HYDRO-GEOLOGICAL/GEOPHYSICAL INVESTIGATION REPORT

FOR

AWARSITU WATER PROJECT

C/O IWASCO P.O. BOX 491 ISIOLO

ON COMMUNITY LAND

SIBILTOKOCH AREA, MERTI SUB-COUNTY, ISIOLO COUNTY

Prepared by

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This report has been printed on both sides reduce paper consumption and save trees.

Summary

This report describes a hydro-geological assessment study conducted in support of an application for a Water Permit in respect of a borehole for Awarsitu water project Sibiltokoch area, Bulesa Location, Chari Ward of Merti Sub-County, Isiolo County.

A hydro-geological assessment is a study carried out to establish the availability of groundwater and its quality where possible. This supplemented by a geophysical survey that investigates the rock resistivities. The data obtained from the resistivities is used to infer the geology below the point of investigation. The obtained information, after the assessment and survey, guides the Client to proceed with drilling the borehole. It also guides the driller to what depth to drill and expected lithology and thickness of the aquifer. The assessment is essential in improving the success rate of boreholes drilled. The assessment also assists in the management and protection of groundwater in the area.

The study was carried out as follows by desk study, geophysical/hydro-geological study, analysis of geophysical data and correlation with neighbouring boreholes, data analyses and reporting.

The project location is in a community land situated in Sibiltokoch area, Bulesa Location, Chari Ward of Merti Sub-County, Isiolo County**.** The geographic location of a point in the land is It lies within the 1:250,000 Survey of Kenya topographic for Garba Tula (sheet No. NA-37-14). The site is approximately 168 kilometres by road to the north-east of Isiolo and 7 kilometres to the south of Bulesa market by road.

It is important to note that the Client must obtain all approvals before drilling commences. These maybe, but not limited to, authorization to drill from WRA and an EIA license from NEMA.

The topography is virtually level to gently undulating plains rising in altitude to the north where they are interrupted by isolated inselbergs or discontinuous hills and ridges of erosion-resistant rocks. The drainage ways generally are broad and shallow and many are ill defined. A few of the major drainage ways are extensive and form fairly well integrated systems that extend entirely across or nearly across the area. The area is drained by river Ewaso Ng'iro. The river has variable drainage from the headwaters at Mt. Kenya.

The climate of the area is semi-arid. The average temperature is 26.8 °C. About 317 mm of precipitation falls annually. Precipitation is the lowest in June, with an average of 0 mm. The greatest amount of precipitation occurs in April, with an average of 104 mm.

The geology of the area is composed of colluvial deposits and alluvium. Geology of the project area is characterized by Quaternary sediments which overlies Pliocene sediments which are clayey. The local aquifers are alluvial aquifers scattered and spread all along River Ewaso Ng'iro and on top of other systems composed of coarse alluvial deposits.

The most important objective of any geophysical survey for groundwater prospecting is to translate the result of geophysical interpretation in terms of the subsurface hydrogeology. For this purpose a location map of potential sites for drilling to groundwater are prepared. The resistivity of subsurface materials depends more on the pore volume including fractures, degree of saturation, weathering, and conductivity of the saturant than on the rock type.

Geophysical investigations as applied to this investigation was essential to determine the subsurface layering (depth and thickness) and to identify presence of sub-surface water. Magnetotelluric method was used in this investigation. 4 (four) profiles were carries out in the area.

Groundwater quality from the borehole is expected to be potable and may not infringe on KeBS or WHO standards.

Conclusions and Recommendations

Conclusion

Based on the collected and analysed data, the hydro geological prevailing conditions it can be concluded as follows:

- There are good prospects of striking groundwater within the investigated site.
- Water from this borehole is expected to be of fairly good quality.

Recommendations

Based on the above, it is recommended that:

- A borehole may be drilled at the site indicated in Profile 4 at the land. The site is known to the the Client. The location of the proposed drilling site is latitude 0.9638^0 North 38.55759^0 East.
- The borehole should have a diameter of at least 8″ and a minimum depth of 150 meters and a maximum of 200 metres.
- It should be lined with appropriate casings and screens.
- It should be protected from possible sources of contamination by grouting at least 2 meters length of the borehole from the ground surface.
- The borehole should be properly gravel packed to enhance yield.
- The drilling and test pumping should be supervised by a Hydrogeologist/ Licensed Water Resources Professional.
- Upon completion, the borehole must be fitted with an airline/ piezometer and a master meter to facilitate monitoring of static water level and groundwater abstractions respectively.
- A two (2) litres water sample of this water is to be collected in a clean container and be taken to any competent water-testing laboratory for a chemical, physical and bacteriological analysis before the water is made available for use.
- It is a legal requirement, stipulated in the Water Act 2016, that the Client applies for an authorization to drill from WRA. After drilling, the borehole completion record, test pumping results, completion certificate and water quality analysis results must be submitted to WRA for issuance of a permit.
  - An authorization to drill does not constitute a permit to use the water.

Contents

List of Figures

List of Tables

Nomenclature

Alluvial	Pertaining to or composed of alluvium or deposited by a stream or running water
Aquifer	May be broadly defined as saturated fractured rock or sand from which usable volumes of groundwater can be extracted
Authority	Water Resources Management Authority
Borehole	A machine-drilled engineered structure designed to remove water from an aquifer
Drawdown	The difference between static water level and dynamic water level in a pumped borehole or well, expressed in metres
Dynamic water level	The level of water in a pumped well or borehole (also called pumping water level, or pwl).
Fracture	A break or crack in the bedrock.
Groundwater	water found beneath the earth's surface in pores and fractures of soil and rocks
Hydraulic conductivity	The rate of flow of water through a cross section of unit area under a unit hydraulic gradient expressed as volume per unit area per unit time, usually as m3/day/m2, reducing to m/day.
Igneous rocks	Rocks that solidified from molten or partly molten materials, that is from a magma or lava.
Lithology	All the physical properties, the visible characteristics of mineral composition, structure, grain size etc. which give individuality to a rock.
Metamorphic rocks	Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.
Pumping test	A test that is conducted to determine aquifer and/or well characteristics.
Recharge	A general term used to describe the volume of and mechanism by which water enters groundwater storage. The recharge path, and changes in the environment which may affect recharge, are important considerations in groundwater resources analysis. Recharge may be expressed as m3/yr, or mm/yr, or as a percentage of mean annual rainfall.
Regolith	The layer of incoherent rock material that nearly everywhere forms the surface of the land and rests on Bedrock, or weathered residual overburden.

Sedimentary rocks	Clastic rocks resulting from the consolidation of loose sediments that has accumulated in layers or carbonate rocks originated from chemical precipitation and accumulation of organic matter.
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 (m2/day).
Weathering	The in-situ physical disintegration and chemical de-composition of rock materials at or near the earth's surface.
Yield	Volume of water discharged from a well.

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1. Baseline information

1.1. Introduction

This report describes a hydro-geological assessment study conducted in support of an application for a Water Permit in respect of a borehole for Awarsitu water project Sibiltokoch area, Bulesa Location, Chari Ward of Merti Sub-County, Isiolo County.

A hydro-geological assessment is a study carried out to establish the availability of groundwater and its quality where possible. This supplemented by a geophysical survey that investigates the rock resistivities. The data obtained from the resistivities is used to infer the geology below the point of investigation. The obtained information, after the assessment and survey, guides the Client to proceed with drilling the borehole. It also guides the driller to what depth to drill and expected lithology and thickness of the aquifer. The assessment is essential in improving the success rate of boreholes drilled. The assessment also assists in the management and protection of groundwater in the area.

1.2. Study methodology

The study was carried out as follows:

- Detailed desk study. This included review of existing information, maps, and reports in the vicinity of the project area, borehole data etc.
- Geophysical/Hydro-geological study,
- Analysis of geophysical data and correlation with neighbouring boreholes.
- Data analyses and reporting.

1.3. The Client

The Client is

Awarsitu Water Project
c/o IWASCO
P.O. Box 491,
Isiolo

IWASCO shall hereafter be referred to as the Client.

