HYDROGEOLOGICAL SURVEY

REPORT

FOR

DANIEL MUEMA KIKWA

P.O. BOX 13339-00200

NAIROBI

CARRIED OUT ON

L.R No.MULANGO/KATULANI/311

IN

KWA MULI VILLAGE, KATULANI SUB LOCATION, KATULANI LOCATION, KITUI CENTRAL SUB-COUNTY, KITUI COUNTY

July 2016

EXECUTIVE SUMMARY

This detailed report is presented as a technical site investigations report for the groundwater Survey program for Daniel Muema Kikwa specific as a water supply facility for his residence located in kwa Muli Village, Katulani Sub Location, Katulani Location,Kitui central Divison, Kitui central Sub County of Kitui County.

The sole objective of this survey was geared towards developing a sustainable water supply facility in the clients' farm where he is currently practicing crop and animal farming. The clients is wishing to invest modern farming technology taking into consideration the ever changing and of late unpredictable rainfall trends in the region. Currently they relying on water from KITUWASCO, seasonal streams and privately owned boreholes being the main source of water. Earth pans are also other sources of water but they are far from the area. Quality of water from these earth pans is doubtful. Our client has also invested in roof catchment which again is dependent on rainfall and hence very unreliable .Their activities of development are expected to go high in the course of the year and approximately 20m^3/day of water is required for sustainable supply to farm.

It is against this background that our Client proposes to drill a borehole within his massive land in order to have reliable and enough water supply to meet his domestic and crop farming needs. To achieve his objectives, an investigation was launched to establish the groundwater potential of this area and if possible determine the optimum locations within the parcel of land where the proposed borehole can be sunk.

The program entailed a thorough and detailed hydro geological and geophysical borehole site investigations conforming to the WRMA requirements and standards.

The Clients' mailing address details for the purpose of specific reference:

DANIEL MUEMA KIKWA
P.O BOX 13339-00200

NAIROBI

His ID and PIN details are shown below
ID – 3570838
PIN – A001339875l

About 20m^3/day of water is required as part of his water augment exercise, which is to be obtained from groundwater sources; which apparently becomes the only feasible water supply source in the absence of any other source. The study concludes that on the basis of geological evidence, and the accompanying geophysical study/investigations, the groundwater prospects for moderate abstractions are good for the proposed groundwater development activities.

The report based on the assessment findings, is quite detailed and includes amongst others quantifiable recharge and discharge assessments, statistical data on groundwater flux evaluations, statistical aquifer data evaluations Vis computed values of aquifer transmissivities and typical specific capacities associated with the aquifers of the area.

Geologically, the area is to some extend associated with the formation of the Great Rift Valley that led to a series of widespread eruptions and lava flows, which occurred from Mid-Miocene to Upper Pleistocene times. The area is characterized by basement complex system of rocks (probably more than 700 m) by metamorphic rocks of the Basement complex (gneisses and schists) of the Mozambican System. The Tertiary volcanic period lasted approximately 13 million years, and was characterized by cyclic activity: eruptive episodes, marked by the ejection of lava flows, pyroclastic bombs, and ashes, were punctuated by periods of erosion and landmass denudation. During these times of relative quiescence, Old Land Surfaces were formed, which today important water is bearing layers within the volcanic succession.

The project area is covered sandy gravely soils that overly a layer of sediments and Basement Rocks. Basement rocks in the area comprises biotite-hornblende gneisses, biotite gneisses, garnet-quartz-felspar gneisses, granitoid gneisses and Biotite-hornblende-garnet gneisses and hornblende-garnet gneisses hidden beneath a layer of Recent soils.

Field reconnaissance and field visit was done on 15th July 2016 and the study was carried out as follows:

i. Detailed desk study. They included review of existing information, maps, and reports in the vicinity of the project area, surrounding borehole data analyses etc.Field reconnaissance and collection of field data for the project area. The area has several drilled boreholes upon whose data we relied alongside approaches of water dowsing and geophysical investigation.

ii. Analysis of all gathered information including field data, geological logs of surrounding boreholes, groundwater water level in the boreholes and water quality parameters.

iii. Data analyses and reporting

iv. Conclusions and recommendations

Below is a tabulation of the construction summary to be adopted to realize the project objectives:-

SITE COORDINATES	VES NO. & RANKING IN YIELD POTENTIAL	RECOMMENDED DEPTH IN METERS	CONSTRUCTION REQUIREMENTS.	ANTICIPATED YIELD(M^3/HR)
37M 0383974 UTM 9837587 ELEVATION 1050 m a.s.l	VES 2	180 metres	203mm/153mm	3.0m^3/hr

ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS

asl	above sea level
VES	Vertical Electrical Sounding
HEP	Horizontal Electrical Profiling
TDS	Total Dissolved Solids
DTH	Down The Hummer, (rotary drilling method)
m bgl	metres below ground level
PWL	Pumped Water Level
Q	discharge (m^3/hr)
SWL	Static Water Level
T	transmissivity (m^2/day)
WSL	Water Struck Level
WRMA	Water Resources and Management Authority

GLOSSARY OF TERMS

Aquifer A geological formation or structure that stores and transmits water and which is able to supply water to wells, boreholes or springs.

