Ref No: 2024/006/1

HYDROGEOLOGICAL AND GEOPHYSICAL SURVEY REPORT FOR ONE PRODUCTION BOREHOLE AT MBOLOLO WARD, VOI CONSTITUENCY, TAITA TAVETA COUNTY

PROJECT: INSTITUTIONAL WATER SUPPLY

Cover illustration: Geophysical Exploration at The Site

Consulting Firm:	Client
Bostec Drilling Limited **P.O Box 2702** **Mombasa-Kenya,** **Tel: (+254) 753324828)** info@bostec.africa	**VOI NG-CDF BOARD OFFICES** **P. O BOX 168-80300,** **VOI-KENYA** **0729548867**

COMPILED BY: REGISTERED GEOLOGIST: LUCAS JOHN SHUMA

CHECKED AND REVIEWED BY: LESLIE DULLO
REGISTERED HYDROGEOLOGIST

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Executive Summary

Introduction

This report describes the results of hydrogeological and geophysical borehole site investigations on a parcel of land located in Mwakingali village, Voi Constituency, Taita Taveta County. The aim of the investigations was to locate a suitable a Hand dug or a borehole drilling site within her parcel of land. To accomplish this, detailed hydrogeological and geophysical investigations were executed.

The study focused on availability of fresh groundwater in sufficient quantity for domestic and general-purpose use within the premise.

Climate

Most of the area is part of the semi-arid land.

Geology and Structures

The site lies within undifferentiated basement rocks dominated by hornblende biotite gneisses rocks. The area has in parts fairly simple structures due to the superimposition of minor folds and contortions on the major folds. Past drilling experience in area, shows that fairly good groundwater resources can be expected where there are natural channels (such as underground Rivers, and recharge from the adjacent Mountains such as Sagalla Hills & Seasonal streams such as Voi River) and storage basins in the weathered zone, such as are formed where barriers of compacted 'unweathered' rock cross otherwise deeply weathered valleys, or within deep faults and fractures of the basement rocks. The area lies adjacent to Voi River.

Hydrogeology

The major water bearing formations in the area are as follows: weathered basement rocks, fractured basement rocks, faulted zones in the intrusive succession, contact zones between the metamorphic successions.

Geophysical Fieldwork

Geophysical measurements were used to determine the thickness of the underlying layers, their potential as aquifers. Vertical Electrical Sounding method was executed at the site with the view of determining the resistivity structure to a depth of **500** M by Using PQWT TC 500 SERIES and ultimately unveils the hydrostatigraphy of the surveyed area.

Conclusions

The study concludes that, on the basis of hydrogeological evidence, groundwater prospects in the study area are inherently low due to the Medium fractured Intrusive and preponderance of natural precipitation. Moreover, the resistivity structure depicts a more suitable site with a likely hood of intercepting aquifers at depths exceeding 55M, and a possibility of intercepting a perched aquifer **(albeit ephemeral)** at shallow depths however more sustainable and high yielding aquifer can be struck at greater depths. In addition, records of neighboring boreholes give yield in the range of 1 to 15m^3/hour with depths spanning between 40m to 180 m bgl.

Recommended Drilling Location for the Investigated Sites

In view of the geophysical results and hydrogeological nature of the surveyed area, it is recommended a borehole be air drilled at **PROFILE 1 POINT 3 (E 451333.00 N 9625434.00 Alt 538M ASL)** of this site to a **maximum depth of 200m** meters bgl and a possible **minimum of 180 m**. It is imperative to note that the yield increases with progressive depth as deeper lying aquifers are penetrated as guided by Geologist.

A summary of all the investigations done and the recommended drilling site are given below: -

No. of Profiles Done	Recommended profile point at	Min Depth (m)	Max Depth (m)	Groundwater Prospects
2	Profile 1- point 19	180	200	Fair to Good

The point at profile 1 point 19 was pegged with the respective numbers clearly written during the field investigations. The profile station coordinates were obtained using Global Positioning System (GPS) and were shown to the client's representatives at the sites. The recommended site was pegged using a peg.

Monitoring

Regular monitoring should be instituted and maintained in the boreholes in order to keep track of groundwater levels. A monitoring tube should be installed in the borehole to be able to monitor the water level in the borehole.

Borehole Construction

Recommendations are given for borehole construction and completion methods. The importance of correct and comprehensive techniques in this particular aspect cannot be over-emphasized.

Drilling Permits

A drilling permit must be applied from the Water Resources Management Authority Regional office under the Ministry of Water and Irrigation.

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List of abbreviations

"	Inch
µS/cm	Micro-Siemens Per Centimeter: Unit for Electrical Conductivity
Agl	Above Ground Level
AMT	Audio-Magneto telluric
Asl	Above Sea Level
bgl	Below Ground Level
E	East
EC	Electrical Conductivity (µS/Cm)
GDC	Geothermal Development Company
hr	Hour
M	Metre
N	North
PWL	Pumped Water Level
Q	Discharge (M^3/Hr)
S	Drawdown (M)
S	South
SWL	Static Water Level
T	Transmissivity (M^2/Day)
W	West
W	Water Struck Level

Glossary of Terms

Abstraction	Means removal of water from any water source, either permanently or temporarily.
Airline	Means the tube installed in a borehole or well for the purposes of measuring water level.
Alien species	Means any exotic non-indigenous life forms originating from outside a given ecological location
Alluvium	General term for detrital material deposited by flowing water
Alteration	Means any physical change in the depth, diameter, casing, screen or any other structural change in an existing borehole, or any consequent change in the Permit yield as a result of an approved variation
Analysis	Means the testing or examination of any matter, substance or process for the process for the purpose of determining its composition or qualities or its effects (weathering by physical, chemical or biological) on any segment of water or examination thereof.
Aquifer	A geological formation or structure which bears and transmits water and which may supply water to wells, boreholes or springs.
Artificial Ground Water Recharge	Means the intentional augmentation of ground water resources by directly improving the infiltration of water to a target aquifer through the construction of suitable recharge structures.
Authority	Means the Water Resources Management Authority established under Section 7 of the Act,
Colluvium	General term for detrital material deposited by hill slope gravitational processes, with or without water as an agent. Usually of mixed texture
Confined aquifer	A formation in which the groundwater is isolated from the atmosphere by impermeable geologic formations. Confined water is generally at greater pressure than atmospheric, and will therefore rise above the struck level in a borehole.
Fault	A larger fracture surface along which appreciable displacement has taken place.

Gradient	The rate of change in total head per unit of distance, which causes flow in the direction of the lowest >head.
Hydraulic head	Energy contained in a water mass, produced by elevation, pressure or velocity.
Hydrogeological	Those factors that deal with subsurface waters and related geological aspects of surface waters
Infiltration	Process of water entering the soil through the ground surface.
Joint	Fractures along which no significant displacement has taken place
Percolation	Process of water seeping through the unsaturated zone, generally from a surface source to the saturated zone.
Permeability	The capacity of a porous medium for transmitting fluid.
Phenocryst	Large, conspicuous crystals in porphyritic rocks (i.e., rocks with visible mineral crystals in a generally fine groundmass).
Piezometric level	An imaginary water table, representing the total head in a confined aquifer: it is defined by the level to which water would rise in a well.
Porosity	The portion of bulk volume in a rock or sediment that is occupied by openings, whether isolated or connected.
Pumping test	A test that is conducted to determine aquifer and/or well characteristics
Recharge	General term applied to the passage of water from surface or subsurface sources (e.g. rivers, rainfall, lateral groundwater flow) to the aquifer zones
Static water level	The level of water in a well that is not being affected by pumping (a.k.a. "rest water level")
Transmissivity	A measure for the capacity of an aquifer to conduct water through its saturated thickness (m^2/day).
Yield	Volume of water discharged from a well.

1.0 INTRODUCTION

1.1 Introduction

Consulting geologist under the auspices of BOSTEC DRILLING LIMITED was commissioned to carry out a hydrogeological survey on his parcel of land located at Mwakingali village, Voi constituency located in Taita Taveta County.

The Client requires detailed information on the availability of groundwater to be used for domestic use and general purposes in the premises at least $20M^3$/Day.

The objective of the present study is to assess the availability of groundwater, to recommend a drill-site and to comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality.

1.2 Objectives

The objective of the present study is to assess the availability of groundwater, based on the hydrostatigraphy depicted from geophysical signatures, with the view of ultimately recommending the best target drill-site. In addition, the purpose of this hydrogeological investigation was to recommend on the appropriate depth of abstraction of potentially sustainable aquifers, and comment on possible expected yields as well as the possible water quality to be expected. It therefore follows that, all the available hydrogeological information of the surveyed area has been analyzed, and a geophysical survey has been carried out.

