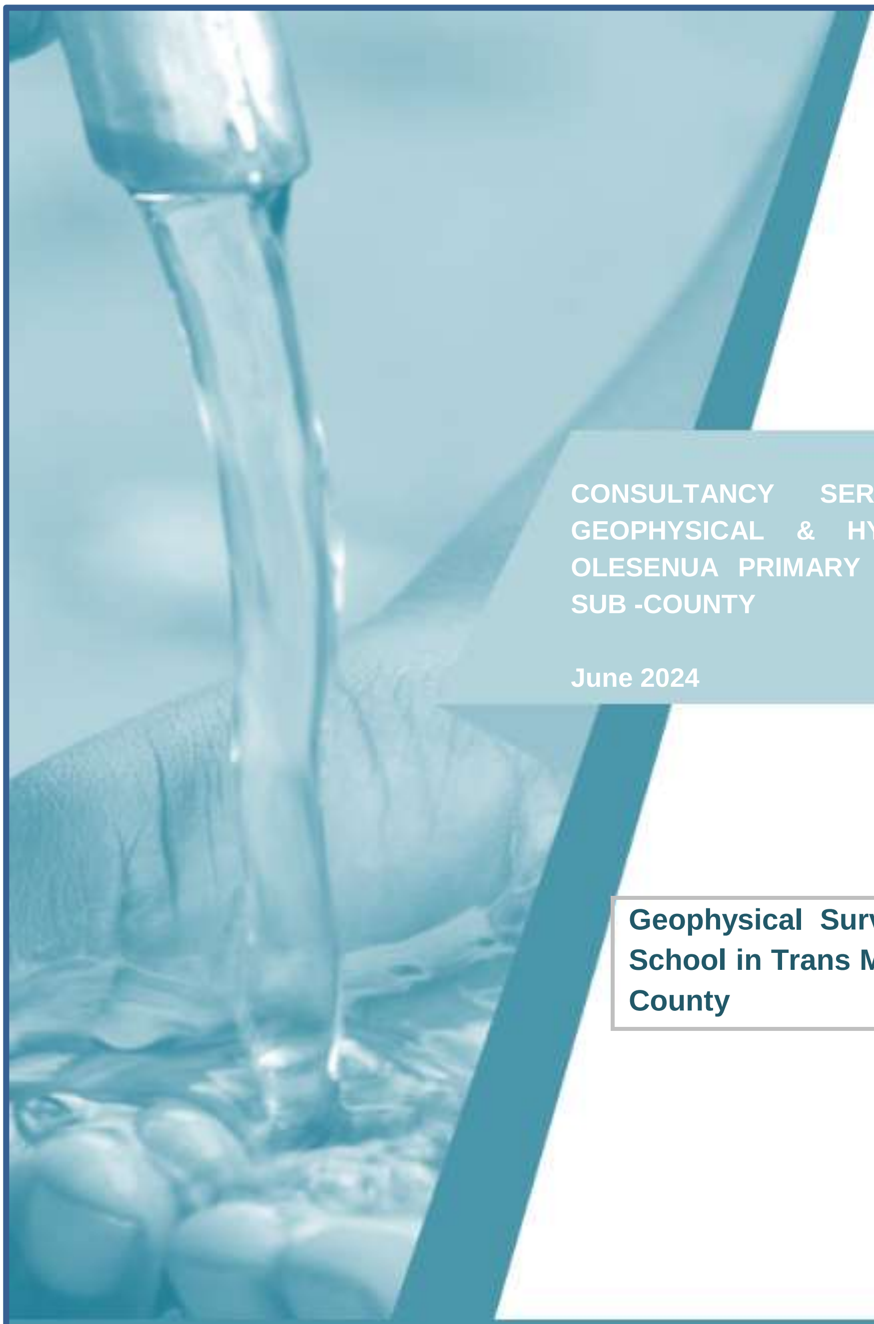

CONSULTANCY SERVICES FOR CONDUCTING GEOPHYSICAL & HYDROGEOLOGICAL SURVEYS OLESENUA PRIMARY SCHOOLTRANS MARA WEST SUB -COUNTY

June 2024

Geophysical Survey for a Olesenua Primary School in Trans Mara West Sub County, Narok County

CONSULTANT	CLIENT
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EXECUTIVE SUMMARY

This present report describes the results of borehole site investigations at Olesenua Primary School in Trans Mara Sub County located at GPS- 00.78703° S 34.96608° E). The study was commissioned by **AMREF HEALTH AFRICA.**

Most of the study area is covered by black soils. The main rock composition is biotite-hornblende granites and gneisses. Shallow aquifers are likely to be struck between the rock overburden and the weathered hornblende biotite gneiss while the deep aquifers shall be struck within the fractured/weathered basement formations.

Results of the data inventory indicates that the borehole yields in the area are generally low, ranging from 0.62m^3/hr to 12m^3/hr. The 6 boreholes whose data was available have an average depth of 223.42mbgl. The tested average discharge from the 6 boreholes whose data was available from WRA with a yield of 2.81m^3/hr. Shallow Aquifers in the project area stuck between 46-70mbgl while deep aquifers are struck between 105mbgl to 220mbgl.

Combined geophysical and hydrogeological fieldwork was carried out on 02.05.24. The main aim of the geophysical investigations was to get an insight into the hydrogeological conditions prevailing in the project area. Furthermore, an attempt was made to find the extent of the water bearing layers.

Based on the available hydrogeological data and the geophysical investigation results, it is recommended that a borehole be drilled at a minimum diameter of 8.5"at the location of **OLSN 002 VES 2 (-1.077799° and 34.6199806°).** The hole should be drilled to an approximate depth of 200 metres. The selected site is known to Mr. Edward, Client's representative. An alternative site is recommended for drilling at **OLSN 003 VES 3 (GPS -00.78751° and 34.96708°)** to a maximum depth of 200mbgl. The site is also known to Mr. Edward

The study recommends that a borehole be drilled within the premises to an approximate depth of 200metres with an estimated yield of 2 - 4 m^3/hr.

To achieve and maintain a high yield, and maximize the efficiency of the borehole, the importance of proper design and construction methods cannot be overemphasized. The water quality of the proposed borehole is expected to be fair to good. The alkalinity and hardness will be moderately high, but not excessive.

The Client should note that before drilling commences, a groundwater abstraction permit must be obtained from the Regional Manager, Water Resources Authority, in Narok.

To be attached to the report and Application form (WRMA 001A dully signed & fully completed) should include client's documents:
Copy of Title Deed of the Farm,
Copy of Site Plan,
Copy PIN Number/KRA Certificate,
Banking Slip and Copy of Official Receipt of Paid Fee,

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ABBREVIATIONS AND GLOSSARY OF TERMS

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

agl	above ground level
amsl	above mean sea level
bgl	below ground level
d	day
E	East
EC	electrical conductivity (µS/cm)
h	head
hr	hour
K	hydraulic conductivity (m/day)
l	litre
m	metre
MWI	Ministry of Water and Irrigation
N	North
PWL	pumped water level
Q	discharge (m^3/hr)
Q/s	specific capacity (discharge - drawdown ratio; in m^3/hr/m)
s	drawdown (m)
S	South
sec	second
SWL	static water level
T	transmissivity (m^2/day)
VES	Vertical Electrical Sounding
W	West
WAB	Water Appointment Board
WSL	water struck level
µS/cm	micro-Siemens per centimetre: Unit for electrical conductivity
°C	degrees Celsius: Unit for temperature
Ωm	Ohmm: Unit for apparent resistivity
ρa	Apparent resistivity
"	Inch

GLOSSARY OF TERMS

Alluvium General term for detrital material deposited by flowing water.

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

Colluvium General term for detrital material deposited by hillslope gravitational processes, with or without water as an agent. Usually of mixed texture.

Conductivity Transmissivity per unit length (m/day).

Confined aquifer A formation in which the groundwater is isolated from the atmosphere by impermeable geologic formations. Confined water is generally at greater pressure than atmospheric, and will therefore rise above the struck level in a borehole.

Denudation Surface erosion.

Evapotranspiration Loss of water from a land area through transpiration from plants and evaporation from the surface.

Fault A larger fracture surface along which appreciable displacement has taken place.

Granitization The process by which solid rocks are converted into rocks of granitic character without melting into a magmatic stage.

Gneiss Irregularly banded rock, with predominant quartz and feldspar over micaceous minerals. A product of regional metamorphism, especially of the higher grade.

Gradient The rate of change in total head per unit of distance, which causes flow in the direction of the lowest >head.

Heterogeneous Not uniform in structure or composition throughout.

Hydraulic head Energy contained in a water mass, produced by elevation, pressure or velocity.

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

Infiltration Process of water entering the soil through the ground surface.

Joint Fractures along which no significant displacement has taken place.

Migmatite Rocks in which a granitic component (granite, aplite, pegmatite, etc.) is intimately mixed with a metamorphic component (schist or gneiss).

