Pastoralist Community Initiative and Development Assistance
Building on Indegineous Knowledge and Institutions

HYDRO-GEOLOGICAL ASSESSMENT REPORT

FOR

The Pastoralist Community Initiative and Development Assistance (PACIDA),

P.O. BOX 333 – 60500,

MARSABIT.

Mail: pacida@pacida.org

LOCATION:

BUBISA VILLAGE – NORTH HORR SUB-COUNTY

On a Communal Land

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Date: 8th August, 2020

SUMMARY

This Report discusses the results of a geophysical site survey for one borehole in ***Bubisa*** *Area of* ***North Horr*** *Sub County in* ***Marsabit*** *County. The piece of land is situated off Marsabit – Turbi Road, close to 2 kilometers on a bird's flight from the road to the site.*

The general subsurface geology of the general area is composed of superficial deposits, Basalts and the Basement System, in that stratigraphic succession. The pump assembly got stuck in the single borehole that feed the community hence, need for a replacement borehole. The dynamic borehole yields drilled at such a location are determined by their placement within the volcanic suite and the condition of basement system that acts as a confining to percolating water but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Groundwater occurs within the OLS, highly weathered/ fractured volcanic and basement rocks and the interface between the volcanic and the basement system. Recharge of the aquifers is by direct and indirect replenishment. A preferred site has been located by means of geophysical field measurements to tap water from the main water bearing aquifers within the interface of the volcanic suite and the basement rocks. The report is accompanied by maps, geophysical data and curves. Water quality is expected to be good with exception of normal mineral concentration which may be higher though not above the maximum permissible WHO limits for human consumption. The water quality is expected to be suitable for animals and moderately suitable for domestic use.

It is thus recommended that:

i. *The borehole should be drilled at the selected position:* ***Profile 104, in between station 9-10/VES I*** *to maximum depth of* ***320 meters****.*
ii. *The borehole be installed with mild steel casings and plasma-cut slotted casings.*
iii. *The borehole hydraulical properties and aquifer characteristics should be determined during a 24-hour constant discharge test.*
iv. *Samples taken during test pumping must be submitted to a recognized laboratory for full physical, chemical and bacteriological analyses.*
v. *A monitoring tube and master meter should be installed in the borehole to be able to monitor the water level and water consumption respectively.*

With careful implementation of the project by adhering to the study's findings and recommendations and by following the Water Resources Authority's (WRA) Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

GPS Coordinates	Recommended Depth	Construction Requirements	Expected Yield (m^3/h)
37N 0399365, 0298639: 575m	320	203/153mm	12.02 – 17.29

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ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS

(S.I. Units throughout, unless indicated otherwise)

agl	*above ground level*
amsl	*above mean sea level*
bgl	*below ground level*
E	*East*
EC	*electrical conductivity (S/cm)*
hr	*hour*
l	*liter*
m	*meter*
N	*North*
NEMA	*National Environment Management Authority*
PWL	*pumped water level*
Q	*discharge (m^3/hr.)*
s	*drawdown (m)*
S	*South*
SWL	*static water level*
T	*transmissivity (m^2/day)*
VES	*Vertical Electrical Sounding*
W	*West*
WAB	*Water Apportionment Board*
WRA	*Water Resources Authority*
WSL	*water struck level*
S/cm	*micro-Siemens per centimeter: Unit for electrical conductivity*
°C	*degrees Celsius: Unit for temperature*
"	*Inch*

GLOSSARY OF TERMS

Aquifer	*A geological formation or structure, which stores and transmits water and which is able to supply water to wells, boreholes or springs.*
Conductivity	*Transmissivity per unit length (m/day)*
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.*
Development	*In borehole engineering, this is the general term for procedures applied to repair the damage done to the formation during drilling. Often the borehole walls are partially clogged by an impermeable "wall cake", consisting of fine debris crushed during drilling, and clays from the penetrated formations. Well development removes these clayey cakes, and increases the porosity and permeability of the materials around the intake portion of the well. As a result, a higher sustainable yield can be achieved.*
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.*
Old Land Surface	*Old Land Surface (OLS) is the term given to an ancient erosion surface now covered by younger surface material. In hydrogeology, OLS's frequently make good aquifers, especially where the erosion debris left behind is coarse in nature. OLS's are a frequent occurrence in the Nairobi Volcanic Suite.*
Perched aquifer	*Unconfined groundwater separated from an underlying main aquifer by an unsaturated zone. Downward percolation hindered by an impermeable layer.*
Permeability	*The capacity of a porous medium for transmitting fluid.*

Piezometric level *An imaginary water table, representing the total head in a confined aquifer, and 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.*

Pyroclastic rocks *Group of rocks consisting of volcanic dust, ashes, lapilli and coarse lumps of lava (volcanic bombs), explosively thrown up in molten condition, and deposited by gravity. Hardened masses of dust, ashes and lapilli are known as tuff, while coarse, consolidated pyroclastic debris is referred to as agglomerate.*

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.*

Specific capacity *The rate of discharge from a well per unit drawdown.*

Static water level *The level of water in a well that is not being affected by pumping. (Also known as "rest water level")*

Transmissivity *A measure for the capacity of an aquifer to conduct water through its saturated thickness (m2/day).*

Unconfined *Referring to an aquifer situation whereby the water table is exposed to the atmosphere through openings in the overlying materials (as opposed to >confined conditions).*

Yield *Volume of water discharged from a well.*

1 NAME AND DETAILS OF APPLICANT

The Pastoralist Community Initiative and Development Assistance (PACIDA) herein referred to as the client in collaboration with the Development Partners and the **Bubisa Community** commissioned the present consultants to carry out a hydrogeological and geophysical survey in communal land located in **Bubisa** Village, **Bubisa** Location, **Bubisa** Sub Location of **North Horr** Sub County within **Marsabit** County.

The hydrogeological survey was envisaged to determine the best location for drilling the proposed borehole to supply water for **communal use** within and around the site. The available water sources are the communal boreholes, at a very far distance from this domicile area. The long distance walk in search of water for domestic use and animal watering has forced the community to seek for a replacement borehole.

The Client's contact details are as follows:

The Pastoralist Community Initiative and Development Assistance (PACIDA),

P.O. BOX 333 – 60500,

Marsabit.

Mail: pacida@pacida.org .

PACIDA is an indigenous, non-sectarian, non-profit, Non-Governmental Organization committed to sustainable pastoralist development. PACIDA works with pastoralist communities in Kenya and Ethiopia to end poverty, hunger and disease while addressing the most pressing challenges affecting the communities.

The objective of the survey was to establish the optimum location of a borehole planned to provide water to our Client for **domestic** and **livestock use**.

The project area is not connected to any public water supply system of which should there be, has been projected and reported that won't meet the client water demand. If the client won't be authorized to sink a borehole at the site, they will rely on water vendors which are expensive and unreliable. The domesticated animals within this village have enough pasture supply at this time though conditions are expected to deteriorate over time.

Chronic water shortages have driven the client to think of drilling a replacement borehole to act as the main water supply for this community. It is against this background that a detailed hydrogeological survey was envisaged to determine groundwater potential within the area and the possibility of sinking the proposed borehole.

The hydrogeological assessment report gives the details of drilling depth, water quality and estimated yields. It also assists in registration of the borehole with the Water Resources Authority (WRA) of the Ministry of Water & Sanitation and Irrigation.

Based on the recommendations of the report, the contractor can project cost estimates for the drilling and construction works.

Figure 1.1: Drinking water supplement: secured underground tank meant to store surface water from the hills during the rainy seasons

Figure 1.2: The targeted communal settlement close to the study area

Figure 1.3: Goats grazing near the village.

2 TERMS OF REFERENCE

Under the specific Terms of reference, the client: The Pastoralist Community Initiative and Development Assistance (PACIDA) and Development Partners together with the Tiigo Community represented by the Tiigo School, commissioned the project consultant to undertake Hydro-geological assessments/ Borehole site investigations aimed at developing one production borehole on the piece of land, close to the community in **Bubisa** area, **North Horr** Sub- County of **Marsabit** County.