1.4. Location

The project location is in a community land situated in Sibiltokoch area, Bulesa Location, Chari Ward of Merti Sub-County, Isiolo County. The geographic location of the proposed site is latitude 0.9638^0 North 38.55759^0 East at an altitude of 329.97 metres above sea level. It lies within the 1:250,000 Survey of Kenya topographic for Garba Tula (sheet No. NA-37-14).

The site is approximately 168 kilometres by road to the north-east of Isiolo and 7 kilometres to the south of Bulesa market by road.

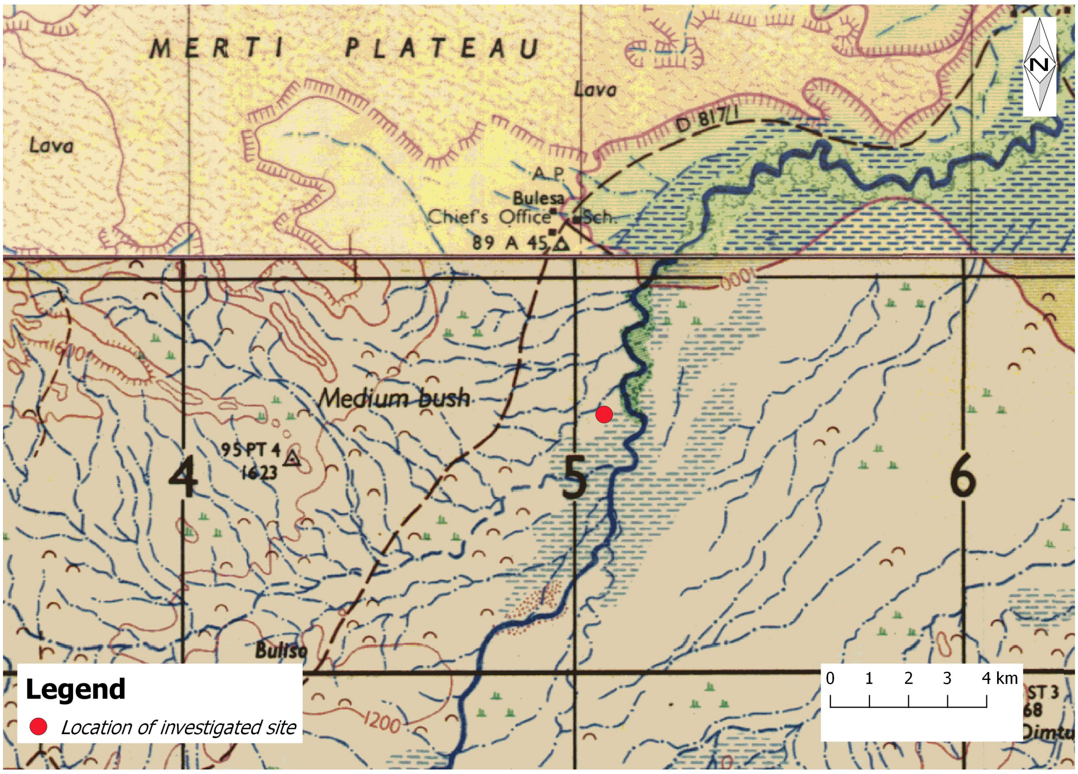

Figure 1.1. – Map extract showing the location of the project

It is important to note that the Client must obtain all approvals before drilling commences. These maybe, but not limited to, authorization to drill from WRA and an EIA license from NEMA.

1.5. Water Demand

The community relies on water supply from river Ewaso Nyiro. Estimated demand is estimated to be 20m^3/day.

1.6. Physiography, Drainage and Land use

The topography is virtually level to gently undulating plains rising in altitude to the north where they are interrupted by isolated inselbergs or discontinuous hills and ridges of erosion-resistant rocks. The entire area is underlain by semi consolidated to consolidated deposits of Pliocene to Holocene age. The extensive, nearly level plains are dissected by broad ephemeral drainage ways. The entire area/County is drained by intermittent streams which generally flow for only a few hours at a time, once or twice a year when rainfall is adequate.

The drainage ways generally are broad and shallow and many are ill defined. A few of the major drainage ways are extensive and form fairly well integrated systems that extend entirely across or nearly across the area. These probably were formed during a period of heavier rainfall than today, presumably during the Pleistocene Epoch(Swarzenski and Mundorff, 1977) .

The area is drained by river Ewaso Ng'iro. The river has variable drainage from the headwaters at Mt. Kenya. In the Mt. Kenya area, its flows is variable and low flows are experienced during the dry period. At the investigated site, it has reached the stage of early maturity. Its course meanders through a wide belt of its own alluvium. When tributary streams reach the alluvium they often flow along the edge instead of cutting directly into the river. The flow diminishes downstream because of evaporation before terminating into the Lorian Swamp. Ewaso Ng'iro is in drainage basin 5 while the investigated area is in sub-basin 5ED.

1.7. Climate

The nearest town is Merti and the climate of the investigated site can be inferred from this. Merti's climate is a desert one. During the year, there is virtually no rainfall. The climate here is classified as BWh by the Köppen-Geiger system. The average temperature in Merti is 26.8 °C. About 317 mm of precipitation falls annually. Precipitation is the lowest in June, with an average of 0 mm. The greatest amount of precipitation occurs in April, with an average of 104 mm (climate data.org, 2018).

Table 1.1. – Climate of Merti

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature (°C)	27.1	27.8	28.3	27.7	27.1	26	25.4	25.5	26.4	27.3	26.8	26.4
Min. Temperature (°C)	19.4	19.9	20.9	21.1	20.3	19.2	18.7	18.6	19.1	20.2	20.2	19.5
Max. Temperature (°C)	34.8	35.7	35.7	34.3	33.9	32.9	32.1	32.5	33.8	34.4	33.4	33.4
Precipitation / Rainfall (mm)	4	12	30	104	18	0	0	0	0	24	90	35

Between the driest and wettest months, the difference in precipitation is 104 mm. The variation in temperatures throughout the year is 2.9 °C.

1.8. Potential Evaporation

Potential evaporation or potential evapo-transpiration (PET) is defined as the amount of evaporation that would occur if a sufficient water source were available. Woodhead (1968) developed an empirical equation relating elevation and annual potential evaporation from 78 climate stations in Kenya, in the form:

$E_o = 2422 - 0.358h \quad (r^2 = 0.66)$,

Where h is site elevation above sea level E_o is potential evaporation in millimetres per year.

From the above formula, potential evaporation around the Client's land (which lies at≈329.9 m asl) is ≈2304 mm/yr

2. Geology and Hydrogeology

2.1. Geology

The geology of the area is composed of colluvial deposits and alluvium.

Pliocene strata are overlain by a relatively thin veneer of soils or Quaternary alluvium. The strata generally consist of interbedded clay, sand, and weathered gravel in a clayey matrix, largely derived from erosion of the basement rocks to the west. These alluvial sediments and sands are deposited in the channels of the major watercourses of the areas (R. Ewaso Ng'iro) and in narrow adjacent flood plains (Swarzenski and Mundorff, 1977).

