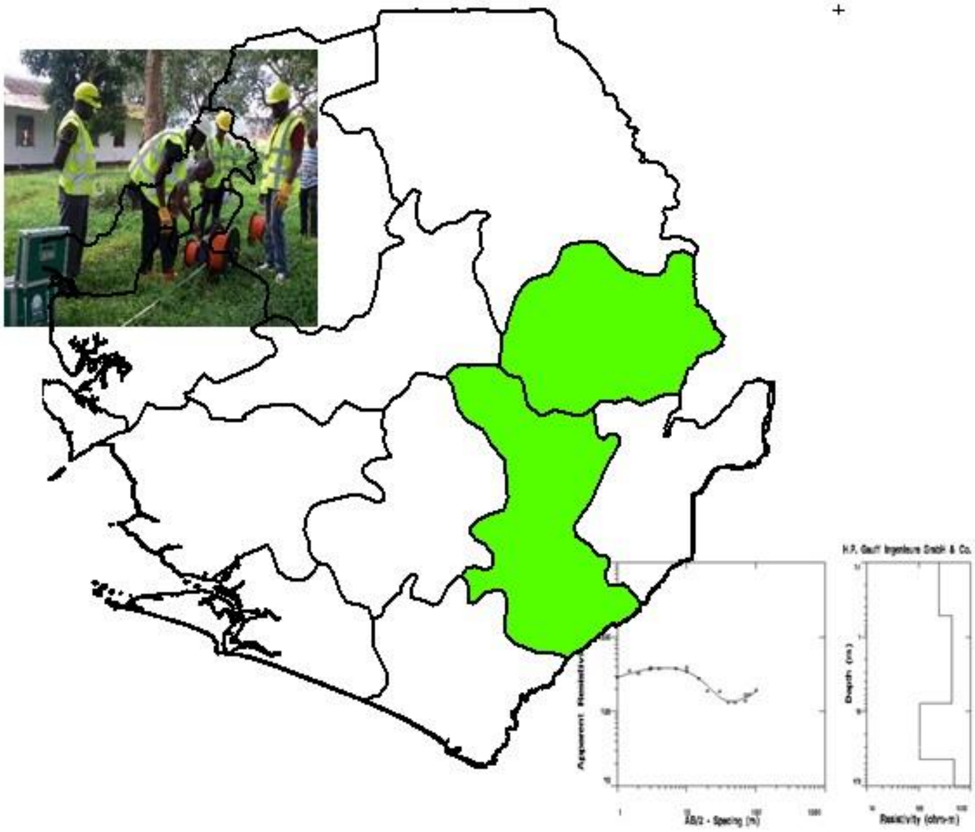
# GOAL SIERRA LEONE

# BOREHOLE GEOPHYSICAL SITING AT AT SELECTED DISTRICTS IN SIERRA LEONE –KENEMA KONO



## SITING REPORT

*8th NOVEMBER 2015*

Dynamic Integrated Geohydro Environmental Services cc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**Document title: GOAL SIERRA LEONE, GEOPHYSICAL SITING OF COMMUNITY HEALTH CENTRES (CHCs) AND CAPACITY BUILDING- KENEMA & KONO DISTRICTS**

# REVISION LOG

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| Version 0 | 02/11/2015 | Brighton Munyai & Enkelbert Chinwada | Enkelbert Chinwada | |
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Project Manager 10/11/2015

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**SUMMARY**

Resistivity profiles and Resistivity soundings were performed at Tungie (Gura Mamende), Kono Government Hospital and Tunkia (Gorahun) CHCs in Kenema District from the 23rd of October 2015 to the 27th of October 2015. Profiles were at three different depth 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 each CHC/Hospital i.e. the priority drilling site and a backup site. Table 11 lists the drilling sites and provides the detailed rationale for the selection of the site and the proposed drilling depths.

At Tungie the ground geophysical survey was done along profile lines KM001P1 and KM001P2 of 60mand 40 m length respectively. Three VES soundings were performed from which two drilling sites were recommended at 0224059E; 0931165N and 0224044E; 0931137N.

At Kono Government Hospital no profiling was done as there was no survey space available, hence investigations were conducted through three VES which were conducted at spots available. Drilling is recommended at points 0283635E, 0956524N and 0283712E, 0956521N

At Tunkia ground geophysical survey done along two profile lines KM003P1 and KM003P2 of 90m and 60m respectively. The profiles were surveyed with resistivity investigating at two different depths of investigations of 25m and 40m. Three soundings were done on the site, two of these on the profile line and one on outside the profile line. Drilling at Tunkia is recommended at points 0253075E, 0835983N and 0256071E, 0825958N. We recommend a revisit of Gurahun Tunkia CHC target areas with Magnetic survey to pick the faults and dykes which are prominent in this area. VES points can then be set on the faults or dykes for better yields.

# 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 Kenema District (Tungie CHC and Tunkia CHC) and Kono Government Hospital in Kono Administrative district, but is administered from Kenema by GOAL. Drilling sites of planned 1 borehole for each health facility are recommended. 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.

Tungie CHC is at presently does not have a water supply within its facility, they instead rely on a community well. While Tunkia CHC, has a seasonal hand dug well at its facility. Both facilities therefore require sustainable water sources.

Kono Government hospital has 5 boreholes (drilled wells) and 3 hand dug (open diameter) wells. Of these only two were in use, one borehole and one hand dug well. The hospital was said to need more water and that the present supply was not sufficient for handwashing and cleaning (World Hope International 2015).

In view of the current supply situation and in particular that concerning water quality, it became necessary to identify additional water sources around the CHCs and Kono Government Hospital.

# 2 BACKGROUND

Considering the unavailability of information regarding results of drilled and hand dug wells in the vicinity of these CHCs and Hospital, the expected success rate for drilling boreholes with sufficient quantities of water require more geophysical techniques are required 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 target 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 three targets for Water, Sanitation and Hygiene activities in District Hospitals and Community Health Centers (CHCs) comprised of Tungie CHC, Tunkia CHC in Kenema District and Kono Government Hospital in Kono District.

Kenema District is a district in the Eastern Province. The district is the most populous district in the Eastern province with a population 545,327. Kenema District has an area of 6,053 $km^2$ and comprises sixteen chiefdoms. The District of Kenema borders Bo District to the west, the Republic of Liberia to the south, Tonkolili and Kono District to the north, Kailahun District to the southwest, and Pujehun District to the southeast. Tunkia CHCs located about 57Km to the South of Kenema town, whilst Tungie CHC is to the North West of Kenema Town. Figure 1: Location of the Target Community Health Centres in Port Loko District.Figure 1, shows the location of the Kenema and Kono District and the CHCs covered in this report.

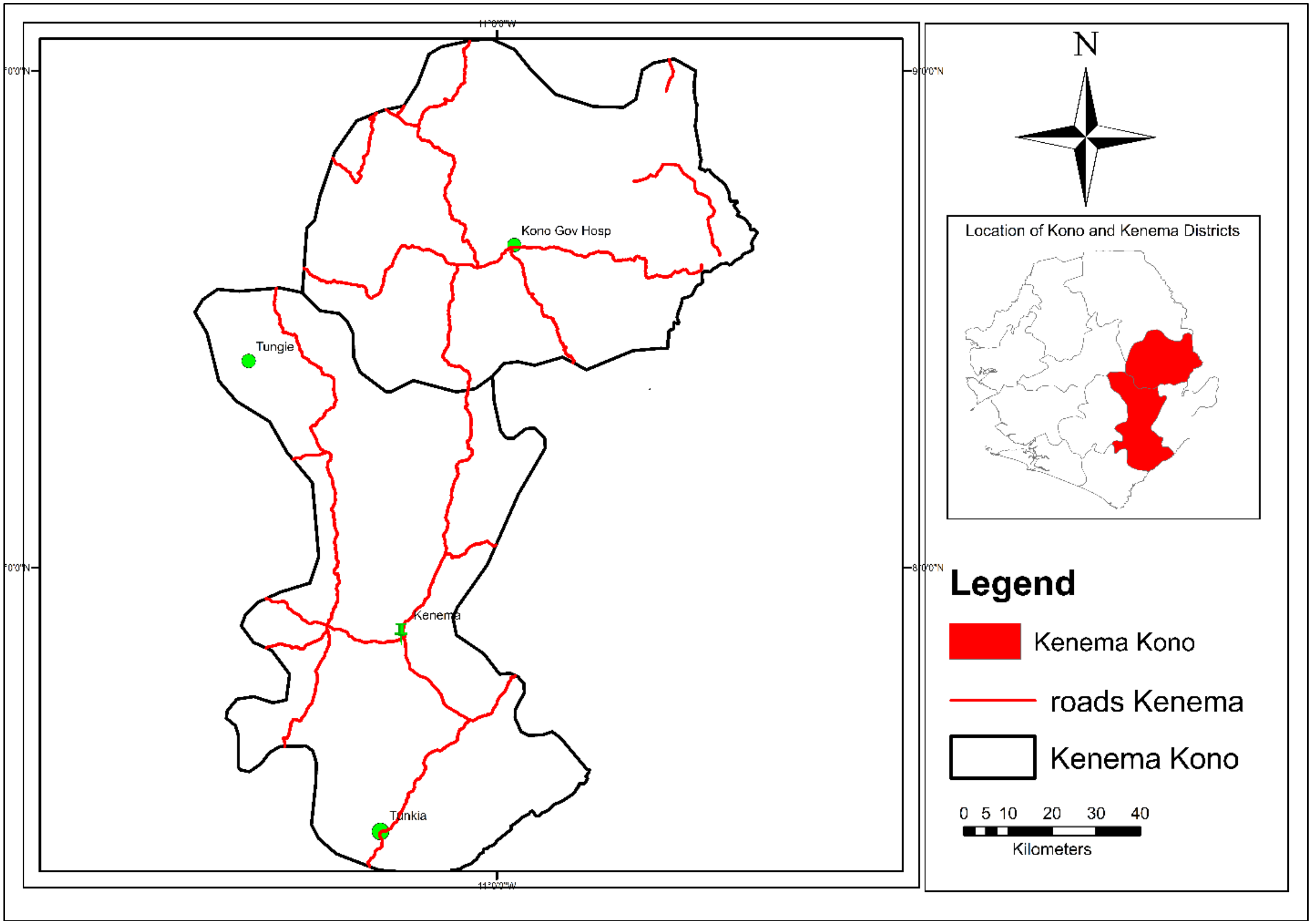


Figure 1: Location of the Target Community Health Centres in Port Loko District.

# 4 REGIONAL SETTING

## 4.1 Geology

The regional geology of the area comprises of rocks of the Archean basement complex. Around the Tungie CHC area the geology is, banded gneiss and granitoids. Inferred regional and local geologic lineaments around Tungie strike in NNW-SSE direction. However no structures have been mapped around the area.

The area around Tunkia is the migmatites and hybrid rocks, structurally the area comprises of a set of dolerite dyke intrusions that trend in a roughly WWN- EES direction. It is anticipated that these dykes manifest at the target area, however the technique employed has limited capabilities of picking these dykes. Also of structural significance is a set of faults that trend in NNW-SSE direction. These units are also anticipated in the area around Tunkia.

Around the Kono Government hospital the geology comprises of banded gneiss and granitoids. Structurally the area has been intruded by NE-SW trending Kimberlite dykes. A set of regional faults also cut across the area in a NNE-SSE direction. The geology of the target areas is shown in Figure 2.