Breccia A coarse-grained rock composed of angular fragments.

Conductivity Transmissivity per unit length (m/day).

Confined aquifer Confined aquifers are those in which the piezzometric level is higher than the elevation at which the aquifer was encountered. Static water levels are at a higher level than the top of the formation.

Drawdown The distance between the static water level and the pumped water level. The term residual drawdown is used for the same distance during recovery of the well.

Development In borehole engineering, ttheir 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 (also referred to as: Head).

Hydrogeological Factors that deal with subsurface waters and related geological aspects of surface waters.

Perched aquifer Accumulation of groundwater on top of a layer of low conductivity, underlain by unsaturated sediments or rocks.

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, and lateral Groundwater flow) to the aquifer zones.

Recovery Return to static water level following abstraction of water.

Specific capacity Ratio of pumping rate and draw down (m^3/hr/m); a measure for the well performance.

Static water levels The level of water in a well that is not being affected by abstraction of groundwater.

Transmissivity A measure for the capacity of an aquifer to conduct water through its saturated thickness (m^2/day).

Well development The act of repairing damage to the formation caused by the drilling process or gradual well deterioration. Increases the porosity and permeability of the materials around the intake portion of a well.

Yield Volume of water discharged from a well.

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- Site sketch
- Location map
- Land ownership documents
- Borehole Drilling

1.0 NAMES AND DETAILS OF THE CLIENT

Mr. Daniel Muema Kikwa owns this farm in kwa Muli Village, Katulani Sub Location, Katulani Location,Kitui central Divison, Kitui central Sub County of Kitui County and would like to develop it fully but is hampered by lack of enough and reliable water supply. The project area does not have water supply system and people rely on private boreholes, shallow wells, nearby rivers, water vendors and roof catchment. All these water sources are not enough, hence the need of the proposed borehole in the farm.

The client intends to drill a borehole within the farm so as to be guaranteed of enough and reliable water supply. The water from the borehole will be used for domestic and subsistence irrigation.Hydrogeological survey was executed to determine the groundwater potential within the project area so as to eventually exploit the resources by drilling the proposed borehole to serve the client with enough water for domestic and subsistence irrigation purposes.

The hydrogeological survey is evaluated by Water Resources Management Authority that is mandated issue authorization to drill and also apportion the amount of groundwater to be abstracted from the proposed borehole. Drilling contractors base their drilling estimates using the hydrogeological survey report.
The client details and contact address are:-

DANIEL MUEMA KIKWA
P.O BOX 13339-00200

NAIROBI
His ID and PIN details are shown below
ID – 3570838
PIN – A0013398751

2.0 LOCATION, WATER SOURCE AND PROPOSED ACTIVITY

The Project site is situated in in kwa Muli Village, Katulani Sub Location, Katulani Location, Kitui central Divison, Kitui central Sub County of Kitui County. Its defining coordinates are 37M 0383974
UTM 9837587 at an elevation of 1050 m a.s.l Access to the site from Kitui town is through wikililye –Kwa muli - Katulani road.

The project area is located within communities that practise mixed farming relying on the rainfall received in the area that is low. Owing to the low and unpredictable rainfall patterns, the area has low to medium ground water potential. People in the area get water from few shallow wells, earth pans and dams, nearby seasonal streams and roof catchment.

This area experiences acute water shortages and doesn't have water supply system which is reliable so there is need to drill the proposed borehole in the farm to be the main source of water for domestic and subsistence irrigation purposes. The soil cover in the project area is brown sandy soils. Vegetation in the surrounding area is mainly shrubs, grass and acacia trees.

Our client requires about 20,000 litres per day for domestic and subsistence irrigation purposes. The project area has no sewer line and the client will construct septic tank and soak pit to dispose waste water from the proposed borehole.

3.0 CLIMATE AND LAND USE

The rainfall pattern is bi-modal distribution and it rains between middle of March and May when we have the long rains while short rains are between October and December.

The mean annual rainfall for this area is about 600 millimetres. Temperatures are highest in the months of January to mid-March before the long rain season and lowest in the months of July to August. The climate is humid highland subtropical in character with seasonal dry and wet periods.

The project area is within Muli Village, Katulani Sub Location, Katulani Location, Kitui central Divison, Kitui central Sub County of Kitui County and the surrounding farms are settled and people practice small scale mixed farming relying on the unreliable rainfall received in the area. There are few farms that are still idle in the project area.

