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GEOPHYSICAL INVESTIGATION FOR BOREHOLE SITING ON A PORTION OF THE TOWNLANDS OF TSUMKWE SETTLEMENT, OTJOZONDJUPA REGION, REPUBLIC OF NAMIBIA

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EXECUTIVE SUMMARY

Otjozondjupa Regional Council, Tsumkwe Settlement and United Nations World Food Program Namibia Country Office are developing and implementing an agricultural community-based project. The project is aimed at employment creation and increasing food security and hence potentially contributing Namibia's national socio-economic development. One of the main activities for the project is drilling of boreholes for water supply to the irrigation infrastructure.

Excel Dynamic Solutions (EDS) Pty Ltd, a Namibian hydrogeological and environmental consulting company, offered to conduct a hydrogeological investigation and identify drill sites for at least three (3) boreholes as parts of its Corporate Social Responsibility. As part of the investigation, field ground geophysical surveys were conducted during 28th – 29th Dec 2023.

The investigation involved a desk study, ground geophysical data collection, and analysis of the collected data for informed scientific decision making. The findings were consolidated into this Report. Drilling recommendations have been made based on the results of the field surveys and desktop literature review.

The following conclusions and recommendations have been made as part of the investigation findings.

<u>Conclusions</u>

- The project area is of little/low groundwater potential, otherwise locally moderate.
- The drill site selection was based mainly on geophysical results only.
- The anomalies were interpreted as conductive wedges (buried palaeochannels).
- geophysical techniques applied are meant to increase the chances of successful drilling merely.

<u>Recommendations</u>

- The recommended drill depths are 140, 150, and 120mbgl based on the AMT profile survey results and depths to water strike zones of existing boreholes.
- The drilling be supervised by a hydrogeologist to carefully analyze the drill cuttings (as the drilling progresses) and define the lithology correctly for informed decisions on the borehole termination and construction.
- The recommended drilling method is air percussion with an ability to switch to Mud Rotary.

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LIST OF ABBREVIATIONS / ACRONYMS

The abbreviations and acronyms defined herein have been adopted for the purposes of this exercise and hence the author will not be responsible for further applications whatsoever.

Acronyms / Abbreviations	Definition
BFC	Best Fit Conductivity
EC	Electrical Conductivity(mS/m)
EM	Electromagnetic
AMT	Audio-frequency Magnetotelluric
HLEM	Horizontal Loop Electromagnetic
IP	In-Phase
Km, h	Kilometre, hour
m^3/h	Cubic metres per hour
mamsl	meters above sea level
MAWLR	Ministry of Agriculture, Water and Land Reform
mbgl	meters below ground level
mS/m	milli-Siemens per metre
OP	Out-of-Phase
Q	Quadrature
R_x /T_x	Receiver/Transmitter
t (minute)	Time
TDS	Total Dissolved Solids

1 INTRODUCTION

1.1 Background

The Otjozondjupa Regional Council, Tsumkwe Settlement and United Nations World Food Program Namibia Country Office are collaborating to develop and implement a community based, market-oriented agribusiness project. The project is aimed at employment creation and increasing food security through agricultural and medium-enterprise development, trade facilitation, market access as well as value chain development. One of the main activities for the project is drilling of boreholes for water supply to the irrigation infrastructure.

Excel Dynamic Solutions (EDS) Pty Ltd, a Namibian hydrogeological and environmental consulting company, offered to conduct a hydrogeological investigation and identify drill sites for at least three (3) boreholes as parts of its Corporate Social Responsibility. As part of the investigation, field ground geophysical surveys were conducted during 28th – 29th December 2023 as per the itinerary in table 1.

Table 1: Work program

No.	Date	Activity
1	22nd Dec	Recon – geology, aeromag
2	23rd Dec	Recon – hydrogeo, structures
3	27th Dec	Travelling: Whk - Tsunkwe
4	28th Dec	Fieldwork (Tsunkwe) - geophysics
5	29th Dec	Fieldwork (Tsunkwe) - geophysics
6	30th Dec	Travelling: Tsunkwe - Whk
7	22nd Jan	Data interpretation
8	24th – 27th Jan	Report writing

The investigation involved a desk study, ground geophysical data collection, and analysis of the collected data for informed scientific decision making. This Report, therefore, details the field work undertaken and the results obtained. The following sections provide description of the study location, geology and hydrogeology of the area, the work done, and the results obtained, as well as analyses thereof, and subsequently the drilling recommendations.

1.2 Objective

The objective of the hydro-geological investigation was to review the existing geological and hydrological information as well as to acquire and qualitatively interpret the ground geophysical data and thereafter identify the potential sites for the drilling of the proposed boreholes within the boundaried of the demarcated project area.

1.3 The Area

The area earmarked for the proposed irrigation under this food sustainability project is situated roughly 2.5km to the south of the settlement within Tsunkwe Town and Townlands No. 370 in the far eastern parts of Otjozondjupa Region, where the region is bounded to the south by Omaheke region, to the east by the international border with Botswana, and to the north by Kavango East Region (Figure 1).

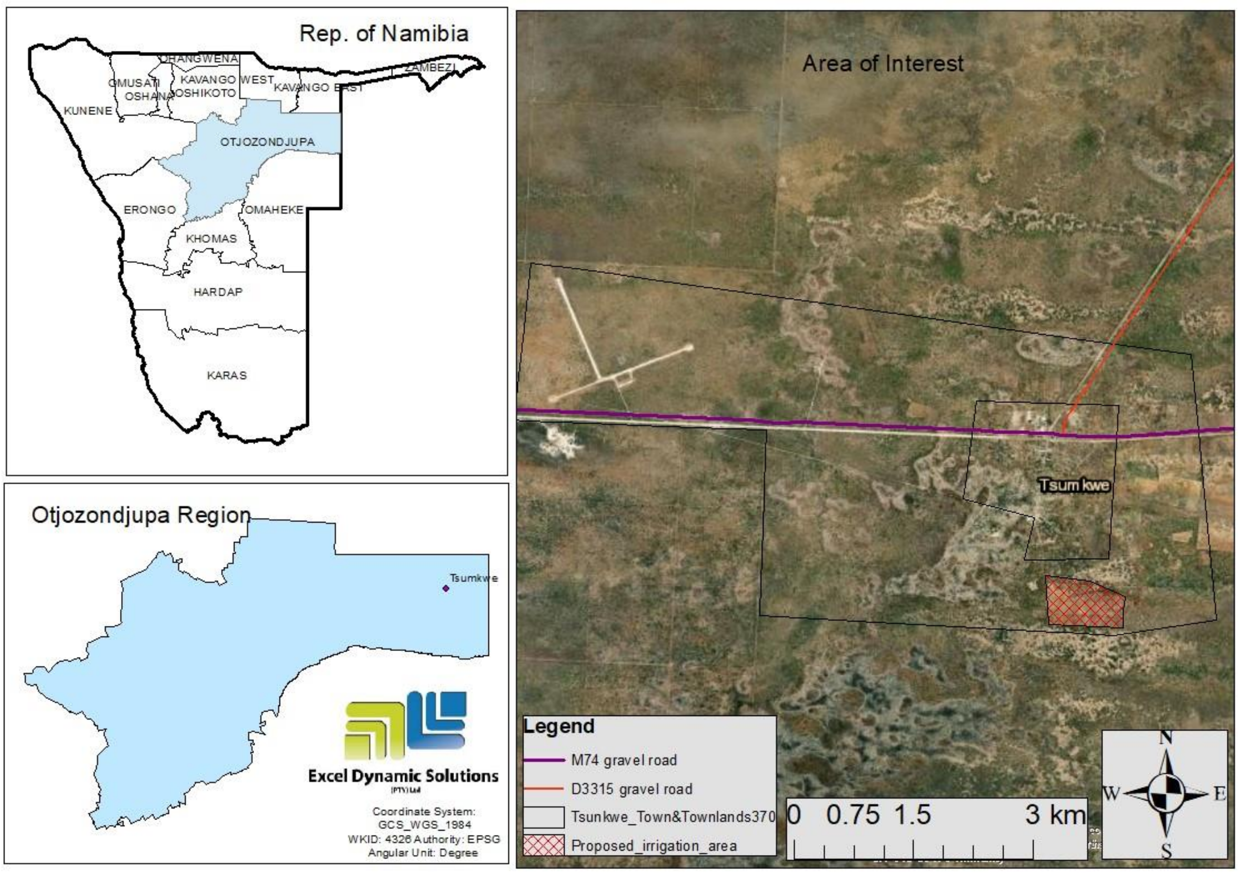

Figure 1: Location of study area

The area lies in between two distinct groups of the San population; the Ju/Wasi, who traditionally lived to the east and the !kung, who traditionally lived to the west of Tsunkwe. The Wasi community has maintained a 'hunter-gatherer' lifestyle, although they it has lately been influenced by the 'subsistence farming' lifestyle of the western !kung population. This community project is expected to contribute potentially to the move towards sedentary, agricultural and market-oriented livelihood among the San community of the area.

2 PHYSIOGRAPHY AND HYDROLOGY

The project area lies between 19 and 20 degrees southern latitude and 20 and 21 degrees eastern longitude. It is predominantly a flat horizon that extents from the permanent longitudinal, easward sand dunes to the north and northwest, and Aha Mountains to the southeast.

A limited run-off takes place in the area due to low relief and Kalahari sand cover with high absorption capacity. The drainage system is majorly comprised of Omatako River to the west, Nhoma River to the north and Danieb River to the south. Within the vicinity of the project area, the limited run-off accumulates in numerous pans (Figure 2).

