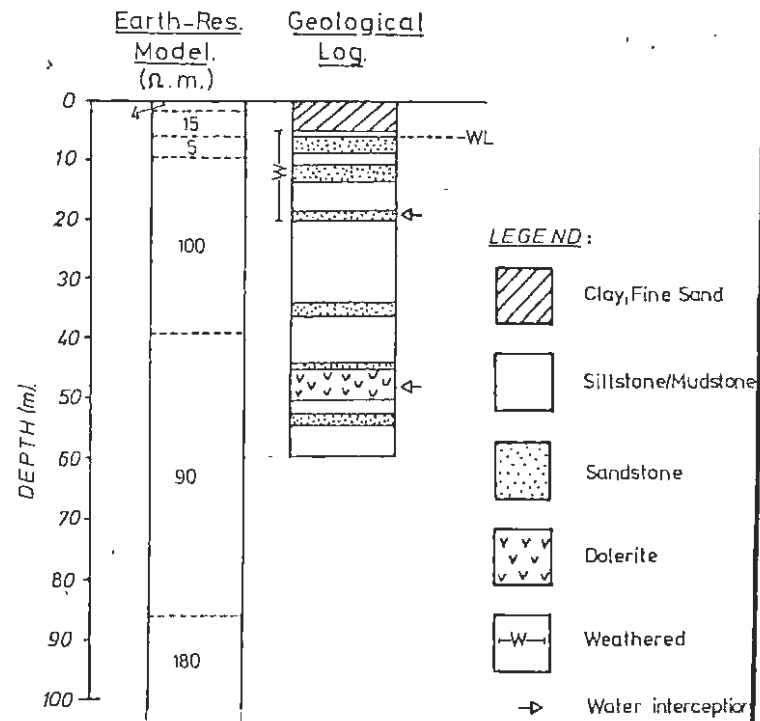
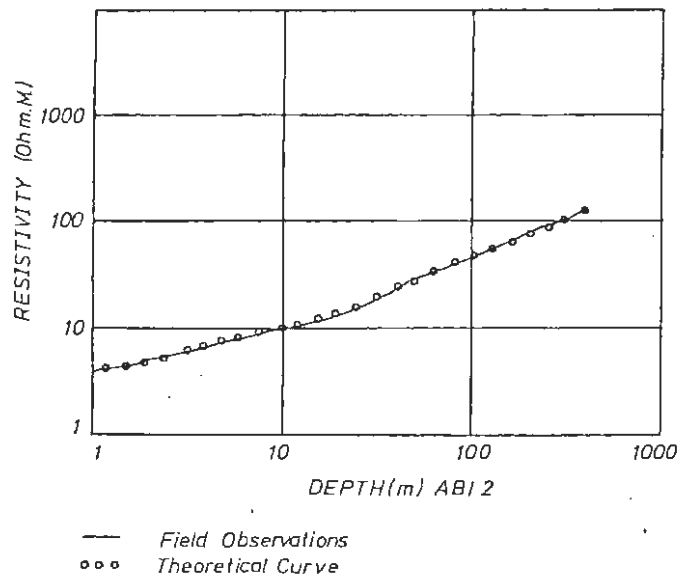


Figure: 13 Calibration Borehole No:33174 Resistivity Sounding No:15

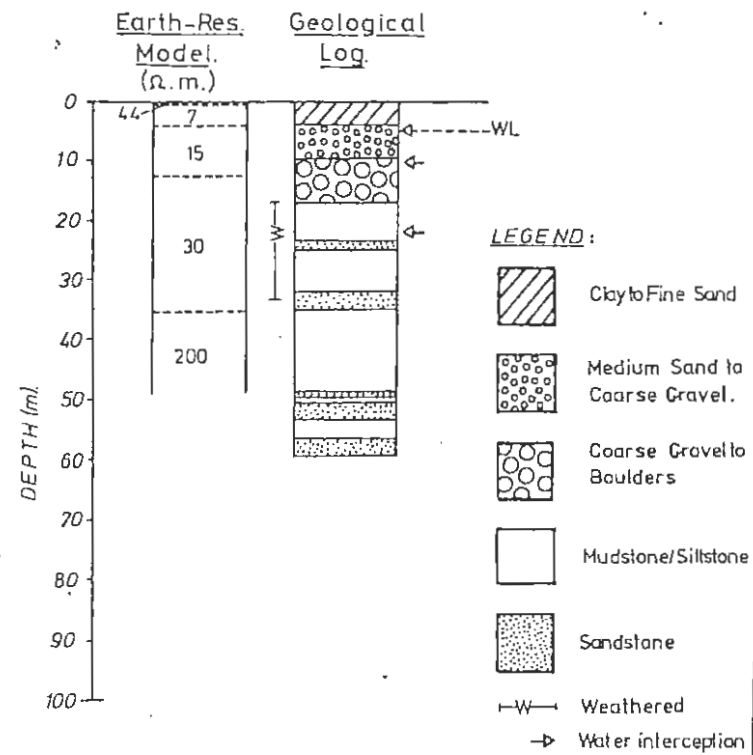
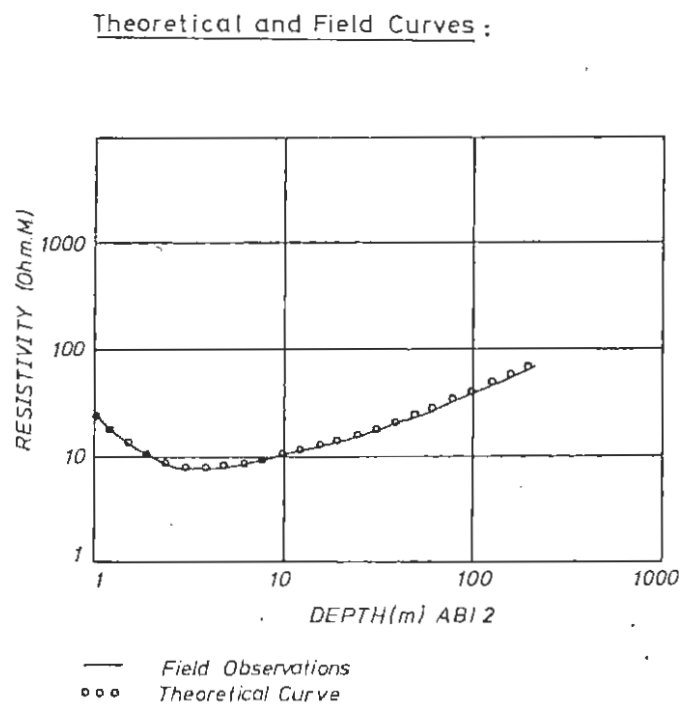


Figure: 14 Calibration Borehole No:33175 Resistivity Sounding No:33

The weathered/jointed sedimentary bedrock exhibits similar geo-electrical properties to that of the saturated alluvium (Table 6). It was therefore difficult to electrically differentiate between the two, without any form of geological control. Furthermore, as was anticipated, little geo-electrical definition of the consolidated formations could be obtained due to the poor quality water, cyclic nature and limited thickness of the sandstone and mudstone layers.

In most cases the water level was well defined by the method, due to the distinct difference in resistivity between saturated and unsaturated material (Figures 11 - 14).

A combination of geo-electrical data and scattered borehole information enabled the construction of an isopach map of the Graaff-Reinet aquifer (Enclosure 6). A geohydrological and geo-electrical profile of traverse line 4 is presented in Enclosure 5. The most striking geohydrological feature of the isopachyte map, is a linear zone of maximum aquifer thickness, which extends from the municipal wellfield to the confluence of the Sundays and the Gats Rivers. This is probably an expression of a deeply incised paleo-channel of the Sundays River system, which was preferentially eroded into the weathered contact zone of the Dalham sheet.

The results of the resistivity work (isopach map, geo-electrical profile etc.), should be interpreted with caution, because of the complex lithology and poor quality of the saturating water. Furthermore, interpretation of electrical soundings in the area north of the Sundays River was limited by the lack of calibration borehole information.

The V.E.S method, although confirming the heterogeneity of the alluvium was of little value in defining the various alluvial subhorizons, in particular, the presence and position of the basal gravel/boulder layer. This is considered to be a major setback of the method, as the horizon is known to be the water-producing zone of the aquifer. It is thought that the reason for this failure lies in the principle of suppression, which occurs as a result of the layer's limited thickness and low resistivity.

From the drilling and hydrocensus information it is known that a coarse basal horizon occurs in the proximity of the municipal wellfield. The drilling data would seem to indicate that this zone extends to the north of the wellfield. However, its thickness and lithological composition varies rapidly over short distances. In general, the thickness of the horizon varies between 3 to 10m in the vicinity of the wellfield and 1 to 8m in the area to the north.

The extent of the coarse basal zone in the direction of the Van Rynevelds Pass Dam is somewhat questionable. Any possible extension of this layer would be of relevance as it could act as a fairly straightforward hydraulic connection between the aquifer and the dam. At the location of boreholes G33175 and G33172 (Enclosure 5), the thickness of this zone is 8 and 3m, respectively. This would suggest a general damward thinning of the basal zone. However, it is possible that a thin, fairly continuous, coarse horizon is present in the dam area.

Resistivity work in the vicinity of the wellfield proved to be inadequate in distinguishing the Dalham dolerite sheet (Enclosure 2), from the overlying and underlying sediments. This is probably due to the masking effect of the poor quality water within the dolerite and sediments, as already discussed. Furthermore, the dolerite is intensely weathered up to thicknesses of 15m (G33233 and G33234 in Appendix 2), in the vicinity of the Sundays River.

#### 5.2.2.2 MAGNETOMETRIC SURVEY

The magnetic method was employed in this investigation, mainly, to locate and trace dolerite dykes overlain by overburden and to a lesser extent dolerite sheets. Generally two basic types of magnetic traverses were performed:

- (1) reconnaissance-traverses, and
- (2) detailed-traverses.

Reconnaissance-traverses were utilised mainly as a mapping aid, while detailed-traverses were undertaken aimed at accurately defining the geometry and position of dolerite dykes.

#### 5.2.2.2.1 PRINCIPLES OF THE MAGNETIC METHOD

Many geological formations by virtue of their magnetic mineral content, mainly magnetite, behave like "large buried magnets" and have associated with them a magnetic field. This local magnetic field is superimposed on the normal magnetic field producing departures from the undisturbed earth's magnetic field, called magnetic anomalies (Roux, 1979).

Magnetic anomalies can<sup>be</sup> either positive or negative. The size and nature of the magnetic anomaly is dependent upon:

- (a) the depth of burial of the body,
- (b) the degree and direction of magnetism, and
- (c) the attitude of the body in relation to the direction of the earth's magnetic field at that locality (Parasnis, 1972).

Magnetic anomalies in the earth's magnetic field are caused by two basic forms of magnetism:

- (1) induced, and
- (2) remnant (permanent) magnetism.

Remnant magnetism is the intensity and direction of magnetism taken on by the ferromagnetic minerals of a rock unit at the time of its formation or deposition.

The earth's magnetic field induces magnetism into ferromagnetic minerals within rocks. The degree of induced magnetism depends on the intensity of the earth's magnetic field at the particular locality and a property of the rock, known as its magnetic susceptibility.

The induced magnetism of a body is in the same direction as the present earth's magnetic field, whereas remnant magnetism need not be in the same direction and could even oppose the earth's field. If the earth's magnetic field could be removed the induced magnetism would disappear, but the remnant magnetism in a rock would remain (Roux, 1979).

#### 5.2.2.2.2 FIELD PROCEDURE AND INTERPRETATION OF MAGNETIC ANOMALIES

Magnetometers are instruments used for measuring the magnetic field and by way of their sensitivity and range are able to measure not only changes in field intensity due to prominent magnetic-iron ore deposits, but also measure changes between two-rock types with only small differences in magnetic content (Keller et al, 1966).

A Geometrix proton-magnetometer was utilised in this investigation. Proton magnetometers measure the interaction between the nuclear spin of protons within its sensor and the earth's magnetic field. The Geometrix magnetometer measures the total field intensity, which is an absolute measurement involving both the disturbing field and the earth's magnetic field. The geometrix instrument gives a 5-digit readout of total field intensity in nanotesla (nT), with a resolution of 1 nT.

Field magnetometric mapping involved, initially, a number of reconnaissance-traverses to locate the position of intrusive bodies obscured by overburden. Whereafter, if necessary, detailed traverses were conducted at specific localities to gain accurate information on the geometry of the body. These traverses were performed to aid in the accurate positioning of exploration boreholes in the indurated contact zones of dolerite dykes and to a lesser extent, sheets.

In general, the magnetic traverse line should, as far as possible, be perpendicular to the known or inferred geological strike of the body for maximum resolution. The station spacing is dictated by the detail needed, the estimated minimum width and maximum depth of the body.

Traverses cannot be performed near power-lines, fences, cables, radio-transmitters and other metallic objects. Obviously, the operator should be divest of magnetic material normally carried on his person. Roux (1979) provides a detailed discussion of the field procedures involved in magnetic surveys.

Magnetic anomalies can be either qualitatively or quantitatively interpreted. Qualitative interpretation involves the

recognition of trends, shapes and patterns in the magnetic data, which are then related to the anticipated geological conditions. The majority of the magnetic work undertaken in this investigation required only a qualitative form of interpretation, ie. the location and nature of the magnetic body.

Generally, the nature of an intrusion can be readily deduced from the shape of the anomaly. The shape of the anomaly is mainly controlled by the geometry, attitude and field inclination of the body. (Reford, 1964). For instance typical dyke anomalies, show a positive peak, indicating the position of the body, with subsidiary negatives, which represent the indurated zone adjacent to the intrusion. Figure 15 indicates the effect of various geometrical forms and depth of burial on the shape of an anomaly.

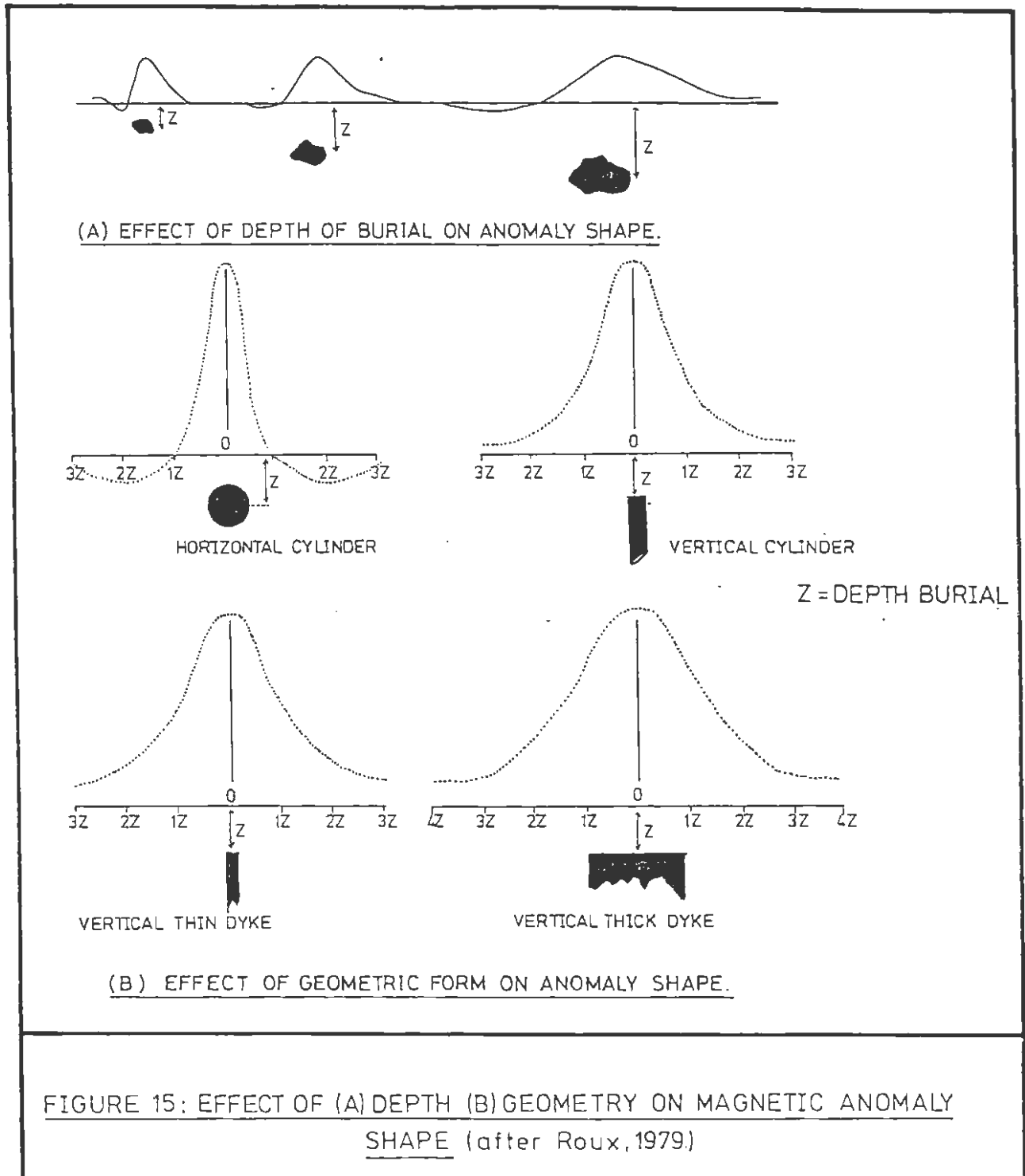
The amplitude of an anomaly is determined by:

- (a) The depth of burial.
- (b) Magnetic susceptibility of the body.
- (c) Intensity of the earth's magnetic field.
- (d) To a lesser extent, altitude of the body (Parasnis, 1972).

Amplitude of an anomaly is of least interest in qualitative interpretation of anomalies, as large ranges of susceptibilities occur in apparently similar rock types.

Quantitative interpretation of magnetic anomalies are performed when more detailed and accurate information is required on the attitude and geometry of a body. Various graphical and curve-matching techniques have been described by Enslin (1950), Werner (1953), Reford (1964), Koulomzine et al (1970) and Richards (1974).

More recently computer curve-matching procedures have been introduced (Richards, 1977; Cooper, 1987). The procedure used in this study is based on the following equation for a uniformly, induced magnetic anomaly produced by two dimensional, infinite magnetic dyke:



$$t = 2.k.T.b.W \{ [h.\text{Sin}(2I-d)]/R - [x.\text{Cos}(2I-d)]/R \}$$

where t - the anomaly (nT) in the direction of the normal  
total intensity of the earth's magnetic field,  
i - inclination of the earth's magnetic field from the  
horizontal,  
T - is the earth's total field intensity (nT),  
A - Strike of the traverse from magnetic north,  
k - is the magnetic susceptibility,  
W - width, and  
d - is the angle of dip of the dyke,  
h - depth to the top of the dyke,  
x - distance (m) of station from centre of dyke,  
 $b = 1 - \text{Cos}^2 i \times \text{Sin}^2 A$   
 $R = x^2 + h^2$   
 $I = \arctan(\tan i / \cos A)$  (Richards, 1977).

Enslin (1950) noted that the susceptibility of dolerite commonly varies between 0.004 and 0.000004.

The above equation assumes that the magnetisation is only produced by induction within the earth's magnetic field. Furthermore, dykes of infinite length and depth do not occur in the field. Koulomzine et al (1970) found that dykes with length to width ratios in excess of ten, tend towards the theoretical length requirements of the equation.

#### 5.2.2.2.3 DISCUSSION OF MAGNETIC SURVEY RESULTS

Some 150 magnetic traverses were run during the course of the investigation. Most of the traverses were of a reconnaissance nature. The earth's magnetic field remained relatively constant throughout the investigation at approximately 28330 nT. Only the detailed magnetic profiles across the Dalham, Perries, Roodebloem, Welgevonden dykes and Dalham sheet have been included in this report (Appendix 5). The position of these structures are indicated in Enclosure 2.

Generally, the nature of the intrusion could readily be deduced from the shape of the anomaly. Dolerite dykes produced good positive anomalies for quantitative interpretation purposes. The results of the computer matched interpretations are contained in Table 7.

TABLE 7 : AVERAGED INTERPRETATION RESULTS OF DYKE ANOMALIES

DYKE	TOTAL MAGNETIC FIELD (nT)	MAGNETIC SUSCEPTIBILITY	WIDTH (m)	DIP	DEPTH OF BURIAL (m)
Dalham	28400	0.0030	2.5	48 S	2.5
Roodebloem	28400	0.0002	4.0	78 W	8.0
Perries	28310	0.0035	9.0	70 W	5.0
Welgevonden	28300	0.0005	7.5	85 W	4.0

Boreholes G33179 and G33188 were successfully sited in the contact zones of the Perries and Welgevonden dykes, respectively, using the computer program (Figure 7, p 42 ).

Remnant magnetisation was found to have a negligible effect on the field data, hence the success obtained with the interpretation of dyke anomalies by the computer technique. This is in accordance with Maree's (1943) findings on Karoo dolerites.

Magnetic profiling across dolerite sheets were of minimal value for quantitative interpretation purposes. In most cases, the magnetic method proved useful in locating and defining of these structures. Attempts at locating the Dalham sheet in the vicinity of the municipal wellfield proved fruitless. This is probably due a combination of the intrusion's weak magnetic properties and depth of burial/weathering (30 m) at this locality. However, in the vicinity of the airfield and the Sundays River the sheet was fairly accurately located (Appendix 5). Here, boreholes G33233 and G33234, were sited in the dolerite sheet using magnetics.

### 5.3 DRILLING PROGRAMME

#### 5.3.1. OBJECTIVES OF THE DRILLING PROGRAMME

The value of an exploration drilling programme lies in the fact that it represents a direct method of obtaining accurate lithostratigraphic information and access to the aquifer(s).

The Johnson Division (1980) state that drilling is undertaken to satisfy the following two main objectives:

- (1) as part of a regional groundwater investigation, and
- (2) as a preliminary to the design and construction of one or more boreholes at a particular site.

In general, the drilling programme was designed to achieve the former, although, initially a few production boreholes were drilled on account of the Graaff-Reinet municipality. The specific aims of the drilling programme were threefold, namely:

- (a) Calibration and verification of resistivity work - calibration boreholes (Section 5.2.2.1).
- (b) Determination of the occurrence, geometry and nature of water-bearing formations - exploration boreholes.
- (c) Evaluation of the hydraulic characteristics of aquifers - test and observation boreholes.

The above aims are very much interrelated with the ultimate objective of defining and assessing the exploitation potential of aquifer units within the investigation area.

### 5.3.2. DRILLING, SAMPLING AND BOREHOLE CONSTRUCTION TECHNIQUES

Mandel et al (1981) lists the following principal factors that need to be considered when selecting the drilling method to be employed:

- (1) expected depths of boreholes,
- (2) number of boreholes,
- (3) specific purpose of boreholes,
- (4) properties of rock formations,
- (5) the availability of drilling rigs and accessories,

(6) time restrictions, and

(7) cost of drilling.

Both the availability of an air-rotary-percussion drilling rig and the need for a relatively large number (23) of fairly shallow (average of 60m) boreholes in as short a time as possible, made the rotary-percussion method the most feasible for this investigation. This method is best suited for hard-rock drilling, and to a lesser extent boulder-free, unconsolidated deposits (Campbell et al, 1973). The major disadvantage of rotary-percussion drilling is the loss of sampling accuracy, especially in unconsolidated deposits.

Collecting of reasonably representative samples when drilling by airlift-rotary-percussion methods, requires special attention and experience (Johnson, 1980). Drill-cuttings are often an admixture of material from the base of the hole, drilling mud and material from higher levels that have caved in. Thus the drill cuttings had to be carefully analysed. Whilst drilling, accurate record was kept of the following:

- (a) Washed and unwashed cuttings, where possible, at 1 metre intervals.
- (b) Water quality - conductivity measurements were made at regular intervals (about 5 metres) and samples for full chemical analysis were collected at water interceptions.
- (c) Depth of water interceptions and rate of water flow airlifted from the borehole using a calibrated v-notch.

Casing was installed, varying according to the thickness of the unconsolidated or weathered/fractured zone. The majority of the boreholes were cased with standard 165mm diameter steel casing, while higher yielding boreholes were cased with 200mm diameter casing. Observation boreholes were cased with 127mm diameter casing. The casing was flame-slotted to optimum slot-length and -width, taking into account the expected yield, lithology and, in the case of the alluvium, the grain size.

Many problems were, as anticipated, encountered with drilling and construction of boreholes in the alluvium, especially where a gravel/boulder horizon was present. Drilling with the casing hampered progress considerably, while further delays occurred as a result of casing being offline, drill bits getting stuck etc.

After completion, the boreholes were developed by surging and jetting (using the drilling rig) for a minimum period of fifteen minutes. This provided an estimation of the boreholes final yield, as well as the removal of fine-material entrapped during the drilling process.

### 5.3.3. DISCUSSION OF DRILLING RESULTS

Initially three production boreholes (GR4, GR10 and GR23) were drilled for the Graaff-Reinet municipality, as part of a scheme to expand the existing wellfield and thus are not included in the exploration drilling programme of this investigation.

Mandel et al (1981) and Enslin (1961) state that a regional groundwater investigation requires a scientifically planned exploration drilling programme, based on working hypotheses regarding prospective aquifers, their extent and distribution within the hydrologic regime.

Initially, drilling operations were concentrated upon the Graaff-Reinet aquifer because of its already established water-bearing potential, mainly for calibration of the resistivity data and aquifer testing purposes. Thereafter, drilling was extended to the hard-rock terrain, where dolerite intrusions were concentrated upon.

During the exploration drilling programme a total of 23 boreholes were completed. The total depth drilled was 1408m, giving an average depth per borehole of 61.2m (maximum 100m and minimum 26m).

Although many of the boreholes were multi-purpose wells, they can be classified into three specific categories:

- (a) Calibration boreholes : 4  
(G33172 to G33175)
- (b) Test and observation boreholes : 7  
(G33178, G33180, G33184, G33230 to G33232 and 33234)
- (c) General exploration boreholes : 12  
(G32176, G33177, G33179, G33181 to G33183, G33185 to G33189 and G33233).

The drilling and geohydrological logs of each borehole are contained in Appendix 2, while their positions are indicated in Enclosure 1.

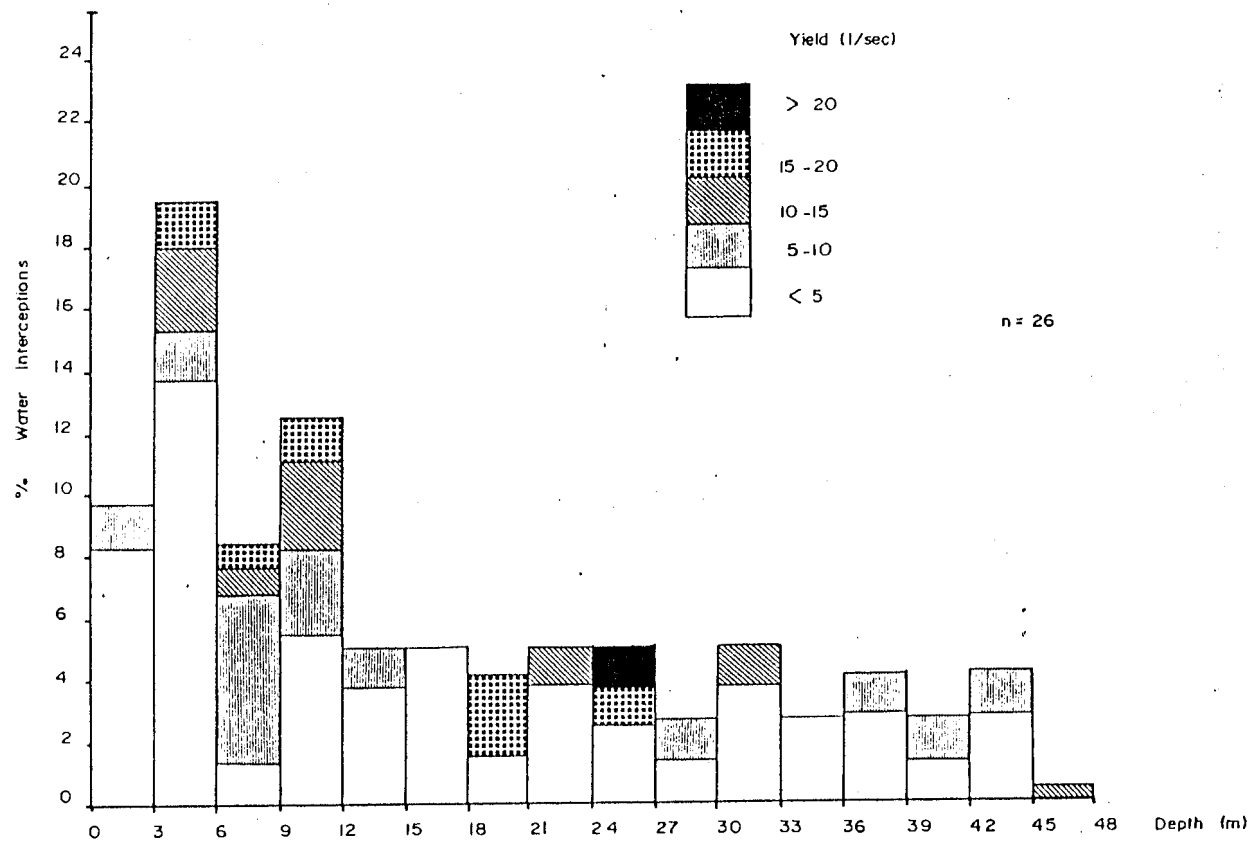
A synthesis of the drilling results are presented in histogram form in Figure 16. The histogram indicates the percentage of water interceptions and relative percentages of blowyield tests for 3m interval drilling depths below the water level. Three main observations can be made:

- (1) The bulk of the water interceptions occurred in the first 12m below the water level, which is to a large extent representative of boreholes in the Graaff-Reinet aquifer.
- (2) The highest yields were encountered between 3 to 9m and 18 to 27m below the water level. The shallower interceptions occurred in the alluvium, while the yields at greater depths were related to dolerite intrusions.
- (3) At depths in excess of 50m below the water level the probability of intercepting water becomes very low. This depth could be considered as a cut-off level for drilling in the area.

The "average" total dissolved solids of water intercepted during the drilling programme was 1118 mg/l, with three boreholes yielding water in excess of 2000 mg/l.

Individual water interceptions reveal the following relationship between geology and groundwater occurrence within the study area:

Fig 16 : Histogram showing percentages of water interceptions and relative percentages of blow test yield for 3m interval drilling depths below waterlevel



**TABLE 8 : RELATIONSHIP BETWEEN LITHOLOGY AND GROUNDWATER INTERCEPTION**

LITHOLOGY	NUMBER OF INTERCEPTIONS YIELDING MORE THAN:		
	<5 l/s	5-10 l/s	>10 l/s
Alluvium	11	4	1
Sandstone	5	1	0
Dolerite contact	10	3	3
Dolerite	6	0	0

Since the number of groundwater interceptions under consideration is very small it is unwise to attach too much significance to the statistics in Table 8. There can, however, be little doubt that the alluvium and dolerite are the most prolific groundwater producing formations in the study area.

Minor quantities of groundwater were intercepted in mudstones and siltstones. Water intercepted in carbonaceous mudstones was often highly sulphurous.

Generally, poor groundwater supplies were intercepted below dolerite sheets at depths in excess of 50m (boreholes G33185, G33182, G33171 and G33181). The Dalham sheet in the vicinity of the wellfield is an exception (G33170, GR18 and GR19). Water interceptions within thick dolerite sheets were confined to discrete fracture zones (G33170 and G33186).

Moderate to good groundwater supplies (5-10 l/s) were intercepted in the following geohydrological situations:

- (a) Contact zones of dolerite dykes (boreholes G33179, G33188 and G33230). Evidence indicates that yields are related to the width and, possibly, the length of the dyke. Low yields being associated with dykes of less than 3m in width. This observation is borne out by Vandoolaeghe (1981) and Von Hoyer (1974), in other parts of the Karoo. Geohydrological profiles of boreholes G33189 and G33188, indicating water interceptions, are presented in Figure 7, p 42.

- (b) Upstream contacts of dolerite sheets that cut the local drainage (boreholes G33233, G33234 and G33184).
- (c) Coarse alluvial deposits with thicknesses in excess of 15m, with a basal gravel/boulder horizon.

Very high yields were intercepted in the municipal wellfield, where large thicknesses of alluvium, underlain by highly jointed/weathered sediments and/or dolerite were encountered (GR4 and GR23). A geohydrological profile of the municipal wellfield is presented in Figure 8, p44.

#### 5.4 AQUIFER TESTING

##### 5.4.1 OBJECTIVES OF AQUIFER TESTS

Depending on the requirements, a well designed aquifer-testing programme will allow the determination of some, if not all, of the following:

- (1) Yield characteristics and potential of the borehole.
- (2) Efficiency of the boreholes performance as an indication of it's hydraulic condition
- (3) Confirmation of the hydrogeological nature of the aquifer.
- (4) Determination of the hydraulic properties of the aquifer system.
- (5) Prediction of the effect(s) of present and/or future abstraction from the borehole on groundwater conditions in the aquifer (Ferris et al, 1962).

In the Graaff-Reinet investigation, items (1) and (2), were determined by employing step-drawdown tests. The remaining items were evaluated using constant-discharge tests.

#### 5.4.2 AQUIFER TYPES AND RESPONSE TO ABSTRACTION

There are four broad categories of aquifers, namely:

- (1) confined,
- (2) unconfined,
- (3) semi-unconfined, and
- (4) semi-confined.

The aquifer type determines the response of a water-bearing formation to abstraction. As a result, different methods of analysis have been developed to evaluate the hydraulic properties of the particular aquifer type.

A confined aquifer is a completely saturated, permeable formation in which the upper and lower boundaries are impervious. The hydrostatic pressure within a confined aquifer is greater than that of the atmosphere, with the result that water in the boreholes penetrating the aquifer are at a higher elevation than the top of the aquifer (Kruseman et al, 1970).

An unconfined aquifer on the otherhand, is a permeable formation only partially filled with water, overlying a relatively impervious layer. The upper boundary of the aquifer is formed by a free- or phreatic water level, which is not subject to any pressure other than that of the atmosphere and that generated by it's own weight (Kruseman et al, 1970).

Semi-confined and semi-unconfined aquifers fall inbetween the above two aquifer types. A semi-confined or "leaky" aquifer is similar to that of a confined aquifer with the exception that the confining layer is not completely impervious (Bouwer, 1978). Abstraction in such an aquifer generates vertical flow or leakage from the overlying semi-pervious layer into the aquifer. Since the hydraulic conductivity of this layer is very low, horizontal flow within the layer is negligible. A semi-unconfined aquifer is one in which the hydraulic conductivity of the semi-pervious layer is sufficiently great for horizontal flow to be significant (Bouwer, 1978). Such an aquifer exhibits delayed-yield effects and is intermediate

between a semi-confined and an unconfined aquifer.

Typical time-drawdown response curves for the major aquifer types are illustrated in Figure 17.

When a borehole is pumped, water is removed from the aquifer surrounding the borehole and the phreatic or piezometric water level, depending on the aquifer type, is lowered. A drawdown curve shows the variation of the drawdown with time at a particular point. In three-dimensions the drawdown curve describes a conical shape known as "the cone of depression".

Generally, at the beginning of pumping the water level drops rapidly. This is due to the water abstracted being derived mainly from borehole storage and from the aquifer immediately surrounding the borehole. As pumping continues, the cone of depression expands outwards from the pumped borehole and the water level begins to drop at a slower rate, due to a larger volume of water becoming available. The decline in the water level is proportional to the pumping rate and decreases logarithmically away from the abstraction borehole.

In an unconfined aquifer exhibiting a delayed yield, the initial rapid decline in the water level corresponds to pressure-release drainage of the pore spaces. This is in a fashion typical of a confined aquifer. After a period of time, the water level drops at a slower rate as more and more water is yielded by gravity drainage of the pore space above the watertable. This results in a drawdown curve more typical of an unconfined aquifer. Similarly, in a leaky aquifer the early portion of the drawdown curve conforms to a typical confined situation. Thereafter the rate of drawdown decreases as an equilibrium, between the discharge rate of the pump and the rate of leakage or recharge through the overlying layer, is established.

#### 5.4.3 PRINCIPLES OF AQUIFER TESTING

##### 5.4.3.1 STEP DRAWDOWN TESTS

During a step drawdown test the drawdown in a borehole is observed while the abstraction rate of the borehole is either increased or decreased (Clark, 1977).

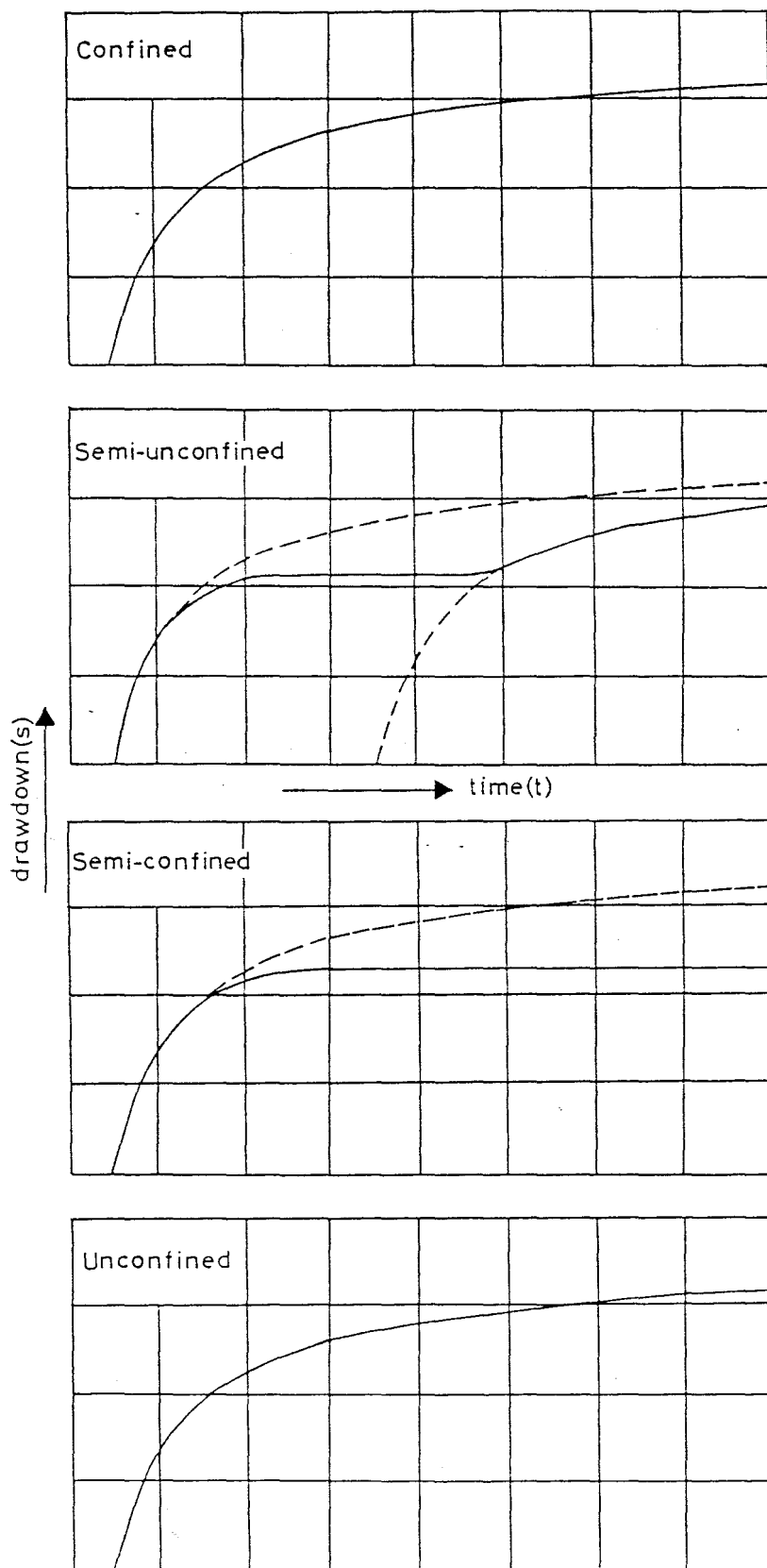


FIGURE 17: TYPICAL S/T CURVES FOR DIFFERENT AQUIFER TYPES.

The theory of the step drawdown tests are discussed in detail by inter alia, Kruseman and de Ridder (1970), Clark (1977), Brereton (1979) and Kaergaard (1982).

Brereton (1979) states that step drawdown tests provide information on the hydraulic conditions in the immediate vicinity of a borehole and should enable the determination of:

- (a) The yield-drawdown (specific drawdown) characteristics of the pumped borehole, allowing prediction of its maximum potential, optimum operating conditions and specifications of permanent pump installations.
- (b) The well-loss coefficient. This provides an estimate of the efficiency of the borehole at the operational abstraction rate.
- (c) The short-term hydraulic characteristics of the aquifer.

During this study, the step test was commonly used to select a suitable yield for the constant discharge test.

The total drawdown induced in a pumped borehole can be subdivided into two main components:

- (1) Formation Losses - due to the viscous drag created by water moving through an aquifer under, essentially, low velocity laminar (Darcian), flow conditions.
- (2) Well Losses - associated with high velocity, turbulent flow encountered in the immediate vicinity of a well (Clark, 1977).

Turbulent flow is usually associated with head losses through the screen, gravel pack and pipes within the borehole.

Jacob's (1946) formula describes the relationship between total drawdown ( $S_w$ ) and the above components:

$$S_w = BQ + CQ^2$$

Where  $S_w$  - Total drawdown(m) in the pumped borehole.

$Q$  - Discharge ( $m^3/day$ ).

- B - Formation losses (day/m<sup>2</sup>).  
 C - Borehole losses (day<sup>2</sup>/m<sup>5</sup> ).

There has been protracted debate over Jacob's proposed value of 2 in the well losses component of the equation. Rorabaugh (1953) and Lennox (1966) have suggested values ranging from 1.5 to 3.5. Clark (1977) used Jacob's equation to analyse the results of numerous pumping tests and concluded that in the majority of field conditions a value of 2 was the most appropriate. Kaergaard (1982) agreed with Clark in the case of normal porous media, where the aquifer in proximity of the borehole is homogeneous. However, he concluded that in many fissured aquifers the Jacob formula is not applicable, as non-Darcian flow occurs within the fractures. In this study, since no step drawdown tests were undertaken in fractured-aquifers, the Bierschenk and Wilson Method (1961) of solving the Jacob equation was applied.

According to Kaergaard (1982), the traditional perception that B-losses take place in the formation and C-losses in the borehole, has often led to the conclusion that a large C-loss was due to poor borehole construction. He found that this was not always necessarily the case, as C-losses normally included contributions from the casing, screens, gravel-packs and formation close to the borehole.

In general, the hydraulic condition of a pumped borehole is described in terms of its efficiency. The efficiency of an abstraction point is an indication of the relative magnitude of drawdowns associated with Darcian type flow through the aquifer and non-Darcian type flow in the immediate vicinity of the borehole. Efficiency (E) can, therefore, be defined as the ratio of theoretical aquifer drawdown to actual drawdown in the borehole:

$$E = 1 / (1 + C/BQ) \quad (\text{Clark, 1977}).$$

It is evident from the equation that, as the proportion of well losses to the total drawdown decreases, the efficiency approaches unity. Efficiency is also a function of the rate of abstraction and is normally quoted with reference to time, as the coefficient of B is time dependent.

Step drawdown tests are only able to provide an estimate of the hydraulic characteristics of an aquifer over a short period. Information on aquifer behaviour over extended periods of abstraction must be derived from longer constant-discharge tests.

#### 5.4.3.2 CONSTANT-DISCHARGE AQUIFER TESTS

Constant-discharge tests were undertaken mainly to provide information on the following:

- (a) the relative value and distribution of hydraulic parameters within the Graaff-Reinet aquifer, and
- (b) in the case of fractured-aquifers, to provide "safe-yield" estimates

Constant-discharge tests may be subdivided into either steady- or transient-state tests. Steady-state tests are those in which pumping is continued until recharge balances abstraction, such that the water levels approach equilibrium. During transient-state tests, water levels drop continuously with time. All aquifer tests conducted during this investigation conformed to the latter conditions and thus the discussion will be confined to transient-state analytical methods.

The hydraulic parameters, transmissivity (T) and storativity (S), of an aquifer are important in providing a quantitative understanding of the natural flow of groundwater through an aquifer and its response to abstraction (Jones et al, in Lloyd, 1981).

Transmissivity is defined as "the rate of flow under a hydraulic gradient equal to unity through a cross-section of unit width over the entire thickness of the aquifer" (Kruseman et al, 1970), and may be thought of as the ease with which an aquifer is able to yield water. It is designated the symbol T and has the dimension of length<sup>2</sup>/time.

The storage coefficient or specific yield is defined as the volume of water that the aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change

in piezometric- or phreatic-water level (Kruseman et al, 1970). The storage coefficient refers only to the confined parts of the aquifer and depends on the elasticity of the aquifer material and fluid, while the specific yield refers to the unconfined portion of the aquifer and depends on the effective porosity of the aquifer (Todd, 1980).

The relative value and distribution of transmissivity and storativity within the Graaff-Reinet aquifer are required for the following purposes:

- (1) Specific Yield - to enable the estimation of the total volume of groundwater stored in the aquifer.
- (2) Transmissivity - to assist in locating areas suitable for production boreholes.

The analytical techniques described below are dependent on a number of general assumptions, namely:

- (a) The aquifer is seemingly infinite in extent.
- (b) The aquifer is homogeneous, isotropic and of uniform thickness over the entire area influenced by the aquifer test.
- (c) Prior to pumping, the piezometric or phreatic surface is approximately horizontal.
- (d) The aquifer is pumped at a constant rate.
- (e) The pumped borehole penetrates the entire thickness of the aquifer and thus receives water from the entire thickness of the aquifer by horizontal flow.
- (f) The diameter of the pumped borehole is small, so that its storage can be neglected.
- (g) Flow in the well is in an unsteady or transient state.  
(Kruseman et al, 1970)

#### 5.4.3.2.1 THEIS METHOD

Theis (1935) was the first to develop a non-steady state formula which introduced the factors of time and storage in confined aquifers. The equation was derived from the analogy between groundwater flow and heat flow, and may be written as follows:

$$S_w = (Q / 4 \times \pi \times T) \times W(u) \quad \dots\dots\dots(1)$$

Where  $S_w$  is the drawdown (m) in the borehole,  
 $Q$  is the discharge ( $m^3/day$ ) of the pumped borehole,  
 $T$  is the transmissivity ( $m^2/day$ ) of the aquifer, and  
 $W(u)$  is the well function of  $u$

$$u = (r^2 \times S) / (T \times t) \text{ or} \\ S = (4 \times T \times t \times u) / r^2 \quad \dots\dots\dots(2)$$

$S$  is the storage coefficient (dimensionless) of the aquifer, and  
 $r$  is the radial distance (m) to the pumped well (Ferris et al, 1962).

The following assumptions are explicit to this method:

- (1) The aquifer is confined.
- (2) Water removed from storage is discharged instantaneously with decline in the piezometric level.

Solving equations (1) and (2), produces the solution to values of  $T$  and  $S$ . Since the parameter  $r$  is included in eq. (2), the solution for storage requires that an observation borehole be located within the zone of influence of the pumping borehole. However, as  $W(u)$  and  $u$  are both functions of  $T$  and  $S$ , the two equations cannot be solved directly.

Theis (1935) developed a graphical method for evaluating storage and transmissivity. If the discharge ( $Q$ ) is kept constant, then drawdown ( $S_w$ ) is related to time ( $t$ ) in a similar manner to the relation of  $W(u)$  to  $1/u$ . A plot of  $W(u)$  against  $1/u$  is known as a Theis-type curve (Figure 18A). The test data of drawdown (ordinate) against time (abscissa) is plotted

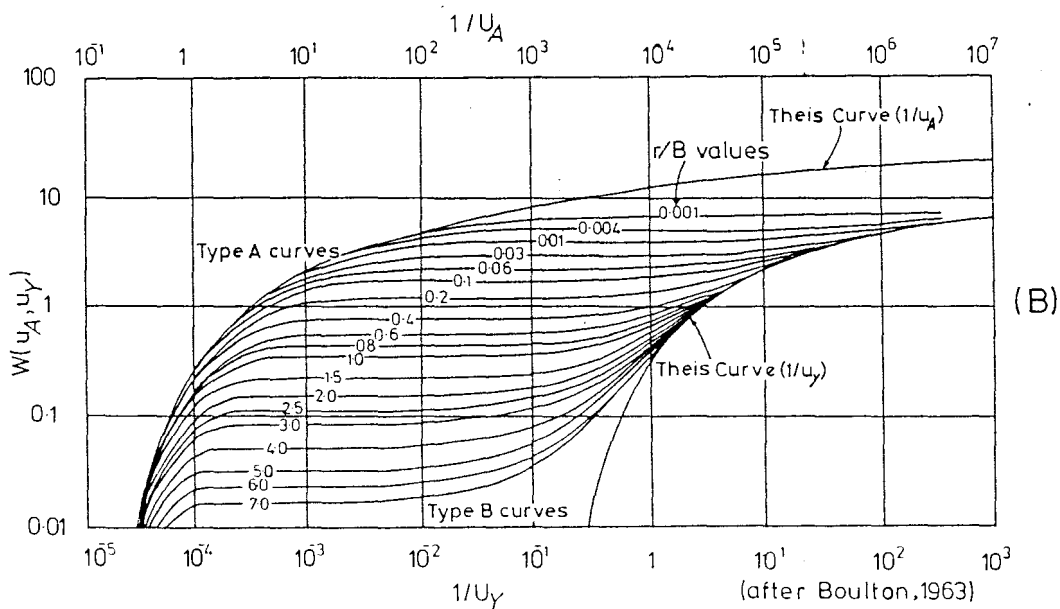
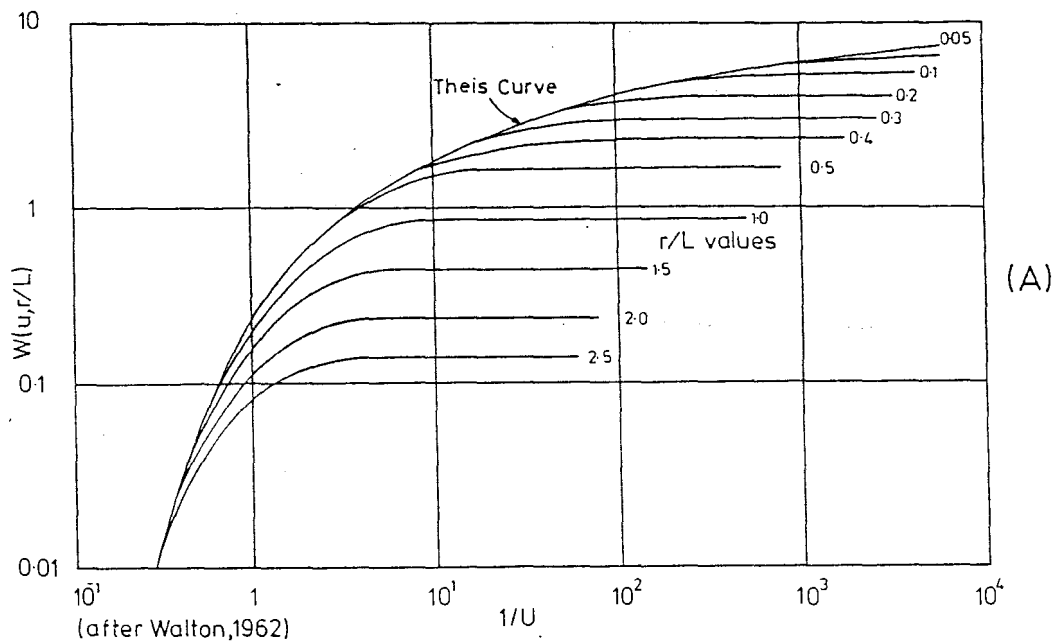


FIGURE 18 (A) WALTON (B) BOULTON TYPE CURVES

on the same modula graph-paper as that of the type curve. If the above defined Theis assumptions are satisfied, the field curve will have the same shape as the type curve, but will be horizontally and vertically offset. Therefore, by placing the field curve over the type curve, keeping the co-ordinate axes parallel, the position of the best-fit between the two curves is located. An arbitrary matchpoint is selected and the related values of  $S_w$ ,  $t$ ,  $W(u)$  and  $1/u$  for the point are noted. Substitution of these values into eq. (1) and (2), enables the solution of the transmissivity and storage coefficient.

#### 5.4.3.2.2 WALTON METHOD

The assumption inherent in the Theis solution that formations overlying and underlying a confined aquifer are completely impervious, is seldom satisfied. Aquifers that receive ground water inflow from adjacent units are called semi-confined or "leaky" aquifers. Walton (1962) developed a graphical solution for leaky aquifers, by following the same line of reasoning as Theis. The Walton method was employed in this investigation, although others are available.

$$S_w = (Q / 4 \times \pi \times T) \times W(u, r/L) \dots\dots\dots (3)$$

Where  $W(u, r/L)$  is the well function for leaky aquifers

$$u = (r^2 \times S) / (4 \times T \times t) \dots\dots\dots (4)$$

$L$  is the so-called leakage factor, which is an indication of the vertical conductivity of the aquitard (Kruseman et al, 1970). Large values of  $L$  are indicative of small leakage affects.

Walton developed a similar graphical method of analysis to Theis. In this case, values of  $W(u, r/L)$  and  $1/u$  are plotted on bilogarithmic paper, resulting in a type curve for each value of  $r/L$ . This furnishes a family of type curves for varying degrees of leakage in which the curve of zero leakage is the original Theis curve (Figure 18A).

In a similar fashion to the Theis method, the field-curve is superimposed on the Walton type-curve and shifted until the best fitting type curve is located, while keeping the co-ordinate axis parallel. An arbitrary matchpoint is selected and the values of  $S_w$ ,  $t$ ,  $1/u$  and  $W(u, r/L)$  are read off from the respective graphs. The type curve number ( $r/L$ ) is also noted. The values of  $S_w$  and  $W(u, r/L)$  are substituted into eq. (3), which yields the transmissivity. Similarly, by substituting the values into eq. (4), the storage coefficient is obtained. The leakage factor ( $L$ ) is obtained from the value of  $r/L$  of the type-curve chosen.

#### 5.4.3.2.3 BOULTON METHOD

A further assumption of the Theis method, that water is released from storage instantaneously with decline in head, is not satisfied in some aquifers (Boulton, 1963). Many aquifers are semi-unconfined and exhibit delayed yield effects. Boulton developed a method of analysing such aquifer conditions, involving a complicated set of differential equations, which symbolically and in analogy to the Theis equation, may be written as:

$$S_w = (Q / 4 \times \pi \times T) \times W(u, r/B) \dots\dots\dots (5)$$

Where  $W(u, r/B)$  is called the Boulton Well Function,

$$u \text{ is either } u_a = (r^2 \times S_a) / 4 \times T \times t \dots\dots\dots (6) \text{ or,}$$

$$u_y = (r^2 \times S_y) / 4 \times T \times t \dots\dots\dots (7)$$

$B$  is the drainage factor and is analogous to the leakage factor in semi-confined aquifers (Hazel, 1975). Large values of  $B$  are indicative of rapid drainage.

Boulton, as with Walton, constructed a family of type-curves for each value of  $r/B$  (Figure 18B). Similarly, analysis of test data is achieved by a process of curve-matching. Initially the field-curve is superimposed on the type-A portion of the theoretical curves. Keeping the co-ordinate axis parallel, the early time portion of the field curve is matched to the type-A curves. An arbitrary point on the overlapping sheets of graph-paper is selected and the values of  $S_w$ ,  $t$ ,

$1/u_a$  and  $W(u_a, r/B)$  for the point is noted. These values are then substituted into eq. (5) and (6), determining the transmissivity (T) and storage coefficient ( $S_a$ ), respectively.

Thereafter, the latter portion of the field-curve is matched to the type-Y portion of the theoretical curves, using the same  $r/B$  value as that selected for the type-A curves. A second arbitrary match-point is selected and the values of  $Sw$ ,  $t$ ,  $1/U_y$  and  $W(U_y, r/B)$  of the point noted. Substituting these values into eq. (5) and (7), yields the transmissivity (T) and storage ( $S_y$ ). The two values of transmissivity thus calculated should be similar. The early time storage ( $S_a$ ) is more typical of confined conditions and the later time storage ( $S_y$ ) more typical of unconfined conditions. It should be noted that, Boulton's method gives no information regarding the properties of the overlying layer, as B is defined within the properties of an unconfined aquifer (Hazel, 1975).

The above discussed techniques of aquifer test analyses are strictly applicable to infinite, homogeneous and isotropic aquifers. However, in practice, many aquifers are heterogeneous, anisotropic, of varying thickness and limited extent. Obviously, the closer the hydrogeological environment approaches the idealised configuration the more reliable the results. Foreman et al (1981), in a study of an alluvial aquifer in the Missouri River valley, found that such aquifers are strongly inhomogeneous. They concluded that, in such cases, the results obtained from standard analyses should be viewed with caution.

#### 5.4.3.2.4 FRACTURED AQUIFER METHODS

Tests in fractured-aquifers are commonly not subject to standard analyses (Enslin et al, 1963; Kiraly, 1971; Gringarten et al, 1972 and Sen, 1986). The main reason for this is that groundwater flow in fractured-aquifers is commonly linear, rather than radial (Kiraly, 1971; Streltsova, 1976; Boulton, 1977; Boulton et al, 1977 and Jenkins et al, 1982). A number of analytical methods for fractured-aquifers have been described by, inter alia, Rofial (1965), Papadopoulos (1965), Gringarten et al (1972), Boulton (1978a, 1978b), Gilding (1979) and Houlden (1984). Houlden applied both conventional

and fracture flow analytical techniques to aquifer test data obtained from various fractured-aquifer systems in South Africa. He concluded that realistic T values could be obtained using conventional methods but resulted in an over estimation of the S value. The above techniques for the evaluation of fractured-aquifers could not be applied in this study due to insufficient optimally located observation boreholes. It is further considered that the ultimate goal of determining the hydraulic parameters by the such methods, is now considered a doubtful matter (Morel et al, 1982; Sagar et al, 1982 and Kohut et al, 1982).

An simplified adaptation of the method proposed by Jenkins et al, (1982) and Sen (1986) was applied to obtain an estimate of the "safe yield" of the aquifer. This method was successfully applied under similar conditions by Seward (1982) in Carnarvon.

Sen (1986) applied the Boltzmann transformation of variables to the modified continuity equation to obtain the following equation in terms of a fracture well function  $W(u)$  for a single vertical fracture:

$$W(u) = (1 - e(\sqrt{\pi})) / (\sqrt{u}) \dots\dots\dots (8)$$

where e is an error function

Similar to Theis, Sen constructed a type curve by plotting  $W(u)$  versus u on double logarithmic graphpaper (Figure 19). It is clear that for small values of u or large times the type curve follows a straight line and groundwater flow becomes linear. He found that as u approached 0, the error function (e) was equal to 0.5. Therefore eq. (8) could be reduced to:

$$W(u) = 1 / (2 \times \sqrt{u}) \dots\dots\dots (9)$$

Sen concluded that drawdowns from observation boreholes very close to the pumped fracture or late time drawdowns could be fitted to a straight line on arithmetic paper with the plot of drawdown versus the square root of time.

This procedure was applied to tests conducted on dolerite dyke aquifers. The test data was extrapolated using linear regres-

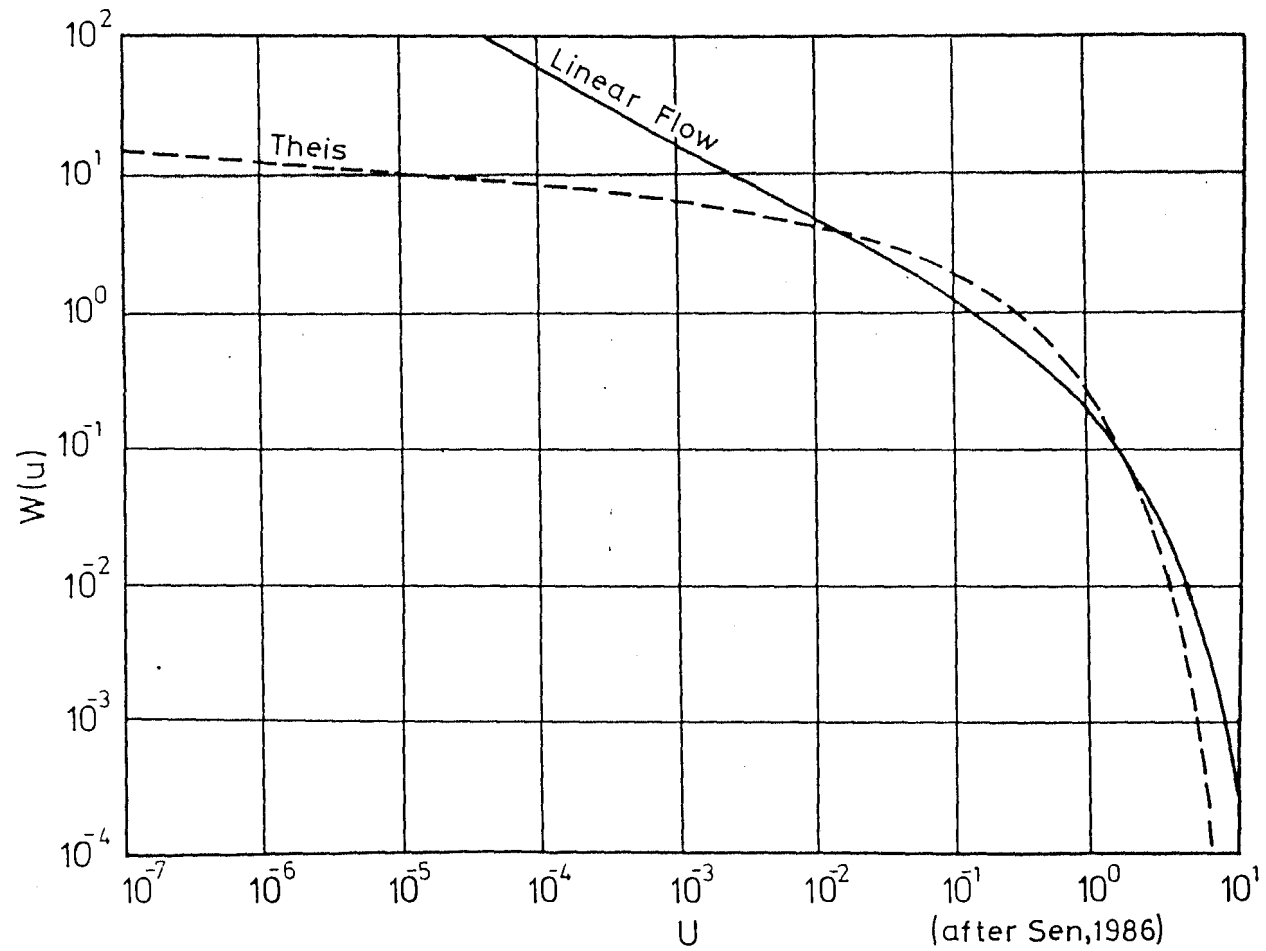


FIGURE 19: VERTICAL FRACTURE TYPE CURVE

sion to provide "safe yield" estimates for the aquifer units. The procedure assumes that flow conditions will remain linear indefinitely.

#### 5.4.3.2.5 RECOVERY METHODS

Once the pump has been shut-down, the water level in the borehole will cease dropping and start rising again towards its original position or rest water level. This is the so-called "recovery phase" of the borehole. The recovery can be measured as residual drawdown, which is the difference between the original water level prior to pumping and the water level measured at a certain time since the pumping stopped. The recovery data may be analysed using similar graphical methods to those described for the drawdown data. The methods will not be elaborated upon here, since the recovery data was used mainly for verification of the drawdown results.

#### 5.4.4 AQUIFER TESTING PROCEDURES

The execution of an aquifer test is usually a simple procedure, but can be hampered by mechanical problems, resulting in erratic variations in the discharge. The following measurements are taken at predetermined time intervals:

- (a) discharge rate, and
- (b) water levels in both pumped and observation boreholes.

The recovery of the water level was monitored after shut down of the pump. In a number of cases the water level in the pump borehole could not be monitored due to inadequate space between the pump's pipes and the borehole casing for observation tubing to be inserted.

Yield determinations using a stop watch and a 1 m<sup>3</sup> tank were taken at logarithmic intervals throughout the test. The groundwater was piped, a minimum of 250m, downstream into natural drainage channels. The electrical conductivity of the groundwater was monitored for quality changes during the test period. In certain cases, water samples were collected for

standard chemical analysis on commencement of pumping and prior to shut-down.

#### 5.4.5 AQUIFER TEST RESULTS

##### 5.4.5.1 STEP DRAWDOWN TESTS

Step drawdown tests were performed on boreholes GR4, BK18, G33173 and G33234 in the Graaff-Reinet aquifer. The test specifications and results are listed in Table 9, while the drawdown curves are contained in Appendix 4.

The negative B value obtained for borehole GR4 is attributed to leakage effects. The well losses for BK18 and G33234 are considered to be excessively high (43% and 51% at a rate of 9.5 l/s for the respective boreholes).

##### 5.4.5.2 CONSTANT-DISCHARGE TESTS

Ten constant-discharge tests were performed, eight of which were conducted at various localities in the Graaff-Reinet aquifer. The duration of the test varied from 720min to 11520 min. Most of the tests were carried out using a mobile 100mm diameter mono pump. Pump and engine failure resulted in certain tests being repeated (eg. G33230 and G33173) or shortened (eg. G33233).

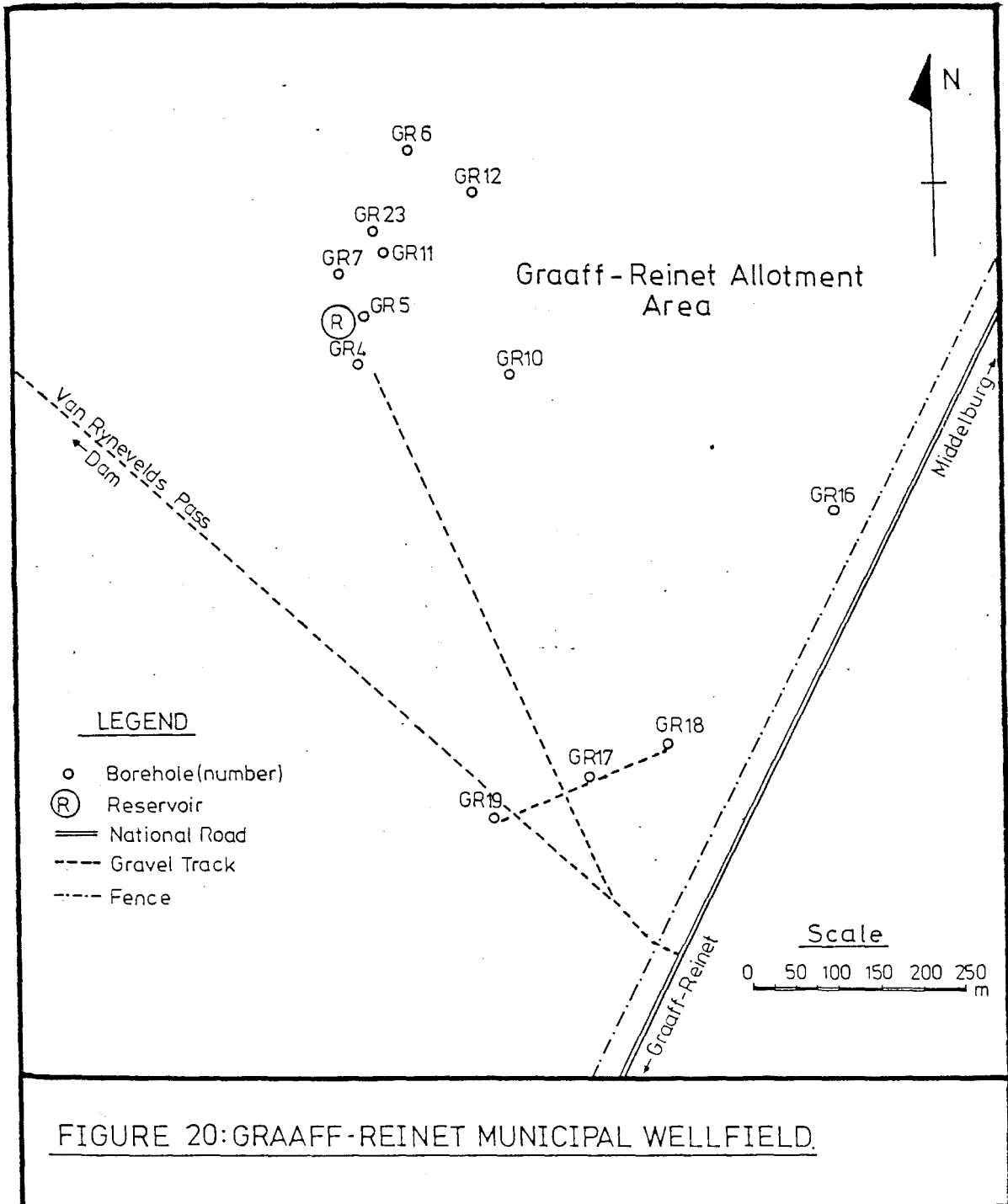
The position of the boreholes tested, excepting those within the municipal wellfield, are shown on Enclosure 1. The wellfield boreholes are indicated in Figure 20, while the pump specifications, yield and EC measurements are contained in Appendix 4.

##### 5.4.5.2.1 GRAAFF-REINET AQUIFER

Difficulty was often experienced in obtaining unique fits when conventional curve-matching techniques were applied to the test data, as a result of the complex nature of the aquifer. The s/t curves featured a number of local aquifer characteristics, eg. linear flow and boundary conditions. At least two

TABLE 9 : SPECIFICATIONS AND RESULTS OF STEP DRAWDOWN AQUIFER TESTS

BH No	DATE	STATIC (m) WATERLEVEL	STEP				COEFFICIENT		WELL EFFICIENCY (%) AT GIVEN RATE (1/s)	RECOMMENDED YIELD FOR CONSTANT RATE TEST (1/s)
			NO	DURATION (min)	YIELD (1/s)	MAX (m) DRAWDOWN	WELL LOSS	AQUIFER LOSS		
GR 4	03/05/83	11.139	1	60	10.6	1.868	$3.61 \times 10^{-7}$	$-1.45 \times 10^{-3}$	-	17.0
			2	100	13.4	2.786				
			3	120	16.9	4.417				
			4	220	19.6	7.361				
			5	230	21.5	14.764				
BK 18	30/01/84	8.660	1	35	3.9	0.275	$5.66 \times 10^{-7}$	$6.11 \times 10^{-4}$	57% @ 9.5 1/s	9.0
			2	40	5.2	0.375				
			3	60	6.4	0.506				
			4	160	7.4	0.638				
			5	180	9.4	0.880				
G33173	06/02/88	9.708	1	60	3.3	0.462	$1.16 \times 10^{-7}$	$1.72 \times 10^{-3}$	95% @ 9.1 1/s	9.0
			2	100	4.9	0.660				
			3	100	6.0	0.834				
			4	160	7.3	1.021				
			5	180	9.1	1.356				
G33234	15/02/84	11.311	1	60	3.7	0.309	$8.75 \times 10^{-7}$	$6.93 \times 10^{-4}$	49% @ 9.5 1/s	9.0
			2	50	5.1	0.442				
			3	100	6.2	0.585				
			4	120	7.1	0.725				
			5	180	8.8	0.996				



appropriate methods of interpretation were applied to the field data. The results considered to be the most representative of the hydrological conditions are contained in Table 10. The drawdown/time curves are filed in Appendix 4.

The aquifer is often two-layered or even multi-layered, and conditions range from unconfined to semi-confined and confined. The following aquifer components were recognised:

- (1) A basal gravel/boulder horizon which is essentially unconfined,
- (2) overlying finer grained alluvium, causing either leaky or delayed conditions, and
- (3) a weathered/jointed bedrock which is commonly confined.

Boreholes GR10 and G33233 intercepted water below the Dalham dolerite sheet. In the wellfield area, specifically GR10, this water is considered to be hydraulically independent of the Graaff-Reinet aquifer.

The range of storage values calculated from the aquifer tests are considered to represent the combined influence of the relatively thick, unconfined, primary- and thinner, secondary-aquifer components. As a result, the storage values calculated cannot be taken to represent either of the two components.

The transmissivity values in Table 10 are representative of the permeability coefficient of both of the aquifer components, namely, the coarse basal horizon and fractured bedrock.