1.3 Background

The objective of the investigations was to assess the availability of groundwater and to advice on the viability of drilling boreholes or other water supply alternatives. The investigations involved hydrogeological, geophysical field investigations and a detailed desk study in which the available relevant geological and hydrogeological data were collected, analyzed, collated and evaluated within the context of Client's requirements. The data sources consulted were mainly in four categories:

a) Published Master Plans, Geological and Hydrogeological Reports and Maps, etc.
b) Ministry of Water and Irrigation (MoW&I) Borehole Completion Records, usually a valuable source of data.
c) Various technical reports of the Rural Domestic Water Supply and Sanitation Programme, BKH Consulting Engineers.

1.4 Approach of hydrogeological investigations

The study is carried out the in the following steps

- Review of drilling history and lithological logs
- Desk review of the existing hydrogeological, hydrological and other relevant data of the area.
- Ground geophysical surveys at the site, using geo-electrical profiling and vertical electrical sounding methods.
- Assessment of the prospects of groundwater development in the selected site, and the feasibility of drilling a borehole.
- Selection of the most suitable location for borehole drilling, considering the prospects of sustainable abstraction, water quality parameters and social aspects.
- Determine the required drilling depth, expected yield and water quality. Recommend on the expected chances of success, drilling specifications and designs, testing requirements, and completion details.

2.0 BACKGROUND INFORMATION OF THE SURVEYED SITE

2.1 Location

The site is located approximately 138M from Voi Prison.The area has a good navigating road network which can be accessed even during harsh seasons.

Figure 1: Digitised satellite image showing site location

2.2 Vegetation

The area with proposed project is partially developed; it covered with natural vegetation area dominated by brown and green grass and medium trees of which most are natural trees.

Figure 2: Photograph showing vegetation of the area.

2. 3 Climate

Most of the area is part is semi-arid plain land.

The climate of Voi area is classified as semi-arid to arid, with fairly hot temperatures. The average annual rainfall decreases towards the north-northeast, decreasing 700 mm. The average annual potential evapotranspiration ranges from 1700 to 2000 mm. It is thus evident that there is a persistent deficit of rainfall in the area, which explains why there are no permanent surface water features.

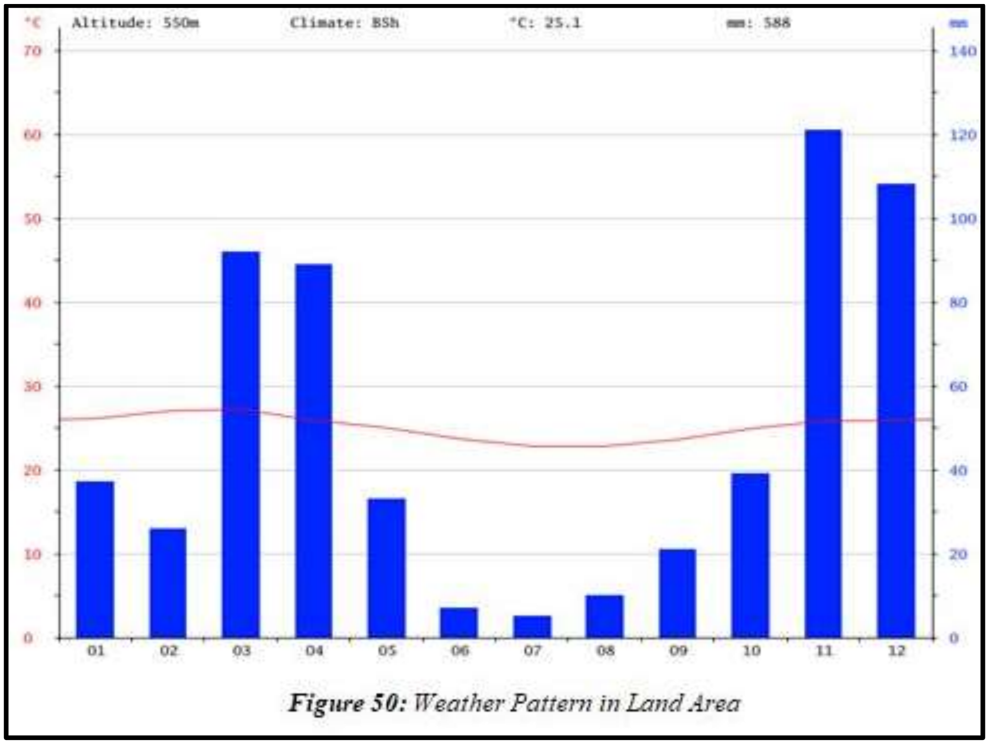


Figure 3: Graph showing the climate of the area.

2.4 Water Supply and Demand

The area depends on Water supplied water from Tavevo Water and Sewerage Company forms a major source of water and rainfall.

2.5 Topography

The investigated area comprises a rolling peneplain of low relief, with an altitude of 538Masl. The configuration of this end-Tertiary surface is strongly influenced by the underlying geology, deviations from a flat surface being an expression of contrasting resistances to erosion of the hard-metamorphic rocks. Local topography is well captured in the map below: -

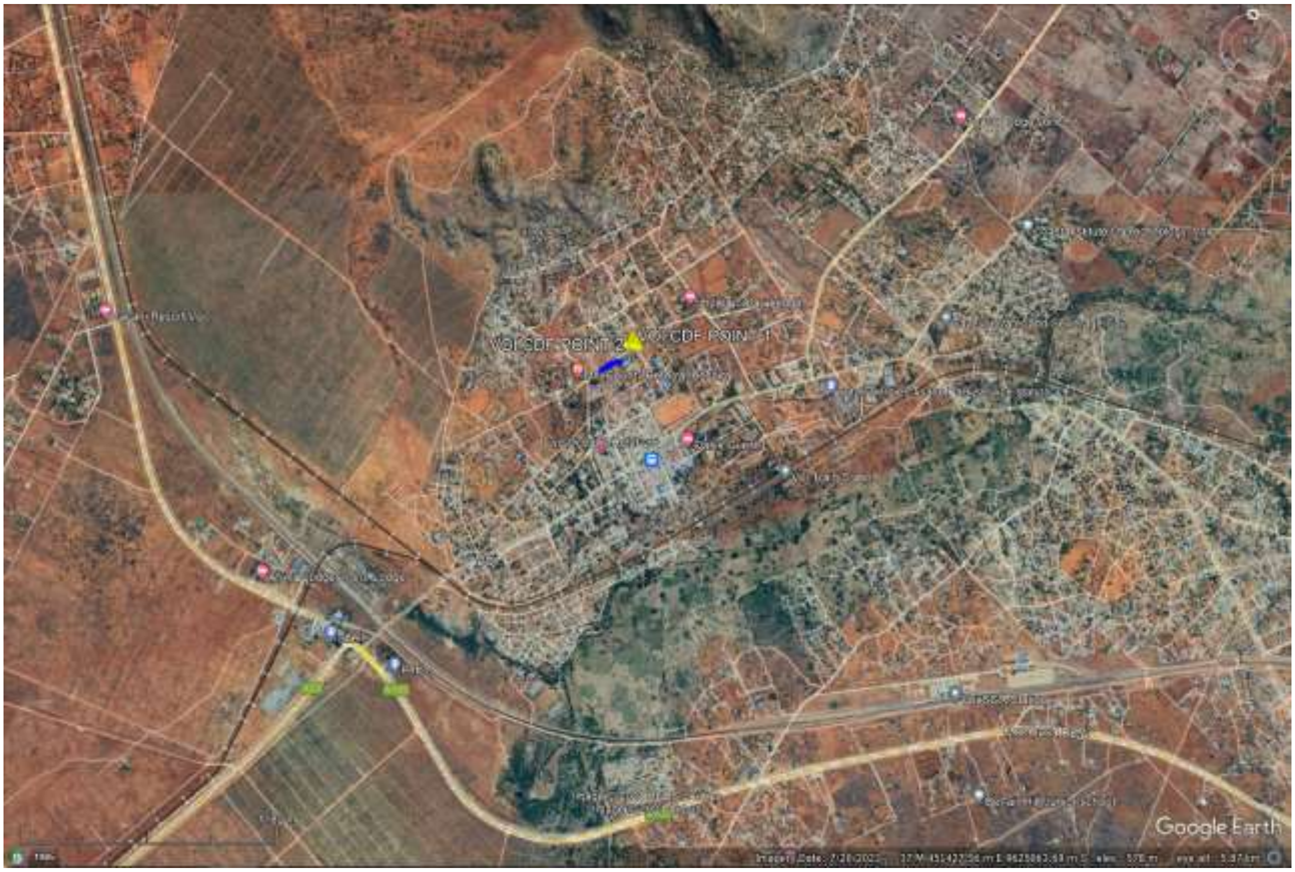


Figure 4: Topography of the study area

2.6 Soils

The study area is covered by red soils. Facies of brownish to reddish brown soils widely distributed.

2.7 Drainage

The area is drained by numerous tributaries all flowing in a southeasterly direction towards Voi River.

