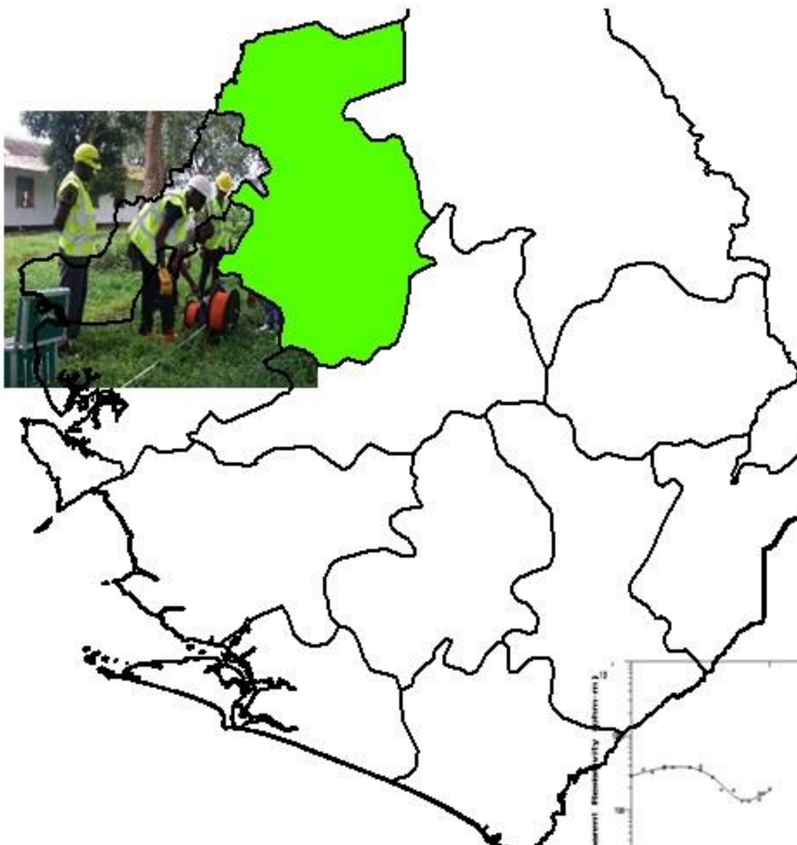
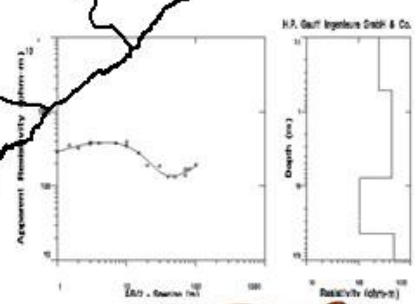
GOAL SIERRA LEONE

BOREHOLE GEOPHYSICAL SITING AT AT SELECTED DISTRICTS IN SIERRA LEONE –BOMBALI DISTRICT





SITING REPORT

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I confirm (by initialing) that the items above have been reviewed for Quality Control, and this document is ready for release.

Signed: ____________________________________ Date: ___________________________________

Project Manager 10/11/2015

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SUMMARY

Resistivity profiles and Resistivity soundings were performed at Makeni Government Hospital in Bombali District between the 21st of October and the 22nd of October 2015, with the objective of recommending suitable drilling sites within the Hospital. The profiles were done at three different depth of investigations i.e. 15m, 25m and 40m, while the soundings were performed at maximum depth of investigation of approximately 100m.

Two drilling points are recommended for the Hospital i.e. the priority drilling site and a backup site.

Table 5 lists the drilling sites, provides the detailed rationale for the selection of the sites and the proposed drilling depths.

Two profiles lines (MK001P1 and MK001P2) of 100m and 170m length were surveyed within the hospital. Three VES soundings were performed from which two drilling sites were recommended at 0823779E, 0981997N and. 0698780, 0936265

1 INTRODUCTION

Universal GeoScience Solutions in Joint Venture with Dynamic Integrated Geo-Hydro Environmental Services have been commissioned by GOAL SIERRA LEONE to train and supervise Department of Water Resources (DWR) personnel to carry out groundwater borehole siting for the implementation of Water, Sanitation and Hygiene activities in District Hospitals and Community Health Centers (CHC, s) in specific districts of Sierra Leone. GOAL has contracted the Department of Water Resources to undertake the siting of the boreholes on selected Hospitals and Community Health Centers under GOAL's remit, (3 in Port Loko District; 2 in Western District; 3 in Bo District; 2 in Kenema District and 2 in Western District).

This report discusses the geophysical surveys which were undertaken in Bombali District's Makeni Government hospital and recommends sites for drilling of planned 1 borehole. The main objective of this project is to identify and develop additional groundwater abstraction points with sufficient volumes of potable water and within the hospital to supplement the existing water sources and to meet the projected water demand.

Water used at Makeni Government Hospital is currently obtained from two hand dug wells with the hospital. However these wells are shallow seasonal wells which get stressed during the dry season. The wells are also close to septic tanks, there by posing a significant threat of pollution by nitrates and possibly faecal contamination. Consequently a new sustainable water supply borehole is required for the hospital.

2 BACKGROUND

A couple of boreholes have been drilled at the Hospital (see GOAL inception report October 2015) none of these boreholes is currently in use and there is no information on yield serve for a dry one drilled next to the main entrance. Considering the unavailability of information regarding results of drilled and hand dug wells in the vicinity of this community, the expected success rate for drilling boreholes with sufficient quantities of water require more geophysical techniques so as to map a number of different aquifer systems which includes weathered basement; fractured basement rocks and faulting zones. Past experiences of the consultant, minimum requirements to facilitate improved groundwater borehole yields will aim at junctions of faults; thick weathered basement which is fractured underneath the weathered zone. Consequently the consultant recommended the use of profiling techniques using Magnetic Method and/or Horizontal Loop Electromagnetic Survey (HLEM) on every line to be surveyed with Resistivity profiling technique to aid better location of best points to be further investigated with VES technique (GOAL Final Geophysical Siting Report, November 2015). However the contractor is not in a position to source the equipment for Magnetic or HLEM surveys.

3 LOCATION

Bombali District is a district in the Northern Province of Sierra Leone. Its capital and largest city is Makeni, which is also the largest city in the north. The other major towns in the district include Kamakwie, Kamabai, Karina and Binkolo. Makeni is the capital and administrative center of Bombali District. The city lies approximately 137 kilometers (85 miles) east of Freetown. Makeni Government Hospital is the Provincial Referral Hospital in Northern Sierra Leone. The location of the Hospital is shown in

Figure 1.