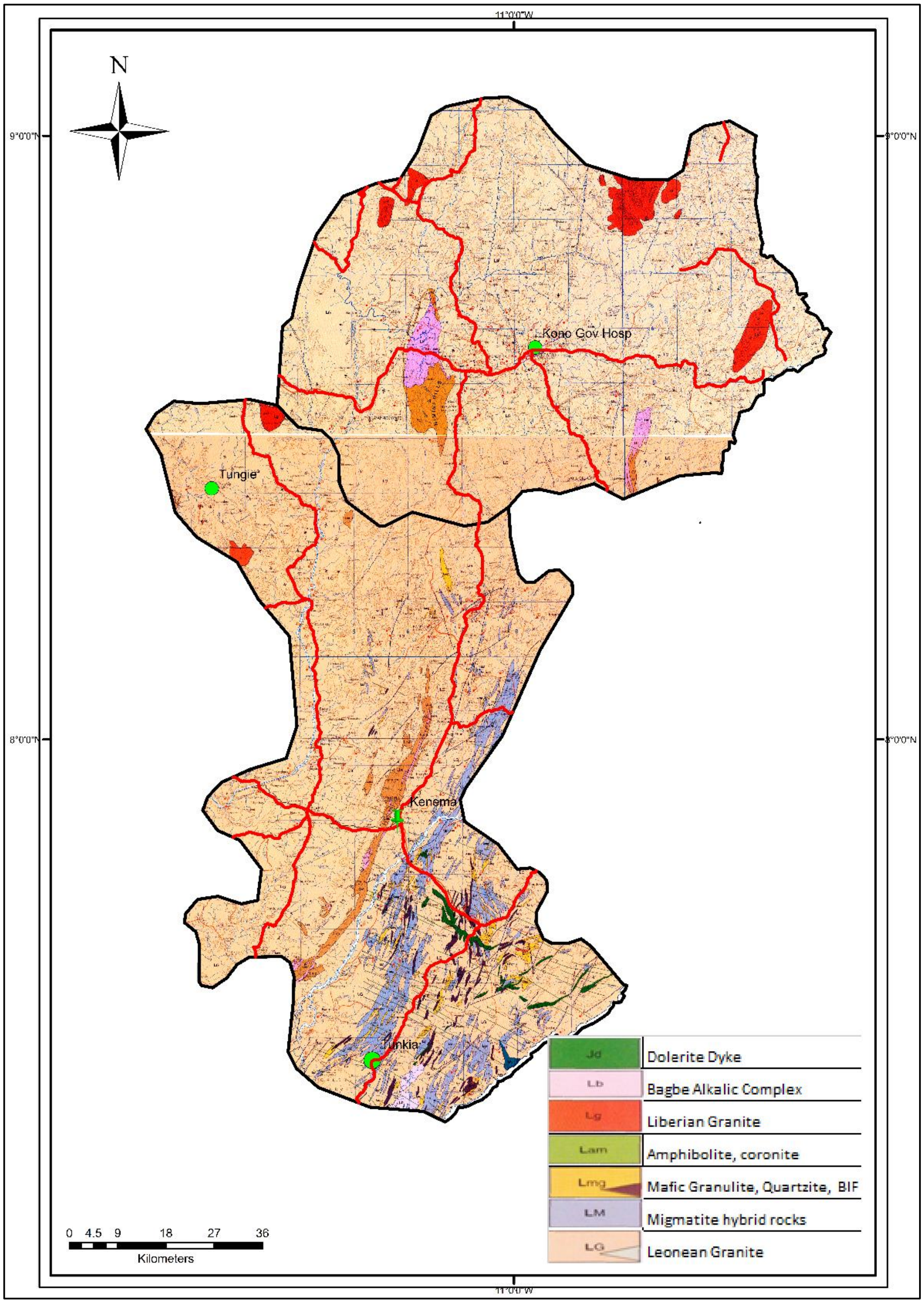


Figure 2: Geology of Kenema and Kono District

### 4.2 Hydrogeological Setting

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)

#### 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 rocks, and fractured bedrocks form the aquifer units in this district. Deep weathered and fractured zones in the bedrock considered as target feature for groundwater development and thus for geophysical surveys. Such features tapping thicker aquifer zones and are generally associated with geological lineaments, faults lithological contacts. In the Inception phase these features were interpreted from geology only was no other variety of data sets including airborne magnetic data, ortho-photographs and imagery was available (Goal, Inception Report, October 2015). Details of the profile lines are summarized in Table 1, Table 2 and

Table 3.

### 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 include 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 to table 3.

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Table 1: Summary of Geophysical Survey, Gura Mamende CHC

| Community Health Centre, CHC | Geophysical Method | Survey Parameters | Name | Location | | | |
|---|---|---|---|---|---|---|---|
| | | | | Start | | End | |
| | | | | Easting (m) | Northing (m) | Easting (m) | Northing (m) |
| Gura Mamende CHC | Resistivity Profiling | Station spacing = 10m<br>AB/2 = 15; 25; 40m<br>MN/2 = 1 | KM001P1 | 0224075 | 0931175 | 0224046 | 0931123 |
| | | | KM001P2 | 0224044 | 0931135 | 0224030 | 931108 |
| | Vertical Electrical Sounding | Schlumberger; Max AB/2 = 100m | KM001S1 | 0224059E | 0931165N | | |
| | | | KM001S2 | 02224046E | 0931144N | | |
| | | | KM001S3 | 0224044E | 0931137N | | |

Table 2: Summary of Geophysical Survey, Kono Government Hospital

| Community Health Centre, CHC | Geophysical Method | Survey Parameters | Name | Location | | | |
|---|---|---|---|---|---|---|---|
| | | | | Start | | End | |
| | | | | Easting (m) | Northing (m) | Easting (m) | Northing (m) |
| Kono Government Hospital | Resistivity Profiling | Station spacing = 10m<br>AB/2 = 15; 25; 40m<br>MN/2 = 1 | Profile 1 | | | | |
| | | | Profile 2 | | | | |
| | | | Profile 3 | | | | |
| | Vertical Electrical Sounding | Schlumberger; Max AB/2 = 100m | KM002S1 | 0283712 | 0956521 | | |
| | | | KM002S2 | 0283724 | 0956510 | | |
| | | | KM002S3 | 0283635 | 0956524 | | |
| | | | KM002S4 | 0283783 | 0956508 | | |

Table 3: Summary of Geophysical Survey at Tunkia CHC

| Community Health Centre, CHC | Geophysical Method | Survey Parameters, Direction | Name | Location | | | |
|---|---|---|---|---|---|---|---|
| | | | | Start | | End | |
| | | | | Easting (m) | Northing (m) | Easting (m) | Northing (m) |
| Gorahun Tunkia CHC | Resistivity Profiling | Station spacing = 10m<br>AB/2 = 15; 25; 40m<br>MN/2 = 1 | KM003P1 | 0253036 | 0825931 | 0253108 | 0825984 |
| | | | KM003P2 | 0253078 | 0825972 | 0826014 | 0253702 |
| | Vertical Electrical Sounding | Schlumberger; Max AB/2 = 100m | KM003S1 | 0253075 | 0825983 | | |
| | | | KM003S2 | 0253071 | 0825958 | | |

# 6 SURVEY RESULTS AND DISCUSSION

The objectives of ground geophysical survey in this area were to delineate fractured/weathered zones associated with geological interpreted lineaments. These were interpreted as important structural features for groundwater development but unfortunately there was virtually no space to undertake profiling at Kono Government Hospital and limited space at Tungie. 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 each CHC area is as follows:

## 6.1 Gura Mamende Tungie CHC – KM001

The ground geophysical survey was planned along two parallel shot lines one profile line (KM001P1) across the geological trends of these features amounting to a total of 100m. Another short profile, KM001P2 of length 40m, was done in the yard of the CHC to confirm some of the anomalies obtained on KM001P1.There was no enough space to do any length more than 40m inside the CHC area. The profile was 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 1. Following the interpretation of profiling data, 3 VES were conducted over low resistivity points which were considered as best groundwater potential anomalies. 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 summarized in **Table 4 to Table 6:**

Table 4: **Summary Resistivity Profiling for line KM001P1**

| Profile Line | Resistivity | Comment |
|---|---|---|
| **KM001P1** | Low resistivity contacts at stations 10m and 50m | No VES was done on this line but corresponding anomalies on KM001P2 were considered. |

Table 5: Summary Resistivity Profiling for line KM001P2

| Profile Line | Resistivity | Comment |
|---|---|---|
| **KM001P2** | Low resistivity contacts at stations 10m and 40m | VES at 10m, 30 and beside 50 of KM001P1. |

Table 6: Summary of Vertical Electrical Soundings and Tungie

| | Coordinates | Layer | Resistivity (Ohm-m) | Depth (m) | Comments |
|---|---|---|---|---|---|
| VES 1 – KM001S1 | 0224059E 0931165N | 1 | 500 | 5 | Priority site A<br>There is thick overburden with a thicker weathered zone. Most like fractured around 35m. |
| | | 2 | 280 | 20 | |
| | | 3 | 2100 | | |
| VES 2 – KM001S2 | 0224046E 0931144N | 1 | 580 | 2 | |
| | | 2 | 155 | 3 | |
| | | 3 | 1233 | 6 | |
| | | 4 | 100 | 15 | |
| | | 5 | 990 | | |
| VES 3 - KM001S3 | 0224044E 0931137N | 1 | 70 | 1 | Priority site B<br>There is thick overburden with a thicker weathered zone. |
| | | 2 | 530 | 15 | |
| | | 3 | 90 | 24 | |
| | | 4 | 21400 | | |

## 6.2 Kono Government Hospital

There was no profiling done on this site as there was no survey space available, hence investigations were conducted through four VES which were conducted at spots available. The area confirms thick overburdens of sediments. VES data plots with geo-electric model are presented in **Appendix 2**. The results of the VES and interpretations are summarized in Table 7.

Table 7: Summary of Vertical Electrical Soundings at Kono Government Hospital

| | Coordinates | Layer | Resistivity (Ohm-m) | Depth (m) | Comments |
|---|---|---|---|---|---|
| VES 1 – KM002S1 | 0283712E 0956521N | 1 | 300 | 5 | Priority site B Thick overburden and clear from pollution. |
| | | 2 | 600 | 40 | |
| | | 3 | 790 | | |
| VES 2 – KM002S2 | 0283724E 0956510N | 1 | 512 | 5 | |
| | | 2 | 340 | 19 | |
| | | 3 | 2290 | | |
| VES 3 – KM002S3 | 0283635E 0956524N | 1 | 208 | 5 | Priority site A There is thick overburden with a thicker weathered zone. Most like fractured around 35m. |
| | | 2 | 1450 | 12 | |
| | | 3 | 50 | 24 | |
| | | 4 | 12115 | | |
| VES 4 – KM002S4 | | 1 | 330 | 4 | |
| | | 2 | 210 | 19 | |
| | | 3 | 1310 | | |
| | | | | | |

### 6.3 Gorahun Tunkia CHC – KM003

The ground geophysical survey was planned along two profile lines (KM003P1 and KM003P2) across the geological trends of these features amounting to a total of 150m, as there was no other available space to extend these profiles. The profile was surveyed with resistivity investigating at three different depths of investigation of 15m, 25m and 40m. The profile results are as plotted and presented in APPENDIX 3. Following the interpretation of profiling data, 3 VES were conducted over low resistivity points which were considered as being possible groundwater potential anomalies. VES data plots with geo-electric model are also presented in APPENDIX 3. The discussion of the survey results along the profile line in the area summarized in Table 8, Table 9 and Table 10.