Percolation Process of water seeping through the unsaturated zone, generally from a surface source to the saturated zone.

Perched aquifer Unconfined groundwater separated from an underlying main aquifer by an unsaturated zone. Downward percolation hindered by an impermeable layer.

Permeability The capacity of a porous medium for transmitting fluid.

Permeation Passage of geochemically mobile components through a rock. >Permeation gneiss: Gneiss formed or modified by permeation.

Phenocrysts The larger crystals in a porphyritic rock.

Piezometric level An imaginary water table, representing the total head in a confined aquifer, and is defined by the level to which water would rise in a well.

Porosity The portion of bulk volume in a rock or sediment that is occupied by openings, whether isolated or connected.

Porphyritic Containing large, visible crystals or phenocrysts in a finer groundmass.

Pumping test	A test that is conducted to determine aquifer and/or well characteristics.
Recharge	General term applied to the passage of water from surface or subsurface sources (e.g. rivers, rainfall, lateral groundwater flow) to the aquifer zones.
Regolith	General term for the layer of weathered, fragmented and unconsolidated rock material that overlies the fresh bedrock.
Specific capacity	The rate of discharge from a well per unit drawdown.
Static water level	The level of water in a well that is not being affected by pumping. (Also known as "rest water level")
Transmissivity	A measure for the capacity of an aquifer to conduct water through its saturated thickness (m^2/day).
Unconfined	Referring to an aquifer situation whereby the water table is exposed to the atmosphere through openings in the overlying materials (as opposed to >confined conditions).
Yield	Volume of water discharged from a well.

1. Introduction

1.1 Scope of Work

In May 2024, Afrique Water & Geotechnical Services Ltd was commissioned by Amref Health Africa to carry out borehole site investigations in Olesenua Primary school in Trans Mara Sub County (Fig. 1.1).

The main objective of this report is to:

- Carry out the geophysical investigation and interpret results: select the most suitable borehole drilling sites in the project area, also considering the legal framework and the requirements of the Water Act 2016.
- Present a Geophysical Report showing the results of the geophysical investigation, including the raw data sets, the qualitative interpretation of the type curves in terms of layer sequence (for VES investigations) and inversions results, and the identification of the drilling locations and precise description of drilling strategy.
- Establish a Well Design as integral part of the Geophysical Report, aiming at maximizing water inflow and minimizing well-head-losses.
- Mark the proposed drilling sites with a concrete marker, shown in topographical maps and indicated on appropriate site sketch maps. GPS coordinates have to be provided.

The address of the Client's is:

Olesenua Water Project,
C/O Amref Health Africa in Kenya
P.O.BOX 30125 – 00100
Wilson Airport,
Nairobi, Kenya.
Tel No: +254 20 699 4000

1.2 Project Location

The project area is located at Olesenua Primary School, Trans Mara West Sub County, Narok County. The school is located 30KM West of Kilgoris Town. The GPS coordinates for the school are (-1.077799°S and 34.6199806°E) The exact location is indicated in figure 1.1 below.

1.3 Climate

Trans Mara West Sub County receives rain for 289.6 days and collects up to 1257mm (49.49") of precipitation. The months with the most sunshine in Kilgoris, are January and February, with an average of 9.6h of sunshine. Peak average temperatures are observed in February, with a high of 27.8°C (82°F) and a low of 15.3°C (59.5°F). With an average relative humidity of 64%, February is the least humid month in Kilgoris. The month with the least rainfall in Kilgoris, Kenya, is February, when the rain falls for 13.8 days and typically collects 56mm (2.2") of precipitation. The month with the most rainfall in Kilgoris is April, when the rain falls for 26.5 days and typically aggregates up to 154mm (6.06") of precipitation. Average lowest temperatures are observed in June, with a high of 23.2°C (73.8°F) and a low of 14°C (57.2°F).

1.4 Water Demand

In the absence of a reliable piped water supply, the client has selected drilling 1No. borehole as the best available option. The proposed water source is for domestic use only. The estimated water demand within the Client's property is 30m^3/day.

1.5 Approach by the Consultant

The borehole site investigations were carried out according to a multi-step approach:

a) A desk study and data-acquisition phase: topographic maps, existing studies and borehole site investigations, geological reports and maps, borehole records, etc.

b) Geological and geomorphological field reconnaissance, including preliminary identification of potential drilling sites, structural features.

c) Geophysical measurements in the most prospective areas.

d) Analysis of geophysical data.

e) Compilation, analysis, and evaluation of the gathered data and information.

f) Site selection and reporting.

The Consultant's hydrogeologist mobilized to the Project Area on 02.05.24, and completed the fieldwork on the same day.

The hydrogeological and geophysical field investigations were combined with a broad desk study, during which the available relevant geological and hydrogeological data was collected, analysed, collated and evaluated. Methods and measurements used in the field are introduced and described in Chapter 4.

The recommended (preliminary) sites were marked in the field by marker and a photo sent to the Client.

Figure 1.1: Location Map of the Study Area

2. Geology

2.1 Regional Geology

The area is underlain by volcanic lava at most areas which are then underlain by Precambrian rocks of the Basement System. Due to its location on the western shoulder of the Gregory Rift Valley, the original crystalline rocks of the Mozambican Belt have locally been covered by younger volcanic deposits.

The oldest rocks in the area are formed by various types of gneisses, limestones and quartzites. The original rocks of sedimentary origin were presumably laid down in a geosyncline that covers a large part of East and Central Africa. The lower succession consists of relatively coarse psammitic gneisses, probably produced by rapid deposition in relatively deep water. The upper part, the Loita Series, is mainly pelitic (fine-grained) in character, and numerous limestones and quartzites indicate the calmer environment of a relatively shallow basin. Minor igneous activity is represented by amphibolites, which are thin and concordant.

After their deposition, the sediments were metamorphosed and folded. Metamorphosed granite (an intrusive) was formed during this period. The compression and folding led to the formation of mountain chains, which were intensively eroded at a later stage.

The final event was the formation of Recent soils. In the Basement areas, the soils are usually reddish brown and sandy, but black cotton soils may occur in areas of poor drainage. The Basement System in the Rift Valley yields grey sandy soil. Black cotton soil is formed on most of the volcanic rocks.

2.2 Geology of the Study Area

Most of the study area is covered by black soils. The main rock composition is biotite-hornblende granites and gneisses. Shallow aquifers are likely to be struck between the rock overburden and the weathered hornblende biotite gneiss while the deep aquifers shall be struck within the fractured/weathered basement formations.