#### 5.4.5.2.2 FRACTURED AQUIFERS

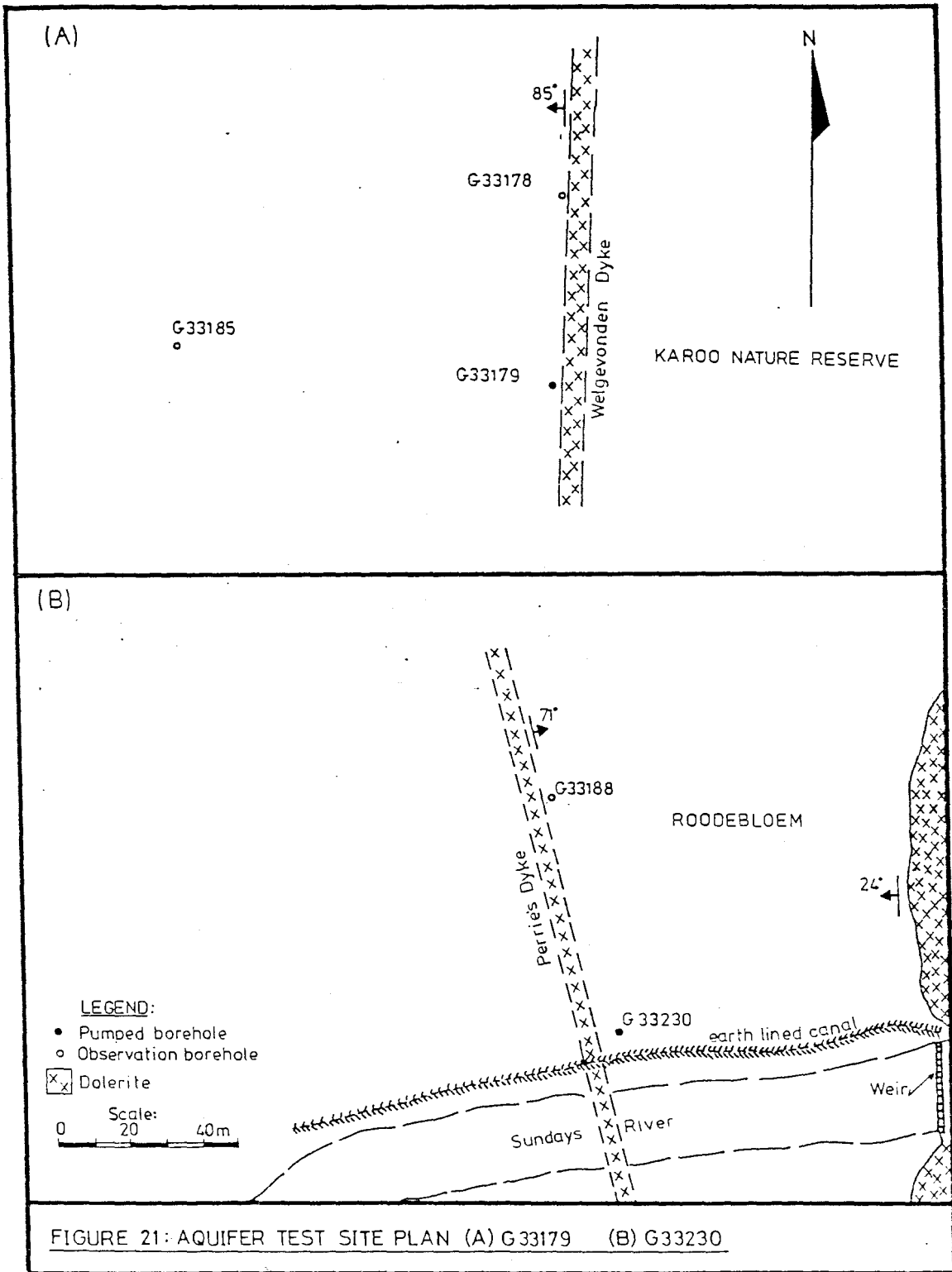
Two aquifer tests were conducted on boreholes G33179 and G33230 at the Welgevonden and Perries dykes, respectively. The relevant test specifications, yield and EC measurements are contained in Appendix 4.

Test site plans for boreholes G33179 and G33230 are presented in Figure 21. The field data of drawdown versus the square

TABLE 10 : CONSTANT DISCHARGE AQUIFER TESTS - HYDRAULIC CHARACTERISTICS OF THE AQUIFER UNITS.

BH No	DATE	DISTANCE (m) TO OBS. BH.	AQUIFER(S)	METHOD OF EVALUATION	TRANS. "T" (m <sup>2</sup> /day)	STORAGE "S" (S <sub>y</sub> )	LEAKAGE "L"	DRAINAGE "B"	REMARKS
GR-4	12/05/83	-	A	Theis	225	-	-	-	no observation borehole.
GR 10	09/05/83	-	A	Theis	41	-	-	-	no observation borehole.
GR-23	15/06/83	-	A	Walton	152	-	-	-	observation data unreliable
GR-5		-			173	-	-	-	little is known about the geohydrological particulars and construction of GR-11, 7,6,5 and GR-12. Automatic waterlevel recorders were installed on GR-10 and 12.
GR-11		-			1169	-	-	-	
GR-4		100			1433	0.0052	-	166	
GR-7	15/11-	57	A	Boulton	2540	0.0082	-	570	
GR-23	25/11/83	62			1461	0.0410	-	6200	
GR-6		166			1634	0.0370	-	278	
GR-12		-			-	-	-	-	
GR-10		198			-	0.0760	-	19800	
BK-18	31/01-	-	A	Walton	187 (187)	-	-	-	BK-18 indicated high well losses. Recalculate T = 436 m <sup>2</sup> /day.
G33232	06/02/84	16			1436 (1420)	0.0073 (0.0058)	161	-	
G33173	07/02-	-	A	Walton	165 (303)	-	-	-	irregularities in G33231 ignored, attributed to improper bh. construction.
G33231	13/02/84	23			1045 (1409)	0.075 (0.069)	116	-	
G33233	22/02-	-	A	Boulton	50 (50)	-	-	216	borehole G33233 yield dropped towards end test due to sand pumping.
G33234	26/02/84	22			732 (734)	0.031 (0.011)	-	216	
RB-34	13/01/84	-	A	Boulton	-	-	-	-	No access could be gained to pumped borehole.
RB-23		42			275	0.00033	-	4200	
G33230	23/01-	-	B	linear frac-	-	-	-	-	unable to evaluate using standard methods.
G33188	29/01/84	130		ture flow	-	-	-	-	
G33179	16/01-	-	B	linear frac-	-	-	-	-	unable to evaluate using standard methods.
G33178	22/01/84	50		ture flow	-	-	-	-	
G33180		114			-	-	-	-	

\* Bracketed "T" and "S" values obtained from Recovery Data.  
 \* AQUIFER INDEX : A = Alluvium/ weathered, jointed bedrock.  
 B = Sediment/dolerite dyke contact zone.



root of time for both tests are plotted in Figures 22 and 23. The characteristic straight line portion of the field data was analysed using linear regression (Table 11).

**TABLE 11 : REGRESSION ANALYSES OF FRACTURED AQUIFER TESTS**

TEST SITE	BOREHOLE	RELATIONSHIP
Welgevonden	G33179	$s = (Q \times t \times 1.9 \times 10^{-5}) + 3.227$
	G33178	$s = (Q \times t \times 1.1 \times 10^{-3}) + 1.424$
	G33180	$s = (Q \times t \times 9.7 \times 10^{-4}) + 0.665$
Perries	G33230	$s = (Q \times t \times 8.0 \times 10^{-4}) + 9.80$
	G33188	$s = (Q \times t \times 7.3 \times 10^{-4}) - 0.35$

Q = yield (m<sup>3</sup>/day) s = drawdown (m) t = time (days)

From Figure 23 it is evident that the water level in borehole G33230 stabilised rapidly after 28 minutes. This is probably due to recharge from a weir in the nearby Sundays River. It was therefore assumed that, without recharge having occurred, the slope of borehole G33230's graph would have been similar to that of G33188. The time-drawdown slope displayed by borehole G33230, prior to the 28 minute mark, was not utilised as the depth of the major water interception (32m) had to be taken into account.

The slopes of the time-drawdown graphs of observation boreholes G33188 and G33180 are similar. The difference in slope between the observation boreholes and the pumped borehole G33179 is ascribed to the effect of turbulent flow about the well. The regression equations in Table 11 are used in Section 6.2 to estimate the long term behaviour and "safe yields" of the aquifer units.

## 5.5 HYDROCHEMISTRY

According to Aastrup et al (1984), the chemical composition of groundwater is determined by:

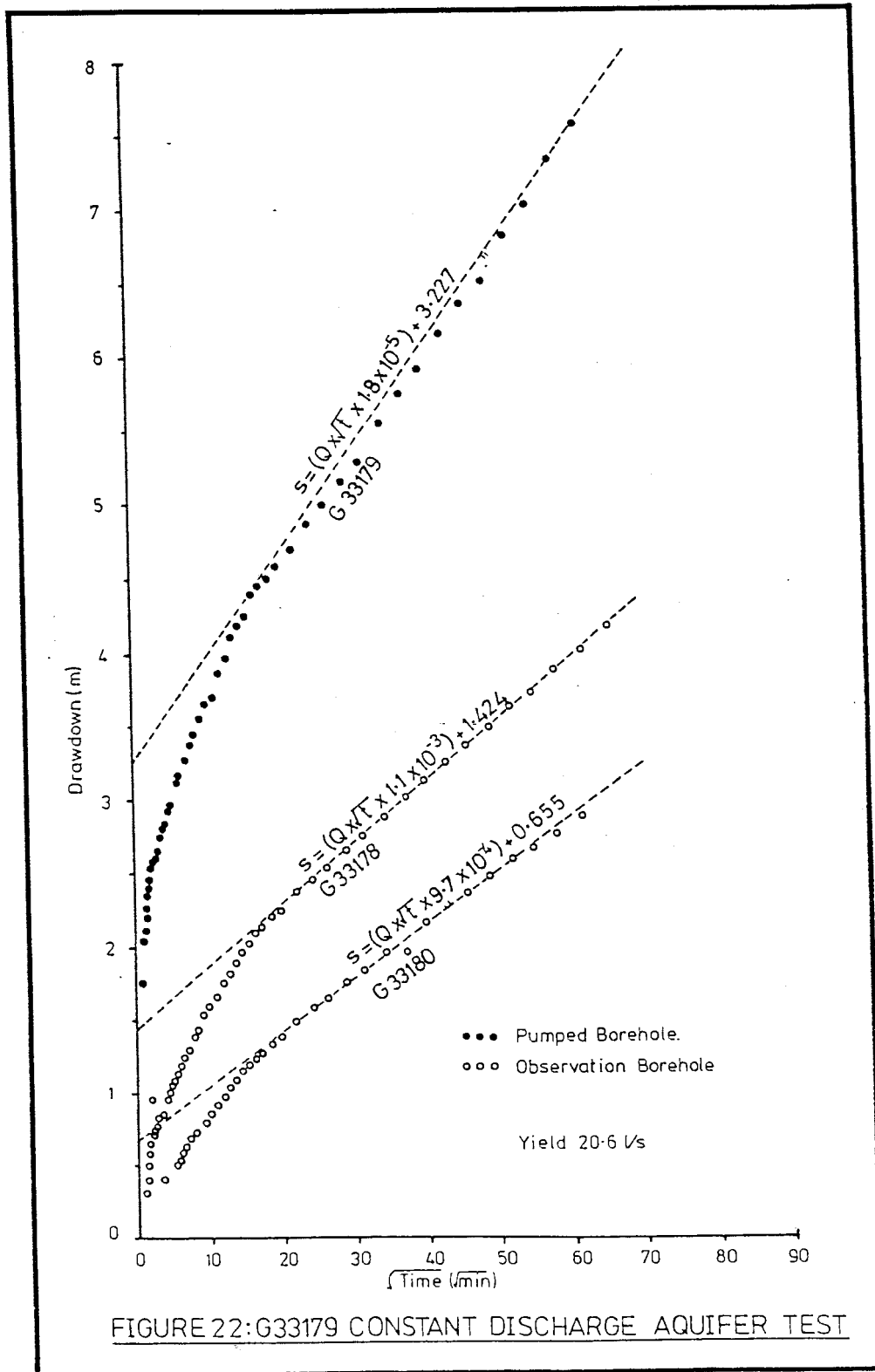
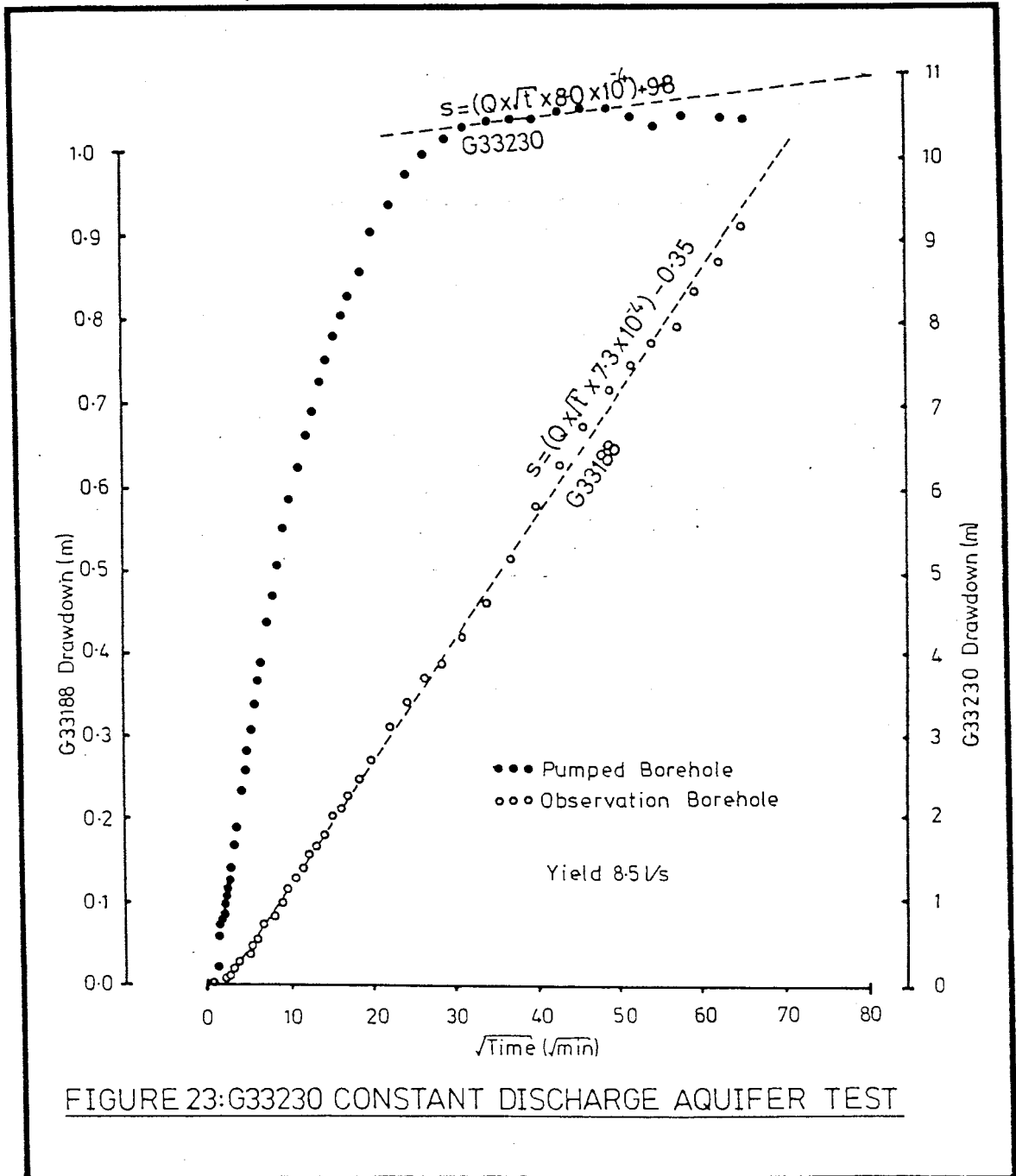


FIGURE 22: G33179 CONSTANT DISCHARGE AQUIFER TEST



- (a) Reaction velocity between the water and rock minerals.
- (b) Residence time of the water in the aquifer.
- (c) Contact area between water and minerals.

The reaction velocity is determined by the resistance of the rock material to weathering. The topography and hydraulic characteristics of the aquifer determine the residence time, while the reactive area is controlled by the aquifer type (primary/secondary) and grain or fracture size.

#### 5.5.1 DISSOLVED CONSTITUENTS IN GROUNDWATER

Groundwater samples collected during this study were analysed for the following major dissolved constituents:

Cations:	Sodium	Anions:	Chloride
	Calcium		Sulphate
	Magnesium		Nitrogen
	Silica		Fluoride
	Potassium		Phosphate

Samples were also tested for total dissolved solids (TDS), electrical conductivity (EC), total alkalinity (TAL) and hydrogen ion concentration (pH).

##### 5.5.1.1 CATIONS

- (1) Sodium (Na) - Na is one of the most abundant cations in natural waters, but is not a major rock-forming mineral. The element has a high solubility and thus tends to remain in solution. Na participates in base exchange reactions whereby it replaces other cations, commonly magnesium and calcium, in clay minerals (Hem, 1970). Na is an important constituent of igneous rocks, evaporite deposits and seawater.
- (2) Calcium (Ca) - Ca is the most abundant cation in many groundwater systems. Calcium is widespread in most soil

and rock types, and is readily soluble. High concentrations of Ca can occur in aquifers where large amounts of carbon dioxide are available (Freeze et al, 1979). Ca is readily exchanged for Na in clay minerals.

- (3) Magnesium (Mg) - Mg is abundant in carbonate rocks (dolomite) and to a lesser extent in igneous rocks. Hem (1970) notes that Mg has a relatively high solubility, but is a minor dissolved constituent of groundwater owing to its low abundance. Mg has a stronger tendency to remain in solution than does calcium (Bouwer, 1978). Ca and Mg are the major constituents causing hardness in water.
- (4) Silica (Si) - Si is the most abundant element in igneous and sedimentary rocks. The majority of the dissolved silica in water is thought to originate from the chemical breakdown of silicates during the processes of metamorphism and weathering (Hem, 1970). Silica generally occurs in low concentrations in groundwater. High Si concentrations are thought to be present only in waters with a pH greater than 9 (Davies et al, 1966). The low Si concentrations probably reflect the low solubility of clay minerals, feldspars, quartz and other common silicate minerals.
- (5) Potassium (K) - K is commonly derived from the weathering of orthoclase, microcline, biotite, leucite and nephelene in igneous and metamorphic rocks. Waters percolating through evaporitic deposits may contain very large quantities of K, derived from the dissolution of sylvite (Freeze et al, 1979). Potassium concentrations are generally low in groundwater because of its relatively weak mobility. However, K salts are highly soluble and thus are not easily removed from solution (Davies et al, 1966).

#### 5.5.1.2 ANIONS

- (a) Chloride (Cl) - Chloride is a minor constituent of the earth's crust, but a major dissolved constituent in most natural waters (Moreira-Nordemann, 1984). Davies et al

(1966), list the following major sources of Cl in groundwater:

- (1) Ancient seawater entrapped in sediments.
- (2) Solution of halite and associated minerals in evaporite deposits.
- (3) Concentration by evaporation.
- (4) Solution of dry fallout from the atmosphere, particularly in arid regions.

Cl is highly soluble and chemically inert. Thus dissolved chlorides tends to remain in solution.

- (b) Sulphate ( $\text{SO}_4$ ) - Evaporites are the most extensive sources of sulphates, where calcium sulphate in the form of gypsum and anhydrite are abundant (Freeze et al, 1979). Sulphur is a minor constituent of igneous rocks, most commonly associated with heavy minerals. Sedimentary rocks, particularly organic shales, may yield large amounts of sulphates through the oxidation of marcasite and pyrite (Davies et al, 1966). In groundwater, sulphur commonly occurs as oxidised  $\text{SO}_4$ , which is stable over a wide range of pH. Hydrogen sulphide is a reduced form of sulphur but is only stable in waters with a pH of less than 7 (Hem, 1970). High sulphate concentrations may accumulate in groundwater because cations taken into solution from rocks generally do not form insoluble compounds with sulphate (Lawrence et al, 1982).
- (c) Nitrogen (N) - Dissolved nitrogen in groundwater commonly occurs in the form of nitrate ( $\text{NO}_3$ ). Other forms are ammonium ( $\text{NH}_4$ ), ammonia ( $\text{NH}_3$ ) and nitrite ( $\text{NO}_2$ ). Igneous rocks contain small amounts of soluble nitrate or ammonia. Most of the nitrates in groundwater originate from organic or industrial/ agricultural sources (Reddy et al, 1984). Nitrates are highly soluble and thus are only removed from natural water through biological activity or evaporation.

- (d) Fluoride (F) - Fluoride occurs in small amounts in igneous, metamorphic and sedimentary rocks and has a low solubility. Fluoride is an important constituent of drinking water because it is taken up by the human body and incorporated into the teeth and bones. However, excessive fluoride concentrations are toxic.
- (e) Phosphate (P) - Standard chemical analysis report P in terms of orthophosphate ions ( $\text{PO}_4$ ). Phosphates are commonly present in trace amounts in groundwater and have moderately high solubilities. Solubility is therefore not considered to be a limiting factor controlling phosphate concentrations, but rather it's scarcity in nature (Hem, 1970).

#### 5.5.1.3 HYDROGEN ION CONCENTRATION (pH)

The symbol pH is used to designate the logarithm (base 10) of the reciprocal of the  $\text{H}^+$  concentration and varies from 0 to 14. A pH of 7 is taken to be neutral, while a value greater than 7 is alkaline and lower than 7 is acidic.

The pH of a water is largely controlled by chemical reactions and equilibria existing in solution. The pH of a water is modified by changes in the  $\text{CO}_2$  solubility which depends on the temperature and pressure. Thus pH values obtained from chemical analyses can be significantly altered during pumping and sample storage. Values of pH are often used as a measure of the solvent power of a water or as an indicator of the chemical behaviour of certain solutions towards different rock minerals.

#### 5.5.1.4 TOTAL DISSOLVED SOLIDS (TDS) AND ELECTRICAL CONDUCTIVITY (EC)

Theoretically, TDS is the total number of dissolved solids in solution and is calculated by totalling the major ion concentrations, as determined by the hydrochemical analysis.

The electrical conductivity (EC) of water is a function of the dissolved solids and temperature of the water. Therefore the

temperature of the water has to be standardised before a TDS value may be calculated from an EC measurement :

$$\text{TDS} = (\text{EC} \times \text{K}) \times \text{A}$$

Where TDS is the total dissolved solids in mg/l  
 EC is the measured electrical conductivity (S/m).  
 K is a constant, dependent on the temperature of the water  
 A is a conversion factor that varies between 0.55 and 0.75, depending on the ionic composition of the solution (Hem, 1970).

Non-dissociated ions are not conductive and will result in inaccuracies when the EC is converted to TDS. EC has the units of the reciprocal ohm.metres, denoted in the SI System as siemens per metre (Freeze et al, 1979).

All EC values presented in this study are referred to a standard temperature of 25° C. Differences between field conductances and laboratory results of a magnitude of 10% are not considered significant (Hem, 1970).

#### 5.5.1.5 TOTAL ALKALINITY (TAL)

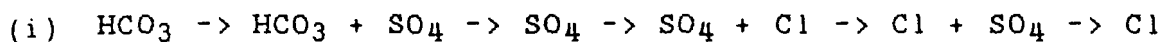
"TAL is the capacity of a solution to neutralise an acid" (Hem, 1970, p152), and is measured in terms of bicarbonates ( $\text{HCO}_3$ ) and carbonates ( $\text{CO}_3$ ). Bicarbonates are commonly abundant in recently recharged groundwater (Johnson, 1975).

#### 5.5.2 CHEMICAL EVOLUTION OF GROUNDWATER

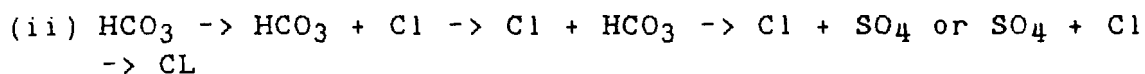
The total dissolved solids in groundwater commonly increases as it moves from recharge to discharge areas in a basin environment. The groundwater changes from a bicarbonate/carbonate water to a chloride water (Johnson, 1975).

Hydrochemical sequences describing the processes involved in the chemical evolution of groundwater in a basin have been put forward by various authors:

In 1952, the Russian Bektchourine proposed the following sequence



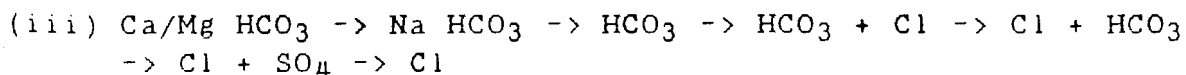
Cheboratev (1955a, 1955b) studied more than 10 000 chemical analyses of groundwater samples from Australia and concluded that groundwater tended to evolve chemically towards the composition of seawater. He observed that this process was normally accompanied by the following regional changes in the dominant anion species:



Schoeller (1959) refers to this sequence as the Ignatovich-Souline sequence, where the age of the groundwater increases along the path of flow. Domenico in Freeze et al (1979) found that, in large sedimentary basins, the Cheboratev sequence could be subdivided into three major zones, which correlate with depth:

- (1) Upper Zone - characterised by active groundwater flushing through relatively well leached rocks. Groundwater in this zone has bicarbonate as the dominant anion and is low in TDS.
- (2) Intermediate Zone - with a lower flow regime and a higher TDS content. Sulphate is normally the dominant anion.
- (3) Lower Zone - with sluggish groundwater movement. Highly soluble minerals are commonly present in this zone because of the lack of groundwater flushing. A high chloride and TDS content is characteristic of this zone.

Johnson (1975) believes that sequences (i) and (ii) represent only the latter half of the evolution process and has suggested the following sequence:



Johnson states that recharge water has a predominant Ca/Mg  $\text{HCO}_3$  nature. During underflow the water assumes a more Na  $\text{HCO}_3$  character by the process of base exchange. At this stage, the water may evolve towards a more Cl dominant character if the hydraulic gradient or transmissivity factor is low. Finally, the total dissolved solids increase and the groundwater becomes saturated with respect to sodium chloride in the discharge areas, resulting in the precipitation of less soluble carbonates.

Johnson (1975) subdivided groundwater in a basin environment into three basic classes, namely:

- (a) recent recharge (Ca/Mg  $\text{HCO}_3$ ) water,
- (b) dynamic underflow (Na  $\text{HCO}_3$ ) water, and
- (c) stagnant (NaCl or  $\text{Na}_2\text{SO}_4$ ) water.

Johnson found the chemical classes of groundwater to be independent of the basin geology. The main criteria determining the dynamic quality of the groundwater being the basin flow regime or hydraulic characteristics of the aquifer.

Moreira-Nordemann (1984) and Van der Rys (1981) found that climate played an important role in the groundwater quality in semi- to arid regions, where salts are accumulated as a result of the low rainfall and high rates of evaporation.

### 5.5.3 CHEMICAL CLASSIFICATION OF GROUNDWATER

The concept of "hydrochemical facies" was developed as an outgrowth of the sequence approach, discussed in Section 5.5.2 (Palmer et al, 1985). A set of facies is defined by a combination of dominant cations and/or anions, reflecting both geochemical and groundwater flow processes. The geochemical evolution of groundwater is therefore described in terms of evolving from one hydrochemical facies to another.

According to Zaporozec (1972), the main techniques used to interpret water quality data can be grouped into four categories, namely: classification, correlation, analytical and

illustrative methods. The chemical data collected during this study was analysed using the following methods of classification:

- (1) Simple Total Dissolved Solids (TDS) Classification.
- (2) Trilinear Piper Diagram as adapted by Johnson (1975).

These classification techniques were used to describe the basic hydrochemical characteristics and possible evolutionary sequence of groundwater in the study area.

#### 5.5.3.1 TDS CLASSIFICATION

The total dissolved solids classification is based on an arbitrary subdivision of TDS (mg/l) into four classes:

- |                    |                  |
|--------------------|------------------|
| (a) Freshwater     | 0 - 1000         |
| (b) Brackish water | 1000 - 10 000    |
| (c) Salty          | 10 000 - 100 000 |
| (d) Brine          | > 100 000        |
- (After Gorrel, in Davies et al, 1966).

#### 5.5.3.2 TRILINEAR PIPER DIAGRAM

The trilinear diagram developed by Piper (1944) is one of the most widely used classification techniques. He proposed that groundwater be considered in terms of the three major cations (Na, Mg and Ca) and three major anions (Cl, SO<sub>4</sub> and HCO<sub>3</sub>). The diagram consists of three plotting fields, two triangular fields for each of the cations and anions, and a central rhomboidal field combining the two triangular fields. The concentration of each of the participating ions are plotted in the respective triangular fields. The two points in the cation and anion triangular grids are then projected into the central rhomboid grid. One drawback of this method is that waters of different TDS can plot at the same point.

A combined Johnson (1975) and Rodda et al (1976) Piper classification of groundwaters types was used in this study (Figure 24).

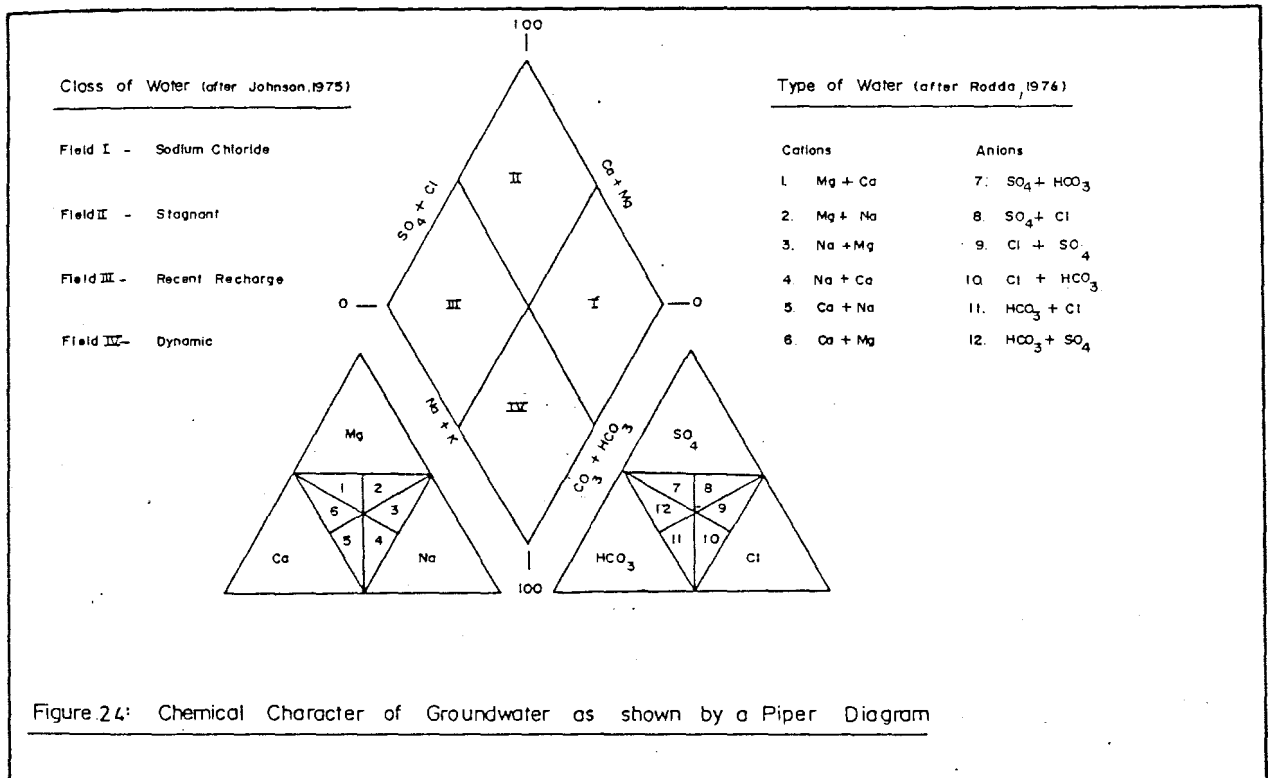


Figure 24: Chemical Character of Groundwater as shown by a Piper Diagram

#### 5.5.4 FIELD PROCEDURE AND SAMPLE COLLECTION

The hydrochemical study involved the collection of groundwater samples for standard chemical analysis and field conductivity measurements from both project and private boreholes. The field EC measurements were converted to TDS values for inclusion in the text. The principle aim of groundwater sampling was to assess its suitability for domestic use.

Conductivity measurements were obtained from the majority of private boreholes during the hydrocensus (Appendix 1). Certain private boreholes were selected for standard chemical analysis, based on water level and conductivity results obtained during the hydrocensus. These results are filed in Appendix 3.

The project boreholes were sampled throughout the duration of the investigation, more specifically during the aquifer testing and drilling. Results of the chemical analyses are contained in Appendix 3. Conductivity measurements obtained during drilling and aquifer testing are filed in Appendices 2 and 4, respectively.

Certain municipal production boreholes were sampled on a number of occasions to assess any temporal changes in groundwater quality, especially following the high rainfall in May/June.

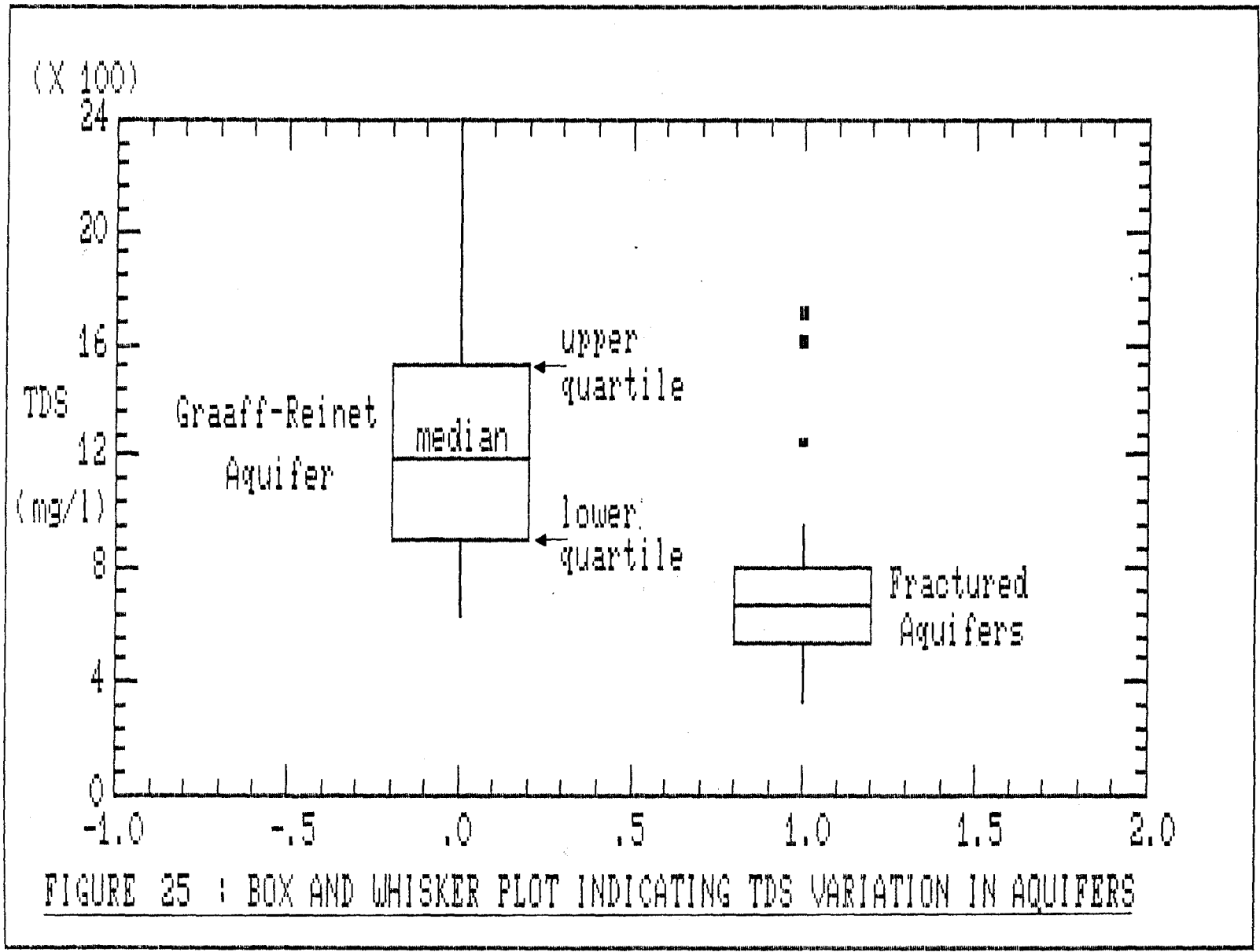
#### 5.5.5 INTERPRETATION AND DISCUSSION OF RESULTS

##### 5.5.5.1 TOTAL GROUNDWATER MINERALISATION

The conductivity measurements made during the hydrocensus and drilling programme were utilised to construct a TDS isopach map (Enclosure 8). The following general observations can be made:

- (a) Boreholes with high TDS ( $>1000$  mg/l) are generally located in the Graaff-Reinet aquifer (Figure 25). Exceptionally high TDS (2000 mg/l) values occur in the vicinity of the municipal wellfield.
- (b) Boreholes with low TDS groundwater ( $<1000$  mg/l) are generally located along and beyond the basin edges.
- (c) Mineralisation in the Graaff-Reinet aquifer increases in the direction of groundwater flow, ie. from north to south (discussed in Section 5.6).

The groundwater varies from fresh in the fractured aquifers to brackish in the Graaff-Reinet aquifer, according to the TDS



classification discussed in Section 5.5.3.1. The quality variation between the two aquifers is summarised in Figure 25.

#### 5.5.5.2 CHEMICAL CHARACTERISTICS

The results of the chemical analyses of samples from private, municipal and project boreholes are presented in Appendix 3. The data have been processed and are presented on a Piper diagram (Enclosure 9).

The chemical sampling programme was geared towards assessing the suitability of the groundwater for domestic use and was thus of limited value in providing detailed evaluation of the hydrochemical processes in the study area.

The waters are almost exclusively of a "mixed type". According to Johnson's (1975) Piper classification of groundwater types (Figure 24, p 107), the majority of the waters sampled belong to the static or stagnant type.

The Piper diagram indicates three basic water types:

- (1) Mixed water with a high  $\text{HCO}_3$  content,
- (2) a complex mixing of waters, and
- (3) mixed water with a high Na/Cl content.

The above three types roughly indicate the chemical cycle of the groundwater in the investigation area. The movement of more recently recharge water (boreholes BT5, BT6 BT8 and G33187) from the upland edges of the basin (1), to the more static waters (GR4, GR5, GR11, G33171, G33170 and RB41), associated with the alluvial basin (3). This essentially involves the removal of Ca/Mg  $\text{HCO}_3$  and the introduction of Na/Cl salts to the groundwater. The hydrochemical cycle agrees in broad terms with that proposed by Johnson (1975).

Tordiffe (1978) found the natural hydrochemical evolution to be the dominant factor controlling the groundwater quality in the Middleton Formation. The major factors controlling this process include geology, topography, climate and time. For

practical purposes the former two factors are considered constant. The semi-arid climate is thought to be the main factor controlling the hydrochemical processes within the basin. Low recharge and high rates of evapotranspiration result in the concentration of salts (Na/Cl) in the groundwater. This is especially the case in the Graaff-Reinet aquifer where relatively shallow watertable conditions exist. Residence time of groundwater in the Graaff-Reinet aquifer is also considered to be important, where groundwater movement is sluggish and base exchange (Ca/Mg for Na cations), in clay minerals is thought to occur.

It is not possible to statistically establish the impact of agriculture on groundwater quality in the study area. However, it is possible that irrigation practices could accelerate and/or increase groundwater mineralisation in the Graaff-Reinet aquifer by:

- (a) re-cycling of mineralised groundwater by flood irrigation,
- (b) leaching out of salts in the soil by irrigation return flow,
- (c) application of fertilizers to the irrigation lands. It is thought that the addition of a gypsum-based fertilizer could account for the high  $\text{SO}_4$  content in boreholes G33233, G33234, G33171, RB26, RB41, RB34, RB43 and BK17.

#### 5.5.5.3 WATER QUALITY VARIATIONS WITH DEPTH

Generally the TDS content of groundwater does not vary greatly with depth, except in the case of the Graaff-Reinet aquifer. Boreholes penetrating the aquifer show a slight decrease in TDS with depth.

No marked evidence was found that the concentration of the major ions varies with depth.

#### 5.5.5.4 TEMPORAL VARIATIONS IN WATER QUALITY

##### 5.5.5.4.1 SHORT-TERM VARIATIONS

Total dissolved solid measurements taken during the aquifer tests are graphically presented in Appendix 4. In general, the water quality remained relatively constant, although minor fluctuations occurred during the testing. A notable exception is borehole G33233 where the TDS of groundwater increased by approximately 25%. This is thought to be as a result of the inflow of highly mineralised water from the wellfield area.

##### 5.5.5.4.2 LONG-TERM VARIATIONS

The lack of earlier hydrochemical records makes it difficult to assess the long-term quality trends within the study area. However, historical chemical data for the municipal production borehole GR5 are available (Table 12).

Table 12 indicates a marked deterioration in quality of the groundwater in the wellfield area over the past 27 years. The variation of TDS and Cl in borehole GR5 is indicated graphically in Figure 26. The apparent sudden increase in TDS and Cl content after 1980 is thought to be due to the following:

- (a) below average rainfall (Figure 4, p.13) and,
- (b) increased abstraction from the municipal wellfield, coupled with
- (c) low Van Rynevelds Pass dam water levels (Enclosure 3).

The deterioration in the water quality of the municipal production boreholes during such periods is probably due to the inflow of poor quality groundwater from beneath the dam. This aspect will be elaborated upon in Section 5.6.

The overall trend is towards an increase in mineralisation of the groundwater in the Graaff-Reinet aquifer. This process may be accelerated by agricultural practices and increased groundwater abstraction.

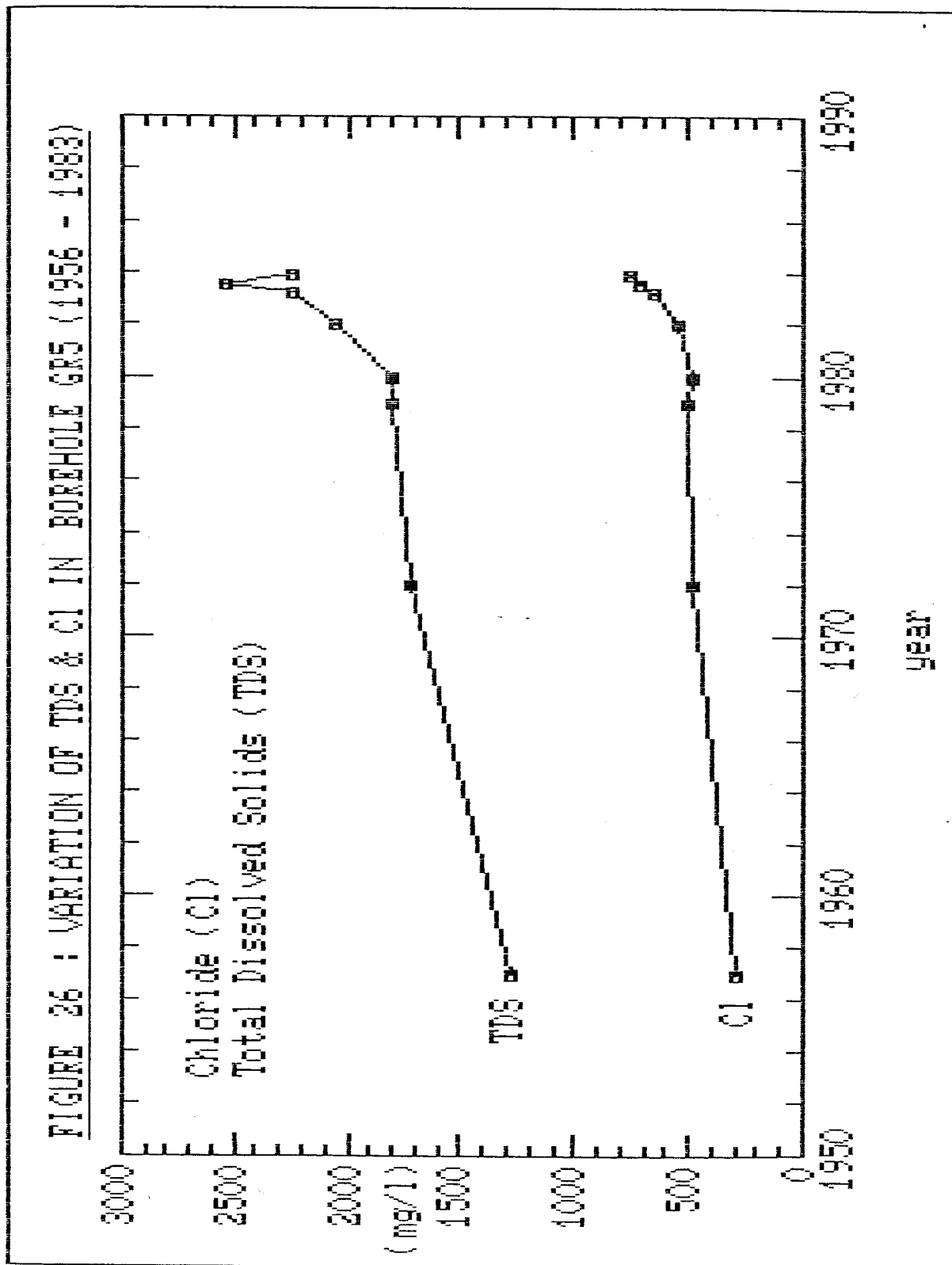


TABLE 12 : BOREHOLE GR5 - HISTORICAL HYDROCHEMICAL DATA

Element (mg/l)	Date							
	1956	1972	1979	1980	1982	Mar. 1983	July 1983	Nov. 1983
TDS	1285	1715	1801	1799	2044	2250	2534	2244
TAL	338	389	338	352	464	446	525	750
T.Hard.	544	896	772	900	750	1250	1110	1251
SO <sub>4</sub>	186	320	274	281	299	411	492	454
Cl	298	472	508	480	535	660	705	750
F	-	0.4	-	0.6	0.3	0.4	0.3	0.3
Ca	767	165	124	-	-	-	-	193
Mg	98	-	112	-	-	-	-	177
Na	-	207	-	-	-	-	-	285

note -TAL and T.Hard. (Total Hardness) as CaCO<sub>3</sub>.

-Chemical data prior to March 1983 obtained from Municipal archives.

#### 5.5.5.5 SUITABILITY OF GROUNDWATER FOR DOMESTIC USE

The criteria used to assess the suitability of groundwater for domestic consumption are presented in Table 13. Certain boreholes tap groundwater that exceeds the maximum permissible limits set out in Table 13. These boreholes and the respective chemical constituents are tabulated in Table 14. The following observations can be made from Table 14:

- (a) The majority of the boreholes in the Van Rynevelds Pass Dam and wellfield area produce water which exceeds the maximum permissible TDS limits and are very hard.
- (b) Water from boreholes RB34, RB41 and RB43 exceed the maximum permissible SO<sub>4</sub> limits. As already discussed in Section 5.5.5.2, this is probably related to agricultural practices.

**TABLE 13 : CONCENTRATION LIMITS AFFECTING THE SUITABILITY OF WATER FOR DOMESTIC PURPOSES.**

PROPERTY	RECOMMENDED LIMIT (mg/l)	MAXIMUM ALLOWABLE LIMIT (mg/l)
TDS	500	2000
pH	6 - 9	5.5 - 9.0
Na	100	400
K	200	400
Mg	100	150
Cl	250	600
SO <sub>4</sub>	250	400
F	1.1	1.5
Nitrate (as N)	10	-

(S.A.B.S, 1971)

**TABLE 14 : BOREHOLE WATER EXCEEDING MAXIMUM CHEMICAL LIMITS.**

Borehole	TDS	Na	Mg	Cl	SO <sub>4</sub>	F
GR 5	*		*	*	*	
GR 6	*			*	*	
GR 7	*			*	*	
GR 11	*		*	*	*	
GR 23	*		*	*	*	
G 33173	*					
G 33175	*					
G 33230						*
G 33231				*	*	
G 33233		*			*	
RB 34	*				*	
RB 41	*		*	*	*	
RB 43					*	

## 5.6 WATER LEVEL FLUCTUATIONS IN THE GRAAFF-REINET AQUIFER AND VAN RYNEVELDS PASS DAM

A contour map indicating the water level conditions in the Graaff-Reinet aquifer, prior to May 1983, is presented in Enclosure 7. In general, the groundwater flows from north to south in the aquifer. The groundwater gradient in the well-field area (0.006) is double that in the aquifer to the north of the Sundays River (0.003), due to large scale abstraction from the municipal production boreholes during 1982/83.

The water levels in the Graaff-Reinet aquifer (municipal well-field) and the Van Rynevelds Pass dam for the period 1960 to 1983 are presented in Enclosure 3. The hydrographs indicate that water levels in the dam are closely mirrored by those in the aquifer. The following conclusions can be drawn from the hydrographs:

- (1) Large scale recharging of the aquifer takes place when the dam is full. Such periods of recharge occurred during 1961-1964, 1970-1972 and 1974-1977.
- (2) The aquifer is effluent to the dam during low dam levels, generally below the 30% level. Such periods occurred during 1965-1969 and 1978 to July 1983.
- (3) Rapid recharge of the aquifer occurs following heavy precipitation.
- (4) Groundwater levels in the municipal wellfield recover rapidly following runoff to the dam. This is attributed to:
  - (a) recharge from the dam, and
  - (b) recovery of the water level due to the cessation of pumping from the aquifer, particularly from the municipal wellfield.

The quality of groundwater beneath the dam is poor. The present TDS of the Mackies Pits water is 2770 mg/l. Water level contours (Enclosure 7), indicate that when the dam is empty and large-scale abstraction from the aquifer occurs, the nor-

mal groundwater gradient is reversed and the dam becomes effluent to the aquifer. This is supported by rapid decline in water quality during such a period in 1982/1983 (Table 12, p114).

## CHAPTER 6

### EXPLOITATION POTENTIAL OF THE AQUIFER UNITS

Exploitation potential or "safe yield" refers to the assessment of the quantity of water stored in an aquifer, in relation to the its storage potential, capacity to transmit water and the degree to which discharge could be compensated by recharge (Dijon, 1983). Recharge is one of the most difficult parameters to assess when estimating the exploitation potential of an aquifer.

The potential of a groundwater resource can only really be verified by systematic, long term monitoring of the groundwater regime under the proposed abstraction conditions.

#### 6.1 THE GRAAFF-REINET AQUIFER

##### 6.1.1 GROUNDWATER STORAGE POTENTIAL

The Graaff-Reinet aquifer is a rather complex groundwater occurrence. It is composed of both primary and secondary aquifer components, and each component in turn is heterogeneous and anisotropic, with hydraulic properties varying in any given direction.

Evidently, in the absence of reliable data on specific yields for the entire aquifer unit, a somewhat deterministic model had to be constructed to arrive at the most accurate storage estimate possible.

The aquifer unit was divided into four major zones (Figure 27), based mainly on geohydrological considerations (aquifer thickness, extent of the basal gravel horizon, degree of weathering/fracturing of the bedrock etc). The zones were further subdivided into the three basic components of the aquifer profile and a specific yield value was assigned to each component, as follows:

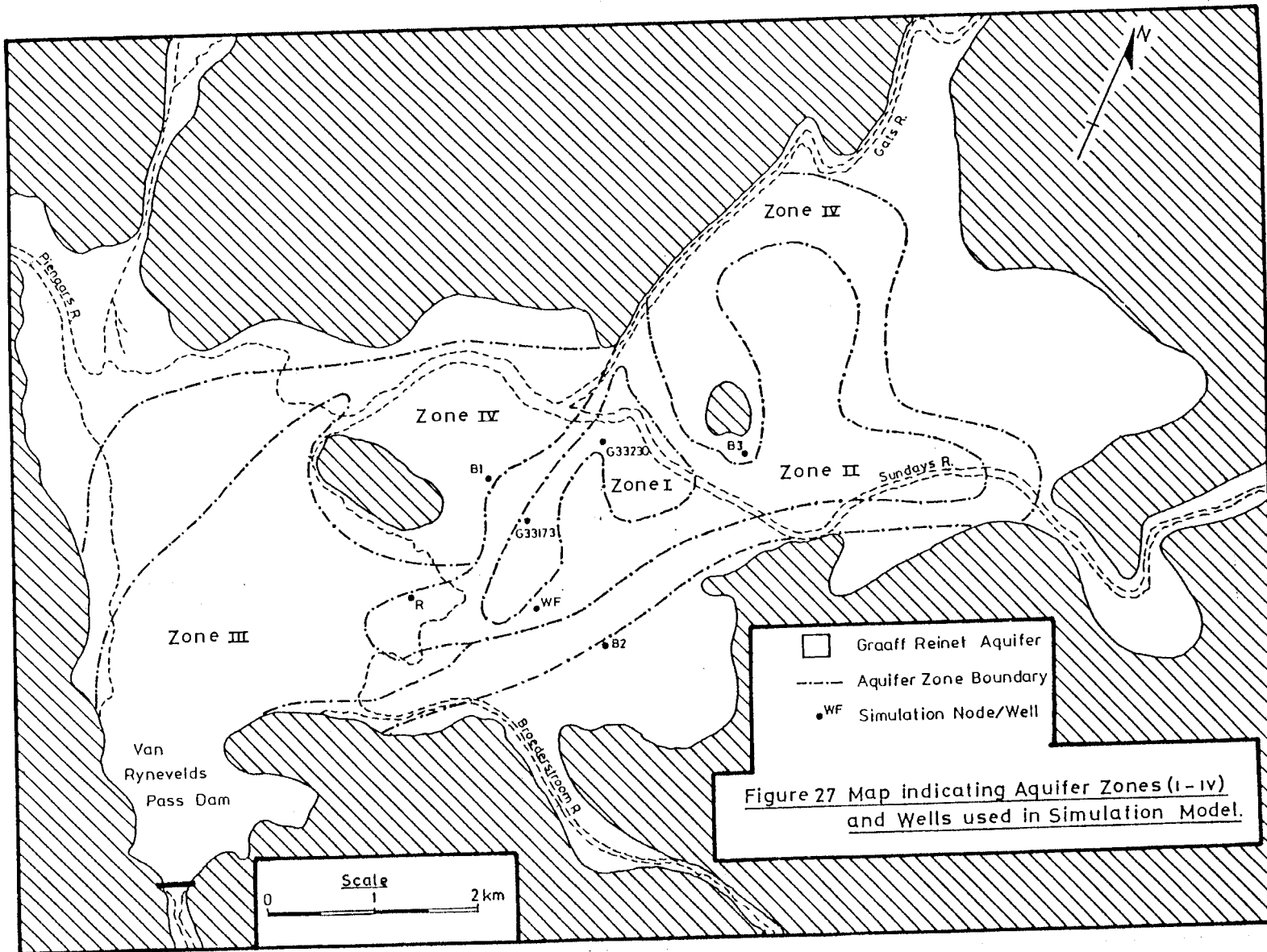


Figure 27 Map indicating Aquifer Zones (I-IV) and Wells used in Simulation Model.

- (1) Coarse basal alluvial component - S = 0.25
- (2) Overlying finer alluvial component - S = 0.08
- (3) Weathered/fractured bedrock - S = 0.01

The given specific yield values are in accordance with figures for similar deposits given by Davies et al, 1966 and Vandool-aeghe, 1977.

After study of the geological and geo-electrical data (Enclosure 6), an average thickness was assigned to each of the aquifer components in the four zones, from which the volume of each component was calculated. The results of the aquifer storage approximation are presented in Table 15.

The volume of groundwater stored in the aquifer ( $27.1 \times 10^6 \text{m}^3$ ) is considered to represent a minimum figure, as peripheral areas of the aquifer are not included in the estimation. Furthermore, the volume of groundwater stored in Zone III does not include dam water.

#### 6.1.2 RECHARGE CHARACTERISTICS

Very little is known about the recharge characteristics of the aquifer. The following aspects concerning recharge are synthesized from earlier discussions on the matter, in particular Section 5.6;

- (1) A recharge/discharge relationship exists between the Van Rynevelds Pass Dam and the aquifer. When the dam is full, large-scale recharging of the aquifer takes place and visa versa.
- (2) Rapid recharge of the aquifer occurs following heavy precipitation.
- (3) Recharge of the aquifer also takes place as a result of ephemeral flow in the Sundays and Gats Rivers. However, this type of recharge is considered to be minimal as a result of infrequent runoff in both river channels.

TABLE 15 : ESTIMATE OF TOTAL VOLUME OF GROUNDWATER STORED IN THE GRAAFF-REINET AQUIFER

Zone	Aquifer Component	Total volume of saturated aquifer component ( $\times 10^6 m^3$ )	Specific Yield	Volume of water stored in aquifer component ( $\times 10^6 m^3$ )	Volume of water stored in zone ( $\times 10^6 m^3$ )	Major geohydrological characteristic of zone
I	A	6.4	0.08	0.51	2.4	Extensive thick basal gravel horizon (ave. 7m) and extensively weathered/jointed bedrock.
	B	11.2	0.25	2.80		
	C	5.7	0.01	0.06		
II	A	27.6	0.08	2.20	11.1	Basal gravel horizon varies considerably in thickness (average between 3 to 5m).
	B	34.5	0.25	8.63		
	C	22.3	0.01	0.22		
III	A	44.4	0.08	9.60	9.3	Thin basal gravel horizon (average thickness of 1m)
	B	22.2	0.25	5.60		
	C	11.0	0.01	0.10		
IV	A	15.4	0.08	1.20	3.3	Thin basal gravel horizon (average thickness of 1m)
	B	7.7	0.25	1.90		
	C	14.5	0.01	0.15		

Total volume of groundwater stored in aquifer =  $27.1 \times 10^6 m^3$

A = fine alluvial component B = coarse alluvial component C = weathered/jointed bedrock

- (4) The groundwater levels in the vicinity of the wellfield recover rapidly following runoff to the dam.

Arguably the most convenient way to discuss recharge to the aquifer is to consider the possible gains and losses of the system.

#### (1) AQUIFER GAINS

- (a) When making an assessment of the exploitation potential of the aquifer, the dry dam/aquifer relationship is most important, as it is normally at this stage that pumping in the municipal wellfield commences. During this initial stage the groundwater gradient slopes gently towards the dam (Enclosure 3). However, with prolonged heavy abstraction in the municipal wellfield, a considerable cone of depression develops in the area (Enclosure 7). As a result, local recharging of the aquifer from beneath the dam is induced.
- (b) The amount of direct recharge to the aquifer from precipitation is unknown. However, if any direct recharge from precipitation occurs it is considered to be less than 2% of the mean annual precipitation, mainly because of the loamy nature of the superficial deposits, relatively deep watertable and anticipated high evapotranspiration due to the dense vegetation. Direct recharge probably takes place in areas with sandy soil and subsoil as in the riverbeds and floodplain, as well as the upper reaches of the dam.
- (c) Subsurface inflow is expected to occur at the basin edges, mainly through the alluvial beds of the Sundays, Pienaars and Gats Rivers and where the rain falls directly onto fractured rock outcrop.

#### (2) AQUIFER LOSSES

- (a) The aquifer is effluent to the dam during periods when the dam level is below the 30% full mark.

(b) During the 1977-1978 period the watertable declined by 0.6 metres (Enclosure 3). The drop in the watertable was due to evapotranspiration losses and pumping from private boreholes to the north of the wellfield, as:

(1) the municipal boreholes were not utilised at the time, and

(2) the dam was influent to the aquifer during most of this period.

This is in agreement with Vegter's study in 1957. Clearly, this "natural decline" in the watertable will be higher during periods when the dam level is low and the aquifer is effluent.

(c) Mackies Pits represents the only outflow from the dam/aquifer system.

### 6.1.3 WATER QUALITY CONSIDERATIONS

Boreholes located in the area between the Van Rynevelds Pass Dam and the airfield yield water with a TDS concentration which exceeds the upper limit of 2000 mg/l as set by the S.A.B.S. (1971). To the north of the Sundays River the TDS of the groundwater varies between 1000 and 1700 mg/l.

As discussed in Section 5.5.5, the groundwater in the wellfield area has shown a marked deterioration in quality over the past 30 years. As pumping continues, this natural trend will continue, but is expected to proceed at a slower rate than in the past. However, during periods of low dam levels and large-scale groundwater abstraction, the quality of the water deteriorates rapidly in the municipal wellfield (as discussed in Section 5.6). It is therefore necessary that abstraction from the wellfield be managed in such a way as to maintain a damward groundwater gradient and thus minimise the inflow of poorer quality water from beneath the dam. Furthermore, the quality of the water can be improved artificially (desalination), or by blending with a better quality groundwater (north of the Sundays River).

#### 6.1.4 EXPLOITATION POTENTIAL

The total volume of groundwater stored in the Graaff-Reinet aquifer was conservatively estimated at  $27 \times 10^6 \text{ m}^3$  (Table 15).

However, the maximum volume of groundwater that can be economically abstracted from the aquifer under conditions of no-recharge, is that water which is:

- (a) stored in the fine alluvial component, as well as
- (b) a portion of the water stored in the coarse alluvial component. The exact proportion that could be abstracted is unknown. However, it can safely be assumed that at least half of the water stored in this component could be withdrawn.

This amounts to an approximate volume of  $17 \times 10^6 \text{ m}^3$  of exploitable groundwater.

If it is assumed that the volume of exploitable groundwater stored in the aquifer will have to be capable of meeting the demand during a five year run without recharge (the maximum duration with below average rainfall on record, Section 2.2.2), the safe abstraction yield of the aquifer unit is estimated at  $9315 \text{ m}^3/\text{day}$ . It hardly needs to be pointed out that, because of the nature of the approximation, this estimate is likely to contain a considerable margin of error.

#### 6.1.5 SIMULATION OF ABSTRACTION FROM THE MUNICIPAL WELLFIELD

##### 6.1.5.1 MODEL INPUTS/OUTPUTS

The behaviour of the water level in the wellfield area, under various pumping conditions, were simulated using a programmable HP 41C calculator model, developed by Rayner (1983).

The model (AQMODL) is a simple analytical mathematical modelling program for the HP 41C calculator. The model enables the simulation of water level responses in an aquifer due to the

effects of discharging and/or recharging wells, by solving the Theis equation. The model was applied to the Graaff-Reinet aquifer using the following inputs and outputs (Figure 27):

(1) INPUTS - The following discharging wells were utilised to simulate the various pumping conditions to be considered:

(a) Well (WF) represents the municipal wellfield as a single abstraction point,

(b) well GR12 is an observation well, placed 200m north-east of the wellfield.

Boundary conditions - in the aquifer unit were simulated using the following discharging and/or recharging wells:

(a) B1 - an impermeable geological boundary to the north west of the wellfield. Boundary conditions are assumed when drawdowns at this point exceed 1.5m.

(b) B2 - similarly, is a geological boundary to the east and south-east of the wellfield. Boundary conditions are assumed when drawdowns in the area exceed 0.7m.

(c) B3 - is an impervious boundary, which takes into account private groundwater abstraction to the north of the wellfield. Boundary conditions are assumed after drawdowns in excess of 1.5m.

(d) R - represents a recharge/discharge well, used to simulate the Van Rynevelds Pass Dam/aquifer interaction. Heavy abstraction from the wellfield induces local recharging of the aquifer from beneath the dam (Section 6.1.2). As a result, the well initially acts as a recharge boundary until a certain cut-off level is reached, whereafter it behaves as a discharge boundary. It is assumed that, after a fixed volume ( $3.8 \times 10^6 \text{ m}^3$ ) of groundwater stored below the dam has been recharged to the aquifer, the recharge conditions are replaced by a discharging boundary.

It must be noted that the above calculated volume of groundwater stored beneath the dam is highly simplistic and does not

take into account possible recharge and subsurface inflow from the west. Recharge and discharge boundaries (B1, B2, B3 and R) were inserted according to knowledge of the local hydrology.

The position of wells are input in polar or cartesian coordinates. The following aquifer parameters are required for simulation purposes:

- (1) The regional water level gradients (ft/mile),
- (2) natural changes in regional water levels (ft/year), and
- (3) an average storage and transmissivity (gal/day/ft) for the aquifer.

A regional water level gradient of 3.8 ft/mile and a natural decline in the watertable of 1 ft/yr are used in the model. An average transmissivity and storage value of 96 500 gal/day/ft and 0.03, respectively, produced the most realistic results.

- (2) OUTPUT - the drawdown is simulated at a given point, as affected by the interaction of all pumping/recharging wells and regional water level changes.

#### 6.1.5.2 LIMITATIONS OF THE MODEL

As a result of the complexity of the Graaff-Reinet aquifer, the following major limitations of the model should be borne in mind:

- (a) The model assumes that drawdown in the aquifer occurs in a standard confined way (Theis), and
- (b) that the entire aquifer can be adequately modelled using a single average storage and transmissivity parameter.

### 6.1.5.3 RESULTS AND DISCUSSION

Initially the model was calibrated by simulating drawdowns in the municipal borehole GR12 for the period August 1982 to May 1983. Aquifer conditions were adequately simulated using an average transmissivity of  $1200 \text{ m}^2/\text{day}$  and a storage value of 0.03.

Using the above hydraulic parameters, drawdowns were simulated for the following wellfield situations:

- (a) pumping of the well (WF) at a rate of  $4000 \text{ m}^3/\text{day}$  (the average rate of municipal abstraction during the 1982/83 period), and
- (b) pumping of the well (WF) at a rate of  $8500 \text{ m}^3/\text{day}$  (equal to the approximate maximum capacity of the existing wellfield pumps).

Simulations were continued until drawdowns in WF or GR12 exceeded 10m or 5m, respectively. These water levels were used as "cut-off" levels, beyond which pumping rates are expected to increasingly decline. A summary of the simulation results are presented in Table 16.

The volume of groundwater available for municipal abstraction is in the order of  $6.2 - 7.3 \times 10^6 \text{ m}^3$ , depending on the pumping conditions. During the calibration period (August 1982 to May 1983), a volume of  $1.19 \times 10^6 \text{ m}^3$  ( $3970 \text{ m}^3/\text{day}$ ) of groundwater was abstracted from the municipal wellfield, for a decline in water level of 2.3m. Therefore, assuming similar conditions, a volume of approximately  $5.2 \times 10^6 \text{ m}^3$  of water could be abstracted from the wellfield, for a maximum drawdown of 9m. This figure is thought to approximate the production potential of the existing municipal wellfield.

While examining the Table 16 the following points should be borne in mind:

- (1) It is assumed that, with time, abstraction from the municipal production boreholes can be represented by a single discharging well. This assumption may result in an over estimation of the expected drawdown in any of the actual pumped boreholes.

TABLE 16 : SIMULATION OF WATERTABLE BEHAVIOUR UNDER VARIOUS ABSTRACTION CONDITIONS

Simulation Number	Well Number	Abstraction conditions (m <sup>3</sup> /day)	Drawdown (m)						Total volume of water abstracted during simulation period (m <sup>3</sup> )
			0.5 yr	1 yr	2 yr	3 yr	4 yr	5 yr	
1	WF	WF at 4 000	4.56	5.15	5.59	6.55	7.37	9.18	7.3 × 10 <sup>6</sup>
	GR12		1.39	2.24	2.44	3.38	4.20	5.02*	
	B1		0.33	1.02	1.09	2.28	3.18	3.82	
	B2		0.65	1.65	2.00	2.81	3.57	4.17	
	B3		0.22	0.62	1.08	1.76	2.57	3.18	
	R	0.15	0.27	0.85	2.30	3.16	3.77		
2	WF	WF at 8 500	9.27	10.07	11.57*				6.2 × 10 <sup>6</sup>
	GR12		2.87	3.70	5.16*				
	B1		0.54	1.05	2.55	-	-	-	
	B2		1.79	2.77	4.05				
	B3		0.33	0.94	1.85				
	R	0.17	0.06	2.97					

Note: \* - waterlevel exceeds drawdown limit.

- (2) No account is made for drawdowns induced by well losses in the pumped well. However, this under estimation is probably countered by the over estimation discussed under (1) above.
- (3) Limitations of the model (Section 6.1.5.2).

#### 6.1.6 OPTIMAL ABSTRACTION RATES AND UTILISATION OF THE MUNICIPAL WELLFIELD

At present the municipal wellfield is only fully utilised when the Van Rynevelds Pass Dam is dry. If the anticipated municipal consumption is taken into account (Section 1.3), this water management strategy is likely to continue until at least the year 2010. Although the combined yields of both the production boreholes and dam would be required to meet municipal water requirements during peak consumption periods. It is therefore evident that, on short to medium term basis, the "safe yield" of the existing wellfield will be gauged against the longest period over which the dam is likely to be dry. According to the dam level records this period is approximately two years.

The simulation results (Section 6.1.5.) indicate that, in order to span a two year no recharge period, the existing municipal boreholes could be pumped at a maximum rate of 8 500 m<sup>3</sup>/day. However, if the wellfield boreholes are pumped at a lower rate, a greater volume of groundwater could be abstracted over a longer period (Table 16, p128 - simulation 1). Clearly, the total volume of groundwater that can be abstracted from the wellfield depends on the prevalent pumping conditions.

Optimal exploitation of the aquifer can only be obtained by a more dispersed location of abstraction points. The advantage of this pattern of abstraction would be:

- (a) greater volumes of groundwater abstracted per unit drawdown of the water level, and
- (b) an increase in the period over which a certain abstraction rate could be maintained.

Furthermore, the inflow of poor quality water from the dam would be reduced by a lower drawdown per volume of groundwater removed. Drawdown of the water level over a larger area would also salvage part of the evapotranspiration losses.

In the future, if the aquifer is to be optimally exploited, it is imperative that the above be implemented. It is to be recommended that, if necessary, further boreholes be located in the highly transmissive zone between the wellfield and the intersection of the Sundays and Gats Rivers. This zone more or less coincides with the subsurface position of the Dalham dolerite sheet.

However, boreholes G33173, G33231, G33233 and G33234 drilled within this zone, deliver water with only a slightly lower TDS content than that in the wellfield. Further it is anticipated that, in the long term, abstraction in the area could result in the water quality deteriorating in a similar fashion to that in the present wellfield. It would therefore appear that the only possibility of acquiring better quality water is in the basin north of the Sundays River.

## 6.2 FRACTURED AQUIFER UNITS

The following two fractured aquifer units are considered:

- (1) the Welgevonden dolerite dyke, and
- (2) the Perries dolerite dyke.

It is difficult to estimate the exploitation potential of these aquifer units, as little information concerning the storage, geometry and recharge characteristics of the units are available. A safe yield estimate can however be calculated from the aquifer test data. Using the linear regression equations computed in Section 5.4.5.2.2; the following safe yield estimates are put forward:

- (a) Welgevonden aquifer unit =  $385 \text{ m}^3/\text{day}$
- (b) Perries aquifer unit =  $476 \text{ m}^3/\text{day}$

When considering the above safe yield estimates, the following should be borne in mind:

- (1) The estimates are based on the maximum abstraction rate that could be maintained over a five year no-recharge period, without the water level dropping below the major water interception.
- (2) The estimate of the Welgevonden aquifer unit is based on the linear regression equation for observation borehole G 33178, as considerable well losses occurred in the pumped well.
- (3) The extent to which the Perries dyke aquifer test data reflects possible recharge from a nearby weir is unknown.
- (4) Similarly, the possibility of the Welgevonden aquifer unit being recharged from the Van Rynevelds Pass Dam cannot be ruled out, although water quality measurements taken during the aquifer test indicate the contrary (Appendix 4). It is recommended that the borehole be re-tested under dry dam conditions.

The quality of the groundwater in both aquifer units is good, with TDS contents of less than 1 000 mg/l.

## CHAPTER 7

### FULFILLMENT OF STUDY OBJECTIVES AND HYPOTHESIS TESTING

The principle objective and specific aims of the investigation were proposed in Chapter 1, while the hypotheses were formulated in Chapter 3. In Chapters 4 and 5 the various research components and geohydrology of the study area were discussed in detail. The exploitation potential of the aquifer units are estimated in Chapter 6.

This Chapter serves to verify whether the objectives and hypotheses of the study have been fulfilled.

#### 7.1 FULFILLMENT OF THE STUDY OBJECTIVES

The principle objective of the investigation was to provide a quantitative assessment of the groundwater potential of the study area, in terms of its development and exploitation as a municipal supply.

The existing municipal groundwater resource was investigated with the view to possible expansion of the wellfield, while two new aquifer units were identified within the study area.

The Graaff-Reinet aquifer has been tapped as a municipal water supply since 1956. However, prior to this study, the exact nature, geographical extent and exploitation potential of the aquifer was unknown. The physical nature and boundaries of the aquifer were accurately defined by geological/geophysical mapping, drilling and aquifer testing (Sections 5.2 to 5.4). A simple deterministic aquifer storage model was constructed (Section 6.1), based on above results. The total volume of groundwater stored in the aquifer is estimated at  $27.1 \times 10^6$  m<sup>3</sup>, with a exploitation potential of 9300 m<sup>3</sup>/day. The Graaff-Reinet aquifer is thus capable of meeting Graaff-Reinet's daily consumption requirements until the year 2020. However, the limiting factor was found to be the steadily deteriorating quality of the groundwater (Section 5.5.5.4), which is unfit for direct domestic consumption.

Two new fractured aquifer units were evaluated in the study area (Section 6.2). The Welgevonden and Perries aquifer units are estimated to be able to deliver good quality water in the order of 385 m<sup>3</sup>/day and 476 m<sup>3</sup>/day, respectively.

In order to fulfill the above objective, a number of specific aims and hypotheses were formulated. As the aims and hypotheses are interrelated the two are discussed together in Section 7.2.

## 7.2 TESTING OF HYPOTHESES

### 7.2.1 AQUIFER LITHOLOGY AND GEOMETRY

Hypothesis 1 : The major groundwater unit is a laterally extensive alluvial/weathered bedrock aquifer (Graaff-Reinet aquifer).

From the outset of the investigation it was evident that large quantities of water could be abstracted from the Graaff-Reinet aquifer (Sections 1.5 and 3.1). The aquifer covers a large portion of the study area (Section 5.2.1.3) and is now known to be a prolific groundwater producer (Section 7.1). The hypothesis is therefore accepted.

Hypothesis 2 : Well developed fractured aquifer(s) in consolidated sediments represent discrete groundwater units and are directly related to dolerite intrusions.

Drilling indicated that a large portion (36%) of the groundwater interceptions were associated with dolerite intrusions (Section 5.3.3). Furthermore, three out of the four high yielding (>10 l/s) interceptions occurred in dolerite/sediment contacts (Table 8). Such aquifers are of limited extent depending on the geometry of the intrusion. Apart from the Graaff-Reinet aquifer, the only further aquifer units of possible production status are the Welgevonden and Perries dykes (discussed in Section 6.2). They form elongated, strip-like fractured aquifers depending on the dimensions of the respective dykes (Section 5.2.1.4.1). This is illustrated by

different yields intercepted in boreholes located in the dyke contact (G33179 and G33178), and in the adjoining country rock (G33180). Based on the results of the geological mapping and drilling, the hypothesis is accepted.

Hypothesis 3 : Dolerite intrusions, themselves, do not contain large amounts of groundwater.

A large number of boreholes (G33177, G33181, G33182 and G33185 to G33187) were drilled through thick dolerite sheets, without intercepting water within the intrusions. However, a number of boreholes (GR10, G33233 and G33234), intercepted water in weathered/fractured dolerite in the Dalham sheet. Some 14% of the water interceptions made during the drilling programme occurred in dolerites, although constituting minor (<5 l/s) amounts (Table 8, p73). The hypothesis is rejected.

#### 7.2.2 HYDRAULIC PROPERTIES OF THE AQUIFERS

Hypothesis 4 : The alluvial/weathered bedrock aquifer is unconfined to semi-confined with the principle zone of transmission represented by a basal gravel/boulder layer.