4.0 GEOLOGY AND HYDROGEOLOGY

The geology of area is to some extend associated with the formation of the Great Rift Valley that led to a series of widespread eruptions and lava flows, which occurred from Mid-Miocene to Upper Pleistocene times. The area is characterized by basement complex system of rocks (probably more than 700 m) by metamorphic rocks of the Basement complex (gneisses and schists) of the Mozambican System..The Tertiary volcanic period lasted approximately 13 million years, and was characterized by cyclic activity: eruptive episodes, marked by the ejection of lava flows, pyroclastic bombs, and ashes, were punctuated by periods of erosion and landmass denudation. During these times of relative quiescence, Old Land Surfaces were formed, which today important water is bearing layers within the volcanic succession.

The project area is covered sandy gravely soils that overly a layer of sediments and Basement Rocks. Basement rocks in the area comprises biotite-hornblende gneisses, biotite gneisses, garnet-quartz-felspar gneisses, granitoid gneisses and Biocide-hornblende-garnet gneisses and hornblende-garnet gneisses hidden beneath a layer of Recent soils.

Basement System Rocks that are the oldest and outcrop as iselburgs in the southern side of the project area and form then Hills to the east.

5.0 EXISTING BOREHOLES AND RECHARGE

There are no available borehole data for this area in the ministry of water data base and therefore the aquifer parameters could not be calculated.

5.1 Borehole specific capacities, transmissivities specific yields/ storage coefficients

Borehole specific capacities have been calculated using the formula **S=Q/s** (Driscoll, 1986) where **Q** is the yield during pump test and s is the drawdown that is represented by pumping water level less static water level **W(P L–SWL)**.

Transmissivity is calculated using the formula using the formula **T=0.183Q/s**. This formula has a limitation because borehole completion data from Ministry of Water and Irrigation gives the summary of pump test. It is ideal if the test pump data is in log scale.

Logan's formula **T=1.22 Q/s** is the best for estimating transmissivity.
The area does not have aquifer tests and it is difficult to ascertain specific yields, storage coefficients of existing boreholes in the project area. From Driscoll 1986 the following summary of Specific Yield ranges for earth materials.

Table showing specific yield ranges of different materials

Earth Material	Specific Yield %
Limestone and shale	0.5 - 5%
Sandstone	5 - 15%
Clay	1 - 10%
Sand and Gravel	15 - 25%
Gravel	15 - 30%
Sand	10 - 30%

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

Thus, in absence of proper pump test data, the **Logan method of approximation** has been employed (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

5.2 Hydraulic conductivity and groundwater flux

Locations laboratory investigations and Isotope methods are very expensive methods and are the best for determining hydraulic conductivity and groundwater flux correctly. The results are confined to few locations, and they depend on the scale of the investigation method. Rock sample measurements in laboratory vary from well test results. Ministry of Water and Irrigation data is also not very reliable. Hydraulic is conductivity calculated using the formula **k=T/D** where **k** is the hydraulic conductivity, **T** is the transmissivity and **D** is aquifer thickness. In the Ministry of Water and Irrigation data the start of the aquifer is the one recorded and most of the time the thickness is not given. Data available is therefore not useful in the computation of groundwater flux.

Darcy's formula is used to calculate groundwater flux it is given as **Q=T.i.W,** where it **T** is the transmissivity of the borehole, is the gradient and W the width.

5.3 Recharge/discharge considerations

Aquifer potential is always influenced by the suitability of storage media existing in the underlying rocks.

In case it is not possible to have rainfall or river flow to percolate to a sandy weathered and fractured Basement aquifer due to the presence of an aquitard (impermeable layer) probably clay, the actual potential is very low.

Both Basement Rocks and Volcanic systems suffer the same limitations so far as recharge is concerned: if rainfall is low the volume of water which may eventually percolate to a suitable aquifer is likely to be relatively small, and possibly mineralised due to high evaporation rate.

Percolation is dependent on soil structure, vegetable coverage and the erosion state of the parent rock. Rocks which weather to clayey soils will naturally inhibit percolation (such as black cotton soils); conversely, the sandy soils resulting from the erosion of some Basement rocks are eminently suited to deep, swift percolation.

Recharge is the term applied to the whole mechanism, and includes all the aspects of parent geology, effective rainfall and percolation. Some aquifer systems are recharged by water falling a substantial distance away.

Percolation takes place in high grounds at to the north and this reaches the faults from where it is distributed into permeable aquifers.
Annual recharge of the project area is not known and the aquifers vary from one site to another.

5.4 Assessment of availability of groundwater

Aquifers in this area are within the weathered, fractured and decomposed underlying Basement Rocks. These aquifers are not uniformly distributed and that is why there is wide variation in drilled depths, water struck levels, water rest levels and yields.

5.5 Analysis of reserve and groundwater level evolution

It is difficult to accurately determine the storage of groundwater in the underlying aquifer. To determine this it requires a very intensive exercise and accurate data that will show the boundaries and it's extend both horizontal and vertical. So many techniques are also involved.