The Consultants were thus commissioned by the client to carry out the subject survey of the project site and subsequently present a hydro-geological report under the following Terms of Reference:

i. Carry out a reconnaissance survey at the project site and generate a datum reference for the borehole site investigations; to conform to the WRA requirements.

ii. Integrate reconnaissance survey data with Geophysical borehole data obtained in the conduct of the surveys to define the recharge/discharge boundaries for the project site, i.e. calibrate the exploration data against known geological settings.

iii. Undertake comprehensive assessments of the existing borehole facilities located in the neighboring areas with a view to quantify their inherent potential; and in addition use such data to define the operational aquifer parameters.

iv. Compile all the additional available hydro-geological, geological, geophysical, hydrological data for the project area.

v. Compute the hydraulic parameters of the aquifers in the general **Bubisa** area, the general Aquifer Transmissivities and the specific capacity of the operational aquifer data.

vi. Analyze the above data in order to fully quantify the groundwater potential; and subsequently provide a comprehensive report on the groundwater exploration program.

vii. Optimize the drilling depth, and in addition re-evaluate the likely aquifer performance in the proposed water supply borehole.

To achieve the specified Terms of Reference, the Consultant aimed at establishing and optimizing the base line conditions of the groundwater flow patterns, using the following conceptual approach.

2.1 Concept on the Anticipated Approach

The approach to this study is expected to apply the standard methods applied in the determination of aquifer parameters in order to establish the baseline conditions in aquifers underlying the project area.

Once these baseline conditions are established, the effects of both abstraction to adjacent boreholes and the general impact on the regional and the localized effects on the aquifer system can be evaluated.

2.2 Concept: - Anticipated Methodology

A review on the existing data and collating it with the field data will be encompassed in this study.

The recommendations of the drilling procedure will lay emphasis on the construction methodologies that will allow for the development and design of a highly efficient system to meet the client's requirements.

To achieve these objectives, the Consultant proposes to undertake a detailed desk study of the database inventory for boreholes located in the immediate vicinity of the project site, for the purposes of statistical evaluation of the down-hole borehole data, and also to define the general aquifer parameters and characteristics.

The results of the project findings need to be consolidated in this survey report in total conformity to the WRA requirements.

The current study lays emphasis on the client's specific water requirements and is geared towards development of a high capacity borehole system with an adequate design flow according to the productivity of the surrounding boreholes.

3 BACKGROUND INFORMATION

3.1 Site Location

The site is situated in **Bubisa** Village, **Bubisa** Location, **Bubisa** Sub Location, **Turbi** Division, **North Horr** Sub - County of **Marsabit** County. It lies within the Survey of Kenya topographic sheets for **Mount Marsabit (Gombo Area)**, **Sheet No. NA 37**
– 06: Y 503 Series. Its defining coordinates are 37N 0399365 E UTM 0298639N as shown on figure 3.1 below.

Figure 3.1: Showing the proposed borehole site general location (Adapted from Google Earth)

3.2 Climate

3.2.1 Precipitation

The climate in Marsabit is referred to as a local steppe climate. During the year there is little rainfall. The Köppen-Geiger climate classification is BSh. The average temperature in Log-Logo is 25.9 °C. The rainfall here averages 393 mm.

The least amount of rainfall occurs in June. The average in this month is 1 mm. Most of the precipitation here falls in April, averaging 126 mm.

3.2.2 Temperature:

The temperatures are highest on average in March, at around 27.4 °C. July is the coldest month, with temperatures averaging 24.6 °C. The variation in the precipitation between the driest and wettest months is 125 mm. Throughout the year, temperatures vary by 2.8 °C.

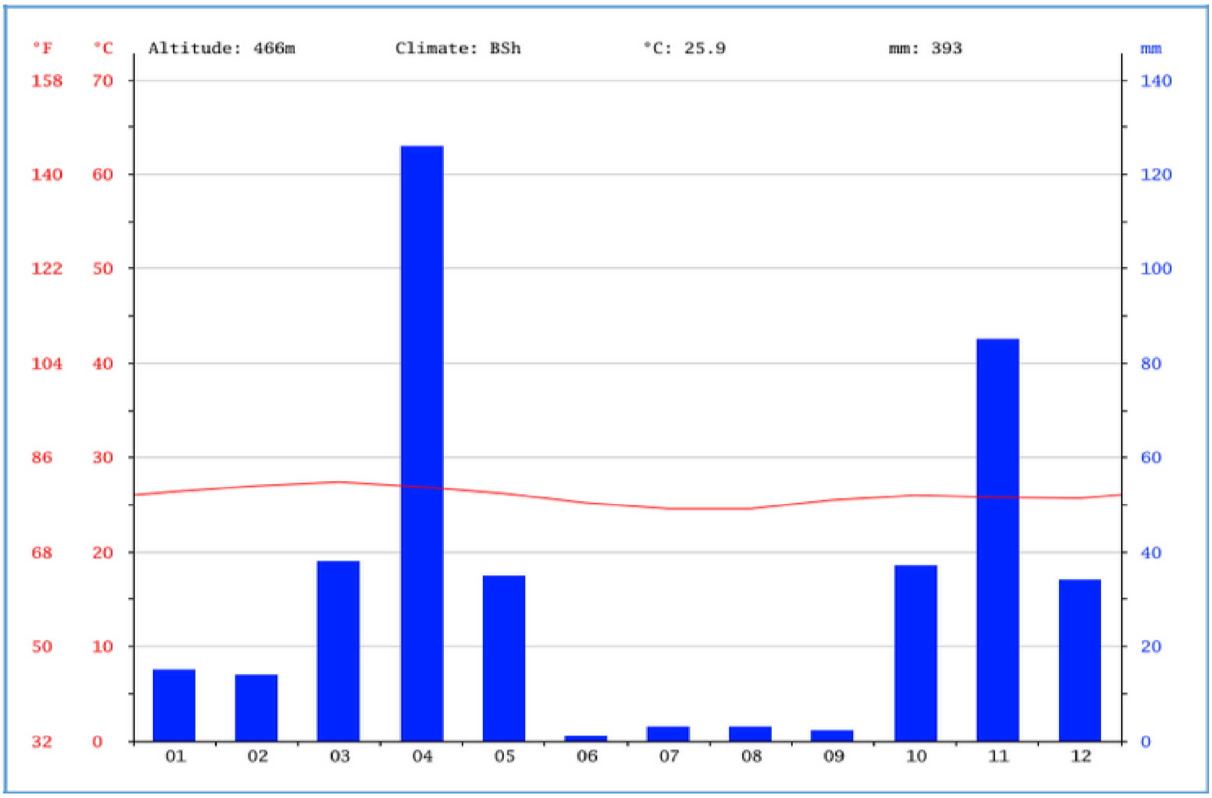


Figure 3.2: Marsabit climatic graph (Adapted from climatedata.org)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	26.4	27	27.4	26.9	26.2	25.2	24.6	24.6	25.5	26	25.8	25.7
Min. Temperature (°C)	18.3	18.6	19.3	19.6	18.8	17.9	17.3	17.2	17.5	18.2	18.5	18
Max. Temperature (°C)	34.6	35.5	35.5	34.2	33.6	32.6	31.9	32.1	33.5	33.9	33.2	33.4
Avg. Temperature (°F)	79.5	80.6	81.3	80.4	79.2	77.4	76.3	76.3	77.9	78.8	78.4	78.3
Min. Temperature (°F)	64.9	65.5	66.7	67.3	65.8	64.2	63.1	63.0	63.5	64.8	65.3	64.4
Max. Temperature (°F)	94.3	95.9	95.9	93.6	92.5	90.7	89.4	89.8	92.3	93.0	91.8	92.1
Precipitation / Rainfall (mm)	15	14	38	126	35	1	3	3	2	37	85	34

Figure 3.3: Marsabit Annual climate averages (Adapted from climatedata.org)

3.3 Physiography

The site lies at an altitude of about 575m amsl. The ground surface at the site is flat lying with a very gentle slope towards east. The site is overlain by clay soils. This area is relatively undisturbed by faults. The site is highly disturbed by volcanism creating numerous volcanic centres around the site.

3.4 Water Demand

Water from the proposed borehole will be used for domestic and communal purposes within the selected piece of land. Water requirement is estimated to be **50m³/day.** There is therefore need to sink a borehole/well in order to tap more reliable water from the underlying aquifers. Supply from the proposed borehole source will meet the estimated daily water demand.

4 GEOLOGICAL DETAILS

4.1 Regional Geology

The geology of the general Marsabit area and its environs consists of a massive alkaline basaltic rock system that overlies Precambrian basement rock complex at depth. These volcanic rocks referred to as the Marsabit Shield cover the entire mountain forming basaltic rapilli breccia volcanic ash cones, and cinder cones interlayed with extensive olivine basalt flows. These miorene-oliocene basalts unconformably overlie undifferentiated basement rock system at depth.