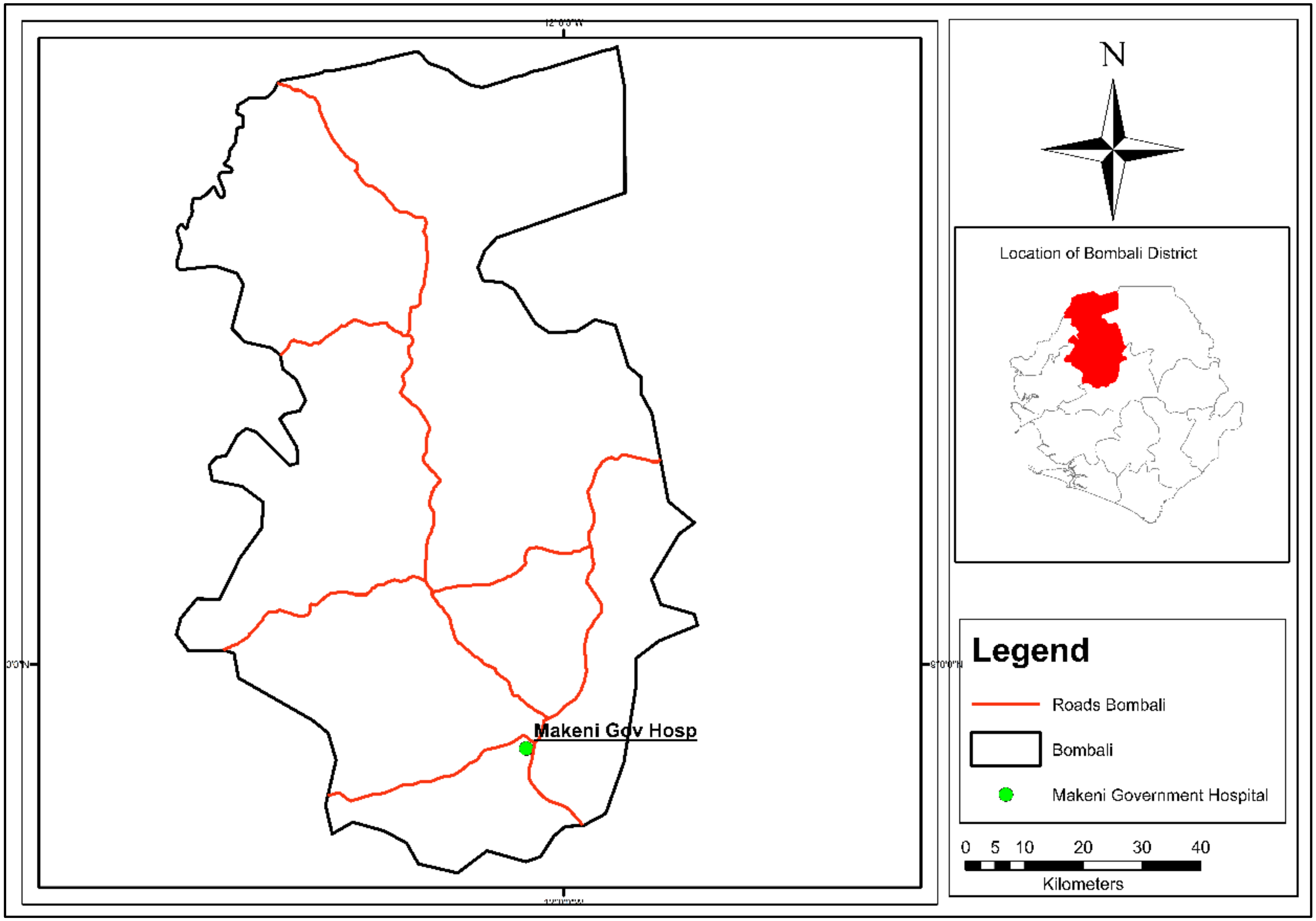


Figure 1: Location of Makeni Government hospital

4 REGIONAL SETTING

4.1 Geology

Two major geologic units are found win the districts i.e. the younger rocks of the Kasila Group to the Western side and rocks of the Liberian Granite of the Basement complex, with a contact trending in a NW-SE direction between the two groups.

Kasila Group rocks comprise of quartzo feldspathic gneisses, and olivine bearing meta-gabroo. Inferred lineaments in this area are striking in a general NW-SE direction. To the east of the Kasila group sediments are rocks of the Leonian Granite, these rocks have mapped and inferred structures striking in a NW-SE direction showing some signs of isoclinal folding and intensive shearing, inferred regional structures/lineaments run parallel to the regional geologic contacts. The surface geology of the area at Makeni comprises of the Liberian Granite. Dolerite Dykes of Mesozoic age have intruded the area to the North of Makeni Government hospital, however these have not been mapped/identified at Makeni hospital. Figure 2 shows the location of Makeni hospital on the geology map of Bombali district.

4.2 Hydrogeological Setting

The major hydrogeological targets are classified into two, being the basement aquifers and unconsolidated sandstone and gravels. Groundwater in this area generally occurs in the fractured rocks and frequently at the base of the top weathered rock or alluvium (overburden). Consequently, two different types of aquifer may be expected in the area. These are the Basement aquifer and sandstone and sand/gravel aquifer. Due to the varying nature of these two aquifers and their potentially different groundwater potential they will be discussed separately.

The Precambrian Basement Complex consisting of ancient crystalline granitic gneiss with supracrustal volcanic and sedimentary belts is described as having metasediments, volcanic basement granites, gneisses and migmatites and amphibolites. The aquifers expected in this area are characterized by fractured contacts at the base of the relatively thick weathered zones, fractured contacts between gneiss and dolerite or amphibolites, fractured geological contacts and faults which are trending NW-SE. We also target thick weathered zones of the basement rock. These can be very important if they occur on fractured basins of the basement rock, (Goal Inception Report, October 2015). Typical yields in both aquifer units have been reported to range between 0.3l/s ands to 1.5l/s.

