

**REPUBLIC OF BOTSWANA  
DEPARTMENT OF WATER AFFAIRS**

**INTEGRATED RURAL VILLAGE WATER SUPPLY PROGRAMME**

**Siting of Boreholes, Supervision of Drilling,  
Borehole Construction and Test Pumping Works**

**BOBIRWA SUB DISTRICT VILLAGES**

**MATHATHANE**

**FINAL REPORT**

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**Presented by**

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## 1 INTRODUCTION

Wellfield Consulting Services has been commissioned by the Department of Water Affairs to carry a groundwater resources investigation under the Integrated Rural Villages Water Supply Programme in four villages of Sefophe, Mathathane, Lentswelemoriti and Damochujenaa in Bobirwa Sub District. This report is on groundwater resources exploration and development activities carried out for Mathathane village for the purpose of supplementing existing water sources. Map 1 shows the location of Mathathane village in the Bobirwa Sub District. The objectives of the project are to identify and develop additional groundwater abstraction points with sufficient volumes of potable water within acceptable distance of the village to supplement existing sources. It is therefore understood from the project objectives that the project was a rehabilitation programme and not a groundwater exploration or resources evaluation exercise. To meet the projected Mathathane village water demand geophysical investigations were required to identify new drill sites. The 1999 and 2001 projected population and water demands for Mathathane village are presented in Tables 2.4.1 and 2.4.2.

The initial activity of the project was compilation of all essential borehole data from existing records at various institutions and this data was supplemented with field data such as water levels, water quality, borehole/well locations coordinates of new borehole located during the reconnaissance survey.

A total of eight (8) boreholes were drilled for Mathathane village water supply during this project, however, only three boreholes, BH 9314, BH 9315 and BH 9316 were successful with blow out yields of 12 m<sup>3</sup>/hr, 13.5 m<sup>3</sup>/hr and 17 m<sup>3</sup>/hr respectively. These three boreholes were tested at respective yields of 8 m<sup>3</sup>/hr, 28 m<sup>3</sup>/hr and 33 m<sup>3</sup>/hr, while the low yielding boreholes BH 9164, BH 9176, BH 9177 and BH 9178, were not tested.

## **2 THE PROJECT AREA**

### **2.1 Location**

Mathathane village is located in Bobirwa Sub District. It is accessible from Bobonong by a tarred road and by dirt motorable roads from Tsetsebjwe to the south and from Motlhabaneng to the north.

Groundwater investigation activities were carried outside the village settlement area but within a radius of 10 kilometers from the village centre.

### **2.2 Physiography**

The land surface of the area around Mathathane village is generally flat but slopes gently from the west to the east and north-east towards the confluence of Thune and Motloutse rivers. The main topographical features are koppies of Karoo sediments south of Thune and Motloutse rivers which rise above land surface to attain heights of about 200 m above the general elevation of about 650 m.

The Project Area is densely vegetated, Mophane tree savanna is predominant with several species of acacia savanna.

### **2.3 Climate**

The climate of the area is semi arid with hot wet summers and mild to cold winters. Rainfall season begins in October and ends in April and occurs as intense localised storms with average rainfall of more than 400 mm per year. Temperatures vary from a mean maximum January temperature of 30°C to a mean minimum of 5°C in June. Vegetation can be described as Tree Savanna type of vegetation which consists of trees and shrubs and Mopane trees.

### **2.4 Population, Current Water Supply and Projected Demand**

The projected 1999 and 2009 populations for Mathathane are 1395 and 1529 people and projected water demands 112.7 m<sup>3</sup>/day and 124.5 m<sup>3</sup>/day respectively (Table 2.4.1).

Two boreholes BH 4908 and 2650 are currently equipped and supplying water to Mathathane. Both boreholes are located within the village settlement area. Borehole BH 4908 is situated next to a primary school and is only about 50 metres from a school pit latrine and also about 50 metres from another pit latrine in an adjacent homestead. The second borehole (BH 2650) supplying Mathathane is located about 100 metres from a pit latrine in the adjacent yard. These boreholes are pumped simultaneously every day for about 12 hours and the water is pumped into a 60 cubic metre reservoir supplying the village and into two other reservoirs of 48 and 27 cubic metres supplying a junior community secondary school. Inspection of existing water quality analysis results show water from both boreholes BH 4908 and BH 2650 to have nitrate levels of 340 mg/l and 135.9 mg/l respectively. Considering that the World Health Organisation (WHO) and Botswana Bureau of Standards (BOBS) recommend nitrate levels of maximum 45 mg/l, the water from both boreholes is not suitable for human consumption. Once alternative sources of water are found the use of the current boreholes should be discontinued forthwith.

Two other boreholes BH 4909 and BH 4911 are located in the central part of the village adjacent to homesteads and there is also a potential to pollution risk if these boreholes are equipped as alternative sources to supply the village.

In addition to the two equipped boreholes supplying the village other existing wells and unequipped boreholes were also visited during the reconnaissance survey on commencement of the project. Table 2.4.2 summarises locational details of these other boreholes and wells.

**TABLE 2.4.1 Projected Village Population and Water Demand for Mathathane**

Year	Population	Water Demand m <sup>3</sup> /day
1999	1395	112.7
2009	1529	124.5

**TABLE 2.4.2 Locational Details of Existing Boreholes and Wells around Mathathane**

Water Source	UTM		Comments
	X	Y	
BH 3798	0677119	7537752	Abandoned, reported brackish water blocked, lost tools.
Unknown BH No	0680278	7536966	BH never used. Drilled for road construction within the village.
Unknown BH No	0680751	7536709	Drilled for road construction on Mathathane River Bank.
Well	0680954	7536820	On Mathathane River bank blocked. Mr Mafela's well, abandoned.
Unknown BH No	0681355	7536178	Drilled for road construction.
BH 4911	0680372	7536294	Within village centre, 3 metres from a gneiss outcrop, sealed. Next to a homestead.
BH 4909	0680164	7536614	Drilled next to a gneiss outcrop. Within the village centre, sealed next to a homestead

The numerous wells and boreholes drilled within the village settlement area and those outside the village indicate that there has been considerable drilling of boreholes and well digging, and most of these are dry or low yielding. The success rates for drilling boreholes with sufficient water to supply a large community is thus low.

## 2.5 Previous Work

### 2.5.1 Early Exploration Activities

A review of existing records and field observations indicate that significant groundwater exploration activities have been carried out in Mathathane village area. Most of the groundwater exploration activities with some documented records were carried out by government departments mainly by the Department of Water Affairs and by the Department of Geological Surveys or by Consultants and Contractors contracted by relevant government departments. However, considerable amount of groundwater activities were carried out by private individuals hiring private drilling rigs and private individuals to site and dig/drill wells and boreholes for their private use. Most of the exploration work carried out by private individuals was not documented or the documents are not available. In cases where attempts to keep records were made the data were poorly recorded and incomplete and is of limited use. In some cases the only evidence of previous work carried out in these areas is the observations of existing (mostly abandoned) boreholes or wells on the ground. It is difficult to trace the records of these often unlabelled water sources and it is equally difficult to reliably establish the methods used to site these boreholes and wells as no records are available from the original owners of these water sources. Information on these water sources is normally voluntarily provided by the local community and it is always difficult to confirm.

Records of boreholes sited and drilled by government departments in general were documented, however early data records, especially drilling information, were poorly recorded and incomplete. More recent drilling records data showed significant improvements. Data records on siting techniques used even on work carried out by government departments are generally not available especially on boreholes sited more than two decades ago. However, more recent work especially work carried out by consulting companies is well documented as reports and raw data and is normally available at the Department of Water Affairs and Department of Geological Survey.

### **2.5.2 Pre 1970 Siting Techniques**

Due to unavailability of siting records, especially siting of private boreholes and wells, it is not known how most of the boreholes and wells were sited. However, it is understood that most siting activities by private individuals were carried out by water diviners/dowsers since the use of scientific methods were very limited to few individuals and organisations. Early siting activities carried out by government departments were mainly based on the following methods.

- Geology, mapping of geological features such as fault lines, fracture zone, shear zones, weathered zones and mapping of contacts of different lithologies.
- Positioning of drill sites close to drainage channels.
- Use of vegetation, especially in shallow groundwater occurrence areas where borehole sites were positioned close to trees.
- Groundwater divining was used by hiring people who previously sited successful boreholes and who claim to “feel” the presence of water at certain locations.

### **2.5.3 Post 1970 Siting Techniques**

Private individuals continued to use water divining to site boreholes or wells for their private use mainly because it was the cheapest of all available siting techniques. However, government department and some individuals relied on scientific siting techniques as more organisations and individuals became available to provide these services. Techniques used included the following:

- Geological mapping, which included the mapping of geological features such as fault lines, contacts of different lithologies and mapping of different rock types.
- Use of various geophysical methods such as resistivity, electromagnetic methods, magnetics and seismics.
- Aerial photographs and satellite imagery.

### **2.5.4 Mathathane Village**

Available borehole records show that the Department of Geological Survey drilled borehole BH 2650 that is currently supplying Mathathane in 1974. Additional boreholes for village water supply were sited by the Department of Water Affairs and drilled by TGB Drill Contractors on behalf of the Department of Water in 1985. Borehole BH 4908 also supplying Mathathane village was drilled during this

period. Other exploration activities around Mathathane include drilling of several boreholes for the construction of the Bobonong-Lekkerpoet Road. It is not known how these borehole sites were identified but those sited by the Department of Water Affairs were sited using magnetic, electromagnetic survey using one frequency (Slingram), and vertical electrical soundings.

Photo lineament analysis of Mathathane area shows a number of other existing boreholes, several of which were drilled close to drainage channels. It can be concluded that these boreholes were sited on the basis of structural features and along drainage channels.

### 3 GEOLOGY AND STRUCTURE

#### 3.1 Geology

The Project Area falls in quarter degree sheet 2228B, which was mapped by the Department of Geological Survey in 1964 (R. Mason). The geology of the area around Mathathane village shown in Map 2 and Tables 3.1.1 and 3.1.2 outline the regional lithostratigraphy of both the basement rocks to the south and the Karoo sediments to the north.

Mathathane village area is underlain by early Precambrian quartzo-feldspathic paragneisses interbedded with discrete amphibolite horizons. The gneisses are banded and are intercalated with complex successions of quartzites, calcareous rocks, amphibolites and hornblende plagioclase gneiss in some places.

The Karoo succession, which outcrops to the north of the village, consists of coarse Ecca quartzite and feldspathic grits, siltstone, mudstones and minor ironstone horizons, overlain by mottled calcareous siltstones and fine sandstones that in turn are overlain by massive Lebung aeolian sandstones. This sedimentary succession of both Ecca and Lebung is overlain in part by a thick sequence of Upper Karoo basalt lava. This northern Mathathane area forms the southern margins of the Karoo Tuli Basin.

Post-Karoo dykes occur in the Mathathane area and most trend in an approximately east-northeast direction. Dolerite sills, probably of the same age as the dykes, intrude the Karoo and the metamorphic complex rocks. Faults are common and follow either an approximate east-northeast or west-northwest trend and conform to the Limpopo Mobile Belt deformation trends.

Limited occurrences of Quaternary deposits, mainly sandy alluvium, are confined to drainage channels.

**TABLE 3.1.1 Regional Precambrian Rock Units**

Age	Lithology	Brief Description
Precambrian	Paragneisses	Interbanded – ironstone, amphibolite, marble and calcsilicate, ultramafics, meta quartzites, meta-arkose, banded ironstone and magnetite quartzite.
	Banded Gneisses	Intimately interbanded sequence of hornblende plagioclase gneiss, amphibolite, marble, quartzite and quartzo feldspathic gneiss.  Quartzo-feldspathic gneisses interbanded with amphibolites and minor quartzites.
	Granitic Gneisses	Undifferentiated granitic gneisses and migmatites, coarse gneissic granites, some porphyroblastic augen gneisses.
	Ultramafics	Ultramafics metamorphites: Sepentinities, tremolite schists, granulites, Pyroxenites, norites.

**TABLE 3.1.2 Regional Karoo Lithostratigraphy**

Super Group	Group	Formation	Lithological Description
Karoo	Stormberg Lava	Bobonong Lava Formation	Basalt in part porphyritic, massive amygdaloidal basalt including sandstone lenses intercalated with the basalt (Madikama Beds).
Karoo	Lebung	Tsheung Sandstone Formation	Fine grained well sorted, pink-brown to pale grey or white sandstone
		Thune Formation	Fine grained sandstones and siltstones with cross-bedded medium to coarse grained sandstone
		Korebo Formation	Minor coarse to medium grained sandstone predominantly. Purplish grey to red mudstones and siltstones minor sandstone and a basal conglomerate
	Ecca	Seswe Formation	<u>S<sub>2</sub> Upper non carbonaceous member</u> . Non carbonaceous mudstones and siltstones, grey to khaki, purple with bluish-grey patches coarse grained sandstone and conglomerate. <u>S<sub>1</sub> Lower Carbonaceous member</u> Carbonaceous mudstones with bright coal bands, silty mudstones and sandy black mudstones.
		Mofdiaholo Formation	Mudstones, cream to grey brown coloured, sideritic with some fine grained sandstone bands  Basal argillaceous sandstone with some coarse sand pebbles, coarsens towards base

### 3.2 Structure

Considering the complex tectonic history of the Limpopo Mobile Belt the structural fabric of the area is expected to be complicated as a reflection of the numerous tectonic events in the geological history of the area. Several foliations considered to be tectonic imprints of the whole region of different orientations are present, such as the persistent foliation parallel to the lithological banding, and many other foliations of different orientations thought to be related to several phases of folding have been reported in the area (Thomas 1970). No major faults are present in the area but numerous minor faults, some indicated by displacement of foliation, are infilled with Karoo dolerite dykes. Shear zones, notably reported along Chokanan River (Thomas 1970) to the south east of Mogapi where mylonitised gneiss occurs are clear evidence of structural movement. Aerial photograph lineament interpretations indicate major lineaments trending ENE, NE, NW, WNW, with some drainage channels influenced by these structures during their development.

Karoo dolerite dykes occur in the area and form distinctive lineaments on aerials photographs. However, they crop out only locally along rivers or streams or in wells. These dykes mostly trend approximately in a west-northwest, or westerly direction.

#### 4 REGIONAL HYDROGEOLOGICAL REGIME

Groundwater in this area generally occurs in the fractured rocks and less frequently at the base of the top weathered rock or alluvium (overburden). However, some primary porosity may be expected in the north in the Karoo sandstone, although the groundwater potential of this area has not been explored and is largely unknown. Consequently, two different types of aquifer were expected in the area surrounding the village of Mathathane. These are the Basement aquifer and Karoo sandstone aquifer. Due to the varying nature of these two aquifers and their different groundwater potential they will be discussed separately.

##### **Basement Aquifers**

This unit may be divided into weathered and fractured aquifers. The weathered Basement aquifer often has high transmissivity and storage values to provide some yield, but such aquifers are severely affected by recharge and size of the catchment area. The higher yielding aquifers are found in areas where the contact zone between the weathered overburden and fresh rock is deeply fractured, but it is very sensitive to the amount of the recharge received. The highest yielding Basement aquifers are found in the fractured bedrock, which possesses high transmissivity and at locations where deeply weathered overburden provides some storage. Such fractured aquifers are often recharged through a system of interconnected fractures and fissures. Therefore, when siting high yielding boreholes, it was important to consider the distance to the prospective direct recharge area (current drainage system). Typical aquifers found in the Basement areas are illustrated on Figure 1 below.

##### **Figure 1 Typical Basement Aquifers**

Consequently, the major potential targets for the development of a successful water source in the Basement area are:

- Fractured contacts at the base of the relatively thick weathered zone
- Fractured contacts between gneiss and dolerite or amphibolite
- Fracture, fault or shear zones

**Karoo Sandstone Aquifer**

Due to the fact that sandstone possesses some inter-granular space, which may be available to the groundwater (provides storage), this type of aquifer is regarded as having a high groundwater potential. Unlike the Basement aquifers which are localised and very sensitive to recharge, the sandstone aquifer due to its primary porosity (inter-granular space filled with groundwater) may withstand long periods of drought and lack of recharge. Consequently, the sandstone aquifer is regarded as a more reliable and longer-lasting source of groundwater as compared with any other aquifer. It was therefore preferred to establish water sources for the current village in this aquifer type, however, the Karoo strata is located at a considerable distance from the village. The groundwater potential of the Karoo sandstone in this particular area is also unknown.

## 5 GENERAL PROJECT METHODOLOGY

The general approach adopted for this project can essentially be divided into four stages and each of these stages is briefly outlined below.

### 5.1 Data Assessment

The first stage of the project was the data collection and assessment stage. This involved collection and assessment of all relevant existing data and detailed examination of remote sensing data such as aerial photographs to determine structural and geological patterns within the Project Area which may lead to delineation of Target Areas selected on the basis of favourable structures for further ground geophysical investigations. A general review of the hydrogeological regime, the nature and performance of existing sources and the current populations projections were undertaken. As part of the data collection and assessment a field reconnaissance survey was carried out and locational data such as GPS coordinates water levels, in some cases water samples were collected. A number of potential investigation areas were assessed on site through geological and structural mapping. Site mapping and assessment included identification of rock types, lithological contacts, degree of fracturing and weathering, continuity of lineaments proximity to drainage channels drilling results of nearby well and boreholes, dolerite dykes contacts with host rock near drainage channels and vegetation occurrence such as big trees which appear to have been influenced by some geological structural control.

Potential sites located away from the drainage zones were discarded and, where possible, areas of intersections between structured features and drainage zones were targeted. All the data was then compiled into an Inception Report (DWA, 1999 Bobirwa Sub District Villages Water Supply, WCS). Groundwater geophysics borehole drilling and test pumping followed in the subsequent months.

### 5.2 Ground Geophysical Surveys

Ground geophysical survey were employed to assist in locating the most suitable sites for groundwater development within the pre-selected target areas. Selection of Target Areas was based on aerial photographs and regional aeromagnetic data interpretations and proximity of the drainage system as prospective recharge areas. Areas of numerous photo lineaments are believed to represent high density fracturing and/or faulting where higher borehole yields are expected were the main target of interest. In addition, a general review of the hydrogeological regime, the nature and performance of existing sources and the current population projections was also undertaken. All surveys were carried out outside the populated village area. The high accuracy aeromagnetic data available from the recent survey carried out for the Department of Geological Surveys (Limpopo Central Zone) was utilised to guide the positioning of some of the geophysical traverse lines. Most lines are short as they were positioned on specific targets. The general philosophy was to transect aerial photo lineaments, geological contacts, inferred faults, fractures and dykes (from aeromagnetic image), especially in areas where these intersect each other or are located near a drainage system. Areas in which more than one of the above conditions occurred were of particular interest.

As the target was largely secondary fractured crystalline basement aquifers it was considered most appropriate to employ the electromagnetic technique in order to map the sub-vertical fracture system, if present. Such sub-vertical conductive features would normally produce attractive targets for groundwater development, especially if the subvertical fractures were being supplemented by horizontal fractures.

To aid the electromagnetic data interpretations the magnetic technique was also deployed along all traverses, as it is best suited for mapping magnetic intrusions such as dolerite dykes

and sills. These profiling techniques were supplemented by vertical electrical soundings (VES) undertaken at anomalous locations to provide the depth resistivity profiles.

For calibration purposes some reference measurements were carried out in the proximity of the current supply borehole BH 4908 and BH 2650. At each location two perpendicular short profiles were positioned and surveyed. This exercise was to provide reference geophysical responses in order to appreciate the local subsurface conditions and aid the interpretation of the data along exploration traverses in the Target Areas.

Magnetic profiling was undertaken using a memory proton precession magnetometer GSM-19 series. Electromagnetic data were collected with a multi-frequency Apex MaxMin II system. The VES were undertaken using a CSIR built resistivity meter. Both magnetic and electromagnetic data were interpreted qualitatively, focusing on identification of fault/shear zones, subvertical fractures and dolerite dykes. A total of 35.4 kilometers were traversed with magnetometer and electromagnetic (HLEM) maxmin. A total of fifty VES were also carried out at selected sites during this project.

### **5.3 Drilling and Test Pumping Activities**

A total of eight (8) boreholes were drilled around Mathathane village area for the purpose of supplementing existing water sources. All drilling contracting works were undertaken by the Contractor Pula Groundwater Developers employed by the Department of Water Affairs under the Uniform Rates Contract and under the supervision of the Consultant. Test pumping contracting works were carried out by Sediba Testing Services (Pty) who were awarded the contract under the new tendering system. Three boreholes BH 9314, BH 9315 and BH 9316 were tested at discharge rates of 9 m<sup>3</sup>/hr and 33 m<sup>3</sup>/hr for durations of 72, 120 and 80 hours respectively using mechanically driven positive displacement pumps.

The drilling technique adopted was rotary air percussion. The initial diameter was 254 mm (10") and the boreholes were completed with a final diameter of 165 mm (6½") open hole. The initial four boreholes were not screened as it was expected that no formation collapse could take place in crystalline basement environment. The remaining boreholes were either cased to the bottom with screens at appropriate depths or completed with a final diameter of 203 mm (8") open hole. The depth to which casing was grouted depended on ground conditions on each specific drill site. On completion of initial drilling contracting works in December 1999 which resulted in only low yielding or dry holes it was found essential to carry out additional geophysical investigations during the month of February 2000. As a result 4 additional drill sites were drilled resulting in four additional boreholes. Thus a total of (8) eight boreholes were drilled during this project for Mathathane Village Water Supply.

### **5.4 Data Evaluation and Reporting**

Mathathane village data was gathered on an on going basis whilst being continually evaluated from the onset of the project. During the initial geophysical and drilling investigations in the study area, all relevant information was presented to the Client in the form of Monthly Progress Reports and a Project Review Report. Further geophysical investigations and contracting works were found essential after poor drilling results during the initial drilling phase and were carried out in February and May 2000 respectively.

All the Mathathane data gathered during the project was then compiled, evaluated and put together into a draft final report specific to this village alone.

## 6 GEOPHYSICAL SURVEY PROGRAMME

In the past, several boreholes and wells were drilled and dug within the settlement area and in the immediate vicinity of Mathathane, however, most of these are dry or low yielding (DWA, 1985 Borehole Siting for 9 Villages in Central District, WCS). Several abandoned and sealed boreholes were located in and around Mathathane during the Reconnaissance Survey, however, little information is available. Some of these boreholes were reported to have been drilled for the construction of the road from Bobonong to Lekkerpoet. Locations of these boreholes are shown on Map 3 (WCS1, WCS2 and WCS3). Boreholes BH4909 and 4911 were drilled by the Department of Water Affairs and were subsequently tested at 3.9 and 4.5 m<sup>3</sup>/hr, respectively. They are however located within the populated village area, some 100m from the homesteads, and pollution risk is high.

Considering the previous results of drilling water holes in the vicinity of this village, the expected success rate for drilling boreholes with sufficient quantities of water to facilitate diesel pump installation was assumed to be low. Consequently a larger number of boreholes was proposed to be sited and drilled in this village. It was assumed that at least 6 boreholes would be necessary to satisfy the projected water demands.

Following the desk study undertaken during the Inception Phase, eight Target Areas were selected for follow up with ground geophysical surveys. During the months of July to September 1999, all the initially selected Target Areas (Areas A-E) were surveyed with other areas (Areas F-H) surveyed during February-May 2000. The geophysical data, its interpretation in relation to the hydrogeological concepts, and interpretation of the drilling results are presented below.

### 6.1 Data Acquisition and Processing

All field activities related to the initial geophysical surveying were carried out and completed between July and September 1999 with other supplementary surveying completed between February and May 2000. This involved clearing and pegging of 27 survey lines, 30.5 km of profiling along these lines as well as carrying out 28 VES at selected localities. The profiling data was acquired at 10m station intervals along lines varying in length from 0.6 km to 2.8 km and located in 8 Target Areas. GPS co-ordinates of all survey lines are tabulated below (Table 6.1.1) and their locations are shown on Maps 2 and 3. Twenty-eight VES were carried out in total and their locations are marked on the profile data plots (Appendices A1 to A28).

The HLEM data was plotted together with the magnetic data using the Geosoft mapping and processing software package while the VES were processed and interpreted with the Interpex forward and inverse modelling software RESIXIP. Modelling of the major magnetic anomalies was undertaken with MAGMOD – magnetic 2.5-dimensional forward and inverse modelling software (module of Geosoft package) for simple geological bodies which can be approximated by a ‘ribbon’ (thin dyke), ‘tabular’ dyke (infinite or limited depth) and ‘step’ (fault).

**TABLE 6.1.1 Summary of Ground Geophysical Surveys**

UTM 35 Clarke 1880	Easting	Northing	Easting	Northing	Length (km)	VES (number)
	START		END			
<b>Target Area A</b>						
Line 11	683034	7534639	682165	7535913	1.4	1
Line 12	681504	7535602	681915	7536983	1.4	1
Line 13	684320	7535312	683872	7536451	0.9	1
Line 14	684634	7535435	684871	7536208	0.7	1
<b>Target Area B</b>						
Line 21	676215	7535721	677064	7535221	0.9	1
Line 22	676115	7535005	677076	7534499	1	1
Line 23	676189	7533911	677096	7533649	0.9	0
<b>Target Area C</b>						
Line 31	673311	7532233	672702	7533634	1.5	1
Line 32	673007	7532892	673707	7533084	0.6	1
Line 33	673962	7532230	673392	7533503	1.4	1
Line 34	673565	7533168	674111	7533468	0.6	1
<b>Target Area D</b>						
Line 41	673324	7538136	672042	7540476	2.8	1
Line 42	674183	7537996	673937	7539014	1.1	1
Line 43	673697	7539346	673301	7540477	1.2	1
Line 44	675545	7537532	675294	7538473	1	1
Line 45	676631	7537206	676286	7538150	1	1
Line 46	676809	7537141	677453	7538521	1.5	1
<b>Target Area E</b>						
Line 51	680567	7538245	679708	7539366	1.3	1
Line 52	681594	7538902	681254	7539799	1	1
<b>Target Area F</b>						
Line 61	685938	7537437	686294	7538817	1.4	1
Line 62	685693	7538451	686754	7538312	1	1
<b>Target Area G</b>						
Line 71	678483	7541411	677869	7541911	0.8	0
Line 72	679973	7542436	679986	7543460	1	3
Line 73	680680	7543297	680274	7544116	0.9	0
Line 74	680401	7540897	681176	7539916	1.2	1
<b>Target Area H</b>						
Line 81	672841	7543245	673503	7544184	1	2
Line 82	675154	7542825	675184	7543756	1	1
<b>TOTALS:</b>					<b>30.5</b>	<b>28*</b>

\* One additional VES was carried out at the existing production borehole.

## 6.2 Geophysical Interpretation Results

The eight investigated Target Areas (Map 3) were selected based on the hydrogeological setting of the area, aeromagnetic data interpretation, existing access routes, aerial photo interpretation and the proximity of the drainage system (prospective recharge areas). All surveying was carried out outside the populated village area. The high accuracy aeromagnetic data available from the recent survey carried out for the Department of Geological Surveys (Limpopo Central Zone) was utilised to guide the positioning of some of the lines. Most lines are short as they were positioned on definite targets. The general

philosophy was to transect aerial-photo lineaments, geological contacts, inferred faults, fractures and dykes (from aeromagnetic image), especially in areas where such intersect each other or are located near drainage systems. Areas in which more than one of the above conditions occurred were of particular interest. In addition several lines were positioned in the Karoo area to the north and east of the village. Target Area G was extended to the south to cover the contact between the Basement and Karoo lithologies.

### 6.2.1 Reference Measurements

It was not possible to carry out any reference profiling in the proximity of the existing supply boreholes due to the surrounding infrastructure and the proximity of buildings. However, one VES sounding was carried out near the current supply borehole BH 2650, which is located within the river channel. This borehole was drilled in 1974 to the final depth of 46m, however no lithology is available. Water strike was registered at about 9m depth and water level at the time of drilling was about 4.8m below the ground level. This borehole is currently pumping at about 5 m<sup>3</sup>/hr. The VES indicated fractured rock down to about 30-50m depth.

Other reference measurements are available in the proximity of the abandoned borehole BH3798, which is located on the Selepswane River bank to the west of the village. Conflicting reports about the reasons for abandoning this borehole exist, but they are consistent with the fact that the borehole has been used in the past. It was originally drilled in 1981 down to 28m in gravel (to 6m) and 'granite'. Water was struck at 6.2 m and a yield of 6 m<sup>3</sup>/hr was reported. This borehole falls at 800m peg on line 46 (Appendix A18). There is no apparent anomaly associated with this borehole either on the HLEM or magnetic profile and it was not possible to carry out the VES at this locality due to the very steep riverbank and kraal in its proximity.

There was no boreholes located in the Karoo covered Areas F, G and H therefore there was no reference measurements undertaken in this prospective aquifer.

Taking into account the character of the investigated Basement aquifers the interpretation of ground geophysical surveys focussed on identification of areas with thicker overburden, subvertical conductors (possible fractures) and dolerite intrusions. All the above are clearly expressed on the HLEM and magnetic profiles, respectively. Selected HLEM and magnetic anomalies were followed up with a VES, which provides good understanding of the thickness and composition of the overburden and identifies intensive fracturing in some cases. On completion of the initial interpretation all sites with possibly enhanced groundwater potential were listed (Table 6.3.1) and evaluated further in order to select those with the highest potential. This process is described in Section 6.4, while the interpretation results of the geophysical surveys are discussed in Sections 6.2.2-6.2.5 below, for each geophysical technique separately.

The potential Karoo aquifer was evaluated in terms of the overall thickness of sediments and the potential fractured zones, which would enhance the overall yield from the single borehole. Such are indicated on the HLEM profile data as a characteristic negative anomaly, which is generated due to the higher conductivity within the fractured and weathered zone as compared to the surrounding undisturbed sandstone.

All prospective sites were further evaluated according to the adopted rating system for the Karoo aquifer and are shown on Table 6.3.2. The final recommended sites are also highlighted on this Table.

## 6.2.2 Aeromagnetic Interpretation - Summary Results

The high resolution Limpopo Central Zone Aeromagnetic Survey data was made available to the Consultant by the Department of Geological Survey, Lobatse. The grids of the Total Magnetic Intensity (TMI) and 1<sup>st</sup> Vertical Derivative (1VD) were received and utilised to set the ground surveys and later to model some selected magnetic anomalies selected from the ground profiles (see Section 6.3). The colour image and contours of the Total Magnetic Intensity are shown on Figure 2 and the colour image of the 1<sup>st</sup> Vertical Derivative is shown on Figure 3. No effort was made to further process or to enhance the images supplied by the DGS, as their quality was regarded satisfactory for the purposes of the current project.

The whole area is underlain by various lithologies of the Archean Basement, some of which are highly magnetic (amphibolites and ultramafic rocks) and therefore clearly represented on the aeromagnetic images. In addition, various dolerite dykes are recognised throughout this area through numerous outcrops and on the aeromagnetic images. In the northern and eastern section of the area the Basement anomalies appear subdued due to the presence of the Karoo sedimentary cover (Figure 3).

The primary objective of this component of the project was to identify and model all the significant structures found within the selected Target Areas as to assist in locating suitable sites for the development of water sources. The identified dolerite dykes often represent barriers to the groundwater flow on a local scale or conduits to such flow along their fractured and altered margins and contact zones with the host rock (gneisses, amphibolites).

A two-step approach to the interpretation was taken. First step constituted qualitative interpretation - observation of magnetic relief and continuity of anomalies and trends (lineaments). The second step concentrated on the inverse modelling of some selected anomalies. This second step is discussed in detail in Section 6.3 due to the fact that in the absence of the original aeromagnetic line data the inverse modelling was undertaken utilising ground profiling data instead.

Qualitative interpretation of magnetic images (contours) relies on the recognition of the magnetic relief patterns and magnetic lineaments. Magnetic relief describes the patterns of magnetic anomalies in terms of anomaly amplitudes, wavelengths, directions and continuity. The high amplitude, low wavelength anomalies aligned predominantly NE and ESE represent various generations of dolerite dykes, some of which are very old and acquired reverse magnetisation (negative high amplitude anomaly). The south north and NNE aligned positive anomalies are likely to be associated with certain highly magnetic units in the Basement complex. The main magnetic trends are often interrupted by other structures, resulting in discontinuity or lateral displacement. Such cross-points and discontinuities are particularly interesting from the point of view of the groundwater occurrence in the Basement areas, as they may be a source of increased transmissivity.

Some of the anomalies/structures mapped during the airborne survey are simplified and others that were observed on the ground data are absent on the aeromagnetic gridded data set. This happens largely due to the automatic processing of the acquired line data, which often filters out some small wavelength anomalies thought to be data 'spikes' or noise. The gridding process also smoothes the anomalies, simplifying their appearance. However, this is of no concern if ground data is modelled or if the original airborne line data is available.

Fifteen dyke-like positive anomalies were identified in the investigated Target Areas and all were modelled. The resulting modelled parameters are summarised on

Table 6.2.1. All of these anomalies could be modelled assuming only induced magnetisation ( $Q=0$ ). Dykes numbered DD2 to DD12 are consistently oriented about  $70^{\circ}$  NE, while dykes DD13 to DD15 are oriented almost west east. A major post-Karoo dolerite dyke DD1 is located in the north and it is oriented ESE. Another major ESE oriented structure L1 transect the entire Project Area and appear as a negative anomaly. The other five such structures are oriented NE and are named L2 to L6.

More details concerning these major structures can be found in Appendix B and on Table 6.2.1 in Section 6.2.3 below. In summary, the structural pattern of the investigated area is highly complex, as the magnetite-rich lithologies of the banded gneiss formation and the numerous dolerite dykes represented in this area contribute to this complexity. Based on the aeromagnetic data image it was also possible to delineate the approximate extent of the Karoo sediments and Stormberg basalt, which are present to the north of the village (Figure 3). There is also some indication of a tongue-like shaped extension of the lower Karoo sediments to the east of Mathathane.

### 6.2.3 Ground Magnetic Profiling and Modelling Results

The magnetic profiling was carried out along all traverses in all Target Areas. The total magnetic intensity readings were taken at 10m stations along traverses and it is this data that was utilised to generate models of some of the anomalies. All clear anomalies, which could be separated from the others, were selected for inverse modelling using simple geometric shapes that may be used to approximate some simple geological bodies such as dykes.

This component of the project was considered particularly important due to the presence of numerous magnetic (ultramafic) rocks and dolerite intrusions in this area, which are evident on the aeromagnetic images and the interpretation map (Figs 3 & 4). Such rocks do not constitute aquifers as they do not possess any porosity; however, the process of their emplacement into the host rock often creates fractures and fissures in the surrounding rock and thus may form preferential weathering zones. Such fractured and weathered contact zones often constitute good Basement aquifers, especially if the ultramafic intrusion is not very thick or is disrupted in places by other structural events. Such structurally disturbed areas are often targeted in the groundwater studies in the Basement areas.

Several parameters affect the shape of the anomaly across magnetic body. These are shape, depth, attitude (dip), orientation (strike direction), extent, induced and remnant magnetisation. It is only the induced magnetisation, orientation and extent of the body that are known prior to modelling. Body shape may be also constrained based on the previous geological knowledge. The remaining unknowns in any inversion are dip, depth thickness, magnetic susceptibility and remnant magnetisation vectors ( $Q$ , Inclination and Declination). The amplitude of any given anomaly is affected by the body thickness and magnetisation while its shape is a function of the dip and magnetic magnetisation vector (both induced and remnant). The total magnetisation ( $J$ ) of the rock is a vector sum of its induced ( $J_i$ ) and remnant ( $J_r$ ) magnetisation and can be expressed as follows:

$$\mathbf{J} = \mathbf{J}_i + \mathbf{J}_r$$

Where  $J_r = Q$  (Koenigsberg ratio) \*  $J_i$   
and  $J_i = k$  (susceptibility) \*  $B$  (Earth's magnetic field strength)

The magnetic susceptibility of rocks ( $k$ ) is proportional to the volume content of magnetite and to a lesser extent the content of haematite and pyrrhotite. In

crystalline rocks in particular the susceptibility is directly linked to the rocks geochemical composition with basic rocks being significantly more magnetic than acidic rocks. Since the magnetic minerals form a small portion of the bulk rock (<10%), only small variations in its geochemical composition can result in large variations in magnetic properties. Consequently, similar rock types occurring in areas of different geological histories may be significantly different and misleading. Remnant magnetisation may also vary considerably in similar rock types depending on the cooling, metamorphic and tectonic history. Variations in the susceptibility and the Natural Remnant Magnetisation (NRM) directions within individual dykes are also common and indicate multiple intrusions and lateral differences in cooling histories of some dykes. Only direct measurements of these values for representative rocks in the project area would give a reliable estimate of these properties. Examples of measured parameters for Basement lithologies from other areas of Botswana are given below:

- Palla Road Project Area – Ironstone (Shoshong unit) –  $k=0.04$  emu
- Serowe Project Area – Dolerite dykes (post Karoo) –  $k=0.0088-0.0304$  SI and  $Q=2.8-38.2$ , NRM inclination: -51 to 3 deg, NRM declination: -3 to 141 deg.

Frequent limitation to the accurate interpretation of the magnetic data is the superposition of anomalies arising from the adjacent or overlying sources. This applies in the current Project Area as well and such complex anomalies were not modelled where separation of contributing anomalies was not possible.

Some of the encountered anomalies are complex in nature as they probably consist of more than one simple body such as multiple dipping dykes (DD1). These were modelled separately due to the constraints of the available software, which allows only simple geometric models to be modelled.

Most of the anomalies could be modelled using a dipping dyke model (Tabular). The summary of the inverse modelling results of all the dykes that could be modelled assuming only induced magnetisation is tabulated below (Table 6.2.1) for each structure separately and the relevant models are enclosed in the Appendix B.

**TABLE 6.2.1 Magnetic Models – Dolerite Dykes – Summary Results**

Position (centre)	Depth (m)	Thick (m)	Dip (deg)	Q ratio	K (emu)	Strike Direction	Anomaly Type
<b>DD1 – Dolerite Dyke</b>							
L73/313m	1.7	22.0	77N	0	0.0175	110	NEGATIVE/POSITIVE
<b>DD2 – Dolerite Dyke</b>							
L41/2325m	3.1m	27.2	70N	0	0.0155	70	NEGATIVE/POSITIVE
<b>DD3 – Dolerite Dyke</b>							
L41/1703m	4.1m	33.0	118S	0	0.0301	70	LARGELY POSITIVE
L43/453m	1.8m	46.8m	128S	0	0.0343	70	LARGELY POSITIVE
<b>DD4 – Dolerite Dyke -</b>							
L42/806m	1m	62.8	151S	0	0.0240	70	POSITIVE COMPLEX
<b>DD5 – Dolerite Dyke</b>							
L74/1022m	15.6m	62.4	130S	0	0.0118	70	LARGELY POSITIVE
<b>DD6 – Dolerite Dyke</b>							
L45/800m	14.4m	4.6	127S	0	0.198	70	LARGELY POSITIVE
L46/1368m	3.9m	22.6	121S	0	0.0197	70	LARGELY POSITIVE
L51/1229m	20m	7.0	109S	0	0.0848	70	LARGELY POSITIVE
L52/931m	18.4m	27.0	118S	0	0.0377	70	LARGELY POSITIVE
<b>DD7- Dolerite Dyke</b>							
L45/430m				0		70	LARGELY POSITIVE
L46/1116m	4.8m	15.6	116S	0	0.0320	70	LARGELY POSITIVE
L51/916m	11.5m	24.6	104S	0	0.0159	70	LARGELY POSITIVE
L52/767m	12.6m	21.8	120S	0	0.007	70	LARGELY POSITIVE
<b>DD8 – Dolerite Dyke</b>							
L51/585m	4.8m	47.4	133S	0	0.0230	70	POSITIVE
<b>DD9 – Dolerite Dyke</b>							
L52/296m	16.1m	23.0	100S	0	0.0212	70	POSITIVE
<b>DD10 – Dyke or Contact/Fault</b>							
L51/67m	5.8m	3.5	144S	0	0.0339	70	POSITIVE
<b>DD11 – Dolerite Dyke</b>							
L31/1143m	2.5m	26.6	122S	0	0.0244	90	POSITIVE
L22/107m	6.9m	55.6	117S	0	0.0085	80	POSITIVE/NEGATIVE
<b>DD12 – Dolerite Dyke</b>							
L12/869m	9.3m	5.2	139S	0	0.207	70	POSITIVE COMPLEX
<b>DD13 – Dolerite Dyke</b>							
L31/1319m	7.7m	47.8	92S	0	0.0248	90	NEGATIVE/POSITIVE
<b>DD14 – Dolerite Dyke</b>							
L31/343m	1.3m	21.4	135S	0	0.0117	90	POSITIVE
L33/202m	3.5m	26.6	115S	0	0.0081	90	POSITIVE
<b>DD15 – Dolerite Dyke</b>							
L11/1034m	3.1m	22.4	92S	0	0.0010	90	NEGATIVE/POSITIVE
<b>H1 – Dyke</b>							
L22/882m	29.2m	8.6	99S	0	0.142	0	POSITIVE

Note - All dykes were modelled using the 'tabular' model with a flat top and extending to infinite depth.

The above dykes dip mostly to the south with an exception of DD1 and DD2, which dip to the north. Dip angles vary between almost vertical (DD 13, DD15 and H1) to 144 degrees. All dykes are very shallow (1 – 18m) with an exception of structure H1, which is likely to be other than dolerite dyke. Most Basement dolerite dykes are oriented NE ( $70^{\circ}$ ) while the post-Karoo dyke DD1 is oriented ESE (about  $100^{\circ}$ ).

The negative type linear anomalies L1 to L6 are likely to be associated with very old ultramafic Basement lithologies that usually do not form suitable groundwater drilling targets and these were therefore not modelled.

In consequence to the assumed simplifications regarding the magnetic parameters of the modelled structures the dip direction estimates remain the most unreliable parameter. In the mathematical process of the magnetic inverse modelling, the dip angles of the modelled structure are inseparable from the direction of the magnetisation vectors, neither of which can be controlled by any independent constraints. This fact needs to be taken into account when positioning boreholes. Some additional guidance regarding the dip direction may be sought from the inclination of the EM anomalies associated with the magnetic body but may be only confirmed through the exploration drilling. This limitation may be quite important in water borehole siting projects.

#### **6.2.4 Electromagnetic Profiling Results**

The Horizontal Loop frequency domain Electromagnetic (HLEM) profiling undertaken in this project was focussed on the shallow steeply dipping conductors that may be representative of fracture systems and or fractured margins of magnetic bodies identified from the aeromagnetic and ground surveys. In addition, the HLEM profiling allowed identify the presence of the Karoo cover in Target Areas F, G and H.

In most cases the HLEM conductors were identified at the anticipated locations. There are only very few profiles that did not transect such conductors (Lines 11, 12 and 41). It is also common to find a typical HLEM subvertical conductor anomaly at the margins of the interpreted magnetic structure or at their intersection point. In some cases it is not possible to separate the effects of the dyke itself and the possible associated fracturing on the margins of the magnetic body. In these cases information from the VES played a deciding role in selecting the particular location as a potential drill site. The presence of a thick weathered zone and/or fracturing down to a considerable depth was considered essential in the final rating of the prospective sites.

The HLEM responses to the fractured conductive sub-vertical zones within the Karoo sediments are reflected through negative type anomalies on both the In-phase and Quadrature components, which are separated (vertical shift) due to the layered nature of the Karoo formations.

#### **6.2.5 VES Modelling Results**

All the twenty-eight VES undertaken (including one VES at the reference borehole) were modelled and the results are shown on the composite data plots in the Appendix A.

Two distinct types of VES were obtained and the two types reflect the underlying geology: the Basement rocks and Karoo sediments. Excluding the top 2 m, the great majority of the VES carried out in the Basement areas (Target Areas A to E) fit a simple H-type 3-layers model (resistive top layer, conductive intermediate layer and very resistive basal layer). However, in some cases it was necessary to introduce an

additional 2 layers to account for a conductive layer at depth, which represents fractured bedrock.

The VES carried out in the Karoo area (Target Areas F-H) resulted in multi-layer sounding curves. The resistivities of the Karoo sediments vary from 10 to 50 ohmm and their interpreted thickness varies between 20m (on the margins in the east) to about 140m in the north (line 72).

The interpretation of the VES was undertaken in several steps, which are outlined below:

- enter all VES into RESIXIP
- interpret all VES - layered model with a minimum number of layers to fit the curve
- interpret all VES - “smooth model”
- compare the layered and “smooth” models and re-interpret where necessary
- discard all sites where the basal resistive layer is shallower than 10m and/or its resistivity is lower than 10 ohmm (which would imply a clay-filled channel rather than fractured bedrock). Fourteen VES fall into this category.
- rate all the remaining VES according to the adopted scoring system explained in Section 6.4.

In summary, the most desired VES results in the Basement areas constituted these models in which the overburden was more than 10m thick, its resistivity ranged from 20 to 100 ohmm and where fracturing was indicated at depth through more than 3 layers. Five layers were rated highest, with the resistivity of the fourth layer lower than 100 ohmm. The Karoo-type VES were rated based on the overall thickness and the resistivity of the sediments. The highest score was assigned to the VES which indicated more than 50 m of Karoo sediments, which are unlikely to constitute mudstones only (resistivity > 15 ohmm).

### 6.3 Integrated Data Interpretation Results

On completing the evaluation of all the ground geophysical surveys and the aeromagnetic images, a detailed interpretation of the relevant aerial-photos (AP) was undertaken in order to accurately locate all the major AP lineaments observed in the investigated Target Areas. These were, however, not re-digitised but instead they were marked on the individual working profile plots in order to allow their correlation with the observed geophysical responses. Any apparent objects (such as fences, roads, bridges, power lines, etc.) that may have caused so called ‘cultural noise’ effects on the profiling data were also marked on the traverses. Similarly, the positions of all the rivers and streams were also marked on the working profile plots.

In order to best evaluate this multi-parameter data set, it has been decided to define a systematic evaluation tool, where all contributing data would be rated according to the previously defined scoring system. Firstly, ‘positive hydrogeological indicators’ were defined for both potential aquifers in the area and they are as follows:

1. Thick overburden (Karoo sediments) and presence of fractures at depth (**VES and HLEM category**)
2. Presence of AP lineaments (**PHOTO category**)
3. Presence of subvertical conductor(s) (**HLEM category**)
4. Presence of magnetic structures such as dyke, fault, fracture, contact (**MAG category**)
5. Proximity to the present drainage system and potential higher recharge (**DRAINAGE category**)

6. Lithology type which exhibits higher groundwater potential (**LITHOLOGY category**)

The above constitute the scoring categories. In keeping with the above, all prospective sites that may have increased groundwater potential were identified and listed for each aquifer type separately (Tables 6.3.1 and 6.3.2). Each site was allocated a score in each category according to the clearly defined system, which is outlined below.

**BASEMENT AQUIFERS**

**VES CATEGORY**

- **0 pts** - thickness of the overburden < 10m, no fracturing and/or resistivity of the overburden <15 ohmm
- **1 pt** - thickness of the overburden > 10m and/or fracturing to >30m depth
- **2 pts** - resistivity of the overburden: 20-100 ohmm and thickness of the overburden > 10m
- **3 pts** - fracturing to > 30m depth and the resistivity of the fractured layer < 100 ohmm

Note! - In absence of the VES the score is 0 was assigned.

**MAG CATEGORY**

- **0 pts** - no anomaly/structure
- **1 pt** - single anomaly/structure (thin dyke, fault, fracture or contact) less than 100m away
- **2 pts** - intersection of two or more structures (thin intrusions only)

**HLEM CATEGORY**

- **0 pts** - no anomaly or OP anomaly on 7040 Hz < 10%
- **1 pt** - OP anomaly on 7040 Hz > 10%
- **2 pts** - OP anomaly on 3520 Hz > 10%
- **3 pts** - IP and OP anomaly on 3520 Hz

**PHOTOS CATEGORY**

- **0 pts** - no apparent AP lineaments or such are shorter than 500m
- **1 pt** - AP lineament 500 -1500m long
- **2 pts** - dark-toned AP lineament longer than 1500m
- **3 pts** - intersection of two or more AP lineaments

Note! - Absence of AP lineaments may be due to cultivation.

**DRAINAGE CATEGORY**

- **0 pts** - drainage further than 600m
- **1 pt** - site located 200-600m away from a river or stream
- **2 pts** - site located < 200m away from a river or stream
- **3 pts** - site located on the main river bank or near a tributary stream to the main river

**LITHOLOGY CATEGORY**

- **1 pt** – presence of calcrete or amphibolites
- **2 pts** - site located near lithological contact

## **KAROO AQUIFER**

### **VES CATEGORY**

- **0 pts** - resistivity of sediments <15 ohmm
- **1 pt** – resistivity of sediments >15 ohmm
- **2 pts** – resistivity of sediments >15 ohmm and thickness of sediments > 50m

Note! - In absence of the VES the score is 0\*.

### **MAG CATEGORY**

- **0 pts** - no anomaly/structure
- **1 pt** - single anomaly/structure (thin dyke, fault, fracture or contact) less than 100 m away
- **2 pts** - intersection of two or more structures (thin intrusions only)

### **HLEM CATEGORY**

- **0 pts** - no anomaly or OP anomaly on 7040 Hz < 10%
- **1 pt** - OP anomaly on 7040 Hz > 10%
- **2 pts** - OP anomaly on 3520 Hz > 10%
- **3 pts** - IP and OP anomaly on 3520 Hz

### **PHOTOS CATEGORY**

- **0 pts** - no apparent AP lineaments or such are shorter than 500m
- **1 pt** - AP lineament 500 -1500m long
- **2 pts** - dark-toned AP lineament longer than 1500m
- **3 pts** - intersection of two or more AP lineaments

Note! - Absence of AP lineaments may be due to cultivation.

### **DRAINAGE CATEGORY**

- **0 pts** - drainage further than 600m
- **1 pt** - site located 200-600m away from a river or stream
- **2 pts** - site located < 200m away from a river or stream
- **3 pts** - site located on the main river bank or near a tributary stream to the main river

### **LITHOLOGY CATEGORY**

- **1 pt** – presence of calcrete
- **2 pts** – presence of grit and sandstone
- **3 pts** – presence of sandstone or lithological contact

On completion of the scoring process in each category and for each selected site in the 8 Target Areas, a total score for each site was calculated and all sites were rated accordingly. The results of this scoring and rating system are presented below for each aquifer type (Tables 5.3 and 5.4) and they are discussed for each Target Area separately in Sections that follow.

**TABLE 6.3.1 Prospective Basement Sites (Rated) - Target Areas A-E**

Location	VES	MAG	HLEM	Photos	Drainage	Lithology	Sum Geoph	Sum P-geology	Total	W-total	Final Rating
L13/450	*	1	3	2	2	1	4	5	9	5.7	Site 2
L13/790	*	0	3	1	1	0	3	2	5	3.7	
L14/200	3	1	1	3	3	2	5	8	13	7.6	Site 1
L21/760	3	0	0	2	3	2	3	7	10	5.3	Site 4
L22/390	0	0	1	2	3	0	1	5	6	2.7	
L22/860	*	1	0	2	3	2	1	7	8	3.3	
L23/750	*	2	1	2	3	2	3	7	10	5.3	Site 3
L33/120	2	1	1	0	1	0	4	1	5	4.3	
L34/320	2	0	2	0	1	0	4	1	5	4.3	
L42/720	1	1	1	2	1	0	3	3	6	4.0	
L43/1200	2	0	2	2	1	0	4	3	7	5.0	
L45/120	1	0	3	1	3	0	4	4	8	5.3	Site 5
L46/1125	*	1	1	2	2	2	2	6	8	4.0	
L46/1330	*	1	1	2	2	2	2	6	8	4.0	
L52/560	0	0	3	1	1	1	3	3	6	4.0	
L52/800	*	1	3	0	2	0	4	2	6	4.7	

\*- VES not available

**Sum Geoph** is a sum of scores from the first three categories (VES, MAG and HLEM) which represent geophysical criteria.

**Sum P-geology** is a sum of all scores from the remaining categories, which are associated with photo-geological criteria.

**W-Total** is weighted total score, which was obtained as follows:

$$\text{W-Total} = \text{Sum Geoph} + 0.33 \times \text{Sum P-geology}$$

From the previous experiences with the above rating system it was realised that the photo-geological categories scores need to be slightly suppressed and that the geophysical responses need to be given more weight in the final score. Consequently the final total score was weighted giving the photo-geological categories a weight of about 33% as compared to 100% for the geophysics categories. It has to be noted that this scoring system is in its experimental stage and that it needs to be verified through the drilling results. It is hoped that through such verification process a more refined and accurate scoring system can be developed and applied in the future projects.

**TABLE 6.3.2 Prospective Karoo Sites (Rated) – Target Areas F-H**

No	Location	VES	MAG	HLEM	A-Photos	Drainage	Lithology	Sum Geoph	Sum P-Geology	Total	W-total	RATING
1	L61/790	1	0	1	2	2	2	2	6	8	5.0	
2	L62/60	2	0	2	1	1	2	4	4	8	6.0	Site 3
3	L71/430	*	0	3	1	2	3	3	6	9	6.0	Site 5
4	L72/550	2	0	2	1	3	3	4	7	11	7.5	Site 1
5	L73/370	*	1	1	2	3	3	2	8	10	6.0	Site 4
6	L74/450	0	0	3	1	2	2	3	5	8	5.5	
7	L81/350	2	0	1	1	3	3	3	7	10	6.5	Site 2
8	L82/490	*	0	1	2	2	3	1	7	8	4.5	

\* - VES not available

The final weighted score **W-Total** in the Karoo area was obtained as follows:

$$\mathbf{W-Total = Sum Geoph + 0.5 \times Sum P-geology}$$

In this particular aquifer type the photo-geological categories (lithology in particular) play an important role in the overall groundwater potential. Consequently a higher weight of 50% was assigned to this category. This is an experimental approach and it needs considerable verification through the correlation of the drilling results with the applied rating system, before it can be used as a standard approach in the borehole siting.

### 6.3.1 Target Area A - Basement

Target Area A is located immediately to the east of the village on the boundary with the Tuli Block Farms and near the prominent dolerite hill that has been transected by a WNW structure L1 (Figure 3). This structure is apparent on the aeromagnetic image as a persistent narrow linear low that transects the entire Project Area and it can be modelled as a remnant magnetised dyke or a lithological contact (also with remnant magnetisation). It also coincides with a clear AP lineament. The origin of this anomaly is evidently a highly magnetic Basement lithology with its edge aligned along this persistent structure L1.

Three prospective sites were listed in this area and they are shown on Table 6.3.1. Two of them have been subsequently selected as drilling sites. Drilling Site 1 is located along line 14 at 200m peg and it had the highest score in the accumulated geophysical categories (5 points). Its rating in the photo-geological categories was also the highest. Consequently both the total and weighted total were the highest amongst all the Basement sites shown on Table 6.3.1. However, it is possible that the anomalously thick overburden interpreted at this site may be in fact of a Karoo origin, rather than the weathered Basement. The VES would support this interpretation and both the HLEM and magnetic profiles suggest that the contact between the Basement and Karoo is located at about 150m.

Another drilling site was selected at 450m along line 13, where a large amplitude HLEM conductor was mapped and the VES carried out some 300m away has indicated anomalously thick overburden. Due to the large HLEM amplitude the overall score in the geophysical category was one of the highest and the weighted total score was the second highest amongst all the Basement sites. This site also appears to be located along the major aeromagnetic structure L1 (although not represented on the ground profile) that coincides with a major photo-lineament. There is also some possibility that the marginal Karoo sediments underlie this site.

### 6.3.2 Target Area B - Basement

Target Area B is located some 4 km south west of the village and is underlain by gneiss and metaquartzite, which, according to the published geological map, may be locally magnetic. This magnetic unit is probably represented on the aeromagnetic image as a NNW aligned magnetic high anomaly (H1). Main target in this area is constituted by series of west easterly structures inferred from the airborne magnetic survey (DD13, DD14 and L6). These appear to coincide with the AP lineaments and they interrupt the NNW aligned highly magnetic units (H1) mentioned above.

Four prospective sites were evaluated in this Target Area. Although none of these sites were ranked high on the geophysical criteria, three of them acquired very high scores in the photo-geology category. Consequently the final scores for two sites in this Target Area were very high (10 pts). These two sites were therefore selected as

drilling sites and they are located at L21/760m and L23/750m. (Sites 3 and 4) The VES carried out on the drilling site along line 21 has received the highest score due to the fracturing indicators down to depths of 42m and this site should be regarded as first priority in this Target Area.

### **6.3.3 Target Area C - Basement**

Target Area C is located some 8 km south west of the village where massive feldspathic gneiss is banded with narrow amphibolite strips which are up to 300 m wide (Map 2). Several dolerite dykes and possible fractures transect this area as well (Figure 2). Most ENE aeromagnetic structures correspond to the lineaments observed on the aerial photos and coincide with dolerite dykes interpreted from the aeromagnetic data. The northerly metaquartzite bands are also visible on the aerial photos. Although there are only few pronounced AP lineaments in this area, its groundwater potential was assumed based on the aeromagnetic structures and on the presence of amphibolite, which is known to constitute aquifers elsewhere due to its favourable weathering patterns. Two NW traverses were positioned in this area to transect the aeromagnetic features. Additional two short ENE traverses were aimed at the lithological contact between the gneiss and amphibolite. Recharge is expected to take place at this locality through the present drainage system.

Despite the assumed groundwater potential of this area the geophysical survey results were rather discouraging as very few indicators of sub-vertical fracturing were found. Only two potential sites were assessed and their scores are shown on Table 6.3.1. No obvious AP lineaments could be associated with the selected sites and the overall scores in the photo-geology category were very low. This has contributed to the low overall scores acquired by these two prospective sites, despite the encouraging initial VES results. Consequently there was no drilling site recommended in this area.

### **6.3.4 Target Area D - Basement**

Target Area D is the largest of the proposed exploration areas and it is located along the major ESE oriented structure L1, which is apparent on both the airborne magnetic image and on the aerial photographs. Exploration traverses are oriented mostly NNW and aim at the intersection points of this major structure with other structures inferred from the aeromagnetic data and from the AP interpretation. The geology of this area consists mostly of gneiss and amphibolite bands, which are clear on the AP as well. Lithological contacts between these two units were targeted by some of the exploration traverses.

Out of the five prospective sites evaluated in this Target Area two are recommended as drilling sites. The two recommended sites are located at L43/1200m and L45/120m. Both sites received high scores in the geophysical category and high weighted final scores were one of the highest as well. However, it is a possibility that the site located at the end of line 43 is in fact located at the contact zone between the Basement and the Karoo sediments, so the site on Line 45 was preferred (Site 5).

### **6.3.5 Target Area E - Basement**

Target Area E is located some 2 km to the north of the village centre and is underlain by gneiss and thin bands of amphibolite. The NE structures prevail in this area and they appear as dykes on the aeromagnetic image and are also represented on the aerial photographs. Two NW traverses were surveyed in this area and two potential sites located along line 52 were evaluated. They are located at 560 and 800m, respectively and both fall in the area with anomalously thick

overburden as indicated by both the HLEM and VES results. However, the interpreted resistivity of the overburden suggests that it is clayey in nature. In absence of any clear indication of deep fracturing at these two localities, none were recommended for drilling.

#### **6.3.6 Target Area F - Karoo**

Target Area F is located about 6 km to the east of the village centre along the boundary with the Tuli Block Farms fence. It is positioned on major ENE aeromagnetic structures DD12 and L5. A west-east oriented fault is also inferred in this area on the published geological map. According to the geological map grits and sandstone of the Karoo Supergroup underlie this area.

The above is supported by the results of geophysical surveying which confirmed the presence of Karoo sediments, which may be in excess of 80 m thickness. The resistivity of these sediments varies between 25 and 40 ohmm, which is characteristic for mudstone but may also represent saturated grits and sandstones. There is no existing borehole in that area to verify this uncertainty. Two prospective sites were evaluated in this area and their scores are shown on Table 6.3.2. However, the site located along Line 61/790m was discarded in favour of site at Line 62/60m (Site 3) due to the relatively smaller thickness of sediments and lower overall rating score.

#### **6.3.7 Target Area G - Karoo**

Target Area G is located in the area underlain by Karoo sediments about 6 km to the north of the village. A NE oriented dolerite dyke DD4 intersects this area together with the ENE oriented dolerite dyke DD1 and a possible fault aligned along its strike. One exploration traverse was positioned on the contact zone between the Karoo grits and Karoo sandstone and other was to cross the dolerite dyke DD1 at the point where it is interrupted by a NE structure. Third traverse is positioned along the river at the point where is transected by a dolerite dyke DD4, which is also clear on the AP. The fourth and last line in this area was aimed at the southern edge of the Karoo deposits, where they wedge off against the Basement. One prospective site was selected along each of the four lines in this Target Area and their respective ratings are shown on Table 6.3.2. Sites located on lines 71, 72 and 73 (Sites 5, 1 and 4) acquired the highest total scores and consequently were selected as drilling sites. At all these sites Karoo sandstone is expected, however its groundwater potential at this particular location is largely unknown due to the lack of borehole information.

#### **6.3.8 Target Area H - Karoo**

This furthestmost Target Area is located some 9 to 10 km to the north west from the village centre and similarly to Target Area G is underlain by Karoo grits in the south and Karoo sandstone in its northern section. Two short traverses were surveyed in this area. The western traverse transects inferred aeromagnetic structure, which is aligned along the southern edge of the sandstone and parallels dolerite dyke DD1. The second traverse is aimed at the intersection point of two aeromagnetic structures and falls in the sandstone outcrop area. The NE structure has its reflection on the ground as it cuts through the sandstone hills aligned in a SE direction.

From the two selected prospective sites that were evaluated in this area site located along line 81 (Site 2) was recommended for drilling, largely due to the favourable lithology (sandstone) and high score in the overall geophysics category.

## 6.4 Drilling Site Selection

The required drilling sites were selected based on the evaluation of the ground geophysical surveys, airborne magnetic survey and other photo-geological criteria. These criteria relate to presence of extensive AP lineaments, proximity of the drainage system and the information contained in the published geological map. The information acquired during geological mapping undertaken along the geophysical survey lines was also utilised during the evaluation. Five Target Areas were positioned in the village proximity, where Basement rocks occur. Another three areas were located to the north and east of the village where Karoo rocks are known to occur. On completion of data collection and interpretation several prospective sites were selected in each Target Area and are tabulated separately for the Basement and Karoo aquifers respectively (Tables 6.3.1 and 6.3.2) and Figure 4. These were further evaluated adopting an experimental scoring system, which is described in Section 6.2. This system attempts to 'quantify' the factors that contribute to the overall groundwater potential of the particular site. Based on this scoring system potential sites are rated and prioritised accordingly. In this evaluation all photo-geological criteria were weighted less than the geophysical criteria with a weighting factor of 30% introduced for the Basement aquifers and 50% factor for the Karoo aquifer. This is to suppress the influence of the proximity to the drainage system and role of the photo-lineaments that originate from large dykes, which may not be very good target for groundwater abstraction as recently experienced in the Sefophe area. Final selection of drilling sites was then based on the final weighted score.

All initially selected prospective drilling sites were tabulated and evaluated in Section 6.3. In summary, out of all 16 selected Basement sites (Table 6.3.1) one scored 13 points, two scored 10 points, one scored 9 points and four scored 8 points. In other words, there are four sites that scored 9 and more points and four sites that scored 8 points. The four sites that scored 9 points and more are located in Target Area A (2 sites) and Target Area B (2 sites). Sites which scored 8 points are located in Target Areas B and D. The deciding factor in prioritising the 8-point sites was the overall geophysics category.

Amongst the 8 evaluated Karoo sites one scored 11 points, two scored 10 points, one scored 9 points and the rest scored 8 points each (Table 6.3.2). Subsequent to evaluating all the Karoo sites, five sites with the highest weighted final scores were recommended for drilling.

Based on the evaluation of the existing water supply, the average yield which may be expected from a single new borehole, and the current as well as projected demand estimates, it was concluded that up to six new boreholes may be required in this village. The village itself is located on the Archean Basement Complex and the existing water supply is from the Basement type aquifers. These are known to be sensitive to the amount of recharge obtained and tend to be vulnerable to pollution when located close to the village.

During the current project several Target Areas were positioned and subsequently investigated in the Basement area in the vicinity of the village. After evaluation of the data five drilling sites were recommended (Table 6.3.1). However, it was kept in mind that these were not potential high yielding sites due to the nature of the Basement aquifer. In addition, three Target Areas F to H were located on Karoo sediments to the east and north of the village. Five drilling sites were also recommended in those areas, although they are located at a greater distance from the village centre than the Basement sites. It is also worth noting that although the Karoo sandstone, in particular, was known to constitute reliable aquifers elsewhere, the groundwater potential of Karoo sediments present in this particular area was largely unknown.

Taking into consideration the available options in this particular village it was recommended that drilling commence in the Basement sites (Areas A and B) which were located near the village and that these be carefully evaluated as drilling progresses. In case of unsatisfactory results it was proposed to move drilling operations to the more distant areas that are

underlain by Karoo sandstones (Areas F, G and H) with an aim of investigating its groundwater potential.