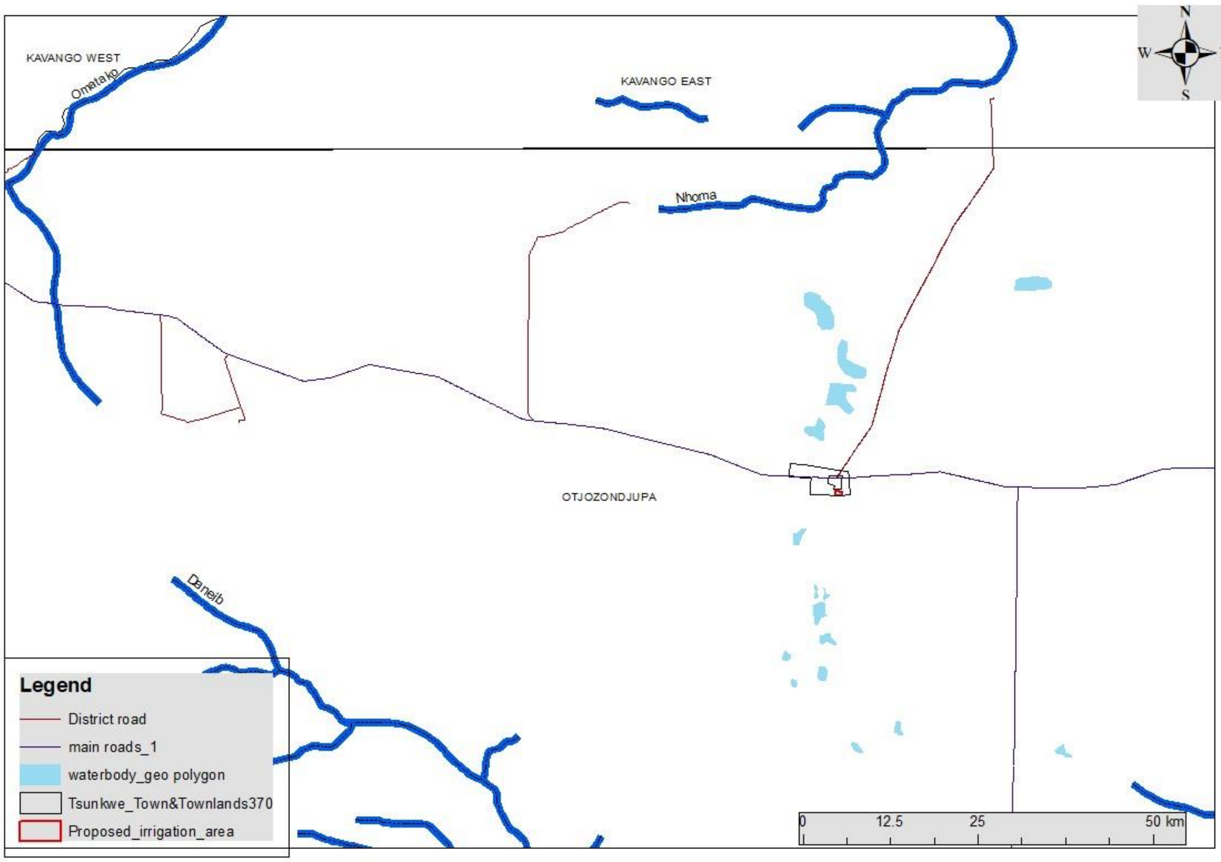

Figure 2: Regional drainage of Tsunkwe area

The area is transected by a poor road network comprised mainly of M74 connecting the area to Grootfontein, which is the main nearest town in Otjozondjupa region. Another gravel road, M113, connects the area to Gam and Eiseb settlements, which are the nearest population centers situated in Otjozondjupa and Omaheke region, respectively, to the south.

3 VEGETATION

The vegetation of the area is dominated by thorny shcrubs, caused by the calcrete deposits as part of the Kalahary group sediments, mixed with trees. This type of vegetation is classified as forest savanah. It extends northeastwards from the woodlands of the sandier territories west of Gam to the south and southwest of Tsunkwe.

4 CLIMATE

The climate of the study area is classified as semi-arid with average temperatures range from 17°C in winter to 25°C in summer. The Maximum temperatures of 30-35°C occur from September to December, minimum temperatures of around 8°C in June. The average annual rainfall ranges between 400mm and 500mm, which occurs mostly during October to March. The average evapotranspiration rates are exceptionally higher than the average rainfall rates, ranging between 2600 and 2800 mm/a.

5 GEOLOGICAL AND HYDROGEOLOGICAL OVERVIEW

5.1 Geological setting

The geology of the area is comprised of basal rocks of the Damara Sequence followed by the Karoo Sequence. The Karoo Sequence is overlain and intruded by the post Karoo volcanics, which are furthermore covered by the cretaceous sediments of the Kalahari Group. The Kalahari Group sediments include the loose sand and while calcretes, which mask off the rest of the geology at and around the worksite.

The basement ridge to the east of the study area (Figure 3) marks the eastern limit of the Kalahari basin, a large depression, which formed due to Cretaceous erosion under extremely humid conditions The base of the Kalahari basin is referred to as the African surface. To the north the basin limit is indicated by the basement high exposed by the Omatako River, while to the west and southwest it is indicated by the irregularities of the African surface (borehole intersections).

The Kalahari basin is therefore deepening westwards, such that the project area is situated on its eastern edge. Deep river systems were incised into the African surface within the present-day Southern Africa. Sediments of the Kalahari succession were deposited onto the African surface (Miller et al., 2017, Lohe and Miller, 2019).

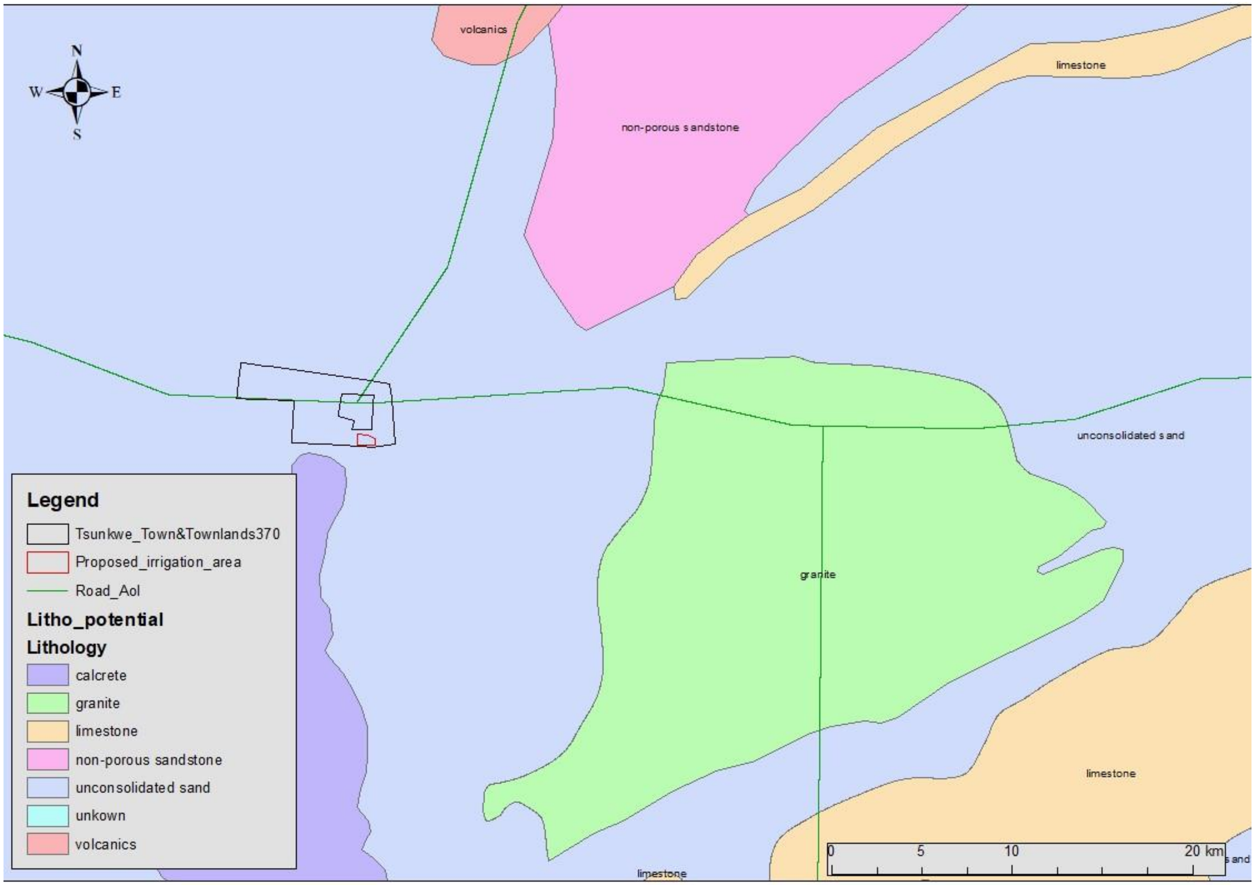

Figure 3: Regional geological setting of Tsunkwe area

5.2 Hydrogeological overview

During the hydro-census information on 10 boreholes within a radius of 10km from project area was obtained from the national database and reviewed for hydrogeological overview (Table 2). As indicated above, the study area falls onto the eastern limit of the basin, where the Kalahari sediment layer is relatively thin and therefore do not provide reliable aquifers.