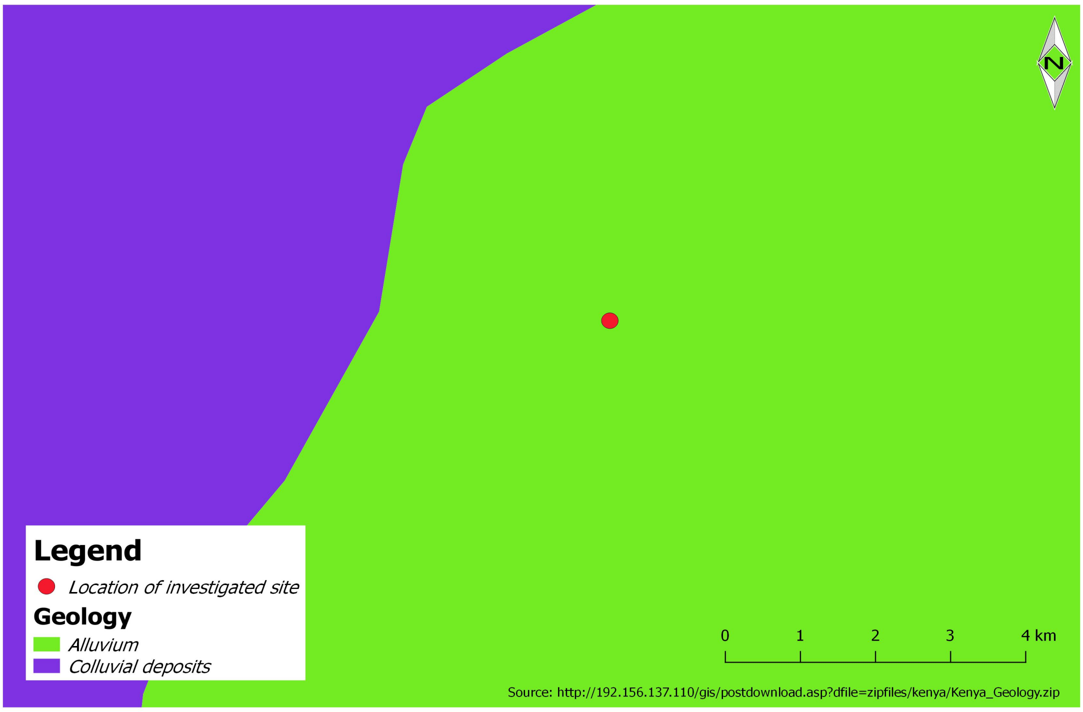

Figure 2.1. – Map showing geology of the project site

2.2. Hydrogeology

The hydrogeology of an area is normally dependent upon the nature of the parent rock, structural features, weathering processes, recharge mechanism and the form and frequency of precipitation. The regional hydrogeology where the project area lies is characterised by sedimentary deposits which are pure, unconsolidated sands that are highly transmissive. However, permeability rapidly decreases in the presence of clays even when the percentage volume of clay is small. Heavy clays, which may be marked by porosity as high as 50%, have low Transmissivity. Clays do not transmit water due their impervious character. Groundwater in sedimentary rocks is limited to pores, fractures, faults and erosion layers within the sedimentary succession.

2.2.1. Groundwater occurrence

Geology of the project area is characterized by Quaternary sediments which overlies Pliocene sediments which are clayey. Vegetation cover comprises thorny shrubs and thickets. The local aquifers are alluvial aquifers scattered and spread all along River Ewaso Ng'iro and on top of other systems composed of coarse alluvial deposits.

Some boreholes have been drilled in the project area. Available records were studied for 5 boreholes within a radius of about 26-km from the present site. Results of the data inventory are presented in table 2.1below (Waweru, 2018).

Table 2.1. – Boreholes around

BH No.	Owner	Location	Depth	WSL	WRL	Q	PWL
C-		(X km dir)	(m bgl)	(m bgl)	(m bgl)	(m3/hr)	(m)
3689	MOWD	25 SW	153	51	16	1.5	97
3853	DWD	26 NE	67	34	22	4.62	-
10527	Merti Quran Centre	25 NE	57	8, 26, 36	15.8	13.3	18.1
-	Kenya Red Cross Bulesa Bh	0.49 E	42	20, 34	25.59	15.9	30.05
-	Awarsitu Bh	2.0 E	64	-	2.84	5.1	-

2.2.2. Aquifer Characteristics

Aquifer characteristics enable the hydro geologist to quantify the amount of groundwater that can be abstracted from a given aquifer. This enables the hydro geologist calculate rather than infer the flow beneath. Characteristics specific capacity (Q/s), transmissivity (T), Storage coefficient, hydraulic conductivity (K) and groundwater flux of the aquifer surrounding the investigated site are discussed below.

To calculate the area aquifer properties, testing pumping data of borehole Kenya Red Cross Bulesa was adopted.

The borehole has a total drilled depth of 42m, yield of 15.9 m^3/hr, Water Struck levels of 20, 34 m, Water Rest level of 25.59 m and pumping water level of 30.05 m. It had a drawdown of 2.3m.

2.2.2.1. Specific Capacity, Q/s

The specific capacity (S_c) is a crude indication of the efficiency of the borehole as an engineered structure, and is calculated by dividing the discharge rate (as m^3/day) by the total drawdown in metres.

$$SC = Q/\triangle s$$

where

SC = Specific capacity, m^2/d
Q = yield in m^3/day
$\triangle$s = total drawdown in metres

High specific capacities generally indicate high transmissivities, low specific capacities the opposite. It is useful for comparing the efficiency of the same well through time (e.g., to see if the well requires rehabilitation).

Q = 381.6 m^3/day
$\triangle$s = 2.3m
SC= 165.913 m^2/day.

The Specific Capacity obtained just after a well is drilled and properly developed is typically the highest value that will be produced and is the baseline for comparison for all future values. As time goes by, the Specific Capacity will decline as plugging of the well's perforations or filter pack occurs or as static water levels change. Specific

Capacity testing should be performed at least semi-annually and water levels (static and pumping) should be collected monthly to provide early detection of potential well problems. Rehabilitation work should be scheduled when a well's Specific Capacity drops by 15% or more (Southeast Hydrogeology, 2017).

2.2.2.2. Transmissivity, T

The transmissivity is a measure of how much water can be transmitted horizontally, such as to a pumping well.

It is the product of the average hydraulic conductivity (or permeability) and the thickness of the aquifer. Consequently, it is the rate of flow under hydraulic gradient equal to unity through a cross-section of unit width over the whole thickness of the aquifer. It is designated by symbol Kd or T. It has the dimensions of Length^3/Time x Length or Length^2/Time and is, for example, expressed in m^2/day.

Strictly speaking, transmissivity should be determined from the analysis of a well test.

The Thiem's formula is only applicable where the test pumping data is available and is read as follows:

$$T = \frac{2.3 \cdot Q}{4\pi \cdot \triangle s}$$

where

T = coefficient of transmissivity in m^2/day
Q = pumping rate or yield m^3/day
Δs = change in drawdown between any two times on the log scale whose ratio is 10 (one log cycle).

Logan method is also used to estimate Transmissivity where test pump data is not available. Logan (1964) developed a relationship between specific capacity and transmissivity. To estimate the transmissivity using the Logan's method a far reaching simplified approach of Thiem's method is used. It only requires as input parameters the yield and drawdown in the pumped well. Because of the simplifications, it is an approximate method. The Logan formula reads as follows:

$$T = 1.22 \cdot \frac{Q}{s}$$

Where

T = Transmissivity (m^2/day)
Q = Tested yield (m^3/day)
s = Drawdown (m)

Therefore,

$$T = 1.22 \cdot \frac{381.6m^3/d}{2.3m} = 202.41m^2/d$$

2.2.2.3. Specific Retention or Specific Yield, S_y

Specific yield tells how much water is available for man's use, and specific retention tells how much water remains in the rock after it is drained by gravity. Thus,

$$n = S_y + S_r$$

$$S_y = \frac{V_d}{V_t}$$

$$S_t = \frac{V_r}{V_t}$$

where

n is porosity, $S_y$is specific yield, $S_r$is specific retention, V_d is the volume of water that drains from total volume of V_t, V_r is the volume of water retained in a total volume of V_t, and V_t is the total volume of a soil or rock sample.

There is no data to calculate this parameter. The parameter can only be inferred from the following table (Heath et al., 1982)

Table 2.2. – Selected values of porosity, specific yield and specific retention

Material	Porosity (%)	Specific yield (%)	Specific retention (%)	
Soil	55	40	15	
Clay	50	2	48	
Sand	25	22	3	Inferred for this site
Gravel	20	19	1	
Limestone	20	18	2	
Sandstone (semi-consolidated)	11	6	5	
Granite	0.1	0.09	0.01	
Basalt (young)	11	8	3	

2.2.2.4. Hydraulic Conductivity, K

Typical values of hydraulic conductivity for different materials vary from several hundreds of metres per day for gravels, down to imperceptible rates for consolidated hard rocks such as schist. While the dimensions of hydraulic conductivity have the units of velocity (distance divided by time), it is in fact a flux representing a discharge of water per unit area under a hydraulic gradient of 1, with the full units of m ^{3} /day/m ^{2} . In other words, the volume of water passing through a square cross-sectional area of the aquifer in a given time. It can't be used to describe the rate of groundwater flow on its own without knowledge of the hydraulic grade, which is the driving force causing water to move and the pore space through which the water movement occurs.

