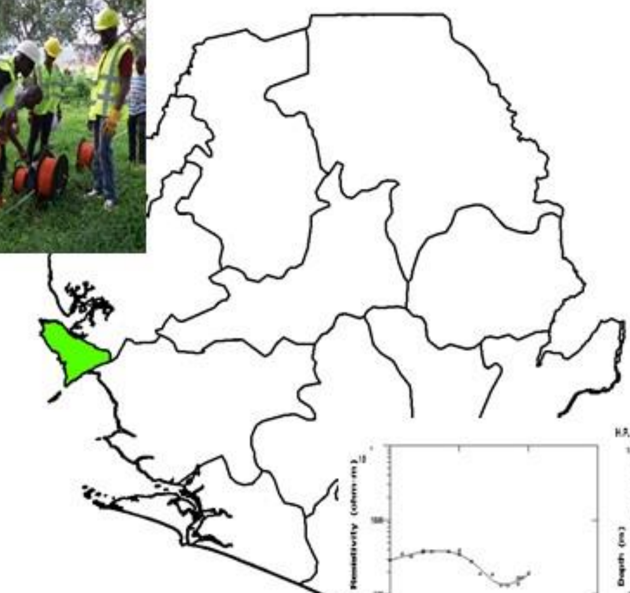
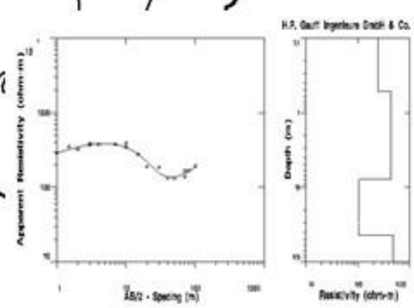
GOAL SIERRA LEONE

BOREHOLE GEOPHYSICAL SITING AT KISSY MENTAL HOSPITAL AND KISSY COMMUNITY WESTERN DISTRICT OF SIERRA LEONE





SITING REPORT

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Project Manager 10/11/2015

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SUMMARY

Resistivity profiles and Resistivity soundings were performed at Kissy Mental Hospital and Kissy community on the 3rd of November 2015 and the 4th of November 2015. One profile line was run at Kissy Mental Hospital (70m) and one sounding at the Mosque. Profiles were done at three different depths of investigations i.e. 15m, 25m and 40m, while the soundings were performed at maximum depths of approximately 100m.

Two drilling points are recommended for the Mental hospital i.e. the priority drilling site and a backup site while one point is recommended for the community.

Table 6 lists the drilling sites and provides the detailed rationale for the selection of the site and the proposed drilling depths. Drilling at Kissy Mental Hospital is recommended at 0698779E, 0936220N and 0698780E, 0936265N while for the community drilling is recommended at point 0698733E, 0936267.

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 Centres 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 Western District at Kissy mental hospital and Kissy Community and recommends sites for drilling of planned 1 borehole for each site. The main objective of this project is to identify and develop additional groundwater abstraction points with sufficient volumes of potable water and within acceptable distance to the CHC to supplement the existing water sources and to meet the projected water demand.

Water supply at Kissy mental hospital is currently from a hand dug well equipped with a submersible pump, however the well is seasonal and dries up in the dry season, leaving the hospital to rely on water from bulk suppliers whose supplies are erratic. There is therefore a need to supply drill a new bore for the supply to ensure sustainable water supplies for the community and the hospital.

2 BACKGROUND

There is a dearth 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. Considering the 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

The Western Area Rural District is located mostly around the peninsula in the western area of Sierra Leone. The Western Area Rural District has an estimated population of 197,098. The district capital and largest city is Waterloo. The district occupies a total area of 5,719 km^2 and comprises of ten chiefdoms. The location of the district and the Hospital is shown in Figure 1: Location of the Kissy Mental Hospital and Kissy Community. Note the community for which water supply is proposed is a few hundreds of meters from Kissy Hospital and as such shows as a single point of the scale of Figure 1.