Table 8: **Summary Resistivity Profiling for line KM003P1 (Tunkia)**

| Profile Line | Resistivity | Comment |
|---|---|---|
| **KM003P1** | Generally the resistivities in this area are high, there are lots of dykes and faults in this area, it would have been best if magnetic method was deployed here, but we have relative Low resistivity at stations 50m and 70m. | VES 2 at 50; VES 3 at 70. |

Table 9: **Summary Resistivity Profiling for line KM003P2 (Tunkia)**

| Profile Line | Resistivity | Comment |
|---|---|---|
| **KM003P1** | Generally the resistivities in this area are high but we have relative Low resistivity at stations 50m and 70m. | VES 1 at station 10m. |

Table 10: **Summary of Vertical Electrical Soundings (Tunkia)**

| | Coordinates | Layer | Resistivity (Ohm-m) | Depth (m) | Comments |
|---|---|---|---|---|---|
| VES 1 – KM003S1 | 0253075E 0835983N | 1 | 90 | 4 | Priority site A – There is a weathered layer after 8 m to a depth of 18m |
| | | 2 | 960 | 8 | |
| | | 3 | 160 | 18 | |
| | | 4 | | | |
| VES 2 – KM003S2 | 0256071E 0825958N | 1 | 580 | 3 | Backup Site B - The site has very high resistivities and the weathered layer is not big. |
| | | 2 | 1000 | 6 | |
| | | 3 | 280 | 12 | |

# 7. RECOMMENDATIONS FOR DRILLING

## 7.1. Recommended Drilling Sites

A total of three drilling sites including two backup sites have been recommended for drilling. The list of sites with selection criteria and recommended drilling depths are provided in Table 11. There is need to verify and evaluation of incoming drilling results from these sites in for correlation with the geophysical data. We recommend a revisit of Gurahun Tunkia CHC target areas with Magnetic survey to pick the faults and dykes in this area. We can then set VES points on the faults of dykes for better yields

Table 11: List of Recommended Drilling Sites Kono and Kenema Districts

| Site | Site Reference | Coordinates | Site Selection Criteria | Recommended Maximum Drilling Depth (m) |
|---|---|---|---|---|
| KM003DS1 – Gurahun Tunkia CHC | VES 1 – KM003S1<br><br>Priority site A | 0253075E<br><br>0835983N | - Priority site A – There is a weathered layer after 8 m to a depth of 18m. | 40 m |
| KM003DS2 Gurahun Tunkia CHC | VES 2 – KM003S2<br><br>Backup Drill Site | 0256071E<br><br>0825958N | Backup Site B - The site has very high resistivities and the weathered layer is not big. | 40 m |
| KM002DS1 – Kono Government Hospital | VES 3 – KM002S3<br><br>Priority site A | 0283635E<br><br>0956524N | Priority site A<br><br>There is thick overburden with a thicker weathered zone. Most like fractured around 35m. | 70m |
| KM002DS2<br><br>Kono Government Hospital | VES 1 – KM002S1 | 0283712E<br><br>0956521N | Priority site B Thick overburden and clear from pollution. | 70m |
| KM001DS1<br><br>Gura Mamende Tungie CHC | VES 1 – KM001S1<br><br>Priority site A | 0224059E<br><br>0931165N | Priority site A<br><br>There is thick overburden with a thicker weathered zone. Most like fractured around 35m. | 65m |
| KM001DS2<br><br>Gura Mamende Tungie CHC | VES 3 - KM001S3<br><br>Priority Site B | 0224044E<br><br>0931137N | Priority site B<br><br>There is thick overburden with a thicker weathered zone | 65m |

## 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

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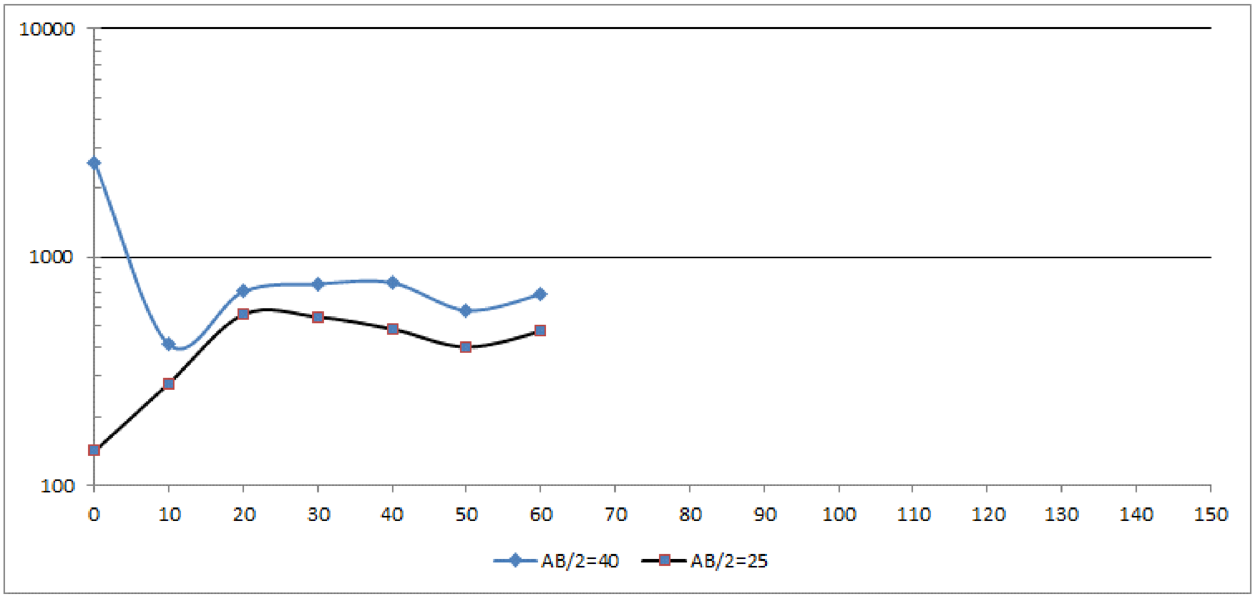
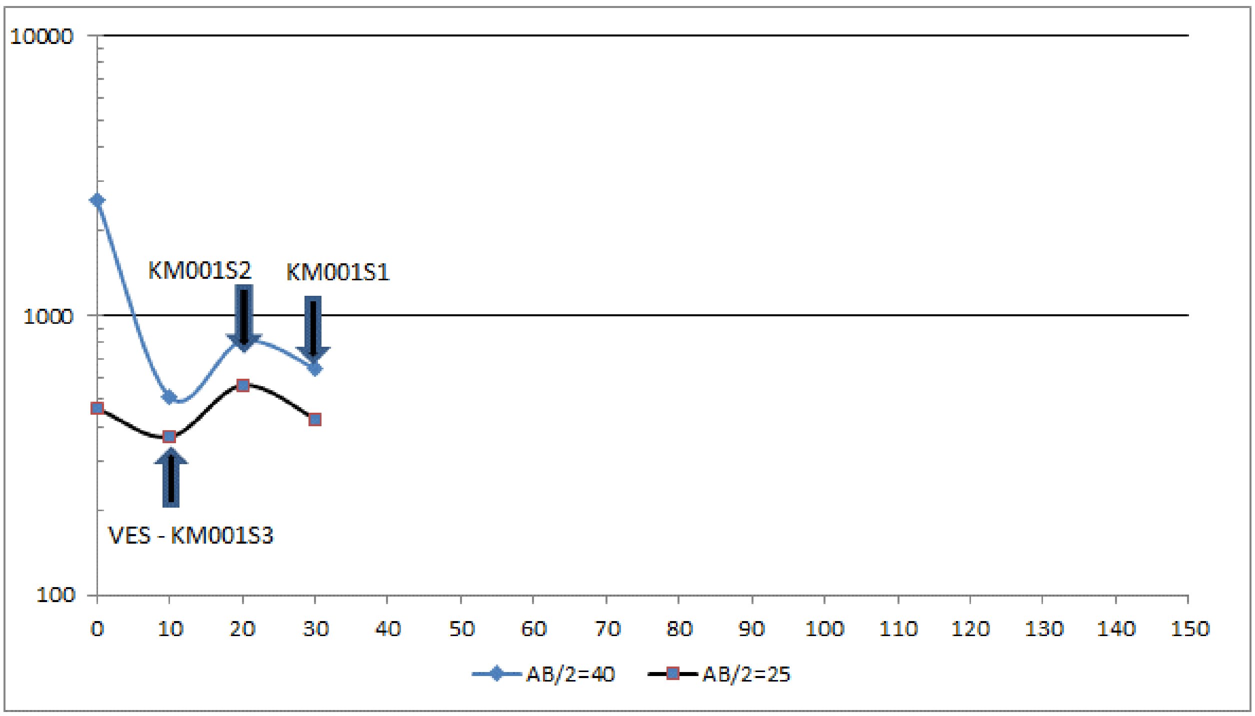
# APPENDICES

