HYDROGEOLOGICAL SURVEY REPORT

FOR

ISINTIN PRIMARY SCHOOL
P. O. BOX
NAROK, KENYA.

LOCATED ON

THEIR PARCEL OF LAND

IN

ISINTIN VILLAGE, ISINTIN SUB-LOCATION, OLKINYEI LOCATION, MARA DIVISION, NAROK SOUTH SUB-COUNTY, NAROK COUNTY.

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Summary

This report documents on the hydrogeological resurvey results and findings that was conducted on the parcel of land that belongs to Isintin Primary School on 2nd April 2023 with the major aim of providing sufficient and clean water for domestic use within the school and the neighboring community in Isintin area of Narok County.

The area was formerly left for grazing of animals owing to suitability of the land. The main constrain is that the area doesn't have a water supply system. The area mainly depends on roof catchment, small earth dams, seasonal rivers and few far community owned boreholes. The main objective for this resurvey is to develop a borehole water source supply for the client in view of no water supply by any water service providers. The above resurvey program was envisaged and commissioned by project site owner to confirm the previous recommendations.

About 25m^3 borehole water is required per day. The area's climate is classified as warm and temperate. The warm seasons are much rainier than the cold seasons. The temperature here averages 20.8 °C. The average annual rainfall is 619 mm. The project site is geologically underlain by Ngong Volcanics composed of Basanites, tephrites, atlantites and ankaratites. The Ngong Volcanics are underlain by Ol Doinyo Narok agglomerates. Aquifers where water is expected is located at the contact zones between the volcanic rocks and the weathered and fractured zones of the volcanic rocks at depth. Recharge of these aquifers is either directly through percolation of rain water or at distant locations within catchment areas. Geophysical survey was conducted on site that enabled the selection of a suitable point to drill the proposed borehole.

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

One suitable site (VES 2) has been located by means of geophysical field measurements, where the rock is found to be deeply weathered and fractured to greater depths. Below is a tabulation of the construction summary to be adopted to realize the project objectives:

Summary of the proposed site

Site coordinates	VES No. & ranking in Yield Potential	Recommended depth in meters	Construction Requirements.	Anticipated Yield m^3/hr
36M 763898 E UTM 9866571 S Elev. 1905m	**VES 2**	**200m**	**216mm/153mm**	**5-10**

In addition to the hydro geologic assessment outlined above, a detailed coordinated planning with the Government Authorities [Water Resources Authority} - must be implemented to obtain relevant permits and consent for the project implementation.

Table of Contents

1.0 INTRODUCTION

1.1. Background Information

Isintin Primary school through AMREF, commissioned groundwater consultants to carry out groundwater survey on their parcel of land located in Isintin area, Narok County. Hence this report documents on the hydrogeological survey results and findings that was conducted on the client's site with the major aim of determining the groundwater potential of the area that will lead to the drilling of one productive borehole.

The client has developed this piece of land with a school and close to 25m^3/day of water is required for domestic and minor irrigations. The area is not connected to any water supply system and the fact that pastoralists are the most occupants, they travel long distances in search of water.

Hence, the main objective for this survey is to develop a borehole water source supply for the client in view of the inadequate water supply in the area. The above survey program was envisaged and commissioned by the project site owner. About 25m^3 borehole water is required per day.

1.2. Scope of Works

The Scope of works for the execution of the Hydro-geological assessments/Borehole site investigations within the premise, include but not limited to:

    i. Undertake comprehensive feasibility study of the groundwater occurrence within the plot. ii. Optimize an ideal –survey location for the proposed borehole project,
   iii. Integrate reconnaissance survey data with Geophysical borehole data obtained in the conduct of the surveys and assimilate the borehole data to define the recharge/discharge boundaries for the project site i.e. calibrate the exploration data against known geological settings.
   iv. Undertake comprehensive assessments of the existing borehole facilities located in the neighboring areas with a view to quantify the inherent potential; and confirm the actual development of other boreholes subsequent to development of Borehole.
    v. 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.

The entire study will be contained in a detailed report on the investigations and recommendations. The current study further lays emphasis on the client's specific water requirements and is geared towards attaining a sustainable domestic water supply component of at least 25.0 m3/day.

1.3. Project Site Location

The project site is located in Isintin Village, Isintin Sub-Location, Olkinyei Location, Mara Division, Narok South Sub-County, Narok County off Ololunga -Aitong road to join the road that leads to Olkinyei Market. Access to the site from Olkinyei market is through the exit to join the road that connects to Isintin Primary School. Once on this road you drive 10.24 kilometers then a left turn-off exit 0.1km to the project site as directed by the site sketch attached (sketch map annexed in the appendices).