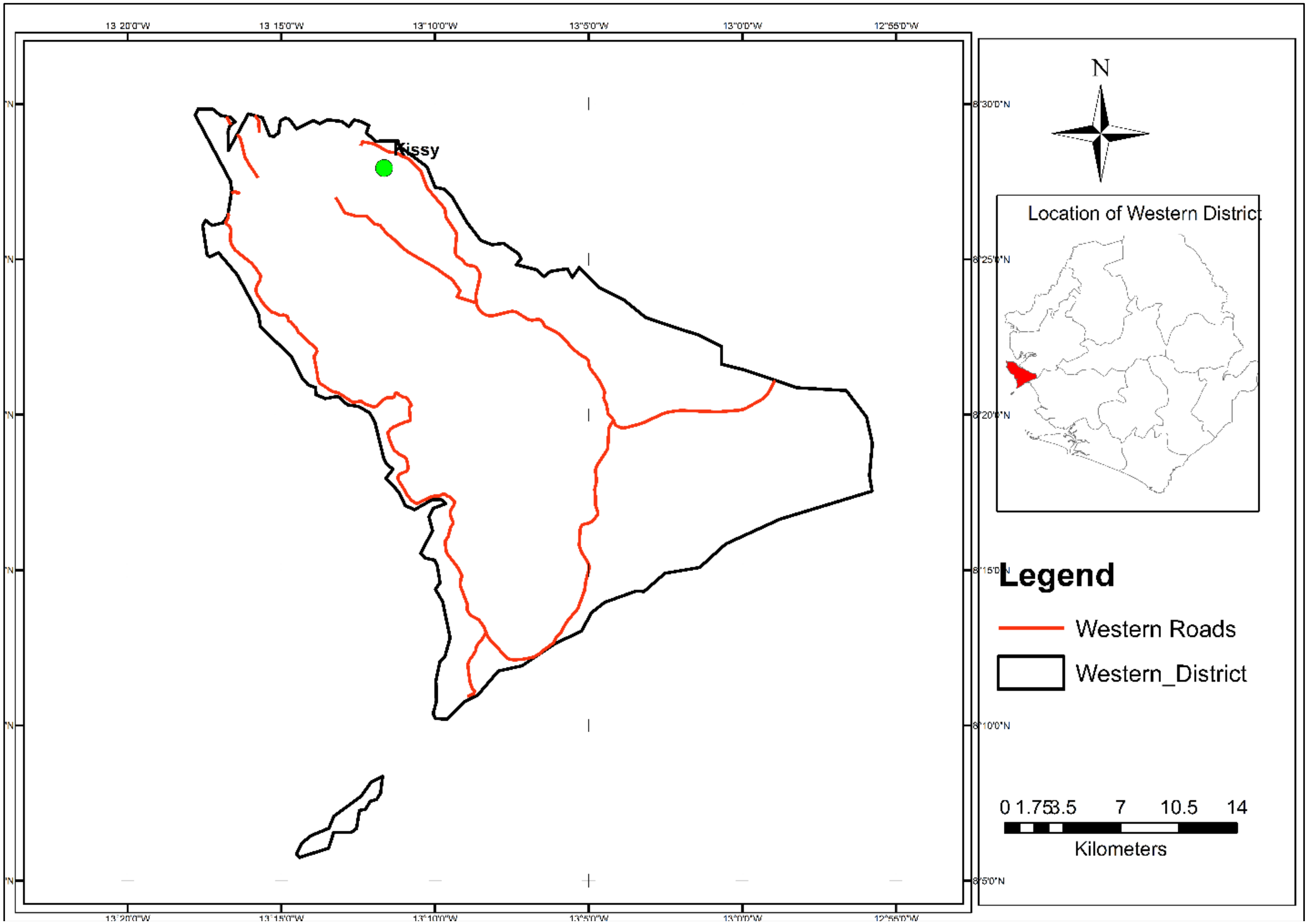


Figure 1: Location of the Kissy Mental Hospital and Kissy Community.

4 REGIONAL SETTING

4.1 Geology

The large part of the district is underlain by rocks of the Freetown complex. To the South East of the district are rocks of the Bullom group.

The Freetown complex are essentially, a series of cumulate rocks of gabbroic composition, containing layers of dunite, troctolite, olivine-gabbro, gabbro, leucogabbro and anorthosite . The complex is intruded into the gneisses of the Kasila Group and overlain by sediments of the Bullom Group whose lower beds are of Eocene age. Sedimentation structures such as cross-bedding are common in the gabbro layers and some 6,000 m of thickness is exposed. The complex has been reliably dated as 193 Ma.

The Bullom group comprises of deposits which extend up to 50 km inland and are found at heights of up to 40 m above present sea level. Outcrops are rare and generally poor with the exception of 25 m high sea-cliffs at Bullom, N of Freetown. The Bullom Group consists of a laterally variable sequence of poorly consolidated, near horizontal, often iron-stained gravels, sands and clays with occasional intraformational laterites and lenticular seams of lignite. The clays are generally kaolinitic, red, purple and white in colour and in the Bullom cliffs contain plant remains. The sands, sometimes graded, but rarely cross-bedded, are generally poorly sorted, with a clay matrix; partially disintegrated feldspars occur. Interbedded with the sands are occasional grit beds, stringers of rounded quartz pebbles, and horizons of kaolin clay clasts. Figure 2, shows the geology of the Western District.

4.2 Hydrogeological Setting

The major hydrogeological targets are classified into two, being the basement aquifers and consolidated to 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).

However, some primary porosity may be expected in the north in the sandstone, although the groundwater potential of this area has not been explored and is largely unknown. 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 Bullom Group is characterized by unconsolidated sedimentary rocks which can be described as poorly consolidated marine and estuarine sediments, sands, gravels and kaolinitic clays with some lignite. 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).