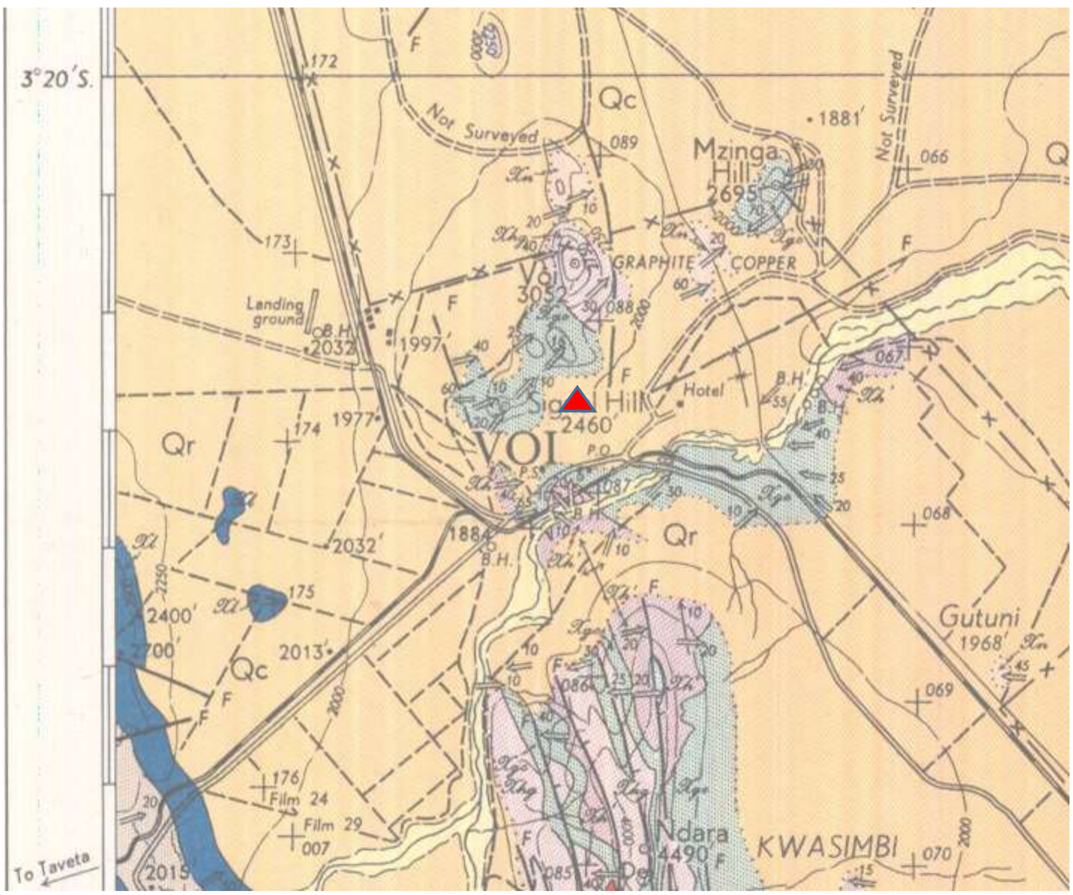
3.0 GEOLOGY

3.1 Local Geology

This Section examines the geology of the area to some detail based on studies done Walsh, (1955) who has mapped the area and has studied its geology to some detailed.

Walsh, (1955), shows that the site lies within **undifferentiated basement rocks** (Denoted as Xn) dominated by Granitoid gneisses and biotite-garnet gneisses of the Archean Age. The area has in parts fairly simple structures due to the superimposition of minor folds and contortions on the major folds. Past drilling experience in area, shows that fairly good groundwater resources can be expected where there are natural channels (such as parts of Voi River) and storage basins in the weathered zone, such as are formed where barriers of compacted 'unweathered' rock cross otherwise deeply weathered valleys, or within deep faults and fractures of the basement rock.

<u>GEOLOGICAL MAP OF THE STUDY AREA</u>



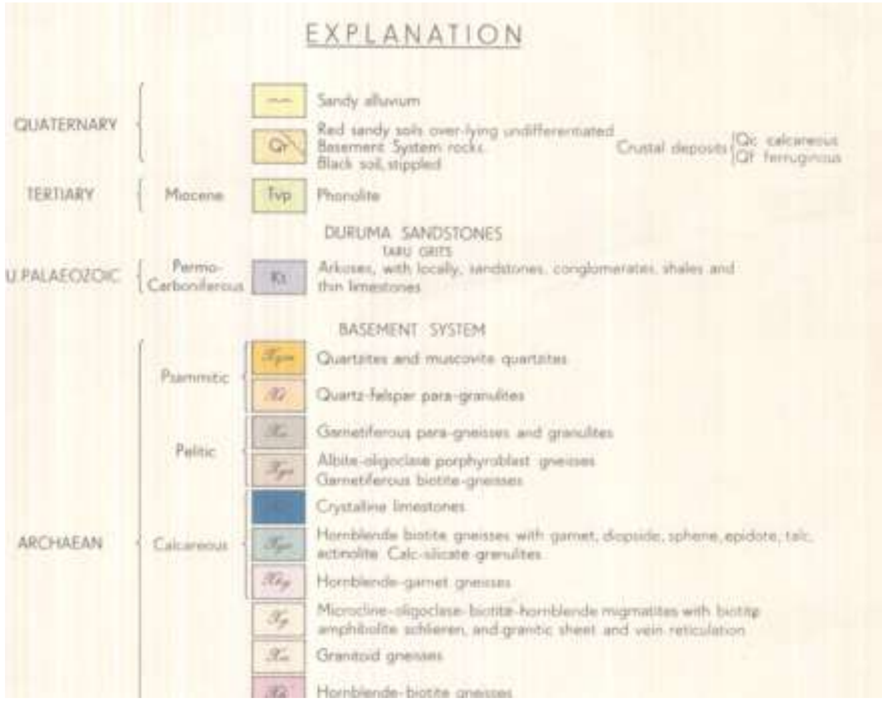


Figure 5: Regional Geological map enclosing the study area

3.2 Regional Geology

3.2.1 Superficial Deposits of Pleistocene to Recent Age

Superficial deposits in the area comprise reddish brown Soils denoted as Qr.

3.2.2 Mozambique Belt

The geology of this area is described in "**Geology of South of Taita Hills Area"** (Saggerson 1962)" The area is exclusively underlain by metamorphic rocks of the Precambrian Basement System, which along the floodplain of Voi River are covered by Pleistocene to Recent alluvial deposits. Outcrops of the Basement System are mainly observed at the inselbergs and kopjes; the rest of the area is covered by relatively thick soils, and occasional colluvial and alluvial deposits. The Maungu Hill towards the southeast is formed by migmatites with pelitic (fine-grained) host rocks. Towards the south on Nyangala Hill and at smaller outcrops, graphite and biotite gneisses are the dominant rock types. However, a wide range of different gneisses are found in addition: granitoid, quartz-feldspar, biotite-hornblende, etc. The rocks are arranged in a synclinal structure, which form the core of Maungu Hills. Due to the large abundance of different lithologies, it is difficult to predict which rocks will be encountered at the base of the weathered zone: Garnetiferous biotite-hornblende gneisses, which also occur on Sagalla Hill, are the most likely, but graphite gneisses or migmatites are possible as well. Rock debris scattered on the site is mainly composed of black, fairly coarse grained, biotite-hornblende gneiss with quartzitic bands, and some graphite gneiss. The general trend of the geological formations in the area is N-S. This is clearly seen from the trend of the inselbergs, the foliation displayed in outcrops, and the ribbed topography as seen from the air

The Mozambique Belt contains numerous usually small ultramafic bodies, frequently associated with mafic rocks and generally concordant to strike and dip of the country rocks. These rocks are deformed and metamorphosed to the same degree as their country rocks
The area lies along the Precambrian Mozambique belt under Turoka Group.
The Turoka Group which largely comprises the Kurase – Kasigau metasediments, is a large tract which trends from S.E Kenya through Voi-Namanga, Kajiado – east of the Kenya Rift to the Cherengani Hills. From S.E

Kenya it also trends NNE through Voi, Kitui, and Archers Post to Baragoi. It also consists of well differentiated metasediments which include massive crystalline limestone with subordinate quartzites, graphitic-schist and gneisses, kyanite and localized hornblende gneisses and pelitic gneisses with kyanite and silimanite which is dominated by metamorphic rocks. The surface is also covered by mountains referred to as inselbergs. The deposits derived from their weathering are what which have become potential aquifer systems. The geology of the area is characterized by the quaternary deposits mainly from the basement rocks that are mainly of the Achaean calcareous hornblende gneisses and granitoid gneisses. The surface geology is dominated by red sandy soils of quaternary age overlying differentiated basement system rocks. From previous studies it has been mentioned that the Taita hills have properly been lowered by several hundred meters by tectonism, erosion and weathering from the late Mesozoic.