The drilling and aquifer testing revealed a highly complex aquifer system, composed of both primary and secondary components. The aquifer tests indicated a range of aquifer conditions, from unconfined to semi-confined and confined (Section 5.4.5.2.1). Unfortunately, the aquifer testing methods did not facilitate the estimation of an individual T value for the gravel/boulder layer. Drilling results confirmed the importance of the coarse basal layer as the major transmissive zone in the aquifer (Section 5.3.3), as well as the fractured sediments overlying the Dalham sheet in the wellfield (boreholes GR4, GR10 and GR23). The hypothesis is rejected as an oversimplified interpretation of the aquifer system.

Hypothesis 5 : The fractured aquifers are confined and anisotropic.

Fractured aquifers in the study area are directly related to the occurrence of dolerite intrusives (Hypothesis 3). The drilling and aquifer test results indicated that these aquifers are both confined and anisotropic. The difference between the depth to the major water interception and the rest-water level (piezometric head), as well as the relative changes in piezometric levels during aquifer testing, are indicative of the confined nature of the aquifer. Structural control of permeability along fractured aquifers results in anisotropic groundwater conditions. Aquifer tests conducted at the Welgevonden and Perries dykes exhibited linear-type flow (Section 5.4.5.2.2). This results from a predominant fracture system which is orientated parallel to the strike of the body. The hypothesis is accepted.

#### 7.2.3 HYDRAULIC CONNECTION BETWEEN THE VAN RYNEVELDS PASS DAM AND THE GRAAFF-REINET AQUIFER

Hypothesis 6 : A discharge/recharge relationship exists between the Van Rynevelds Pass Dam and the Graaff-Reinet aquifer.

The Graaff-Reinet aquifer is normally effluent to the Van Rynevelds Pass Dam during periods of low (<30% full) dam levels and visa versa (Section 5.6). Large scale recharging of the aquifer takes place when the dam is full. The coarse layer at the base of the alluvium acts as a direct hydraulic connection between the dam and the aquifer (Section 5.2.2.1.4). The marked deterioration in the quality of the water in the wellfield during periods of low dam levels (Section 5.5.5.4.2), is a result of the inflow of poorer quality water from beneath the dam. The hypothesis is therefore accepted.

#### 7.2.4 HYDROCHEMISTRY OF THE GROUNDWATER

Hypothesis 7 : The quality of the groundwater associated with the Graaff-Reinet aquifer is of a poorer chemical quality than with that associated with fractured aquifers in hardrock terrain.

The results of the hydrocensus (Section 5.1) and the drilling programme (discussed in Section 5.5.5.1) showed a marked difference in the water quality between the Graaff-Reinet aquifer and fractured aquifers. The TDS content of groundwater associated with the Graaff-Reinet aquifer is generally in excess of 1000 mg/l, while that of the fractured aquifers is less than 1000 mg/l (Figure 25, p109). The hypothesis is accepted.

Hypothesis 8 : In the Graaff-Reinet aquifer the quality of the water decreases in the direction of groundwater flow.

Conductivity measurements collected during the hydrocensus and drilling programme exhibit a general decrease in the quality of groundwater in the direction of flow (discussed in Section 5.5.5). Groundwater flows from north to south in the Graaff-Reinet aquifer (Section 5.6), while it's TDS content increases from 800 mg/l in upper reaches of the basin to in excess of 2000 mg/l in the wellfield (Enclosure 8). At the outflow of the aquifer system, Mackies Pits, the TDS content of the water is 2770 mg/l. The hypothesis is accepted.

Hypothesis 9 : During periods of drought the decrease in the quality of the groundwater in the vicinity of the wellfield is as a result of induced inflow of poor quality water from beneath the Van Rynevelds Pass Dam.

The groundwater gradient normally has a gentle damward slope under low dam levels (Enclosure 3). However, this gradient was reversed during 1982/1983, when the dam was dry and the wellfield pumped at full capacity (Enclosure 7). The TDS content of the water in borehole GR5 increased from 1800 mg/l in 1980 to 2534 mg/l in 1983 (Section 5.5.5.4.2). This sudden deterioration in the water quality in the wellfield is a result of induced inflow of poorer quality water from beneath the dam. The quality of this water is in the order of 2770 mg/l (Mackies Pits). The hypothesis is therefore accepted.

## CHAPTER 8

### CONCLUSIONS AND RECOMMENDATIONS

#### 8.1 CONCLUSIONS

The investigation revealed that the most significant groundwater occurrence in the study area is the alluvial/weathered bedrock aquifer (Graaff-Reinet aquifer), while two minor fractured aquifers were also identified.

The Graaff-Reinet aquifer covers a major portion of the study area to the northeast of the Van Rynevelds Pass Dam. The total volume of groundwater stored in the aquifer unit is in the order of  $27 \times 10^6 \text{ m}^3$ , while its exploitation potential is conservatively estimated at  $9300 \text{ m}^3/\text{day}$ . However, the steadily declining quality of groundwater places serious doubt as to the aquifer's long term potential as a solution to the municipal water supply problem, unless the water is artificially treated or blended with a better quality water.

The municipal wellfield is situated in the Graaff-Reinet aquifer and comprises nine high-yielding boreholes, with a maximum combined output of  $8\,500 \text{ m}^3/\text{day}$ . It is strongly recommended that the existing boreholes are not pumped at this rate and that future expansion of wellfield takes place along a linear zone extending towards the confluence of the Sundays and Gats Rivers, where similar geohydrological conditions are encountered. The siting of additional production boreholes in this area would enable larger volumes of groundwater to be abstracted per unit drawdown of the watertable and increase the period over which a certain abstraction rate could be maintained. Furthermore, the more dispersed pattern of pumping would reduce the inflow of poorer quality water from beneath the Rynevelds Pass Dam. However, the quality of groundwater in this zone is only marginally better than that in the wellfield. Better quality water can only be obtained in the basin north of the Sundays River, although abstraction conditions are not as favourable, which would necessitate pumping more boreholes.

Two new fractured aquifers were evaluated within the study area. The Welgevonden and Perries aquifer units are capable

of producing good quality water in the order of 385 m<sup>3</sup>/day and 476 m<sup>3</sup>/day, respectively.

A major portion of the investigation effort was directed at the definition and evaluation of the Graaff-Reinet aquifer. The resistivity work proved invaluable in determining the geometry of the aquifer. One of the major drawbacks of this method was the inability to define the coarse horizon at the base of the alluvium, due mainly to the masking effects of the poor quality groundwater. However, the extent of this horizon was relatively accurately determined by drilling and information gleaned from the hydrocensus.

## 8.2 RECOMMENDATIONS FOR FURTHER RESEARCH

In order to verify and possibly re-evaluate the exploitation potential of the Graaff-Reinet aquifer, the following recommendations are made:

- (1) A hydrocensus of all waterpoints in the aquifer should be conducted on a regular basis (ie. every five years). The quality of the groundwater should be carefully monitored, especially in the municipal wellfield.
- (2) Permanent water level recorders were installed on boreholes G33175, G33233, and G33174, in the vicinity of the wellfield. They will provide information, along with the recorder already installed on GR12, on the recharge mechanisms (from the dam and Sundays River) and the groundwater flow regime in the aquifer.
- (3) Abstraction from the aquifer, both municipal and private, should be accurately monitored. The latter is somewhat problematic and could be most effectively achieved by conducting a regular land and water-use survey in conjunction with the hydrocensus.

The data collected under items (1) to (3) would provide valuable information for the effective utilisation of the groundwater resource.

The Graaff-Reinet aquifer could be suitable for a groundwater management modelling study, as:

- (a) The only input to the system is recharge from precipitation.
- (b) The geometry and hydraulic characteristics of the aquifer are well defined.
- (c) Outputs from the basin are abstraction, springs (Mackies Pits) and evapotranspiration.
- (d) Historical abstraction and water level records from the wellfield are available.

The research could prove beneficial to the planning and management of similar Karoo groundwater schemes (Beaufort West, De Aar and Middelburg). This contention would have to be rigorously tested.

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THE EXPLORATION AND EVALUATION OF GROUNDWATER UNITS IN THE  
VAN RYNEVELDS PASS DAM BASIN, NORTH OF GRAAFF-REINET,  
CAPE PROVINCE

VOLUME 2 : APPENDICES

by

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Submitted in partial fulfillment of the requirements for the  
degree of Master of Science in the Department of Geography,  
Rhodes University, Grahamstown.

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APPENDIX 1:  
HYDROCENSUS

EQUIPMENT INDEX:

F - Fountain  
M - Mono Engine  
O - Open Borehole  
S - Submersible Pump  
T - Turbine Engine  
W - Windpump  
WH - Working Head Pump.

CADASTRAL FARM: Bloems Kraal  
 LOCAL FARM: Dalham  
 OWNER: R.C. Holmes

1/11

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
BK 1	W	S	>1.5	18.0	-	-	-	alluvium	drilled 1960 by Geological Survey
BK 2	O	-	dry	6.0	-	-	-	alluvium	
BK 3	O	-	dry	9.0	-	-	-	alluvium	drilled 1960 by Geological Survey
BK 4	T	I	8.8	75.0	-	-	-	0-14 alluvium -75 sediments	cyl.diam - 100mm, pump 443 m3/day pump inlet @ 45m.
BK 5	W	S	1.9	14.4	7.865	797.257	-	alluvium	
BK 6	O	-	-	11.2	8.961	798.883	942	alluvium	w1 - 13/2/84=8.568m. Well pit.
BK 7	O	-	-	10.0	8.825	799.218	-	alluvium	well pit.
BK 8	O	-	-	18.3	9.053	807.428	-	alluvium	
BK 9	W	S	4.5	18.0	-	-	960	sediment	
BK 10	O	-	-	72.0	9.492	799.974	-	sediments	drill 1982, casing 16.5m, H2S
BK 11	W	S	-	15.0	6.083	+816.6	-	sediment/dolerite sheet	drill 1949, 1983 tested @ 2l l/s for 7 hours, after 13 hrs declined 3 l/s
BK 12	W	S	>1.5	75.0	32.821	+854.4	550	sediment	
BK 13	W	S	-	42.0	-	-	710	sed/dolerite	
BK 14	T	I	3.4	45.0	-	-	-	alluvium	pump inlet 42m, tested at 10 l/s, H2S cyl.diam 100mm, pump 147 m3/day.
BK 15	S	O	1.8	25.6	7.456	798.348	894	alluvium	pump inlet 17.6m, pump 140 m3/day
BK 16	T	I	12.0	75.0	-	-	-	alluvium	cyl.diam 100mm, drilled 1951 pump inlet 45m, pump 734 m3/day.
BK 17	O	-	>1.5	48.0	9.327	779.045	1087	0-11 Coarse sand gravel -48 sediment	drill Nov 1983, 12m casing, water at 15 and 36 (major) m. 36-45m weathered sandstone.
BK 18	O	-	9.5	75.0	8.631	796.935	931	0-13.5 med-fine -17 coarse sand -75 sediment	drill Nov 1983, 17m casing, water @ 10.5, 39 and 51m.
BK 19	O	-	>1.5	60.0	10.111	799.017	785	0-16 alluvium -60 sediments	drill Dec 1983, water @ 12, 15(major) 37 and 52m.
BK 20	O	-	-	-	-	-	-	-	drilling in progress
F 3	F	O	0.4	-	-	-	506	sediment	
F 4	F	S	+2.5	-	-	-	1361	sediment	

CADASTRAL FARM: Boschkraal  
 LOCAL FARM: Riverdale  
 OWNER: F.P van der Merwe

2/11

BH No	EQUIP MENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
BL 1	O	-	>1.5	90.0	8.050	-	-	sediment	
BL 2	O	-	dry	75.0	-	-	-	sediment	
BL 3	O	-	>1.5	60.0	9.650	-	-	sediment	
BL 4	S	O	3.0	75.0	10.366	-	782	alluvium/seds	
BL 5	O	-	-	60.0	8.972	-	-	sediments	
BL 6	O	-	>1.5	54.0	14.578	-	-	sediments	drill 1983, water at 36m.
BL 7	M	I	3.6	108.0	-	-	812	sediments	100mm cyl. inlet @ 42m, drill 1983 water @ 36m.
BL 8	O	-	>1.5	78.0	7.362	-	-	0-10 alluvium -78 sediment	drill 1981, water @ 9 + 24m.
BL 9	O	-	>1.5	48.0	12.230	-	-	sediments	
BL 10	O	-	-	69.0	12.175	-	-	sediments	
BL 11	O	-	>1.5	70.0	-	-	-	sediments	
BL 12	O	-	>1.5	60.0	-	-	-	-	
BL 13	M	I	2.5	75.0	-	-	772	-	75mm cyl.
BL 14	W	S	>1.5	75.0	8.958	-	-	-	
BL 15	W	S	1.9	60.0	8.755	-	639	alluvium+seds	
BL 16	T	I	6.0	60.0	-	-	813	sediments	75mm cyl. pump inlet 27m.
BL 17	O	-	>1.5	75.0	13.750	-	-	sediments	
BL 18	W	S	-	-	-	-	1152	-	
BL 19	W	S	-	-	-	-	506	-	
BL 20	O	-	dry	30.0	-	-	-	sediments	
BL 21	W	S	>1.5	48.0	-	-	403	sediments	
BL 22	O	-	>1.5	-	28.485	-	-	sediments	

CADASTRAL FARM: Brakfontein  
 LOCAL FARM: Weltevrede & Brakfontein  
 OWNER: J Kemp

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BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
BT 1	W	S/O	<1.5	40.0	-	-	-	sediments	out order
BT 2	W	S	<1.5	60.0	30.069	-	-	sediments	
BT 3	W	D	<1.5	-	-	-	-	sediments	
BT 4	O	-	-	50.0	6.297	-	-	sediments	
BT 5	W	S	<1.5	+50.0	-	-	506	sediment/dolerite	
BT 6	W	S	1.8	45.0	-	-	550	sediments	
BT 7	O	-	-	blocked	23.378	-	-	sediments	
BT 8	W	S	1.8	+50.0	11.642	-	-	alluvium/seds	
BT 9	P	S	2.2	+60.0	-	-	684	sediments	

CADASTRAL FARM: Buffelshoek  
 LOCAL FARM: Buffelshoek  
 OWNER: P Nel

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
BF 1	T	I	25.0	45.0	-	-	708	0-14 sediment -37 dolerite	drill 1982, 125mm cyl., pump @ 15m Water @ 37m, tested 34.1 l/s for 18hr in 1983.
BF 2	O	-	-	14.0	2.181	-	-	alluvium/seds	75mm cyl. diameter
BF 3	W	S	<1.5	57.6	12.891	-	639	sediment	
BF 4	M	N	2.5	45.0	-	-	-	sediment	
BF 5	W	S	<1.5	30.0	7.592	-	536	sediments	
BF 6	W	S	<1.5	40.0	26.522	-	-	sediment/dolerite	
BF 7	W	O/S	<1.5	22.3	6.458	-	494	alluvium seds	
BF 8	W	S	<1.5	45.0	-	-	-	sediments	

CADASTRAL FARM: Good Hope  
 LOCAL FARM: Brakfontein  
 OWNER: I Opperman

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BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
GH 1	W	S	<1.5	+56.0	-	-	896	sediments	
GH 2	W	S	<1.5	+45.0	-	-	742	sediments	
GH 3	M	D	2.8	80.0	17.696	-	621	sediment/dolerite	75mm cyl.diameter
GH 4	O	-	dry	15.0	-	-	-	sediment/dolerite	
GH 5	O	-	dry	19.0	-	-	-	sediments	
GH 6	W	S	<1.5	+45.0	-	-	534	sediments	

CADASTRAL FARM: Gannaleegte  
 LOCAL FARM: Suikerbult  
 OWNER: D van Rensburg

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
GL 1	W	S	<1.5	30.0	-	-	-	alluvium/seds	
GL 2	W	S	<1.5	36.0	13.850	-	-	sediments	
GL 3	T	I	11.4	+36.0	6.331	-	768	dolerite	100mm Cyl.diameter
GL 4	W	N	-	+40.0	10.236	-	-	sediments	
GL 5	W	S	<1.5	+30.0	12.043	-	635	sediments	

CRASTRAL FARM: Graaff-Reinet Allotment Area  
 LOCAL FARM: -  
 OWNER: -

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BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
GR 1	O	-	-	-	-	-	-	0-37 sediments	golf course
GR 2	O	-	-	36.0	-	-	-	23m dolerite	drilled to 36m, water @ 22m, yield tested @ 2.5 l/s.
GR 3	O	-	-	2.5	-	-	-	-	Karoo Nature Reserve, unable to locate, drilled 1960's.
GR 4	-	-	-	-	9.324	789.614	-	-	SEE detailed log in Appendix 2
GR 5	T	O	22.4	34.0	9.132	791.106	2247	0-21 alluvium -40 sediments	Municipal Prod. borehole, 125mm cyl. drill to 39m in 1956, tested for 66hr @ 21.4l/s, final drawdown 4.9m. Static waterlevel 8.8m(1957), pump @24m Casing(perforated) 200mm diam to 37m. 10mm cyl.diameter, drill 1956 to 29m, waterlevel 9.56m, cased(200mm) to 21m 6/5/83 hole cleaned to 24m. Casing (165mm) to 24m -perforated.
GR 6	T	O	9.5	24.0	9.451	789.424	2132	0-21 alluvium -25 sediments	drill 1956 to 78m, casing to 22m, yield tested @ 12 l/s, wl=9.12m(1956) 100mm cyl.diameter.
GR 7	T	O	11.0	79.0	9.470	789.803	2036	0-21 alluvium -79 sediment(?)	unable to locate, drill 1960's.
GR 8	O	-	dry	2.0	-	-	-	-	unable to locate, drill 1960's
GR 9	O	-	dry	3.0	-	-	-	-	unable to locate, drill 1960's
GR 10	-	-	-	-	10.374	790.342	-	-	SEE Appendix II
GR 11	T	O	11.3	24.0	9.670	789.077	2145	0-21 alluvium -24 sediments	100mm cyl.diameter, inlet 20m, wl=9.165m(1957), cleaned and cased (perforated) to 24m.
GR 12	O	-	4.1	20.0	10.385	790.081	-	0-19.2 alluvium	drill 1957 -wl=9.855m. waterlevel recorder(stat.WINDOOS) since 1972.
GR 13	O	-	dry	9.8	-	791.928	-	-	drilled to 22m. 1972 tested at 12.5l/s - static wl 10.700m
GR 14	O	-	-	15.0	11.672	793.098	-	-	drill to 36m, wl=10.97m(1957)
GR 15	O	-	-	23.5	12.252	793.906	-	-	drill to 55m, wl=11.76m(1957)
GR 16	O	-	dry	11.5	-	-	-	-	unable to locate, drill 1960's

CADASTRAL FARM: Graaff-Reinet Allotment Area  
 LOCAL FARM: -

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BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
GR 17	O	-	<1.5	51.0	33.000	790.63	-	0-43 dolerite -51 sandstone	drill Sept.1980, last water @ 44m - wl=8.00m, 3.5m casing.
GR 18	T	D	5.0	57.0	-	791.751	1710	0-41 dolerite -57 sandstone	75mm cyl.diameter, drill Aug 1980, last water @ 48m -wl=9.40m, casing 2.5m, tested 17l/s for 9hrs, pump intake 45.7m, in use since 1981.
GR 19	T	D	12.0	57.0	-	793.109	1620	0-4 clay -40 dolerite -57 sandstone	100mm cyl.diameter, drill Aug 1980, last water @ 40m -wl=20.0m, casing 6.1m, tested 19l/s for 9hrs, pump intake at 36.6m.
GR 20	W	S	-	-	13.912	795.402	1310	-	pump inlet 18m.
GR 21	O	-	<1.5	91.0	11.521	-	-	0-5 alluvium -6 sandstone -93 dolerite	drill Aug.1983, casing 6.1m, water- level (2/3/83 = 13.924m)
GR 22	W	N	dry	11.3	-	-	-	0-7.8 alluvium -42 sediment	drill 1955, wl=13.50m(1956), tested 22 l/s for 9hrs, methane gas. SEE Appendix II
GR 23	-	-	-	-	-	789.413	-	-	-
GR 24	W	S	<1.5	-	-	812.883	-	-	-
GR 25	W	S	<1.5	31.0	8.386	791.172	1872	-	WL=9.53m(10/3/83), = 8.39(1/11/83)
GR 26	O	-	-	15.6	10.888	791.933	-	-	WL=12.24(10/3/83), 11.03(14/1/84), 10.888m(14/1/84)
GR 27	W	S	<1.5	23.0	7.881	791.622	-	-	-
GR 28	W	D	<1.5	24.9	-	796.535	402	alluvium/seds	-
GR 29	O	-	-	2.0	-	-	-	-	Geological Survey, drill 1960
GR 30	W	S	<1.5	-	18.670	808.912	-	-	-
GR 31	O	-	-	2.5	-	-	-	-	Geological Survey, drill 1960
GR 32	O	-	-	4.0	-	792.737	-	-	brickfields
GR 33	O	-	-	10.0	-	-	-	18m- dolerite	Karoo Nature Reserve
GR 34	O	-	-	3.0	-	-	-	-	Geological Survey, drill 1960
GR 35	O	-	-	10.1	8.878	788.710	-	-	Geological Survey, drill 1960
GR 36	W	S	<1.5	29.0	-	-	-	sediment	Rifle Range
GR 37	WH	D/S	<1.5	36.0	-	-	2208	0-22 alluvium -36 dolerite	Brickfield 60mm cyl.diameter 75mm cyl.diameter
GR 38	T	D	2.5	24.0	-	793.264	1130	-	Golf Course
GR 39	W	D	-	-	30.454	796.878	1240	-	-
GR 40	W	S	<1.5	36.0	-	-	790	sediment	Karoo Nature Reserve
GR 41	O	-	-	-	-	-	-	-	Geological Survey, drill 1960
GR 42	O	-	-	3.0	-	-	-	alluvium/seds	-

CADASTRAL FARM: Roodebloem  
 LOCAL FARM: Roodebloem  
 OWNER: E.R. Murray

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BH No	EQUIP MENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
RB 1	O	-	dry	14.0	-	-	-	sediments	
RB 2	W	S	<1.5	37.0	16.490	-	740	sediments	inlet pump @ 33m, wl=12.0(1980)
RB 3	O	-	dry	11.0	-	-	-	sediments	
RB 4	O	-	<1.5	29.0	20.481	-	-	sediments	
RB 5	W	S	<1.5	42.0	-	-	-	sediments	
RB 6	O	-	<1.5	18.2	10.09	-	-	dolerite/seds	water @ 4.5m, drill 1981
RB 7	WH	S	2.5	56.0	-	-	-	dolerite/seds	50mm cyl.diameter,drill 1950, inlet 30m, pump 1800 Kl/week, water @ 6.3m
RB 8	O	-	<1.5	90.0	38.603	-	-	sediments	
RB 9	O	-	dry	22.3	-	-	-	sediments	
RB 10	W	S	<1.5	33.0	26.404	-	-	sediments	
RB 11	W	D	<1.5	36.0	-	-	-	alluvium/seds	
RB 12	O	-	dry	3.0	-	-	-	sediments	
RB 13	T	D	2.5	53.0	-	-	785	sediments	75mm cyl.diameter, drill 1948, pump +- 46 Kl/day.
RB 14	O	-	7.0	100.0	16.142	805.300	-	0-12 sand/silt -18 boulders -100 sediments	drill 1981 wl = 12.60m(7/2/84)
RB 15	T	I/S	3.8	27.0	-	-	-	alluvium	100mm cyl.diameter. Pump 234 Kl/day Pump inlet at 26m.
RB 16	S	D/S	2.0	75.0	17.250	799.259	902	alluvium (boulders)	Pump inlet at 24m. Abstraction approx 144 Kl/day.
RB 17	S	I	2.5	72.0	16.722	799.204	745	alluvium/seds.	Waterlevel (9/2/84)=12.710m, Pump inlet 24m, pump 180 Kl/day.
RB 18	W	D	<1.5	54.0	-	-	-	alluvium/seds.	
RB 19	W	D	<1.5	45.0	-	-	-	alluvium/seds.	

CADASTRAL FARM: Roodebloem  
 LOCAL FARM: Roodebloem  
 OWNER: E.R. Murray

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BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
RB 20	S	D	2.3	25.0	16.610	800.586	-	alluvium	Waterlevel (9/2/84)=11.504m, pump inlet @ 24m, pump 54.3 Kl/day.
RB 21	W	S	<1.5	36.0	15.210	793.214	1528	alluvium	
RB 22	W	S	<1.5	45.0	-	-	-	alluvium	
RB 23	W	S	<1.5	36.0	13.285	793.586	-	alluvium	Waterlevel (12/1/84)=11.278m.
RB 24	W	S	<1.5	55.0	-	802.159	1338	alluvium/seds.	
RB 25	W	S/D	2.2	90.0	-	-	-	alluvium/seds.	
RB 26	W	S	<1.5	36.0	12.931	-	1045	dyke contact	
RB 27	W	S	<1.5	40.0	-	-	1071	sediments	
RB 28	W	S	<1.5	36.0	-	-	-	sediments	
RB 29	W	S	<1.5	36.0	-	-	-	sediments	
RB 30	W	S	2.3	45.0	-	-	781	alluvium/seds.	
RB 31	W	S	<1.5	30.0	-	-	-	sediments	
RB 32	W	S	<1.5	36.0	6.756	-	-	alluvium/seds.	
RB 33	M	I	6.3	100.0	-	-	737	0-24 alluvium -100 sediments	75mm cyl.diameter, drilled 1981, pump inlet 33m, water @ 24m, pump 476 Kl/d
RB 34	M	I	10.0	94.5	-	-	1895	as above	75mm cyl.diameter, drilled 1981, pump inlet 42m, water @ 21m, pump 756 Kl/d
RB 35	O	-	dry	8.0	-	-	-	alluvium	Drilled 1960's by Geological Survey.
RB 36	S	I	3.4	77.0	16.783	799.655	-	0-18 alluvium -77 sediments	Drilled 1981, pump 257 Kl/day, waterlevel (7/2/84) = 12.765m.
RB 37	O	-	-	0.0	-	-	-	sediments	sealed.
RB 38	O	-	<1.5	40.0	20.220	-	-	sediments	

CADASTRAL FARM: Roodebloem  
 LOCAL FARM: Wonderdal  
 OWNER: R. Rubidge

9/11

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
RB 39	T	I	6.3	60.0	-	-	-	0-21 alluvium -60 sediments	100mm cyl.diameter, tested @ 10 l/s, pump inlet 21m, pump 476 Kl/day.
RB 40	S	O	1.5	51.0	-	-	1312	as above	
RB 41	T	I	7.5	71.0	-	-	1466	as above (boulders)	100mm cyl.diameter, tested @ 15 l/s, pump inlet 27m, pump 567 Kl/day.
RB 42	T	I	8.8	78.0	-	-	1267	as above	100 mm cyl.diameter, drilled 1981, pump 668 Kl/day, tested @ 12.6 l/s, pump inlet 45m, 21m casing.
RB 43	T	I	7.6	69.0	-	-	-	alluvium/seds	75mm cyl.diameter, inlet @ 22.5m, tested @ 12.6 l/s, pump 575 Kl/day.
RB 44	O	-	dry	26.0	-	-	-	alluvium seds	

CADASTRAL FARM: Roodebloem  
 LOCAL FARM: Lingo  
 OWNER: F. Kingwell

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
RB 45	T	I	-	36.0	-	-	-	alluvium	tested yield 22.2 l/s, pump out order
RB 46	O	-	dry	6.0	-	-	-	alluvium	
RB 47	T	-	-	42.0	-	-	-	alluvium	tested yield 15 l/s, pump out order.

CADASTRAL FARM: Roodebloem  
 LOCAL FARM: Lingo  
 OWNER: W. Murray

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
RB 48	W	S	<1.5	-	-	-	-	alluvium	
RB 49	O	-	-	25.0	-	-	-	alluvium	

CADASTRAL FARM: Springfield  
 LOCAL FARM: Riverdale  
 OWNER: F.P. Van der Merwe

10/11

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
SF 1	W	S	<1.5	30.0	-	-	639	sediments	

CADASTRAL FARM: Thornlands  
 LOCAL FARM: Gannaleegte  
 OWNER: D. Van Rensburg

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
TH 1	O	-	-	36.0	11.744	-	-	alluvium/seds.	Last used in 1976, yield approx. 17l/s
TH 2	O	-	dry	blocked	-	-	-	alluvium/seds.	Last used in 1976, yield 14 l/s, waterlevel (20/9/83) = 9.154m.
TH 3	W	S	<1.5	30.0	10.170	-	-	alluvium/seds	Waterlevel (27/2/84) = 8.600m.
TH 4	T	I	3.8	40.0	-	-	-	alluvium/seds	75mm cyl.diameter, not in use
TH 5	C	-	dry	4	-	-	-	alluvium	open pit.
TH 6	W	S	<1.5	30.0	-	-	-	alluvium/seds	

CADASTRAL FARM: Waterloo  
 LOCAL FARM: Waterloo  
 OWNER: F. Kingwell

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
WL 1	O	-	-	blocked	-	-	-	alluvium	
WL 2	W	S/O	<1.5	36.0	-	-	934	alluvium/seds	
WL 3	T	-	-	-	-	-	-	sheet contact	Tested @ 11l/s, were silted up after 1976 floods, 100mm cyl.diameter.
WL 4	T	-	-	-	-	-	-	as above	as above
WL 5	T	-	-	-	-	-	-	dolerite/seds.	Not used, 75mm cyl.diameter, tested
WL 6	W	S	<1.5	blocked	-	-	-	alluvium/seds.	

CADASTRAL FARM: Welgevonden  
 LOCAL FARM: Welgevonden  
 OWNER: I. Opperman

11/11

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
WN 1	W	S	<1.5	32.0	14.405	-	700	alluvium/seds.	Waterlevel (14/1/84)=19.022m.
WN 2	W	S	<1.5	20.0	16.893	-	575	sediments	Waterlevel (14/1/84)=13.918
WN 3	W	S	<1.5	40.0	14.372	-	-	dyke contact	
WN 4	W	D	<1.5	45.0	-	-	343	sediments	
WN 5	W	D/S	1.9	46.0	-	-	426	sediments	
WN 6	D	-	dry	16.0	-	-	-	sediments	
WN 7	D	-	-	10.0	8.660	-	-	sediments	
WN 8	W	S	<1.5	60.0	-	-	-	sediments	
WN 9	W	S	<1.5	-	-	-	-	sediments	
WN 10	W	S	<1.5	77.0	-	-	-	dolerite/seds.	
WN 11	W	S	<1.5	38.0	6.900	-	515	-	
F 2	F	-	<1.5	-	-	-	-	Sheet contact	

CADASTRAL FARM: Winterhoek  
 LOCAL FARM: Winterhoek  
 OWNER: D. Van Rensburg

BH No	EQUIPMENT	WATER USE	YIELD (l/s)	DEPTH (m)	WATERLEVEL (m)	COLLAR ELV (m) amsl	TDS (mg/l)	GEOLOGY	REMARK
WH 1	D	-	<1.5	32.0	27.962	-	-	sediments	
WH 2	W	D	<1.5	30.0	7.168	-	-	0-6 alluvium -30 dolerite	Waterlevel (27/2/84) = 5.750m
WH 3	D	-	<1.5	30.0	12.578	-	-	0-5 sandstone -30 dolerite	Waterlevel (27/2/84) = 10.237m.
WH 4	W	S	1.8	60.0	-	-	789	0-6 alluvium -30 sediments	Major water interception @ 24m, pump inlet at 27m.
WH 5	W	S	<1.5	45.0	19.480	-	-	sediments	
WH 6	W	S/D	<1.5	50.0	9.325	-	677	sediments	
WH 7	W	S	<1.5	35.0	-	-	-	sediment	
WH 8	W	S	<1.5	60.0	-	-	-	sediment	out of order.
WH 9	W	S	<1.5	70.0	20.173	-	-	sediments	
F 1	F	D	0.5	-	-	-	630	dolerite contact	

APPENDIX 2:  
PROJECT BOREHOLE LOGS

BOREHOLE NUMBER: GR 4

PROJECT: Graaff-Reinet

DATE-

START: 22/02/1983

COMPLETE: 03/03/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 32° 12' 04"

LONGITUDE: 24° 22' 57"

TOTAL DEPTH(m): 38

COLLAR ELEV(m): 782.451

WATER LEVEL(m):

10.935 (04/03/83)

9.481 (23/02/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
18	8.1	1284
21	14.4	1234
34	17.5	1084

FINAL YIELD (l/s): 17.5 FINAL TDS. (mg/l): 1208

---

DEPTH (m)	GEOLOGY
0 - 3	Clay, silt and very fine sand.
- 7	Clay, silt to medium sand. Minor gravel.
- 10	Clay, silt to fine sand. Minor gravel.
- 15	Clay, silt to medium sand. Minor gravel.
- 19	Silt to coarse gravel, poorly sorted.
- 21.5	Fine to coarse sand, gravel and boulders. Poorly sorted.
- 24	Weathered/ jointed, olive green mudstone.
- 26	Weathered/ jointed, grey/green siltstone.
- 33.5	Weakly jointed, light grey/green, speckled, fine to medium grained sandstone. Highly jointed at 28-30 and 32-33.5m.
- 34	Baked, weakly jointed, dark grey/blue mudstone.
- 38	Medium grained dolerite. Weakly jointed to 35m.

---

CONSTRUCTION:

Casing: 0-20m Plain Steel (Ø 200mm)

20-38m Perforated steel (Ø 200mm)

BOREHOLE NUMBER: GR 10

PROJECT: Graaff-Reinet DATE-

START: 04/03/1983

COMPLETE: 25/03/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 32° 12' 06"

LONGITUDE: 24° 32' 55"

TOTAL DEPTH(m): 100

COLLAR ELEV(m): 783.379

WATER LEVEL(m):

11.820 (25/03/83)

10.493 (23/03/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
18	2.0	1537
21	5.5	1482
59	10.1	1254

FINAL YIELD (l/s): 10.1 FINAL TDS. (mg/l): 1097

---

DEPTH (m)	GEOLOGY
0 - 2	Clay, silt to very fine sand.
- 4	Clay, silt to medium sand. Minor gravel.
- 5	Clay, silt to very fine sand.
- 9	Silt to fine sand. Minor gravel.
- 15	Silt to coarse sand and gravel. poorly sorted. Calcrete nodules.
- 19	Fine sand to coarse gravel, boulders. Minor finer material.
- 22	Weathered, weakly jointed, medium grained dolerite.
- 58	Massive, medium grained dolerite. Jointed at 28m, with calcite joint fill.
- 60	Jointed, medium grained dolerite. Calcite and pyrite on joint surfaces.
- 61	Baked/jointed, dark grey siltstone. Calcite joint fill.
- 63	Baked/jointed, grey/green, fine grained sandstone.
- 64	Dark grey/blue siltstone.
- 65	Light grey/green, fine grained sandstone.
- 67	Light grey/green siltstone.
- 70	Grey/blue, fine grained sandstone. Pyrite.
- 72	Light grey/green siltstone.
- 75	Dark grey/blue fine grained sandstone.
- 77	Dark grey/maroon mudstone.
- 82	Light grey/green, speckled, medium grained sandstone.
- 84	Dark grey/blue, siltstone. Maroon discolouration.
- 96	Grey/green mudstone. Maroon discolouration.
- 100	Grey/green, fine grained sandstone.

---

CONSTRUCTION:

Casing: 0 - 20.5 Plain steel (Ø 200mm)

BOREHOLE NUMBER: GR 23 (G33171)

PROJECT: Graaff-Reinet DATE-

START: 10/05/1983  
COMPLETE: 19/05/1988

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 32° 12' 05"

LONGITUDE: 24° 32' 00"

TOTAL DEPTH(m): 49.5

COLLAR ELEV(m): 782.825

WATER LEVEL(m):

11.062 (21/05/83)

9.381 (23/02/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
12	1.6	2394
20	12.1	2254
36	19.5	2222

FINAL YIELD (l/s): 19.5 FINAL TDS. (mg/l): 2296

---

DEPTH (m)	GEOLOGY
0 - 3	Clay, silt to very fine sand. Minor coarser material
- 7	Clay, silt to medium sand.
- 10	Silt to coarse sand, gravel. Poorly sorted.
- 19	Medium to coarse gravel, boulders. Poorly sorted.
- 21	Weathered/jointed, blue/black mudstone.
- 25	Weathered/jointed, dark grey siltstone.
- 27	Weathered/jointed, blue/black mudstone.
- 29	Light olive green siltstone.
- 43	Weakly jointed, baked, light grey/green, mottled, medium grained sandstone. Well jointed 36-38m.
- 49.5	Medium grained dolerite. Weakly jointed/weathered to 44.5m.

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CONSTRUCTION:

Casing: 0 -19 Plain Steel (Ø 200mm)  
-31 Perforated (Ø 200mm)

BOREHOLE NUMBER: G 33172

PROJECT: Graaff-Reinet

DATE-

START: 19/07/1983

COMPLETE: 20/07/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 31' 52"

LONGITUDE: 32° 12' 10"

TOTAL DEPTH(m): 59

COLLAR ELEV(m): 779.756

WATER LEVEL(m):

4.702 (20/07/83)

2.545 (23/02/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
10.5	2.4	1856
15.0	7.2	1792
48.0	1.9*	1216

\* yield declined after casing off alluvium

FINAL YIELD (l/s): 1.9 FINAL TDS. (mg/l): 1216

---

DEPTH (m)	GEOLOGY
0 - 6	Clay, silt to medium sand. Minor coarser material.
- 10	Fine to coarse sand. Minor finer material. Calcrete.
- 14	Medium to coarse sand, gravel. Minor clay.
- 17	Fine sand to coarse gravel, boulders. Poorly sorted.
- 29	Weathered, maroon/grey mudstone and blue/green siltstone.
- 32	Dark grey/green, very fine grained sandstone. Pyrite staining.
- 34	Maroon/grey mudstone.
- 36	Light grey, medium grained, speckled sandstone. Pyrite staining.
- 42	Maroon/grey, mudstone and grey/green siltstone.
- 43	Light grey/green, very fine grained sandstone.
- 48	Maroon/grey mudstone and grey/blue to grey/green siltstone.
- 49	Grey/blue, speckled, very fine grained sandstone.
- 59	Grey/green siltstone.

---

CONSTRUCTION:

Casing: 0 -18 Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33173

PROJECT: Graaff-Reinet DATE-

START: 22/07/1983  
COMPLETE: 31/08/1983

CADASTRAL FARM: Graaff-Reinet

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 32' 42"

LONGITUDE: 32° 10' 37"

TOTAL DEPTH(m): 65.5

COLLAR ELEV(m): 789.170

WATER LEVEL(m):

10.079 (31/08/83)

9.762 (31/01/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
14.0	6.4	2349
17.0	16.0	2277
20.0	16.9	2064

FINAL YIELD (l/s): 16.9 FINAL TDS. (mg/l): 2064

---

DEPTH (m)	GEOLOGY
0 - 7	Clay, silt to medium sand. Minor coarser material.
- 12	Silt to medium sand. Minor clay.
- 17.5	Fine to coarse sand, gravel, boulders. Poorly sorted.
- 20	Weathered, weakly jointed, light grey, speckled, medium grained sandstone.
- 26	Weathered, dark grey/black siltstone. Pyrite staining.
- 29	Dark grey/green siltstone and mudstone. Pyrite staining.
- 31	Dark grey/blue, very fine grained sandstone.
- 34	Dark grey/maroon mudstone and grey/green siltstone.
- 35	Weakly jointed/weathered, blue/grey, fine grained sandstone. Pyrite staining.
- 36	Dark grey/black siltstone. Pyrite staining.
- 40	Grey/green, speckled, fine grained sandstone. Calcite and pyrite.
- 43	Grey/green mudstone. Maroon discolouration.
- 45	Light grey/blue, very fine grained sandstone.
- 47	Grey/green, mudstone. Maroon discolouration.
- 48	Light grey, fine grained sandstone. Slightly weathered.
- 58	Light grey, speckled, fine to medium grained sandstone. Slightly weathered.
- 65.5	Dark grey/black siltstone and grey/maroon mudstone. Calcite and pyrite.

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CONSTRUCTION:

Casing: 0 -10 Plain Steel (Ø 165mm)  
-18 Perforated Steel (Ø 165mm).

BOREHOLE NUMBER: G 33174

PROJECT: Graaff-Reinet DATE-

START: 01/09/1983  
COMPLETE: 14/09/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 31' 45"

LONGITUDE: 32° 11' 21"

TOTAL DEPTH(m): 60

COLLAR ELEV(m): 786.423

WATER LEVEL(m):

6.199 (14/09/83)

6.652 (31/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
20.0	0.6	1253
49.0	2.6	1190

FINAL YIELD (l/s): 2.6 FINAL TDS. (mg/l): 1190

---

DEPTH (m)	GEOLOGY
0 - 5	Clay, fine to medium sand. Calcrete nodules.
- 6	Weathered, grey/maroon mudstone.
- 9	Weathered, light grey/green, speckled, fine to medium grained sandstone.
- 11	Weathered, light grey/mudstone.
- 14	Weathered, light green, speckled, fine grained sandstone. Pyrite staining.
- 19	Weathered, olive green siltstone and grey/maroon mudstone.
- 21	Weakly jointed/weathered, dark green, speckled, medium grained sandstone. Pyrite staining.
- 35	Dark grey/green to grey/maroon mudstone and grey/green siltstone.
- 37.5	Dark grey, speckled, fine to medium grained sandstone.
- 39	Light grey/maroon mudstone.
- 40	Dark grey/green, speckled, fine grained sandstone.
- 45	Light grey/maroon, mudstone and grey/green siltstone.
- 46	Baked, dark grey/green, very fine grained sandstone.
- 51.5	Weakly jointed/weathered, very fine to fine grained dolerite.
- 53	Grey/maroon mudstone.
- 55	Dark grey, speckled, fine grained sandstone. Slightly weathered.
- 60	Grey/green siltstone and grey/maroon mudstone.

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CONSTRUCTION:

Casing: 0 -11.5 Plain Steel ( Ø 165mm)

BOREHOLE NUMBER: G 33175

PROJECT: Graaff-Reinet

DATE-

START: 14/09/1983  
COMPLETE: 23/09/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 32' 23"

LONGITUDE: 35° 12' 03"

TOTAL DEPTH(m): 60

COLLAR ELEV(m): 784.473

WATER LEVEL(m):

5.404 (23/09/83)

5.557 (13/12/83)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
5.0	0.3	2530
11.0	4.2	2470
23.0	4.3	1991

FINAL YIELD (l/s): 4.3 FINAL TDS. (mg/l): 2240

---

DEPTH (m)	GEOLOGY
0 - 4	Clay, silt to medium sand. Calcified.
- 10	Fine to coarse sand, gravel. Poorly sorted.
- 17.5	Fine to medium sand, gravel, boulders. Poorly sorted. Minor finer material.
- 24	Weathered, maroon/grey mudstone and grey/green siltstone.
- 26	Weathered, grey/green, fine grained sandstone.
- 33	Weathered, grey/green/maroon mudstone and grey/green siltstone.
- 36	Dark grey/green, fine grained sandstone. Pyrite staining.
- 49	Maroon/grey/green mudstone and grey/green siltstone.
- 50	Dark grey/green, fine grained sandstone.
- 51	Grey/green siltstone.
- 54	Grey/green, very fine grained sandstone.
- 57	Grey/green siltstone and grey/green/maroon mudstone.
- 60	Grey/green, very fine grained sandstone.

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CONSTRUCTION:

Casing: 0 -17 Plain Steel (Ø 127mm)

-23 Perforated Steel (Ø 127mm)

BOREHOLE NUMBER: G 33176

PROJECT: Graaff-Reinet DATE-

START: 28/09/1983

COMPLETE: 29/09/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 30' 39"

LONGITUDE: 32° 10' 36"

TOTAL DEPTH(m): 75

COLLAR ELEV(m): 809.172

WATER LEVEL(m):

22.521 (29/09/83)

22.337 (18/01/84)

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
57.0	0.2	739
59.0	0.5	749

FINAL YIELD (l/s): 0.5 FINAL TDS. (mg/l): 749

DEPTH (m)	GEOLOGY
0 - 2	Weathered, weakly jointed, light grey, fine grained sandstone.
- 14	Weathered, weakly jointed, fine grained dolerite. Pyrite staining.
- 54	Massive, medium to coarse grained dolerite. Pyrite.
- 56	Fine grained dolerite. Calcite joint fill and pyrite.
- 56.5	Baked, weakly jointed, maroon mudstone.
- 62	Baked, weakly jointed, grey, very fine grained sandstone. Calcite joint fill.
- 63	Light grey/green, speckled, fine grained sandstone.
- 64	Grey, very fine grained sandstone.
- 68	Grey/blue siltstone and chocolate brown mudstone. Calcite joint fill and pyrite staining.
- 71	Grey/blue, very fine grained sandstone. Pyrite.
- 74	Dark brown mudstone.
- 75	Light grey/blue, very fine grained sandstone.

CONSTRUCTION:

Casing: 0 -6 Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33177

PROJECT: Graaff-Reinet DATE-

START: 29/09/1983  
COMPLETE: 04/10/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 29' 16"

LONGITUDE: 32° 10' 31"

TOTAL DEPTH(m): 81

COLLAR ELEV(m): 807.802

WATER LEVEL(m):

12.946 (12/10/83)

13.157 (28/02/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
55.0	0.1	653

FINAL YIELD (l/s): 0.1 FINAL TDS. (mg/l): 653

---

DEPTH (m)	GEOLOGY
0 - 0.5	Clay, silt to fine sand.
- 5	Weathered/baked, weakly jointed, grey, fine grained sandstone.
- 57.5	Medium to coarse grained dolerite. Pyrite staining. Weakly jointed from 54m onwards, calcite joint fill.
- 63.5	Baked, weakly jointed, light grey/blue, fine grained sandstone. Calcite joint fill.
- 64	Baked, dark brown mudstone.
- 69	Baked, weakly jointed, light grey, fine grained sandstone. Calcite joint fill.
- 73	Baked, weakly jointed, grey siltstone.
- 74	Chocolate brown mudstone. Pyrite staining.
- 75	Light grey, very fine grained sandstone.
- 78	Dark grey/green siltstone. Minor calcite.
- 81	Light grey/green, very fine grained sandstone.

---

CONSTRUCTION:

Casing: 0 -7.5 Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33178

PROJECT: Graaff-Reinet DATE-

START: 04/10/1983  
COMPLETE: 12/10/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 30' 41"

LONGITUDE: 32° 11' 21"

TOTAL DEPTH(m): 26

COLLAR ELEV(m): 786.423

WATER LEVEL(m):

4.153 (12/10/83)

4.022 (12/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
9.5	11.3	870
12.0	12.0	692

FINAL YIELD (l/s): 12.0 FINAL TDS. (mg/l): 904

---

DEPTH (m)	GEOLOGY
0 - 0.5	Clay, silt to fine sand.
- 7	Weathered/baked, jointed, light grey, very fine to medium grained sandstone.
- 9	Baked/jointed, light grey siltstone.
- 13	Weathered/baked, well jointed, grey/green, fine to medium grained sandstone.
- 26	Very fine to fine grained dolerite. Weakly jointed/ weathered to 14m. Calcite joint fill.

---

CONSTRUCTION:

Casing: 0 -6 Plain Steel (Ø 200mm)  
-17 Perforated Steel (Ø 200mm)

BOREHOLE NUMBER: G 33179

PROJECT: Graaff-Reinet DATE-

START: 15/10/1983  
COMPLETE: 26/10/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 30' 41"

LONGITUDE: 32° 11' 22"

TOTAL DEPTH(m): 41

COLLAR ELEV(m): 785.978

WATER LEVEL(m):

4.094 (26/10/83)

3.682 (12/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
9.0	16.5	856
24.0	18.5	856
29.0	21.0	870

FINAL YIELD (l/s): 21.0 FINAL TDS. (mg/l): 863

---

DEPTH (m)	GEOLOGY
0 - 0.5	Clay, silt to fine sand. Calcified.
- 3	Weathered/baked, light grey/blue, fine grained sandstone.
- 8	Weathered/baked, grey siltstone.
- 11	Weathered/baked, well jointed, grey, fine grained sandstone.
- 16	Weathered/baked, jointed, grey/green, fine to medium grained, crossbedded sandstone.
- 18	Baked, weakly jointed, grey/blue, very fine grained sandstone. Pyrite staining.
- 19	Baked, dark grey/blue siltstone.
- 20	Baked, light grey, speckled, fine to medium grained sandstone.
- 23	Baked, dark grey/blue siltstone. Pyrite staining.
- 25	Baked, light grey, speckled, fine to medium grained sandstone. Pyrite staining.
- 29	Baked, jointed, dark grey/maroon siltstone. Calcite joint fill and pyrite staining.
- 31	Baked, weakly jointed, grey/blue, very fine grained sandstone. Pyrite staining.
- 34	Baked, light grey/blue siltstone. Calcite.
- 41	Massive, very fine to fine grained dolerite.

---

CONSTRUCTION:

Casing: 0 - 3m Plain Steel (Ø 200mm)  
- 18m Perforated Steel (Ø 200mm)

BOREHOLE NUMBER: G 33180

PROJECT: Graaff-Reinet

DATE-

START: 27/10/1983

COMPLETE: 30/10/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 30' 39"

LONGITUDE: 32° 11' 21"

TOTAL DEPTH(m): 66

COLLAR ELEV(m): 786.627

WATER LEVEL(m):

4.551 (30/10/83)

4.323 (16/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
11.0	5.0	803
13.0	5.6	803

FINAL YIELD (l/s): 6.0 FINAL TDS. (mg/l): 803

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Calcified.
- 8	Weathered, weakly jointed, grey/green/maroon mudstone and grey/blue siltstone.
- 10	Weathered, grey/blue, very fine to fine grained sandstone.
- 12	Weathered, highly jointed, light, grey, speckled, medium grained sandstone. Calcite joint fill.
- 14	Weathered, weakly jointed, dark grey/blue, siltstone Calcite joint fill and pyrite staining.
- 21	Dark grey/blue siltstone. Pyrite staining.
- 24	Light grey, very fine grained sandstone.
- 28	Dark grey siltstone. Pyrite staining.
- 32	Baked, jointed, light grey/green, speckled, fine grained sandstone.
- 38	Weakly jointed/weathered, very fine to fine grained dolerite.
- 43	Weathered/baked, weakly jointed, dark grey/blue mudstone. Pyrite staining.
- 45	Light grey/blue, very fine grained sandstone.
- 51	Dark grey/green/maroon mudstone and grey/green siltstone.
- 54	Light grey/blue, very fine to fine grained sandstone
- 56	Grey/green siltstone. Pyrite staining.
- 58	Light grey/blue, very fine to fine grained sandstone
- 61	Grey/green siltstone.
- 66	Light grey, speckled, fine to medium grained sandstone.

---

CONSTRUCTION:

Casing: 0 - 4.5m Plain Steel (Ø 127mm)  
- 16.5m Perforated Steel (Ø 127mm)

BOREHOLE NUMBER: G 33181

PROJECT: Graaff-Reinet DATE-

START: 31/10/1983  
COMPLETE: 02/11/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 29' 25"

LONGITUDE: 32° 10' 20"

TOTAL DEPTH(m): 86

COLLAR ELEV(m): -

WATER LEVEL(m):

8.728 (02/11/83)

8.347 (18/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
11.0	0.3	-
14.0	2.1	-
19.0	3.1	784
31.0	3.6	784
44.0	4.5	612

FINAL YIELD (l/s): 4.5 FINAL TDS. (mg/l): 681

---

DEPTH (m)	GEOLOGY
0 - 4	Clay, silt to fine sand. Minor coarser material.
- 5	Very fine to coarse sand, gravel. Minor finer material.
- 9	Highly weathered, light grey/blue, speckled, fine to medium grained sandstone.
- 21	Weathered/baked, light grey/green, very fine to fine grained sandstone.
- 23	Weathered, very fine grained dolerite. Calcite.
- 26	Baked, weakly jointed, light grey, fine to medium grained sandstone. Calcite joint fill.
- 73.5	Very fine to fine grained dolerite. Jointed to 28m with calcite and from 71m onwards.
- 77.5	Baked, weakly jointed, grey/blue, very fine to fine grained sandstone.
- 78.5	Baked, weakly jointed, dark grey/blue siltstone. Pyrite staining.
- 80	Baked, blue/grey, very fine grained sandstone.
- 86	Baked, light grey, speckled, medium grained sandstone.

---

CONSTRUCTION:

Casing: 0 - 9.3m Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33182

PROJECT: Graaff-Reinet DATE-

START: 04/11/1983  
COMPLETE: 07/11/1983

CADASTRAL FARM: Welgevonden

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 30' 41"

LONGITUDE: 32° 10' 15"

TOTAL DEPTH(m): 80

COLLAR ELEV(m): 822.799

WATER LEVEL(m):

37.987 (04/11/83)

37.994 (18/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
70.0	0.1	1599
75.0	0.2	1599

FINAL YIELD (l/s): 0.2 FINAL TDS. (mg/l): 1599

---

DEPTH (m)	GEOLOGY
0 - 4	Weathered, weakly jointed, grey/green, very fine grained sandstone.
- 9.5	Weathered, grey/green siltstone.
- 13	Baked, weakly jointed, light grey/blue, speckled, fine to medium grained sandstone. Pyrite staining.
- 20	Baked, dark grey/blue siltstone.
- 25.5	Weakly jointed, very fine to fine grained dolerite. Pyrite staining.
- 26.5	Baked, weakly jointed, very fine to fine grained sandstone.
- 29.5	Baked, weakly jointed, light grey, speckled, fine to medium grained sandstone.
- 30	Baked, chocolate brown mudstone.
- 70.5	Very fine to medium grained dolerite. Weakly jointed with calcite to 34m and from 67m onwards.
- 75	Baked, weakly jointed, dark grey/blue siltstone and grey/green mudstone. Pyrite staining.
- 77	Baked, weakly jointed, light grey, speckled, fine to medium grained sandstone.
- 80	Baked, dark grey siltstone. Calcite joint fill.

---

CONSTRUCTION:

Casing: 0 - 12m Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33183

PROJECT: Graaff-Reinet

DATE-

START: 09/11/1983  
COMPLETE: 10/11/1983

CADASTRAL FARM: Thornlands

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 27 '42"

LONGITUDE: 32° 11 '44"

TOTAL DEPTH(m): 60

COLLAR ELEV(m): -

WATER LEVEL(m):

7.722 (29/11/83)

6.739 (27/02/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
25.0	0.4	810
34.0	0.5	817
39.0	0.8	641

FINAL YIELD (l/s): 0.8 FINAL TDS. (mg/l): 644

---

DEPTH (m)	GEOLOGY
0 - 4	Clay, silt to fine sand. Minor coarser material.
- 6	Poorly sorted, silt to coarse sand, gravel.
- 7	Poorly sorted, fine to coarse sand, gravel and boulders. Minor finer material.
- 28.5	Weathered, grey/green to grey/blue, very fine to medium grained sandstone. Weakly jointed at 28m with calcite joint fill.
- 29	Dark grey/maroon mudstone.
- 31	Weakly jointed, grey/blue, very fine grained sandstone.
- 34	Weakly jointed, grey/blue siltstone.
- 35	Weakly jointed, light grey/blue, speckled, fine to medium grained sandstone.
- 40	Dark grey/blue siltstone.
- 43	Dark grey, speckled, fine to medium grained sandstone.
- 48.5	Dark grey mudstone and dark grey/green siltstone.
- 49	Light grey, speckled, fine to medium grained sandstone.
- 60	Dark grey/green siltstone and dark grey/maroon mudstone.

---

CONSTRUCTION:

Casing: 0 -11m Plain Steel (Ø 127mm)

BOREHOLE NUMBER: G 33184  
PROJECT: Graaff-Reinet

DATE-

START: 10/11/1983  
COMPLETE: 14/11/1983

CADASTRAL FARM: Thornlands  
MAP REFERENCE: 3224 AB  
COORDINATES:

LATITUDE: 24° 27' 41"      LONGITUDE: 32° 11' 55"  
TOTAL DEPTH(m): 65  
WATER LEVEL(m):

10.003 (14/11/83)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
14.5	2.4	688
26.0	3.8	763
39.0	4.6	718

FINAL YIELD (l/s): 5.9      FINAL TDS. (mg/l): 672

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Minor coarser material.
- 3	Poorly sorted, fine to coarse sand, gravel. Minor finer material.
- 5	Poorly sorted, clay, silt to medium sand.
- 7	Poorly sorted, fine to coarse sand, gravel.
- 15	Weathered, weakly jointed, light grey to grey/green, speckled, very fine to medium grained sandstone.
- 16.5	Weathered, grey/green, siltstone. Calcite joint fill.
- 18	Weathered, light grey/green, fine grained sandstone.
- 19	Weathered, grey/green siltstone.
- 20.5	Weathered, baked, grey/blue, fine grained sandstone.
- 24.5	Chocolate brown mudstone and olive green siltstone.
- 25	Grey/blue, very fine grained sandstone.
- 25.5	Dark grey/brown siltstone.
- 29	Weakly jointed, light grey to grey/blue, speckled, fine to medium grained sandstone.
- 30.5	Slightly weathered, olive/green siltstone.
- 31	Grey, speckled, fine grained sandstone.
- 32	Weakly jointed/weathered, dark grey/blue siltstone.
- 34.5	Chocolate brown mudstone and grey/green siltstone.
- 36	Light grey/blue, speckled, fine to medium grained sandstone.
- 38.5	Olive green siltstone.
- 40	Blue/grey, very fine grained sandstone.
- 41	Dark grey/maroon mudstone.
- 46.5	Dark grey, speckled, fine- medium grained sandstone.
- 47	Slightly weathered, dark grey/blue siltstone.
- 48	Dark grey, very fine grained sandstone.
- 51	Dark grey/black siltstone.
- 56.5	Light grey, speckled, fine to medium sandstone.
- 65	Dark grey/black to grey/green siltstone and grey/ maroon mudstone.

---

CONSTRUCTION:

Casing: 0 - 10m Plain Steel (Ø 165mm)  
- 21.5 Perforated Steel (Ø 165mm)

BOREHOLE NUMBER: G 33185

PROJECT: Graaff-Reinet DATE-

START: 14/11/1983  
COMPLETE: 16/11/1983

CADASTRAL FARM: Thornlands

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 28' 02"

LONGITUDE: 32° 11' 42"

TOTAL DEPTH(m): 80

COLLAR ELEV(m): -

WATER LEVEL(m):

4.667 (16/11/83)

3.937 (27/02/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
6.0	0.1	-
23.0	0.2	454

FINAL YIELD (l/s): 0.2 FINAL TDS. (mg/l): 525

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Minor coarser material.
- 4	Poorly sorted, fine to coarse sand and gravel. Minor finer material.
- 5	Poorly sorted, medium to coarse sand, gravel and boulders. Minor finer material.
- 34	Fine to coarse grained dolerite. Weakly jointed/ weathered to 7m and from 34m onwards. Metasedimentary dyke intercepted at 22-23, with calcite joint fill.
- 38.5	Baked, weakly jointed, grey/blue, crossbedded, fine to medium grained sandstone. Calcite joint fill.
- 39	Baked, chocolate brown mudstone.
- 44	Baked, grey/blue, fine to medium grained sandstone.
- 45	Grey/green siltstone.
- 56	Light grey, very fine to fine grained sandstone.
- 60	Dark grey/green siltstone.
- 62	Dark grey/black mudstone.
- 63.5	Light grey, speckled, fine to medium grained sandstone.
- 66	Dark grey/brown siltstone.
- 68	Dark grey/green, very fine to fine grained sandstone.
- 71	Dark grey/green siltstone.
- 80	Light grey, speckled, medium grained sandstone.

---

CONSTRUCTION:

Casing: 0 - 8.9m Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33186

PROJECT: Graaff-Reinet DATE-

START: 17/11/1983  
COMPLETE: 21/11/1983

CADASTRAL FARM: Thornlands

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 27' 41"

LONGITUDE: 32° 11' 37"

TOTAL DEPTH(m): 68

COLLAR ELEV(m): -

WATER LEVEL(m):

11.253 (21/11/83)

11.277 (27/02/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
34.0	2.6	615
44.0	3.4	675
54.0	7.0	702

FINAL YIELD (l/s): 7.0 FINAL TDS. (mg/l): 691

---

DEPTH (m)	GEOLOGY
0 - 33	Coarse grained dolerite. Highly weathered to 1m. Weathered/weakly jointed to 4m. Jointed at 14m, with calcite joint fill.
- 34.5	Highly baked metasediment and calcite joint fill.
- 43	Weakly jointed, very fine to fine grained dolerite. Calcite joint fill and pyrite staining.
- 44.5	Baked, jointed, grey, fine to medium grained sandstone.
- 45.5	Baked, dark brown/black siltstone.
- 52	Weakly jointed, light grey, fine to medium grained sandstone. Calcite joint fill.
- 56	Grey/blue siltstone and chocolate brown mudstone. Calcite.
- 59	Grey/green, very fine grained sandstone. Calcite.
- 68	Grey/maroon mudstone and grey/green siltstone.

---

CONSTRUCTION:

Casing: 0 - 2.0m Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33187

PROJECT: Graaff-Reinet

DATE-

START: 22/11/1983  
COMPLETE: 24/11/1983

CADASTRAL FARM: Brakfontein

MAP REFERENCE: 3224 AB

COORDINATES:

LATITUDE: 24° 26' 58"

LONGITUDE: 32° 08' 07"

TOTAL DEPTH(m): 60

COLLAR ELEV(m): -

WATER LEVEL(m):

12.402 (24/11/83)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
18.0	0.4	-
22.0	1.4	507

FINAL YIELD (l/s): 1.4 FINAL TDS. (mg/l): 575

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand.
- 2	Clay, silt to medium sand. Calcified.
- 4	Fine to coarse sand. Minor gravel.
- 8	Poorly sorted, fine to coarse sand, gravel.
- 12	Highly weathered, grey/green, fine to medium grained sandstone.
- 14	Highly weathered, olive green siltstone.
- 19	Weathered, weakly jointed, grey/green, fine to medium grained sandstone.
- 20	Weathered, grey/maroon mudstone.
- 21	Weathered, weakly jointed, grey/blue, very fine grained sandstone.
- 22	Weathered/baked, grey/maroon mudstone.
- 26	Weathered/baked, grey/blue, medium grained sandstone. Weakly jointed 24-25m.
- 46	Massive, very fine to medium grained dolerite. Weakly jointed at 40 and 45m, with calcite joint fill.
- 50	Baked, grey/blue fine grained sandstone.
- 52	Baked, dark grey/blue siltstone.
- 56	Grey, speckled, fine to medium grained sandstone.
- 60	Grey/green siltstone and grey/maroon mudstone.

---

CONSTRUCTION:

Casing: 0 - 15.8m Plain Steel (Ø 165mm)

BOREHOLE NUMBER: G 33188

PROJECT: Graaff-Reinet DATE-

START: 22/11/1983  
COMPLETE: 29/11/1983

CADASTRAL FARM: Roodebloem

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 35' 16"

LONGITUDE: 32° 10' 21"

TOTAL DEPTH(m): 56

COLLAR ELEV(m): 806.068

WATER LEVEL(m):

9.000 (29/11/83)

8.812 (02/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
11.0	5.6	1316
13.0	10.2	1196
32.0	12.0	846

FINAL YIELD (l/s): 12.0 FINAL TDS. (mg/l): 841

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Calcified.
- 2	Weathered, grey/green, medium grained sandstone. Calcrite in joints.
- 10	Weathered, olive green siltstone and grey/green mudstone.
- 13	Highly weathered/jointed, light grey, speckled, medium grained sandstone.
- 27	Weathered/jointed olive green siltstone and chocolate brown mudstone.
- 28	Dark blue/grey, fine grained sandstone.
- 29	Grey/blue, very fine grained sandstone.
- 31	Olive green siltstone.
- 37	Baked/jointed, light grey, speckled, fine to medium grained sandstone. Calcite joint fill and pyrite staining.
- 56	Very fine to medium grained dolerite. Weakly jointed to 39m, with calcite joint fill.

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CONSTRUCTION:

Casing: 0 - 6.3m Plain Steel (Ø 165mm)  
- 18.3 Perforated Steel (Ø 165mm)

BOREHOLE NUMBER: G 33189

PROJECT: Graaff-Reinet DATE-

START: 28/11/1983  
COMPLETE: 30/11/1983

CADASTRAL FARM: Roodebloem

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 35' 02"

LONGITUDE: 32° 09' 36"

TOTAL DEPTH(m): 50

COLLAR ELEV(m): 816.921

WATER LEVEL(m):  
14.555 (30/11/83)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
22.0	<0.1	-
27.0	0.2	1245
32.0	0.8	1306

FINAL YIELD (l/s): 0.8 FINAL TDS. (mg/l): 1306

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Minor coarser material.
- 4	Poorly sorted, fine to medium sand, gravel.
- 9	Poorly sorted, fine to coarse sand, gravel. Minor coarser material.
- 12	Highly weathered, grey/green fine grained sandstone.
- 16	Highly weathered, grey/blue, speckled, fine to medium sandstone.
- 21	Weathered, weakly jointed, grey/green, very fine grained sandstone.
- 25	Weathered, grey/maroon, mudstone and grey/blue siltstone.
- 32	Grey/blue siltstone and grey/maroon mudstone.
- 35	Weakly jointed, grey/blue, very fine grained sandstone. Calcite joint fill.
- 41.5	Grey/blue siltstone.
- 42.5	Slightly weathered, light grey, speckled, medium grained sandstone.
- 45	Dark grey/blue, very fine grained sandstone.
- 50	Dark grey/green siltstone and grey/blue mudstone.

---

CONSTRUCTION:

Casing: 0 - 9.4 Plain Steel (Ø 200mm)

BOREHOLE NUMBER: G 33230

PROJECT: Graaff-Reinet DATE-

START: 02/12/1983  
COMPLETE: 06/12/1983

CADASTRAL FARM: Roodebloem

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 35 '18"

LONGITUDE: 32° 10 '25"

TOTAL DEPTH(m): 80

COLLAR ELEV(m): 803.242

WATER LEVEL(m):

5.928 (06/12/83)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
11.0 (sulphurous)	0.1	1214
18.0	0.8	879
32.0	14.2	605

FINAL YIELD (l/s): 14.2 FINAL TDS. (mg/l): 536

---

DEPTH (m)	GEOLOGY
0 - 1	Clay, silt to fine sand. Minor gravel.
- 2	Silt to coarse sand. Calcified.
- 14	Weathered/jointed, olive green siltstone. Calcrete development at 2-7m.
- 17	Weathered, grey/green/maroon mudstone.
- 21	Weathered, grey/blue, fine grained sandstone.
- 27	Dark grey/blue siltstone and mudstone. Pyrite staining.
- 34	Weathered, jointed, grey, crossbedded, medium grained sandstone. Calcite joint fill.
- 36.5	Dark grey/brown siltstone. Pyrite staining.
- 38.5	Grey, speckled, fine to medium grained sandstone. Calcite joint fill.
- 44	Dark grey/brown siltstone and mudstone. Pyrite staining.
- 46	Grey/green, very fine grained sandstone.
- 47	Weakly jointed, light grey/green, speckled, medium grained sandstone.
- 49	Grey/brown siltstone. Pyrite staining.
- 59	Baked, weakly jointed, light grey/blue, speckled, fine to medium grained sandstone. Calcite joint fill and pyrite staining.
- 80	Fine to medium grained dolerite. Weakly jointed at 59-61m and 77m, with calcite.

---

CONSTRUCTION:

Casing: 0 - 11.5m Plain Steel (Ø 165mm)  
- 23.5m Perforated Steel (Ø 165mm)

BOREHOLE NUMBER: G 33231

PROJECT: Graaff-Reinet

DATE-

START: 08/12/1983

COMPLETE: 12/12/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 32' 33"

LONGITUDE: 32° 11' 21"

TOTAL DEPTH(m): 45

COLLAR ELEV(m): 787.121

WATER LEVEL(m):

10.522 (12/12/83)

10.368 (31/01/84)

---

WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
15.0	0.2	-
22.0	0.5	961

FINAL YIELD (l/s): 0.5 FINAL TDS. (mg/l): 1058

---

DEPTH (m)	GEOLOGY
0 - 4	Clay, silt to medium sand. Minor coarser material.
- 15	Poorly sorted, fine to coarse sand, gravels.
- 17	Fine to coarse sand, gravel and boulders. Poorly sorted.
- 22	Weathered, grey/green, speckled, fine to medium grained sandstone. Calcite in joints 21-22m.
- 29	Dark grey/blue siltstone and mudstone. Pyrite staining.
- 31	Light grey, speckled, fine to medium grained sandstone.
- 45	Dark grey/blue/maroon mudstone and siltstone. Pyrite staining.

---

CONSTRUCTION:

Casing: 0 - 18m Plain Steel (Ø 200mm)

BOREHOLE NUMBER: G 33232

PROJECT: Graaff-Reinet DATE-

START: 12/12/1983  
COMPLETE: 14/12/1983

CADASTRAL FARM: Bloems Kraal  
MAP REFERENCE: 3224 BA  
COORDINATES:

LATITUDE: 24° 33' 09"

LONGITUDE: 32° 10' 05"

TOTAL DEPTH(m): 50

COLLAR ELEV(m): 790.284

WATER LEVEL(m):

8.746 (15/12/83)

8.735 (31/01/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
11	1.3	480
14	3.2	786
19	3.8	855
35	4.3	1069

FINAL YIELD (l/s): 4.3 FINAL TDS. (mg/l): 1069

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DEPTH (m)	GEOLOGY
0 - 2	Clay, silt to fine sand. Minor coarser material.
- 5	Moderately sorted, fine to coarse sand.
- 8	Poorly sorted, silt to medium sand. Calcified. Minor coarser material.
- 11	Poorly sorted, fine to coarse sand, gravel. Minor finer material.
- 15	Poorly sorted, fine to coarse sand, gravel and boulders. Minor finer material.
- 21	Weathered, weakly jointed, grey/green siltstone and grey/maroon mudstone.
- 23	Weathered, grey/green, fine grained sandstone.
- 31	Grey/blue siltstone and grey/maroon mudstone.
- 35	Grey/green, very fine to fine grained sandstone.
- 38	Weakly jointed, light grey, speckled, fine to medium grained sandstone. Calcite joint fill.
- 40	Grey/blue siltstone. Calcite joint fill.
- 44	Grey/blue, speckled, very fine to fine grained sandstone.
- 50	Grey/green siltstone and grey/maroon mudstone.

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CONSTRUCTION:

Casing: 0 - 7m Plain Steel (Ø 127mm)  
- 18m Perforated Steel (Ø 127mm)

BOREHOLE NUMBER: G 33233

PROJECT: Graaff-Reinet

DATE-

START: 15/12/1983

COMPLETE: 19/12/1983

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24°32'43"

LONGITUDE: 32°11'03"

TOTAL DEPTH(m): 74

COLLAR ELEV(m): 791.150

WATER LEVEL(m):

11.488 (19/12/83)

11.492 (31/01/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
23.0	2.4	2155
40.0	7.2	1859
48.0	8.1	1665

FINAL YIELD (l/s): 8.1 FINAL TDS. (mg/l): 1632

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DEPTH (m)	GEOLOGY
0 - 4	Poorly sorted, clay, silt to coarse sand. Minor gravel.
- 6	Poorly sorted, fine to coarse sand, gravel.
- 10	Poorly sorted, calcified, clay, silt to medium sand.
- 25	Highly weathered, weakly jointed, medium to coarse grained dolerite.
- 36	Massive, medium to coarse grained dolerite.
- 40	Weathered, weakly jointed, medium to fine grained dolerite. Calcite joint fill.
- 43.5	Baked/jointed, light grey/blue, fine grained sandstone.
- 45	Baked, dark grey/brown siltstone.
- 48	Baked, weakly jointed, light grey, speckled, medium grained sandstone.
- 49	Grey/green siltstone.
- 51	Grey, speckled, fine to medium grained sandstone.
- 52	Grey/green siltstone.
- 53	Light grey, speckled, medium grained sandstone.
- 55	Dark grey/brown siltstone.
- 57	Light grey, fine grained sandstone.
- 64	Dark grey/blue siltstone.
- 66	Grey, speckled, fine grained sandstone.
- 71	Dark grey/blue siltstone. Calcite joint fill.
- 74	Dark grey/blue/maroon mudstone.

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CONSTRUCTION:

Casing: 0 - 23.4m Plain Steel (Ø 165mm)

- 28.4m Perforated Steel (Ø 165mm)

BOREHOLE NUMBER: G 33234

PROJECT: Graaff-Reinet

DATE-

START: 20/12/1983

COMPLETE: 03/01/1984

CADASTRAL FARM: Graaff-Reinet Allotment Area

MAP REFERENCE: 3224 BA

COORDINATES:

LATITUDE: 24° 32' 44"

LONGITUDE: 32° 11' 04"

TOTAL DEPTH(m): 70

COLLAR ELEV(m): 791.027

WATER LEVEL(m):

11.089 (03/01/84)

11.322 (20/02/84)

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WATER INTERCEPTION (m)	BLOWOUT YIELD (l/s)	TDS. (mg/l):
13.0	0.9	-
16.0	4.6	1409
26.0	7.5	1446
39.0	9.5	1669

FINAL YIELD (l/s): 9.5 FINAL TDS. (mg/l): 1320

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DEPTH (m)	GEOLOGY
0 - 5	Poorly sorted, clay, silt to coarse sand. Calcrete nodules.
- 13	Poorly sorted, fine to coarse sand, gravel. Calcified horizons.
- 22.5	Poorly sorted, fine to coarse sand, gravel and boulders. Minor finer material.
- 26	Highly weathered, jointed, medium to coarse grained dolerite. Calcite joint fill up to 4mm thick.
- 31	Massive, medium grained dolerite. Minor calcite.
- 33.5	Baked, weakly jointed, grey/green, fine grained sandstone.
- 34.5	Baked, dark grey/black siltstone.
- 41	Weathered, grey/green, speckled, fine to medium grained sandstone. Weakly jointed 39-40m, with calcite joint fill.
- 43.5	Baked, dark grey, fine grained sandstone.
- 35.5	Dark grey/black siltstone.
- 47	Light, grey, speckled, medium grained sandstone.
- 48	Grey/blue, fine grained sandstone.
- 49	Dark grey/blue siltstone.
- 51	Light grey, speckled, medium grained sandstone.
- 52	Dark grey/blue siltstone.
- 53	Light grey, speckled, medium grained sandstone.
- 55	Dark grey/brown siltstone.
- 59	Grey/blue, very fine to fine grained sandstone.
- 70	Dark grey/blue/maroon siltstone and mudstone.

