HYDRO-GEOLOGICAL &GEOPHYSICAL GROUNDWATER SURVEY REPORT FOR A REPLACEMENT BOREHOLE FACILITY AT

SYENGONI PRIMARY SCHOOL
P.O BOX 72– 90138
MAKINDU.

LOCATED IN

SYENGONI AREA, MAKINDU LOCATION, KIBWEZI WEST CONSTITUENCY, MAKUENI COUNTY.

Report No. GEO/2020/09/516

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SUMMARY

Background information

As per the terms of reference, The Client **ATHI WATER WORKS DEVELOPMENT AGENCY**; *has been* mandated through **The Government of Kenya** to improve water supply systems for the school based on the pre-assessed supply constrains; a borehole water supply system is to be constructed on the Primary School. The proposed water supply source needs to be sufficient and conforming to high-quality standards for the school and any community distribution to be considered.

The main objective for this survey is to develop a replacement borehole water source supply, to supplement the domestic supply for Syengoni Primary School and the neighboring community in view of the arid condition of the area. The existing borehole was vandalized and render impossible for rehabilitation thus the need to develop the new borehole. The entire school has an approximate population of about 750 Pupils with a projected increase to 1,000 in the coming years. The primary school currently has a very unreliable pipeline connection to Kibwezi water supply which has been overstretched by the over-dependency by the ever increasing Kibwezi area population. There is thus the need to develop a reliable and potable domestic water supply borehole.

The above survey program was envisaged and commissioned by the client. About **30m^3/day** borehole water is required to supplement the unreliable and insufficient water supply from Kibwezi Water Company. The project is set on an approximately 5 acres of land off the Syengoni Road.

The Makindu area can be classified as an agricultural area that falls in a medium to poor groundwater potential locality, as it is located on the basement complex. The study concludes that on the basis of geological evidence, groundwater prospects for medium – scale abstraction are good. The geology of the Makindu area is characterized by the Basement Complex which are mainly metamorphosed to various grades. The survey program has to rely heavily on the fundamental base data covering the underground hydrography of the wide Basement aquifer system.

It is the clients' intention to conduct the borehole construction program in total conformity with the WRA requirements, with a view to develop a consistent and sustainable groundwater supply. This calls for a fundamental understanding of the local aquifer hydrogeology of the Makindu area and in general, the Kibwezi area, in order to develop a feasible groundwater model for this specific area; based on the standard assessments document policy laid down by the Water Resources Authority.

Table 1; Summary of the proposed replacement facility site

Site coordinates	*VES No.*	*Recommended depth*	*Construction*	*Yield (m^3/hr.)*
37M 0372724 E UTM 9745554 S Elev. 1000m	**VES 1**	**250m**	**216mm/154m**	**4.0-8.0**

ABBREVIATIONS AND GLOSSARY OF TERMS

ABBREVIATIONS:	(Note: SI spellings used throughout).
EC	Electrical Conductivity (µS/cm)
Km	Kilometres
M	Metres
M amsl	Metres above mean sea level
M bgl	Metres below ground level
Ppm	Parts per million, equivalent to mg/l
SWL	static water level (in m bgl)
TDS	Total Dissolved Solids (ppm)
WSL	water struck level (in m bgl.

GLOSSARY OF TERMS:	(> refers to another entry in this glossary)
Aquifer	A geological formation or structure which stores and transmits water and which may supply water to wells, boreholes or springs.
Confined aquifers	are those in which the piezo-metric level is higher (i.e. at a greater elevation relative to sea level) than the elevation at which the aquifer was encountered.
Intercalated	Interbedded – a lava flow that may occur between layers of sediment or vice-versa
Old Land Surface	Old Land Surface (OLS's) is the term given to ancient erosion surfaces now covered by younger surface material. In hydrogeology OLS's frequently make good aquifers, especially where the erosion debris left behind is coarse in nature.
Porphyritic	A rock containing large crystals (phenocrysts) in a finer groundmass
Recharge	The general term indicating the process of transport of water from surface sources (i.e., from rivers or rainfall) to the groundwater system.
Unconformable	The representation in physical geology (i.e. in the rock record) of a break in the ordered succession of rocks
Volcanics	Here used as a general term describing geological material of volcanic origin.

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1 BACKGROUND INFORMATION

1.1: General site details.

Syengoni Primary School project site is located in Kai sub-location of Kibwezi West district. The site lies approximately 3km of the Makindu – Emali Road along the Syengoni Road.

On the site there exists an abandoned borehole with co-ordinates **37M 0372728 E & UTM 9745546 S** that has been vandalized and which used to serve the school and the neighbouring Syengoni community.

However, it is reported that this borehole adopted a depth of 160 m and was pushing out a flow of 3m^3/hr. The facility later, due to local insecurity faced vandalization that rendered the borehole non-functional and was closed down.

This report is documented for the purpose of consent to replace the borehole facility – vide the Water Act Subsidiary Legislation Part IV, Section 72 (5) that states; **"before any well or borehole is replaced, deepened or widened, the owner of the well or the borehole, or is duly authorized representative, shall file with the authority an application for the authority to carry out such replacement, deepening or widening of an existing well or borehole, for any water use category"**

The site coordinates for the investigated site is 37M **0372724 E** and UTM **9745554 S** on **Topographical map sheet 174/4 of the Survey of Kenya** that covers **Kibwezi &** its Environs.

1.2: Drainage

The are no permanent rivers that drain the immediate area with the exception of the Kiumbi water course draining the immediate North of Makindu town. Most of the major farming practices takes place along this water course. The Kilongoni seasonal swamp situated to the immediate North of the Primary school is the source of seasonal Kilongoni stream that drains northwardly and forms part of the extensive tributaries draining the Galana River.

1.3: Climate and Vegetation

The climate is typical semi-arid and the district is representative of many other zones with similar ecological conditions throughout Kenya, characterized by low and unreliable supply of soil moisture for plant growth. The semi-arid lands of Kenya occupy approximately 30% of the total land area. These areas have average annual rainfall, evaporation and temperatures of 600, 2000 mm and 23°C respectively (Michieka and van der Pouw, 1977; Braunn, 1977). Rainfall comes in high intensities and is usually concentrated at the beginning of the long or short rains. The natural vegetation in the area is woodland and savanna, with several tree species, mainly *Acacia*

2 TERMS OF REFERENCE.

Enek Geo-Consultants Limited– (Water Resource Development Consultants) was commissioned by the **Athi Water Works Development Agency** – to undertake Hydrogeological assessments/ Borehole site investigations for Syengoni Primary School located in Syengoni area, Makindu Location, Kibwezi West - Sub County of Makueni County.

The requirement to construct a replacement borehole in the school was necessitated by the vandalization of the existing borehole rendering it un-usable and with the obvious - shortfalls in the climatic condition of the area, a result of very low rainfall seasons. The proposed facility is intended for the provision of water supply for the domestic requirement at the school premises as well as for community distribution through a pipeline connection.

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

i. *Undertake comprehensive feasibility study of the groundwater occurrence within the site.*
ii. *Optimize an ideal location for the proposed borehole project,*
iii. *Integrate reconnaissance survey data with the existing borehole data*
iv. *Compilation/documentation of all the additional available hydro-geological, geological, geophysical, hydrological data and the subsequent provision of a comprehensive report on the groundwater exploration program for the project area.*

In addition to the above-outlined Terms of Reference, the Consultants aimed at establishing and optimizing the baseline conditions of the groundwater flow patterns, using the following conceptual approach.

2.1 Anticipated Approach.

The approach to this study is expected to apply standard methods to calculate or estimate aquifer parameters and establish the baseline conditions in aquifers underlying the Basement Complex rocks.

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

2.2 Concept: - Anticipated Methodology.

Review of existing data and collection and review of additional data has been encompassed in this study. The recommendation of the drilling procedure has laid emphasis on the construction methodologies that would attain high performance efficiency through both chemical and physical aquifer development.

The site investigations findings and geophysical data – as part of the Hydro-geological investigation has been documented vide the report here in – and contains the entire study; amongst others the conclusive recommendations and finding. The current study lays emphasis on the client's specific water requirements and is geared towards development of a moderate flow borehole system with an estimated capacity of **4 - 8m³/hr**.

To achieve the project objectives, the consultants collates the vast database for boreholes located in the Makindu area and looks at their inherent potential as an additional data input to the geophysical investigations data.

3 DETAILS OF GEOLOGY

The project area is covered by dark red to brown soils and in some parts by clayey soils. Geologically, the project area is situated in an area covered by thin carpet of volcanic rocks above gneisses and schists of Precambrian rocks. The top red brown sandy soils overly layers of weathered lava, gneisses and schists of Precambrian rocks. These rocks are sometimes intercalated with sediments of old land surfaces deposits and highly fractured layers at depth. This is then underlain by massive gneiss at depth.