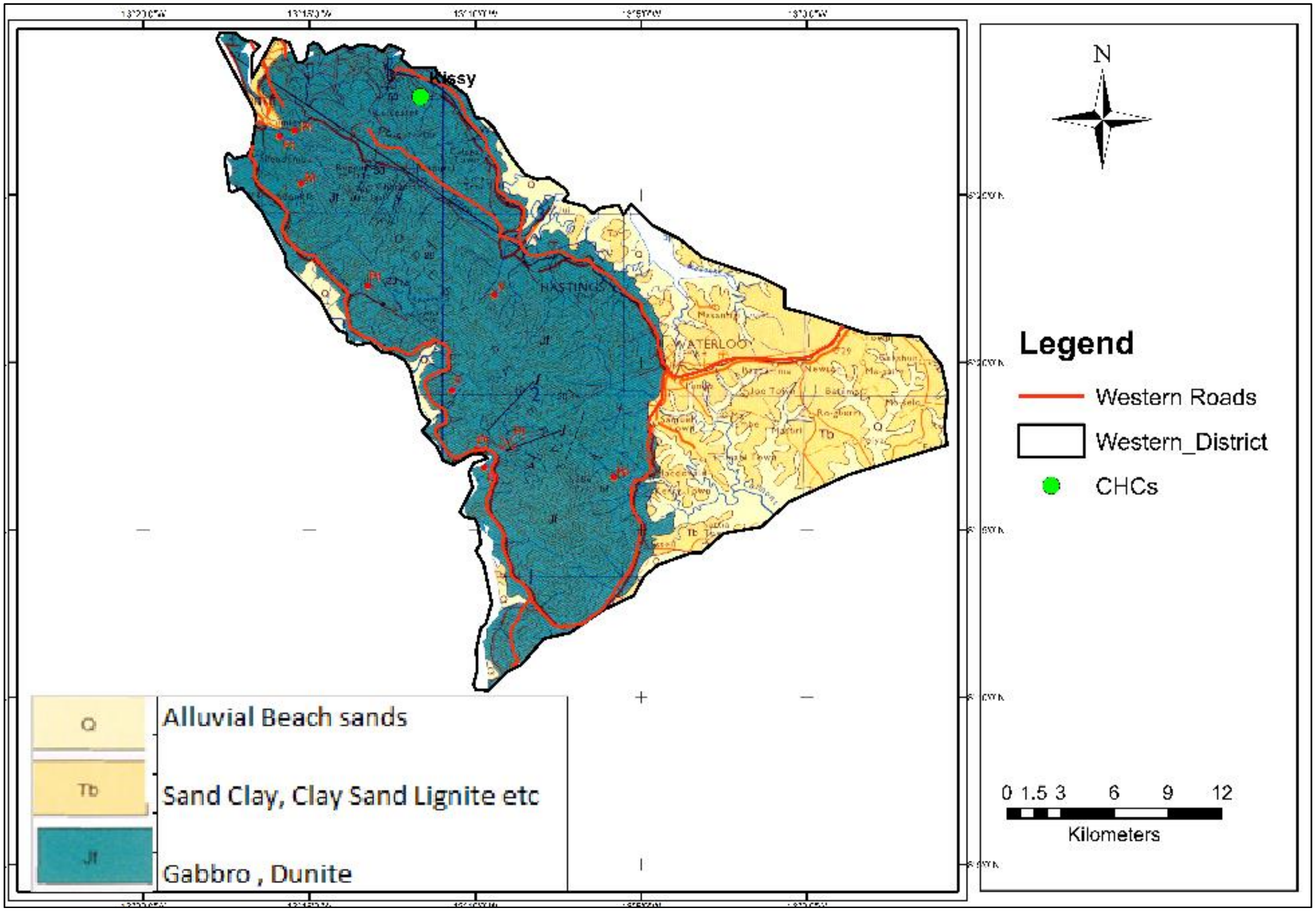


Figure 2 Geology map of Western District

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.

The area around Kissy would be comprised of Groundwater flow within fractures, usually with a poorly developed weathered zone.

4.2.2 Sandstone/Gravels/sand aquifer

Due to the fact that sandstone, gravel and sand 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.

The sandstone aquifer may be investigated by means of several geophysical techniques, amongst them the HLEM profiling and VES soundings, which provide the information on the lateral and vertical distribution of formation resistivities. These in turn are characteristic of the particular lithologies such as resistive sandstone and conductive mudstone. Although it is possible to identify sediments based on the above techniques it is not always possible to differentiate between its lithologies, especially if sandstone is friable and saturated as in such case its resistivity would be comparable with the resistivity of a dry mudstone and grit. It is therefore not possible to identify the aquifer based only on the geophysical data hence additional information would be required to ascertain that the aquifer is indeed present.