Palaeovaleys that have been incised into the basement rocks extending beneath the water table consist of sediment load of sufficient thickness, which, if associated with a fracture in the basement, can account for reliable aquifers with moderate groundwater potential locally. The water was believed to be flowing into the sediments through the fractures from the adjacent aquifers and recharge areas, however recharge in the area is limited. Two main aquifer types have therefore been identified, the combination of which have formed the main targets for the ground geophysical surveys.

Table 1: Borehole information within 10km radius

Bh No.	Lat	Long	Drill date	Yield (m3/h)	Location	RWL (mbgl)	Depth (mbgl)	Diameter (mm)
WW16587	-19.58180	20.47830	19/03/1905	12.0	Tsumkwe	15	49.5	150.0
WW27304	-19.61850	20.46250	07/06/1905	5		6		
WW32842	-19.59540	20.50070		10.2	Tsumkwe	6	31.0	168.0
WW34331	-19.61920	20.52000		13.5	Tsumkwe	7.96	42.0	165.0
WW6497	-19.60690	20.50280	16/05/1905	3.3	Tsumkwe	5.2	299.0	150.0
WW7789	-19.58780	20.50120	17/05/1905	5.9	Tsumkwe	10.7	35.0	150.0
WW7790	-19.59270	20.50040	01/01/1964	13.6	Tsumkwe	9.1	37.0	150.0
WW6431	-19.59210	20.50330	01/01/1961	0.2	Tsumkwe	2.4	28.0	150.0
WW32655	-19.59540	20.50070		13.2	Tsumkwe	6.4	20.8	150.0
WW16561	-19.59470	20.50500		7.2	Tsumkwe	6	35.1	150.0

The two main aquifers are (1) the primary-porosity aquifers comprised of sands and sandstones of the Kalahari Group; and (2) secondary porosity aquifers comprised of fractured and weathered pre-Kalahari bedrock. The project area was found to be underlain by rocks with low to limited groundwater potential, but can be of locally moderate potential when structures are accurately located (Figure 4)

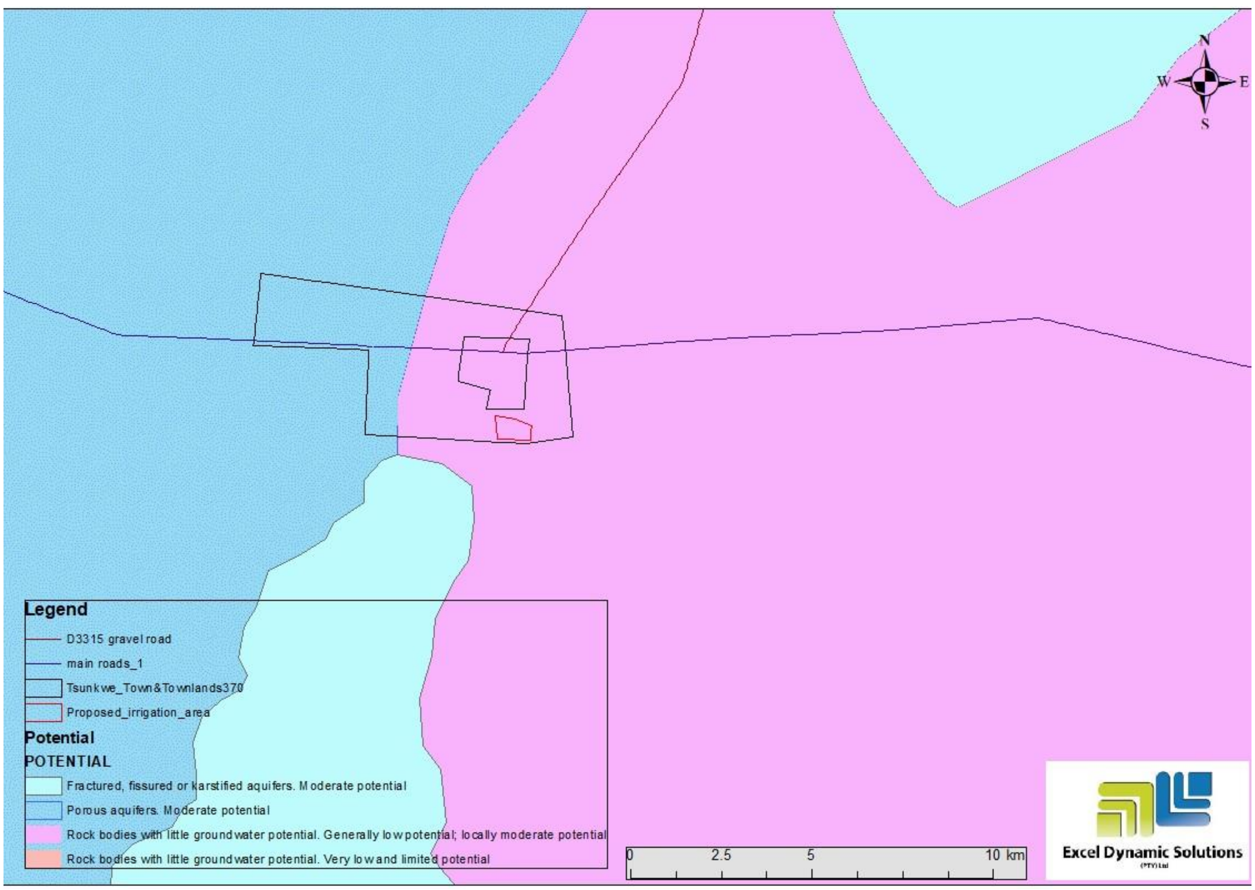

Figure 4: Groundwater potential for the project area

The borehole yields were found to be highly variable, ranging between 0.2 and 12m^3/h. The highest yielding boreholes were drilled into the carbonate rocks of the undulating pre-Kalahari surface. The water quality is good (Group A) to fair where alkalinity and hardness are slightly higher, belonging to group B according to Namibian national standards for drinking water (Figure 5).

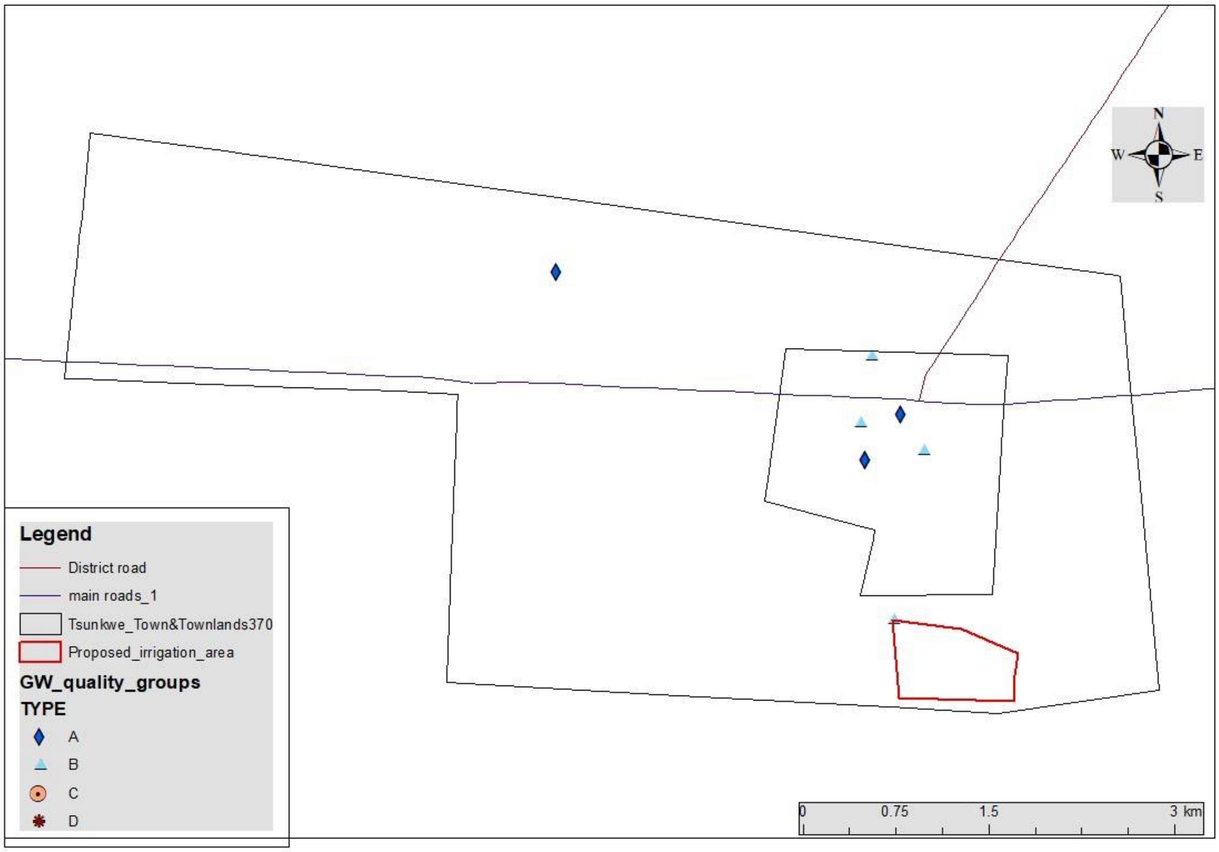

Figure 5: Groundwater type within 5km radius

5.2.1. Groundwater Vulnerability in the area

In order to contribute towards the sustainable use of groundwater resources and protection against contamination and depletion, groundwater vulnerability was briefly assessed. The aquifers are hydrogeologically unconfined with relatively shallow water tables and limited direct rainfall recharge. The project site falls onto the area with low aquifer vulnerability (Figure 6) mainly because of the fractured basement and presence of the clay within the overlying Kalahari sediments, although this does not constitute a confining layer.