**TABLE 6.4.1 Summary of the Basement and Karoo Drilling Sites (not prioritised)**

Site No	Location	Final Score	Final Weighted Score	Drilled BH No.	Comments
1	L14/200m	13	7.6	BH 9164	Basement Site, contact with Karoo
2	L13/450m	9	5.7		Basement Site, contact with Karoo?
3	L23/750m	10	5.3	BH 9177	Basement Site
4	L21/760m	10	5.3	BH 9178	Basement Site
5	L45/120m	8	5.3		Basement Site
6	L72/550m	11	7.5		Karoo site, sandstone
7	L81/350m	10	6.5		Karoo site, sandstone
8	L62/60m	8	6.0	BH 9176	Karoo site, calcrete, grit and sandstone
9	L73/370m	10	6.0		Karoo site, sandstone
10	L71/430m	9	6.0		Karoo site, sandstone

The final recommended drilling sites and the summary of the siting criteria are tabulated above (Table 6.4.1). Not all sites were drilled as indicated in the table. Sites were listed to allow for flexibility during the drilling operations as drilling results became available. Drilling depths in the Basement area were not to exceed 150 m, but Karoo boreholes were expected to be deeper with an average depth of 200 m. The analysis of the drilling results in relation to the geophysical data interpretation is included in Section 7.2.

After the drilling of the basement sites (BH 9164, BH 9176, BH 9177 and BH 9178) additional geophysical work was also carried out in the Karoo in new Target Area near Thune River. The lines were mainly aimed at penetrating the Karoo in an attempt to enhance groundwater potential at the resulting drilling sites. A total of 5 km of both EM and magnetic profiling were carried out and 15 resistivity soundings were carried out at selected points. Details of the survey lines are given in Table 6.4.2. The drilling sites were selected in a similar manner as described in Section 6.3.6 under the Karoo Aquifer sub section. The final selected sites for drilling are tabulated in Table 6.4.3 below.

**TABLE 6.4.2 Additional Geophysical Survey Lines Location Details**

Line Number	START		END		Length (km)
	Easting	Northing	Easting	Northing	
Line 1	685405	7545758	687035	7545413	1.60
Line 2	686032	7544884	685968	7546067	1.20
Line 3	686478	7545604	687838	7545717	1.30
Line 4	687094	7545327	686963	7546112	0.80

**TABLE 6.4.3 Additional Karoo Drill Sites**

Site No.	Location	Final Score	Final Weighted Score	BH Drilled	Comments
1	L1/110 m	9	7	9313	Karoo Site
2	L2/360 m	9	7	9314	Karoo Site
3	L1/1530 m	7	5	9315	Karoo Site
4	L2/1100 m	6	4	9316	Karoo Site

## 7 GROUNDWATER DEVELOPMENT

### 7.1 Drilling Programme

One air rotary rig with support vehicles were deployed by the Contractor Pula Groundwater Developers to drill Mathathane boreholes under the Uniform Rates Contract.

Drilling penetration rates were recorded and formation samples were collected for every metre drilled. The samples were laid on the ground and lithologically logged by the site geologist on site. Water samples at major water strikes and at terminal depths were collected for laboratory analysis and wellhead chemistry parameters measurements such as TDS (Total Dissolved Solids), EC (Electrical Conductivity), Dissolved Oxygen, pH, water temperature total and phenolphthalein alkalinity were measured at the well head during drilling activities.

Daily drilling progress reports were checked by the site geologist at the end of each day's activities.

The initial drilling programme commenced on 4<sup>th</sup> of December and was completed on the 14<sup>th</sup> December 1999. A total of four (4) boreholes (BH 9164, BH 9176, BH 9177 and BH 9178) were drilled into the Basement rocks in the immediate surroundings of Mathathane village. The drilling results were poor (Table 6.1) with the best borehole yielding only 1.8 m<sup>3</sup>/hr. Due to these poor drilling results it was considered essential to increase the number of boreholes for Mathathane village and as a result drilling of four additional boreholes (BH 9313, BH 9314, BH 9315 and BH 9316) was undertaken in the Karoo from the 1<sup>st</sup> of May to the 27<sup>th</sup> of May 2000.

All the boreholes drilled in Mathathane were constructed according to the specifications agreed upon at the drilling pre-mobilisation meeting. The first four boreholes were started with a 10 inch (254 mm) drilling diameter and subsequently lined with 8 inch casing to just below the weathered horizon. The lower section of these holes were left open. The second batch of four boreholes were started from surface with a 12 inch (304 mm) drilling diameter and subsequently lined with 10 inch casing to just below the weathered horizon. The lower section of these Karoo borehole was drilled 10 inches to the bottom. Boreholes with sufficient yield were lined with 8 inch casing and screens were placed across water bearing zones.

For sanitary purposes in both borehole batches both 8 inch and 10 inch casings were then grouted with cement and the grout was allowed to cure for a minimum period of 8 hours if a cement accelerator (calcium chloride) was used.

After grouting the boreholes were drilled to completion with an 8 inch drilling diameter in the case of the first batch and 10 inch for the latter. Complete borehole construction details are tabulated in Table 7.2.2 below.

By the end of all drilling activities in Mathathane a total of eight (8) boreholes had been drilled and of these boreholes only three boreholes BH 9314, BH 9315 and BH 9316 had significant yields of 12 m<sup>3</sup>/hr, 13.5 m<sup>3</sup>/hr and 17 m<sup>3</sup>/hr respectively. The rest of the boreholes were completely dry or less than 2 m<sup>3</sup>/hr.

### 7.2 Drilling Results and Correlation with Geophysical Interpretations

The Mathathane borehole drilling results details are presented below in Tables 7.2.1. A brief geological description of each individual project borehole is presented below and each borehole lithological log shown in Appendix D.

### **Borehole BH 9164**

Drilling of borehole BH 9164 started on the 4<sup>th</sup> of December and was completed on the 8<sup>th</sup> of December 1999. The borehole was drilled to a terminal depth of 200 metres in a dolerite sill.

A lithological profile of the borehole is presented in Appendix D. The first 59 metres of the geological log consist of carbonaceous mudstones. The rest of the geological log comprises moderately to fresh dolerite of variable degrees of fracturing. A minor seepage was recorded at a depth of 163 metres below ground level and water samples collected at completion of the hole at 200 metres indicate Total Dissolved Solids of 430 mg/l. This borehole was essentially a dry hole due to no major fractures.

The geophysical interpretations were largely obscured by the presence the lower Karoo argillaceous sequence of predominantly carbonaceous mudstones. The presence of this upper unit could have lowered the formation resistivities. The presence of the basal dolerite contributed to the strong magnetic signatures.

### **Borehole BH 9176**

Borehole BH 9176 was drilled about 4 kilometres south of the village approximately 500 metres east of Mathathane-Tsetsebjwe gravel road. Drilling commenced on the 9<sup>th</sup> of December and was completed on the 11<sup>th</sup> of December 1999. The borehole was drilled to a terminal depth of 200 metres in a banded gneiss. The top 95 metres of the geological profile consists of carbonaceous mudstones interbedded with sandstone and the rest of the amphibolite with minor fractures. A minor water strike was recorded at 186 metres in amphibolite. A rest water level of 19.49 metres was measured after drilling activities were completed. This borehole was essentially a dry borehole. A water sample collected at 200 metres on completion of drilling indicated water TDS of 860 mg/l.

Again as was the case with BH 9164 site, the geophysical interpretation was obscured by the presence of 95 m of lower Karoo sequence of carbonaceous mudstones and sandstones. The faulted lithological contract was evident from the geophysical profiles. It is possible that the site was slightly off Basement and should have been classified as a Karoo drill site judging from the thickness of the Karoo sequence.

### **Borehole BH 9177**

Borehole BH 9177 was drilled approximately 4.5 kilometres to the south of Mathathane Clinic about 500 metres south of BH 9176. Drilling activities were carried out during the period of 11<sup>th</sup> – 12<sup>th</sup> of December 1999. The borehole was drilled to a final depth of 212 metres in a banded gneiss. The top 14 metres of the borehole log comprise loose sand and moderately weathered banded gneiss residue. The rest of the geological log is an alternating sequence of moderately weathered to fresh quartzo-feldspathic gneiss and amphibolite indicating limited signs of fracturing and this borehole was completely dry as no water strike or seepage was recorded during drilling of the borehole.

Very little fracturing was reported in this boreholes indicating that the identified single anomaly might have originated from a minor fracture system.

### **Borehole BH 9178**

Borehole BH 9178 was drilled to the south of the village and west of the Mathathane-Tsetsebjwe road. Drilling started on the 12<sup>th</sup> and was completed on the 14<sup>th</sup> of December 1999. The borehole was drilled to a terminal depth of 200 metres in a banded grey gneiss. The top 13 metres of overburden consists of extremely weathered quartzite and schist material. The rest of the lithological log is predominantly amphibolite with subordinate banded gneiss and quartzo-feldspathic gneiss.

The first water was recorded as a seepage at 32 metres a yield 1.8 m<sup>3</sup>/hr was recorded at 25 m below ground level and a rest water level of 30.60 was measured two days after completion of drilling works. Wellhead chemistry measurements indicate TDS of 410 mg/l.

The drilling results confirmed the deep weathering and fracturing interpreted at 30 m depth although insignificant yield was encountered at that depth.

### **Borehole BH 9313**

Borehole BH 9313 was drilled near the Thune River from the 1<sup>st</sup> to 3<sup>rd</sup> of May 2000 and was terminated at 140 metres muddy siltstone. The top 65 metres of the geological log consists of amygdaloidal basalt underlain by a sequence sandstone, siltstone and muddy mudstone. A single water strike with blowout estimate of 2 m<sup>3</sup>/hr was recorded at 69 metres. A rest water level of 8.4 metres was measured after completion of drilling activities with a corresponding conductivity of 990 µS/cm.

The drilling results confirm the geophysical results that indicated a resistive layer down to 140-150 m depth. Both basalt and the Lebung Group appear to have high resistivity. No significant fracturing was reported during drilling although it is possible that in the sandstone unit fractures were missed due to the soft nature of the formation.

### **Borehole BH 9314**

Drilling of borehole BH 9314 started on the 4<sup>th</sup> May and was completed on the 9<sup>th</sup> of May 2000. The borehole was drilled 12 kilometres to the north of Mathathane village on the southern bank of Motloutse River.

The borehole was drilled to a terminal depth of 180 metres in reddish brown mudstone. The top 102 metres of the geological log consisted of variably fractured amygdaloidal basalt underlain by friable sandstone and minor siltstone and mudstone. Two water strikes of approximately 2.5 m<sup>3</sup>/hr and 12 m<sup>3</sup>/hr were recorded at 107 metres and 120 metres in a friable sandstone. These results are in support of the geophysical data interpretation that indicated fracturing and the major fractures were mapped as moderate conductors.

A rest water level of 24.83 metres was measured after completion of drilling activities and a water sample collected at 180 metres indicate wellhead chemistry of 960 µS/cm and pH of 8.6.

### **Borehole BH 9315**

Borehole BH 9315 was drilled during the period from 10<sup>th</sup> to 17<sup>th</sup> May 2000 to the north of the village on the southern bank of Thune River. The borehole was drilled to a terminal depth of 210 metres in reddish brown siltstone. Amygdaloidal basalt predominates the top 132 metres of the lithological profile of the borehole. The rest of the borehole geological profile consists of friable cream sandstone with muddy siltstone becoming predominant towards the bottom.

Two water strikes were encountered at 110 metres and 132 metres with blowout yields of 3.4 m<sup>3</sup>/hr and 13.5 m<sup>3</sup>/hr respectively. However, after developing for 3 hours the final yield was 23 m<sup>3</sup>/hr. The conductivity of the water was 1070 µS/cm with pH of 8.4. The geophysical data interpretations appears to have mapped out fracture variations within the basalt layer although the fracturing is thought to affect all the units underlying the basalt unit. The thick basalt unit (132 m) had a screening effect on the Lebung aquifer underneath.

### **Borehole BH 9316**

Borehole BH 9316 was drilled during the period from 17<sup>th</sup> to 27<sup>th</sup> May 2000. The borehole

was drilled on the southern bank of the Thune/Motloutse River confluence. The borehole was drilled to a terminal depth of 152 metres. The top eight (8) metres of the lithological profile consists of gravel. The rest of the borehole lithological profile is a sequence predominantly of amygdaloidal basalt to fine grained sandstone and muddy siltstone at the bottom.

Two water strikes were encountered at 60 and 107 metres with blowout yields of 4 and 17 m<sup>3</sup>/hr respectively. The final yield estimate during development was 38 m<sup>3</sup>/hr thus making this borehole the highest yielding borehole in the Project Area. Electrical conductivity and pH were measured at 1930 µS/cm and 7.8 respectively. On the basis of the first 3 Karoo boreholes this borehole was sited in a structurally disturbed area mapped out by HLEM. No magnetic anomaly was evident and the site was assumed to be off the basalt. However, from the results it appears that extremely weathered basalt has a similar geophysical signature as the sandstone.

**TABLE 7.2.1 Summary of Project Drilling Results**

BH No.	X-Coord UTM	Y-Coord UTM	Depth (mbgl)	Water Strike (mbgl)	Static Water Level (mbgl)	Blowout Est. Yield (m <sup>3</sup> /hr)	Test Yield (m <sup>3</sup> /hr)	Field (pH)	Field TDS (mbgl)
9164	684773	7535599	200						430
9176	685892	7538394	200	186	19.49	1.5			860
9177	676955	7533678	212	41 123 140 195					
9178	676965	7535240	200	32 42	30.60	1.8			410
9313	685495	7545710	140	69	8.4	2			495
9314	686036	7545181	180	107 120	24.38	11.78	20	8.6	480
9315	686823	7545399	210.6	110 132 133	15.98	13.5	27	8.4	535
9316	680849	7546038	152	60	18.24	16.90	45	7.8	975

**TABLE 7.2.2 Project Boreholes Drilled Diameters and Casing Details**

BH No.	Drilled Diameter			Casing in the hole		
	Diameter (mm)	Depth from (m)	Depth to (m)	Diameter (mm)	Depth from (m)	Depth (m)
9164	254 203	48	48 200	203	+ 0.5	48
9176	254 203	0 51	51 200	203	+ 0.5	51
9177	254 203	0 30	30 212	203	+ 0.5	30
9178	254 203	0 18	18 200	203	+ 0.5	18
9313	304 254	0 12	12 140	254	+ 0.5	12
9314	304 254 203	0 18	18 180	254 203 203 203 203 203 203	+ 0.5 + 0.5 121.10 132.76 144.41 156.07 167.72 104.34	18 104.54 127.24 138.9 150.55 162.2 180.0 121.10 Louvre

				203	127.24	132.76 Louvre
				203	138.9	144.41 Louvre
				203	150.55	156.07 Louvre
				203	162.21	167.72 Louvre

**TABLE 7.2.2 Project Borehole Drilled Diameters and Casing Details (Contd)**

BH No.	Drilled Diameter			Casing in the hole		
	Diameter (mm)	Depth from (m)	Depth to (m)	Diameter (mm)	Depth from (m)	Depth (m)
9315	304	0	16	254	+ 0.53	16
	254	16	210	203	+ 0.5	108.21
				203	113.72	119.87
				203	125.39	131.53
				203	148.06	154.20
				203	159.70	165.84
				203	198.96	210.60
				203	108.21	113.12 Louvre
				203	119.87	125.39 Louvre
				203	131.53	148.06 Louvre
				203	154.20	159.70 Louvre
				203	165.84	198.96 Louvre
9316	304	0	26	254	0	26
	254	26	152	203	+ 0.6	57.56
				203	63.4	69.55
				203	75.1	81.25
				203	86.61	99.11
				203	143.46	152
				203	57.86	63.4 Louvre
				203	69.55	75.1 Louvre
				203	81.25	86.61 Louvre
				203	99.11	143.46 Louvre

### 7.3 Test Pumping Results and Analysis

Three boreholes BH 9314, BH 9315 and BH 9316 with blow-out estimate yields of 12 m<sup>3</sup>/hr, 23 m<sup>3</sup>/hr and 38 m<sup>3</sup>/hr respectively were tested. The three other boreholes BH 9176, BH 9178 and BH 9313 although had some water were not tested since the blow-out yields were considered to be too low (<2 m<sup>3</sup>/hr) for any meaningful test.

The test pumping schedule of each borehole involved three stages of calibration test, step drawdown test and constant rate test and each of these stages was followed by a recovery phase before the preceding stage was initiated. Throughout the test water levels were monitored and discharge measurements were recorded on standard government forms for test pumping data records. Water pumped from the borehole was discharged 200 to 250 metres down gradient away from the borehole to avoid recycling the water through infiltration or by direct flooding of the wellhead.

Wellhead chemistry measurements such as pH, conductivity, water temperature, dissolved oxygen, total alkalinity and phenolphthalein alkalinity were regularly measured throughout the test to monitor any significant changes in the water chemistry during pumping of the boreholes. All hydrochemical data collected during the test pumping programme is presented in Section 8.

After installation of the pump to the required depth a calibration test was performed in each borehole before a step drawdown test was carried out. The calibration test involved pumping the borehole in steps at increasing discharge rates. Each step lasted for a duration of 15 minutes. The purpose of the calibration test was to determine the optimum pumping rate of the borehole by assessing the response of the borehole to pumping at different yields from the lowest to the maximum possible rate. The calibration test also assisted in calibrating the revolutions of the pump shafting and their relationship to discharge rates.

Step drawdown tests were carried out after the water level attained its original level or close to its original level after completion of a calibration recovery monitoring. Step drawdown tests were carried in a similar manner to calibration tests but each step lasted for 120 minutes before the pumping rate was changed to a higher yield. The purpose of the step drawdown test was to test the well performance by determining the borehole performance characteristics such as well and aquifer loss coefficients using different abstraction rates and to determine the optimum pumping rate for the subsequent constant rate test. Water samples (acidified + non-acidified) for laboratory water chemistry analysis were collected, one sample set at the beginning of the test and another set at the end of the test. Table 7.3.1 presents a summary of test pumping details of the boreholes tested in Mathathane.

**TABLE 7.3.1 Summary of Borehole Test Pumping Details**

BH No.	Calibration Steps (No)	Step Test (No)	Constant Rate (m <sup>3</sup> /hr)	Constant Rate Duration (hrs)	Constant Rate Final Drawdown (m)
BH 9314	8	5	8	72	76.39
BH 9315	8	6	28	144	76.11
BH 9316	6	7	33	80	47.69

### 7.3.1 Test Pumping Data Interpretation

#### 7.3.1.1 Borehole BH 9314

Borehole BH 9314 construction details are presented in Table 7.2.2. The borehole is cased from the surface to 18 metres and the rest of the borehole is 203 mm diameter casings and screens. A water strike yielding approximately 2.45 m<sup>3</sup>/hr was encountered at 107 metres. A second water strike was encountered at 120 metres with a blowout yield estimated at approximately 12 m<sup>3</sup>/hr. A rest water level of 24.83 metres was measured before commencement of the calibration test indicating a substantial degree of groundwater confinement in the borehole. The borehole was pumped using a mechanically driven positive displacement Orbit pump 5403 installed to a depth of 210 metres. The borehole was pumped for 72 hours. The test pumping programme was carried out from the 21<sup>st</sup> to the 28<sup>th</sup> of January 2001.

#### Calibration Test

Eight calibration steps were carried out with discharge steps ranging from 2 m<sup>3</sup>/hr to 26 m<sup>3</sup>/hr. The final drawdown at the end of the eighth step was 133.30 m with 20.74 metres of available drawdown remaining. Table 7.3.1.1 summarises the calibration test results. Evaluation of this data indicated that the borehole may not sustain these discharge rates during the longer step drawdown test.

**TABLE 7.3.1.1 Calibration Test Results**

Step	Discharge (m <sup>3</sup> /hr)	Water Level (m)	Drawdown (m)
1	2.71	26.41	5.67
2	5.82	36.56	15.82
3	9.37	51.74	31.00
4	11.80	66.61	45.87
5	15.51	84.32	63.58
6	18.86	103.95	83.21
7	21.93	122.21	101.47

8	25.81	154.04	133.30
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### Step Drawdown Test

Five complete steps were carried out. Table 7.3.1.2 summarises the step drawdown test results. None of the steps approached equilibrium conditions as shown by a drawdown rate of not less than 0.45 metres every ten minutes at the end of each step. During the last step the rate of drawdown increased to more than 6 metres every ten minutes thereby almost reaching the pump intake level. A summary of step drawdown measurements is presented in Table 7.3.1.2 below.

**TABLE 7.3.1.2 Step Drawdown Test Results**

Step	Discharge (m <sup>3</sup> /hr)	Water Level (m)	Drawdown (m)	pH	EC
1	3.34	39.43	17.46	7.9	880
2	6.17	57.43	35.46	8.9	830
3	9.12	80.03	58.06	9.1	850
4	11.55	102.04	80.07	8.8	830
5	14.57	149.81	127.84	8.8	840

Appendix D1 is a time-drawdown plot and specific drawdown versus discharge rate.

### Constant Rate Test

A discharge rate of 8 m<sup>3</sup>/hr was selected for a constant rate test based on the results of the step drawdown test. The test was performed over a period of 72 hours at the end of which the water level was more than 50 metres above the pump intake depth. A time-drawdown plot of the data collected during the constant rate test is presented in Appendix D2 & D3.

The graphs shows an increased drawdown rate during the first 70 hours of pumping and the water level at 70 minutes was 68.42 metres which is within the basalt. During this period of pumping water level drawdown rate was high due to the confined aquifer response. After 70 minutes the rate of drawdown decreased because the water level was almost at the basalt/sandstone interface where the first water strike was recorded. Water abstracted from the borehole during this period was from the intragranular spaces within the friable sandstone and unconfined responses were dominant.

The late time gradient of the graph remained fairly constant until the pump was switched off after pumping for 72 hours.

Constant rate test data was analysed for transmissivity using Jacob-Cooper and DWA Testurv method. The results of these approaches are summarised in Table 7.3.1.7. A Jacob-Cooper analysis on the semi log plot Appendix D3 produced transmissivity values of 1.2 m<sup>2</sup>/day and 1.7 m<sup>2</sup>/day for early and late time data respectively. DWA Testcurve match of the data was not very good since the first segment of the plot is almost a sub horizontal line. However the match with the third stage segment of the data gives a transmissivity of 1.7 m<sup>2</sup>/day Appendix D2. Specific capacity has been determined over 24 hour interval over the duration of the pumping and the figures are shown in Table 7.3.1.8.

### Recovery Test

The results of the recovery test are not presented due to the unavailability of the data.

#### 7.3.1.2 Borehole BH 9315

Borehole BH 9315 was drilled to a terminal depth of 210 metres and borehole drilling results and construction details are summarised in Table 7.2.1 and 7.2.2 respectively. The borehole was tested during the period 30<sup>th</sup> January to 7<sup>th</sup> February 2001. Water strikes were encountered at 110 and 132 metres in fractured basalt and friable sandstone. A rest water level of 15.92 metres was measured before commencement of calibration test indicating substantial groundwater confinement. The borehole was pumped with a positive displacement pump Orbit 5403 installed to depth of 162.5 metres.

### Calibration Test

Calibration steps were carried out at discharge increments from 4.95 m<sup>3</sup>/hr to 46.10 m<sup>3</sup>/hr over eight steps. The last step was completed when water level was 30 metres above pump setting at a water level of 132.43 metres. A summary of calibration test results is shown in Table 7.3.1.3. Each step lasted for duration of 15 minutes.

**TABLE 7.3.1.3 Calibration Test Results**

Step No.	Discharge (m <sup>3</sup> /hr)	Water Level (m)	Drawdown (m)
1	4.95	22.87	6.95
2	9.95	30.81	14.89
3	15.46	41.70	25.78
4	21.77	59.14	43.22
5	28.69	68.85	52.93
6	36.97	84.66	68.74
7	43.98	114.92	99.00
8	46.10	132.43	116.51

### Step Drawdown Test

A total of six steps were performed each step being 120 minutes in duration. The discharge rates ranged from 2.27 m<sup>3</sup>/hr to 12.11 m<sup>3</sup>/hr and pH and conductivity of the water were measured for each step. A final drawdown of 126.48 metres with the water level at 141.34 was recorded at the end of the sixth step leaving out 8.66 metres of available drawdown. Table 7.3.1.4 presents a summary of data collected during the step drawdown test and Appendix D4 presents analysis of the data using Hantush-Bierschenk method.

**TABLE 7.3.1.4 Step Drawdown Test Results**

Step	Water Level (m)	Drawdown (m)	Discharge (m <sup>3</sup> /hr)	pH	E.C. (μS/cm)
1	25.80	9.76	6.16	10.0	960
2	37.34	21.30	11.85	9.7	840
3	51.13	35.09	17.72	9.7	830
4	66.05	50.01	24.43	9.8	830
5	84.58	68.54	30.38	9.7	870
6	121.82	105.78	40.08	9.5	910

A plot of specific drawdown versus discharge shows data points falling approximately in a straight line but after the fifth discharge rate of 30.4 m<sup>3</sup>/hr turbulent flow is dominant over laminar flow as shown by the high well loss of 19.38 m. Thus the large drawdown during the last step can only be attributed to higher pumping rate as the borehole efficiencies are quite high with 70.5% for the fifth step at 30.4 m<sup>3</sup>/hr and 92.2% for the first step at 6.2 m<sup>3</sup>/hr. Based on the high efficiencies and large drawdowns observed during the steps a constant discharge rate of 28 m<sup>3</sup>/hr was selected for the constant rate test.

#### **Step Recovery Test**

The step drawdown water level recovery was monitored for 13 hours before the water level recovered by 98% to a water level of 17.96 metres. The constant discharge rate test was carried out after an overnight when the last recovery reading was taken.

#### **Constant Rate Test**

The constant rate test at a discharge rate of 28 m<sup>3</sup>/hr was performed for 144 hours before the test was terminated. The last water level measured before the pump was switched off was 93.74 metres with a drawdown of 76.11 metres leaving an unexploited 68.26 metres of the available drawdown.

A drawdown time semi log plot shows a smooth curve up to about 1500 minutes. There after some scattered data points appear due to poor performance of the diesel pump motor.

The curve shows three gradients, the first gradient defined by data collected during the elastic aquifer response during the first 40 minutes and the second gradient defined by data collected after 40 and 1500 minutes is a gentle slope. The third gradient which is defined by data beyond 1500 minutes is slightly steeper than the second.

The time drawdown semi log data plot is presented in Appendix D6. The graph shows a fairly constant drawdown rate until reaching 69 metres after 40 minutes to 1500 minutes of pumping when the rate of drawdown significantly slowed down, defining a less steep gradient compared to that of the first 40 minutes. Although the response seems to follow the three phase model for unconfined aquifers where steep, early and late drawdown segments are segmented by a flat intermediate segment reflecting dewatering that accompanies the falling water table, a confined, dual porosity aquifer type could be considered more appropriate since the static water level rose considerably above the level of the first water strike.

Analysis of the drawdown data using the Jacob-Cooper method (Appendix D6) gave a transmissivity of 7.3 m<sup>2</sup>/day for the late time slope and 4.2 m<sup>2</sup>/day for the early time slope.

Appendix D5 represents a plot of the data from DWA Testcurve. Data analysis show transmissivity of 7.3 m<sup>2</sup>/day. The two approaches give similar values of transmissivity although early time data is slightly less.

**Recovery:** The recovery data is presented in Appendix D7. Recovery was monitored for 48 hours with the borehole recovering to 97% at the end of the test. This recovery method gave a transmissivity of 10.2 m<sup>2</sup>/day for the late time data.

### 7.3.1.3 Borehole BH 9316

Borehole BH 9316 was drilled to a terminal depth of 152 metres and drilling results and construction details are summarised in Tables 7.2.1 and 7.2.2 respectively. The borehole was tested during the period 20<sup>th</sup> November 2000 to 16<sup>th</sup> January 2001. Water strikes were encountered at 60 and 107 metres in friable sandstone. A rest water level of 13.72 metres was measured before commencement of calibration test indicating groundwater confinement. The borehole was pumped with a positive displacement pump Orbit 5403 installed to depth of 131.5 metres.

#### Calibration Test

Calibration steps were carried out at discharge increments from 8.36 m<sup>3</sup>/hr to 39.99 m<sup>3</sup>/hr over six steps. The sixth step was completed 80 metres above pump setting at a water level of 55.8 metres. A summary of calibration test results is shown in Table 7.3.1.5. Each step lasted for duration of 15 minutes.

**TABLE 7.3.1.5 Calibration Test Results**

Step No.	Water Level (m)	Drawdown (m)	Discharge Rate (m <sup>3</sup> /hr)
1	19.93	6.21	8.36
2	27.68	13.96	16.11
3	36.66	22.94	24.22
4	42.99	29.27	29.33
5	51.34	37.62	35.10
6	55.80	42.08	39.99

#### Step Drawdown Test

A total of seven steps were performed each step being 120 minutes in duration. The discharge rates ranged from 8.14 m<sup>3</sup>/hr to 45.82 m<sup>3</sup>/hr and pH and conductivity of the water were measured for the last step. A final drawdown of 61.62 metres with the water level at 75.45 metres was recorded at the end of the seventh step leaving 56.04 metres of unexploited drawdown. Table 7.3.1.6 presents a summary of data collected during the step drawdown test.

**TABLE 7.3.1.6 Step Drawdown Test Results**

Step No.	Water Level (m)	Drawdown (m)	Discharge Rate (m <sup>3</sup> /hr)	E.C.	pH
1	21.43	7.59	8.14		
2	30.15	16.31	16.17		
3	39.97	26.13	24.89		
4	48.37	34.53	30.69		
5	57.00	43.16	36.52	1950	8.4
6	64.78	50.94	39.79		
7	75.46	61.62	45.82	2040	8.9

### Constant Rate Test

The constant rate test at a discharge rate of 33 m<sup>3</sup>/hr was performed for 80 hours before the test was terminated. The last water level measured before the pump switched off was 62.25 metres with a drawdown of 47.69 metres leaving an unexploited 69.25 metres of the available drawdown.

The curve shows three gradient segments, the first gradient segment defined by data collected during the first 15 minutes and the second is defined by data collected between 15 and 300 minutes when a gentle gradient is evident. The third gradient segment is after 300 minutes with a less gentle gradient.

The response seems to follow the three-phase model for unconfined aquifers where steep early and late drawdown segments are separated by a flat intermediate segment reflecting dewatering that accompanies the falling water table. However, a confined dual porosity aquifer type could be considered more appropriate since the static water level rose considerably above the level of the first water strike.

Analysis of the drawdown data using the Jacob-Cooper method (Appendix D8) gave a transmissivity of 12.7 m<sup>2</sup>/day for the late time slope and 11.9 m<sup>2</sup>/day for the early time slope.

Appendix D9 represents a plot of the data from DWA Testcurve. Data match was not good for both early and the late time data due to the near linear nature of the data plots. A transmissivity of 9.5 m<sup>2</sup>/day was determined from the late time data. The two approaches give similar values of transmissivity although the Cooper-Jacob values are slightly higher.

**Recovery:** The recovery data is presented in Appendix D10. Recovery was monitored for 24 hours with the borehole recovering to 95% at the end of the test. The Theis recovery method gave a transmissivity of 15 m<sup>2</sup>/day for the late time data.

A summary of transmissivities and specific capacities for all the project boreholes is presented in Tables 7.3.1.7 and 7.3.1.8 respectively.

**TABLE 7.3.1.7 Project Boreholes Transmissivity Values**

BH No	Transmissivity (m <sup>2</sup> /d)				Comments
	Jacob-Cooper Method	DWA TestCurve Method	Recovery Jacob Method	Average	
BH 9314	1.7	1.7	?	1.7?	Recovery data lost
BH 9315	7.3	7.3	10.2	8.3	-
BH 9316	12.5	9.5	15	12.3	-

Jacob-Cooper and DWA Testcurve give transmissivities values that are very close as shown by values in Table 7.3.1.7 above. Recovery data analysis in general tend to give higher values. Early data from the Jacob-Cooper method has not been included because the data is frequently affected by borehole storage during the early stages of the test.

**TABLE 7.3.1.8 Project Boreholes Specific Capacities**

BH No	Pumping Rate (m <sup>3</sup> /hr)	Specific Capacities (m <sup>3</sup> /hr/m)					
		12 hrs	24 hrs	36 hrs	48 hrs	60 hrs	72 hrs
BH 9314	8	0.1311	0.1205	0.1145	0.1104	0.1073	0.1047
BH 9315	28	0.4503	0.4351	0.4089	0.4019	0.3924	0.3891
BH 9316	33	0.8234	0.7813	0.7581	0.7348	0.7131	0.7109

For comparison purposes specific capacities from 12 to 72 hours are included in Table 7.3.1.8 above. Borehole BH 9316 was pumped for 144 hours and the final specific capacity was calculated at 0.4336 m<sup>3</sup>/hr/m, which is close to half the value calculated at 12 hours interval. From these values it obvious that boreholes BH 9315 and BH 9316 are much better than borehole BH 9314 which shows very low specific capacity.

### 7.3.2 Recommended Yields for Individual Boreholes

The DWA Recomm2 program for recommending the yield at which a production borehole should be pumped at in order to sustain five years of continuous pumping period was used to determine abstraction rates for the three Mathathane boreholes BH 9314, BH 9315 and BH 9316. The results of the calculations are presented in Tables 7.3.2.1 and 7.3.2.2 below.

#### Borehole BH 9314

Borehole BH 9314 was drilled to a terminal depth of 180 metres in reddish brown mudstone. Two water strikes of approximately 2.5 m<sup>3</sup>/hr and 12 m<sup>3</sup>/hr were recorded at 107 metres and 120 metres in a friable sandstone. The final water level after 72 hours of pumping the borehole at 8.0 m<sup>3</sup>/hr was 101.48 metres, more than 50 metres above the pump intake level. However, during step testing none of the steps approached equilibrium conditions as shown by the drawdown rate of not less than 0.45 metres every ten minutes at the end of each step.

The abstraction yield was calculated using the DWA Recomm2 package with a corresponding available drawdown of 124 m. The calculations gave a pumping rate of 5.04 m<sup>3</sup>/hr for double slope method and 7.22 m<sup>3</sup>/hr for single slope method. For comparison purposes the pumping rate was also calculated by multiplying half the specific capacity (24 hours) by the available drawdown which produced a discharge rate of 6.4 m<sup>3</sup>/hr. From these calculations and the performance of the borehole it is recommended that the borehole be pumped at 5.0 m<sup>3</sup>/hr from pump setting of 145 m.

### Borehole BH 9315

Borehole BH 9315 was drilled to a terminal depth of 210 metres. Water strikes were encountered at 110 metres and 132 metres in fractured basalt and friable sandstone. After the fifth discharge rate of 30.4 m<sup>3</sup>/hr turbulent flow is dominant over laminar flow as evidenced by the high well loss of 19.38 m. Even though high efficiencies (70-92%) characterised this borehole large drawdown were also observed. The recommended yield for BH 9315 has been calculated using DWA Recomm2 package with a corresponding available drawdown of 129 m. The calculation gave an abstraction rate of 23.3 m<sup>3</sup>/hr for double slope method and 32.3 m<sup>3</sup>/hr for single slope method. The specific capacity method (i.e. multiplying half the specific capacity by the available drawdown) gave an abstraction rate of 23.7 m<sup>3</sup>/hr.

From the above calculation a more conservative figure of 23 m<sup>3</sup>/hr was recommended for production purposes, with a pump setting of 145 m depth.

### Borehole BH 9316

Borehole BH 9316 was drilled to a terminal depth of 152 m. Water strikes were encountered at 60 and 107 metres in friable sandstone. Elevated drawdown between the 5<sup>th</sup> and 6<sup>th</sup> step coincides with water levels at first water strike depth of 60 m. The borehole was pumped at 33 m<sup>3</sup>/hr for a period of 80 hrs as a result of high efficiencies and low drawdown values observed during step test. Using the DWA Recomm2 package with a corresponding available drawdown of 120 m abstraction rate calculations indicated a recommended abstraction of 27 m<sup>3</sup>/hr for the double slope method and 38.5 m<sup>3</sup>/hr for single slope method. By multiplying half the specific capacity by the available drawdown an abstraction rate of 40.9 m<sup>3</sup>/hr was calculated. It is thus recommended that the borehole be pumped at 30 m<sup>3</sup>/hr from pump setting of 145 m.

**TABLE 7.3.2.1 Calculated Yields for Individual Boreholes**

BH No	Major Water Strikes (m)	RWL (m)	Pump Intake Level (m)	Calculated Yield (m <sup>3</sup> /hr)		
				DWA <sub>ss</sub> Single Slope	DWA Double Slope	Specific Capacity
9314	120	20.7	145	7.22	5.04	6.4
9315	132	15.92	145	32.3	23.3	23.7
9316	107	13.72	135	38.5	27.0	40.9

**TABLE 7.3.2.2 Recommended Abstraction Rate and Pump Setting Depths**

BH No	Water Strikes	RWL (m)	Recommended Pump Level (m)	Recommended Abstraction Rate (m <sup>3</sup> /hr)
9314	120	20.7	145	5.0
9315	132	15.92	145	23.0
9316	107	13.72	135	30.0
			Total	58.0

## 8 HYDROGEOLOGICAL ASSESSMENT

### 8.1 Hydrochemistry

Table 8.1.1 indicates both WHO and BOBS standards for drinking water, with the BOBS (2002) standards taking precedence in assessing potability.

#### 8.1.1 Existing Data

As noted in Section 2.4 two boreholes (BH 4908 and BH 2650) are currently equipped and supplying water to Mathathane. Both boreholes are located within the village settlement area and with respect to nitrate level the water from both boreholes is not suitable for human consumption. Once alternative sources of water are found the use of the current boreholes should be discontinued forthwith.

Two additional boreholes (BH 4909 and BH 4911) drilled by the Department of Water Affairs are also located in the central part of the village and there is also a potential pollution risk if these boreholes are equipped as alternative sources to supply. The new sources of water identified outside the village settlement should be utilized to avoid possible pollution from the village community.

**TABLE 8.1.1 National and International Drinking Water Standards**

Parameter	WHO (1986) Standards	BOBS (2002) Standards
pH		5.0 – 10
Total Dissolved Solids (mg/l)		2000
Sodium (mg/l)	200	400
Manganese (mg/l)	0.1	0.5
Iron (mg/l)	0.3	2.0
Sulphate (mg/l)	6.5 – 8.5	400
Chloride (mg/l)	1000	600
Nitrate (mg/l)	45	45
Fluoride (mg/l)	1.5	1.5

#### 8.1.2 Hydrochemistry Data on Project Boreholes

Both well head chemistry as well as water samples for laboratory analysis were collected during the drilling and test pumping of project boreholes. Well head data is tabulated in Table 8.1.2 below.

**TABLE 8.1.2 Well Head Measured Parameters**

BH (No)	Sample Type	Total Alkalinity (g/l CaCO <sub>3</sub> )	Dissolved Oxygen (mg/l)	pH	Conductivity (µS/cm)
BH 9314	CT (2 hrs)	-	-	9.2	730
BH 9314	SDT (12 hrs)	231	4.35	8.8	840
BH 9314	CRT (24 hrs)	195	0.85	8.7	910
BH 9314	CRT (72 hrs)	216	2.35	8.8	890
BH 9315	CT (2 hrs)	-	-	9.9	780
BH 9315	SDT (12 hrs)	177	1.35	9.5	910
BH 9315	CRT (144 hrs)	174	0.65	9.6	1000
BH 9316	CT (2 hrs)	171	1.0	9.6	1020
BH 9316	SDT (12 hrs)	-	-	8.6	1760
BH 9316	CRT (24 hrs)	315		8.9	2040
BH 9316	CRT (80 hrs)	315		7.7	1950
BH 9176	Drilling	-	-	7.7	3200

BH 9178	Drilling	-	-	8.1	1300
BH 9313	Drilling	-	-	8.3	990

The limited well head data are a good indication of some minor variation of hydrochemical composition with pumping as more water is drawn into the pumped boreholes. In general the changes are minor and have very little influences on the water quality for domestic purposes. Borehole BH 9316 has slightly elevated conductivity values but these are still within the acceptable limits. Hydrochemistry results of boreholes BH 9176, BH 9178 and BH 9313 are from low yielding boreholes that were not test pumped.

### 8.1.3 Hydrochemical Water Types

All project hydrochemistry data has been entered into a Aquachem database and plots (Stiff and Piper) to facilitate data interpretation have been generated. Boreholes BH 9313, BH 9314 and BH 9315 show Na-Cl-HCO<sub>3</sub> water types indicating possible different waters mixing. The presence of Na-Mg-Cl water in BH 9316 also indicates that a Ca-HCO<sub>3</sub> recharge water could have been mixed up with the Na-Mg-Cl to generate Na-Cl-HCO<sub>3</sub> and the ion exchange process could have replaced Ca<sup>2+</sup> with Na<sup>+</sup>. The presence of K<sup>+</sup> is likely to be associated with the basaltic lavas that overlie the aquifer.

The water type from BH 9313, BH 9314 and BH 9315 are similar in character as shown by Stiff digrams (Appendix E1). Stiff diagrams provide a good visual indication of predominant anions and cations. Project borehole data is included in Appendix E3. With respect to anions, chloride tends to be dominant followed by bicarbonate and sulphate close behind. The cations are dominated by Na followed by Ca/Mg indicating the mixing processes.

The Piper diagram (Appendix E2) indicate saline waters which are dominated by Na<sup>+</sup> and Cl<sup>-</sup> ions. Due to mixing and cation exchange both Ca<sup>2+</sup> and Mg<sup>2+</sup> have been removed from the system. Although the ratios indicate saline water the mineralization of the water is relatively low and all parameters are within the BOBS and WHO acceptable limits.

### 8.1.4 Potability and Drinking Water Standards

A variety of agreed standards exist against which the potability of water, or suitability of water for human consumption can be assessed. These include World Health Organisation (WHO, 1986) standards and more applicable locally, the Botswana Bureau of Standards BOBS (2002) Standards for drinking water. The six boreholes (BH 9176, BH 9178, BH 9313, BH 9314, BH 9315 and BH 9316) meet the BOBS Standards although in some cases parameters such as TDS are above the WHO drinking water standards.

### 8.1.5 Hardness and Corrosion/Encrustation Potential

Hard waters are generally considered to be those waters that require a considerable amount of soap to produce a foam and that also produce scale in hot water pipes (encrusting). Water hardness is expressed as equivalent milligrams per litre of calcium carbonate. Water with a total hardness value greater than 180 mg/l is classified as being very hard. In the Project Area hardness values range from 12.94 mg/l to 433.40 mg/l, Appendix E. It should be noted that water in Borehole BH 9316 is categorised as being very hard and although this does not have implications with respect to useage it could lead to problems of encrustation and scaling. Cognisance should be taken of this in specification of materials for pumps and distribution systems. Water from boreholes BH 9314 and BH 9315 is soft.

## 8.2 Hydrogeological Characteristics

The hydrogeological regime of the area consists of fractured Basement Complex to the south and the Karoo aquifer is to the north. The Pre Cambrian Basement aquifer is poor and degree of fracturing, faulting, weathering and interconnection of the fracture systems has a great bearing on the aquifer storage. Aquifer lithologies predominantly consist of granitic gneisses and amphibolites.

To the north of the village the geology is mostly Karoo sediments and groundwater potential is good. Initial drilling of 4 boreholes around the village within the Basement Complex indicated very low yields with a maximum yield of 1.8 m<sup>3</sup>/hr at BH 9178. Both water strikes and rest water levels are variable. Water levels ranged from 8 m to 31 m below ground level. The significance of the weathered zone evident in borehole BH 9178 with the rest of the Basement boreholes indicating fracture flow with deep (> 100 m) water strikes.

The Karoo sediments to the north have proven to be a dependable aquifer with yields ranging from 2 m<sup>3</sup>/hr along the edge of the basin to about 33 m<sup>3</sup>/hr within the Karoo basin where the sediments are overlain by thin extensively weathered basalts. In fracture zones transmissivity values of about 10 m<sup>2</sup>/day are evident.

Water quality in the Karoo aquifer is good and TDS values ranges from 500 mg/l to about 1200 mg/l. The remainder of the water quality details are included in Section 8.1 below.

## 9 DEVELOPMENT RECOMMENDATIONS

### 9.1 Production Yields

The projected 1999 and 2009 populations for Mathathane was 1395 and 1529 people and water demands of 112.7 m<sup>3</sup>/day and 124.5 m<sup>3</sup>/day respectively (Table 2.4.1).

Two boreholes BH 4908 and BH 2650 are currently equipped and supplying water to Mathathane. Both boreholes are located within the village settlement area and both indicate serious nitrate (and thus possibly bacterial) pollution. Two other boreholes BH 4909 and BH 4911 are located in the central part of the village adjacent to homesteads and there is also a potential to pollution risk if these boreholes are equipped as alternative sources to supply the village.

It is recommended that three project (boreholes BH 9314, BH 9315 and BH 9316) which were tested at 8 m<sup>3</sup>/hr, 28 m<sup>3</sup>/hr and 33 m<sup>3</sup>/hr for durations of 72, 144 and 80 hrs respectively should be connected to the Mathathane village delivery system. The recommended abstraction and equipping details are indicated in Table 9.1 below.

**TABLE 9.1 Recommended Abstraction Rates and Pump Setting Depths**

BH No.	Pump Intake Depth (mbgl)	Recommended Abstraction Rate (10 hr pumping cycle) (m <sup>3</sup> /hr)
9314	145	5.0
9315	145	23.0
9316	135	30.0

Two boreholes BH 9314 and BH 9315 will supply a total of 280 m<sup>3</sup>/day assuming a 10 hr pumping day. The daily demand for the village can thus be met by pumping the two boreholes for 5 hours. Borehole BH 9316 will supply a total of 300 m<sup>3</sup>/day assuming a 10 hr pumping day. The daily demand for the village could thus be met by pumping this borehole for 5 hours.

Recommendations for developing an upgraded water supply system and for commissioning the newly drilled boreholes are summarised below.

- design and install a delivery main and interconnecting collector between Mathathane village reservoir and BH 9314, BH 9315 and BH 9316.
- Boreholes BH 9314 and BH 9315 should then be commissioned to supplement the supply to Mathathane village.
- Borehole BH 9316 should be equipped and used as a back up supply to both BH 9314 and BH 9315. In order to maintain stable water which is suitable for public supply the three boreholes should be operated simultaneously (see Section 9.2).
- Boreholes BH 4908 and BH 2650 which are currently supplying the village should be systematically taken out of the new supply scheme as soon as possible.

From the evaluation of production yields it is apparent that the lower yielding boreholes that have potable quality water (BH 9314 and BH 9315) can possibly supply the total anticipated demand of 124.5 m<sup>3</sup>/day, but with a small margin of safety. However, if all three (3) boreholes could be utilised then the total output would be significantly higher and may, by either blending or treatment, provide a volume of up to four times the current demand and so

enable this resource to supply other communities in the area.

## 9.2 Blending

In order to make a preliminary assessment of one of the possible approaches to maximising the use of this generally prolific but variable quality groundwater resource area, the process of blending the various boreholes waters has been examined.

Parameters commonly used to specify the corrosivity or scaling potential of water are Langelier Saturation Index (LSI) and Calcium Carbonate Precipitation Potential (CCPP). In both cases, a zero value indicates a balanced water which is neither corrosive nor scaling. Negative values indicate corrosive waters and positive values indicate scaling waters. When considering the corrosion or scaling potential in a distribution network, CCPP is more useful because it gives a quantitative indication of the amount of Calcium Carbonate which can be deposited. Borehole BH 9316 yields hard water but the CCPP is moderate at 29.2 mg/l (see Table 9.2). This compares with figures of over 50 mg/l and as high as 140 mg/l for boreholes where there has been an observed scaling problem. In boreholes BH 9314 and BH 9315, there is a slight calcium carbonate deficit, with CCPP values of -6.1 and -3.3 mg/l respectively. The blended water has a CCPP of 11.3 mg/l which is a stable water with a slightly positive scaling potential which is suitable for public supply.

In terms of other parameters, TDS, sodium, chloride and iron exceed the Class II limits in the blend. The values are however, moderate and no health hazard should be expected. The slightly high value of iron could lead to staining of laundry over time.

No time-based trend in the chemistry can be deduced from the historical data provided and it cannot be predicted at this stage whether the salinity of the borehole waters will increase or decrease with time.

With the above in view, it would seem unnecessary to treat water, but rather, to put controls in place to ensure that the blending is carried out consistently. The risk would be that if one or two boreholes are out of service, the remaining borehole would be supplying unblended. In this case it is notable that there are no parameters in any of the individual boreholes, which exceed the Class III limits. Such water is allowable therefore, providing it is for a limited period.

**TABLE 9.2 Borehole Water Blending Calculation**

BH No.	9314	9315	9316	Blend	BOS 32	BOS 32
Location	Mathathane	Mathathane	Mathathane	All boreholes	Class I limit	Class II limit
Discharge	5	23	30	58		
Date sampled	1/26/01	2/7/01	1/13/01			
EC	689	985	2195	1537	700	1500
pH	7.78	8.08	7.84	7.91	6.5-8.5	5.5-9.5
TDS, measured	508	556	1240		450	1000
TDS, calculated	610	798	1532	1132		
Ca	11.3	7.3	74.4	40.3	80.0	150.0
Mg	2.5	0.8	58.4	29.0	30.0	70.0
Na	181.3	253.8	355.6	294.7	100.0	200.0
K	1.7	1.8	3.7	2.7	25.0	50.0
Cl	134.4	185.9	529.6	346.6	100.0	200.0
SO <sub>4</sub>	68.5	114.9	172.8	137.5	200.0	250.0
NO <sub>3</sub>		0.9		0.4	45.0	45.0
F	0.78	1.12	0.45	0.75	0.70	1.00
CO <sub>3</sub>	0.8	1.9	1.8	1.7		
HCO <sub>3</sub>	209	230	335	278		
Fe	0.20	0.20	0.69	0.44	0.03	0.30
Mn					0.05	0.10
E. Coli						
Faecal strept.						
Total Hardness, mg/l CaCO <sub>3</sub>	38.38	21.53	425.44	219.53		
Ca, mg/l CaCO <sub>3</sub>	28.18	18.25	186.00	100.83		
pCa	3.55	3.74	2.73	3.00		
M Alk, mg/l CaCO <sub>3</sub>	172.5	191.4	277.5	231.0		
pAlk	2.46	2.42	2.26	2.34		
C	2.21	2.23	2.25	2.24		
pHs	8.22	8.39	7.24	7.57		
LSI	-0.44	-0.31	0.60	0.34		
CCPP	-6.1	-3.3	29.2	11.3		

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# **APPENDICES**

# **APPENDIX A**

## **Composite Geophysical Data Plots**

## **APPENDIX B**

### **Magnetic Modelling Results and VES Models**

## **APPENDIX C**

### **Borehole Lithological Logs**

## **APPENDIX D**

### **Test Pumping Data Plots**

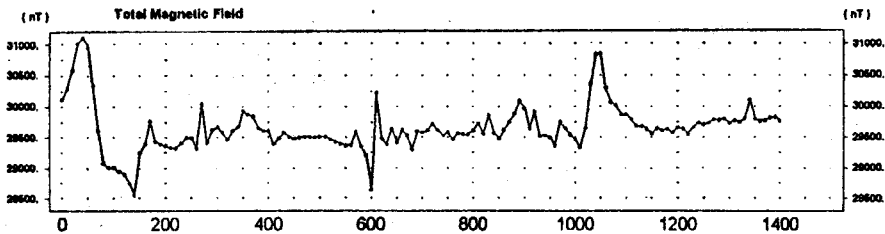
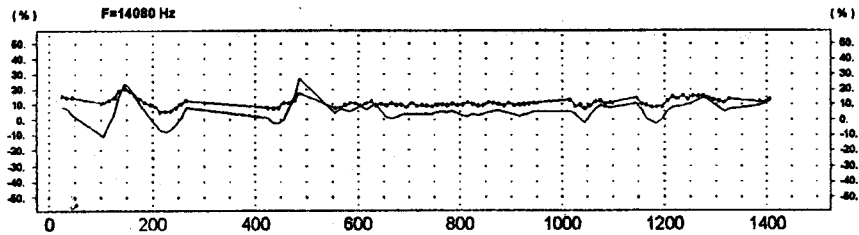
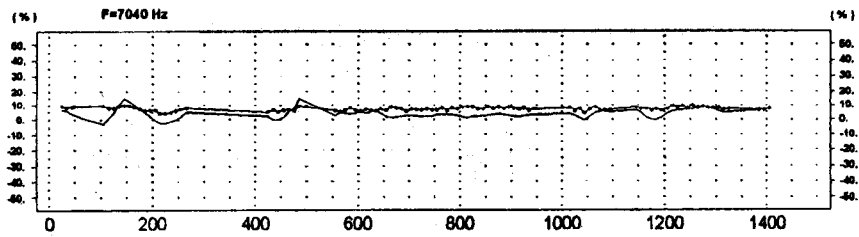
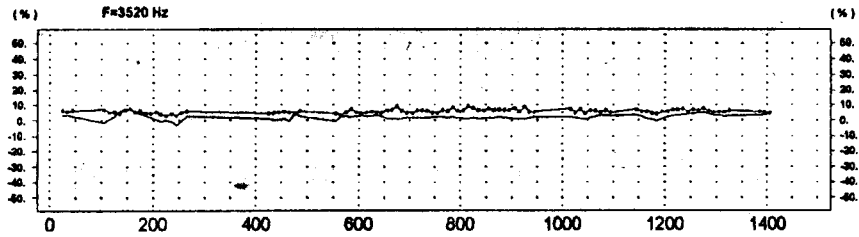
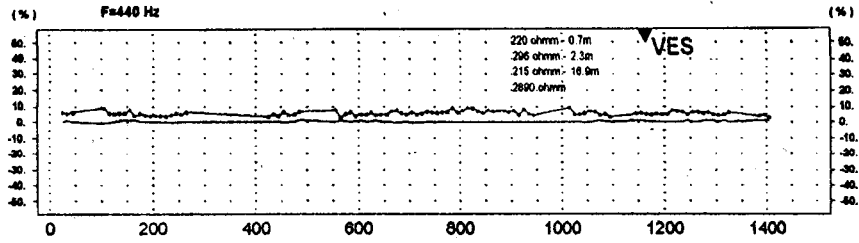
## **APPENDIX E**

### **Hydrochemistry Results**

## **APPENDIX A**

### **Composite Geophysical Data Plots**

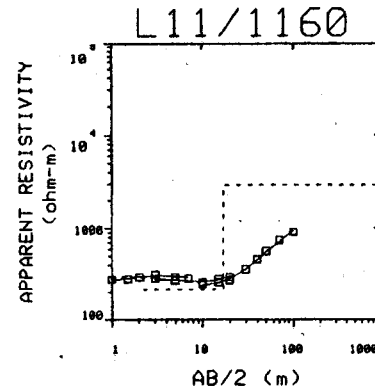
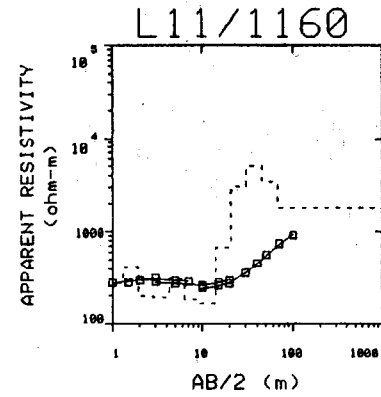
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 \_\_\_\_\_ Quadrature Component

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 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

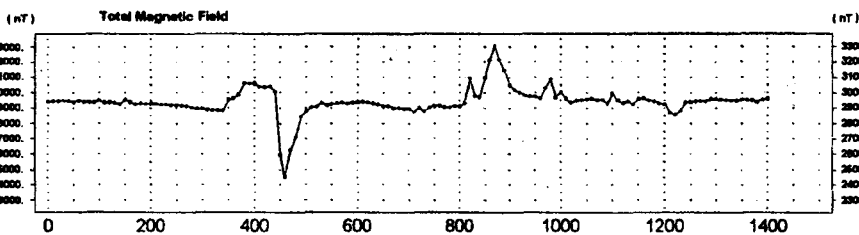
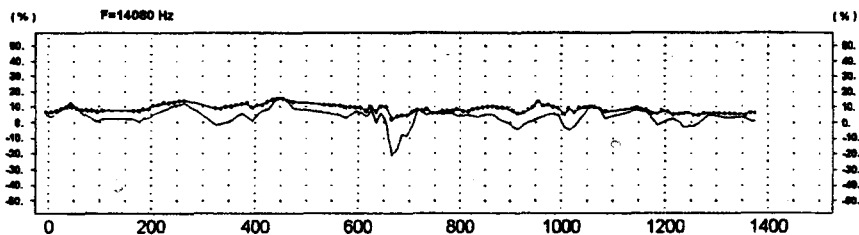
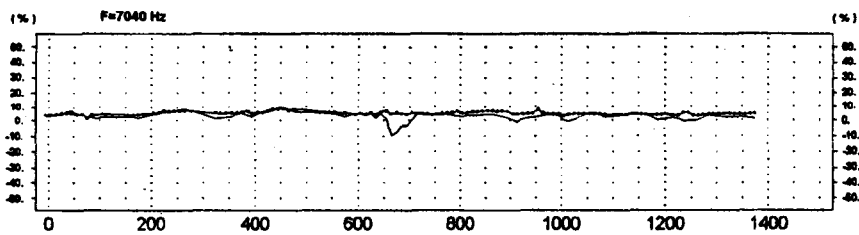
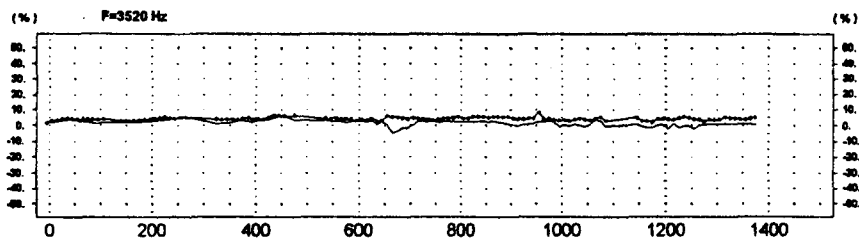
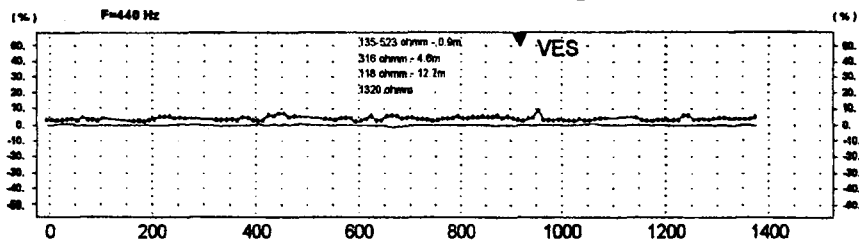
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A1

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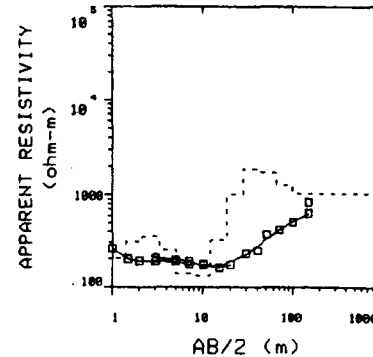


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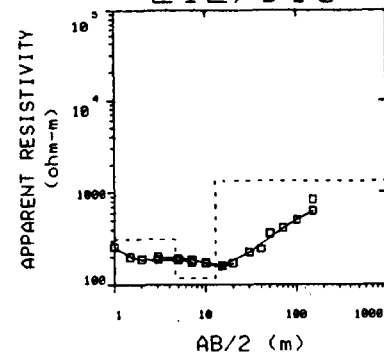
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# VES MODELS

L12/915



L12/915



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

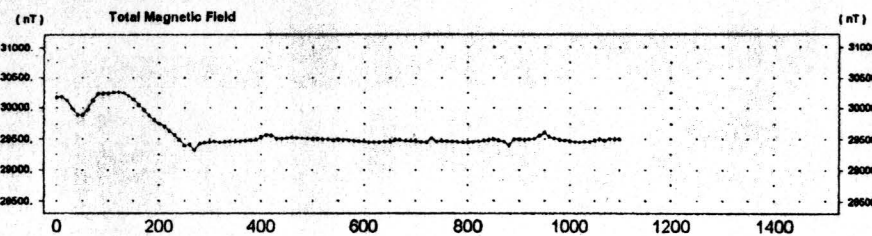
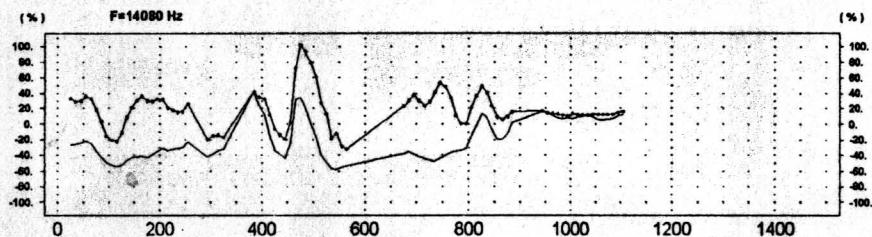
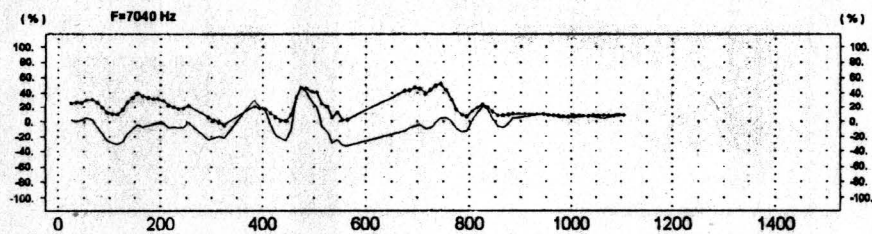
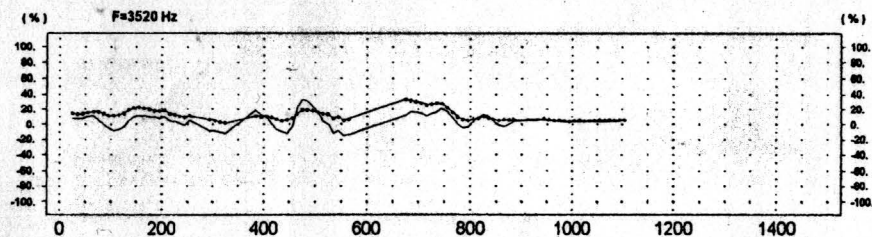
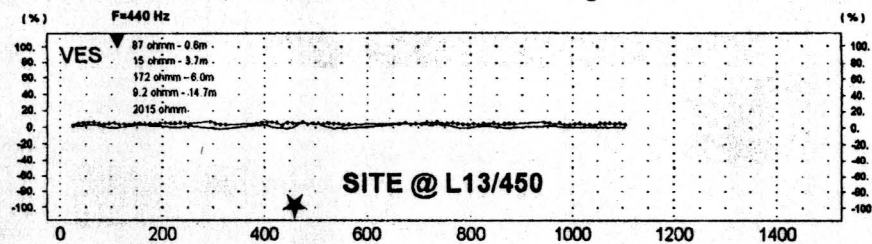
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A2

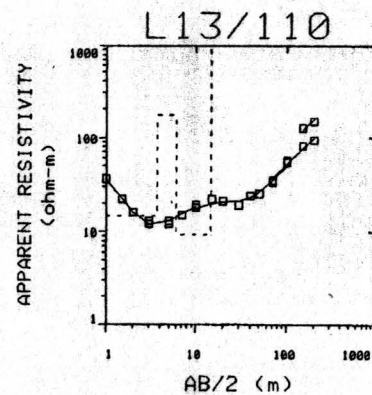
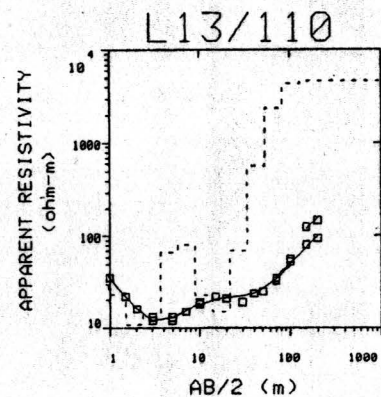
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 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