There are two different types of aquifers encountered in both the volcanic and Basement rocks;

- *those associated with faults and fractures, the better by far of the two,*
- *and those associated with weathered rock, usually encountered beneath the soil cover overlying the compact, or unweathered rock.*

The latter aquifers, located in the regolith, are highly variable in terms of potential yield since the physical transmission of water within the aquifer body itself. It is dependent upon the total clay fraction present after weathering of the parent rock which itself depends on the chemical constituent of the parent rock and the mechanism of weathering.

The project area has very complicated geology and that is the reason we have dry to medium yielding boreholes in the area. The sections below are a description of the structures and lithological units of the project area.

3.1 Geological Structures

The rocks of the basement system in the Simba-Kibwezi area have been intensely folded, metamorphosed and partly granitized, all of which are thought to have occurred more or less at the same time. The principal structural features of the area include foliations, lineation, folds, faults, joints and other minor structures.

Though faulting has affected both the Basement System gneisses and volcanic rocks the folding is confined mainly to the Archaean gneisses. Fold axes trend generally north to north-north-east, swinging to a north-north-westerly direction near the northern margin of the area. The folds are overturned to the west in the Mureshi area and elsewhere are normal, frequently with symmetrically disposed limbs. All the folds plunge in a northerly direction.

The main faults of the area trend north-west – south-east and north-south, though a few strike nearly due east-west along the Muoni Valley. Minor faults and slides have affected the rocks forming the cores of folds and are seen exposed in river valleys.

3.2 The Recent Sediments/ soils

The recent soils in the area are variable, their character depending on the drainage of the area in which they are found. In the project site area that lies in the Yatta plateau, parts the soils are red murram and brown types, while on the steeper hill-slopes grey or reddish brown soils predominate. In the numerous deep erosion gullies on hill-slopes considerable thicknesses (***up to 75ft***) of un-bedded red-brown soils of loessic appearance are often seen.

Lateritic iron stones developed in thin patches at Nthumbini hill; coarse detritus and boulders of the hill slopes west of Katende, which are well-exposed in vertical-sided gullies on the hill flanks, and land slide deposit.

3.3 The Basement System

The Basement system comprises of sedimentary rocks – which include psammitic quartzite's and biotite gneisses, the migmatitic banded and streaky gneisses of mixed appearance, pegmatites, and the granitoid rocks – homogeneous, massive quartz-feldspar-biotite-muscovite gneisses, augment gneisses. Much of the Basement System is bedded and regular sequences of beds can be traced for considerable distances. They sharply dip into the foliated planes – synclinal dips of the systems in what apparently fold thrusts.

The banding in the gneisses is so uniform over distances of several hundred yards that it must be concluded that it is due partly, at least, to original differences in the composition of a sedimentary series. The granitoid gneisses represent the end products of the metasomatic process and in some cases became mobile at the height of metasomatism. The migmatites and granitoid rocks are considered to have arisen by varying degrees of metasomatism of the originally metamorphosed basement system rocks.

The granitoid gneisses are buff to dirty cream in colour and medium-grained. They are homogeneous and un-bedded, and often outcrop in tors, as large slabs or blocks on the summits of hills, or form more or less flat exfoliation pavements. Pegmatites are few in the granitoid masses and only rare ptygmatic pegmatite veins are seen. Quartz lenticels and "schlieren" are more common and appear to cross-cut the foliation.

3.4 Volcanics of the Chyulu Range

Volcanic eruptions, which have continued intermittently from the Pleistocene times in the Simba-Kibwezi area, took place from a number of centres that occurred successively further south east, the most recent lavas being poured out near Mzima Springs, 30 miles south east of Kibwezi. No flows of historic age have been recorded, however, from the present area

The oldest lava in the Kiboko valley is that exposed between the two ridges at Kiboko (on the main Mombasa-Nairobi road) and is thought to be approximately the same age as if not part of, the lower flows east of Mathaioni. These lavas are overlain by the pahoehoe lavas that occupy the Kiboko and Makindu. These pahoehoe lavas are probably north-flowing branches of the same lava that was extruded from the Tindima region.

The typical formation layout – on the Client's farm may comprise the following in-situ rocks.

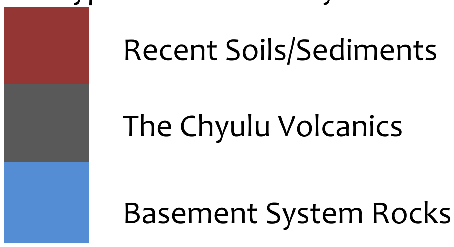


Figure 1; The Geologic setting of the project site

4 HYDROGEOLOGY.

4.1 Geo-Hydrology of Makindu area

The occurrence of groundwater at the site is controlled by climate and geological structure. This section briefly discusses some of the hydro-geological characteristics of the aquifers and boreholes within the Makindu area and the surroundings environs.

The hydro-geology of the area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within the Basement System rocks, groundwater primarily occurs within the sediment beds, fractures, and lithological contacts. The water table in this area is unlikely to be far below the level of the principal watercourses, and as the relief is low, depth to water should not be excessive in boreholes on the plains.

A general conclusion can be made from the borehole database. In cases where the basement is highly fractured, the potential yield is high; and where it's compact to render high confining pressures, to the aquifer, the boreholes got to rely on the contact aquifer for the deployable yields.

The most reliable geological datum in the area is the surface overlain by the Yatta plateau lava, which is seen in two places east of the Athi River. In the neighboring areas Schoeman (1948) and Dodson (1953) considered that the phonolite forming the plateau flowed over the sub-Miocene peneplain and that its base has an average gradient of about 15 ft, to the mile. The peneplain, which has an elevation between 3000 and 3800 ft. sloping to the south east south at approximately 20 ft. per mile, is considered to bevel a large part of the area north of the Railway. It forms the plain between the hills of Matha and Nguu and can be recognized in the vicinity of Makindu and Kibwezi.

Recharge for the Makindu *area* Basement gneiss system can be inferred to be constituted of both localized vertical percolation – and lateral recharge through the discordant intrusive of the Basement system. The hydraulic head results to lateral flows through the permeable and fractured layers of the fractured and deformed gneiss and host rocks.

4.2 Surface Water Resources

Surface water sources within the Makindu area are limited. There are practically no water sources within the area with most of the drainage features being dry over most periods of the year i.e. most rivers are seasonal.

Due to lack of perennial surface water flows, there are a number of shallow wells along the sandy beds of the dry river courses and especially along the Kiumbi Water course and some private boreholes meant to supply domestic water to the local population. Earth dams would not suffice the harsh climatic trends, and are quite rare. The shortfall in supply would require the necessity of sinking water boreholes in the area as a supplemental source.

The rivers provide an extensive hydrological catchments extending into the Athi Basin to the north – the discharge boundary being defined along the floodplain of the Athi. *The Rivers* – like most of the systems draining the hills - is affected by the climatic patterns; the associated ground structural control and thus exhibits a characteristic low flow during the dry spells

4.3 Groundwater Resources

In the absence of the surface water source, groundwater thus suffices as the practical and feasible option for sustainable domestic/irrigation source point. The Makindu area can be considered as falling in a zone with moderate to low groundwater potential whereupon recharge is obtained through a concentration of groundwater drainage from the surface percolation during the rainy seasons as well as from the seasonal rivers and streams within the area. Within economic drill depths of 250m – the aquifer transmissivities are high and boreholes will tend to post high capacity outputs, this is ascribed to deep aquifer penetration.

4.4 Existing boreholes

It is stipulated in the Kenyan Law (Water Act), that special conditions permitting a borehole may not be drilled within 800 metres from any existing well unless, water is abstracted from an aquifer (or aquifer) not tapped by the existing well/borehole(s).

Table 2; Borehole data Base within the Syengoni- Kai area of Makindu

BH No. C	Locality/Owner	TD	WSL	PWL	Q, m^3/h
	Dr. Kimeu	160	12.41	119.45	1.2
130		83	20, 76	-	5.53
2114		-	-	-	-
1875		45	24	-	10.615
1876		51	31	-	5.688
493	Mbui nzao	56	15,44	-	8.18
2208		37	37	-	12.55
2194		34	9	-	12.99
3813		91.4	18.3	-	8.2
	Julius Wambua	130	27.18	118.75	3
	Japhet Mbingu	189	34.8	142.0	4
	CRBC - Makindu	200	19.0	80.91	12

The borehole log shows water strike at relatively low depths; this depending on degree of fracturing / weathering. The boreholes in these areas are located on the crystalline Basement;

5 GEOPHYSICAL INVESTIGATION METHODS.

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions. In the present survey resistivity (geo-electrical) in the VES modes has been used. Resistivity measurements were thus carried out in the form of profiles (Wenner Array) and vertical electrical soundings (*Schlumberger array*).