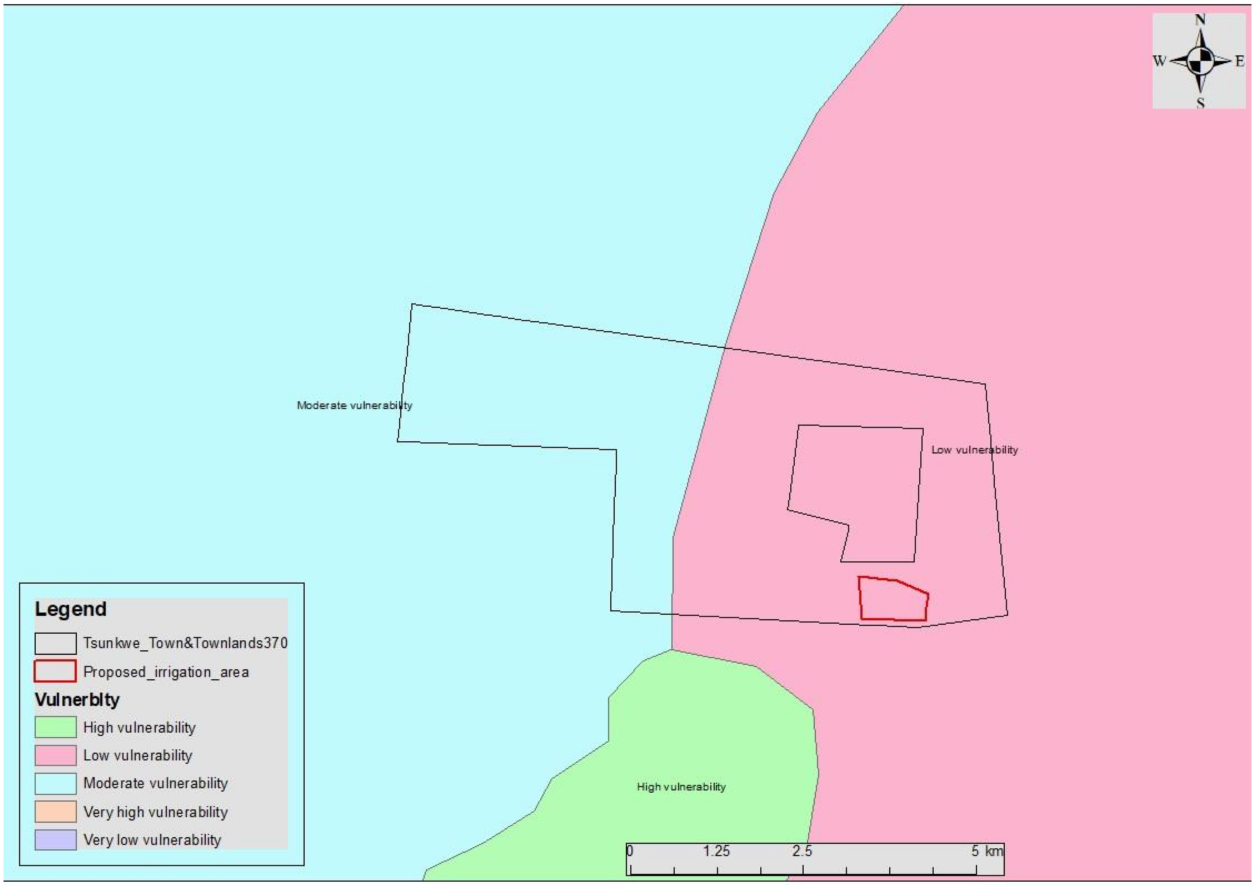

Figure 6: Aquifer vulnerability in Tsunkwe area

6 GEOPHYSICAL APPROACH

Due to the general limitations of the geophysical instruments and the complexity of the subsurface geology, which at the project area is completely masked off by the loose sand deposits of the Kalahari Group, a dual approach was chosen for the field ground geophysical surveys, in order to increase the drilling success rate. The approach involved application of two different geophysical techniques (horizontal loop electromagnetic profiling and magnetotelluric method) to complement one another.

6.1 HLEM Profiling

MaxMin EM instrument was chosen for its fastness in use, and ability to identify vertical conductors identified as deep-seated fracture zones which are the main aquifers in the area. The approach for the field survey work was as follows; 1) lay out survey lines based on orientation of targets 2) carry out HLEM and qualitative interpretation and 3) identify anomaly due to the inferred structure.

The MaxMin EM instrument has the advantage of flexibility over most other EM units in that it can operate with different modes and frequencies as well as having a variety of distances between transmitter and receiver. The transmitter induces an alternating magnetic field (called the primary field) by passing a strong alternating current through a coil. The primary field travels through any medium and if a conductive structure is present, the primary field induces a secondary alternating current in the conductor and this current in turn induces a secondary electromagnetic field.

The receiver picks up the primary field as well as the secondary field if a conductor is present. The fields are expressed as a vector with two components as the in-phase (or real component) and the out-of-phase (or quadrature component). The results are expressed as the percent deviation of each component from what the values would be if no secondary field (and therefore no conductor) was present.

Since the fields lose strength proportionally with the distance they travel, a distant conductor has less of an effect than a close conductor. Also, the lower the frequency of the primary field, the further the field can travel and therefore the greater the depth of penetration. The MaxMin II EM unit can vary the strength of the primary field and so the use different separations between transmitter and receiver coils, and changing the frequency of the primary field for varying depth penetrations, as well as the ability to use different coils orientations to duplicate improves the accuracy of the survey results.

6.2 AMT sounding

An audio-frequency magnetotelluric (AMT) method was applied as part of the ground geophysical surveys to complement the results obtained from the HLEM technique. The AMT profile surveys were set up across the HLEM anomalies in order to assess the depths to and thicknesses of the inferred aquifers. The lengths of the profile surveys were 15-20m, stretching perpendicular to the geological strikes with inter-AMT station separations of 1 m.

The method probes the electrical properties of the subsurface using natural electromagnetic (EM) field as the field source. The electromagnetic fields originate from global lightning or sferics (short period signals) and solar wind activities in the ionosphere (long-period signals). Based on frequency, the natural magnetotelluric fields can be clustered into audiomagnetotellurics (AMT) with frequencies f = 1–10,000 Hz and broadband magnetotelluric (BBMT) with f = 0.001–300 Hz.

In principle, the earth is viewed as a horizontal medium and the magnetotelluric fields as the plane electromagnetic waves are projected vertically onto the ground (earth). When these waves impinge the ground, large proportions of them are reflected, and a small fraction is transmitted into the subsurface. Electromagnetic induction (i.e., the fluctuating magnetic field) causes telluric currents to flow into the subsurface. The magnitude depends on electrical conductivity. Diffusive signal transmission occurs, resulting in signal attenuation/decay as the depth increases.

Low frequencies penetrate to greater depths, and high frequencies are limited to shallow depths. On the ground, orthogonal electromagnetic field components are observed. The frequency response reflects the distribution of the electrical properties of the subsurface medium. The variation of the magnetotelluric field component with time is converted into a frequency spectrum. Magnetotelluric frequency domain responses—such as apparent resistivity and the impedance phase—can be computed.

6.3 GPS Coordinates

All Geographic Positioning System (GPS) coordinates were reported in degree decimal format (dd) using WGS84 Datum. The dd format was chosen since it is the widely used format in Namibia, so that no transformations may be necessary in the proceeding phases of the project.

7 RESULTS

7.1 HLEM line survey

At least three survey lines were pegged and profiled across the project area in north-south and east-west directions (Table 3; Figure 7) to locate possible palaeo-channels that have been incised into the pre-Kalahari surface by means of a Horizontal Loop Electromagnetic (HLEM) technique using MaxMin EM instrument.

Table 2: Survey line coordinates

Line No.	Start		End		Line Length
	Lat	Long	Lat	Long	
1	-19.61387	20.50680	-19.60786	20.50657	750
2	-19.61189	20.50687	-19.61568	20.50649	475
3	-19.61240	20.51055	-19.61062	20.50239	1050
4	-19.61101	20.51201	-19.60913	20.50202	Network tower interference