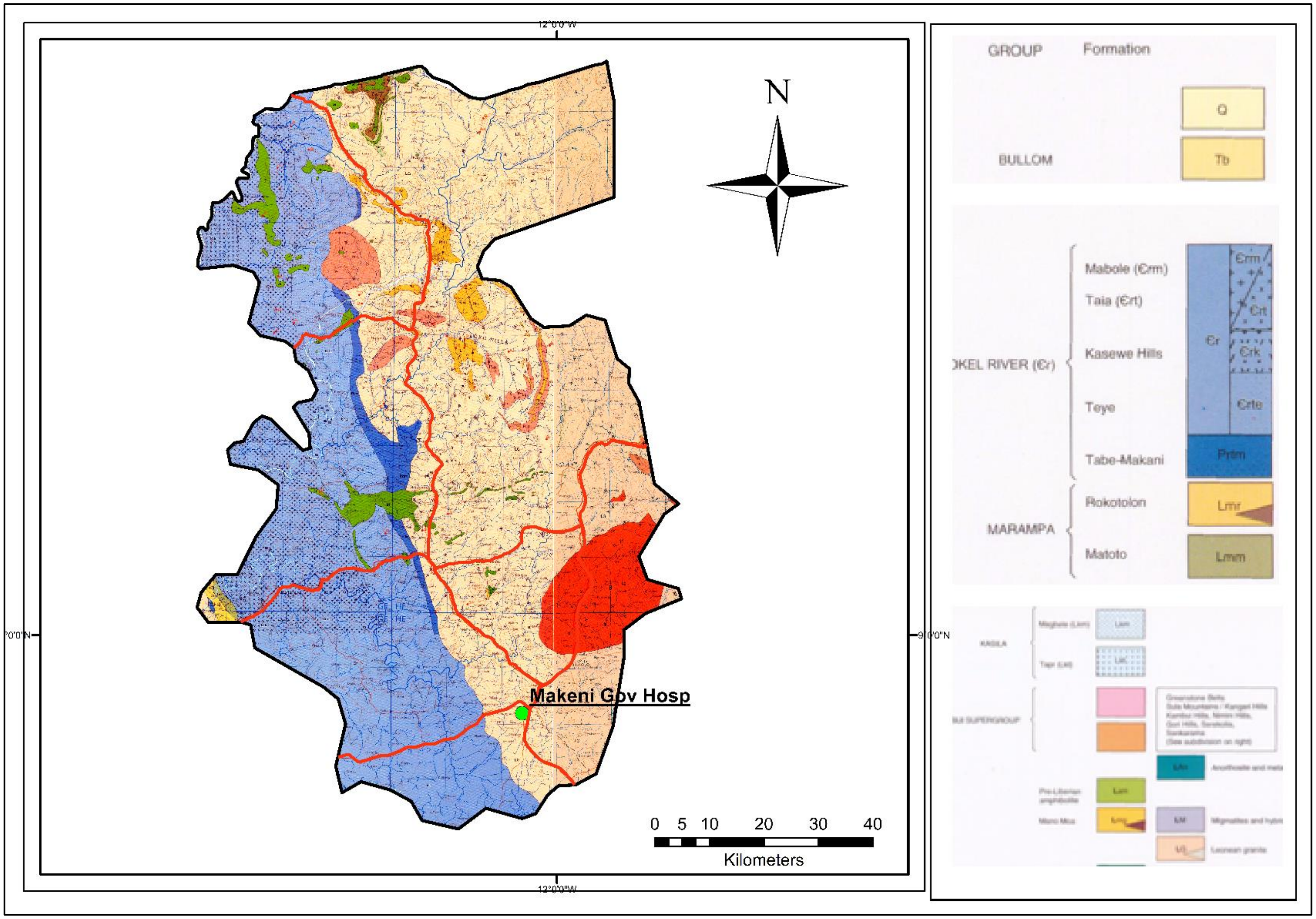


Figure 2 Geology map of Bombali District

4.2.1 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 is important to consider the distance to the prospective direct recharge area (current drainage system). Typical aquifers found in the Basement areas are:

- fractured contacts at the base of the relatively thick weathered zones,
- fractured contacts between gneiss and dolerite or amphibolites,
- fractured geological contacts and faults which are trending NW-SE in the project area.
- thick weathered zones of the basement rock. These can be very important if they occur on fractured basins of the basement rock, (Goal, Inception Report, and October 2015).

All the above targets can be readily mapped by means of geophysical techniques such as the applied Horizontal-Loop frequency domain ElectroMagnetic (HLEM) commonly done with MaxMin instrument and EM34 system, Resistivity profiling, Vertical Electric Soundings (VES) and Magnetic profiling. The EM system maps the variation in the overburden thickness and any subvertical conductive fractures, faults or contacts. The magnetic technique allows mapping any intrusions of dolerites, faults or contacts between lithologies, if such possess varying magnetic susceptibilities (readiness to magnetise in the Earth's magnetic field). Resistivity profiling will map the areas with thick weathered zones, finally VES is a direct way to map the thickness and composition of the overburden and to assess the fracturing at its base. Such a comprehensive suite of geophysical techniques is likely to provide a highly effective siting strategy.

5 GEOPHYSICAL SURVEY

5.1 Exploration Strategy

As discussed previously that underlying thick weathered and fractured bedrocks form the main aquifer units in this district. Deep weathered and fractured zones in the bedrock were considered as the main target feature for groundwater development and thus for geophysical surveys. Fractured aquifer zones are generally associated with geological lineaments, faults and lithological contacts. In the Inception these features were interpreted from geology only as there was no other variety of data sets including airborne magnetic data, ortho-photographs and Landsat imagery was available (Goal, Inception Report, October 2015). Details of the profile lines are summarized in

Table 1.

5.2 Siting Criteria

In the inception report, the criterion for siting boreholes at the hospital was highlighted. In order of priority these are:

1) The site should be chosen principally on hydrogeological and related geophysical grounds so that the greatest chance of obtaining an adequate yield was achieved.
2) The site should be free from potential pollution by latrines, waste and animals.
3) The site should be within the hospital for security of the bore and associated infrastructure.
4) The site should be either free from risk of flooding or capable of being protected from flooding by suitably designed headworks (i.e. a raised concrete).
5) The site should be one which was not a risk from erosion due to usage by animals.

Clearly it is not always possible to achieve all these criteria at all sites since the overriding criterion that of finding water, is often in conflict with one or more of the others. In most cases however, it was possible to achieve a reasonable compromise.

5.3 Survey Techniques and Equipments

Resistivity plus magnetic profiling followed by VES of Schlumberger array were considered to be the minimum geophysical techniques for this type of survey in this district. Resistivity profiling followed by VES techniques were the only available methods to consider for delineation of weathered and fractured zones in the project area. Magnetic profiling is an effective technique in delineating dolerite intrusions, lithological contacts and faults, while HLEM profiling is effective in delineating vertical and sub-vertical fractures zones but these were not available as the contractor couldn't source the equipment. Integrated use of both profiling techniques is very effective in areas like this, where significant resistivity conductivity contrast is expected in the bedrock geology such as highly resistive granites and less resistive weathered granites and gneiss rocks. Following profiling, potential anomalies were identified for further assessment using VES. VES provides depth and thickness estimates of weathered and fractured zones based on the resistivity values. Weathered and fractured bedrocks are generally represented by low resistivity values compared with massive bedrocks.

Geophysical techniques applied include resistivity profiling at a station spacing of 10 m. Where the space permits, two resistivity profiles of minimum 100m in Schlumberger array configuration were out at three different levels of investigation being 15m; 25m and 40m. Vertical Electrical Soundings were carried out at low resistivity anomalies picked by the profiling method. This was surveyed to a of AB/2 equal to 100 m. The geophysical survey techniques, instruments, survey parameters and total input for district are provided in

Table 1.