6.0 Geophysics

Several geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey, the resistivity method (also known as the geo-electrical method) and the Horizontal Electrical Profiling methods has been used. The latter was used to detect any anomalous conductive zones in the subsurface that might be associated with faulted or fractured zones.

Vertical Electrical Soundings **(VES)** are carried out to probe the conditions at such anomalous zones within the sub-surface and to confirm the existence of deep groundwater. The **VES** probes the resistivity layering below the site of measurement. The techniques are described below.

6.1Basic Principles of the Resistivity Methods

The electrical properties of the upper parts of the earth's crust are dependent upon the lithology, porosity, and 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 saturated rocks, 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 (in Ohm)　　　(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 (Ohm)　　　(2)

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

Rs = (A/L) *(dV/I) (in Ohm.m)　　　(3)

6.2 Methods

6.2.1 Vertical Electrical Soundings (VES)

Vertical Electrical Soundings are executed to probe the electrical properties and depth to sub-surface layered formations below the site of measurement at the most anomalous zones.

When carrying out a resistivity sounding, electric current is led into the ground by means of two electrodes and the potential field generated by the current is measured. 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. The observed resistivity values are plotted on log-log paper and the graph obtained depicts resistivity variation against 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 hydro geologist with information on the geological layering and thus the occurrence of groundwater

6.3 Fieldwork

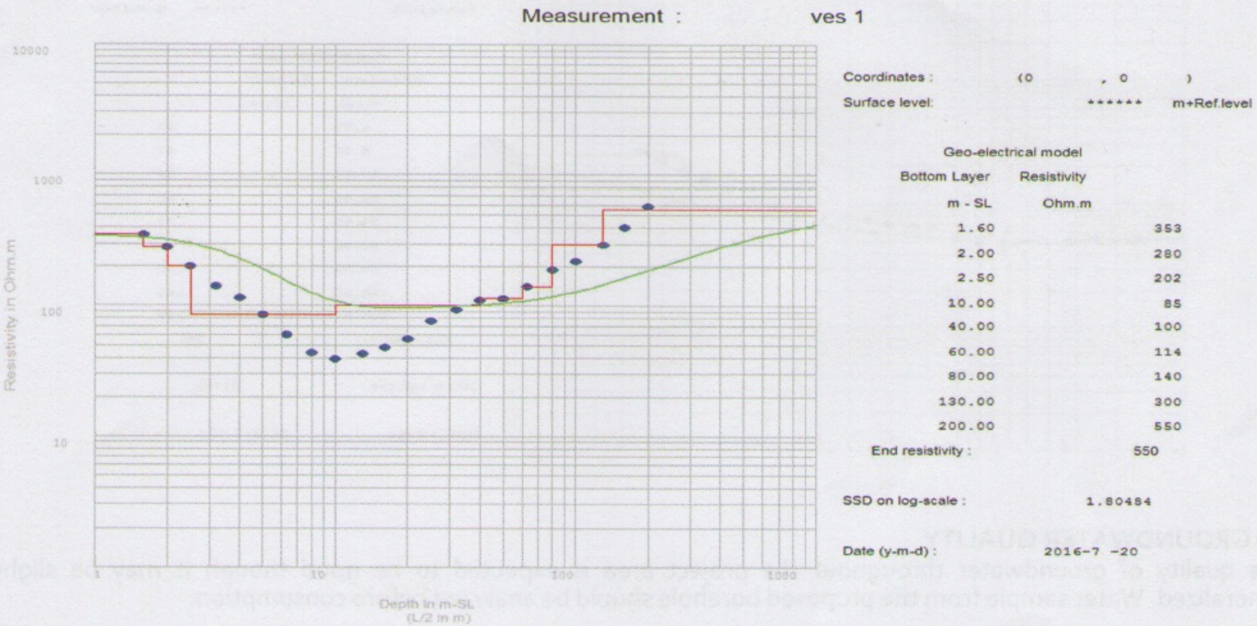
Field work was carried out on 15th July 2016. One Horizontal Electrical Profile (H.E.P) from the lower side of the shamba all across to the upper side of the shamba.Two (2) Vertical Electrical Sounding (VES) were further executed at the project site on the best considered stations along the HEP. The aim of the soundings was to determine the prevailing hydrostratigraphy at the project site. Prior to the geophysical investigation inventory of the hydrogeology and other related aspects were carried out within, and in the surroundings of the farm.

Results of Sounding Curve (VES1) at lower part of the shamba

The results of **VES-01** measurements show that the site is covered at the surface by top depositional colluviums sands to a depth of about 3 m. These are underlain by highly decomposed gravelly sediments intercalated with pebbly quartzo -conglomerations to depth of about 10 m. A relatively less resistivity layer is present below the latter, which is interpreted to represent highly weathered & fractured feldspathic gneisess to depth of about 40.0 m.These are in turn underlain by a less resistant layer of highly weathered and fractured hornblende biotite gneisses to a depth 80 m and beyond 130 m we have a very a high resistivity layer which is interpreted to be slightly weathered Basement System. Several water bearing layers are expected within the porous layers and sediments (paleo-soils).