Since transmissivity is the product of aquifer thickness d and hydraulic conductivity K, we can calculate K for the aquifer exploited by the boreholes around.

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

Thus,

$$K = \frac{202.41m^2}{10m} = 20.241m/day$$

2.2.2.5. Groundwater Flux

Groundwater flux can be defined as the rate of discharge of groundwater per unit area of a porous medium measured at right angle to the direction of flow. Groundwater flux can be calculated using Darcy's equation, thus:

$\mathbf{Q = T.i.W}$,

Where:

T = transmissivity (m^2/d), i = hydraulic gradient, W = aquifer width (L).

There was no sufficient data to calculate this parameter.

3. Geophysics

3.1. Introduction

The most important objective of any geophysical survey for groundwater prospecting is to translate the result of geophysical interpretation in terms of the subsurface hydrogeology. For this purpose a location map of potential sites for drilling to groundwater are prepared. The resistivity of subsurface materials depends more on the pore volume including fractures, degree of saturation, weathering, and conductivity of the saturant than on the rock type.

Geophysical investigations as applied to this investigation was essential to determine the subsurface layering (depth and thickness) and to identify presence of sub-surface water. Magnetotelluric method was used in this investigation.

3.2. Method

The magnetotelluric method or magnetotellurics (MT) is an electromagnetic geophysical exploration technique that images the electrical properties (distribution) of the earth at subsurface depths. The energy for the magnetotelluric technique is from natural source of external origin. When this external energy, known as the primary electromagnetic field, reaches the earth's surface, part of it is reflected back and remaining part penetrates into the earth. Earth acts as a good conductor, thus electric currents (known as telluric currents) are induced in turn produce a secondary magnetic field (Naidu, 2012).

The concept finds its applications in all types of geological settings like plate boundaries, fault zones, volcanic regions as well as in the exploration of mineral resources. It is used for hydrogeological investigations, archaeological studies and waste disposal monitoring, using integrated interpretation and joint inversion with information from other geophysical and geological observations. Due to recent advances in instrumentation, processing algorithms and computational power it has become feasible to resolve the subsurface in two or three dimensions (Hübert, 2012).

The map in figure 3.1 on the following page shows the profiles carried out in the land.

3.3. Interpretation

Aidu Intelligent Data Processing Software is a specialized software used to analyse data obtained from the magnetotelluric equipment used. The software is used to correct broken data from the field, calculate the depth and make plane profile diagram. This software was used to automatically draw a diagram where anomalies were detected. Depths and distances were extracted with reference to frequencies and saved as a data file. The data file was then gridded using Surfer software (the use of brand names does not constitute endorsement), and a contour diagram plotted showing the potential areas for drilling.

Due to the different signal strength of each frequency in natural electric field, the field data is corrected by mathematical model first, and then the Surfer software used to make profile diagrams to accurately judge where an anomaly is.

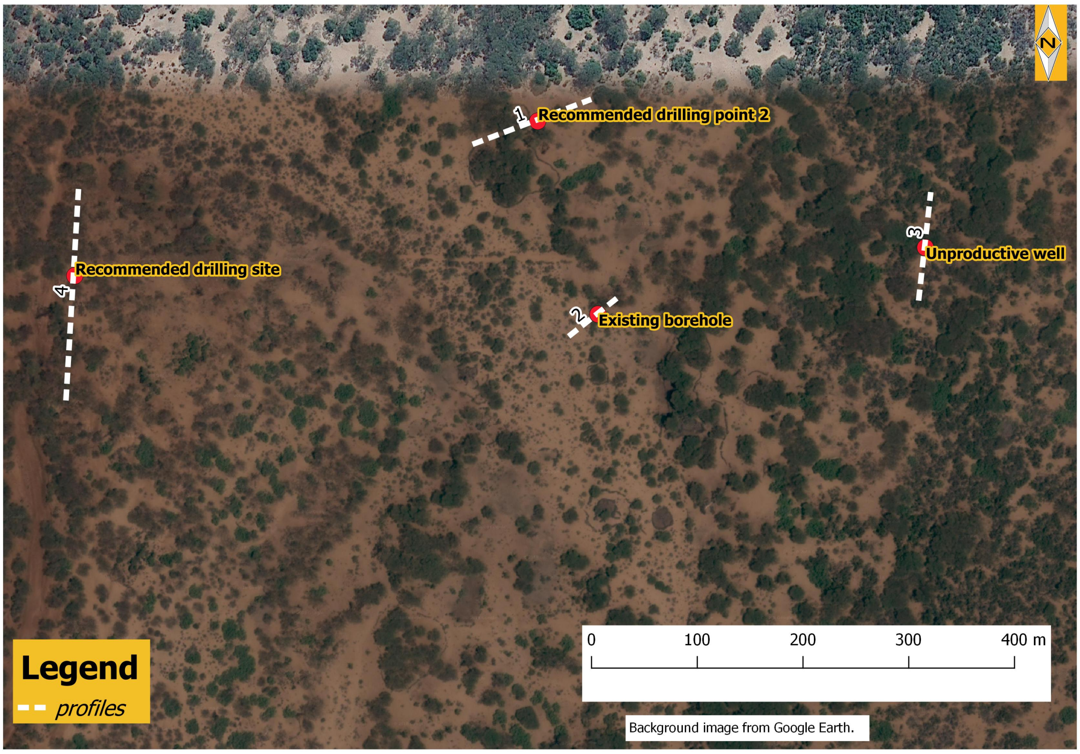

Figure 3.1. – Map of profiles

3.4. Results

The value of any geophysical method of survey is measured by the amount of geological information that can be deduced from the interpretation of the data obtained. In the survey, a natural electric field detector equipment was used. The distance between electrodes was 5 meters. The data was interpreted using specialized software, where the collected data was corrected and finally plotted using Surfer software. This gave an image of the variations in resistivities with respect to the geology. The units of measure of resistivity is millivolts. The lower the resistivity, the higher the potential of encountering an aquifer.

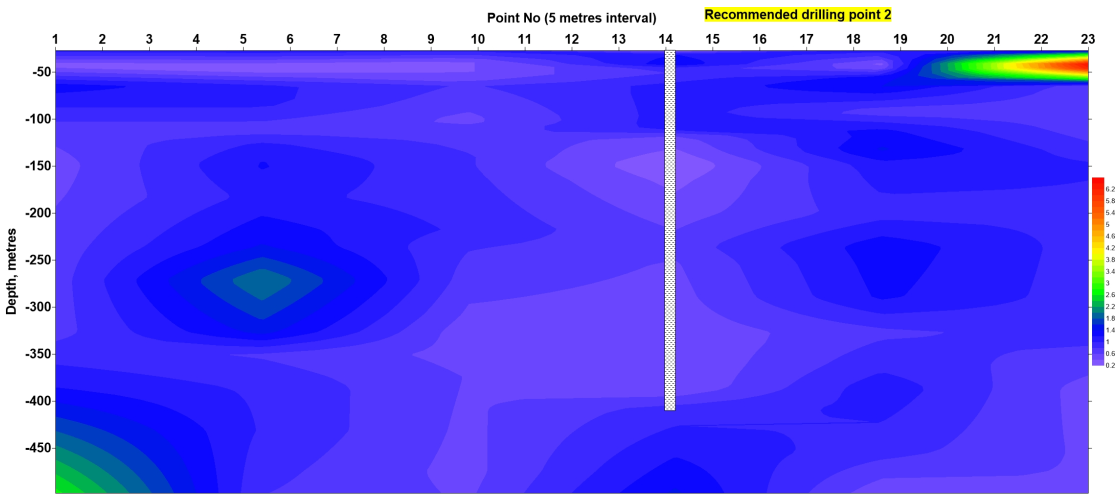

Figure 3.2. – Results of profile-1

Figure 3.2 shows a survey that was carried out on the community land. This is shown as profile 1 in figure 3.1 on the preceding page above. The length of the profile was 110 metres. A potential point was identified where a borehole could be drilled. The minimum depth in this location of 120 metres and maximum 400 metres.