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CONSTRUCTION:

Casing: 0 - 14.5m Plain Steel (Ø 165mm)  
- 26.5m Perforated Steel (Ø 165mm)

APPENDIX 3:  
HYDROCHEMICAL DATA

Borehole Number	Sampling Date	pH	Conductivity (mS/m)	Na	K	Ca	Mg	HCO3	SO4	CL (mg/l)	TAL	NH4	NO3	F	Si	P	Remark
G33170	090583	7.8	196.0	146	1.3	120	96	338.1	191	355	277.3	0.036	7.88	0.7	18.6	0.004	1-560
G33171	190583	7.6	371.2	362	8.6	175	191	297.5	541	902	244.0	0.090	2.10	0.6	16.3	0.090	2-17
G33171	030583	7.6	367.4	327	11.7	202	201	348.7	551	850	286.0	0.040	3.14	0.4	16.0	0.016	2-22
G33171	190583	7.8	358.4	319	12.3	185	202	323.1	537	838	265.0	0.030	8.99	0.4	15.6	0.010	2-43
G33178	051083	7.7	136.0	101	3.7	78	53	195.0	124	190	242.0	0.300	26.52	0.6	13.4	0.024	2-13
G33179	141083	7.8	134.0	99	3.6	77	54	282.9	125	196	232.0	0.030	31.16	0.4	14.7	0.025	2-10
G33180	301083	7.8	127.0	97	3.4	71	51	291.4	113	182	239.0	0.020	30.60	0.4	14.2	0.021	2-65
G33180	281083	7.8	131.0	94	6.9	73	53	271.9	113	182	223.0	0.030	34.00	0.4	13.5	0.033	2-13
G33180	281083	7.7	133.0	98	7.7	75	53	247.5	115	191	203.0	0.050	30.32	0.4	13.6	0.032	2-11
G33181	211083	7.7	104.0	95	18.1	53	39	315.8	74	114	259.0	0.050	1.15	0.4	7.9	0.027	2-11
G33181	011183	7.7	105.0	88	17.8	58	40	297.5	61	120	244.0	0.050	12.84	0.3	8.1	0.019	2-14
G33181	211183	7.8	111.4	95	3.0	71	38	243.8	166	103	200.0	0.030	26.03	0.3	13.3	0.019	2-86
G33183	091183	7.9	112.2	138	31.3	36	35	360.9	107	101	296.0	0.050	8.06	1.1	7.4	0.025	2-25
G33183	101183	8.0	110.9	117	12.0	69	33	362.1	117	89	297.0	0.040	17.53	1.1	11.8	0.034	2-60
G33184	101183	7.9	120.5	134	4.2	69	44	431.6	98	100	354.0	0.040	16.29	0.9	14.8	0.018	2-15
G33184	141183	8.0	117.8	125	5.0	61	43	406.0	96	100	333.0	0.040	23.64	0.8	16.7	0.020	2-65
G33185	161183	8.1	76.0	87	8.5	39	24	273.1	32	73	224.0	0.030	0.0	0.7	7.6	0.024	2-80
G33186	181183	8.2	91.2	87	7.7	41	42	291.4	93	88	239.0	0.030	0.0	0.7	15.2	0.015	2-23
G33186	201183	8.2	109.3	98	6.3	73	48	335.3	121	112	275.0	0.030	18.77	0.9	15.4	0.018	2-54
G33186	211183	8.2	112.3	100	2.7	75	49	335.2	151	112	275.0	0.030	16.69	0.9	16.5	0.012	2-70
G33187	231183	8.2	82.9	74	23.8	51	28	324.3	74	44	266.0	0.030	0.27	1.2	8.4	0.030	2-20
G33187	241187	8.0	76.1	54	9.1	60	27	310.9	52	36	255.0	0.040	9.47	1.0	11.7	0.045	2-60
G33188	221183	8.0	184.5	177	5.7	12	83	396.2	235	283	325.0	0.030	0.27	0.8	15.0	0.019	2-11
G33188	251183	8.0	159.2	145	4.1	103	83	338.9	195	265	278.0	0.030	0.53	0.9	17.4	0.210	2-56
G33230	061283	7.9	176.8	200	7.8	80	71	347.5	220	274	285.0	0.030	0.0	0.9	11.8	0.051	2-11
G33230	061283	7.9	106.0	88	2.2	62	50	337.7	81	131	277.0	0.030	0.0	1.6	19.1	0.006	2-19
G33231	081283	7.4	228.2	207	6.9	132	86	337.7	202	459	277.0	0.040	0.0	0.4	11.7	0.013	2-21
G33231	121283	7.6	295.0	301	19.2	159	107	308.5	432	634	253.0	0.050	0.53	0.5	10.7	0.011	2-45
G33232	121283	8.2	61.3	106	1.1	17	12	179.2	88	69	147.0	0.030	0.0	1.1	5.9	0.045	2-11
G33232	141283	8.2	139.0	245	6.6	32	26	469.4	143	137	385.0	0.040	0.0	1.4	7.9	0.058	2-36
G33233	151283	7.6	312.7	432	12.7	96	98	438.9	503	563	360.0	0.040	0.0	0.7	9.8	0.014	2-24
G33233	171283	7.8	275.6	351	7.5	94	88	426.7	400	477	350.0	0.050	0.49	0.5	14.2	0.004	2-40
G33233	191283	7.8	247.6	321	3.3	64	79	469.4	286	389	385.0	0.050	3.45	0.5	15.6	0.011	2-75
G33234	211283	7.9	251.9	333	6.0	84	81	475.5	296	377	390.0	0.020	0.49	0.6	15.2	0.009	2-39
G33234	020183	8.1	190.4	339	3.7	37	45	501.1	237	232	411.0	0.070	0.0	1.3	12.6	0.067	2-56

REMARKS 1- Sampled during aquifer test (minutes)  
2- Sampled during drilling (depth metres)

AQUIFER TEST - TECHNICAL SPECIFICATIONS

BOREHOLE NUMBER	DATE OF TEST	EQUIPMENT	DEPTH OF PUMP INTAKE (m)	WATER DISCHARGE
GR-4	12/05/83	100 mm Mono Pump	36	into municipal reservoir
GR-10	09/05/83	100 mm Mono Pump	93	170m downstream into a furrow
GR-23	15/06/83	100 mm Mono Pump	47	into municipal reservoir
GR-5	15/01-25/01/84	100 mm Turb Pump	24	into municipal reservoir
GR-11		100 mm Turb Pump	20	into municipal reservoir
BK-18	31/01-06/02/84	100 mm Mono Pump	36	250m downstream of pumped borehole
G33173	07/02-13/02/84	100 mm Mono Pump	36	270m downstream of pumped borehole
G33233	22/02-26/02/84	100 mm Mono Pump	35	220m downstream of pumped borehole
RB-34	13/01/84	75 mm Mono Pump	42	200m downstream into furrow
G33179	16/01-29/01/84	100 mm Mono Pump	35	350m downstream of pumped borehole
G33230	23/01-29/01/84	100 mm Mono Pump	47	170m downstream into furrow

CONSTANT DISCHARGE AQUIFER TEST - DATA AND RESULTS:

BOREHOLE NUMBER	DATE	DURATION OF TEST (min)	AVERAGE YIELD (l/s)	STATIC (m) WATERLEVEL	MAXIMUM (m) DRAWDOWN	RECOVERY PERIOD (min)	WATERLEVEL DEFICIT (m)	TOTAL VOLUME ABSTRACTED (Kl)
GR-4 (P)	12/05/83	560	17.7	11.353	8.101	180	0.085	594
GR-10 (P)	09/05/83	560	8.9	12.211	12.546	140	0.165	298
GR-23 (P)	15/06/83	600	19.8	11.142	7.297	120	0.106	713
GR-5 (P)	15-25/01/84	11 520	22.5	9.132	5.219	2 880	0.159	15 552
GR-11 (P)			11.5	9.670	2.073		0.244	7 949
GR-4 (O)				9.324	0.833		0.251	
GR-7 (O)				9.470	0.796		0.102	23 501
GR-23 (O)				9.175	0.829		0.253	
GR-6 (O)				9.451	0.524		-	
GR-12 (O)				10.385	0.331		0.297	
GR-10 (O)				10.374	0.447		0.258	
BK-18 (P) 633232(O)	31/01-06/02/84	4 320	9.4	8.655 8.739	0.928 0.174	4 320	0.001 0.004	2 437
633173(P) 633231(O)	07-13/02/84	4 320	9.1	9.731 10.387	1.461 0.141	4 320	0.001 0.030	2 326
633233(P) 633234(O)	22-26/02/84	3 000	9.1	11.387 11.338	6.058 0.516	3 000	0.0 0.0	1 627
633179(P) 633178(O) 633180(O)	16-22/01/84	4 320	20.6	4.656 3.985 4.323	8.027 4.182 3.997	4 320	0.400 0.432 0.470	5 443
633230(P) 633188(O)	23-29/01/84	4 320	8.5	5.885 8.812	10.436 0.918	4 320	0.343 0.386	2 333
RB-34 (P) RB-23 (O)	13/01/84	720	10.2	- 11.160	- 2.150	300	- 1.224	441

(P) = Pumped Borehole

(O) = Observation Borehole

APPENDIX 4:  
AQUIFER TEST DATA

AQUIFER TEST - TECHNICAL SPECIFICATIONS

BOREHOLE NUMBER	DATE OF TEST	EQUIPMENT	DEPTH OF PUMP INTAKE (m)	WATER DISCHARGE
GR-4	12/05/83	100 mm Mono Pump	36	into municipal reservoir
GR-10	09/05/83	100 mm Mono Pump	93	170m downstream into a furrow
GR-23	15/06/83	100 mm Mono Pump	47	into municipal reservoir
GR-5	15/01-25/01/84	100 mm Turb Pump	24	into municipal reservoir
GR-11		100 mm Turb Pump	20	into municipal reservoir
BK-18	31/01-06/02/84	100 mm Mono Pump	36	250m downstream of pumped borehole
G33173	07/02-13/02/84	100 mm Mono Pump	36	270m downstream of pumped borehole
G33233	22/02-26/02/84	100 mm Mono Pump	35	220m downstream of pumped borehole
RB-34	13/01/84	75 mm Mono Pump	42	200m downstream into furrow
G33179	16/01-29/01/84	100 mm Mono Pump	35	350m downstream of pumped borehole
G33230	23/01-29/01/84	100 mm Mono Pump	47	170m downstream into furrow

CONSTANT DISCHARGE AQUIFER TEST - DATA AND RESULTS:

BOREHOLE NUMBER	DATE	DURATION OF TEST (min)	AVERAGE YIELD (l/s)	STATIC (m) WATERLEVEL	MAXIMUM (m) DRAWDOWN	RECOVERY PERIOD (min)	WATERLEVEL DEFICIT (m)	TOTAL VOLUME ABSTRACTED (Kl)
GR-4 (P)	12/05/83	560	17.7	11.353	8.101	180	0.085	594
GR-10 (P)	09/05/83	560	8.9	12.211	12.546	140	0.165	298
GR-23 (P)	15/06/83	600	19.8	11.142	7.297	120	0.106	713
GR-5 (P)	15-25/01/84	11 520	22.5	9.132	5.219	2 880	0.159	15 552
GR-11 (P)			11.5	9.670	2.073		0.244	7 949
GR-4 (O)				9.324	0.833		0.251	
GR-7 (O)				9.470	0.796		0.102	23 501
GR-23 (O)				9.175	0.829		0.253	
GR-6 (O)				9.451	0.524		-	
GR-12 (O)				10.385	0.331		0.297	
GR-10 (O)				10.374	0.447		0.258	
BK-18 (P) 633232(O)	31/01-06/02/84	4 320	9.4	8.655 8.739	0.928 0.174	4 320	0.001 0.004	2 437
633173(P) 633231(O)	07-13/02/84	4 320	9.1	9.731 10.387	1.461 0.141	4 320	0.001 0.030	2 326
633233(P) 633234(O)	22-26/02/84	3 000	9.1	11.387 11.338	6.058 0.516	3 000	0.0 0.0	1 627
633179(P) 633178(O) 633180(O)	16-22/01/84	4 320	20.6	4.656 3.985 4.323	8.027 4.182 3.997	4 320	0.400 0.432 0.470	5 443
633230(P) 633188(O)	23-29/01/84	4 320	8.5	5.885 8.812	10.436 0.918	4 320	0.343 0.386	2 333
RB-34 (P) RB-23 (O)	13/01/84	720	10.2	- 11.160	- 2.150	300	- 1.224	441

(P) = Pumped Borehole

(O) = Observation Borehole

Appendix 4A:  
Test Specifications

Appendix 4A:  
Test Specifications

Borehole Number	Sampling Date	pH	Conductivity (mS/m)	Na	K	Ca	Mg	HC03	SO4	CL (mg/l)	TAL	NH4	NO3	F	Si	P	Remark
BF 1	110184	7.9	124.4	118	1.4	127	19	319.4	223	97	262.0	0.020	1.20	1.0	16.1	0.012	-
BF 7	110184	7.9	81.2	80	0.6	64	15	260.9	87	65	214.0	0.030	0.40	0.7	11.1	0.020	-
BK 15	041183	7.9	139.8	174	2.7	64	58	505.9	147	136	415.0	0.040	0.0	0.7	16.1	0.009	-
BK 17	141183	7.9	170.1	265	4.4	69	45	514.5	188	236	422.0	0.040	0.53	1.0	15.3	0.036	-
BT 5	281083	7.9	79.0	55	1.1	64	36	360.9	34	47	296.0	0.020	6.24	0.6	16.9	0.002	-
BT 6	281083	8.1	86.0	63	1.7	83	35	378.0	39	64	310.0	0.010	23.86	0.7	14.3	0.002	-
BT 8	281083	7.7	106.8	120	4.1	20	61	481.6	48	77	395.0	0.840	5.98	1.2	20.4	0.022	-
GR 4	300383	7.4	205.5	184	2.5	96	94	323.1	187	372	265.0	0.040	1.39	0.6	17.0	0.022	2-21
GR 4	300383	7.5	203.3	189	2.3	77	97	268.3	190	383	220.0	0.300	1.83	0.6	18.3	0.017	2-24
GR 4	300383	7.5	161.9	154	1.8	69	77	235.3	149	309	193.0	0.050	1.73	0.6	15.7	0.032	2-31
GR 4	030583	7.7	211.2	197	2.2	109	105	322.0	203	422	264.1	0.045	9.87	0.7	18.2	0.001	1-560
GR 4	030583	7.8	211.2	192	2.4	132	104	419.8	190	400	344.3	0.056	10.09	0.8	19.5	0.011	1-60
GR 4	030583	7.8	217.6	202	2.4	120	107	352.2	207	429	288.9	0.044	9.87	0.8	20.0	0.004	1-230
GR 5	151183	7.7	341.3	289	2.3	183	173	342.6	448	738	281.0	0.040	9.07	0.3	18.1	0.010	1-70
GR 5	231183	7.7	345.3	285	2.2	193	177	358.5	454	750	294.0	0.040	9.34	0.3	18.6	0.004	1-11500
GR 11	151183	7.7	334.2	274	2.2	183	175	375.5	433	702	308.0	0.040	11.42	0.3	18.5	0.004	1-70
GR 11	231183	7.7	343.8	282	2.2	191	181	375.5	468	726	308.0	0.050	8.90+	0.2	18.5	0.004	1-11500
GR 23	200683	7.7	409.6	334	4.3	224	200	439.0	524	843	360.1	0.041	10.62	0.6	18.0	0.010	1-600
GR 23	200683	7.9	394.2	335	11.5	256	213	480.4	563	919	394.0	0.030	10.37	0.5	17.1	0.050	1-1
GR 28	311183	8.0	134.0	173	1.8	54	48	452.3	93	147	371.0	0.020	28.91	0.4	17.2	0.016	-
GR 38	311083	8.0	211.8	364	2.2	63	59	581.6	277	272	477.0	0.020	3.85	0.6	16.9	0.035	-
RB 2	110184	8.0	137.2	156	1.9	68	52	401.1	165	130	329.0	0.020	16.87	0.7	16.4	0.054	-
RB 13	221283	7.5	142.0	202	1.0	63	41	432.8	180	148	355.0	0.030	4.21	0.6	14.7	0.027	-
RB 24	221283	7.9	249.8	208	3.2	175	100	386.5	265	464	317.0	0.040	14.56	0.7	15.6	0.006	-
RB 26	031183	7.8	241.9	326	5.0	77	76	469.4	206	373	385.0	0.030	0.0	0.7	14.6	0.014	-
RB 33	221283	8.0	115.2	152	0.4	96	3	328.0	127	134	269.0	0.010	0.0	1.0	10.3	0.012	-
RB 34	221283	7.9	296.1	351	1.8	151	110	480.4	435	543	349.0	0.030	7.97	0.6	16.0	0.027	-
RB 41	020184	7.9	347.0	338	8.4	179	156	299.9	527	680	246.0	0.020	16.20	0.3	17.1	0.015	-
RB 43	050184	8.0	280.0	270	7.2	176	120	410.9	496	444	337.0	0.010	12.75	0.5	16.8	0.043	-
WL 2	231283	7.9	185.1	206	2.3	116	58	413.3	234	259	339.0	0.020	5.36	0.8	14.6	0.007	-

Note : GR 23 = G 33171

REMARKS 1- Sampled during aquifer test (minutes)  
2- Sampled during drilling (depth metres)

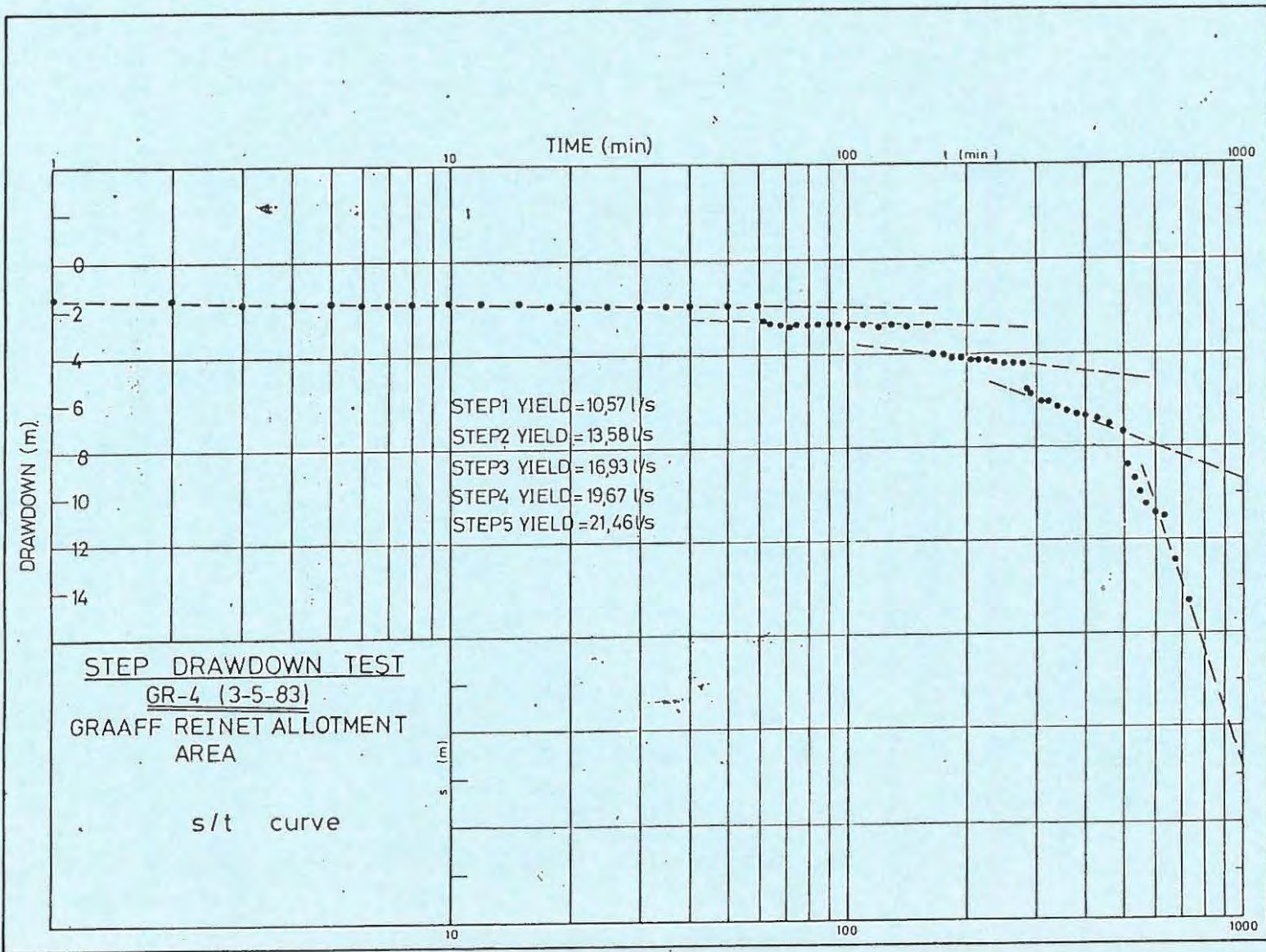
Appendix 4A:  
Test Specifications

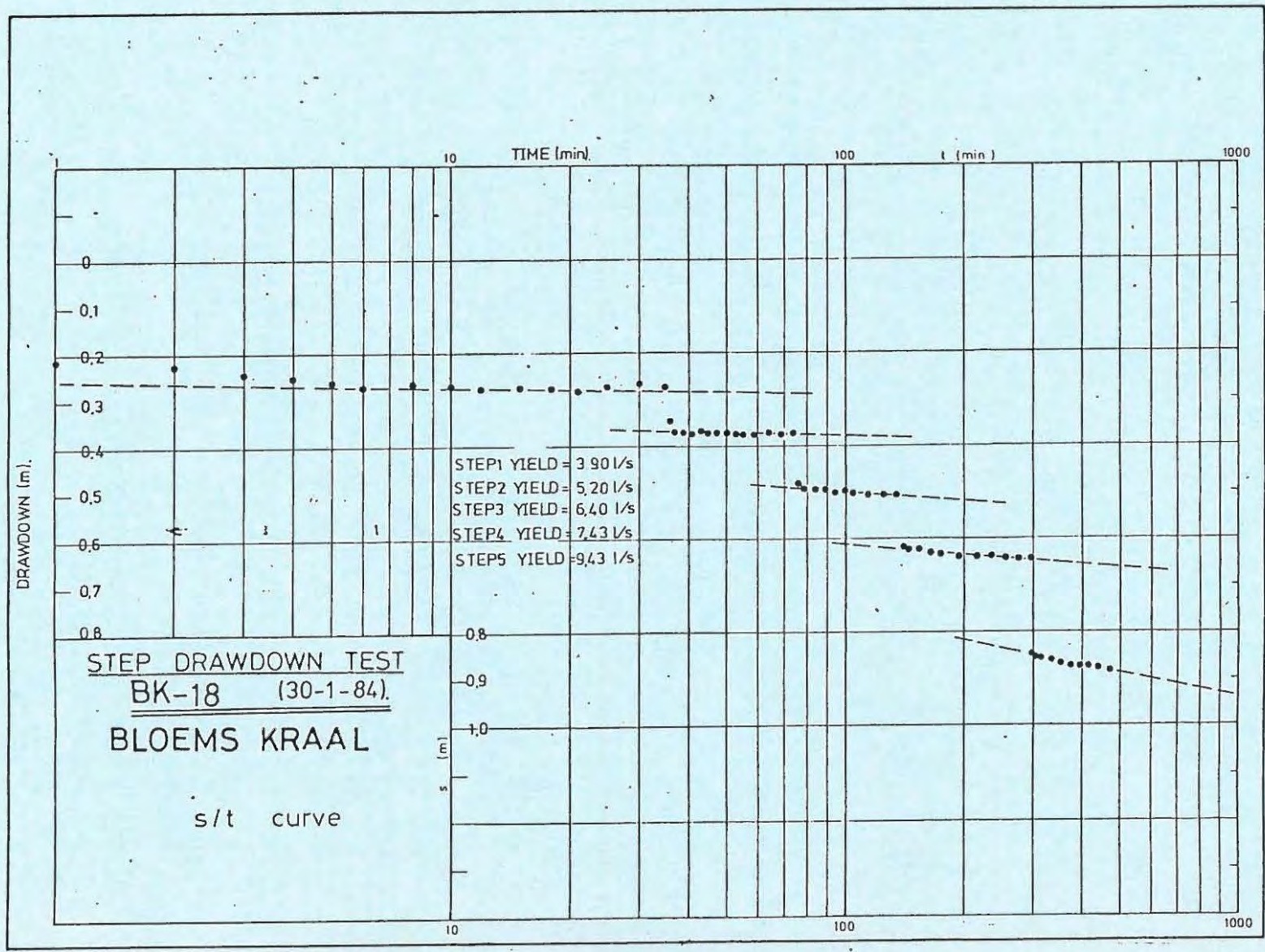
AQUIFER TEST - TECHNICAL SPECIFICATIONS

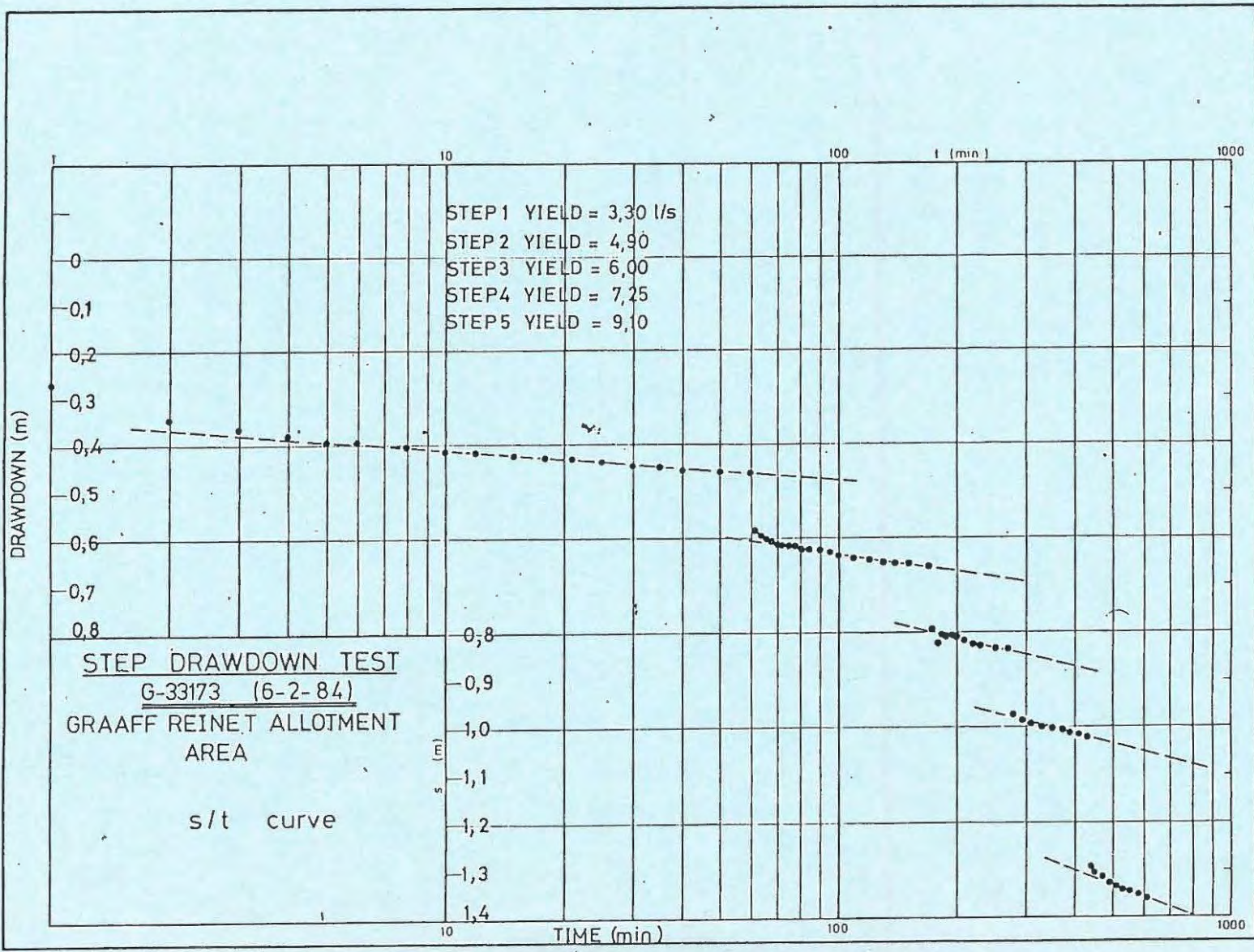
BOREHOLE NUMBER	DATE OF TEST	EQUIPMENT	DEPTH OF PUMP INTAKE (m)	WATER DISCHARGE
GR-4	12/05/83	100 mm Mono Pump	36	into municipal reservoir
GR-10	09/05/83	100 mm Mono Pump	93	170m downstream into a furrow
GR-23	15/06/83	100 mm Mono Pump	47	into municipal reservoir
GR-5	15/01-25/01/84	100 mm Turb Pump	24	into municipal reservoir
GR-11		100 mm Turb Pump	20	into municipal reservoir
BK-18	31/01-06/02/84	100 mm Mono Pump	36	250m downstream of pumped borehole
G33173	07/02-13/02/84	100 mm Mono Pump	36	270m downstream of pumped borehole
G33233	22/02-26/02/84	100 mm Mono Pump	35	220m downstream of pumped borehole
RB-34	13/01/84	75 mm Mono Pump	42	200m downstream into furrow
G33179	16/01-29/01/84	100 mm Mono Pump	35	350m downstream of pumped borehole
G33230	23/01-29/01/84	100 mm Mono Pump	47	170m downstream into furrow

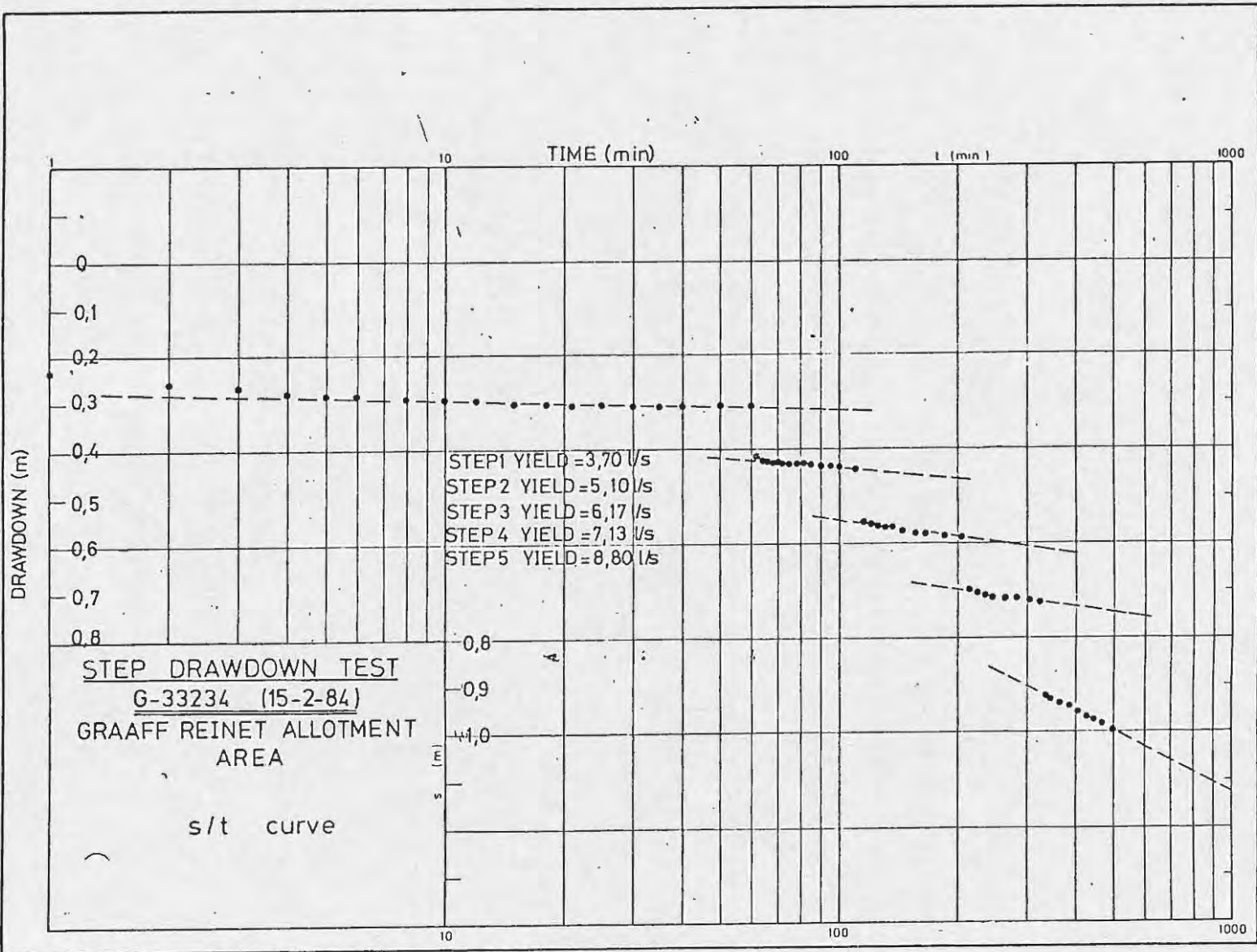
033333/01 22-26/02/84 2 000 0.1 11 287 6 050 2 000 0.0 1 623

Appendix 4B:  
Step-drawdown test curves

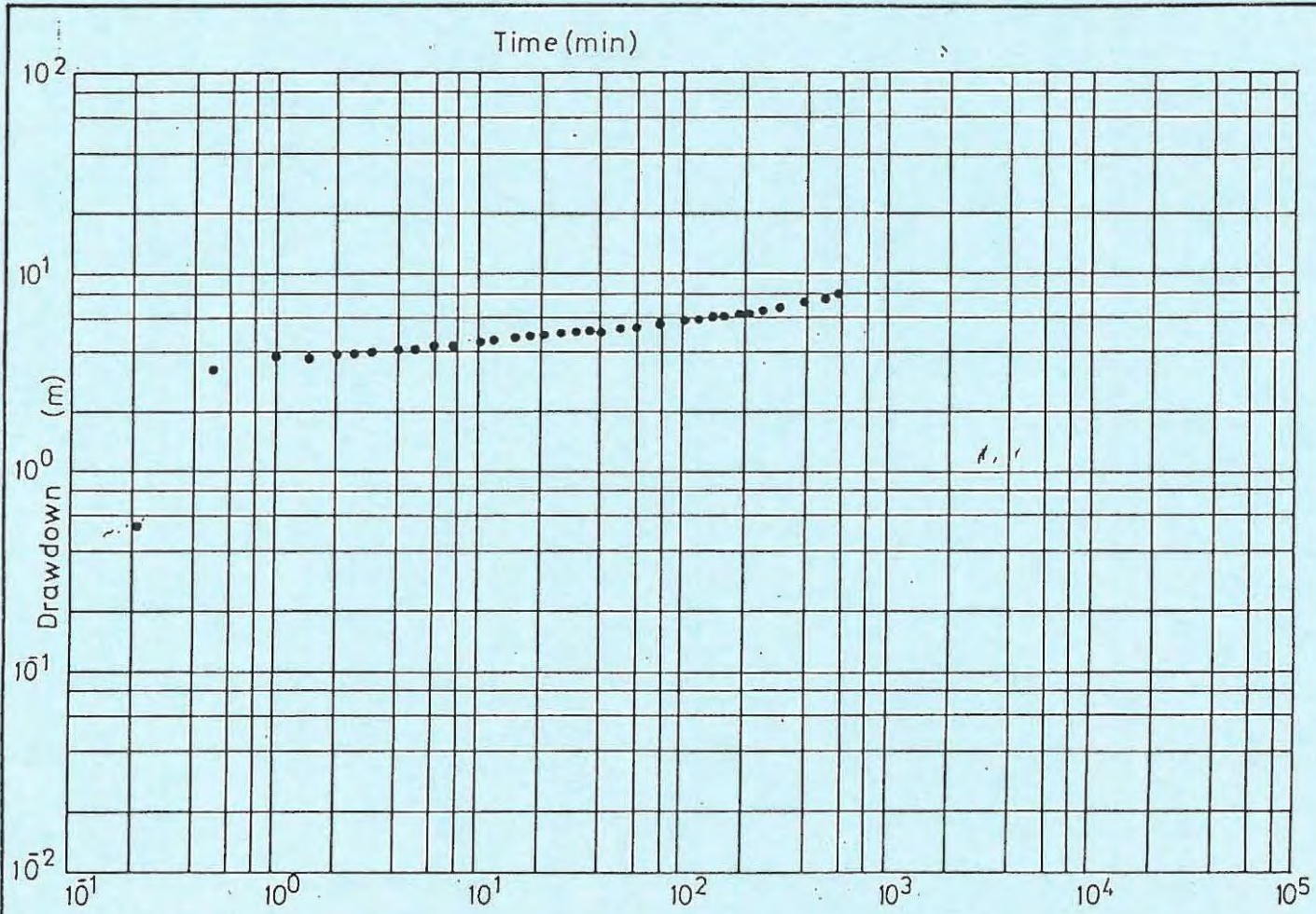








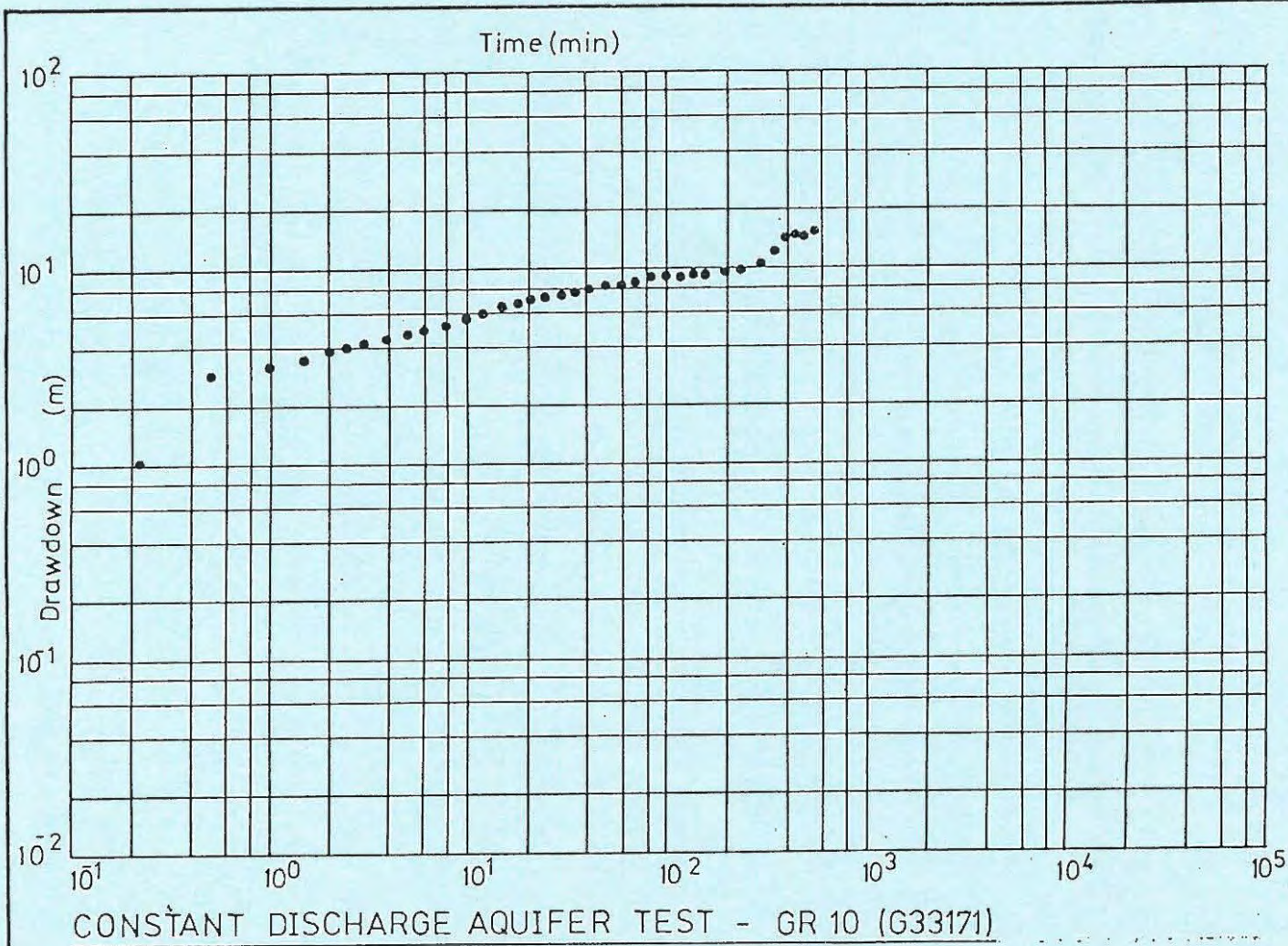
Appendix 4C:  
Constant discharge test curves



REMARKS:  
 Production Borehole  
 GR4 •••••

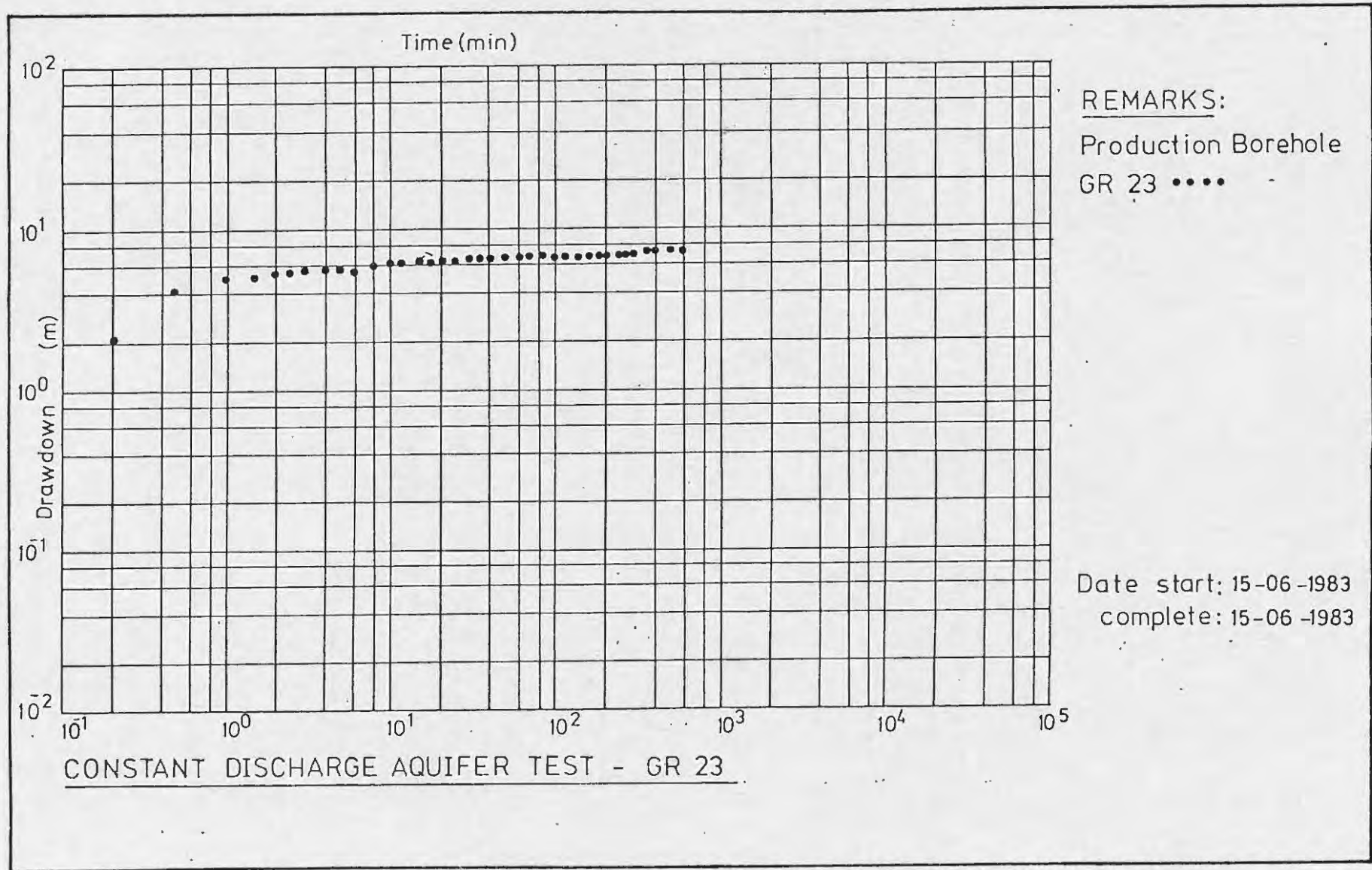
Date start:12-05-1983  
 complete:12-05-1983

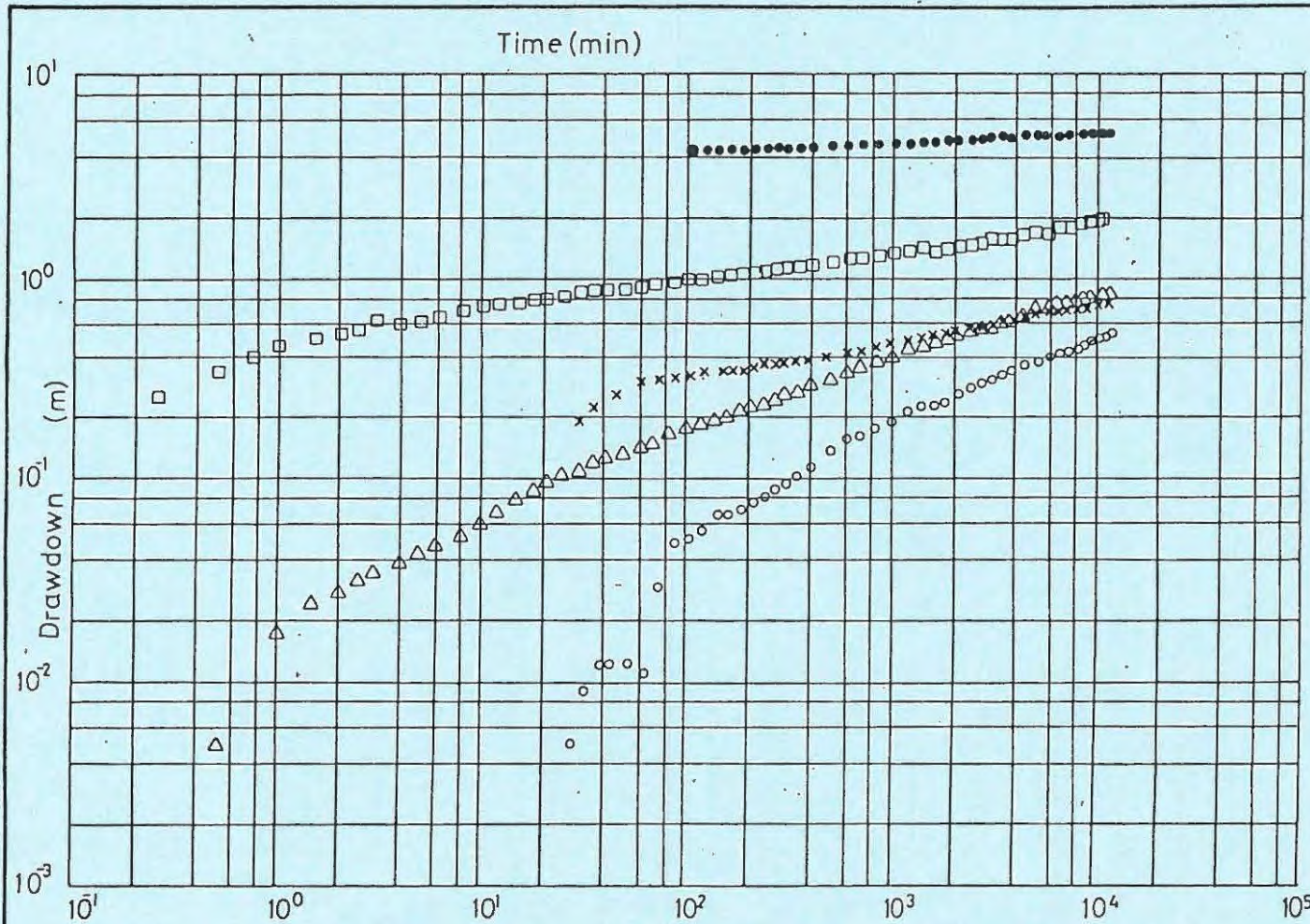
CONSTANT DISCHARGE AQUIFER TEST - GR 4



REMARKS:  
 Production Borehole  
 G33171 •••••

Date start: 09-05-83  
 complete: 09-05-83





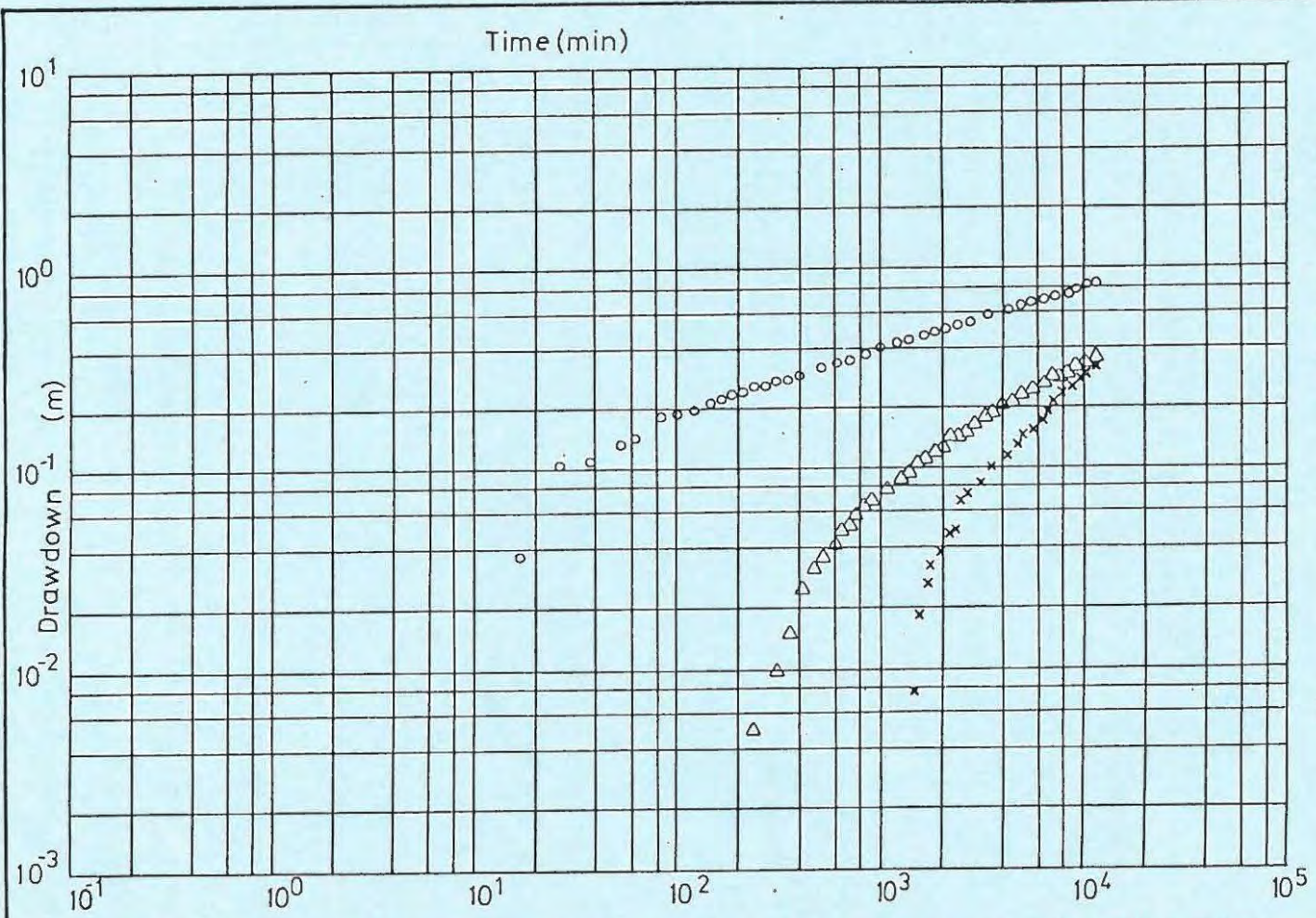
REMARKS:

- Production Boreholes:  
 GR 5 ●●●●  
 GR 11 □□□□
- Observation Boreholes:  
 GR 7 ××××  
 GR 6 ○○○○  
 G33170 △△△△

Date start: 15-11-1983  
 complete: 23-11-1983

CONSTANT DISCHARGE AQUIFER TEST - GR 5,6,7,11 AND G33170

Graph 1



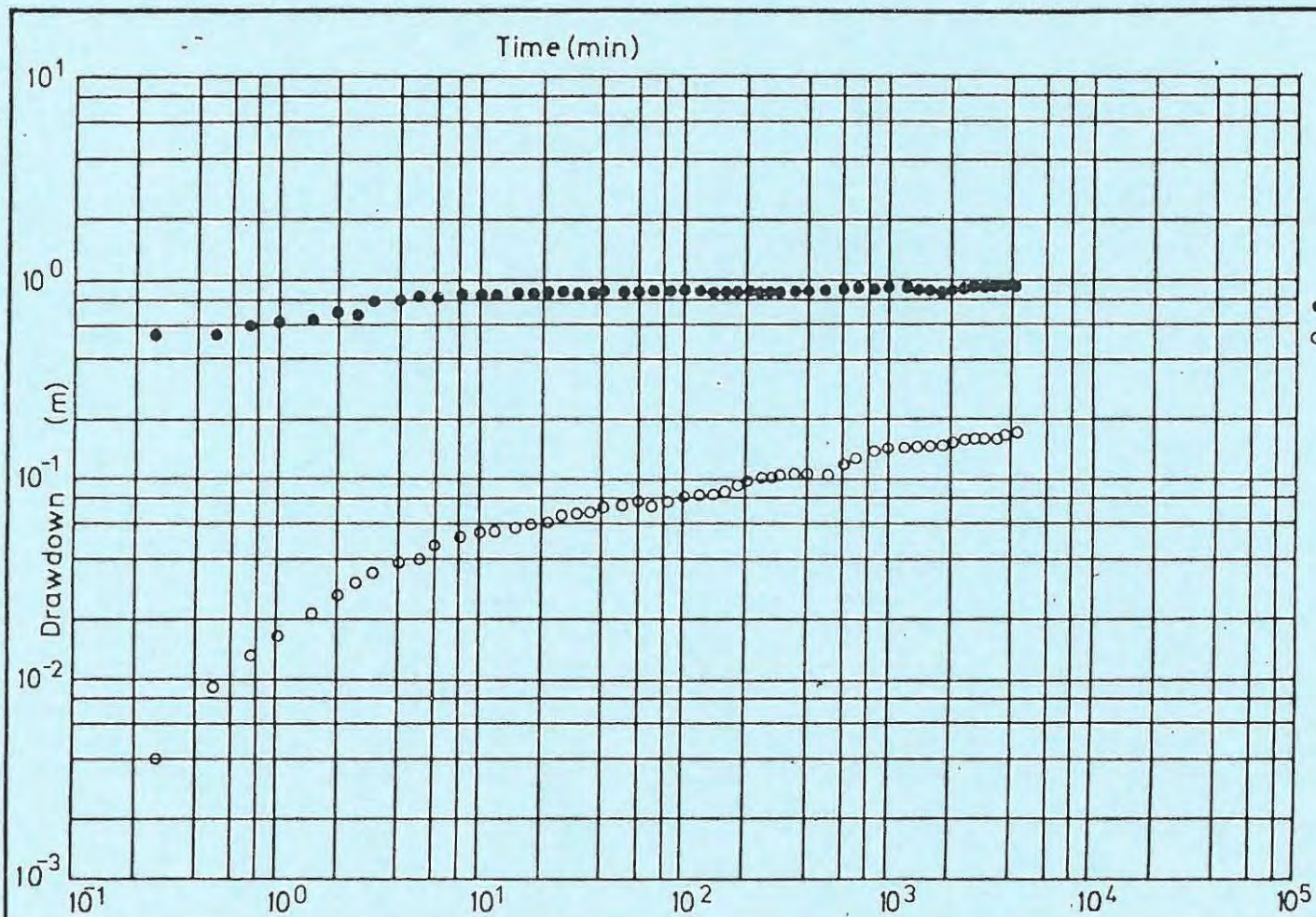
REMARKS:

Production Boreholes  
 GR5 } see graph I  
 GR11 }

Observation Boreholes  
 GR4    o o o o  
 GR12    Δ Δ Δ Δ  
 G33171   x x x x

Date start: 15-11-1983  
 complete: 23-11-1983

CONSTANT DISCHARGE AQUIFER TEST - GR 4, GR12 and G33171 (GR 5 & 11)  
 Graph II



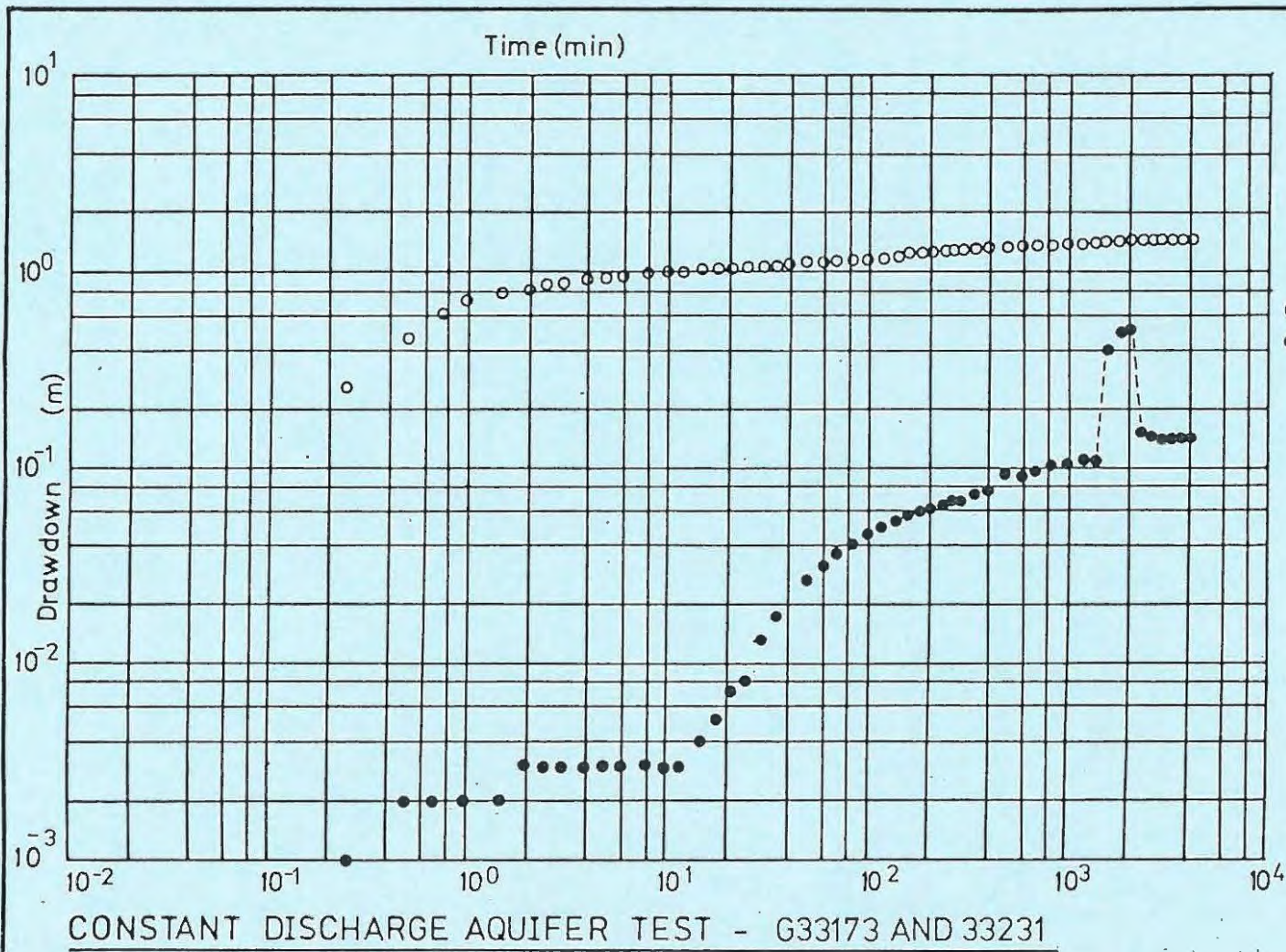
REMARKS:

BK 18 Production Well.  
 G33232 Observation Well.

●●●BK18 Drawdown  
 ○○○G33232 Drawdown

Date start: 31/01/84  
 complete: 02/02/84

CONSTANT DISCHARGE AQUIFER TEST - BK 18 AND G 33232.

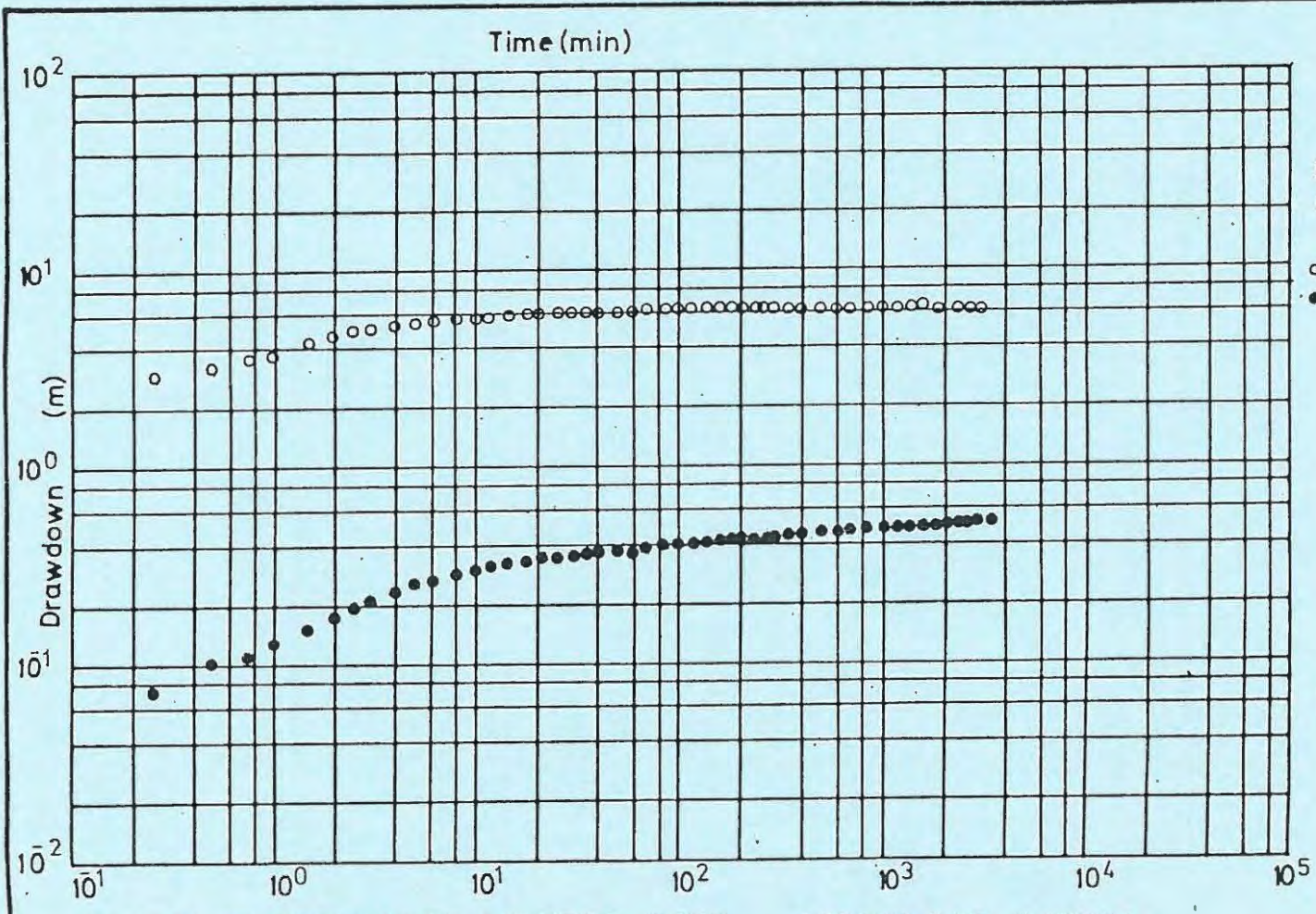


REMARKS:

G33173 Production Well.  
G33231 Observation Well.

- ○ ○ G33173 Drawdown.
- ● ● G33231 Drawdown.

Date start: 07/02/84  
complete: 10/02/84



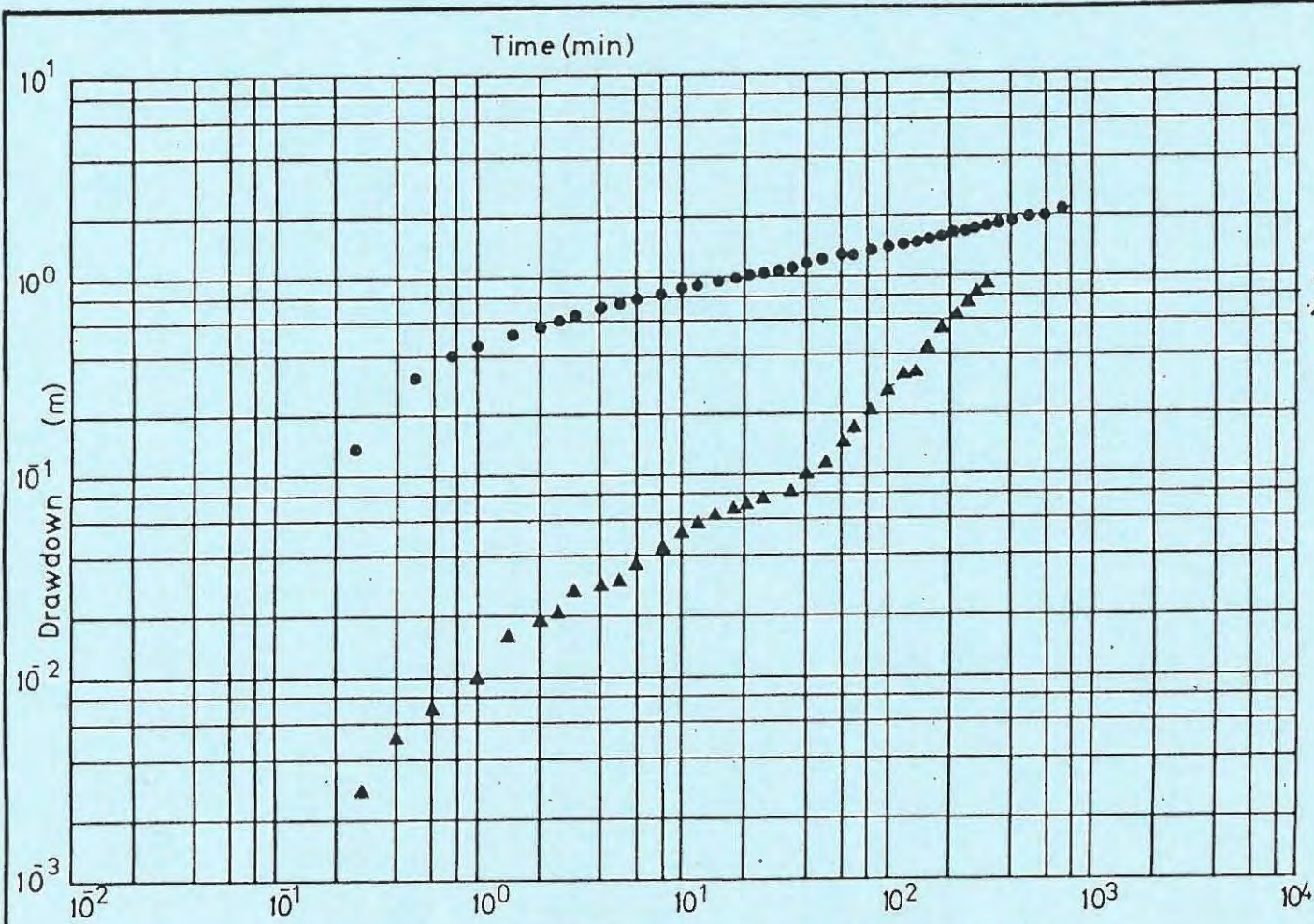
REMARKS:

G33233 Production Well.  
 G33234 Observation Well.