The formation of the Marsabit Shield (evolution of Marsabit Mountain), took place in a series of volcanic eruptions. Volcanism in the Marsabit Shield commenced at the same time with the Rift system faulting in the Pliocene and continued into the Quaternary period according to the recorded basal basalt rock ages dated 2.5 and 0.5 million years respectively.

The volcanic centers comprising of cinder cones and block and ash cones (or maars) are concentrated trending northwest and northeast through the shield summit. The initial lava flows are uniformly thin and laterally extensive fissure controlled basal basalts erupted during the late Miocene to Pliocene periods.

Subsequent violent eruptions during the Quaternary period produced intervals of pyroclastic accumulations from cinder cones and maars with faulting accompanying volcanism. The major faults were concealed by later volcanic flows with eruptions of narrow lava tongues of olivine basalts emerging from the cones (Refer to the geological map below).

4.2 Geology of the study area

The eastern volcanic complex in including the Marsabit town best describes the geology of the surveyed area. The Huri Shield and Marsabit shield being the main source of the widespread volcanic ashes and basaltic breccia. They share a basalt platform, the south end of the Huri Shield form a raised plateau abutting into the Chalbi playa. Elevated piles of Basalt blocks are separated by irregular hollows partly in filled by unconsolidated sediments.

The Marsabit shield has a more varied morphology caused by the different weathering characteristics of the assorted volcanic lithologies. The shield itself has a typical shallow dome shape profile with overall surface slope of less than 6^0. The Basal platform is exposed east of Maikona where its most distinguishing features are a massive concentration of dark circles on aerial photographs due to the abandoned rock foundations of the former Rendile settlements.

According to Charsley (1986), Basalts underlying the Huri shield were extruded from fissure sources during the late Miocene and stating that Volcanism of the Marsabit shield commenced in the Pliocene, 2.5 Ma. The Marsabit shield has an oval plan with a NE – SW long axis of about 90km. The volcanic centres are concentrated in two belts, about 15km wide, trending NW and NE through the summit of the shield. The Marsabit shield has a surface area of about 6300km^2 with a total volume of 910km^3 of basaltic material with a summit thickness of 1200m of intercalated basaltic lavas and pyroclasts. The individual flow units have thicknesses from about 5 to 20m whereas the various pyroclastic wedges may be up to 200m of maximum thickness.

The platform basalt exposed south east of Moikona is a homogenous well jointed ad locally well-developed vertical columnar joints, aphanitic basalt weathering to shades of dark brown. Immediately north of Moikona the Huri Shield consists of several flows stacked on top of each other to define a scarp which is about 30m high. The basalts are well jointed, vesicular with a ferromagnesian phase weathering to orange brown against a dark brown background. Secondary carbonates are common along joint planes.

Figure 4.1: Massive blocks of basalts close to the site

Most of the cinder cones consists of red brown weathering, thickly bedded lapilli breccia. The beds have radial dips of up to 40^0. Although basal beds tend to sub horizontal, i.e. the dip angles increase up the succession. Angular scoriaceous basalt lapilli are the principal component of breccias with minor convoluted bombs and blocks of the same material up to 40cm in length. A secondary carbonate cement is ubiquitous: a friable red brown matrix is confined to discrete beds.

The largest intrusive is the discordant vertical granite sheet cropping out on the northern summit of Halisurwa. This is a massive, pink weathering, feldspathic rock with euhedral quartz grains visible in hand specimen. Minor intrusives include quartz reefs and stringers, carbonate veins in marbles, white mica bearing felsic veins quartzofeldspathic pegmatites and grey microgranite dykes. The latter are relatively common, especially to the east of Korr Mission. They have sharply discordant contacts with the host gneisses and are 1m thick.

The quaternary sediments covering this complex include the **Pleistocene lacustrine depostits at Olturot**: a pan like depression in basalts on the margin of the NW Volcanic province at Olturo. It consists of mounds and composed of a dull white, earthy calcareous (micritic) sediment containing fine root strands and complete mollusc shells. The soils and **superficial sediments including the North West volcanic province** overly the platform basalts between the Asie and Kulal shields, relatively deep, friable, strongly calcareous and sodic gravel sands.

Figure 4.2: Transported basaltic blocks at the site

Figure 4.3: Plate showing the nearby structures as displayed by the neighboring hill

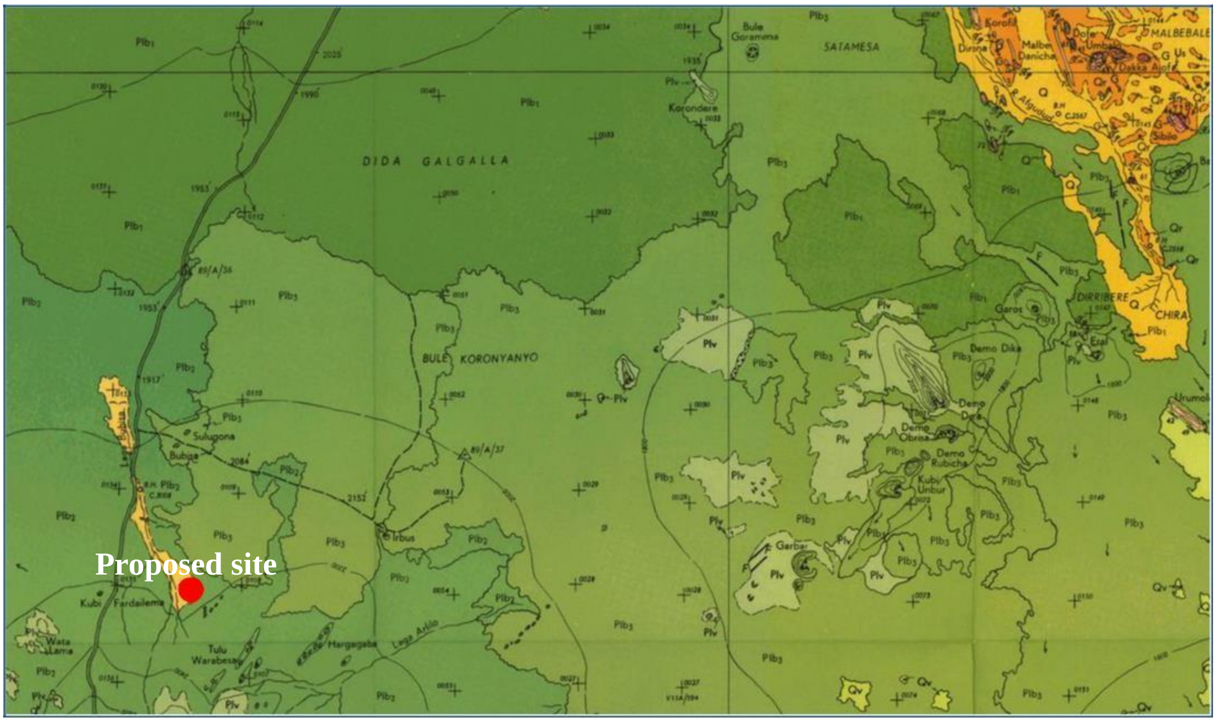
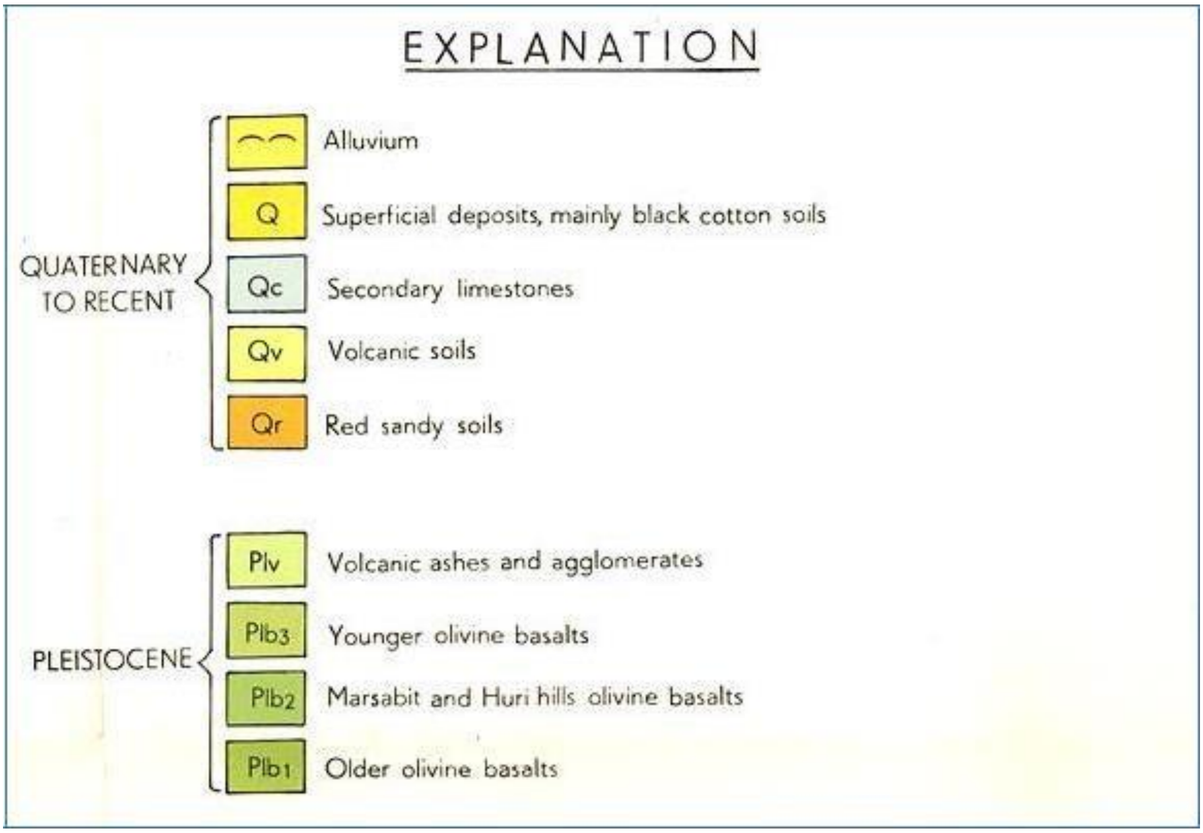