A second profile, indicated as profile 2 on figure 3.1 on the previous page, was a control point to enable the investigators infer potential for groundwater.

The borehole was drilled to a depth of 45 metres, and from the drilling log, the lithology was composed of sands and gravel. The borehole may not have penetrated the full length of the aquifer.

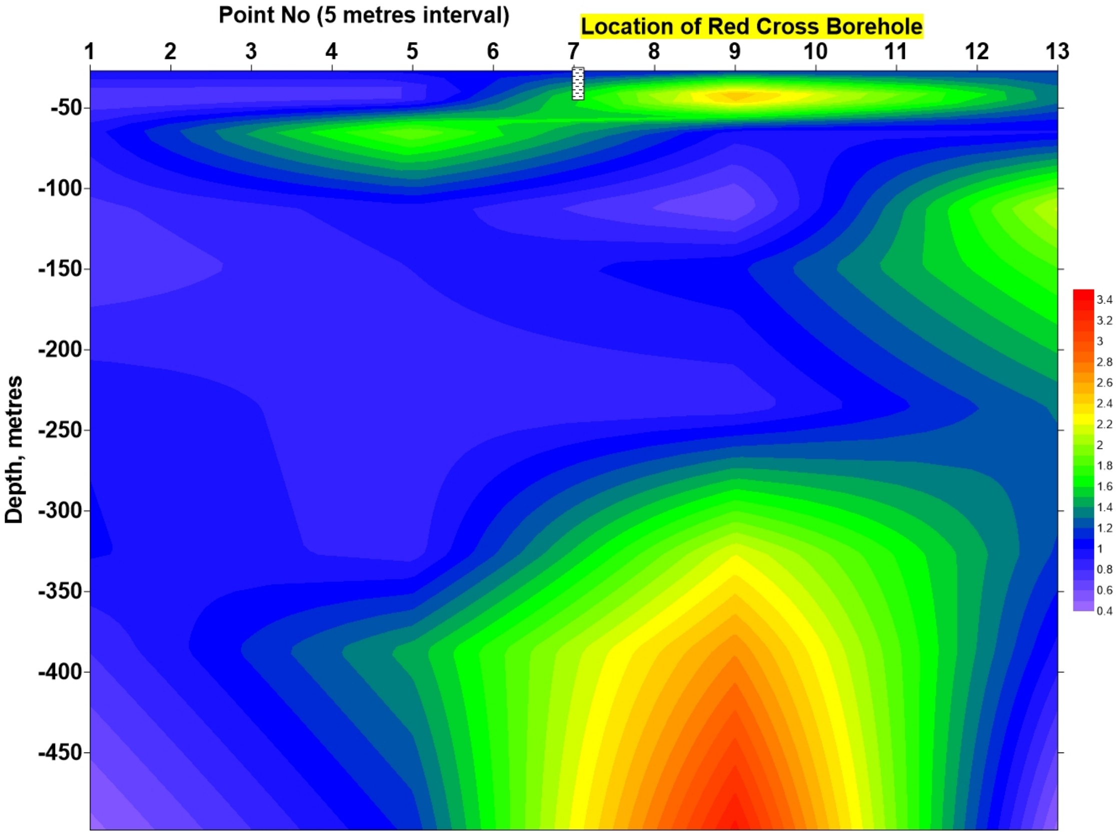

Figure 3.3. – Results of profile 2

The third profile was carried out within the community land as shown in figure 3.4 on the following page.

The profile shown in figure 3.4 on the next pagewas carried out as a control on a borehole that was recently drilled and was unproductive. The reported lithology of the borehole was sandy mud from 70 to 100 metres in depth. This spot is not recommended for any further exploration.

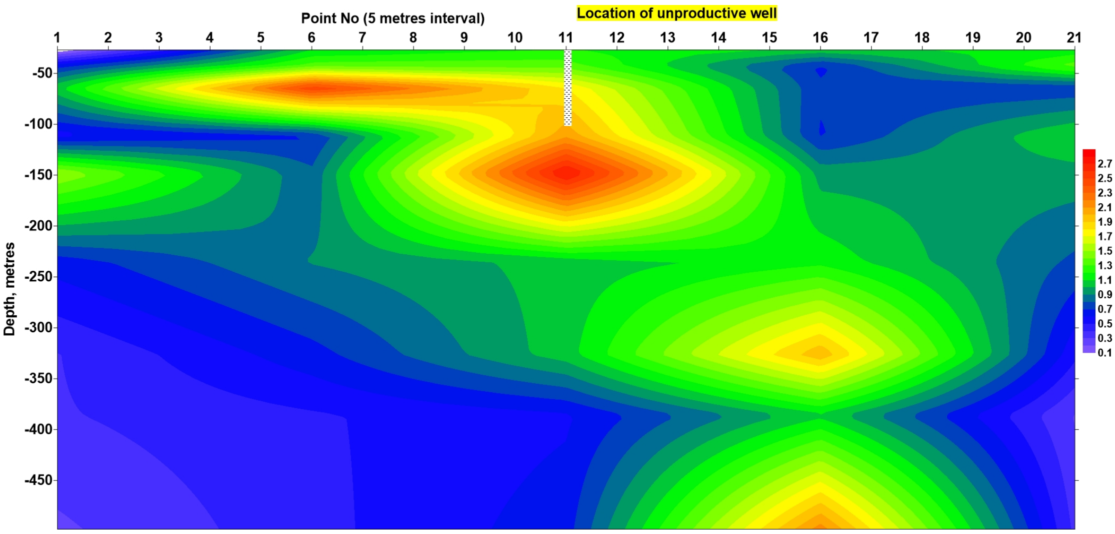

Figure 3.4. – Results of profile 3

A fourth profile was carried out close to a lagga 500 metres to the west of the productive borehole as shown in figure 3.5. This site is recommended for drilling.

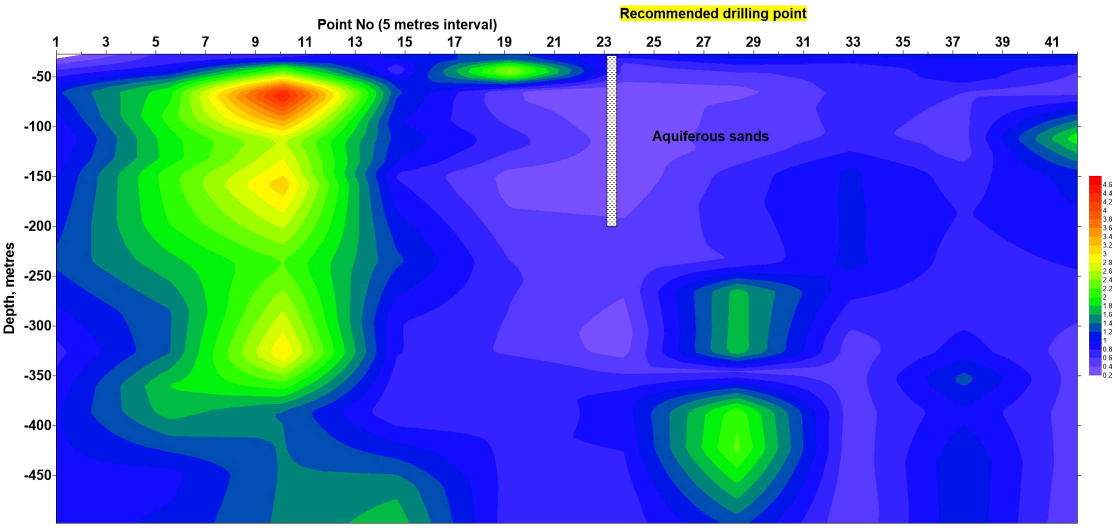

Figure 3.5. – Results of profile 4

A borehole may drilled at this point to a minimum depth of 150 metres and a maximum of 200 metres. The borehole may be drilled to a maximum of 320 metres.