5.1 Resistivity Method

5.1.1 Basic Principles

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, the 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 rock the lower its resistivity. 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 the 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 inversely proportional to its cross-sectional area A, expressed as:

$R = \rho * L/A$ ………………………………………… (1)

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

$R = \Delta V/I$ ……………………………………………… (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:

$\rho = (A/L)\, \Delta V/I)$ ……………………………………… (3)

5.1.2 Resistivity Sounding Method

When carrying out a resistivity sounding, also called vertical electrical sounding (VES), an electric current (I) is passed into the ground through two metal pegs, 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 pegs and the potential electrodes placed near the center of the array. The ratio (V/I) provides a direct measurement of the ground resistance and from this and the electrode spacing, the apparent resistivity (ρ) of the ground is calculated.

A series of measurements made with an expanding array of current electrodes (Schlumberger Array), allows the flow of current to penetrate greater depths, providing information on the vertical variation in resistivity. 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 the sounding curve is based upon the convolution method of Ghosh, (1971) a mathematical curve-fitting procedure. Without additional data for correlation it can easily lead to a fitting solution that does not quite correspond to reality. The layered earth model is actually very much a simplification of the many different layers, which may be present. The various equivalent solutions which can be generated a single resistively sounding should never be interpreted in isolation as this leads to a meaningless result.

5.1.3 Horizontal Electric (HEP) Method

The horizontal electric profile method is one of a supplement group of geophysical exploration methods that make use of constant probe depth to reveal fracture zones located beneath the surface.

For the present survey, the HEP method in the Werner configuration has not been used, a probing concept at a constant depth of either 50/63/ 80/100 metres below ground level with the potential electrodes at 10 metres separation is commonly used. The anomalous sections are further investigated using the resistivity Vertical electric soundings in the (Schlumberger Array)

5.1.4 The Combined Wenner/VES Method

The combined Wenner/VES method locates suitable groundwater zones by making use of the resistivity contrast, which exists between fresh unproductive rocks and water bearing zones. The resistivity of fresh basement exceeds 1880 Ω-m, whereas that of water-bearing zones is lower, being dependent upon the degree of weathering and the groundwater quality. The method exploits the different operating characteristics of two methodologies.

First HEP configuration is used to carry out a conductivity traverse across the area of interest. In most cases, two parallel profiles are run, in order to assess the significance and the direction of the observed anomalies. Vertical Electrical Soundings are then carried out at the most promising locations on the Wenner profiles, using an ABEM SAS 1000 Terrameter. The VES is used to assess the nature of the feature, because a variety of sub-surface conditions can give rise to similar profiling data.

In addition, the VES is used to predict the thickness of different layers and depth to the aquifer. By combining VES, and the resistivity profiling, a ground resistivity model can be obtained which best fits both sets of data. The joint computer interpretation helps to reduce the ambiguity caused by equivalence.

6 FIELDWORK

Fieldwork – for this project was carried out on 18th September, 2020. The investigations were conducted in Vertical electric soundings with the objective to optimize the drilled depth different directions of the school farm with a view to verify degrees of fracturing and detail the fracturing depth respectively within the farm settings.

6.1: Resistivity Soundings (VES)

Two vertical sounding were carried out in the farm with a view to verify to fine detail the Stratigraphy type of the farm. An interpreted result of the vertical electrical soundings is shown in table 3&4 below while the resistivity curves are presented in the **Appendix 4**.

Table 3; Interpretation of VES-1

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION
0.0 – 4.2	162.79	Reddish-brown top soils Overburden sub-base
4.2 – 8.3	12.84	sediments
8.3 – 15.8	1029.30	Highly weathered & Altered gneisses
15.8 – 84.8	170.77	Weathered to highly fractured gneiss
84.8 – 147.6	1127.2	Partly fractured granitoid gneisses
147.6 – 266.9	827.9	Fractured gneisses to compact gneisses
>266.9	2776	Compact gneisses

Table 4; Interpretation of VES-2

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION
0.0 – 0.9	491.59	Reddish-brown top soils
0.9 – 1.9	64.447	Overburden
1.9 – 3.8	111.38	Partly compact sediments
3.8-7.4	149.83	Compact sediments
7.4 – 89.0	356	Compact sediments Partly weathered gneiss
< 89	973.64	Compact gneisses

Evaluation of the VES Probe.

The field Curves of the study, generally suggest four geo-electric layers. From the apparent resistivity model of the curves and information from a borehole log and published resistivity data (Telford et al; 1990), their equivalent geologic units are the top soil, weathered basement, fractured and fresh basement rock. The weathered and the fractured were considered as the aquiferous components of the study area because of their role as water bearing geologic units in basement complex (Olowu, 1967). The aquiferous unit (The weathered and the fractured), with a thickness range of 15-147m, is overlain by top soil and sediments that is characterized by resistivity and depth range of 12.84– 162.79Ωm and 0 – 15m respectively. The resistivity value range suggests composition of sand, silt, clay and laterite. According to Eigbefo (1978), superficial deposits (or top soils) act as recharge materials, especially where they are underlain by weathered basement. The fourth layer, which underlain the aquiferous unit, has an infinite thickness and resistivity values that are greater than 827 Ωm.

The investigation has addressed its intended purpose. In all the delineated geologic layers, the weathered and fractured basement, considered as the aquifer unit, has been interpreted to vary in thickness across the VES stations. Amongst these stations, VES 1 is the promising point with sustainable volume of water for construction of a borehole because the aquifer thickness is highest at the station (about 132m for the station). It is thus recommended that, for appreciable volume of water to be pumped, boreholes should be constructed at VES 1.

7 GROUNDWATER QUALITY

Practically all types of water, i.e. runoff water, groundwater and even rainwater, contain some dissolved salts and impurities. If certain elements are present in high concentrations, the application of the water for domestic and/or irrigation uses may be restricted.

The groundwater quality in the Makindu – Kibwezi area is generally saline to some extended but is within the range recommended by WHO for both domestic and/ irrigation application.

High fluoride intake, especially by growing infants, may cause dental or skeletal fluorosis. Over a short time span, the consumption of water with excess fluoride is not necessarily harmful to adults, especially if they rely on alternative sources for their main drinking water purposes.

In addition to high fluoride concentrations, a greenish or brown colouration may occur, due to high iron and/or manganese concentrations. In most cases, the unaesthetic colour can be removed by simple aeration and subsequent filtration

8 CONCLUSIONS AND RECOMMENDATIONS

Based on the geology, hydro-geology and other information on the site area, it can be concluded that the area is characterized by one hydro-geological regime. The groundwater regime in the area is associated with crystalline sediments overlying the weathered Basement Aquifer.

Good water prospects exist at the project site with optimum conditions of transmissivity and storage occurring within the weathered granitoid gneisses. Due to good recharge and the expansive catchments at the recharge source, the groundwater quality and quantity within the project site is expected to be good.

A borehole drilled at the surveyed prospect is likely to exhibit a yield of over 4-5m^3/hr.; that could meet close to 90% of the specific water requirements for the proposed water supply project to the construction camp. An assessment of the catchment factors and discharge elements indicate suitable storage conditions at the project site that could provide a reliable well drilling prospect.

In view of the fore-going discussions and survey findings, it is recommended that a borehole be drilled at the location marked as **VES 1 -** to a maximum depth of 250.0m below ground level. The borehole is to be drilled at a nominal drilling diameter of 203(8”) mm open hole; and lined with 153mm steel casings; with the plasma screens at the aquiferous sections of the borehole.

In view of the above it is recommended that:

A water supply replacement borehole is to be developed on **Syengoni Primary School,** GPS coordinates **UTM 37M 0372724 E and 9745554 S**, to a recommended terminal depth of **250m** below ground level; to conform to the VES 1 sounding. The site has been marked on the School as BH location VES 1, and is to be drilled at 203mm drilling diameter and cased at 153mm –6”.

The location which is shown in the site sketch – (**Back pocket map extract of Kibwezi area; Topographical map sheet No.174/4)** is well marked with a metallic peg in the field. A tabulation of the construction summary is as tabulated below Table 5.

Table 5; The construction summary

VES No. & ranking in Yield Potential	Recommended depth in metres	Anticipated Water Strike depths.	Construction Requirements.
1.0: VES 01	250.0 metres	40.0 - 130.0	203mm/153mm

8.1 Specific Construction Requirements.

i) *A monitoring tube should be installed in the drilled intake to allow regular measurements of the water levels in the intake wells. This is a requirement for the final pumping equipment installation and is a specific WRMA Requirement.*

ii) *In case shallow aquifers are encountered it is recommended to seal these off within the upper 10 metres, in order to avoid any risk of chemical contamination. Installing a clay or cement seal in the annular space between the borehole wall and the metal casing should achieve the expected sealing tightness.*

iii) *Screens should only be installed at the deeper aquifers. We emphasize the use of plasma slotted pipes with enhanced density of slots to improve the lifespan of the bore. Torch cut well screens are not recommended due to their associated problems of encrustation development when exposed to air – damp.*

iv) *The recommendations on well construction cannot be considered complete without the mention of the requirement to test pump the water supply borehole to British standards BS 6316 (1992), which is an industry standard. This standard generates qualitative and quantitative discharge variations over time in response to the abstraction. At least 10 hours of the step test at –2-hour interval followed by a CRT test for 30 hours is recommended. Recovery must be carried out to full Static Water Levels.*

v) *The drilling should ideally be carried out with a percussion/rotary drilling plant to contain imminent strata collapse in the highly weathered and unconsolidated sediments of the aquifer system.*

Great care should be taken over the completion and development of the well. This latter aspect is too often neglected in well construction in Kenya, which often leads to a reduction in maximum possible yield and a decrease in the hydraulic efficiency of the screens – which can mean higher pumping costs and shorter well life.