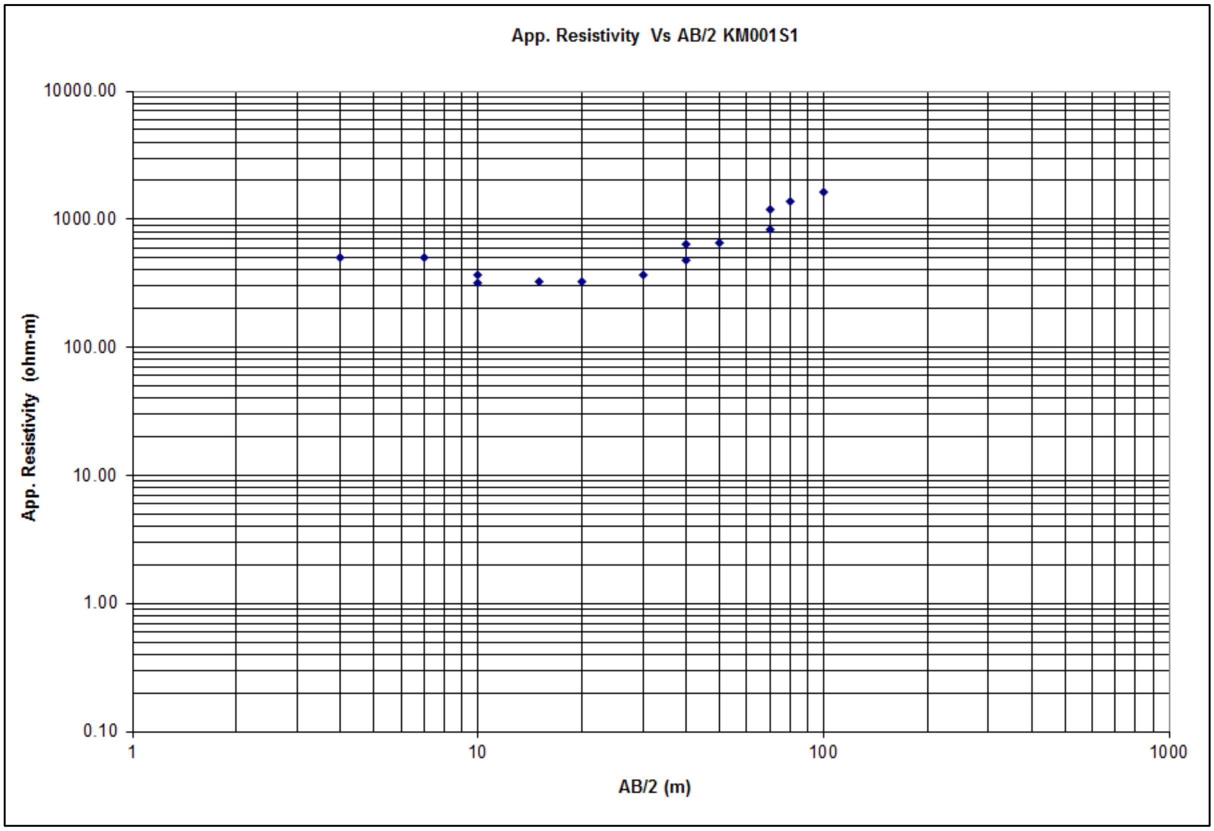
APPENDIX 1: TUNGIE GEOPHYSICAL RESULTS

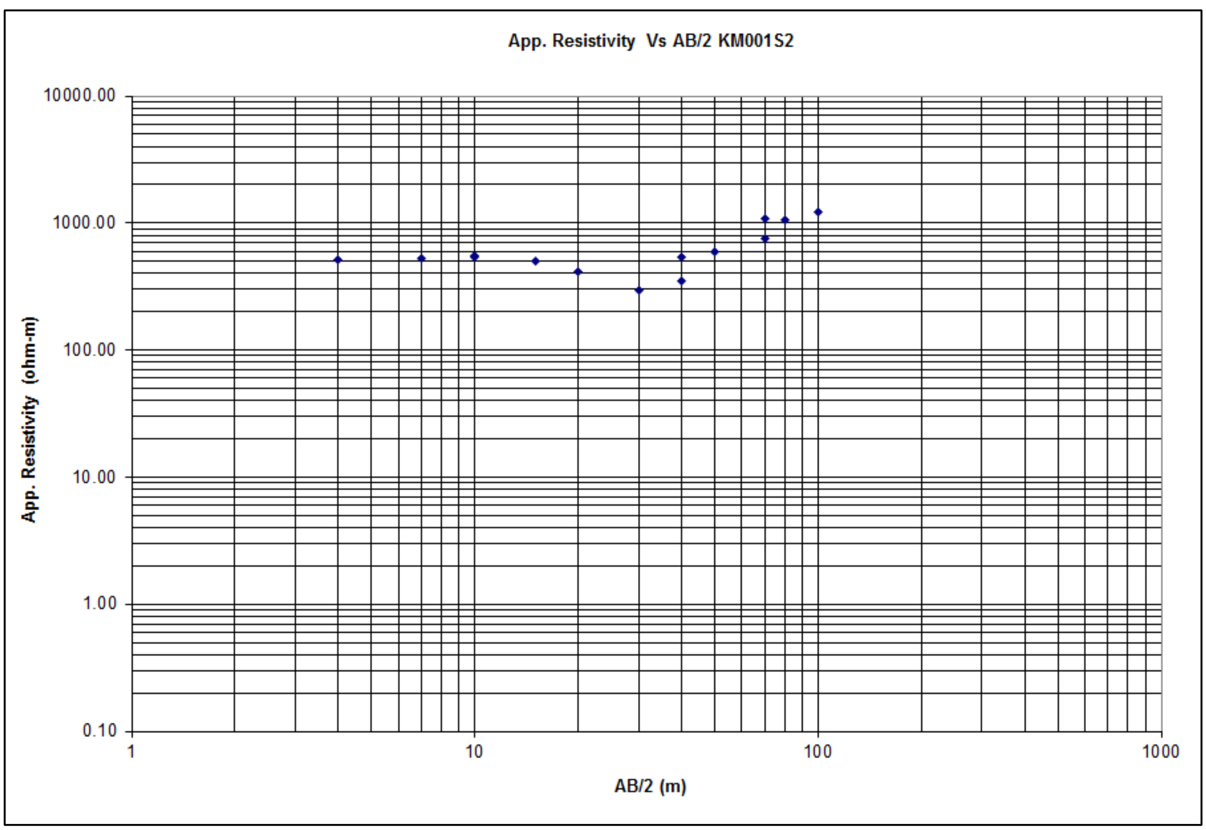
**KM001P1**

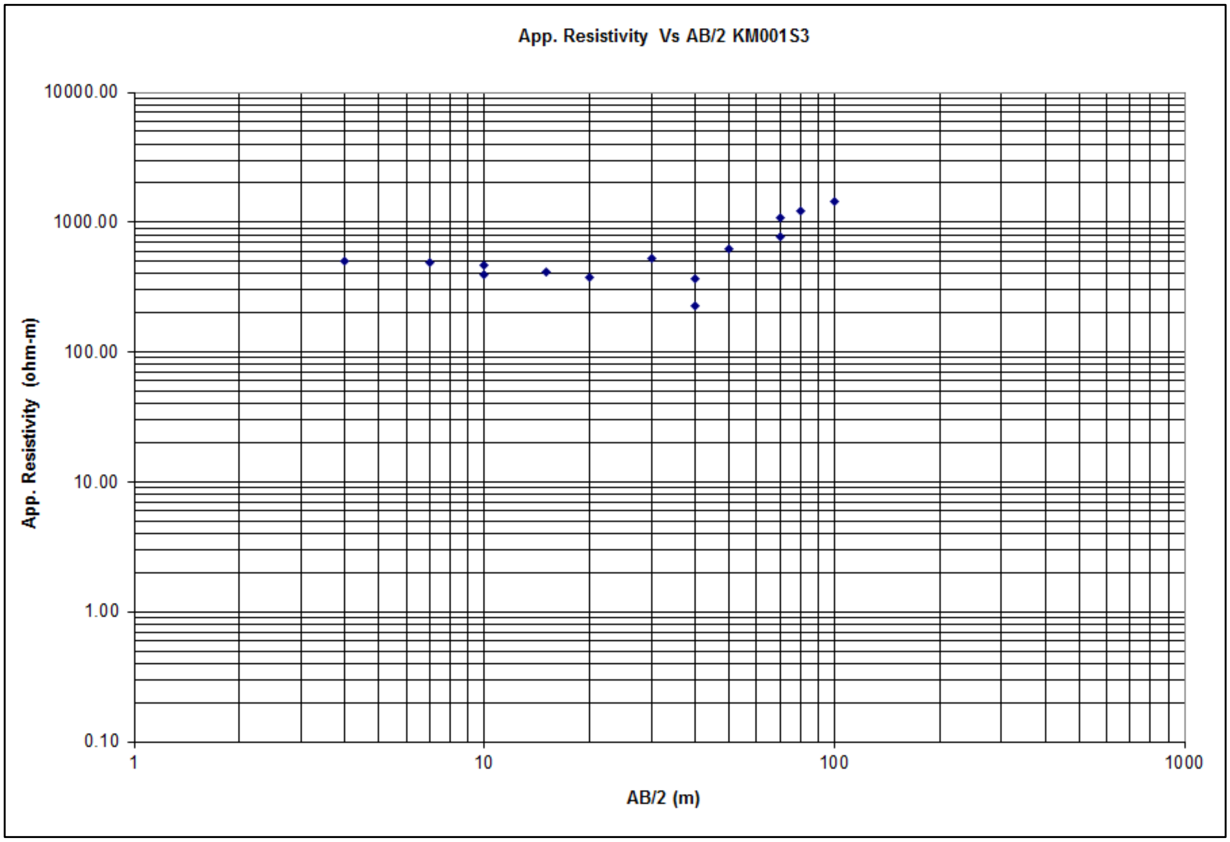

10000
1000
100
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
AB/2=40
AB/2=25

**KM001P2**

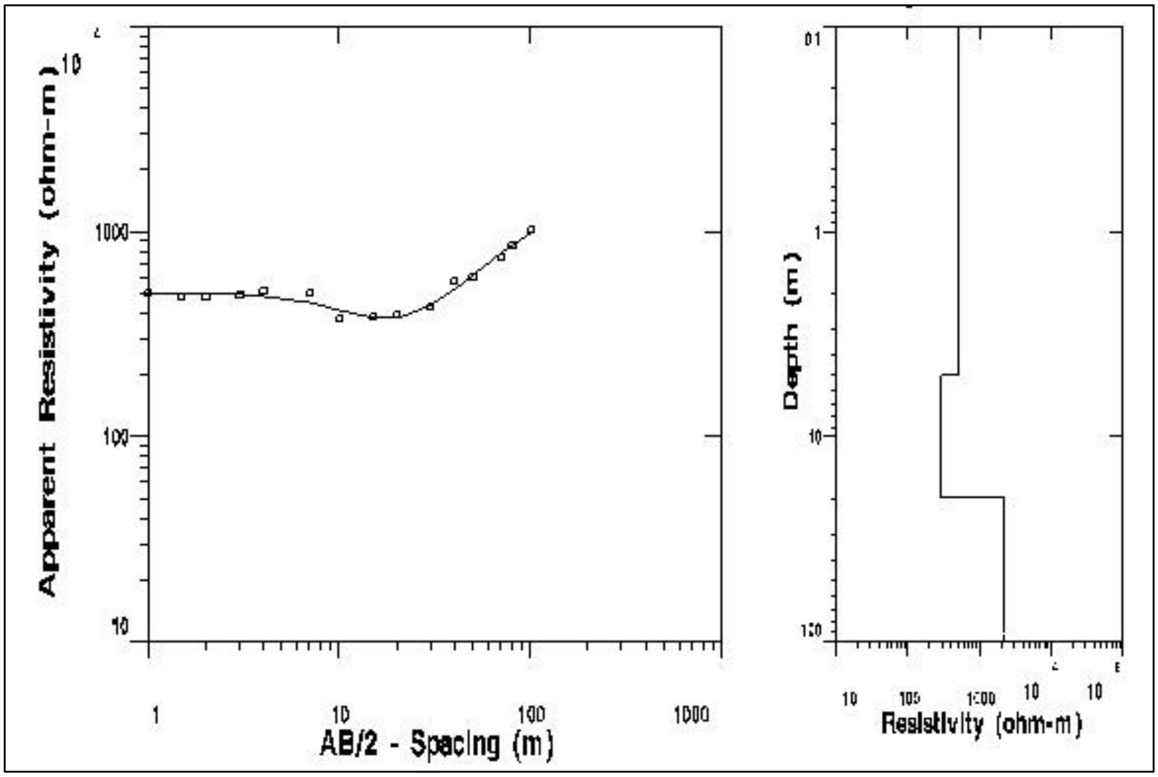

10000
1000
100
KM001S2
KM001S1
VES - KM001S3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
AB/2=40
AB/2=25


App. Resistivity Vs AB/2 KM001S1
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)

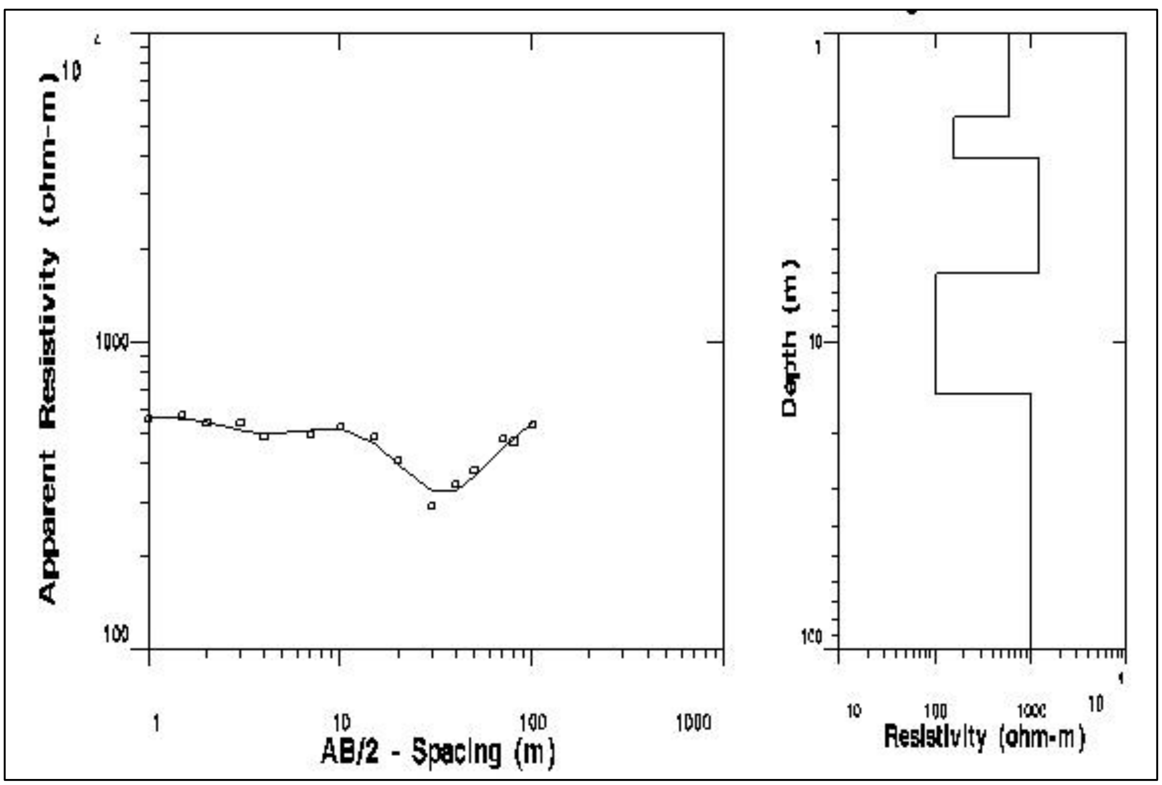

App. Resistivity Vs AB/2 KM001S2
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)