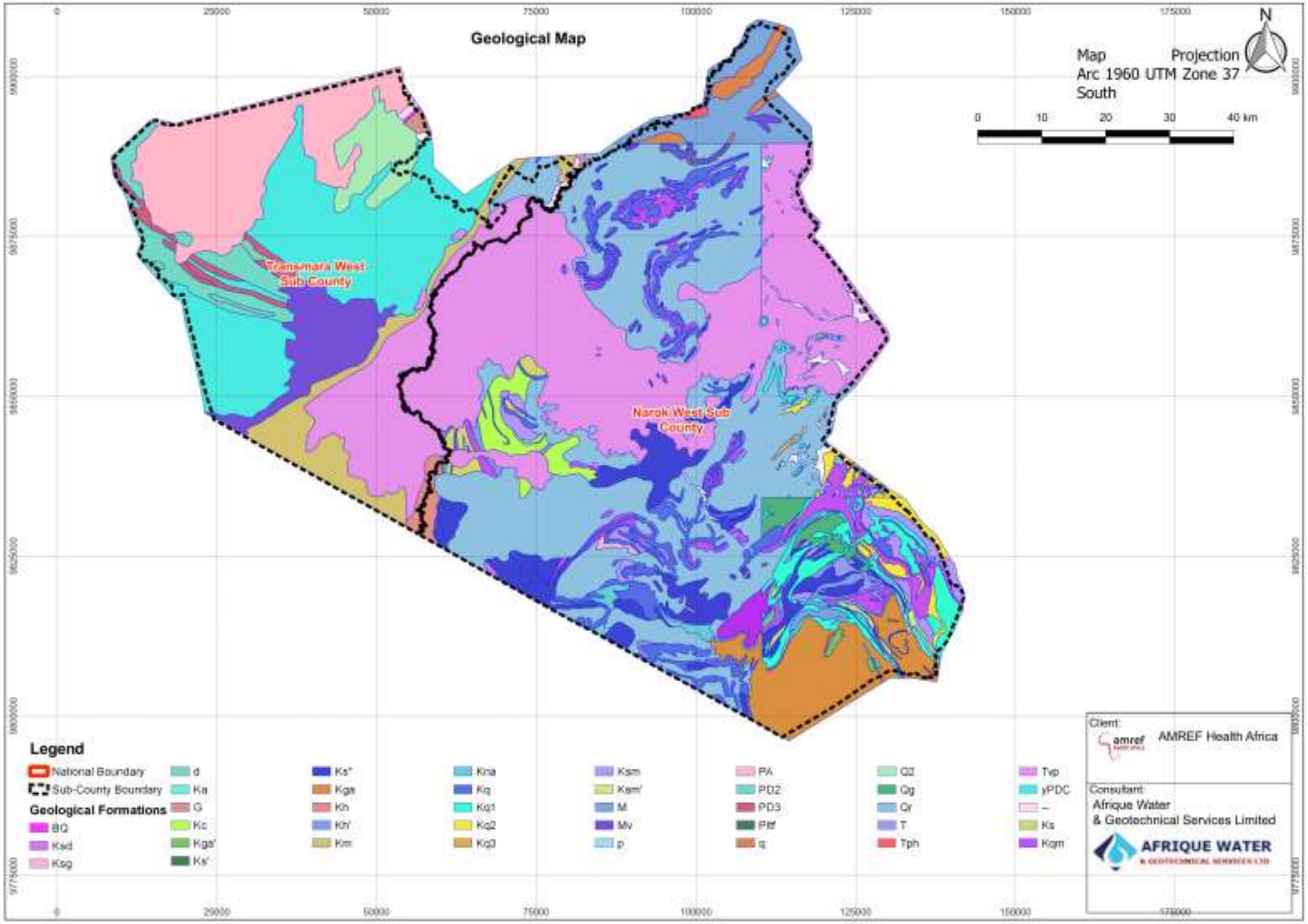


Figure 2.1: Geology of Trans Mara West & Narok West Sub Counties

3. Hydrogeology

3.1 Introduction

The study area is marked by generally unfavourable hydrogeological conditions, which are determined by a combination of largely impermeable bedrock, generally thin soils, and lack of recharge due to a structural rainfall deficit. However, the prospects for groundwater development are fair along the faults and general lines of weakness. Here, weathering has not only resulted in secondary porosity, but has also created a storage media in the regolith, saprolite and saprock. Along the streams recharge is provided by the infiltration of surface discharge, and underflow through the alluvium, faults and the weathered zones.

The area is underlain exclusively by Basement System formations, covered by a layer of weathered rocks, soils and local alluvial deposits. Unaltered metamorphic rocks, such as biotite and quartzo-felspathic gneisses and granulites, are generally hard and compact, and possess no primary porosity. However, depending on the parent material, water may be struck in the weathered zone (regolith, saprolite and saprock). The underlying fresh Basement is in most cases dry, and significant volumes of groundwater can only be expected in fracture zones (cracks, joints, fissures, and faults). An overview of groundwater occurrence in Basement rocks is given in Figure 3.1.

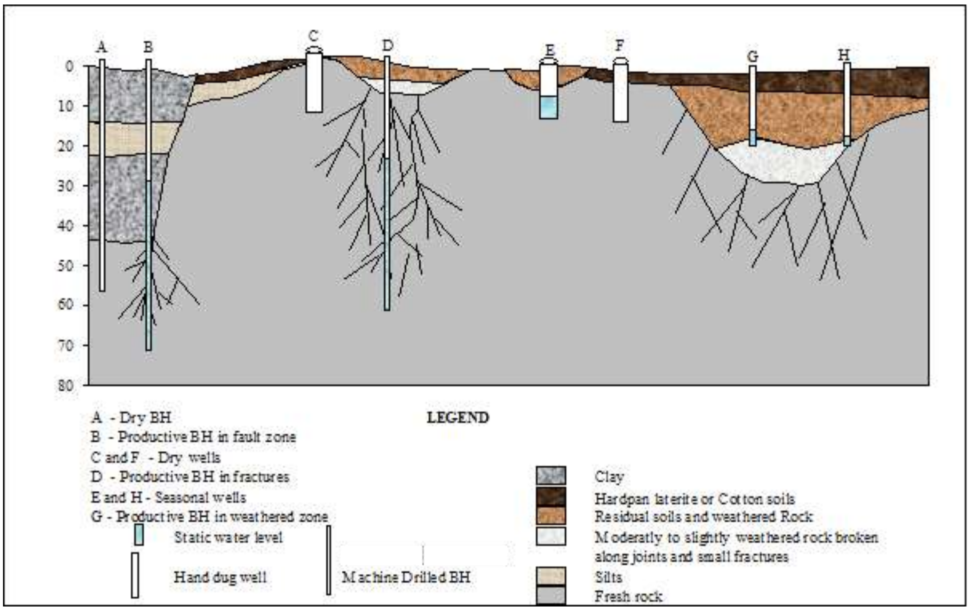


Figure 3.1: Groundwater Occurrence in Basement System Rocks

3.4 Recharge

Recharge is the process through which water is added to the groundwater reservoir. Some aquifers do not receive any recharge at all; in this case, the water is connate or fossil, and pumping results in irreversible depletion. Usually, aquifers with little recharge and consequently long residence times are marked by high levels of mineralisation and salinity. Unless the underground water body is of vast extent, it is essential that not more water is abstracted than the annual amount of replenishment.

3.4 Existing Boreholes

The rivers and streams are a perennial source of water for most people in the area. For this reason, only a few boreholes have been drilled. The locations of the boreholes are marked on Figure 3.1 and the technical details tabulated below

Table 3.1 - Boreholes within the Vicinity of the Investigated Area

Bore Name/ID	OWNER	Sub County	Long	Lat	ATL	Totall Depth (m)	WSL 1	SWL	YIELD (m3/hr)	DRAWDOWN
1	2	3	4	5	6	7	8	9	10	11
Oloontare	AMREF	Transmara west				180	105, 128, 152	5.95	0.75	161.06
Enemasi	AMREF	Transmara west	34.6850455	-1.1169901	1536					
Tororet	AMREF	Transmara west	35.0040637	-1.0053591	1746	200				
Kotolian high	COUNTY	Transmara west				252		104.6	12	13.97
Kondamet	COUNTY	Transmara west	34.81662064	-1.371408564		289	46,124, 250	45		
Endoinyo onkopit	AMREF	Transmara west	34.8286058	-0.9864778	1834	175		8.8	1.2	117.1
Endoinyo onkopit	AMREF	Transmara west	34.8299385	-0.9874979	1797	248	70,220	26.24	0.74	121.72
Narolong	AMREF	Transmara west	34.672253	-1.1479248	1470	220	82,200	22.08	0.62	170.01
Narolong	AMREF	Transmara west	34.6832704	-1.1543292	1512				1.5	

NOTES:
1 Ministry of Water and Irrigation Borehole Identification Number.
2 Longitude and Latitude
3 Borehole Owner
4 Locality
5 Altitude
6 Borehole Completion Date
7 Total Depth
8 Main Water Struck Level
9 Water Rest Level
10 Yield
11 Drawdown

Records of some of the boreholes and their geologic log were analysed and evaluated. Results of the data inventory are presented in Table 3.1 above. In the present study the borehole data have been used to identify aquifer characteristics and their variations with depth.

The borehole yields in the area are generally low, ranging from 0.62m^3/hr to 12m^3/hr. The 4 boreholes whose data was available have an average depth of 223.42mbgl. The tested average discharge from the 6 boreholes whose data was available from WRA with a yield of 2.81m^3/hr.

Shallow Aquifers in the project area stuck between 46-70mbgl while deep aquifers are struck between 105mbgl to 220mbgl.

- ***Specific Capacity***

The specific capacities of the 3 boreholes has been calculated using the formula Sc = Q/Sw, where Sc is specific Capacity, Q is the discharge and Sw is the drawdown. To obtain an insight to the general characteristics, the average specific capacity of the aquifer in general has been assumed as the average of the 5 sample boreholes with drawdown values, resulting in an average specific capacity of **0.176722842m^2/hr.**

- ***Transmissivity***

During pump test, the borehole is pumped at a constant rate and the amount of drawdown is noted. Specific capacity **Sc** is then defined as the pumping rate **Q** divided by Drawdown **Sw.**

Sc = Q / Sw (Discharge per unit of Drawdown).

The following equation, based on the Cooper-Jacob (1946) solution for flow to a borehole in a confined aquifer, computes the Specific Capacity, **Q / Sw** of a borehole:

Q / Sw = T / 0.183 log {2.25 T t / Rw2 S}

Where **Rw** is radius of borehole [m], **S** is storativity [Dimensionless Coefficient], **T** is transmissivity [m/day] and **t** is time [day]. Using the equation, Driscoll (1986) developed approximate formulas for estimating transmissivity from specific capacity in Confined and Unconfined aquifers:

T = 1.385 [Q / Sw]….Confined aquifer

.

T = 1.042 [Q / Sw]….Unconfined aquifer.

Taking the average discharge and pumping drawdown of the 3 sampled boreholes:

Specific Capacity Sc = **0.095240244m^2/hr.**

Transmissivity ***T = 1.385 [0. 0.176722842m2/hr.] = 5.87 m/day***

- ***Hydraulic Conductivity***

The hydraulic conductivity **K** is computed from transmissivity **T** using **K = T / b.**

Where **b** is the saturated thickness of the aquifer. Boreholes should be screened only in the most productive parts of the aquifer if total screen length is to correspond to **b.** For the current sample boreholes in the study area, the total thickness of the main aquifers could not be determined.