Data Interpretation for VES 1

DEPTH (M)	RESISTIVITY	GEOLOGICAL FORMATION
0.0– 1.6	353	Decomposed lateritic overburden.
1.6 – 2	280	Highly decomposed gravelly sediments intercalated wi pebbly quartzo -conglomerations
2 – 2.5	202	Fractured & weathered feldspathic gneisess
2.5– 10	85	Weathered and fractured hornblende biotite gneisses
10.0 - 40	100	Highly weathered to fractured biotitic gneisses
40 - 60	114	Weathered gneisses
60 – 80	140	Highly to weathered to fractured granitic gneisses
80 – 130	300.0	Slightly weathered to fractured gneisses
130 – 200	287.0	Fractured to fresh biotite gneisses tending massive



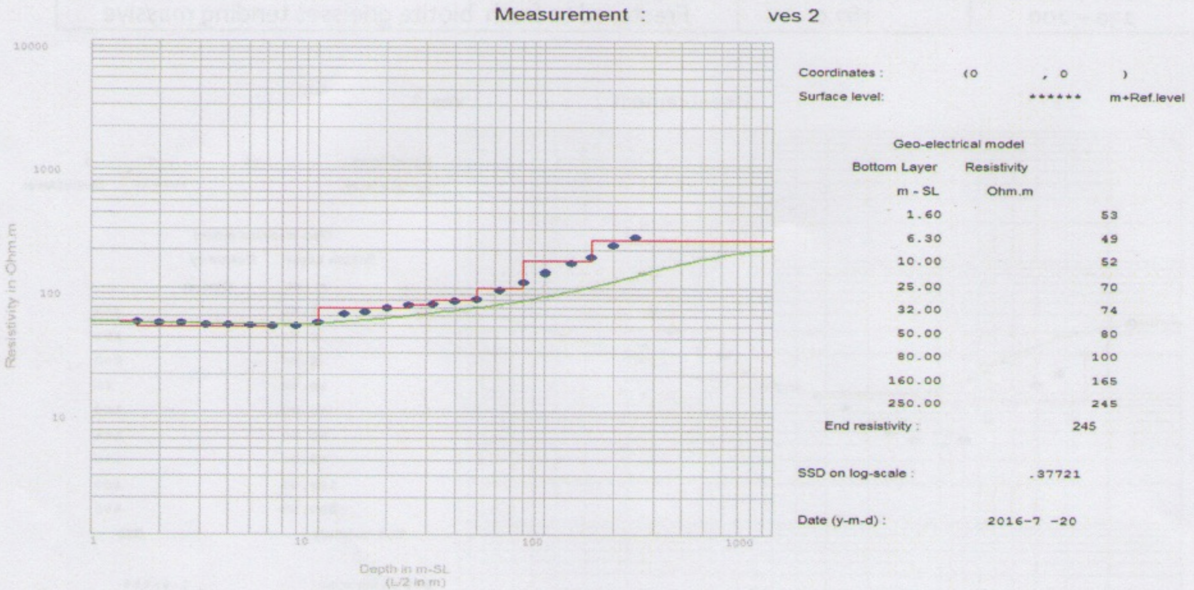
VES 2

Results of Sounding Curve (VES2) at the homestead

The **VES-02** measurements were done at the homestead. It shows that the site is covered at the surface by top depositional colluviums sands to a depth of about 3 m. These are underlain by highly weathered and decomposed gravelly sediments intercalated with pebbly quartzo -conglomerations to depth of about 10 m. A relatively less resistivity layer is present below the latter, which is interpreted to represent highly weathered & fractured feldspathic gneisess to depth of about 32.0 m.These are in turn underlain by slightly higher resistant layers of slightly weathered and fractured hornblende biotite gneisses to a depth 100 all through to 200 m and beyond 250 m.Below this layer we have a slightly higher resistivity which is interpreted to be slightly weathered Basement System. Several water bearing layers are expected within the porous layers and sediments (paleo-soils). Groundwater Potential at the surveyed area is good and has been **RECOMMENDED** for the proposed borehole drilling

Data Interpretation for VES 2

DEPTH (M)	RESISTIVITY	GEOLOGICAL FORMATION
0.0– 1.6	53	Decomposed lateritic overburden.
1.6 – 6.3	49	Highly decomposed gravelly sediments intercalated wi pebbly quartzo -conglomerations
6.3 – 10	52	Fractured & weathered feldspathic gneisess
10 – 32	74	Highly Weathered and fractured biotite gneisses
32 - 50	80	Weathered gneisses
80 – 160	165	Highly to weathered to fractured granitic gneisses
160 – 250	245	Fractured to fresh biotite gneisses tending massive



7.0 GROUNDWATER QUALITY

The quality of groundwater throughout the project area is expected to be good though it may be slightly mineralized. Water sample from the proposed borehole should be analyzed before consumption.