Figure 4.4: Geology of the study area (Geology of the North East Marsabit)



5 HYDROGEOLOGICAL DETAILS

5.1 Introduction

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within volcanic rocks, groundwater primarily occurs within fissure zones, fractures, sedimentary beds, lithological contacts and Old Land Surfaces (OLS) which characterize periods of erosion between volcanic eruptions and subsequent lava flows.

These OLS's comprise soils, weathered rocks and water-lain erosional material of volcanic origin. Lava flows rarely possess significant pores pace; instead, their porosity is largely determined by secondary features, such as cracks. However, pyroclastic deposits and especially sediments do have a primary porosity: the cavities between the mineral grains or clasts are usually open and interconnected. Consequently, they can contain and transmit water and are therefore potential aquifers

5.2 Groundwater Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has 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.

In the case of regional aquifer systems, it is possible to have the recharge occurring on one side of the aquifer and the groundwater traveling through the aquifer to its distant sections where it is either stored or discharged naturally as springs or swamps.

Areas of high altitude and therefore with higher rainfall and good vegetation cover are usually the commonest groundwater recharge zones in the project area i.e. **Mount Marsabit**.

5.3 Existing boreholes

Currently, the available boreholes have been done and are functional in Bubisa, Marsabit Town and Kubi Bagassa areas. Some of the boreholes at Turbi were pronounced dry because the driller encountered numerous challenges including loss of circulation and could not drill to the recommended depth. The successful boreholes close to the dry ones are massively successful with very good quality water.

Table 5.1: Boreholes within the vicinity of the project site (ministry of water &sanitation borehole database)

Borehole Name	TD (m)	WSL (m)	WRL (m)	PWL (m)	Depth of pump	Yield (m^3/hr)
REF: Bubisa Site						
Bubisa 3(Centre)	275	252	215.80	216.73	259	**14.54**
Bubisa 2(Tinga)	285	270	233.70	234.24	268	**12.02**
Bubisa 4 Youth camp	245	184, 204	187.30	188.30	231	**17.29**
Bubisa I	286	-	-	-	-	-
Range	**245-286**	**184-270**	**187.3-233.7**	**188.3-234.24**	**231-268**	**12.02-17.29**

Figure 5.1: Satellite extract showing the neighboring boreholes in relation to the proposed area

The boreholes drilled above show a good hydrogeological trend. The neighboring boreholes have been drilled to varied depths ranging from 245meters to 286meters. The deeper recommended boreholes towards Marsabit town posed a lot of drilling challenges as reported in a number of drilling reports.

The aquifer is deeper and attaining the total depth is normally blocked by a loose formation lying above it. Air Circulation is lost at this level making it difficult to drill past it. The successful boreholes at Bubisa often strike water at 252m, 270m and between 184m and 204m as displayed in the Table 5.1 above. The water rises due to its confined nature with the three boreholes recording water rest levels of 188.3m, 216.73m and 234.24m.

The listed three boreholes are highly productive, producing a range between 12.02 and 17.29 cubic meters per hour.

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

From the records, there is NO productive borehole located within 800m radius. However, considering that upper aquifers in the entire aquifer are quite vulnerable to depletion, all aquifers encountered from ground level down to a penetration depth of about 50m should be screened for even better productivity during higher recharge seasons. The proposed borehole will only abstract water from the deepest aquifers with penetration depth of below 150m from the data given above.

Thus there is no foreseeable interference with the existing boreholes or the groundwater abstraction trends since wants to abstract water for communal purposes only.

5.4 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has 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 zones are the northern part **of Mount Marsabit**. These areas receive higher rainfall than the investigated site. As a result, the aquifers identified are indirectly recharged by underground drainage of water falling some distance from their present locations.

5.4.1 Mean Annual Recharge

Although rainfall within the study area is not very high, regional recharge is of great essence in this area. Much of regional recharge occurs within the eastern flanks of the rift valley followed by base flow within the thick volcanic sheets and faults which characterise the region. However, this recharge mechanism is mainly important for the replenishment of (regional) volcanic aquifers and is what has been used to estimate the Mean Annul Recharge.

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

X mm x 5%

Mean Annual Recharge = N mm

However, this recharge amount is probably estimation due to the possibility of influent local recharge through local rivers and rainwater percolation through faults into the weathered/fractured basement rock system and overlaying old land surface (OLS).

5.5 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 number of boreholes in the area this is 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.

5.6 Aquifer Properties

5.6.1 Estimation Aquifer Transmissivity

The raw test Pumping Data of the above boreholes in Table 5.1 were not available to assist in calculation of Aquifer Transmissivity using **Jacob's formula (Driscoll 1986):**

Thus, in absence of proper pump test data, and lack of proper parameter indications the **Logan method of approximation** has been shown (Logan, 1965). This method however has errors of 50% or more and is thus used for estimation purpose only.

Aquifer Transmissivity (T) is thus estimated as follows:

$T=1.22Q/\Delta S$ Where: Q = Yield per day

ΔS = Draw down

5.6.2 Hydraulic Conductivity

The Hydraulic Conductivity (K) is estimated as follows:

K = T/Aquifer Thickness

5.6.3 Specific Capacity

The aquifer Specific Capacity (S) = $Q/\Delta s$.

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

D = Drawdown (m)

5.6.4 Groundwater Flux

The Groundwater Flux (F): F = K.i.h.w Where K- Hydraulic Conductivity = m/day

Where: i – Slope

h- Aquifer Thickness

w- Arbitrary distance,

5.7 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 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 ec 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.

6 GEOPHYSICAL INVESTIGATION METHODS

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 geo-electrical method) has been used.

6.1 Resistivity Method

Vertical electrical soundings (VES) were carried out to probe the condition of the sub-surface and to confirm the existence of deep groundwater. The VES investigates the resistivity layering below the site of measurement. This technique is described below.

6.2 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of the satu-rated rock the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces 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:

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

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

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

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:

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

6.3 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 Centre of the array, the potential field generated by the current is measured. From the observations of the current strength and the potential difference, and taking into account 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.