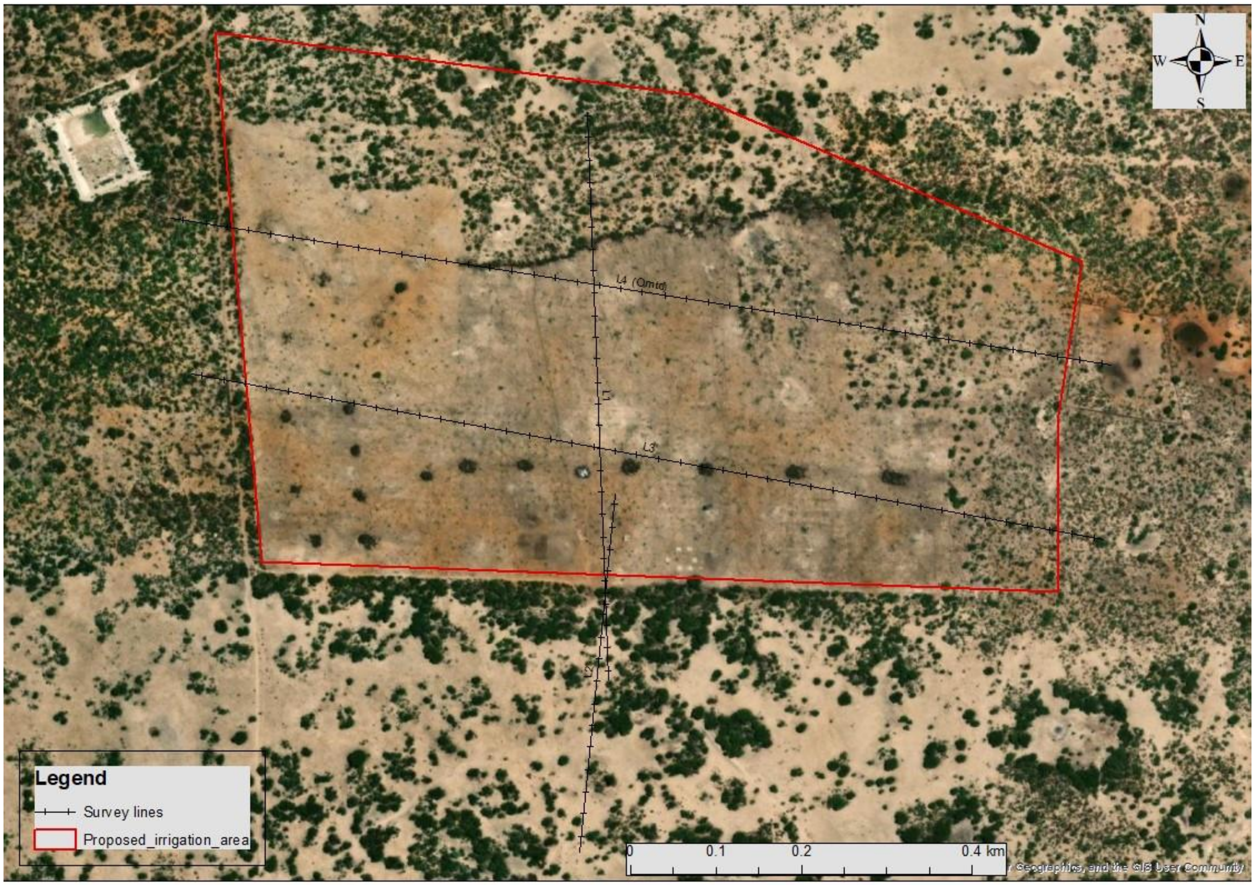

Figure 7: Geophysical survey lines

For all the horizontal loop electromagnetic line surveys the coil separation was set at 150m and sampling intervals at 25m. The quadrature responses were recorded alongside the apparent conductivity responses, which were used to compute the best fit conductivity. Each parameter response was profiled against the distance for qualitative interpretation to identify anomalies and the associated conductors (aquifers).

7.1.1. Line 1

The first line, line 1, was started in and before the center of the anomaly as observed from both low and high frequencies (Figure 8).

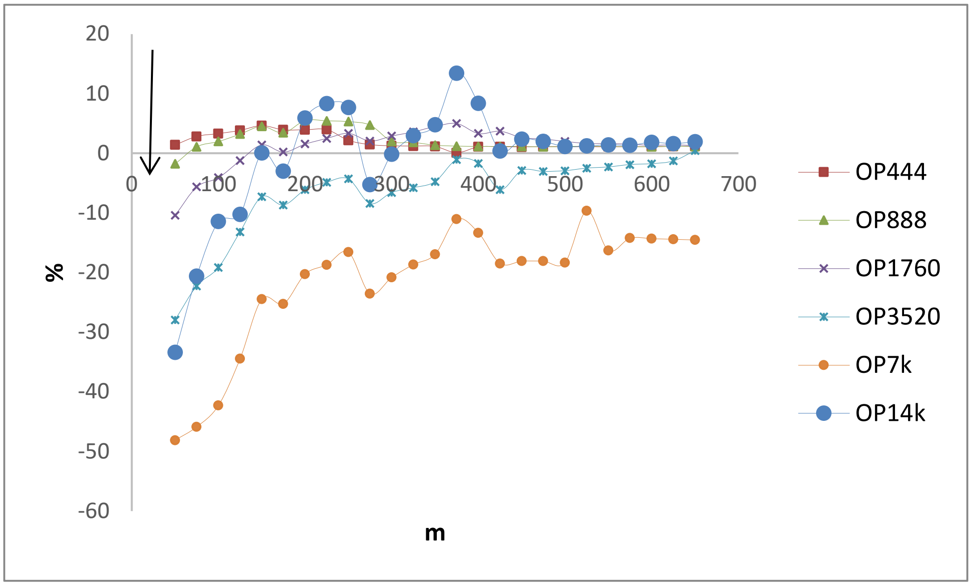

Figure 8: Q responses for Line 1

The best-fit-conductivities were computed for each sampling station and the signature similarly indicated that the line was started just before the center of the anomaly (Figure 9).

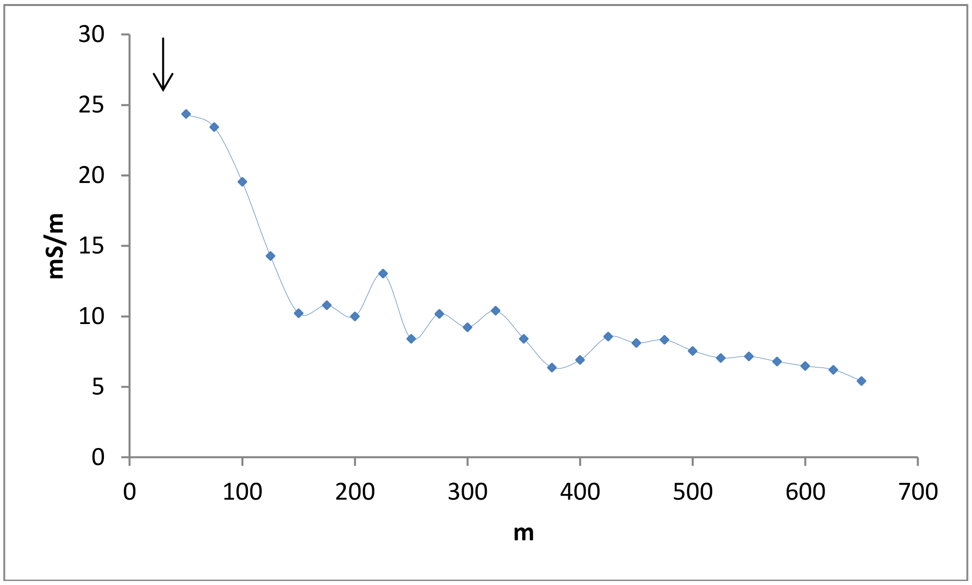

Figure 9: BFC for Line 1

A supplementary line was therefore pegged and profiled in an opposite direction (south), starting outside the anomalous region of line 1, parallel to/coinciding with line 1, so that the inferred anomaly is transected.

7.1.2. Line 2

The center of the anomaly was located at sampling station 200m from the start of the line, which is approximately 50m before the first sampling station on line 1 (Figure 10).

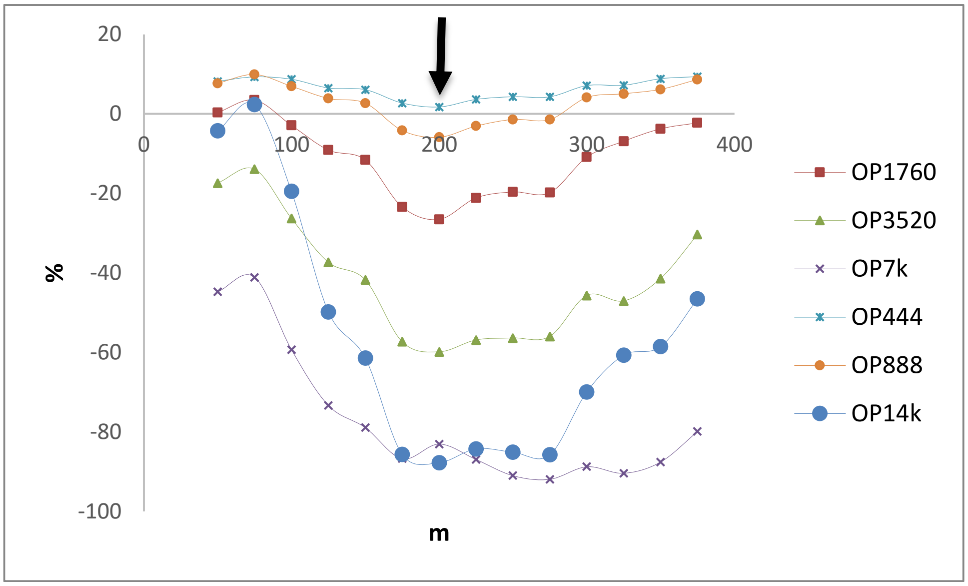

Figure 10: Q responses for Line 2

The best-fit-conductivity was also calculated, and the results have indicated an anomaly within the same region (Figure 11) indicated on quadrature profile.