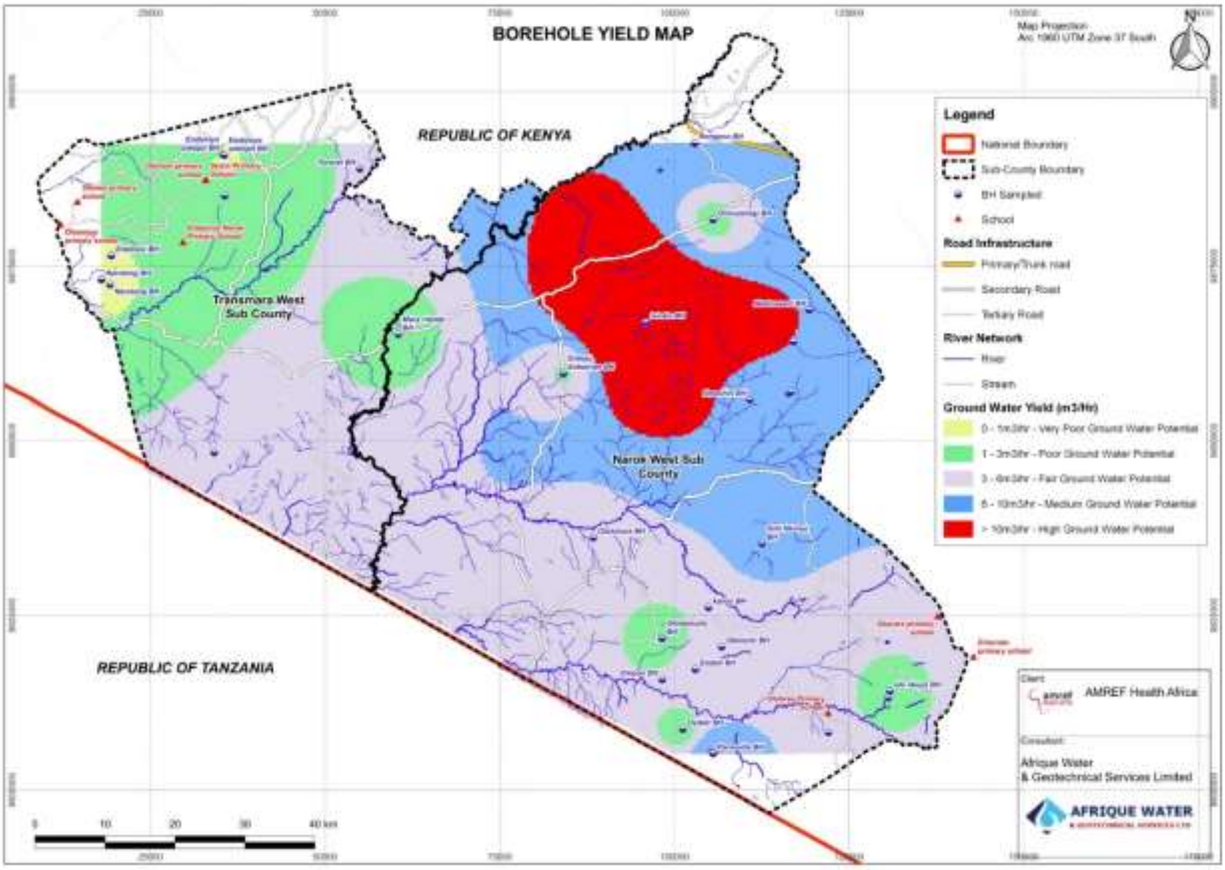


Figure 3.1: Existing Boreholes in Trans Mara West & Narok West (Source, Amref , WRA & Narok County Water Department)

4. GEOPHYSICAL INVESTIGATION METHODS

4.1 Introduction

Great varieties of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey, the resistivity sounding technique was applied, using an ABEM DC resistivity set comprising a Terrameter/Resistivity Meter, connecting cables and crocodile clips, stainless steel non-polarising current electrodes and copper potential electrodes.

This dedicated equipment measures both V and I and presents a calculated resistance (see Section 4.2). In order to improve the validity of the data the equipment takes an average of 4, 16 or exceptionally, 64 readings (determined by the operator). This allows the effects of noise to be minimised.

In Appendix I, graphical plots of the apparent resistivity versus electrode spacing AB/2 are presented, together with raw field data and the resulting geophysical interpretation model.

4.2 Resistivity Method

4.2.1 Basic Principles of the Resistivity Method

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:

$R = \rho a * L/A$ (Ω) (1),

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

$R = \delta V/I$ (Ω) (2),

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

$\rho a = (A/L) * (\delta V/I)$ ((Ωm) (3)

The electrical properties of rocks in the upper part of the earth's crust are determined by the lithology, porosity, the degree of pore space satu¬ration and the salinity of the pore water. These factors all contribute to the resistivity of a material (the reciprocal of the electrical conductivity).

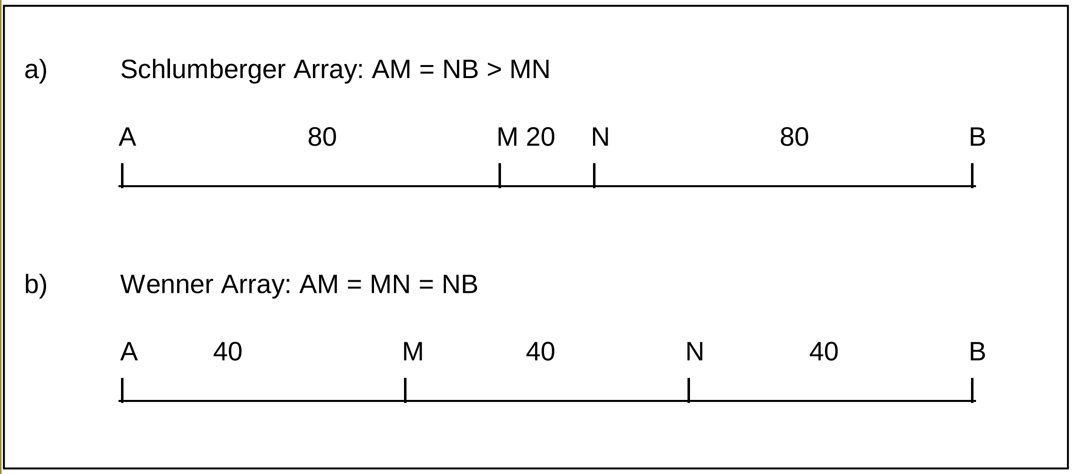
The resistivity of earth materials can be studied by measuring the electrical potential distribution pro¬duced at the earth's surface by an electric current that is passed through the earth. Vertical electrical soundings are point measurements that provide information on the vertical resistivity layering at a certain location. Resistivity profiles, on the other hand, are carried out to obtain information on lateral changes in apparent resistivity along a cross section.

4.2.2 Resistivity Sounding Technique

When carrying out a resistivity sounding, also called vertical electrical sounding (VES), an electrical current (I) is passed into the ground through two metal pins, the current electrodes. Subsurface variations in electrical conductivity determine the pattern of current flow in the ground and thus the distribution of electrical potential. A measure of this is obtained in terms of the voltage drop (δV) between a second pair of metal stakes, the potential electrodes placed near the centre of the array. The ratio (δV/I) provides a direct measurement of the ground resistance and from this, and the electrode spacing, the apparent resistivity (ρa) of the ground is calculated.

The measuring setup consists of a resistivity instrument (usually placed in the middle of the array), connected to two current electrodes (AB), and two potential electrodes (MN) towards the centre. Usually a so-called "Schlumberger" array is used for vertical electrical soundings, while profiles are generally carried out in "Wenner" configuration (Figure 4.1).

Figure 4:1: Examples of Schlumberger and Wenner Configurations for Resistivity Measurements, where: AB = current electrodes; MN = potential electrodes



A series of measurements made with an expanding array of current electrodes (Schlumberger Array) allows the flow of current to penetrate progressively greater depths. The *apparent resistivity* as a function of the electrode separation AB provides information on the vertical variation in resistivity. The depth of penetration varies according to the electrode array, but is also affected by the nature of the material beneath the array.

The point at which a change in earth layering is observed depends on the resistivity contrast, but is generally of the order of a quarter of the current electrode spacing AB (Milsom 1989). By contrast, in an homogeneous medium the depth penetration is of the order 0.12 AB (Roy & Apparao 1971).

The calculated apparent resistivity is plotted against current electrode half separation on a bi-logarithmic graph paper to constitute the so-called sounding curve. The curve depicts a layered earth model composed of individual layers of specific thickness and resistivity.