Table 1: Summary of Geophysical Survey, Makeni Government Hospital

Community Health Centre, CHC	Geophysical Method	Survey Parameters, Direction	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Makeni Government Hospital	Resistivity Profiling	Station spacing = 10m AB/2 = 15; 25; 40m MN/2 = 1	MK001P1	0823829	98207026	0823727	0982078
			MK001P2	0823832	0982054	0823793	0981888
	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	MK001S1	0823821	0982006		
			MK001S2	0823814	0981982		
			MK001S3	0823781	0982046		
			MK001S4	0823779	0981997		

6 SURVEY RESULTS AND DISCUSSION

The objectives of ground geophysical survey in this area were to delineate fractured/weathered zones associated with geological lineaments which were interpreted from the geology map. These are known as important structural features for groundwater development but unfortunately there was not enough space to carry out detailed ground water studies because of space constrains. The other available spaces were susceptible to pollution as there were several sewage tanks in the vicinity. The resistivity profiling data were plotted using Microsoft Excel and interpreted qualitatively to locate the best positions for carrying out depth investigations (VES). Vertical Electrical Soundings (VES) were carried out at low resistivity anomalies. The soundings were surveyed to a stretch of AB/2 equal to 100 m which gives a theoretical investigation depth of 100m.

The VES were processed and interpreted with Interpex forward and inverse modeling software RESIXIP. Discussion of the survey results in these two target areas is as follows:

6.1 Makeni Government Hospital – MK001

Two resistivity profiles were setup with MK001P1 being 70m long and MK001P2 running orthogonal and of length 150m. The profiles were surveyed with resistivity investigating at three different depths of investigation of 15m, 25m and 40m. The most important being the deep zones which were picked at 25m and 40m deep. The profile results are as plotted and presented in **Appendix A**. Following the interpretation of profiling data, 4 VES were conducted over low resistivity points which were considered as best groundwater potential anomalies, another 5th VES was conducted close to a well from which the hospital used to get their water before the pump broke down. VES data plots with geo-electric model are also presented in **Appendix A**. The discussion of the survey results along the profile line in the area is as follows:

Table 2**: Summary Resistivity Profiling for line MK001P1**

Profile Line	Resistivity	Comment
KM001P1	Low resistivity contrast at stations 70m representing a possible fault and generally low resistivities from stations 0 to 30m.	At station 70 m there is a borehole nearby with water. No VES on this line.

Table 3: **Summary Resistivity Profiling for line MK001P1**

Profile Line	Resistivity	Comment
KM001P2	Low resistivity contrast at stations 50m, 70m, and 120m. Generally very high resistivities in this area.	VES at stations 50m, 70m, 90m. Station 120m is on front of entrance gate so no VES

Table 4: Summary of Vertical Electrical Soundings

	Coordinates	Layer	Resistivity (Ohm-m)	Depth (m)	Comments
VES 1 – MK001S1	0823821E 00982006N	1	420	1	.
		2	2000	5	
		3	470	18	
		4	88000		
VES 2 – MK001S2	0823814E 0981982N	1	400	2	
		2	800	6	
		3	700	25	
		4	7260		
VES 3 – MK001S2	0823812E 0981966N	1	240	2	Priority site A There is thick conductive layer overlain by weathered overburden. The very deep layer might also be an aquifer at depth.
		2	680	2	
		3	400	44	
		4	77530		
VES 4 MK001SWetHole		1	1917	2	There is water in the borehole, the pump needs rehabilitation
		2	1080	15	
		3	21300		
VES 5 – MK001S5	0823779E 0981997N	1	1330	3	Priority Site B. Less conductive layers to depth which might contain water. This might be fractured at depth after 35m deep.
		2	150	4	
		3	1830	10	
		4	315	25	
		5	25020		

7. RECOMMENDATIONS FOR DRILLING

7.1. Recommended Drilling Sites

A total of two drilling sites and two backup sites have been recommended for drilling. There is need to verification and evaluation of incoming drilling results from these sites in for correlation with the geophysical data. The list of sites with selection criteria and recommended drilling depths are provided in **Table 5**. There is need to verify and evaluation of incoming drilling results from these sites in for correlation with the geophysical data. If the yields are not enough we recommend a revisit of the Hospital with additional survey with magnetic survey which is more ideal for this type of geology and targeted aquifers. The aim will be to locate faults and dykes which are passing through the target area. We can then set VES points on the faults and dykes for better yields.

Table 5: List of Recommended Drilling Sites

Site	**Site Reference**	**Coordinates**	**Site Selection Criteria**	**Maximum Drilling Depth (m)**
MK001DS1 – Makeni Hospital Priority Site A	VES 5 – MK001S5	0823779E 0981997N	- There is thick conductive layer overlain by weathered overburden. The very deep layer might also be an aquifer at depth.	70 m
MK001DS2 – Makeni Hospital Priority Site B	VES 2 – WN001S2	0698780 0936265	Less conductive layers to depth which might contain water.	7

7.2. Drilling, Borehole Construction, Development and Testing

7.2.1. Drilling

- It is proposed to use 40m as normal minimum drilling depth and 70 m as a normal maximum drilling depth which shall only be exceeded under typical circumstances and when drilling takes place in rock under the sediments found in Kissy and Port Loko targets. In the extreme situations, the drill depth may go to a maximum of 100m.
- It is proposed to use 15 m as the normal minimum depth to the top screen in order to avoid contamination of boreholes.
- It was observed during the hydrogeological reconnaissance survey that many boreholes in the area have failed due to siltation, which is the result of improper well design or construction. The

well design and construction is of particular importance due to abundant fine grained material in the aquifer. It will thus be crucial that gravel pack of suitable grain size is placed against the screens and that correct gravel pack installation is done. It is there by recommended that Goal follow this up in order to achieve high quality borehole construction.

- It is recommended that a sump of minimum 6 m shall be installed below the screen for boreholes in unconsolidated formations. For boreholes in consolidated formations, the sump shall be of minimum 3 m
- Yield should be measured at least every six meters, and recorded after the first water strike, such information is critical in determining when to terminate the bore.
- It is highly recommended that drill chips are logged by a qualified geologist before installation of casing, and that such installation is supervised by a qualified hydrogeologist.

7.2.2. Borehole Development

- We recommend Air lifting and jetting methods using a single pipe system as the most effective borehole development method to be employed.

7.2.3. Test Pumping

- It is recommended that test pumping shall comprise of a 4 stage steps test of minimum 2 hours (120 minutes) each step with measurement of yield, drawdown and recovery.
- We also recommend a Constant Rate Test (CRT) for a minimum of 24 hours.
- The above is followed by a Recovery test, which will consists of measurement of residual drawdown after constant rate test until static water level is achieved.

7.2.4. Groundwater Sampling and Hydro-chemical Analysis

- We recommend that water samples for chemical analysis of major ions, selected metals and bacteriological contamination be taken at the end of borehole development and at the end of CRT.

- Field water quality parameters should be measured during drilling and test pumping. Typical water quality meters will measure TDS, EC, pH and Temperature. Measuring these field water quality parameters serves to provide an early indication of deteriorating water quality. This is important in cases where saline water intrusion might be expected.

7.2.5. Disinfection

- It is recommended that disinfection could be carried out immediately after pump installation, using chlorine granules. This would make disinfection of the pump parts unnecessary. The drilling contractor will accordingly be given a choice between disinfecting after test pumping, and disinfecting after pump installation.