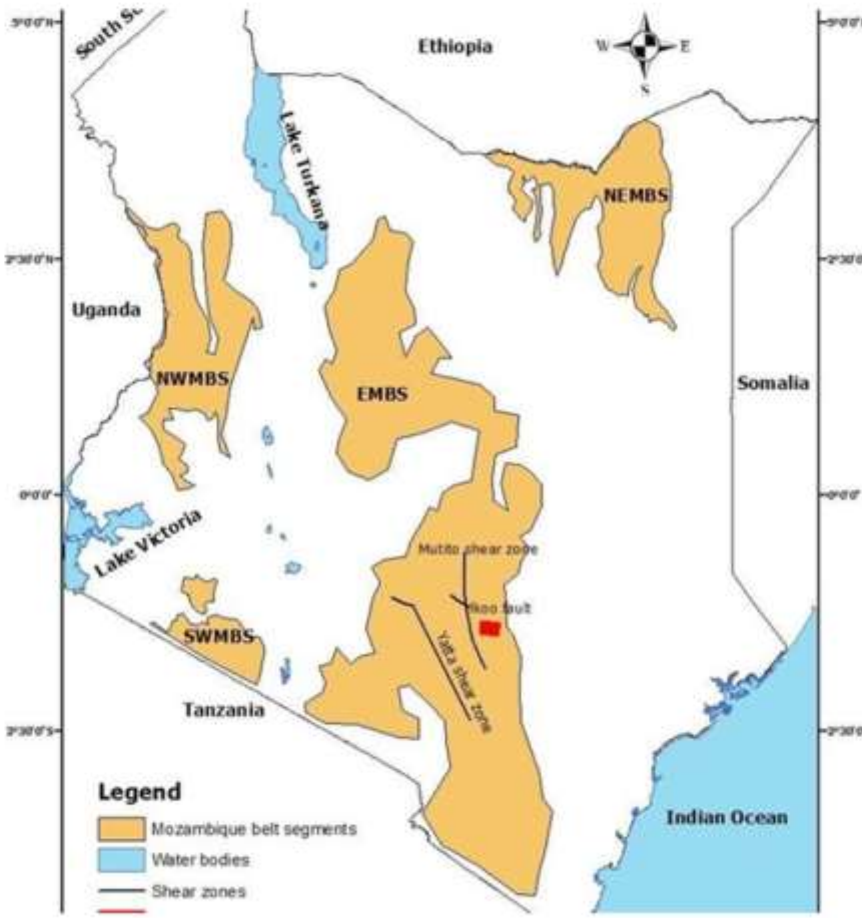


Figure 6: Map showing the Mozambique Belt

3.2.3 Structural Geology

Structural features such as faults in the rocks often optimize storage, transmissivity and recharge, particularly when they occur adjacent to, or within, surface drainage systems. In the general study area, a series of N-S trending semi parallel faults while some younger subsidiary faults trend orthogonally to the regional strike.

4.0 HYDROGEOLOGY

4.1 Background

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. The hydrogeology of an area is normally intimately dependent upon the nature of the parent rock, structural features, weathering processes, recharge mechanism and the form and frequency of precipitation. It is evident that the borehole yields in the general area are very variable, depending on the coarseness, sorting, compaction and cementation of the aquifer material. The aquifers are basically confined as evidenced by the rise of the water level above the water struck levels.

4.2 Regional Hydrogeology

With a mean rainfall figure close to **500 mm,** and a geology marked by a succession of metamorphics and sediments, the general potential for groundwater development can be termed as good.

It therefore follows that the potential aquifers can thus be inferred to occur as follows;

- **Weathered metamorphic basement rocks**
- **Fractured basement rocks**
- **Contact zones**
- **Fault zones in gneisses**

General Aquifer Characteristics by Rock Type

Rock types remarkably influence groundwater occurrence. This influence of rock type on aquifer characteristic is summarized in the table below:

Rock type	Elevation (m)	Total depth (m)	Water Struck	Water Rest	Yield	Specific Yield	Drawdown
Volcanics (V)	1763	124	94	48.68	7.45	0.20	37.05
Basements (B)	1266	80	55	26.40	4.54	0.15	31.08
Sediments (S)	439	81	54	34.80	5.55	0.32	17.39
V over B	1079	82	54	28.53	7.39	0.29	25.87
S over B	1073	91	51	25.97	5.67	0.18	32.28
S over V	1266	90	63	28.98	7.57	0.32	24.14
V over S	1332	106	79	26.60	10.76	0.26	41.22

Note

From the table above

I. The boreholes in volcanics have the highest value of elevation (1763m) whereas those in sediments have the lowest (439m).
II. The total depth of boreholes in volcanics is the deepest (averagely 125m). Those in sediments are shallower (averagely 80 and 81m respectively).
III. The struck water level of boreholes in volcanics is the deepest (94m) whereas that in sediments is the shallowest (54m).
IV. The rest water level of boreholes in volcanics is the deepest (49m) whilst that in basement is the shallowest (26m).
V. Boreholes in volcanics have the highest value of artesian pressure (45m) whereas those in sediments have the lowest (20m).
VI. The yield in volcanics is the highest.

VII. The specific capacity in basement rocks is the lowest (0.15m^3/h/m) whereas that in sediment is by far the highest (3.4m^3/h/m). Sediments have a higher groundwater potential than the basement system.

Note

There are no discrete records of the aforementioned parameters in regard to boreholes neighboring this site of survey

4.3 Boreholes in the Immediate Vicinity of the Area

A number of boreholes documented and undocumented have been drilled in the project area. However, available records were studied for the 5 boreholes are Within a radius of about 1km-8km from the site.

SERIAL NO:	NAME	LOCATION	DEPTH	YIELD IN M³/Hr
1	Levy Mghalu	Msinga B	170	6
2	Mwamunga Estate	Msinga B	55	5
3	St. Jude Academy	Kaloleni	120	9
4	Ngutuni Lodge	Ngutuni	140	14
5	Nyambu	Msinga A	170	8

4.3.1 Borehole Data Analyses

When correlated with the geologic logs of the boreholes, the aquifers are located within weathered and fractured Metamorphics.

4.3.2 Impacts to Abstraction Trends and Analyses of Boreholes within 800-m from the Proposed Site

*Considering that the upper aquifers in this region are quite vulnerable to depletion, all aquifers encountered from ground level down to a penetration depth of about **80m** **should not** be sealed off with plain casings and bentonite cement to avoid any possible further depletion of these shallow groundwater resources and in turn avoid any impact to any surrounding borehole abstracting water from this vulnerable level. These boreholes will only abstract water from the deepest aquifers within the fractured metamorphic rocks.*

4.4 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers have not been fully established. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults and/or other aquifers.

Direct recharge is obtained through downward percolation of rainfall or river water into aquifer. If the infiltration rate is low due to the presence of an aquiclude (such as clay), the recharge to the aquifer is low. Percolation will depend on the soil structure, vegetation cover and the state of erosion of the parent rock. Rocks weathering to clayey soils naturally inhibit infiltration and downward percolation. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

In the present study area, the principal recharge is through direct recharge at surface (percolation) through the pores of the existing sand formation. The investigated area probably receives medium to high rainfall.

Recharge also comes from underground percolation from Voi River.

4.4.1 Mean Annual Recharge

Rainfall within the study area is average **(600 mm)** and regional recharge is of great essence in this area followed by base flow within the marbles that characterizes the region.

At the present location, water also percolates directly into the faults, fractures, local rivers and streams (via fractures) thus deeper and adjacent units are recharged over time.

Mean Annual Recharge has therefore been estimated as follows:

The Recharge is estimated as 5% of the Mean Annual Rainfall of the recharge area

600mm x 5%

Mean Annual Recharge = 30mm

However, this recharge amount is probably estimation due to the possibility of influent regional recharge through the fractures of the characteristic metamorphic formation exacerbated by the proximity to the regional structure.

4.5 Discharge

Discharge from aquifers is either through natural processes as base-flow to streams and springs, or artificial discharge through human activities. However, considering the few numbers of boreholes in the area this as form of discharge is not much pronounced.

The total effective discharge from the aquifers via either of the above means is not known, and should in fact be studied. The main form of discharge is through flow along formations and faults/ interconnected fractures.

4.6 Aquifer Properties

4.6.1 Challenges Associated with Calculation of Aquifer Properties.

Very little ***documented*** information is available concerning the aquifer characteristics in this area. It is not possible for example to determine if proper pump test were carried out on the existing borehole since some data of the analyzed borehole are missing.

Thus, in absence of proper pump test data, the *Logan method of approximation* has been employed (Logan, 1965). This method however is thus used for estimation purpose only due to uncertainties related to data error.

4.6.2 Estimated Aquifer Transmissivity

Transmissivity (T) is the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

$T=Kb=$ (m/day) (m) $=m^2$/day where, b=saturated thickness of the aquifer.

There are no details of transmissivity and all the other aforementioned aquifer parameters.