Interpretation of field data can be done with hand-fitted curves, but this method is time consuming, and practically limited to 3-layer solutions. Modern interpretation is computer-aided, using a curve fitting procedure based on a mathematical convolution method developed by Ghosh (1971).

While the resistivity method is a useful tool in groundwater investigations and borehole site surveys, its applicability and reliability should not be overestimated. The modelling of field data is often attended by problems of equivalence and suppression. Each curve has an infinite number of possible solutions with different layer resistivities and depths (this is known as equivalence). Mathematical convolution can easily lead to a well-fitting solution, which nonetheless does not correspond to reality. In general, the number of possible solutions is reduced by mutual correlation of several sounding curves, knowledge of the local geology and drilling data.

When deposits with similar resistivities border each other, it is usually not possible to make a differentiation. Intermediate layers, occurring between deposits of contrasting conductivity, may go undetected, as they tend to be obscured within the rising or falling limb of the sounding graph (suppression). Additional data, in the form of borehole records, air photography and geological field observations, are required to produce a realistic interpretation.

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

4.2.3 Resistivity Profiles

Resistivity profiles are usually carried in Wenner configuration, i.e. an electrode set-up with a uniform distance between potential and current electrodes (see Fig. 5.1). The entire array is moved across the area of interest. By doing so, lateral changes in apparent resistivity are measured, which reflect variations in the lithology, the depth of weathering or the water content.

So-called "anomalies" may indicate the intersection of a fault (usually a negative anomaly), quartzite band (positive anomaly) or buried riverbed (anomaly depends on nature of surrounding deposits). Usually such lineaments, which may also be observed on aerial photographs, are linked to the occurrence of groundwater.

It must be noted that resistivity differences in a single profile array may largely reflect variations at the surface rather than underground. For this reason, it is usually not sufficient to carry out single-spaced profiles. The depth of penetration increases at greater electrode separations. A series of profiles at variable electrode separations will provide an indication of vertical resistivity trends. Moreover, by repeating the same profile at a different configuration, it will become clear if the observed resistivity patterns are caused by surface phenomena or underground features.

4.3 Geo-electrical Layer Response

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

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

$$\rho = F \times \rho_w = F \times 10{,}000 / EC\ (\mu S/cm), \qquad \text{where: } \rho_w = \text{resistivity of water}$$

In sediments or unconsolidated layers produced by weathering, the formation factor varies between 1 (for sandy clays) and 7 (for coarse sands).

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

Clayey formations with fresh water will respond similarly to deposits with brackish or saline water: the fact that the same resistivity can be obtained for completely different hydrogeological units is known as the "equivalence-problem".

Fresh and dry Basement rocks are marked by very high resistivities, with a common range from 1,000 to 10,000 Ohms. Moderately to slightly weathered but dry layers are less resistive, and usually show values between 100 and 500 Ohms, depending on the portion of clays, the degree of weathering and the water content. The resistivity further decreases if the deposits are water-bearing, to 20 to 200 Ωm. The resistivity of impermeable clay layers (alluvial or produced by intensive weathering of clay-forming minerals) usually varies between 2 and 10Ohmm, while similar figures are recorded for aquifers with brackish to saline water.

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

a) *Equivalence*: the similar geophysical properties of layers with contrasting hydrogeological characteristics (e.g. clay layers and layers with brackish water),

b) *Absence of distinct layer boundaries*: the decreasing degree of weathering with depth is usually not well-defined, but gradual. This will result in a gradual increase in resistivity, and not in a distinct set of geophysical layers.

c) *Suppression #1*: Potential aquifer layers of moderate thickness may fail to show a significant response in the recorded resistivity data (especially where these are deep). Thin aquifers embedded within a very thick deposit can easily remain undetected by surface geophysics. They will however show up in down-hole geophysical logs.

d) *Suppression #2*: The resistivity contrast between the (clayey) weathered zone and the fresh bedrock may be so high, that an intermediate saprock aquifer cannot be distinguished in the graphic plot of the sounding.

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

5. GEOPHYSICAL FIELDWORK, RESULTS AND EVALUATION

5.1 Fieldwork

Combined geophysical and hydrogeological fieldwork was carried out on 02.05.24. The main aim of the geophysical investigations was to get an insight into the hydrogeological conditions prevailing in the vicinity of the within the project site. Furthermore, an attempt was made to find the extent of the water bearing layers.

5.1.1 Vertical electrical method

A total of 4 electrical soundings (VES) were carried out at **Olesenua Primary School**. The geophysical investigations were mainly aimed at the determination of the following parameters:

a) lateral and vertical extent of the water body,
b) texture of the aquifer deposits (grain-size distribution),
c) depth and nature of the layers underlying the groundwater store.

5.2 Results and Discussion

Vertical electrical soundings (VES) provide quantitative depth-resistivity information for a particular site. VES sites were selected at representative points in relation to geomorphological observations, and locations of particular interest for groundwater resources development.

The measurements were executed in an expanding Schlumberger array, with electrode spreads AB/2 between 200 and 400 m. This separation gives fairly reliable interpretations down to a depth of respectively 120 to 300m, but only approximate solutions for resistivity layering at deeper levels. Depths beyond this level are only indicative, and do not give the precise position of the interpreted layers. However, the selected configuration provided adequate information on the depth of weathering.

Apparent resistivity curves were interpreted using IXD program, combined with raw field data and interpreted geo-electrical models are included in Annex 1.

The main aim of the measurements was to determine the degree of fracturing at depth, which should be directly related to the layer transmissivity and thus the potential yield. As a general rule, it can be assumed that the soundings with the lowest basal resistivities in the expected water bearing range represent the most favourable drilling sites. However, this does not apply if the resistivity is excessively low (say < 20 Ohmm): figures close to 10 Ohmm are indicative of high clay contents and/or brackish water.
The sounding curves (in Annex 1), all display a similar stratigraphy of miscellaneous shallow deposits, underlain by weathered volcanic rocks (potentially water-bearing) and fresh

volcanic formation (dry). The three VES interpreted in Tables 5a-b have their resistivity influenced to some degree by fracturing.
The Consultant carried out geophysical investigations at 4 locations within Olesenua Primary School property. Detailed analysis of the geophysical models for only recommended below while the raw data is attached to Annex 1.

Geophysical Interpretation of the VES Models

OLSN 002 VES 2-GPS -1.077799° and 34.6199806°

The geophysical model shows that the top most layer is composed of Black Cotton Soil to a maximum depth of 1.5m. This formation is underlain by Sandy Clay from 1.5mbgl to 3.2mbgl. A Weathered Basement formation occurs from 3.2mbgl to 13.2mbgl. This formation is further underlain by Fresh Basement between 13.2m and 80.4mbgl. The main aquifer shall be encountered between 80.4 to 173mbgl. Fresh Basement occurs below 173mbgl

Drilling is recommended at this location to a maximum depth of 200mbgl. Water is expected to be struck between 80.4mbgl and 173mbgl within the fractured/weathered Basement rocks. This site is known to Mr. Edward, the Client's representative.

Table 5a - Hydrogeological Interpretation of VES 2

Depth (m)	Resistivity (Ohmm)	Interpretation	Aquiferous?
0-1.5	21.71	Black Cotton Soil	No
1.5-3.2	13.8	Sandy Clay	No
3.2-13.2	47.9	Weathered Basement	No
13.2-80.4	1013	Fresh Basement	No
80.4-173	170	Weathered/Fractured Basement	Yes-Main Aquifer
>173-	1629	Fresh Basement	No

OLSN 003 (GPS -00.78751° and 34.96708°)

The geophysical model shows that the top layer is composed of Black Cotton Soil of 0.81 m thick with resistivity of 46.7 Ohm-m. Sandy Clay underlies this formation from 6.84mbgl to 10.03mbgl. Weathered Basement formation is encountered between10.03mbgl and 24.4mbgl. A shallow aquifer is likely to be struck between 24.4mbgl and 37.1mbgl. within the weathered/fractured basement formation. A deeper aquifer shall be struck from 110-171mbgl also within the weathered/fractured Basement formation. A fresh Basement shall be encountered below 171mbgl.

Drilling of alternative site is recommended at this location to a maximum depth of 200mbgl. The main aquifer is expected to be struck between 110-within the weathered/fractured Basement formation. The site is known to the Mr. Edward, Client's Representative.

Table 5b - Hydrogeological Interpretation of VES 3

Depth (m)	Resistivity (Ohmm)	Interpretation	Aquiferous?
0-0.81	46.7	Black cotton soil	No
0.81-6.84	29.7	Moist Sandy Clay	No
6.84-10.03	39.7	Sandy Clay	No
10.03-24.4	303.7	Weathered Basement	No
24.4-37.1	215	Weathered/Fractured Basement	Yes-Shallow Aquifer
37.1-110	3046	Fresh Basement	No
110-171	232	Weathered/Fractured Basement	Yes-Main Aquifer
>171	2030	Fresh Basement	No

5.3 Evaluation

Based on the available hydrogeological data and the geophysical investigation results, it is recommended that a borehole be drilled at a minimum diameter of 8.5"at the location of **OLSN 002 VES 2 (-1.077799° and 34.6199806°).** The hole should be drilled to an approximate depth of 200 metres. The selected site is known to Mr. Edward, Client's representative.