- ○ ○ G 33233 Drawdown
- ● ● G 33234 Drawdown

Date start: 22/02/84  
 complete: 26/02/84

CONSTANT DISCHARGE AQUIFER TEST - G33233 AND G 33234



REMARKS:

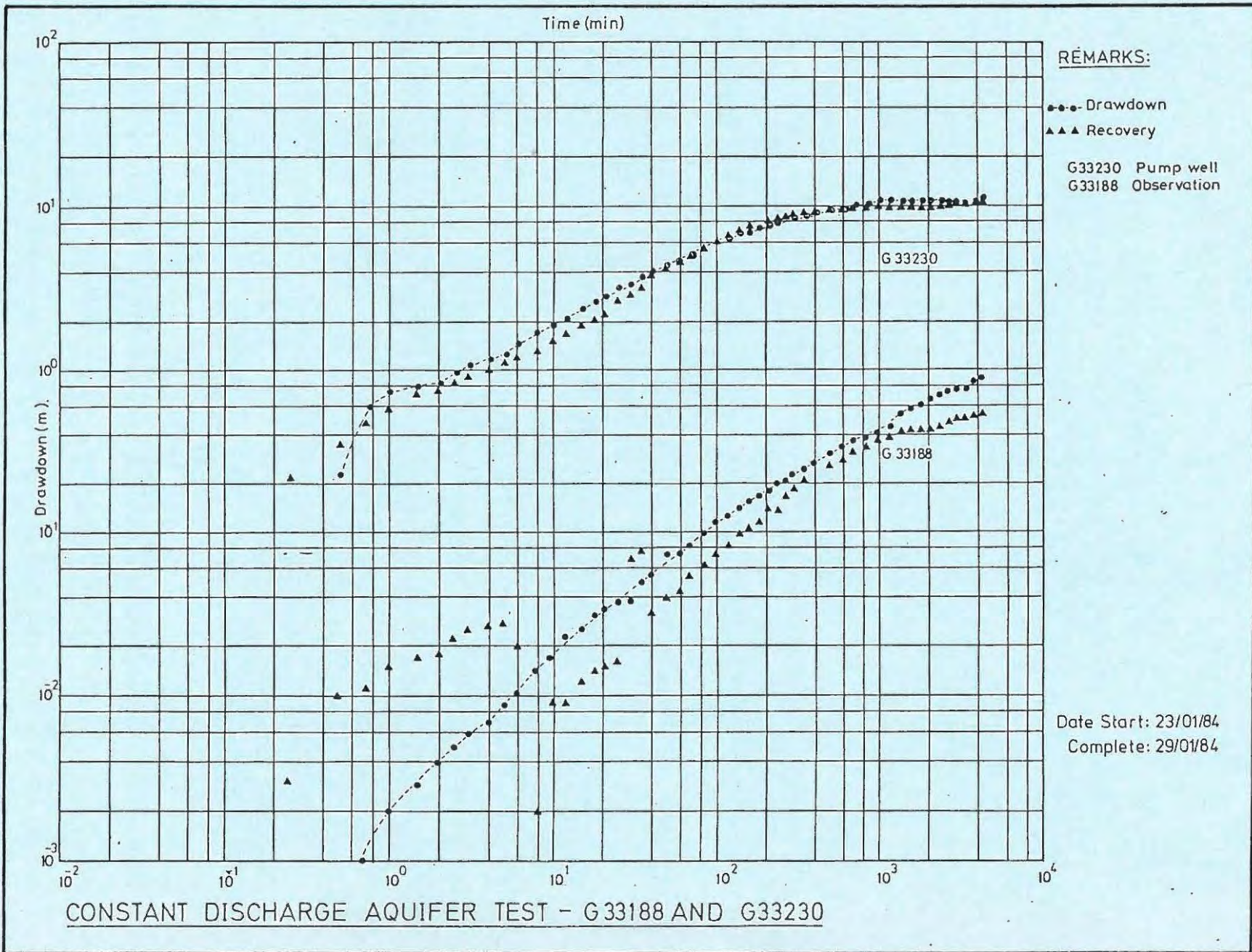
RB34 Production Well  
 RB23 Observation Well

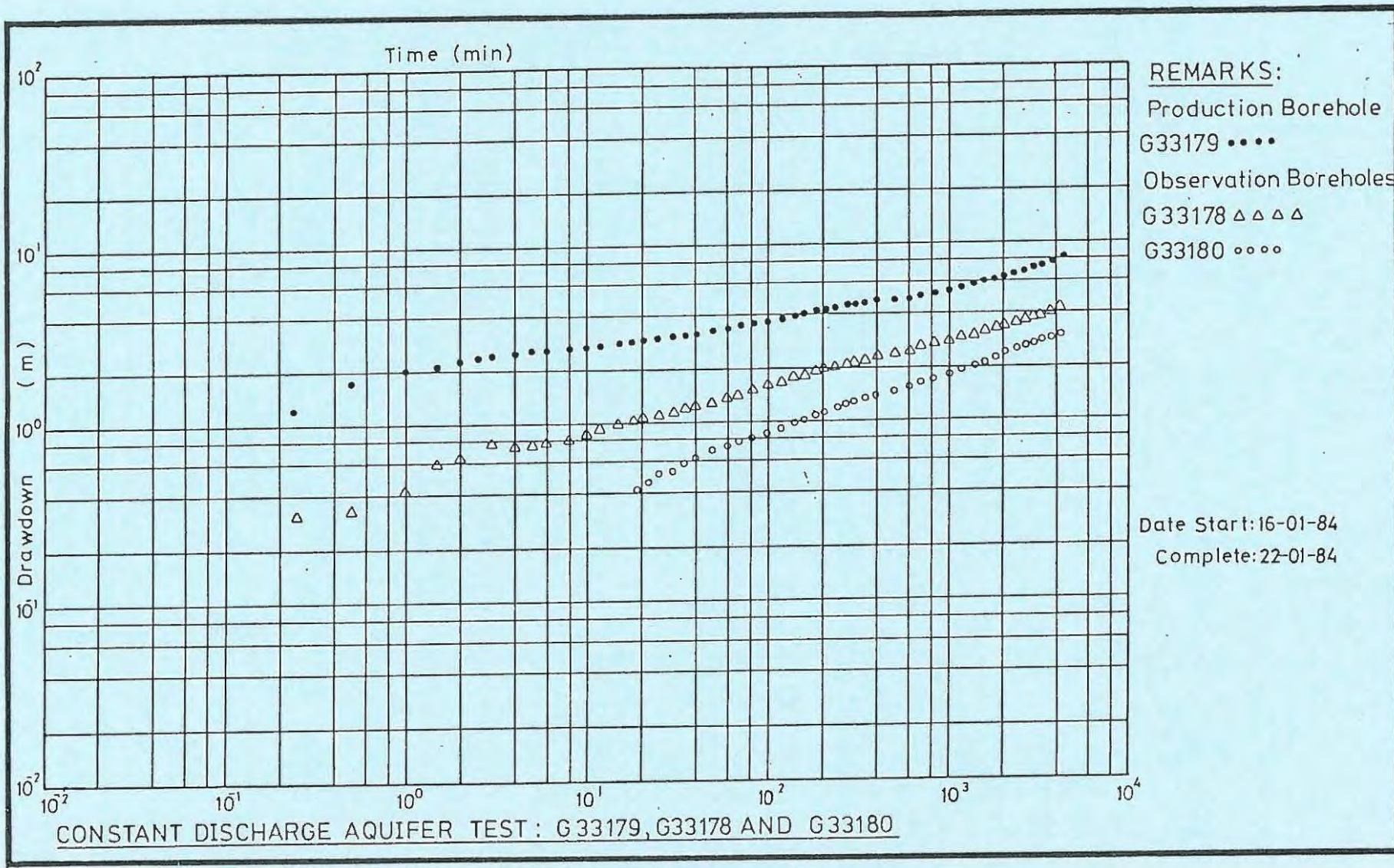
- Drawdown RB23
- ▲▲▲ Recovery RB23

RB34 No access to water-level

Date start: 13/01/84  
 complete: 13/01/84

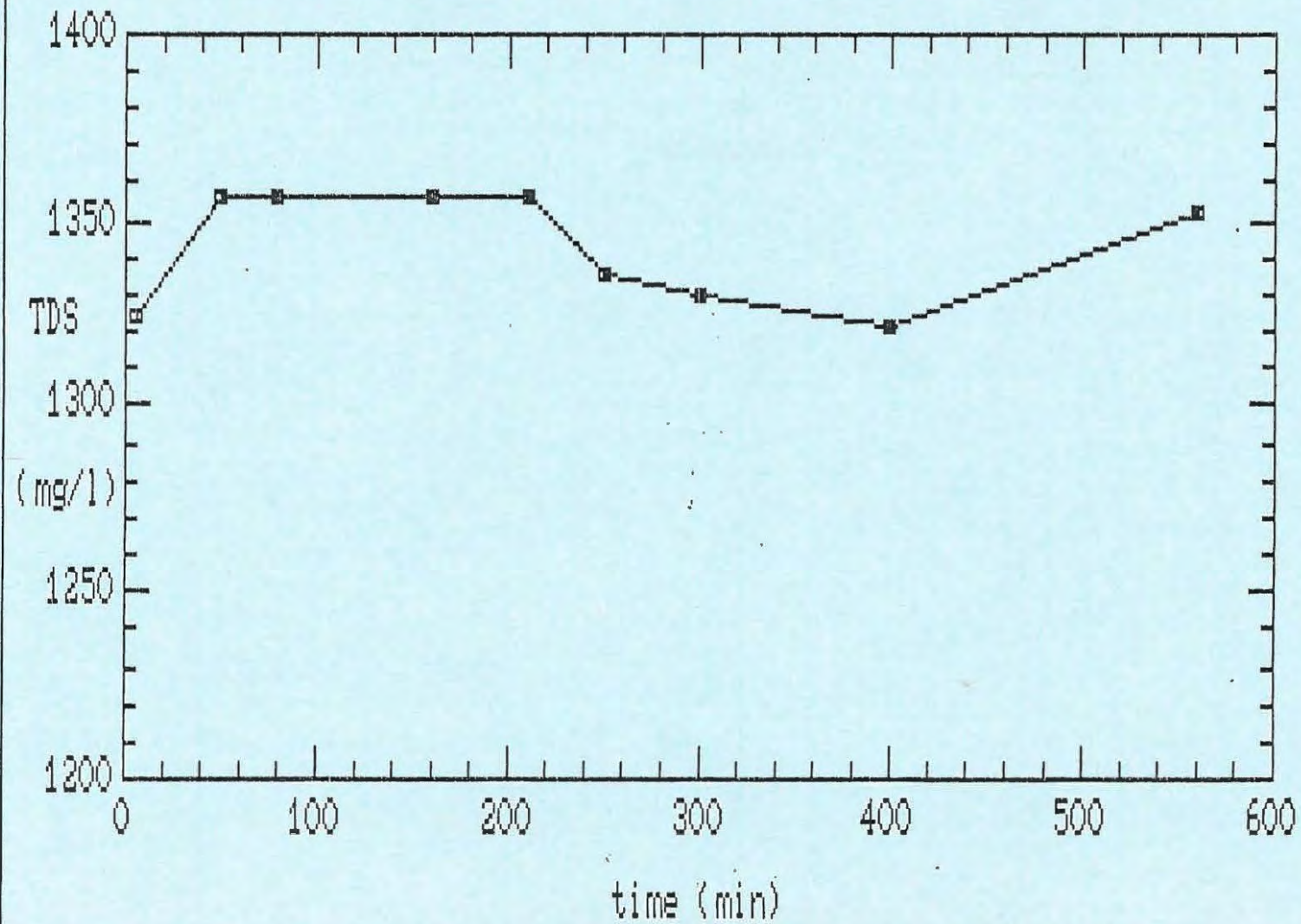
CONSTANT DISCHARGE AQUIFER TEST - RB 34 AND RB 23.



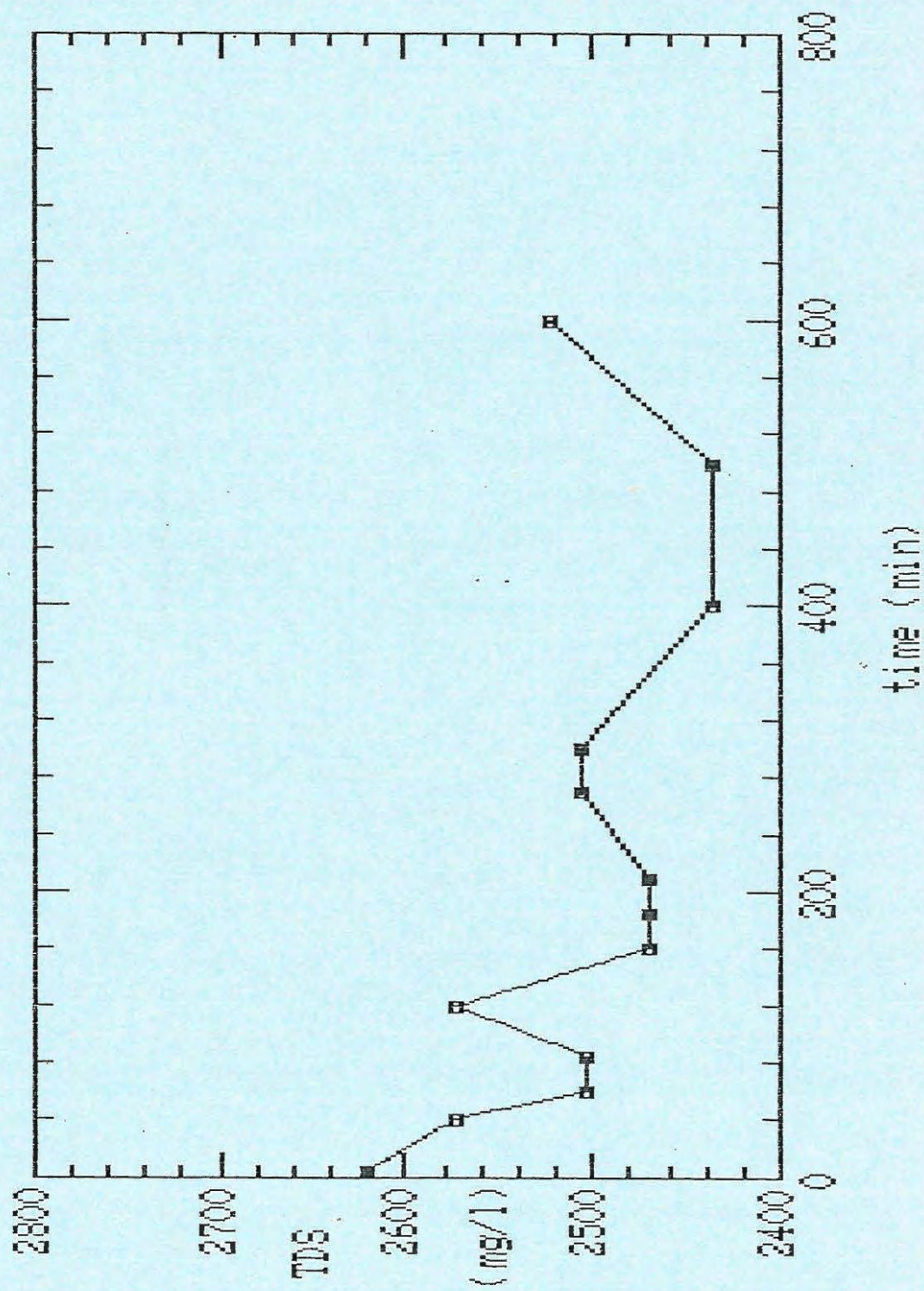


Appendix 4D:  
TDS variation during testing

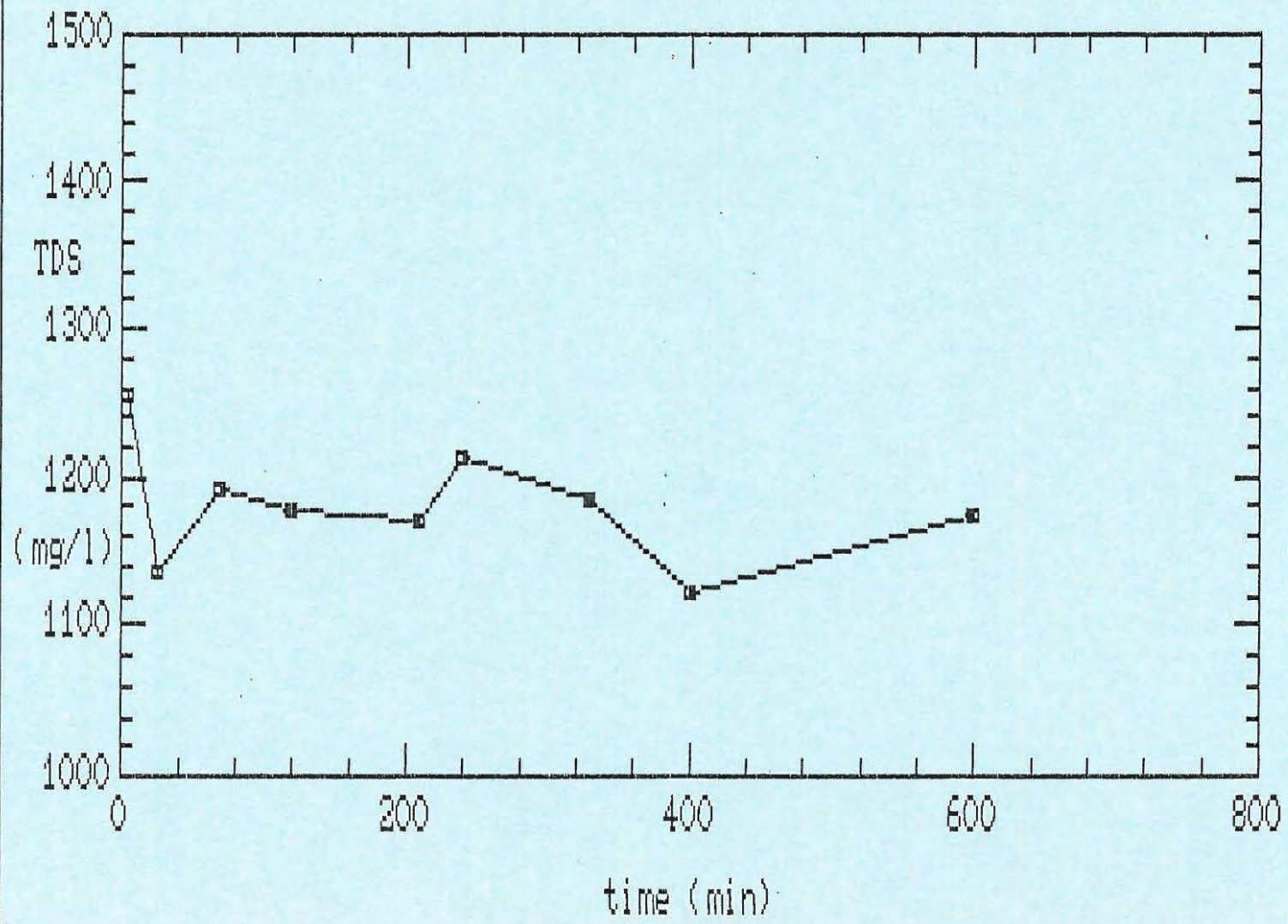
AQUIFER TEST GR4 : TDS VARIATION IN BOREHOLE GR4



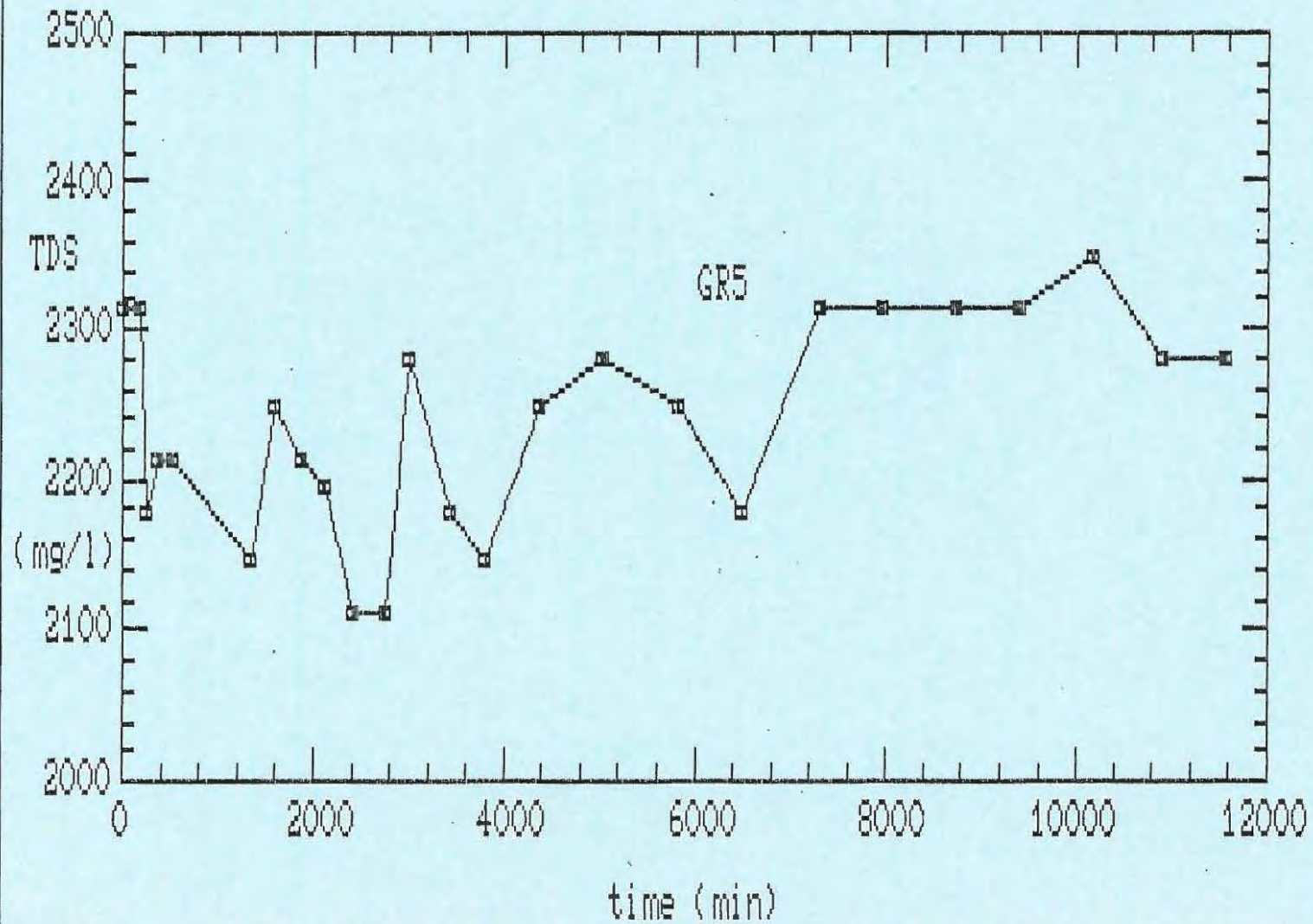
AQUIFER TEST G33174 : TDS VARIATION IN BOREHOLE G33171



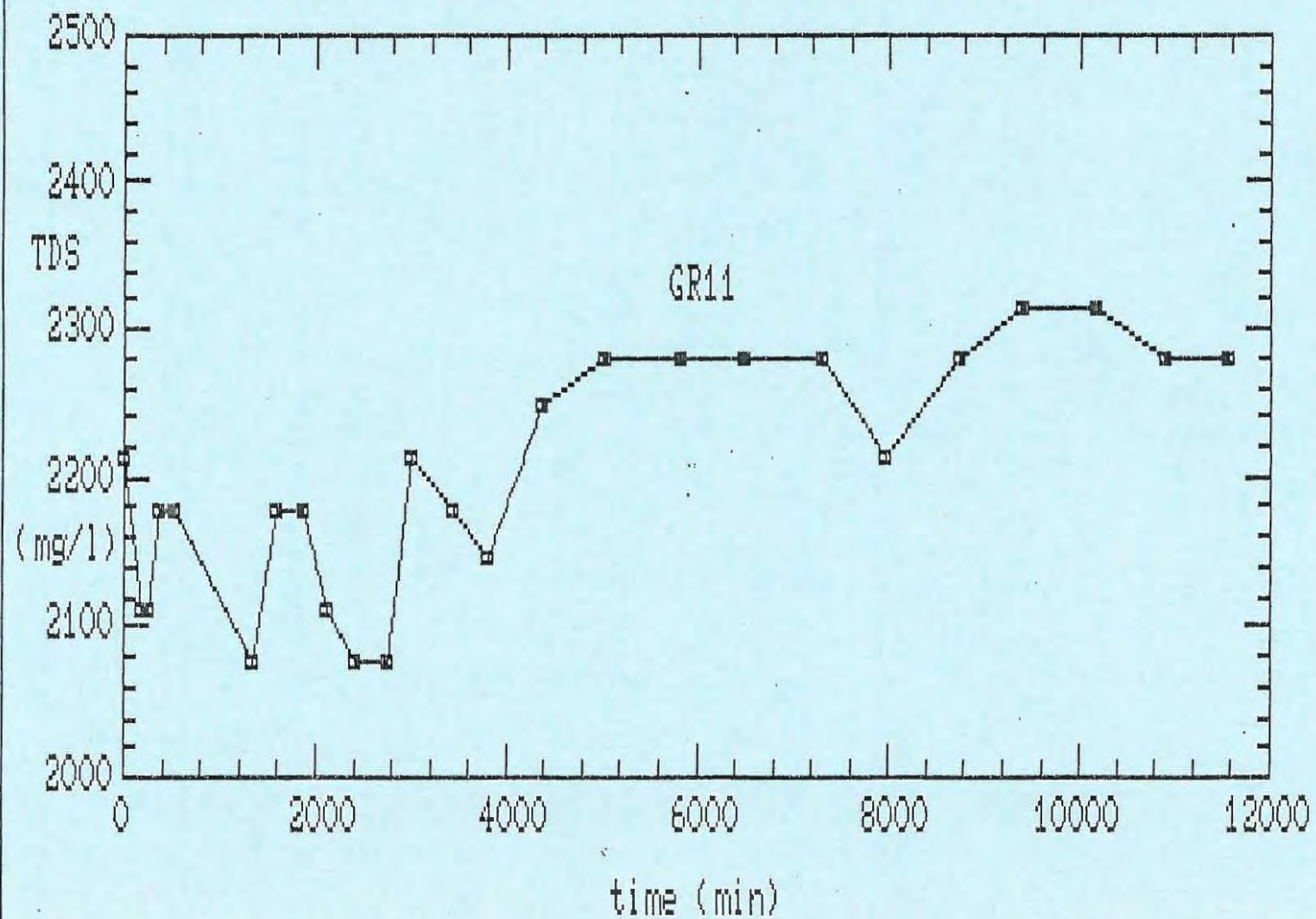
AQUIFER TEST G33170 : TDS VARIATION IN BOREHOLE G33170



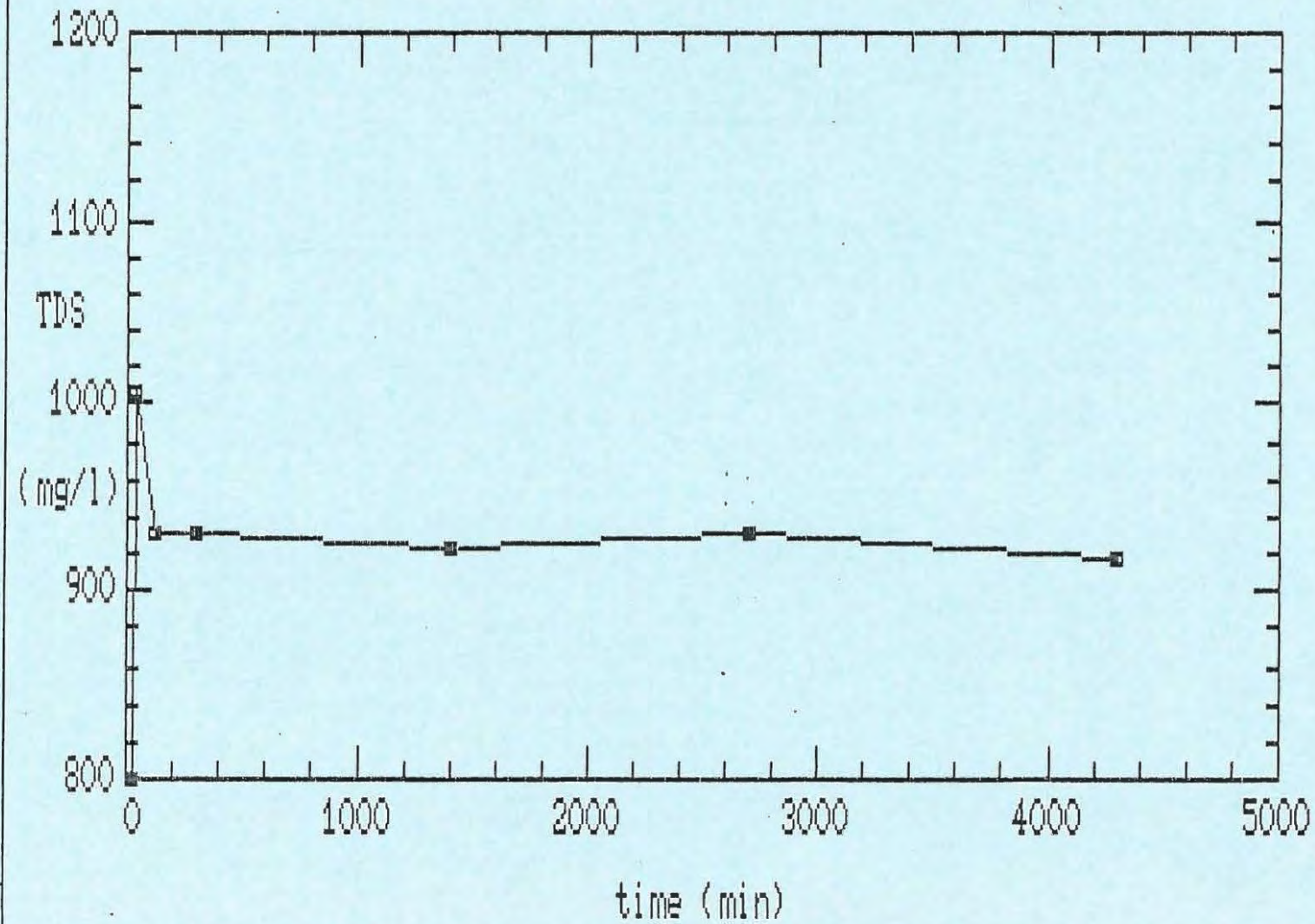
AQUIFER TEST GR11 & GR5 : TDS VARIATION IN BOREHOLE GR5



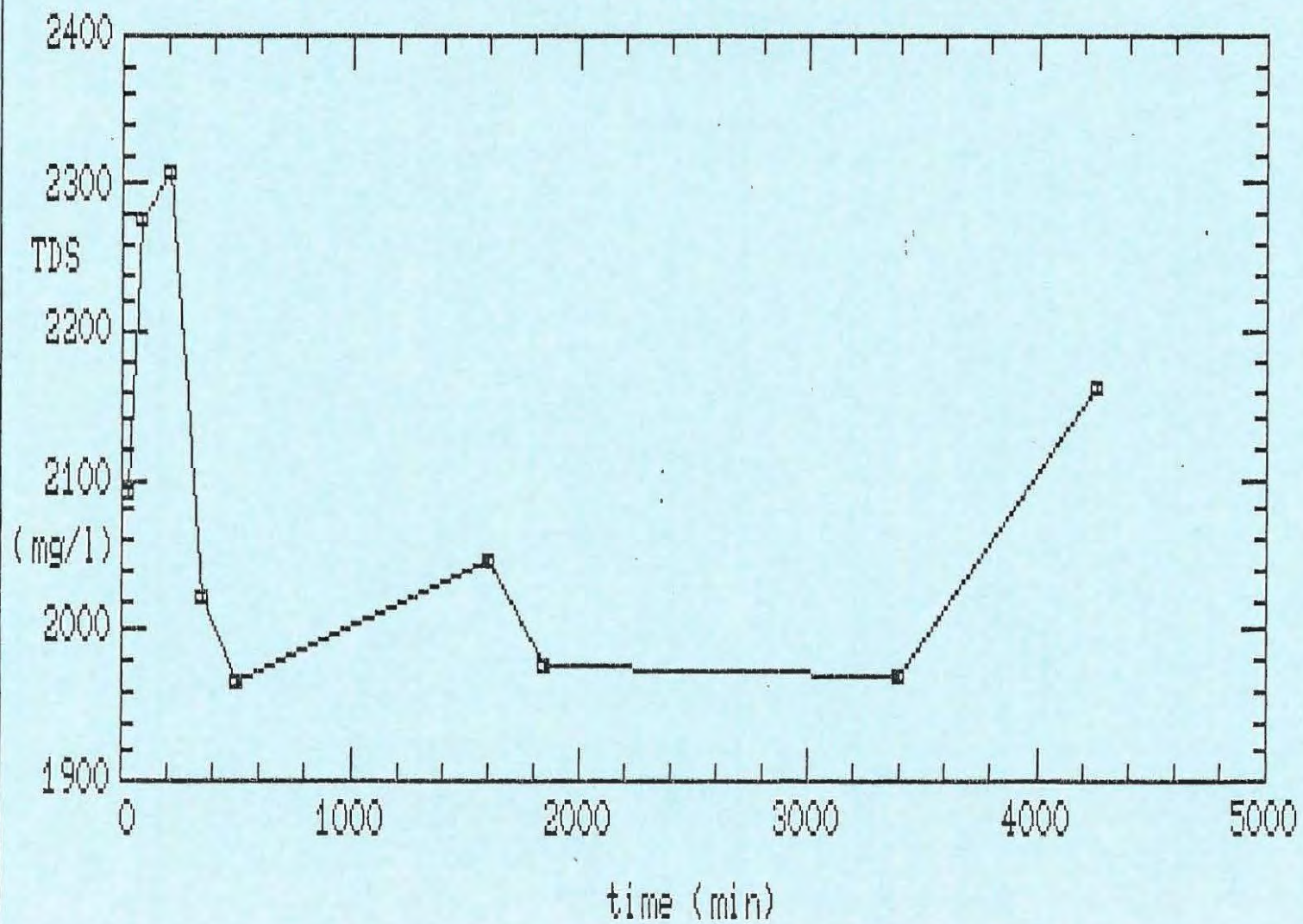
AQUIFER TEST GR11 & GR5 : TDS VARIATION IN BOREHOLE GR11



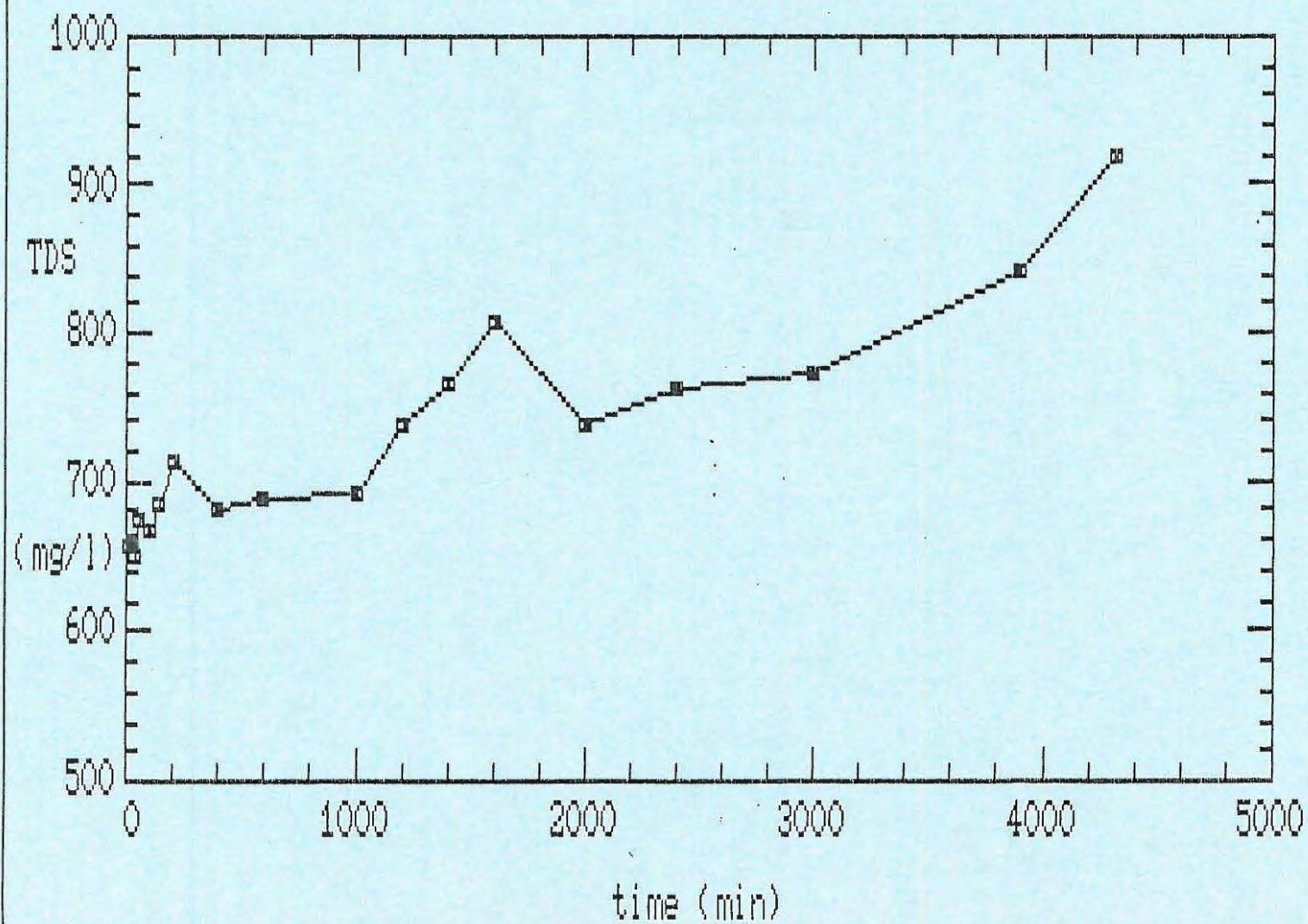
AQUIFER TEST BK18 : TDS VARIATION IN BOREHOLE BK18



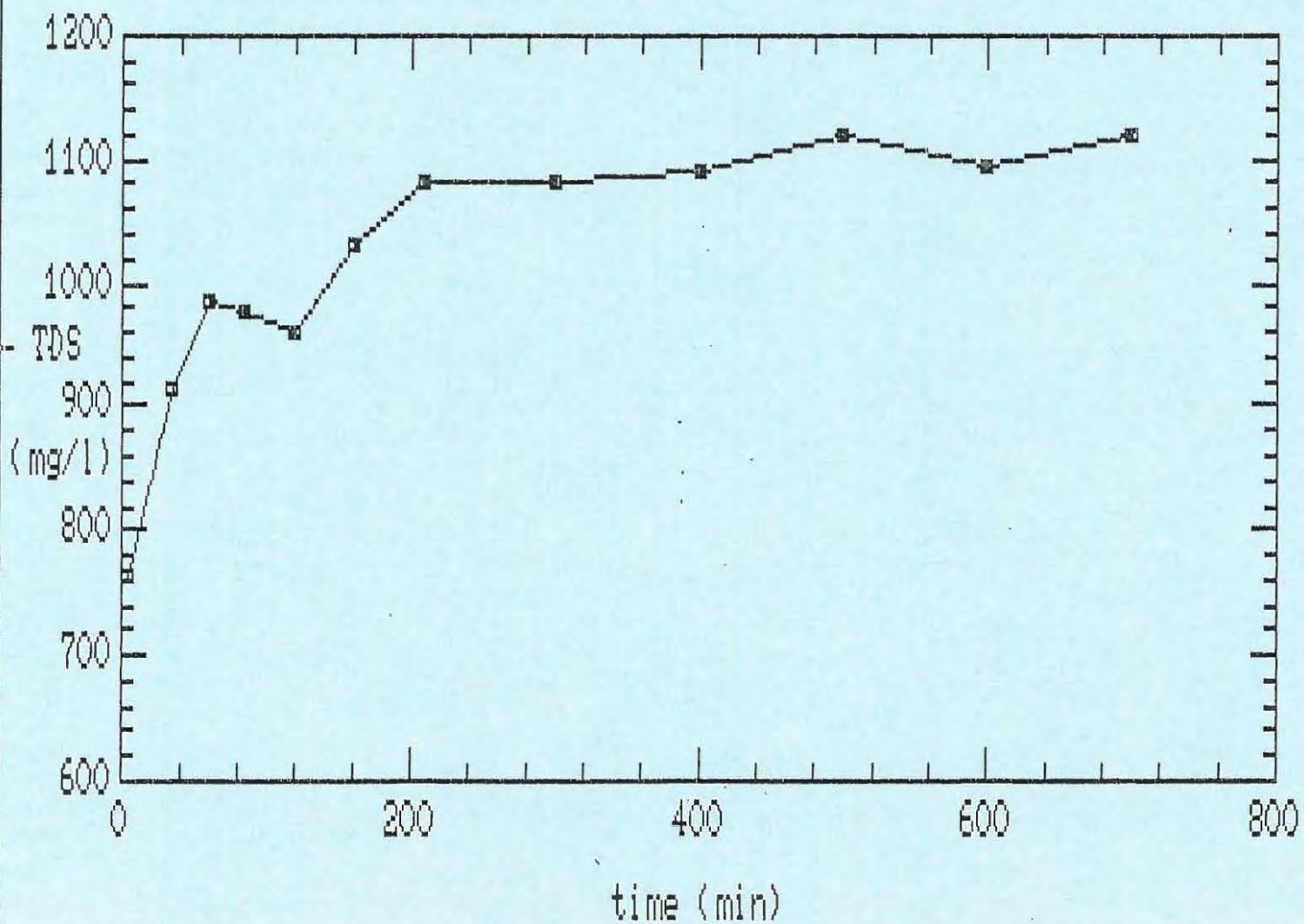
AQUIFER TEST G33173 : TDS VARIATION IN BOREHOLE G33173



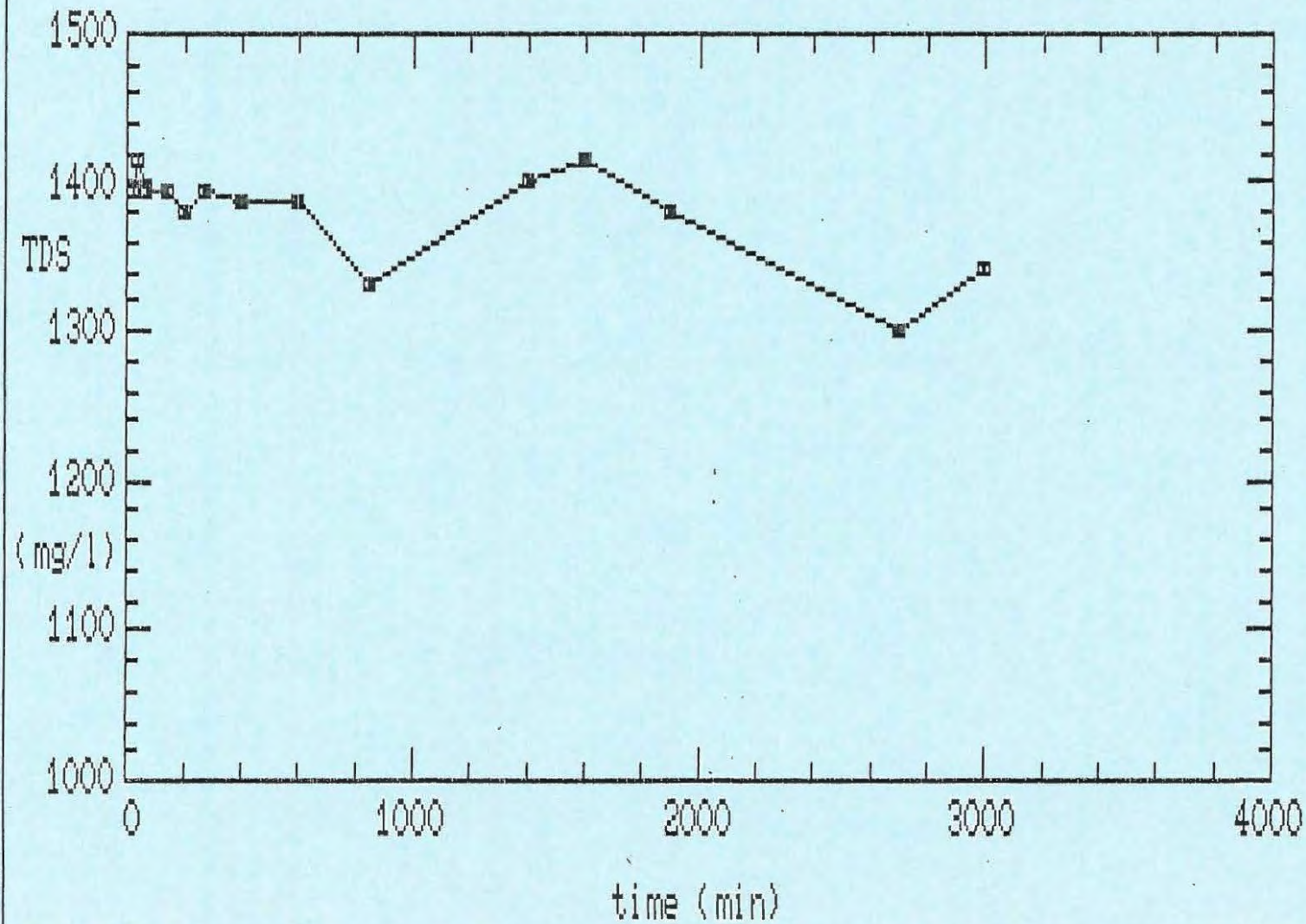
AQUIFER TEST G33233 : TDS VARIATION IN BOREHOLE G33233



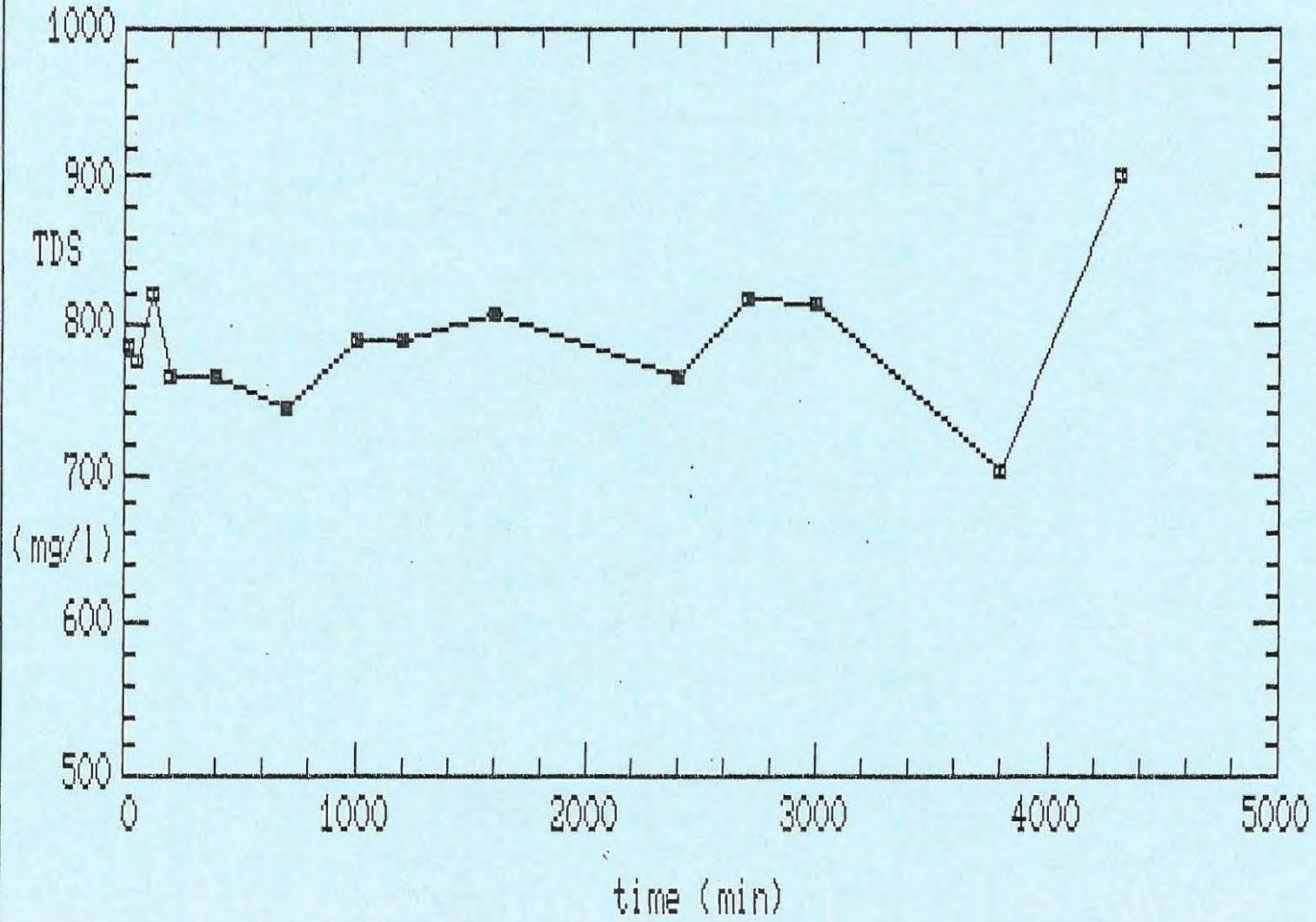
AQUIFER TEST RB34 : TDS VARIATION IN BOREHOLE RB34



AQUIFER TEST G33230 : TDS VARIATION IN BOREHOLE G33230



AQUIFER TEST G33179 : TDS VARIATION IN BOREHOLE G33179



APPENDIX 5:  
GEOPHYSICAL DATA

Appendix 5A:  
V.E.S earth models

INDEX

○○○○ - Field curve  
—— - Theoretical curve

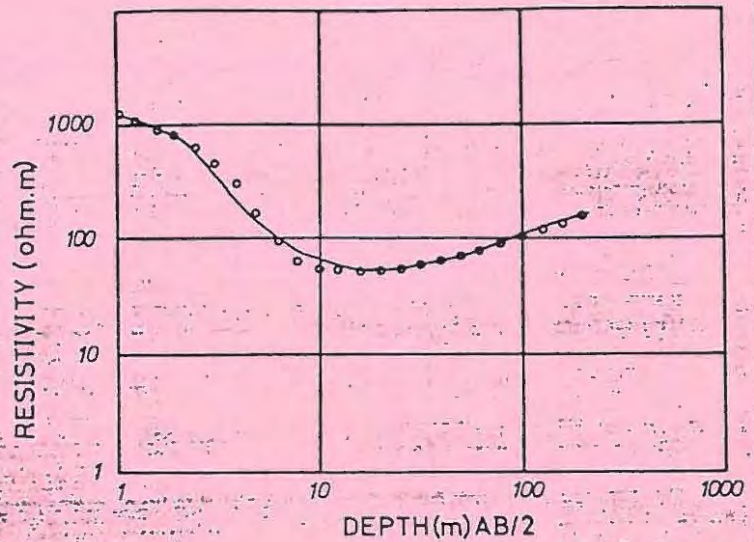
Sounding No: 1

**EARTH MODEL**

Layer Thickness (m)	Resistivity (ohm.m)
0.1	1500.0
1.4	1100.0
3.0	45.0
18.8	50.0
53.0	120.0
	500.0

TOTAL S=0.886 Siemens

TYPE :



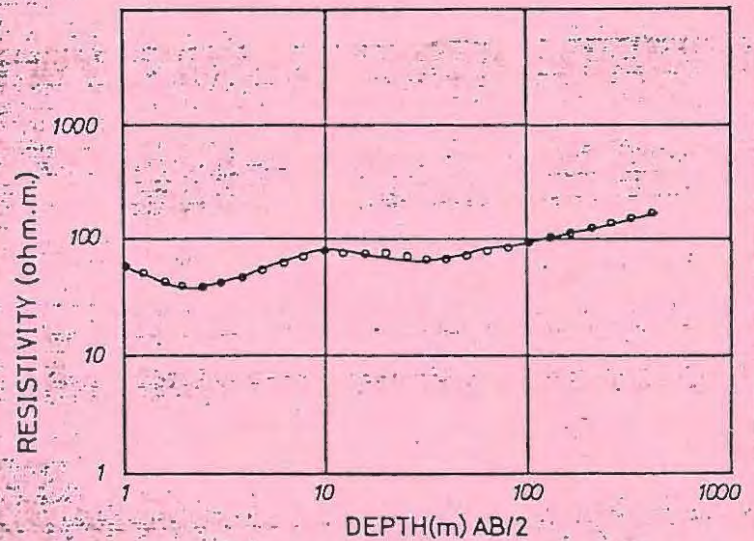
Sounding No: 2

**EARTH MODEL**

Layer Thickness (m)	Resistivity (ohm.m)
0.6	80.0
1.2	20.0
4.1	170.0
15.9	40.0
45.0	130.0
17.0	90.0
	220

TOTAL S =1.024 Siemens

TYPE :



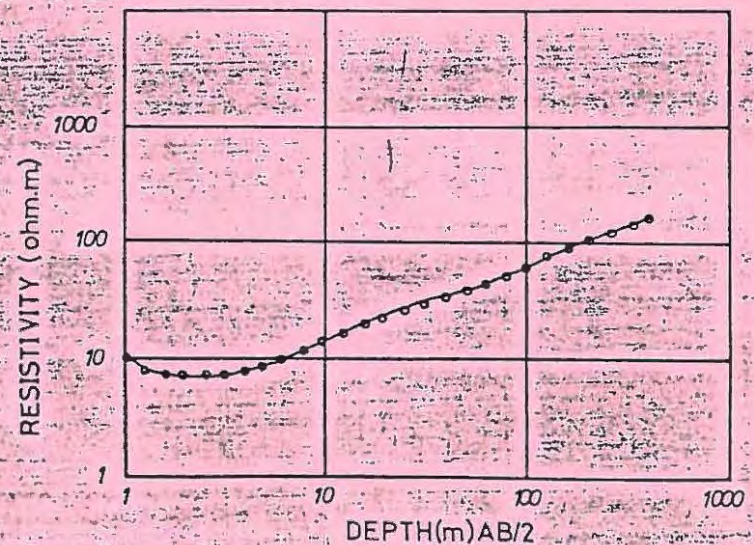
Sounding No: 3

**EARTH MODEL**

Layer Thickness (m)	Resistivity (ohm.m)
0.3	42.0
3.6	6.5
15.0	55.0
16.0	35.0
	3500

TOTAL S =1.290 Siemens

TYPE :



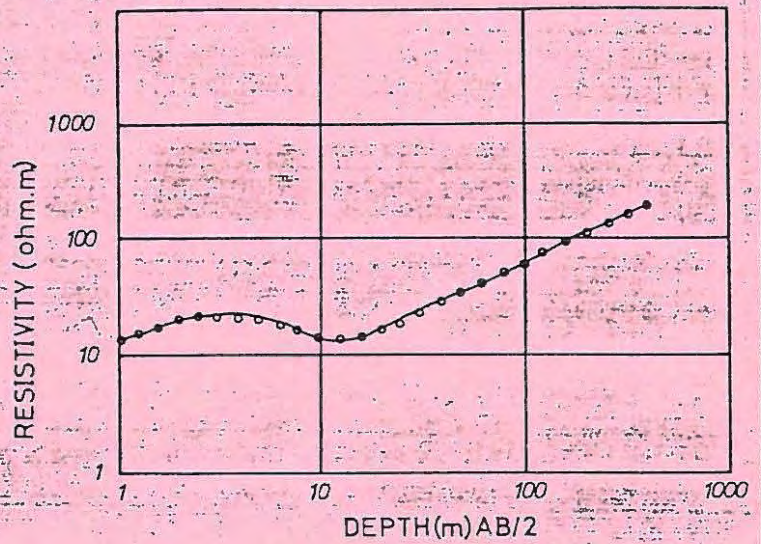
Sounding No: 4

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	9.0
2.0	35.0
8.0	7.5
11.7	120.0
5.1	60.0
	600.0

TOTAL S = 1380 Siemens.

TYPE :



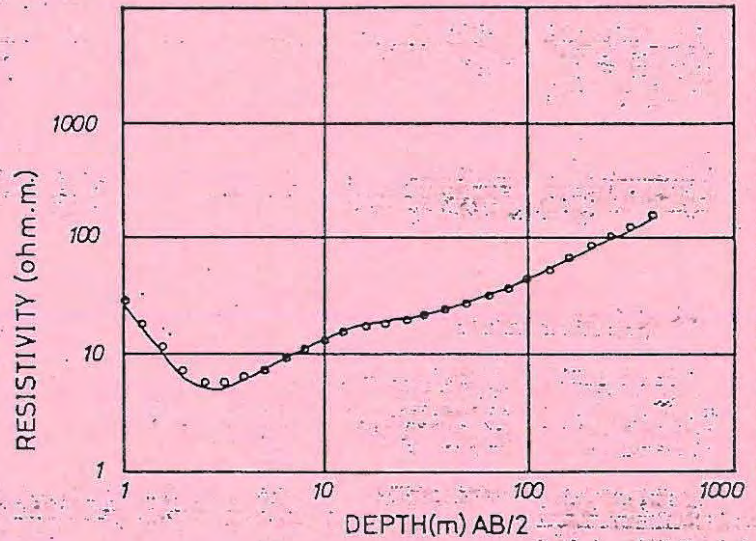
Sounding No: 5

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	74.0
2.2	4.0
10.0	40.0
15.9	15.0
40.6	110.0
	3000.0

TOTAL S = 2232 Siemens.

TYPE :



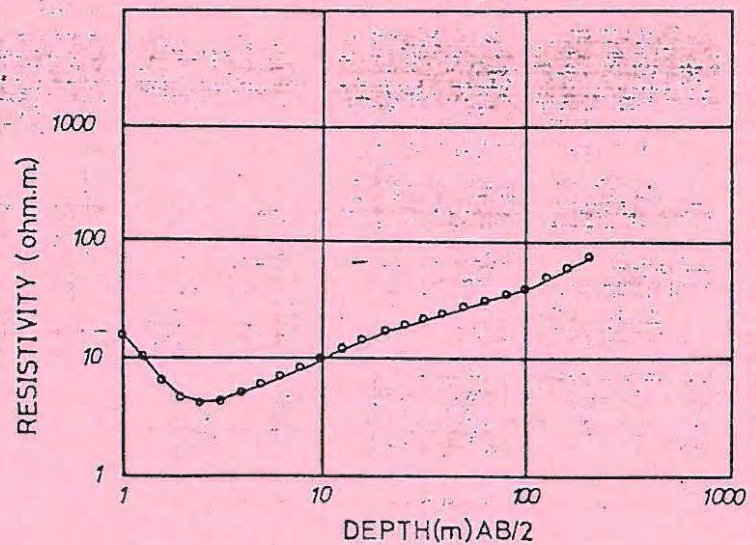
Sounding No: 6

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	47.5
2.3	3.0
25.0	42.0
22.3	20.0
	3000.0

TOTAL S = 2486 Siemens.

TYPE :



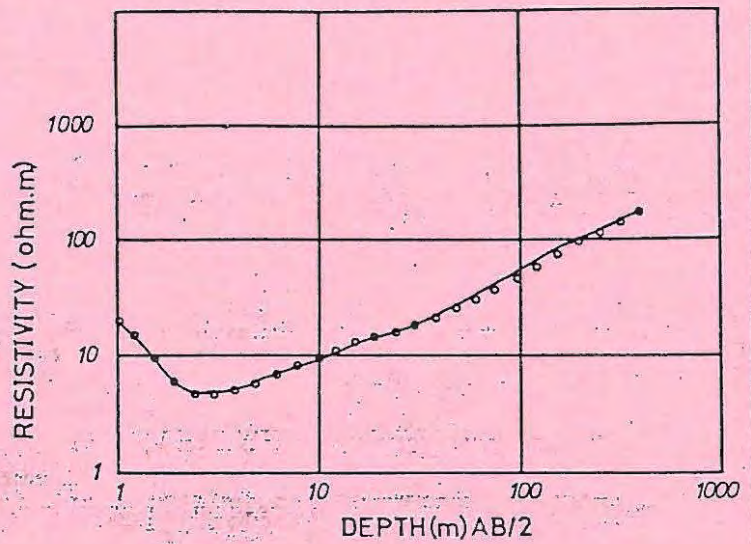
Sounding No: 7

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	57.0
2.5	3.5
8.0	30.0
10.0	10.0
15.0	1000.0
	2000.0

TOTAL S = 2.004 Siemens.

TYPE :



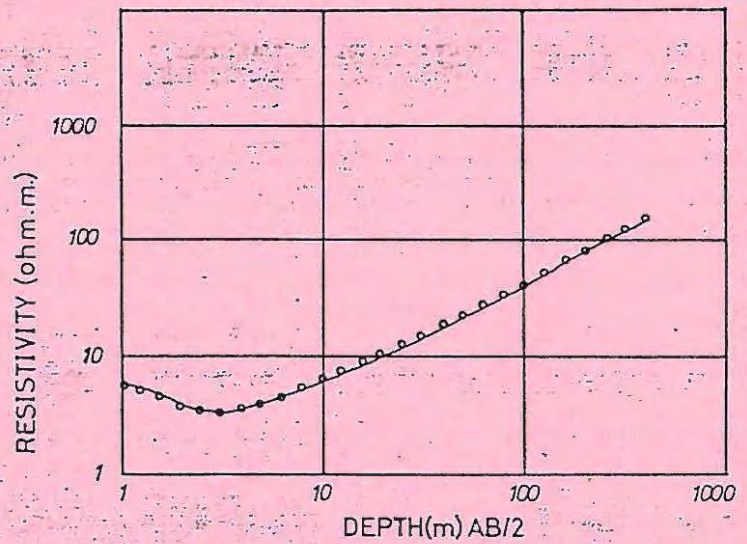
Sounding No: 8

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.7	7.4
2.4	2.4
10.0	20.0
16.0	30.0
	2000.0

TOTAL S = 2.128 Siemens.

TYPE :



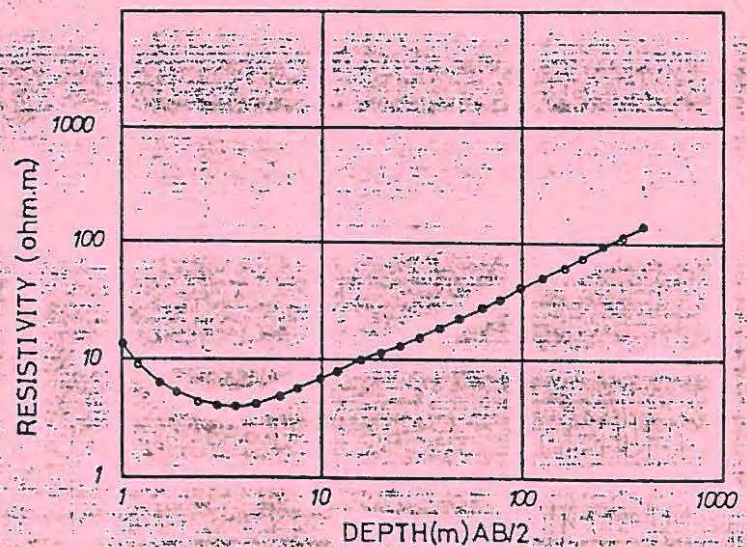
Sounding No: 9

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	75.0
0.6	14.0
4.0	3.2
11.0	35.0
15.0	20.0
	1600

TOTAL S = 2.355 Siemens.

TYPE :



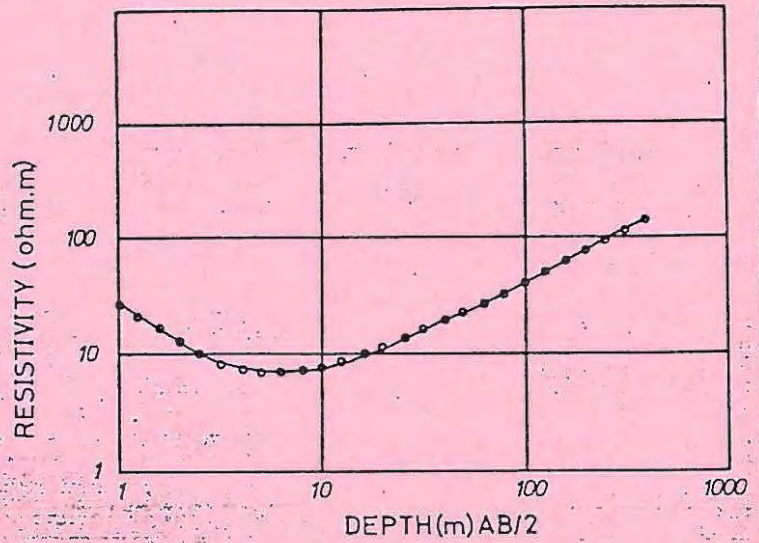
Sounding No: 10

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.8	300
7.0	6.0
9.6	25.0
32.0	40.0
	2000.0

TOTAL S = 2374 Siemens.

TYPE :



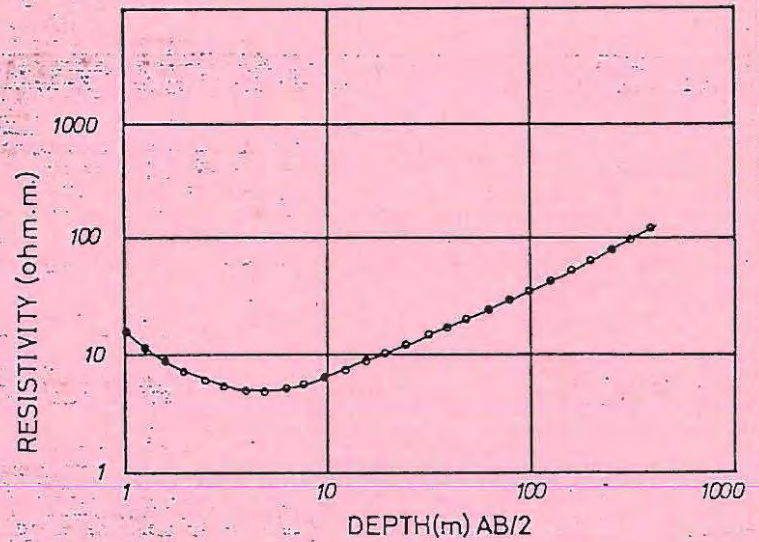
Sounding No: 11

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	110.0
0.8	100
4.5	4.0
8.0	20.0
43.0	40.0
	1500.0

TOTAL S = 2.681 Siemens.

TYPE :



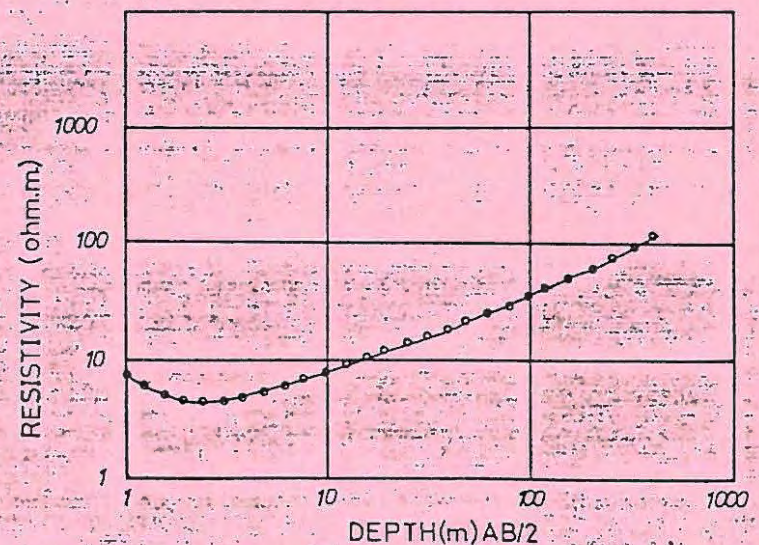
Sounding No: 12

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	14.0
2.6	3.6
12.0	18.0
24.0	32.0
70.0	100.0
	1500.0

TOTAL S = 2.869 Siemens.

TYPE :



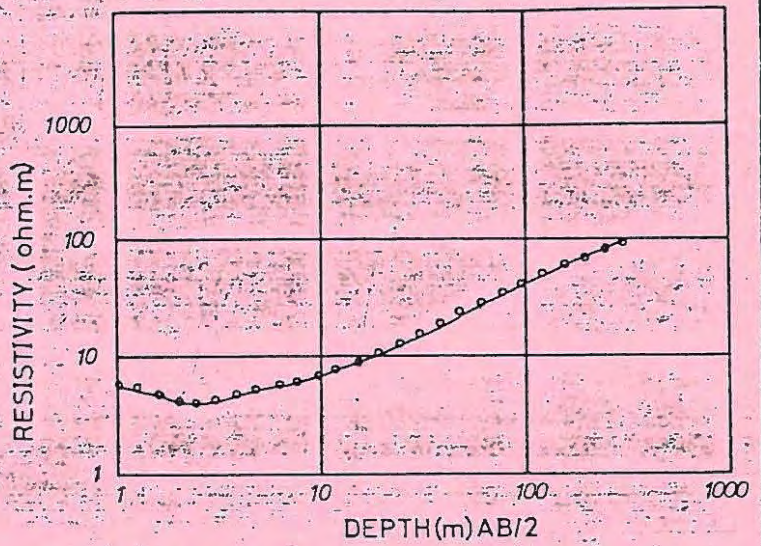
Sounding No: 13

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	6.8
0.9	2.1
9.5	7.2
	200.0

TOTAL S = 1.851 Siemens

TYPE :



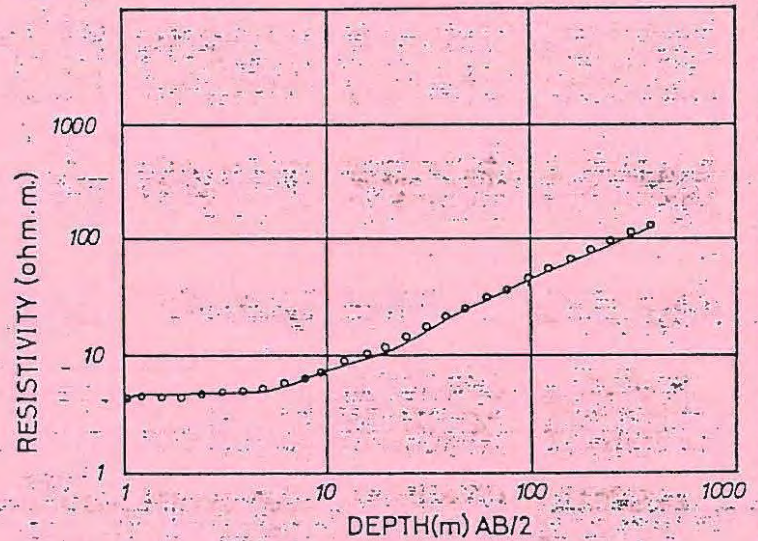
Sounding No: 14

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	4.
1.3	5.5
1.8	3.2
16.0	20.0
	280.0

TOTAL S = 1.749 Siemens

TYPE :



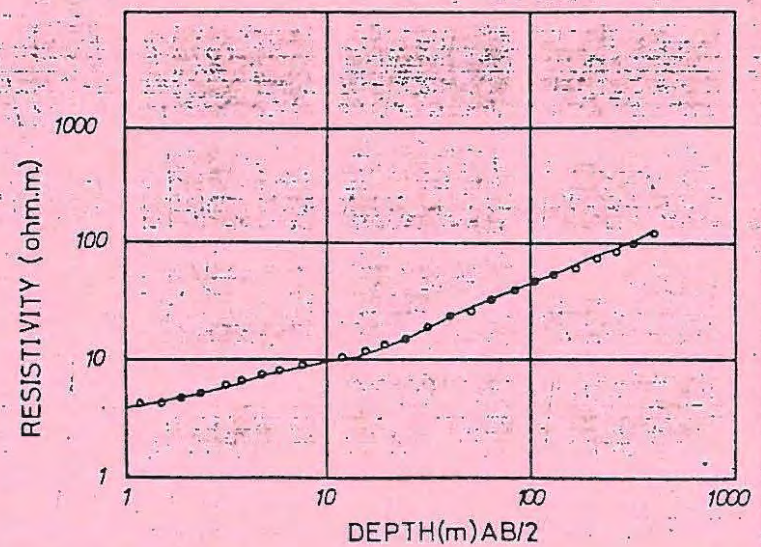
Sounding No: 15

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.7	3.6
4.2	15.0
3.5	5.0
30.0	100.0
49.5	90.0
38.2	180.0

TOTAL S = 2.501 Siemens

TYPE :



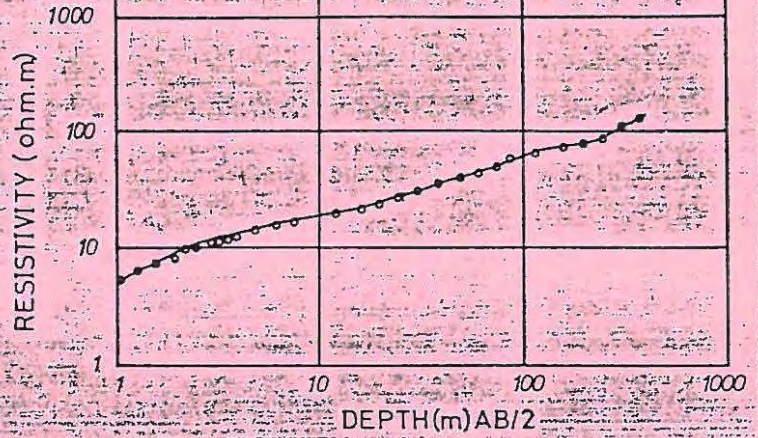
Sounding No: 16

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	2.8
2.6	25.0
1.0	5.5
19.2	37.0
96.0	100.0
	300.0

TOTAL S=1929 Siemens.

TYPE :



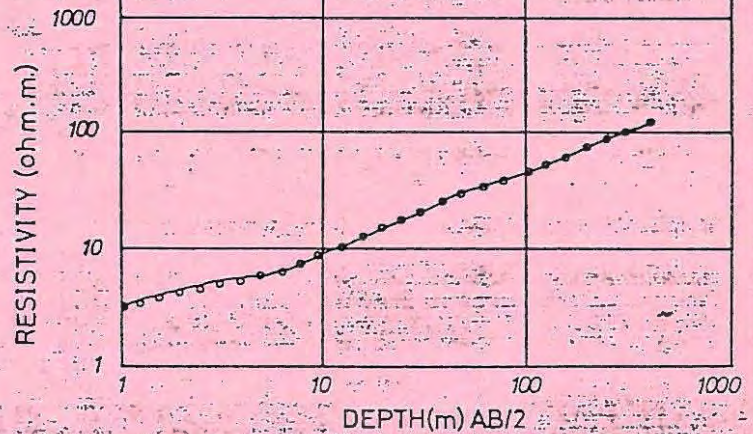
Sounding No: 17

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	2.3
1.1	9.0
2.0	3.0
26.0	65.0
50.0	50.0
	500.0

TOTAL S = 2480 Siemens.

TYPE :



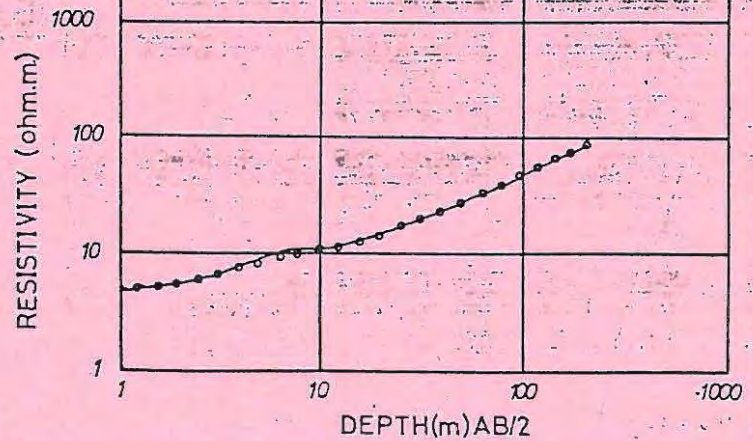
Sounding No: 18

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.7	4.4
3.3	17.0
4.4	6.0
33.0	70.0
	350.0

TOTAL S = 1789 Siemens.

TYPE :



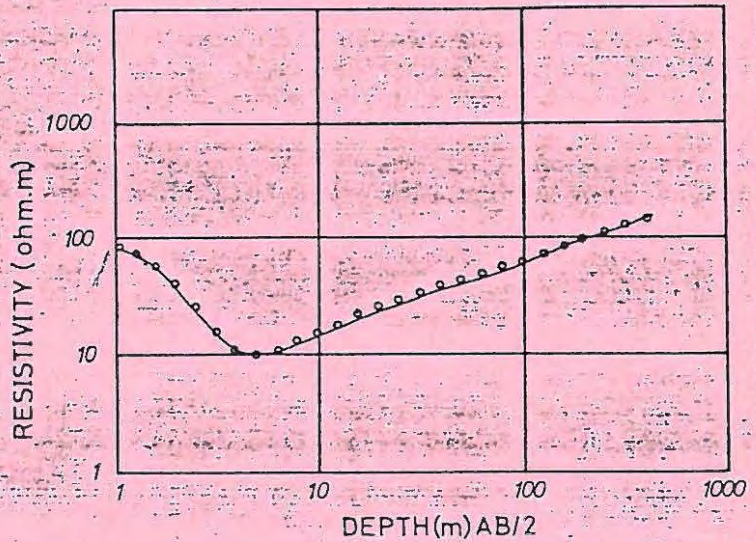
Sounding No: 19

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	121.0
0.4	70.0
1.9	4.0
37.4	63.0
108.6	130.0
	500.0

TOTAL S = 1.915 Siemens.

TYPE :



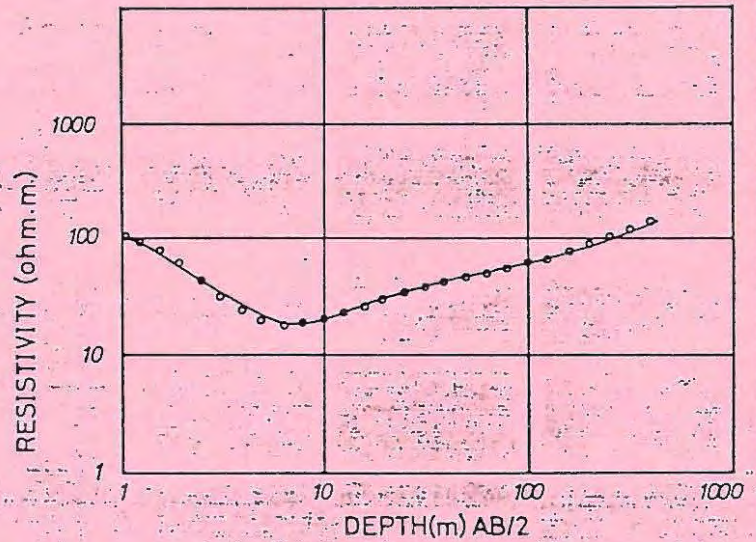
Sounding No: 20

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	121.0
0.2	70.0
6.0	15.0
42.6	65.0
39.6	52.0
	400.0

TOTAL S = 1.827 Siemens.