5 GEOPHYSICAL SURVEY

5.1 Exploration Strategy

As discussed previously that underlying thick weathered basement and fractured bedrocks form the main aquifer units in this district. Deep weathered and fractured zones in the bedrock underlying thick sedimentary beds were considered as the main target feature for groundwater development and thus for geophysical surveys. Such features allow tapping thicker aquifer zones and are generally associated with geological lineaments, faults and lithological contacts. In the Inception phase 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 Table 1.

5.2 Siting Criteria

In the inception report, the criterion for siting boreholes at the given Community Health Centres 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 400m of the community and preferably very close to the Health Centre.
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 were resistivity profiling at a station spacing of 10 m. Where the survey space permits, two resistivity profiles of minimum 100m in Schlumberger array configuration were carried out at three different levels of investigation being 15m; 25m and 40m. Vertical Electrical Soundings (VES) were carried out at low resistivity anomalies picked by the profiling method. This was surveyed to a stretch of AB/2 equal to 100 m. The geophysical survey techniques, instruments, survey parameters and total input for district are provided in Table 1 and Table 2**.**

Table 1: Summary of Geophysical Survey, Kissy CHC

Community Health Centre, CHC	Geophysical Method	Survey Parameters, Direction	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Kissy CHC	Resistivity Profiling	Station spacing = 10m AB/2 = 15; 25; 40m MN/2 = 1	Profile 1	0698784	0936201	0698773	0936275
	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	WN001S1	0698779	0936220		
			WN001S2	0698780	0936265		

Table 2: Summary of Geophysical Survey, Kissy Community

	Geophysical Method	Survey Parameters	Name	Location			
				Start		End	
				Easting (m)	Northing (m)	Easting (m)	Northing (m)
Kissy Community	Vertical Electrical Sounding	Schlumberger; Max AB/2 = 100m	WN002S1	0698733	0936267		

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 virtually no space to undertake reasonable lengths of profiling lines. 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 the Interpex forward and inverse modeling software RESIXIP. Discussion of the survey results in these two target areas is as follows:

6.1 Kissy CHC – WN001

The ground geophysical survey was planned along two lines perpendicular to each other (WN001P1) and (WN001P2), but there wasn't enough space to perform adequate profiling. Only profile WN001P1 was surveyed for a length equal to 70m. 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 1Following the interpretation of profiling data, 2 VES were conducted over low resistivity points which were considered as best groundwater potential anomalies. There wasn't enough space to undertake the third VES as we always consider three soundings for one site as a minimum good number to choose a site from. VES data plots with geo-electric model are also presented in Appendix 1. The discussion of the survey results along the profile line in the area is are given in Table 3 and Table 4:

Table 3: **Summary Resistivity Profiling for line WN001P1- Kissy Mental Hospital**

Profile Line	**Resistivity**	**Comment**
KM001P1	Low resistivity contrast at stations 20m and 50m to 70m	VES at 20m and 50m.

Table 4: Summary of Vertical Electrical Soundings-Kissy mental Hospital

	Coordinates	Layer	Resistivity (Ohm-m)	Depth (m)	Comments
VES 1 – WN001S1	0698779 0936220	1	250	1	Priority site A There is thick conductive layer overlain by weathered overburden. The very deep layer might also be an aquifer at depth.
		2	430	8	
		3	100	44	
		4	480		
VES 2 – WN001S2	0698780 0936265	1	400	1	Priority Site B. Less conductive layers to depth which might contain water.
		2	630	7	
		3	120	17	
		4	640		

6.2 Kissy Community

No profile was done at this site. Only an area of size 5m x 5m was available for siting of the borehole. VES was conducted to test the potential of this point. The area confirms thick overburdens of sediments. VES data plots with geo-electric model and the profiles are presented in Appendix 2.

Table 5: Summary of Vertical Electrical Soundings

	Coordinates	Layer	Resistivity (Ohm-m)	Depth (m)	Comments
VES 1 – WN002S1	0698733 0936267	1	400	1	Priority site B Thick overburden and resistivity relatively lower than that for VES 2.
		2	630	15	
		3	120	34	
		4	640		
		4	1022		

7. RECOMMENDATIONS FOR DRILLING

7.1. Recommended Drilling Sites

A total of three drilling sites including one backup site have been recommended for drilling. The list of sites with selection criteria and recommended drilling depths are provided in Table 6. There is need to verify and evaluation of incoming drilling results from these sites in for correlation with the geophysical data.

Table 6: List of Recommended Drilling Sites

Site	Site Reference	Coordinates	Site Selection Criteria	Recommended Maximum Drilling Depth (m)
WN001DS1 – Kissy CHC Priority Site A	VES 1 – WN001S1	0698779 0936220	- There is thick conductive layer overlain by weathered overburden. The very deep layer might also be an aquifer at depth	70 m
WN001DS1 – Kissy CHC Priority Site B	VES 2 – WN001S2	0698780 0936265	Less conductive layers to depth which might contain water.	70 m
WN002DS1 Kissy Community Priority Site A	VES 1 – WN002S1	0698733 0936267	- Thick overburden and resistivity relatively lower than that for VES 2.	70m

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.