In summary, results of the sites investigated are as shown in table 3.1 on the next page

Table 3.1. – Summary of results of results

Profile No.	**Aquifer (metres below ground level)**	**Maximum recommended depth (metres below ground level)**	**Remarks**
1	110-390	400	
2	-	-	Control profile. No borehole is recommended close to this site
3	-	100	Control profile. No borehole is recommended close to this site
4	50-190	200	The borehole may be drilled to a possible depth of 320 metres

4. Estimated Mean Annual Recharge, and Sensitivity to External Factors

4.1. Introduction

Rates of groundwater recharge are difficult to quantify since other related processes, such as evaporation, transpiration (or evapotranspiration) and infiltration processes must first be measured or estimated to determine the balance. Several methods exist to estimate recharge and are briefly discussed below (Wikipedia, 2018) .

4.1.1. Physical

Physical methods use the principles of soil physics to estimate recharge. The direct physical methods are those that attempt to actually measure the volume of water passing below the root zone. Indirect physical methods rely on the measurement or estimation of soil physical parameters, which along with soil physical principles, can be used to estimate the potential or actual recharge. After months without rain the level of the rivers under humid climate is low and represents solely drained groundwater. Thus, the recharge can be calculated from this base flow if the catchment area is already known.

4.1.2. Chemical

Chemical methods use the presence of relatively inert water-soluble substances, such as an isotopic tracer or chloride moving through the soil, as deep drainage occurs.

4.1.3. Numerical models

Recharge can be estimated using numerical methods, using such codes as Hydrologic Evaluation of Landfill Performance, UNSAT-H, SHAW, WEAP, and MIKE SHE. The 1D-program HYDRUS1D is available online. The codes generally use climate and soil data to arrive at a recharge estimate and use the Richards equation in some form to model groundwater flow in the vadose zone.

4.2. Types of Recharge

There are essentially three modes of recharge in groundwater engineering:

- Recharge directly from infiltrating rain into an aquifer unit.
- Recharge from rivers flowing from adjacent geologies over and into an aquifer unit.
- Lateral recharge from one geological unit to another at depth.

Recharge is typically expressed as a proportion of mean annual rainfall, or as millimetres of recharge. Recharge in this area has not been studies and cannot be discussed authoritatively in this report.

5. Groundwater Water Quality

Precipitation usually contains minute amounts of silica and other minerals, and dissolved gases such as carbon dioxide, sulphur dioxide, nitrogen, and oxygen, which are present in the air and become entrained as droplets, form and fall. As a result, the pH value of most precipitation is below 7.0 (acidic) and the water is slightly corrosive. Upon reaching the earth's surface, the rainfall may pick up organic acids from humus and similar materials which increase its corrosive characteristics. While the acidic water is percolating through soil and rock, minerals may be attacked and dissolved, forming salts which are taken into solution. The relative concentrations and variety of the salts depend upon the initial chemical composition of the water; the mineralogy exposed and the weathered state of the rock and soil encountered; and the temperature, pressure, and duration of contact (United States Department of Interior, 1995).

The groundwater composition is also affected by human polluting activities, which include agriculture, cattle breeding, industrial and domestic activities. In this case, shallow aquifers suffer most. As per GoK (2005), the basic requirements for drinking water are that it should be :

- Free from pathogenic (disease causing) organisms.
- Containing no compounds that have an adverse acute or long-term effect on human health.
- Fairly clear (i.e. low turbidity, little colour).
- Not saline (salty).
- Containing no compounds that cause an offensive taste or smell.
- No causing corrosion or encrustation of the water supply system not staining clothes washed in it.

The bacteriological quality is very essential and should be tested before the selection of the sources and during the operation of a supply. In this regard microbiological quality should not be confused with aesthetically pleasing water. A good bacteriological quality is best obtained by selecting a source without contamination, by protecting the intake and by adequate treatment.

Table 5.1 below shows bacteriological quality expected of drinking water.

Table 5.1. – Microbiological limits for drinking water

Type of microorganism	**Limits**
Total viable counts at 37^{0}C per ml, max.	100
Coliforms in 250ml	Shall be absent
E-coli in 250ml	Shall be absent
Staphylococcus aureus in 250ml	Shall be absent
Sulphite reducing anaerobes in 50ml	Shall be absent
Pseudomonas aeruginosa fluorescence in 250ml	Shall be absent
Streptococcus faecalis	Shall be absent
Shigella in 250ml	Shall be absent
Salmonella in 250ml	Shall be absent

The water from the borehole is expected to be of good portable quality.

Table 5.2 below shows the water quality standards from Red Cross borehole 500 metres to the east of investigated site. These are compared with KeBS and WHO standards.

Table 5.2. – Water quality standards

Parameters	**Unit**	**Red Cross borehole**	**WHO Standards**	**KeBS (KS 459-1:2007) Standards**
pH	pH Scale		6.5-8.5	6.5-8.5
Colour	mg Pt/l		Max 15	Max 15
Turbidity	N.T.U.		Max 5	Max 5
Conductivity (25^o C)	µS/cm		Max 2500	-
Iron, Fe^{3+}	mg/l	0.4	Max 0.3	Max 0.3
Manganese, Mn	mg/l	0.07	Max 0.1	Max 0.5
Calcium, Ca	mg/l	23	Max 100	Max 150
Magnesium, mg	mg/l	19	Max 100	Max 100
Sodium, Na	mg/l	93	Max 200	Max 200
Potassium, K	mg/l	7	Max 50	-
Total Hardness	$mgCaCO_3/l$	126	Max 500	Max 300
Total Alkalinity	$mgCaCO_3/l$		Max 500	-
Chloride, Cl	mg/l		Max 250	Max 250
Fluoride, F	mg/l		Max 1.5	Max 1.5
Nitrate	mgN/l		Max 50	Max 50
Nitrite	mgN/l		Max 0.1	Max 0.003
Sulphate, SO_4	mg/l		Max 450	Max 400
Free Carbon Dioxide	mg/l	3.9	-	-
Total Dissolved Solids	mg/l	666	Max 1500	Max 1000
Arsenic, As	µg/l		Max. 10	Max. 10
Permanganate value	mgO_2/l			

Table 5.2 shows that water from the aquifer is fit for human consumption0 and is within allowable limits with respect to its chemical quality.

6. Reserve and Effects of the Borehole to Other Users

The Water Resources Management Rules, 2007 requires that hydro-geological assessment reports must conduct an analysis of the Reserve.

The Authority has offered guidelines on the Reserve (W.R.M.A, 2009). The approach is the maximum daily amount m^3/day that can be abstracted shall be calculated as 25% of tested yield m^3/hour multiplied by 24 hours or it can be defined by the maximum abstraction rate of 25% of tested yield m^3/hour .

The abstraction rate as expressed in cubic meters per day is the same when calculated as 25% of tested yield for 24 hours or 60% of tested yield for 10 hours. The difference is that the 25% of tested yield sets a lower abstraction rate m^3/hour and therefore reduces the likelihood of over-abstraction. The remaining abstraction of 40% after 10-hour pumping or 75% (after 24 hour abstraction) is defined as the reserve.

6.1. Impact of Proposed Borehole

6.1.1. Aquifer Impact

There is limited risk of physical effects of the aquifer structure provided the borehole is correctly constructed. Un-professionally and poorly constructed boreholes may increase the opportunity for groundwater pollution because of inadequate grout seals at surface. A proper grout seal will be installed on the borehole to be constructed at the Client's land.

Boreholes screened in the shallow aquifer will be more sensitive to pollution from land surface than the deeper confined aquifer, due to the direct recharge they benefit from. Within this area any activities likely to lead to the release of pollutants (such as agrochemicals; pit latrines or septic tank leachates) should be prohibited.

6.1.2. Water Quality

Groundwater from a borehole drilled in sedimentary formation is expected to be acceptable for potable purposes; it may be relatively hard and may not infringe National Standards for drinking water.