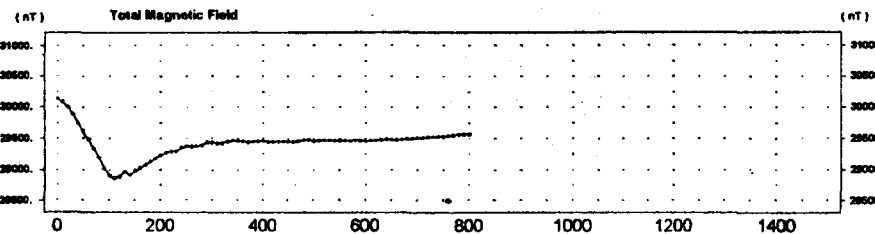
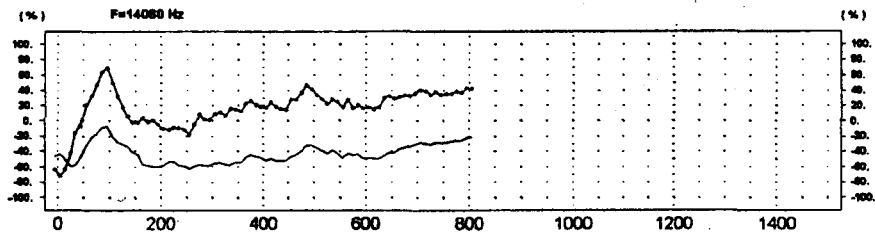
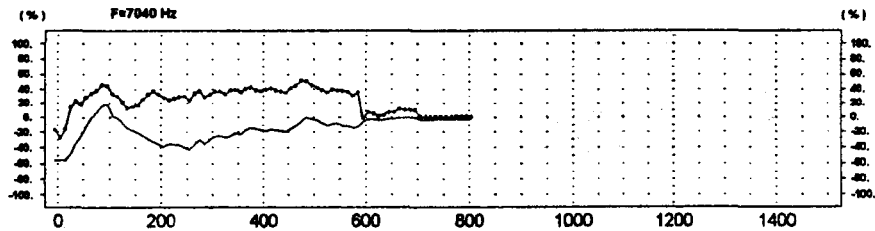
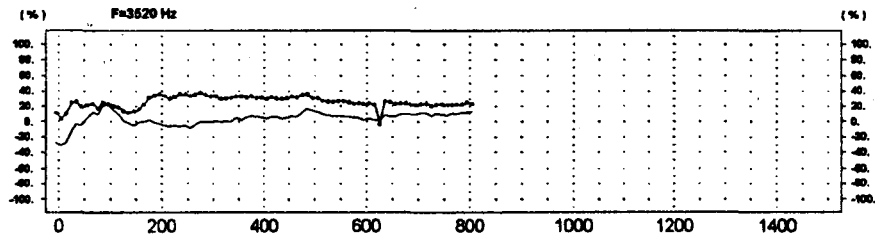
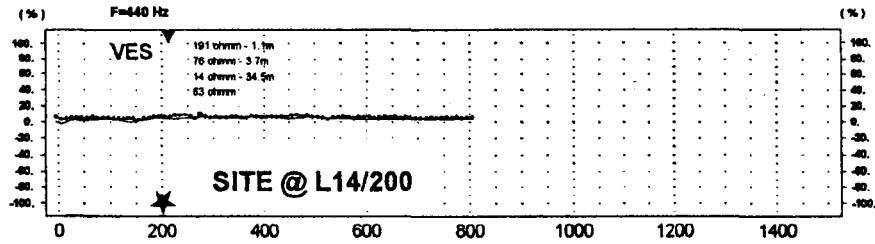
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A3

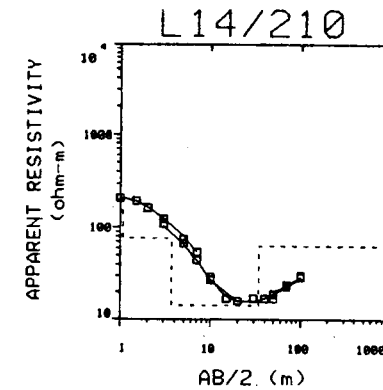
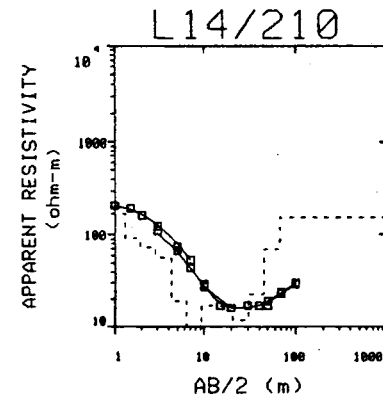
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# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

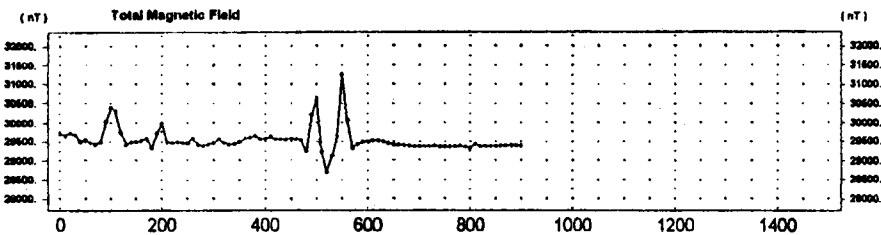
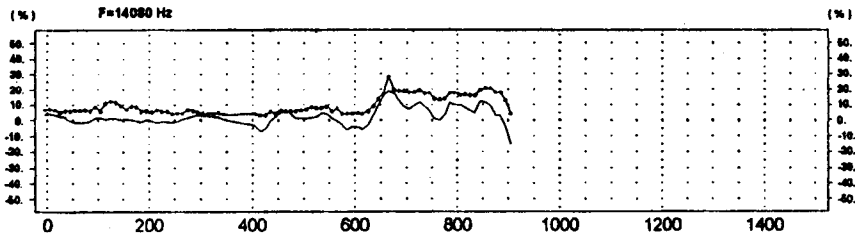
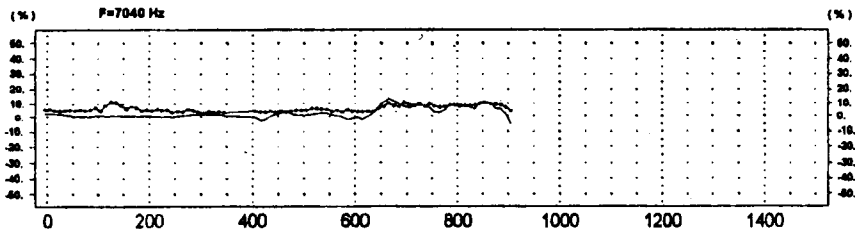
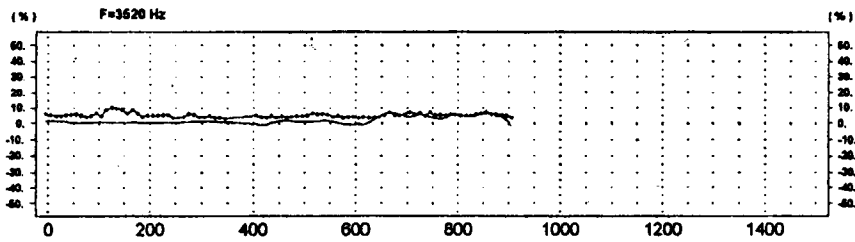
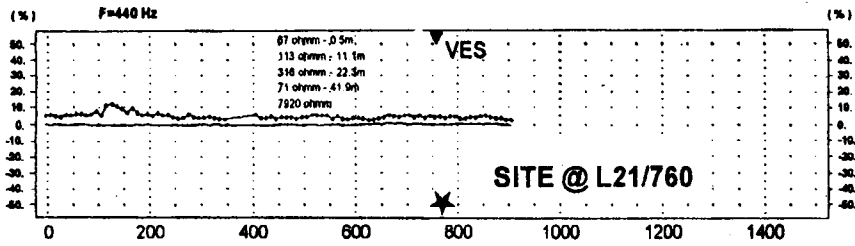
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A4

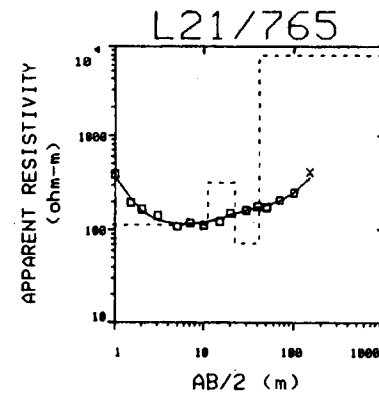
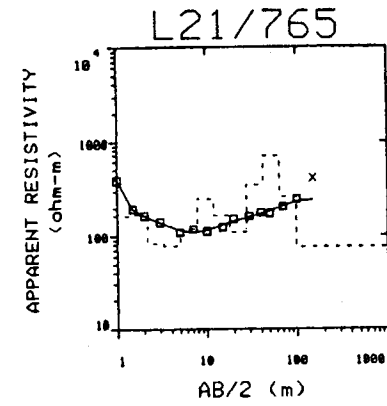
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# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

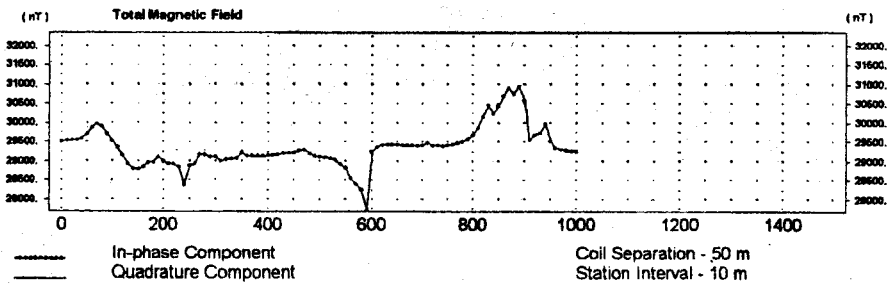
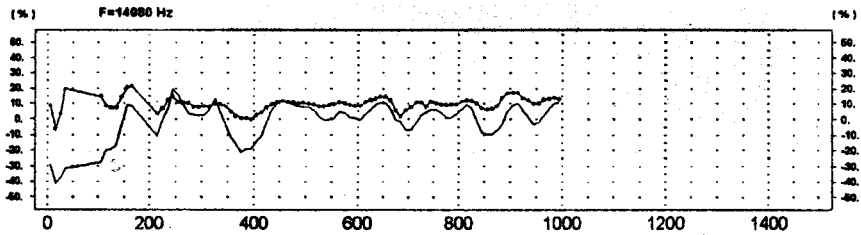
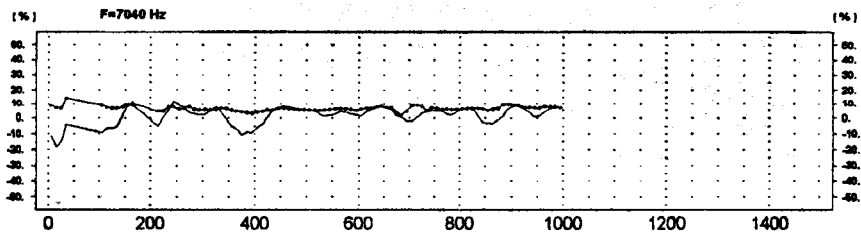
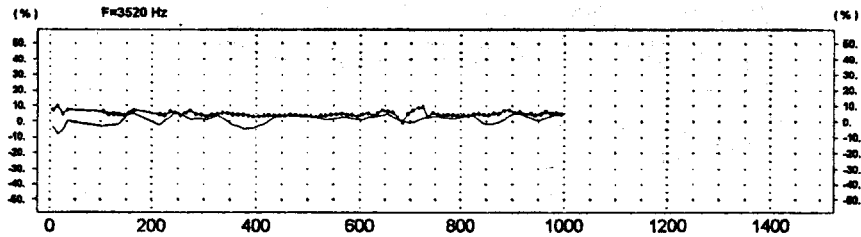
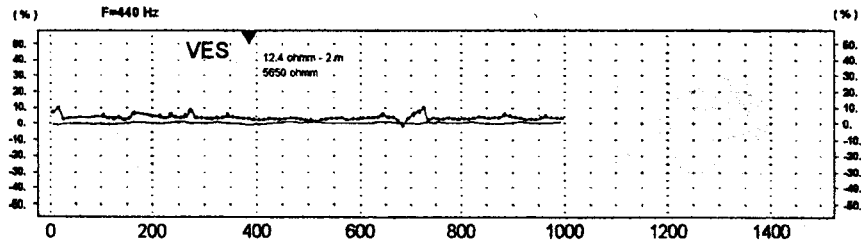
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

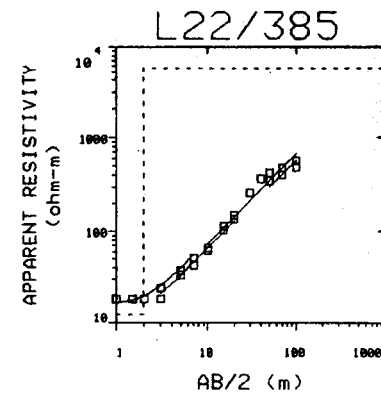
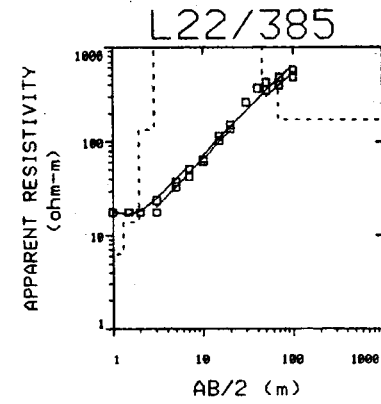
MATHATHANE

APPENDIX A5

LINE 22 - HLEM and Magnetic Data



VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

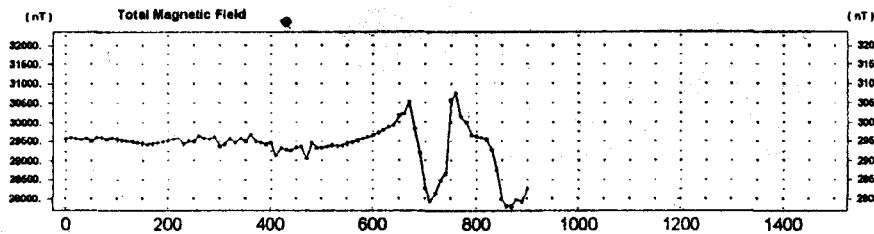
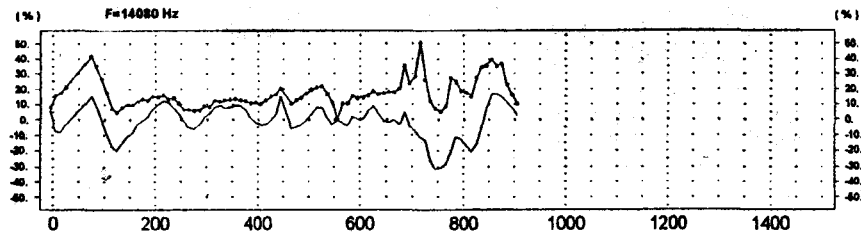
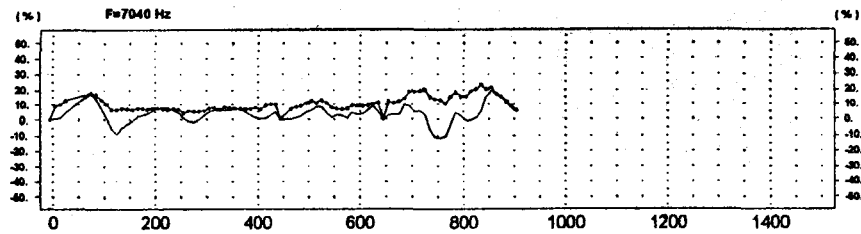
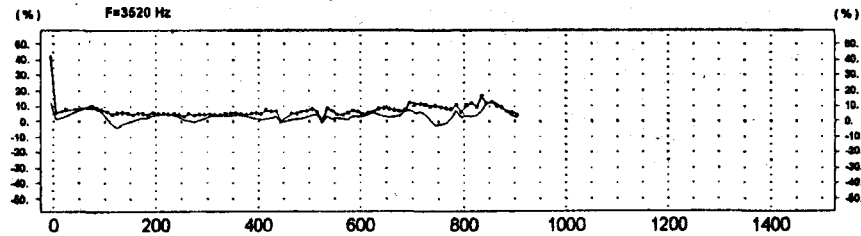
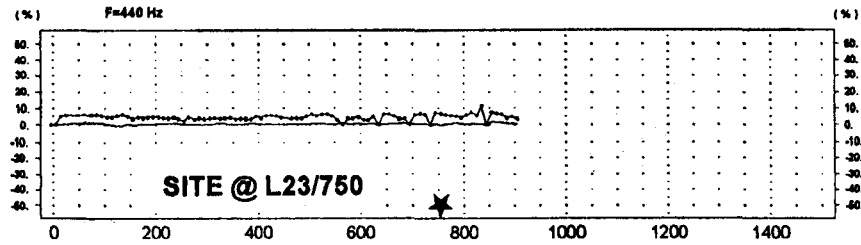
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A6

LINE 23 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

VES MODELS

VES NOT AVAILABLE

INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

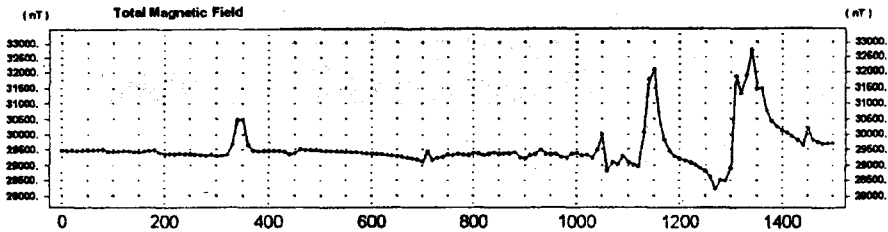
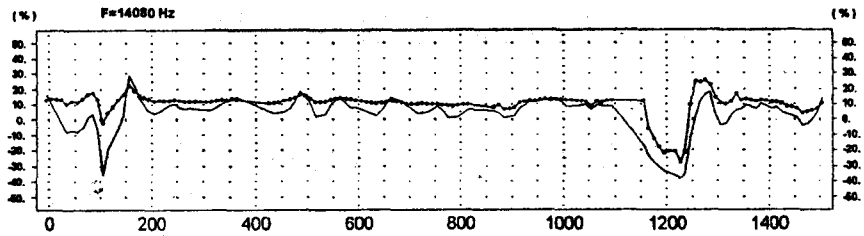
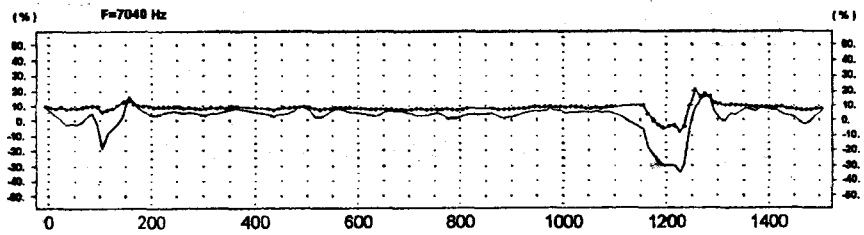
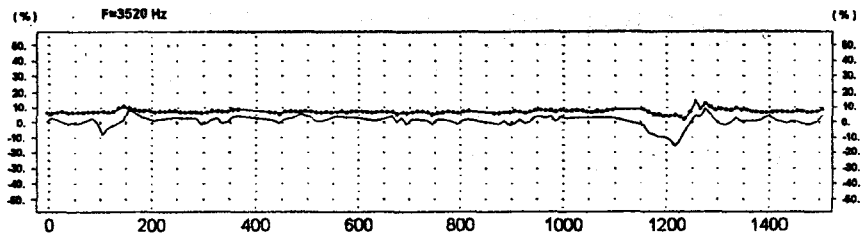
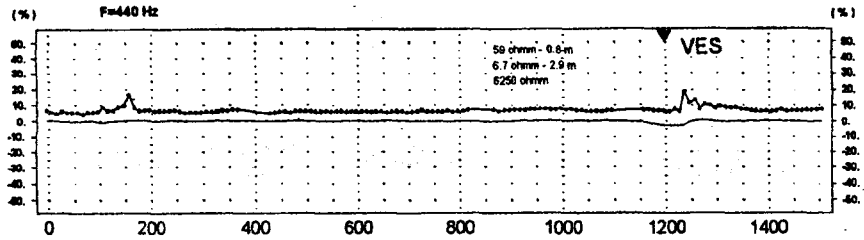
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A7

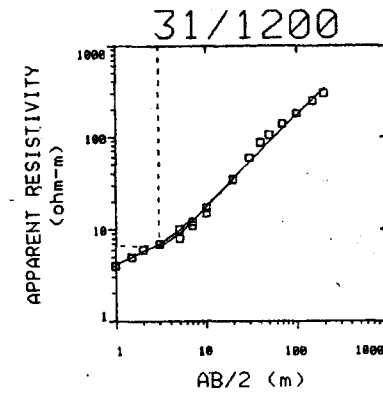
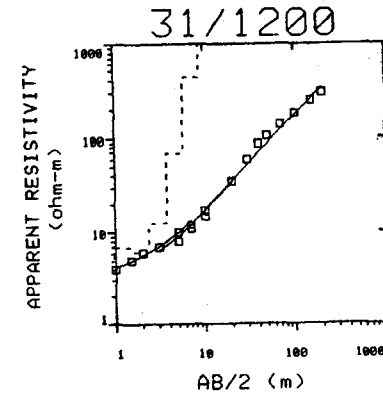
# LINE 31 - HLEM and Magnetic Data



— In-phase Component  
— Quadrature Component

Coil Separation - 50 m  
Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

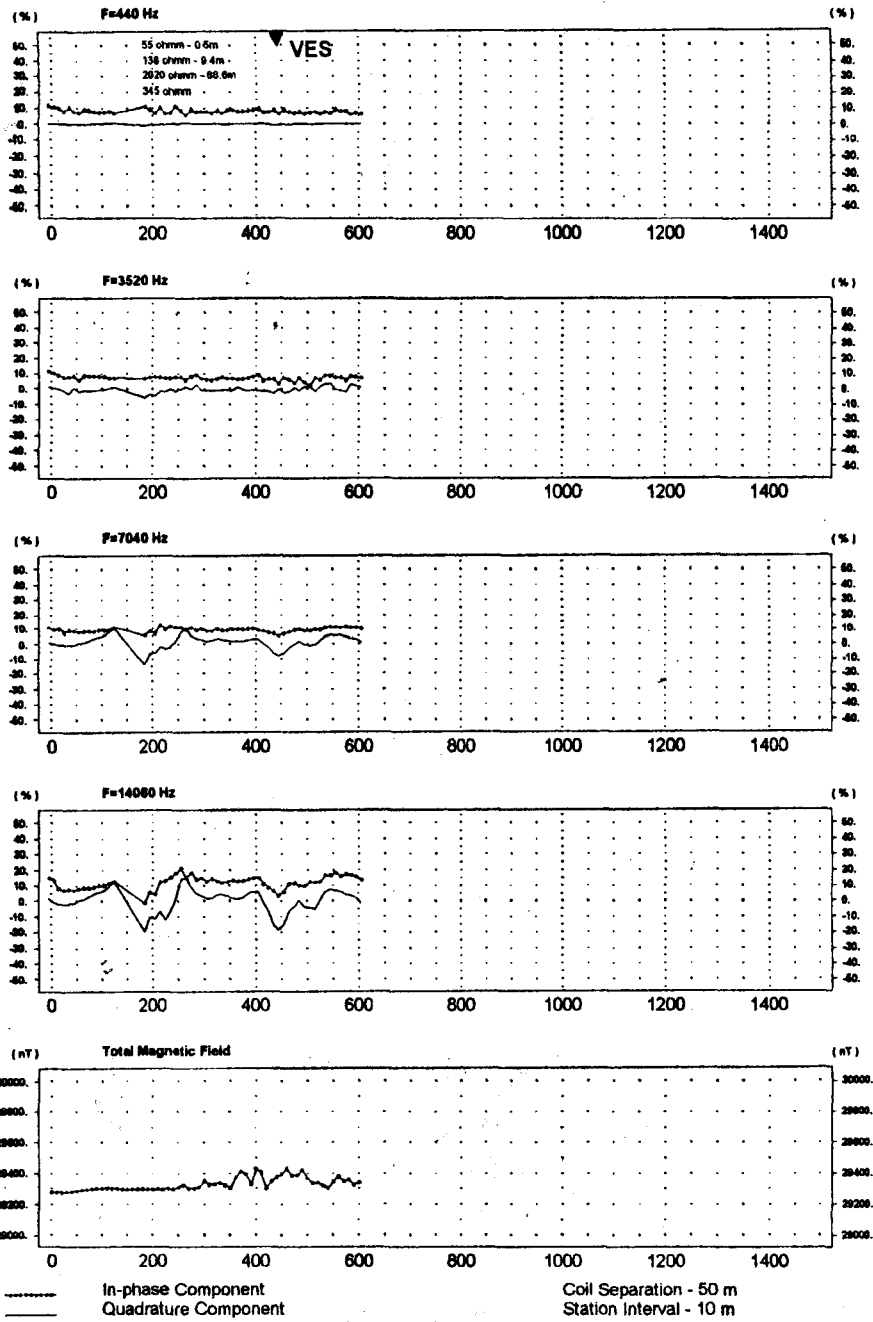
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

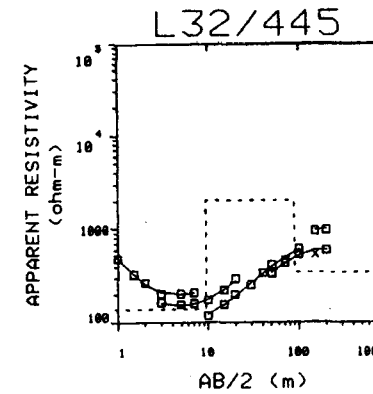
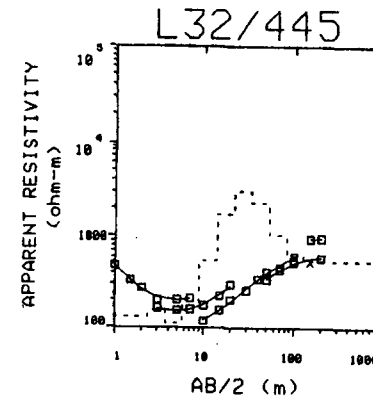
MATHATHANE

APPENDIX A8

# LINE 32 - HLEM and Magnetic Data



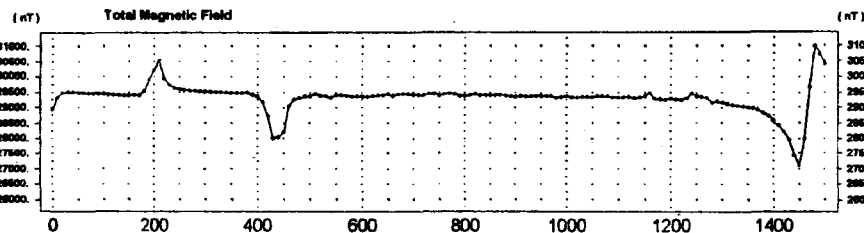
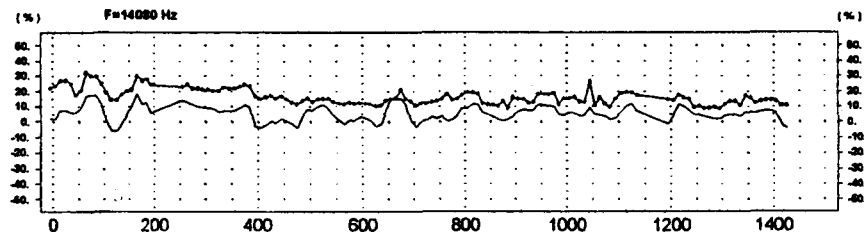
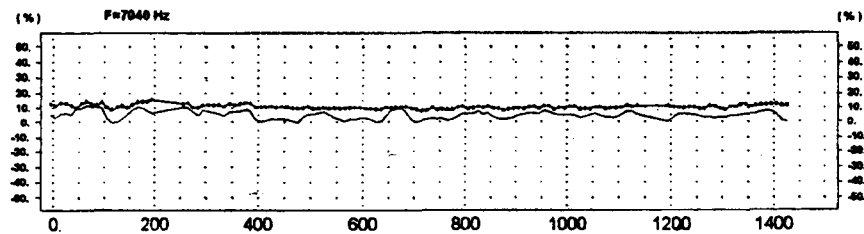
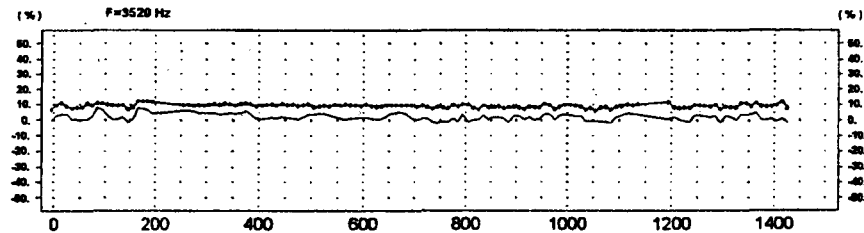
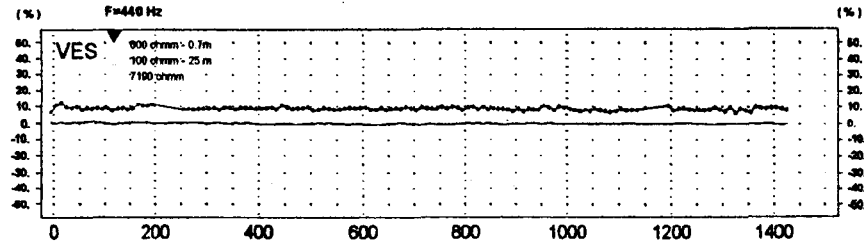
# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME  
 DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

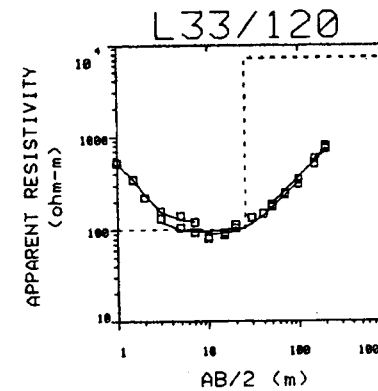
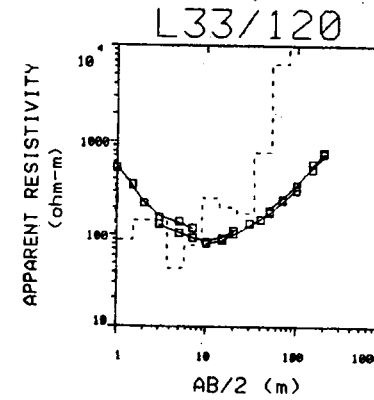
BOBIRWA SUB DISTRICT VILLAGES  
 MATHATHANE  
 APPENDIX A9

# LINE 33 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

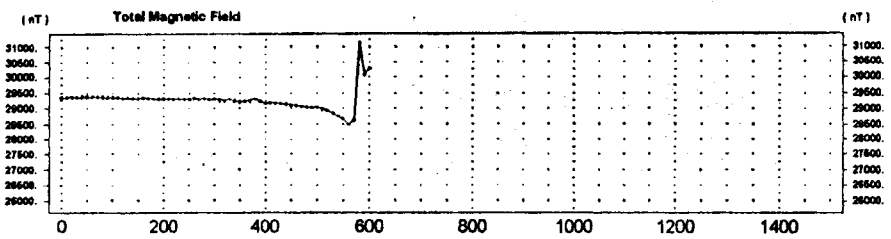
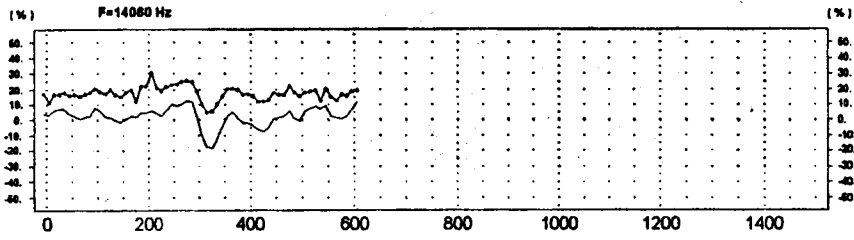
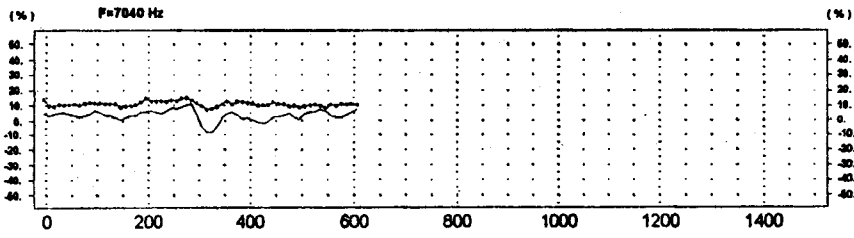
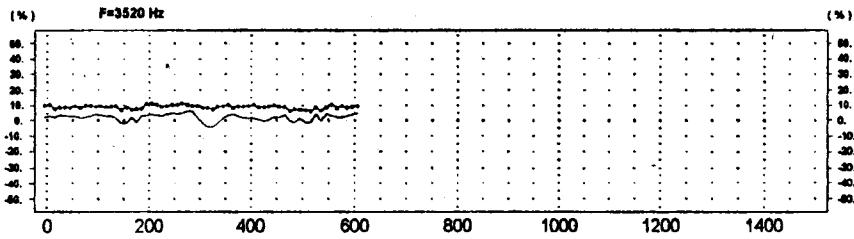
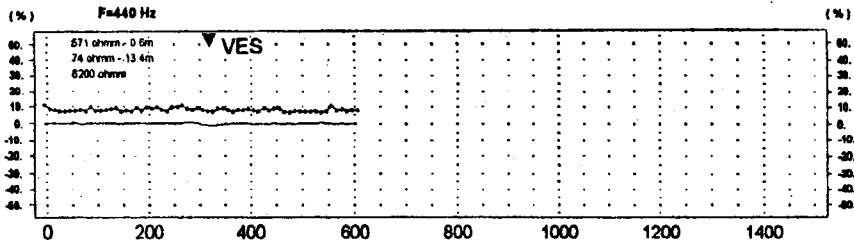
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

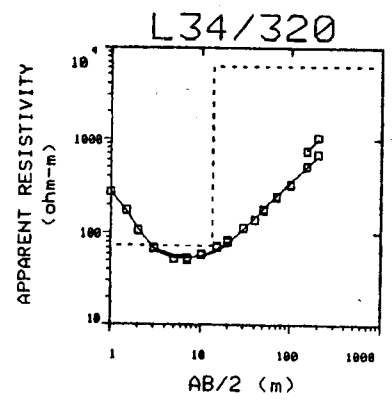
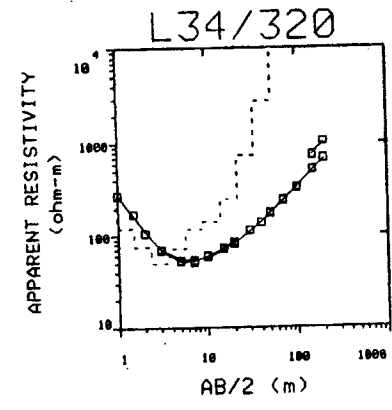
APPENDIX A10

# LINE 34 - HLEM and Magnetic Data



----- In-phase Component  
 \_\_\_\_\_ Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

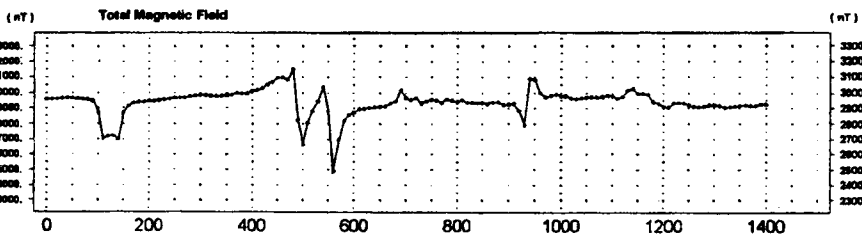
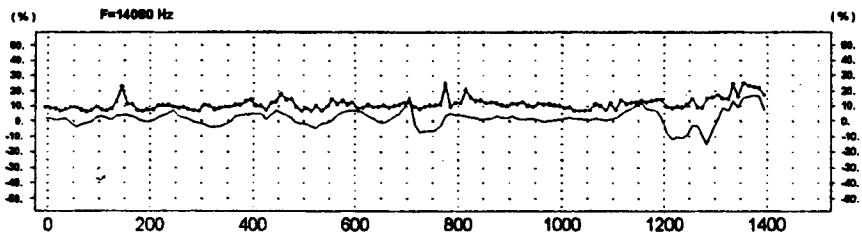
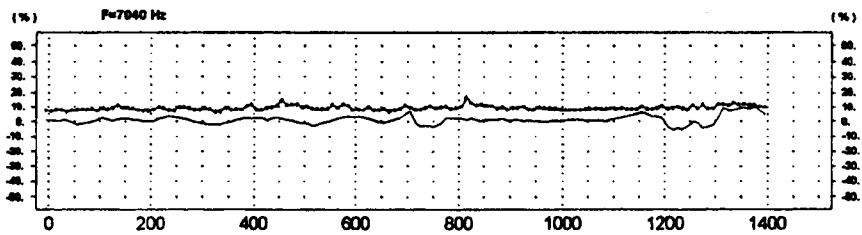
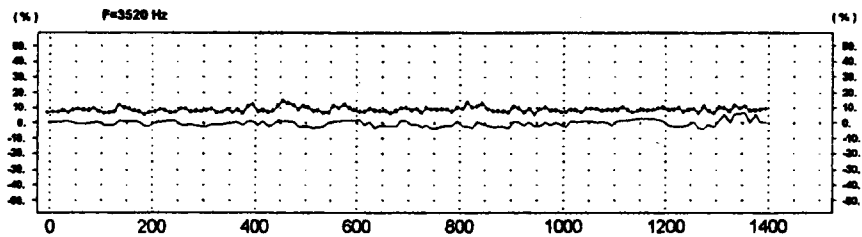
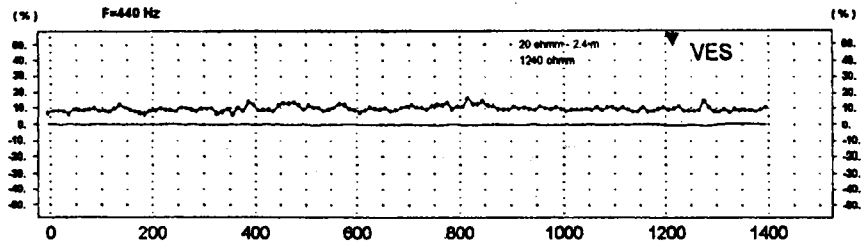
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

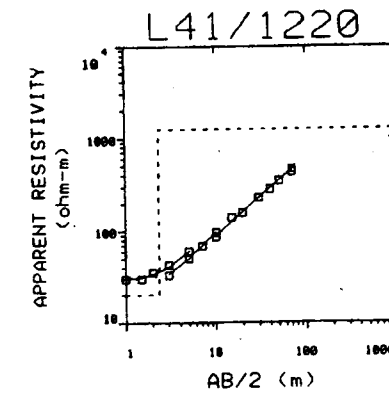
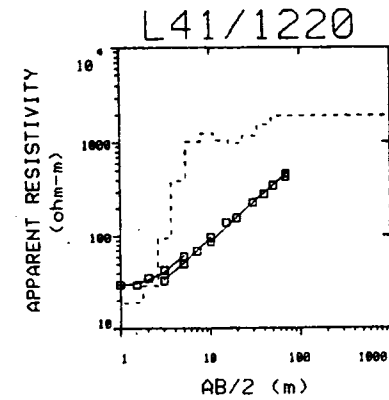
APPENDIX A11

### LINE 41 - HLEM and Magnetic Data



In-phase Component  
 Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

### VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

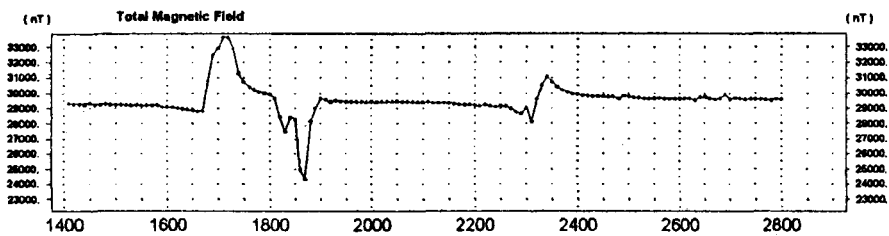
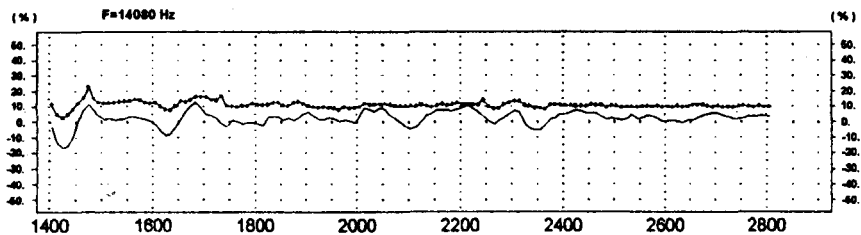
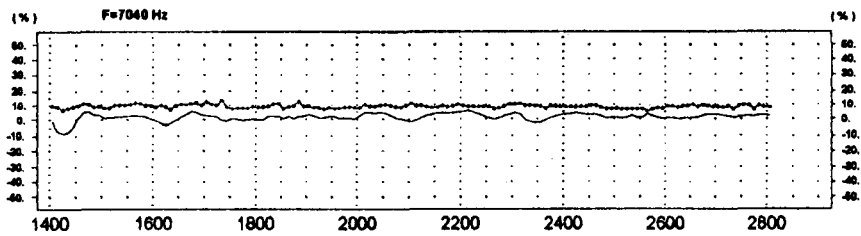
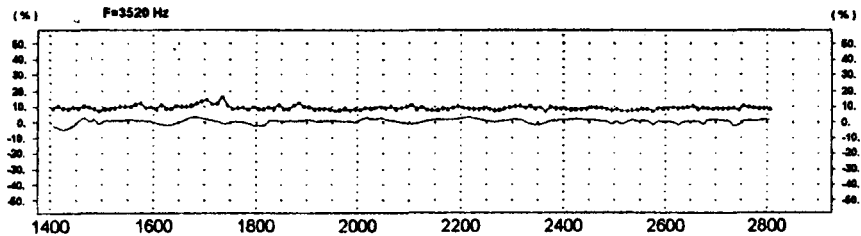
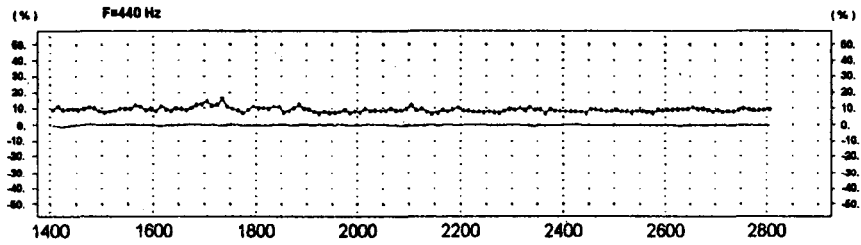
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A12

### LINE 41 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

### VES MODELS

VES NOT AVAILABLE

INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

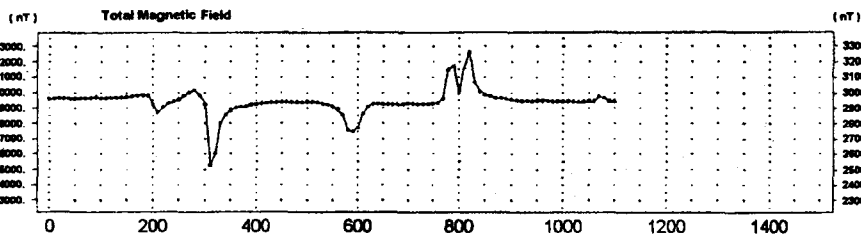
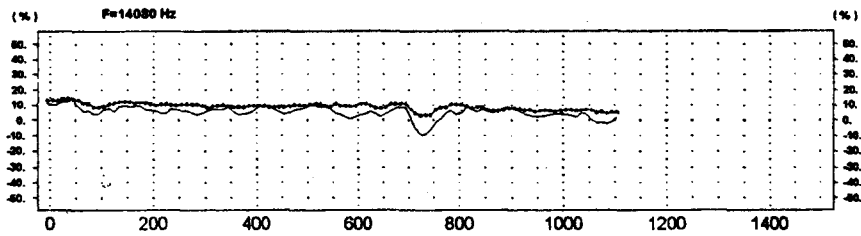
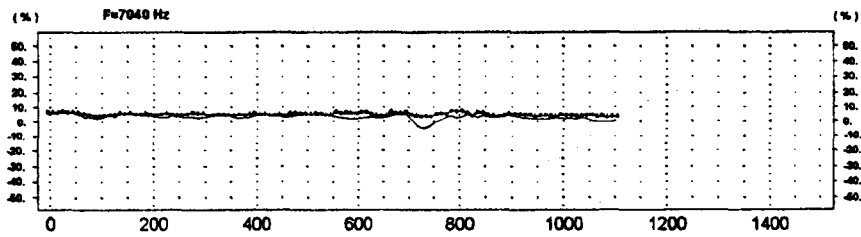
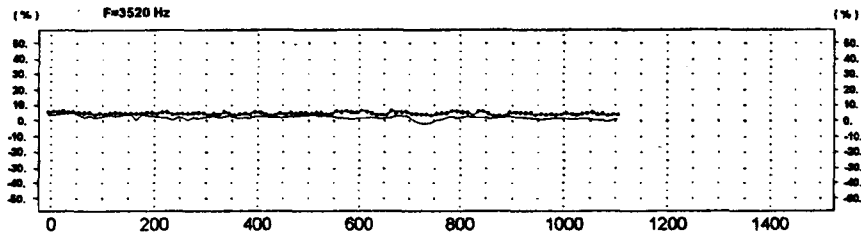
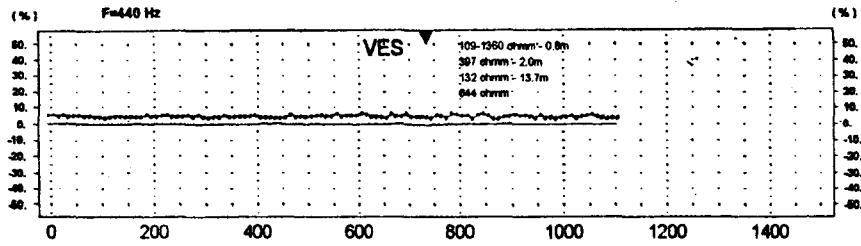
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

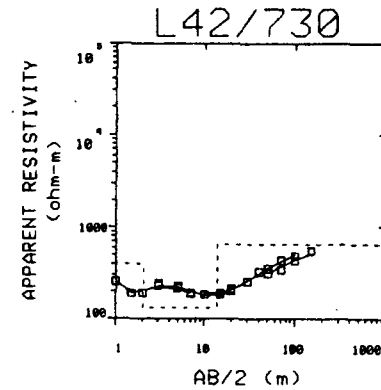
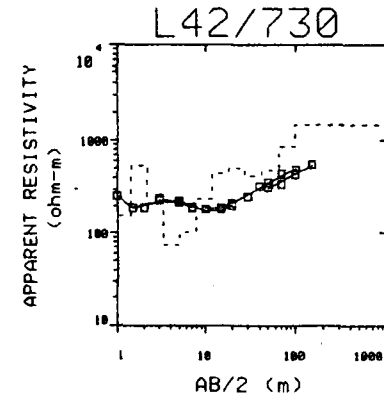
MATHATHANE

APPENDIX A13

# LINE 42 - HLEM and Magnetic Data



# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

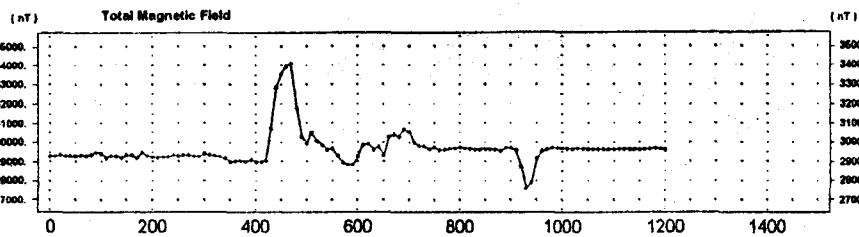
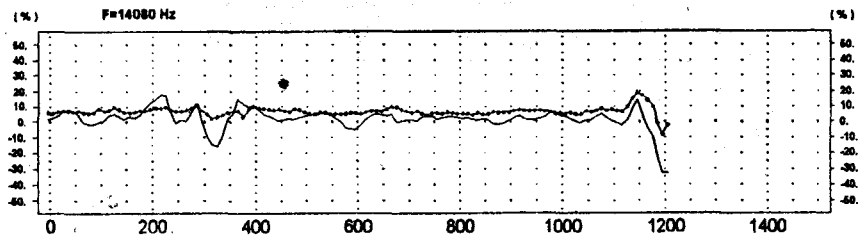
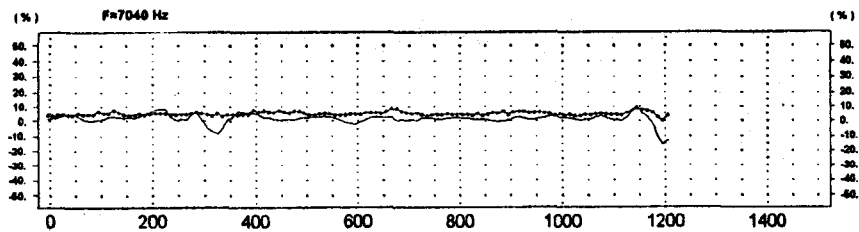
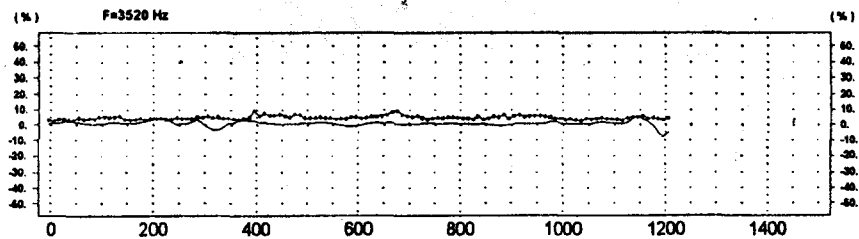
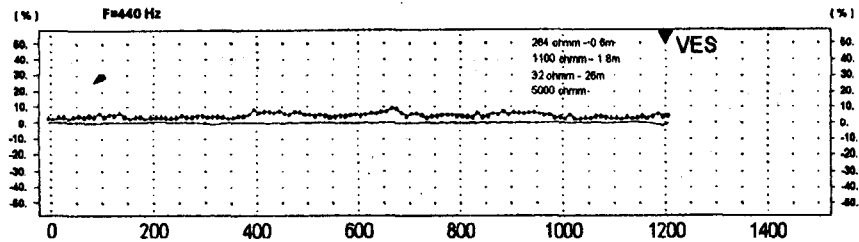
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

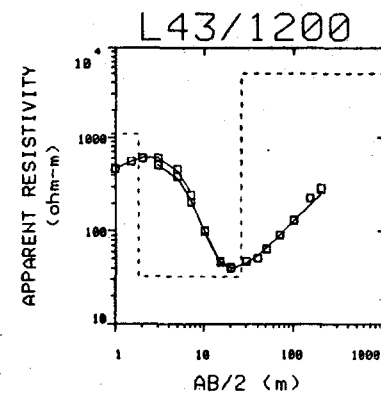
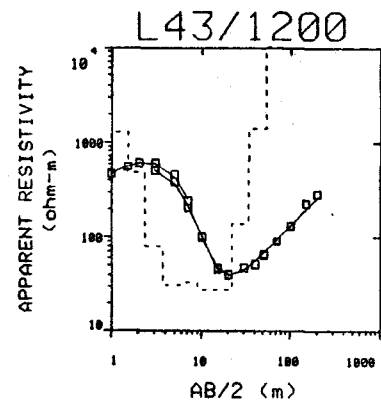
APPENDIX A14

# LINE 43 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

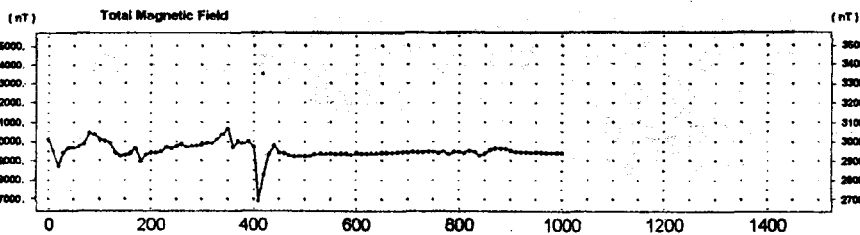
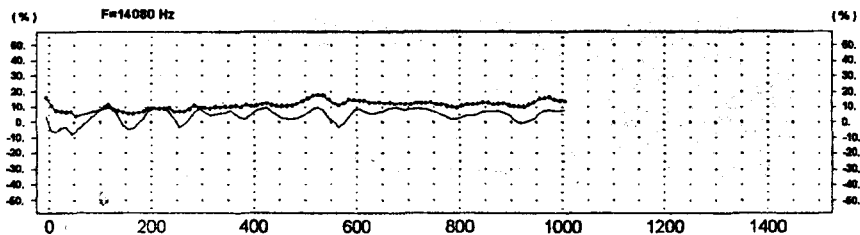
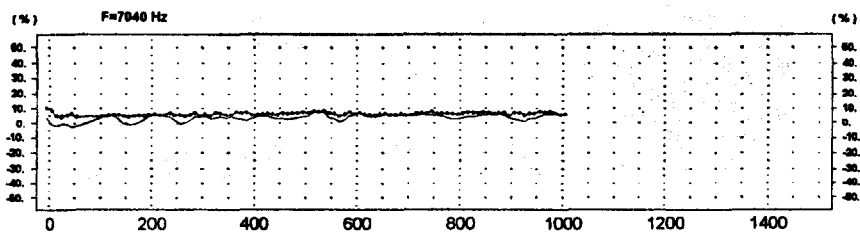
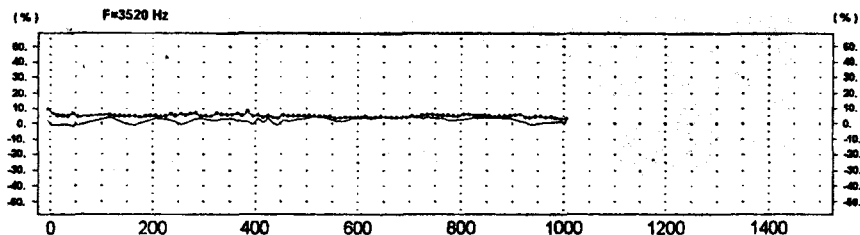
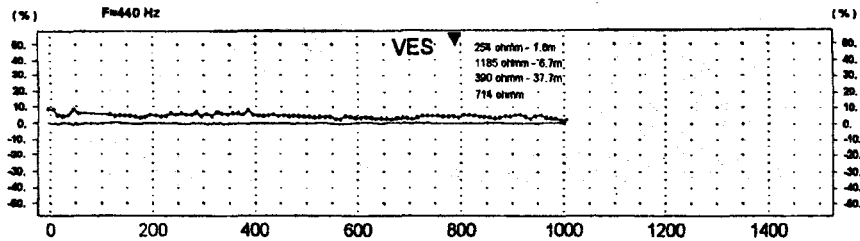
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A15

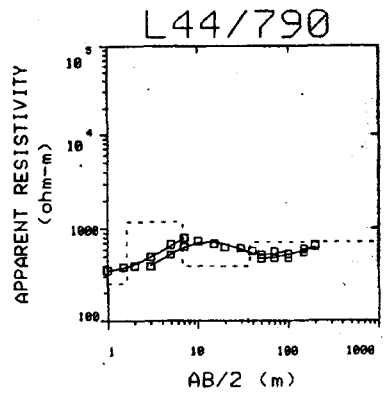
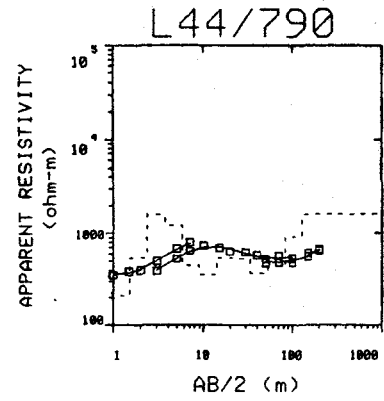
# LINE 44 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

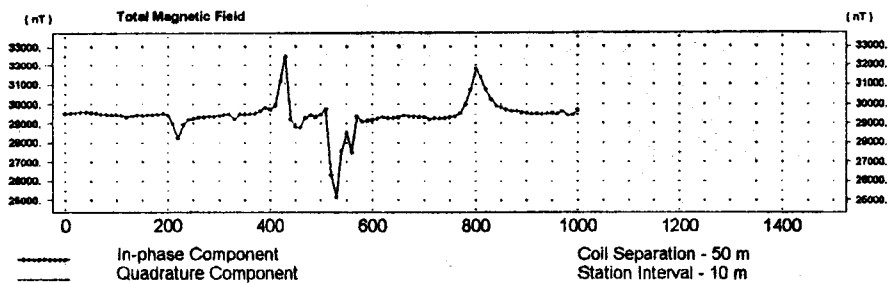
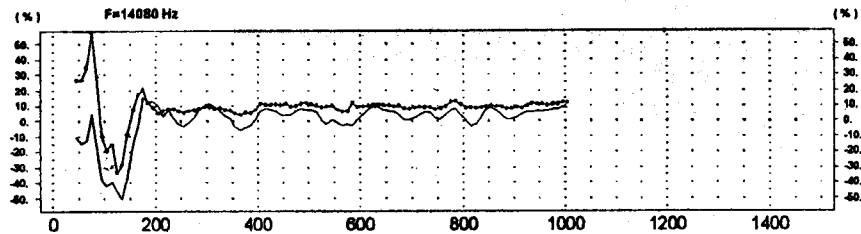
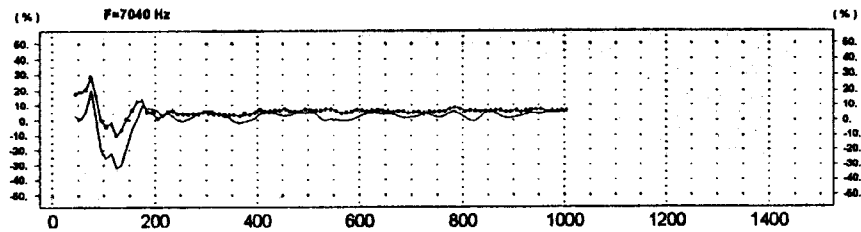
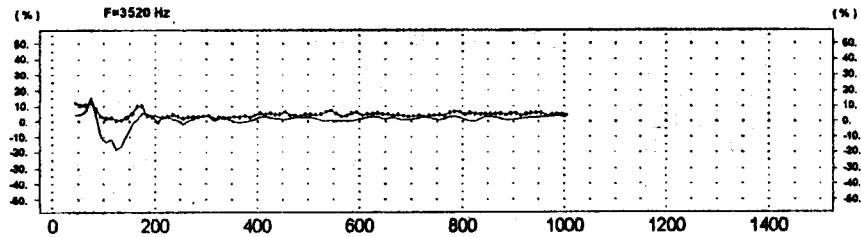
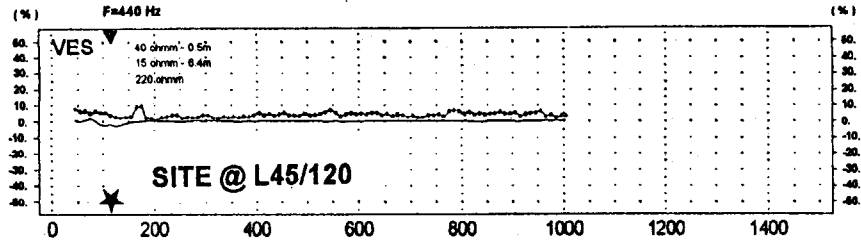
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

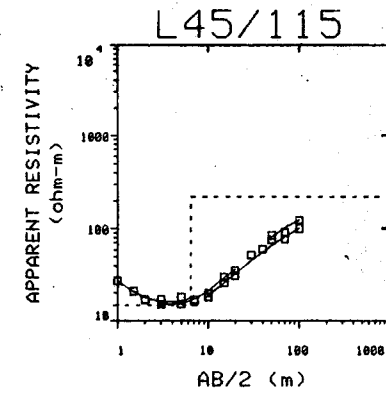
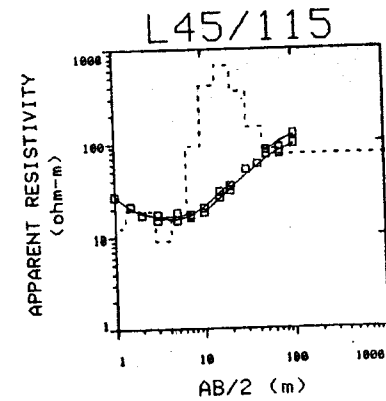
MATHATHANE

APPENDIX A16

# LINE 45 - HLEM and Magnetic Data



# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

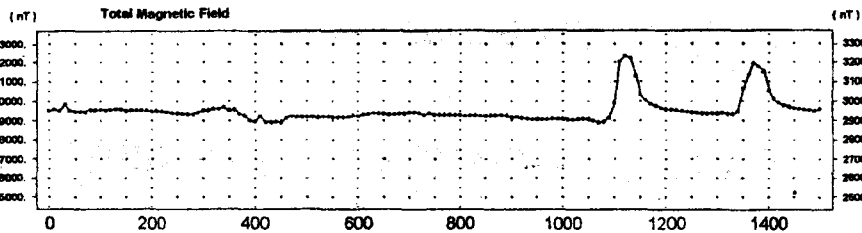
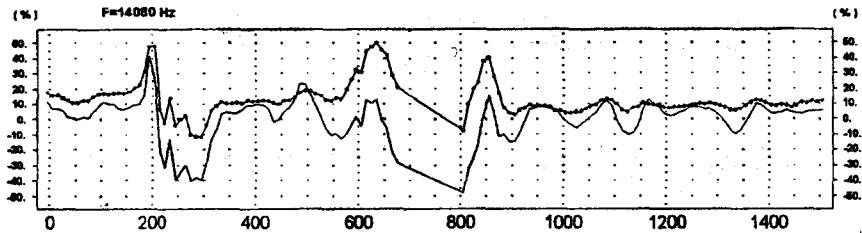
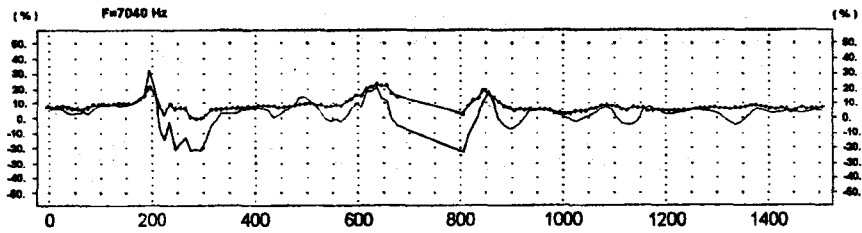
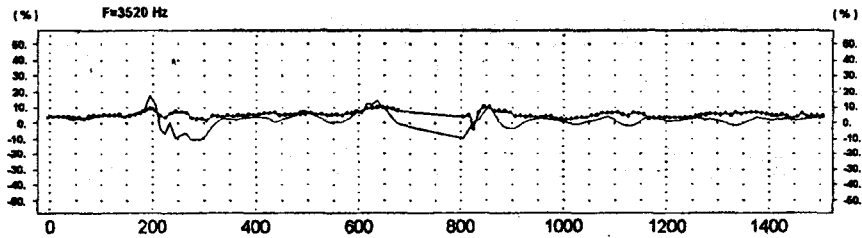
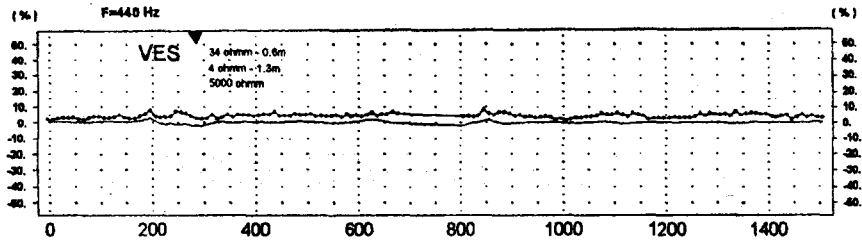
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A17