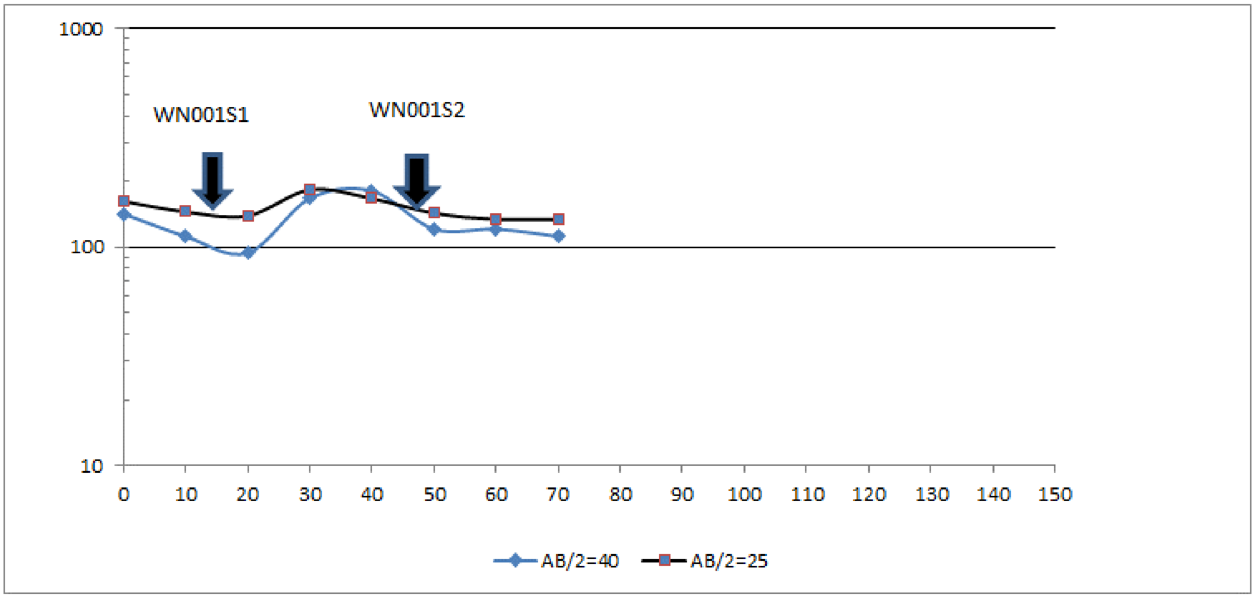
Flinch JF, Huedo JL, Verzi H, Gonzalez H, Gerster R, Mansaray AK, Painuly LP, Rodriguez-Blanco L, Herra A, Brisson I and Gerard J. 2009. The Sierra Leone-Liberia Emerging Deepwater Province. Adapted from oral presentation at AAPG Annual Convention, Denver, Colorado, June 7-10, 2009.

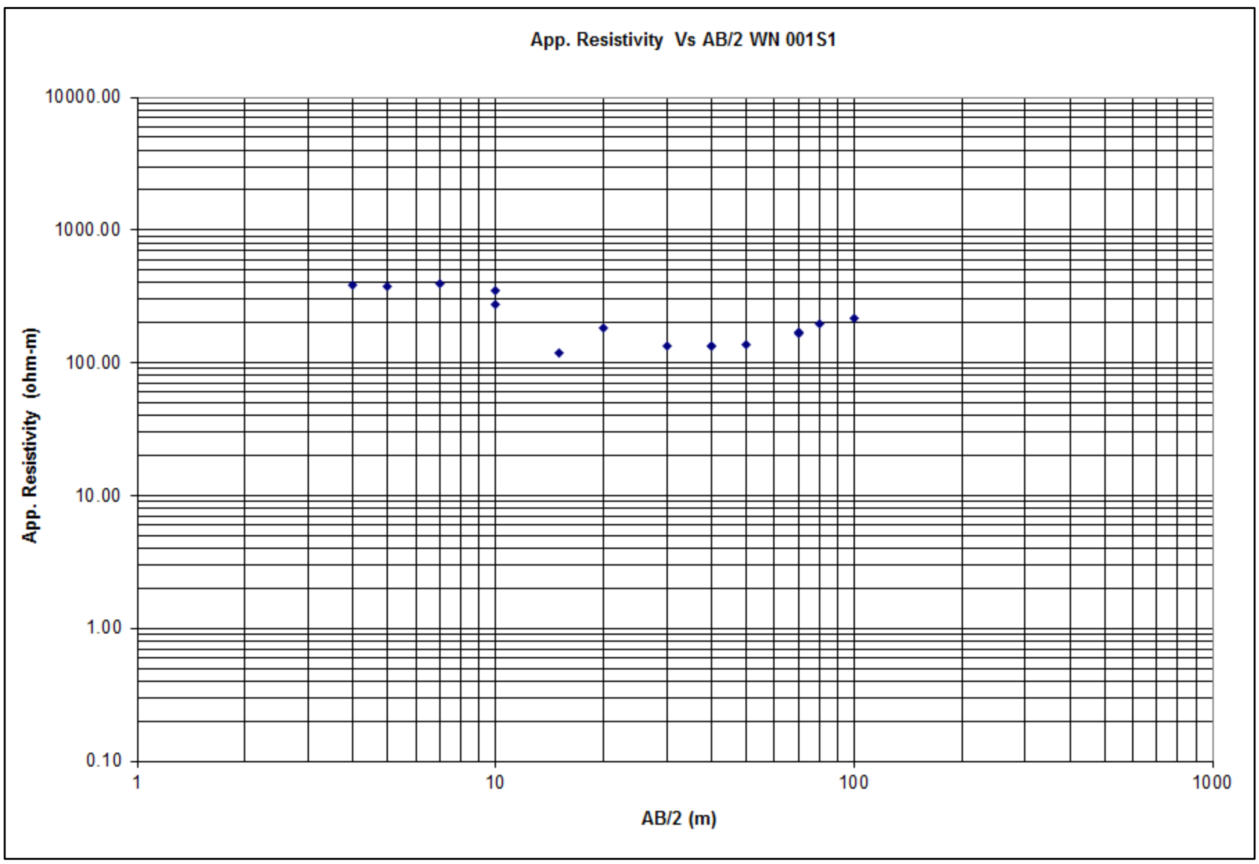
Lapworth DJ, Carter RC, Pedley, S and MacDonald AM. 2015. Threats to groundwater supplies from contamination in Sierra Leone, with special reference to Ebola care facilities. British Geological Survey Technical Report OR/15/009, Nottingham, UK, 87pp.