7.2.6. Criteria for Successful Boreholes

- The criteria for declaring boreholes successful may have to be flexible considering borehole yield, water quality and distance of existing water source in the dry season. The Consultants will liaise with the Client in cases where such a flexible approach appears relevant. The consultant will immediately report cases where WHO water quality limits are exceeded so that a decision to stop superstructure construction or pump installation can be made if needed.

8. REFERENCES

The following reports provide more information on the geology and hydrogeology of Sierra Leone. Some, and others, can be accessed through the Africa Groundwater Literature Archive

Camus Y and Cukor D. 2012. NI 43-101 Technical Report on the Resource Update Nimini Gold Project, Kono Region, Sierra Leone. SGS Canada Inc., submitted to Polo Resources Ltd.

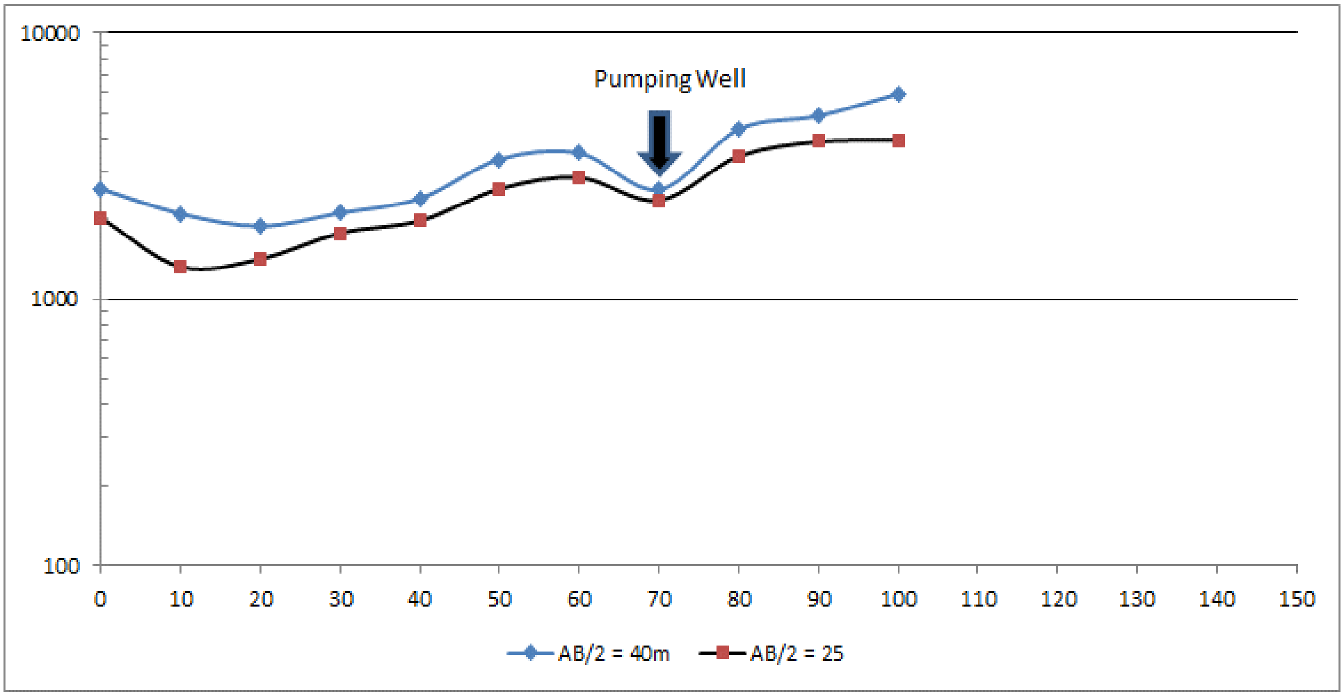
Flinch JF, Huedo JL, Verzi H, Gonzalez H, Gerster R, Mansaray AK, Painuly LP, Rodriguez-Blanco L, Herra A, Brisson I and Gerard J. 2009. The Sierra Leone-Liberia Emerging Deepwater Province. Adapted from oral presentation at AAPG Annual Convention, Denver, Colorado, June 7-10, 2009.

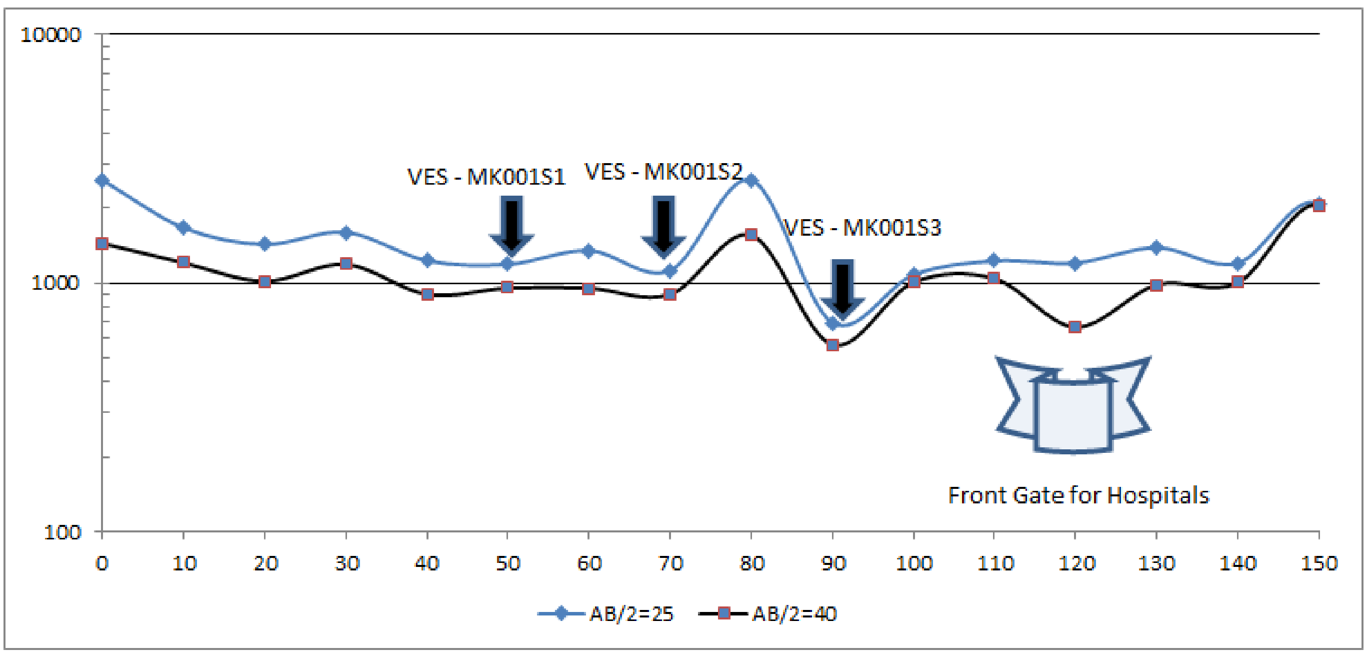
Lapworth DJ, Carter RC, Pedley, S and MacDonald AM. 2015. Threats to groundwater supplies from contamination in Sierra Leone, with special reference to Ebola care facilities. British Geological Survey Technical Report OR/15/009, Nottingham, UK, 87pp.