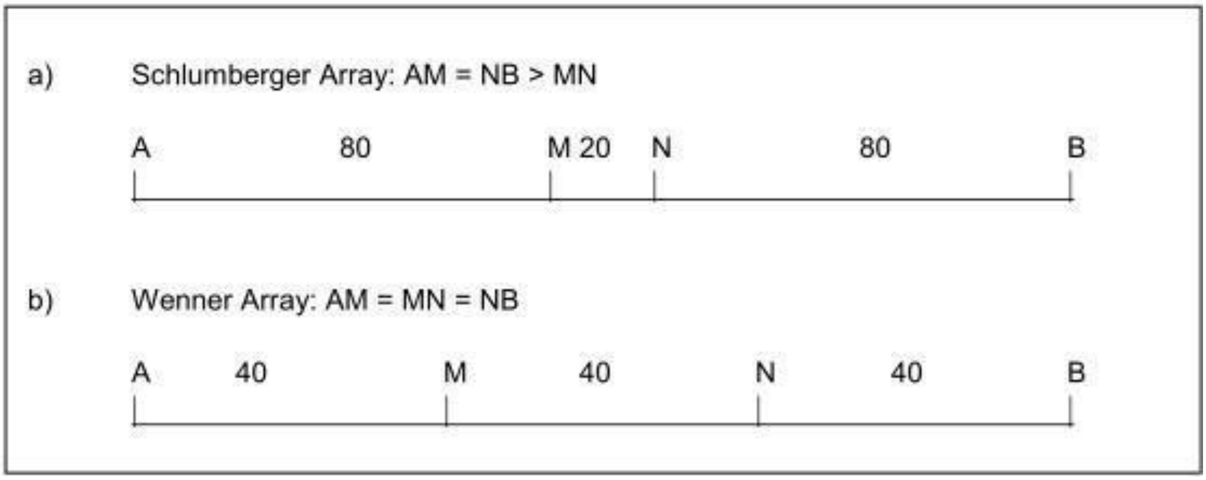


Figure 6.1: Examples of Schlumberger and Wenner Configurations for Resistivity Measurements, where: AB = current electrodes; MN = potential electrodes

A series of measurements made with an expanding array of current electrodes (Schlumberger Array) allows the flow of current to penetrate progressively greater depths. The apparent resistivity as a function of the electrode separation AB provides information on the vertical variation in resistivity. The depth of penetration varies according to the electrode array, but is also affected by the nature of the material beneath the array. The point at which a change in earth layering is observed depends on the resistivity contrast, but is generally of the order of a quarter of the current electrode spacing AB (Milsom 1989). By contrast, in a homogeneous medium the depth penetration is of the order 0.12 AB (Roy & Apparao 1971).

The calculated apparent resistivity is plotted against current electrode half separation on a bi-logarithmic graph paper to constitute the so-called sounding curve. The curve depicts a layered earth model composed of individual layers of specific thickness and resistivity. Interpretation of field data can be done with hand-fitted curves, but this method is time consuming, and practically limited to 3-layer solutions. Modern interpretation is computer-aided, using a curve fitting procedure based on a mathematical convolution method developed by Ghosh (1971).

While the resistivity method is a useful tool in groundwater investigations and borehole site surveys, its applicability and reliability should not be overestimated. The modelling of field data is often attended by problems of equivalence and suppression. Each curve has an infinite number of possible solutions with different layer resistivity's and depths (this is known as equivalence).

Mathematical convolution can easily lead to a well-fitting solution, which nonetheless does not correspond to reality. In general, the number of possible solutions is reduced by mutual correlation of several sounding curves, knowledge of the local geology and drilling data. When deposits with similar resistivities border each other, it is usually not possible to make a differentiation. Intermediate layers, occurring between deposits of contrasting conductivity, may go undetected, as they tend to be obscured within the rising or falling limb of the sounding graph (suppression). Additional data, in the form of borehole records, air photography and geological field observations, are required to produce a realistic interpretation.

It should be noted that the layered earth model is very much a simplification of the many different layers, which may be present. The various equivalent solutions, which can be generated by a computer programme, should therefore be carefully analyzed. In general, resistivity soundings should never be interpreted in isolation as this may lead to erroneous results.

6.4 Resistivity Profiles

In the recent times, this is an **Automatic mapping water detector** and is based on the **Earth's electromagnetic field** as the field source, based on the difference in the conductivity of different underground geological structures, and by studying the variation law of the electric field components at different frequencies to study the geological structure and changes, to find groundwater resources by scientific method. Changes in geological structure are displayed in real-time through multiple curves.

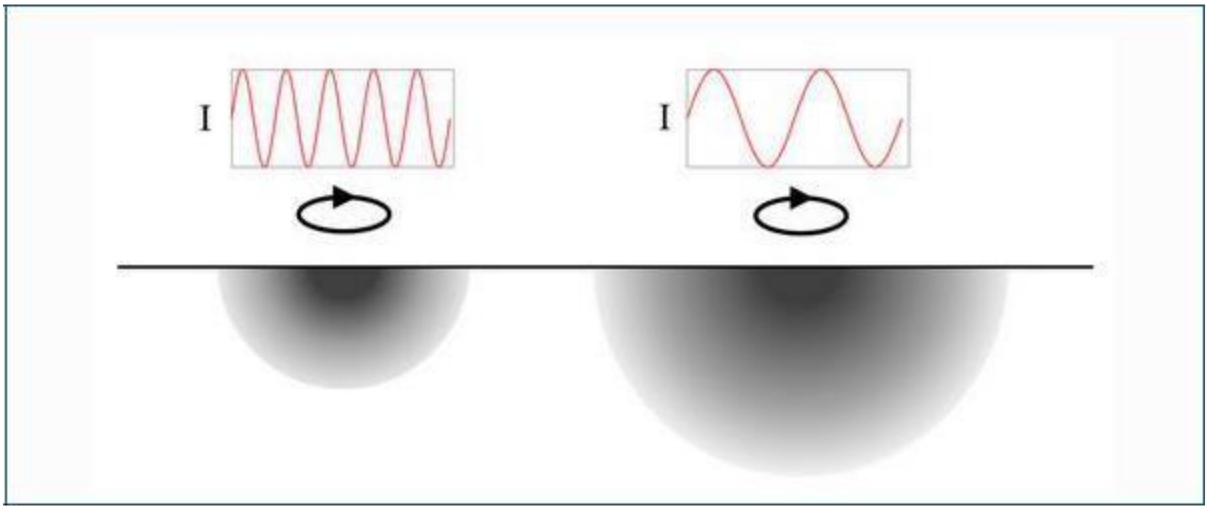


Figure 6.2: Depth Resolution with multiple frequencies

Resistivity profiles are usually carried in Wenner configuration, i.e. An electrode set-up with a uniform distance between potential and current electrodes (see Fig. 6.1). The entire array is moved across the area of interest. By doing so, lateral changes in apparent resistivity are measured, which reflect variations in the lithology, the depth of weathering or the water content. So-called "anomalies" may indicate the intersection of a fault (usually a negative anomaly), quartzite band (positive anomaly) or buried riverbed (anomaly depends on nature of surrounding deposits).

Usually such lineaments, which may also be observed on aerial photographs, are linked to the occurrence of groundwater. It must be noted that resistivity differences in a single profile array may largely reflect variations at the surface rather than underground. For this reason, it is usually not sufficient to carry out single-spaced profiles. The depth of penetration increases at greater electrode separations. A series of profiles at variable electrode separations will provide an indication of vertical resistivity trends.

Moreover, by repeating the same profile at a different configuration, it will become clear if the observed resistivity patterns are caused by surface phenomena or underground features.

6.5 Geo-electrical Layer Response

Vertical electrical soundings (VES) provide quantitative information on electrical resistivity as a function of depth. The computer-interpretation of the sounding data produces a layered model of the underground. The derived resistivity layers are used to infer the presence of water-bearing strata, their texture and salinity.

Water-bearing and/or weathered rocks have lower resistivities than unsaturated (dry) and/or fresh rocks. The higher the porosity of the saturated rock, the lower its resistivity, and the higher the salinity (or electrical conductivity EC) of the saturating fluids, the lower the resistivity. In the presence of clays and conductive minerals the resistivity of the rock is also reduced. The relation between the formation resistivity (ρ) and the salinity is given by the "Formation Factor" (F):

$\rho = F \times \rho_w = F \times 10{,}000 / EC$ (μ S/cm), where: ρ_w = resistivity of water In sediments or unconsolidated layers produced by weathering, the formation factor varies between 1 (for sandy clays) and 7 (for coarse sands).

Example: If a certain aquifer is considered with an average formation factor of 3, then an EC of 300 μ S/cm will give a formation resistivity of 100 μ m. The same material, when containing water with an EC of 1,500 μ S/cm, will have a resistivity of only 20 ρ m. Brackish water is marked by an EC of 2,000 to 10,000 μ S/cm, and a ρ w of 5 to 1. Deposits containing brackish water will therefore in most cases adopt a low formation resistivity (usually less than 10 μ m). Saline water with an EC of about 30,000 μ S/cm will reduce the resistivity of a formation to about 2 Ohms.