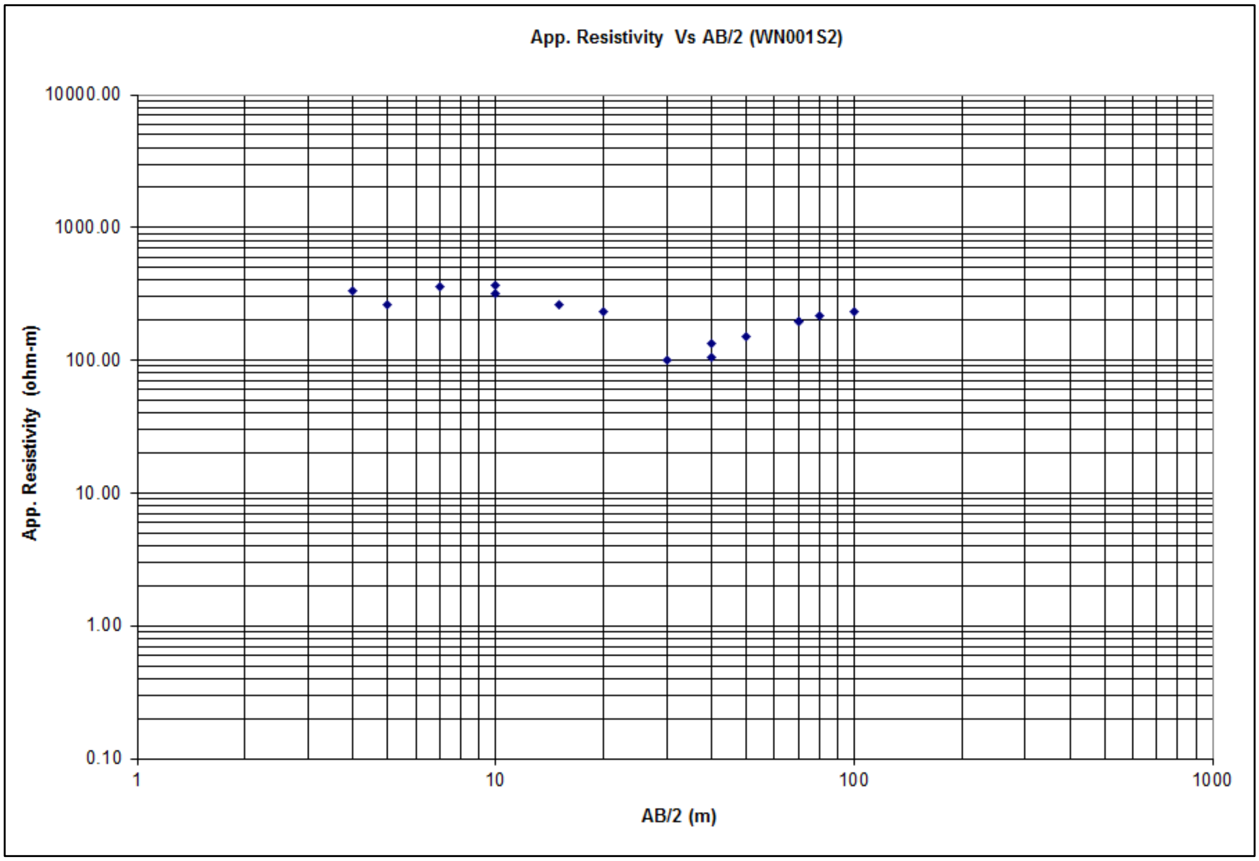
United Nations. 1988. Groundwater in North and West Africa: Sierra Leone. United Nations Department of Technical Cooperation for Development and Economic Commission for Africa. Department of Technical Cooperation for Development and Economic Commission for Africa, Natural Resources/Water Series No. 18.