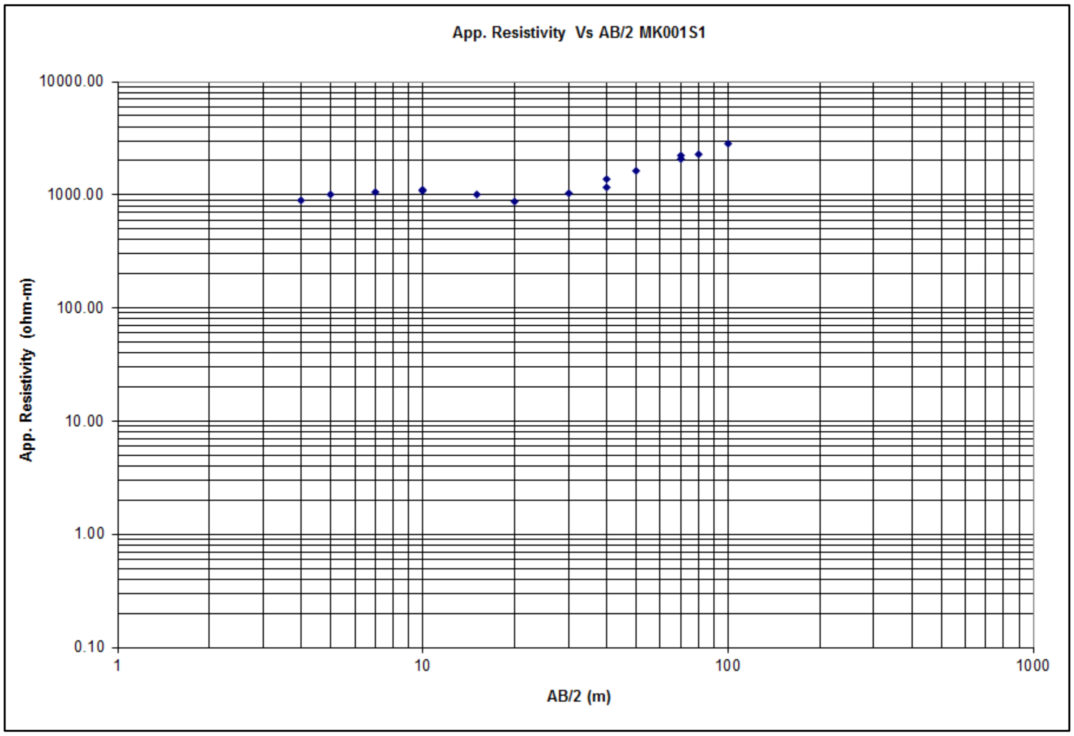
United Nations. 1988. Groundwater in North and West Africa: Sierra Leone. United Nations Department of Technical Cooperation for Development and Economic Commission for Africa. Department of Technical Cooperation for Development and Economic Commission for Africa, Natural Resources/Water Series No. 18.