Some of the factors which determine the degree of mineralization of groundwater are as follows:-

❖ **Evaporation and Transpiration**

Direct evaporation by the heat of the sun and preferential uptake of certain mineral ions by plants can, in certain environments, lead to hardness of water and salinisation.

❖ **Dissolution of Evaporites**

The process of evapotranspiration may, in arid conditions, lead to the precipitation of salts in the unsaturated zone. These salts may then be carried down to the groundwater store during periods of rain, thus leading to high ion concentrations in space and time.

❖ **Dissolution of Host Rock**

Given relatively long residence times and fairly high ambient temperatures in groundwater systems, progressive salinity or mineralization of groundwater can be expected via the solution of various constituents of the host rock. This will vary according to local structures (which may speed the passage of water through an aquifer by means of faults, etc and so limit retention time), local climate and so on.

Considering the above factors the quality of water in our project area is expected to vary from one borehole to the other.

Table showing Groundwater suitability based on dissolved solids content by UNICEF.

TDS* (mg/l)	ory	ABILITY
0 - 1,500	water	Suitable for all normal purposes
1,500 - 3,000		Suitable for livestock, marginal for human consumption
3,000 - 5,000	ish water	Suitable for livestock, unsuitable for human consumption
5,000 - 7,000		Suitable for camels, marginal for other livestock
7,000 - 10,000		Suitable for all camels, marginal for goats and sheep, unsuitable for
10,000 - 15,000		Marginal for camels, only in emergencies for goats and sheep
> 15,000		Unsuitable for any domesticated animal life

*: Total *Dissolved* Solids (in parts per million = mg per litre)

Consumption by humans of waters with concentrations somewhat above the standards limits is not necessarily harmful. Still, the best possible quality should be targeted, and the identified sources should have chemical properties within and/ or to the WHO norms. Appropriate technological solutions must be considered in areas where adverse types of water are likely to have hazardous effects on man and livestock. However, for toxic substances, a maximum permissible concentration limit has been established. The constituents for which these standards have been set (e.g. heavy metals, pesticides, bacteria) all have a significant health hazard potential at concentrations above the specified limits. Hence, the specified limits should not be exceeded in public water supplies.

Table Showing Maximum dissolved constituent limits as per WHO/EU standard

neter	/ EU Guideline
Cations (mg/l)	
Iron	0.2
Manganese	0.5
Calcium	No Guideline
Magnesium	No Guideline
Sodium	200
Potassium	No Guideline
Anions (mg/l)	
Chloride	250
Fluoride	1.5
Nitrate	50
Nitrite	0.50
Sulphate	250
Total Hardness (mg$CaCO_3$/l)	Desirable: 150-500
Total Alkalinity (mg$CaCO_3$/l)	No Guideline
Physical Parameters	
PH	Desirable: 6.5-8.5
Colour (mgPt/l)	Desirable: 15
Turbidity (NTU)	Desirable:< 5
Permanganate Value (mgO_2/l	No Guideline
Conductivity (µS/cm)	250 microS/cm
Total Dissolved Solids (mg/l)	No Guideline
Free Carbon Dioxide (mg/l)	No Guideline

Water bearing zones

Groundwater occurrence depends upon geology, rainfall, erosion, and recharge. The best aquifers are found when a conjunction occurs of optimum recharge (rainfall, soil permeability), storage (porous rocks), and transmissivity (the ease with which water can travel, both vertically and horizontally, within an aquifer).

The main type of aquifer encountered in the area is composed of meteoric water that penetrates the rock through sub-surface infiltration. The quality of meteoric water is influenced by the composition of the conduit rock formation. Longer residence of meteoric water in a formation will generally result in increased mineral concentrations. Although the groundwater quality in the area is expected to be broadly satisfactory, the water will be slightly mineralized. The exact concentration will however be determined upon chemical analysis of the water after drilling.

In the project area aquifers are encountered within the decomposed, weathered and fractured zones in the underlying Basement Rocks.

8.0 Impacts of the proposed drilling project on aquifer

Over abstraction of groundwater from the proposed borehole may lead to depletion of groundwater levels. The project area has low density of boreholes and there is no existing borehole within a radius of 800 metres from the proposed borehole site. The proposed borehole should be drilled to a depth of 130 metres below ground level. All conditions given by Water Resources Management Authority should be adhered to and they include pumping 60% of the tested yield and pump for a period of 10 hours a day.

9.0 Conclusion and recommendations

- The project area receives good groundwater recharge from high grounds on the northern and north-western side.

- The project area has low to medium groundwater potential depending on the degree of weathering and fracturing of the underlying Basement Rocks.

- Yields of boreholes the project area is expected to be low depending on the degree of weathering and fracturing of the underlying rocks. The estimated yield from the proposed borehole is expected to be about 3,000 litres of water per hour. The borehole water will guarantee the surrounding population enough and reliable water supply for domestic and subsistence irrigation purposes.