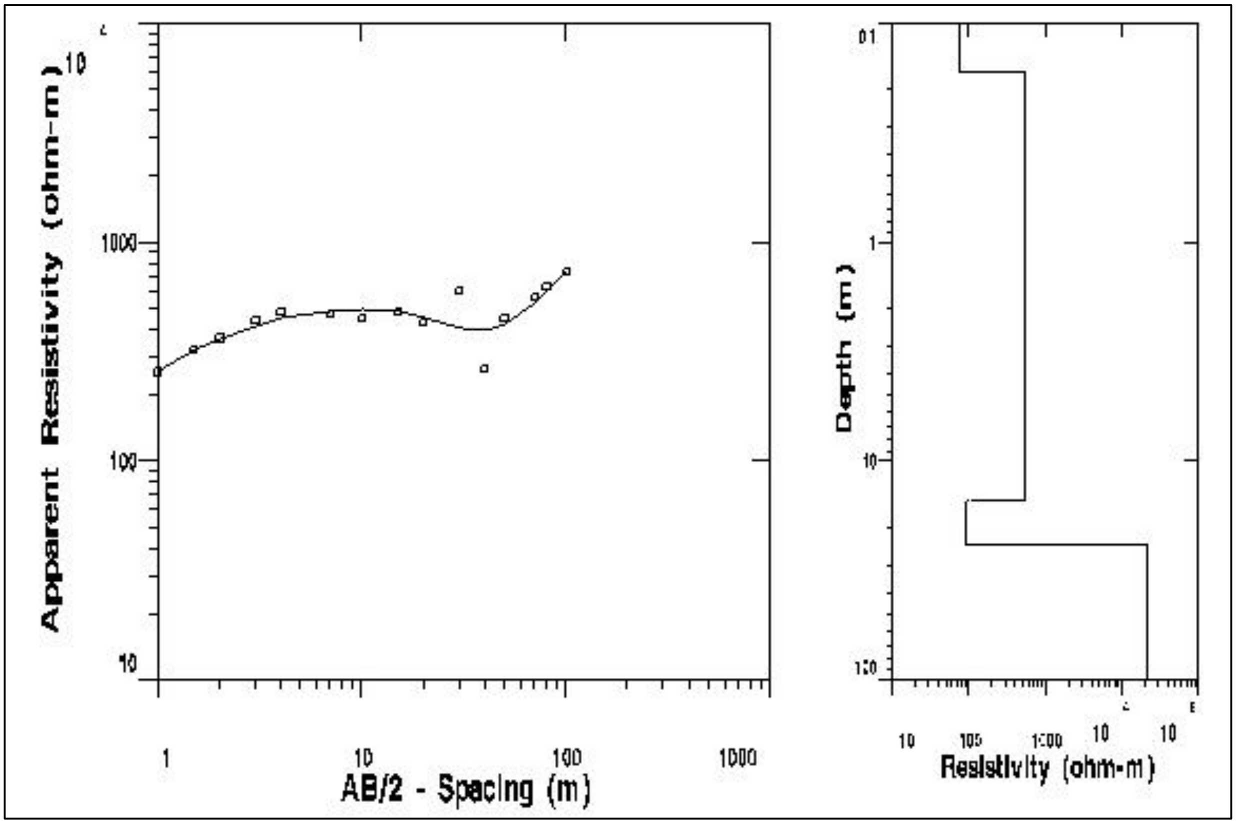

App. Resistivity Vs AB/2 KM001S3
10000.00
1000.00
100.00
10.00
1.00
0.10
App. Resistivity (ohm-m)
1
10
100
1000
AB/2 (m)