There is the technical need to define the Deepest Advisable Pumping water level - (DAPWL) - within the screened sections of the borehole the screens designs during construction. The ultimate scenario without a properly defined DAPWL is the depreciation of the pumping water levels to the screened areas that leads to screen encrustations due to air exposure and water damp.

APPENDICES

APPENDIX 1: Drilling Techniques

i. *Drilling Methodology*

Drilling should be carried out with an appropriate tool – comprised of a high-powered rotary machine, which is considerably faster. Geological rock samples should be collected at 2 meter intervals. Struck and rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

ii. Well Design

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

iii. Casing and Screens

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

iv. 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. An 8½" (216mm) diameter borehole screened at 6" (153mm) 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 grain size of the gravel pack should be an average 2-4mm.

v. Well Construction

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

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

vi. Well Development

Once screen, gravel 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 means of development since it only increases permeability in zones, which are already permeable. Instead, we would recommend the use of air or water jetting, or the use of the mechanical plunger, which physically agitates the gravel pack and adjacent aquifer material. This is an extremely efficient method of developing and cleaning wells.

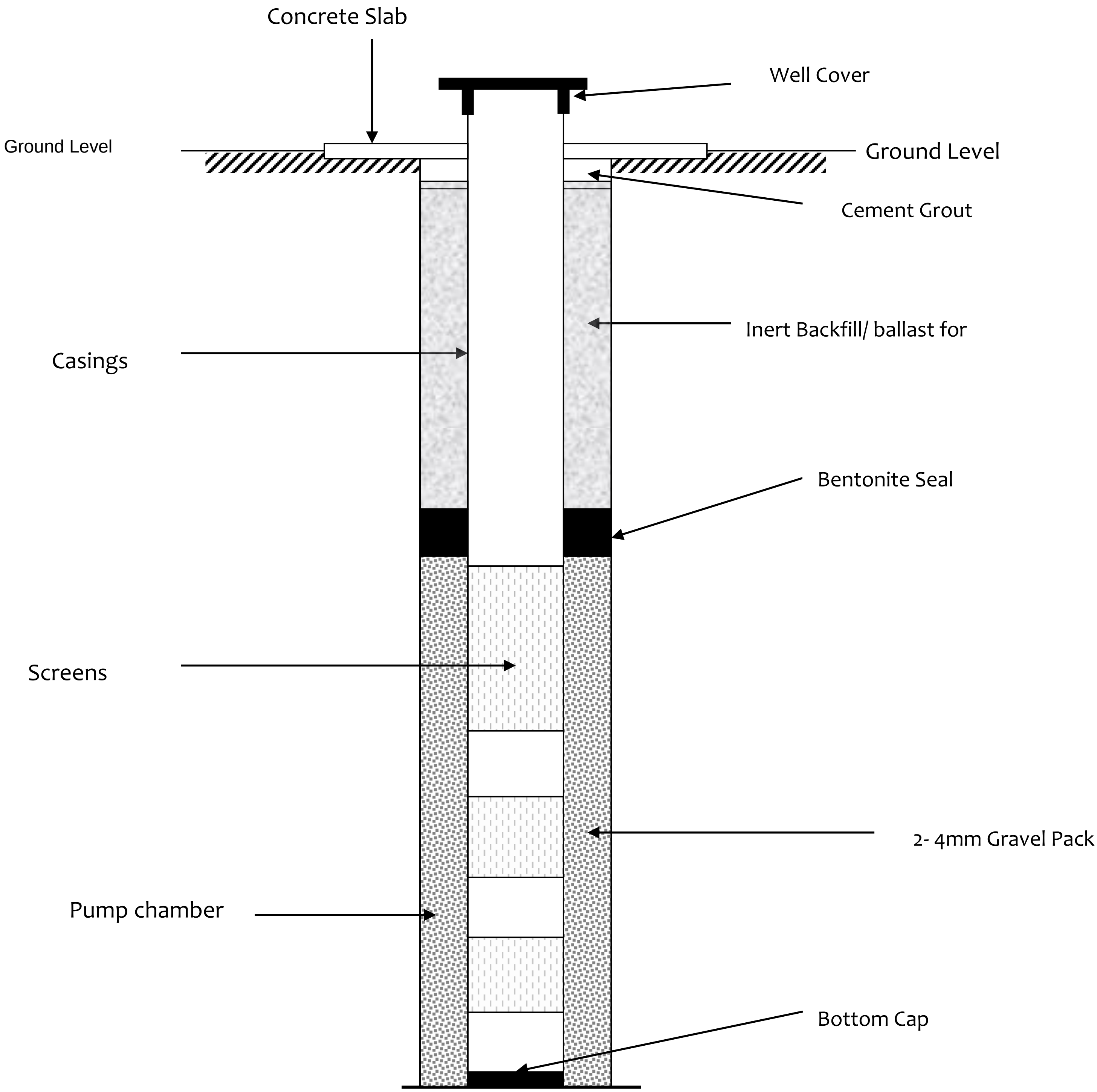
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2m above the screen, certainly not at the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

vii. Well Testing

After development and preliminary tests, a long-duration well test should be carried out on all newly-completed wells, because from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters which are vital to the hydro-geologist. A well test consist 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 draw-downs as a function of time.

Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually the rate of pumping is increased stepwise during the test each time equilibrium has been reached (Step Draw-Down Test). Towards the end of the test a water sample of 2 liters should be collected for chemical analysis. The duration of the test should be 48 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 the project design consultant to calculate the optimum pumping rate, the installation depth, and the draw-down for a given discharge rate.

APPENDIX 2:
SCHEMATIC BOREHOLE DESIGN
(Not drawn to scale)



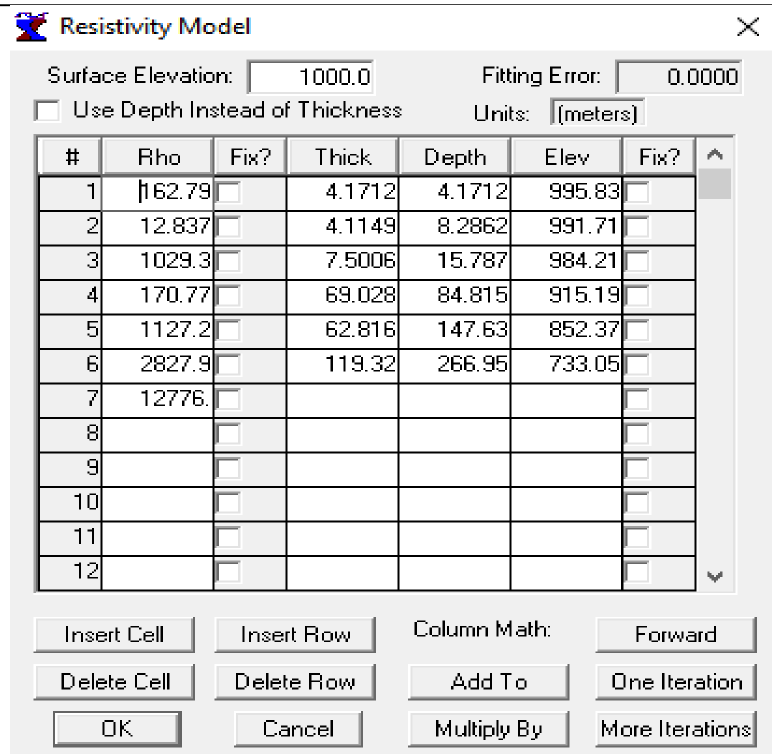
APPENDIX 3:
Ionic Concentration: WHO &Various Authorities

World Health Organization: 1983 Guidelines | 1971 Int. Standards | European Community: EC Directive 1980 relating to the quality of water intended for human consumption