Aquifer Transmissivity (T) is estimated as follows

$T=1.22Q/\Delta S$ Where: Q = Yield per day, ΔS = Draw down

4.6.2 Hydraulic Conductivity

The Hydraulic Conductivity (K) is estimated as follows:

K = T/Aquifer Thickness

Based on the geological logs of the boreholes in the areas, the cumulative aquifer thickness for the purpose of this calculation has been estimated holistically at 10m. Thus,

4.6.3 Specific Capacity

This refers to unconfined parts of aquifers. It may be considered to be equal to the effective porosity or drainable pore spaces because in unconfined aquifers, the effects of elasticity may be of the order 0.1 to 0.2.

The aquifer Specific Capacity (S) = Q/Δs.

Where: Q = Discharge (m^3/day, Δs = Drawdown (m)

4.6.4 Groundwater Flux

The Groundwater Flux (F) is estimated based on borehole for the surveyed area.

The expression for groundwater flux is given as follows:

F = K.i.h.w

Where K- Hydraulic Conductivity = m/day, i – Slope, h- Aquifer Thickness =m, w- Arbitrary distance (m).

4.7 Water Quality Considerations

In the general area, the quality of groundwater is generally good, with the fluoride content, within the permissible W.H.O. upper limit of 1.5 ppm. High fluoride intake, especially in growing infants, may cause dental or skeletal fluorosis. Should the fluoride concentration of the proposed borehole exceed 1.5 ppm, it is advisable to provide an alternative source of drinking water for infants (bottled water would be the best option). Over a short time, span, the consumption of water with excess fluoride is not harmful to adults. W.H.O. and EC guideline concentrations are included for reference in appendix section.

Groundwater may be classified based on salinity as shown in Table 6 below.

Figure 7:Groundwater Classification Based on Salinity

Category	TDS (ppm)	EC (µS/cm)
Fresh water	0-1,500	0-2,000
Brackish water	1,500-10,000	2,000-15,000
Saline water	10,000-100,000	15,000-150,000
Brine	>100,000	> 150,000

TDS : Total Dissolved Solids (in parts per million = mg per liter)

EC : Electrical Conductivity in micro-Siemens per cm

Figure 8: Salinity Limits for Groundwater Use

EC (µS/cm)	TDS (ppm)	Use/Limitation
< 2,000	< 1,500	Potable water
> 2,000	> 1,500	Unsuitable for domestic purposes

2,000-3,000	1,500-2,000	Generally too salty to drink but still fit for livestock
> 3,000	> 2,000	Generally unfit for dairy cattle and young cattle
> 7,000	> 4,500	Unfit for grazing cattle and sheep

QUALITY VARIABLE	MEASURING UNIT	WHO GUIDELINE	COMMENTS
Colour	mg/1 Pt	15 TCU	
Hardness	mg/1 $CaCO_3$	500	
pH	pH Units	6.5 - 8.5	
Turbidity	NTU	5	
Arsenic	As mg/1	10	Toxic in excess e.g. bronchial diseases
Lead	Pb mg/1	10	Toxic to animals
Selenium	Se mg/1	10	Toxic in excess
Aluminum	Al mg/1	0.2	Soluble Al salts exhibit neurotoxicity
Ammonia	NH_3 mg/1	1.5	Toxic particularly to aquatic organisms
Boron	Bo mg/1	0.3	Toxic in high concentration to plants
Calcium	Ca mg/1	NS	No Standard
Chloride	Cl mg/1	250	
Fluoride	Fl mg/1	1.5	Dental and skeletal fluorosis
Iron	Fe mg/1	0.3	High concentrations toxic to children
Magnesium	Mg mg/1	0.1	May cause diarrhoea in new users
Manganese	Mn mg/1	0.1	
Nitrate	NO_3 mg/1	11	Infant blue baby syndrome
Potassium	K mg/1	NS	No Standard
Sodium	Na mg/1	200	Chronic, long term toxic
Sulphate	SO_4 mg/1	250	Taste, odours, cathartic effects
Zinc	Zn mg/1	3	Toxic in excess
Total Coliforms	per 100 ml	Nil	
Faecal Coliforms	per 100 ml	Nil	
Sulphide	H_2S mg/1	Undetectable	

Table 1: World Health Organisation Guidelines

4.8 Groundwater Movement

Groundwater will always flow towards the area with the lowest piezometric head. For this area, this base level is ultimately found east of the investigated site.

With respect to the potential for faults to create aquifers and to recharge the aquifers, it is very important to establish whether the faults occurring in the rocks are groundwater barriers or preferential flow paths. The pervious faults have a larger secondary porosity. This macro porosity accounts for a greater mobility of the groundwater. The water stays in contact with the rock for a relatively short period; hence, mineralization stays low. Mobility in the (primary) microspores, on the contrary, is low. The groundwater in these pores will be highly mineralized by dissolved salts.

4.9 Rainfall, Percolation and Recharge

Assuming that suitable storage media exist below the ground, aquifer potential is also affected by the mechanisms of percolation of rainfall or river water down to the aquifer. If the infiltration capacity is low due to the presence of an aquiclude like clay, the recharge to the aquifer is low.

Percolation will depend on the soil structure, vegetation cover and the permeability of the rocks. Clayey formations naturally inhibit percolation. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

4.10 Impacts of the Proposed Activity to Water Quality, Wetlands.

The Proposed drill site and related works are expected to pose no impact on water quality, either Surface or groundwater resources. There is no any surface water body near the drill site that can be contaminated by waste waters generated during drilling. The entire drilling, borehole construction, pump tests, and completion works will be done under supervision to professional standards. Entry of any foreign material until completion will be avoided to avoid any entry of foreign material into the borehole and only inert materials will be used in construction. The borehole will be properly developed to open up the aquifers and clean the borehole water. Monitoring of etc. during drilling will be done to detect and seal any aquifer with elevated mineralization.

The site is not located within a wetland and has no negative impacts on biodiversity.

5.0 METHODOLOGY OF GEOPHYSICAL INVESTIGATIONS

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey resistivity (also known as the electromagnetic method) has been used.

5.1 DC Resistivity Method

It is sometimes referred to as DC resistivity technique. This method measures the earth's resistivity by driving a direct current (DC) signal into the ground and measuring the resulting potentials (voltages) created in the earth. From that data the electrical properties of the earth (the geoelectric section) can be derived and thereby the geologic properties inferred. The diagram below illustrates the basic electrical array for that measurement.

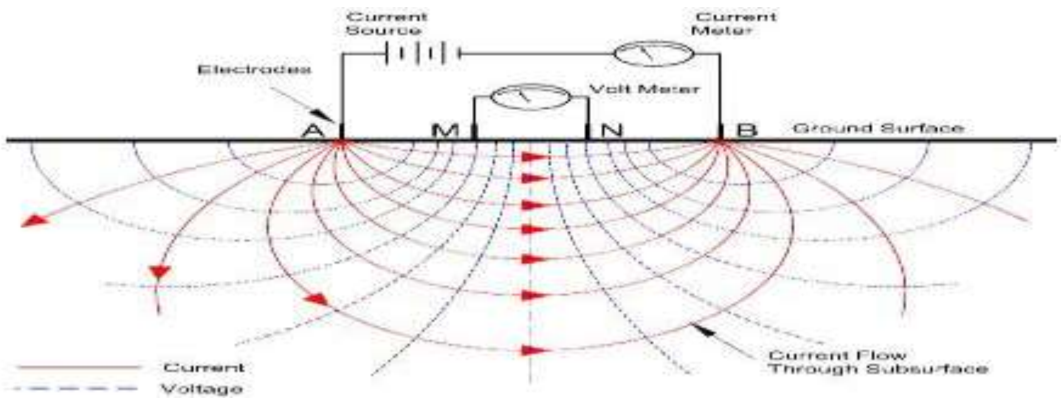


Figure 9: Schematic Diagram of DC Resistivity Method

The figure above is a schematic diagram showing the basic principle of DC resistivity measurements. Two short metallic stakes/current electrodes (AB) are driven about 1 foot into the earth to apply the current to the ground. Two additional potential electrodes (MN) are used to measure the earth voltage (or electrical potential) generated by the current. Depth of investigation is a function of the distance of current electrodes

In this method an electric current is passed into the ground and the potential difference measured to get the Resistivity of the underlying layers

There are many Resistivity arrays used in the field. The one used in this survey was the horizontal resistivity profile and vertical electrical sounding (VES).