An alternative site is recommended for drilling at **OLSN 003 VES 3 (GPS -00.78751° and 34.96708°)** to a maximum depth of 200mbgl. The site is also known to Mr. Edward.

The hole should be installed with good-quality, locally available mild steel casings and screens.

The chemical water quality is likely to be reasonable. Most mineral concentrations are expected to be relatively high, but acceptable for human consumption.

6. CONCLUSIONS AND RECOMMENDATIONS

Summarized conclusions and recommendations from the hydrogeological investigations undertaken at the project study area in Olesenua Primary School, Trans Mara west Sub County are described in the following Sections.

6.1 Geology and Hydrogeology of Investigated Area:

Most of the study area is covered by black soils. The main rock composition is biotite-hornblende granites and gneisses. Shallow aquifers are likely to be struck between the rock overburden and the weathered hornblende biotite gneiss while the deep aquifers shall be struck within the fractured/weathered basement formations.

Results of the data inventory indicates that the borehole yields in the area are generally low, ranging from 0.62m^3/hr to 12m^3/hr. The 6 boreholes whose data was available have an average depth of 223.42mbgl. The tested average discharge from the 6 boreholes whose data was available from WRA with a yield of 2.81m^3/hr. Shallow Aquifers in the project area stuck between 46-70mbgl while deep aquifers are struck between 105mbgl to 220mbgl.

Combined geophysical and hydrogeological fieldwork was carried out on 12th February 2023. The main aim of the geophysical investigations was to get an insight into the hydrogeological conditions prevailing in the project area. Furthermore, an attempt was made to find the extent of the water bearing layers.

Based on the available hydrogeological data and the geophysical investigation results, it is recommended that a borehole be drilled at a minimum diameter of 8.5"at the location of **OLSN 002 VES 2 (-1.077799° and 34.6199806°).** The hole should be drilled to an approximate depth of 200 metres. The selected site is known to Mr. Edward, Client's representative. An alternative site is recommended for drilling at **OLSN 003 VES 3 (GPS -00.78751° and 34.96708°)** to a maximum depth of 200mbgl. The site is also known to Mr. Edward

6.2 Proposed Borehole Drilling:

- The study recommends that a borehole be drilled within the premises to an approximate depth of 200 metres: this site shall provide a sustainable yield of approximately 2- 3 m^3/hr.
- To achieve and maintain a high yield, and maximize the efficiency of the borehole, the importance of proper design and construction methods cannot be overemphasized.
- The water quality of the proposed borehole is expected to be fair to good. The alkalinity and hardness will be moderately high, but not excessive.

6.3 Additional Recommendations and Legal Requirements

- A piezometer (1inch pipe) line and a water meter should be installed to monitor water levels and groundwater abstraction.
- The hydraulical properties of the borehole and the surrounding aquifer should be determined during a step-drawdown test, followed by a 24-hour constant discharge test. After stopping the pump, recovery of the water level should be measured for 12 hours, or, alternatively, a 95% recovery to the static level. Using test-pumping results, the sustainable yield can be calculated. The maximum discharge is restricted to 70% of the rate applied during the constant discharge test.
- Samples taken during test pumping must be submitted to a recognized laboratory for chemical and bacteriological analysis.

In Annex II, further recommendations are given on borehole construction and completion methods.

Prior to drilling, it is required to apply for an authorization to sink a production borehole from the Water Resources Authority. Three copies of the report should be submitted to WRA.

7. REFERENCES

BINGE, F. W., 1962: Geology of the Kericho Area, Geological Survey of Kenya

LBDA, 1988: Rural Domestic Water Resources Assessment, Kisumu District, Rural Domestic Water Supply and Sanitation Programme, DHV Consultants.

SOMBROEK, et al., 1982: Exploratory soil map and agro-climatic zone map of Kenya. Kenya Soil Survey, Exploratory Soil Survey Report E1.

TAMS, 1980: National Master Water Plan, Stage I, Volume V, Report Appendices. Ministry of Water Development, Nairobi.

SAGGERSON, E.P., 1984: Geology of the Kisumu District, Geological Survey of Kenya.

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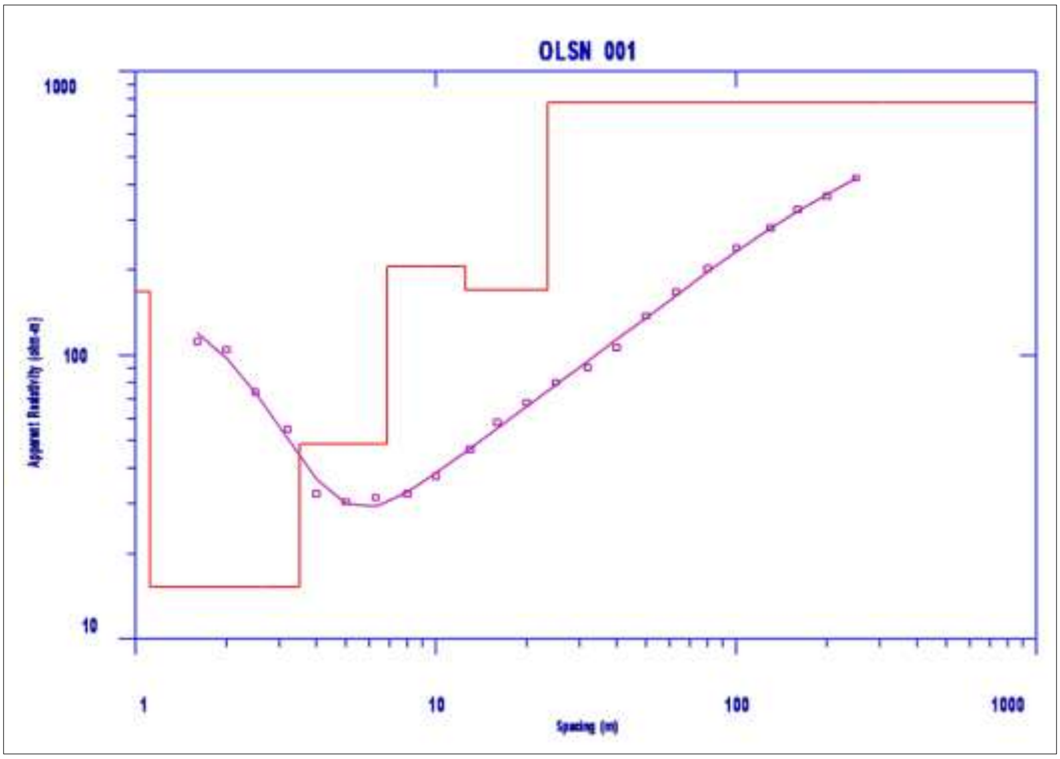
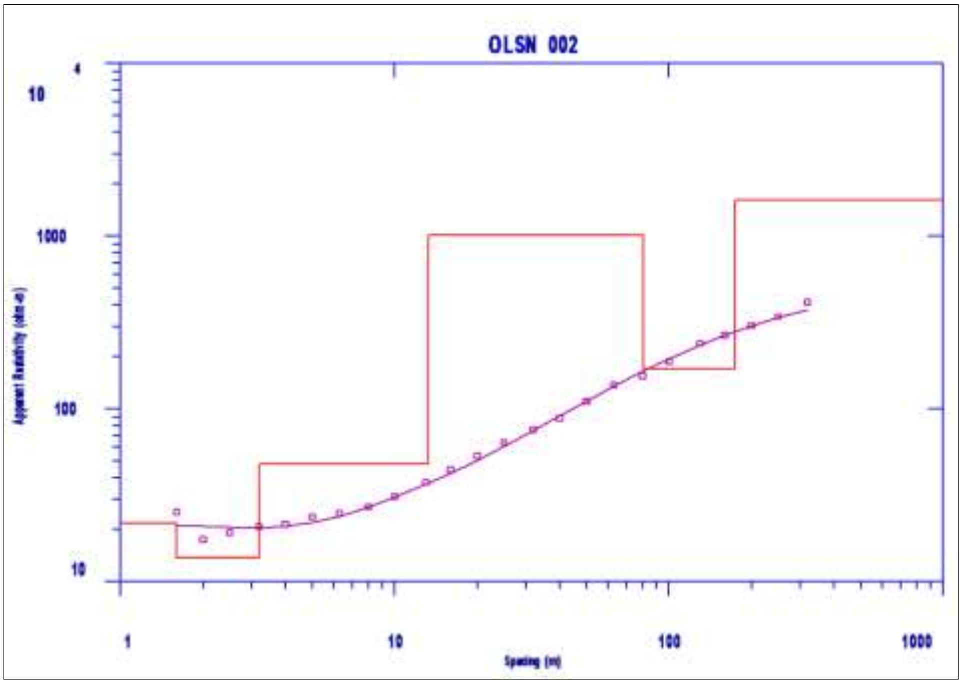
APPENDICES