**KM001S1**

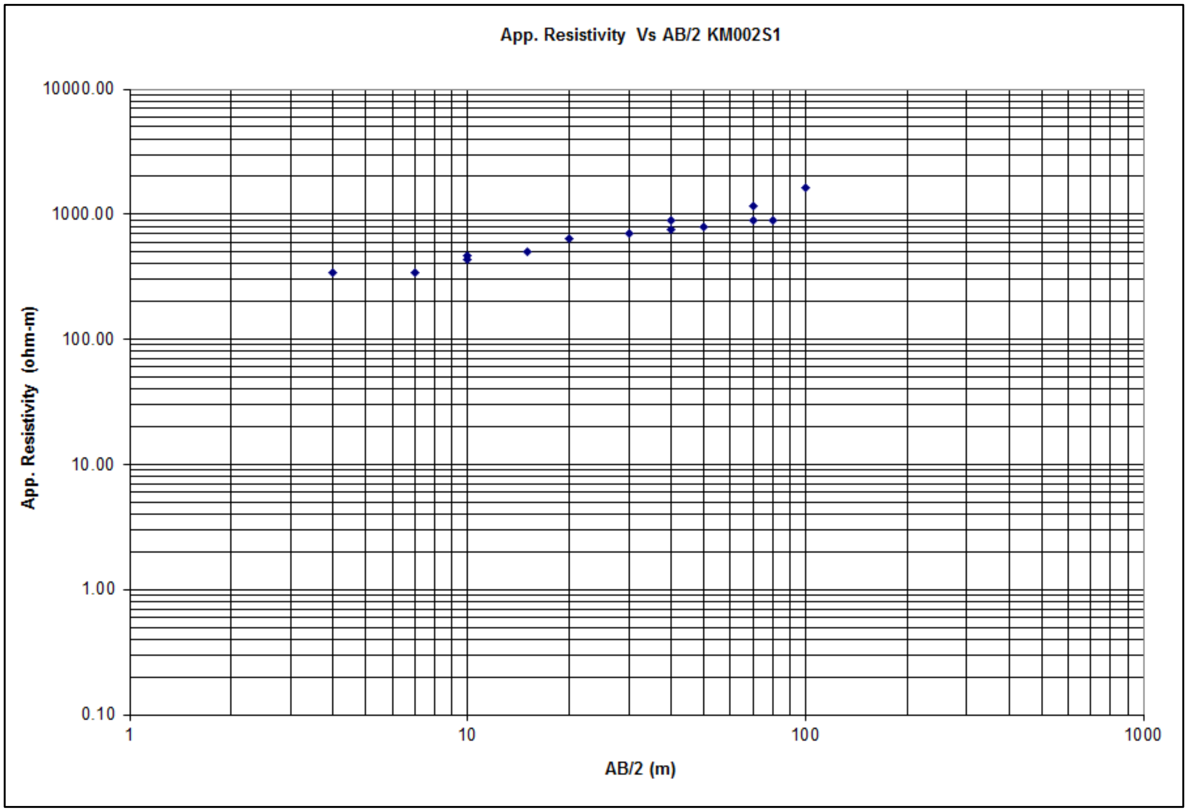


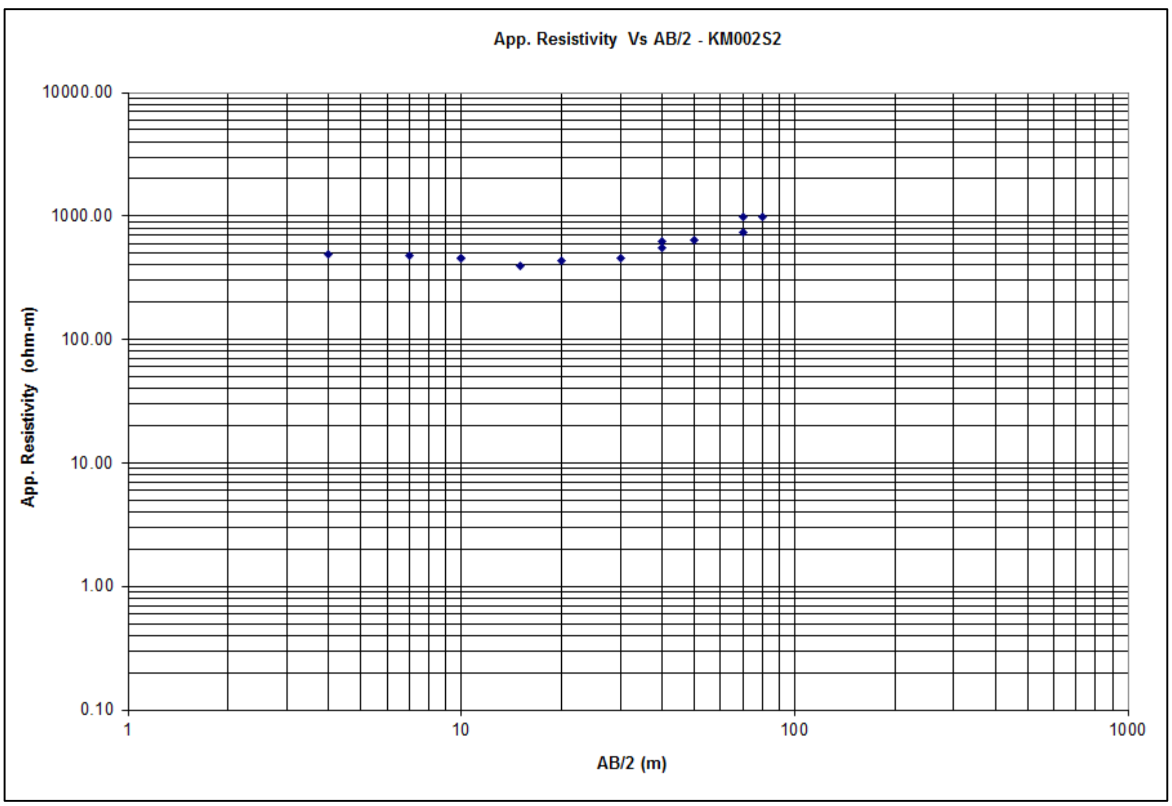

**KM001S2**

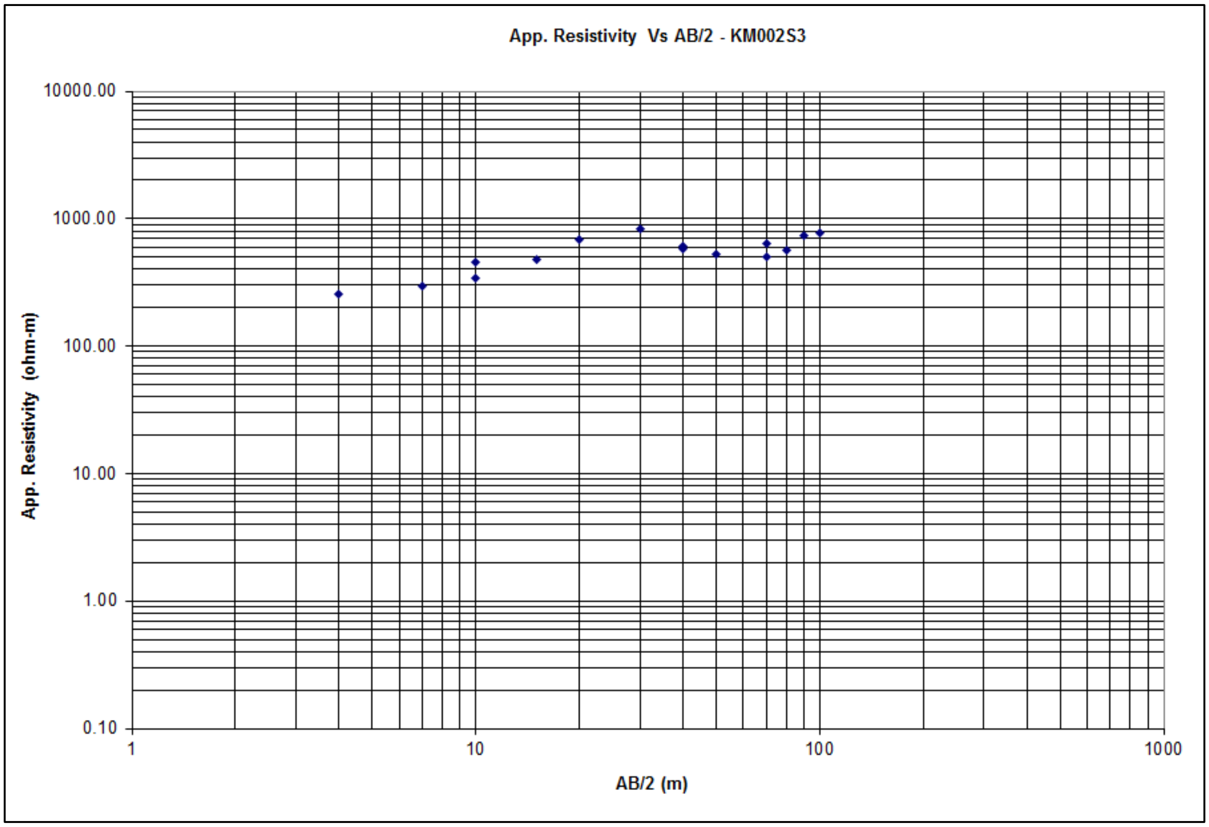


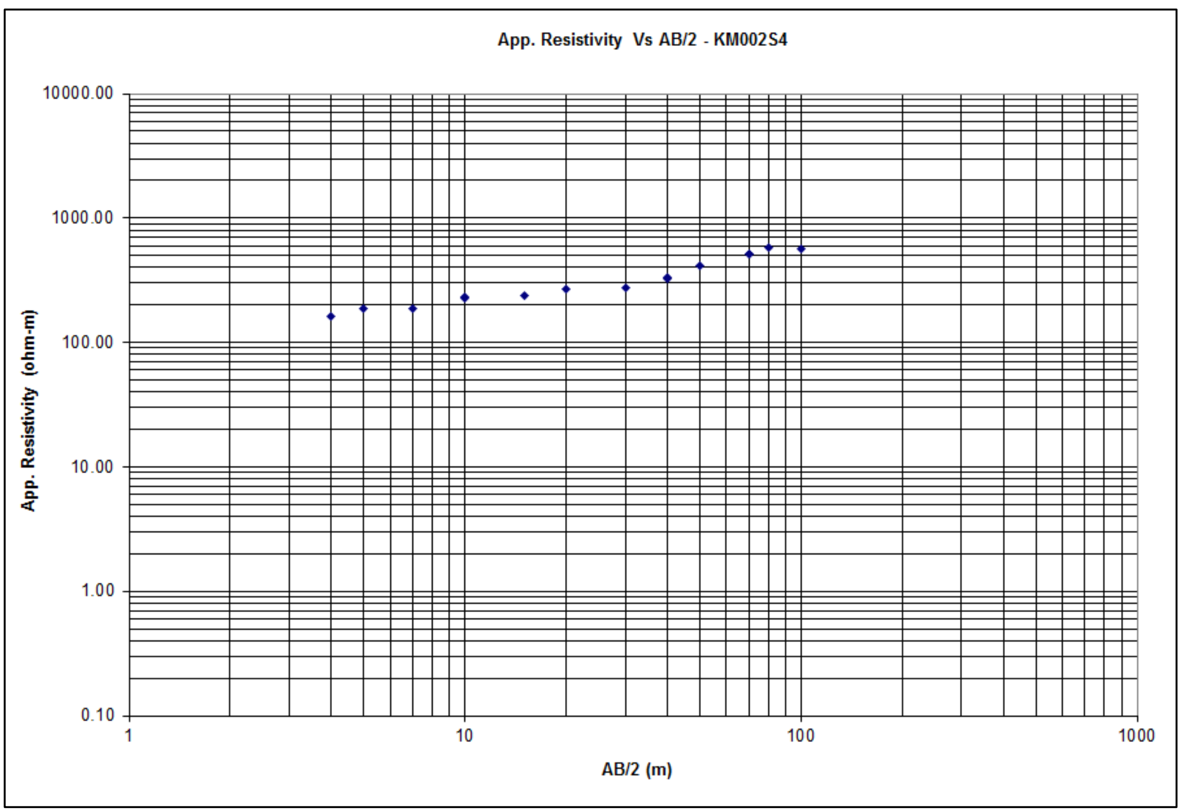

Apparent Resistivity (ohm-m)
AB/2 - Spacing (m)
Depth (m)
Resistivity (ohm-m)

APPENDIX 2: KONO GOVERNMENT HOSPITAL GEOPHYSICAL RESULTS

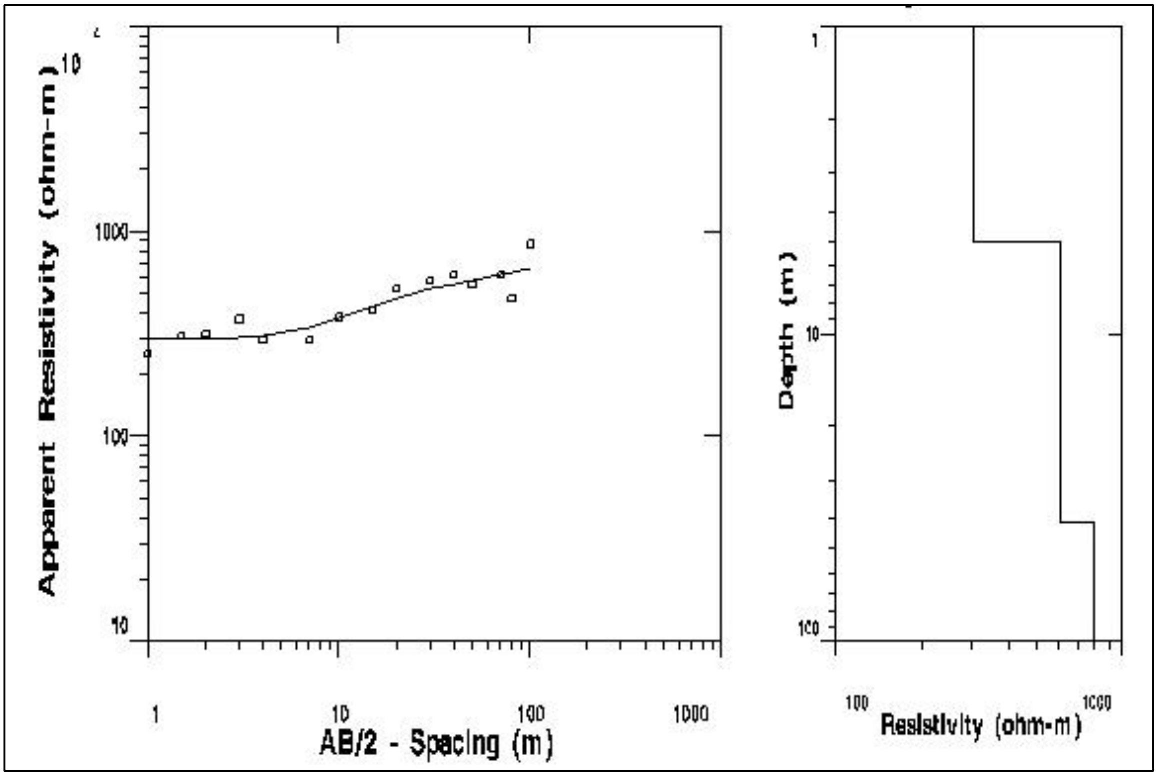


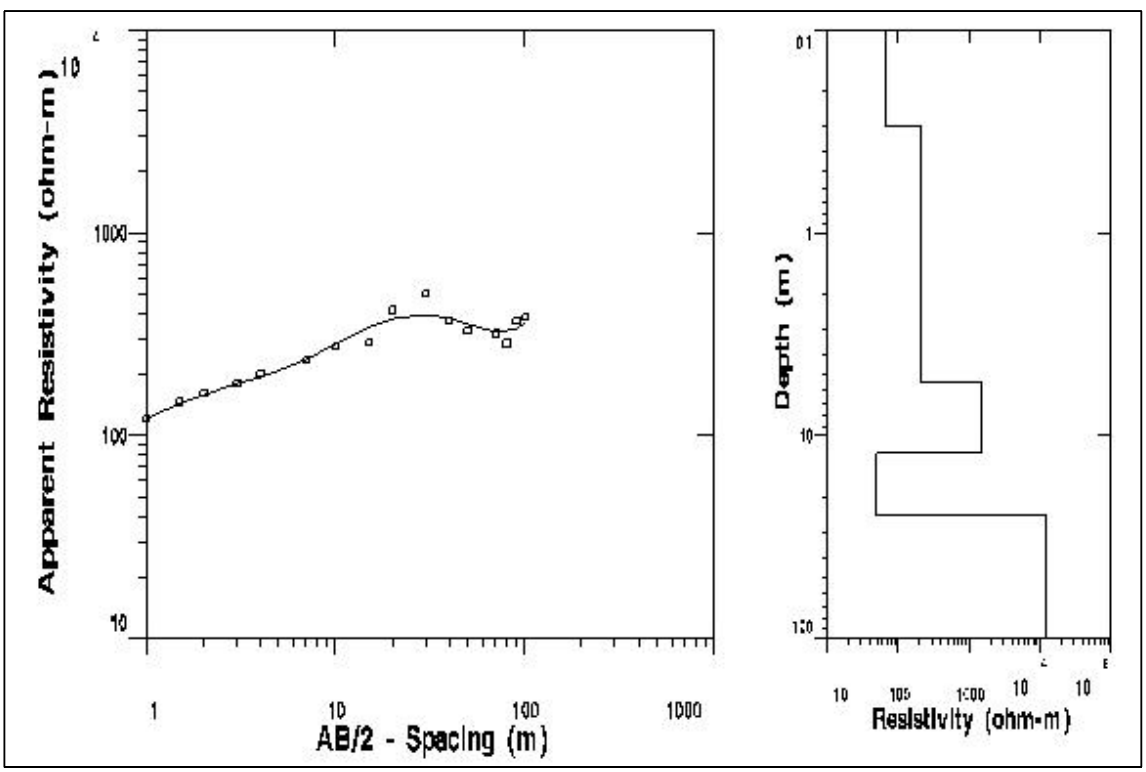

App. Resistivity Vs AB/2 - KM002S3
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)


App. Resistivity Vs AB/2 - KM002S4
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)