Clayey formations with fresh water will respond similarly to deposits with brackish or saline water: the fact that the same resistivity can be obtained for completely different hydrogeological units is known as the "equivalence-problem". Fresh and dry Basement rocks are marked by very high resistivities, with a common range from 1,000 to 10,000 Ohms. Moderately to slightly weathered but dry layers are less resistive, and usually show values between 100 and 500 Ohms, depending on the portion of clays, the degree of weathering and the water content. The resistivity further decreases if the deposits are water-bearing, to 20 to 200 μ m. The resistivity of impermeable clay layers (alluvial, or produced by intensive weathering of clay-forming minerals) usually varies between 2 and 10Ohmm, while similar figures are recorded for aquifers with brackish to saline water.

The greatest difficulty in the interpretation of resistivity measurements in Basement rocks is formed by:

a) *Equivalence*: the similar geophysical properties of layers with contrasting Hydrogeological characteristics (e.g. clay layers and layers with brackish water).
b) *Absence of distinct layer boundaries*: the decreasing degree of weathering with depth is usually not well-defined, but gradual. This will result in a gradual increase in resistivity, and not in a distinct set of geophysical layers.

c) *Suppression #1*: Potential aquifer layers of moderate thickness may fail to show a significant response in the recorded resistivity data (especially where these are deep). Thin aquifers embedded within a very thick deposit can easily remain undetected by surface geophysics. They will however show up in down-hole geophysical logs.
d) *Suppression #2*: The resistivity contrast between the (clayey) weathered zone and the fresh bedrock may be so high, that an intermediate saprock aquifer cannot be distinguished in the Graphic plot of the sounding.

Despite the problems of suppression attributed to the large resistivity contrast between fresh and weathered basement (point d), this is also a favorable attribute. Because of the large difference, the depth of weathering can be measured quite accurately. Considering that aquifers often occur towards the boundary of the weathered zone and the bedrock, the drilling depth can be determined, even if the actual aquifer does not show up as distinct geophysical layer.

Figure 6.3: The community members at the site during the survey

Figure 6.4: The existing nonoperational borehole at the site

7 FIELDWORK AND RESULTS

Field work was carried out on 8th of August, 2020. One – line profile was executed at the site followed by an extensive VES at the most potential point. The aim of the profile and VES was to determine the prevailing hydrostratigraphy, weathered zones, Fracture zones and any fault line at the site location deemed favorable to groundwater transmissivity.

7.1 Results

7.1.1 Site Profile

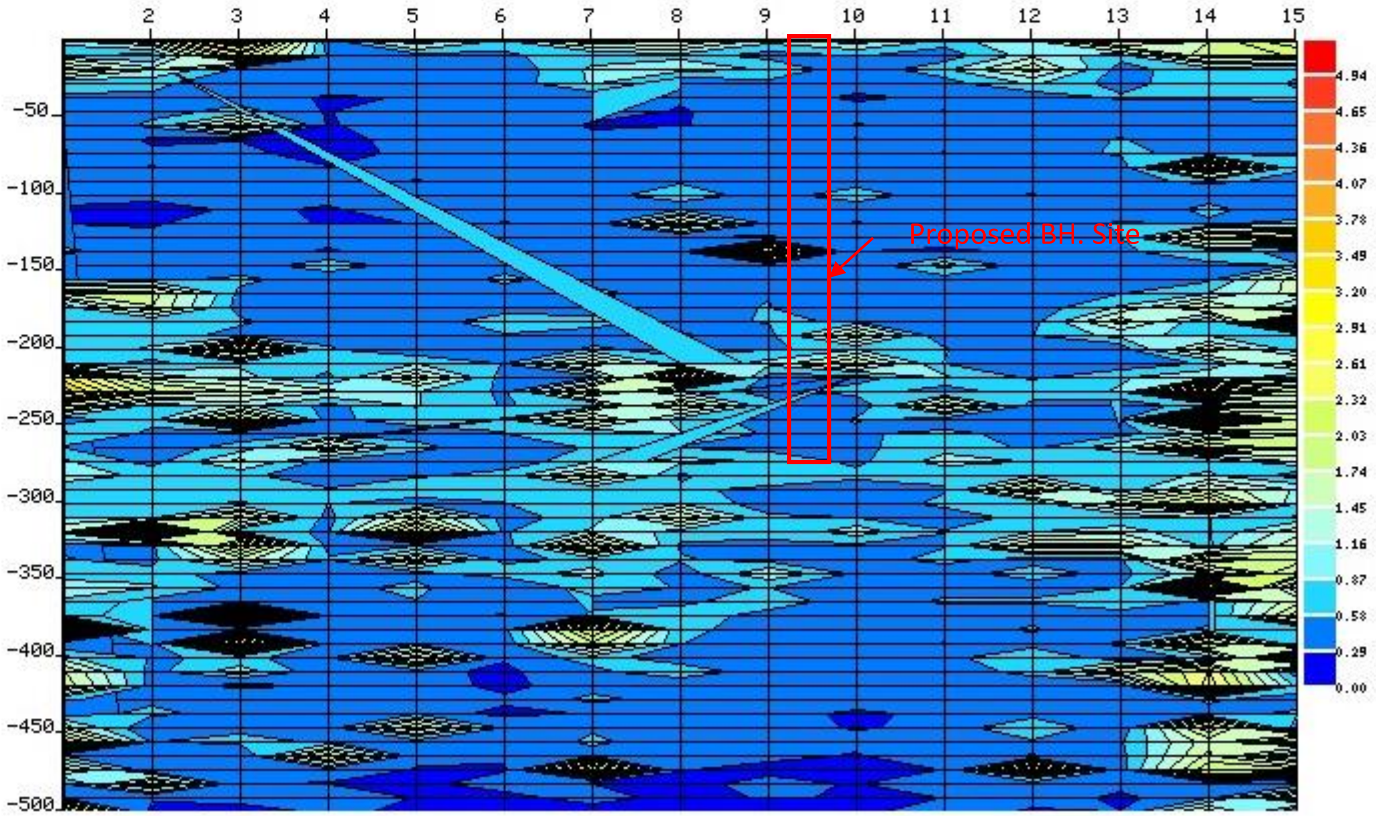


Figure 7.1: Site line processed profile showing a 2D view of the surveyed area.

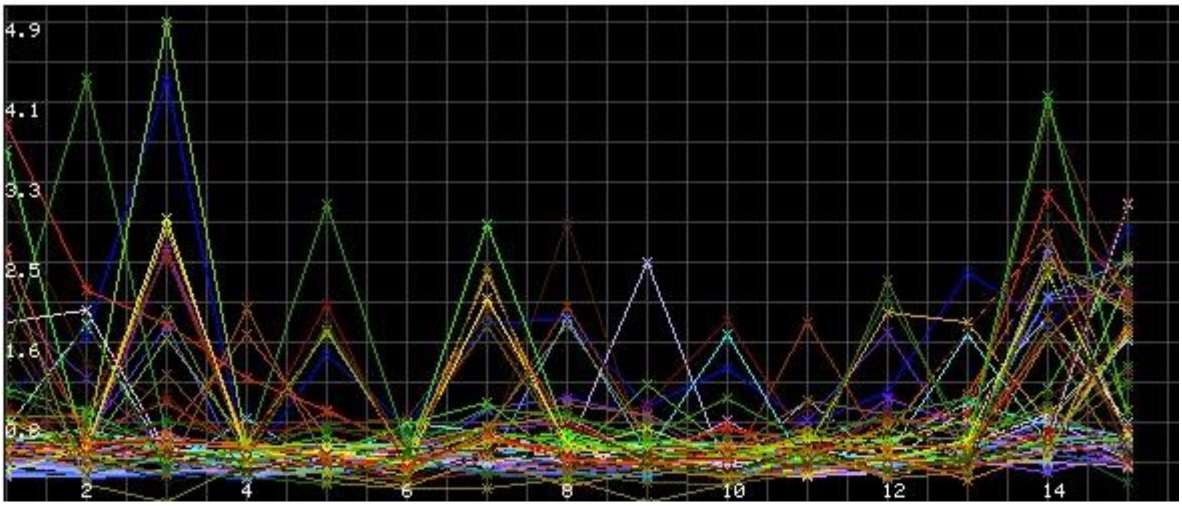


Figure 7.2: Site line raw profile resistivity curves per level

7.1.2 Recommended site VES

Figure 7.3: Surveyed Site VES curve model (Modelled in Gewin)