Substance or Characteristic		Guidelines Value (GV)		Upper limits (HL), tentative			Guide level (GL)		Max. Admissible Conc. (MAC)
Inorganic Constituents of health significance:									
Antimony	Sb								0.01
Arsenic As		0.05		0.05				0.05	
Cadmium	Cd		0.005		0.01				
Chromium	Cr		0.05		0.05				
Cyanide CN		0.10		0.05				0.05	
Fluoride	F		1.5		1.7				1.5
Lead	Pb		0.05		0.10				0.05
Mercury	Hg		0.001		0.001				0.001
Nickel	Ni								0.05
Nitrates			10(as N)		45 (as NO)		25(as (No)		50 (as NO)
Selenium	Se				0.01				0.01
Other Substances		GV: Desirable Level	Highest	Permissible Level:	Max.	GV		MAC	
Aluminum	Al	0.20					0.05		0.20
Ammonium	NH						0.05		0.50
Barium	Ba								0.10
Boron	B								1.0
Calcium Ca	75		50		100				
Chloride	Cl	250		200		600	25		
Copper	CU			0.05					0.10
Hydrogen Sulphide	H_2S.		ND						ND
Iron	Fe	0.30			0.10		1.0	0.05	0.20
Magnesium	Mg	0.10	30	150		30			50
Manganese	Mn	0.10		0.05		0.50		0.02	0.05
Nitrite	No								0.10
Potassium	K						10		12
Silver	Ag								0.01
Sodium	Ng		200			20	175		
Sulphate	So4		400	200		400	25		250
Zinc	Zn			5.0		15	0.10		
Total Dissolved solids		1000	500		1500				1500
Total Hardness as $CaCo_3$		500	100	500					
Colour	Hazen		15	5	50	1	20		
Odour	Inoffensive		Unobjectionable					2 or 3 Ton	
Taste	Inoffensive		Unobjectionable					2 or 3 Ton	
Turbidity			5		5	25	0.4		4
PH	6.5-8.5		7.0-8.5		6.5-9.2	6.5-8.5		9.5 (max)	
Temperature	0C							12	25
EC	us/cm		2000					400	
Notes	*ND-Not Detectable*						*IO-Inoffensive*		
	GL-Guide Level							*UO-Unobjectionable*	

APPENDIX 4:
VES FIELD DATA & CURVE MODELING

MN/2	AB/2	K	ACTUAL ρ
0.5	1.6	7.26	158.40
0.5	2.0	11.8	169.67
0.5	2.5	18.8	165.63
0.5	3.2	31.4	172.41
0.5	4.0	49.5	158.72
0.5	5.0	77.8	136.54
0.5	6.3	124	91.69
0.5	8.0	200	69.36
0.5	10.0	313	60.52
0.5	13.0	530	53.76
0.5	16.0	803	50.63
0.5	20.0	1260	60.45
0.5	25.0	1960	55.99
10.0	32.0	3220	111.65
10.0	40.0	495	120.69
10.0	50.0	788	132.25
10.0	63.0	1240	137.66
10.0	80.0	2000	132.61
10.0	100.0	3130	137.66
10.0	130.0	2640	152.41
10.0	160.0	4010	219.94
10.0	200.0	6270	329.85
10.0	250.0	9800	351.95

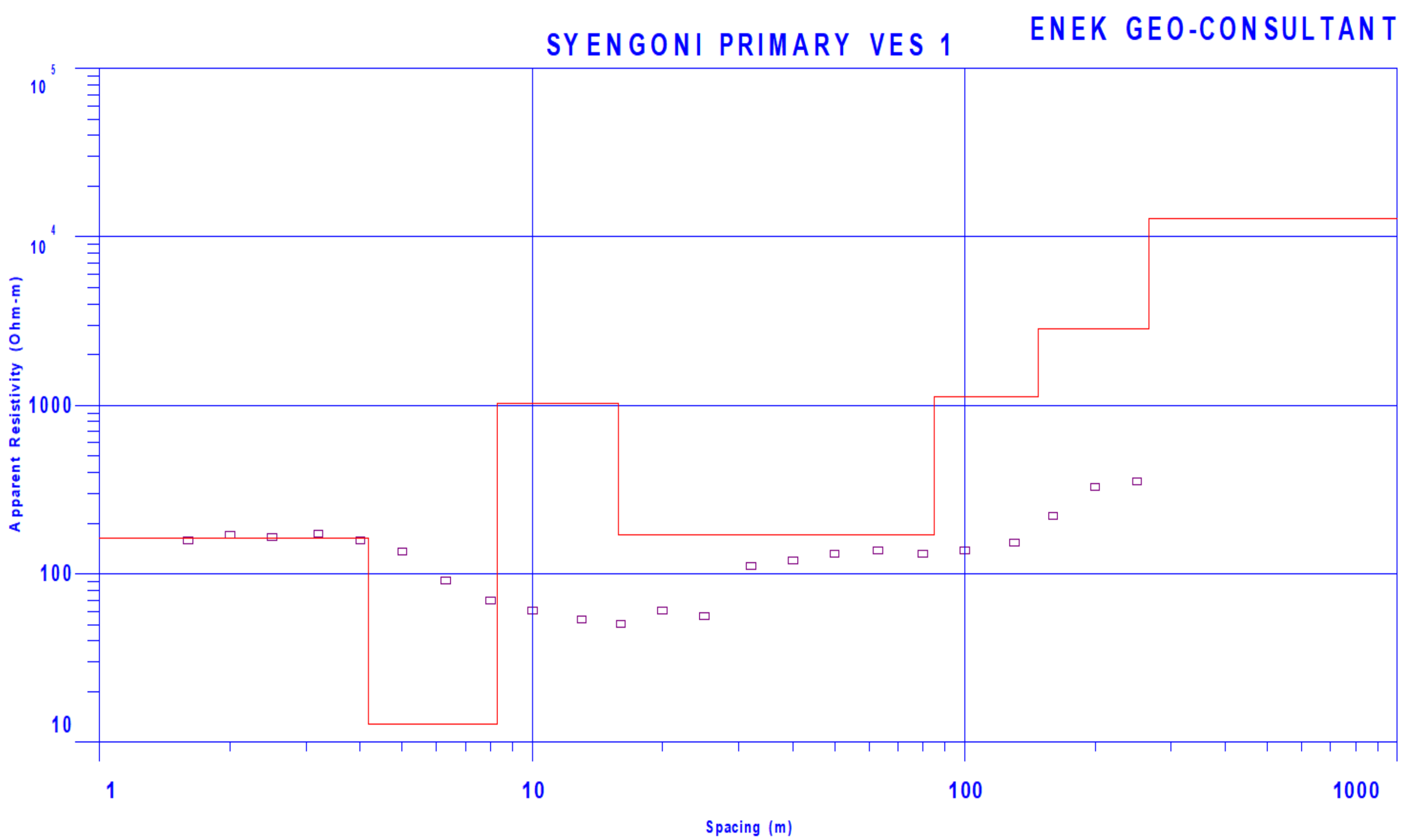

Resistivity Model

Surface Elevation: 1000.0 Fitting Error: 0.0000

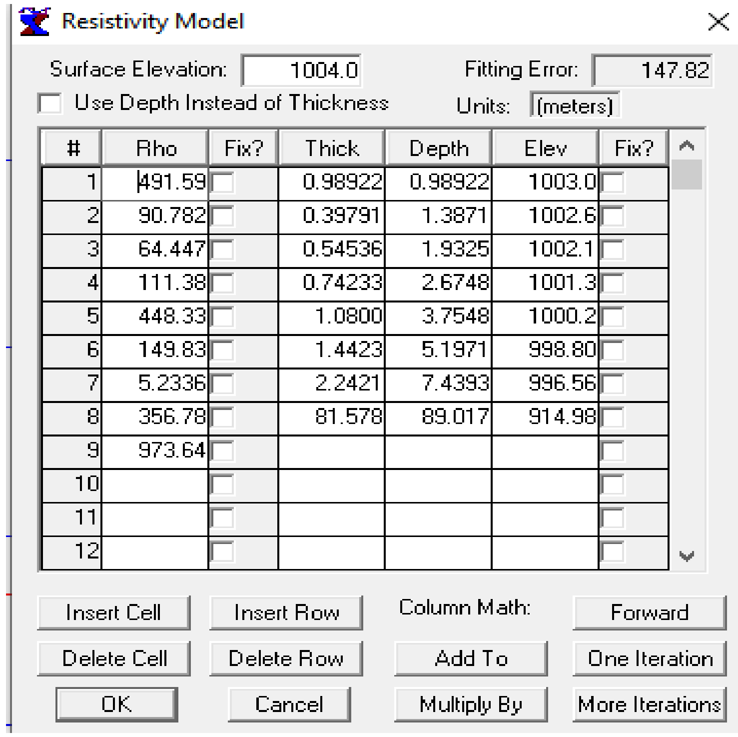
Use Depth Instead of Thickness Units: [meters]