TYPE :



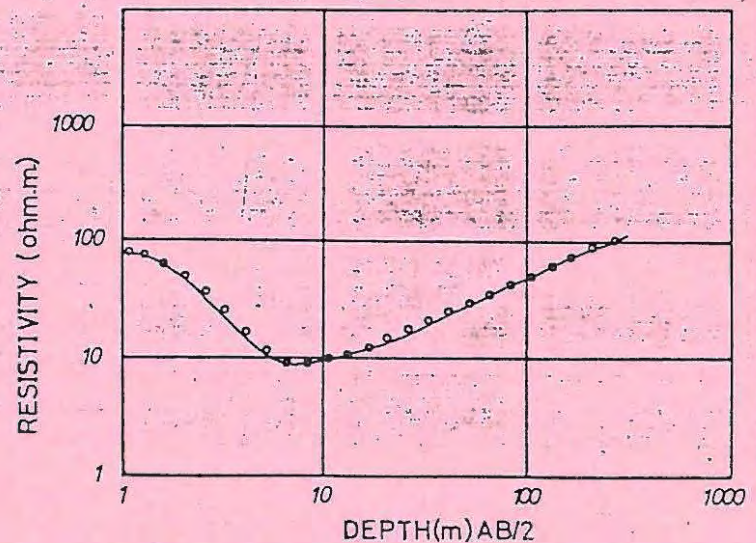
Sounding No: 21

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	106.0
0.8	70.0
6.9	7.0
40.7	50.0
	500.0

TOTAL S = 1.810 Siemens.

TYPE :



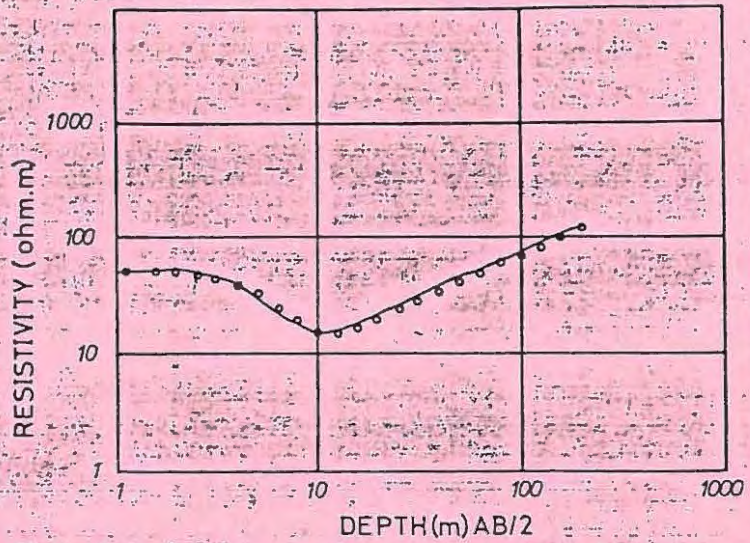
Sounding No: 22

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	48.0
1.6	60.0
5.7	6.8
47.4	110.0
	500.0

TOTAL S = 1.314 Siemens

TYPE :



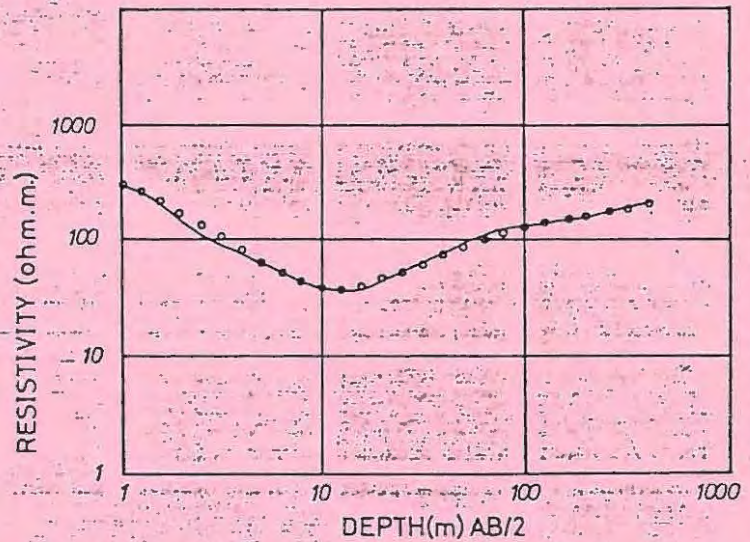
Sounding No: 23

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	400.0
1.8	100.0
12.4	30.0
60.0	300.0
45.0	50.0
	600.0

TOTAL S = 1.533 Siemens

TYPE :



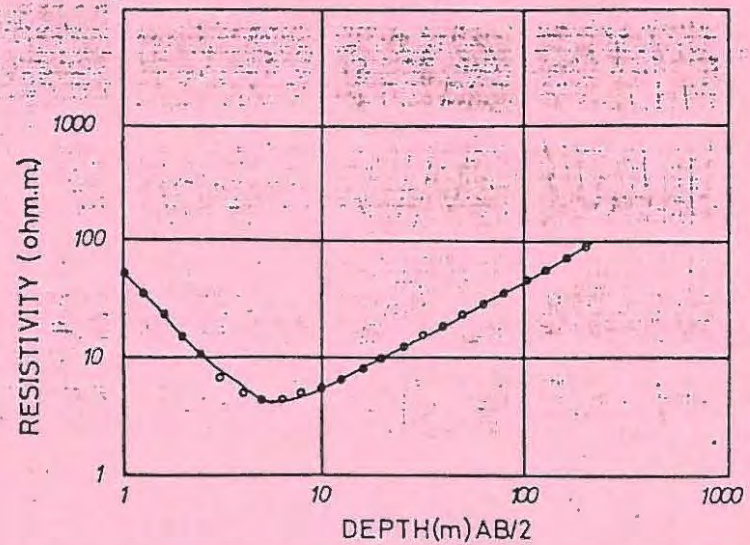
Sounding No: 24

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.3	175.0
0.8	25.0
5.9	3.5
6.1	25.0
	10 000

TOTAL S = 1.965 Siemens

TYPE :



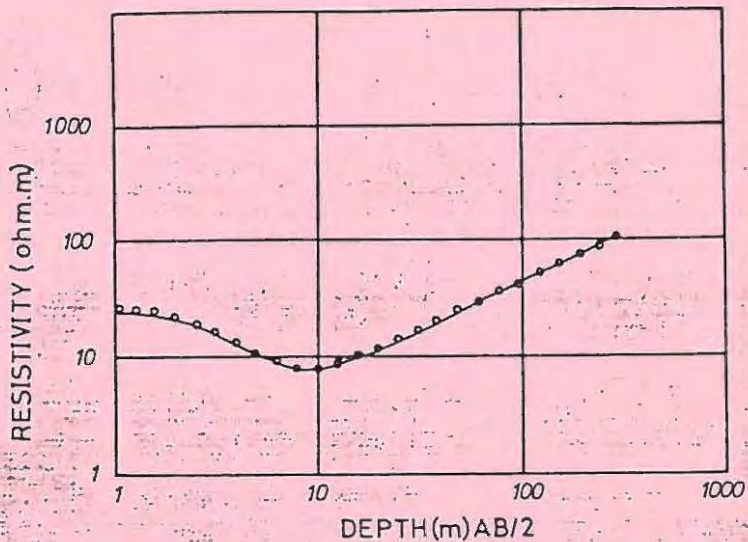
Sounding No: 25

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	28.5
1.1	23.0
8.1	6.0
32.2	45.0
	500.0

TOTAL S = 2.132 Siemens.

TYPE :



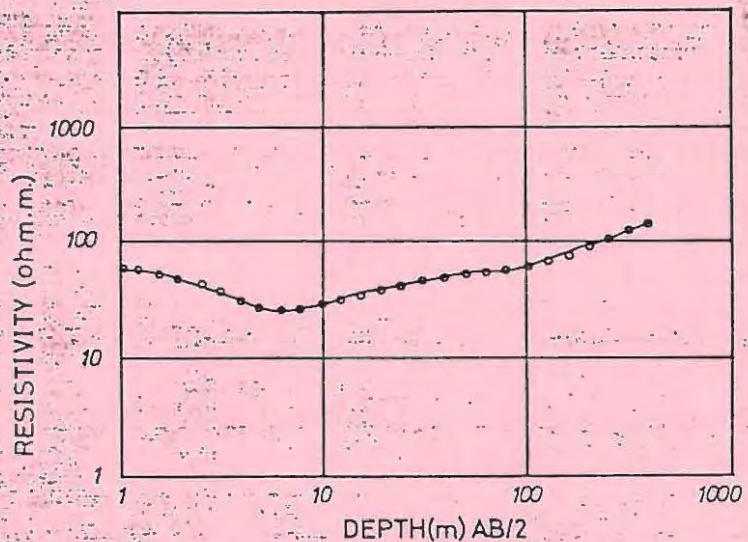
Sounding No: 26

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.5	57.0
4.7	17.0
15.0	80.0
49.0	40.0
	350.0

TOTAL S = 1.718 Siemens.

TYPE :



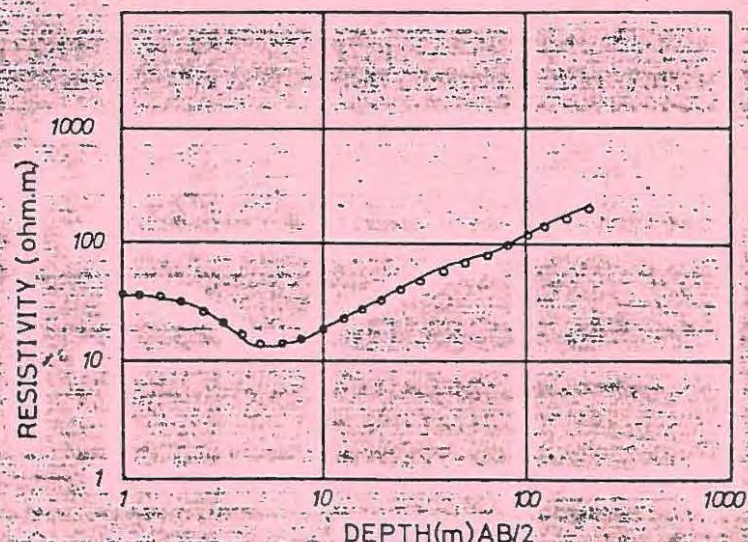
Sounding No: 27

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.0	12.5
1.0	50.0
3.2	7.0
50.0	180.0
11.3	70.0
	100000

TOTAL S = 0.924 Siemens.

TYPE :



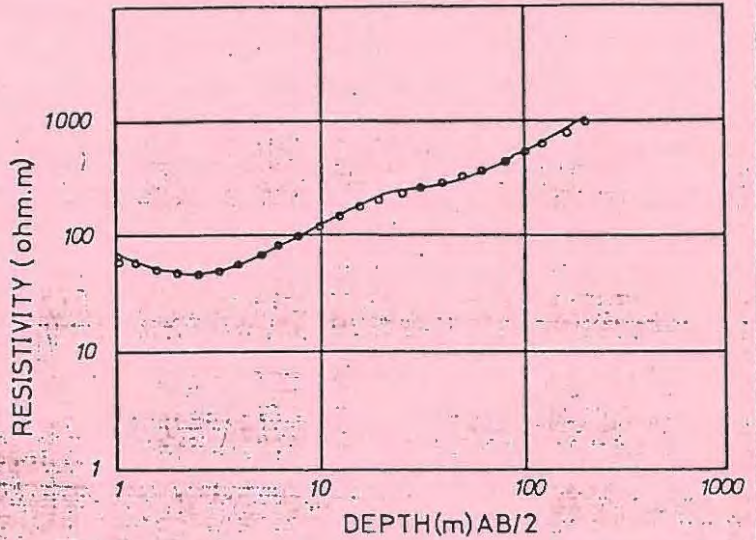
Sounding No: 28

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	67.0
1.9	30.0
10.0	1000.0
9.0	80.0
	100000

TOTAL S=0.196 Siemens

TYPE :



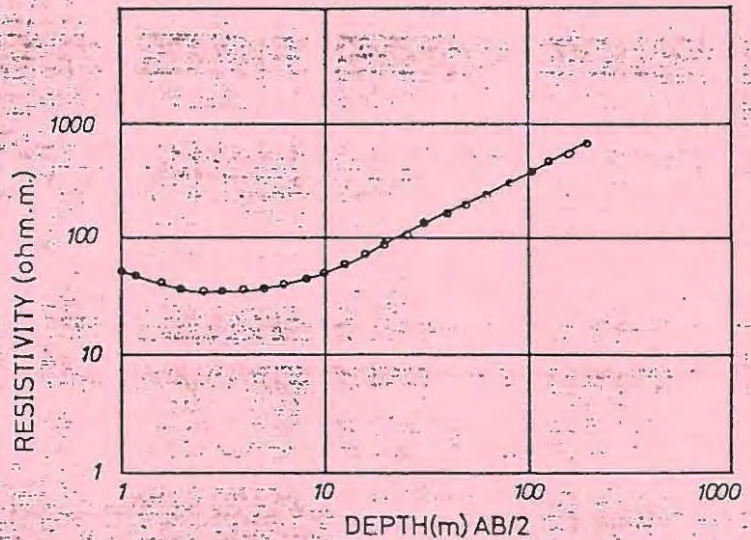
Sounding No: 29

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	72.0
1.1	26.0
2.3	43.0
2.5	25.0
33.0	900.0
	10000

TOTAL S = 0.240 Siemens

TYPE :



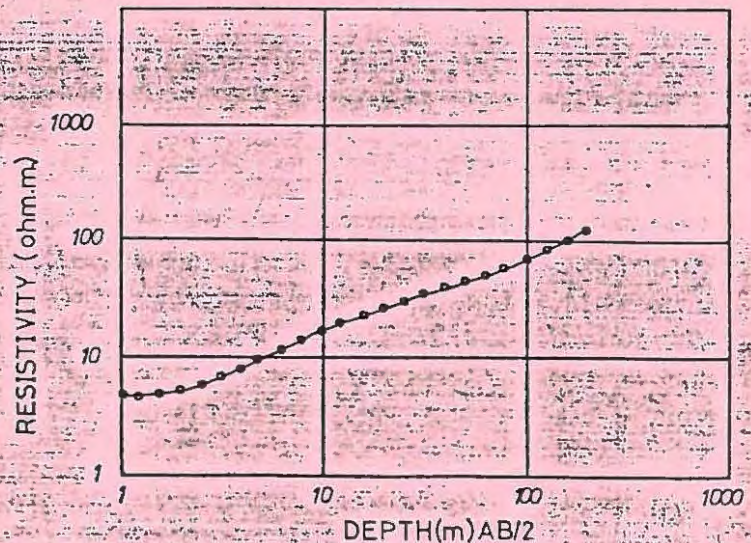
Sounding No: 30

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	4.0
1.6	5.0
30.0	70.0
18.0	30.0
	10000

TOTAL S = 1.491 Siemens

TYPE :



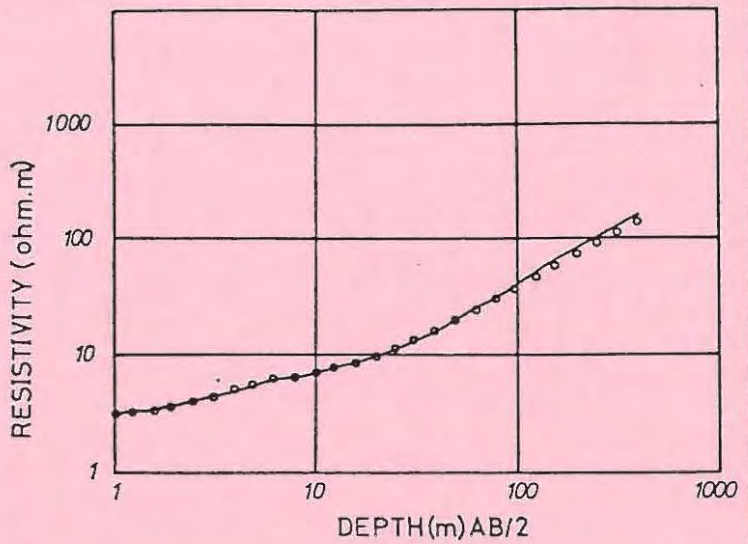
Sounding No: 31

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.3	2.9
0.7	10.0
11.0	8.0
29.5	50.0
	4000.0

TOTAL S=2.478 Siemens.

TYPE :



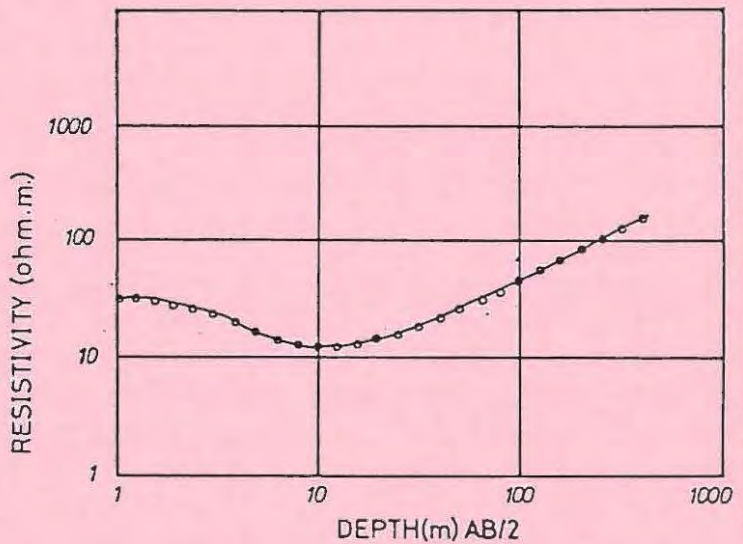
Sounding No:32

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.6	32.0
1.0	15.0
4.1	8.0
9.0	15.0
25.3	30.0
	950.0

TOTAL S = 2.073 Siemens.

TYPE :



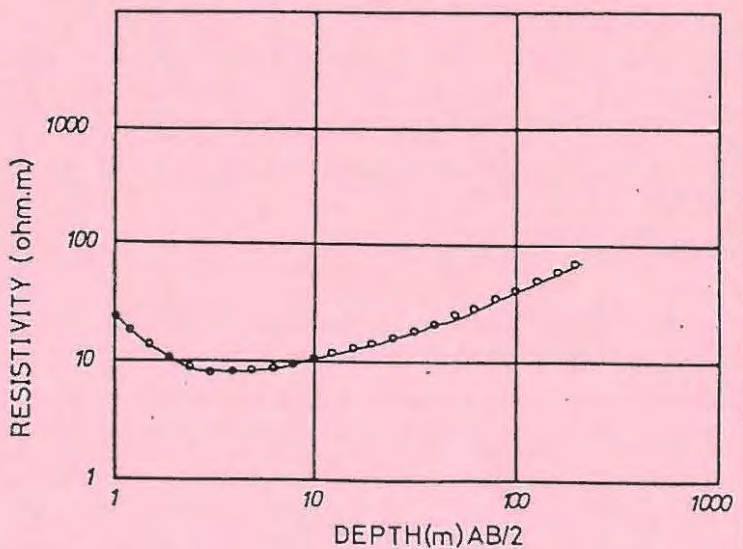
Sounding No: 33

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	44.0
3.4	7.0
9.0	15.0
23.6	30.0
	200.0

TOTAL S = 1.881 Siemens.

TYPE :



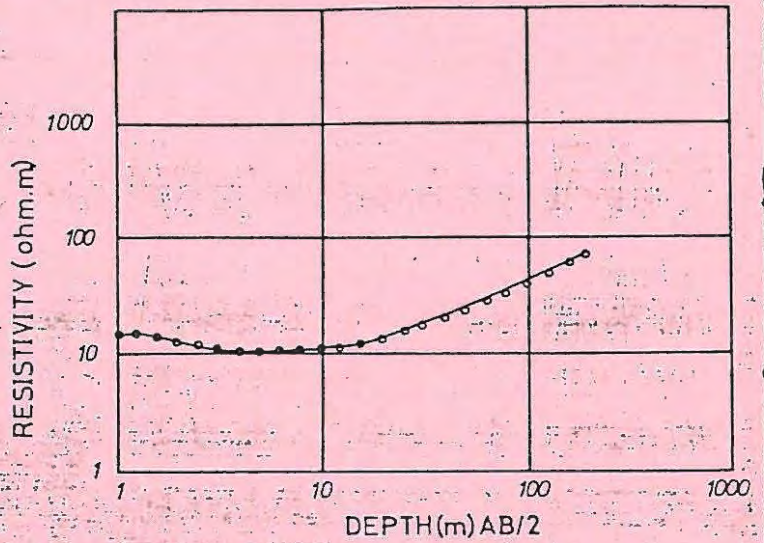
Sounding No: 34

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	18.0
10.7	10.0
28.4	27.0
	400.0

TOTAL S = 2.155 Siemens

TYPE :



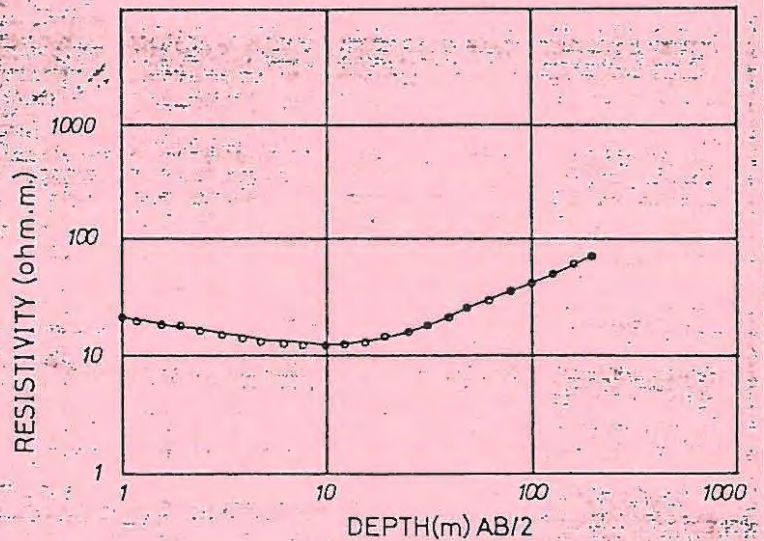
Sounding No: 35

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.0	22.0
12.7	12.0
23.7	30.0
	250.0

TOTAL S = 1.894 Siemens

TYPE :



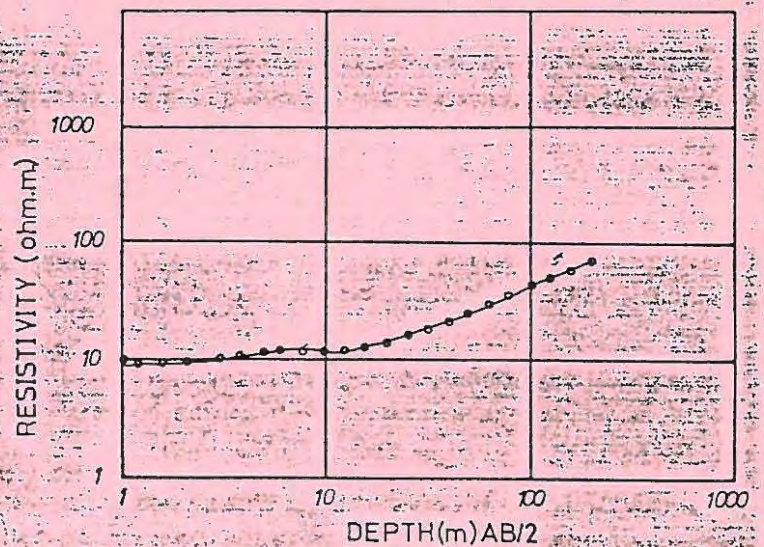
Sounding No: 36

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.3	3.8
4.8	14.0
4.5	6.0
26.4	45.0
	170.0

TOTAL S = 1.818 Siemens

TYPE :



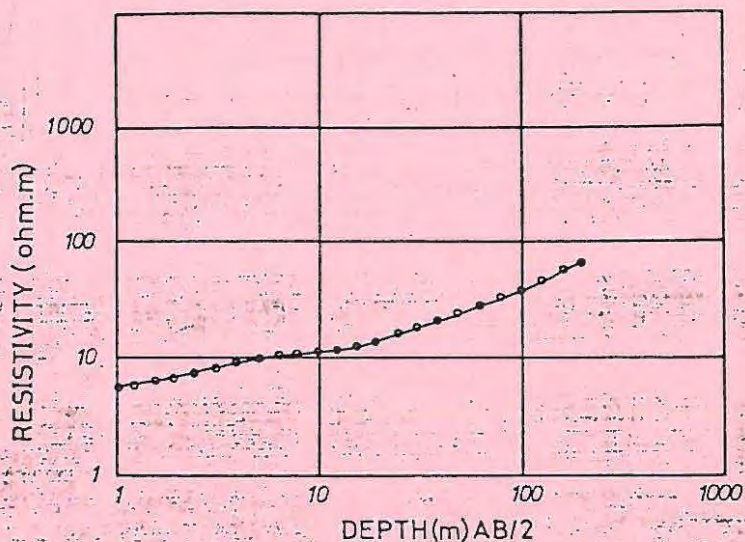
Sounding No: 37

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.1	5.1
4.0	14.0
4.6	7.0
34.0	40.0
	1800

TOTAL S = 2.010 Siemens

TYPE :



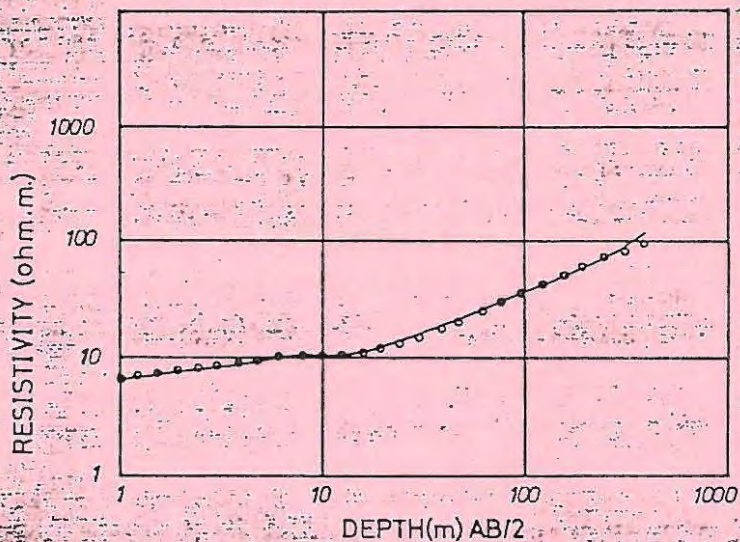
Sounding No: 38

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.4	7.0
5.0	13.0
5.4	6.0
31.7	40.0
	210.0

TOTAL S = 2.277 Siemens

TYPE :



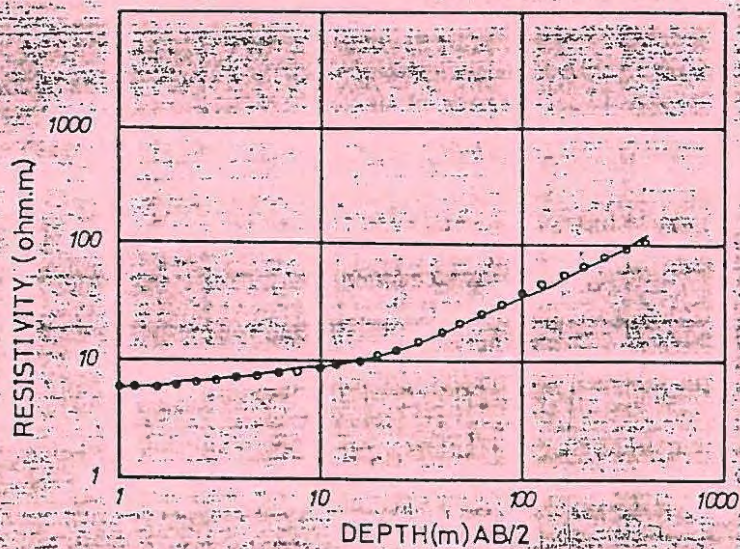
Sounding No: 39

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.4	5.8
8.9	8.5
17.1	20.0
	250.0

TOTAL S = 2.143 Siemens

TYPE :



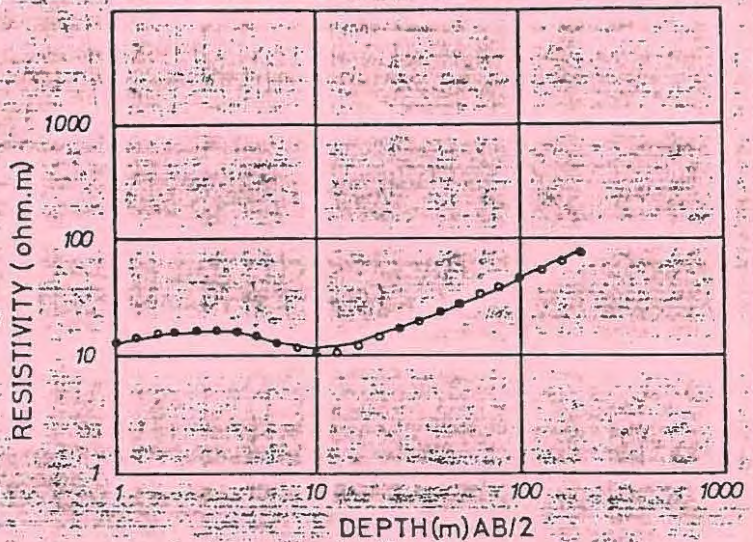
Sounding No: 40

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	11.0
2.0	24.0
4.2	4.0
10.0	100.0
13.0	22.6
	240.0

TOTAL S = 1.868 Siemens.

TYPE :



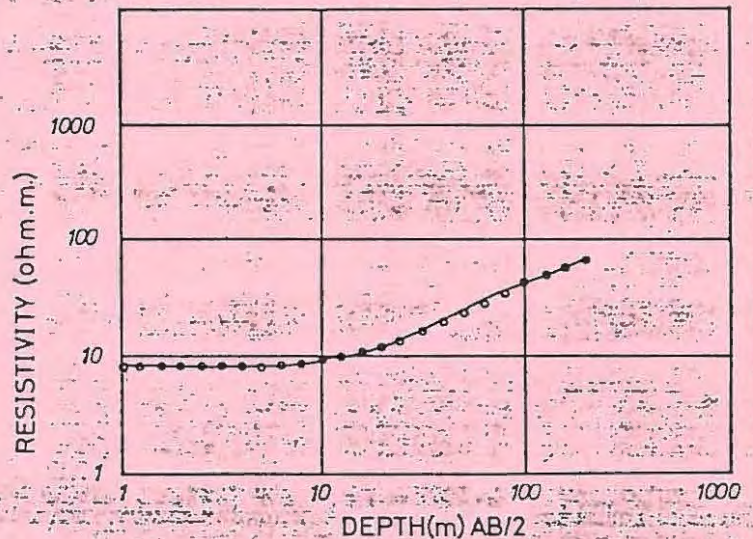
Sounding No: 41

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
10.5	8.0
13.0	25.0
	170.0

TOTAL S = 1.833 Siemens.

TYPE :



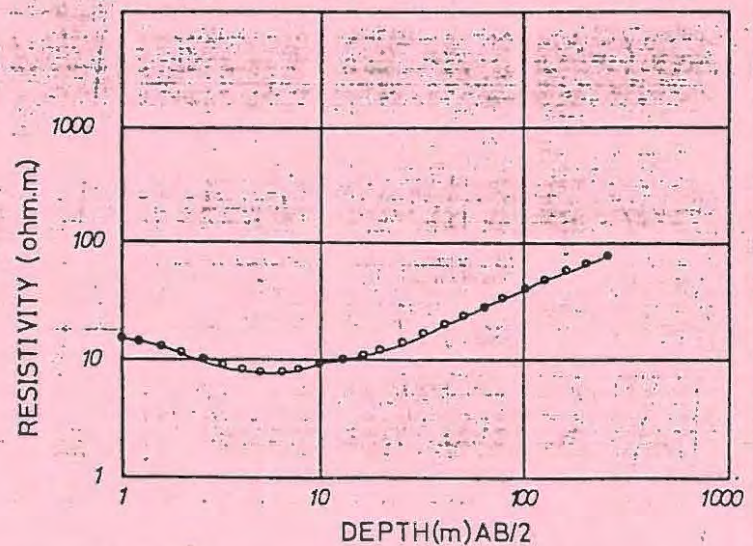
Sounding No: 42

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	18.0
6.4	6.8
21.5	25.0
	170.0

TOTAL S = 1.851 Siemens.

TYPE :



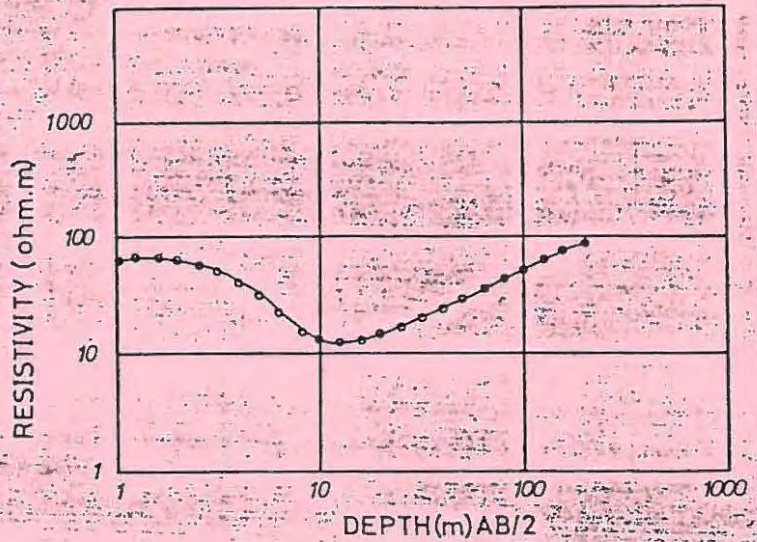
Sounding No: 43

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	46.0
1.7	76.0
10.0	9.0
16.0	45.0
	300.0

TOTAL S=1.494 Siemens.

TYPE :



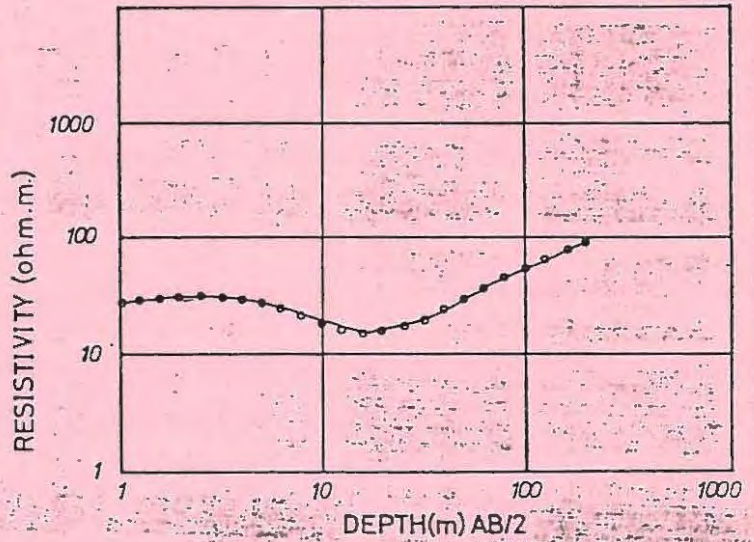
Sounding No: 44

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	13.5
3.4	35.0
12.5	10.5
5.5	38.0
	300.0

TOTAL S =1.442 Siemens.

TYPE :



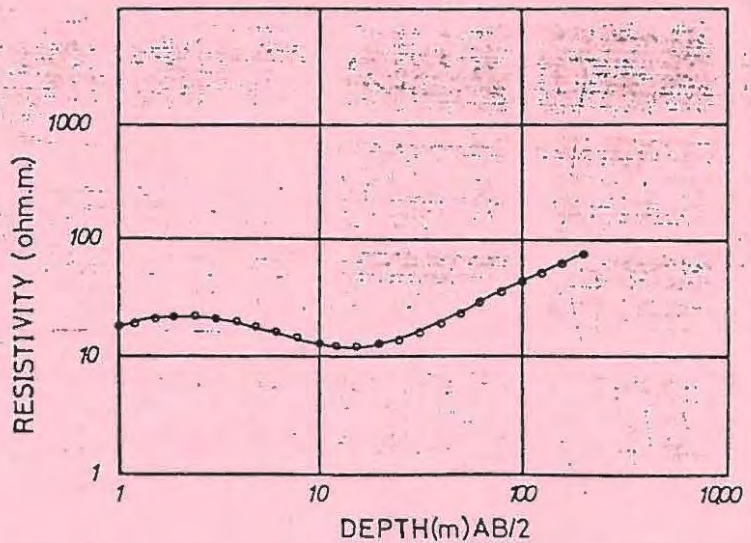
Sounding No: 45

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	6.8
1.9	27.0
17.9	10.0
	280.0

TOTAL S =1.890 Siemens.

TYPE :



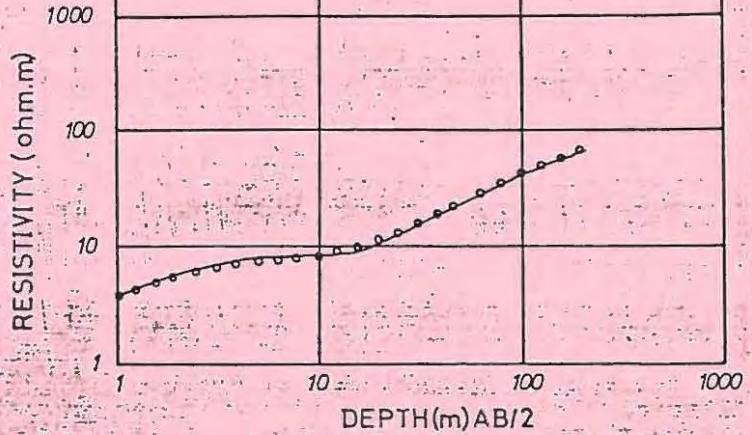
Sounding No: 46

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	2.4
12.0	9.0
3.5	12.0
	200.0

TOTAL S = 1.817 Siemens

TYPE :



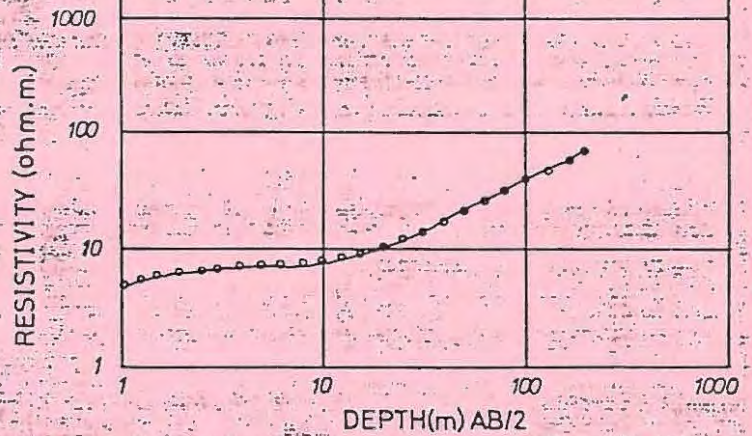
Sounding No: 47

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	4.0
5.0	7.5
13.0	9.0
	400.0

TOTAL S = 2.219 Siemens

TYPE :



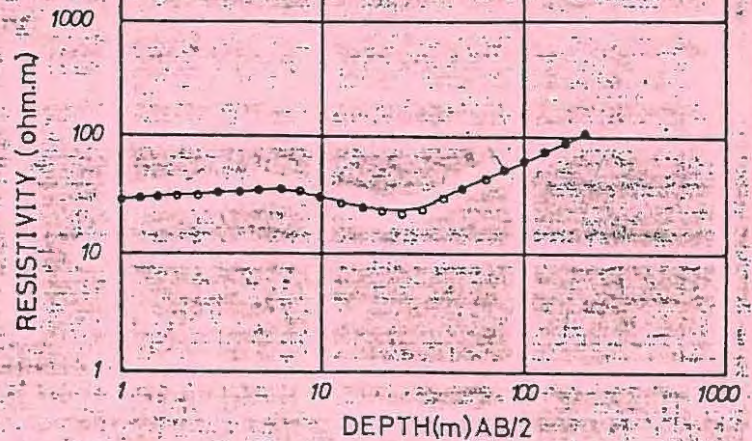
Sounding No: 48

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.8	30.0
4.3	50.0
6.5	8.0
12.0	40.0
	400.0

TOTAL S = 1.259 Siemens

TYPE :



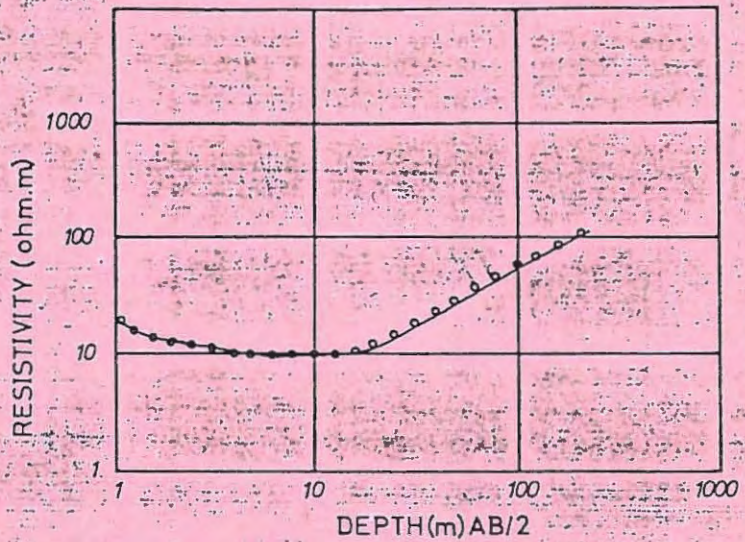
Sounding No: 51

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	26.0
3.0	10.0
0.7	18.0
8.0	6.0
	5000.0

TOTAL S=1.688 Siemens.

TYPE :



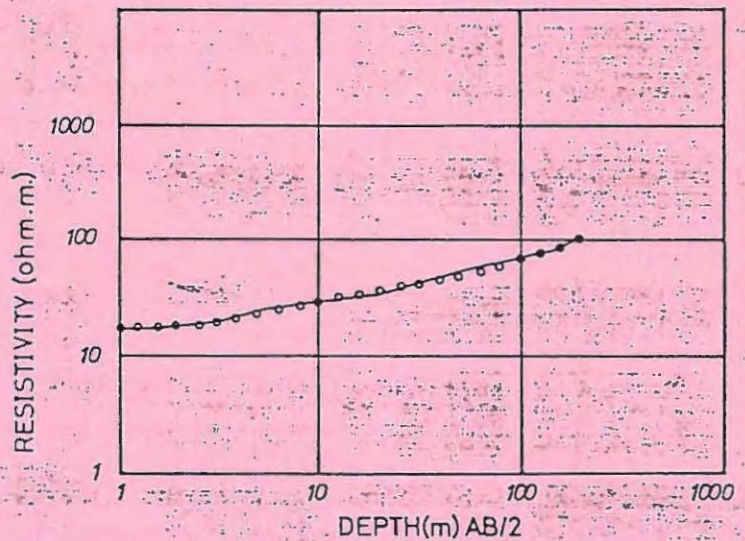
Sounding No: 50

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
2.8	18.0
3.7	55.0
6.8	27.0
54.0	65.0
	270.0

TOTAL S =1.304 Siemens.

TYPE :



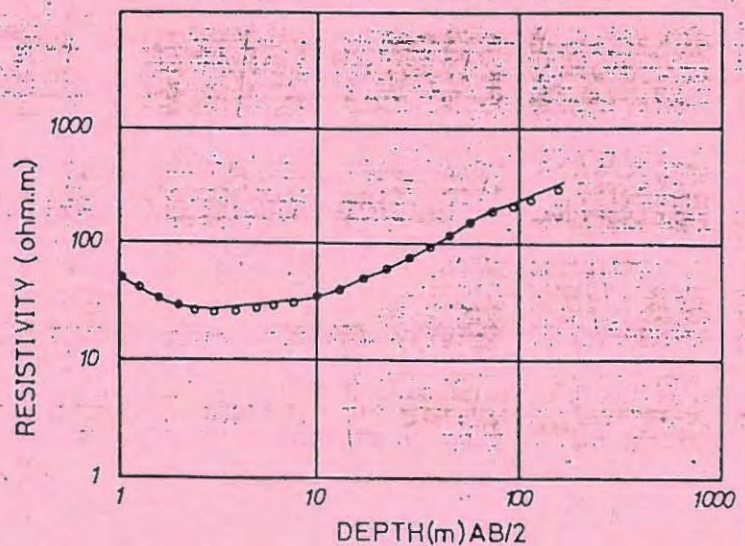
Sounding No: 49

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.5	45.0
4.1	36.0
68.9	110.0
	240.0

TOTAL S =0.772 Siemens.

TYPE :



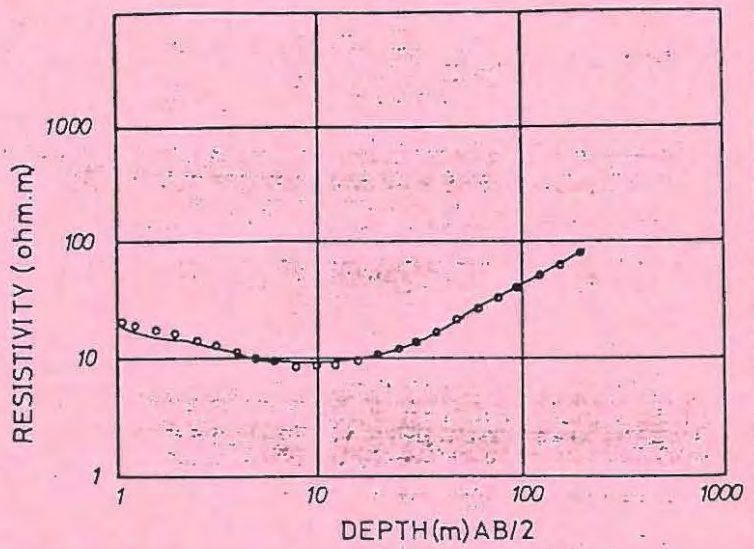
Sounding No: 52

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	22.2
2.6	10.0
2.9	5.5
15.1	9.5
	21000

TOTAL S = 2.415 Siemens.

TYPE :



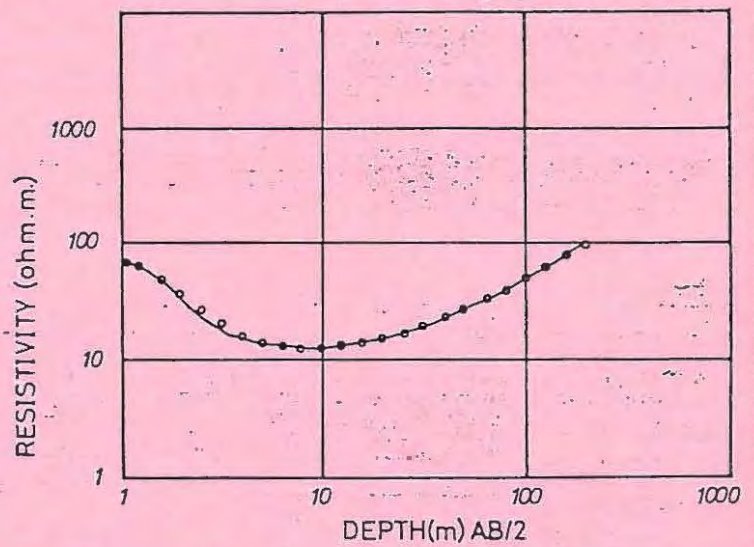
Sounding No: 53

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	110.0
0.7	30.0
13.8	12.0
26.0	40.0
	2000.0

TOTAL S = 1.829 Siemens.

TYPE :



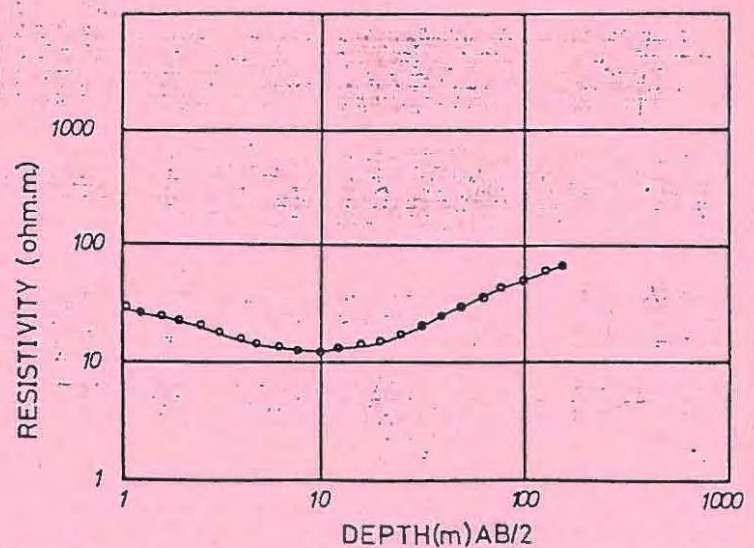
Sounding No: 54

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	13.2
0.9	32.0
17.0	12.0
	200.0

TOTAL S = 1.453 Siemens.

TYPE :



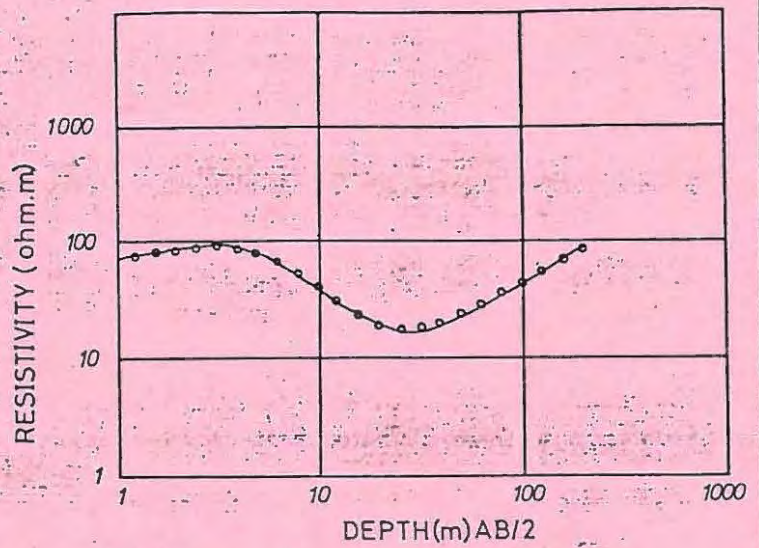
Sounding No: 55

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	44.0
2.8	110.0
8.0	24.0
29.0	14.0
	600.0

TOTAL S = 2.140 Siemens.

TYPE :



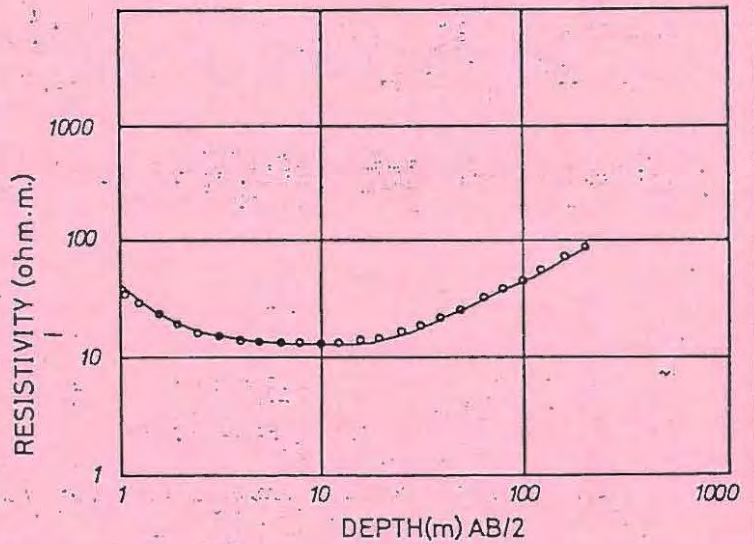
Sounding No: 56

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	53.0
22.6	13.0
	300.0

TOTAL S = 1.749 Siemens.

TYPE :



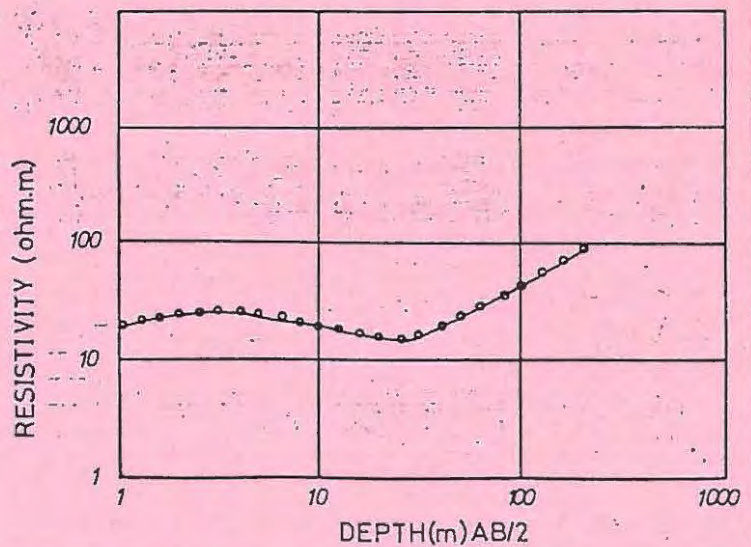
Sounding No: 57

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	13.2
1.8	33.0
8.9	17.0
10.2	6.5
	45000

TOTAL S = 2.178 Siemens.

TYPE :



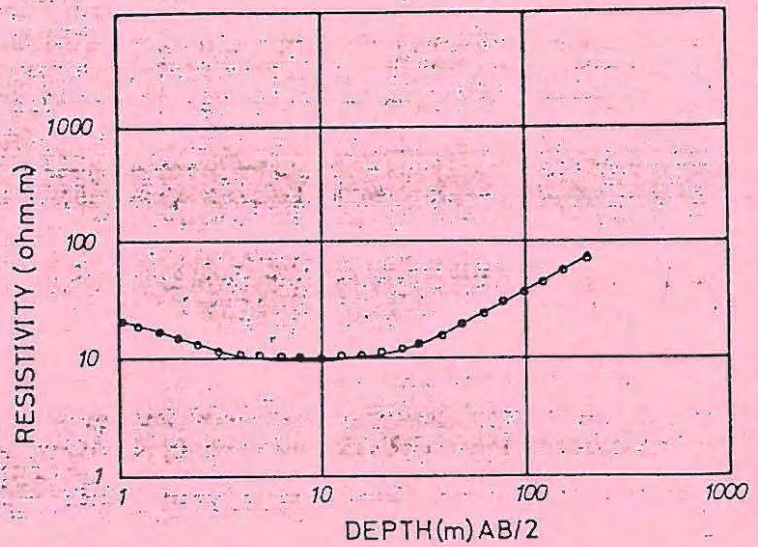
Sounding No:58

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.6	25.0
25.8	10.0
	2600.0

TOTAL S = 2.604 Siemens.

TYPE :



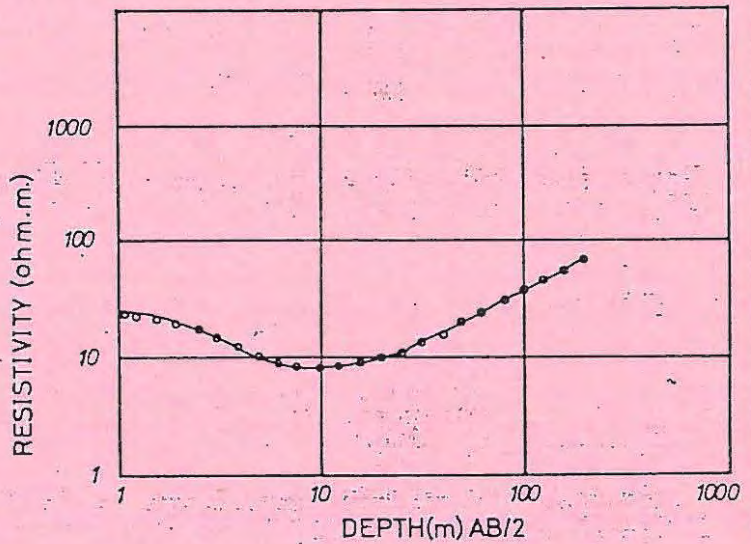
Sounding No: 59

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.6	22.0
5.0	6.0
17.7	11.0
	600.0

TOTAL S = 2.515 Siemens.

TYPE :



Sounding No: 60

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.4	16.0
8.6	8.0
4.9	15.0
46.5	40.0
	3000.0

TOTAL S = 2.651 Siemens.

TYPE :



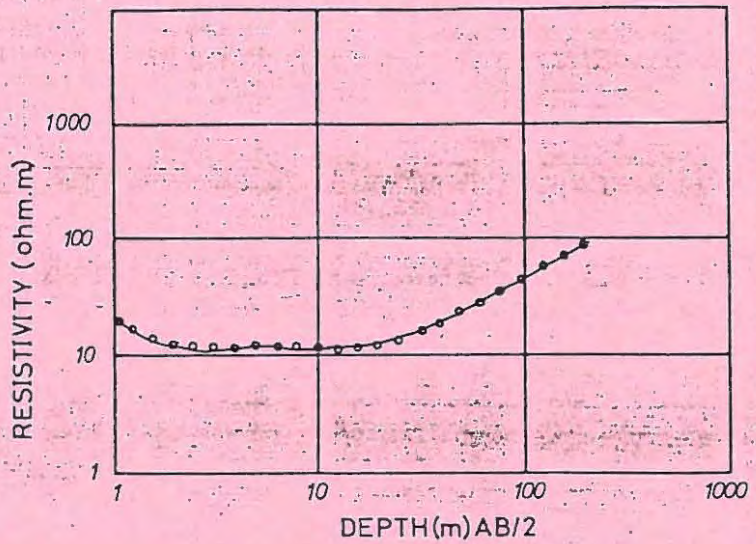
Sounding No: 61

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	30.0
1.5	9.0
2.0	20.0
6.5	7.0
18.9	20.0
	5000.0

TOTAL S = 2.157 Siemens.

TYPE :



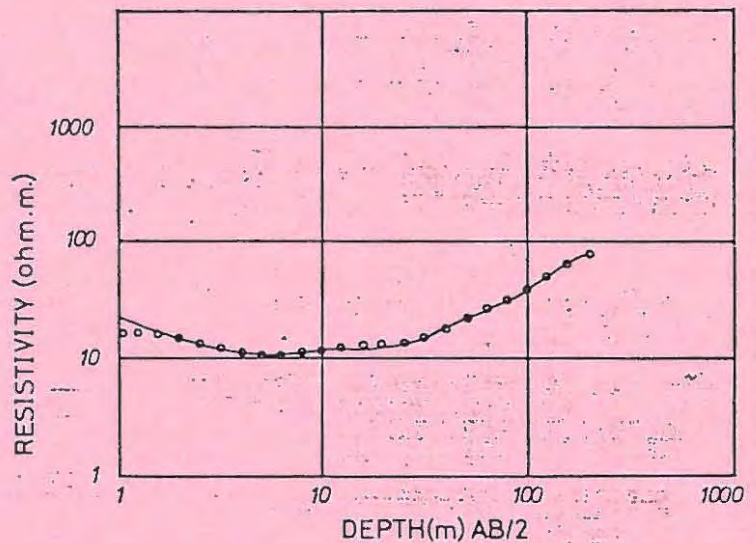
Sounding No: 62

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.3	17.0
2.5	8.0
5.9	15.0
7.2	10.0
18.3	20.0
	4500.0

TOTAL S = 2.417 Siemens.

TYPE :



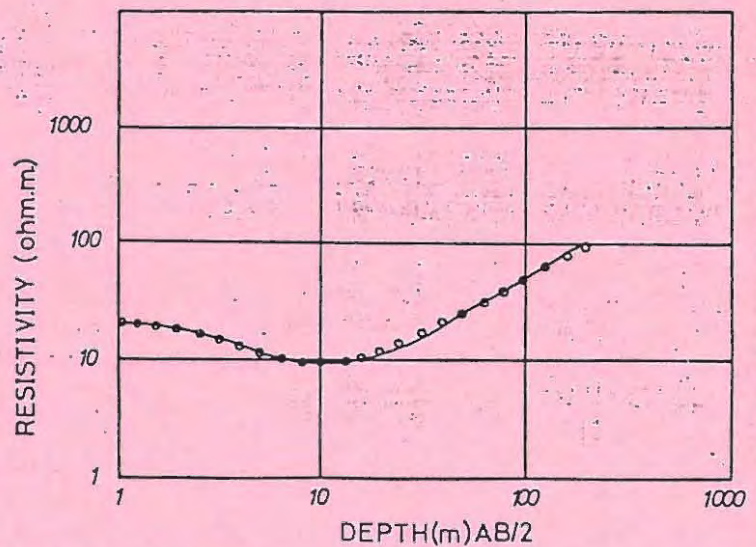
Sounding No: 63

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.5	20.5
9.5	8.5
13.7	18.0
	4000.0

TOTAL S = 1.952 Siemens.

TYPE :



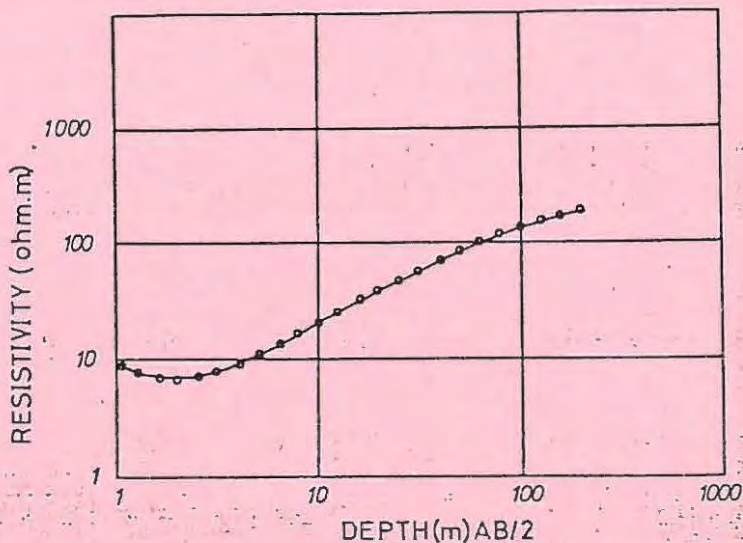
Sounding No: 64

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.3	24.0
2.6	6.0
	3000

TOTAL S = 0.445 Siemens.

TYPE :



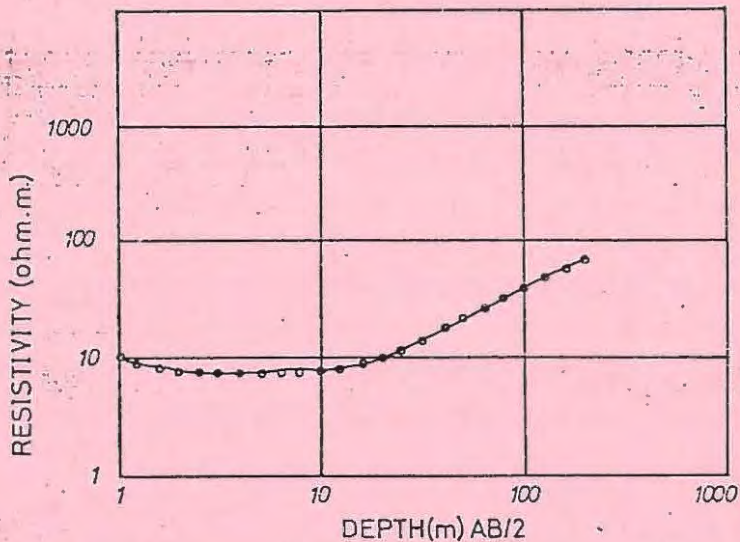
Sounding No: 65

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.3	30.0
7.9	7.5
3.7	9.0
2.5	4.5
	280.0

TOTAL S = 2.029 Siemens.

TYPE :



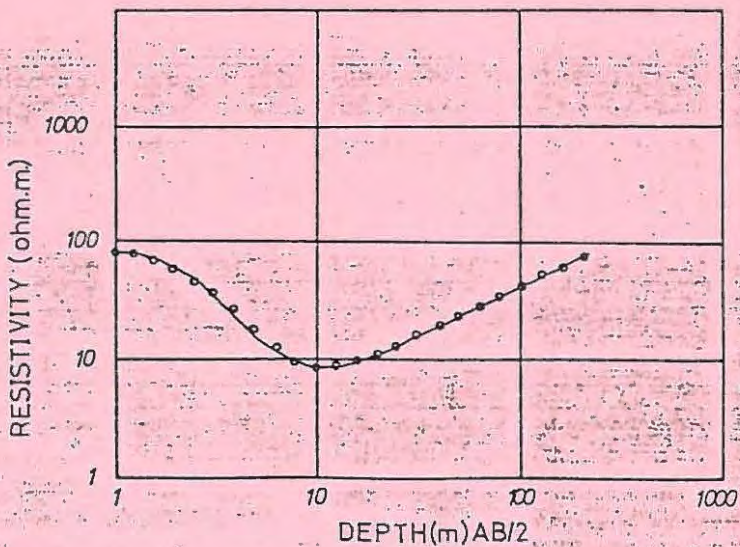
Sounding No: 66

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	97.0
1.3	50.0
9.0	6.0
24.0	55.0
	350.0

TOTAL S = 1.970 Siemens.

TYPE :



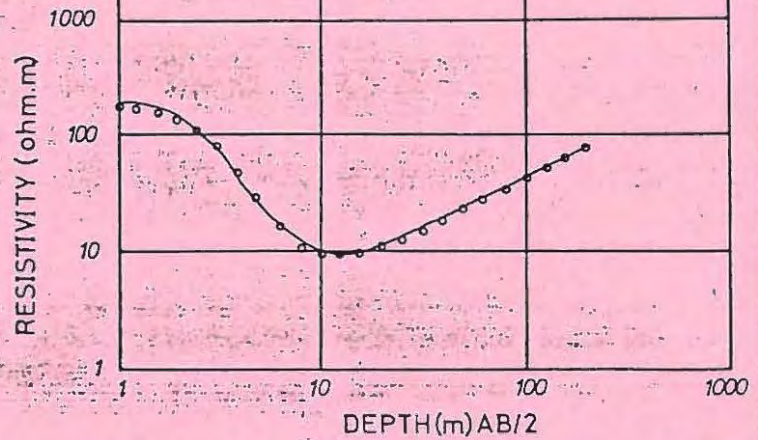
Sounding No: 67

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	140.0
1.3	200.0
16.5	8.0
	400.0

TOTAL S = 2.070 Siemens.

TYPE :



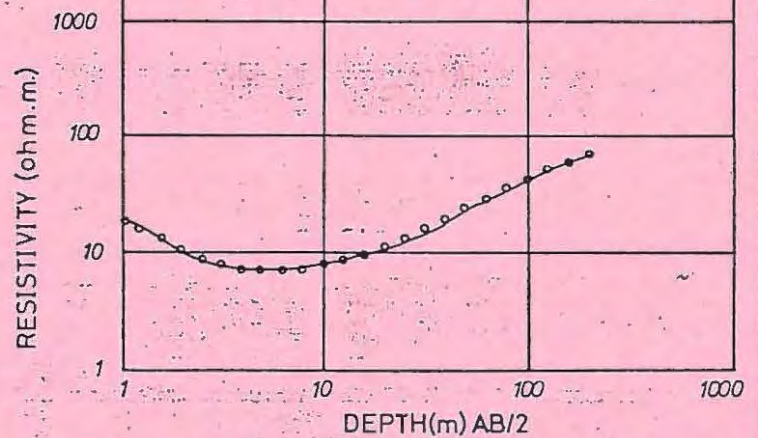
Sounding No: 68

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	26.0
7.0	6.5
9.3	14.0
	200.0

TOTAL S = 1.765 Siemens.

TYPE :



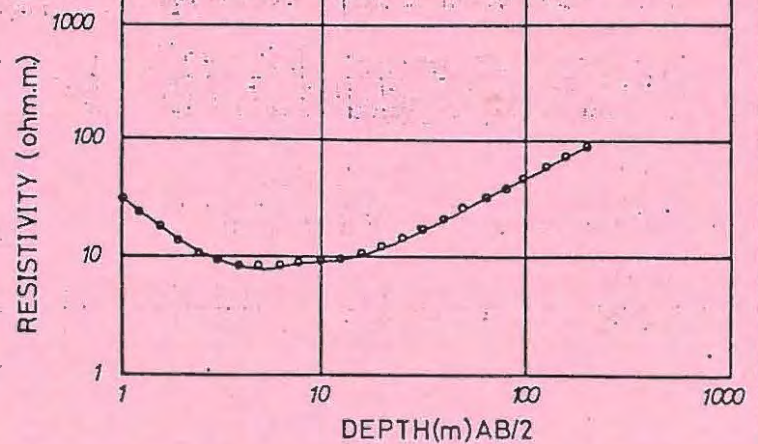
Sounding No: 69

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	48.0
8.7	8.0
16.9	25.0
	550.0

TOTAL S = 1.772 Siemens.

TYPE :



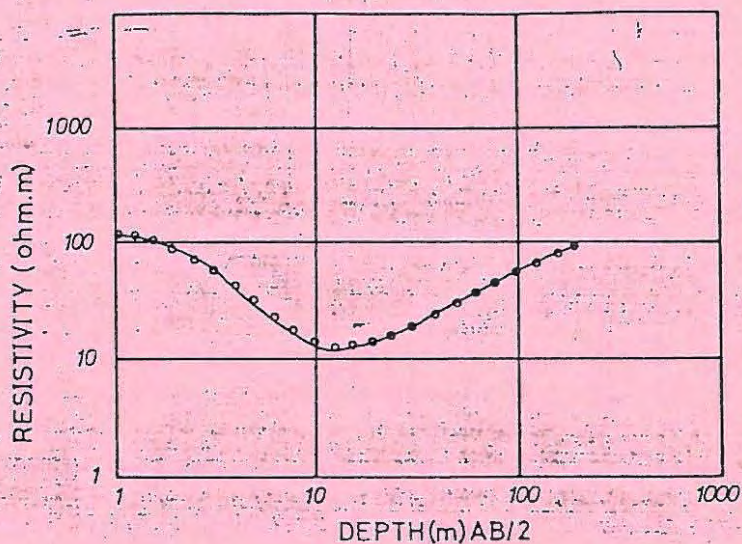
Sounding No: 70

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.0	145.0
1.9	45.0
14.2	10.0
	350.0

TOTAL S=1.469 Siemens.

TYPE :



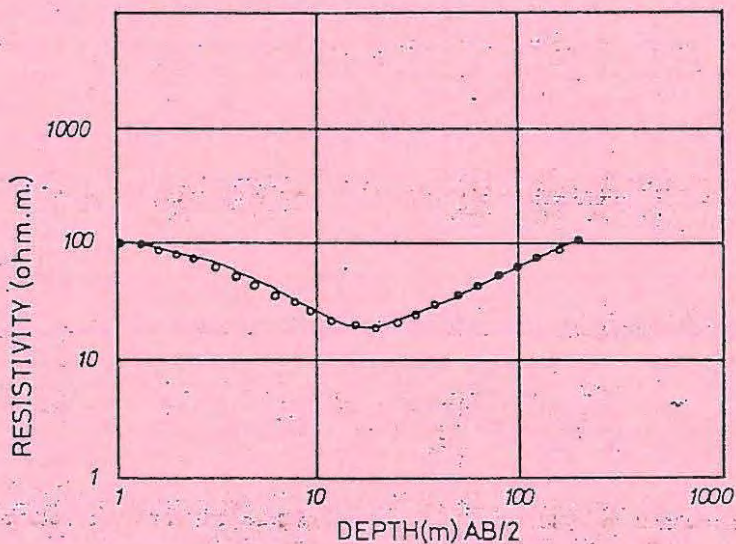
Sounding No: 71

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.2	107.0
4.1	40.0
9.5	10.0
	260.0

TOTAL S =1.164 Siemens.

TYPE :



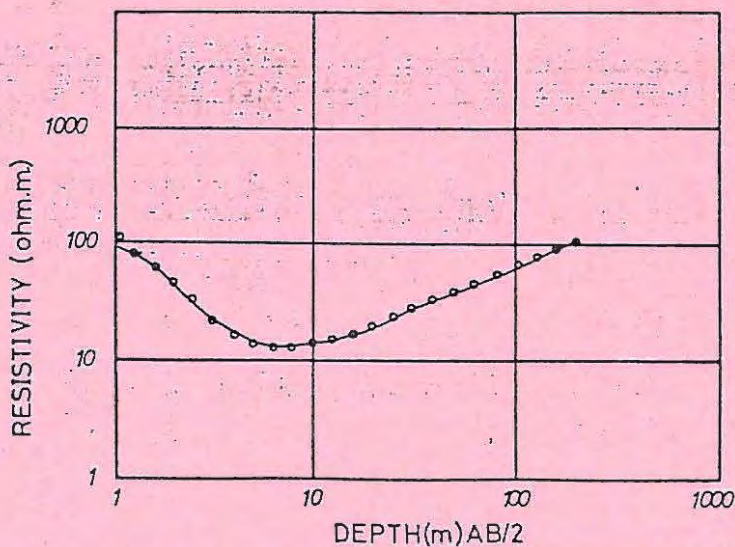
Sounding No: 72

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	130.0
0.7	40.0
6.9	10.0
22.5	50.0
	260.0

TOTAL S =1.162 Siemens.