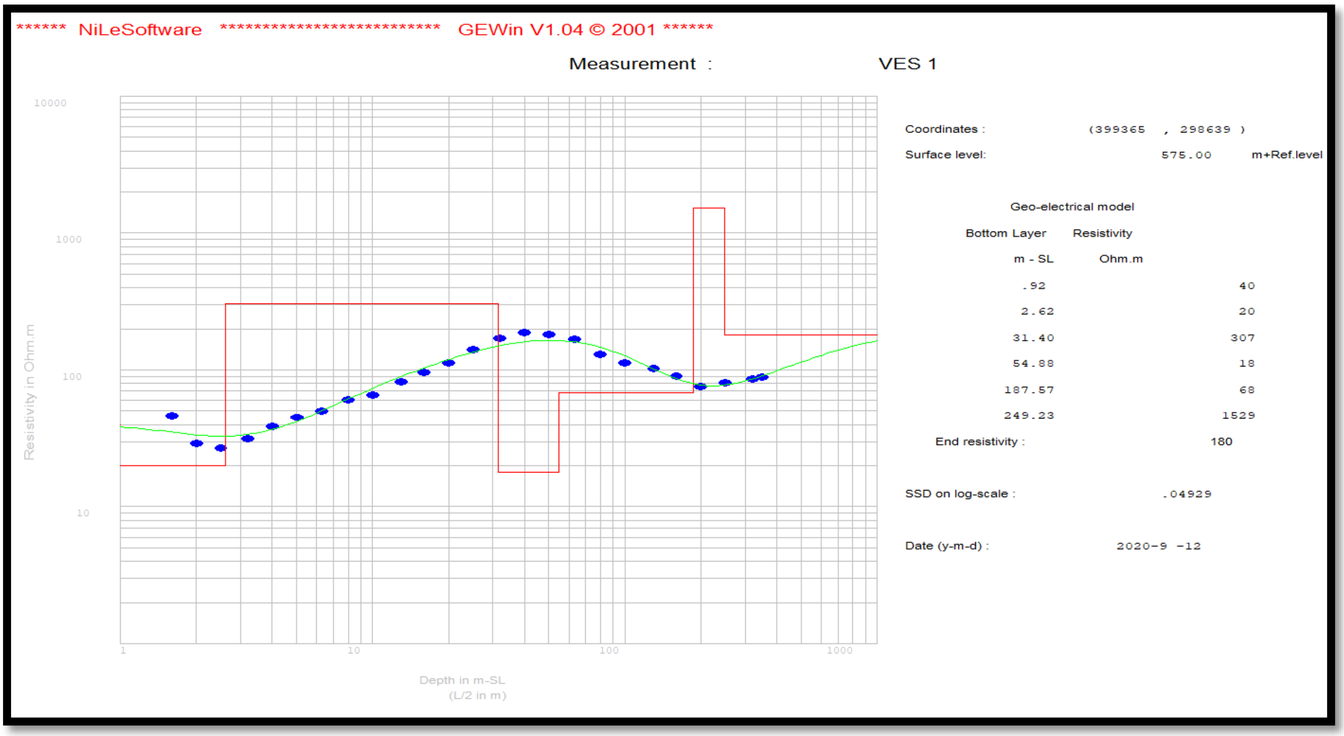


Table 7.1: Surveyed site Input measured curve values.

Input measured curve

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m	don't use
1	1.60	46.30	☐	21	160.00	89.63	☐
2	2.00	29.00	☐	22	200.00	75.51	☐
3	2.50	27.00	☐	23	250.00	80.31	☐
4	3.20	31.50	☐	24	320.00	86.34	☐
5	4.00	38.50	☐	25	350.00	88.32	☐
6	5.00	45.10	☐		.00	.00	☐
7	6.30	50.20	☐		.00	.00	☐
8	8.00	60.20	☐		.00	.00	☐
9	10.00	65.20	☐		.00	.00	☐
10	13.00	81.50	☐		.00	.00	☐
11	16.00	95.60	☐		.00	.00	☐
12	20.00	113.50	☐		.00	.00	☐
13	25.00	141.40	☐		.00	.00	☐
14	32.00	171.43	☐		.00	.00	☐
15	40.00	187.47	☐		.00	.00	☐
16	50.00	180.76	☐		.00	.00	☐
17	63.00	167.19	☐		.00	.00	☐
18	80.00	130.46	☐		.00	.00	☐
19	100.00	113.27	☐		.00	.00	☐
20	130.00	103.12	☐		.00	.00	☐

The site line profile above indicates deep weathering considered optimal for groundwater development due to its confining ability. The profile indicates the occurrence of the highly weathered /fractured basaltic rocks to depths below 300m: bottom of the confining layer thus isolating the location as the most reliable prospect for the proposed development of a borehole facility within this area. Further below 400m is a compact rock to below 450m.

The VES data done at the weathered zone as shown by the profile indicates the occurrence of the highly weathered /fractured basaltic rocks to depths of about 200m as the first minor aquifer. The bottom of the confining layer past 300meters could not be established with a VES but is shown in the above profile thus isolating the location as the most reliable prospect for the proposed development of a borehole facility within this area.

Drilling is recommended between station 9-10, profile 104/VES I (Marked on the profile) to an approximate depth of about 320m or until enough water has been struck according to the client's demand.

7.2 Site Identification

The study thus recommends that the borehole be drilled at between station 9-10, profile 104/VES I **(Marked on the profile) to an approximate depth of about 300m or until enough water has been struck. The site is marked and is well known to the client and their representatives.**

8 CONCLUSIONS AND RECOMMENDATIONS

On the basis of all the information gathered in the field, geological, geophysical and hydrogeological evidence, a borehole is recommended to be drilled at the site of **Station 07, Profile 01/VES - I** to a maximum depth of **about 320m or until sufficient water has been struck.**

The boreholes drilled above show a good hydrogeological trend. The neighboring boreholes have been drilled to varied depths ranging from 245meters to 286meters. The deeper recommended boreholes towards Marsabit town posed a lot of drilling challenges as reported in a number of drilling reports.

The aquifer is deeper and attaining the total depth is normally blocked by a loose formation lying above it. Air Circulation is lost at this level making it difficult to drill past it. The successful boreholes at Bubisa often strike water at 252m, 270m and between 184m and 204m as displayed in the Table 5.1 above. The water rises due to its confined nature with the three boreholes recording water rest levels of 188.3m, 216.73m and 234.24m.

The listed three boreholes are highly productive, producing a range between 12.02 and 17.29 cubic meters per hour. The yield of a borehole drilled at the recommended location is expected to be within the above range but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Water quality is expected to be good with exception of a number of mineral concentration which may be higher though not exceeding the maximum permissible WHO limits for human consumption.

It is thus recommended that:

1. The borehole should be drilled at between station 9-10, profile 104/VES I, position at a minimum of 8 inch diameter and to maximum depth of about **320m or until enough water has been struck.**
2. To install the **borehole** with mild steel casings and plasma cut – slotted screens.
3. The borehole hydraulic properties and aquifer characteristics should be determined during a 24-hour constant discharge test.
4. Samples taken during test pumping must be submitted to a recognized laboratory for full physical, chemical and bacteriological analyses.
5. A monitoring tube and master meter should be installed in the borehole to be able to monitor the water level and water consumption respectively.

With careful implementation of the project by adhering to the study's findings and recommendations and by following the Water Resources Authority's Guidelines (WRA) (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

Table 8.1: Construction summary

GPS Coordinates	Recommended Depth	Construction Requirements	Expected Yield (m^3/h)
37N 399365E, 0298639N: 575m	**320**	**203/153mm**	**12.02 – 17.29**

REFERENCES

Matheson, F.J. (1971)

Geology of the Garba-Tula area – Report 77, Mines and Geology Department, Ministry of Environment and Natural Resources."

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Water Resources Assessment Project – Ministry of Water Resources Development.

Charsley, T. J., et al (1987)

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Geology of the Isiolo area – Report 103, Mines and Geology Department, Ministry of Environment and Natural Resources.

APPENDICES

APPENDIX I: DRILLING TECHNIQUES

Drilling should be carried out with an appropriate tool. A percussion or rotary drilling machine will be suitable, though the latter is considerably faster. Geological rock samples should be collected at 2 meters intervals. Water struck and water rest levels and if possible estimates of the yield of individual aquifers encountered, should also be noted.

1. Well Design

The design of well should ensure that screens are placed against the optimum aquifer zones. The final design should be made by an experienced hydrogeologist.

2. Casing and Screens

The well should be screened with good quality screens considering the depth of the borehole; it is recommended that stainless steel casing and screens of 6" diameter be used. Slots should be of maximum 2mm in size.

We strongly advice against the use of torch-lit steel casings for screens. In general its use will reduce well efficiency (which leads to lower yields) increase pumping costs through greater draw down, increased maintenance's cost, and eventually reduction of the potential effective life of the well.