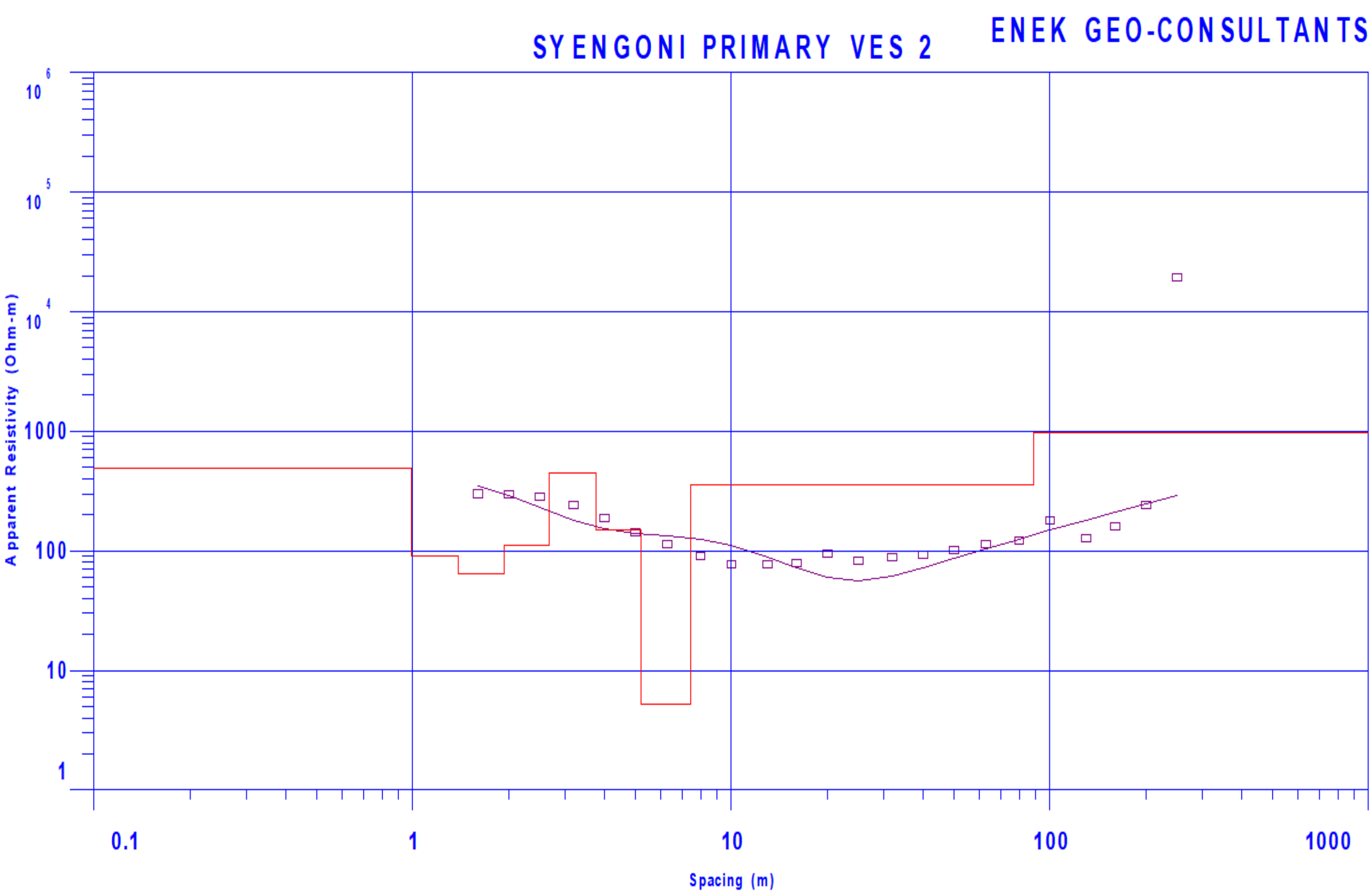
#	Rho	Fix?	Thick	Depth	Elev	Fix?
1	162.79		4.1712	4.1712	995.83	
2	12.837		4.1149	8.2862	991.71	
3	1029.3		7.5006	15.787	984.21	
4	170.77		69.028	84.815	915.19	
5	1127.2		62.816	147.63	852.37	
6	2827.9		119.32	266.95	733.05	
7	12776.					
8						
9						
10						
11						
12						

Insert Cell | Insert Row | Column Math: | Forward
Delete Cell | Delete Row | Add To | One Iteration
OK | Cancel | Multiply By | More Iterations

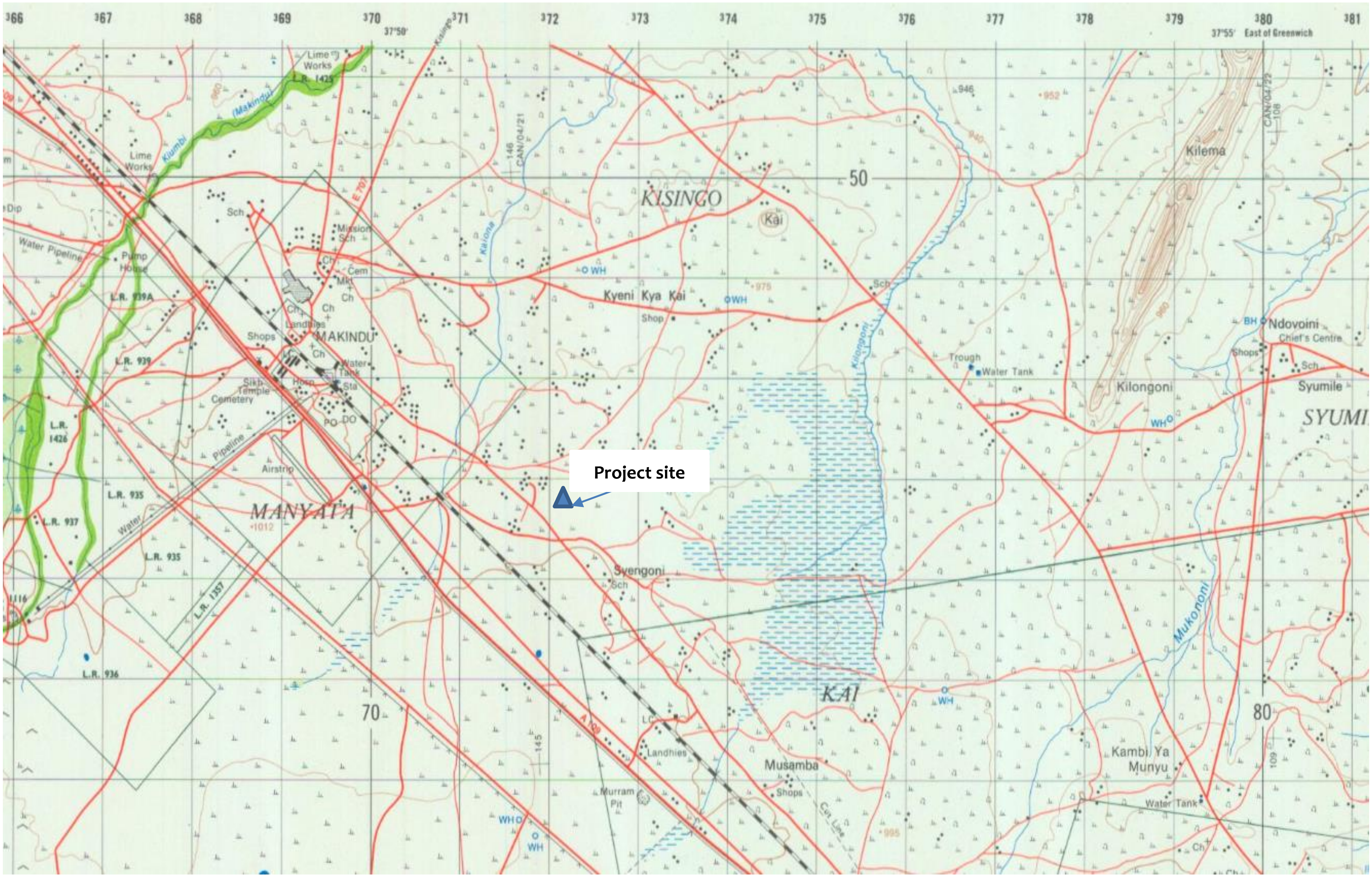


MN/2	AB/2	K	ACTUAL ρ
0.5	1.6	7.26	300.06
0.5	2.0	11.8	299.01
0.5	2.5	18.8	286.09
0.5	3.2	31.4	240.03
0.5	4.0	49.5	188.76
0.5	5.0	77.8	143.30
0.5	6.3	124	114.87
0.5	8.0	200	91.36
0.5	10.0	313	76.90
0.5	13.0	530	77.07
0.5	16.0	803	78.64
0.5	20.0	1260	95.77
0.5	25.0	1960	82.34
10.0	32.0	3220	88.17
10.0	40.0	495	93.50
10.0	50.0	788	101.44
10.0	63.0	1240	112.62
10.0	80.0	2000	122.47
10.0	100.0	3130	179.64
10.0	130.0	2640	126.96
10.0	160.0	4010	161.81
10.0	200.0	6270	239.42
10.0	250.0	9800	19313.00