Considering the above conclusions, it is recommended as follows:

- The proposed borehole should be drilled at the selected site which is known to the client

- The proposed borehole should be drilled at (VES 02) to a depth of **180** meters below ground level and at

- The proposed borehole should be lined with mild steel casings and screens of 152 millimetres diameter and should be gravel packed. The proposed borehole should be installed with:-
  - ❖ Water master meter for monitoring groundwater abstraction.
  - ❖ Airline for monitoring water table fluctuation.

- The borehole should be properly gravel packed, developed, test pumped to establish its yield. It should also be properly sealed at the surface to prevent surface water from entering thus preventing contamination.

- Environmental Impact Assessment of the proposed project should be done as directed in EMCA and Water Act 2002 regulations.

- The drilling, construction and test pumping of the borehole should be properly supervised by a qualified **hydrogeologist.**

- The drilling contractor should inform Water Resources Management Offices before starting drilling of the proposed borehole so that an officer of Water Resources Management Authority is present during drilling, construction and test pumping of the proposed borehole.

REFFERENCES

S. Foster & A. Tuinhof, 2005, The role of groundwater in the water – Supply of Greater Nairobi

L. M. BEAR, B.Sc. (Eng.), F.G.S. Geologist - geological reconnaissance of the area south-east of embu

APPENDIX – Borehole Drilling

Drilling Technique

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

Well Design

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

Casing and Screens

The well should be cased and screened with good quality material. Owing to the depth of the borehole, it is recommended to use steel casings and screens of high open surface area.

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

Gravel Pack

The use of a gravelpack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 8" diameter borehole screened at 6" will leave an annular space of approximately 1", which should be sufficient. Should the slot size chosen be too large, the well will pump sand, thus damaging the pumping plant, and leading to gradual `siltation' of the well. The slot size should be in the order of 1.5 mm. The grain size of the gravel pack should be an average 2 - 4 mm.

Well Construction

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

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

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 the borehole walls. Secondly, it alters the physical characteristics of the aquifer around the screen and removes fine particles.

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

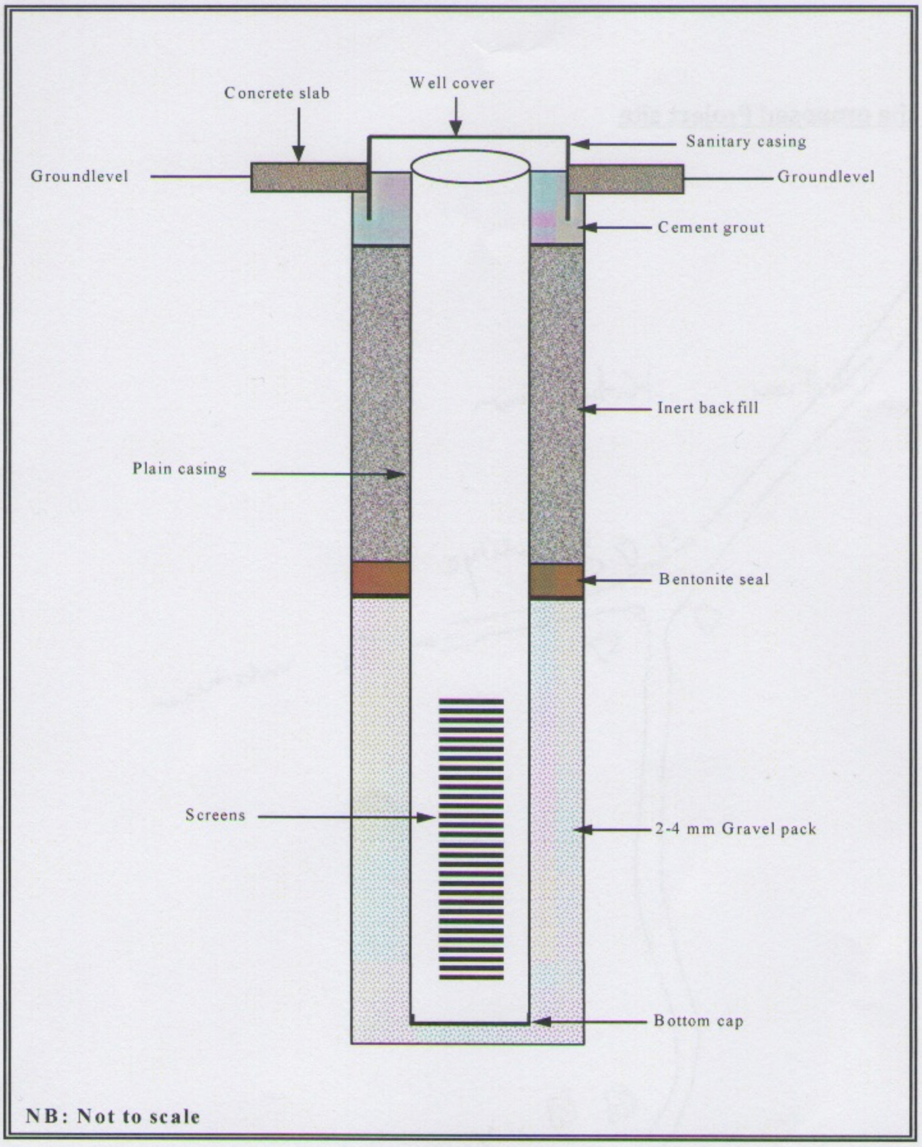
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2 m above the screen, certainly not at the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