3. Gravel pack

The use of gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 81/2 diameter borehole screened at 6", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the plant and leading to gradual siltation of the well. The grain size of the gravel pack should be an average 2-4mm.

4. Well Construction

Once the design has been agreed, construction can be proceeded. In installing screen and casing, centralizers at 6 meter intervals should be used to ensure centrality within the borehole. This is particularly important to insert the artificial gravel pack all around the screen. If installed gravel packed sections should be sealed off, top and bottom with clay (2m), 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 well head can enter the well and thus prevent contamination.

5. Well Development

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 borehole wall. 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 development and cleaning wells.

Wells 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.

6. 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 not only does this give an indication of the success of the drilling, design and development, but it also yields information on aquifer parameters which are vital to a hydro geologist.

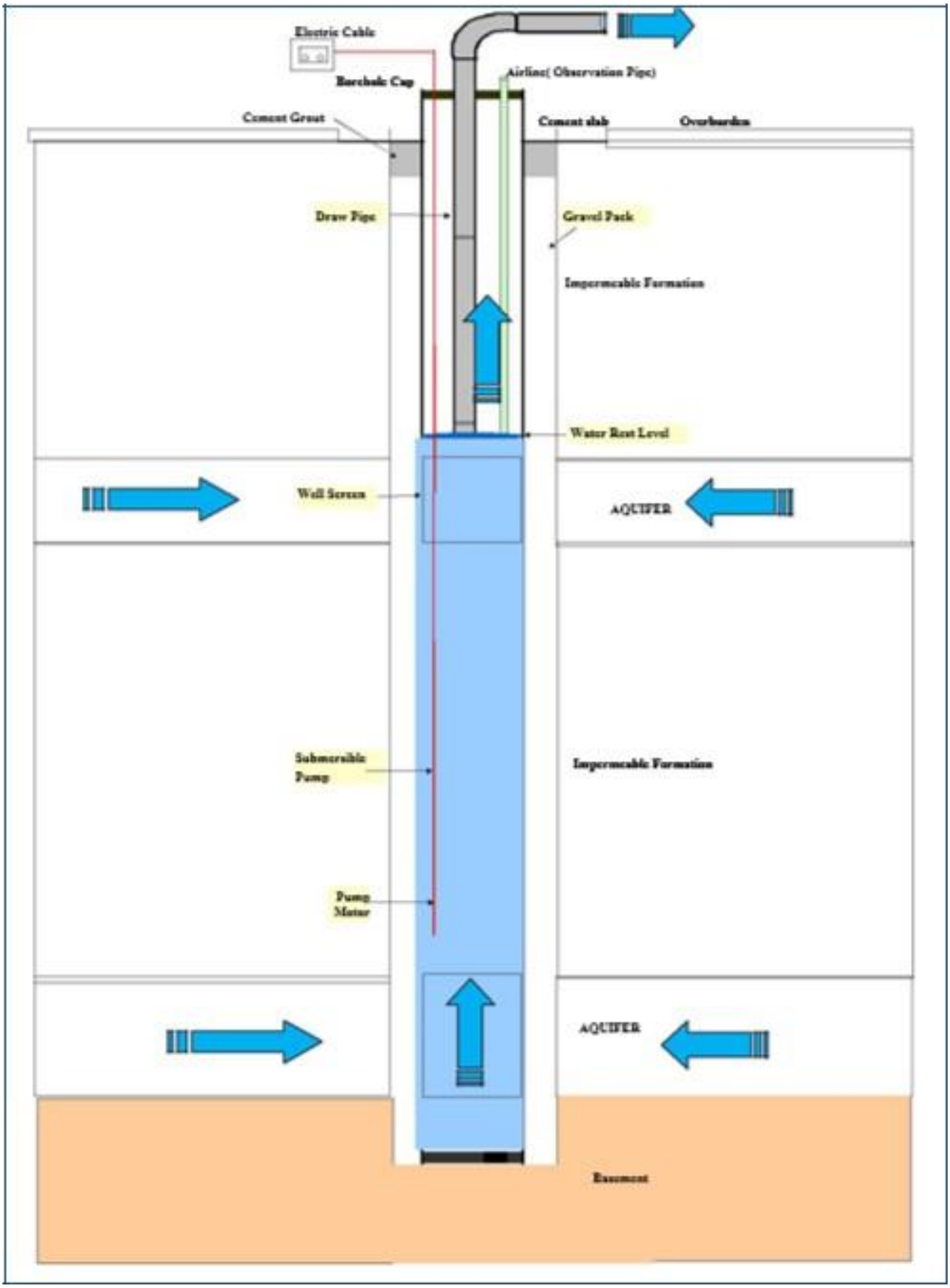
A well test consists of pumping a well from measured start (SWL) at a known or measured yield and recording the rate and pattern by which the water level within the well changes. Once as dynamic water level (DWL) is reached, rate of inflow to the well equals the rate of pumping.

The duration of the test should be 24 hours with a further 24 hours for a recovery test or less depending on the rate of recovery during which the rate discovery to SWL is recorded. The results of the test will enable a hydro geologist to calculate the test recorded. The results of the test pumping rate, the installation depth and the drawdown for a given discharge rate.

It is nowadays-common practice to carry out a so-called step draw down test, in which the yield during testing increases stepwise. Each step is continued until hydraulic equilibrium is reached after which the yield is increased wit 50 to 100% towards the end of the test a water sample of 2 liters should be collected for chemical analysis.

7. Pump Installation

After testing and analysis of the results the pump can be selected and installed. It is important to select the right type of pump, which matches the characteristic of the well. It should have the right capacity to lift the water directly to the storage tank. The pump should never be installed in the slotted section, but at least 2 meters above or below the screened section. The electric submersible pump should be protected with a cut-off switch 2 meters above the pump inlet level.



Standard Borehole design

APPENDIX II: SKETCH

Scaled sketch map showing the borehole location within Bubisa area (Adapted from Google Maps)

APPENDIX III - Acceptable Ionic Concentration - Various Authorities

		World Health Organization: 1983 Guidelines;		1971 Int. Standards;	**European Community:** EC Directive 1980 relating to the quality of water intended for human consumption:		
Substance or Characteristic		Guideline Value (GV)		Upper limit (HL), (tentative)	Guide Level (GL)	Max. Admissible Concentration (MAC)	
Inorganic Constituents of health significance;							
Antimony	Sb						0.01
Arsenic	As	0.05		0.05			0.05
Cadmium Cd	0.005		0.01			0.005	
Chromium	Cr	0.05		0.05			
Cyanide	CN	0.10		0.05			0.05
Fluoride	F	1.5		1.7			1.5
Lead	Pb	0.05		0.10			0.05
Mercury	Hg	0.001		0.001			0.001
Nickel	Ni						0.05
Nitrates		10 (as N)	45 (as N03)		25 (as NO3)	50 (as NO3)	
Selenium Se			0.01			0.01	

Other Substances		**GV:**		**Highest** Desirable	**Maximum** Permissible		**GV:**		**MAC:**	
			Level:		Level:					
Aluminium	Al		0.20					0.05		0.20
Ammonium	NH4							0.05		0.50
Barium	Ba							0.10		
Boron	B							1.0		
Calcium	Ca				75	50		100		
Chloride	Cl		250		200	600		25		
Copper	Cu				0.05			0.10		
Hydrogen Sulphide H2S		ND							ND	
Iron	Fe		0.30		0.10	1.0		0.05		0.20
Magnesium	Mg		0.10		30	150		30		50
Manganese	Mn		0.10		0.05	0.50		0.02		0.05
Nitrite	NO2									0.10
Potassium	K							10		12
Silver	Ag									0.01
Sodium	Na		200					20		175
Sulphate	SO4		400		200	400		25		250
Zinc	Zn				5.0	15		0.10		
Total Dissolved Solids			1000		500	1500				1500
Total Hardness as CaCO3			500		100	500				
Colour	^{o}Hazen		15		5	50		1		20
Odour			Inoffensive		Unobjectionable				2 or 3 TON	
Taste			Inoffensive		Unobjectionable				2 or 3 TON	
Turbidity	(JTU)		5		5	25		0.4		4
pH			6.5 - 8.5 7.0 - 8.5		6.5 - 9.2 6.5 - 8.5	9.5 (max.)				
Temperature	oC							12		25
EC	uS/cm							400		
Notes	ND - Not Detectable				IO - Inoffensive					
	GL - Guide Level				UO - Unobjectionable					

(Based on Table 6.1, in Twort, Law & Crowley, 1985 - Water Supply, Edward Anorld, London).