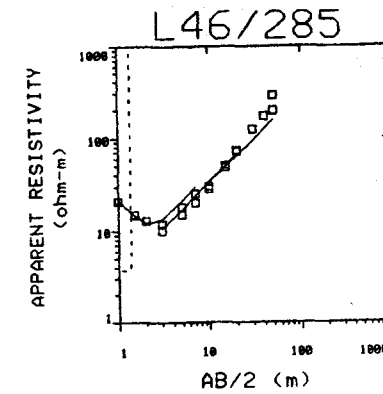
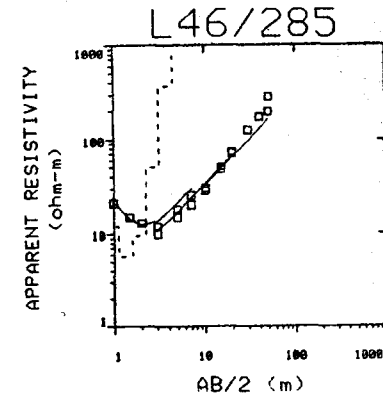
# LINE 46 - HLEM and Magnetic Data



— In-phase Component  
— Quadrature Component

Coil Separation - 50 m  
Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

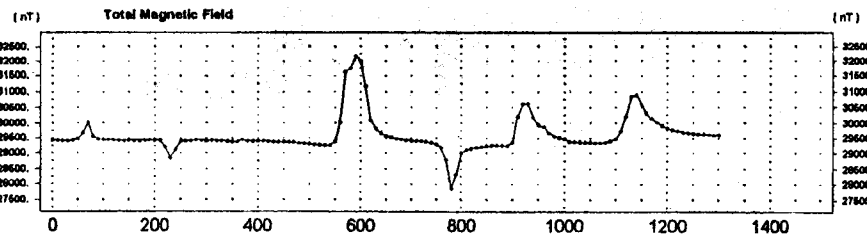
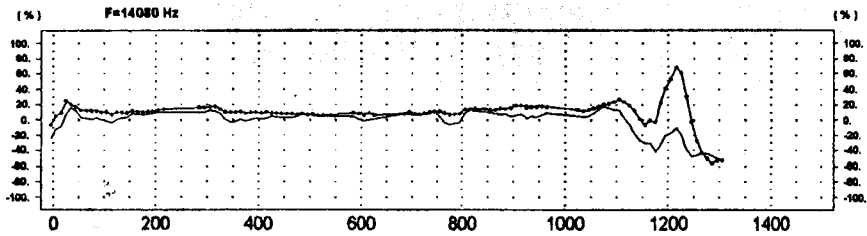
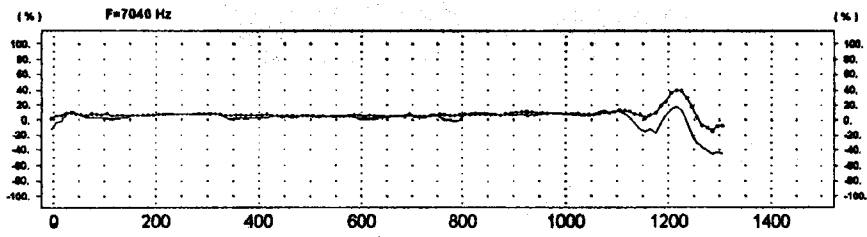
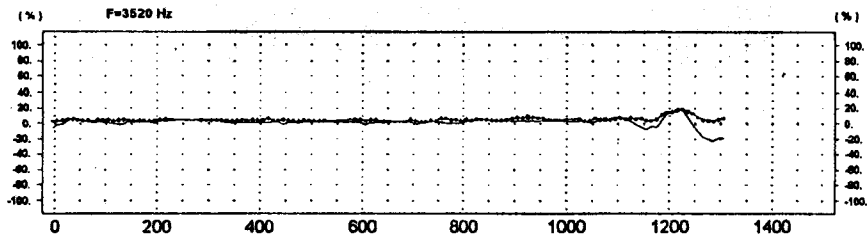
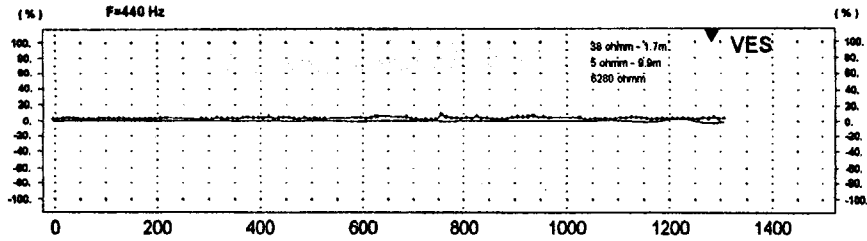
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

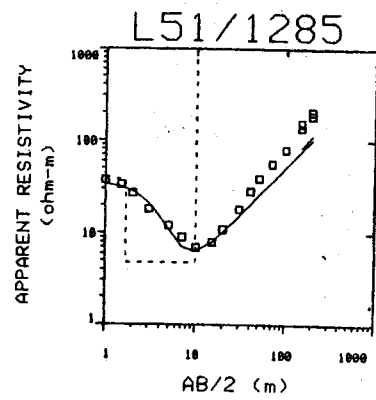
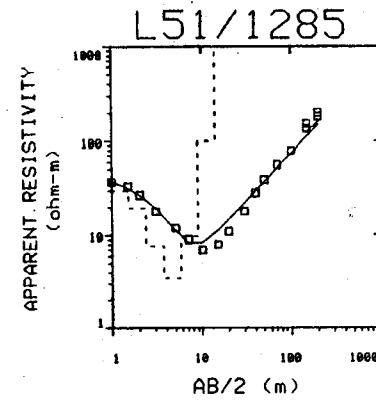
APPENDIX A18

# LINE 51 - HLEM and Magnetic Data



----- In-phase Component  
 ——— Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

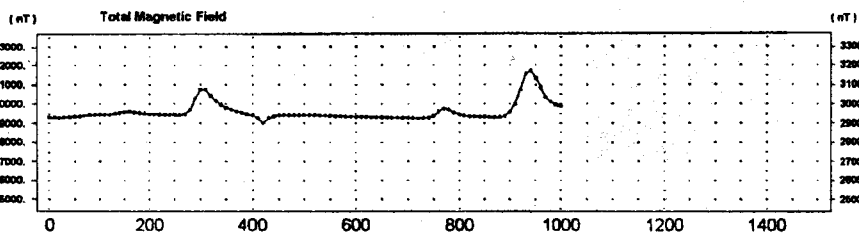
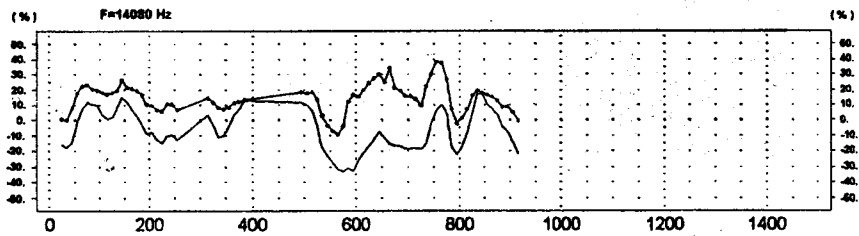
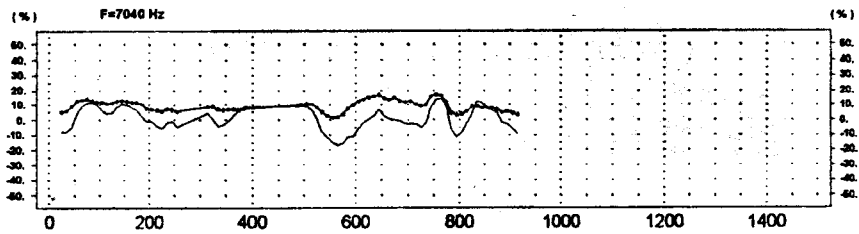
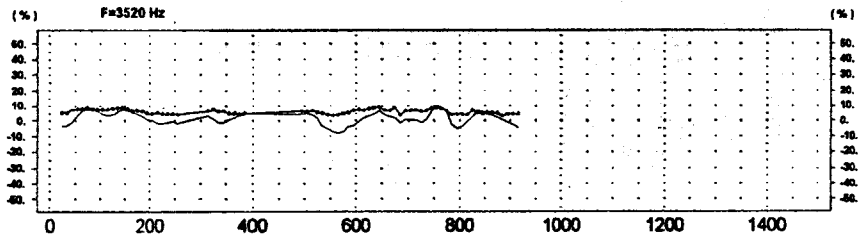
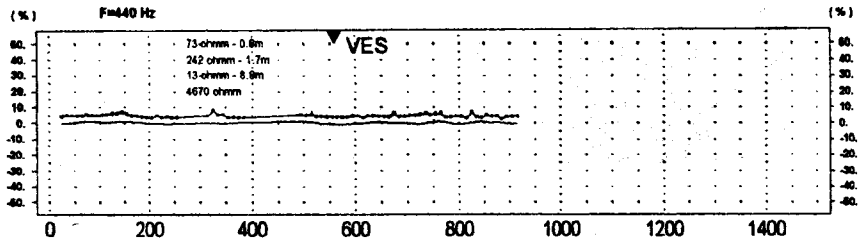
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A19

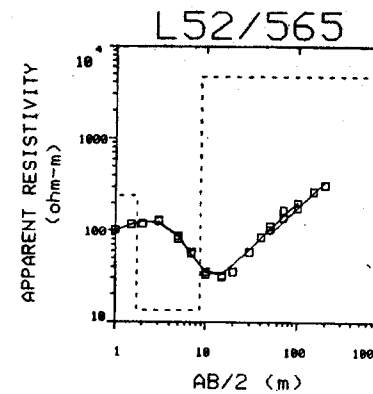
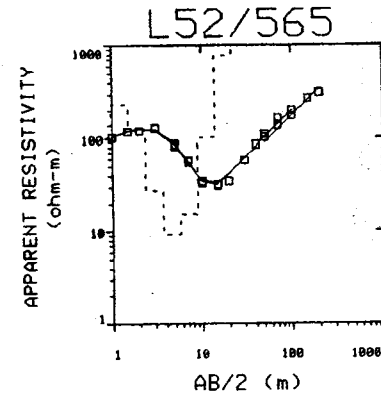
# LINE 52 - HLEM and Magnetic Data



----- In-phase Component  
 \_\_\_\_\_ Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

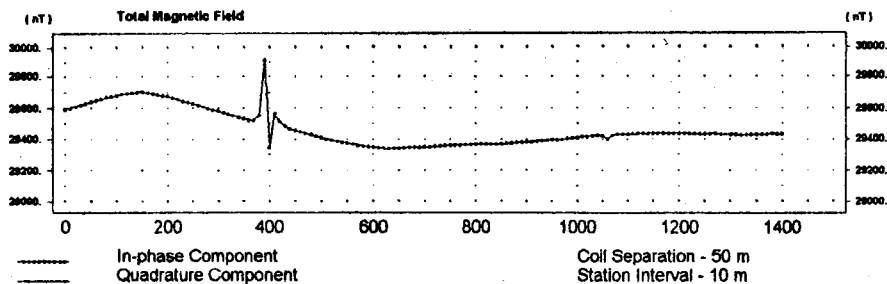
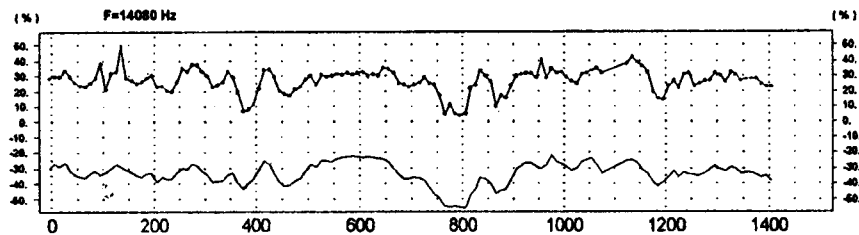
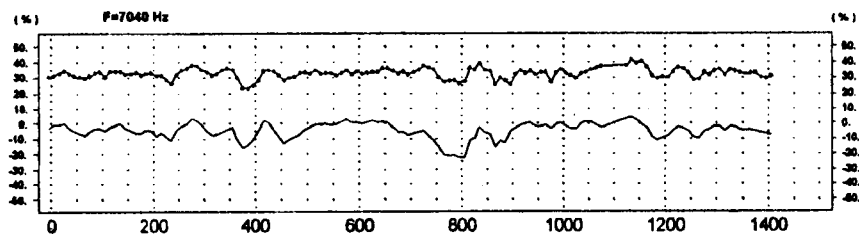
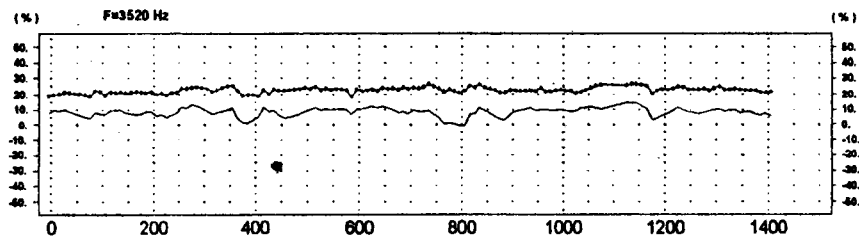
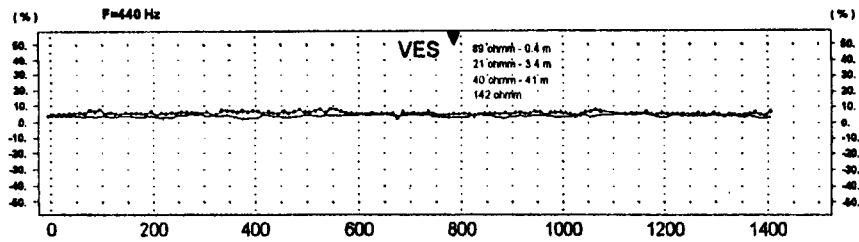
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

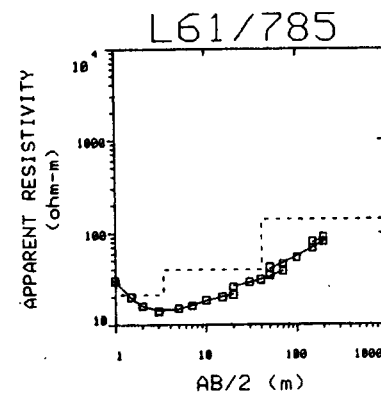
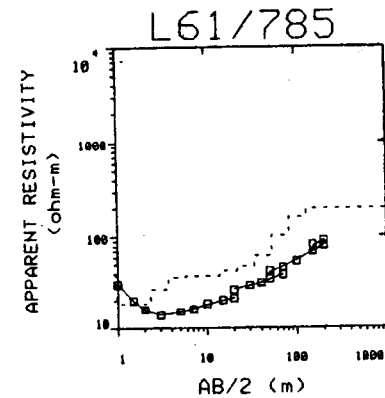
MATHATHANE

APPENDIX A20

# LINE 61 - HLEM and Magnetic Data



# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

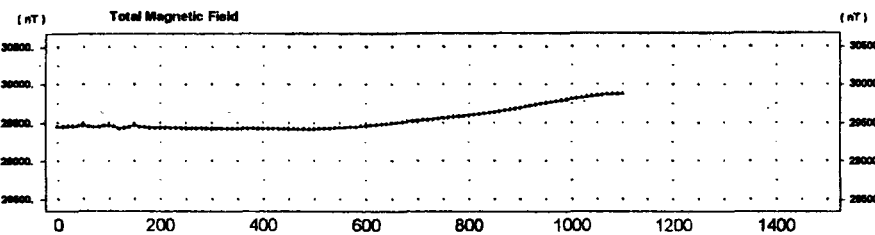
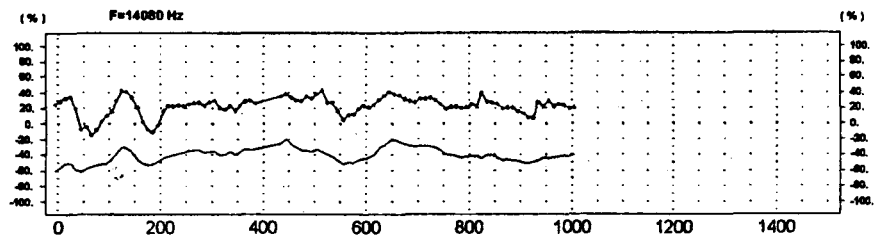
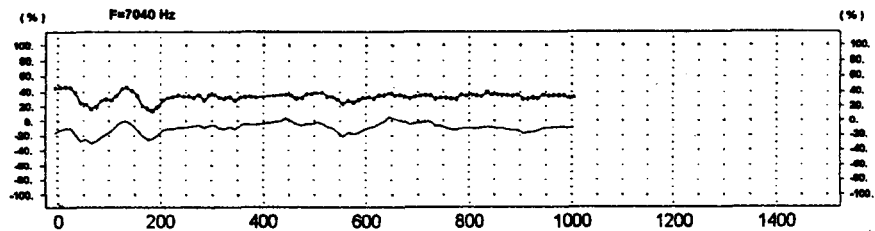
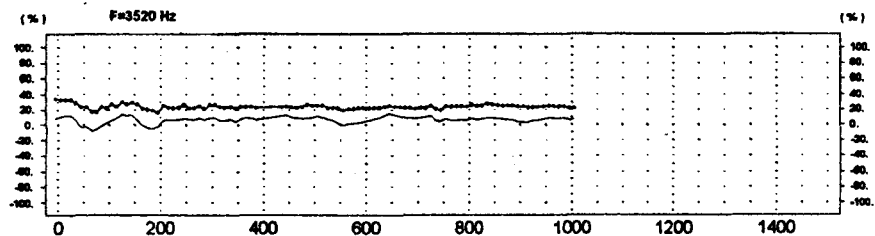
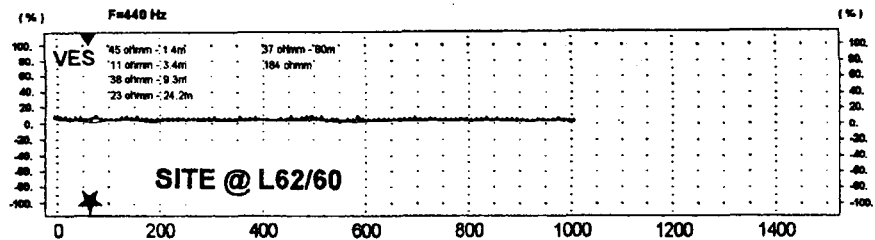
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A21

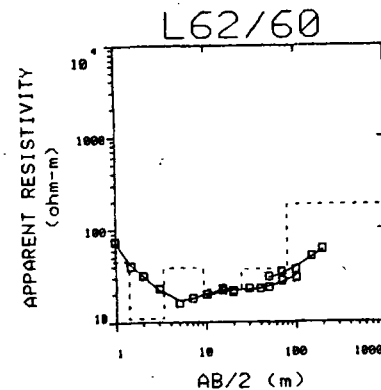
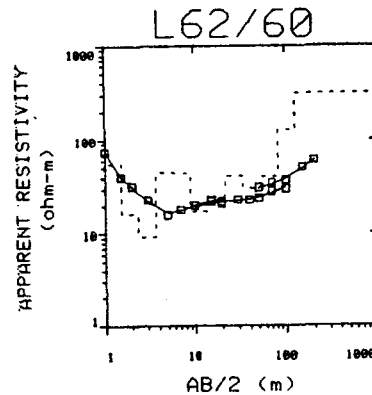
# LINE 62 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

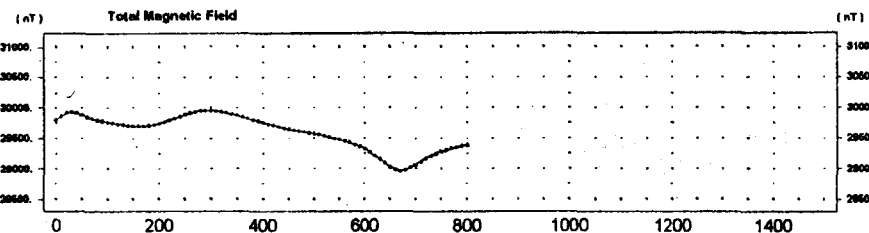
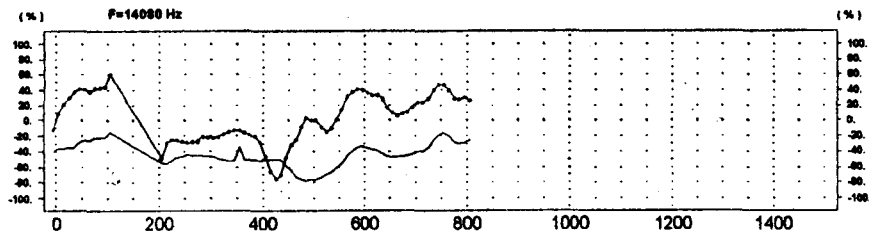
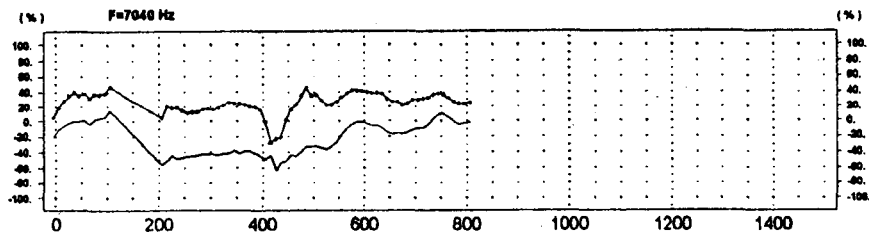
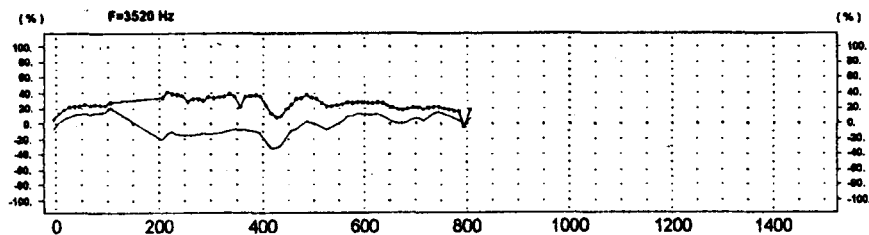
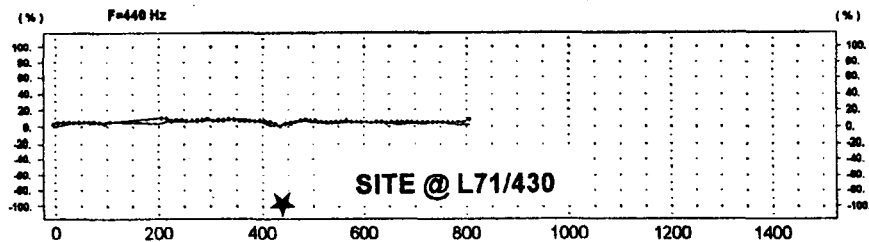
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A22

LINE 71 - HLEM and Magnetic Data



----- In-phase Component  
 \_\_\_\_\_ Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

VES MODELS

VES NOT AVAILABLE

INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

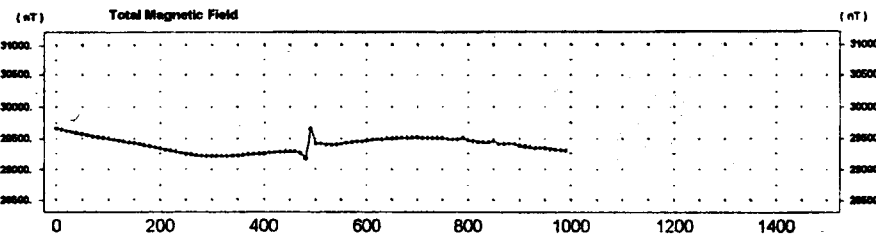
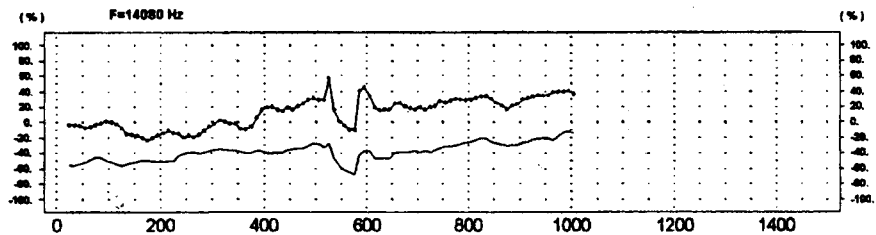
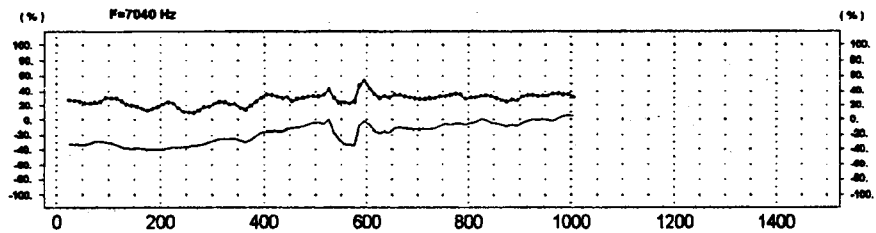
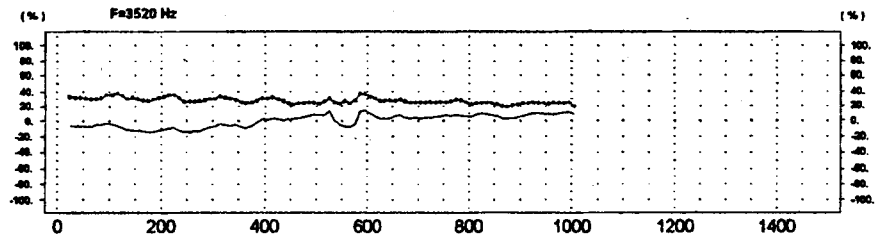
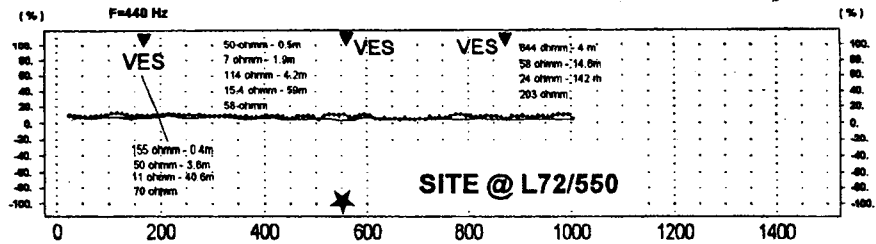
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

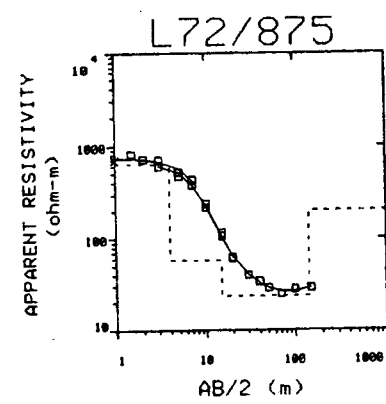
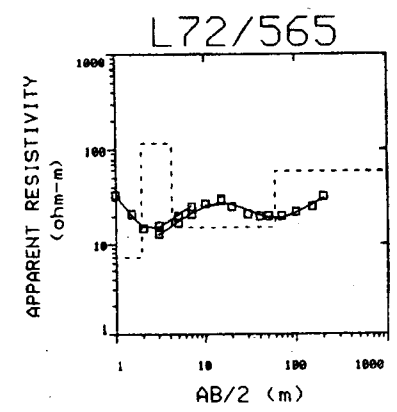
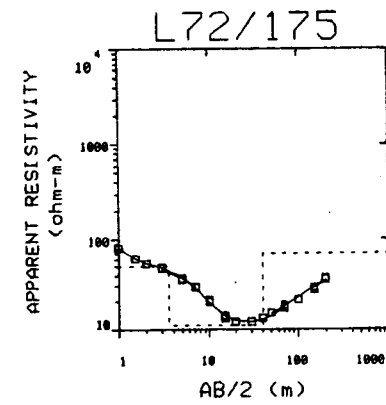
APPENDIX A23

# LINE 72 - HLEM and Magnetic Data



In-phase Component  
 Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

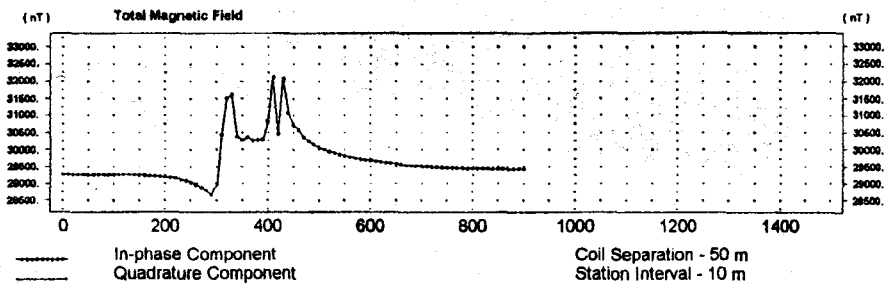
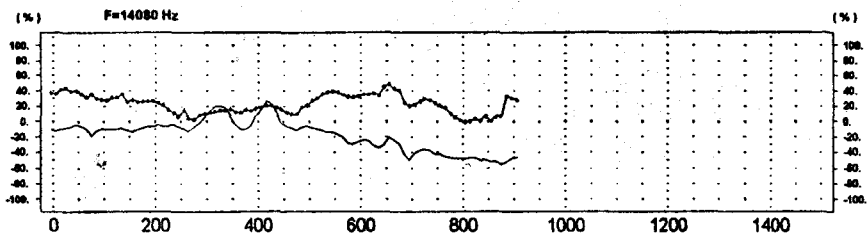
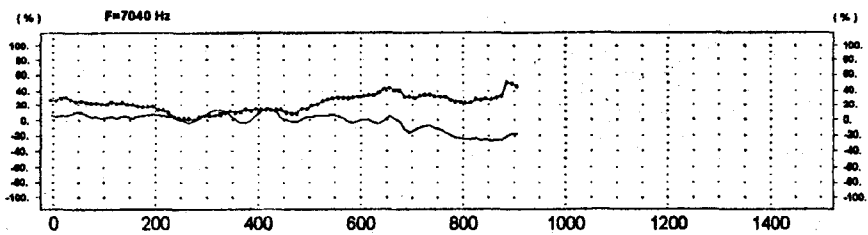
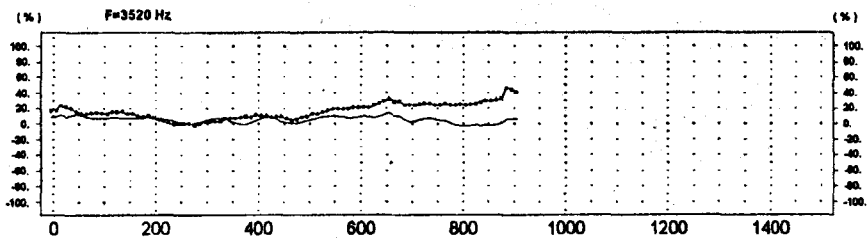
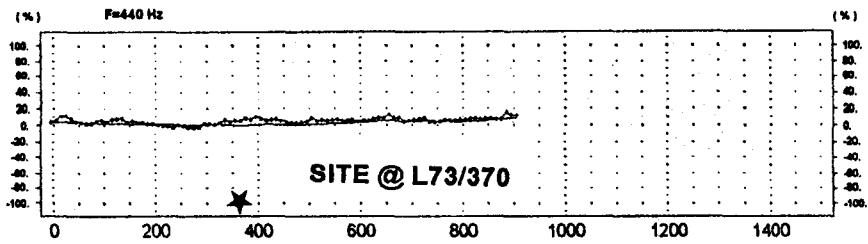
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A24

# LINE 73 - HLEM and Magnetic Data



# VES MODELS

VES NOT AVAILABLE

INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

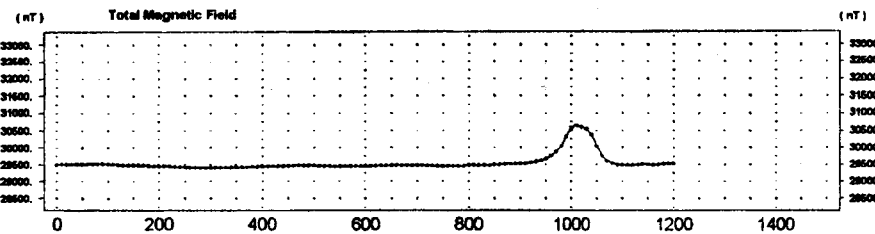
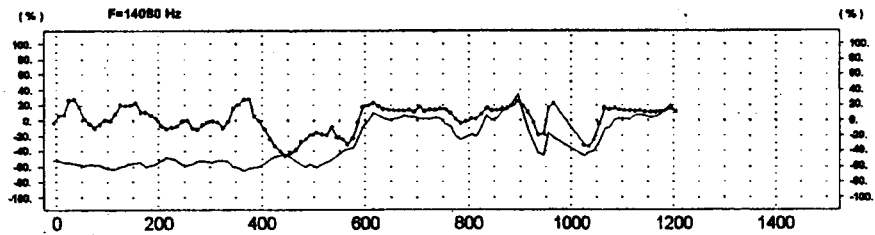
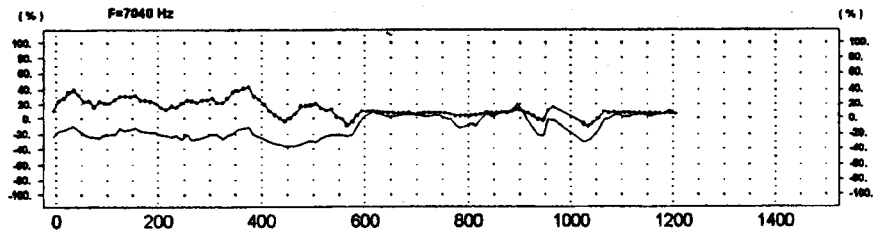
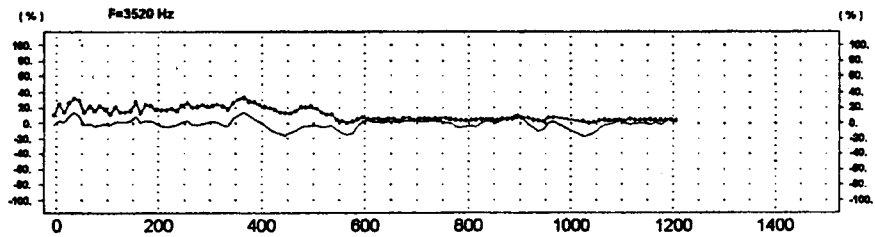
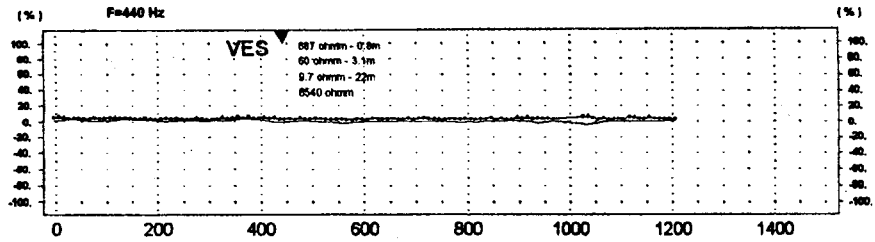
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A25

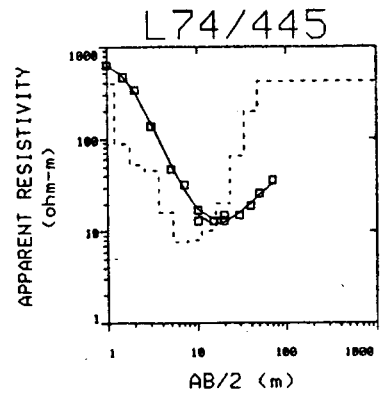
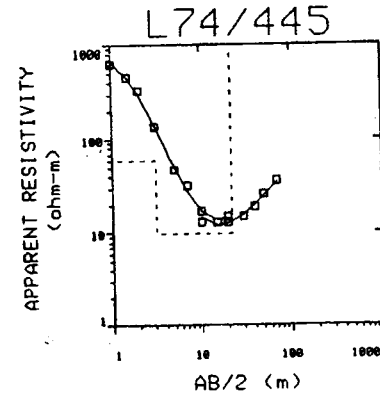
# LINE 74 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

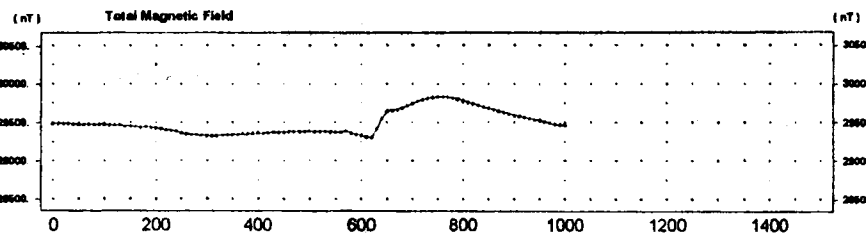
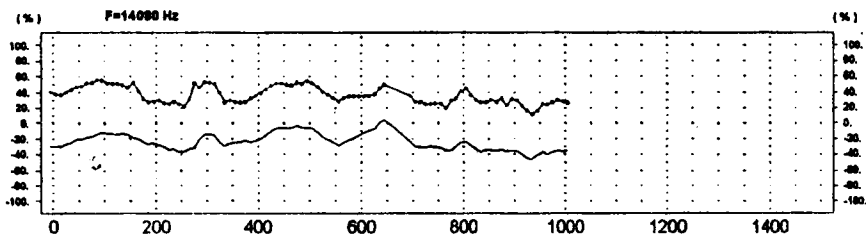
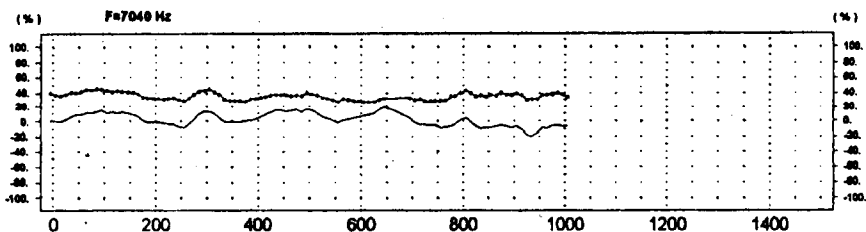
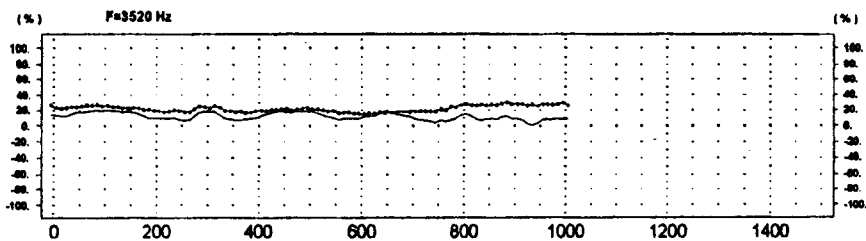
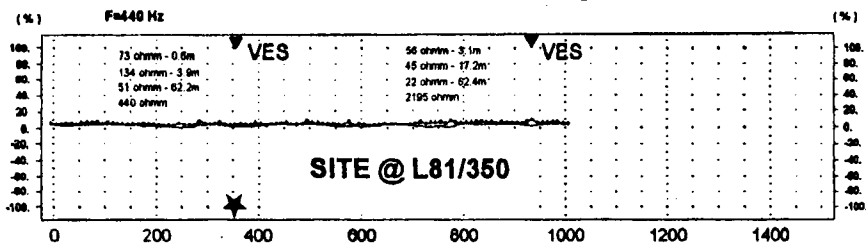
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

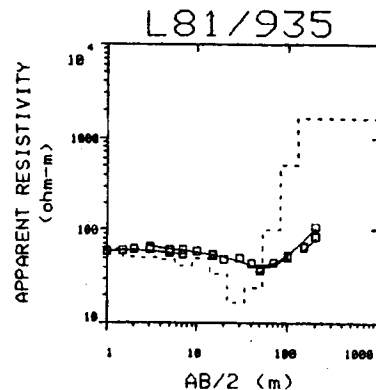
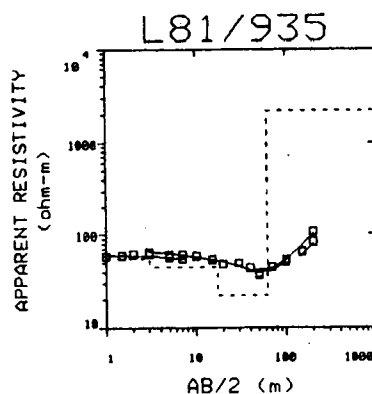
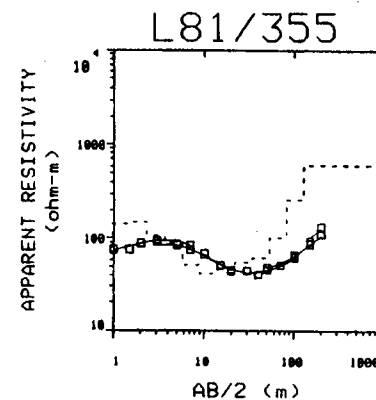
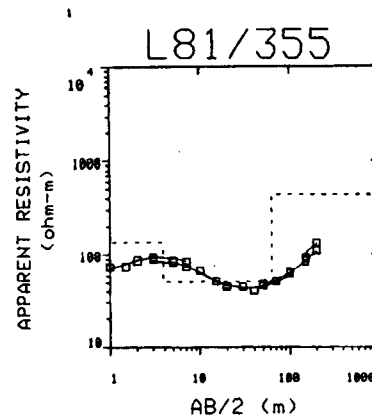
APPENDIX A26

# LINE 81 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

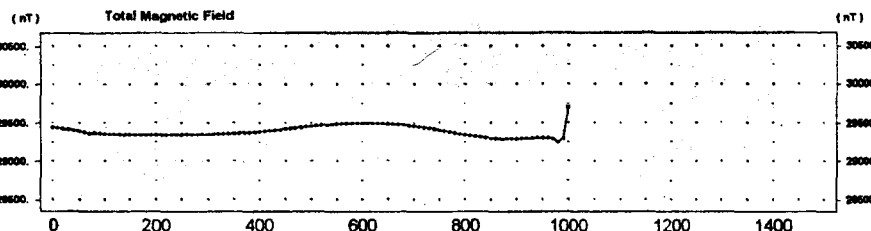
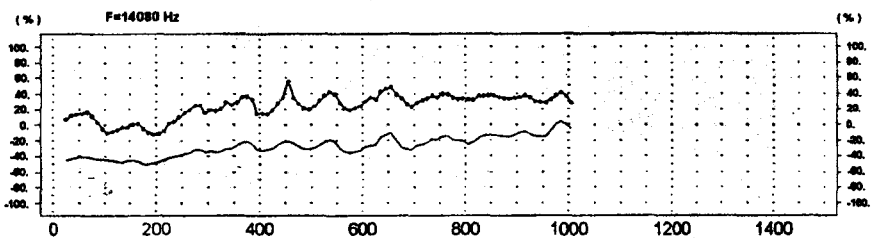
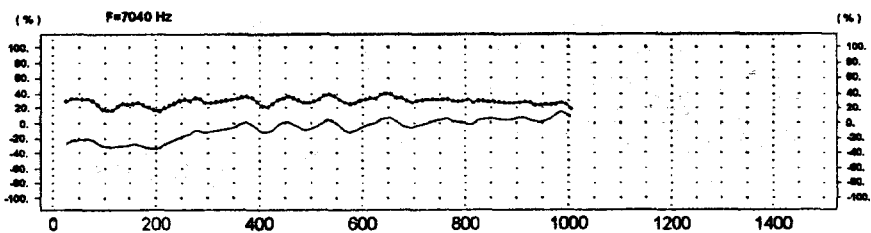
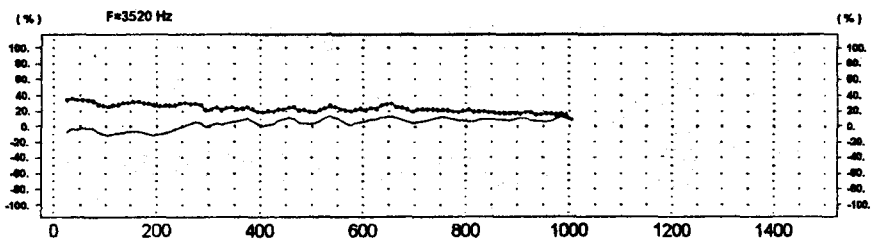
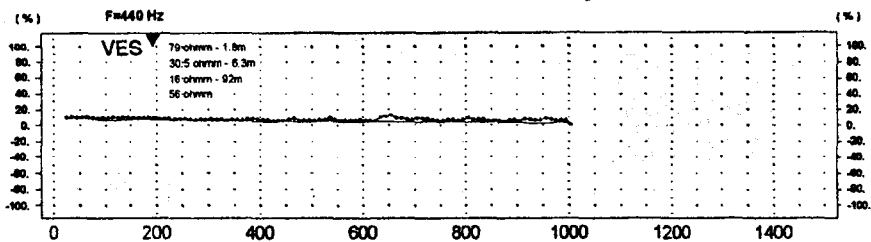
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

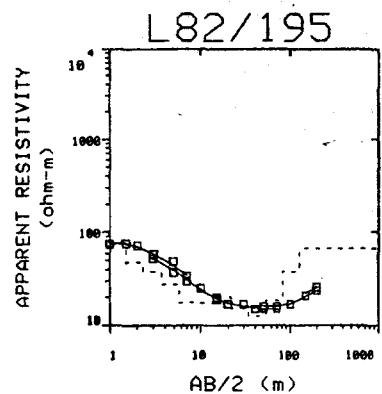
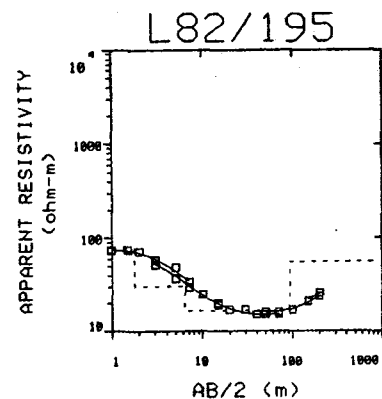
APPENDIX A27

# LINE 82 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component  
 Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

BOBIRWA SUB DISTRICT VILLAGES

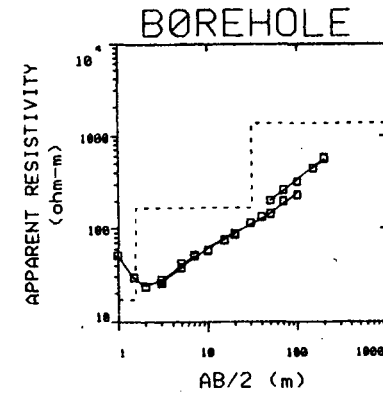
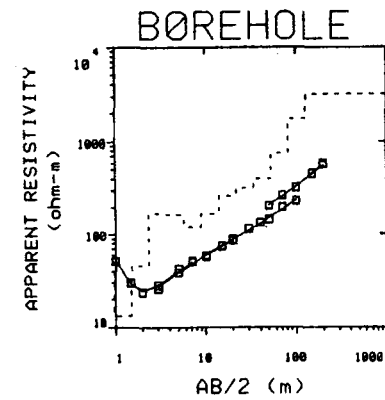
DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A28

NOT AVAILABLE

## VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

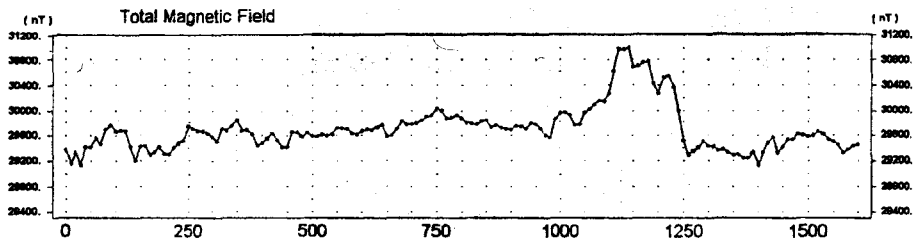
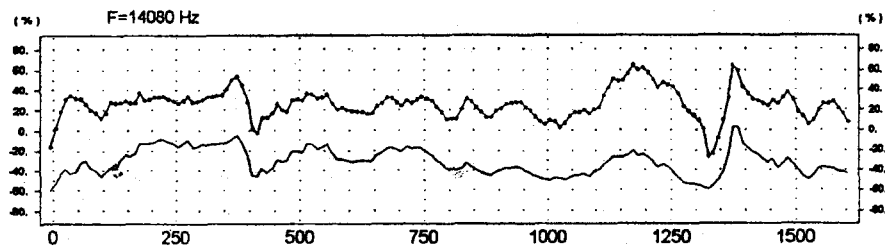
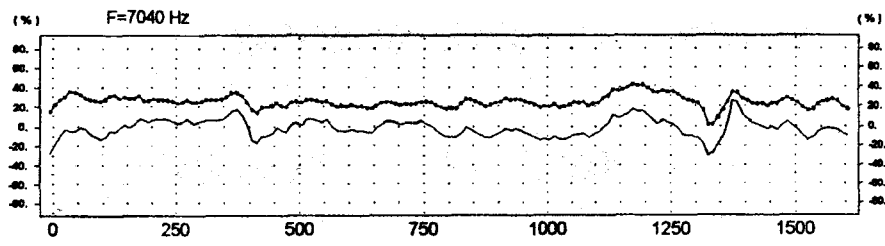
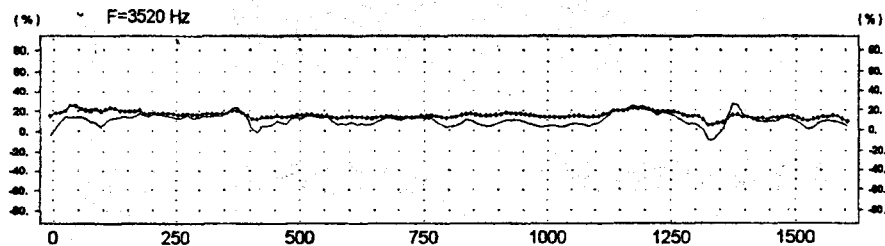
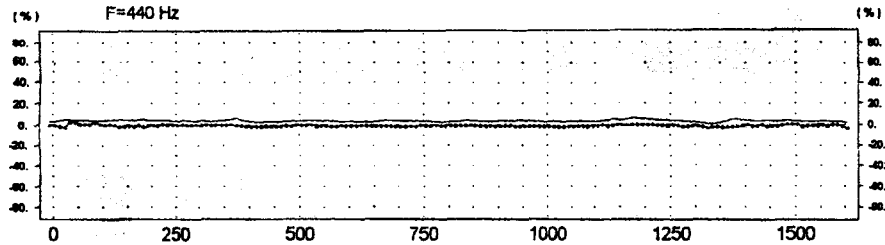
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A29

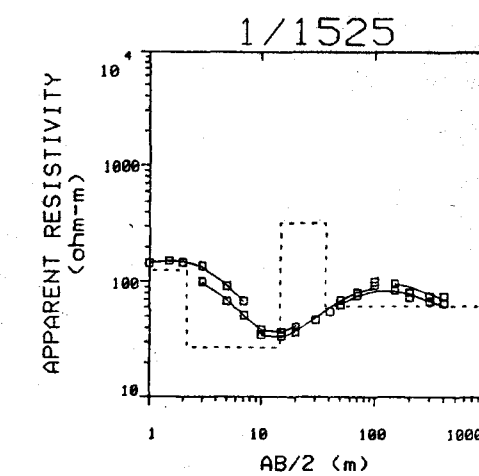
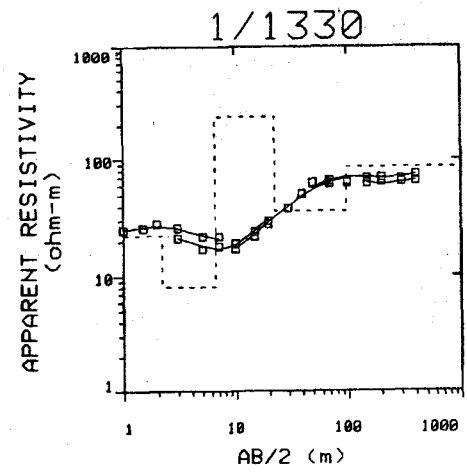
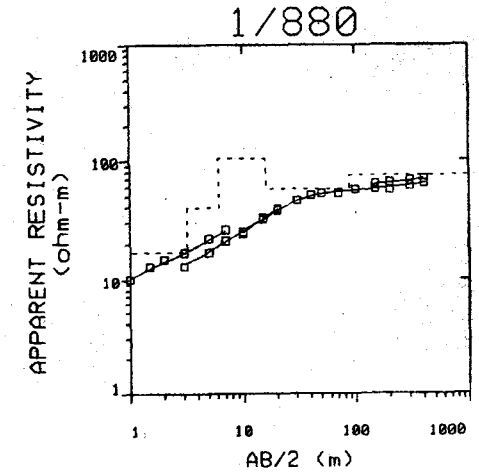
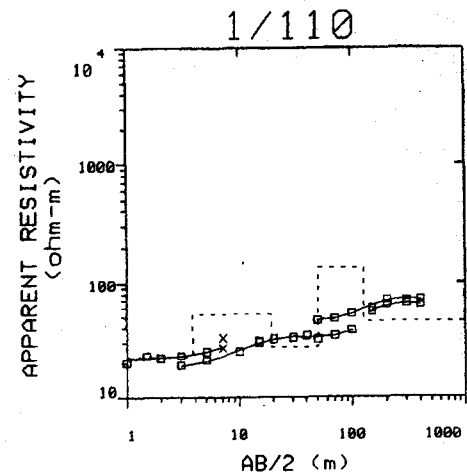
# LINE 1 - HLEM and Magnetic Data



— In-phase Component  
 - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME

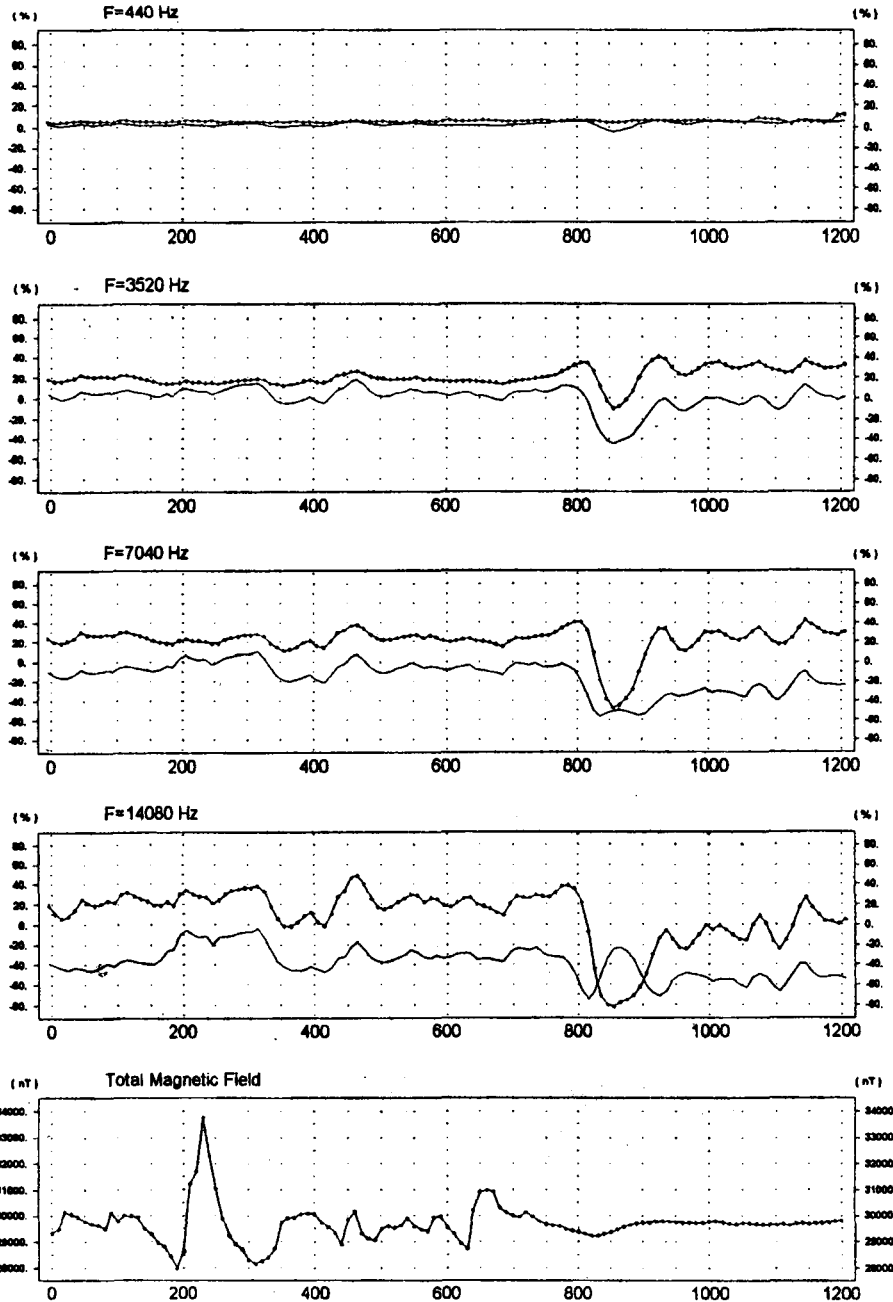
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA

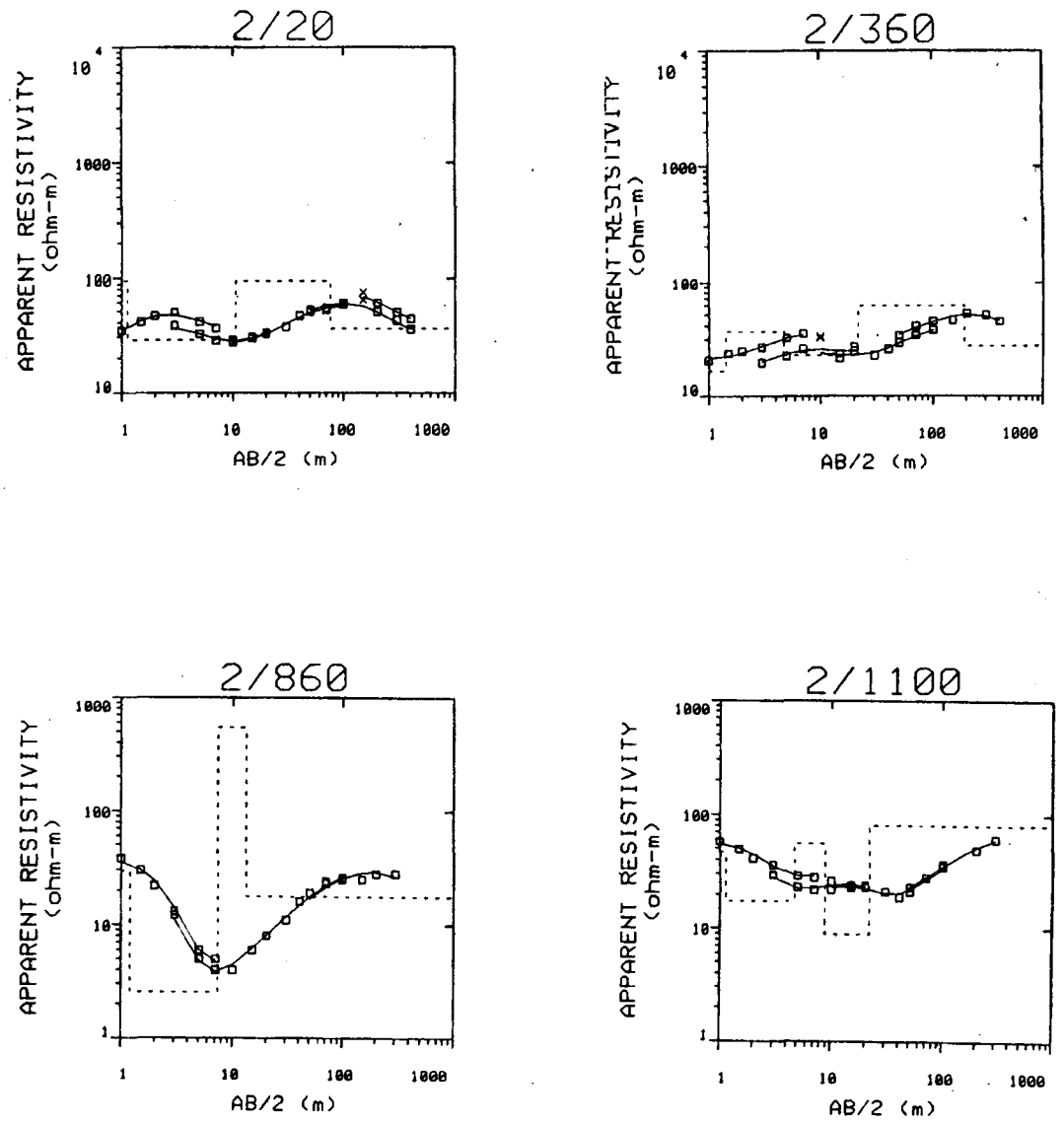
MATHATHANE

APPENDIX A30

### LINE 2 - HLEM and Magnetic Data



### VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

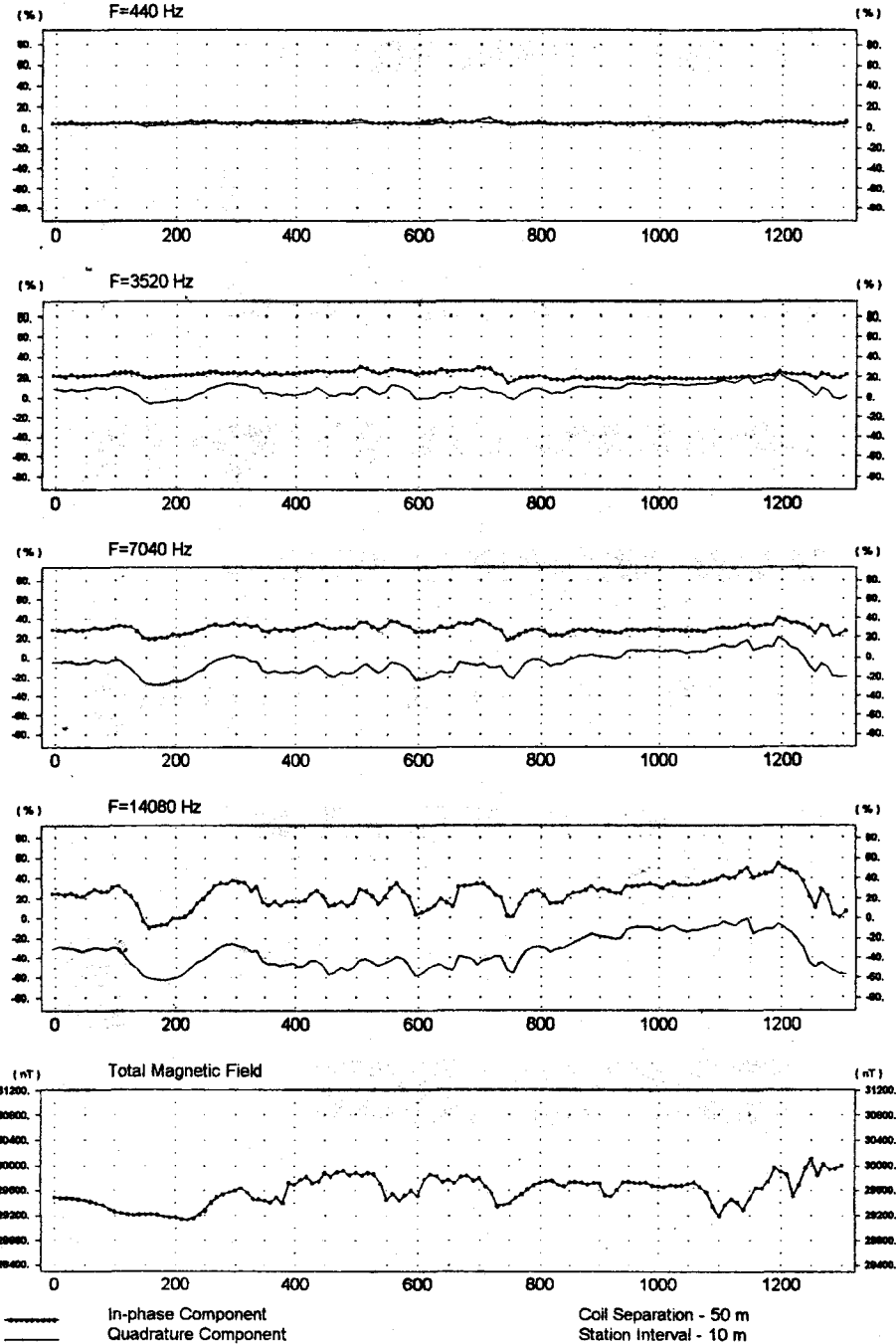
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