APPENDICES

Appendix 1: MAKENI GEOPHYSICAL RESULTS



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App. Resistivity (ohm-m)
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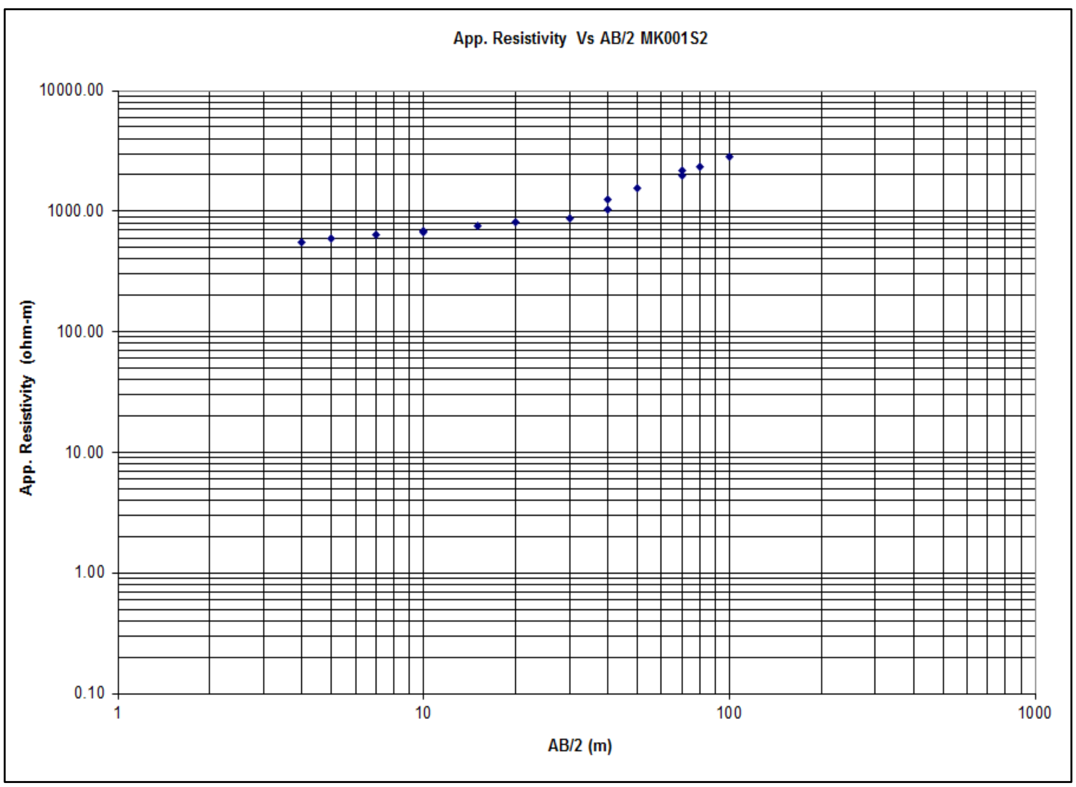
1
10
100
1000
AB/2 (m)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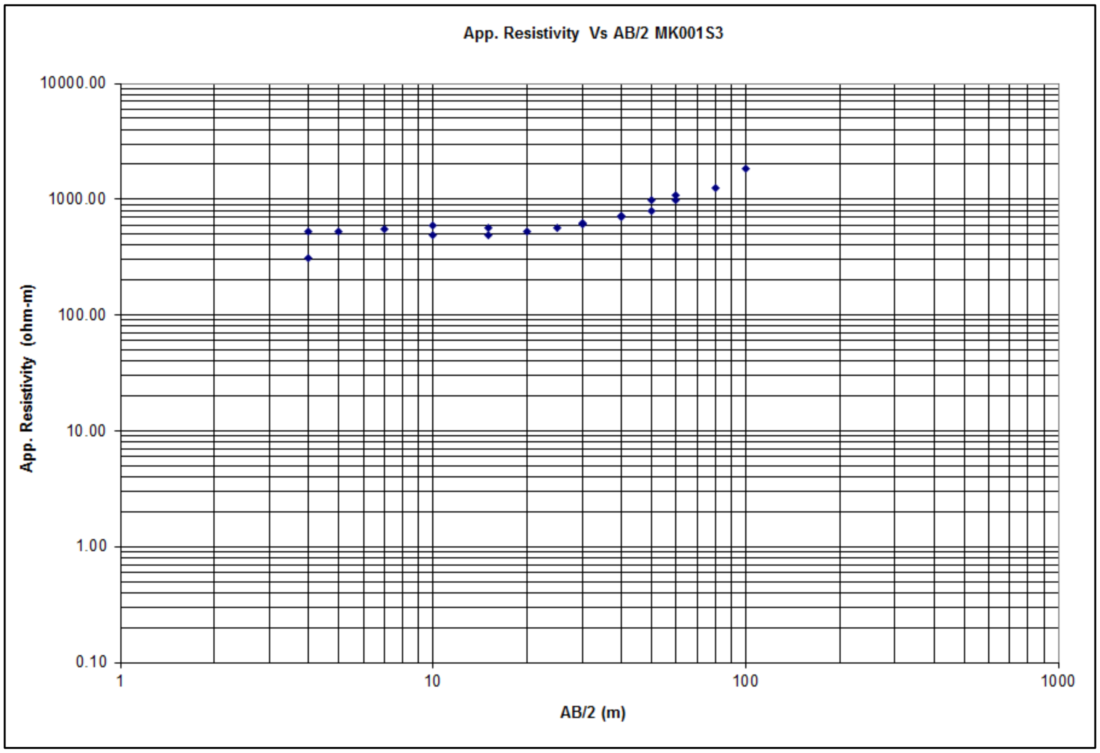
AB/2 (m)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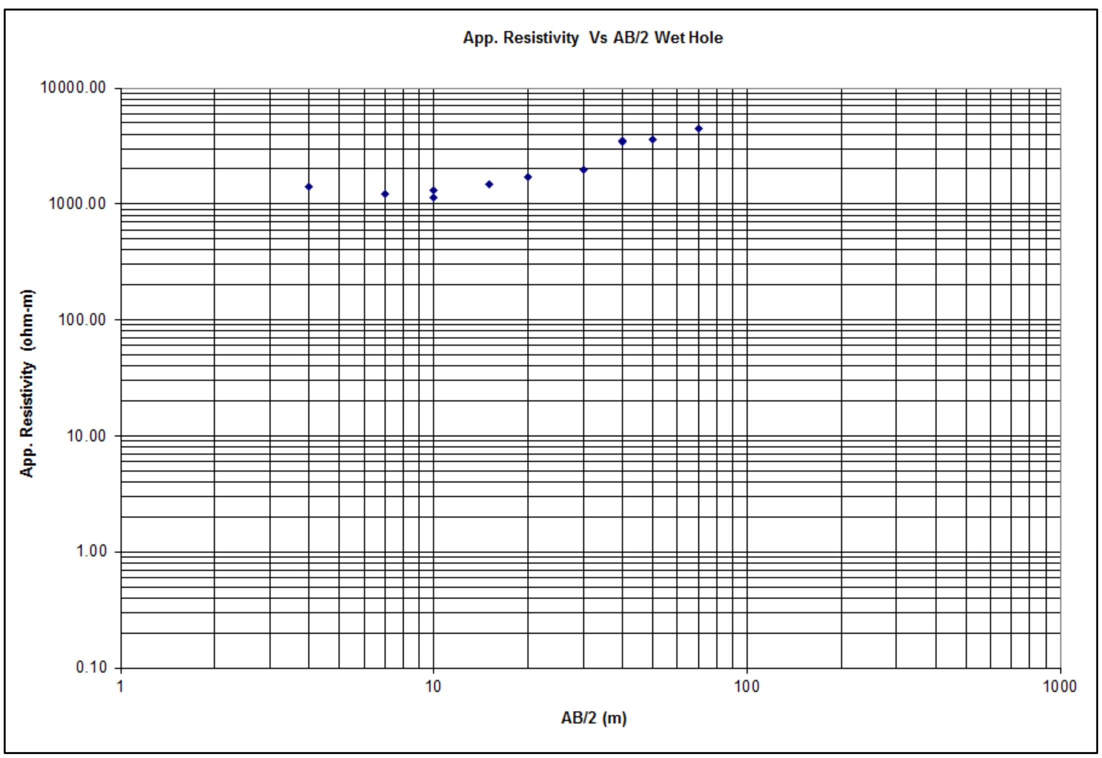
1000
AB/2 (m)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App. Resistivity (ohm-m)
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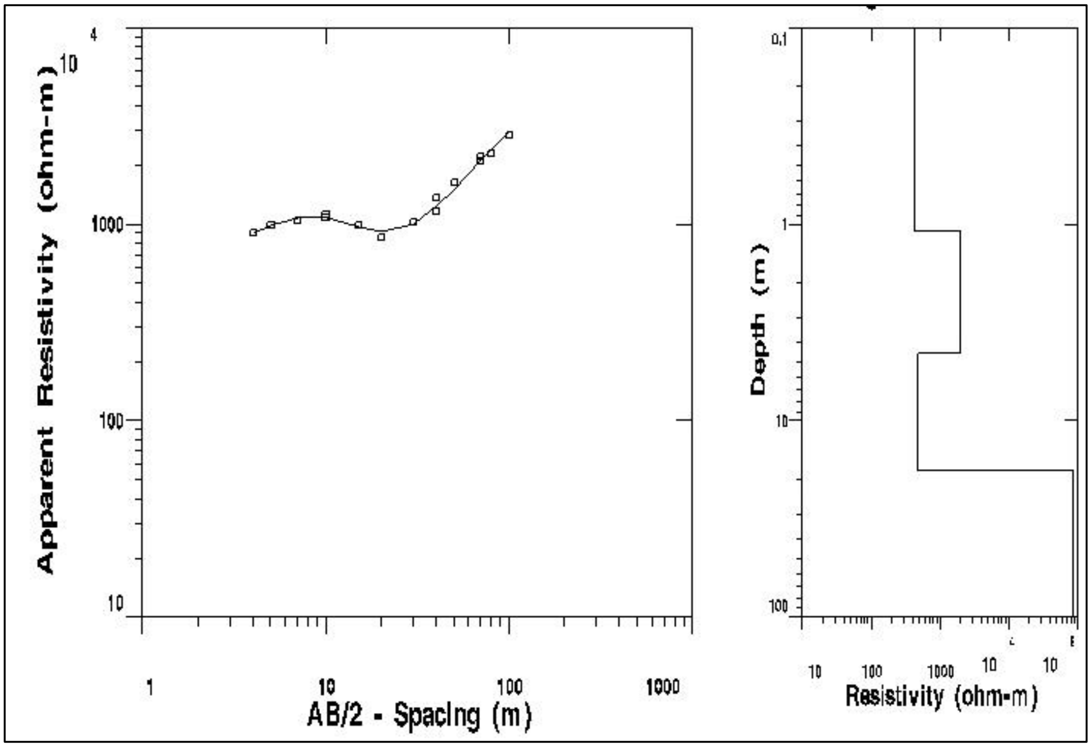
1
10
100
1000
AB/2 (m)