APPENDIX I: VERTICAL ELECTRICAL SOUNDINGS



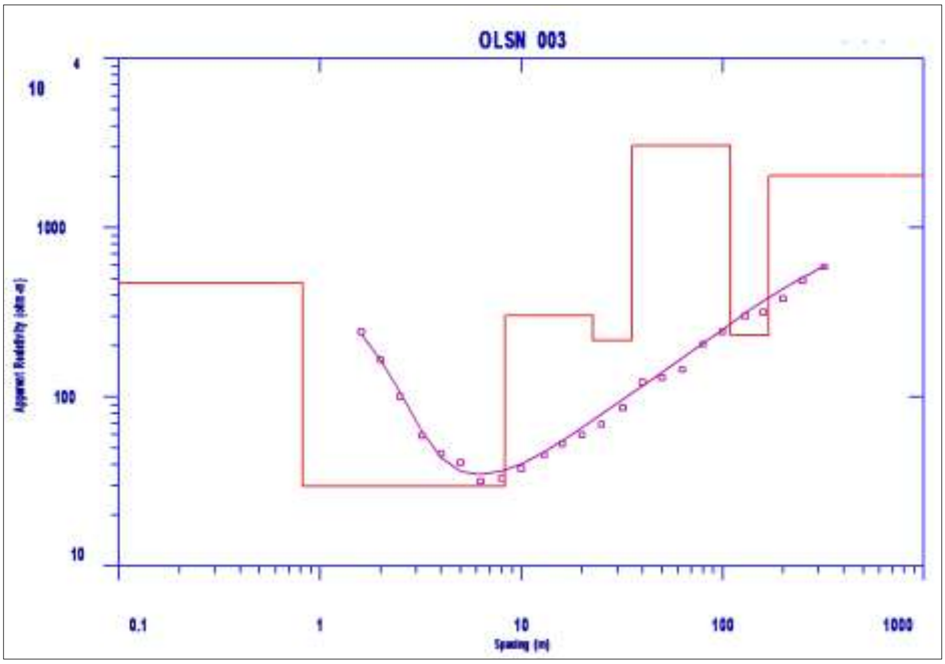
Depth	Resistivity
1.6	111.73
2	104.62
2.5	74.15
3.2	54.85
4	32.5
5	30.47
6.3	31.49
8	32.5
10	37.58
13	46.72
16	57.9
20	68.05
25	80.24
32	90.4
40	106.5
50	137.6
63	167
80	202
100	239
130	281
160	326
200	363
250	421

Resistivity	Depth
167.92	1.1118
15.26	3.5061
48.827	6.8639
206.09	12.544
169.94	23.573
778.34	



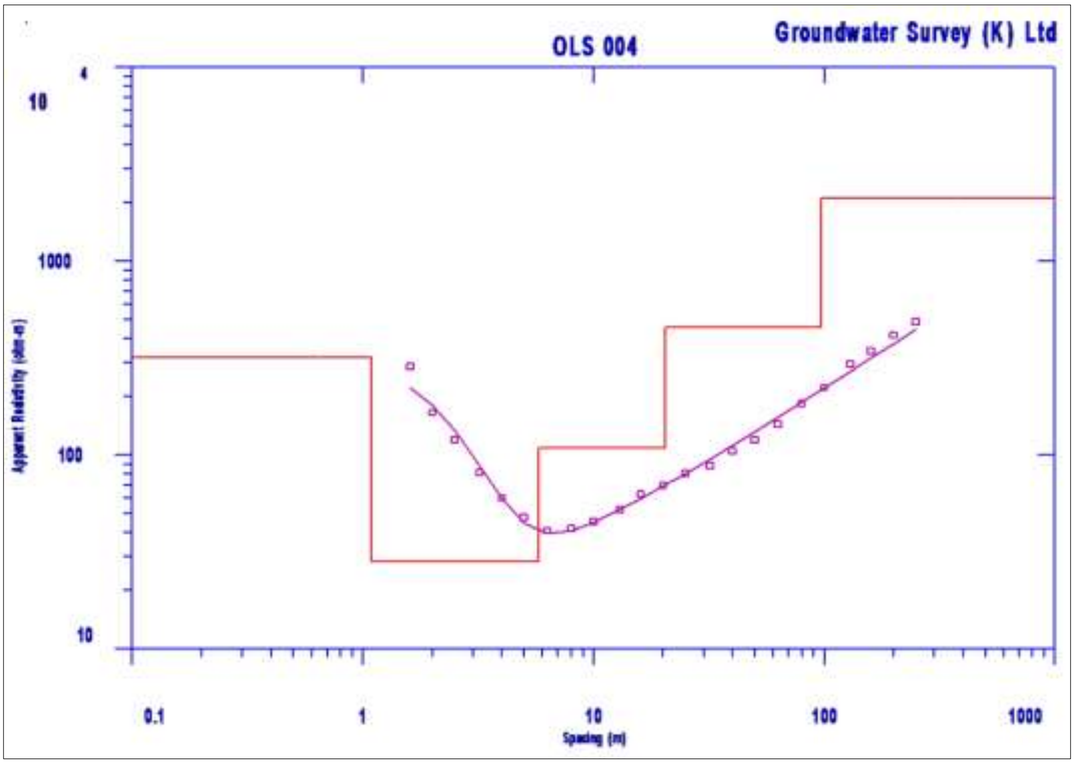
Depth	Resistivity
1.6	25.23
2	17.45
2.5	19.24
3.2	20.81
4	21.55
5	23.65
6.3	24.81
8	27.02
10	31.01
13	37.53
16	44.36
20	53.51
25	63.81
32	75.9
40	88.5
50	110.2
63	136.8
80	154.6
100	188
130	239
160	267
200	303
250	342
320	412

Resistivity	Depth
21.718	1.5967
13.8	3.2107
47.99	13.237
1013.6	80.433
170.84	173.53
1629.1	



Depth	Resistivity
1.6	243.68
2	166.02
2.5	100.97
3.2	59.22
4	46.12
5	41.07
6.3	31.65
8	32.91
10	37.67
13	45.63
16	53.01
20	59.61
25	69.22
32	86.6
40	122
50	130
63	145
80	205
100	243
130	300
160	316
200	381
250	486
320	589

Resistivity	Depth
467.89	0.81693
29.761	8.2996
303.7	22.684
215.71	35.377
3046.9	109.03
232.61	169.6
2030.3	



Depth	Resistivity
1.6	285.99
2	165.36
2.5	119.94
3.2	81.51
4	60.09
5	47.86
6.3	40.76
8	41.92
10	45.41
13	52.4
16	62.88
20	69.87
25	80.35
32	88.5
40	105
50	119.5
63	144.4
80	184
100	222.5
130	295.8
160	343.4
200	415.4
250	486.8

Resistivity	Depth
317.27	1.0898
28.23	5.7695
108.75	20.425
457.16	97.145
2116.1	

APPENDIX II: BOREHOLE DRILLING AND CONSTRUCTION

Drilling Technique

Drilling should be carried out at a diameter of not less than 8.5", preferably using a DTH machine. The drilling rig should be able to drill to a depth of at least 200 m, at the specified diameter. The rig and the drilling method adopted must be suitable for drilling through the Basement formations.

Drilling additives to be used (e.g. foam or polymer) must be non-toxic and bio-degradable. In no circumstances will bentonic additives considered to be acceptable, as they may plug the aquifer zones and are extremely difficult to remove during development.

Percussion tools will considerably prolong the required time for drilling, which may be undesirable if water is required soon. The savings initially believed to be made by opting for percussion drilling are often off-set against the continuing costs for labour, fuel, etc., and the time input of the Client and his representatives. In addition, it should be noted that access to the site may be difficult during the rainy season. As a result, the drilling activities could come to a stand-still.

Geological rock samples should be collected at 2 metre intervals. Struck and rest water levels should be carefully recorded, as well as water quality and estimates of the yield of individual aquifers encountered.

Great care should be taken that the water quality of the different aquifers is accurately determined. Upon the first strike, drilling fluids should be effectively flushed, and after sufficient time, a water sample should be taken of the air-blown yield. On site analysis using an EC meter, and preferably a portable laboratory, is recommended.

Well Design

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

Casing and Screens

The well should be cased and screened with good quality screens. Considering the limited depth of the boreholes and the prevailing alkaline to brackish water quality, it is recommended to use mild steel casings and screens of 6" diameter or uPVC casings.

Gravel Pack

The use of a gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts, which are finer than the screen slot size. A 10" diameter borehole screened at 6" will leave an annular space of approximately 4", which is sufficient to allow the insertion of fine, quartzitic gravel. The grain size of the gravel pack should be within the range of 2 to 4 mm, and granules should be rounded to well-rounded. Over 95% should be siliceous.