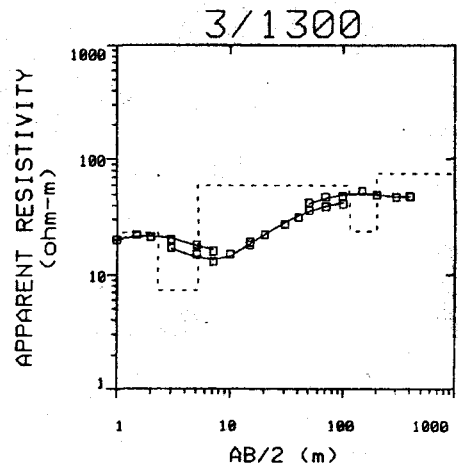
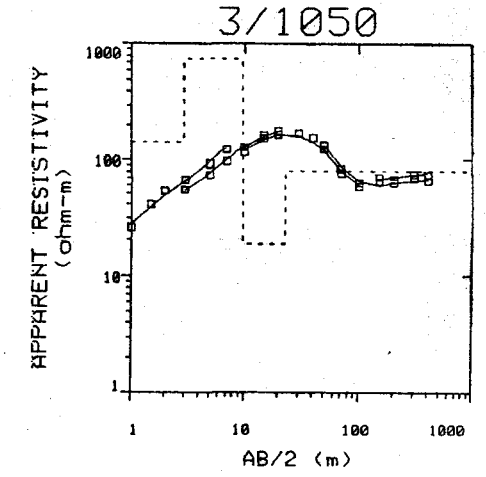
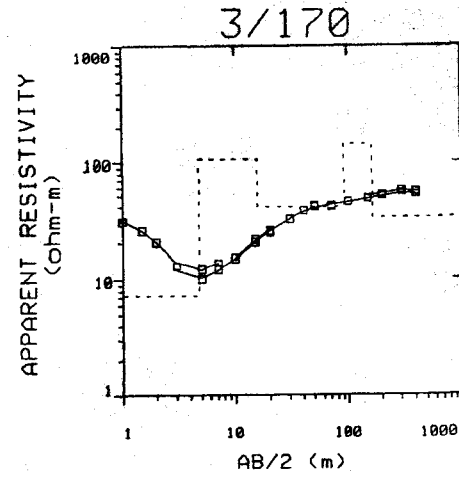
MATHATHANE

APPENDIX A31

### LINE 3 - HLEM and Magnetic Data



### VES MODELS



INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

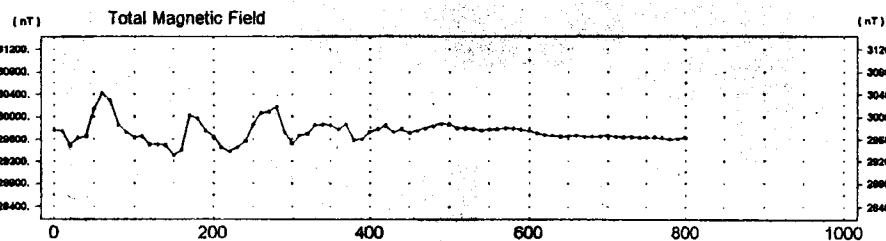
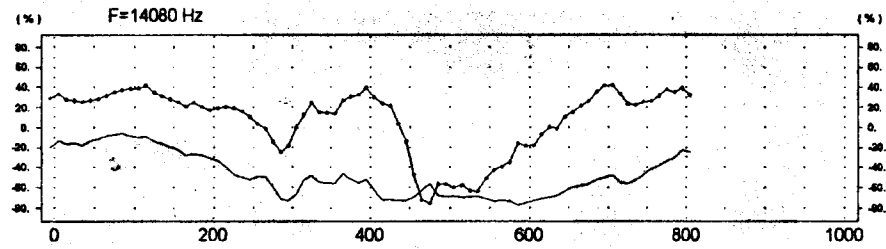
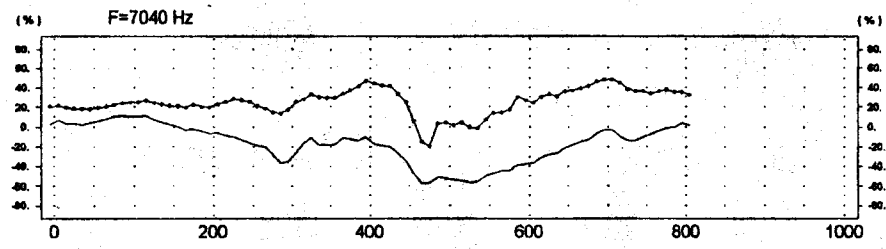
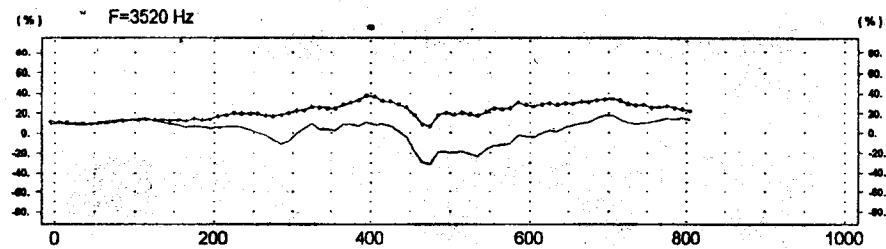
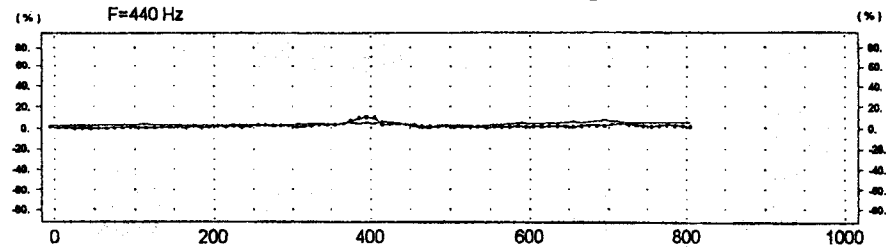
BOBIRWA SUB DISTRICT VILLAGES

DEPARTMENT OF WATER  
AFFAIRS, BOTSWANA

MATHATHANE

APPENDIX A32

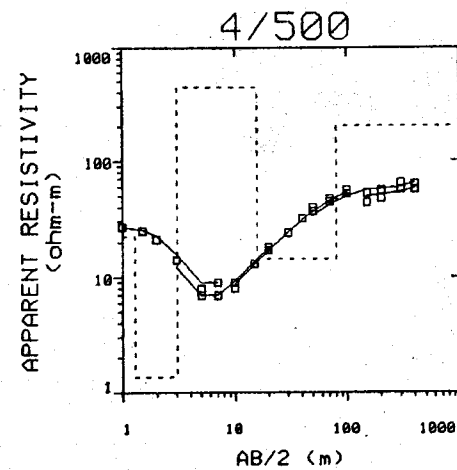
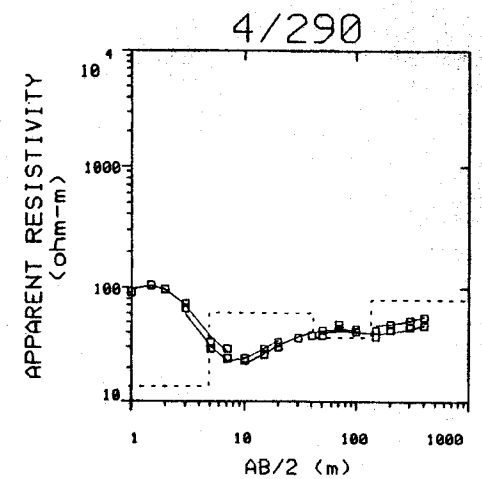
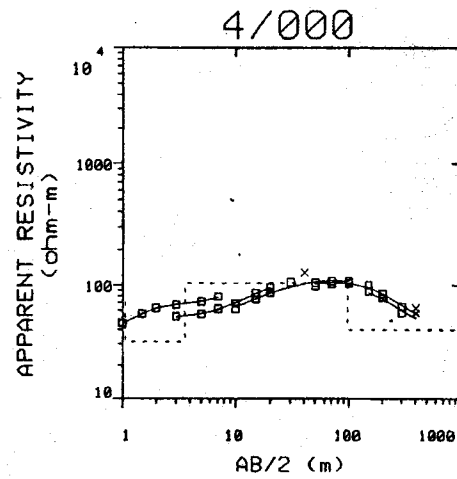
# LINE 4 - HLEM and Magnetic Data



----- In-phase Component  
 - - - - - Quadrature Component

Coil Separation - 50 m  
 Station Interval - 10 m

# VES MODELS



**INTEGRATED RURAL VILLAGE  
 WATER SUPPLY PROGRAMME**

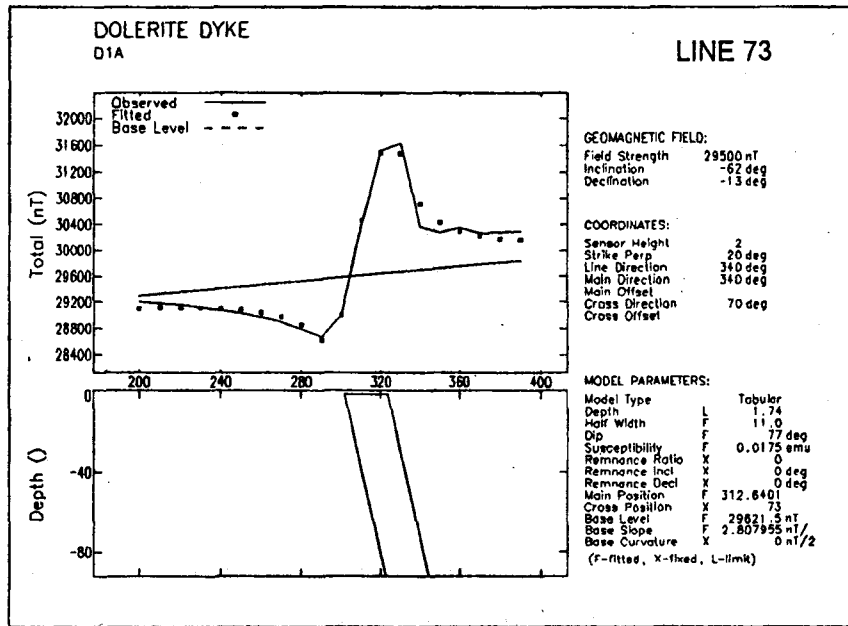
**BOBIRWA SUB DISTRICT VILLAGES**

**DEPARTMENT OF WATER  
 AFFAIRS, BOTSWANA**

**MATHATHANE APPENDIX A33**

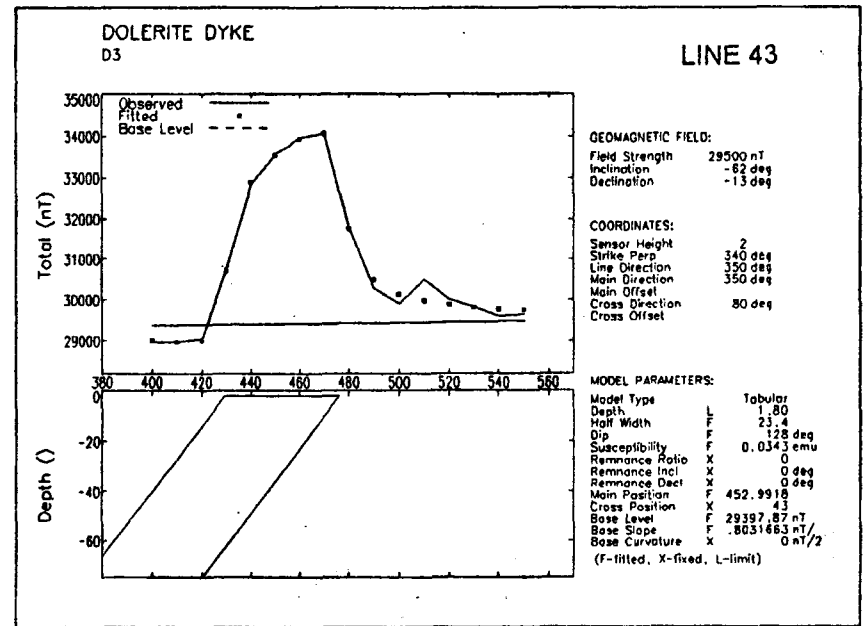
## **APPENDIX B**

### **Magnetic Modelling Results and VES Models**



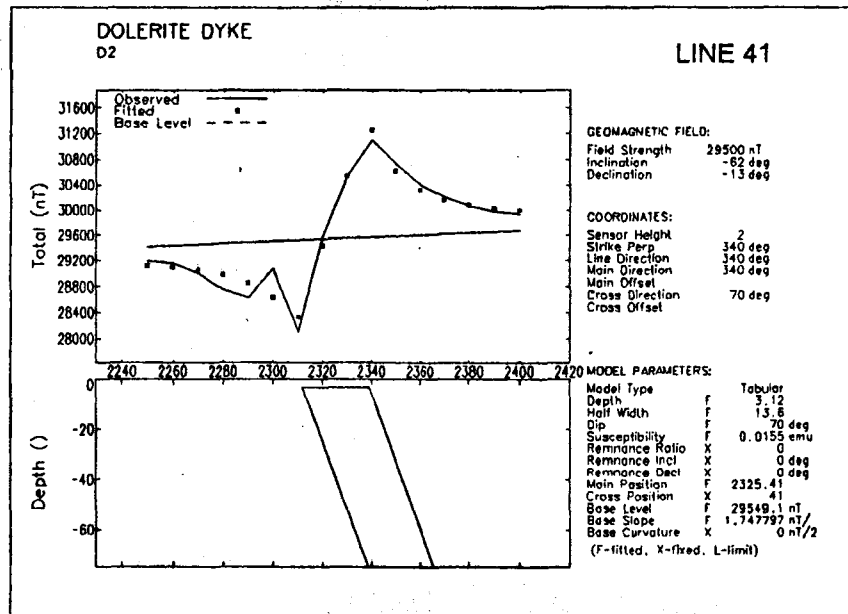
Geosoft MAGMOD-3 Modeling Result

99/11/05



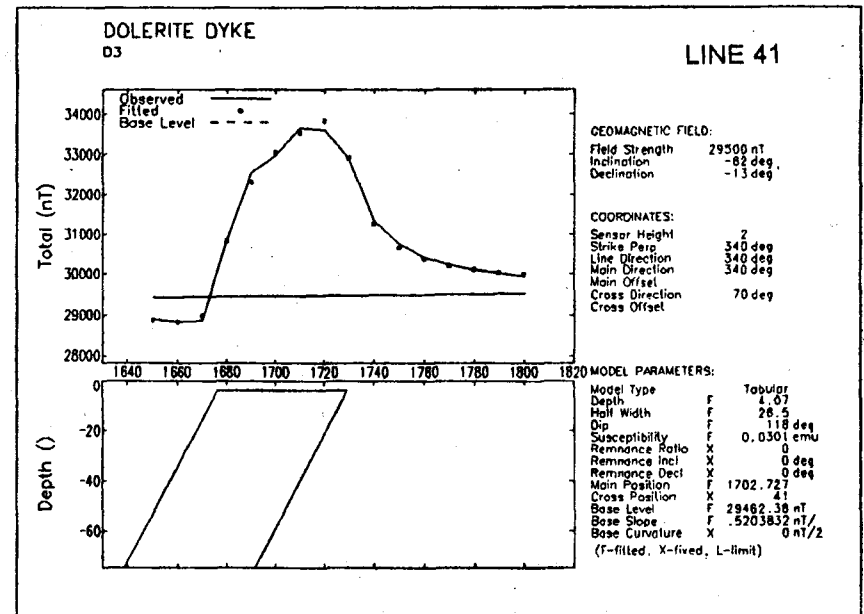
Geosoft MAGMOD-3 Modeling Result

99/11/04



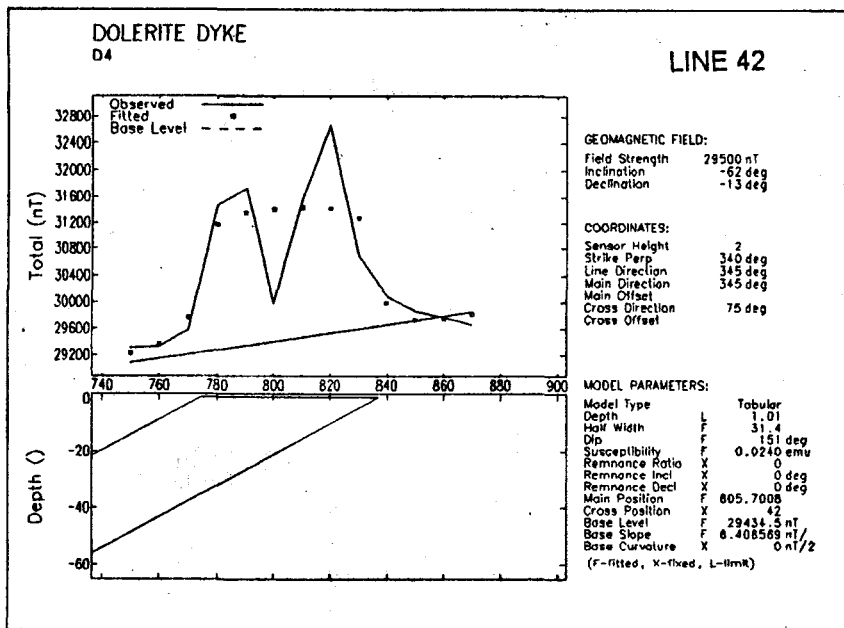
Geosoft MAGMOD-3 Modeling Result

99/11/04



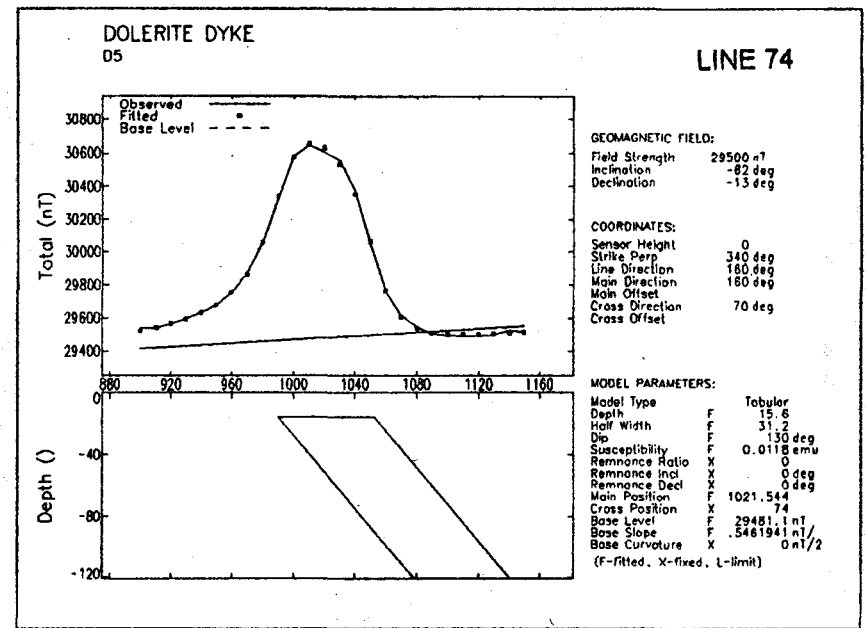
Geosoft MAGMOD-3 Modeling Result

99/11/04



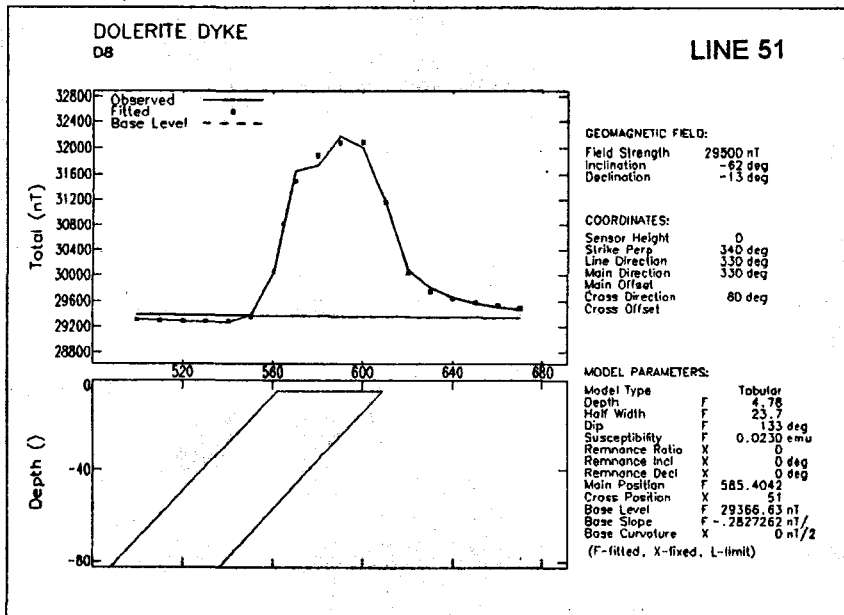
Geosoft MAGMOD-3 Modeling Result

99/11/04



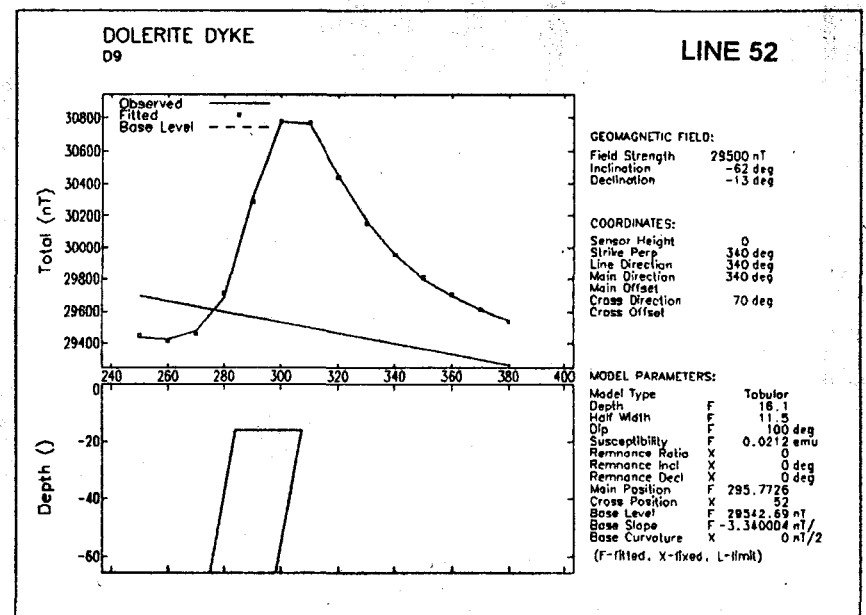
Geosoft MAGMOD-3 Modeling Result

99/11/05



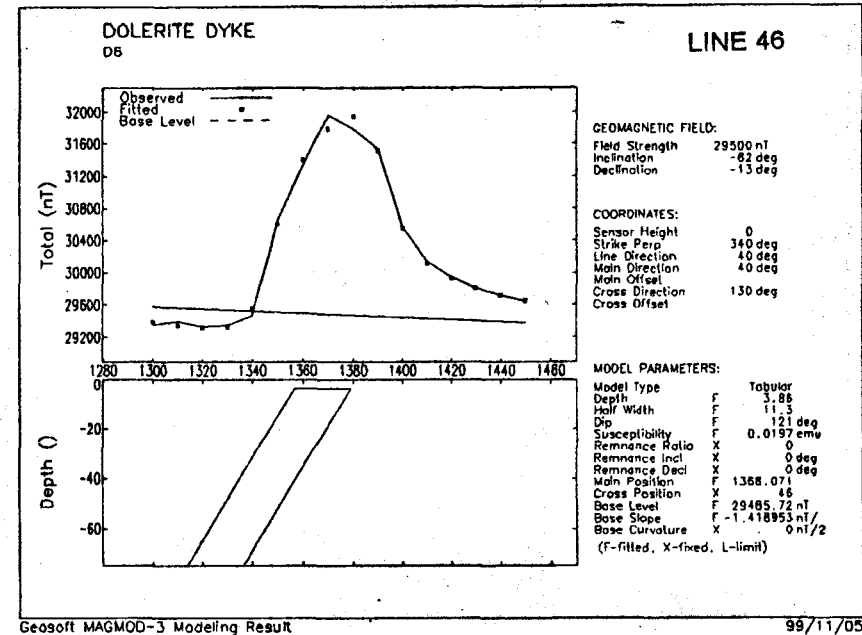
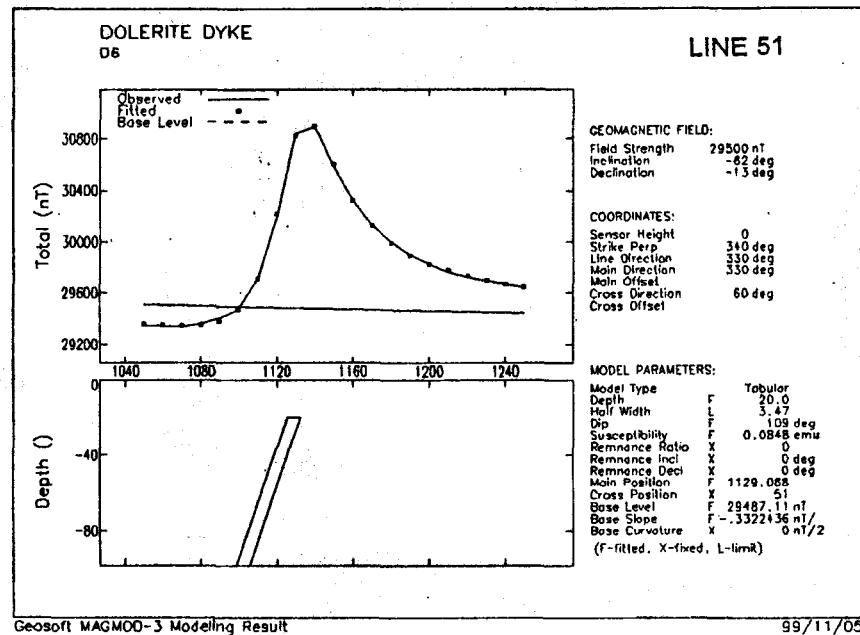
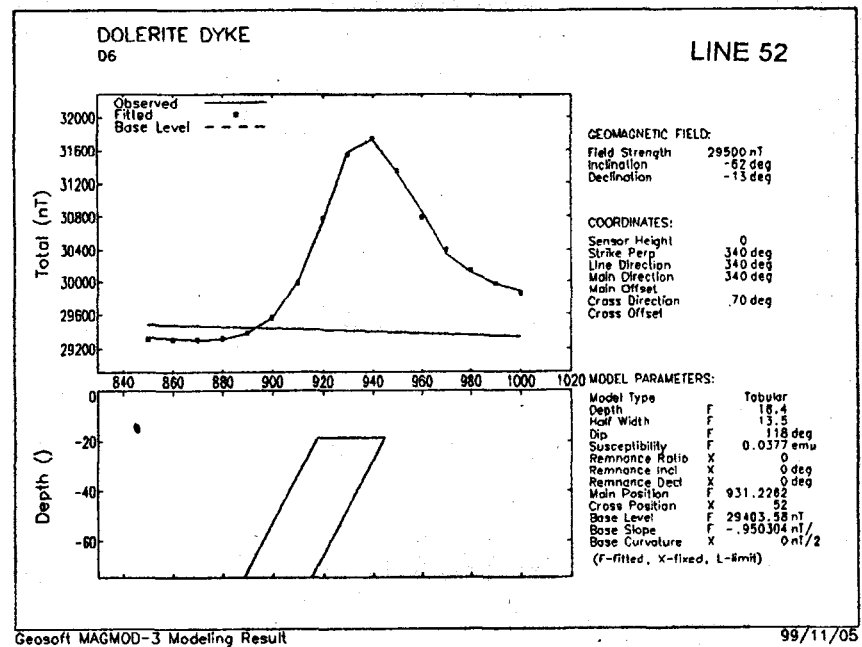
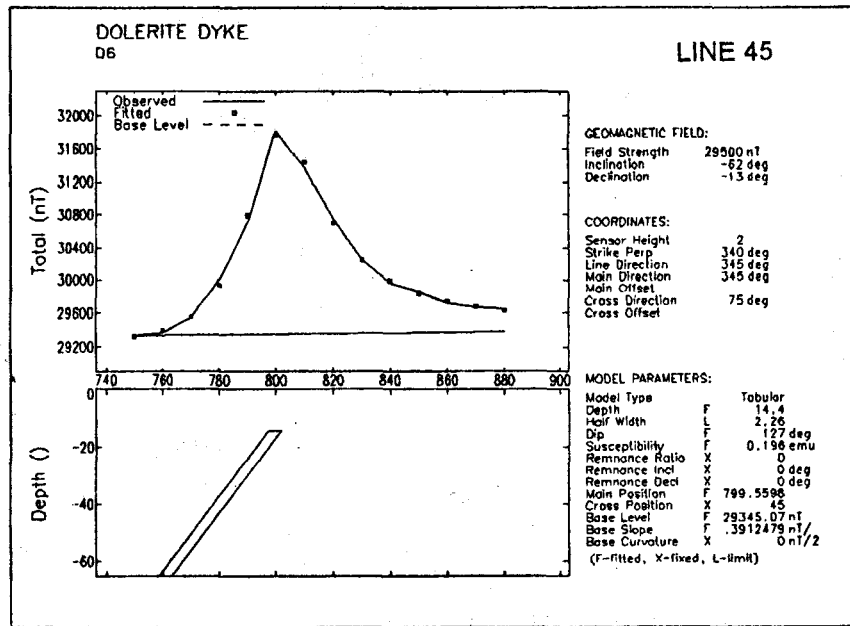
Geosoft MAGMOD-3 Modeling Result

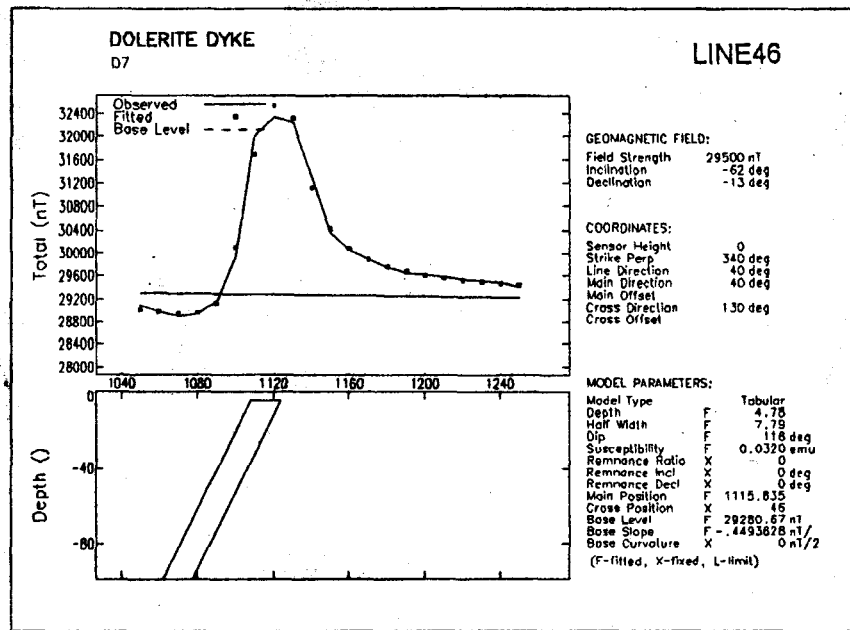
99/11/05



Geosoft MAGMOD-3 Modeling Result

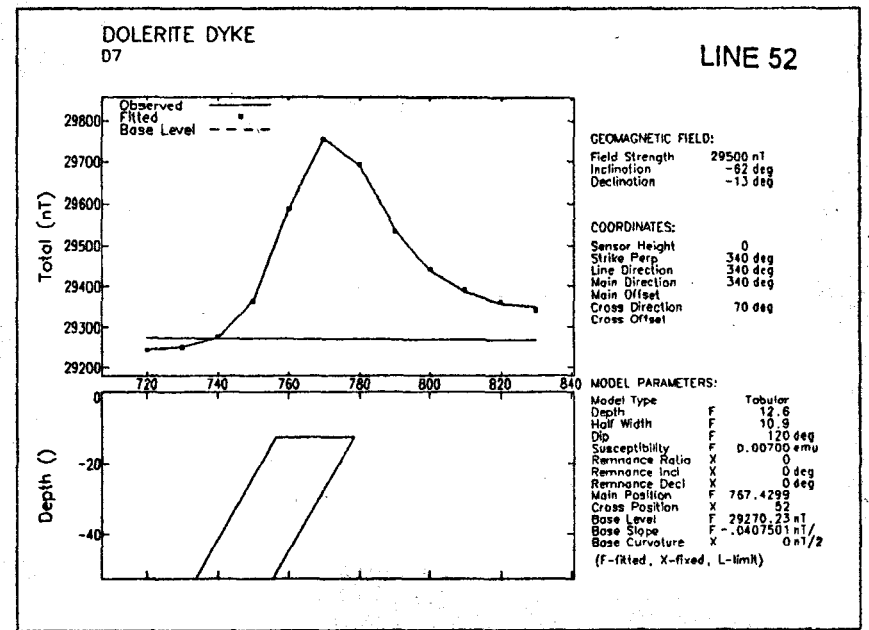
99/11/05





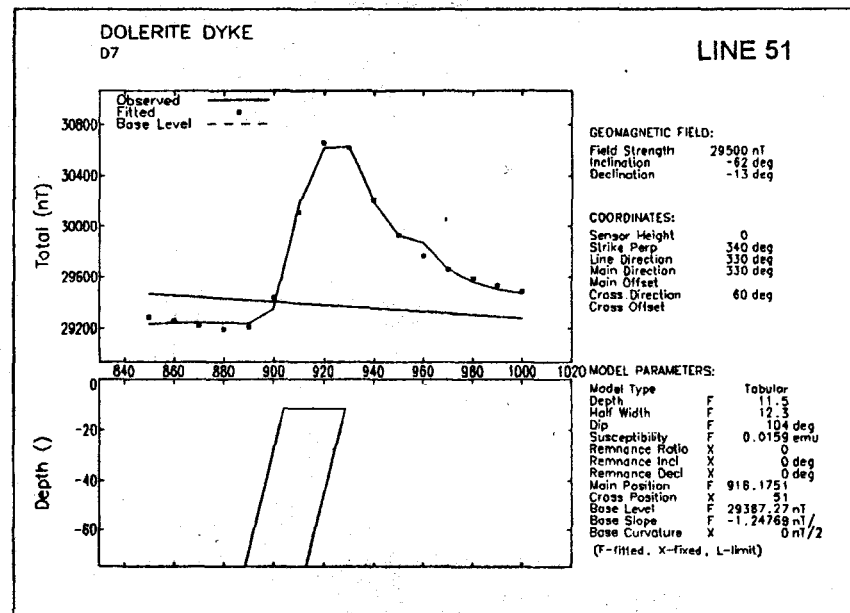
Geosoft MAGMOD-3 Modeling Result

99/11/05



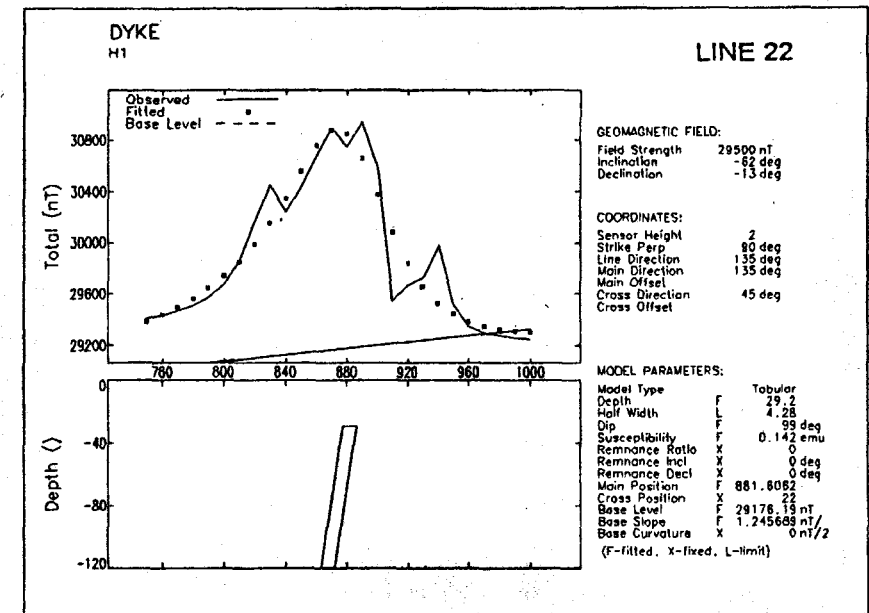
Geosoft MAGMOD-3 Modeling Result

99/11/05



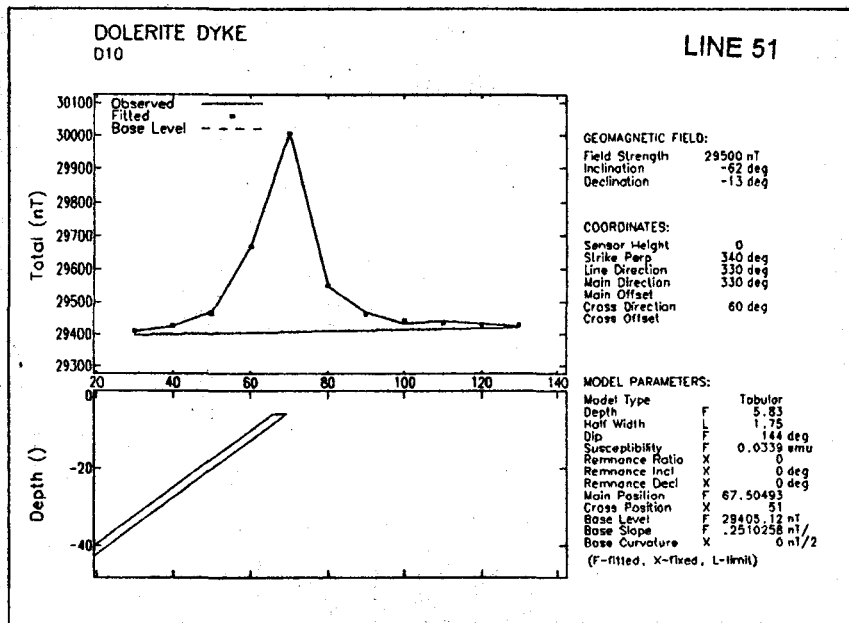
Geosoft MAGMOD-3 Modeling Result

99/11/05



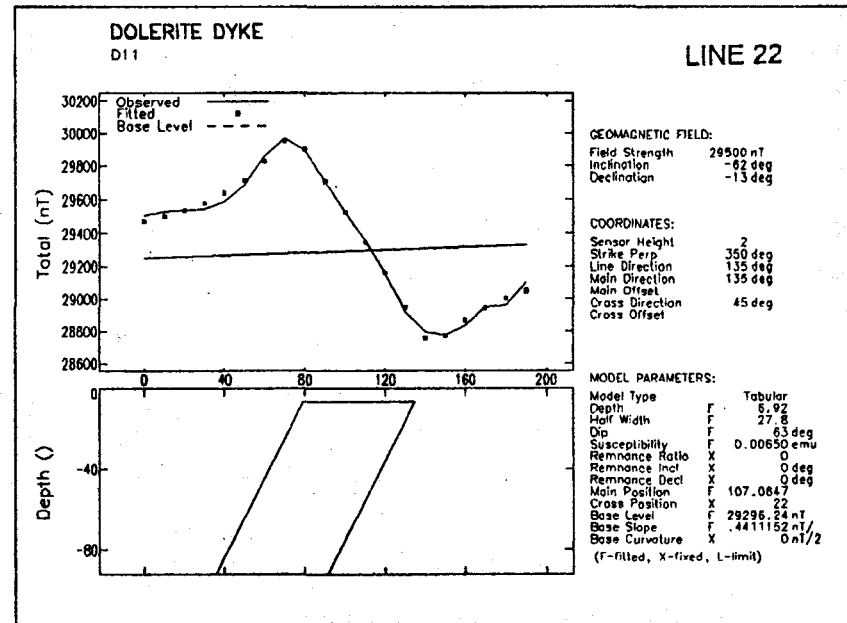
Geosoft MAGMOD-3 Modeling Result

99/11/04



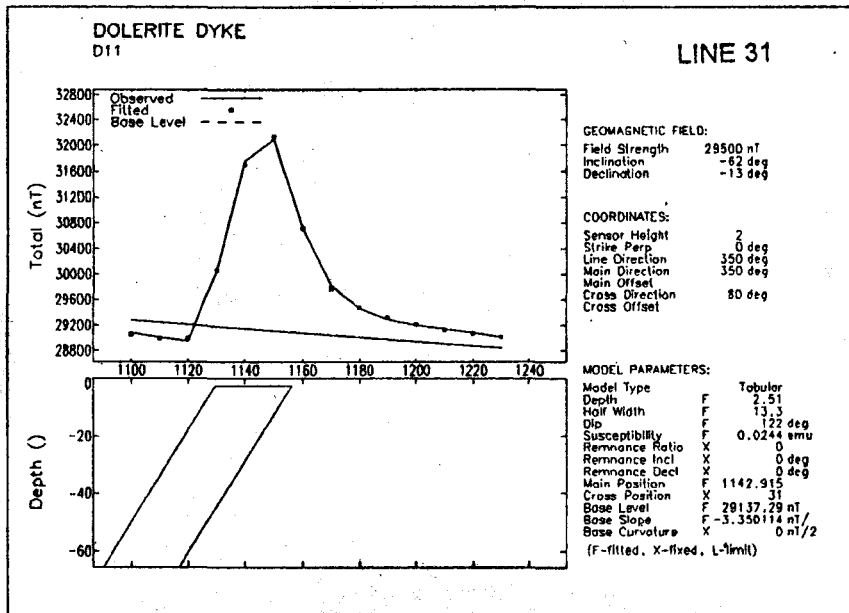
Geosoft MAGMOD-3 Modeling Result

99/11/05



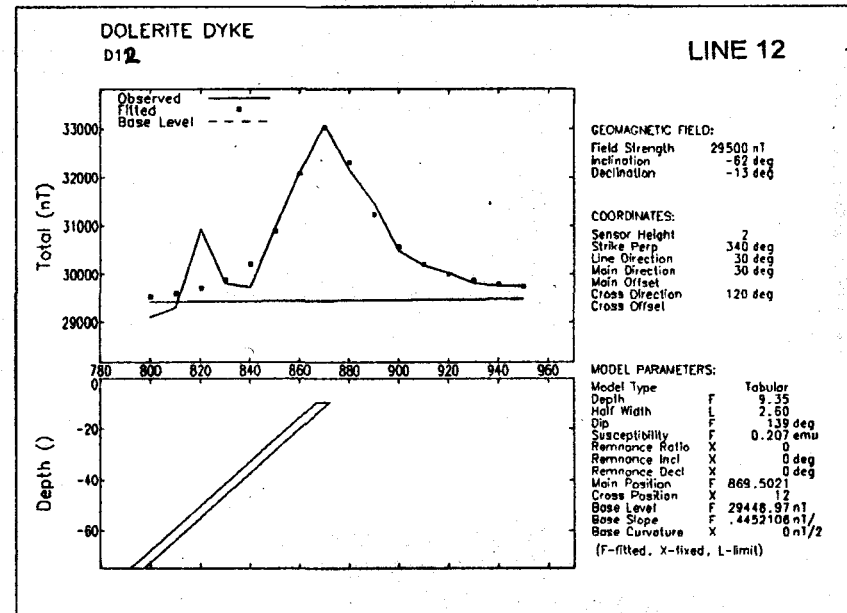
Geosoft MAGMOD-3 Modeling Result

99/11/04



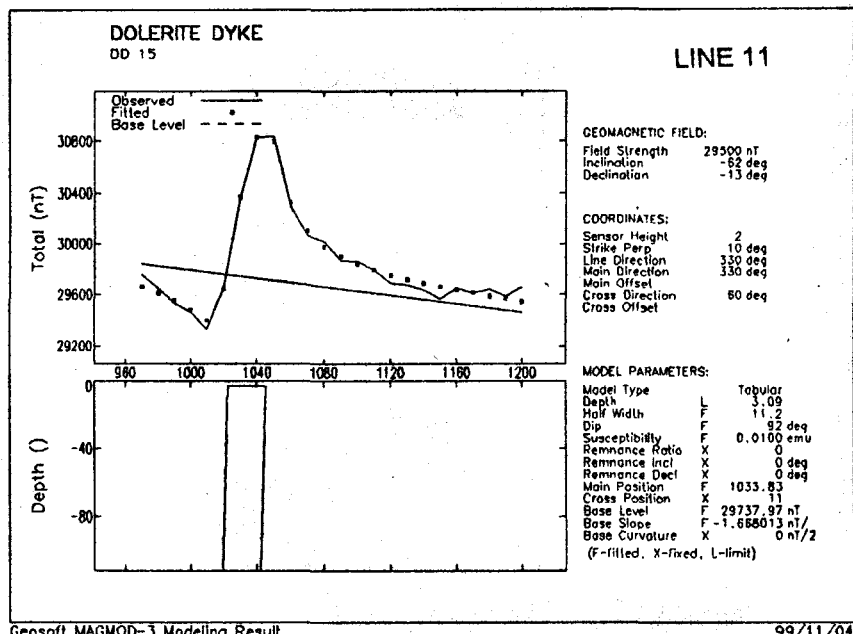
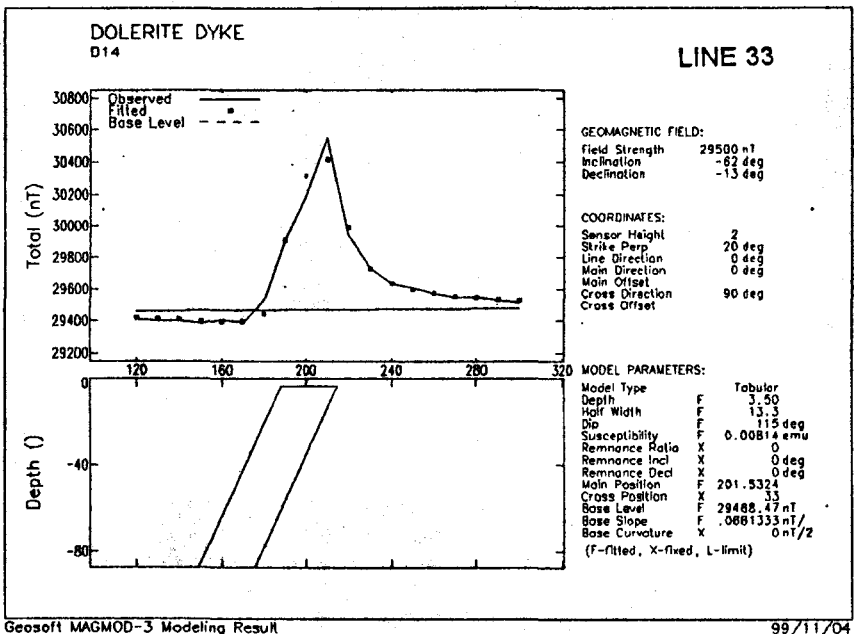
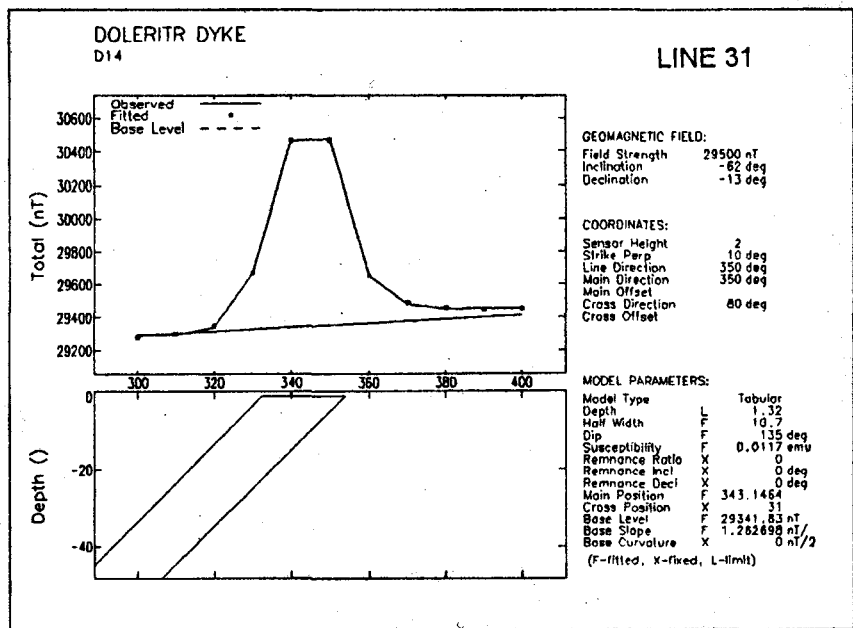
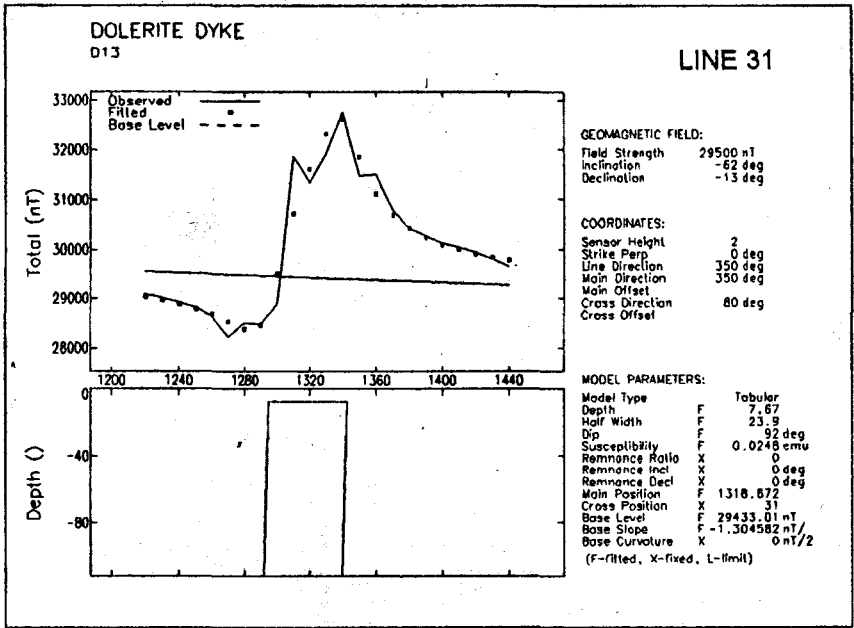
Geosoft MAGMOD-3 Modeling Result

99/11/04



Geosoft MAGMOD-3 Modeling Result

99/11/04

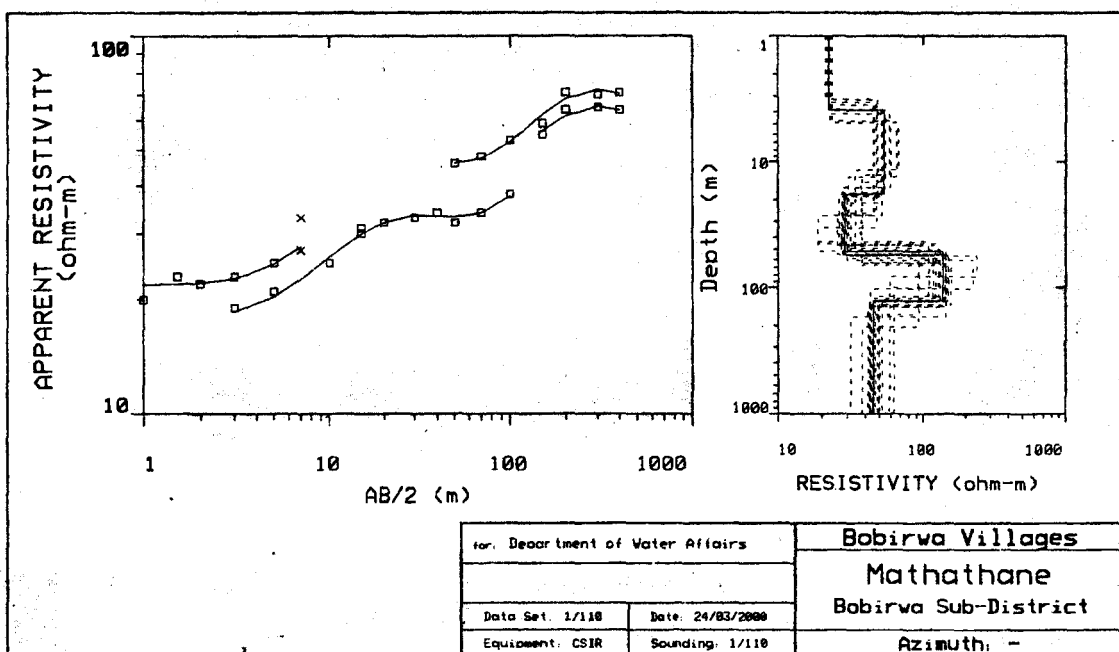


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	22.42		3.86	-3.86	0.172
2	53.38		14.29	-18.16	0.267
3	28.61		33.41	-51.57	1.16
4	136.7		76.01	-127.5	0.555
5	45.17				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	21.250	22.423	23.621
	2	45.107	53.387	67.770
	3	18.778	28.615	37.816
	4	93.207	136.787	238.463
	5	31.504	45.174	62.803
THICK	1	3.167	3.868	4.882
	2	6.779	14.296	29.982
	3	16.561	33.416	52.191
	4	26.498	76.012	157.312
DEPTH	1	3.167	3.868	4.882
	2	11.603	18.164	33.496
	3	43.442	51.580	66.651
	4	82.265	127.592	206.210



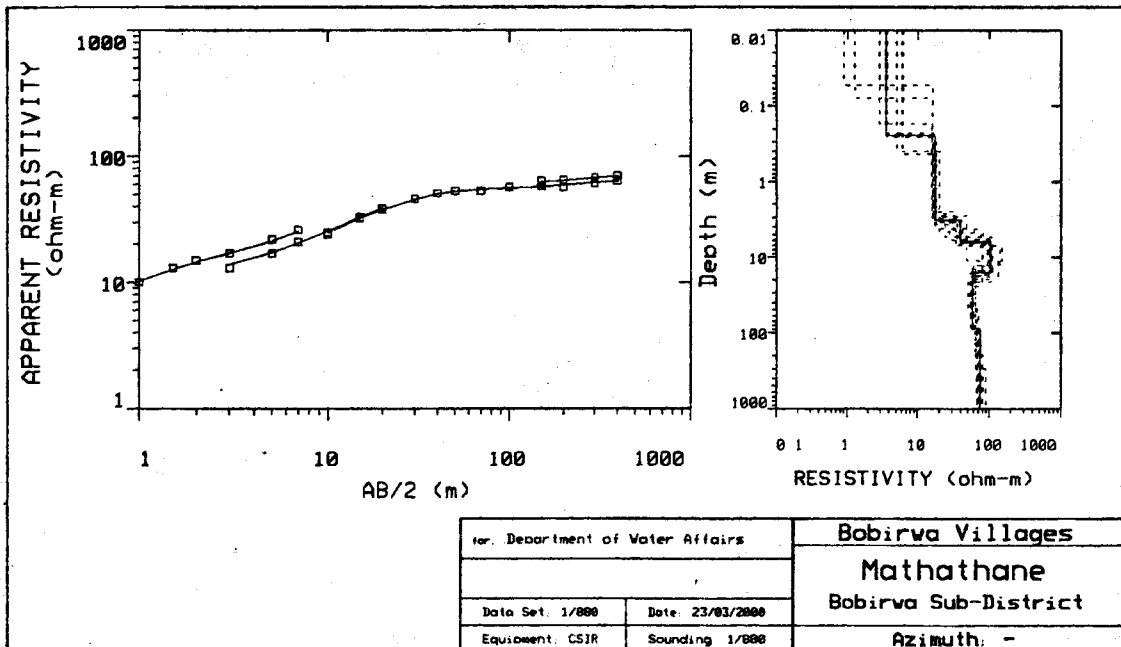
for: Department of Water Affairs		Bobirwa Villages
Data Set: 1/110	Date: 24/03/2000	Mathathane
Equipment: CSIR	Sounding: 1/110	Bobirwa Sub-District
		Azimuth: -

#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	3.62		0.243	-0.243	0.0671
2	17.26		2.96	-3.20	0.171
3	39.34		2.96	-6.16	0.0752
4	102.9		9.63	-15.79	0.0935
5	57.89		71.90	-87.70	1.24
6	74.74				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

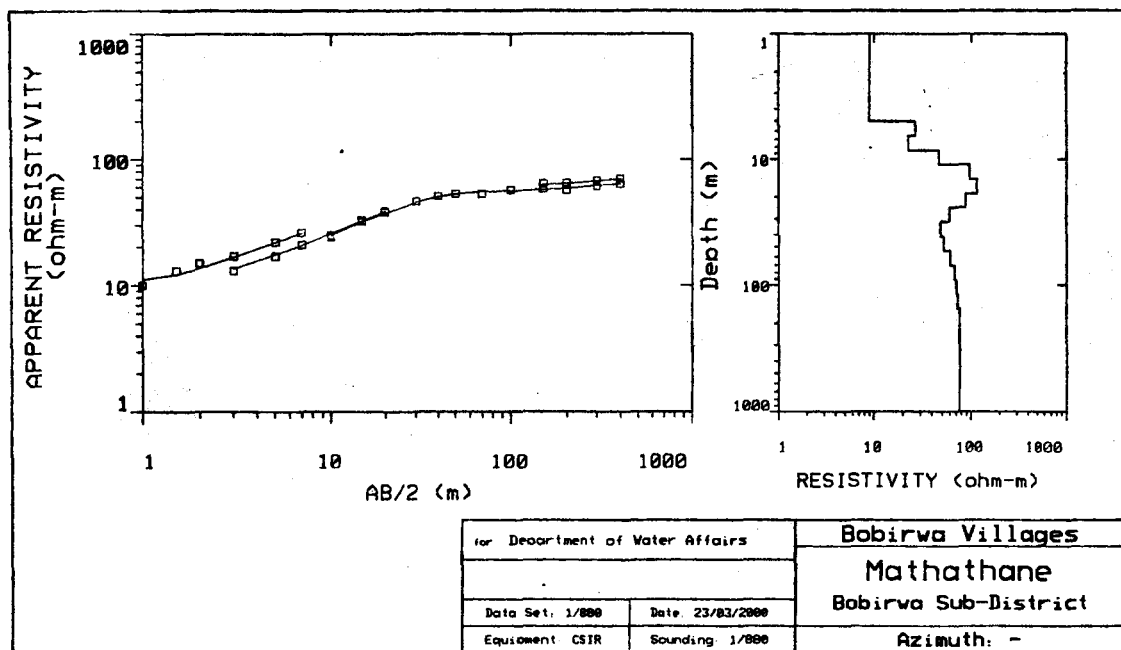
	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	0.890	3.629	6.272
	2	15.617	17.263	20.003
	3	24.082	39.346	75.360
	4	78.567	102.939	148.206
	5	50.838	57.895	64.744
	6	67.602	74.748	89.697
THICK	1	0.054	0.244	0.439
	2	2.333	2.961	4.204
	3	1.092	2.961	8.204
	4	4.003	9.631	18.461
	5	27.951	71.909	283.672
DEPTH	1	0.054	0.244	0.439
	2	2.507	3.205	4.604
	3	4.760	6.166	10.997
	4	11.056	15.797	24.092
	5	47.448	87.705	298.770



for. Department of Water Affairs		<b>Bobirwa Villages</b>
		<b>Mathathane</b>
		<b>Bobirwa Sub-District</b>
Data Set: 1/880	Date: 23/03/2000	
Equipment: CSIR	Sounding: 1/880	Azimuth: -

#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	8.92		5.00	* -5.00	0.560
2	26.90		1.50	* -6.50	0.0560
3	22.47		1.96	* -8.46	0.0873
4	46.13		2.55	* -11.02	0.0553
5	95.09		3.32	* -14.34	0.0349
6	114.3		4.32	* -18.66	0.0378
7	86.50		5.62	* -24.29	0.0650
8	59.04		7.32	* -31.62	0.124
9	48.72		9.53	* -41.15	0.195
10	51.32		12.40	* -53.56	0.241
11	59.87		16.14	* -69.71	0.269
12	66.95		21.01	* -90.72	0.313
13	69.95		27.35	* -118.0	0.390
14	71.92		35.59	* -153.6	0.494
15	75.44				

"\*" INDICATES FIXED PARAMETER

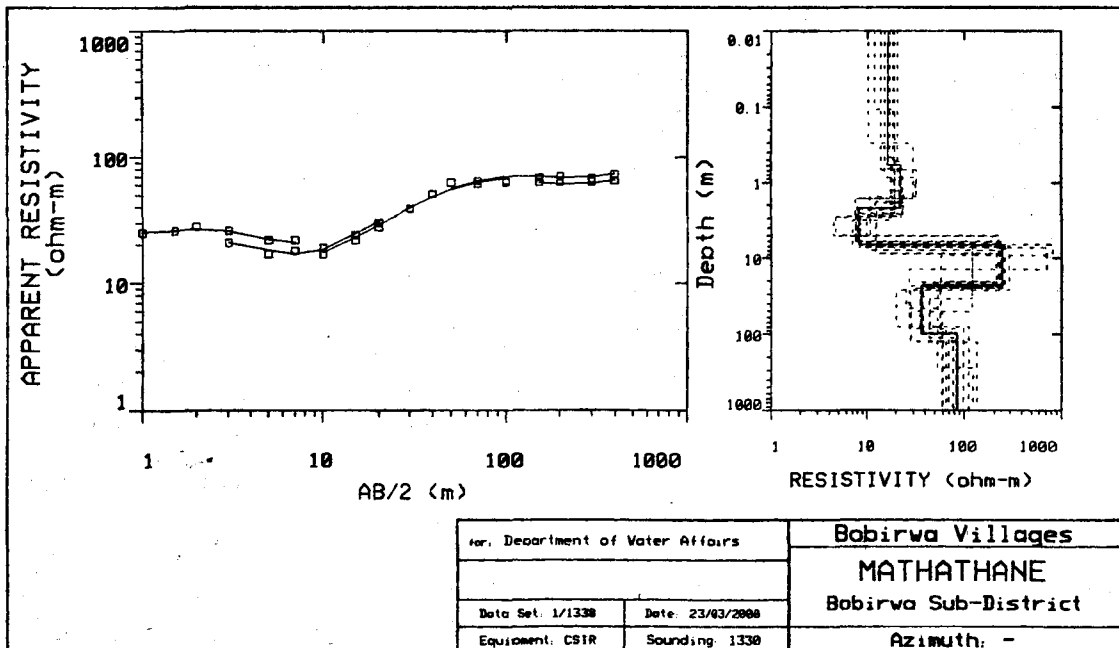


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	16.45		0.581	-0.581	0.0353
2	22.22		1.61	-2.20	0.0728
3	8.10		4.36	-6.56	0.539
4	238.4		16.29	-22.86	0.0683
5	36.39		75.12	-97.98	2.06
6	84.78				

ALL PARAMETERS ARE FREE

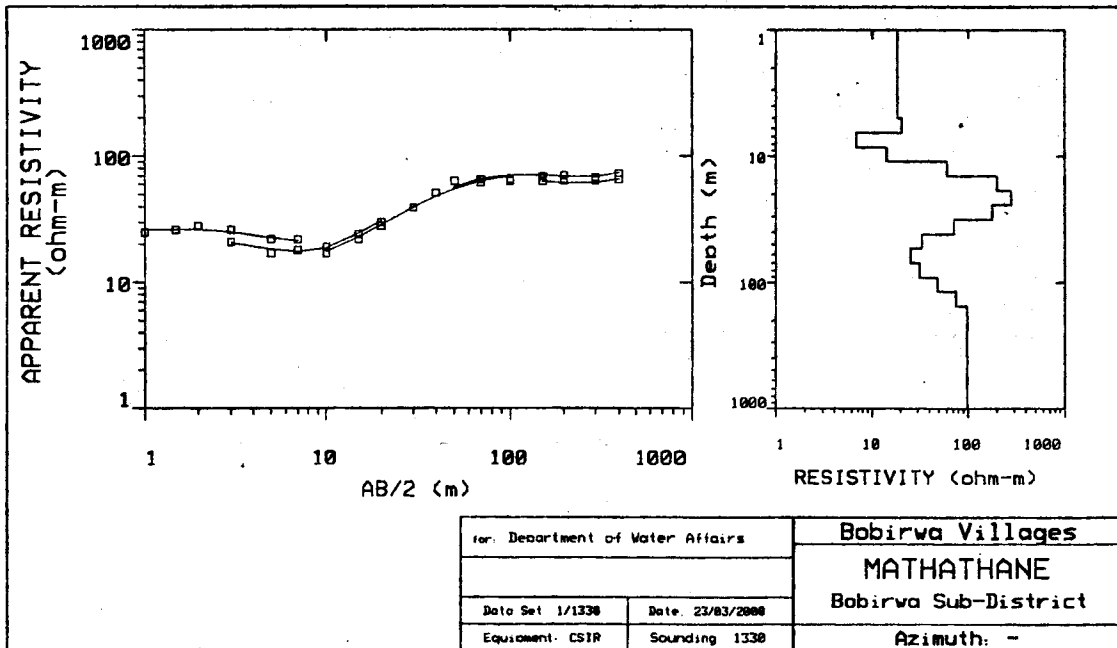
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	10.082	16.450	20.644
	2	17.568	22.224	32.178
	3	4.397	8.100	12.323
	4	120.387	238.457	821.193
	5	19.953	36.397	57.788
	6	59.375	84.787	134.357
THICK	1	0.108	0.581	1.295
	2	0.673	1.619	2.676
	3	2.254	4.368	7.057
	4	2.708	16.299	43.901
	5	22.670	75.122	258.264
DEPTH	1	0.108	0.581	1.295
	2	1.534	2.201	3.140
	3	5.051	6.568	8.867
	4	9.265	22.867	50.476
	5	46.135	97.989	280.539