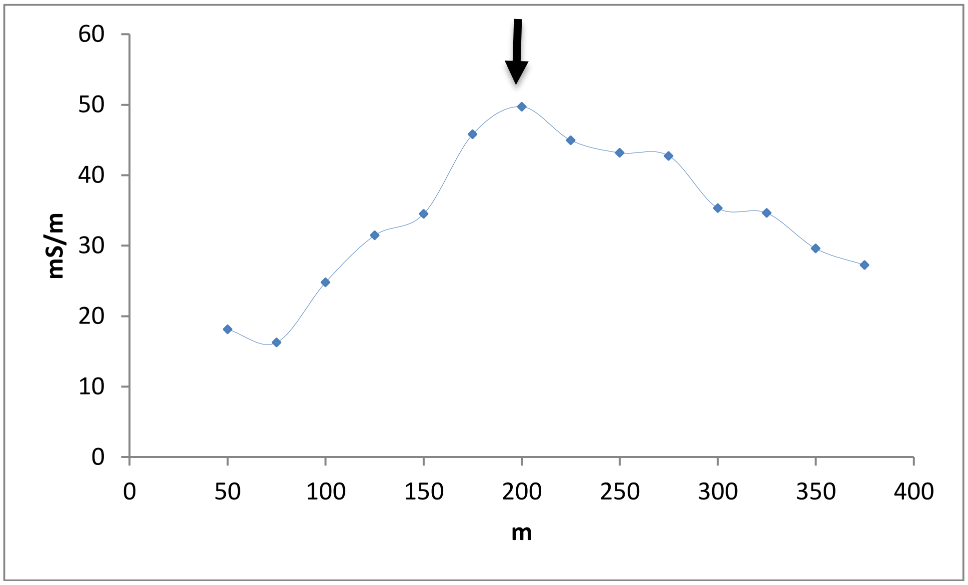

Figure 11: BFC for Line 2

The calculated BFC values increased notably across the anomalous region, which indicative of some degree of saturation, and hence an aquifer has been inferred. The depth and thickness was estimated using AMT sounding (Section 7.2).

7.1.3. Line 3

The 3rd HLEM survey line, L3, was pegged and profiled in the E-W direction through the length of the cleared field earmarked for the proposed irrigation. Similar to line 1, line3 was also started in an anomaly but luckily within the center (Figure 12)

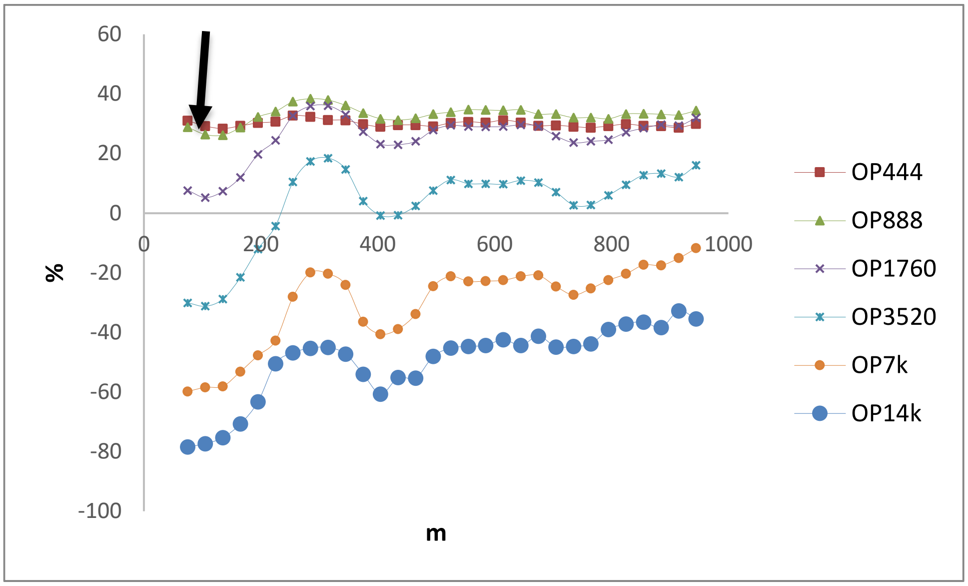

Figure 12: Q responses for Line 3

The quadrature responses of the lowest and hence the deepest frequencies resolved the basement, while the high (shallower) frequencies indicated stratification typical of the Kalahari Group. Since the deeper frequencies also indicated anomaly in the basement, it can be concluded that the anomaly is due to a deep-seated structure associated with wedge (palaeo-valley). Channel conductivities of individual frequencies responded with increased values across the anomaly, and so it the Best-Fit Conductivity (Figure 13).

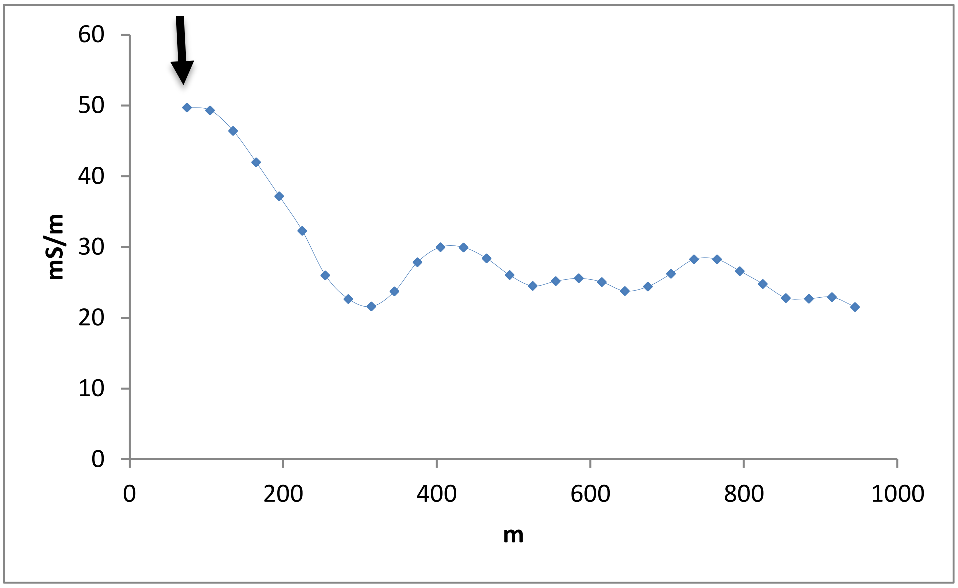

Figure 13: BFC for line 3

A fourth HLEM survey line was set up with the same configulation as the first three but with only the lowest three frquencies as the team ran out of batteries for power supply to the receiver, and the instrument was heavily affected by a nearby telecomunicaticaion network tower.

7.1.4. Line 4

In order to identify the strike of the line 3 anomaly line 4 was made parallel to line 3, as there was no space to extent the survey eastwards. Upon cleaning the aquired data again the external interference, the qualitative interpretation indicated an anomaly with a similar signature as that of line 3 (Figure 14).

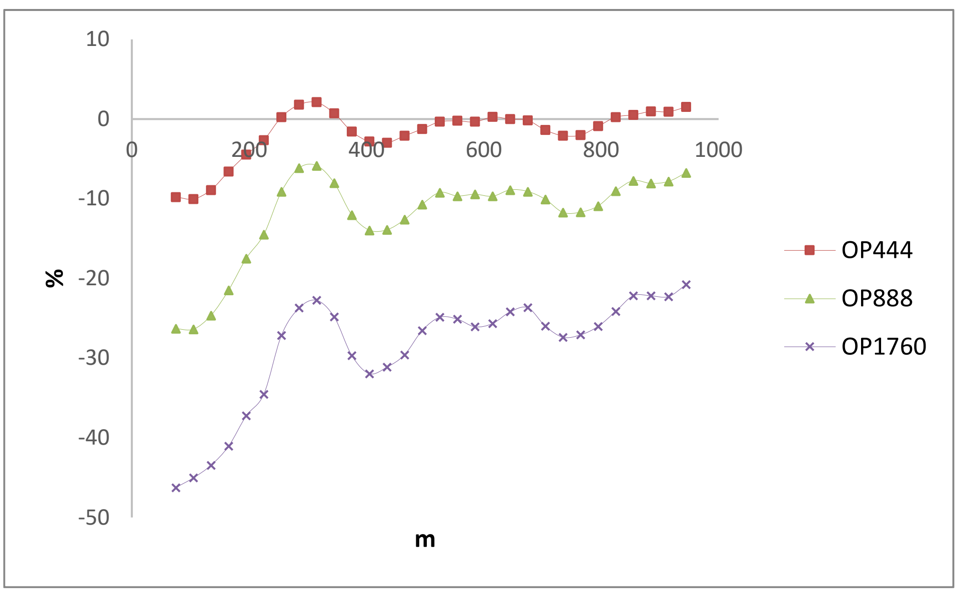

Figure 14: Q responses for line 4

The channel conductivities of the three individual frequencies were profiled against distance to confirm the quadrature anomaly (Figure 15). It is clearly observed on the two plots that the subsurface formation is stratified more than on line 3.

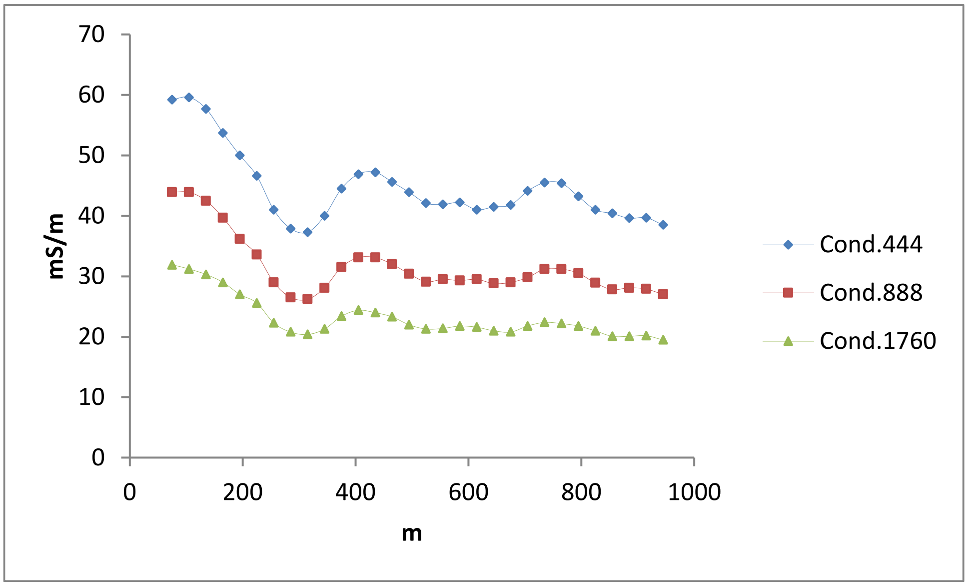

Figure 15: Channel conductivities for line 4

The anomaly was identified as a conductive wedge with a N-S strike. As indicated above the pallaeochannel is fracture dependent and therefore the fracture bears the same strike, which conforms with the Damara Orogen of Neoproterozoic era.