Gravel pack should be washed down with copious volumes of water to avoid bridging. The best method, which is unfortunately rarely used, is insertion with a tremie pipe.

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 to insert the artificial gravel pack all around the screen. If installed, gravel packed sections should be sealed off at the top and bottom with clay or bentonite seals (2 m). In this case it is also recommended to install a 3 m long, cement grout surface plug, to prevent contamination (bacteriological as well as industrial) from entering the borehole.

The remaining annular space should be backfilled with inert material (drill cuttings may be used), and the top five metres grouted with cement to ensure that no surface water at the well head can enter the well bore and thus prevent 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.

The use of overpumping as a means of development is not advocated, since it only increases permeability in zones, which are already permeable. Instead, it is recommended that the Contractor employs air or water jetting, air-lifting or mechanical plunging. These proposed methods physically agitate the gravel pack and adjacent aquifer material, and are extremely efficient methods 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. To avoid sediment ingress, and ensure a long lifespan of both the borehole and the pumping unit, the permanent pump should be installed at least 2 m above, and certainly not within, the screen section.

Well Testing

After development and preliminary tests, a step-drawdown test and a 24-hour long-duration well test at constant discharge rate should be carried out. Well tests have to be performed on all newly-completed wells: apart from providing information on the quality of drilling, design and development, it also enables the hydrogeologist to compute sustainable abstraction rates, design drawdown, and other important well and aquifer parameters.

During the test, the well is pumped from a measured static water level (SWL) at a known yield. Simultaneously, the discharge rate and the pumped water level (PWL) as a function of time are recorded. After stopping the pump, recovery is measured until the water level has returned within 5% of the original level, in comparison with the total pumped drawdown.

The specific capacity and the efficiency of a borehole are determined during a step-drawdown test. Simultaneously, target yields for the constant discharge test can be set. The step-drawdown test usually comprises 4 to 6 steps of 60 to 90 minutes each. The pumping rates are increased step-by-step, e.g. by gradually opening a gate valve. Recovery may be measured after the last step, but this is not really necessary if a constant discharge test is conducted as well. However, before starting the constant discharge test, 95% of the pumped drawdown must be recovered, or, alternatively, no increase in level must be observed for a period of more than 4 hours.
The constant discharge test allows calculation of specific aquifer parameters, such as transmissivity, hydraulic conductivity and storage coefficient. In addition, the sustainable volume of abstraction, the design

drawdown and the final pump specification and setting can be determined. The minimum duration of the test should be 24 hours, followed by 12 hours of recovery observations, or alternatively until 95% of the total drawdown has been regained.

Legal Requirements

It is a legislated condition imposed by the Water Appointment Board (through the Water Amendment Bill 1992), that all boreholes in Kenya be equipped with a flow meter and a means by which water levels can be measured. These measures have been designed to allow the collection of data, which will enable both the authorities and the borehole operators to learn more about the reliability and limitations of their groundwater resources.

Flow meters are readily available in Kenya, e.g. of the helical-flow type such as manufactured by Kent (UK) or Arad (Israel). The easiest method of water level monitoring is through a narrow (1.25" to 2") dipper line which is installed along the rising main. An electric dipper should be used to measure water levels directly, with an accuracy of approximately 1 cm. An electrical dipper with a length of 100 metres would cost about US $ 550 in Europe, but more than double this amount in Kenya.

Pumping Plant

Several options are open to the Client:

a) <u>Windpumps:</u> High quality windpumps are made in Kenya, but obviously the site needs to experience sufficient wind, while substantial storage capacity should be ensured. The advantage of windpumps is that they are environmentally friendly and cheap in maintenance. The Kijito range manufactured in Thika, require a minimum of maintenance and have proved themselves under hostile conditions, e.g. in North-eastern Province.

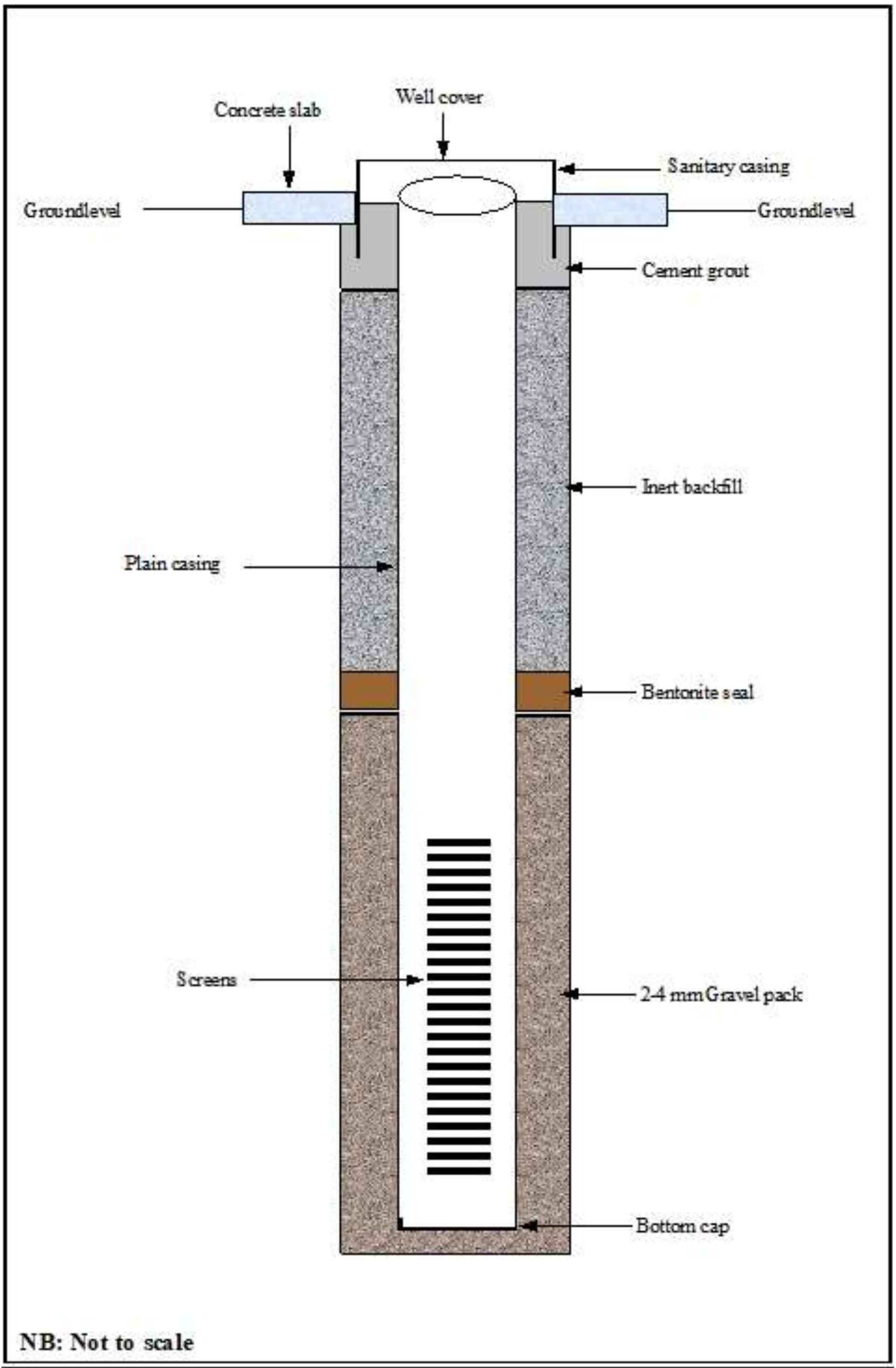
A Kijito windpump can produce 5 to 90 m^3/day, depending on the pump chamber and rotor size, and the average windspeed. The price, including installation, ranges from KShs 600,000 for the small, 12 ft rotor blade to 900,000 for the largest, 24ft rotor diameter (subject to changes by manufacturer).

b) <u>Submersible pumps:</u> Currently, these are arguably the most popular borehole pumps in Kenya. Electrical submersibles are efficient and require little maintenance, though of course they do require electrical power on site, e.g. from a generator set.

c) <u>Electrical solar submersible pumps:</u> These are as yet relatively little used in Kenya, mainly because the plant is comparatively expensive. Generally, solar pumps are not routinely stocked by the main pump suppliers.

d) <u>Turbine or Mono pumps:</u> Given the yield requirements of the Client, both turbine and Mono-type pumps would be needlessly expensive.

e) <u>Reciprocating pumps:</u> Formerly the most popular type of pump used in Kenya. With the introduction of electrical submersibles and modern windpumps, reciprocating pumps (e.g. manufactured by Deming, Southern Cross, etc.) have gradually fallen out of favour. However, when it comes to simplicity and robustness, coupled with a wide range of power plant (almost any suitable diesel driving belt), there is little to beat a reciprocating pump.



Schematic Design for Borehole completion