#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	18.51		5.00	* -5.00	0.270
2	20.24		1.50	* -6.50	0.0744
3	6.67		1.96	* -8.46	0.293
4	14.14		2.55	* -11.02	0.180
5	60.40		3.32	* -14.34	0.0550
6	196.7		4.32	* -18.66	0.0219
7	286.0		5.62	* -24.29	0.0196
8	175.1		7.32	* -31.62	0.0418
9	70.81		9.53	* -41.15	0.134
10	33.22		12.40	* -53.56	0.373
11	25.37		16.14	* -69.71	0.636
12	31.32		21.01	* -90.72	0.670
13	48.72		27.35	* -118.0	0.561
14	74.39		35.59	* -153.6	0.478
15	98.43				

"\*" INDICATES FIXED PARAMETER

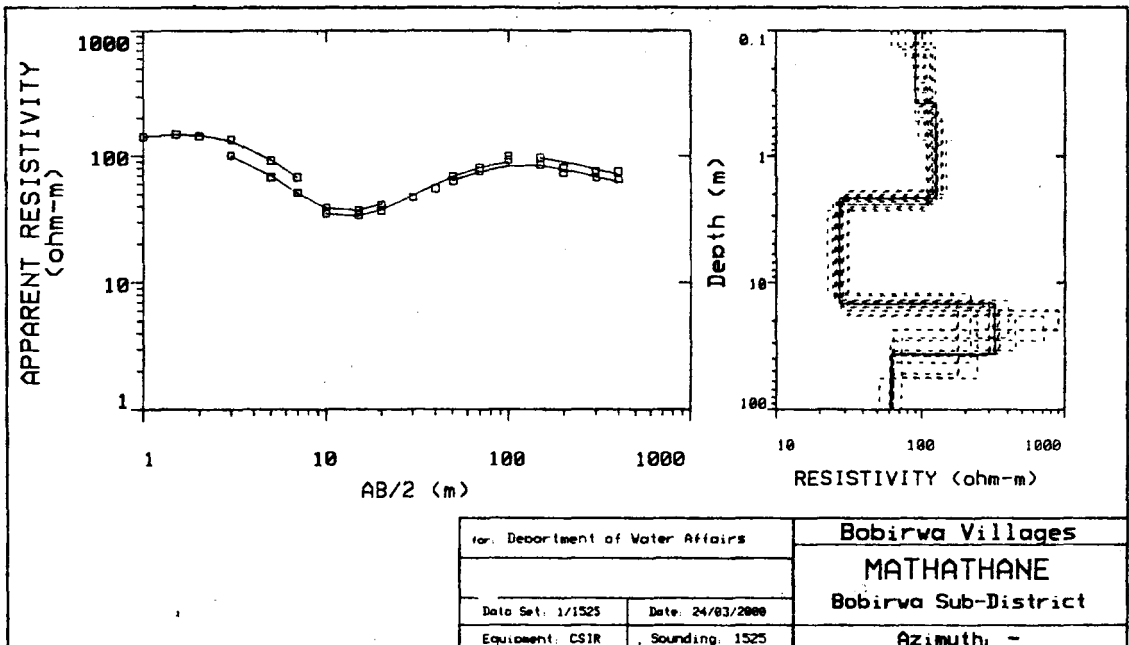


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
1	90.39		0.379	0.0 -0.379	0.00420
2	124.5		1.77	-2.15	0.0142
3	27.12		12.48	-14.63	0.460
4	320.7		22.04	-36.68	0.0687
5	61.99				

ALL PARAMETERS ARE FREE

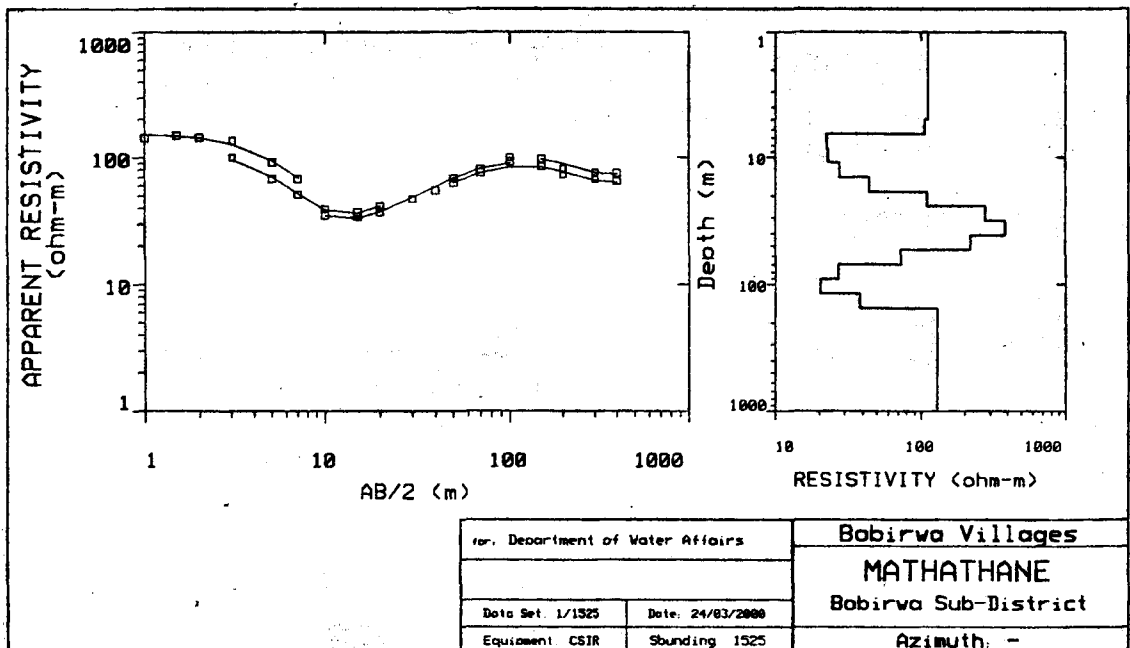
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	61.789	90.391	114.646
	2	107.167	124.518	145.599
	3	22.603	27.123	31.860
	4	176.435	320.764	903.442
	5	51.665	61.998	71.837
THICK	1	0.136	0.379	0.823
	2	1.276	1.774	2.446
	3	9.426	12.482	16.384
	4	6.890	22.048	43.149
DEPTH	1	0.136	0.379	0.823
	2	1.865	2.153	2.706
	3	12.132	14.636	18.291
	4	23.303	36.683	56.868



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	111.0		5.00	* -5.00	0.0450
2	105.1		1.50	* -6.50	0.0143
3	22.44		1.96	* -8.46	0.0874
4	22.82		2.55	* -11.02	0.111
5	27.41		3.32	* -14.34	0.121
6	43.93		4.32	* -18.66	0.0984
7	109.4		5.62	* -24.29	0.0514
8	274.7		7.32	* -31.62	0.0266
9	381.6		9.53	* -41.15	0.0249
10	219.8		12.40	* -53.56	0.0564
11	73.16		16.14	* -69.71	0.220
12	27.10		21.01	* -90.72	0.775
13	20.23		27.35	* -118.0	1.35
14	38.00		35.59	* -153.6	0.936
15	129.6				

"\*" INDICATES FIXED PARAMETER

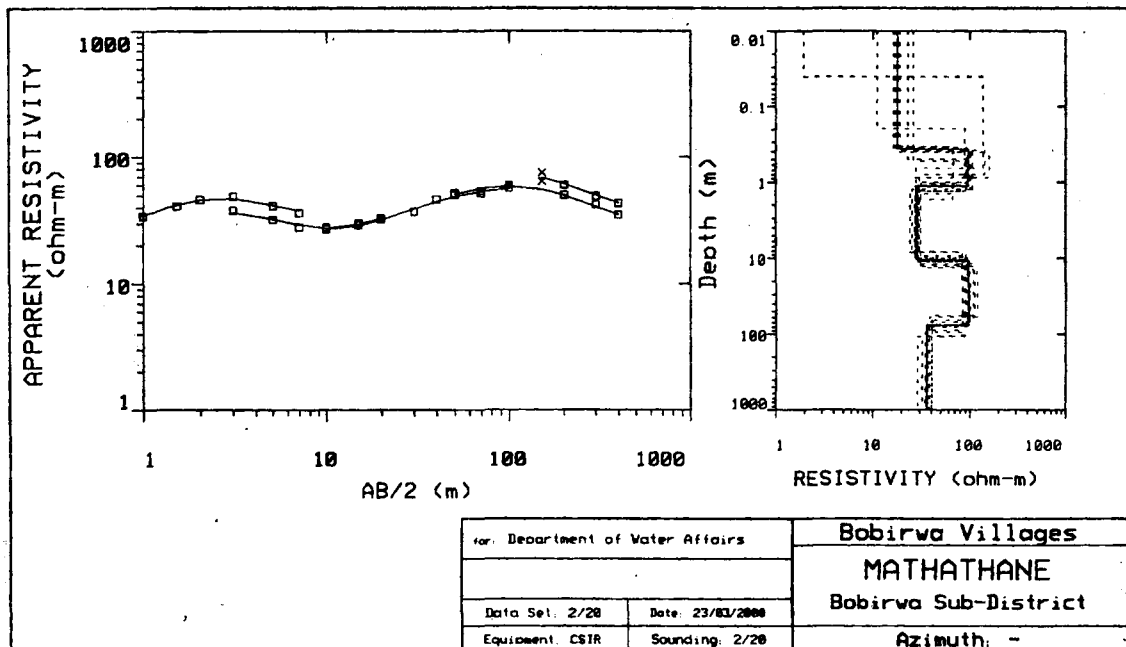


L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	18.16		0.365	-0.365	0.0201
2	96.41		0.767	-1.13	0.00796
3	28.45		9.40	-10.53	0.330
4	96.56		65.72	-76.26	0.680
5	35.92				

ALL PARAMETERS ARE FREE

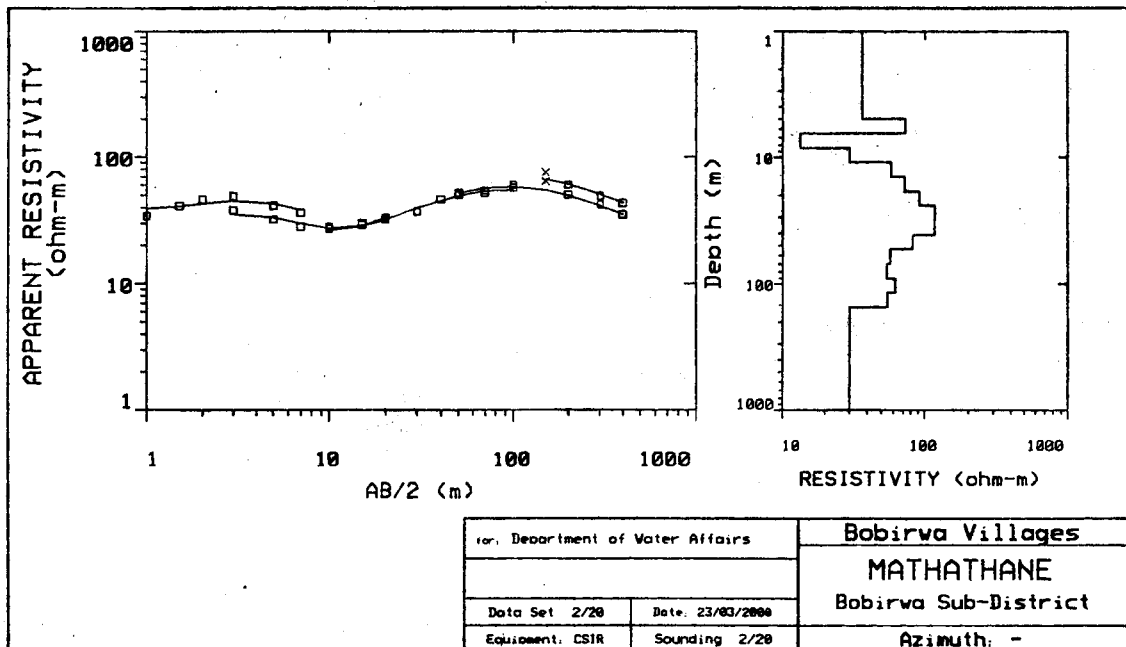
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1.970	18.166	26.401
	2	66.932	96.420	158.334
	3	24.282	28.453	31.196
	4	83.000	96.569	118.398
	5	28.731	35.921	40.165
THICK	1	0.040	0.365	0.530
	2	0.421	0.768	1.357
	3	6.899	9.407	12.124
	4	44.929	65.724	97.897
DEPTH	1	0.040	0.365	0.530
	2	0.662	1.133	1.707
	3	8.156	10.540	13.166
	4	56.848	76.264	108.199



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	36.66		5.00	* -5.00	0.136
2	72.00		1.50	* -6.50	0.0209
3	13.40		1.96	* -8.46	0.146
4	29.76		2.55	* -11.02	0.0857
5	57.32		3.32	* -14.34	0.0579
6	71.59		4.32	* -18.66	0.0604
7	90.98		5.62	* -24.29	0.0618
8	117.6		7.32	* -31.62	0.0622
9	116.1		9.53	* -41.15	0.0820
10	82.20		12.40	* -53.56	0.150
11	57.12		16.14	* -69.71	0.282
12	54.00		21.01	* -90.72	0.389
13	61.83		27.35	* -118.0	0.442
14	54.83		35.59	* -153.6	0.649
15	29.96				

"\*" INDICATES FIXED PARAMETER

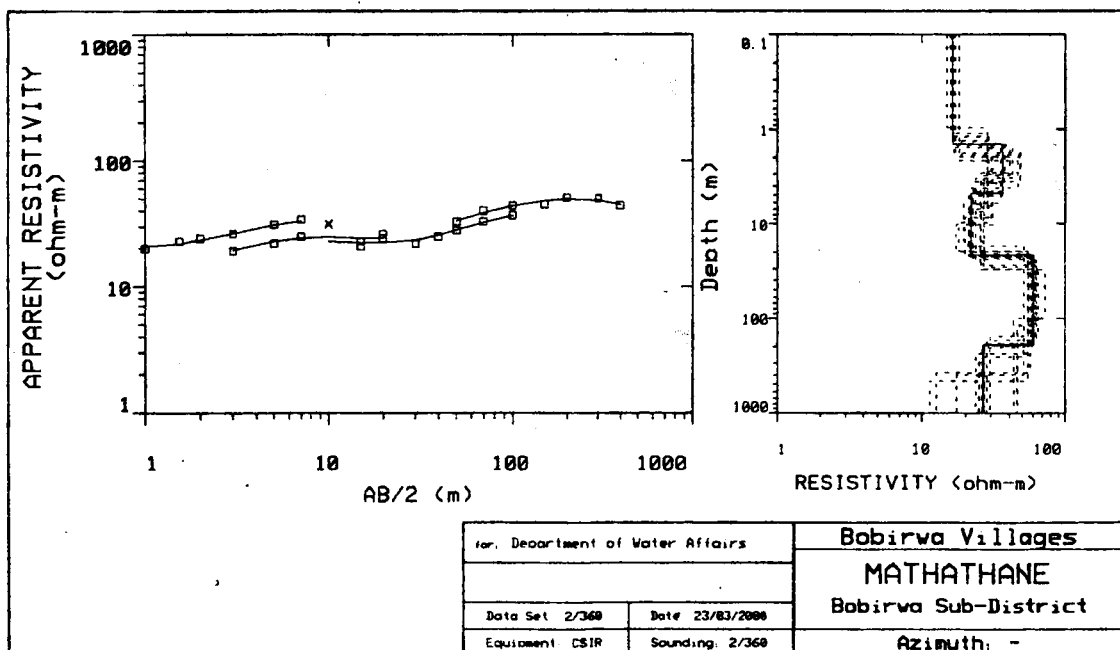


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	16.42		1.42	-1.42	0.0870
2	35.83		3.31	-4.74	0.0924
3	22.08		16.76	-21.50	0.758
4	60.38		170.1	-191.6	2.81
5	26.64				

ALL PARAMETERS ARE FREE

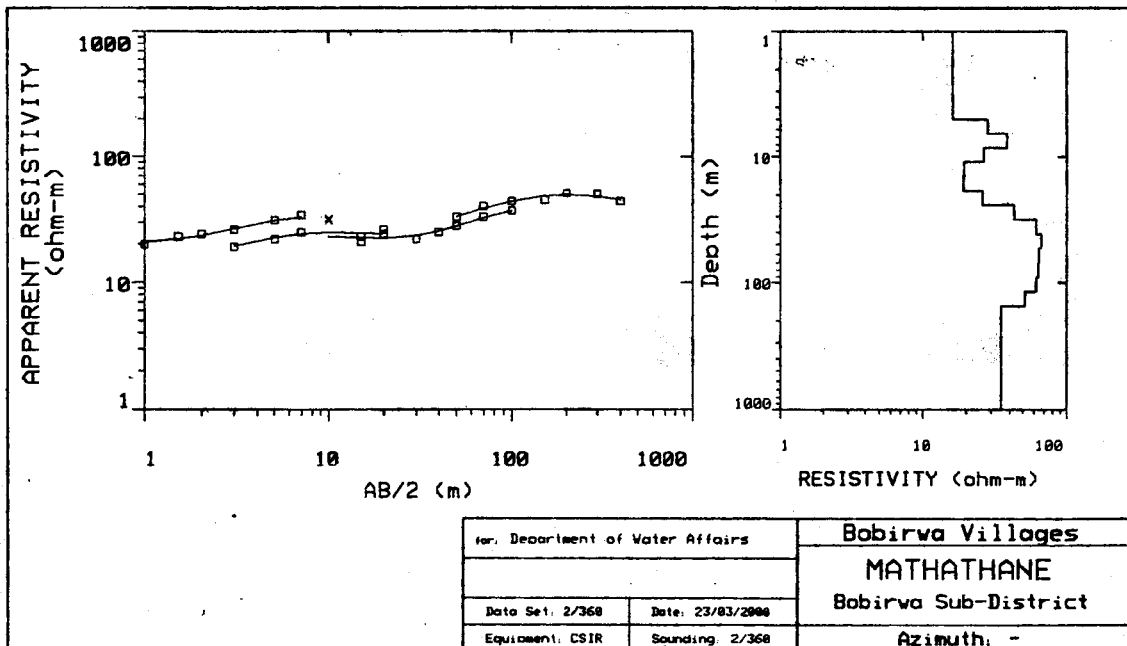
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	14.927	16.424	18.170
	2	28.316	35.836	48.241
	3	17.172	22.089	26.858
	4	51.265	60.384	72.460
	5	11.269	26.643	46.172
THICK	1	0.966	1.429	2.162
	2	1.109	3.314	8.857
	3	9.514	16.764	27.234
	4	70.453	170.167	441.961
DEPTH	1	0.966	1.429	2.162
	2	2.904	4.743	10.207
	3	17.161	21.507	30.312
	4	100.766	191.675	461.483



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	16.15		5.00	* -5.00	0.309
2	28.34		1.50	* -6.50	0.0531
3	38.23		1.96	* -8.46	0.0513
4	26.73		2.55	* -11.02	0.0954
5	19.48		3.32	* -14.34	0.170
6	19.19		4.32	* -18.66	0.225
7	26.21		5.62	* -24.29	0.214
8	42.93		7.32	* -31.62	0.170
9	61.66		9.53	* -41.15	0.154
10	67.37		12.40	* -53.56	0.184
11	64.43		16.14	* -69.71	0.250
12	63.45		21.01	* -90.72	0.331
13	61.91		27.35	* -118.0	0.441
14	51.46		35.59	* -153.6	0.691
15	34.83				

"\*" INDICATES FIXED PARAMETER

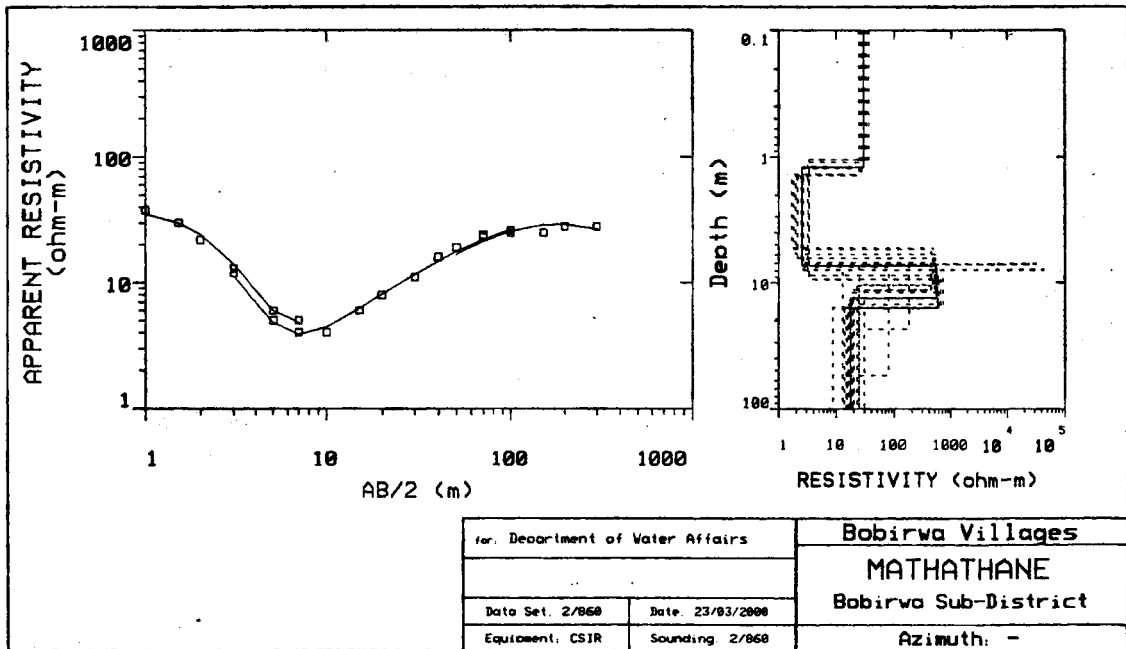


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	29.43		1.21	-1.21	0.0411
2	2.53		6.09	-7.31	2.40
3	541.9		5.86	-13.17	0.0108
4	17.69				

ALL PARAMETERS ARE FREE

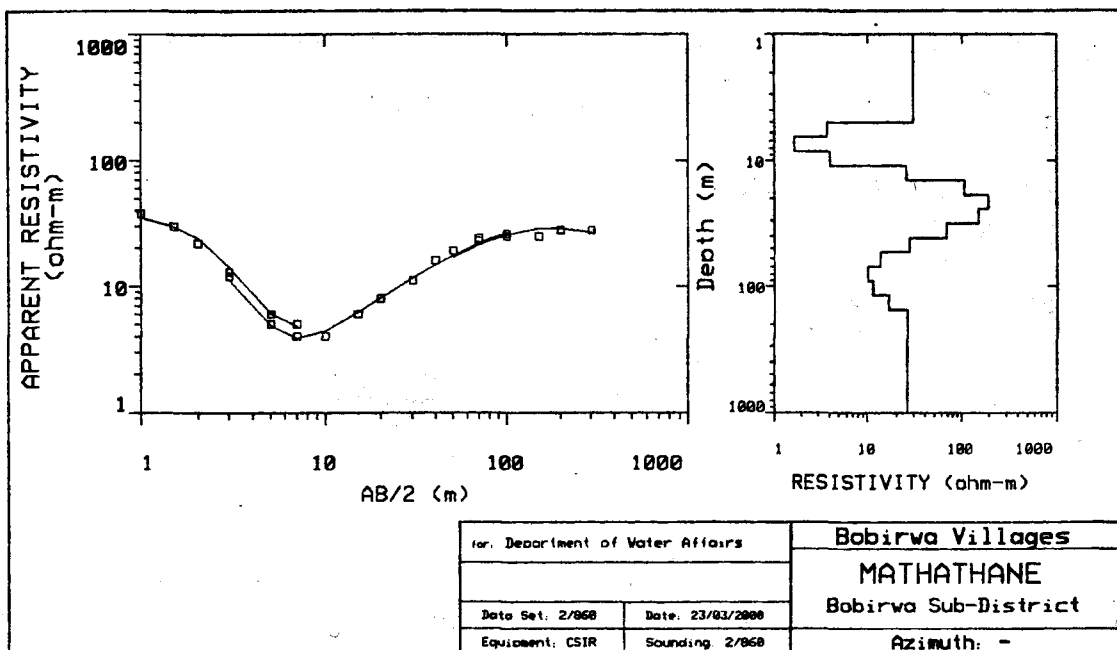
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	24.530	29.436	36.359
	2	1.689	2.532	3.339
	3	79.418	541.980	42928.047
	4	8.892	17.697	30.131
THICK	1	1.043	1.211	1.407
	2	3.858	6.100	8.328
	3	0.072	5.861	46.863
DEPTH	1	1.043	1.211	1.407
	2	5.266	7.311	9.430
	3	7.111	13.173	54.307



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	29.60		5.00	* -5.00	0.168
2	3.74		1.50	* -6.50	0.402
3	1.62		1.96	* -8.46	1.20
4	4.03		2.55	* -11.02	0.633
5	25.31		3.32	* -14.34	0.131
6	105.5		4.32	* -18.66	0.0409
7	193.6		5.62	* -24.29	0.0290
8	152.0		7.32	* -31.62	0.0481
9	68.47		9.53	* -41.15	0.139
10	27.31		12.40	* -53.56	0.454
11	13.62		16.14	* -69.71	1.18
12	10.18		21.01	* -90.72	2.06
13	11.41		27.35	* -118.0	2.39
14	16.61		35.59	* -153.6	2.14
15	25.96				

"\*" INDICATES FIXED PARAMETER

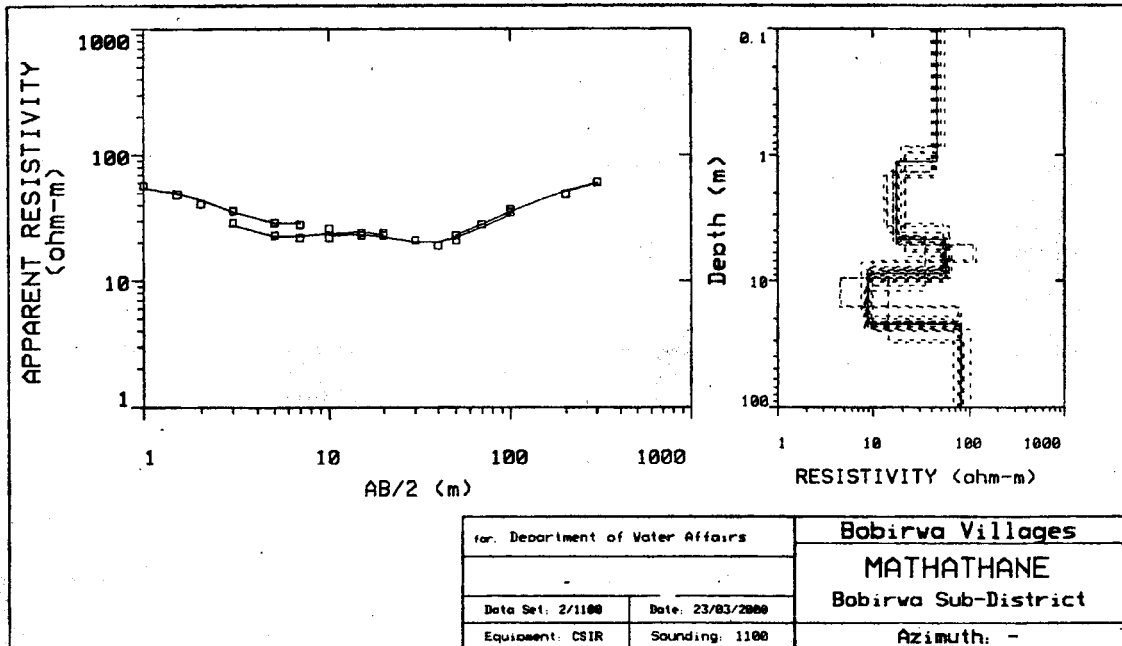


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	46.00		1.12	-1.12	0.0245
2	17.47		3.56	-4.69	0.204
3	55.49		4.08	-8.77	0.0735
4	8.84		13.22	-22.00	1.49
5	80.47				

ALL PARAMETERS ARE FREE

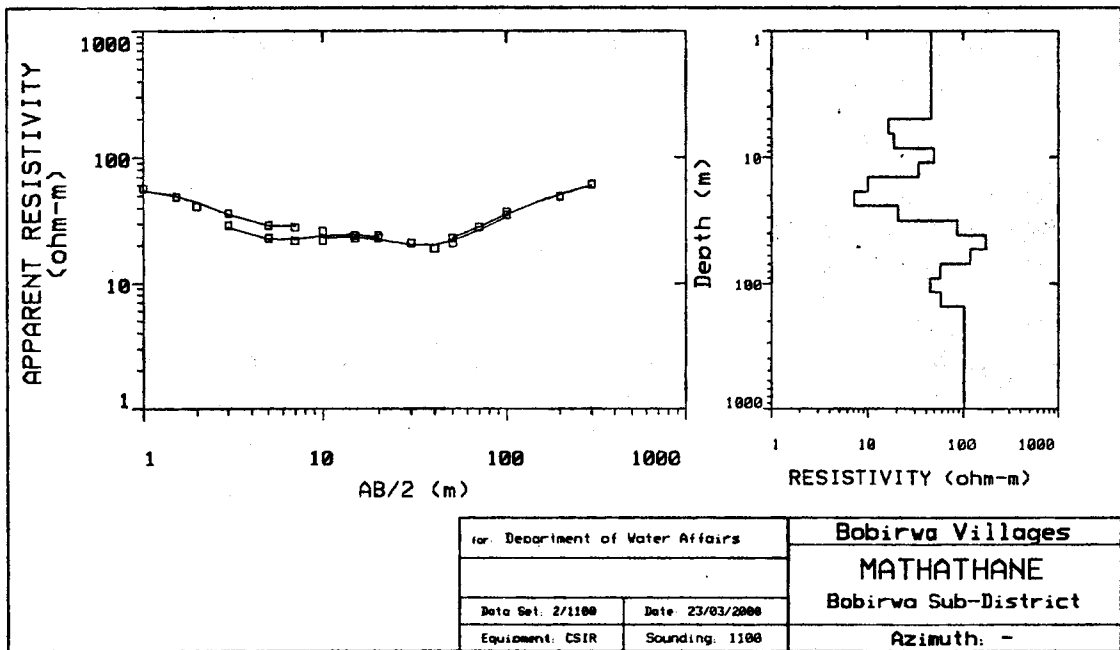
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	40.426	46.005	54.536
	2	13.078	17.478	21.512
	3	34.101	55.496	116.461
	4	4.510	8.840	14.392
	5	66.778	80.472	100.955
THICK	1	0.849	1.127	1.522
	2	2.160	3.569	5.469
	3	1.696	4.083	7.628
	4	6.419	13.223	22.766
DEPTH	1	0.849	1.127	1.522
	2	3.510	4.696	6.436
	3	6.890	8.778	12.006
	4	15.992	22.001	31.001



#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	45.84		5.00	* -5.00	0.109
2	16.56		1.50	* -6.50	0.0909
3	18.81		1.96	* -8.46	0.104
4	49.27		2.55	* -11.02	0.0518
5	33.12		3.32	* -14.34	0.100
6	10.16		4.32	* -18.66	0.425
7	7.14		5.62	* -24.29	0.788
8	20.63		7.32	* -31.62	0.354
9	86.95		9.53	* -41.15	0.109
10	169.6		12.40	* -53.56	0.0731
11	116.4		16.14	* -69.71	0.138
12	57.89		21.01	* -90.72	0.362
13	44.01		27.35	* -118.0	0.621
14	58.75		35.59	* -153.6	0.605
15	101.5				

"\*" INDICATES FIXED PARAMETER

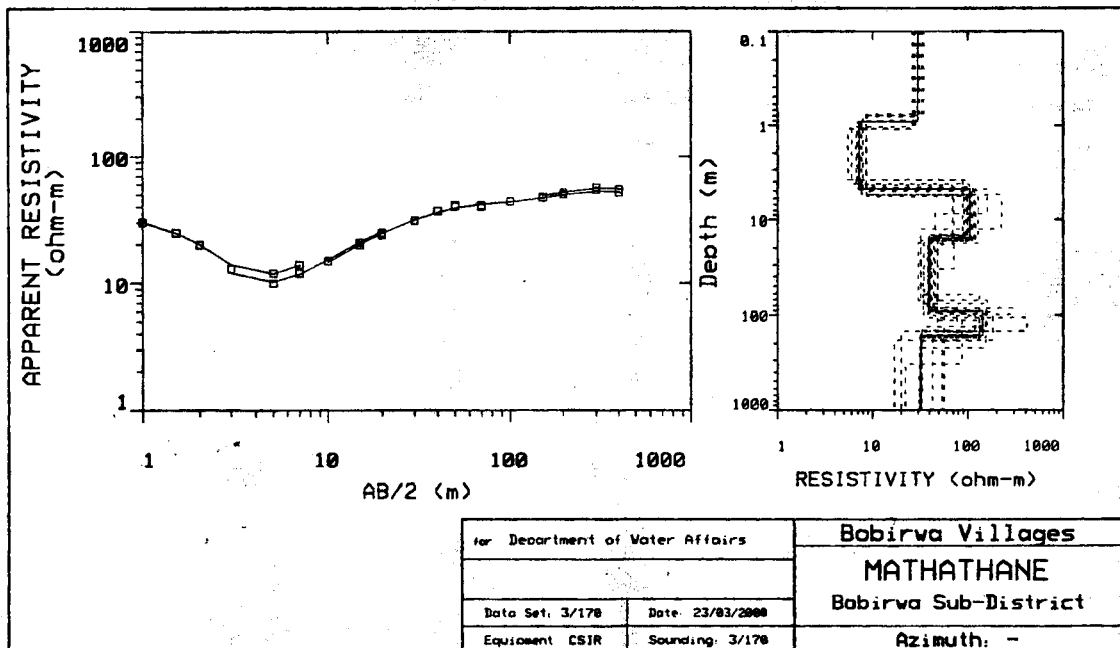


#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
1	29.91		0.912	0.0	0.0305
2	7.20		3.81	-0.912	0.530
3	105.4		10.96	-4.73	0.104
4	39.36		75.47	-15.69	1.91
5	142.6		73.67	-91.17	0.516
6	32.18			-164.8	

ALL PARAMETERS ARE FREE

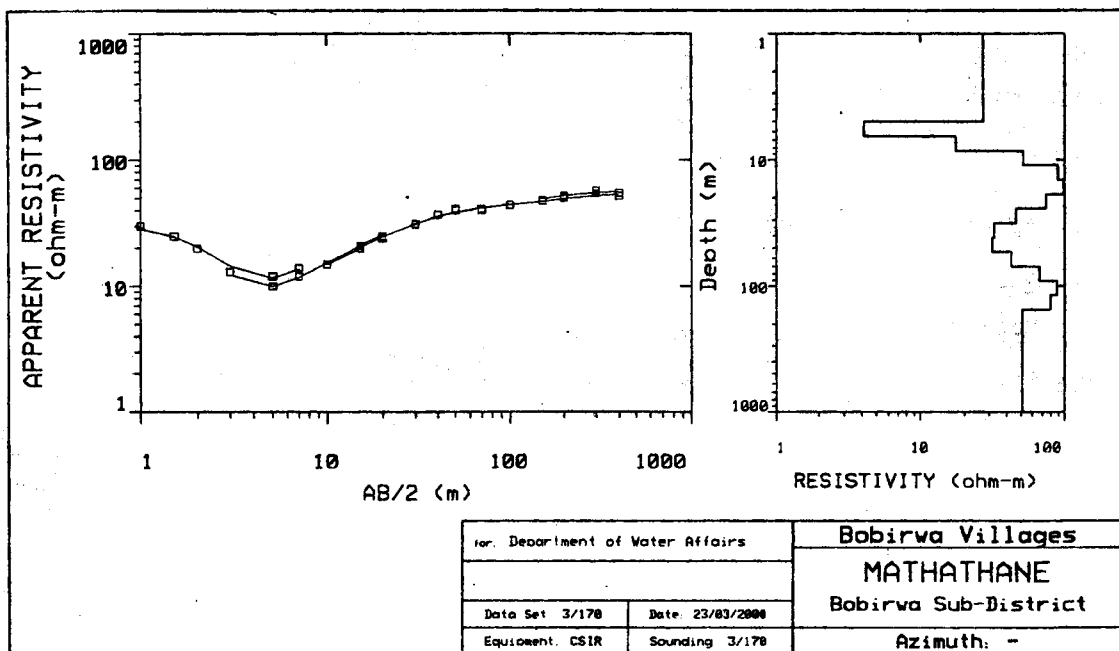
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	26.298	29.911	34.797
	2	5.480	7.206	8.728
	3	69.296	105.405	220.803
	4	30.350	39.369	48.778
	5	77.314	142.695	409.877
	6	16.888	32.186	56.487
THICK	1	0.760	0.913	1.098
	2	2.722	3.819	4.929
	3	3.990	10.962	28.268
	4	44.965	75.480	132.851
	5	13.308	73.680	232.689
DEPTH	1	0.760	0.913	1.098
	2	3.803	4.732	5.733
	3	8.710	15.694	33.011
	4	61.734	91.174	147.471
	5	98.678	164.853	327.992



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	27.06		5.00	* -5.00	0.184
2	4.08		1.50	* -6.50	0.368
3	17.46		1.96	* -8.46	0.112
4	52.11		2.55	* -11.02	0.0490
5	89.71		3.32	* -14.34	0.0370
6	97.84		4.32	* -18.66	0.0442
7	74.05		5.62	* -24.29	0.0760
8	46.62		7.32	* -31.62	0.157
9	32.41		9.53	* -41.15	0.294
10	31.44		12.40	* -53.56	0.394
11	43.19		16.14	* -69.71	0.373
12	67.26		21.01	* -90.72	0.312
13	87.94		27.35	* -118.0	0.311
14	79.61		35.59	* -153.6	0.447
15	51.14				

"\*" INDICATES FIXED PARAMETER

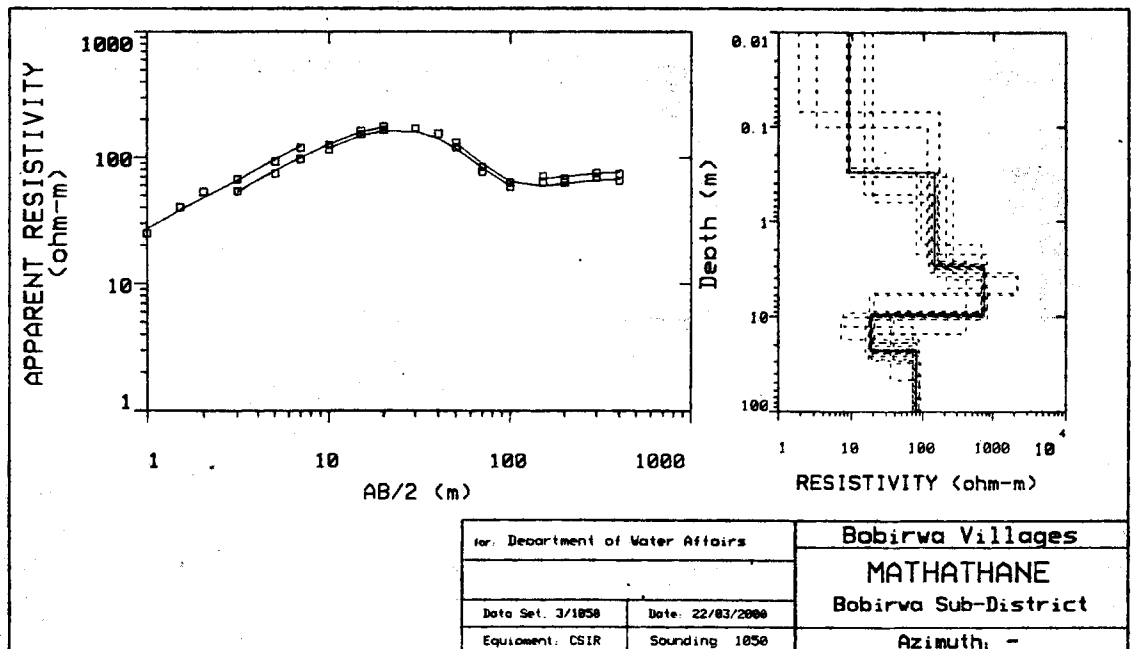


L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	9.06		0.303	-0.303	0.0334
2	142.3		2.67	-2.97	0.0187
3	744.5		6.63	-9.61	0.00891
4	18.19		13.15	-22.77	0.723
5	80.62				

ALL PARAMETERS ARE FREE

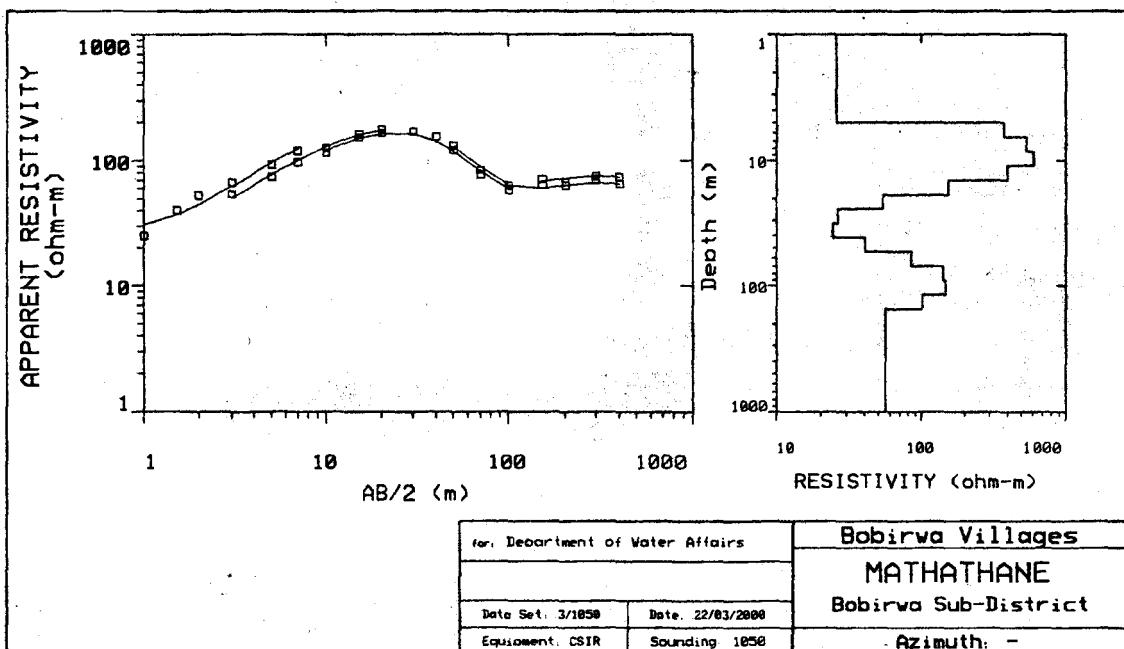
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1.896	9.066	19.571
	2	79.227	142.320	262.203
	3	402.076	744.504	2211.832
	4	7.206	18.190	38.297
	5	71.817	80.629	91.886
THICK	1	0.070	0.303	0.625
	2	1.446	2.674	4.700
	3	2.135	6.635	12.755
	4	3.537	13.159	35.957
DEPTH	1	0.070	0.303	0.625
	2	1.749	2.977	5.004
	3	5.721	9.612	15.355
	4	12.789	22.771	45.853



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	25.57		5.00	* -5.00	0.195
2	375.4		1.50	* -6.50	0.00401
3	543.7		1.96	* -8.46	0.00361
4	612.8		2.55	* -11.02	0.00417
5	397.3		3.32	* -14.34	0.00836
6	153.4		4.32	* -18.66	0.0281
7	53.72		5.62	* -24.29	0.104
8	26.22		7.32	* -31.62	0.279
9	23.99		9.53	* -41.15	0.397
10	40.40		12.40	* -53.56	0.307
11	84.98		16.14	* -69.71	0.190
12	141.8		21.01	* -90.72	0.148
13	148.1		27.35	* -118.0	0.184
14	101.3		35.59	* -153.6	0.351
15	56.03				

"\*" INDICATES FIXED PARAMETER

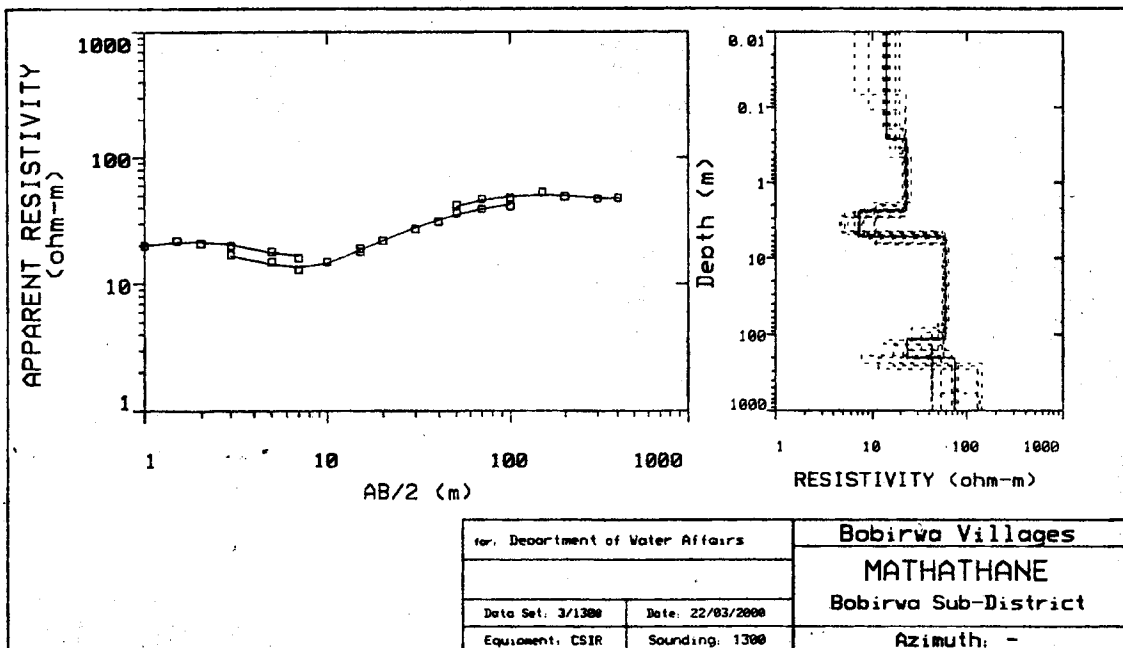


L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	14.07		0.265	-0.265	0.0188
2	23.00		2.03	-2.30	0.0885
3	7.34		2.84	-5.15	0.388
4	59.14		109.2	-114.3	1.84
5	23.50		85.64	-200.0	3.64
6	75.02				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

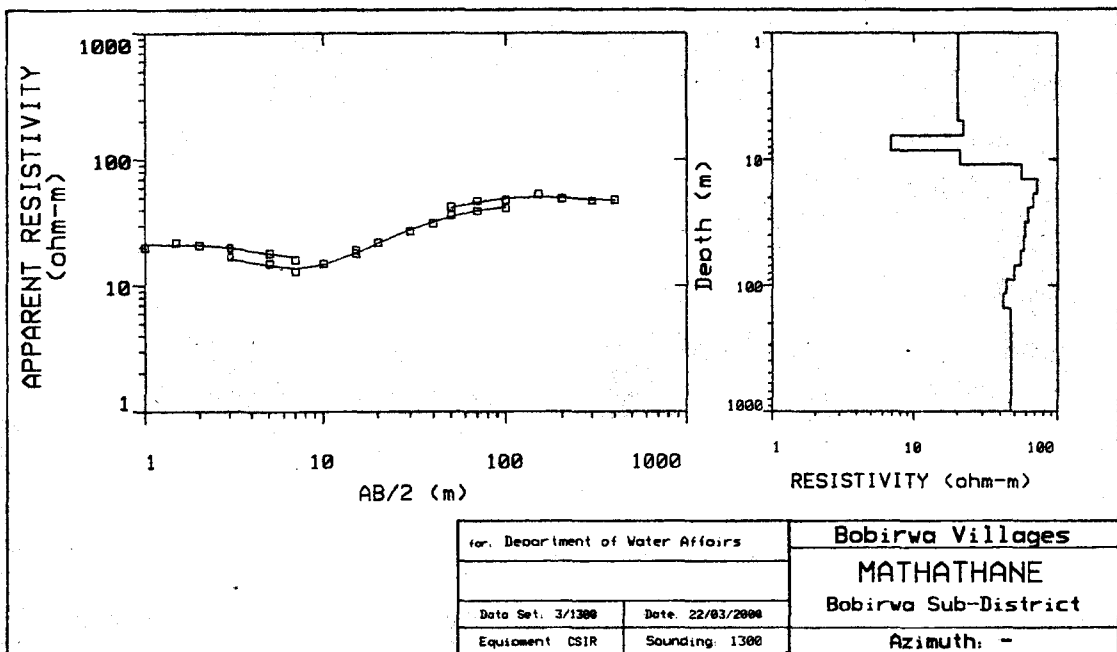
	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	6.589	14.070	19.273
	2	20.907	23.004	26.084
	3	4.642	7.343	10.745
	4	55.258	59.145	63.751
	5	7.697	23.509	49.625
	6	41.957	75.026	141.749
THICK	1	0.068	0.265	0.466
	2	1.380	2.036	2.737
	3	1.692	2.849	4.502
	4	59.375	109.224	196.412
	5	15.733	85.648	487.133
DEPTH	1	0.068	0.265	0.466
	2	1.845	2.302	2.910
	3	4.409	5.151	6.579
	4	64.904	114.375	201.252
	5	133.813	200.024	597.832



for: Department of Water Affairs		Bobirwa Villages	
		MATHATHANE	
		Bobirwa Sub-District	
Data Set: 3/1300	Date: 22/03/2000		
Equipment: CSIR	Sounding: 1300	Azimuth: -	

L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	20.15		5.00	* -5.00	0.248
2	21.93		1.50	* -6.50	0.0687
3	6.83		1.96	* -8.46	0.287
4	20.94		2.55	* -11.02	0.121
5	55.17		3.32	* -14.34	0.0602
6	72.56		4.32	* -18.66	0.0596
7	68.09		5.62	* -24.29	0.0826
8	61.70		7.32	* -31.62	0.118
9	58.70		9.53	* -41.15	0.162
10	57.43		12.40	* -53.56	0.216
11	54.82		16.14	* -69.71	0.294
12	49.23		21.01	* -90.72	0.426
13	43.48		27.35	* -118.0	0.628
14	41.96		35.59	* -153.6	0.848
15	46.69				

"\*" INDICATES FIXED PARAMETER

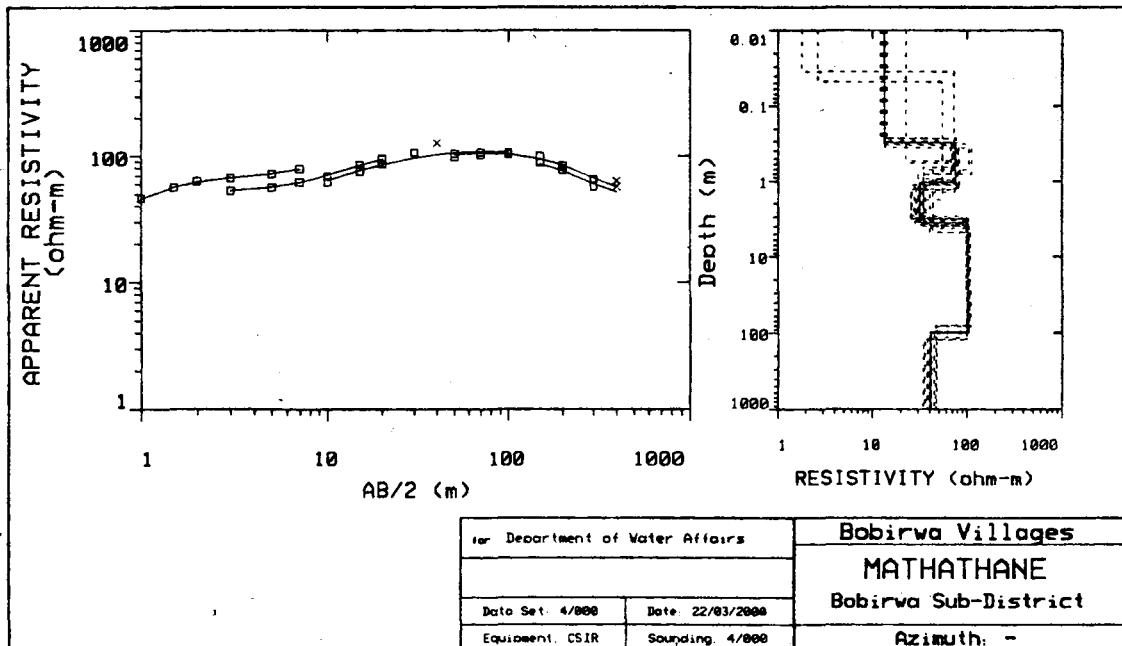


L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
1	13.30		0.308	0.0	0.0232
2	75.58		0.748	-0.308	0.00990
3	31.56		2.52	-1.05	0.0798
4	103.5		94.70	-3.57	0.915
5	40.39			-98.28	

ALL PARAMETERS ARE FREE

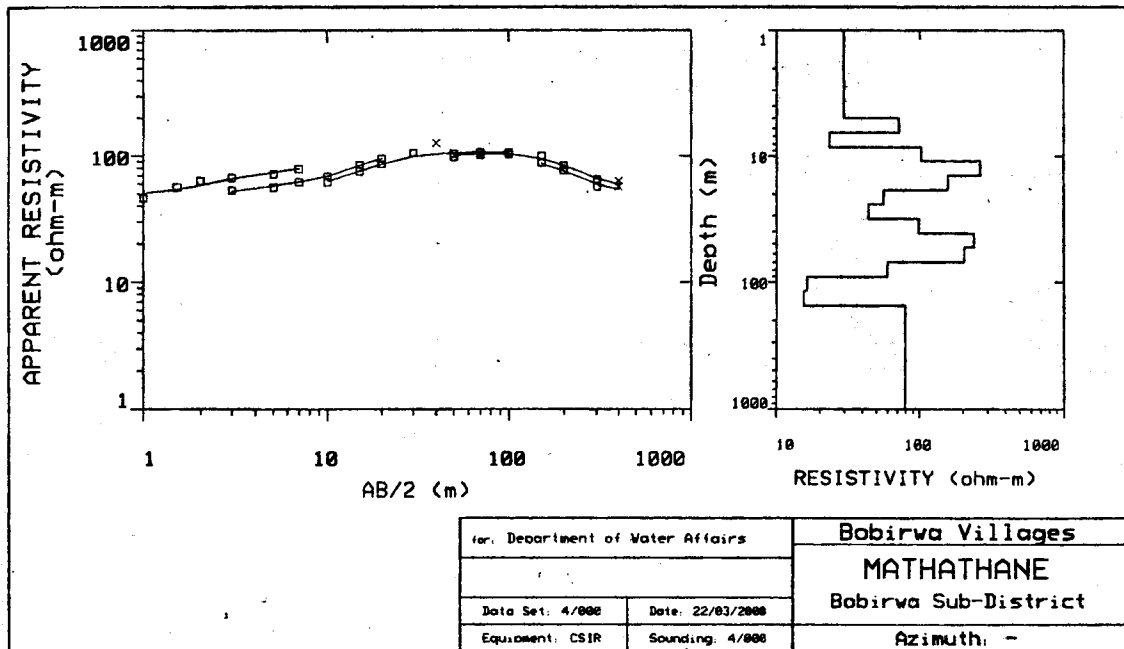
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	1.793	13.301	22.681
	2	54.002	75.582	110.908
	3	25.444	31.568	43.169
	4	98.766	103.503	109.996
	5	33.980	40.397	47.236
THICK	1	0.035	0.309	0.575
	2	0.384	0.748	1.468
	3	1.801	2.521	4.107
	4	74.830	94.706	119.849
DEPTH	1	0.035	0.309	0.575
	2	0.658	1.057	1.762
	3	2.952	3.578	4.826
	4	79.094	98.284	123.073



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	29.69		5.00	* -5.00	0.168
2	71.59		1.50	* -6.50	0.0210
3	23.37		1.96	* -8.46	0.0839
4	102.9		2.55	* -11.02	0.0248
5	264.8		3.32	* -14.34	0.0125
6	156.6		4.32	* -18.66	0.0276
7	56.01		5.62	* -24.29	0.100
8	43.76		7.32	* -31.62	0.167
9	98.53		9.53	* -41.15	0.0967
10	238.3		12.40	* -53.56	0.0520
11	205.6		16.14	* -69.71	0.0785
12	59.48		21.01	* -90.72	0.353
13	16.27		27.35	* -118.0	1.68
14	15.46		35.59	* -153.6	2.30
15	79.39				

"\*" INDICATES FIXED PARAMETER



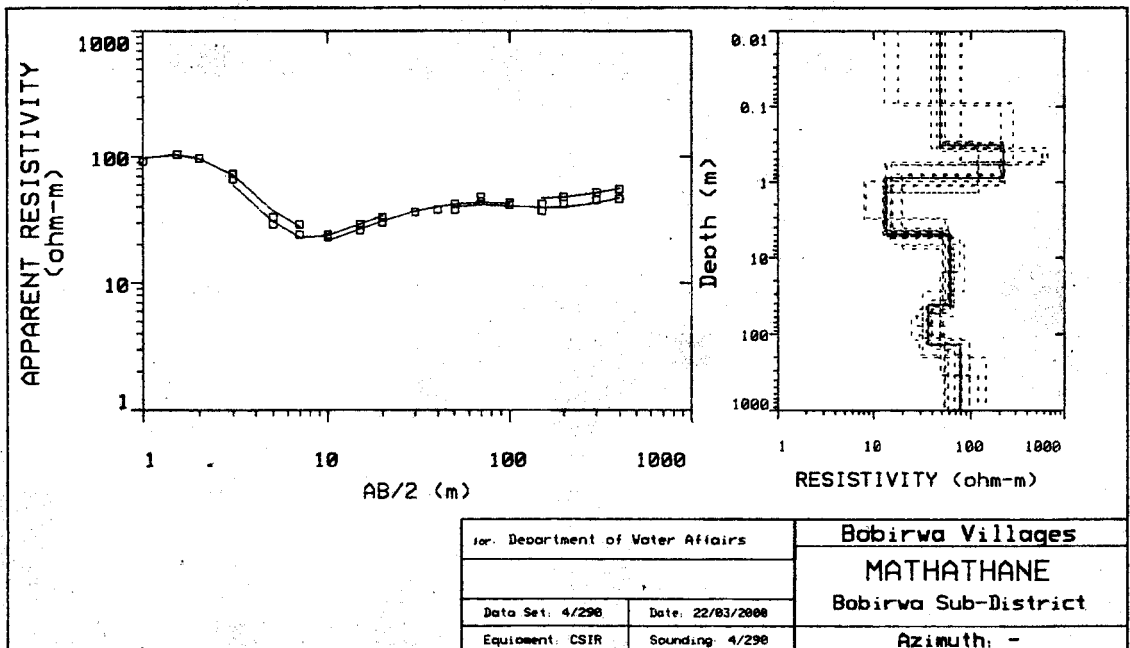
for. Department of Water Affairs		Bobirwa Villages	
		MATHATHANE	
		Bobirwa Sub-District	
Data Set: 4/000	Date: 22/03/2008	Azimuth: -	
Equipment: CSIR	Sounding: 4/000		

#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
1	47.61		0.323	0.0	0.00680
2	222.3		0.558	-0.323	0.00251
3	13.52		3.94	-0.882	0.292
4	61.26		36.25	-4.83	0.591
5	36.31		94.37	-41.09	2.59
6	78.59			-135.4	

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

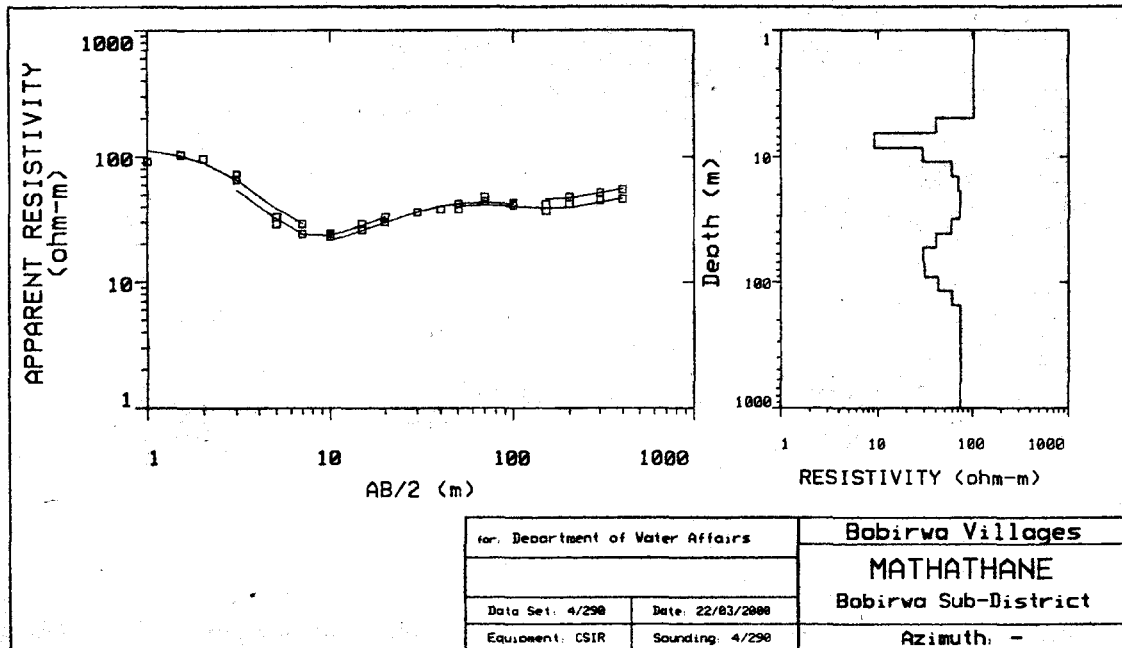
	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	12.980	47.617	80.933
	2	116.130	222.301	660.752
	3	7.980	13.523	19.849
	4	50.647	61.268	86.017
	5	24.332	36.319	48.624
	6	53.251	78.600	142.297
THICK	1	0.090	0.324	0.591
	2	0.187	0.558	1.097
	3	2.035	3.950	6.705
	4	9.657	36.260	97.065
	5	30.263	94.375	310.736
DEPTH	1	0.090	0.324	0.591
	2	0.538	0.882	1.383
	3	2.998	4.832	7.527
	4	15.185	41.092	101.445
	5	77.261	135.467	346.494



for. Department of Water Affairs		<b>Bobirwa Villages</b>
		<b>MATHATHANE</b>
		<b>Bobirwa Sub-District</b>
Data Set: 4/290	Date: 22/03/2006	<b>Azimuth: -</b>
Equipment: CSIR	Sounding: 4/290	

#	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	102.3		5.00	* -5.00	0.0488
2	40.23		1.50	* -6.50	0.0374
3	9.18		1.96	* -8.46	0.213
4	29.41		2.55	* -11.02	0.0868
5	59.06		3.32	* -14.34	0.0562
6	69.94		4.32	* -18.66	0.0618
7	73.18		5.62	* -24.29	0.0769
8	72.84		7.32	* -31.62	0.100
9	59.77		9.53	* -41.15	0.159
10	40.68		12.40	* -53.56	0.304
11	29.91		16.14	* -69.71	0.539
12	30.62		21.01	* -90.72	0.686
13	42.14		27.35	* -118.0	0.649
14	60.65		35.59	* -153.6	0.586
15	75.16				