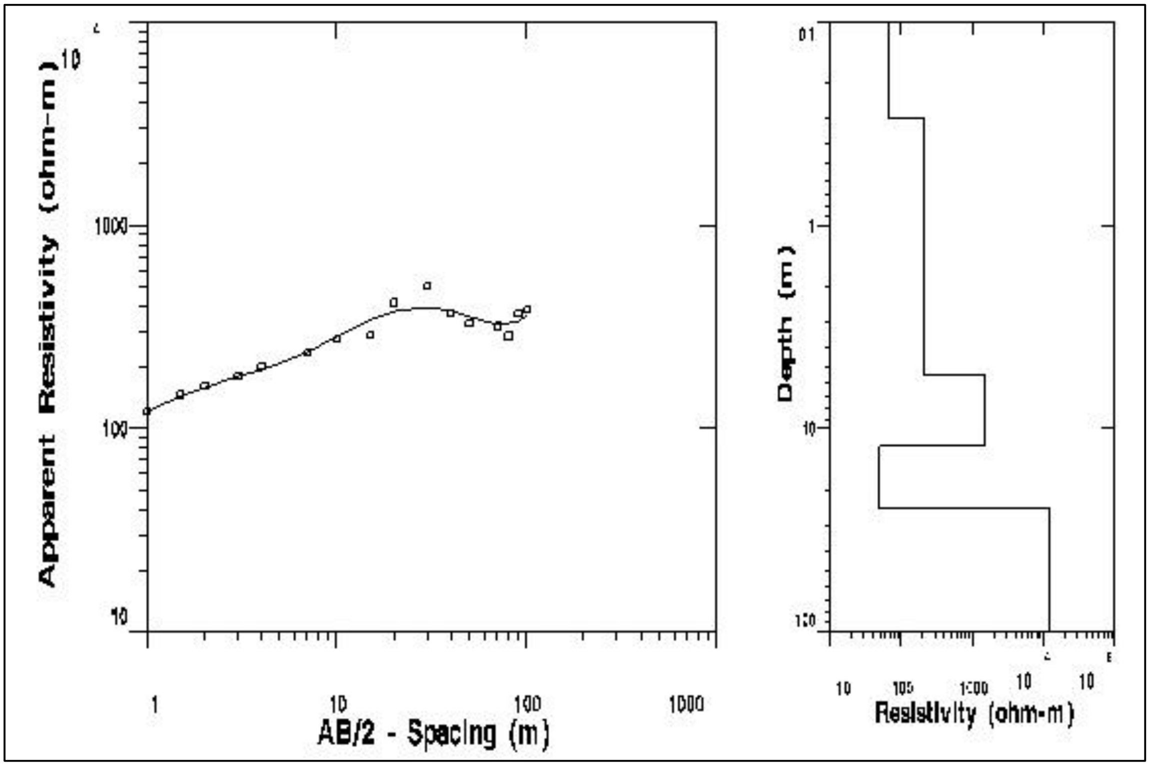
**KM002S1**



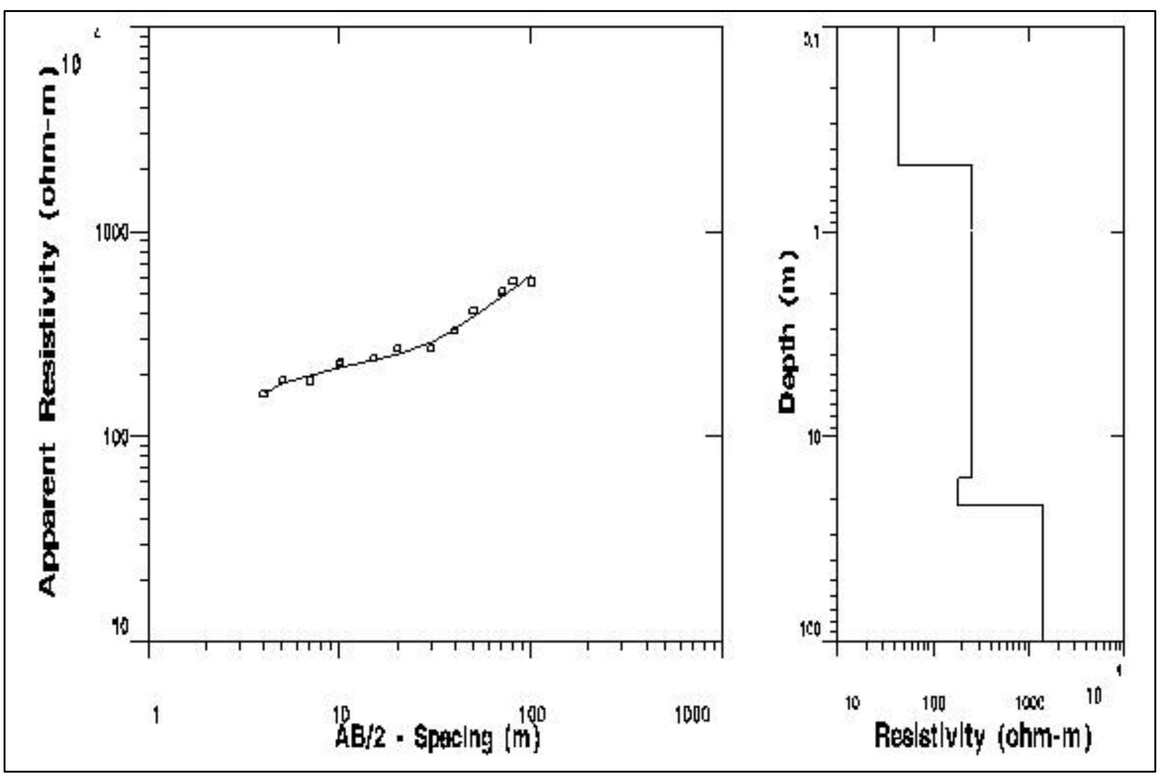

**KM002S2**



**KM002S3**

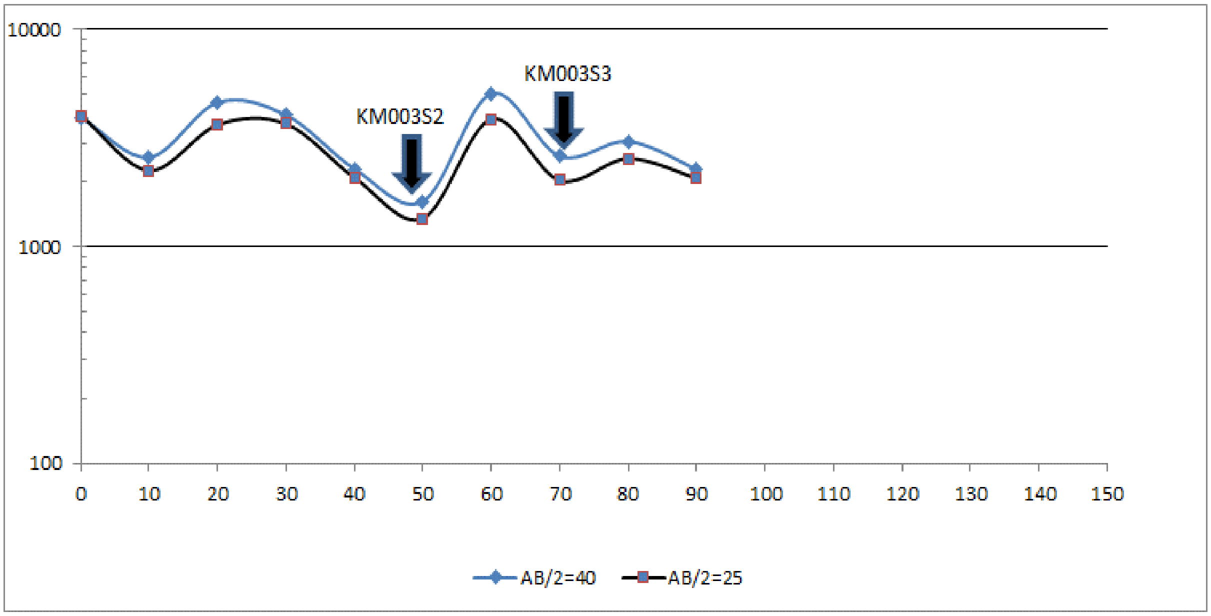



**KM002S4**



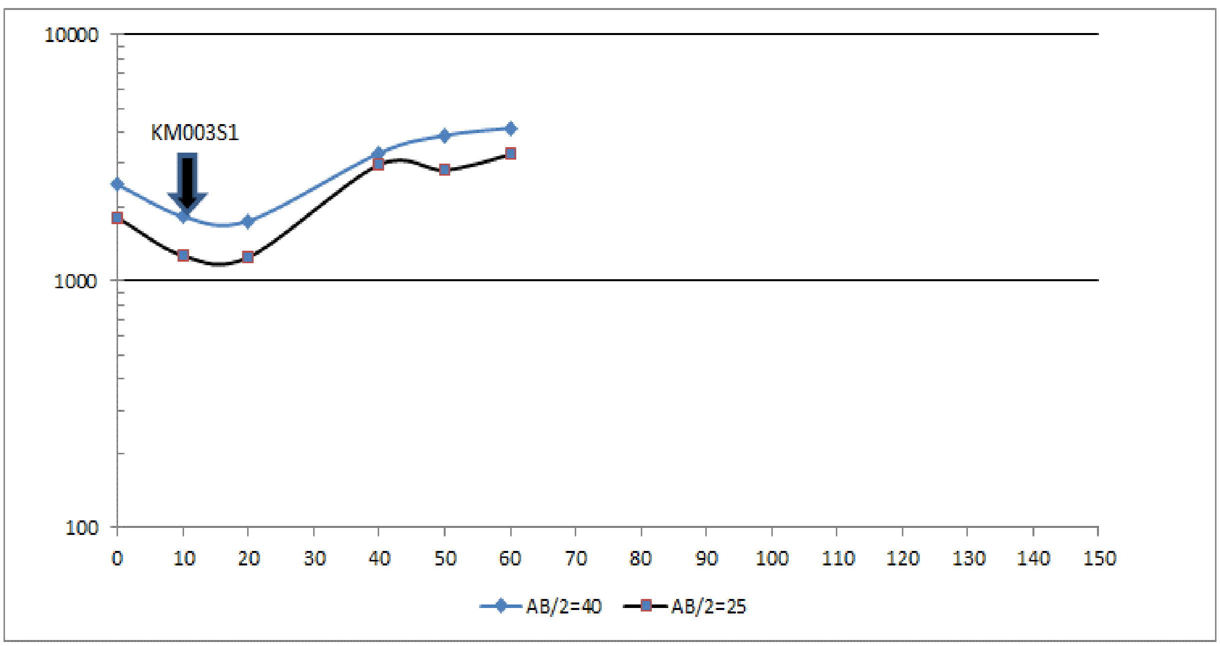
APPENDIX 3: TUNKIA GEOPHYSICAL RESULTS

**KM003P1**

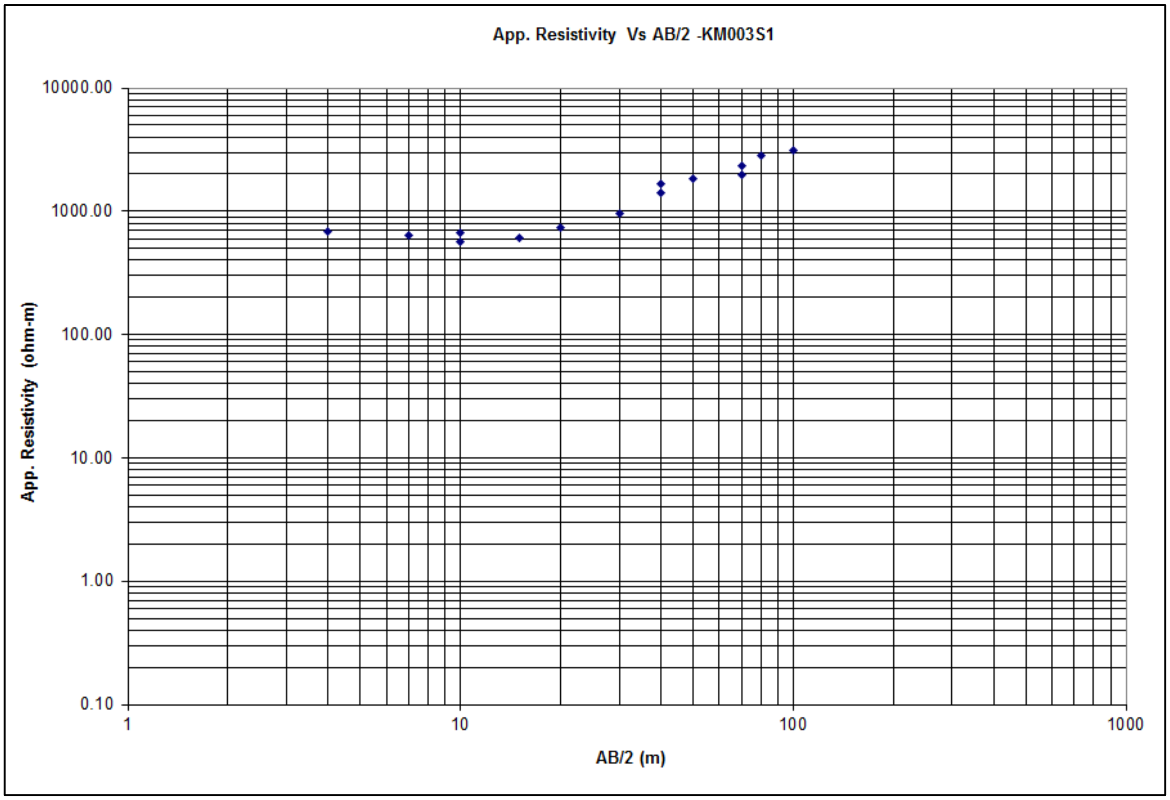


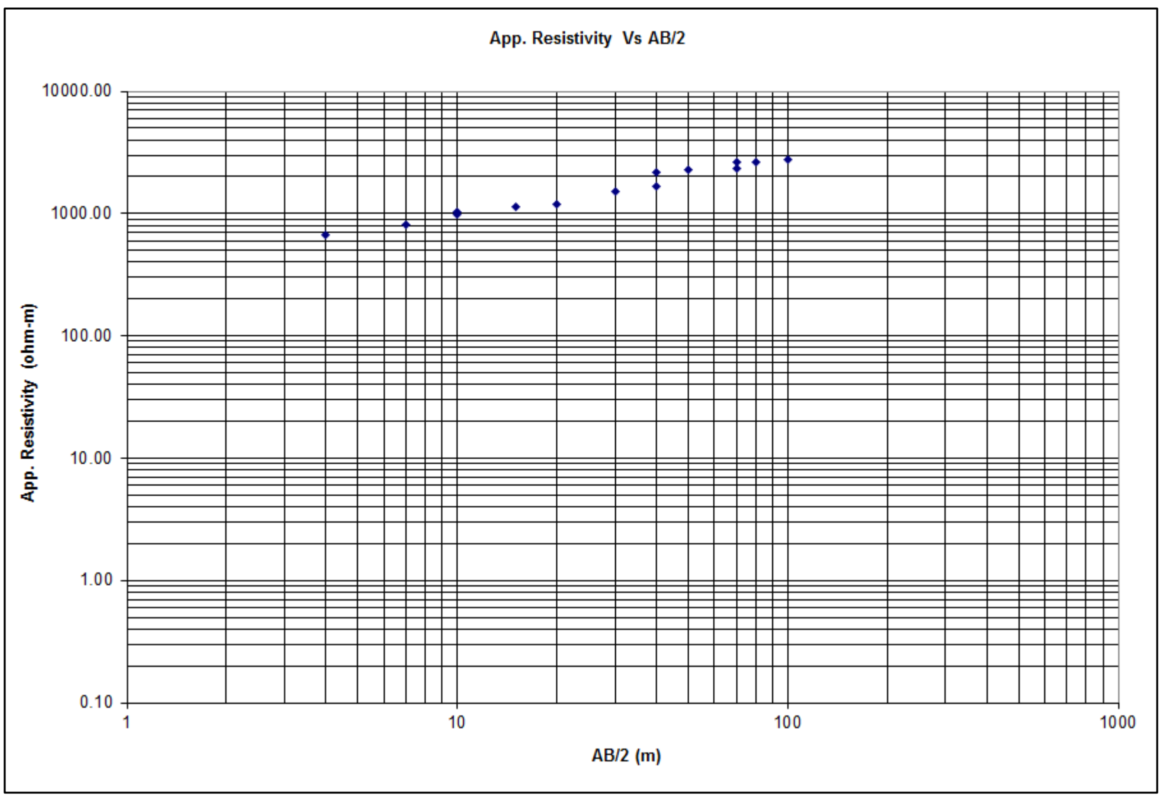
10000
1000
100
KM003S2
KM003S3
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
AB/2=40
AB/2=25

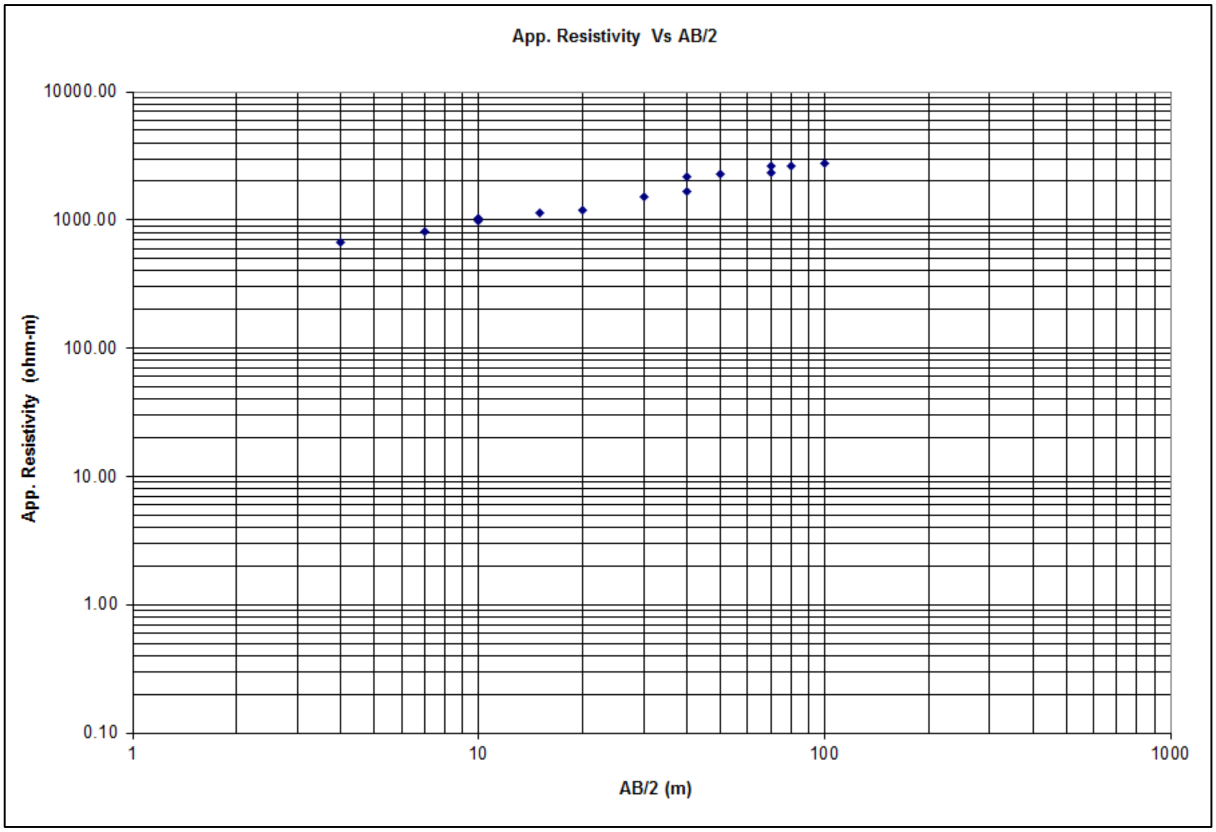