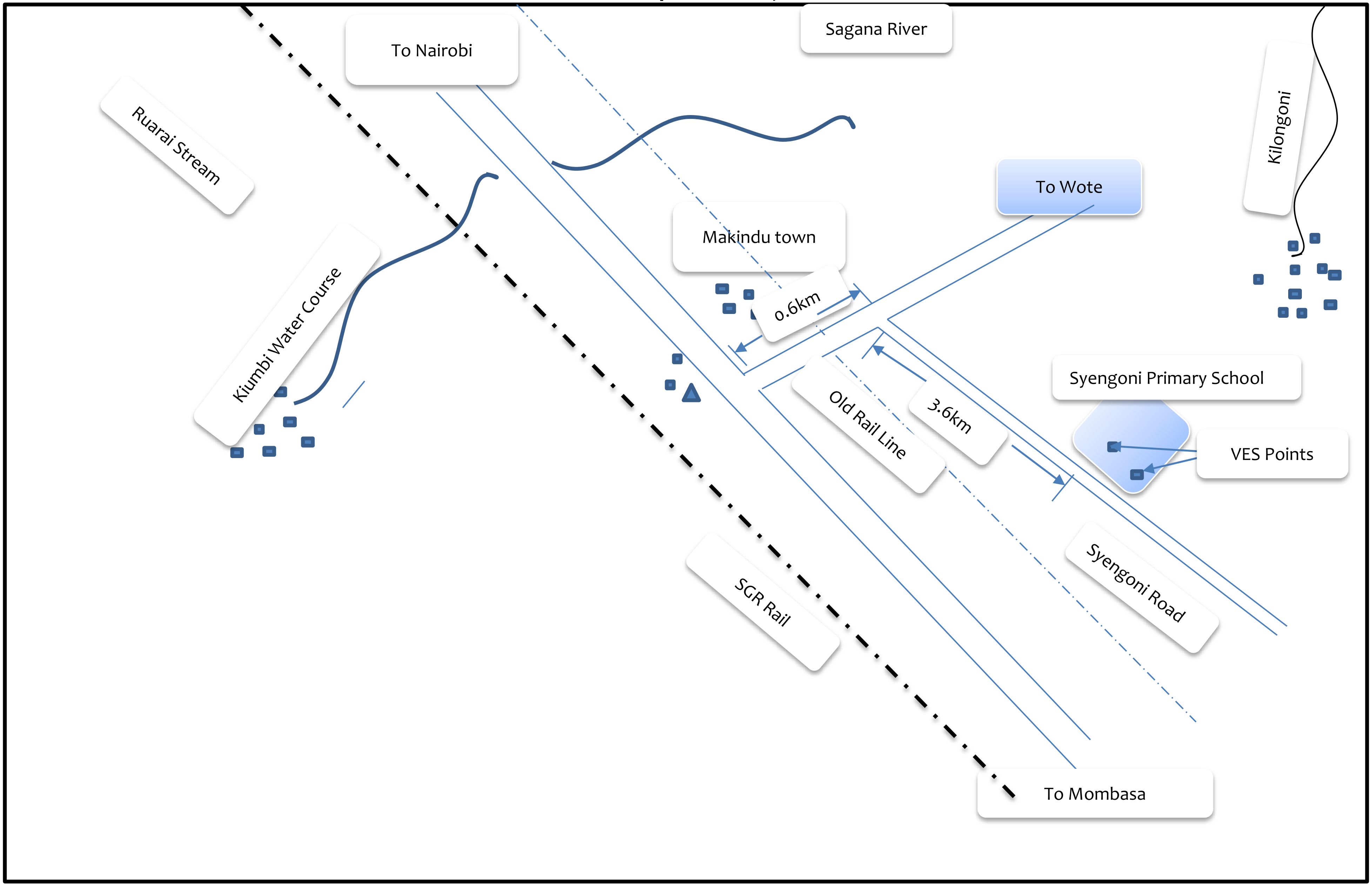




APPENDIX 5:
Topographic map sheet 174/4 – Kibwezi



APPENDIX 6:
Sketch Map of the Project Site.