APPENDICES

Appendix 1: Kissy Mental Hospital Geophysical Results



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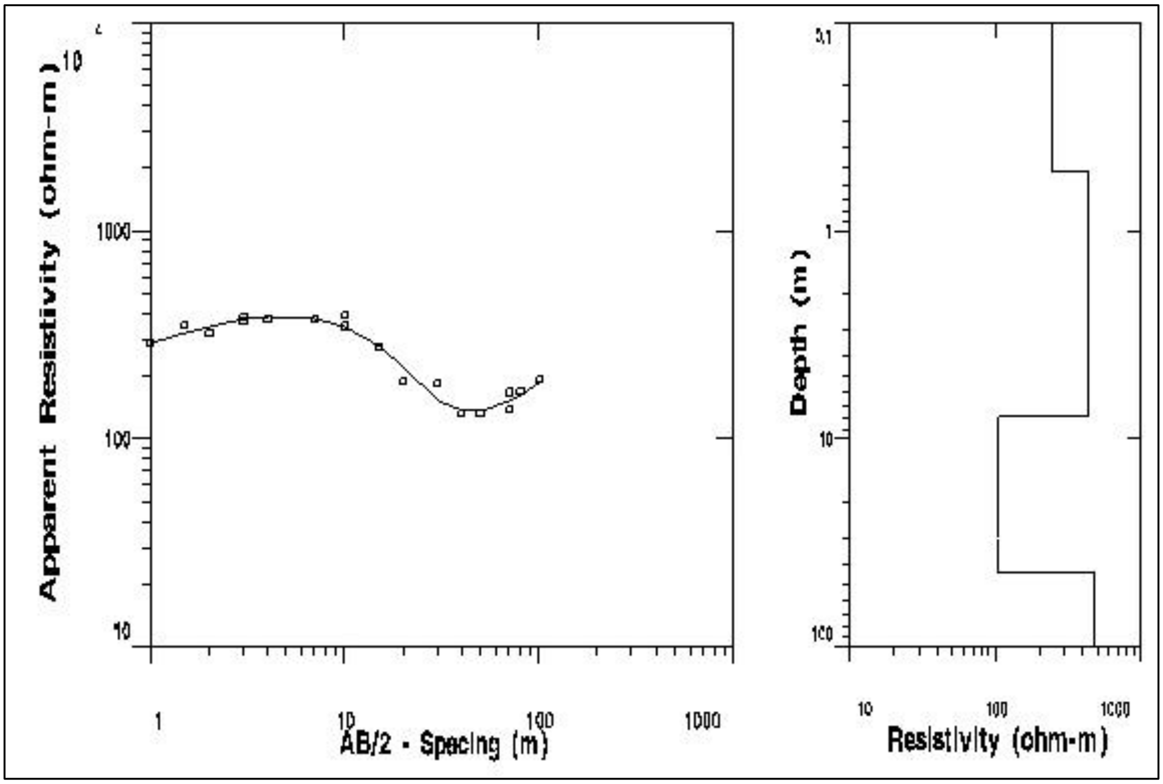