5.1.1 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, and the degree of pore space saturation and the salinity of the water. It is imperative to note that:

- Saturated rocks have lower resistivities than unsaturated and dry rocks.
- The higher the porosity of the saturated rock, the lower its resistivity.
- The higher the salinity of the saturating fluids, the lower resistivity of the host media.
- Clays and conductive minerals also reduce the resistivity of the rock.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

The resistance R of a certain material is directly proportional to its length L and cross-sectional area A, expressed as:

$$R = Rs * L/A \qquad (Ohm) \qquad (1)$$

Where Rs is known as the specific resistivity, characteristic of the material and independent of its shape or size. With Ohm's Law,

$$R = dV/I \qquad (Ohm) \qquad (2)$$

Where dV is the potential difference across the resistor and I is the electric current through the resistor, the specific resistivity may be determined by:

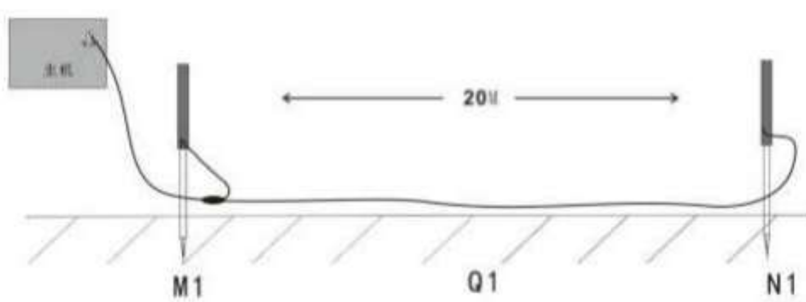
$$Rs = (A/L) * (dV/I) \qquad (Ohm.m) \qquad (3)$$

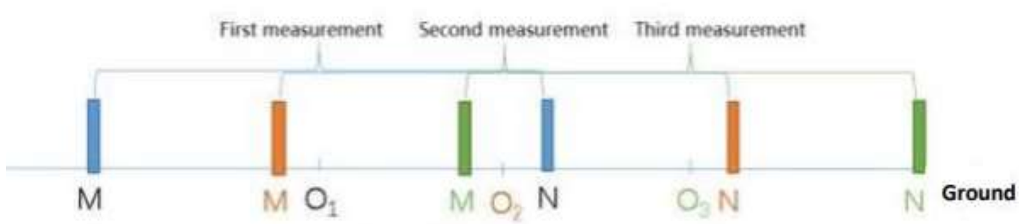
5.1.2 Single channel connection (Wired electrode connection mode)

The PQWT series instruments use natural electromagnetic field of the earth as the working field source to study the electrical structure inside the earth. According to the principle that different frequencies of electromagnetic waves have different skin depths in the conductive coal, the surface is measured from high frequency to the low-frequency Earth electromagnetic response sequence studies the difference in electrical variation of geological bodies at different depths in the subsurface and determines the occurrence of underground geological bodies.

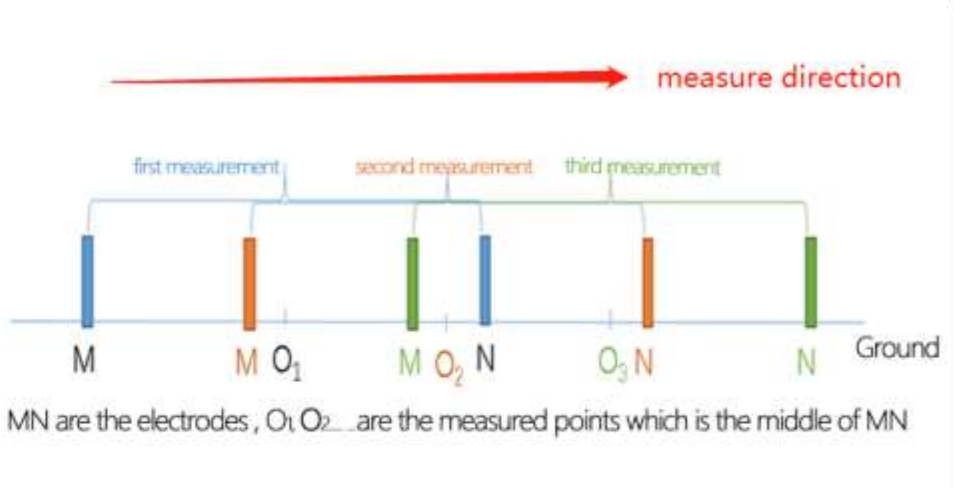
Electromagnetic wave propagation theory

Helmholtz equation Ground electromagnetic waves are sent to the ground, and the propagation of electromagnetic waves in the earth and soil follows the Maxwell equation.





O1, O2, O3 are measurement points, which are located directly under the wireless sensor.



After the instrument is turned on, connect the instrument as shown in the figure above, plug the M and N measuring electrodes into the ground, and start sampling. The measuring point is at the center of the two M and N electrode rods. After sampling at this point, move the M and N electrodes in the same direction at a certain point distance to perform the second measurement point sampling measurement and so on, until the entire profile measurement is complete.

5.1.3 Horizontal Electrical Profile (HEP)

In horizontal Electrical Profile, lateral changes in resistivity are measured at a given depth depending on the values of AB and MN where AB is the distance between the current electrodes and MN is the distance between the potential electrodes. The direction in which a profile is taken is always across the fault line. The profile would therefore detect this region and a VES would be done at the appropriate areas to confirm the presence of water. Apparent resistivities are different from the actual resistivities of the profile because of changes in the electric current that result from its pathway through various earth materials. Therefore, the apparent resistivities often require inversion modeling to convert the raw data to actual resistivities.

5.1.4 Vertical Electrical Soundings (VES)

When carrying out a resistivity sounding, current is led into the ground by means of two electrodes. With two other electrodes, situated near the center of the array, the potential field generated by the current is measured. From the observations of the current strength and the potential difference, and considering the electrode separations, the ground resistivity can be determined.

While carrying out the resistivity sounding the separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

6.0 FIELD WORK, RESULTS AND INTERPRETATIONS

6.1 Field work

Geophysical field survey entailed Vertical Electrical Soundings (VES) measurement was carried out in area. The aim of the sounding was to determine the prevailing hydro stratigraphy and ultimately locate potential target drilling site for groundwater abstraction

The PQWT sounding was deployed at the site with the view of identifying the most suitable drilling site. The resistivity VES sounding was deployed to a depth of 500. The results and interpretations are described as follows.

6.2 Results and Interpretation

The area is characterized by emplaced**, Granitoid Gneisses, biotite Gneisses and basement rocks**, these rock units have herein been collectively referred as **undifferentiated basement formation.**