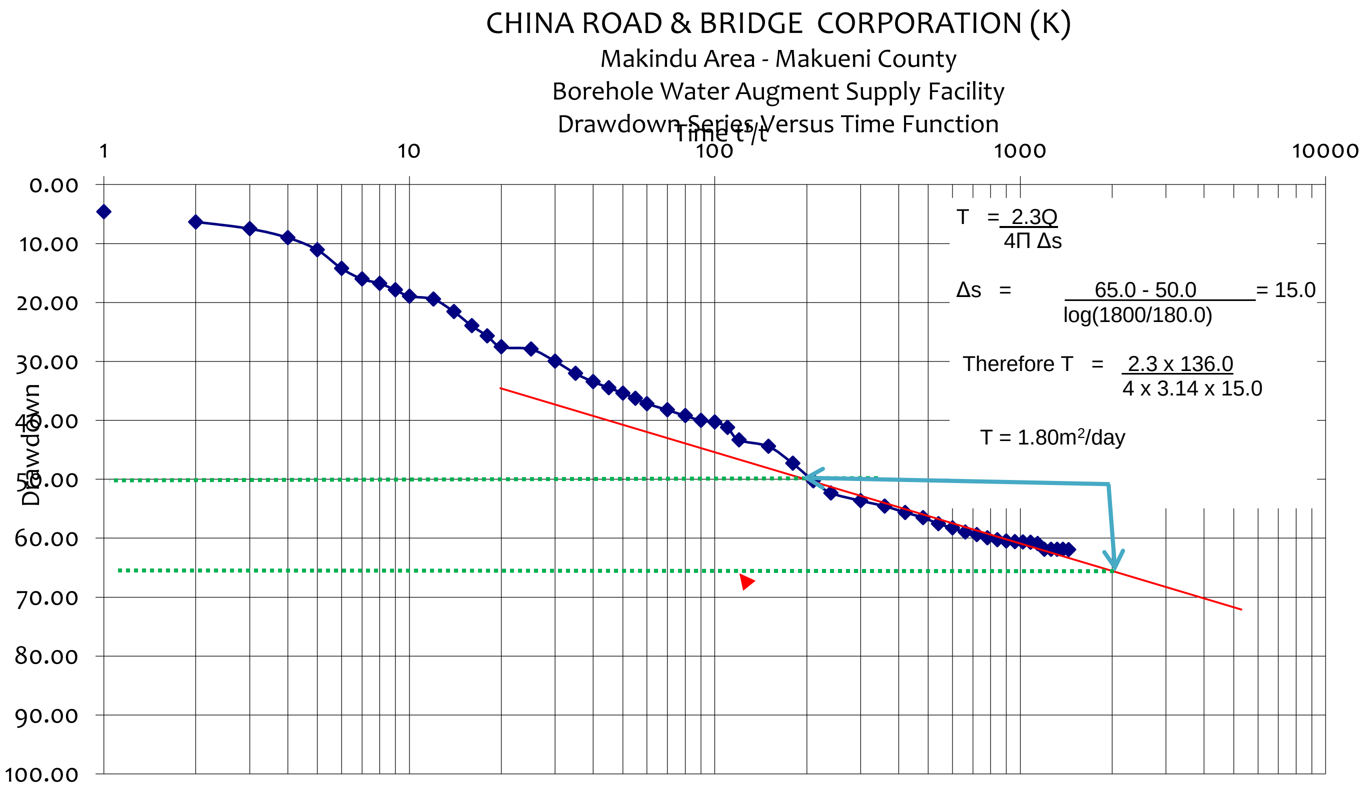


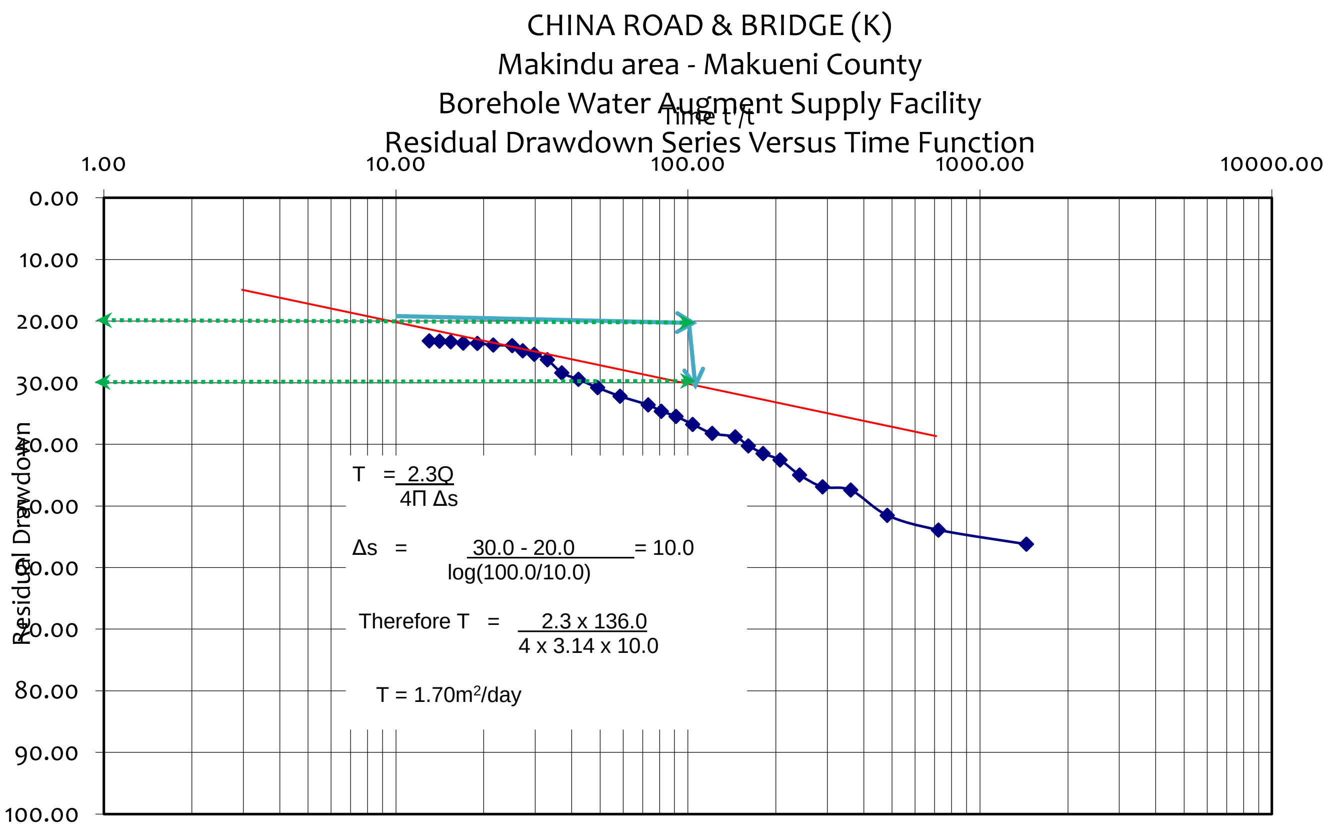
APPENDIX 7:
Test-Pumping Data

TEST PUMPING - DRAWDOWN MEASUREMENTS							
Client: China Road & Bridge Corporation (K)					**Water Sample taken: Yes**		
Borehole Name: China Road & Bridge Corp (K) - Makindu					**Pump intake Depth:162.0mts**		
Borehole Depth: 200mtrs					**Pumping Water Level(PWL): 80.91m**		
SWL: 19.0m					**Pump Type: SP8A - 44**		
Discharge During Test: 14.0m3/hr					**Date:**	**6-Jan-15**	
CLOCK TIME	**Meter Reading**	**ELAP TIME Min:**	**WATER LEVEL M, bgl (x)**		**DRAWDOWN**	**DISCHARGE M3/HR**	**REMARKS**
18.00		0	19.00	0	0.00		G.V. Fully Open
18.01		1	23.60	1	4.60		Dirty Water
18.02		2	25.31	2	6.31		
18.03		3	26.47	3	7.47		
18.04		4	27.99	4	8.99		
18.05		5	30.06	5	11.06	14.8m³/hr	
18.06		6	33.21	6	14.21		
18.07		7	34.99	7	15.99		
18.08		8	35.75	8	16.75		
18.09		9	36.86	9	17.86		
18.10		10	37.91	10	18.91		
18.12		12	38.44	12	19.44		
18.14		14	40.55	14	21.55		
18.16		16	42.93	16	23.93		
18.18		18	44.67	18	25.67		
18.20		20	46.53	20	27.53		
18.25		25	46.90	25	27.90		
18.30		30	48.95	30	29.95		
18.35		35	51.03	35	32.03		
18.40		40	52.45	40	33.45		
18.45		45	53.44	45	34.44		
18.50		50	54.38	50	35.38		
18.55		55	55.25	55	36.25		
19.00		60	56.15	60	37.15	14.4m³/hr	Partially Clear water
19.10		70	57.23	70	38.23		
19.20		80	58.20	80	39.20		
19.30		90	59.00	90	40.00		
19.40		100	59.25	100	40.25		
19.50		110	60.20	110	41.20		
20.00		120	62.32	120	43.32		
20.30		150	63.42	150	44.42		
21.00		180	66.30	180	47.30		
21.30		210	69.24	210	50.24		
22.00		240	71.30	240	52.30	14.0m³/hr	Clear water
23.00		300	72.62	300	53.62		
0.00		360	73.55	360	54.55		
1.00		420	74.61	420	55.61		
2.00		480	75.48	480	56.48		
3.00		540	76.52	540	57.52	13.9m³/hr	Clear water
4.00		600	77.26	600	58.26		
5.00		660	77.95	660	58.95		
6.00		720	78.40	720	59.40		
7.00		780	78.92	780	59.92		
8.00		840	79.25	840	60.25		
9.00		900	79.46	900	60.46	13.8m³/hr	Clear water
10.00		960	79.57	960	60.57		
11.00		1020	79.62	1020	60.62		
12.00		1080	79.67	1080	60.67		
13.00		1140	79.91	1140	60.91		
14.00		1200	80.86	1200	61.86		
15.00		1260	80.87	1260	61.87		

16.00		1320	80.89	1320	61.89			
17.00		1380	80.90	1380	61.90			
18.00		1440	80.91	1440	61.91	$13.8m^3$/hr	Sampled	

	TEST PUMPING - RECOVERY MEASUREMENTS					
Client: China Road & Bridge Corporation (K)			**Borehole Name: China Road & Bridge Corp (K) - Makindu**			
			Date:	7-Jan-15		
Day	**Hour**	**TIME SINCE**	**Pumping**	**RATIO t'/t**	**Residual**	**Water level**
		PUMP STOPPED	**ended t' (Min)**		**DDn in m.**	**in(metres)**
		Min t				
2.00	18.00	0	1440		61.91	80.91
	18.01	1	1441	1441.00	56.22	75.22
	18.02	2	1442	721.00	53.91	72.91
	18.03	3	1443	481.00	51.52	70.52
	18.04	4	1444	361.00	47.44	66.44
	18.05	5	1445	289.00	46.91	65.91
	18.06	6	1446	241.00	44.97	63.97
	18.07	7	1447	206.71	42.56	61.56
	18.08	8	1448	181.00	41.51	60.51
	18.09	9	1449	161.00	40.23	59.23
	18.10	10	1450	145.00	38.80	57.80
	18.12	12	1452	121.00	38.22	57.22
	18.14	14	1454	103.86	36.77	55.77
	18.16	16	1456	91.00	35.47	54.47
	18.18	18	1458	81.00	34.62	53.62
	18.20	20	1460	73.00	33.61	52.61
	18.25	25	1465	58.60	32.20	51.20
	18.30	30	1470	49.00	30.80	49.80
	18.35	35	1475	42.14	29.46	48.46
	18.40	40	1480	37.00	28.40	47.40
	18.45	45	1485	33.00	26.30	45.30
	18.50	50	1490	29.80	25.38	44.38
	18.55	55	1495	27.18	24.80	43.80
	19.00	60	1500	25.00	24.01	43.01
	19.10	70	1510	21.57	23.88	42.88
	19.20	80	1520	19.00	23.60	42.60
	19.30	90	1530	17.00	23.55	42.55
	19.40	100	1540	15.40	23.38	42.38
	19.50	110	1550	14.09	23.27	42.27
	20.00	120	1560	13.00	23.20	42.2


CHINA ROAD & BRIDGE CORPORATION (K)
Makindu Area - Makueni County
Borehole Water Augment Supply Facility
Drawdown Series Versus Time Function
Time t'/t
Drawdown
1
10
100
1000
10000
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
T = 2.3Q / 4Π Δs
Δs = 65.0 - 50.0 / log(1800/180.0) = 15.0
Therefore T = 2.3 x 136.0 / 4 x 3.14 x 15.0
T = 1.80m²/day


CHINA ROAD & BRIDGE (K)
Makindu area - Makueni County
Borehole Water Augment Supply Facility
Residual Drawdown Series Versus Time Function
Time t'/t
1.00
10.00
100.00
1000.00
10000.00
Residual Drawdown
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
T = 2.3Q / 4Π Δs
Δs = 30.0 - 20.0 / log(100.0/10.0) = 10.0
Therefore T = 2.3 x 136.0 / 4 x 3.14 x 10.0
T = 1.70m²/day