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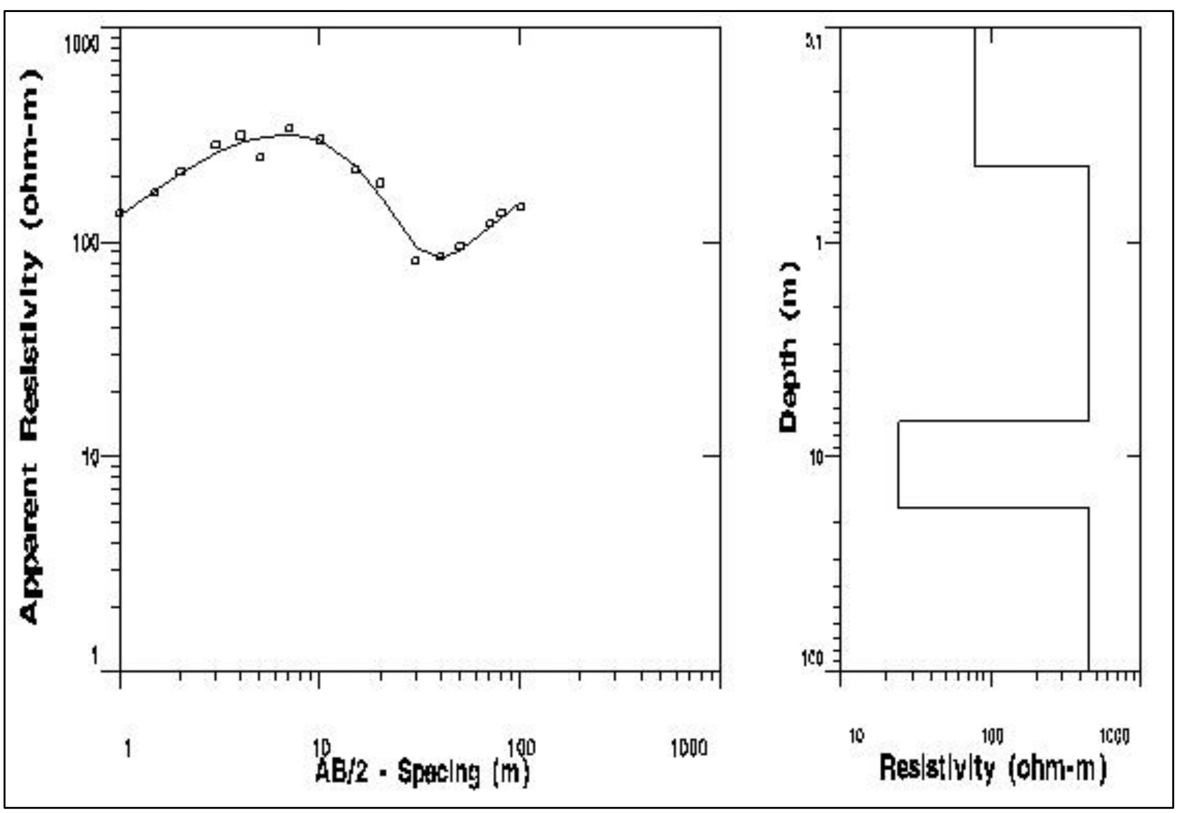
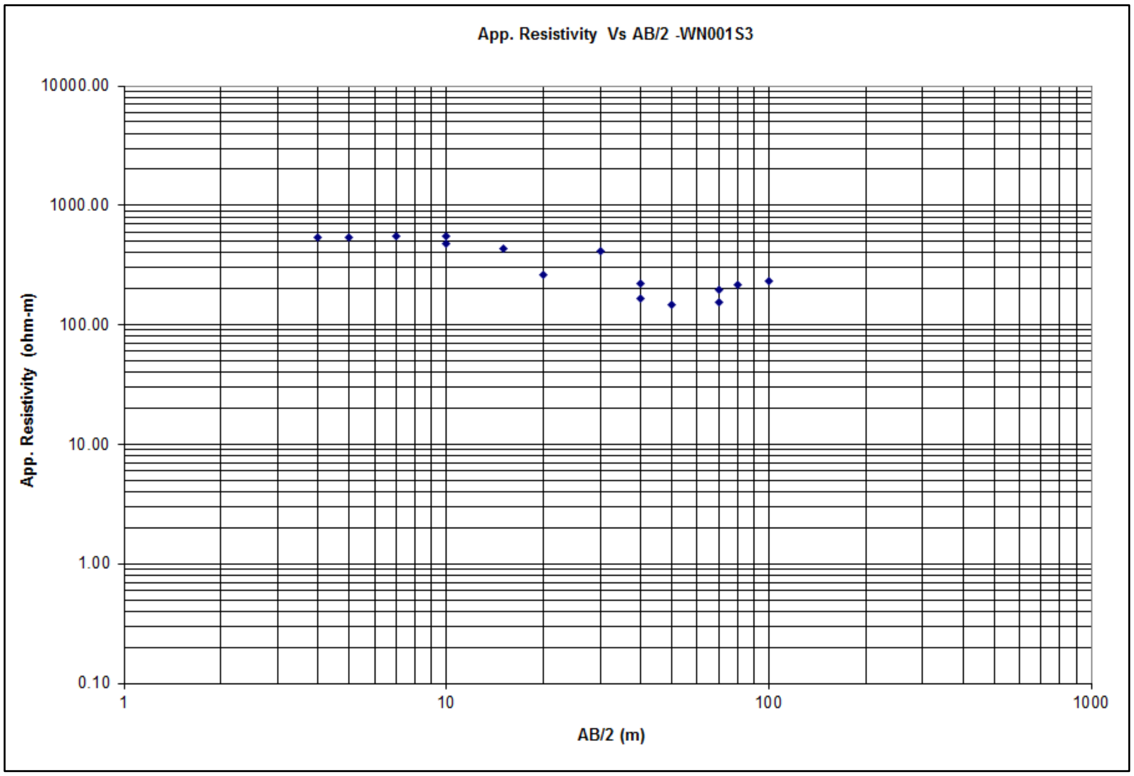


Appendix 2: Kissy Community geophysical results



WN002S3