6.2.1 Interpretation of the processed Resistivity Profile

<u>PROFILING RESULTS</u>

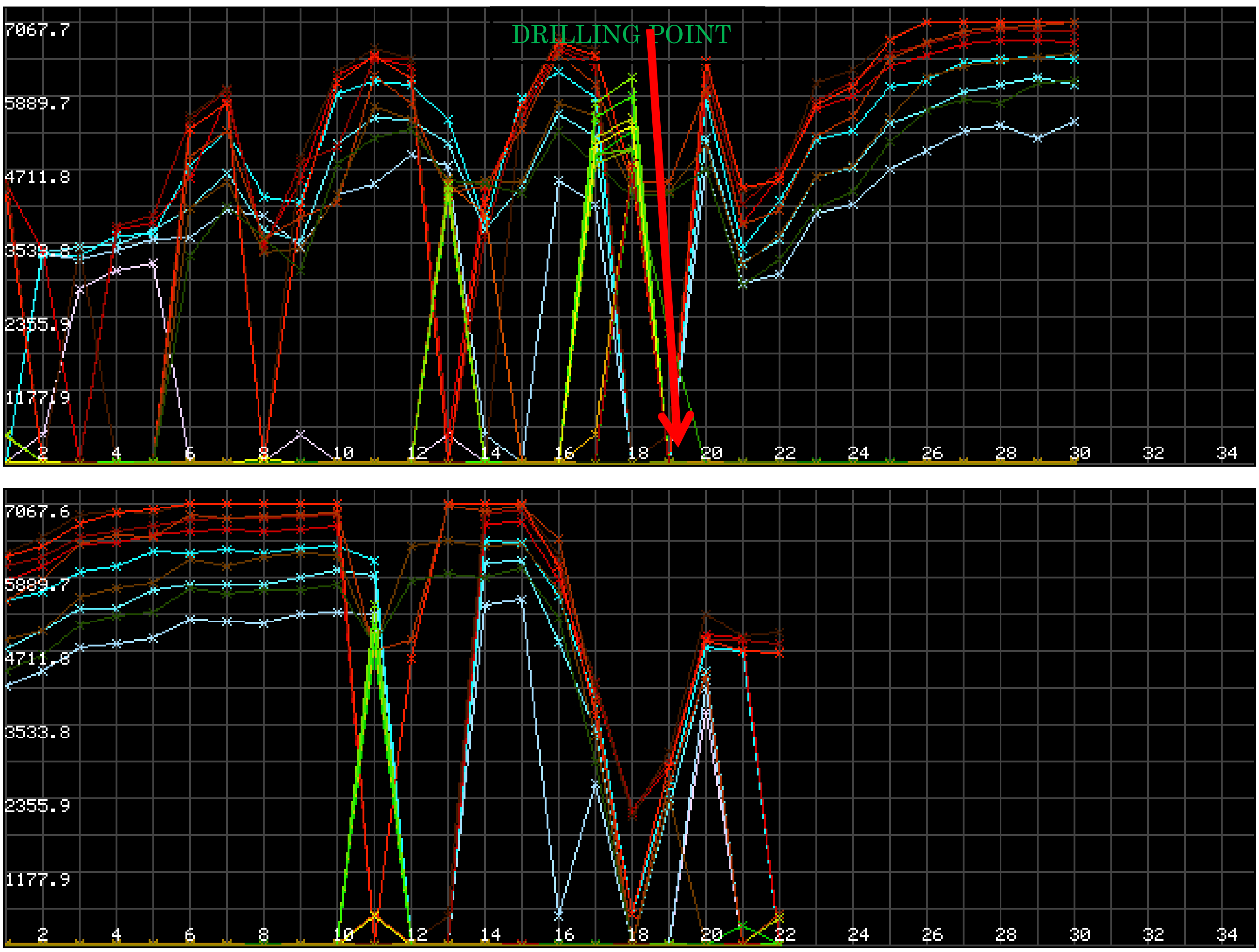
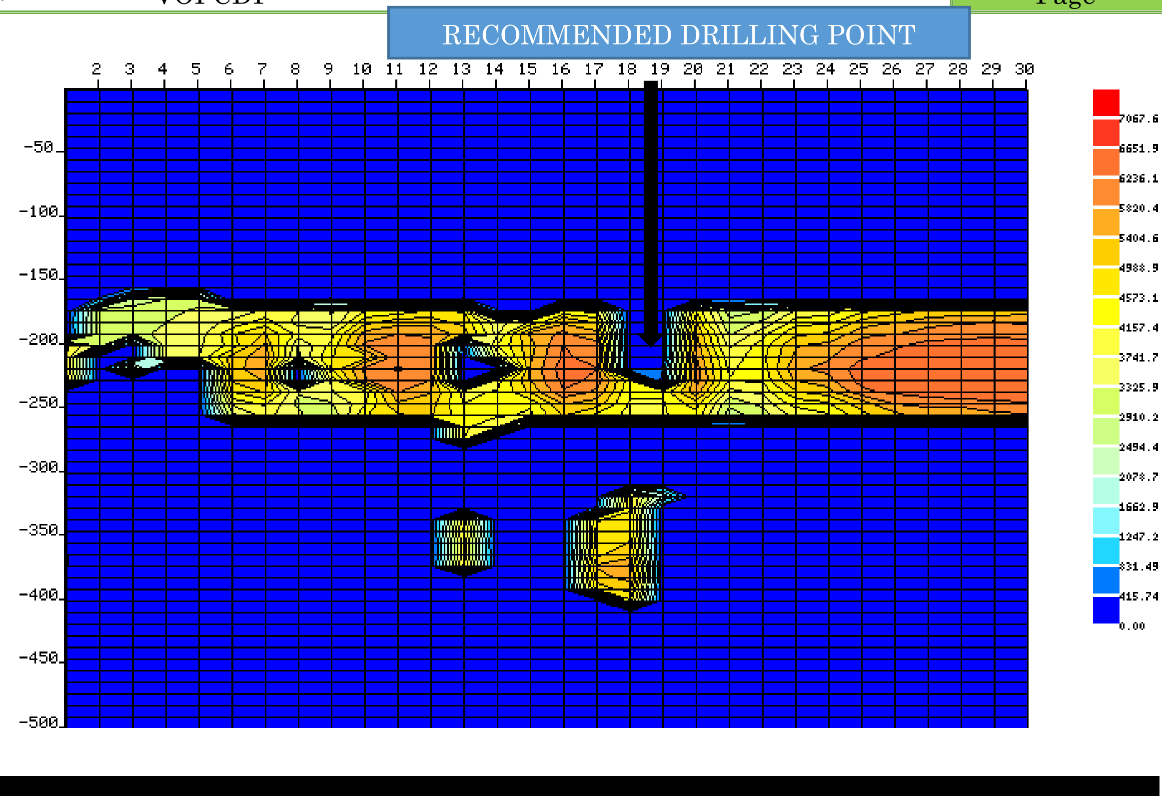


Figure 10: 500M Multiple Frequency for profile 1 and 2 respectively



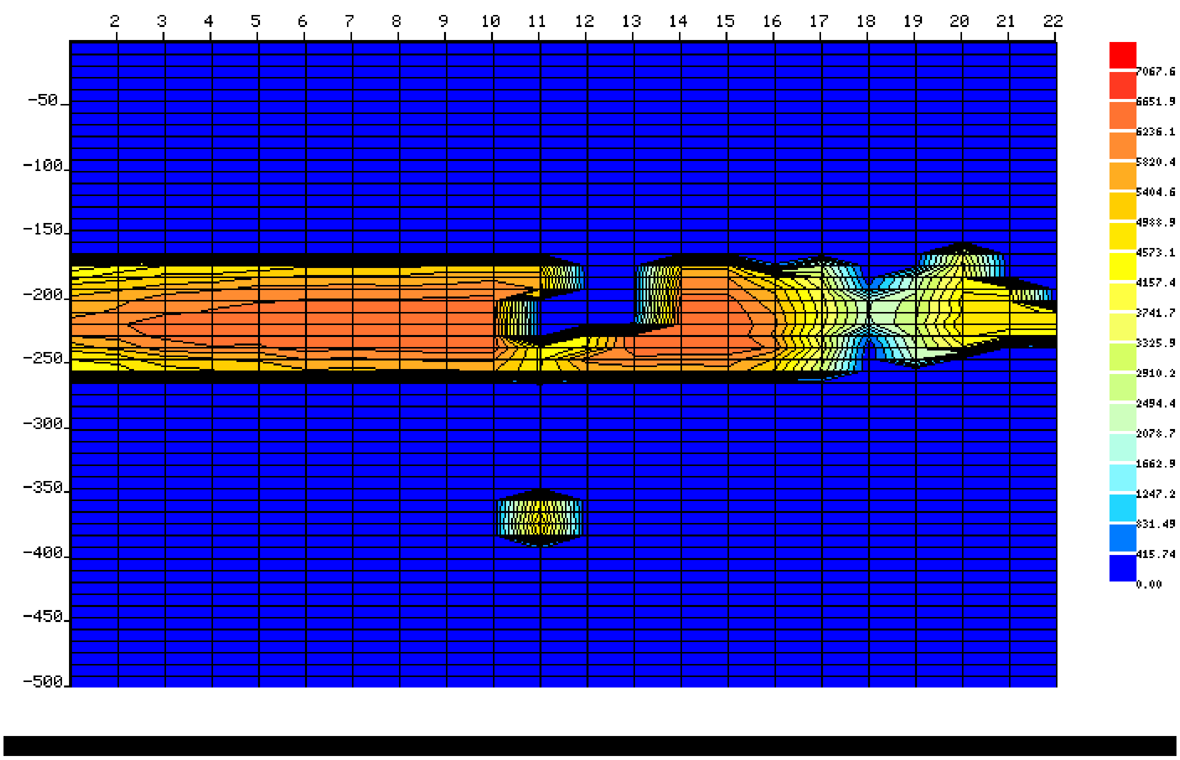
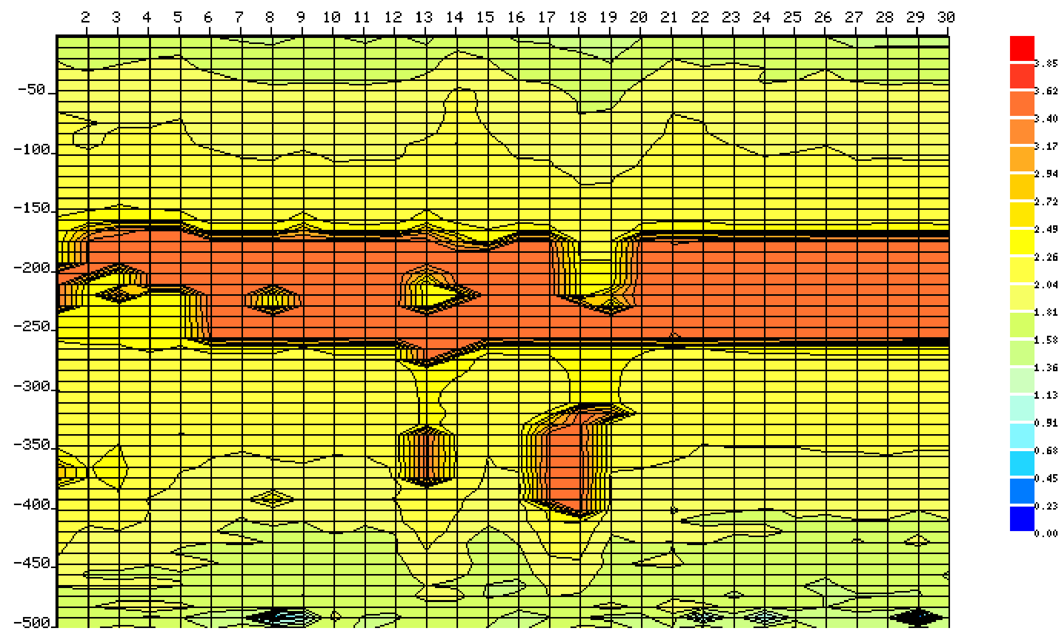