TYPE :



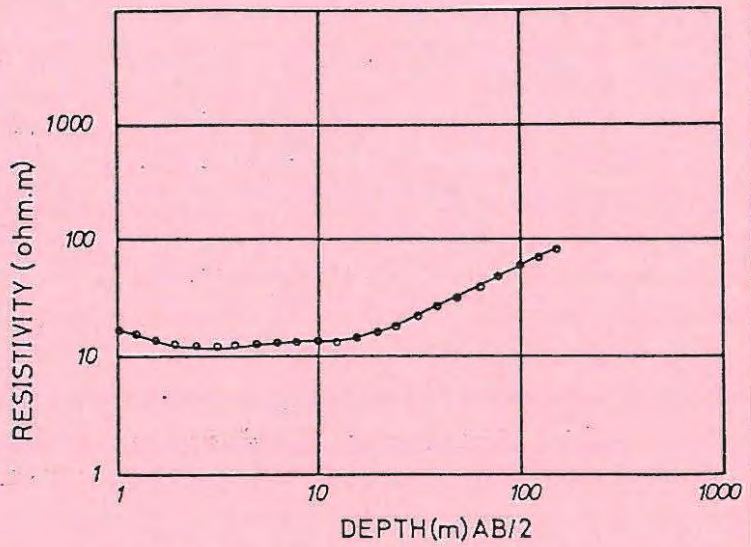
Sounding No: 73

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	25.0
0.3	8.0
16.2	12.0
	310.0

TOTAL S=1.403 Siemens

TYPE :



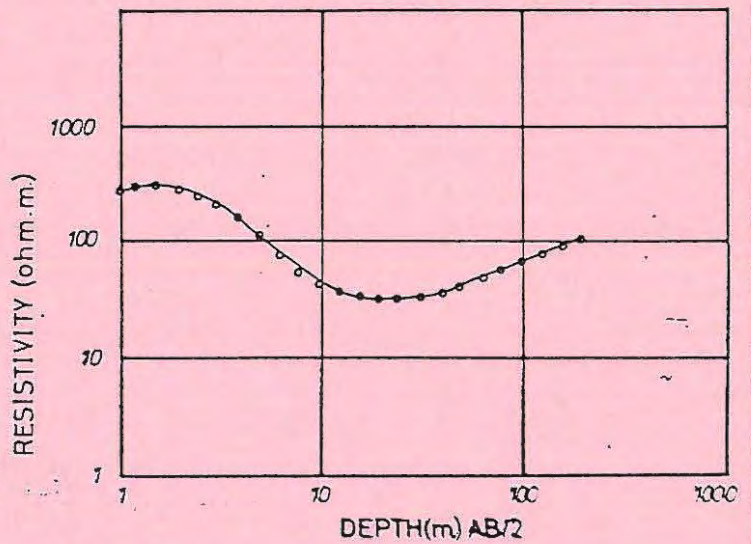
Sounding No: 74

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	70.0
1.3	410.0
7.0	40.0
19.0	25.0
5.0	40.0
	200.0

TOTAL S = 1.064 Siemens

TYPE :



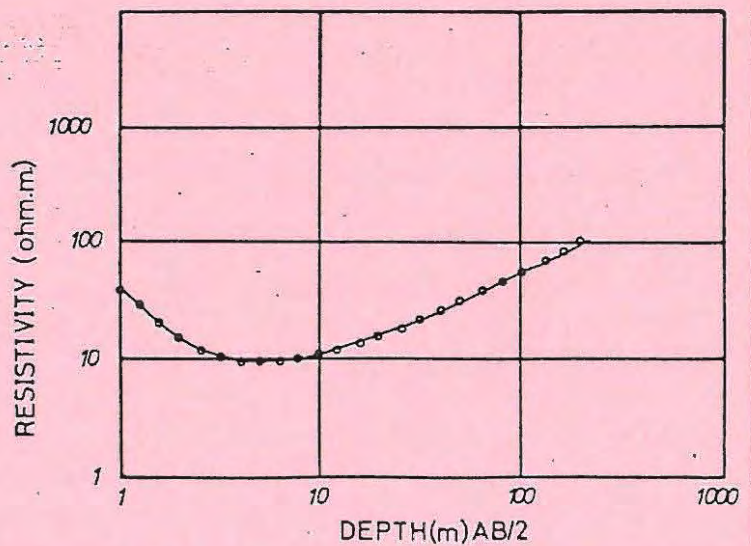
Sounding No: 75

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	74.0
8.1	9.0
16.6	30.0
	500.0

TOTAL S = 1.460 Siemens

TYPE :



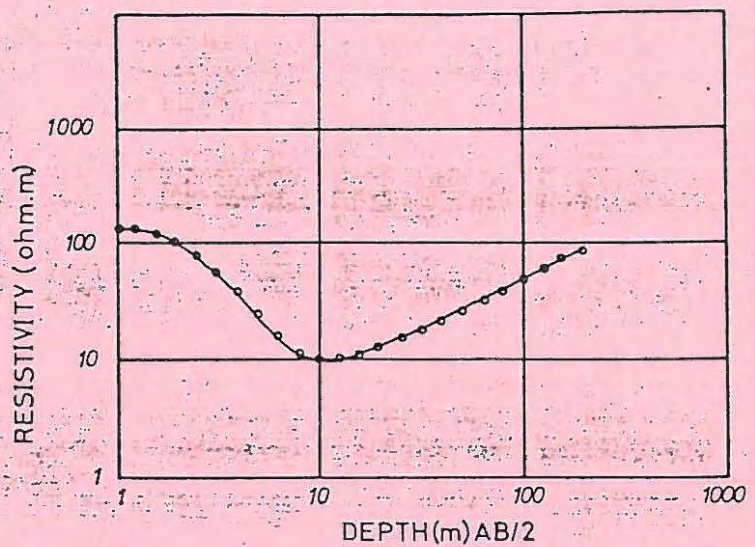
Sounding No: 76

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.9	170.0
1.3	65.0
7.8	7.0
19.7	30.0
	500.0

TOTAL S = 1.796 Siemens.

TYPE :



Sounding No: 77

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.7	24.0
9.4	8.0
25.1	25.0
	500.0

TOTAL S = 2.207 Siemens.

TYPE :



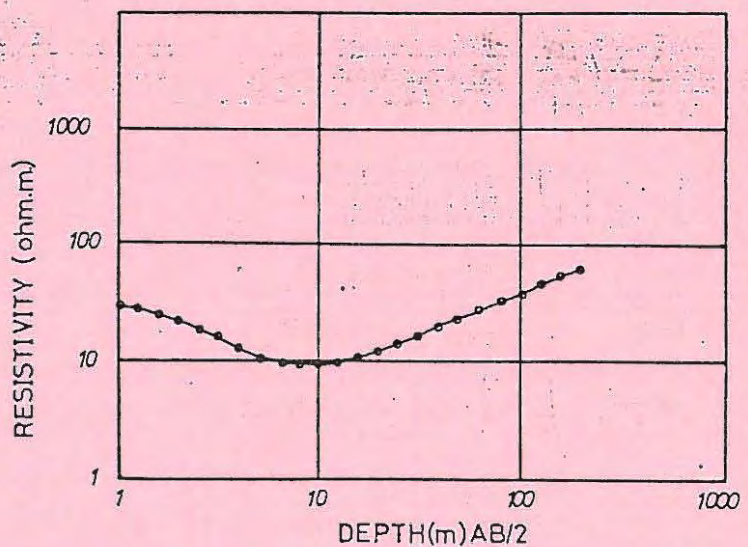
Sounding No: 78

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.3	29.0
9.0	8.0
22.5	30.0
	160.0

TOTAL S = 1.920 Siemens.

TYPE :



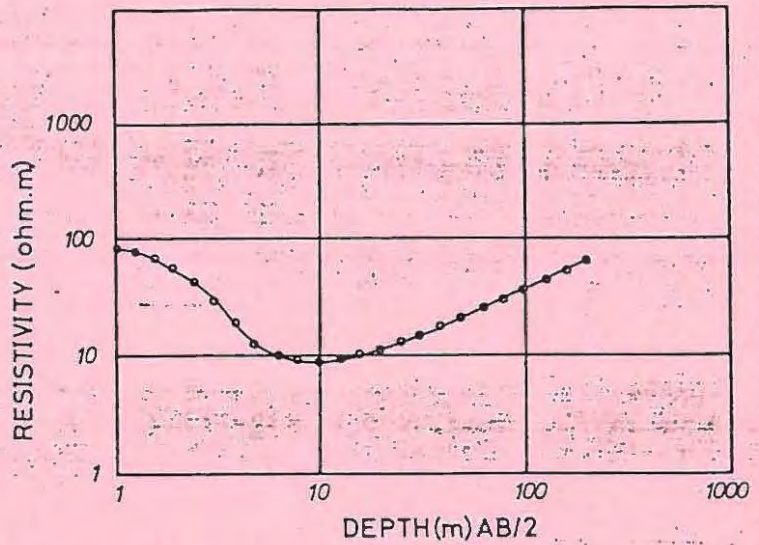
Sounding No: 79

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.2	95.0
9.8	80
26.5	25.0
	3200

TOTAL S = 2.297 Siemens.

TYPE :



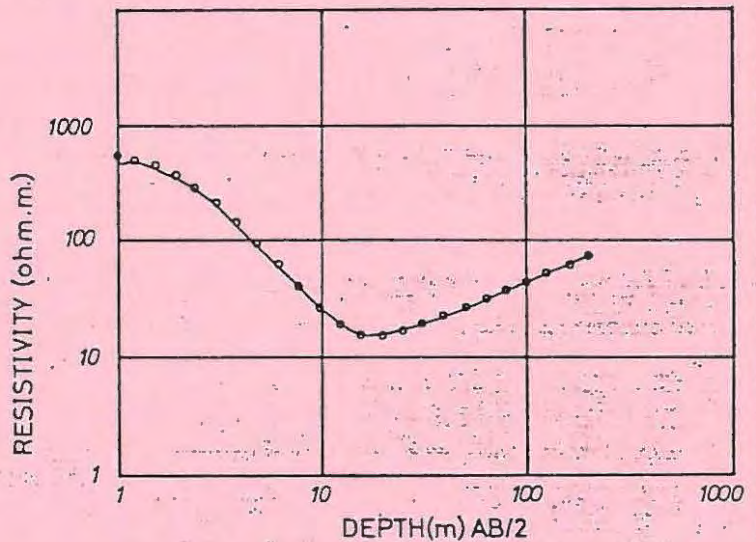
Sounding No: 80

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.1	615.0
2.7	100.0
9.4	10.0
23.3	30.0
	200.0

TOTAL S = 1.746 Siemens.

TYPE :



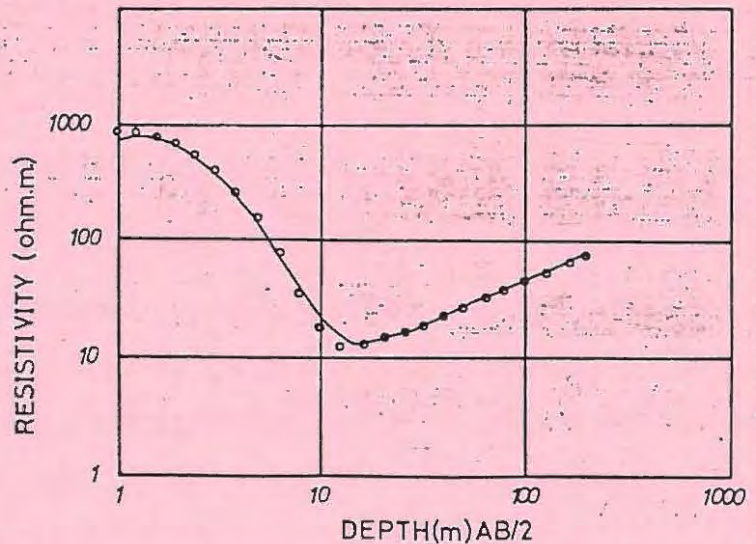
Sounding No: 81

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	150.0
0.8	1200.0
1.4	300.0
9.2	9.0
21.5	30.0
	195.0

TOTAL S = 1.745 Siemens.

TYPE :



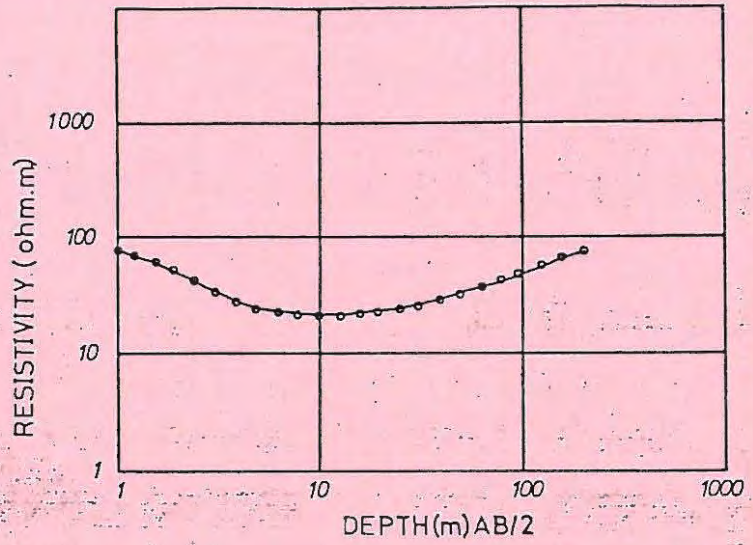
Sounding No: 82

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.0	85.0
12.7	20.0
20.9	30.0
	140.0

TOTAL S=1.343 Siemens.

TYPE :



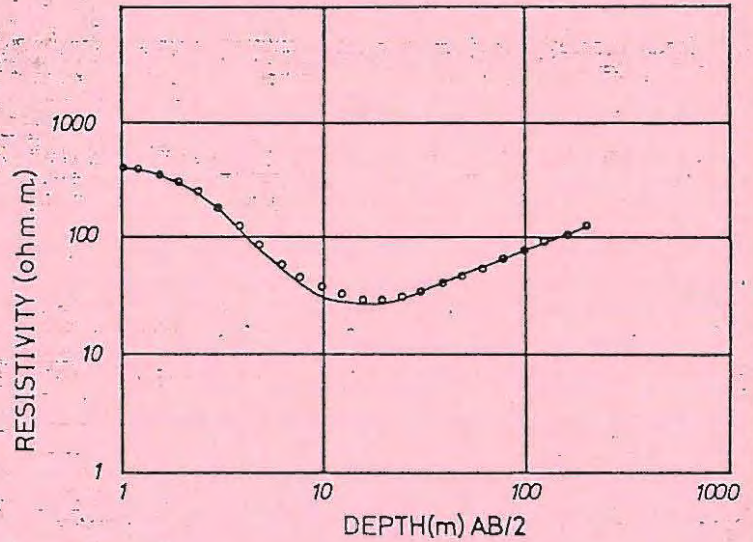
Sounding No: 83

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.4	434.0
4.8	44.0
9.4	16.6
32.0	75.0
	400.0

TOTAL S =1.105 Siemens.

TYPE :



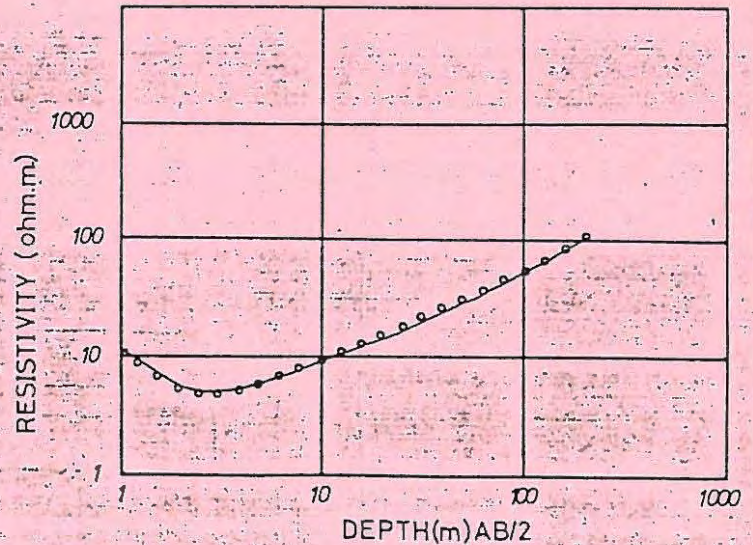
Sounding No: 84

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	19.8
2.8	3.8
22.3	30.0
	600.0

TOTAL S =1.504 Siemens.

TYPE :



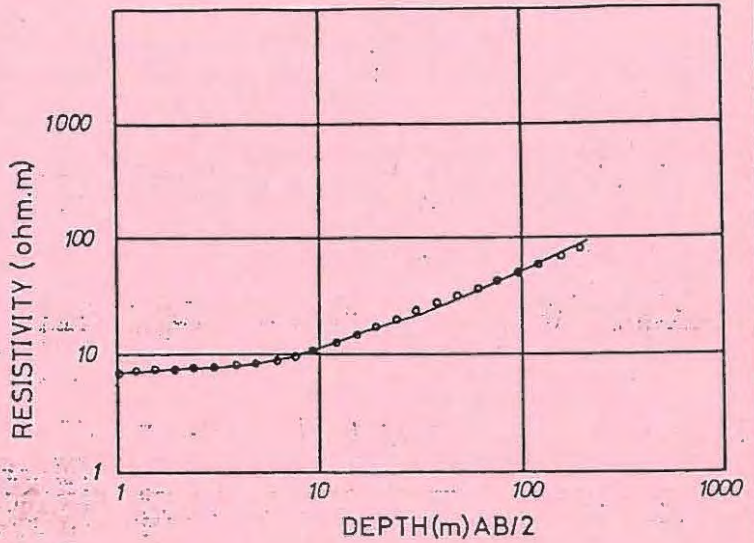
Sounding No: 85

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	5.1
5.0	8.0
3.2	20.0
42.5	50.0
	300.0

TOTAL S = 1.672 Siemens.

TYPE :



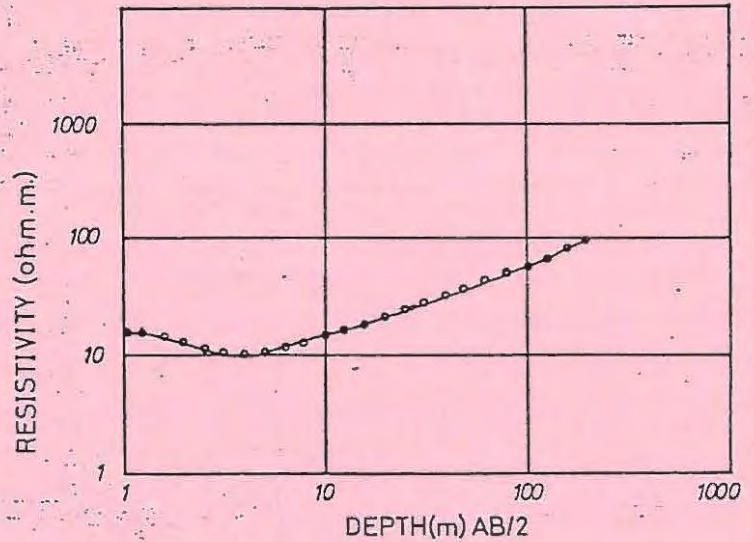
Sounding No: 86

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	18.8
3.1	8.0
6.3	25.0
44.3	50.0
	300.0

TOTAL S = 1.571 Siemens.

TYPE :



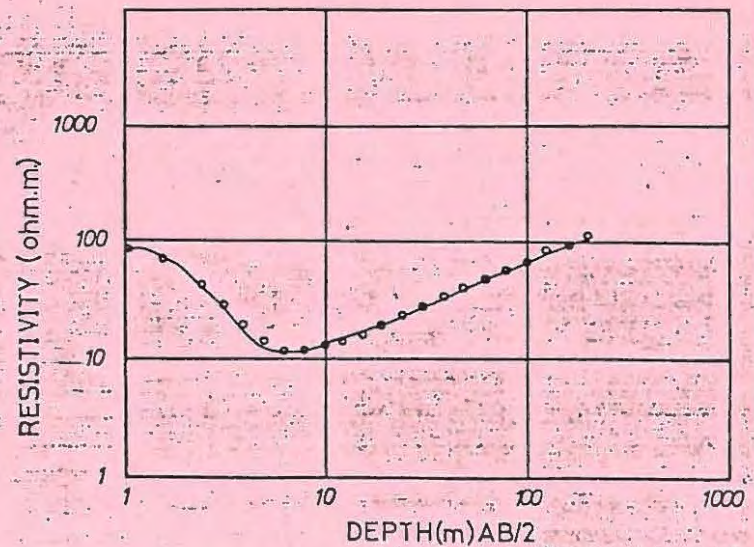
Sounding No: 87

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.1	95.0
5.2	8.0
4.0	25.0
1.5	10.0
	400.0

TOTAL S = 1.309 Siemens.

TYPE :

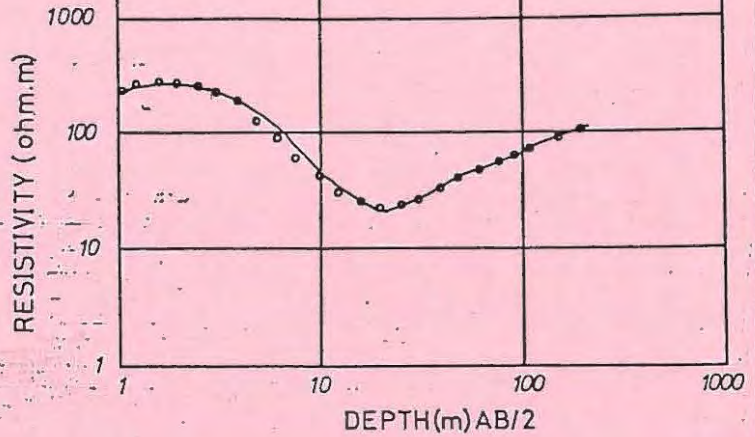


Sounding No: 88

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	60.0
0.6	850.0
5.2	50.0
5.0	10.0
2.5	7.2
7.0	55.0
TOTAL S=1.082 Siemens.	

TYPE :



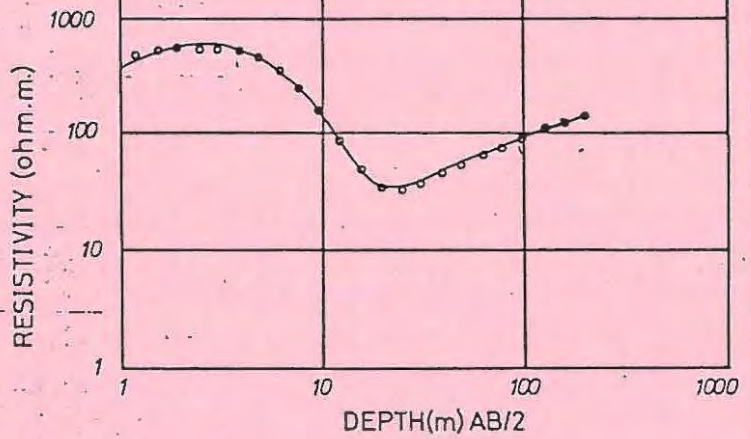
Sounding No: 89

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	120.0
3.0	700.0
15.8	20.0
	300.0

TOTAL S =0.795 Siemens.

TYPE :

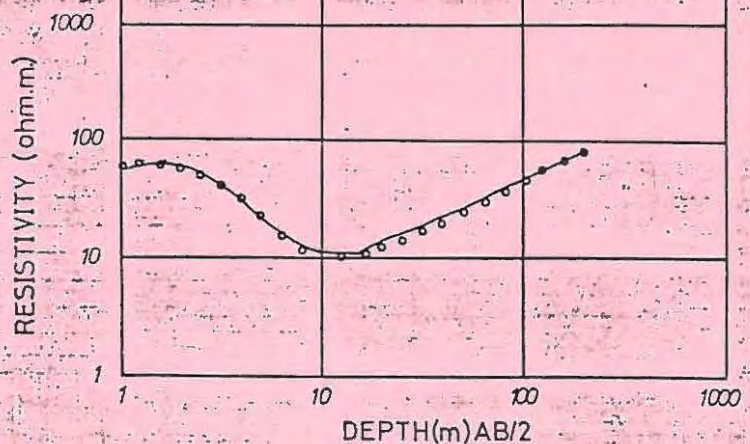


Sounding No: 90

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	50.0
1.1	80.0
1.0	20.0
7.1	7.0
16.7	20.0
TOTAL S =1.913 Siemens.	

TYPE :



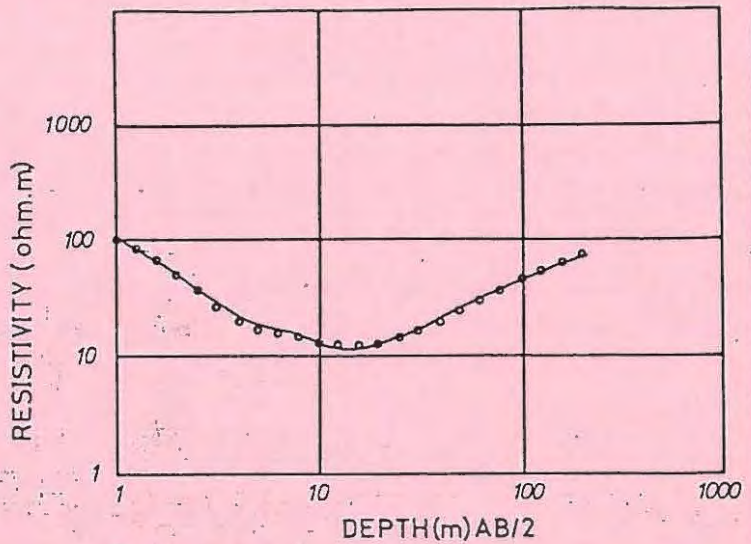
Sounding No: 91

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	115.0
7.0	15.0
6.8	6.0
4.9	20.0
	250.0

TOTAL S=1.852 Siemens.

TYPE :



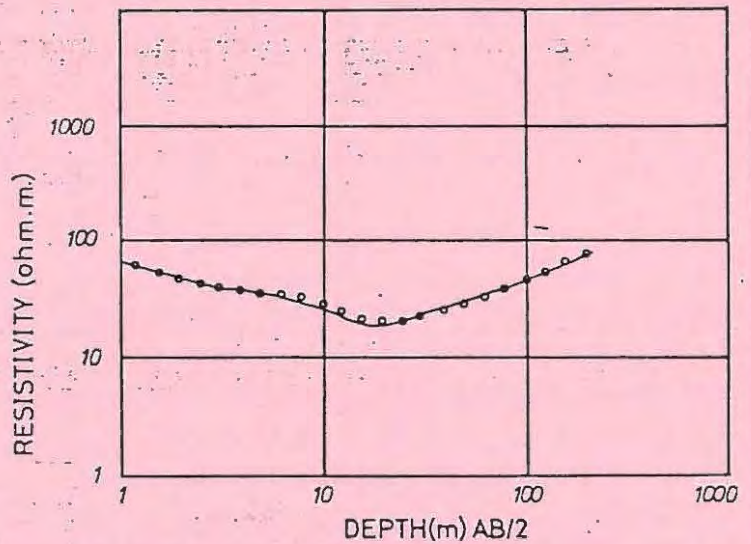
Sounding No: 92

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	90.0
1.3	35.0
4.8	40.0
7.5	9.0
18.0	46.0
16.3	55.0
	250.0

TOTAL S =1.683 Siemens.

TYPE :



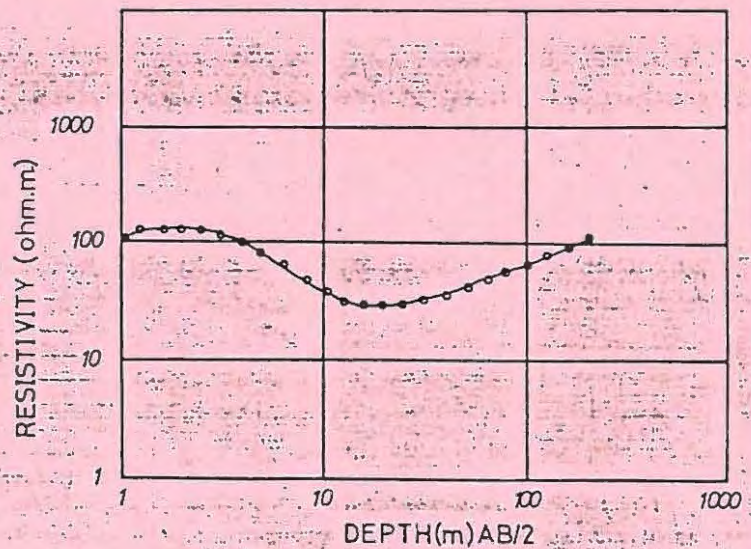
Sounding No: 93

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.3	90.0
1.9	150.0
2.1	40.0
11.7	22.0
30.2	50.0
	350.0

TOTAL S =1.204 Siemens.

TYPE :



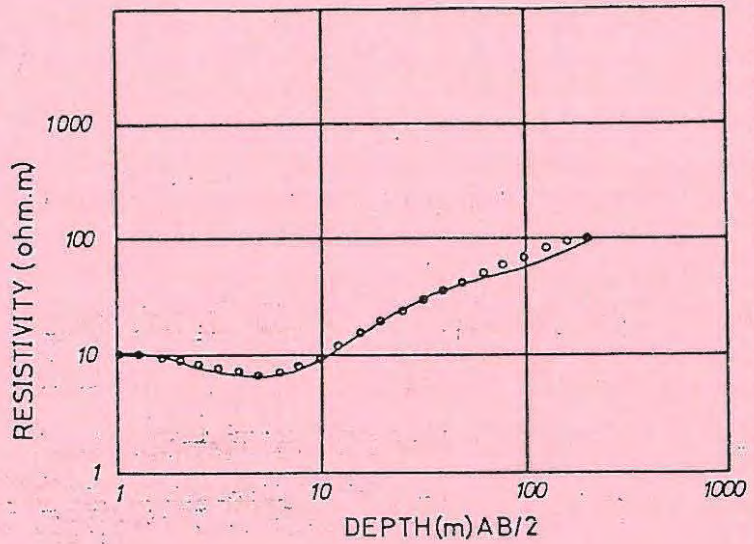
Sounding No: 94

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	10.2
9.0	9.5
2.8	3.5
17.0	650.0
80.0	70.0
	900.0

TOTAL S = 2.147 Siemens.

TYPE :



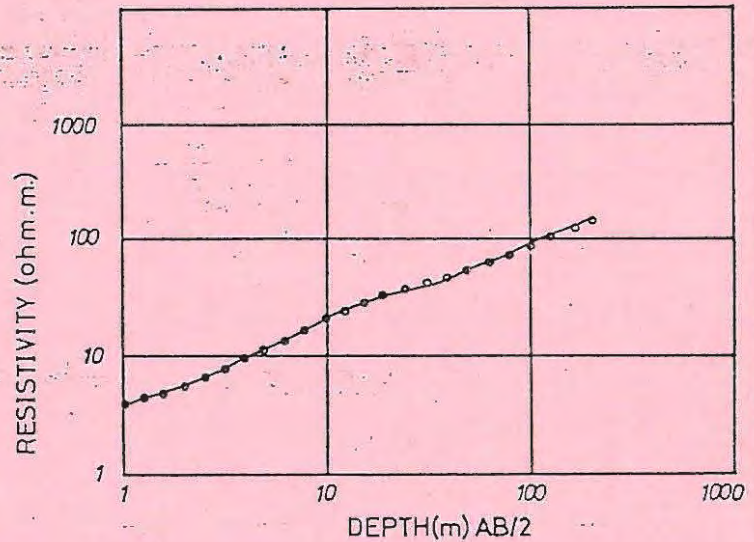
Sounding No: 95

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	3.2
2.0	12.0
8.4	165.0
8.9	15.0
	1000.0

TOTAL S = 1077 Siemens.

TYPE :



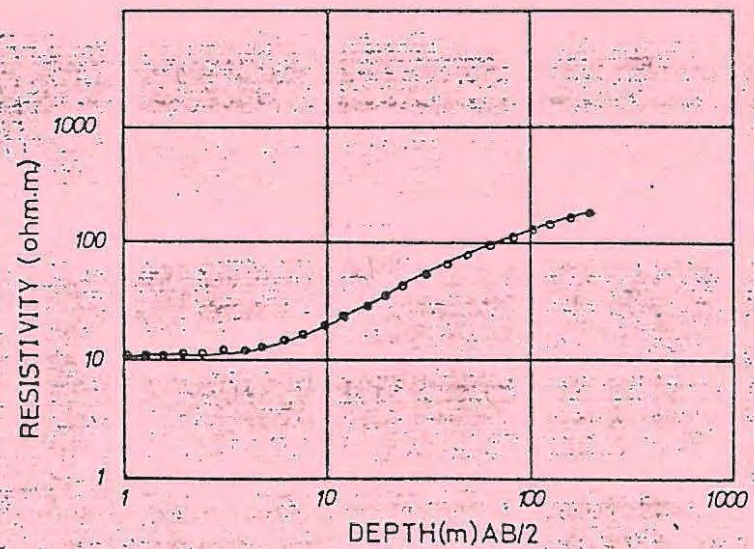
Sounding No: 96

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	7.4
1.2	15.0
0.4	1.8
4.4	42.0
0.4	6.0
60.0	360.0 - 270

TOTAL S = 0.703 Siemens.

TYPE :



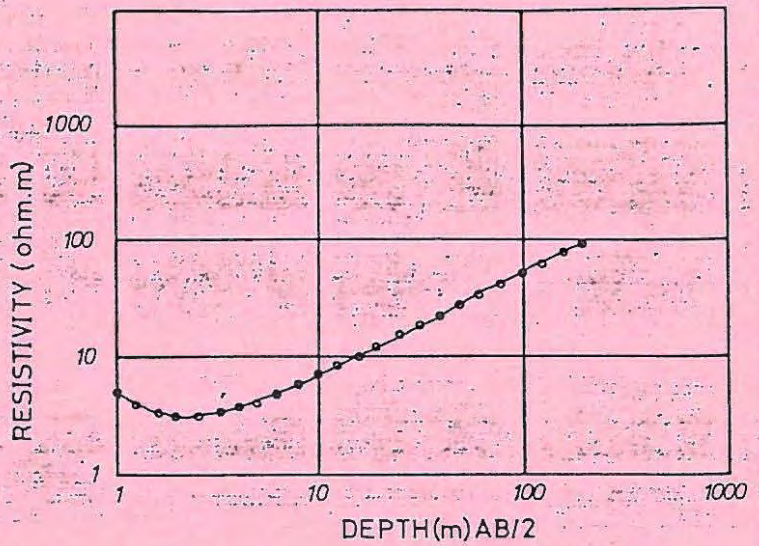
Sounding No: 97

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	10.5
3.2	2.6
13.0	40.0
16.7	150.0
	500.0

TOTAL S = 1.698 Siemens.

TYPE :



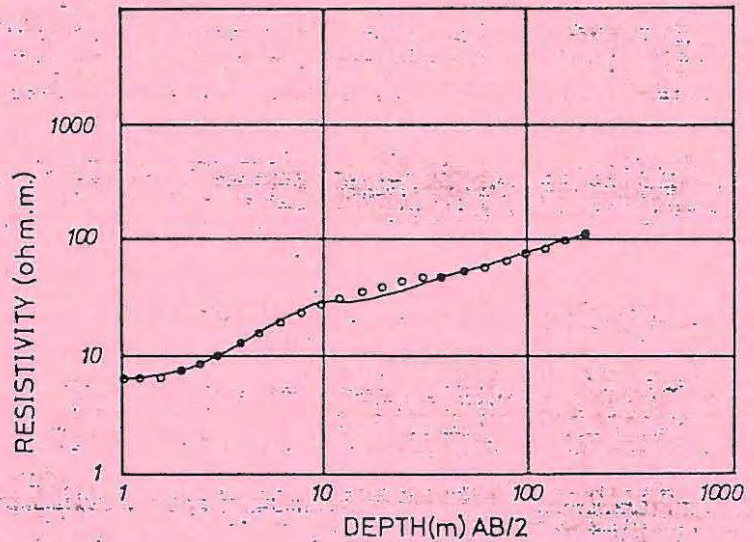
Sounding No: 98

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	7.6
1.2	5.0
4.8	200.0
2.5	4.5
47.0	150.0
	250.0

TOTAL S = 1.181 Siemens.

TYPE :



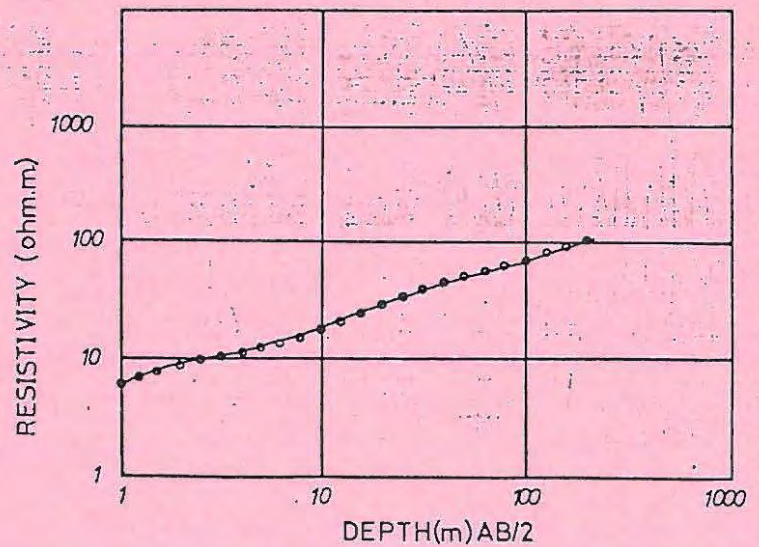
Sounding No: 99

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	2.5
1.9	12.0
2.5	10.0
14.2	96.0
38.0	85.0
	200.0

TOTAL S = 1.109 Siemens.

TYPE :



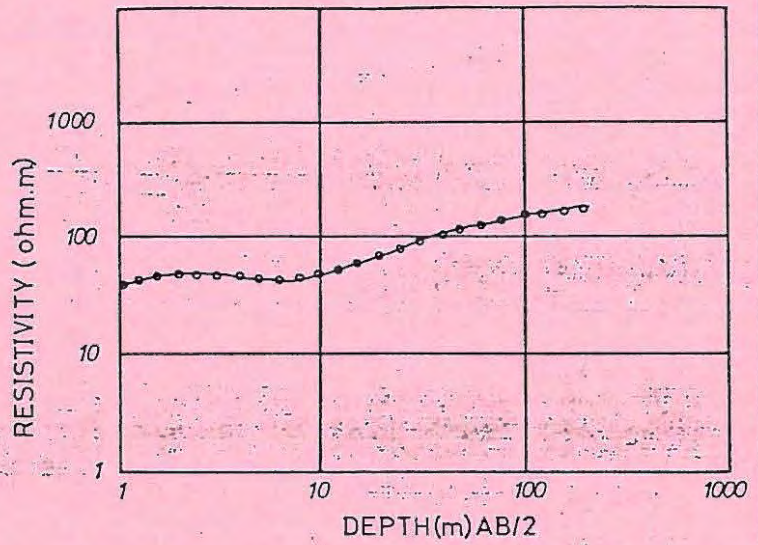
Sounding No: 100

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	23.0
1.1	65.0
5.9	36.0
14.6	172.0
	200.0

TOTAL S = 0.279 Siemens.

TYPE :



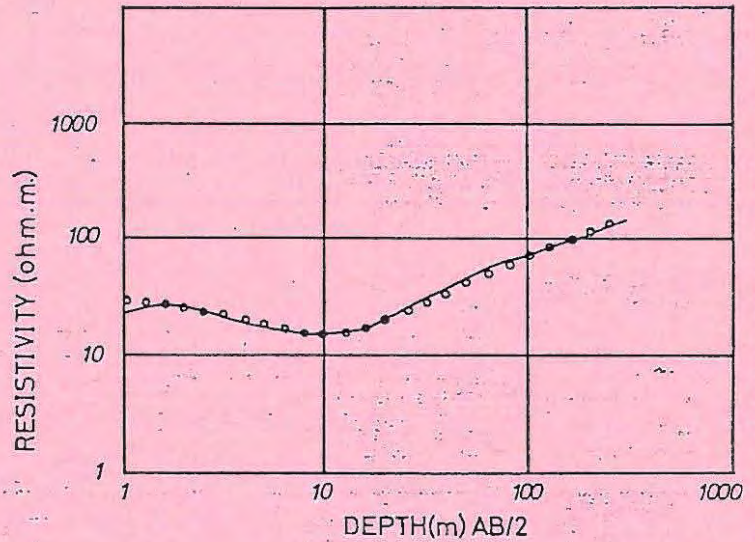
Sounding No: 101

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.2	30.0
2.0	19.0
8.4	11.0
36.0	120.0
	300.0

TOTAL S = 1.209 Siemens.

TYPE :



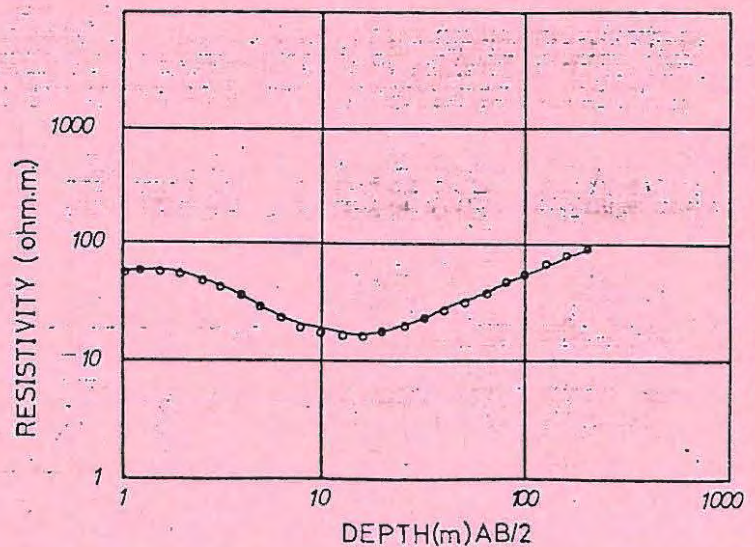
Sounding No: 102

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.9	62.0
14.4	14.0
12.7	38.0
	240.0

TOTAL S = 1.393 Siemens.

TYPE :



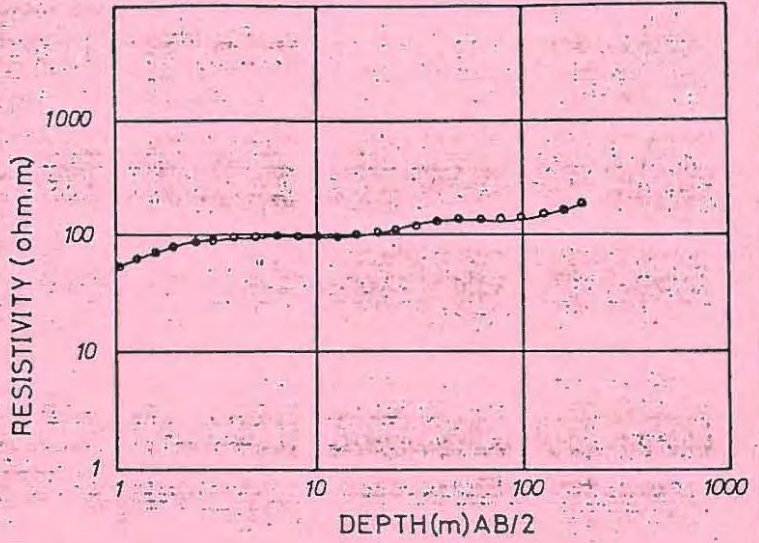
Sounding No: 103

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	38.0
1.1	170.0
11.8	90.0
30.0	200.0
20.0	50.0
	400.0

TOTAL S = 0.703 Siemens.

TYPE :



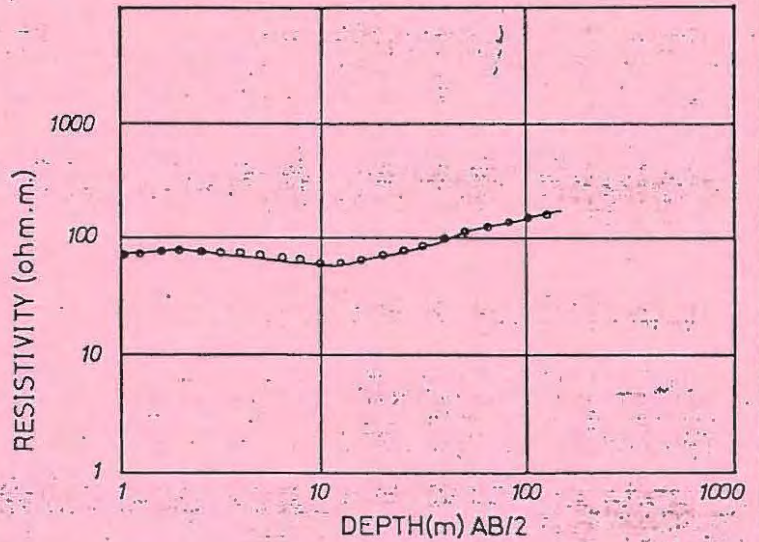
Sounding No: 104

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	40.0
2.8	85.0
9.7	50.0
	200.0

TOTAL S = 0.232 Siemens.

TYPE :



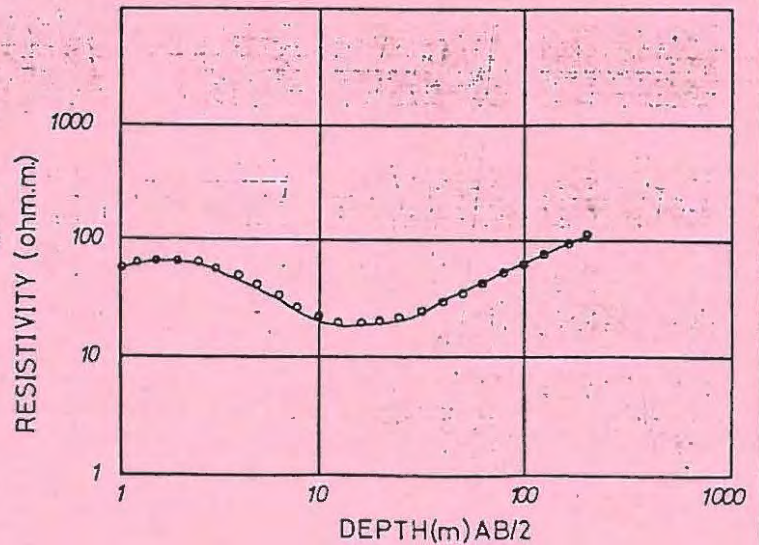
Sounding No: 105

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	5.0
1.9	80.0
19.3	16.2
28.8	150.0
	500.0

TOTAL S = 1.412 Siemens.

TYPE :



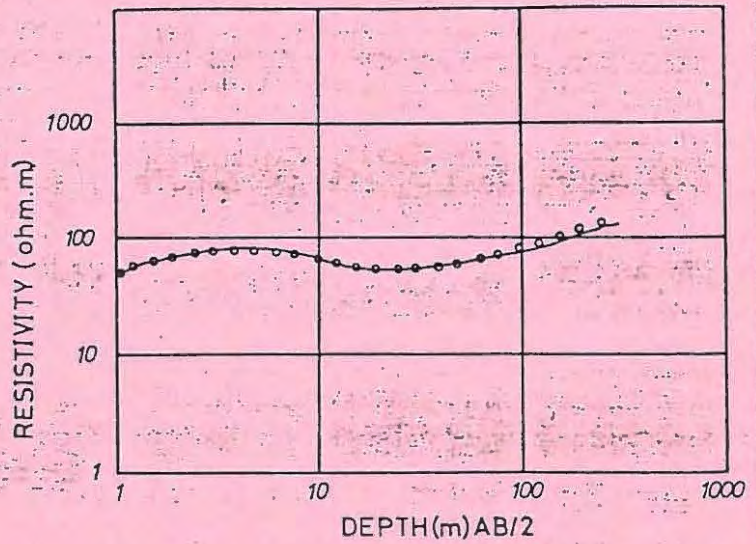
Sounding No: 106

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	4.2
5.1	87.0
8.3	36.0
49.0	65.0
	300.0

TOTAL S=1.052 Siemens.

TYPE :



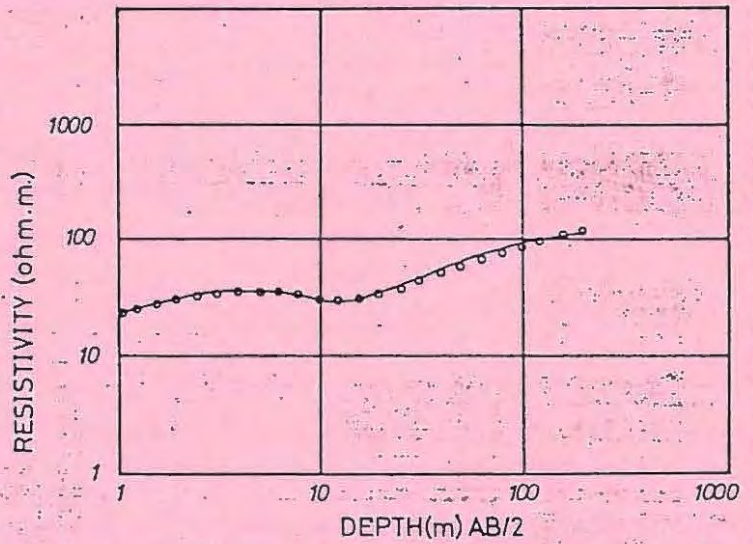
Sounding No: 107

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	18.2
3.4	45.0
8.0	18.0
	150.0

TOTAL S = 0.553 Siemens.

TYPE :



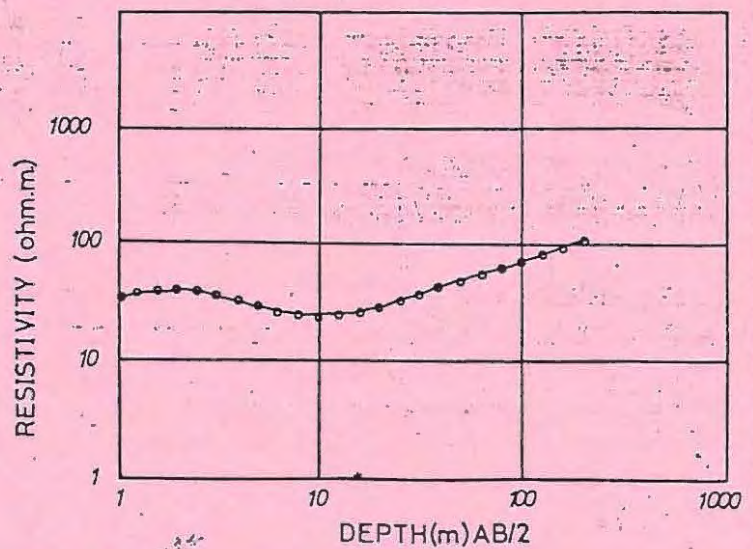
Sounding No: 108

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	14.5
1.0	60.0
11.1	20.0
44.4	80.0
	200.0

TOTAL S = 1.141 Siemens.

TYPE :



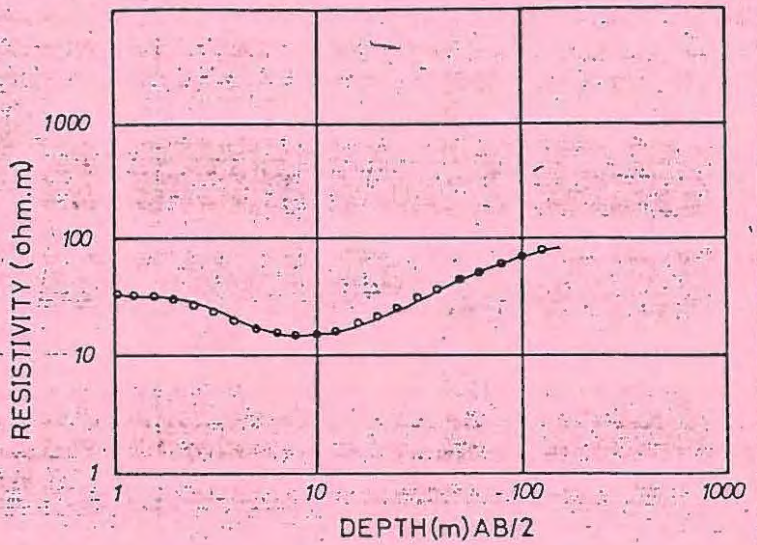
Sounding No: 109

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.4	35.0
9.2	12.7
4.6	40.0
	200.0

TOTAL S = 0.879 Siemens.

TYPE :



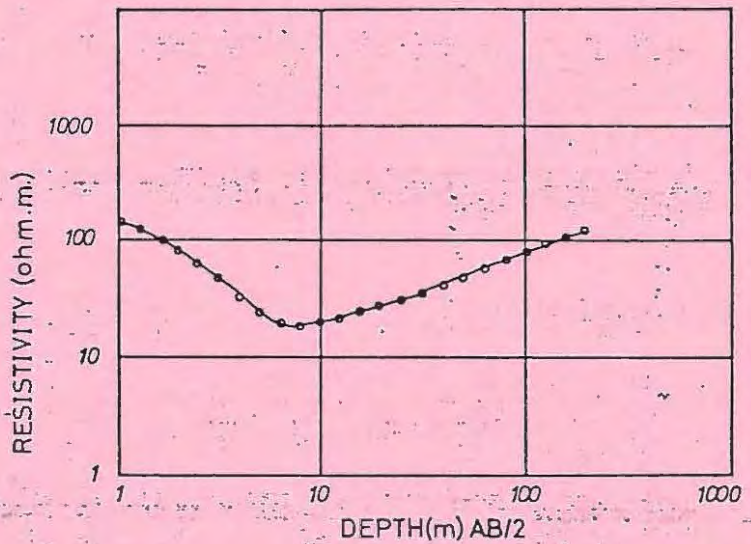
Sounding No: 110

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.7	195.0
1.5	50.0
3.5	10.0
20.7	41.0
	230.0

TOTAL S = 0.889 Siemens.

TYPE :



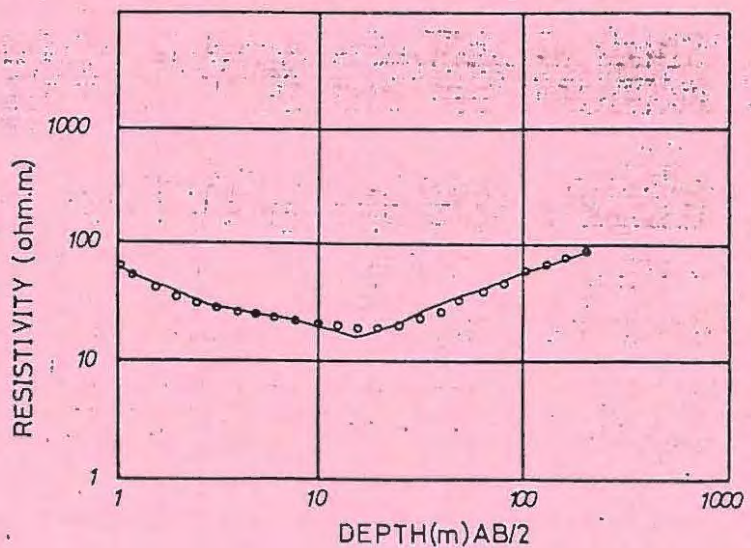
Sounding No: 111

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	150.0
2.4	30.0
0.8	9.5
4.3	32.0
3.8	4.0
	200.0

TOTAL S = 1.251 Siemens.

TYPE :



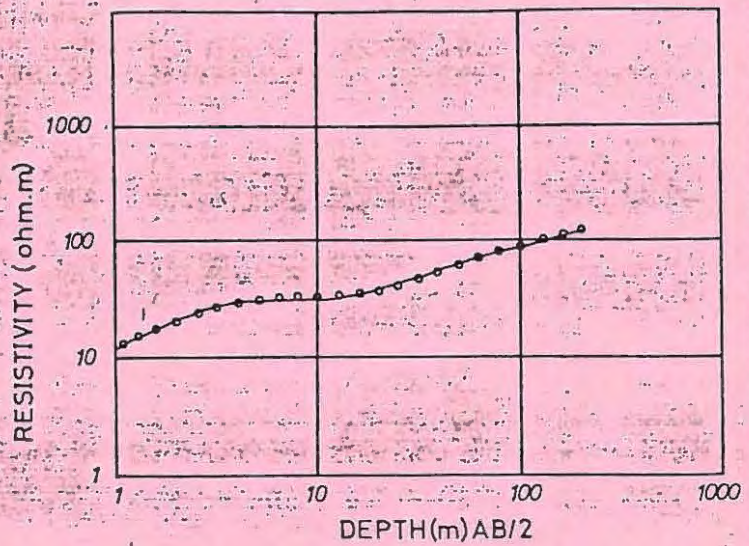
Sounding No: 112

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	4.0
5.0	45.0
2.5	9.0
22.0	100.0
	180.0

TOTAL S = 0.666 Siemens.

TYPE :



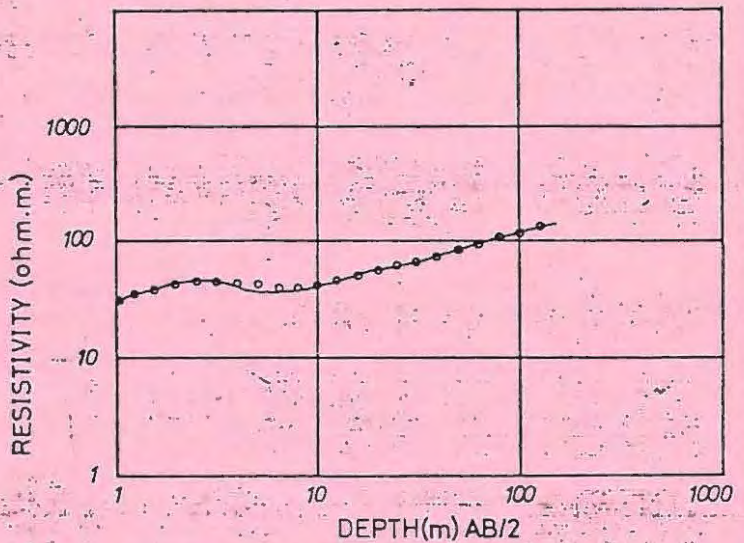
Sounding No: 113

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.2	10.0
1.5	65.0
2.5	20.0
23.0	75.0
	220.0

TOTAL S = 0.474 Siemens.

TYPE :



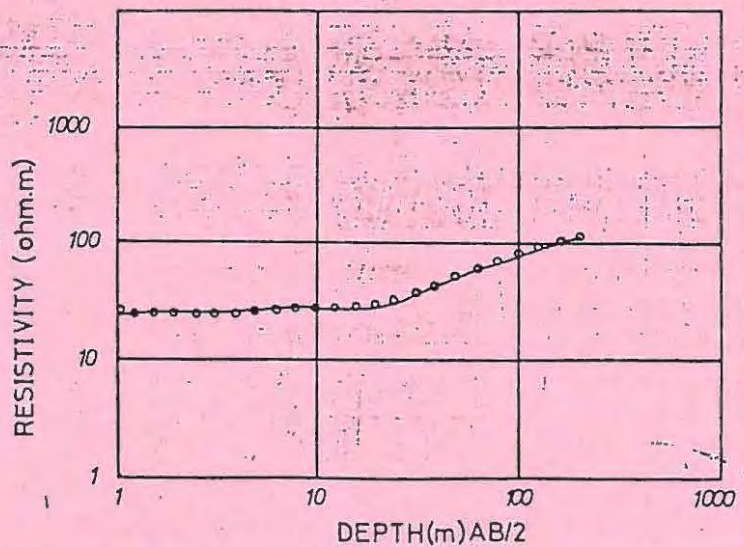
Sounding No: 114

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.2	25.0
1.3	20.0
5.3	35.0
4.2	10.0
	180.0

TOTAL S = 0.684 Siemens.

TYPE :



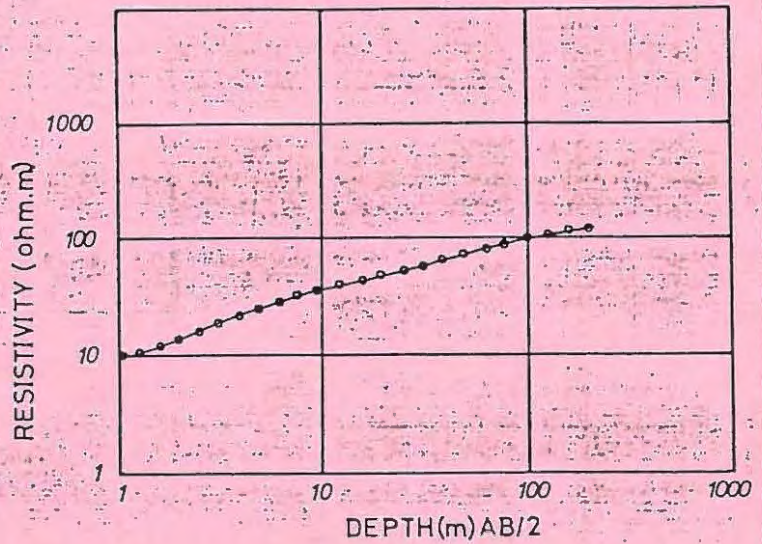
Sounding No: 115

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.1	8.5
18.7	55.0
	150.0

TOTAL S = 0.469 Siemens.

TYPE :



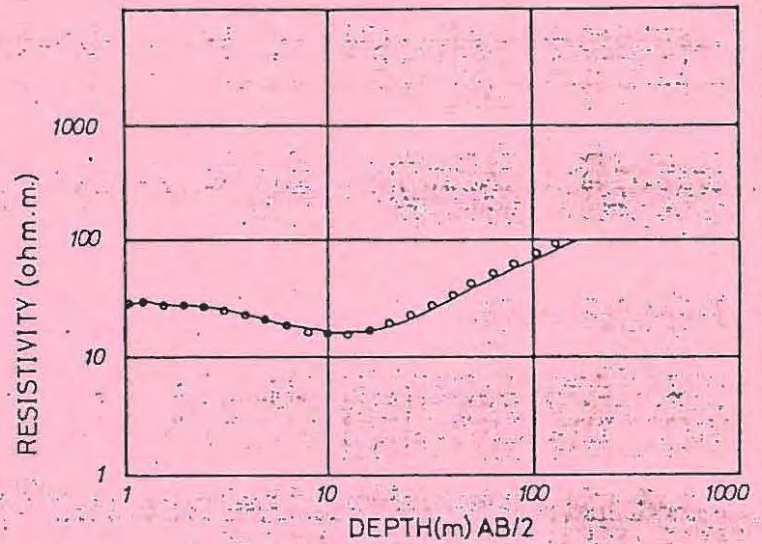
Sounding No: 116

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
2.4	29.0
10.6	11.5
	350.0

TOTAL S = 1.005 Siemens.

TYPE :



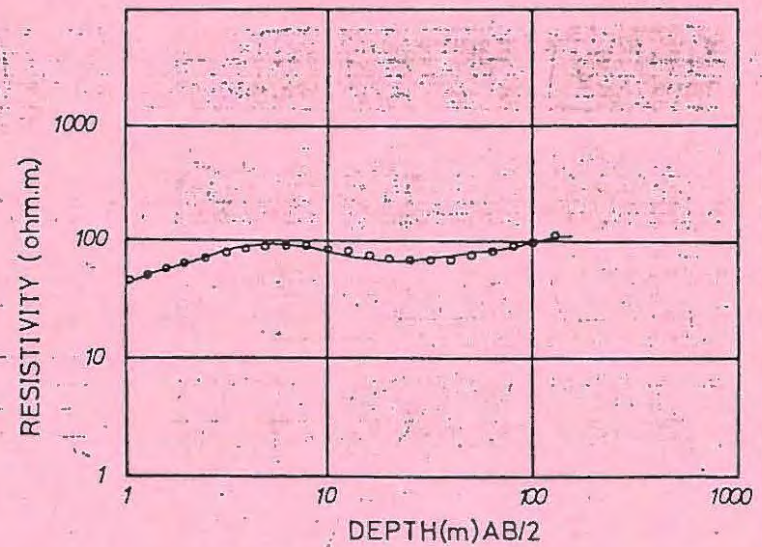
Sounding No: 117

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.6	33.0
4.6	120.0
13.6	50.0
40.3	95.0
	230.0

TOTAL S = 0.753 Siemens.

TYPE :



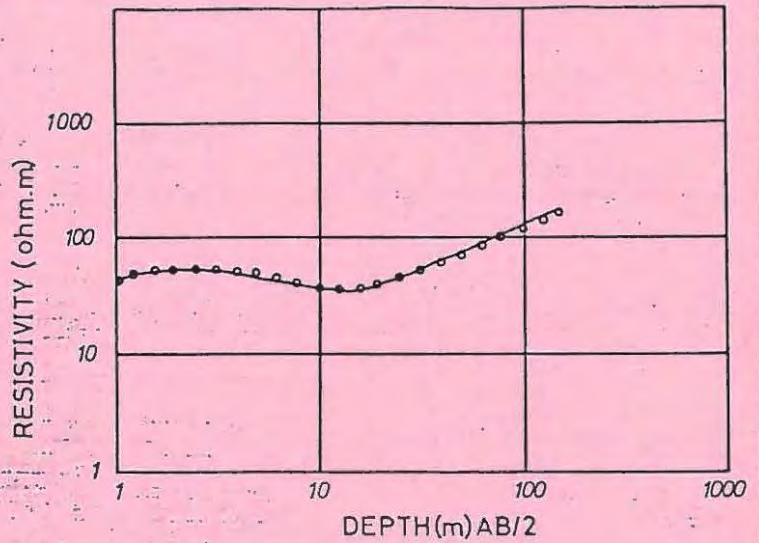
Sounding No: 118

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	24.0
2.6	60.0
10.7	28.0
24.0	100.0
	500.0

TOTAL S = 0.677 Siemens.

TYPE :



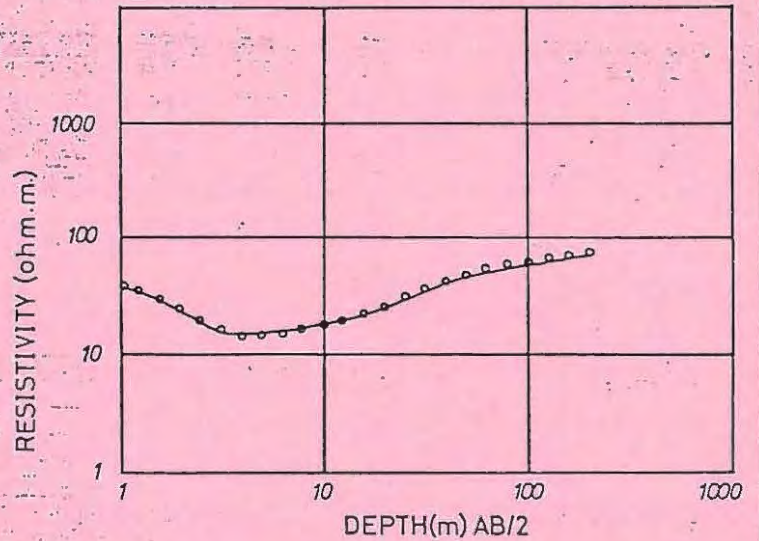
Sounding No: 119

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.9	45.0
1.9	9.5
3.8	19.0
3.3	16.0
22.0	130.0
	80.0

TOTAL S = 0.796 Siemens.

TYPE :



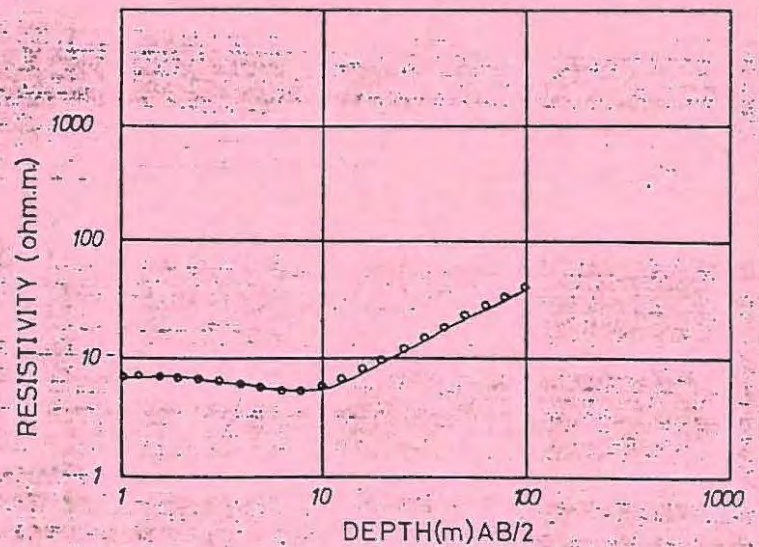
Sounding No: 120

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
2.5	7.5
3.9	3.0
12.4	50.0
	300.0

TOTAL S = 1.881 Siemens.

TYPE :



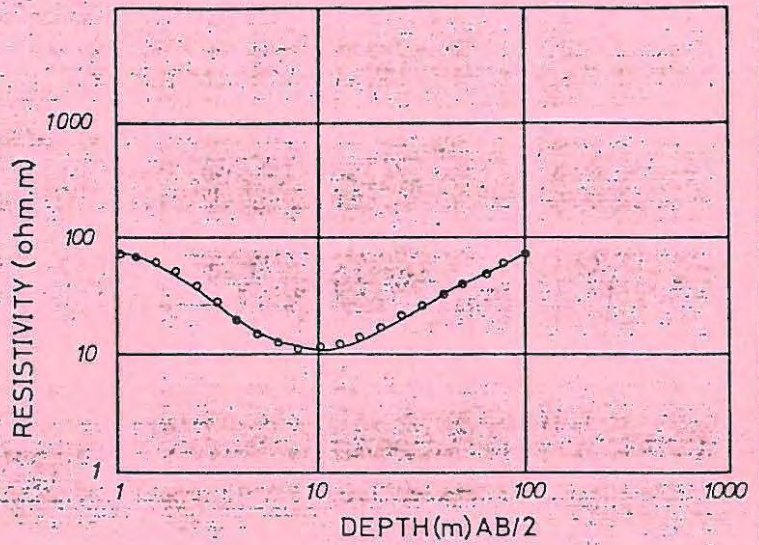
Sounding No: 121

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.1	85.0
0.2	14.0
1.0	12.0
9.2	9.0
	500.0

TOTAL S = 1.133 Siemens.

TYPE :



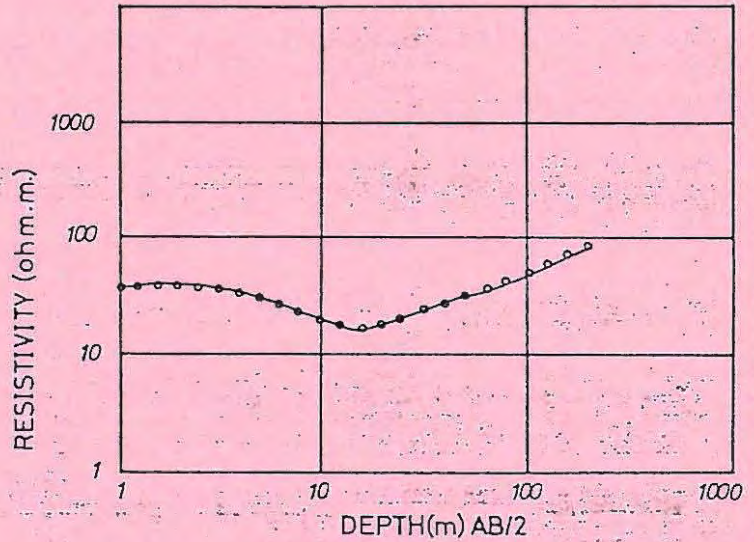
Sounding No: 122

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	25.0
3.0	40.0
10.0	12.0
40.0	50.0
	300.0

TOTAL S = 1.713 Siemens.

TYPE :



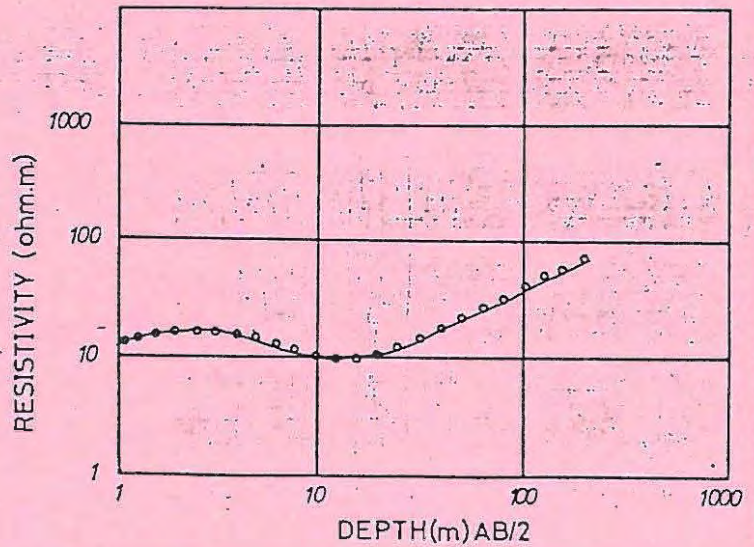
Sounding No: 123

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	8.5
2.4	20.0
12.0	6.5
	250.0

TOTAL S = 2.011 Siemens.

TYPE :



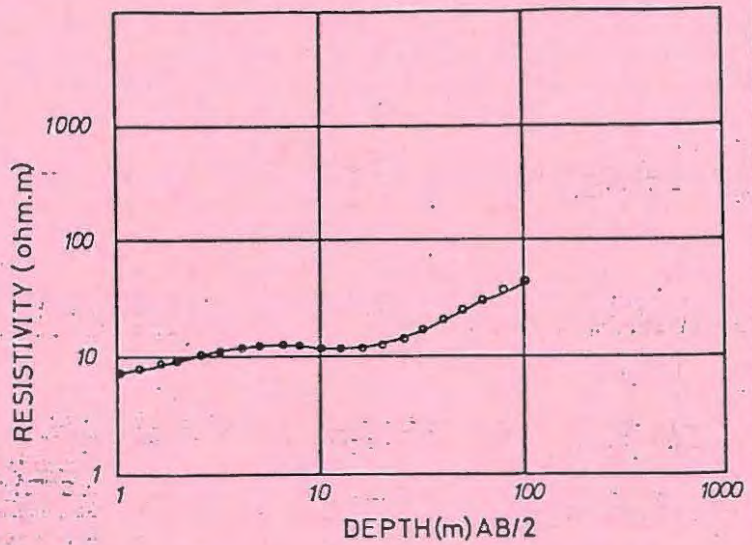
Sounding No: 124

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.9	7.0
3.4	17.0
9.1	6.5
	200.0

TOTAL S=1.734 Siemens.