6.1.3. Effects to other Abstractors

Sedimentary rocks have continuous aquifers. There is one borehole drilled within the land. Any abstraction is anticipated to have negligible effect on the proposed borehole. It will similarly have a negligible effect on base flow to laggas around. If pumped at very high discharge rates – far higher than envisaged to meet the calculated water demand – and if pumping leads to significant dynamic water level drawdown to an elevation lower than the pumping water level, there could be reduction in the yield, or opening up of other fractured to transmit water to the borehole.

Red Cross borehole should be monitored during drilling, test pumping and during use for any hydraulic interference and remedial measures be take if any is detected.

7. Water Permit Application Process

This section discusses the water permit application process as is carried out with WRA.

According to the Water Act (2016), a permit is required ...... for any use of water from a water resource....

The diagram below is illustrative and is explained in the following paragraphs.

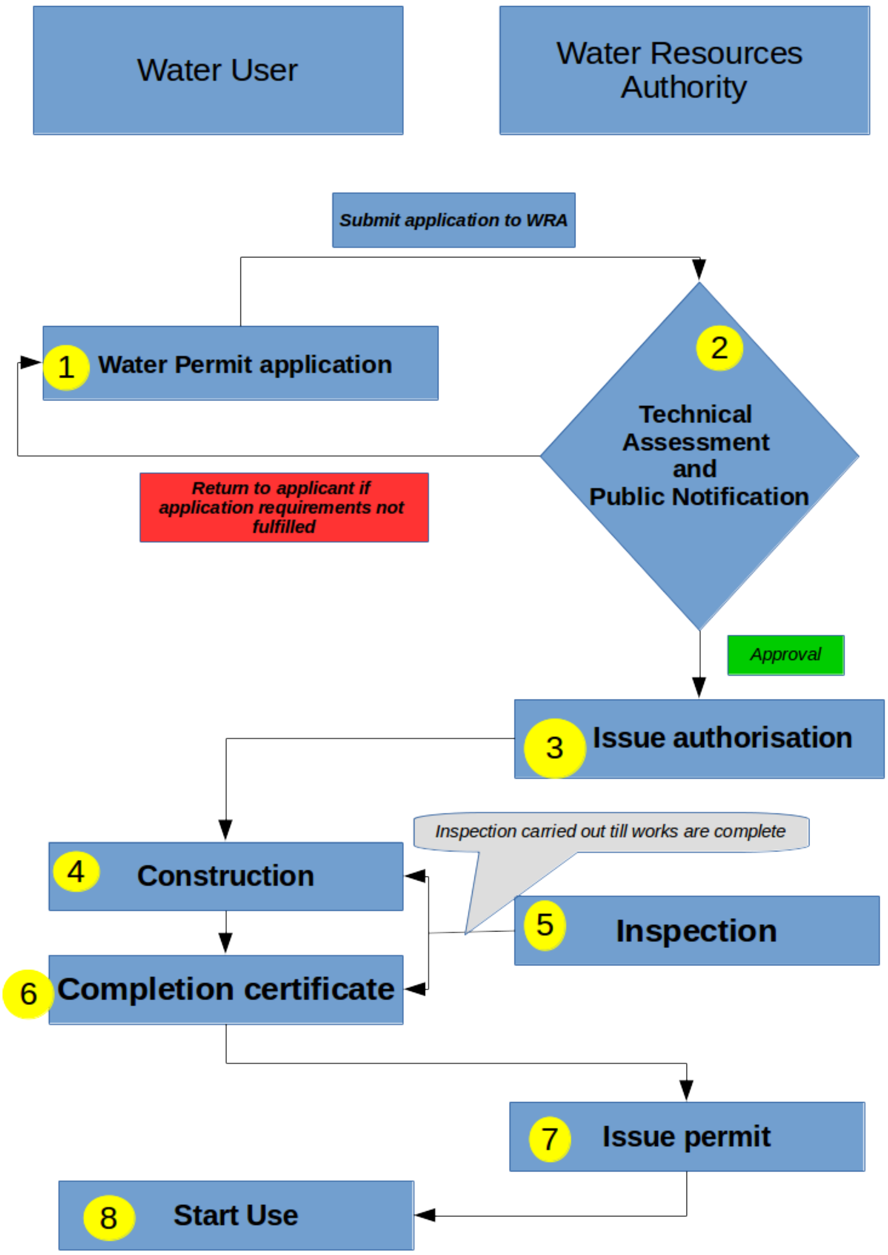

Figure 7.1. – Permit application process

7.1. Application for water permit.

A person intending to apply for a water permit to abstract from must fill form WRMA 001A stating the type of water use, and form WRMA 003 comments on WRUA (where one exists) on application for water permit (GoK, 2007).

Other documents required to be attached to the form are summarised in the table 7.1:

Table 7.1. – Copies of documents required for water permit application

	Individual	**Company, Institution**	**Groups**
Document	PIN	PIN	PIN
	Title deed or any other recognised land document	Title deed	Title deed or any other recognised land document
	Identification Card	Certificate of Registration	Group Registration Certificate Group minutes Group Constitution
Other reports	Soil and water conservation report from the Agricultural Officer [1] Letter of no objection from the local Water Service Provider [2] Environmental Impact Assessment License [3] Hydro-geological Assessment/Survey report [4]		

Notes

[1] *This is in case the Client intends to use the water for irrigation*

[2] *Where there is an existing water service provider (piped water), the water service provider has to commit himself that he does not have the capacity to supply the water to the Client, therefore the Client may seek other alternatives, in this case a drill a borehole.*

[3] *An EIA report is a statutory requirement for all projects that may alter the environment as per EMCA Cap 387.*

[4] *This report must be compiled by a licensed Water Resources Professional.*

The documents must be accompanied by a prescribed fee. This is deposited in an account as advised by WRA officers and varies with the quantity of water applied for. The amount is classified depending on the use, and ranges from Class A to Class D, as illustrated in table 7.2 on the next page (GoK, 2007).

There are guidelines WRA use to allocate and apportion water resources. This is guided by geology and hydrology of the area, intended water use and the location of the proposed borehole.

7.2. Technical assessment and Public notification

Duly filled forms, attachments and fees are submitted to the nearest WRA sub-regional offices for processing. It is important for the Client to ensure that all documents are in order to avoid rejection of the application or delays in processing. Where necessary, the public may be notified of the project through the media to alert them of the project. Should any objections arise, the project is temporarily suspended until all the concerns raised are addressed.

Table 7.2. – Water permit classification

Class	Description	Fee (Kshs)
A	Water use activity deemed by virtue of its scale to have a low risk of impacting the water resource. Applications in this category will be determined by Regional Offices	1,000
B	Water use activity deemed by virtue of its scale to have the potential to make a significant impact on the water resource. Permit applications in this category will be determined by Regional Offices.	5,000
C	Water use activity deemed by virtue of its scale to have a significant impact on the water resource. Permit applications in this category will be determined by Regional Offices in consultation with the Catchment Area Advisory Committee (now called Basin Water Resources Committee) .	20,000
D	Water use activity which involves either two different catchment areas, or is of a large scale or complexity and which is deemed by virtue of its scale to have a measurable impact on the water resource. Permit applications in this category will be determined by Regional Offices in consultation with the Catchment Area Advisory Committee and approval by Authority Headquarters.	40,000

7.3. Issue authorisation.

The application is approved and an authorisation to construct works issued. The authorisation to construct works is issued on a standard form WRMA 004. The authorisation has some conditions stipulated among them depth of drilling, duration of the drilling and any other conditions that WRA may impose. The Client should note that it is illegal to commence any works without first obtaining this document. Should the works fail to commence as scheduled, and there is a delay and the stipulated time has lapsed, the Client is advised to apply for an Extension of Time of Authorisation by filling form WRMA 005. When approved, the extension shall be issued to the Client in the form WRMA 006 (Extension of Authorisation to Construct Works).

7.4. Construction

The Client can now engage a licensed drilling contractor. Drilling terms and conditions shall be agreed between the Client and the contractor. The Client should ensure that the contractor has a good reputation of complete quality works. The drilling cost shall depend on the depth and varies from one contractor to another.