MK001S1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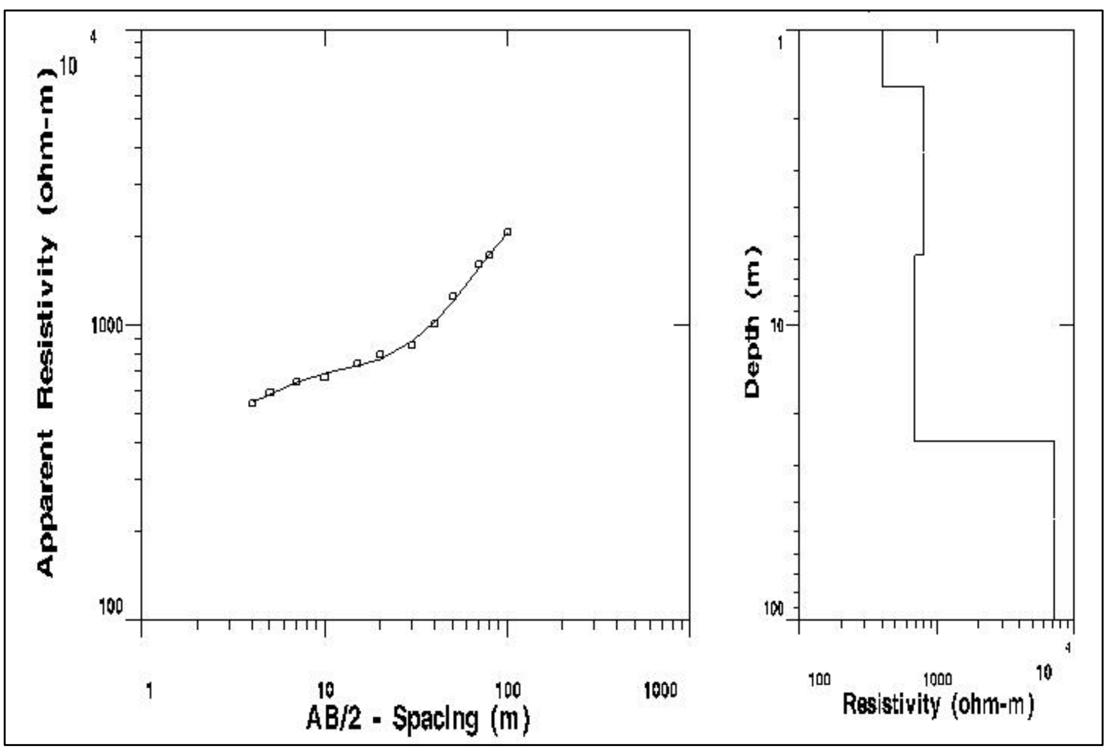
Depth (m)
Resistivity (ohm-m)

MK001S2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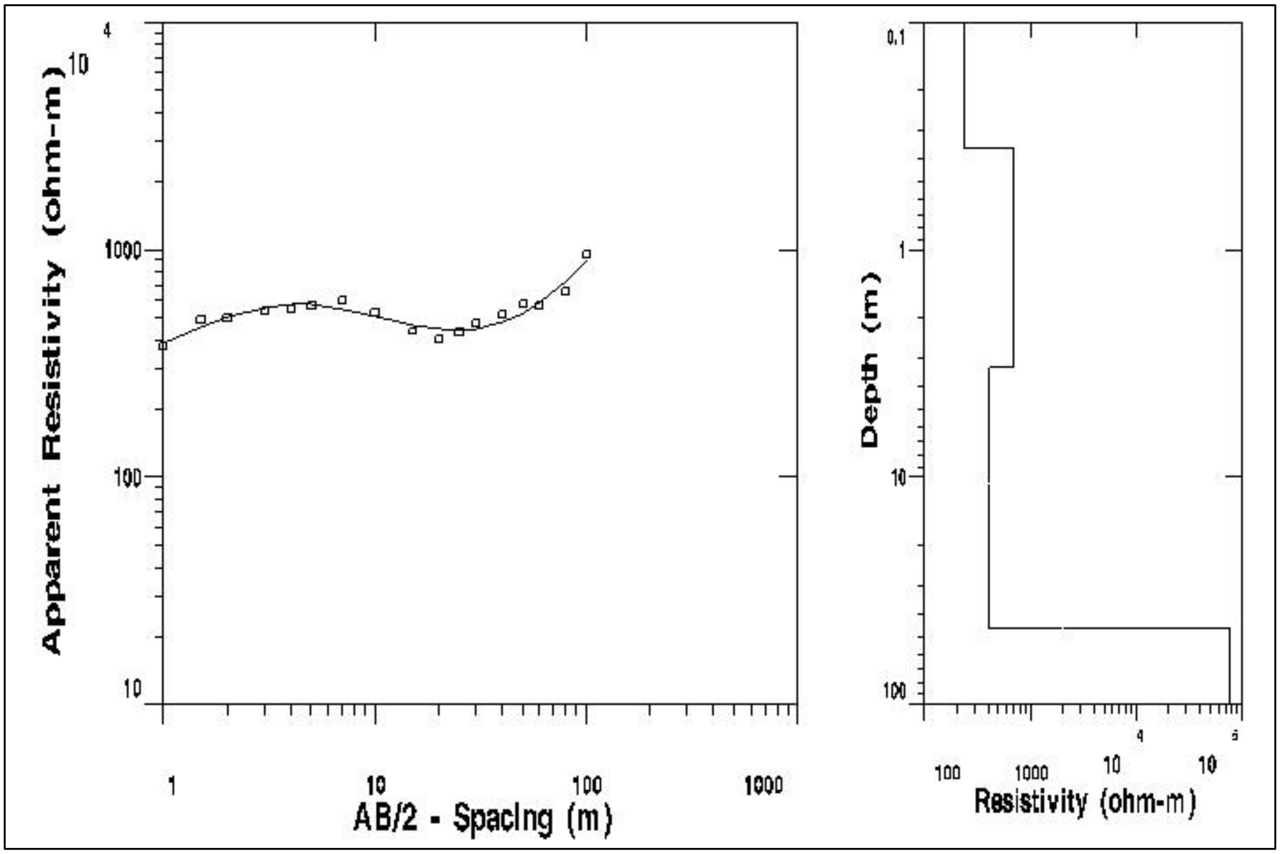
Resistivity (ohm-m)

MK001S3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