Well Testing

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

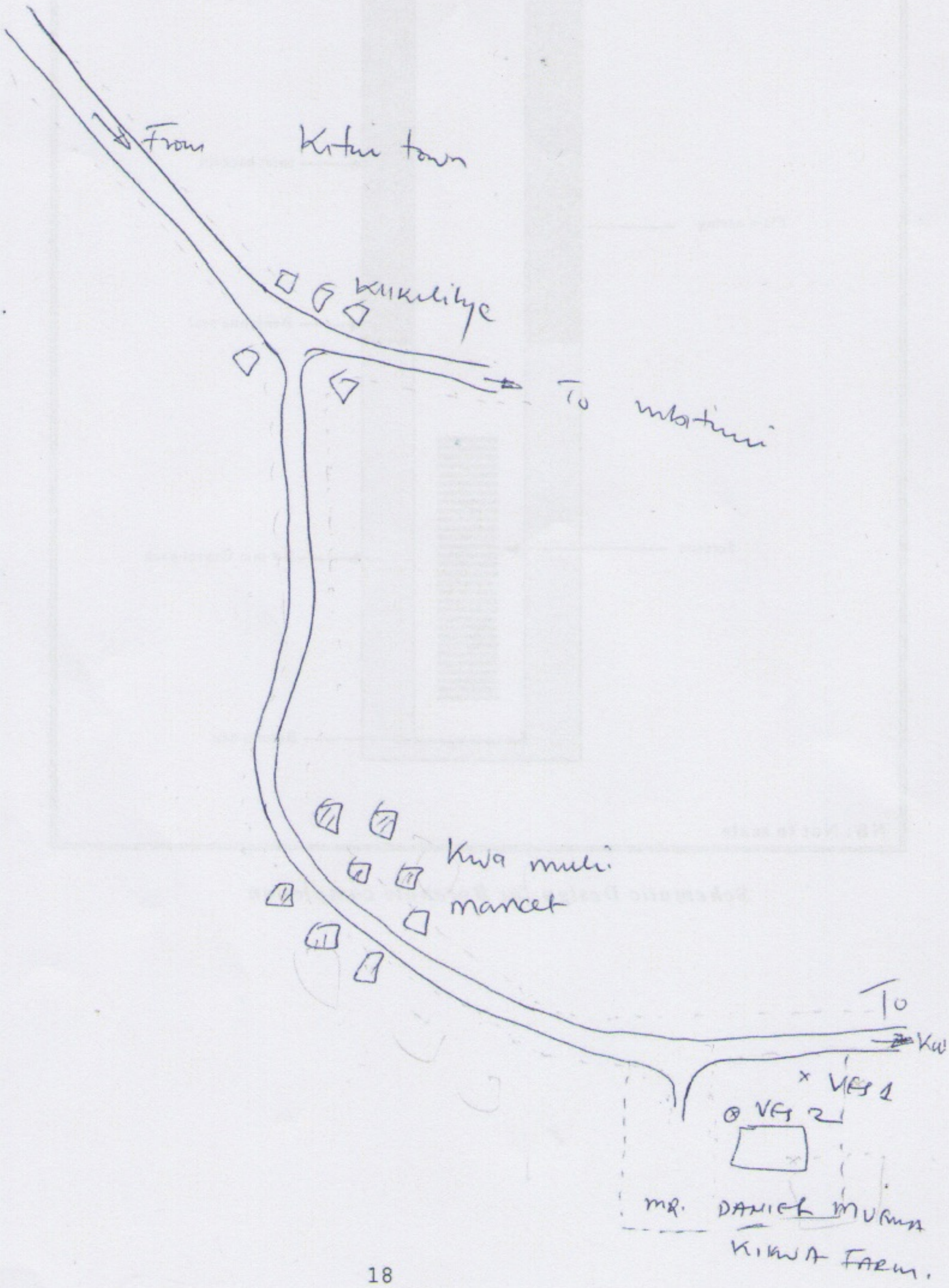
A well test consists of pumping a well from a measured start level (Water Rest Level -(WRL) at a known or measured yield, and simultaneously recording the discharge rate and the resulting drawdowns as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals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

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



Schematic Design for Borehole completion

Sketch map to the proposed Project site



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<u>**Topographical map for the proposed Project site**</u>