7.5. Inspection

WRA Inspectors are mandated by law to visit the drilling site without prior notice. The Contractor and the Client should offer maximum cooperation to them. There are milestones in the authorisation that the Inspectors pay close attention to.

7.6. Completion certificate

When all works are carried out as per the conditions of the authorisation, and all works are complete, the Client is advised to fill form WRMA 008 (Completion Certificate) and submit it duly signed to the nearest WRA sub-regional office. This should be accompanied by the following documents and fees depending on the class of the application.

An inspection report is compiled by WRA officers and submitted in form WRMA 007.

Table 7.3. – Documents required, Class of permit and fees

	B	**C**	**D**
Borehole /Well Completion report (WRMA 009)	7,500	25,000	50,000
Test pumping results			
Water quality analysis report			
Effluent Discharge control Plan[5]			

Notes

[5] *This report is issued in facilities that generate waste water.*

7.7. Permit

A permit is issued when all submitted documents are in order. The permit stipulates the conditions of water use and states the limitations to which the Client may use the water. It is issued by WRA in form WRMA 010.

The permit may be renewed, transferred or varied. The permit is renewable after every five years by filling form WRMA 011 and paying the prescribed fee as shown in table 7.3 above. Should there be any changes in ownership of the land to which the permit is attached to, the Client may transfer it to the new owner. The permit can also be varied when the conditions of the permit are untenable under the conditions of issue at that time.

7.8. Start use

After all the conditions are met and the permit is issued, the Client can start using the water.

Section 104 (1) of the WRM Rules 2007 states that any person in possession of a valid permit or who is required to have a valid permit for water use, shall be required to pay to the Authority water use charges on the basis of the water abstracted, diverted, obstructed or used including energy derived from a water resource at the appropriate rate as set out in the First Schedule (GoK, 2007).

The charges are tabulated below.

Table 7.4. – Water use charges

Type of water use	**Criteria**	**Rate**
DOMESTIC, PUBLIC, LIVESTOCK	Domestic, public and livestock purposes	50 cents/m^3
PUBLIC, LIVESTOCK	Installed capacity	
HYDROPOWER GENERATION	up to 1 MW	No charge
	Over 1 MW	5 cents per kWh

IRRIGATION	First 300 m^3/day	50 cents /m^3
	Over 300 m^3/day	75 cents /m^3
FISH FARMING	Amount of water supplied	5 cents /m^3
COMMERCIAL/ INDUSTRIAL	First 300 m^3/day	50 cents /m^3
	Over 300 m^3/day	75 cents /m^3
EFFLUENT DISCHARGE		Nil

- All water use under category A does not attract any water use charges
- Water use charges apply to water abstracted, diverted, stored, and or used for hydropower generation

In conclusion, the Client is expected to comply with all the rules and regulations as stipulated in the Water Act.

8. Conclusions and Recommendations

8.1. Conclusion

Based on the collected and analysed data, the hydro geological prevailing conditions it can be concluded as follows:

- There are good prospects of striking groundwater within the investigated site.
- Water from this borehole is expected to be of fairly good quality.

8.2. Recommendations

Based on the above, it is recommended that:

- A borehole may be drilled at the site indicated in Profile 4 at the land. The site is known to the the Client. The location of the proposed drilling site is 0.96511 North 38.56152 East.
- The borehole should have a diameter of at least 8″ and a minimum depth of 150 meters and a maximum of 200 metres.
- It should be lined with appropriate casings and screens.
- It should be protected from possible sources of contamination by grouting at least 2 meters length of the borehole from the ground surface.
- The borehole should be properly gravel packed to enhance yield.
- The drilling and test pumping should be supervised by a Hydrogeologist/ Licensed Water Resources Professional.
- Upon completion, the borehole must be fitted with an airline/ piezometer and a master meter to facilitate monitoring of static water level and groundwater abstractions respectively.
- A two (2) litres water sample of this water is to be collected in a clean container and be taken to any competent water-testing laboratory for a chemical, physical and bacteriological analysis before the water is made available for use.
- It is a legal requirement, stipulated in the Water Act 2016, that the Client applies for an authorization to drill from WRA. After drilling, the borehole completion record, test pumping results, completion certificate and water quality analysis results must be submitted to WRA for issuance of a permit.
  - An authorization to drill does not constitute a permit to use the water.

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A. Extracts from the Water Act, 2016

Fourth Schedule (S45)

Abstraction of groundwater

(1) No person shall construct or begin to construct a well without having first given to the Authority notice of his intention to do so and shall comply with such requirements as may be imposed by the Authority.

(2) Unless otherwise exempted a person constructing a well shall keep a record of the progress of the work which shall include –

(a) measurements of the strata through and specimen of such strata;

(b) measurements of the levels at which water was stuck; and

(c) measurements of the quantity of water obtained at each level, the quantity finally obtained and the rest level of the water.

(3) A person to whom subparagraph (2) applies shall allow any person authorized by the Authority at any reasonable time-

(a) to have free access to the well

(b) to inspect the well and the material excavated from it;

(c) to take specimens of such material and of water abstracted from the well; and

(d) to inspect and take copies of or extracts from the record required to be kept under this paragraph.

(4) Where the person constructing a well on any land is not the occupier of the land the obligation to allow any person authorized by the Authority to exercise his rights under this paragraph shall be the obligation of the occupier of the land as well as of the person constructing the well.

(5) The Authority may by notice whether conditionally or subject to specified conditions exempt any person in such circumstances as may be specified in the notice from the operation of subparagraph (2) and (3).

A person constructing a well if required to keep records under this Part shall within one month of the cessation of the construction to and to the Authority –

(a) a complete copy of the record together with the specimens referred to in the record; and

(b) particulars of any test made before such cessation of the construction of the yield of water, specifying –

(i) the rate of flow throughout the test and the duration of the test; and

(ii) where practicable the water levels during the test and thereafter until the water has returned to its natural level; and

(c) a statement of whether in his opinion (as determined by tasting) the water is suitable for drinking or is highly mineralized as the case may be; and

(d) if required by the Authority such water samples as it may consider necessary.

B. Borehole Drilling and Design

Drilling should be carried out with an appropriate tool-either percussion or rotary machine. The latter are considerably faster.

Geological rock samples should be collected at 2 meters intervals. Water struck and water rest levels and if possible, estimate of the yield of individual aquifer encountered should be noted.

Borehole Design

The design of the well should ensure that screens are placed against the optimum aquifer zones. An experienced drilling consultant/hydro geologist should make the final design, and should make the main decision on the screen setting.

Casings and Screens

The well should be cased and screened with good quality screens, considering the depth of the borehole, it is recommended to use steel casing and screens of 152 mm (6") diameter. Slots should be maximum 1mm in size.

We do not encourage the use of torch-cut steel well casing as screens. 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.

Gravel Pack

The use of gravel pack is recommended within the aquifer zones, because the aquifer could contain sands or silts which are finer than the screen slots size. An 8" (203mm) diameter borehole screened at 6" (152mm) will leave an annular space of approximately 1", which should be sufficient. Should the slot size chosen to be too large, the well will pump sand thus damaging the pumping plant and leading to gradual siltation of the well. The grain size of the gravel pack should be having an average of 2-4mm.

Borehole Construction

Once the design has been agreed, constructions can proceed. In installing screens and casing, centralizers at 6 meters interval 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 insert 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.

Borehole Development

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 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 2m above the screen.

Test pumping

After development and preliminary tests, a long duration well test should be carried out on all newly completed wells. This gives an indication of the quality of drilling, design and development. It also yields information on aquifer parameters which are vital to the hydro geologist. A well test consists of pumping a well from measured start level (water rest level - WRL) at a known or measured yield, and simultaneously recording the discharge rate and the resulting drawdown as a function of time. Once a dynamic water level (D.W.L) is reached, the rate of flow to the well is equal to the rate of pumping. Towards the end of the test, a water sample of 2 litres should be collected for chemical analysis.

The duration of the test should be 24 hours; followed by recovery test until the initial W.R.L has been reached (during which the rate of recovery to WRL is recorded. The results of the test will enable the hydro geologist to calculate the following; optimum pumping rate, Installation depth, draw down for a given discharge rate and pump size