Figure 11: unprocessed ISO map for profile 1 and 2 Respectively



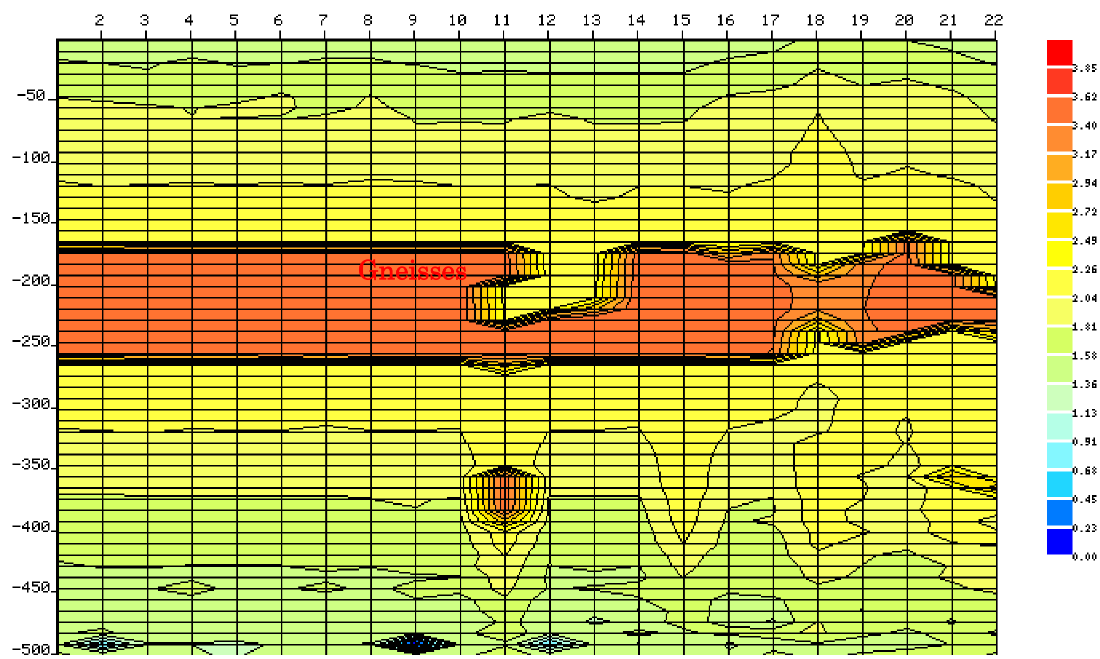


Figure 12: Processed ISO Map for Profile 1 and 2

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based on the available information and the geophysical investigations it is concluded that the investigated site in VOI CDF is located in an area with Medium groundwater prospects as demonstrated by relative low resistivity. Interpreted results from the resistivity structure indicate an aquifer hosted in metamorphics at depths spanning between; 110->180 m bgl (sustainable aquifer), the aquifer at depths between0-100 m is deemed to be ephemeral or perched aquifer. On the other hand, the existing *documented* boreholes were drilled to depths spanning between **110 to 200m bgl.**

7.2 Recommendations

In view of the above the following recommendations can be drawn:

- ✓ An 8.5" borehole should be air drilled to a **maximum depth of 200 m bgl and a minimum of 180M**; yield increases with depth
- ✓ The most suitable location for the borehole is at **PROFILE 1 POINT 19 (ALT 538M)**
- ✓ Considering that the upper aquifers in this region are quite vulnerable to depletion, all aquifers encountered from ground level down to a penetration depth of about **30m** should not be sealed off. This borehole will only abstract water from the deepest aquifers within the fractured metamorphics. Thus, there won't be any foreseen interference in the hydraulic properties of the existing boreholes or their groundwater abstraction trends.
- ✓ The borehole should be cased using machine made Steel screen casings and plain casings.
- ✓ Test pumping should be done for 24 consecutive hours to aid in determining the safe pumping yield and appropriate pump size.
- ✓ A piezometer should be installed in the borehole to enable monitoring of the water level.
- ✓ A master meter should be installed to record the amount of water abstracted from the borehole.
- ✓ A water sample should be collected at the end of the test pumping to be taken to a competent lab for a complete water quality test.

8.0 APPENDIX 1

DRILLING

Drilling Technique

Drilling should be carried out with an appropriate tool is rotary machines/ air drilled will be suitable, though the latter are considerably faster. Geological rock samples should be collected at 2 metre intervals. Struck and rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

Well Design

The design of the well should ensure that screens are placed against the optimum aquifer zones. An experienced Hydrogeologist should make the final design.

Casing and Screens

The well should be cased and screened with good quality material owing to the depth of the borehole. It is recommended to use UPVc casings and screens of high open surface area.

We strongly advise against the use of UPVc well casing as screen. In general, its use will reduce well efficiency (which leads to lower yield), increase pumping costs through greater draw down, increase maintenance costs, and eventually reduction of the potential effective life of the well.

Recommended steel casings and screens, the slotted ones are the screens

Gravel Pack

The use of a gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. A 10" diameter borehole screened at 6" will leave an annular space of approximately 2", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The slot size should be in the order of 1.5 mm. The grain size of the gravel pack should be an average 2 - 4 mm.

Example of gravel pack

Well Construction

Once the design has been agreed, construction can proceed. In installing screen and casing, centralizers at 6 metre intervals should be used to ensure centrality within the borehole. This is particularly important for correct insertion of artificial gravel pack all around the screen. After installation, gravel packed sections should be sealed off top and bottom with clay (2 m).

The remaining annular space should be backfilled with an inert material, and the top five meters grouted with cement to ensure that no surface water at the wellhead can enter the well bore and cause contamination.

Once screen, pack, seals and backfill have been installed, the well should be developed. Development aims at repairing the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls. Secondly, it alters the physical characteristics of the aquifer around the screen and removes fine particles.

We do not advocate the use of over pumping as a means of development since it only increases permeability in zones, which are already permeable. Instead, we would recommend the use of air or water jetting, or the use of the mechanical plunger, which physically agitates the gravel pack and adjacent aquifer material.

This is an extremely efficient method of developing and cleaning wells.
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2 m above the screen, certainly not at the same depth as the screen.

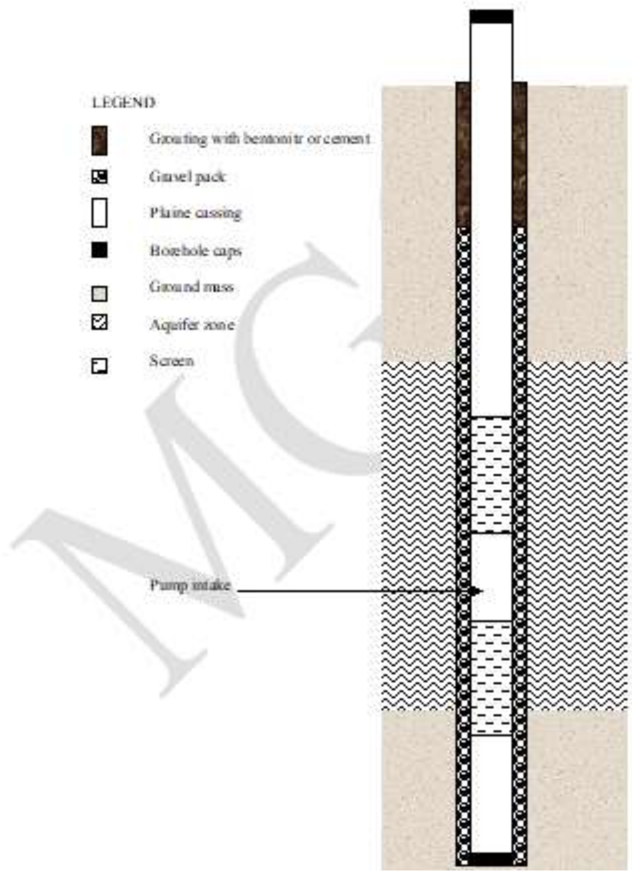
Well Testing

After development and preliminary tests, a long-duration well test should be carried out. Well tests have to be carried out on all newly completed wells, because apart from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters, which are vital to the hydrogeologist.

A well test consists of pumping a well from a measured start level (Water Rest Level - (WRL) at a known or measured yield, and simultaneously recording the discharge rate and the resulting drawdowns as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually, the rate of pumping is increased stepwise during the test, each time equilibrium has been reached (Step Draw down Test). Towards the end of the test a water sample of 2 liters should be collected for chemical analysis.

The duration of the test should be 24 hours, followed by a recovery test for a further 24 hours, or alternatively until the initial WRL has been reached (during which the rate of recovery to WRL is recorded). The results of the test will enable a Hydrogeologist to calculate the optimum pumping rate, the pump installation depth, and the draw down for a given discharge rate.

Schematic Design for Borehole Completion



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