"\*" INDICATES FIXED PARAMETER

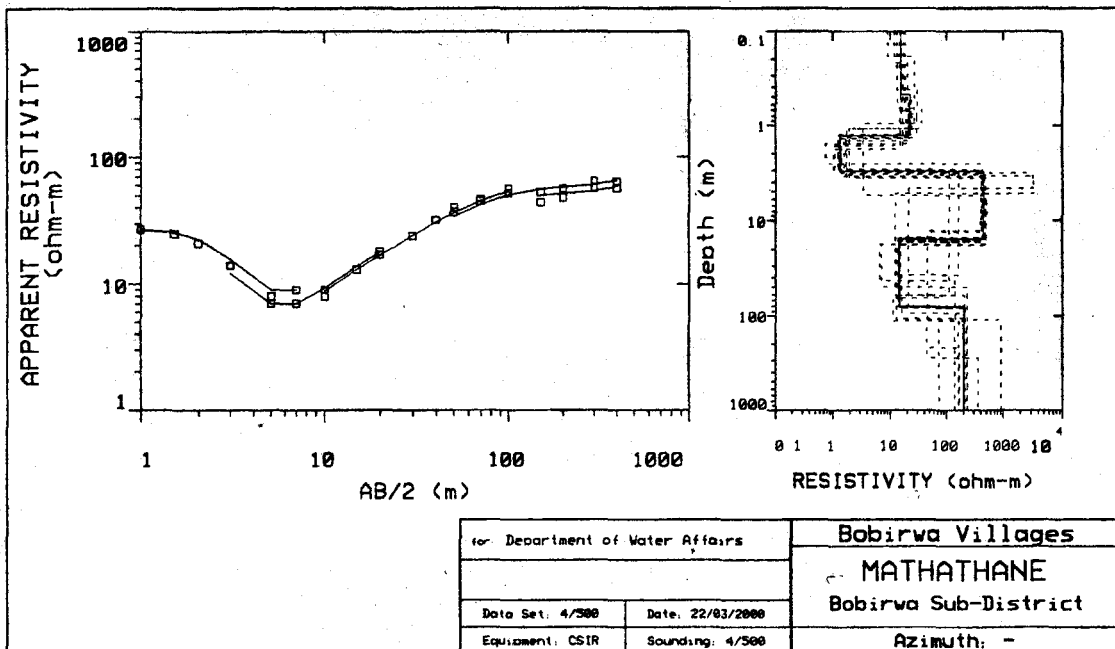


L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
				0.0	
1	15.28		0.476	-0.476	0.0311
2	22.32		0.816	-1.29	0.0365
3	1.37		1.75	-3.04	1.27
4	445.2		12.72	-15.77	0.0285
5	14.41		65.02	-80.79	4.51
6	202.2				

ALL PARAMETERS ARE FREE

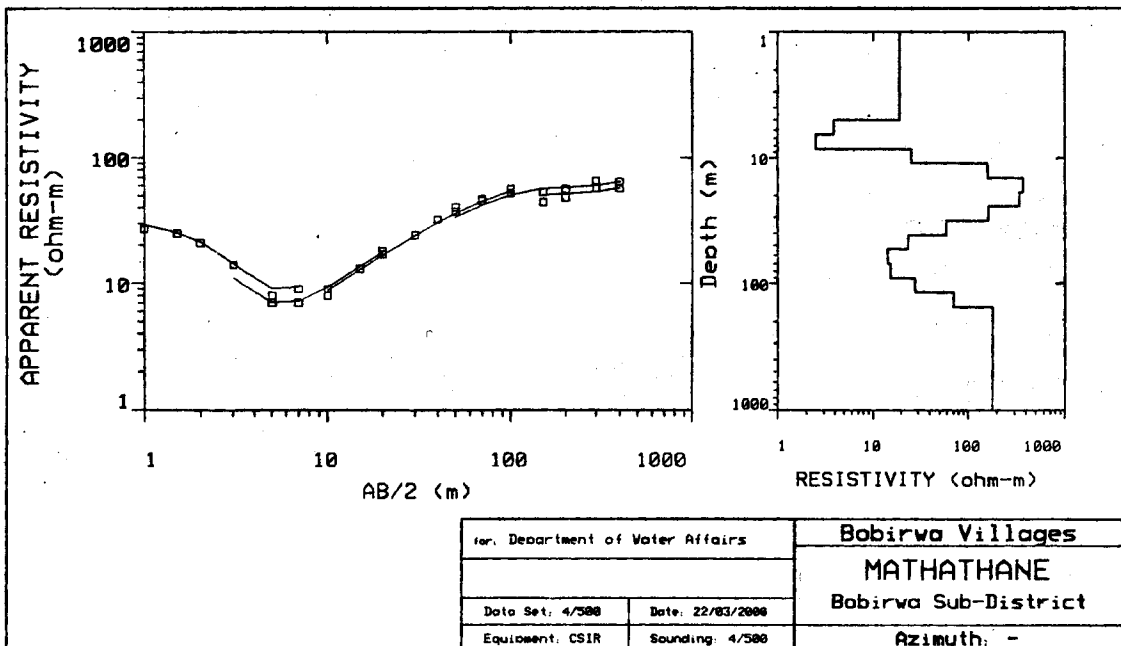
PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

	LAYER	MINIMUM	BEST	MAXIMUM
RHO	1	8.968	15.287	18.592
	2	14.923	22.327	36.018
	3	0.761	1.371	3.443
	4	112.002	445.238	3271.008
	5	6.651	14.418	45.683
	6	72.895	202.201	919.590
THICK	1	0.188	0.476	0.766
	2	0.420	0.816	1.431
	3	0.960	1.754	4.499
	4	1.437	12.723	58.750
	5	25.079	65.026	265.504
DEPTH	1	0.188	0.476	0.766
	2	0.965	1.292	1.790
	3	2.536	3.047	5.464
	4	4.613	15.770	61.710
	5	42.837	80.796	278.801



L #	RESISTIVITY (ohm-m)	CHARGEABILITY (pfe)	THICKNESS (m)	ELEVATION (m)	CONDUCTANCE (Siemens)
1	19.15			0.0	
2	3.87		5.00	* -5.00	0.261
3	2.45		1.50	* -6.50	0.388
4	25.62		1.96	* -8.46	0.798
5	157.5		2.55	* -11.02	0.0996
6	365.9		3.32	* -14.34	0.0210
7	336.6		4.32	* -18.66	0.0118
8	160.5		5.62	* -24.29	0.0167
9	58.57		7.32	* -31.62	0.0456
10	23.64		9.53	* -41.15	0.162
11	14.25		12.40	* -53.56	0.524
12	15.29		16.14	* -69.71	1.13
13	28.11		21.01	* -90.72	1.37
14	69.99		27.35	* -118.0	0.972
15	179.7		35.59	* -153.6	0.508

"\*" INDICATES FIXED PARAMETER

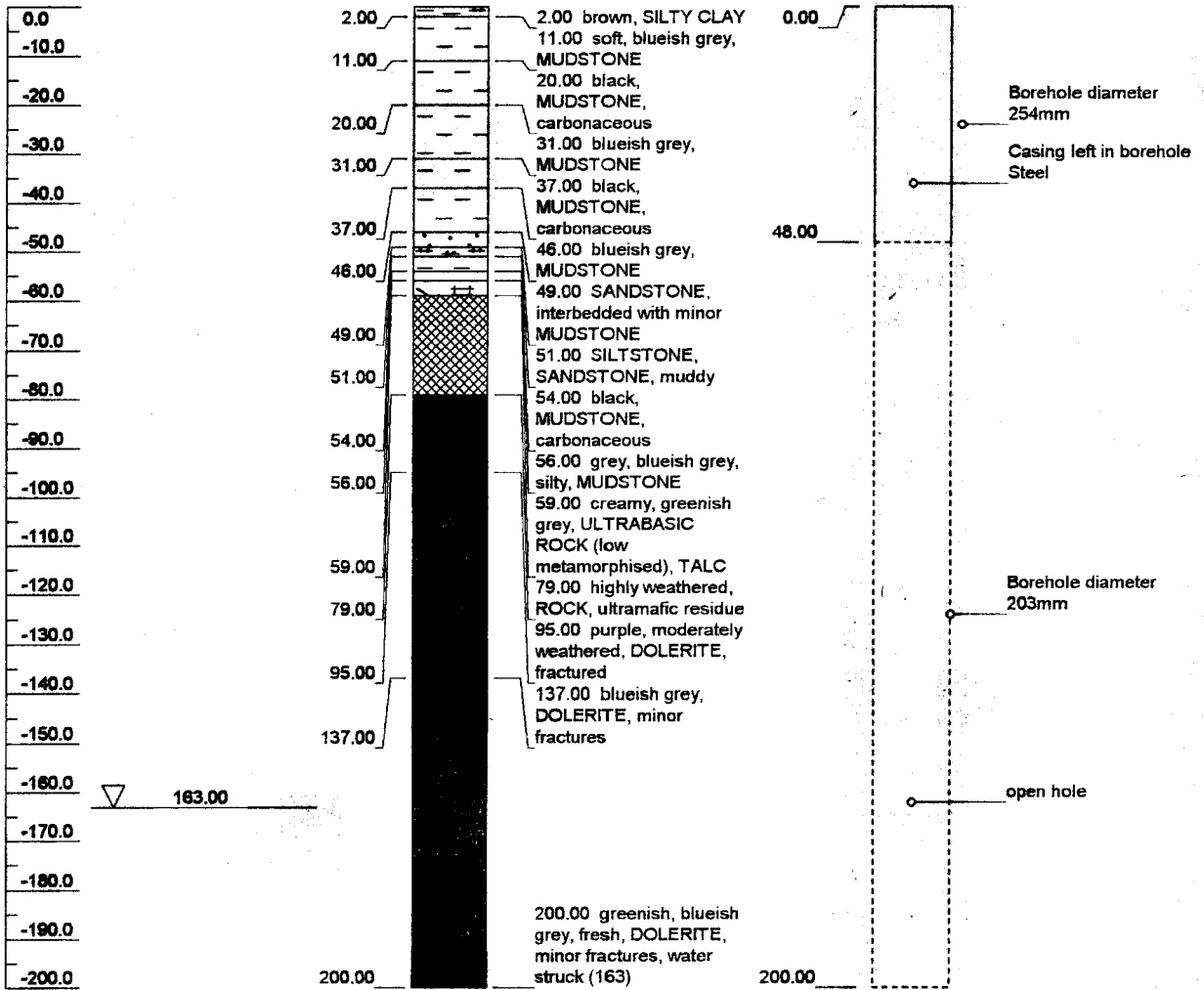


## **APPENDIX C**

### **Borehole Lithological Logs**

# BH 9164

Depth: 0.00  
(m above Datum)



Vertical scale: 1:1500

Page 1 of 1

**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9164**

Client: DEPT. OF WATER AFFAIRS

Easting (X): 28.7933

Author: WELLFIELD CONSULTING

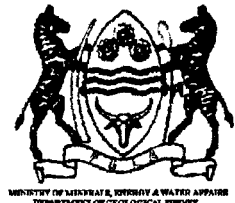
Northing (Y): -22.2774

Checked by:

Ground level: 0.00 m above Datum

Date: 2001/12/14

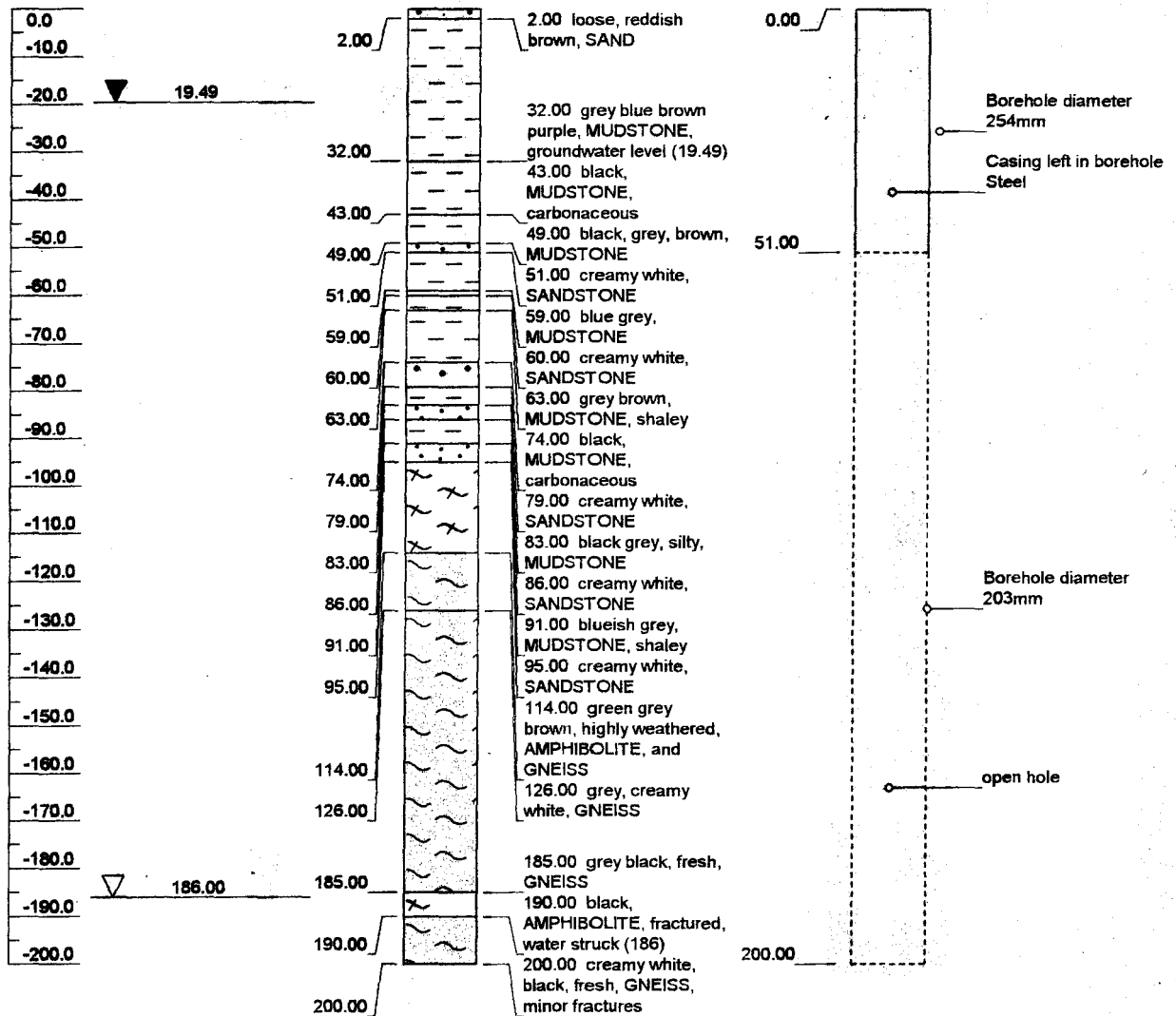
End depth: 200.00 m below ground



MINISTRY OF LANDS, URBAN & WATER AFFAIRS  
DEPARTMENT OF GEOLOGICAL SURVEY

# BH 9176

Depth: 0.00  
(m above Datum)



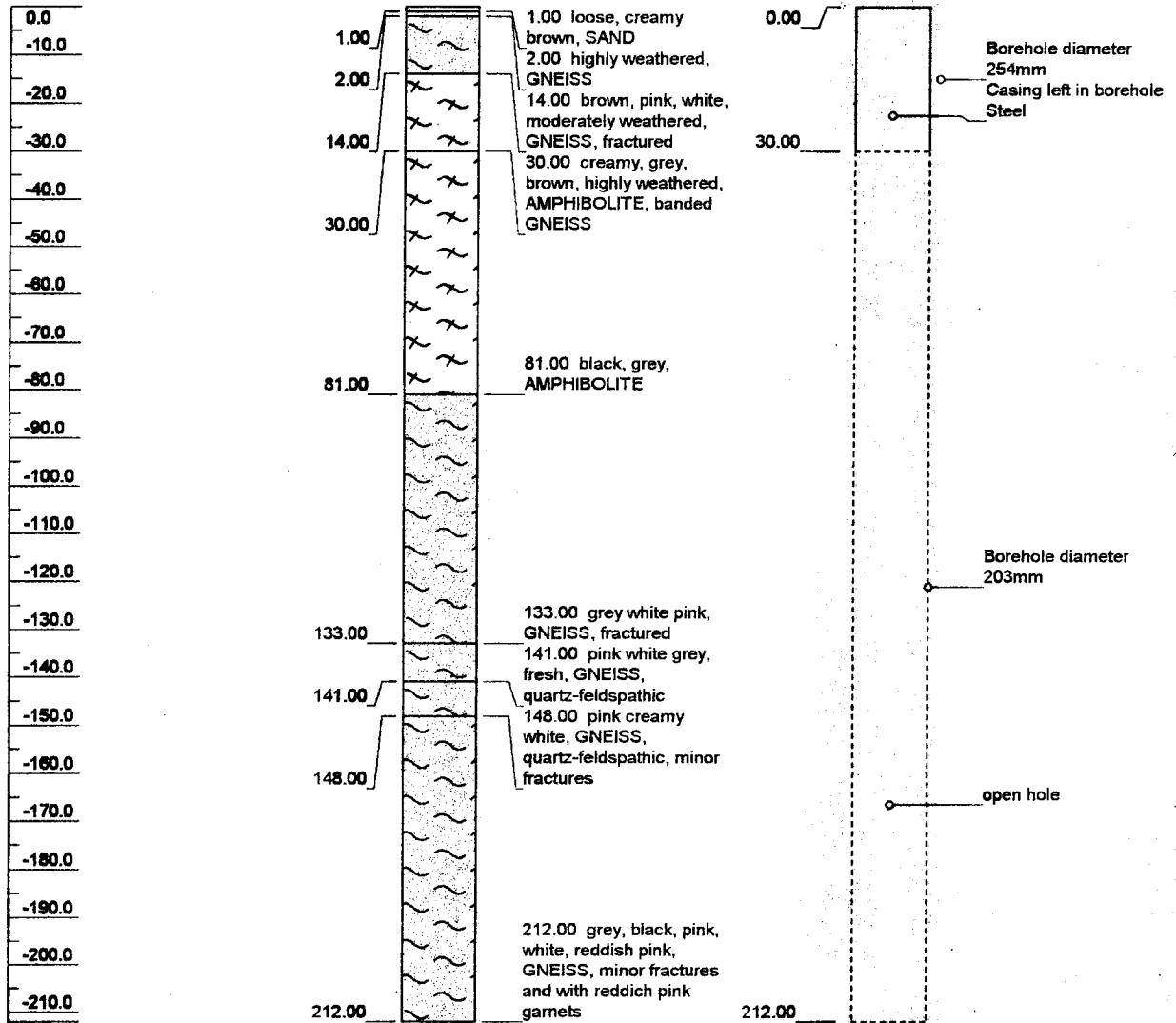
Vertical scale: 1:1500

Page 1 of 1

<b>Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT</b>		<p style="font-size: small;">MINISTRY OF MINERALS, ENERGY &amp; WATER AFFAIRS DEPARTMENT OF GEOLOGICAL SURVEY</p>
<b>Location point: BH 9176</b>		
Client: DEPT. OF WATER AFFAIRS	Easting (X): 28.8039	
Author: WELLFIELD CONSULTING	Northing (Y): -22.2519	
Checked by:	Ground level: 0.00 m above Datum	
Date: 2001/12/14	End depth: 200.00 m below ground	

# BH 9177

Depth: 0.00  
(m above Datum)



Vertical scale: 1:1500

Page 1 of 1

**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9177**

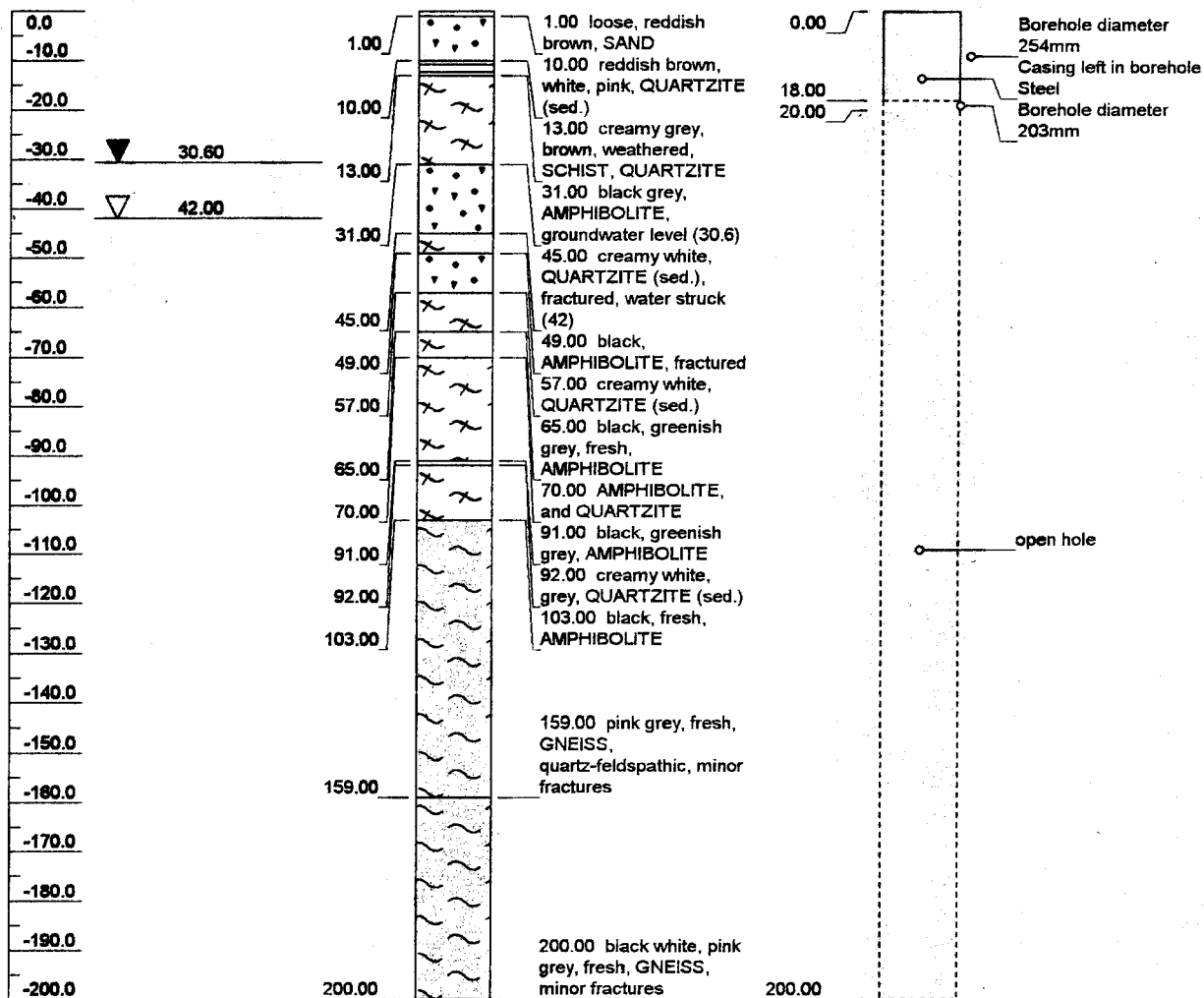
Client:	DEPT. OF WATER AFFAIRS	Easting (X):	28.7269
Author:	WELLFIELD CONSULTING	Northing (Y):	-22.2953
Checked by:		Ground level:	0.00 m above Datum
Date:	2002/01/14	End depth:	212.00 m below ground



MINISTRY OF WATER & FORESTRY  
DEPARTMENT OF GEOLOGICAL SURVEY

## BH 9178

Depth: 0.00  
(m above Datum)



Vertical scale: 1:1500

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**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9178**

Client: DEPT. OF WATER AFFAIRS

Easting (X): 28.7176

Author: WELLFIELD CONSULTING

Northing (Y): -22.2812

Checked by:

Ground level: 0.00 m above Datum

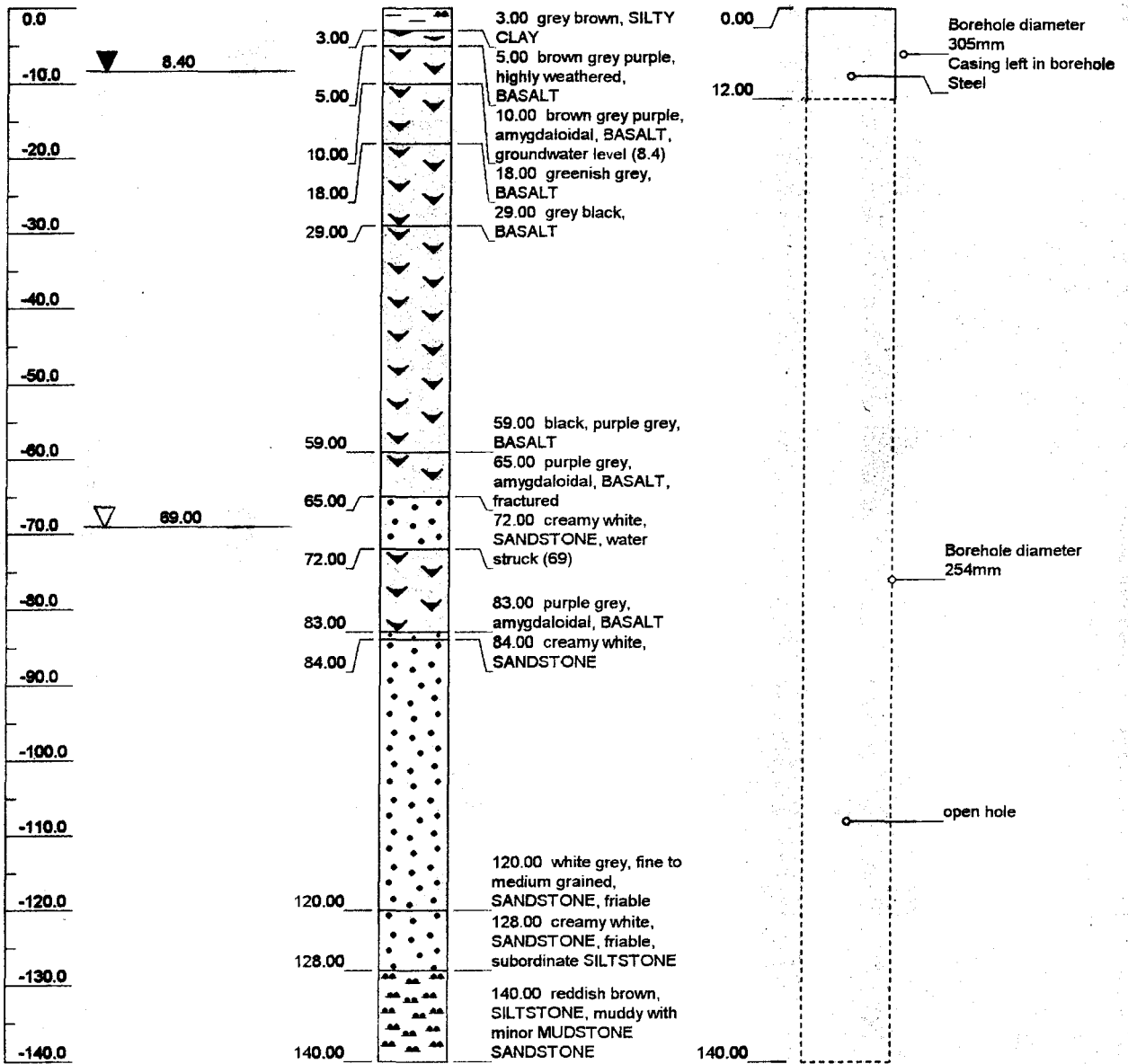
Date: 2002/01/14

End depth: 200.00 m below ground



# BH 9313

Depth: 0.00  
(m above Datum)



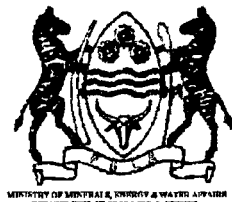
Vertical scale: 1:900

Page 1 of 1

**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9313**

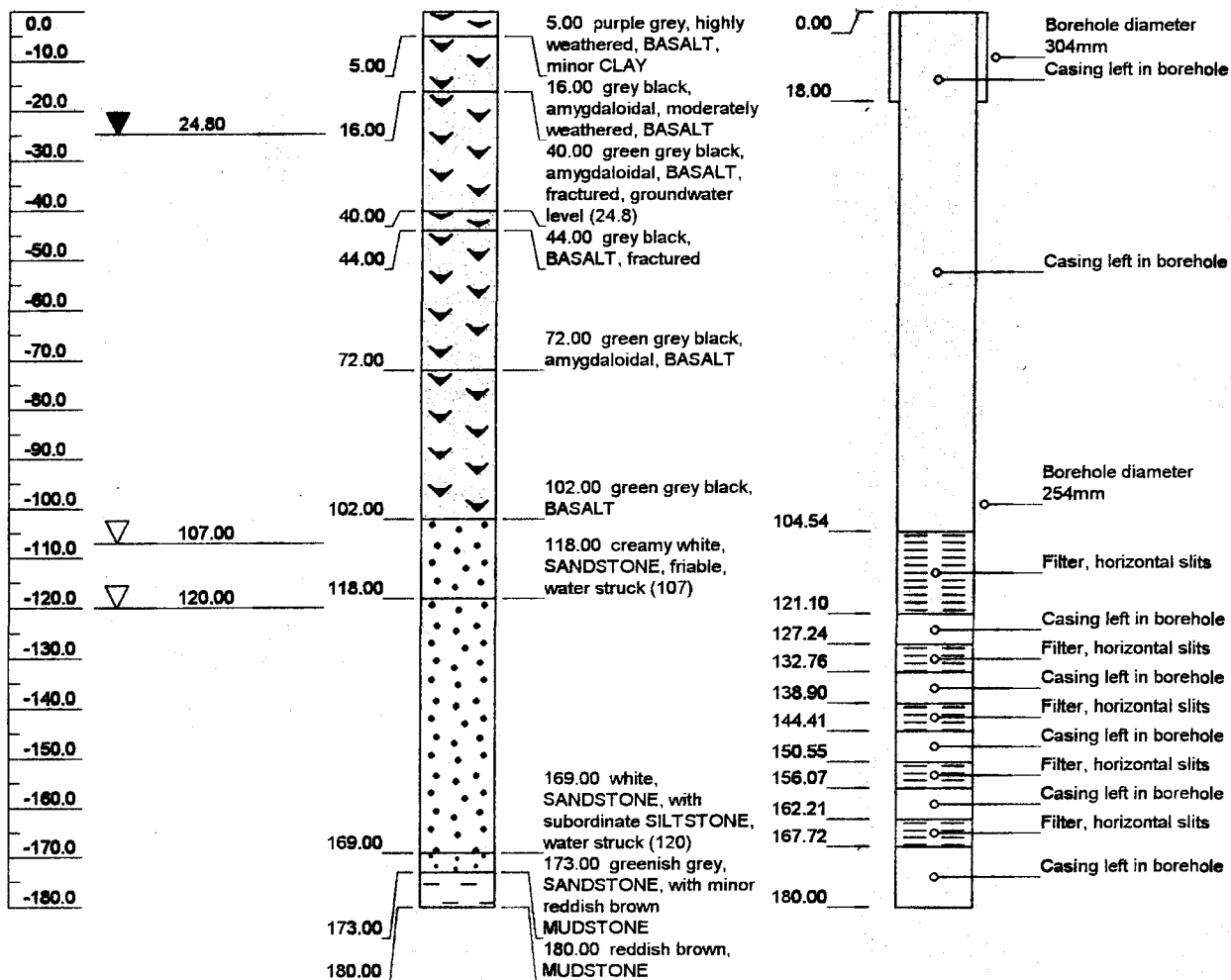
Client:	DEPT. OF WATER AFFAIRS	Easting (X):	28.7992
Author:	WELLFIELD CONSULTING	Northing (Y):	-22.1858
Checked by:		Ground level:	0.00 m above Datum
Date:	2002/01/14	End depth:	140.00 m below ground



MINISTRY OF MINERALS, ENERGY & WATER AFFAIRS  
DEPARTMENT OF GEOLOGICAL SURVEY

# BH 9314

Depth: 0.00  
(m above Datum)



Vertical scale: 1:1500

Page 1 of 1

**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9314**

Client: DEPT. OF WATER AFFAIRS

Easting (X): 28.8045

Author: WELLFIELD CONSULTING

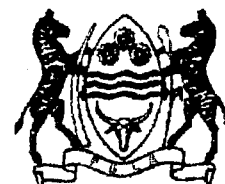
Northing (Y): -22 1906

Checked by:

Ground level: 0.00 m above Datum

Date: 2001/12/14

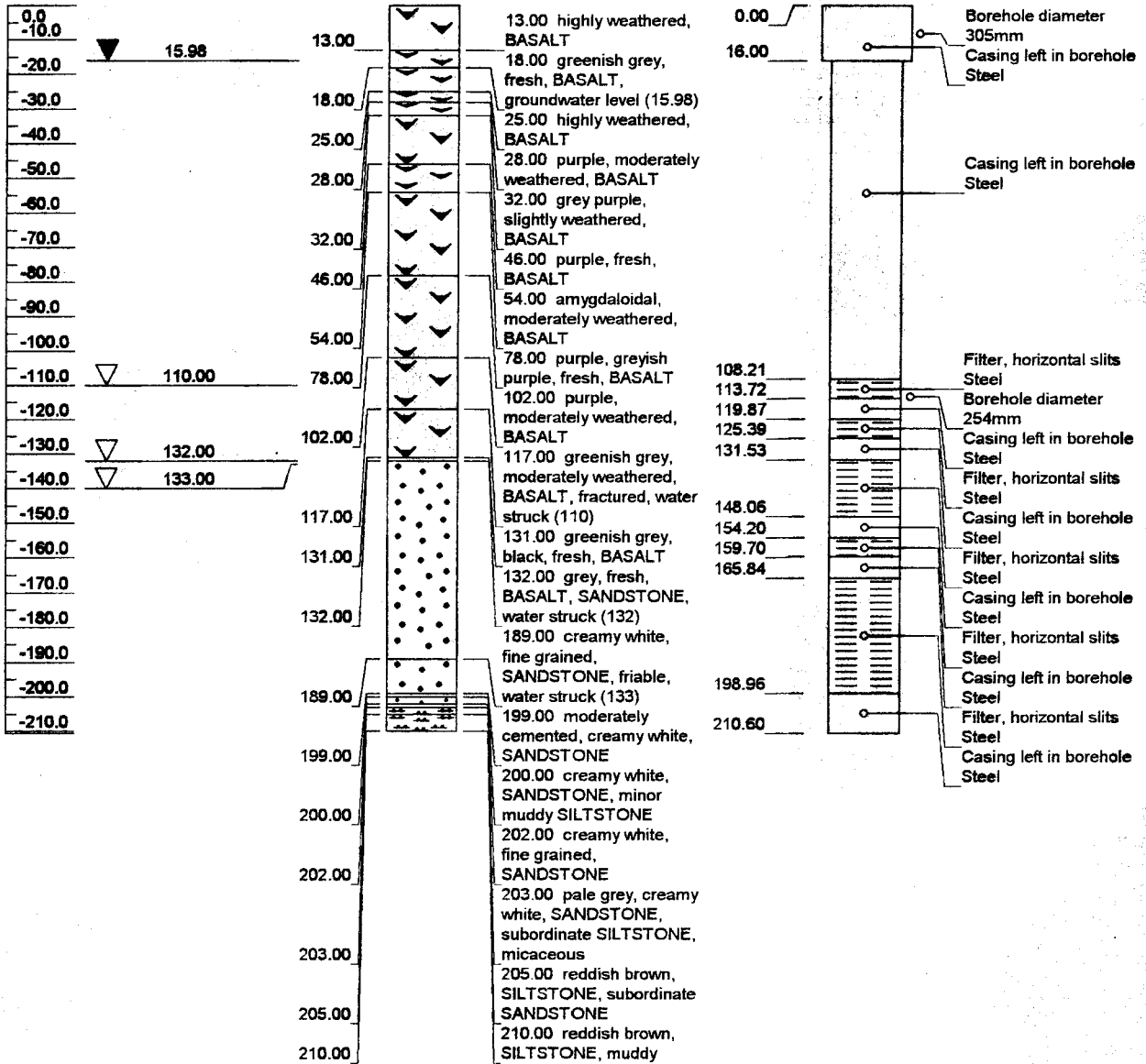
End depth: 180.00 m below ground



MINISTRY OF MINES & ENERGY & WATER AFFAIRS  
DEPARTMENT OF GEOLOGICAL SURVEY

# BH 9315

Depth: 0.00  
(m above Datum)



Vertical scale: 1:2000

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**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9315**

Client: DEPT. OF WATER AFFAIRS

Easting (X): 28.8121

Author: WELLFIELD CONSULTING

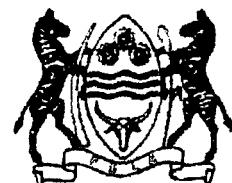
Northing (Y): -22.1885

Checked by:

Ground level: 0.00 m above Datum

Date: 2001/12/14

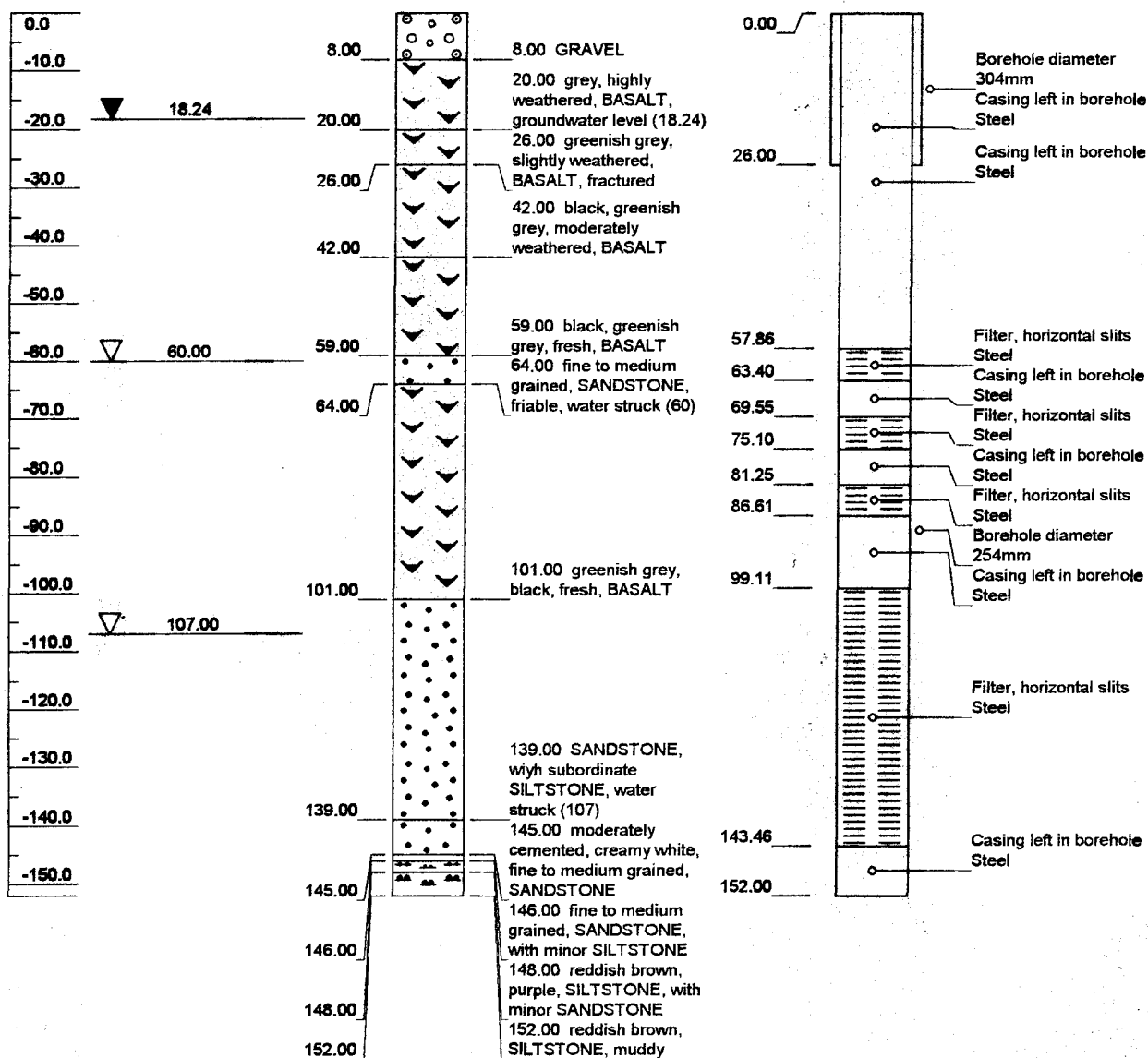
End depth: 210.60 m below ground



MINISTRY OF WATER AFFAIRS & FORESTRY  
DEPARTMENT OF GEOLOGICAL SURVEY

# BH 9316

Depth: 0.00  
(m above Datum)



Vertical scale: 1:1200

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**Project: BOBIRWA SUB DISTRICT VILLAGES PROJECT**

**Location point: BH 9316**

Client: DEPT. OF WATER AFFAIRS

Easting (X): 28.8041

Author: WELLFIELD CONSULTING

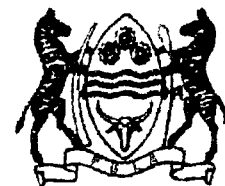
Northing (Y): -22.1973

Checked by:

Ground level: 0.00 m above Datum

Date: 2001/12/14

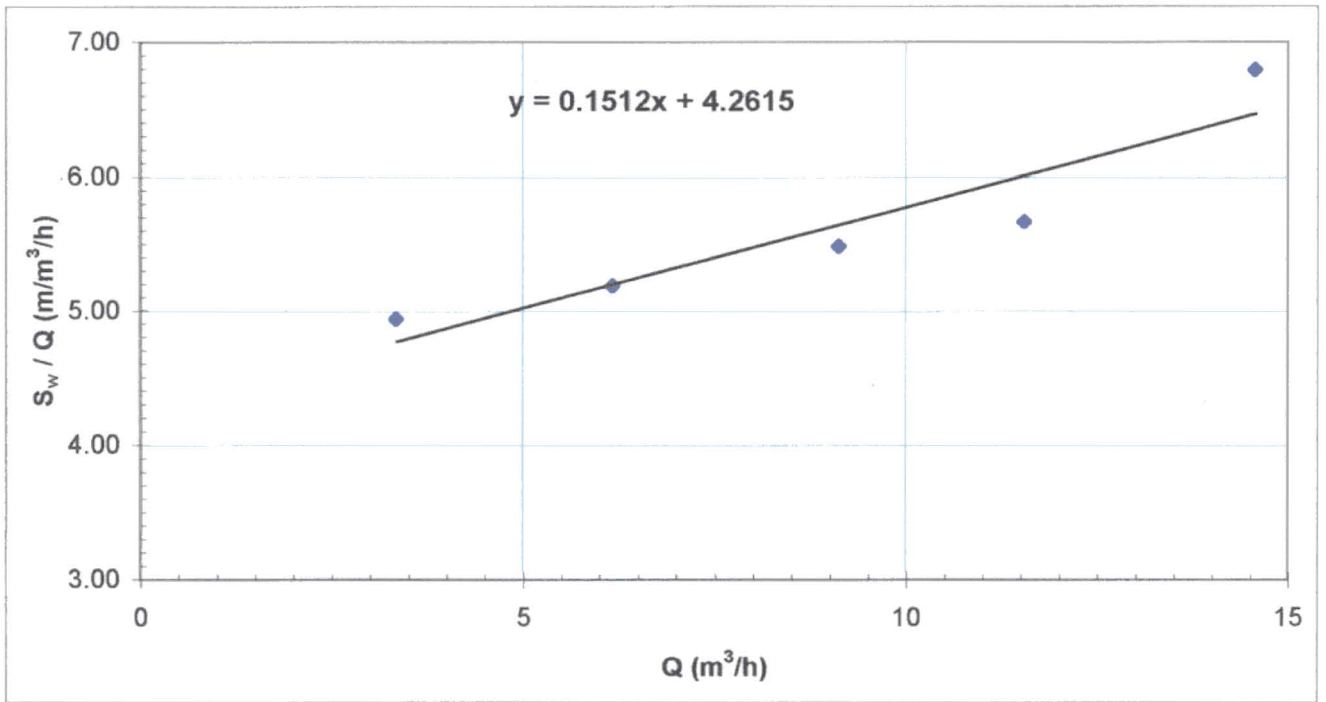
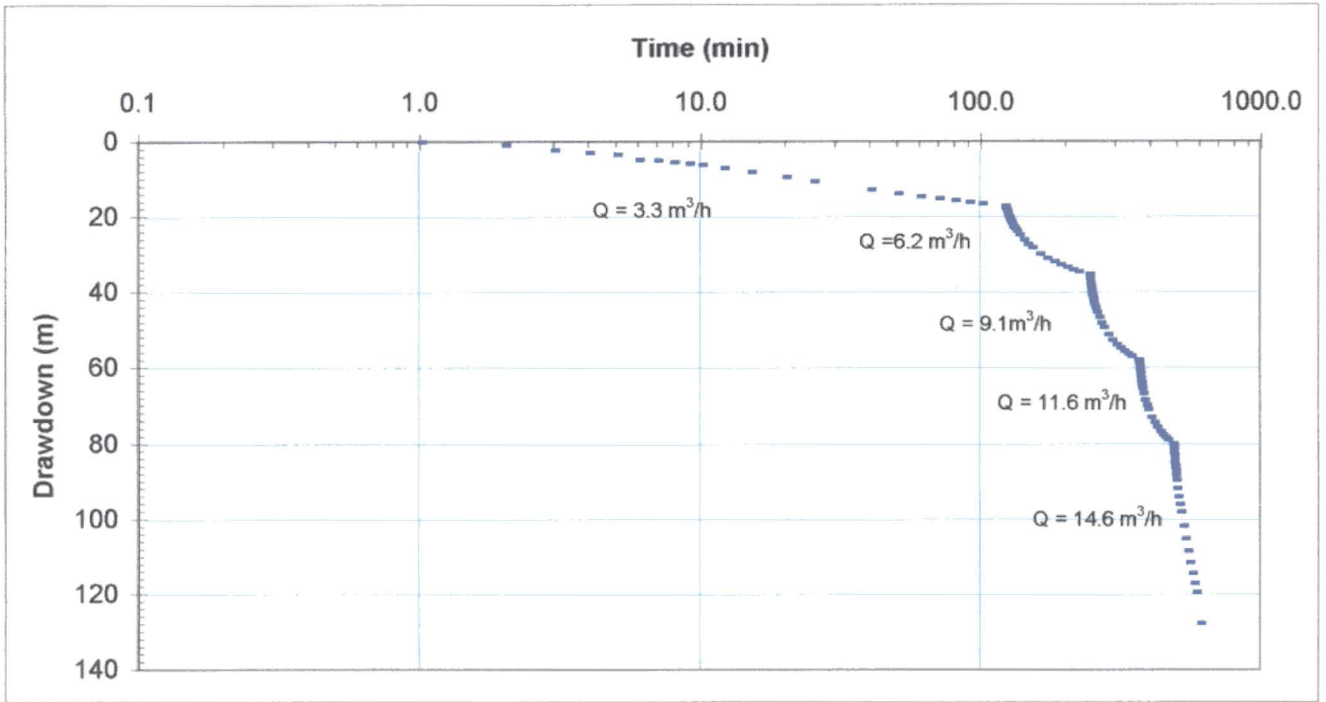
End depth: 152.00 m below ground



MINISTRY OF NATURAL RESOURCES & WATER AFFAIRS  
DEPARTMENT OF GEOLOGICAL SURVEY

## **APPENDIX D**

### **Test Pumping Data Plots**



**Observed**

Step	Q	del S	S <sub>w</sub>	S <sub>w</sub> /Q
1	3.3	16.50	16.50	4.940
2	6.2	15.50	32.00	5.186
3	9.1	18.00	50.00	5.482
4	11.6	15.50	65.50	5.671
5	14.6	33.50	99.00	6.795

**Calculated**

Q	BQ	CQ <sup>2</sup>	S <sub>w</sub>	Eff (%)
3.3	14.23	1.69	15.92	89.4
6.2	26.29	5.76	32.05	82.0
9.1	38.86	12.58	51.44	75.6
11.6	49.22	20.17	69.39	70.9
14.6	62.09	32.10	94.19	65.9

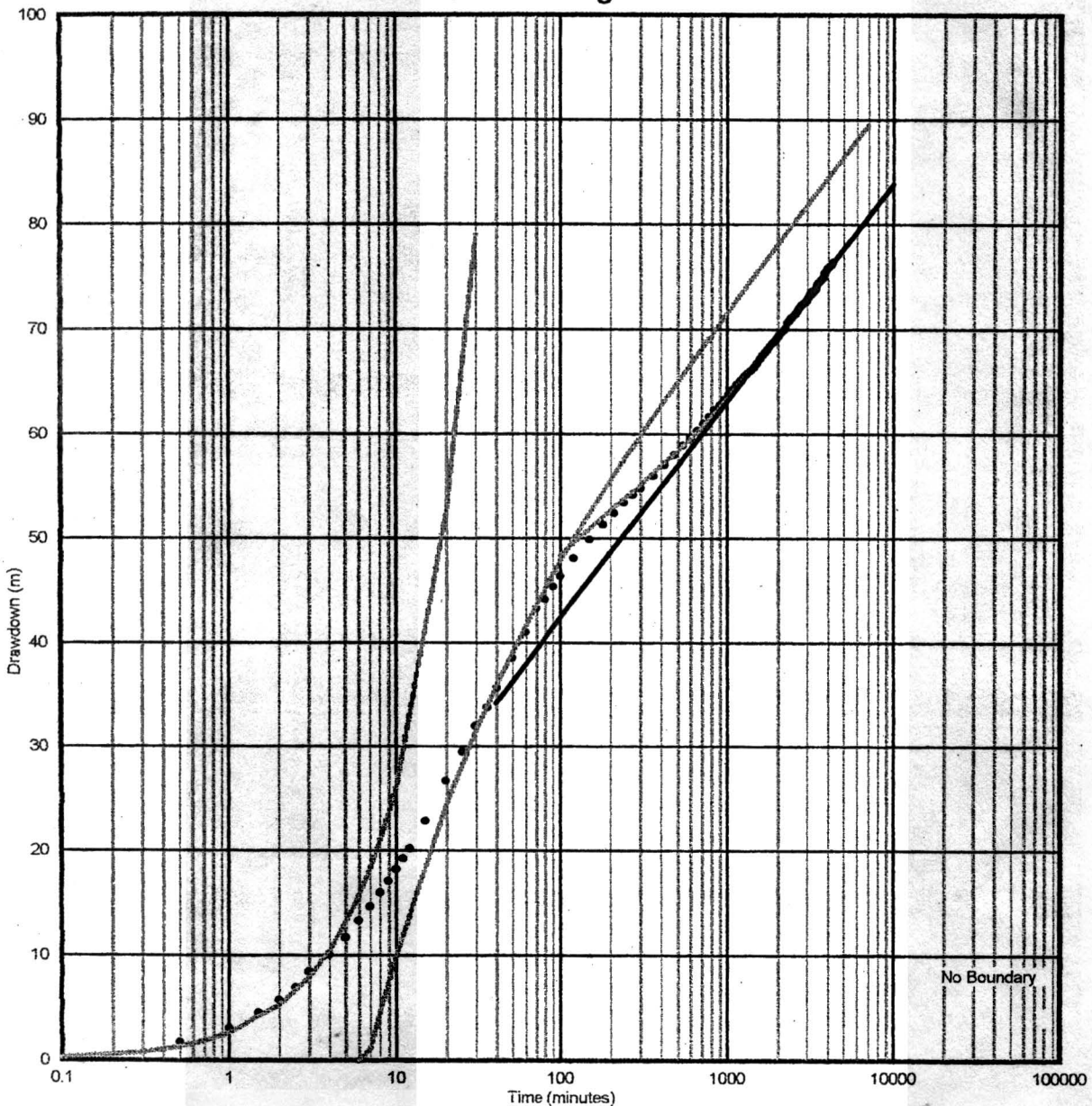
**Appendix D1 BH 9314 - Step Test Data and Analysis**

**OUTPUT FROM TestCurve 9.5**

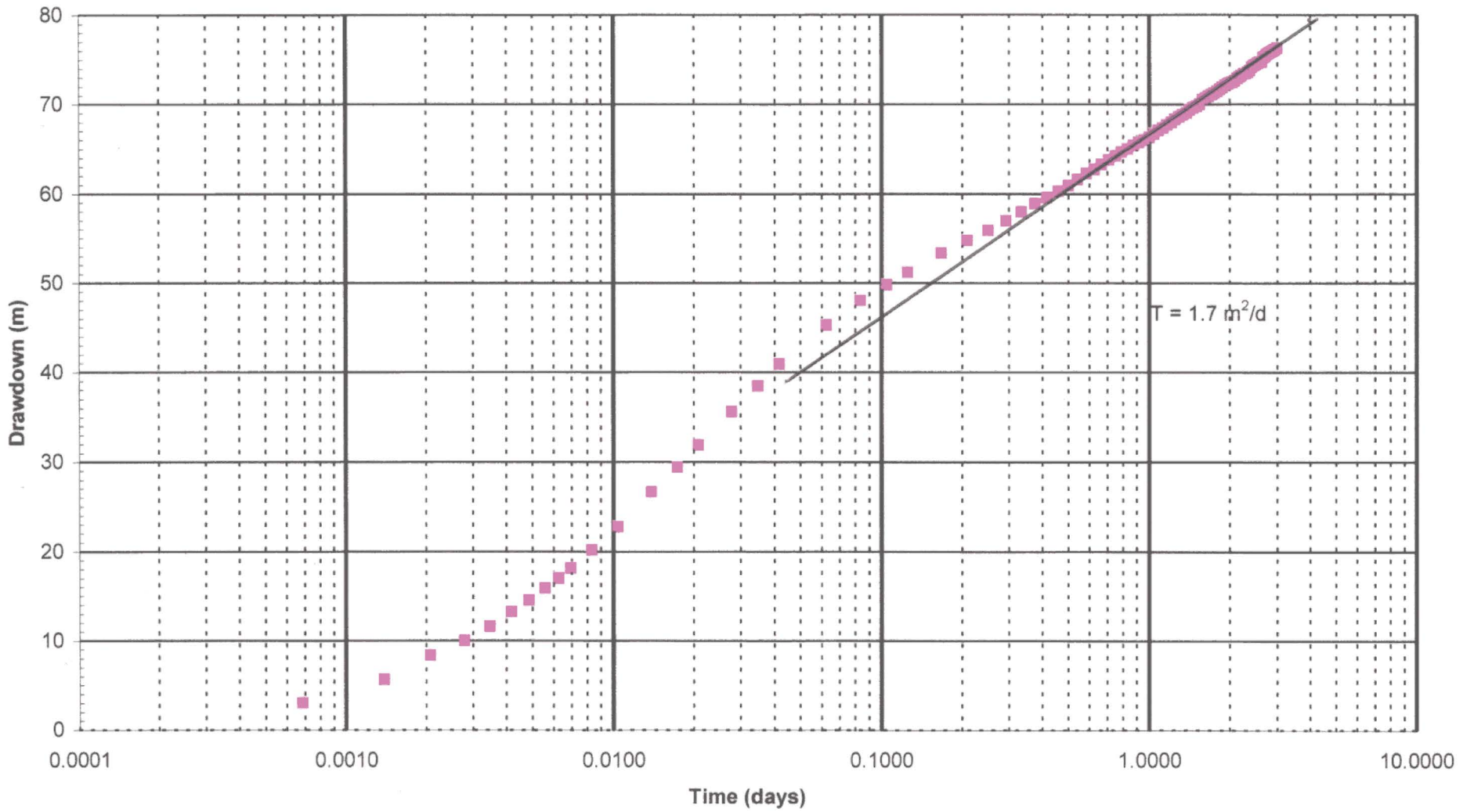
Calculation with WBS, Skin, dual porosity, negative boundaries, closed aquifer

Date : 5/2/02  
 Time : 12:11:51  
 Project : Mathathane Village  
 Inputfile : C:\DWA\Bibirwal\BH9314.dat  
 Outputfile : C:\DWA\Bibirwal\BH9314c5.dat  
 Parameterfile : C:\DWA\Bibirwal\BH9314.par  
 Pump rate (>0 - 50000 m<sup>3</sup>/day) 192  
 Transmissivity (>0 - 50000 m<sup>2</sup>/day) 1.7  
 Storage coeff, early time (>0 - 1) 0.01  
 Storage coeff, late time (>0 - 1) .027  
 Well-diameter (1 - 20 inch) 10  
 Aquifer thickness (1 - 500 m) 62  
 C-Value from step-test (0 - 1000 h<sup>2</sup>/m<sup>4</sup>) .01512  
 Skin-factor (-20 - 50) -0.9  
 Total Well-loss factor (as skin) -0.84617  
 Aquifer interpreted: No Boundary  
 Distance to 1st boundary (0.1 - 50000 m) 0  
 Distance to 2nd boundary (1 - 50000 m) 0  
 Distance to boundary (Closed aquifer) (m) 50000  
 Transmissivity beyond the discontinuity 0  
 Distance to 2nd boundary after discontinuity 0  
 Vertical permeability (m/day) 1.9

**Mathathane Village Bh 9314**



**Appendix D2 BH 9314 Testcurve Drawdown Analysis**



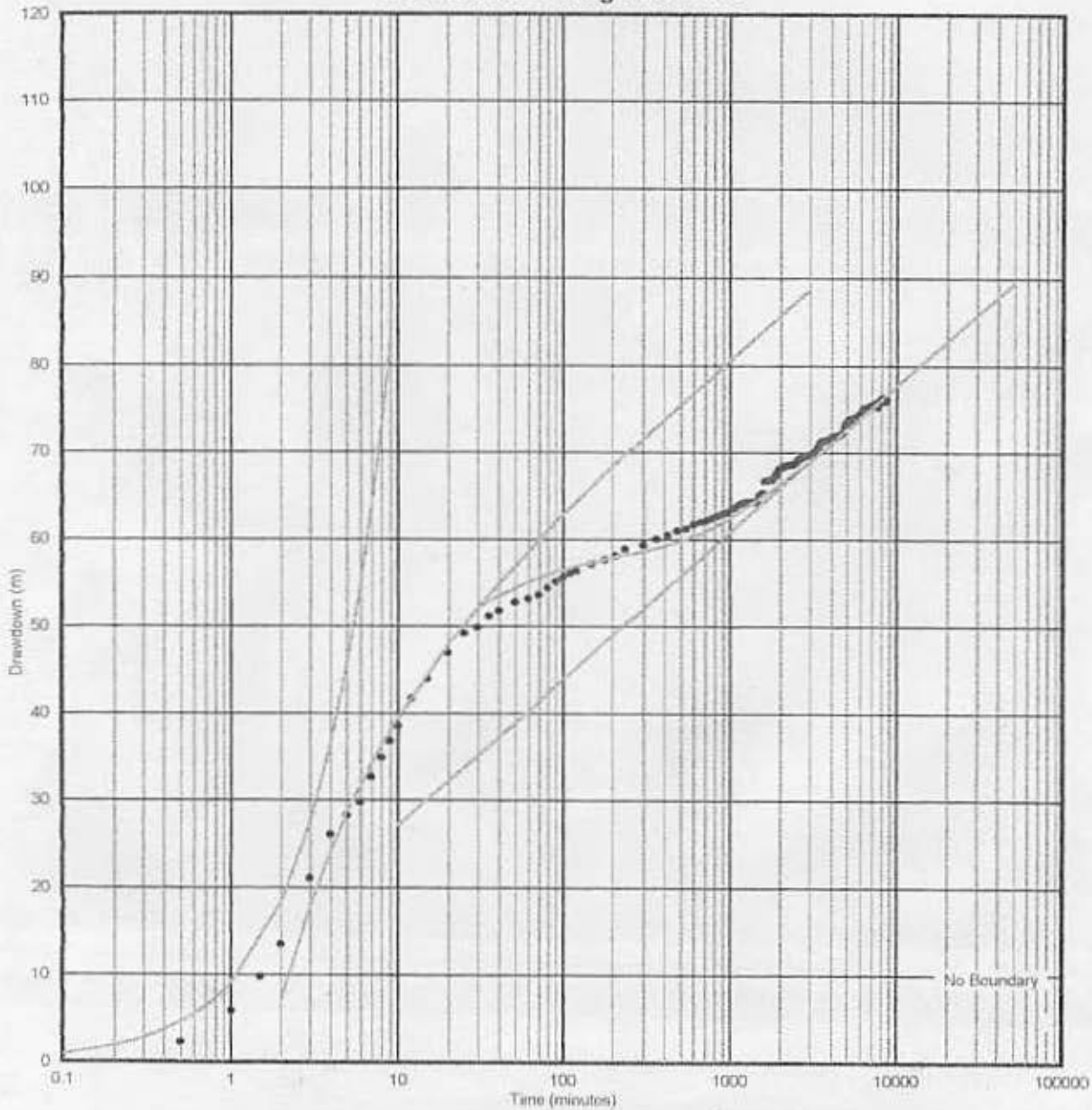
Appendix D3 BH 9314 - Constant Rate Test Data

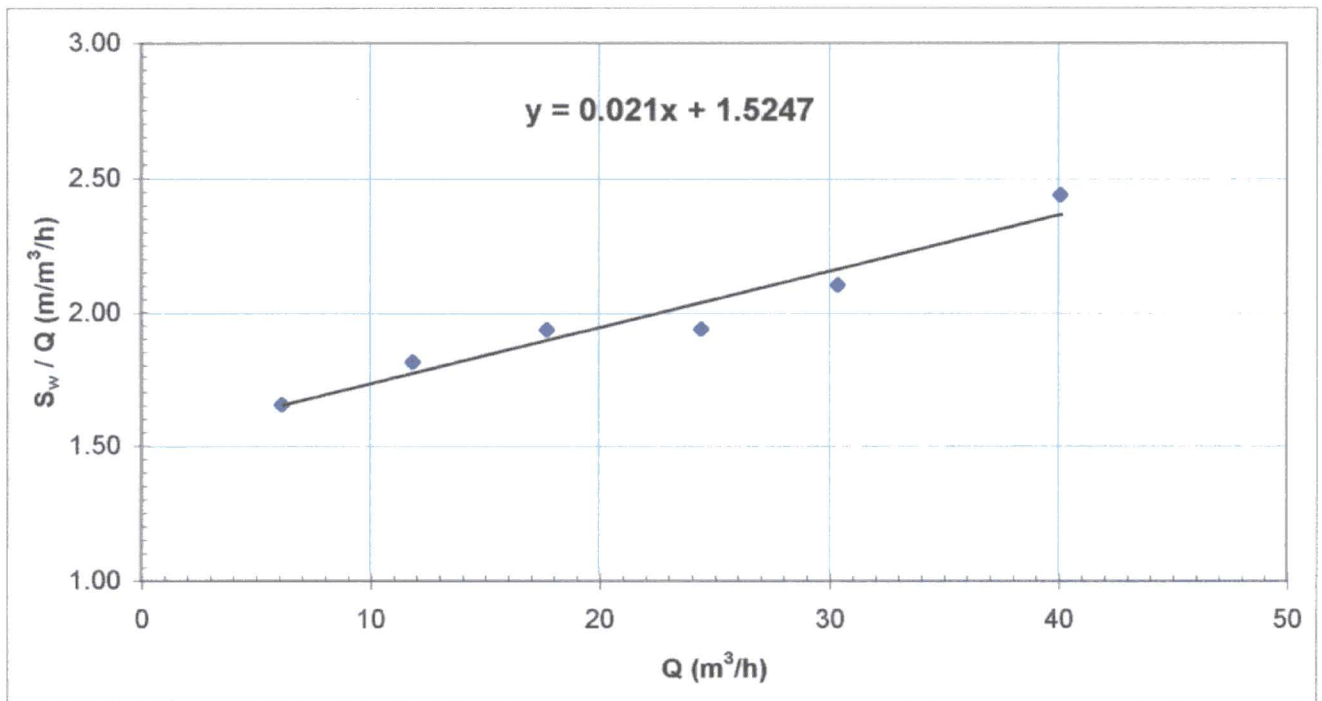
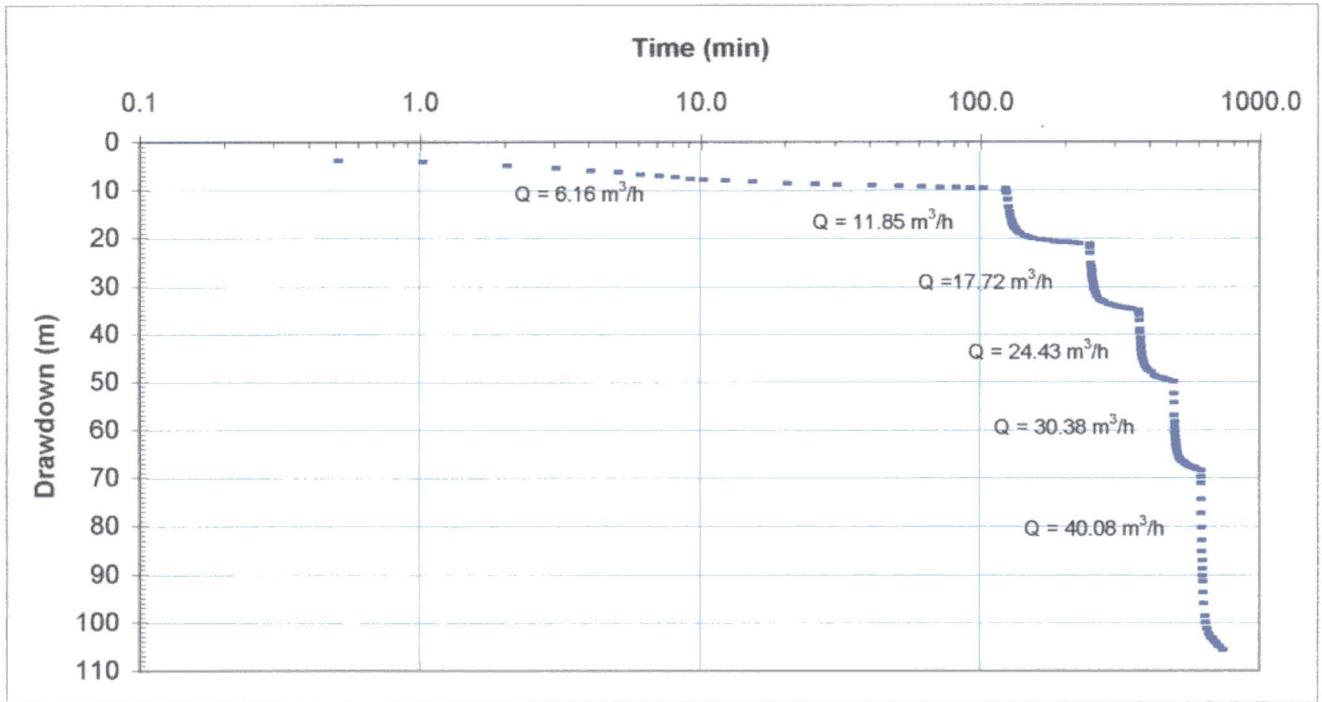
**OUTPUT FROM TestCurve 9.5**