7.2 Magnetotelluric survey

AMT profile surveys were conducted to resolve the vertical electrical variation of the subsurface in order to estimate the depths and thicknesses of the inferred aquifers. The first AMT survey was profiled across the existing borehole. There is no documented information on the existing borehole. It seems to have been used as there are marks of past pumping installation. It is furthermore an old small diameter borehole that is now blocked with surface material to almost the ground surface. It is therefore assumed to have collapsed while in use or pumping equipment were dropped and the users failed to fish them out.

The aquifer was intersected between approximately 45mbgl to approximately 145mbgl (Figure 16). The aquifer is inferred from blue colour coding associated with low electrical resistivities within the subsurface.

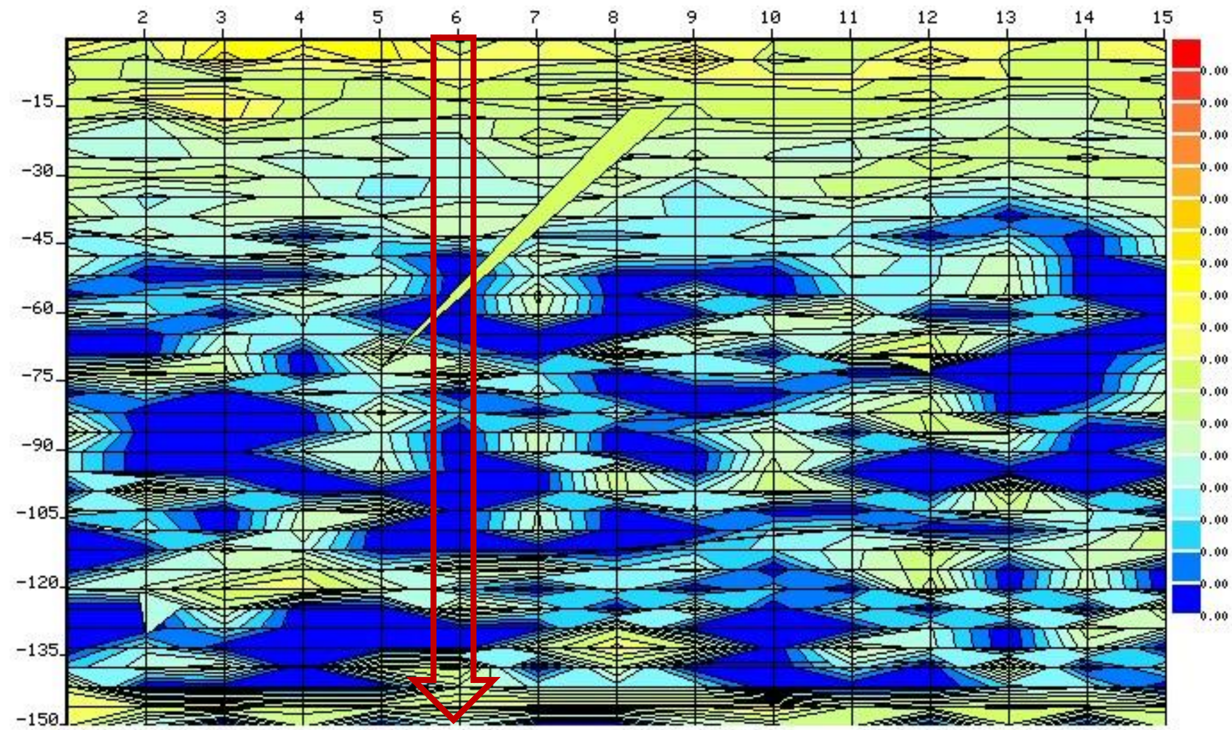

Figure 16: AMT profile survey line1 across existing borehole

The 2nd AMT survey was profiled through the anomaly at 200m on line 2. A high-resistivity top layer, overlays the low-resistivity layer, inferred as the aquifer material between 15 and 90 mbgl (Figure 17).

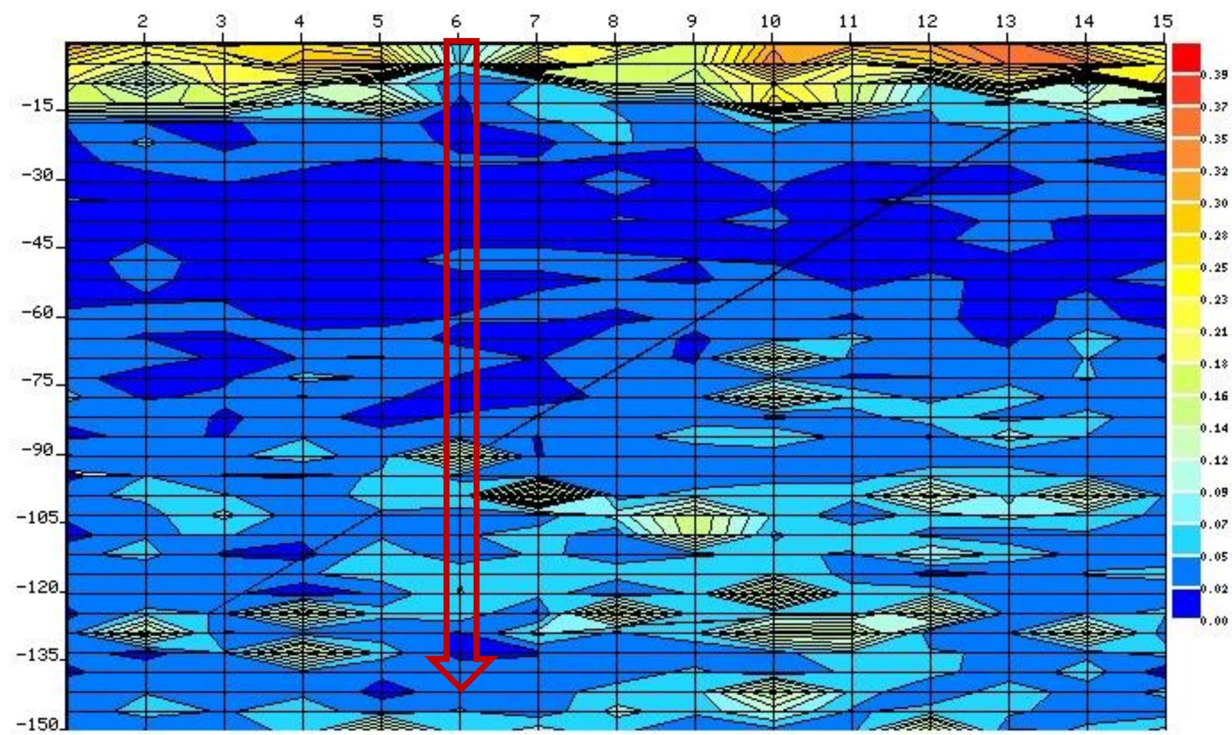

Figure 17: AMT profile survey line2 through 200m station on HLEM line 2

The 3rd AMT survey was profiled through the anomaly at 75m on line 3. A high-resistivity top layer, overlays the low-resistivity layer, inferred as the aquifer material between 45 and 145 mbgl (Figure 18).