TYPE :



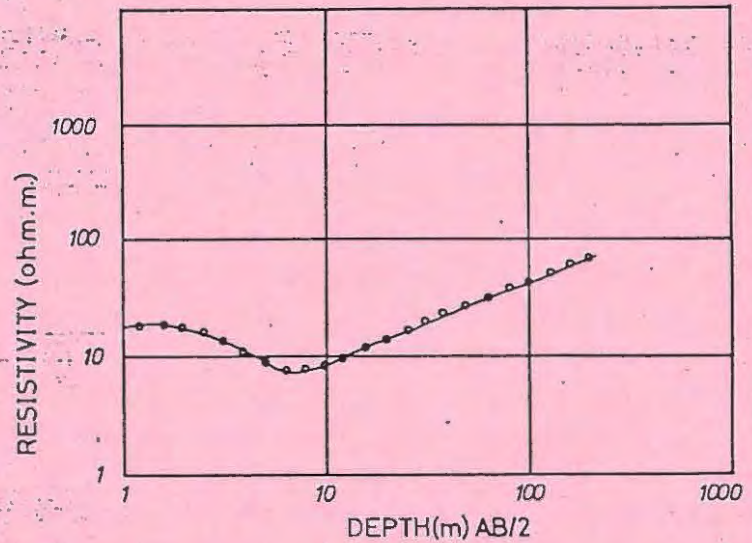
Sounding No: 125

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	7.0
0.6	45.0
5.6	5.5
22.5	45.0
	150.0

TOTAL S =1.562 Siemens.

TYPE :



Sounding No: 126

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	9.0
3.0	17.0
8.6	6.0
	500.0

TOTAL S =1.651 Siemens.

TYPE :



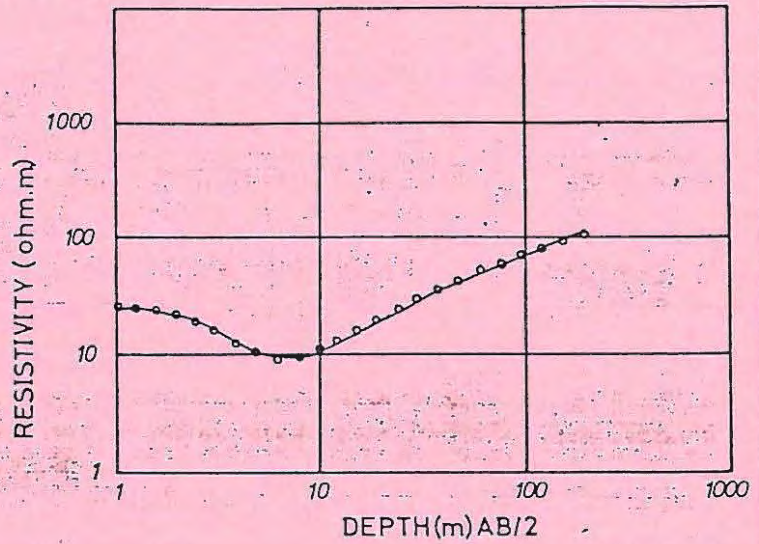
Sounding No:127

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.5	28.0
3.5	4.5
4.5	60.0
	200.0

TOTAL S=0.906 Siemens.

TYPE :



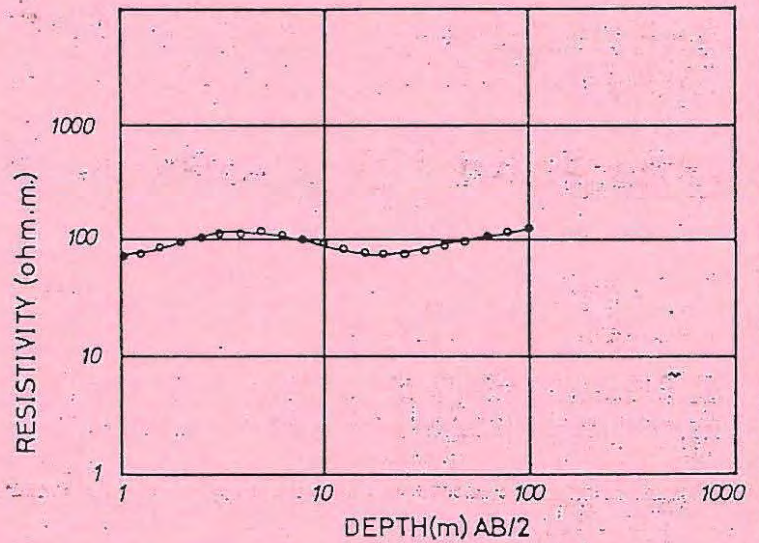
Sounding No: 128

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	42.0
3.0	170.0
13.5	55.0
	180.0

TOTAL S = 0.273 Siemens.

TYPE :



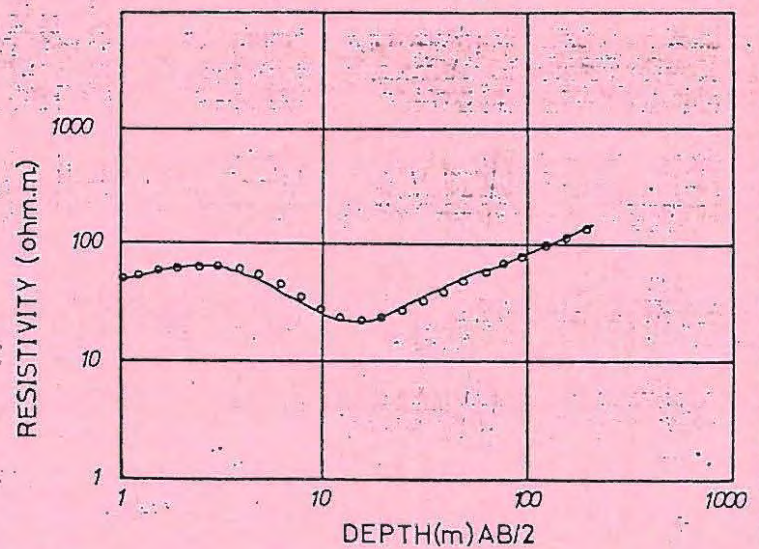
Sounding No:129

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.5	37.0
2.1	90.0
12.0	14.0
17.0	350.0
12.0	50.0
	500.0

TOTAL S = 1.183 Siemens.

TYPE :



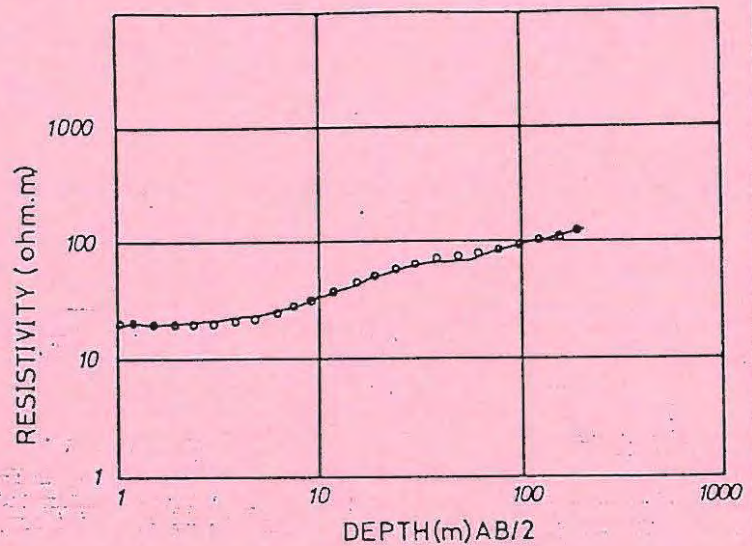
Sounding No:130

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	28.0
5.0	19.0
15.0	170.0
28.0	40.0
	350.0

TOTAL S = 1.058 Siemens.

TYPE :



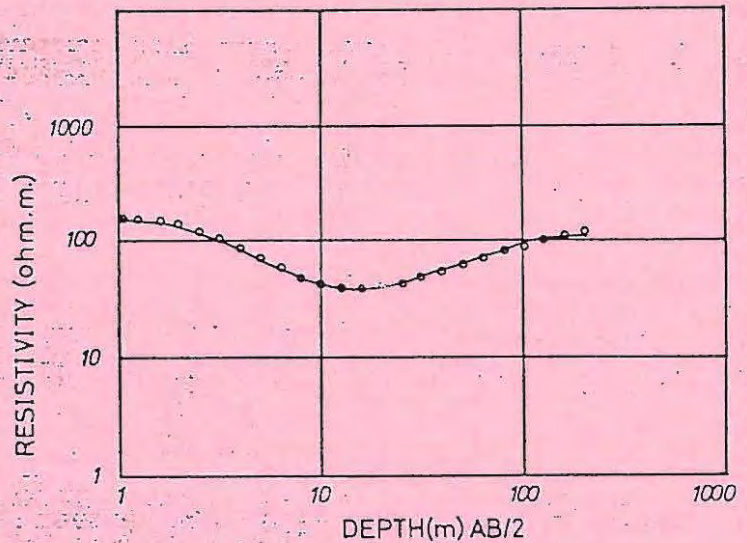
Sounding No:131

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.5	170.0
4.0	50.0
8.0	25.0
40.0	95.0
	200.0

TOTAL S = 0.830 Siemens.

TYPE :



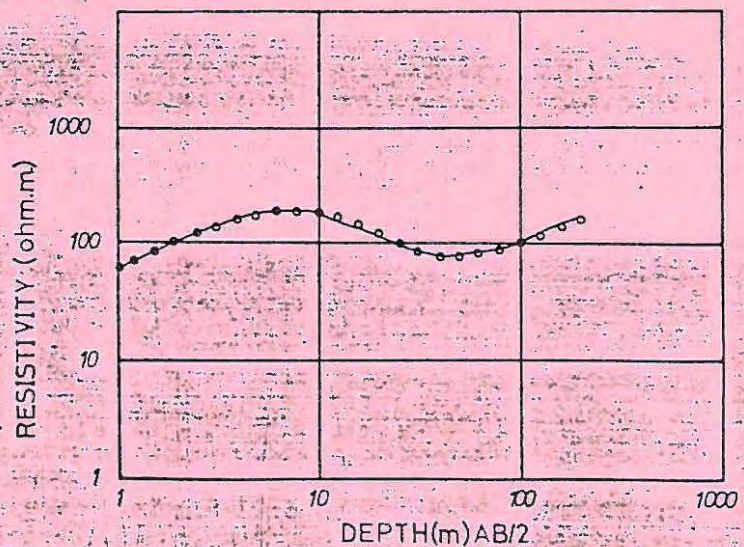
Sounding No:132

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	33.0
3.2	450.0
46.8	600
	400.0

TOTAL S = 0.803 Siemens.

TYPE :



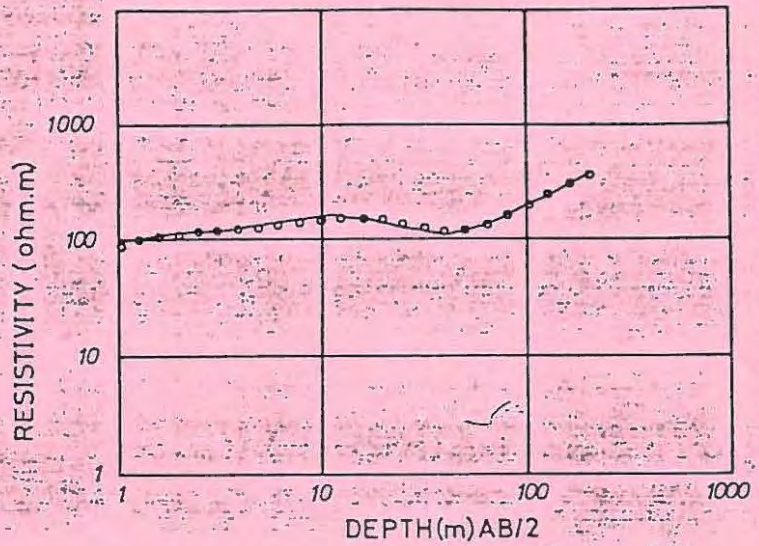
Sounding No: 133

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	22.0
1.4	130.0
1.5	75.0
5.8	300.0
27.0	60.0
	10 000.0

TOTAL S = 0.506 Siemens.

TYPE :



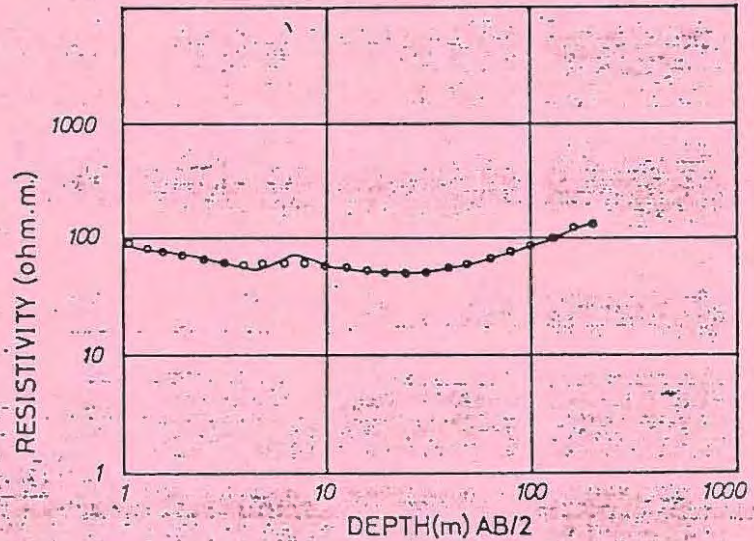
Sounding No: 134

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	95.0
1.8	45.0
1.0	200.0
15.6	40.0
28.0	80.0
	250.0

TOTAL S = 0.794 Siemens.

TYPE :



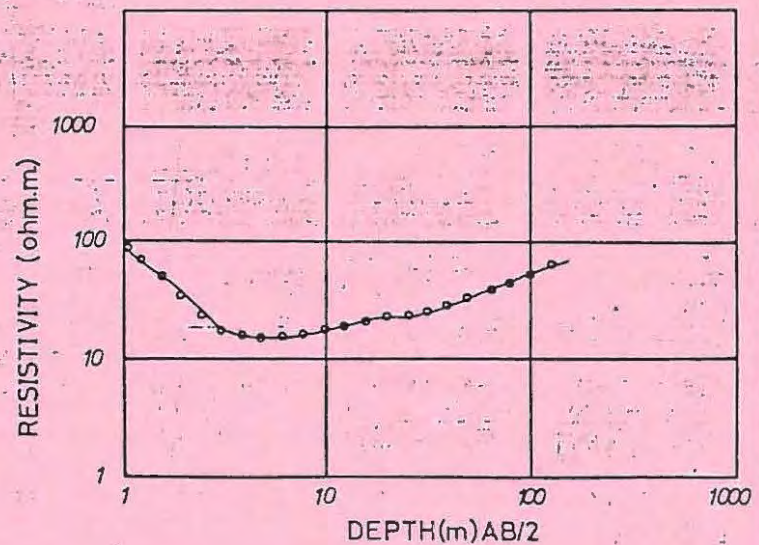
Sounding No: 135

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.6	132.0
5.5	13.0
5.2	55.0
7.0	8.0
	200.0

TOTAL S = 1.398 Siemens.

TYPE :



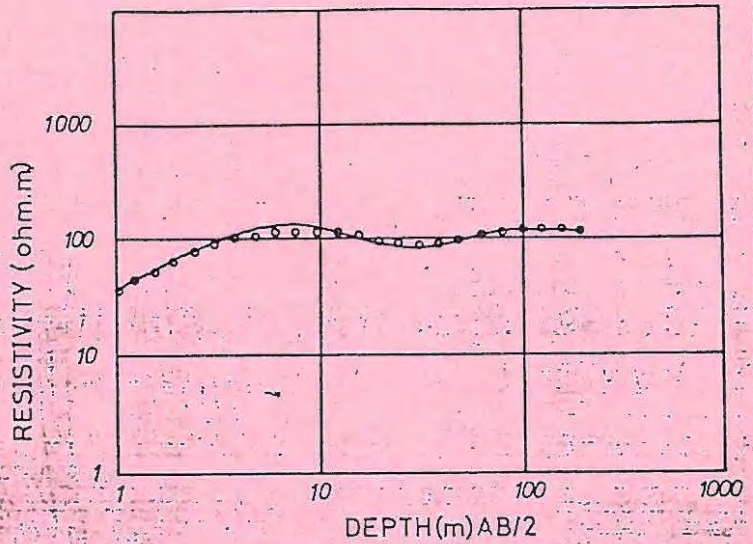
Sounding No: 136

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.3	10.5
2.2	300.0
20.0	70.0
70.0	160.0
	100.0

TOTAL S = 0.755 Siemens.

TYPE :



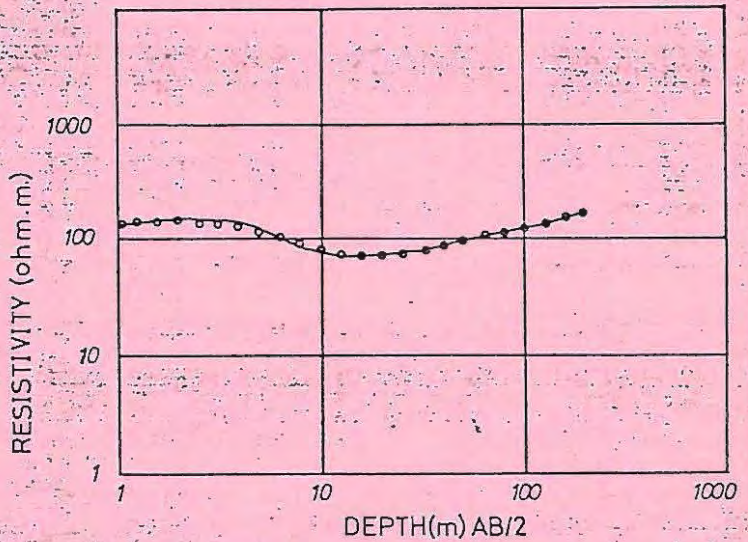
Sounding No: 137

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
2.2	145.0
1.0	160.0
4.0	50.0
22.0	80.0
95.0	180.0
	400.0

TOTAL S = 0.904 Siemens.

TYPE :



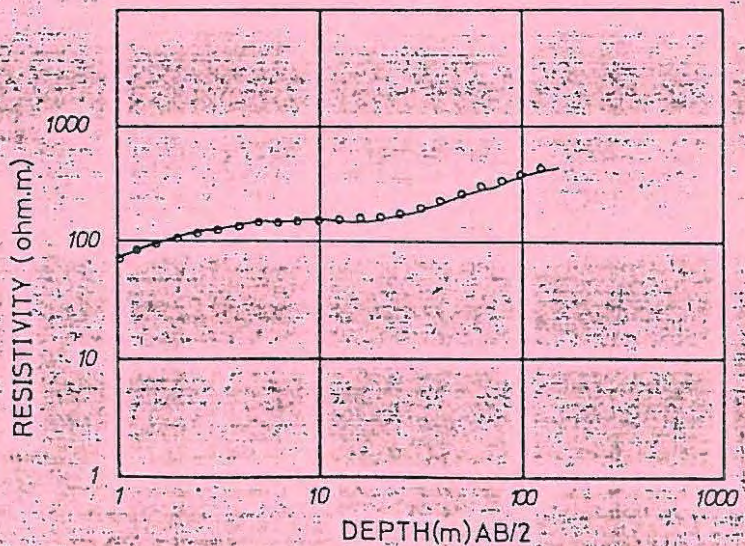
Sounding No: 138

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	2.2
9.0	160.0
3.0	50.0
	650.0

TOTAL S = 0.125 Siemens.

TYPE :



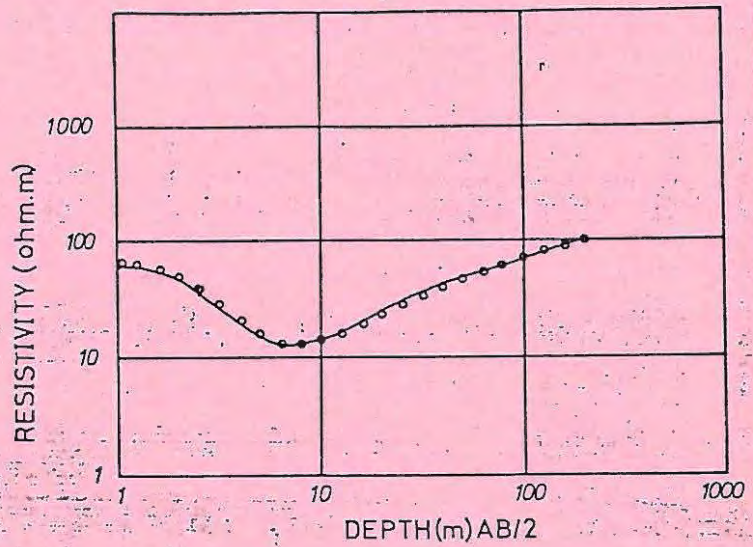
Sounding No:139

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.3	70.0
6.6	9.0
	140.0

TOTAL S=0.752 Siemens.

TYPE :



Sounding No:140

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	30.0
1.0	57.0
2.0	42.0
6.0	16.0
90.6	93.0
	600.0

TOTAL S =1.421 Siemens.

TYPE :



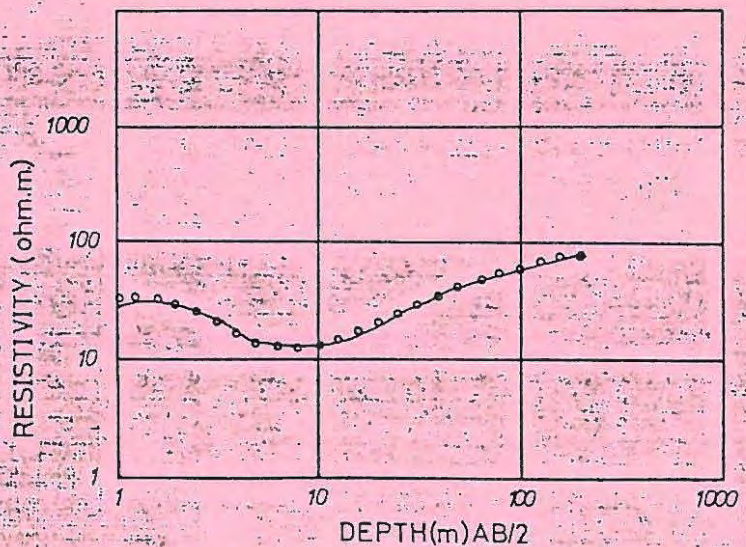
Sounding No:141

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.2	20.0
0.9	45.0
7.7	9.6
50.4	110.0
	100.0

TOTAL S =1.289 Siemens.

TYPE :



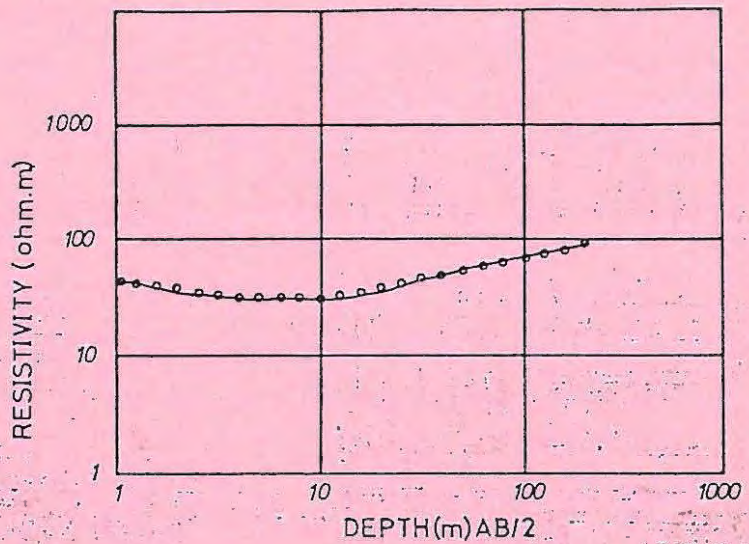
Sounding No:142

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.8	50.0
9.7	30.0
69.7	67.0
	200.0

TOTAL S=1.378 Siemens.

TYPE :



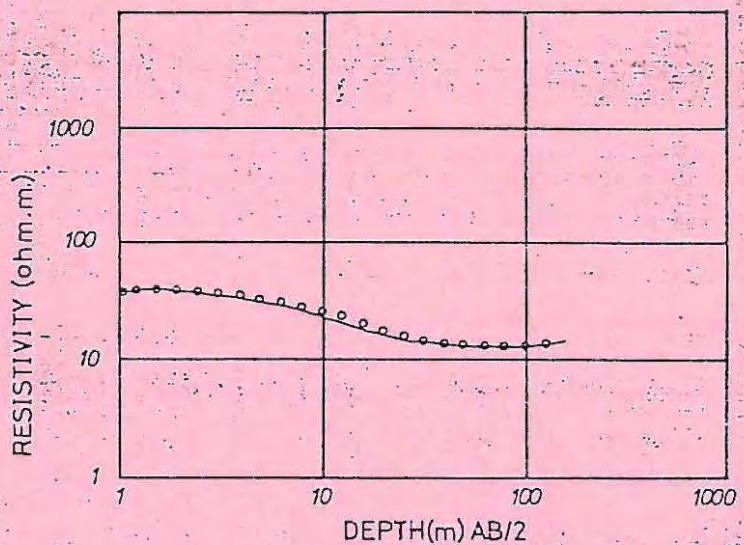
Sounding No: 143

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	35.0
1.3	45.0
5.5	30.0
61.8	12.5

TOTAL S = 5.167 Siemens.

TYPE :



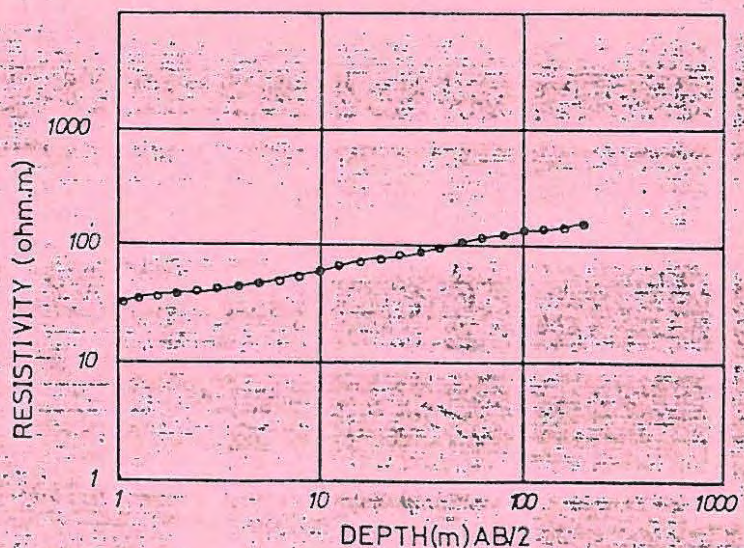
Sounding No:144

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	17.2
1.0	60.0
1.5	30.0
12.1	95.0
3.0	40.0
	180.0

TOTAL S = 0.290 Siemens.

TYPE :



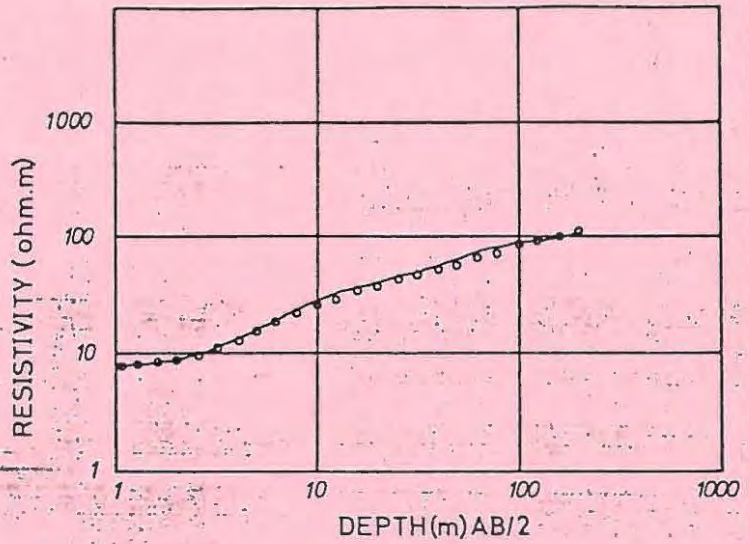
Sounding No:145

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.9	7.5
20.4	60.0
4.8	40.0
	150.0

TOTAL S = 0.716 Siemens.

TYPE :



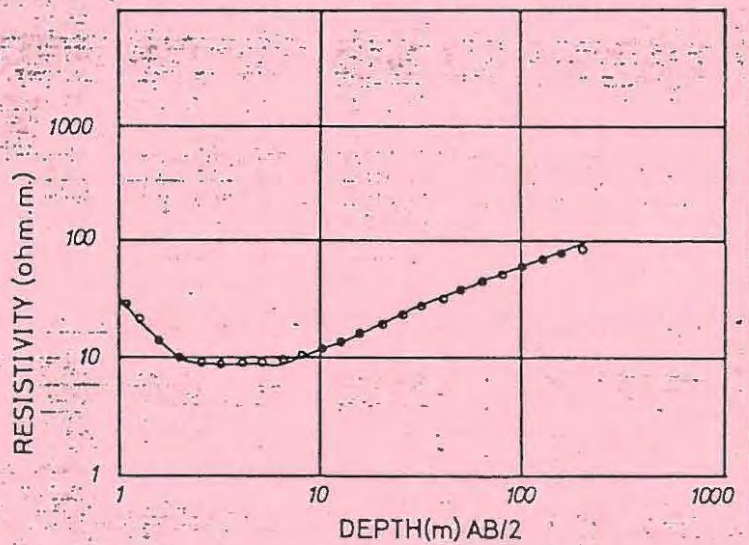
Sounding No: 146

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.3	220.0
7.1	8.5
21.6	77.0
	130.0

TOTAL S = 1.117 Siemens.

TYPE :



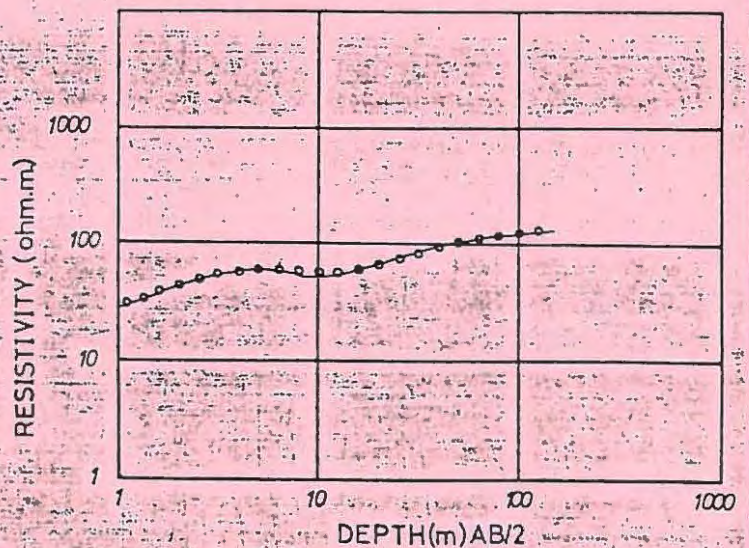
Sounding No: 147

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	2.8
3.0	90.0
4.0	25.0
	150.0

TOTAL S = 0.218 Siemens.

TYPE :



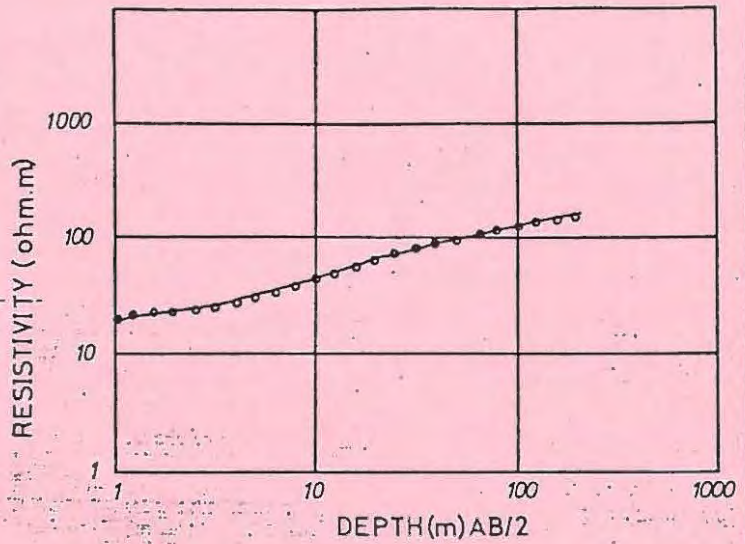
Sounding No: 148

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
2.5	21.0
4.3	50.0
49.1	130.0
	230.0

TOTAL S=0.583 Siemens.

TYPE :



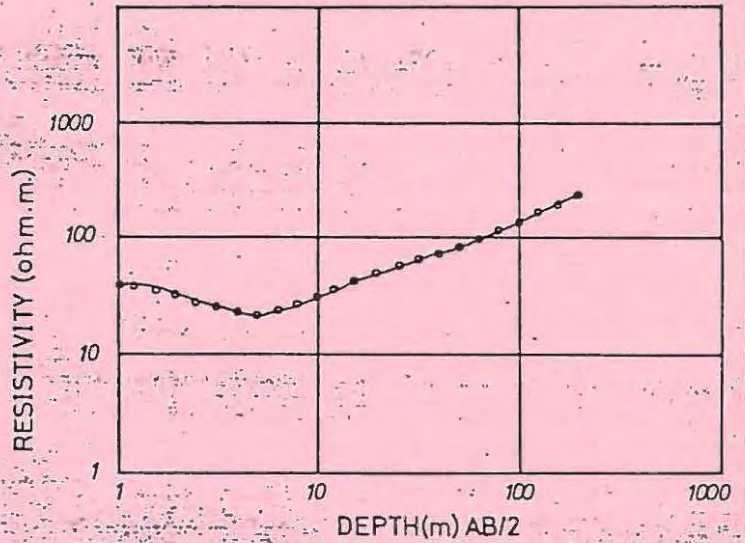
Sounding No: 149

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.2	40.0
3.5	15.0
45.7	110.0
	1500.0

TOTAL S =0.679 Siemens.

TYPE :



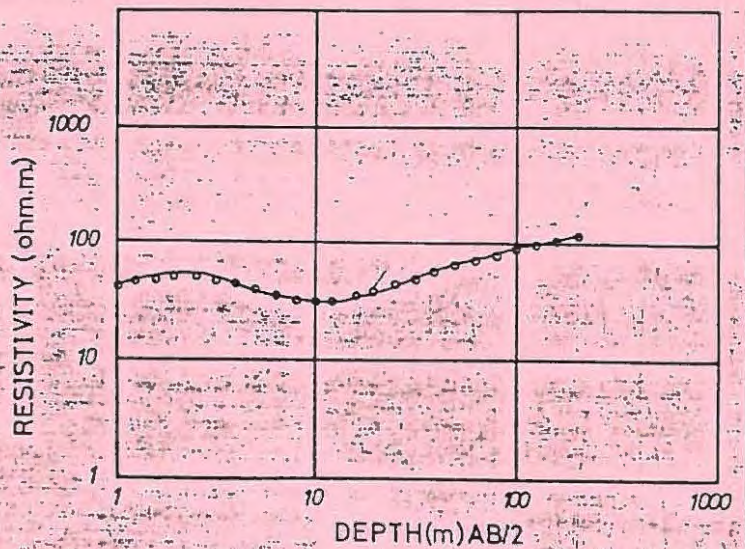
Sounding No: 150

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	24.0
1.2	80.0
8.2	24.0
36.0	100.0
	170.0

TOTAL S =0.732 Siemens.

TYPE :



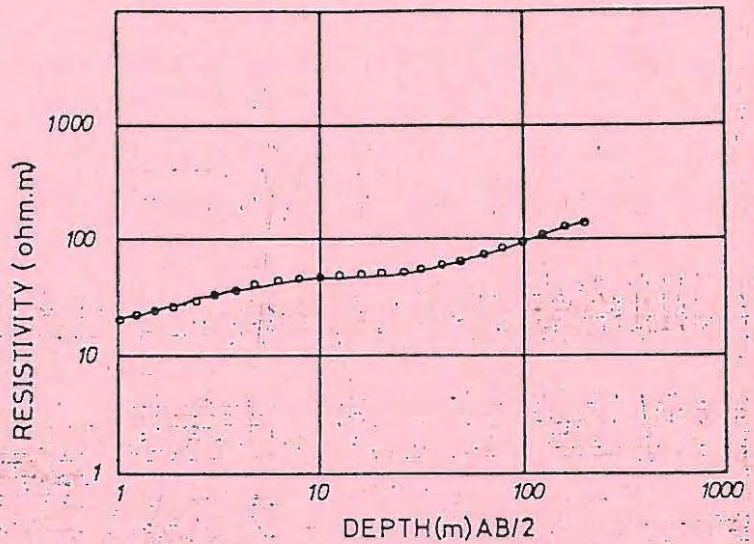
Sounding No: 151

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
1.1	18.0
4.8	58.0
26.0	50.0
	250.0

TOTAL S = 0.662 Siemens

TYPE :



Sounding No: 152

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.1	2.6
4.3	100.0
25.2	10.0
	200.0

TOTAL S = 1.923 Siemens

TYPE :



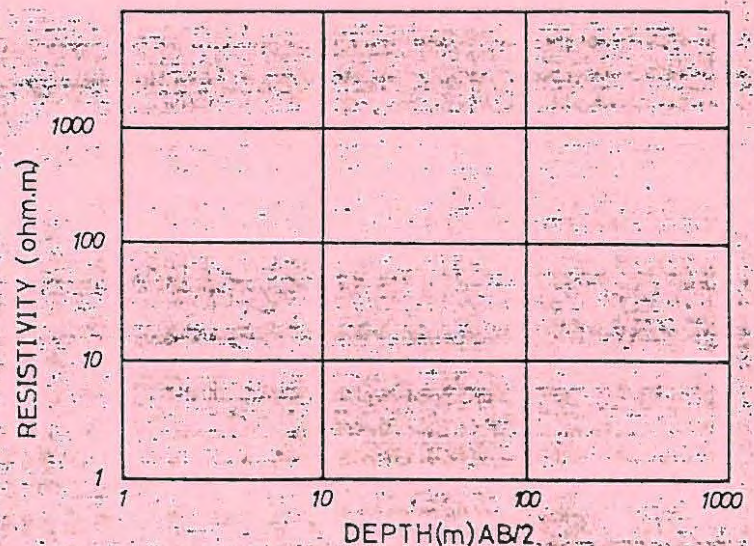
Sounding No:

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
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TOTAL S = Siemens

TYPE :



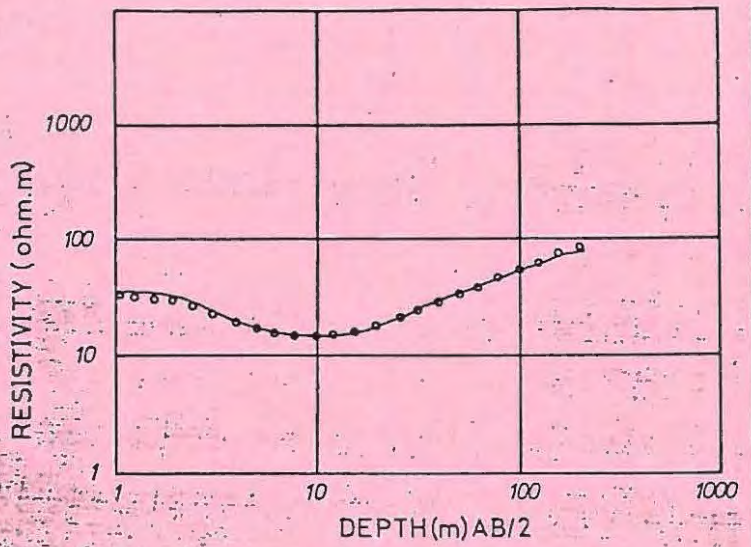
Sounding No: 160

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	32.4
0.8	38.0
11.7	13.0
36.5	75.0
	200.0

TOTAL S = 1.424 Siemens.

TYPE :



Sounding No:

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
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TOTAL S = Siemens.

TYPE :



Sounding No:

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
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TOTAL S = Siemens.

TYPE :



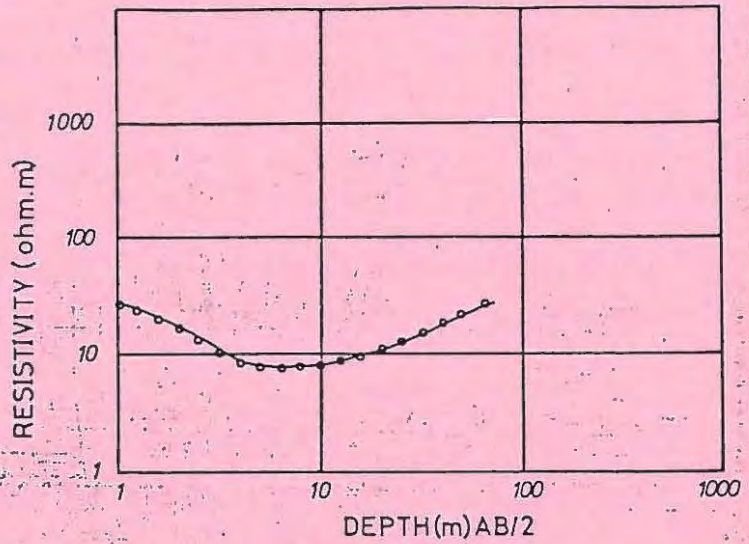
Sounding No: 1A ..

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.9	30.0
7.5	6.4
18.0	20.0
	500.0

TOTAL S = 2.102 Siemens.

TYPE :



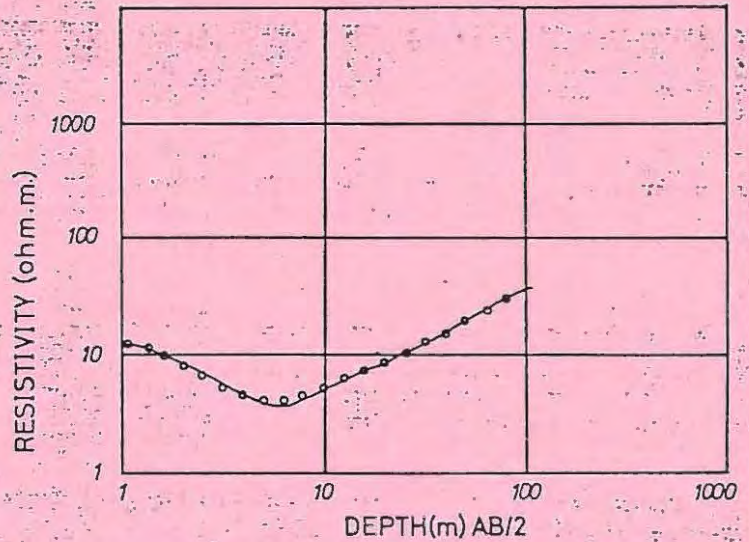
Sounding No: 2A

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.6	0.2
0.9	7.0
3.2	2.6
12.3	15.0
21.6	110.0
	1000.0

TOTAL S = 2.414 Siemens.

TYPE :



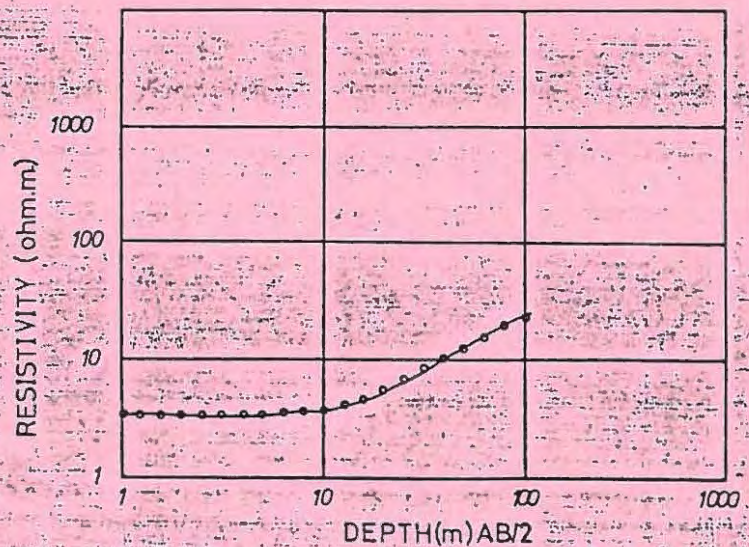
Sounding No: 3A

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
11.0	3.5
45.0	60.0
	1000.0

TOTAL S = 3.893 Siemens.

TYPE :



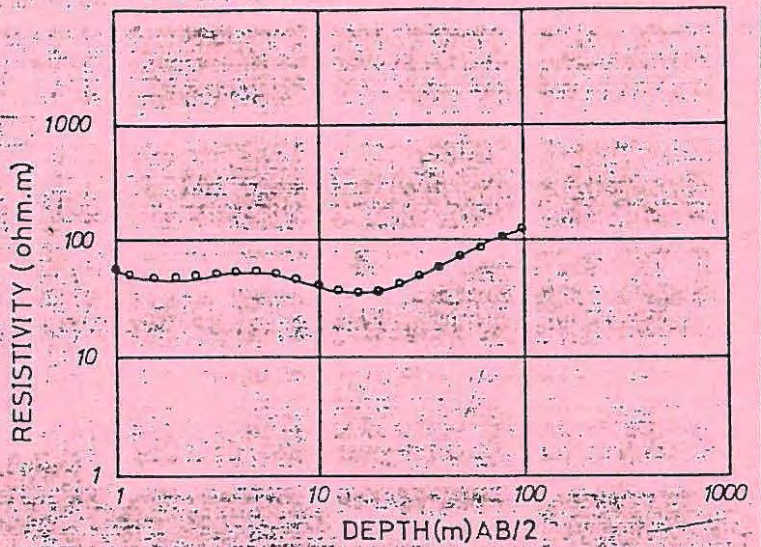
Sounding No: 5A

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	86.0
0.7	30.0
3.1	75.0
9.4	17.0
	900.0

TOTAL S=0.621 Siemens.

TYPE :



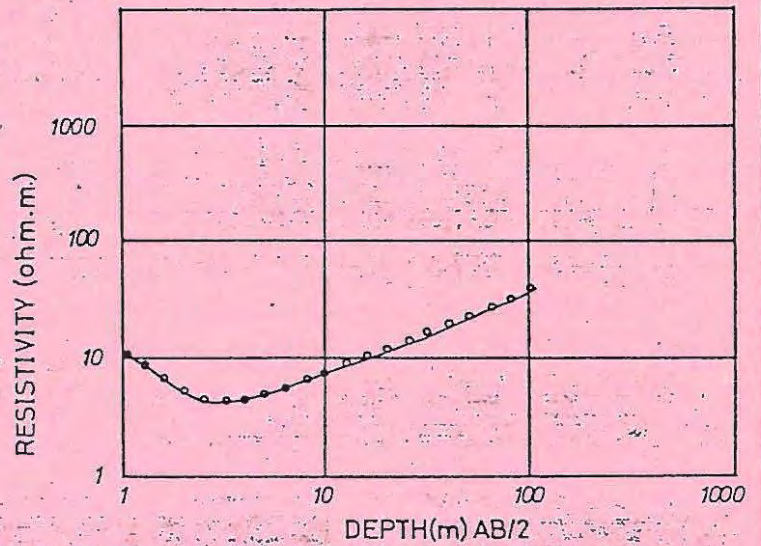
Sounding No: 11A

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.5	25.0
3.2	3.5
7.1	20.0
31.2	30.0
	1000.0

TOTAL S = 2.329 Siemens.

TYPE :



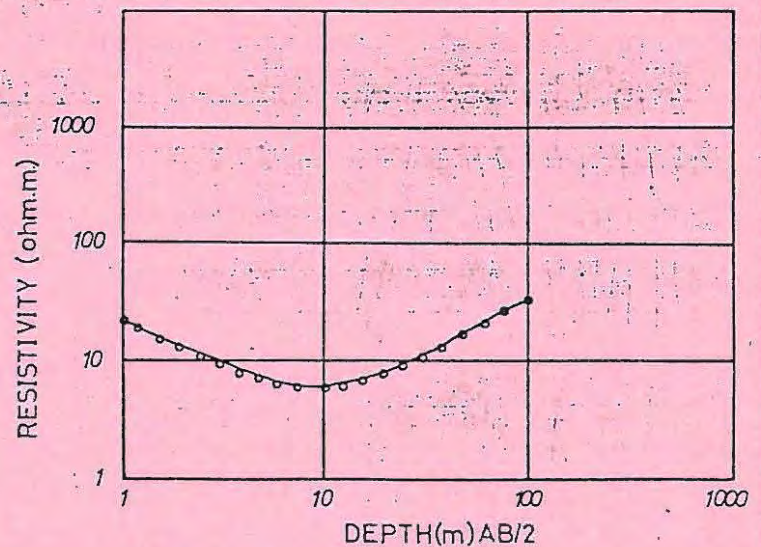
Sounding No: 14A

EARTH MODEL

<u>Layer Thickness</u> (m)	<u>Resistivity</u> (ohm.m)
0.4	37.0
1.2	13.0
9.0	5.2
17.0	20.0
	1000.0

TOTAL S = 2.686 Siemens.

TYPE :



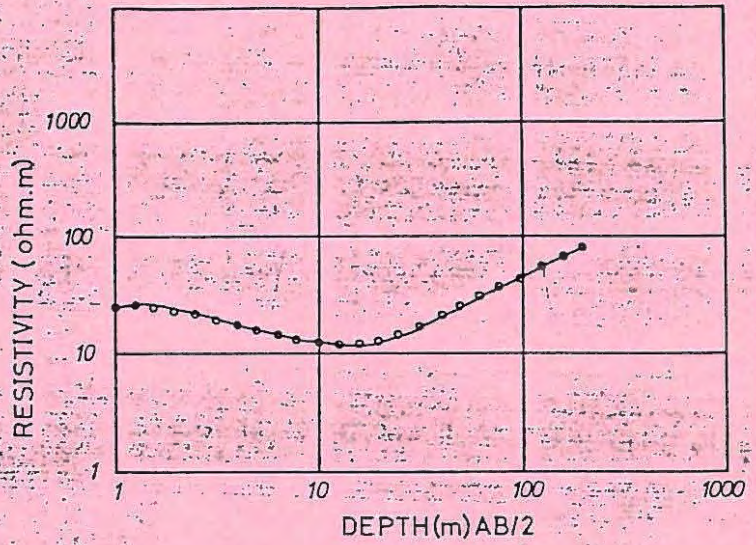
Sounding No: 87A

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.1	20.0
1.5	25.0
5.3	12.0
10.5	8.0
	2500.0

TOTAL S = 1816 Siemens.

TYPE :



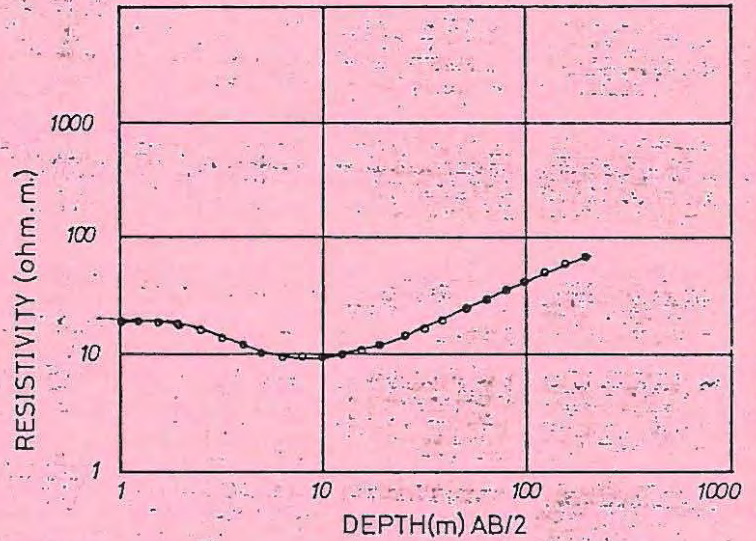
Sounding No: 88A

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.4	14.0
0.6	30.0
7.1	8.0
7.0	15.0
14.0	30.0
	250.0

TOTAL S = 1868 Siemens.

TYPE :



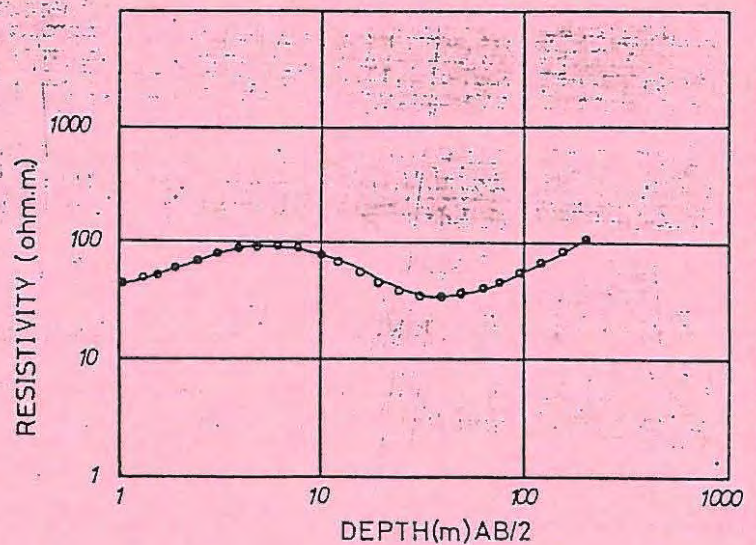
Sounding No: 57A

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	34.0
2.3	220.0
25.0	27.0
42.6	52.0
	2600.0

TOTAL S = 1782 Siemens.

TYPE :



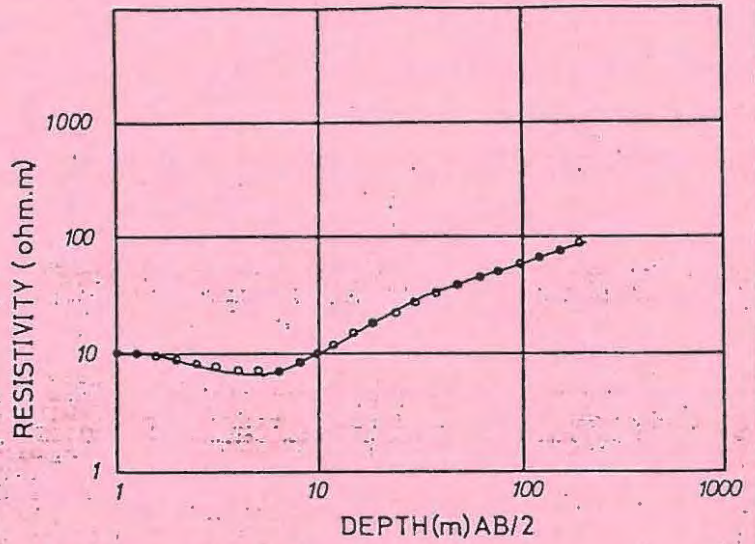
Sounding No: 94 A

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
0.9	10.2
9.0	9.5
3.0	3.5
18.0	400.0
40.3	30.0
	900.0

TOTAL S = 2.424 Siemens

TYPE :



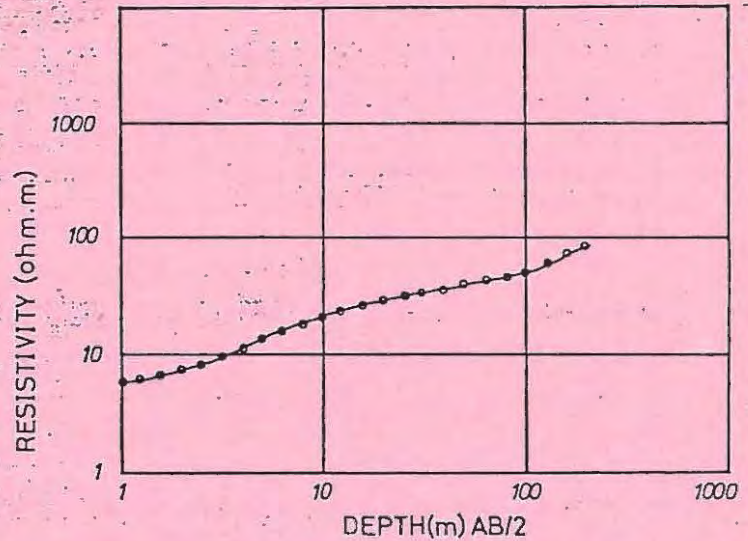
Sounding No: 99A

EARTH MODEL

Layer Thickness (m)	Resistivity (ohm.m)
1.5	5.2
36.4	40.0
5.9	14.0
	240.0

TOTAL S = 1.620 Siemens

TYPE :



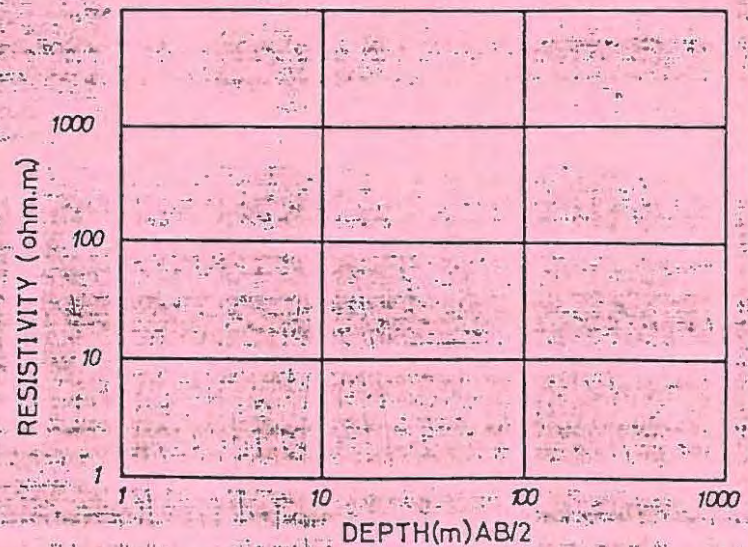
Sounding No: ---

EARTH MODEL

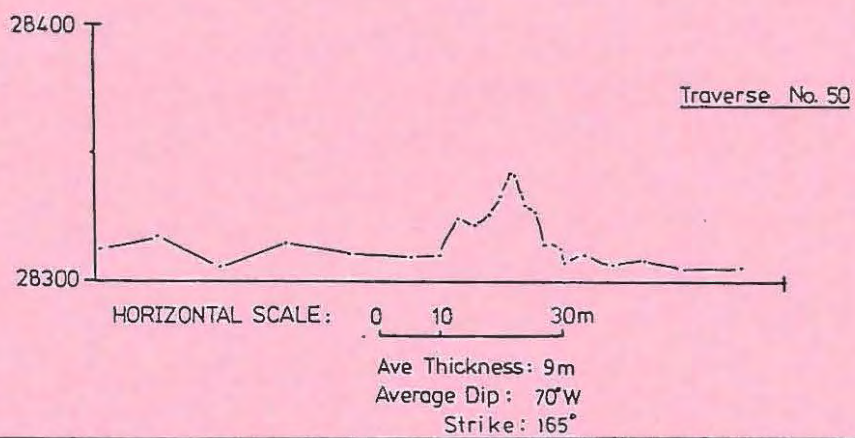
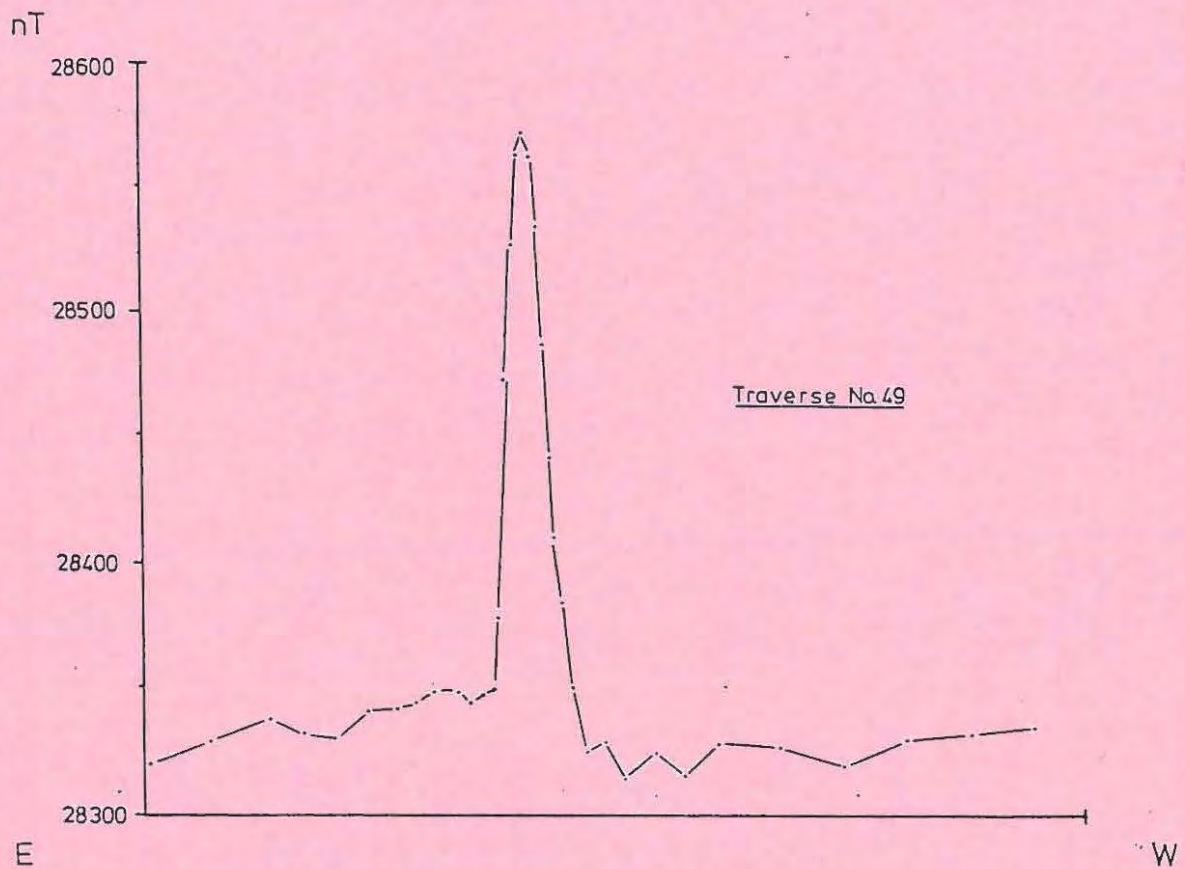
Layer Thickness (m)	Resistivity (ohm.m)

TOTAL S = Siemens

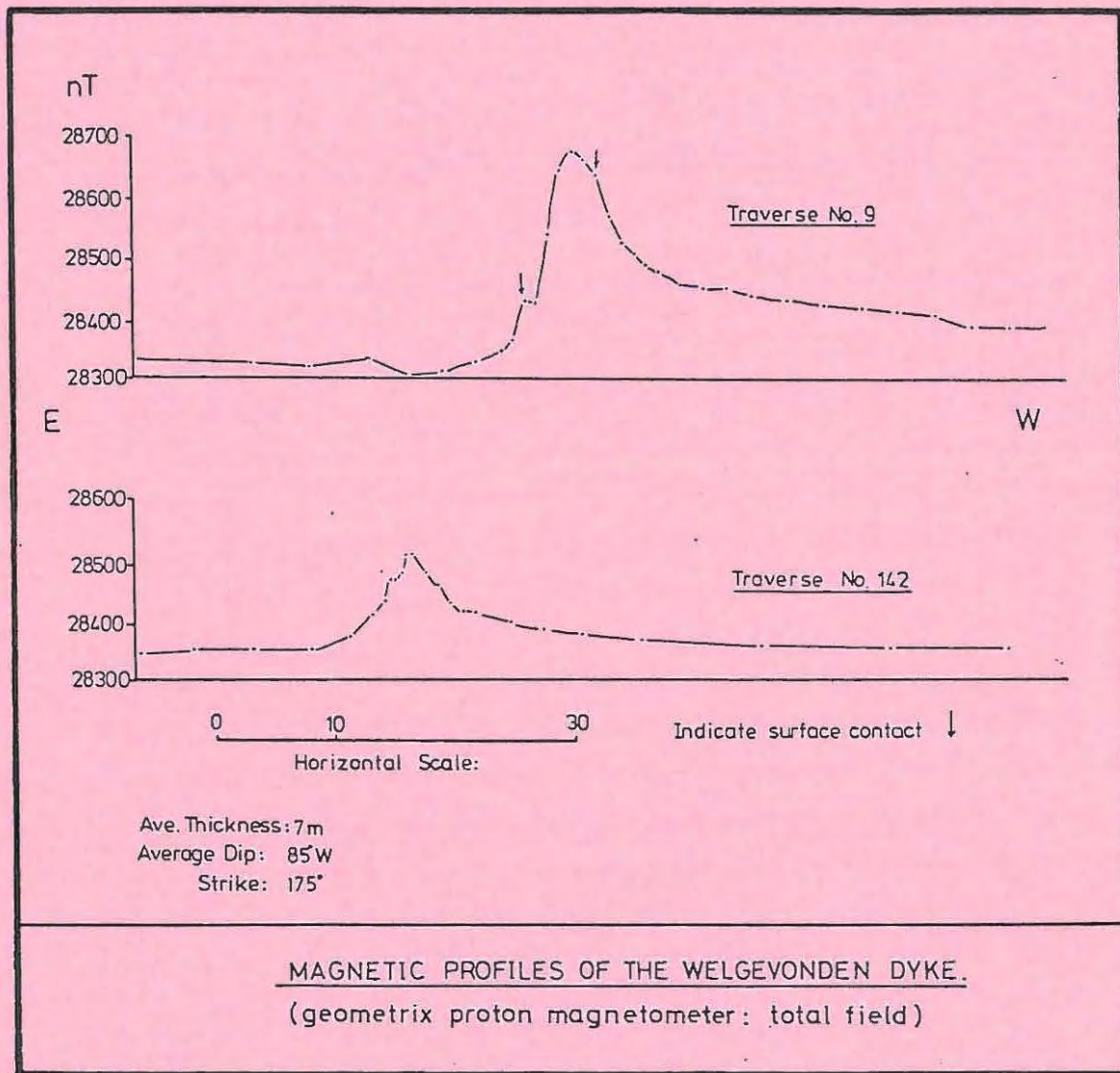
TYPE :



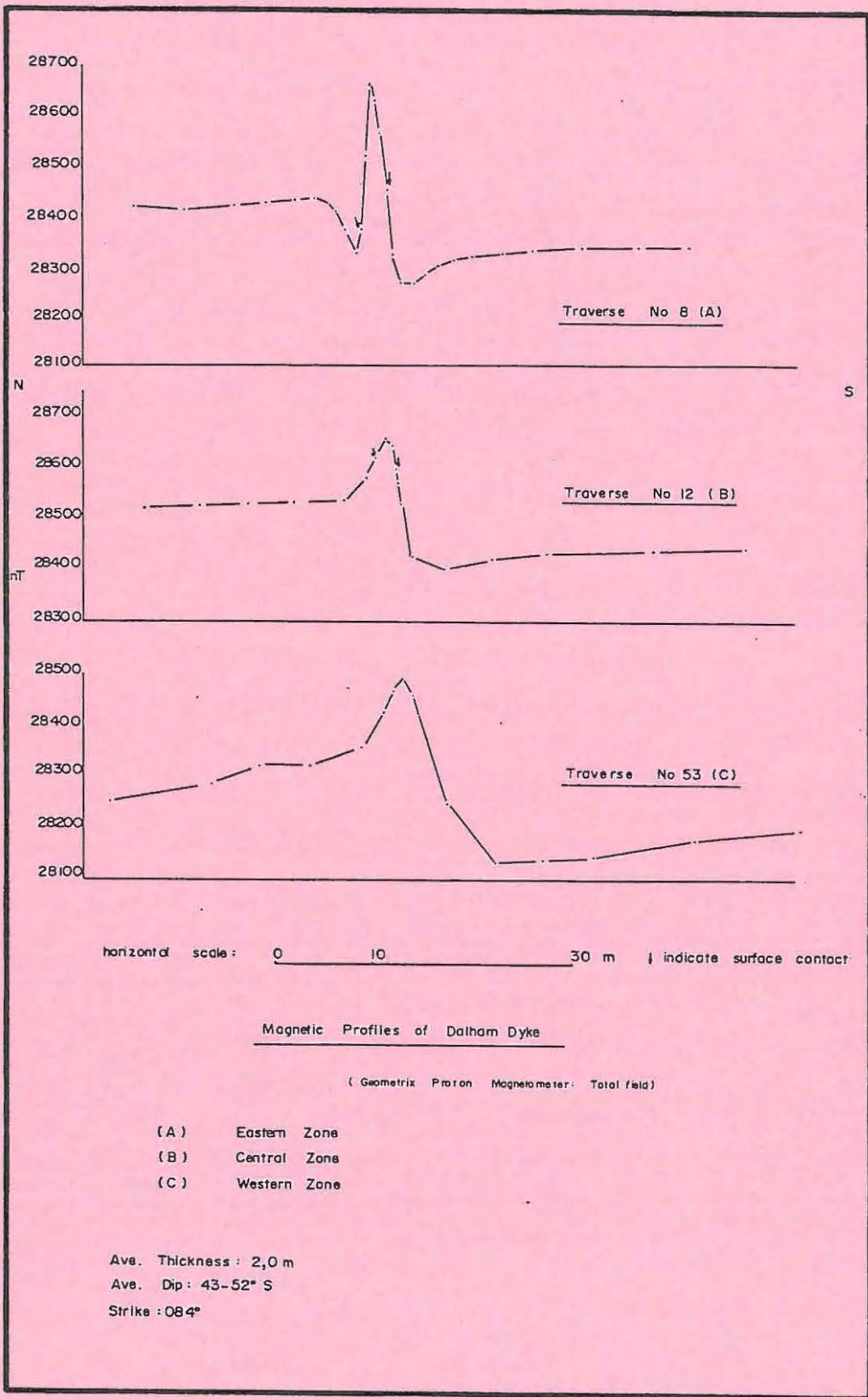
Appendix 5B:  
Magnetic curves

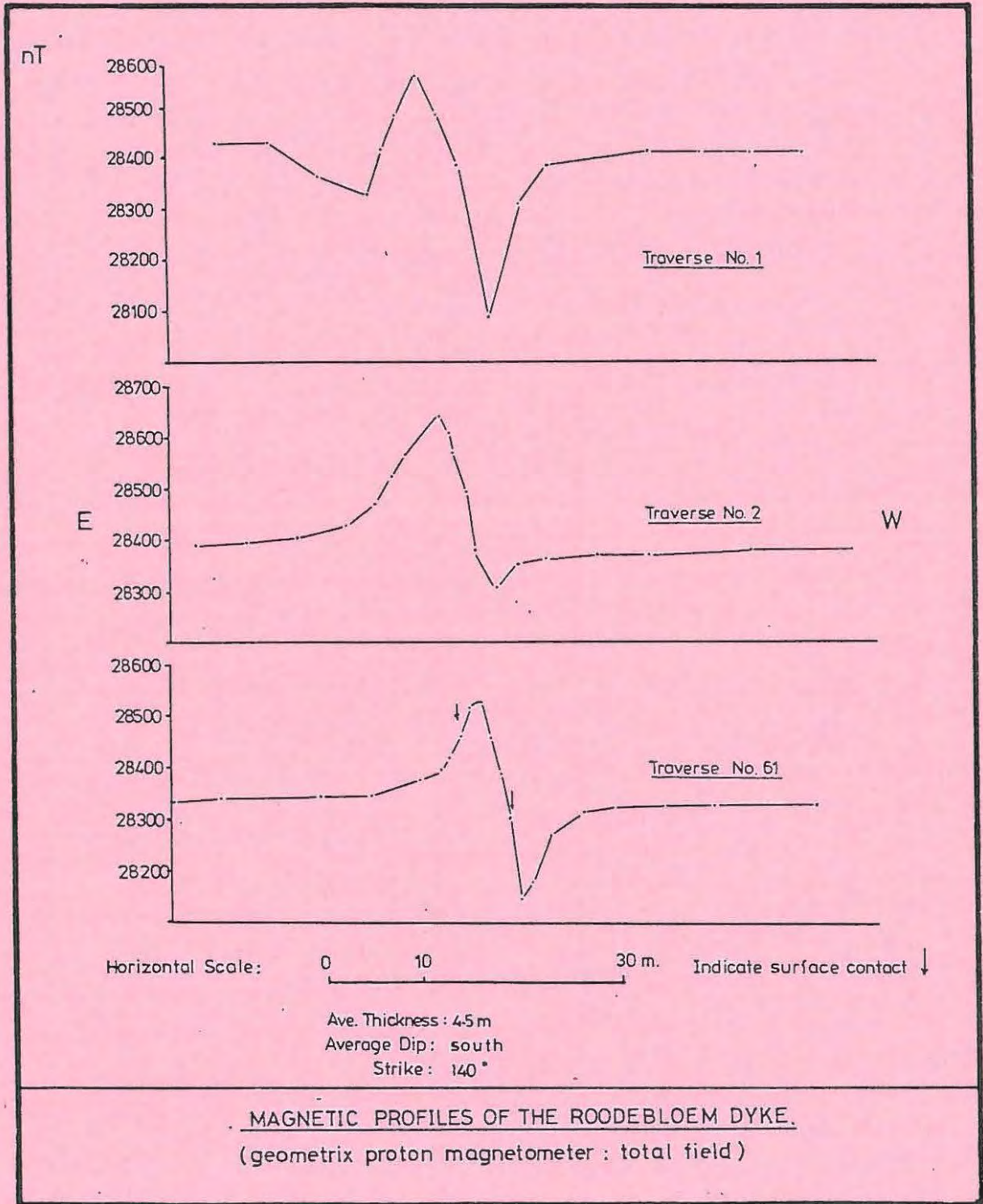


MAGNETIC PROFILES OF THE PERRIES DYKE.  
(Geometrix Proton Magnetometer : Total Field)



MAGNETIC PROFILES OF THE WELGEVONDEN DYKE.  
 (geomatrix proton magnetometer: total field)





Magnetic Profile T-16 (Airfield).

(Geometrix Proton Magnetometer : Total Field)

Dalham Dolerite Sheet