Calculation with WBS, Skin, dual porosity, negative boundaries, closed aquifer

Date : 5/2/02  
 Time : 11:54:23  
 Project : Mathathane Village Bh 9315  
 Inputfile : C:\DWA\Bobirwa\SDTBH9315.dat  
 Outputfile : C:\DWA\Bobirwa\CRT9315c3.dat  
 Parameterfile : C:\DWA\Bobirwa\SDTBH9315.par  
 Pump rate (>0 - 2100 m<sup>3</sup>/hr) 28  
 Transmissivity (>0 - 50000 m<sup>2</sup>/day) 7.3  
 Storage coeff, early time (>0 - 1) .002  
 Storage coeff, late time (>0 - 1) 0.03  
 Well-diameter (1 - 20 inch) 10  
 Aquifer thickness (1 - 500 m) 68  
 C-Value from step-test (0 - 1000 h<sup>2</sup>/m<sup>2</sup>/S) 0.021  
 Skin-factor (-20 - 50) -2.0  
 Total Well-loss factor (as skin) -0.87625  
 Aquifer interpreted: No Boundary  
 Distance to 1st boundary (0.1 - 50000 m) 0  
 Distance to 2nd boundary (1 - 50000 m) 0  
 Distance to boundary (Closed aquifer) (m) 50000  
 Transmissivity beyond the discontinuity 0  
 Distance to 2nd boundary after discontinuity 0  
 Vertical permeability (m/day) 1.0

**Mathathane Village Bh 9315**





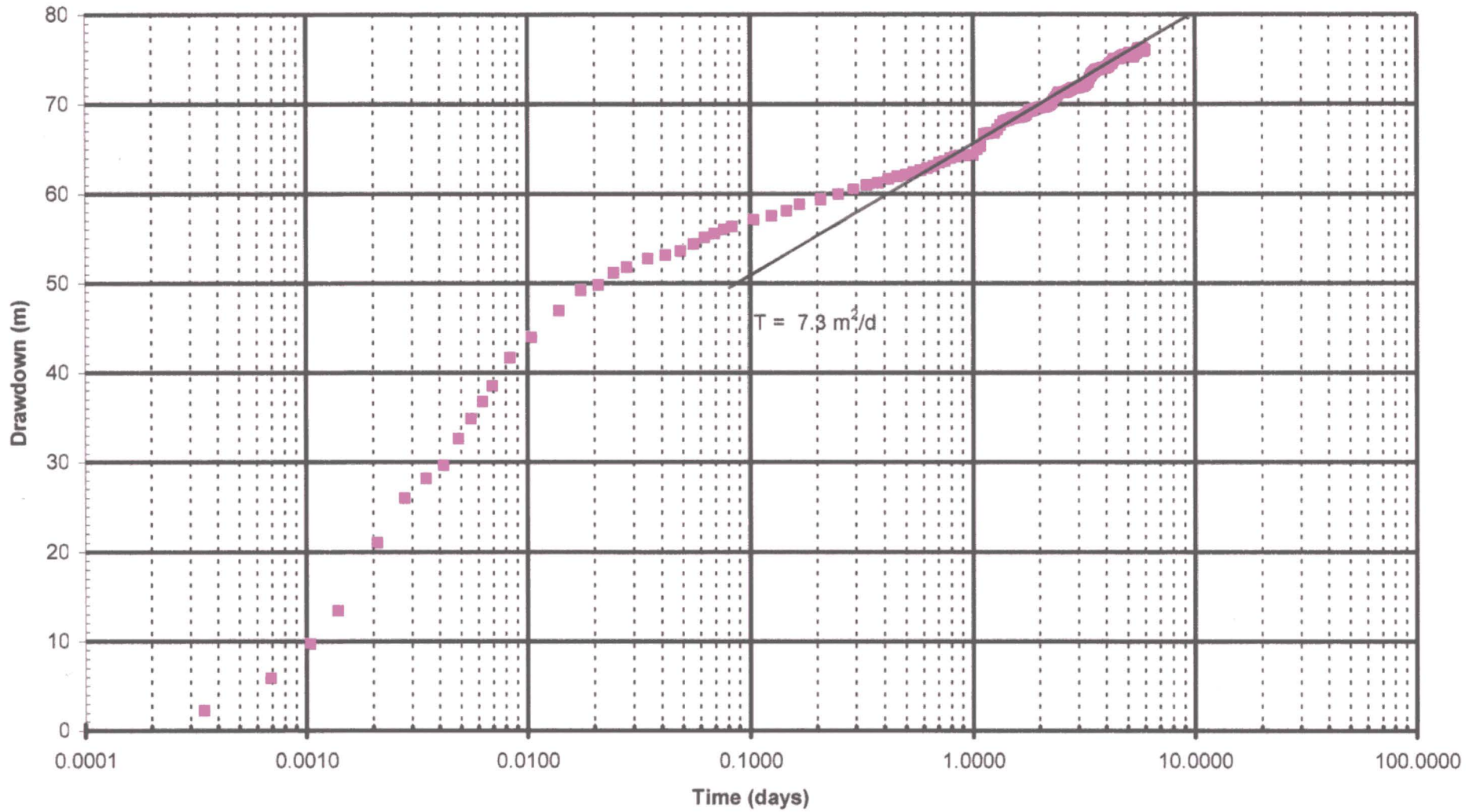
**Observed**

Step	Q	del S	S <sub>w</sub>	S <sub>w</sub> /Q
1	6.2	10.20	10.20	1.656
2	11.9	11.30	21.50	1.814
3	17.7	12.80	34.30	1.936
4	24.4	13.10	47.40	1.940
5	30.4	16.50	63.90	2.103
6	40.1	33.90	97.80	2.440

**Calculated**

Q	BQ	CQ <sup>2</sup>	S <sub>w</sub>	Eff (%)
6.2	9.39	0.80	10.19	92.2
11.9	18.07	2.95	21.02	86.0
17.7	27.02	6.59	33.61	80.4
24.4	37.25	12.53	49.78	74.8
30.4	46.32	19.38	65.70	70.5
40.1	61.11	33.73	94.84	64.4

**Appendix D4 BH 9315 - Step Test Data and Analysis**



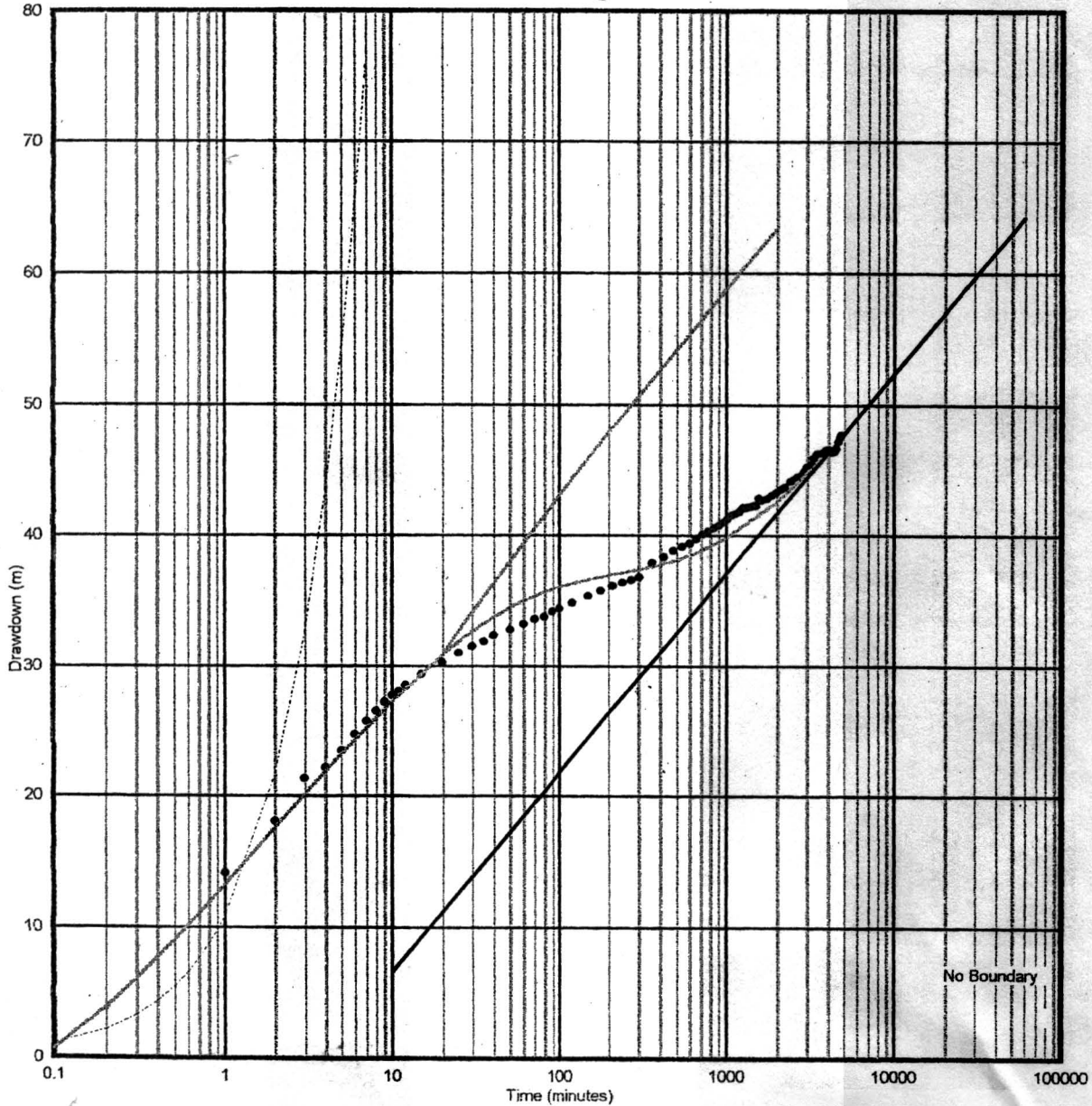
Appendix D6 BH 9315 - Constant Rate Test Data

**OUTPUT FROM TestCurve 9.5**

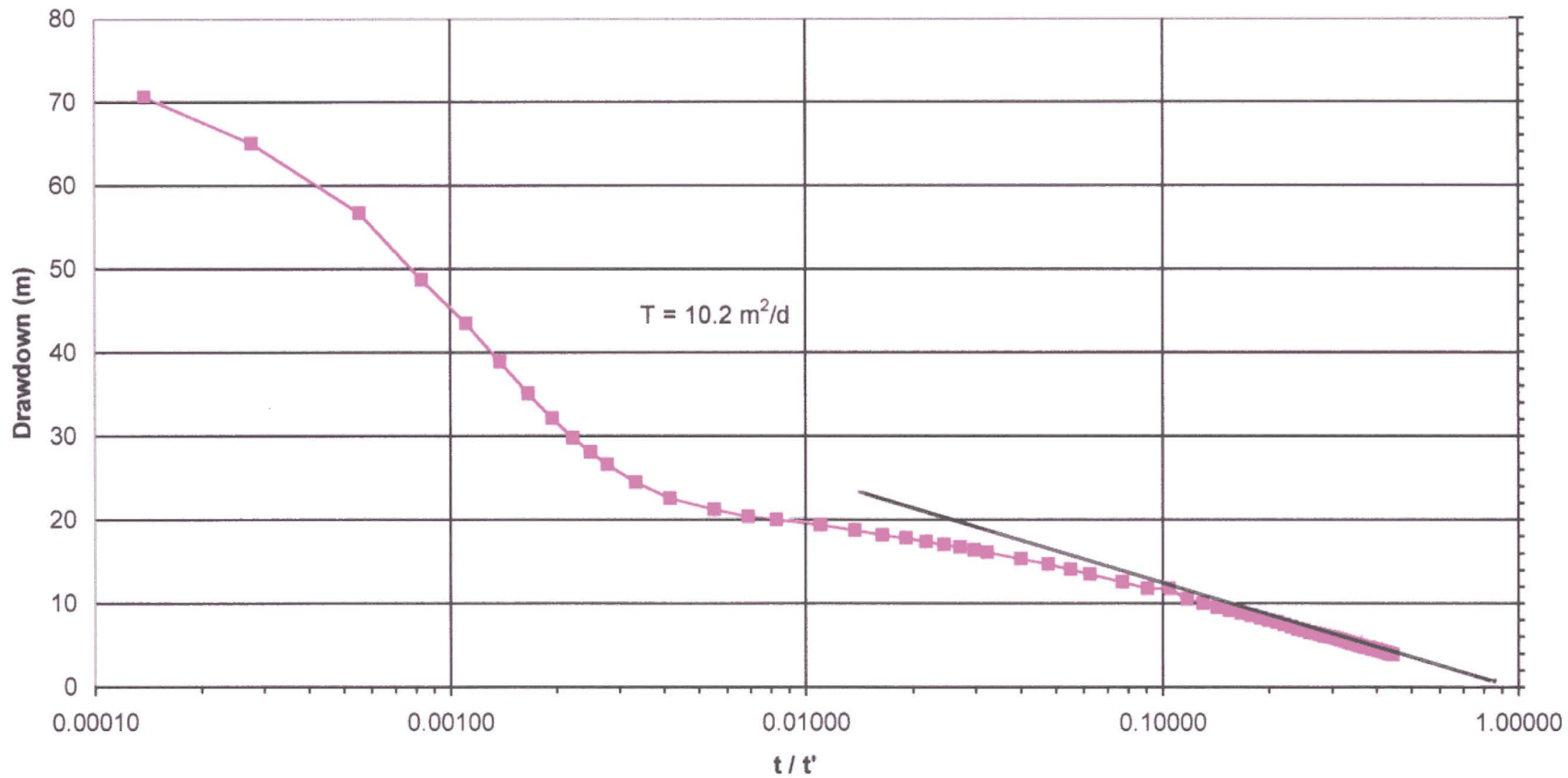
Calculation with WBS, Skin, dual porosity, negative boundaries, closed aquifer

Date : 5/2/02  
 Time : 11:29:59  
 Project : Mathathane Village Bh 9316  
 Inputfile : C:\DWA\Bibirwal\CRT9316.dat  
 Outputfile : C:\DWA\Bibirwal\CRT9316c3.dat  
 Parameterfile : C:\DWA\Bibirwal\CRT9316.par  
 Pump rate (>0 - 50000 m<sup>3</sup>/day) 792  
 Transmissivity (>0 - 50000 m<sup>2</sup>/day) 9.5  
 Storage coeff, early time (>0 - 1) .003  
 Storage coeff, late time (>0 - 1) 0.08  
 Well-diameter (1 - 20 inch) 10  
 Aquifer thickness (1 - 500 m) 40  
 C-Value from step-test (0 - 1000 h<sup>2</sup>/m<sup>4</sup>) 0.021  
 Skin-factor (-20 - 50) -3.6  
 Total Well-loss factor (as skin) -1.8764  
 Aquifer interpreted: No Boundary  
 Distance to 1st boundary (0.1 - 50000 m) 0  
 Distance to 2nd boundary (1 - 50000 m) 0  
 Distance to boundary (Closed aquifer) (m) 50000  
 Transmissivity beyond the discontinuity 0  
 Distance to 2nd boundary after discontinuity 0  
 Vertical permeability (m/day) 1.0

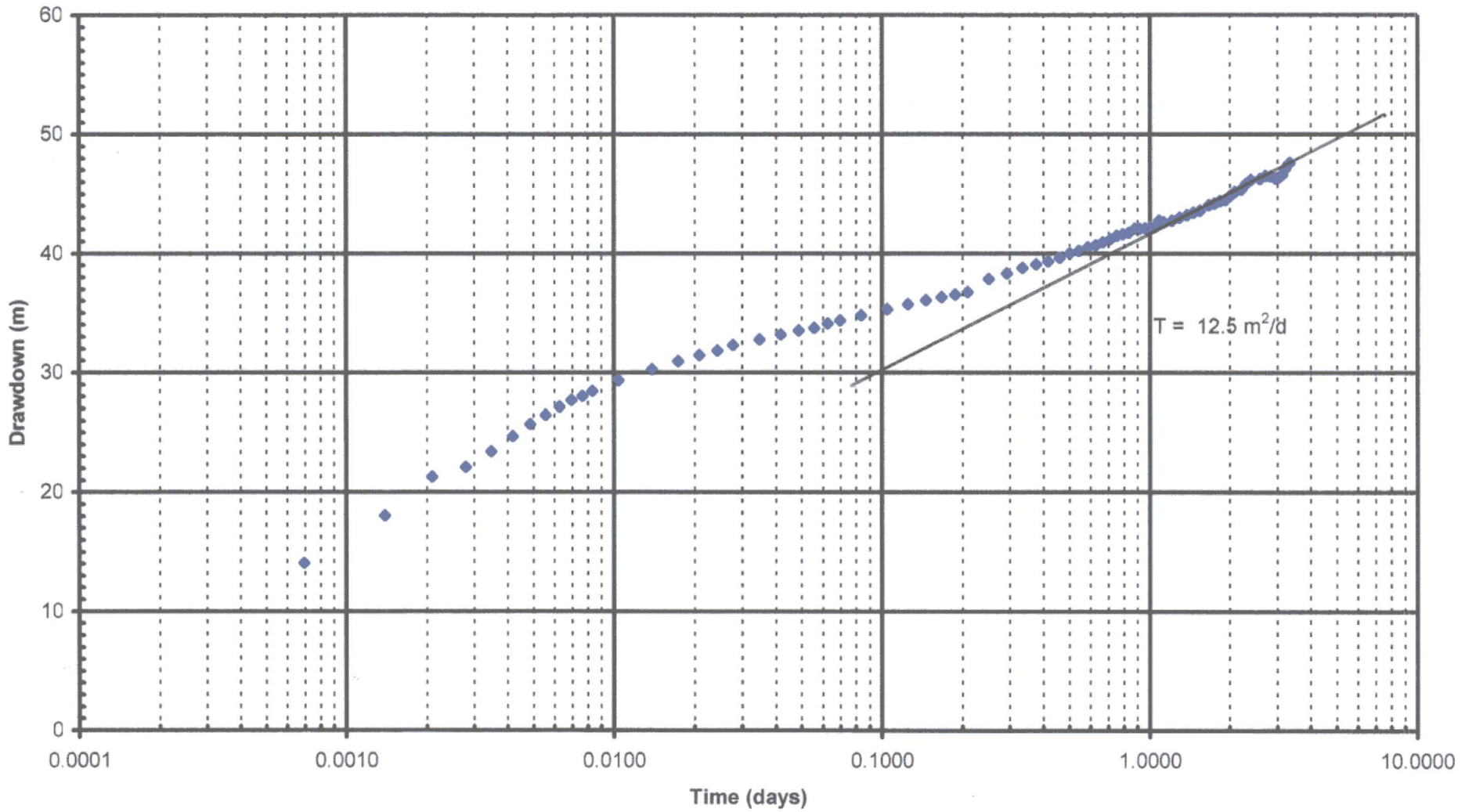
**Mathathane Village Bh 9316**



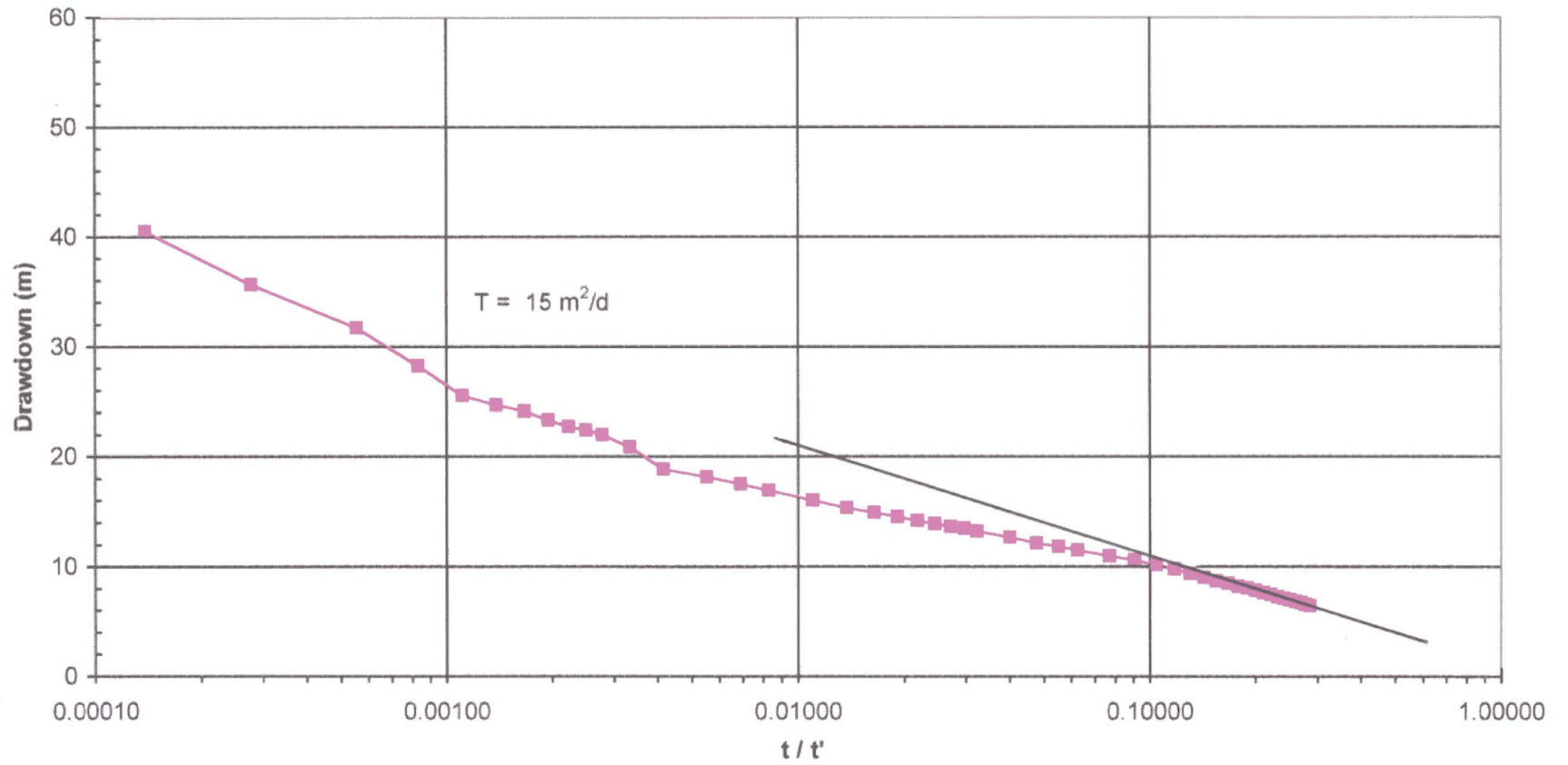
**Appendix D9 BH 9316 Testcurve Drawdown Analysis**



Appendix D7 BH9315 - Recovery Test Data



Appendix D8 BH 9316 - Constant Rate Test Data

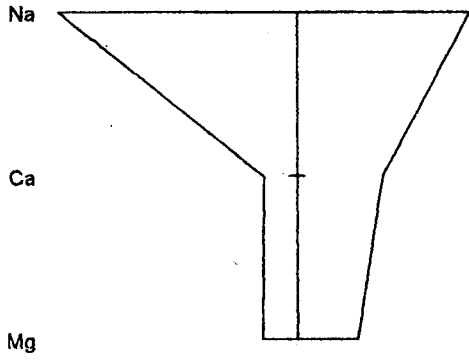


Appendix D10 BH9316 - Recovery Test Data

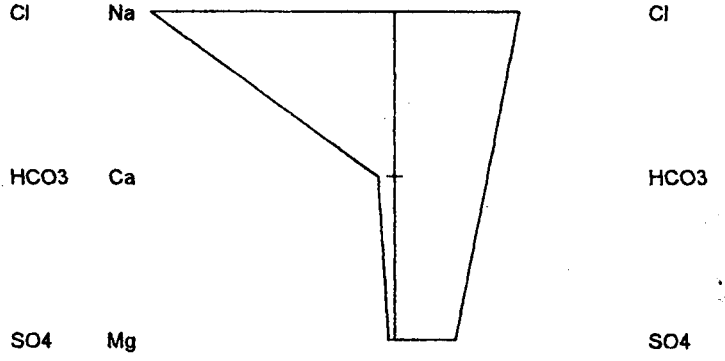
## **APPENDIX E**

### **Hydrochemistry Results**

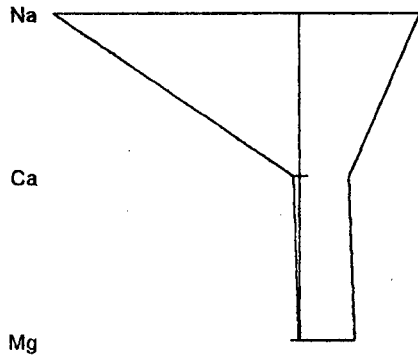
**9313**



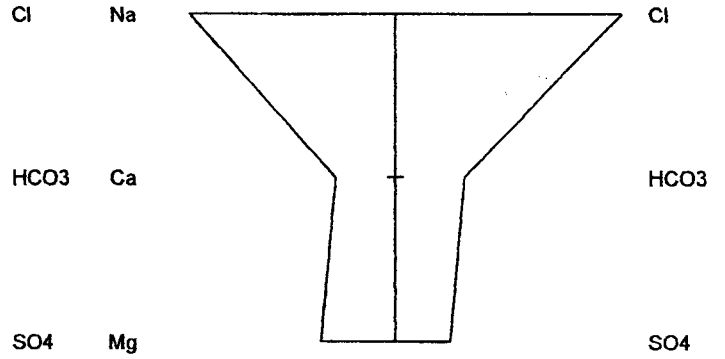
**9314**



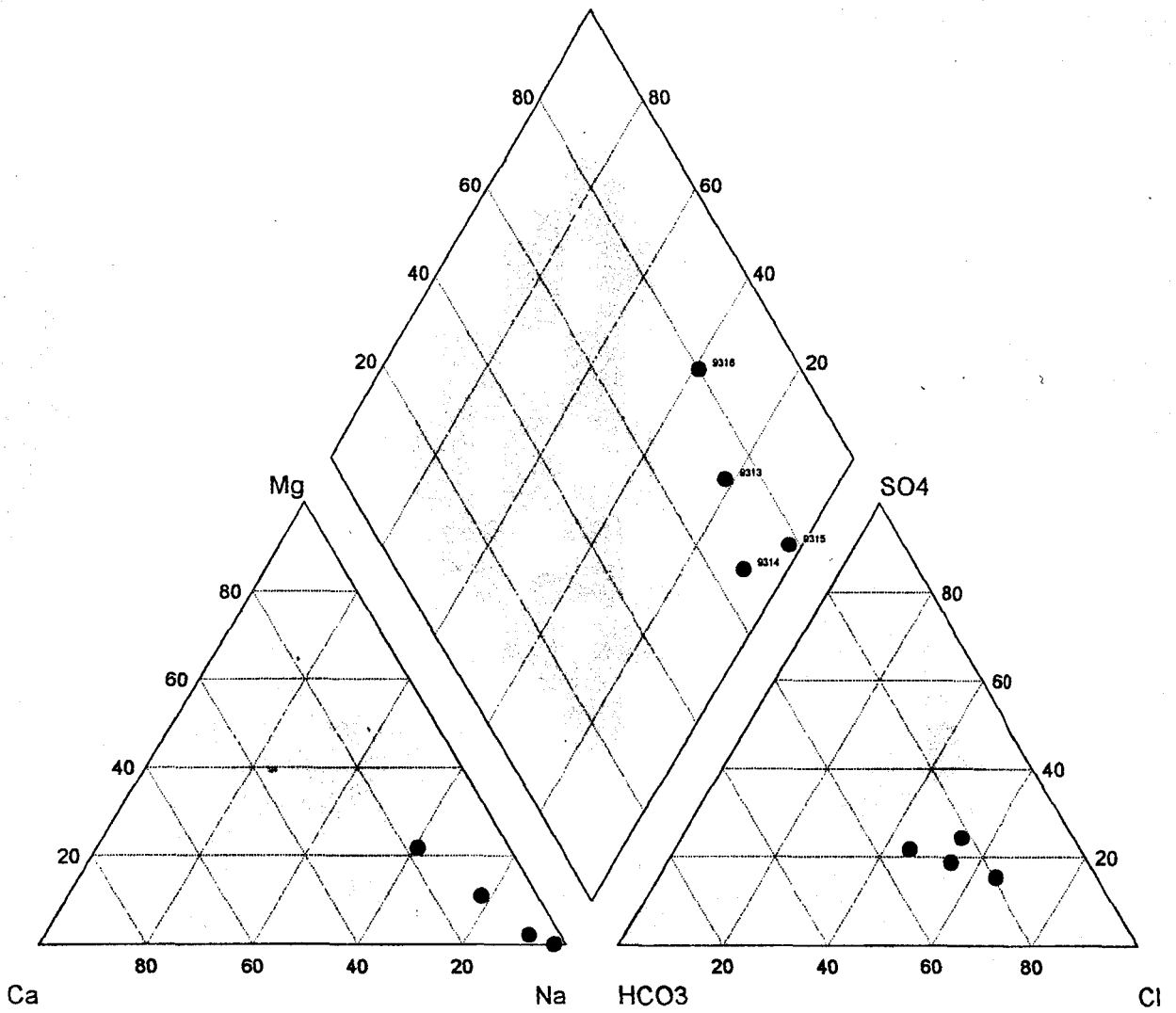
**9315**



**9316**



# Piper Diagram



**General Chemistry and Physical Data**

BH No.	Sample Type	Date Sampled	pH	EC Us/cm	TDS mg/l	Alkalinity	T.Hardness	Ca. Hardness
BH 9314	SDT (10hrs)	22/01/01	8.17	893	520		36.94	36.94
BH 9314	CRT (24hrs)	24/01/01	7.89	890	506		39.99	39.99
BH 9314	CRT (72hrs)	26/01/01	7.78	889	508		38.36	38.36
BH 9315	CRT (144hrs)	7/2/01	8.08	988	556		21.5	21.5
BH 9315	SDT (10hrs)	31/01/01	8.31	994	564		12.94	12.94
BH 9316	SDT (12hrs)	26/11/00	7.91	2225	1248		433.4	265.33
BH 9316	CRT (24hrs)	13/01/01	7.84	2198	1240		425.83	277.43
BH 9316	CRT (24hrs)	7/12/00	7.85	2198	1258		431.78	281.48

**CATION AND ANION DATA**  
all values in mg/l unless otherwise stated

BH No.	Sample Type	Date Sampled	Ca	Mg	Na	K	Fe	Mn	HCO3	Cl	SO4	F	NO3	CO3	Ion Bal.
BH 9314	SDT (10hrs)	22/01/01	10.7	2.49	181.3	1.69	1.2	0	186	145.58	95.1	1.12	1.12	12	-5.16
BH 9314	CRT (24hrs)	24/01/01	11.74	2.6	218.2	1.71	1.47	0	195	147.58	80.9	0.9	0	9	4.79
BH 9314	CRT (72hrs)	26/01/01	11.27	2.49	181.3	1.67	0.2	0	186	124.36	68.52	0.78	0	12	1.59
BH 9315	CRT (144hrs)	7/2/01	7.3	0.8	239.5	1.83	0.2	0	195	185.88	114.92	1.12	0.9	19	-2.87
BH 9315	SDT (10hrs)	31/01/01	1.66	0.32	226.1	1.33	0.2	0	122	174.2	107.05	1.15	0	19	1.46
BH 9316	SDT (12hrs)	26/11/00	77.6	58.3	307	3.7	0.51	0	277	534.2	173.8	0.45	0	23	-4.12
BH 9316	CRT (24hrs)	13/01/01	74.4	58.4	365.6	3.74	0.59	0	306	522.9	172.6	0.45	0	16	1.24
BH 9316	CRT (24hrs)	7/12/00	72.45	61.03	339.7	3.1	1.03	0.12	314.6	482.6	169	0	0	14.2	1.58

**CHEMISTRY REPORT**

Date compiled: 15/04/02

**BASIC SITE INFORMATION:** Site Identifier: 2228E100006 Number: 9314 Site type: Borehole

Distr./Farm No.: CENTRAL Site Name/Des.: MATHATHANE

Region Type: Medical region Region Descr.: MED REGION 04

X Coord. [m]: 22	Reg./BB.: G-Nr.:	Topo-set.:	Depth [m]:
Y Coord. [m]: 28		Site status: In use	Col. ht. [m]:
Altitude [m]:		Site purp.: Production (water supply)	Drain. reg.:
Coord. acc.: Accurate to within 10 000 units		Use applic.: Domestic - all purposes	Diam. [mm]:
Coord. meth.: Interpolated from map		Equipment:	Rep. inst.: DWAB

**SAMPLE INFORMATION:**

Chem. ref.	Sample	Meth. sampled	Sample Type	Date sampl.	Time samp.	Time pump.	Depth Sampl. [m]	Date analysed	Laboratory
50442	CEN01/307	Pump	Drinking water	20010122	0000	10	0	20010327	DWA
50443	CEN01/308	Pump	Drinking water	20010124	0000	24	0	20010327	DWA
50444	CEN01/309	Pump	Drinking water	20010126	0000	72	0	20010327	DWA

**MAIN PARAMETERS:**

Chem. ref. nr.	pH	EC [mS/m]	TDS	Ca	Mg	Na	K	Phen. alk.	Total alk.	Phen. acid	Meth. acid
50442	8.17	89.3	520	10.7	2.49	181.3	1.69				
50443	7.89	89	506	11.74	2.6	218.2	1.71				
50444	7.78	88.9	508	11.27	2.49	181.3	1.67				

Chem. ref. nr.	SI	Cl	SO4	NO3	F	CO3	HCO3	Al	Mn	Fe
50442		145.58	95.1	1.12	1.12	12	186		0	1.2
50443		147.58	80.9	0	0.9	9	195		0	1.47
50444		124.36	68.52	0	0.78	12	186		0	0.2

**ADDITIONAL PARAMETERS:**

Chem. ref. nr.	NH4	NO2	PO4	S	Cn	B	As	Sb	Bi	Cu	Pb
50442		0	0								
50443		0	0								
50444		0	0								

Chem. ref. nr.	Zn	Cr	Ni	Ti	Hg	Mo	Co	Ba	Sr	Cd
50442										
50443										
50444										

**RARE PARAMETERS:**

Chem. ref. nr.	Li	Ce	Au	Ag	Pt	Te	Tl	W	V	U	Se	Be	Br	I
50442													0	
50443													0	
50444													0	

**CALCULATED PARAMETERS:**

Chem. ref. nr.	Sum TDS	TDS-EC*7	Sum of Cations	Sum of Anions	Ion Bal.	Total Hardn.	Calc. Hardn.	Magn. Hardn.	Agress. Index	Langel. Index	Corros. Index	SAR
50442	624.16	625.10	8.67	9.61	-5.16	36.94	36.94	10.25	11.83	-0.23	1.77	12.98
50443	657.96	623.00	10.34	9.39	4.79	39.99	39.99	10.70	11.60	-0.47	1.67	15.01
50444	574.45	622.30	8.70	8.42	1.59	38.36	38.36	10.25	11.47	-0.59	1.43	12.73

Bact. param. in counts/100ml  
 Chemistry Standard: BOS 32: 2000 Drinking Water Spec  
 † Value exceeds recommended maximum limit  
 ‡ Value exceeds maximum allowable limit  
 † Value exceeds recommended minimum limit



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REPORT ON THE EXAMIN. OF WATER

**CHEMISTRY REPORT**

Date compiled: 15/04/02

**BASIC SITE INFORMATION:** Site Identifier: 2228E100005 Number: 9315 Site type: Borehole

Distr./Farm No.: CENTRAL Site Name/Des.: MATHATHANE

Region Type: Medical region Region Descr.: MED REGION 04

X Coord. [m]: 22	Reg./BB.:	Topo-set.:	Depth [m]:
Y Coord. [m]: 28	G-Nr.:	Site status: In use	Col. ht. [m]:
Altitude [m]:		Site purp.: Production (water supply)	Drain. reg.:
Coord. acc.: Accurate to within 10 000 units		Use applic.: Domestic - all purposes	Diam. [mm]:
Coord. meth.: Interpolated from map		Equipment:	Rep. inst.: DWAB

SAMPLE INFORMATION:				Date	Time	Time	Depth	Date
Chem. ref.	Sample	Meth. sampled	Sample Type	sampl.	samp.	pump.	sampl. [m]	analysed Laboratory
50448	CEN01/311	Pump	Drinking water	20010207	0000	144	0	20010327 DWA
50440	CEN01/ 310	Pump	Drinking water	20010131	0000	10	0	20010326 DWA

MAIN PARAMETERS:		EC	TDS	Ca	Mg	Na	K	Phen. alk	Total alk	Phen. acid	Meth. acid
Chem. ref. nr.	pH	[mS/m]									
50448	8.08	98.8	556	7.3	0.8	239.5	1.83				
50440	8.31	99.4	564	4.66	0.32	226.1	1.33				

Chem. ref. nr.	SI	Cl	SO4	NO3	F	CO3	HCO3	Al	Mn	Fe
50448		185.88	114.92	0.9	1.12	19	195		0	0.2
50440		174.2	107.05	0	1.15	19	122		0	0.2

ADDITIONAL PARAMETERS:		NH4	NO2	PO4	S	Cn	B	As	Sb	Bi	Cu	Pb
Chem. ref. nr.												
50448		0	0									
50440		0	0									

Chem. ref. nr.	Zn	Cr	Ni	Ti	Hg	Mo	Co	Ba	Sr	Cd
50448										
50440										

RARE PARAMETERS:		Li	Ce	Au	Ag	Pt	Te	Tl	W	V	U	Se	Be	Br	I
50448														0	
50440														0	

CALCULATED PARAMETERS:		Sum of TDS	TDS-EC*7	Sum of Cations	Sum of Anions	Ion Bal.	Total Hardn.	Calc. Hardn.	Magn. Hardn.	Agress. Index	Langel. Index	Corros. Index	SAR
50448		745.31	691.60	10.90	11.54	-2.87	21.50	21.50	3.29	11.62	-0.46	1.99	22.47
50440		634.87	695.80	10.13	9.84	1.46	12.94	12.94	1.32	11.49	-0.57	2.71	27.34

Bact. param. in counts/100ml  
 Chemistry Standard: BOS 32: 2000 Drinking Water Spec  
 † Value exceeds recommended maximum limit  
 ‡ Value exceeds maximum allowable limit  
 † Value exceeds recommended minimum limit



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REPORT ON THE EXAMIN. OF WATER

**CHEMISTRY REPORT**

Date compiled: 15/04/02

**BASIC SITE INFORMATION:** Site Identifier: 2228E100003 Number: 9316 Site type: Borehole

Distr./Farm No.: CENTRAL Site Name/Des.: MATHATHANE

Region Type: Medical region Region Descr.: MEDICAL REGION 04

<b>X Coord. [m]:</b> 22	<b>Reg./BB.:</b> <b>G-Nr.:</b>	<b>Topo-set.:</b>	<b>Depth [m]:</b>
<b>Y Coord. [m]:</b> 28		<b>Site status:</b> In use	
<b>Altitude [m]:</b>		<b>Site purp.:</b> Production (water supply)	<b>Drain. reg.:</b>
<b>Coord. acc.:</b> Accurate to within 10 000 units		<b>Use applic.:</b> Domestic - all purposes	<b>Diam. [mm]:</b>
<b>Coord. meth.:</b> Interpolated from map		<b>Equipment:</b> No information	<b>Rep. inst.:</b> DWAB

**SAMPLE INFORMATION:**

Chem. ref.	Sample	Meth. sampled	Sample Type	Date sampl.	Time samp.	Time pump.	Depth sampl. [m]	Date analysed	Laboratory
50435	CEN01/305	Pump	Drinking water	20001126	0000	12	0	20010326	DWA
50441	CEN01/306	Pump	Drinking water	20010113	0000	24	0	20010326	DWA
49953	CEN00/2209	Pump	Drinking water	20001207	0000	24		20010112	DWA

**MAIN PARAMETERS:**

Chem. ref. nr.	pH	EC [mS/m]	TDS	Ca	Mg	Na	K	Phen. alk	Total alk.	Phen. acid	Meth. acid
50435	7.91	222.5	1248	77.6	58.3	307	3.7				
50441	7.84	219.8	1240	74.4	58.4	365.6	3.74				
49953	7.85	219.8	1258	72.45	61.03	339.7	3.1				

Chem. ref. nr.	Si	Cl	SO4	NO3	F	CO3	HCO3	Al	Mn	Fe
50435		534.2	173.8	0	0.45	23	277		0	0.51
50441		522.9	172.6	0	0.45	16	306		0	0.59
49953		482.6	169	0	0	14.2	314.6		0.12	1.03

**ADDITIONAL PARAMETERS:**

Chem. ref. nr.	NH4	NO2	PO4	S	Cn	B	As	Sb	Bi	Cu	Pb
50435		0	0								
50441		0	0								
49953		0	0								

Chem. ref. nr.	Zn	Cr	Ni	Tl	Hg	Mo	Co	Ba	Sr	Cd
50435										
50441										
49953										

**RARE PARAMETERS:**

Chem. ref. nr.	Li	Ce	Au	Ag	Pt	Te	Tl	W	V	U	Se	Be	Br	I
50435													0	
50441													0	
49953													0	

**CALCULATED PARAMETERS:**

Chem. ref. nr.	Sum TDS	TDS-EC*7	Sum of Cations	Sum of Anions	Ion Bal.	Total Hardn.	Calc. Hardn.	Magn. Hardn.	Agress. Index	Langel. Index	Corros. Index	SAR
50435	1430.42	1557.50	22.12	24.02	-4.12	433.40	265.33	239.96	12.62	0.45	3.52	6.41
50441	1502.54	1538.60	24.52	23.92	1.24	425.83	277.43	240.37	12.55	0.38	3.31	7.71
49953	1441.37	1538.60	23.49	22.76	1.58	431.78	281.48	251.20	12.56	0.39	3.04	7.11

Bact. param. in counts/100ml  
 Chemistry Standard: BOS 32: 2000 Drinking Water  
 Spec  
 † Value exceeds recommended maximum limit  
 ‡ Value exceeds maximum allowable limit  
 † Value exceeds recommended minimum limit

**WATER  
AFFAIRS**



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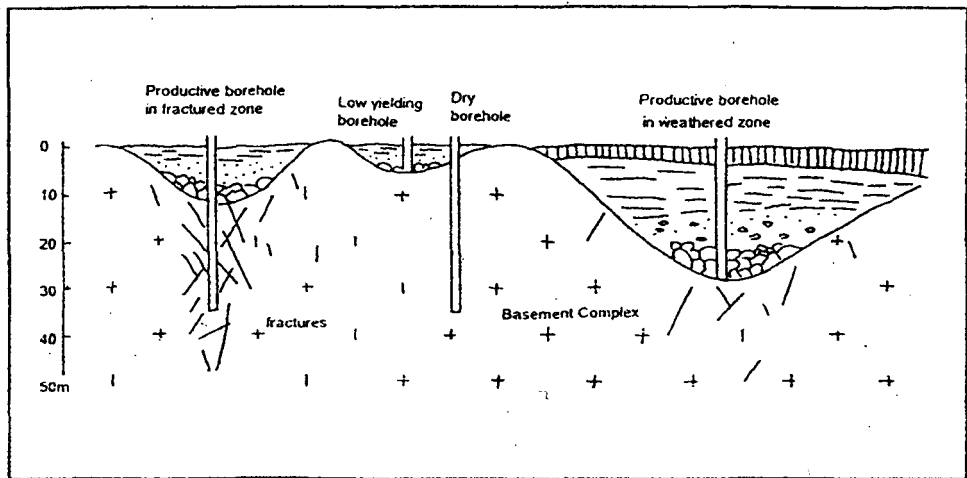


Figure 1

Typical Basement Aquifers

DEPARTMENT OF WATER AFFAIRS  
REPUBLIC OF BOTSWANA

**BOBIRWA VILLAGES**  
INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

**FINAL REPORT**

JUNE 2002

prepared by

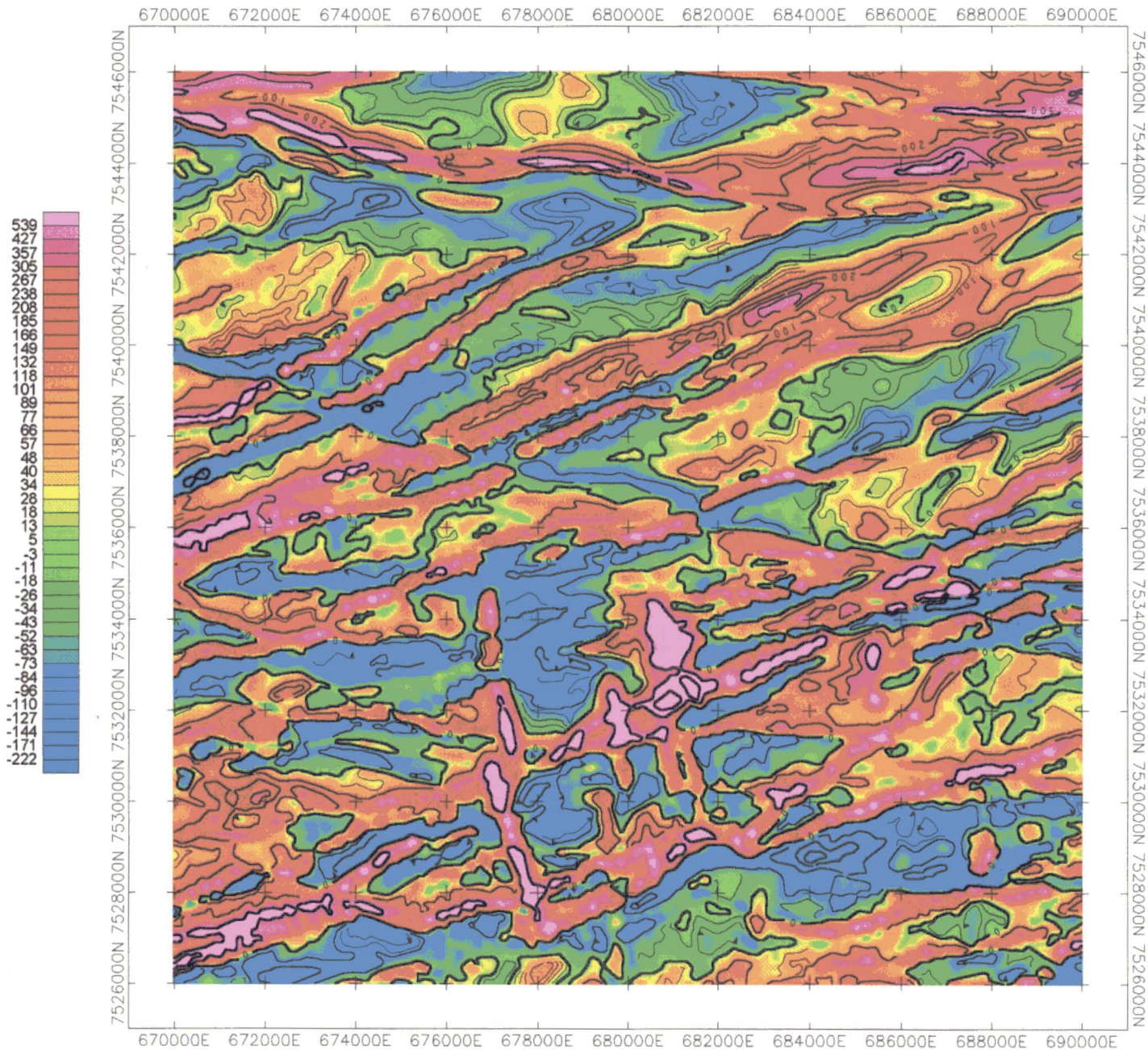
*Wellfield Consulting Services (Pty) Ltd*

**MATHATHANE**

COLOUR IMAGE and CONTOURS  
of the TOTAL MAGNETIC INTENSITY

Extracted from the Limpopo Central Zone Data Set (DGS)

**FIGURE 2**



DEPARTMENT OF WATER AFFAIRS

REPUBLIC OF BOTSWANA

## BOBIRWA VILLAGES

INTEGRATED RURAL VILLAGE  
WATER SUPPLY PROGRAMME

## FINAL REPORT

JUNE 2002

prepared by

*Wellfield Consulting Services (Pty) Ltd*

# MATHATHANE

### LEGEND

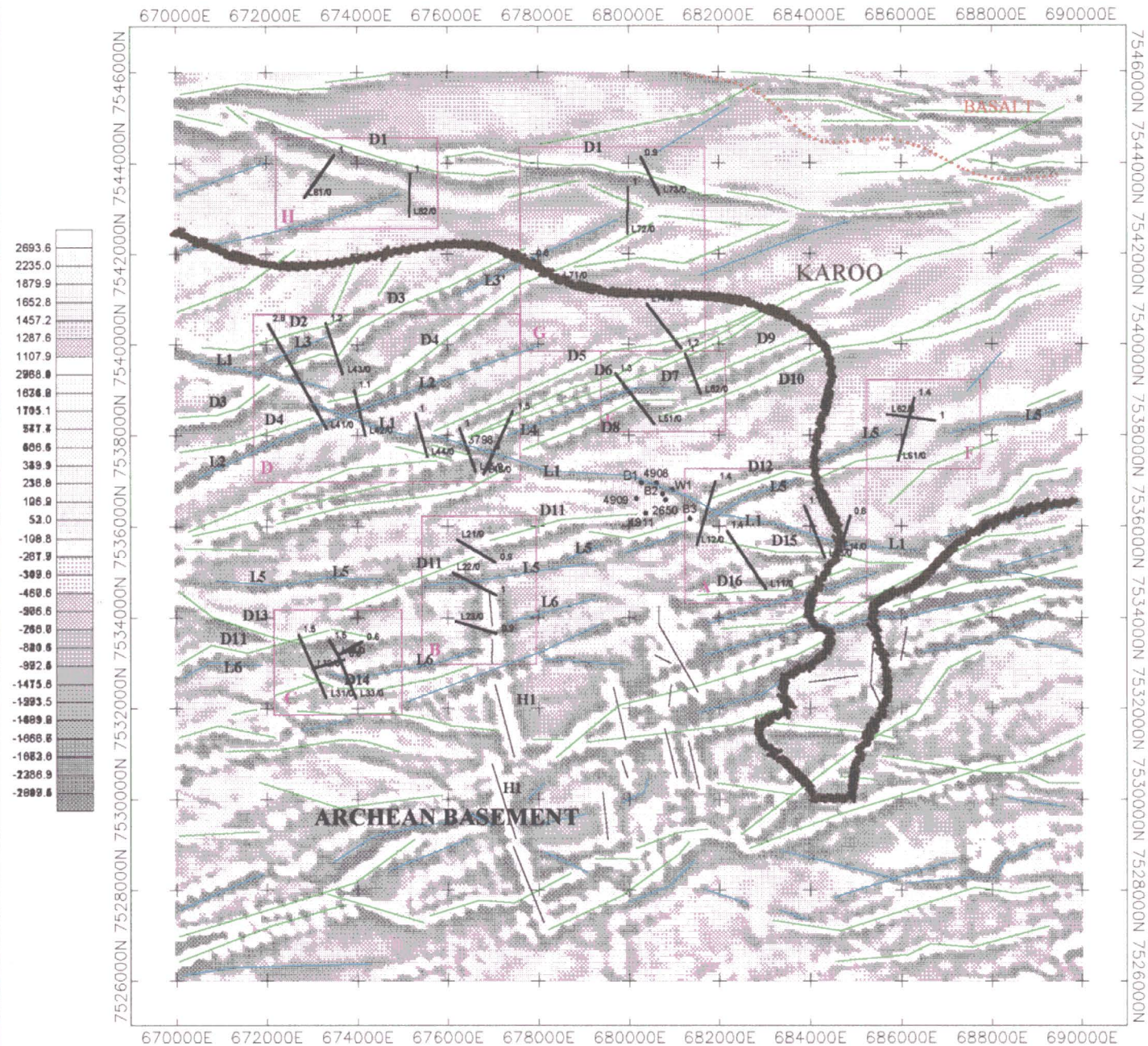
- |   |  |
|---|--|
|  dolerite dyke       |  southern edge of Stormberg Basalt    |
|  magnetic high       |  approximate edge of Karoo Formation |
|  magnetic low        |  geophysical traverse               |
|  Target Area       |  dolerite dyke DD1                  |
|  existing borehole |  existing well                      |

### AEROMAGNETIC INTERPRETATION

1<sup>st</sup> VERTICAL DERIVATIVE

Extracted from the Limpopo Central Zone Data Set (DGS)

## FIGURE 3







**LEGEND**

● Village	— Tarred Road	— Game Reserve Park Boundary
▲ Town	— Secondary Road	- - - District Boundary
■ Project Area	— Railway	— River
■ Pan / Delta	- - - International Boundary	— Fossil River Valley

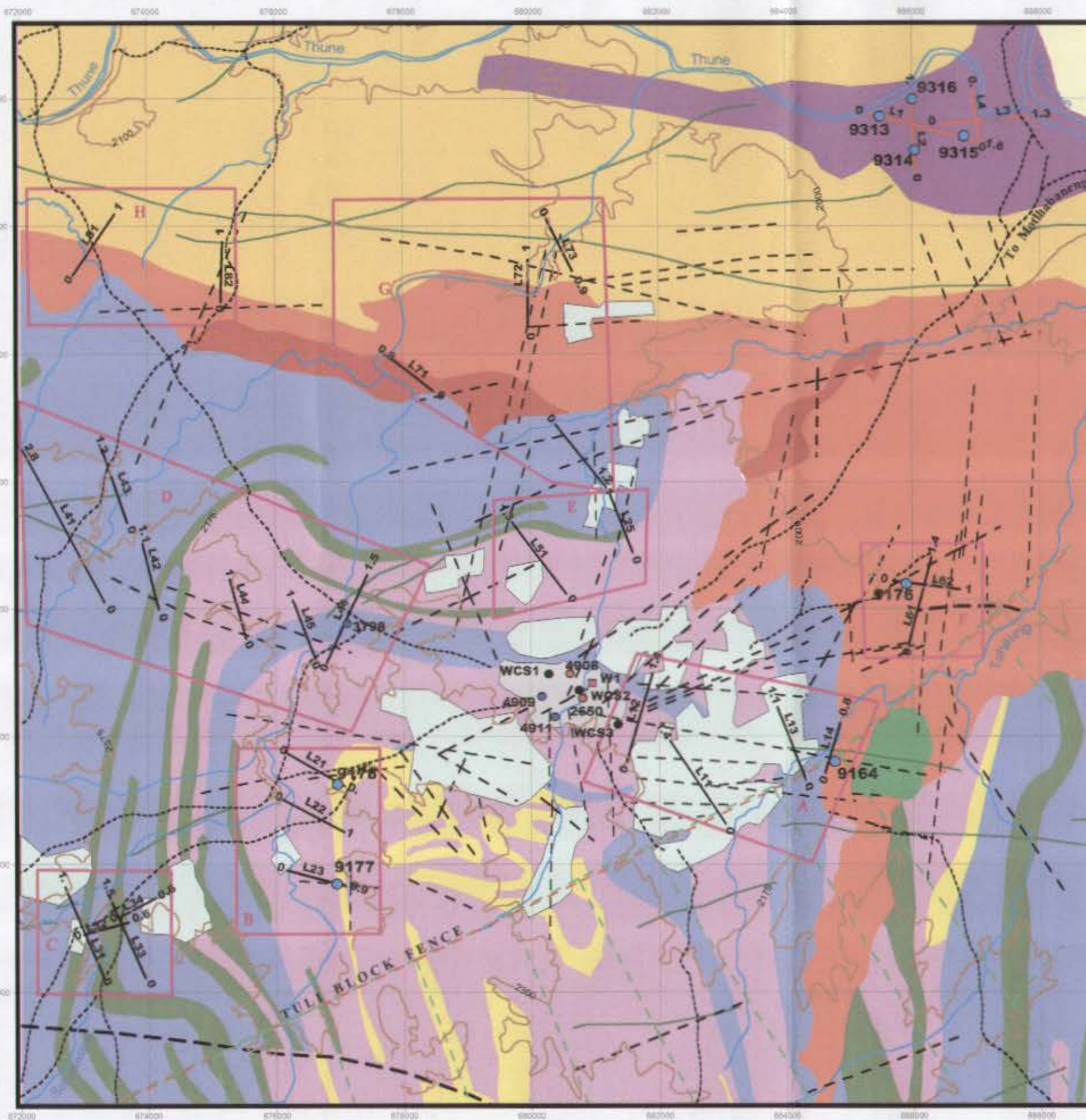
Scale 1: 6 000 000



BOBIRWA SUB DISTRICT VILLAGES WATER SUPPLY  
**PROJECT AREA LOCATION MAP**

Map 1  
**Figure 1**  
08/2002





**LEGEND**

**TOPOGRAPHY**

- Road
- River
- - - Farm Boundary
- - - State Land & Tribal Territory
- ▭ Settlement
- ▭ Fields

**PROJECT INFORMATION**

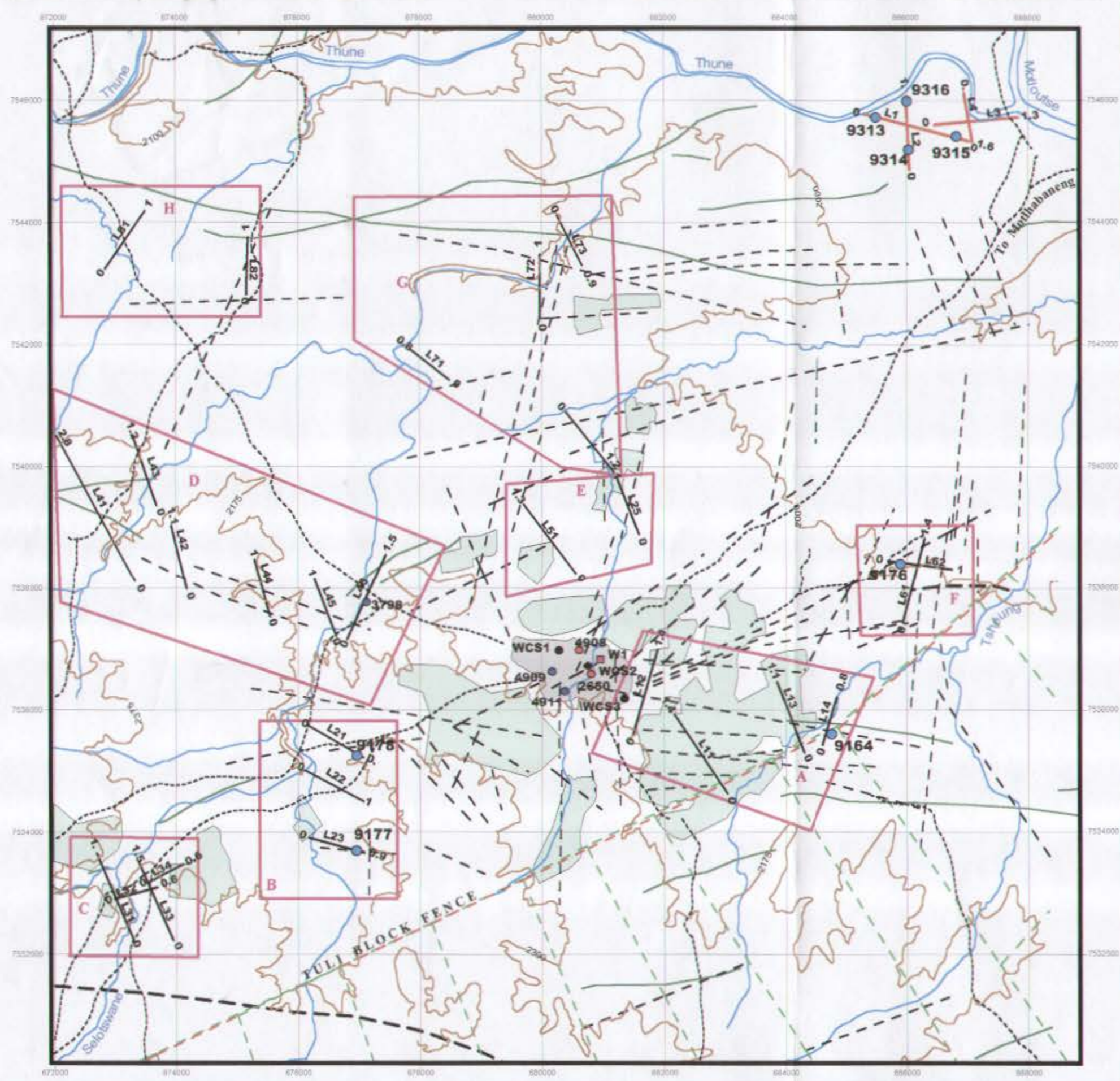
- Existing Borehole
- Current Supply Borehole
- Well
- BH (Official Number Unknown)
- Project Borehole
- Geophysical Traverse
- Add Geophysical Traverse
- Dolerite Dyke
- - - Fault
- - - Lineament
- ▭ Target Area

**GEOLOGY**

- ▭ Sandy Alluvium
  - ▭ Dolerite  
Fine to medium-grained Dolerite
  - ▭ Basalt  
Fine-grained Amygdaloidal Basalt
  - ▭ Sandstones & Siltstones  
Fine, medium-grained Sandstones showing honeycomb weathering; Underlain by grey, pale brown Siltstones
  - ▭ Grits & Sandstones  
Grits and Sandstones with thin Conglomerate lenses; Mudstone bands locally
  - ▭ Mudstones  
Mudstones with thin interbanded Sandstones and thin Imperstant Ironstones
  - ▭ Amphibolites
  - ▭ Metaquartzites  
Course Metaquartzites, Locally Micaceous. Thin Bands of Magnetite Locally
  - ▭ Foliated Quartzose Feldspathic Gneiss  
Massive well foliated Quartzose feldspathic Gneiss, with Hornblende and / or Biotite
  - ▭ Hornbede Plagioclase Gneiss  
Intimately Interbanded sequence of Hornblende-Plagioclase Gneiss, Amphibolite, Marble, Quartzite and Quartzose feldspathic Gneiss
- KAROO SUPERGROUP**
- PRECAMBRIAN BASEMENT**

SCALE 1:70 000





**LEGEND**

**TOPOGRAPHY**

- Road
- River
- Farm Boundary
- State Land & Tribal Territory
- Settlement
- Fields
- Contour

**PROJECT INFORMATION**

- Existing Borehole
- Current Supply Borehole
- Well
- BH (Official Number Unknown)
- Project Borehole
- Geophysical Traverse
- Add Geophysical Traverse
- Lineament
- Target Area



SCALE 1:70 000