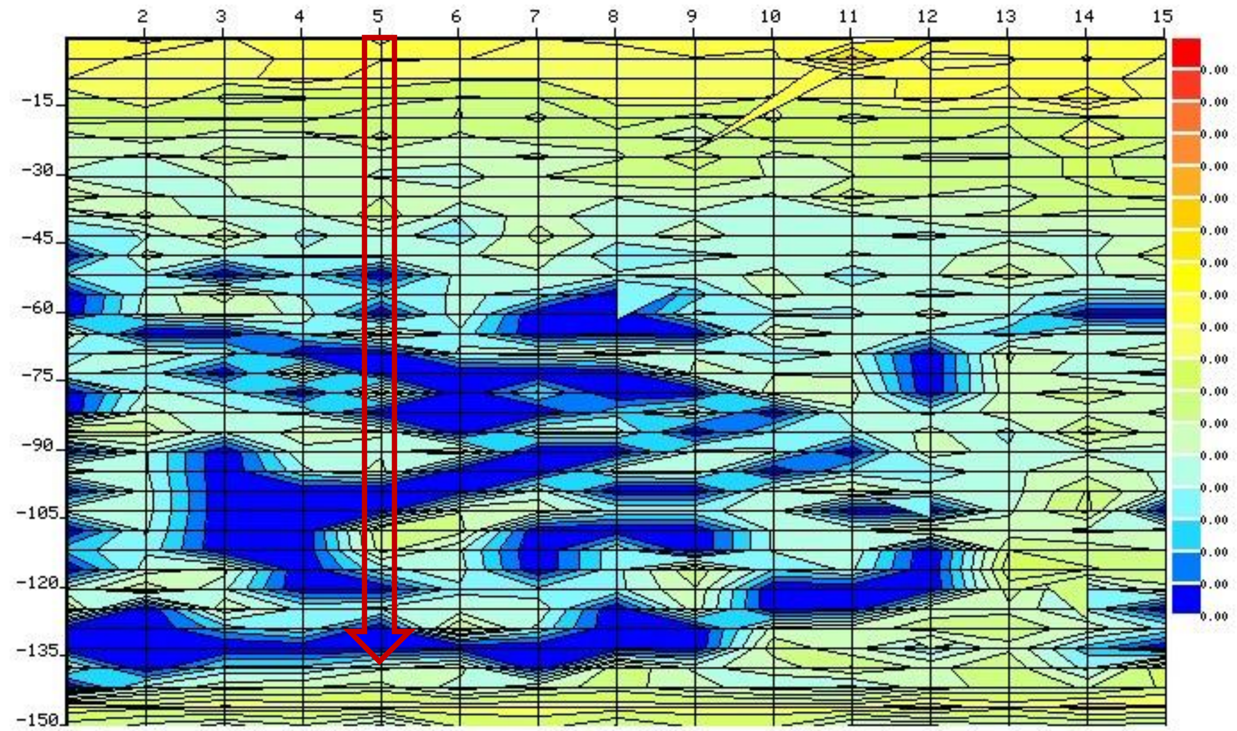

Figure 18: AMT profile survey line3 through 75m station on HLEM line 3

Upon determining the depths and thicknessed of the aquifer layers, the drill sites for the proposed boreholes have been pegged as indicated by red downward arrows in figures 16 – 18.

7.3 Borehole Drill Sites

At least three drill sites have been selected, pegged and shown to the representatives of the project development and implementation partners, Tsunkwe Village council, Otjozondjupa Regional Council, and UN World Food Program, Namibia. The sites were selected at n=5 on AMT profile survey line 1, at 200m on HLEM line 2/n=5 on AMT profile survey line 3, and at 75m on HLEM line 2/n=5 on AMT profile survey line2 (Figure 19). The coordinates were recorded as presented in table 3, listed in order of priority.

Table 3: Coordinates of the selected drill site

Site number	Site Location	
	Latitude	Longitude
Site 1	-19.6126	20.51114
Site 2	-19.6128	20.50695
Site 3	-19.6137	20.50685

Figure 19: Sites selected for the drilling

The drill sites have been prioritized based equally on both HLEM and AMT results. Groundwater occurs in fracture mainly in the project area. The strikes and general orientations of the structures targeted by selected drill sites 2 and 3 are different and hence the well interference during production is expected to be minimal.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The project area is of little/low groundwater potential, which can be moderate, locally, if structures are accurately located. The drill site selection was based mainly on geophysical results, for which the survey lines were designed cross-cut the subsurface structures, which were the only targets in the Damara basement. The structures are locally masked off by sediments of Cenozoic Kalahari cover. The anomalies were interpreted as conductive wedges (buried palaeochannels). It should be noted that geophysical techniques do not detect water physically in the subsurface but collect and interpret data on physical properties. The techniques are therefore merely meant to increase the chances of successful drilling.

8.2 Recommendations

It is recommended that:

- intersected aquifers be fully penetrated and screened,
- grain size analysis be conducted during the drilling to install the correct size of the filter pack
- borehole license be obtained before drilling as per the provisions of the Water Resources Management Act, Act No. 11 of 2013 (as the proposed boreholes are not for domestic water supply purposes)
- drilling be conducted under supervision of a qualified hydrogeologist,
- final drill depths be based on field lithological conditions during the drilling process,
- boreholes be constructed as per the designs proposed in figures 20 and 21. Diameters may be changed to meet the other civil design requirements.
- if the borehole is not dry, it should be sufficiently developed in order to remove the fines and fumes that may have been produced or used during the drilling process. A borehole development report must be fully completed. A complete pumping test should be conducted consisting of step draw-down test (SDT), constant discharge test (CDT) and recovery tests (RT). The SDT should be at least four (4) steps each of which is at least one hour long, CDT at least 48 hours and the RT should be as long as the duration of the preceding pumping or until at least 95% of the total drawdown has been recovered; whichever comes first. Test pumping data sheets must be fully completed and signed by the supervising hydrogeologist. A water sample, at least one (1) litre, must be collected at the end of the CDT and taken to a registered laboratory for chemical analysis to determine the water quality,

Table 4: Drilling recommendations

Selected drill site	Depth (m)	Recomm method	diam (mm)	Casing	Back filling
1	140	Air percussion	165	Steel (6m), UPVC (~100m)	gravel pack when necessary
2	150	Air percussion	165		
3	120	Air percussion	165		

- drilling be done using air percussion with an ability to switch to mud rotary should the need arise
- the drill chip samples, drilling record, completion report, and results of the pumping tests and all other information must be submitted to Division of Geohydrology, DWA.

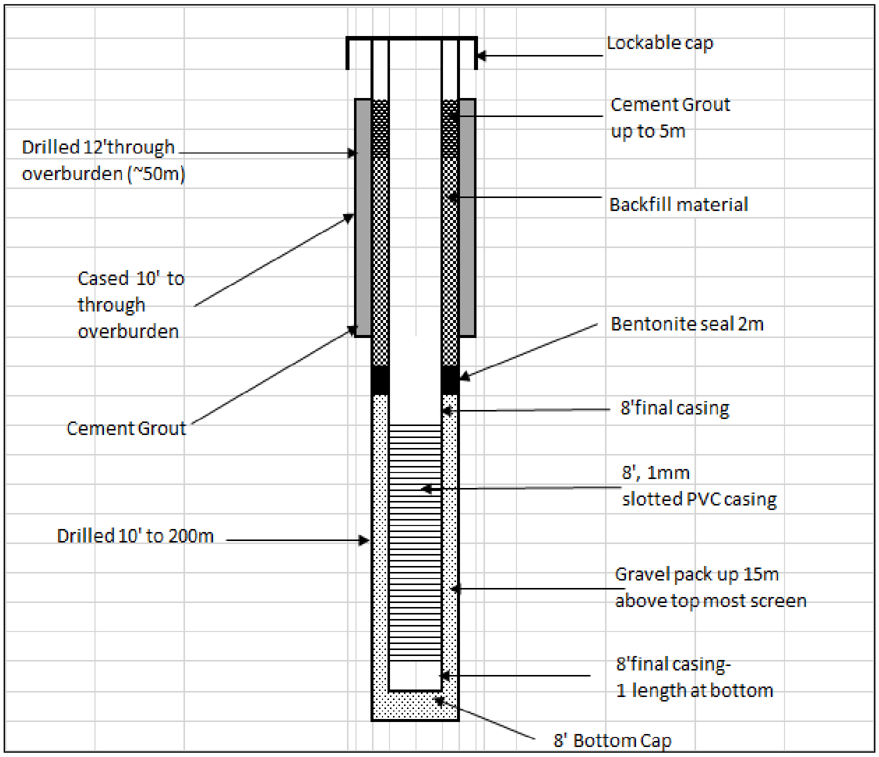

Figure 20: Proposed borehole design in Karoo and semi-consolidated rocks

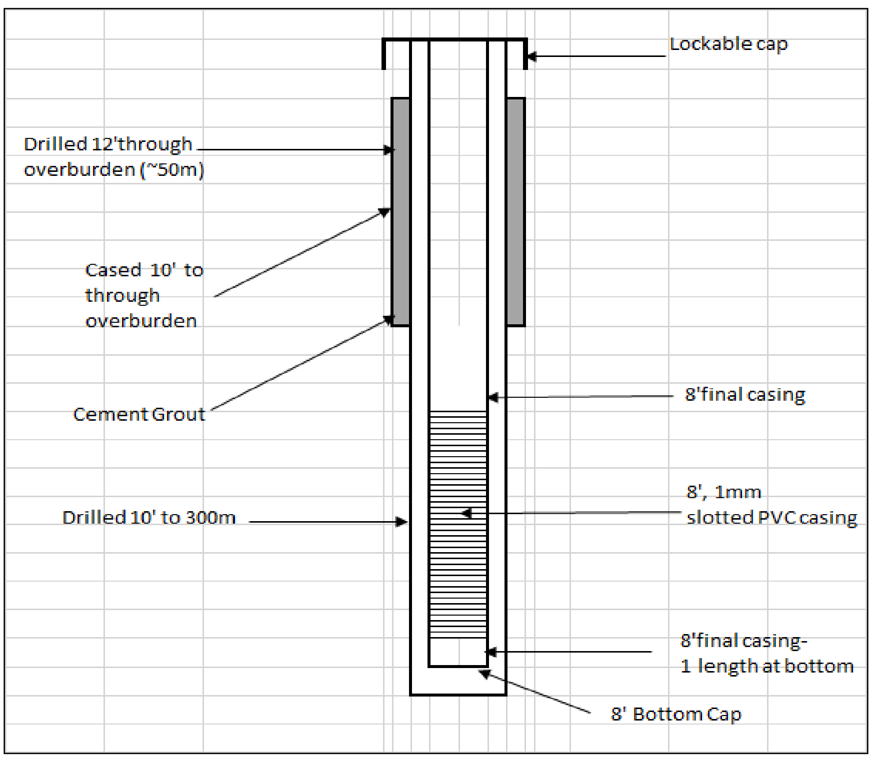

Figure 21: Proposed borehole design in hard rock Formations

9 LIST OF REFERENCES

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