**KM003P2**



10000
1000
100
KM003S1
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
AB/2=40
AB/2=25

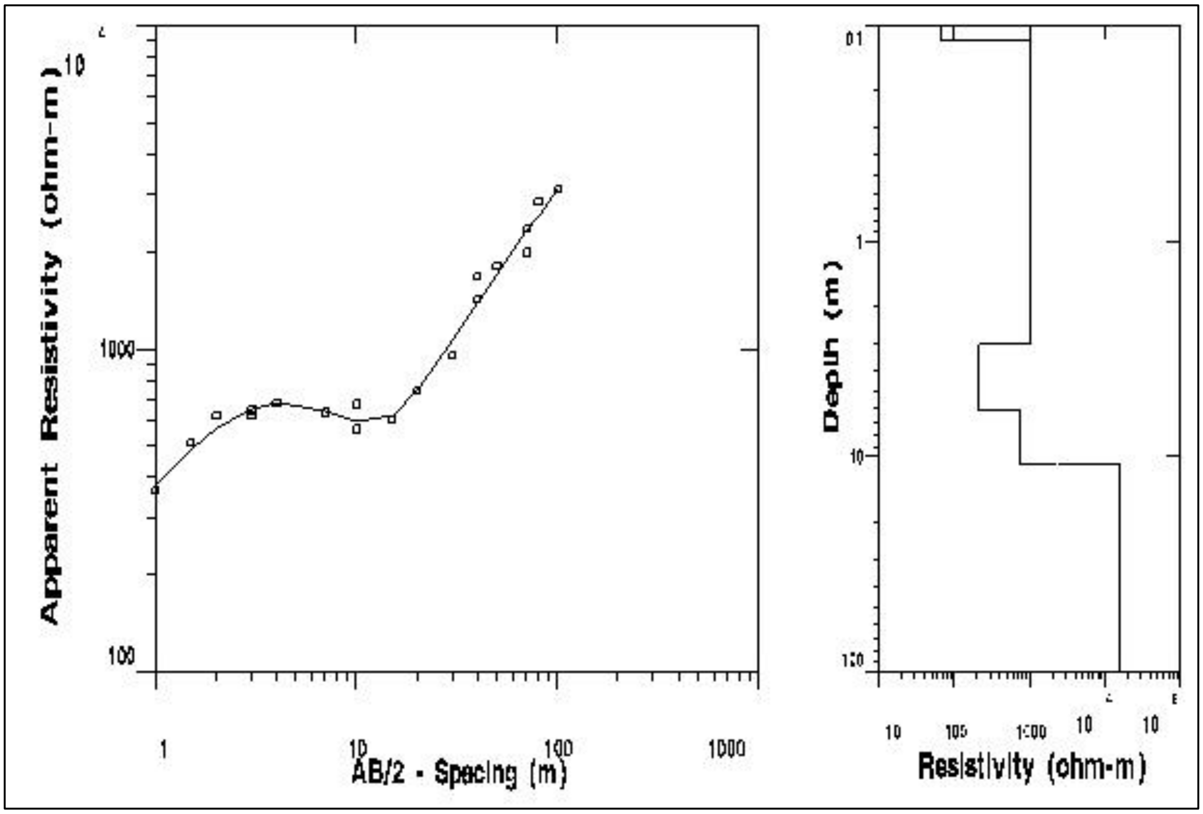

App. Resistivity Vs AB/2 -KM003S1
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)


App. Resistivity Vs AB/2
App. Resistivity (ohm-m)
10000.00
1000.00
100.00
10.00
1.00
0.10
1
10
100
1000
AB/2 (m)



App. Resistivity Vs AB/2
10000.00
1000.00
100.00
10.00
1.00
0.10
App. Resistivity (ohm-m)
1
10
100
1000
AB/2 (m)

**KM003S1**




**KM003S2**