The GPS coordinates for the investigated site falls on – **37M 763898 E UTM 9866571 S Elevation 1905m** above the ground level **Mapsheet Lemek area 145/2.**
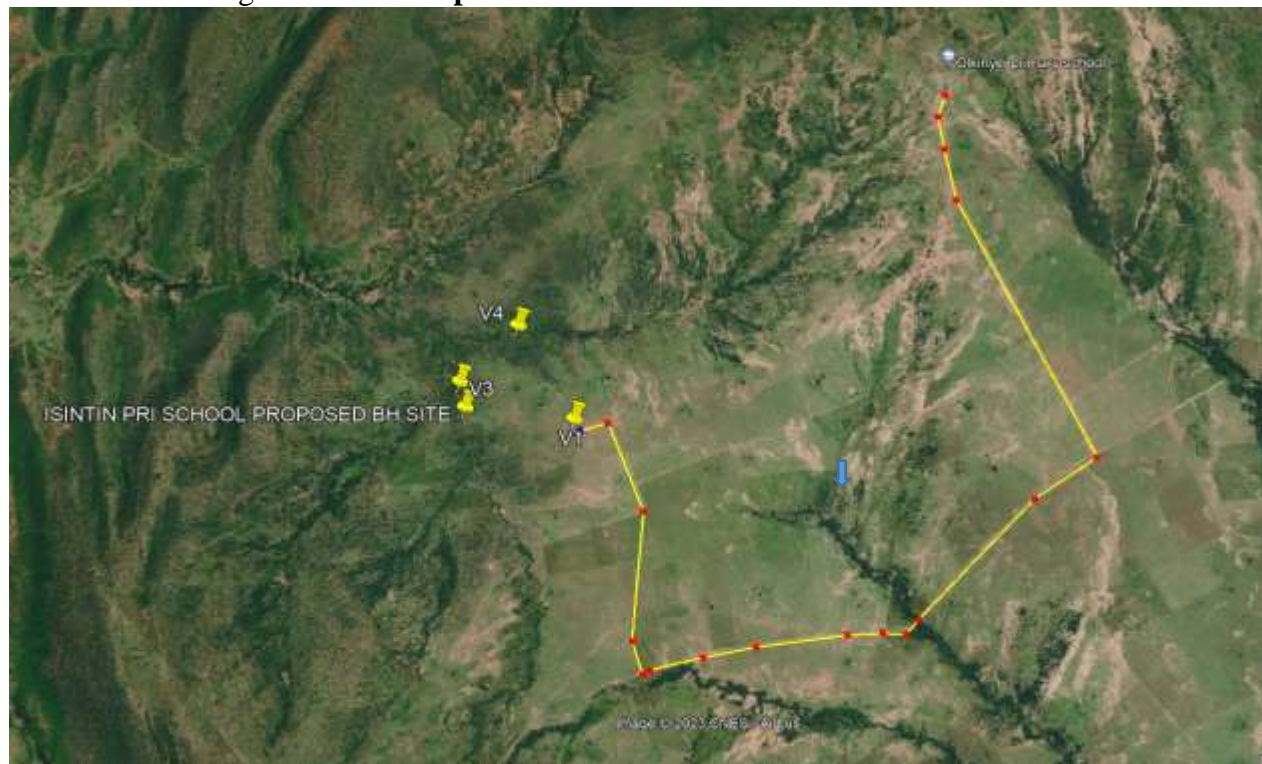
Figure 1.1 Google Earth image showing the location of the proposed borehole site.

The proposed borehole site is in Isintin area and the surrounding plots are mainly open fields occupied by nomadic pastoralists.

1.4. Water Supply Situation

The area residents depend on roof catchments and limited community borehole which are far and unreliable. Other water supply sources being exploited are rainwater, seasonal streams, earth dams, pans and local water supply. All these water sources are limited as their supply highly depends on the ever-changing weather pattern and growing population. In the context above, the investigation was to establish the optimum location of a borehole to act as a source of water supplement for the client's domestic use.

Due to shortages of water in the area and its environs there are few boreholes that have been drilled mainly for domestic uses by private individuals. Perennial drought in the area is responsible for seasonal rivers that remain dry most part of the year. Approximate water demand is 25,000 litres per day to be abstracted from the proposed borehole for a population of approximately 500 people.

1.5. Climate, Drainage and Topography

This area has a tropical climate. In the cold months, there is much less rainfall than in warm months. The average temperature is 20.8 °C. In a year, the average rainfall is 619 mm.
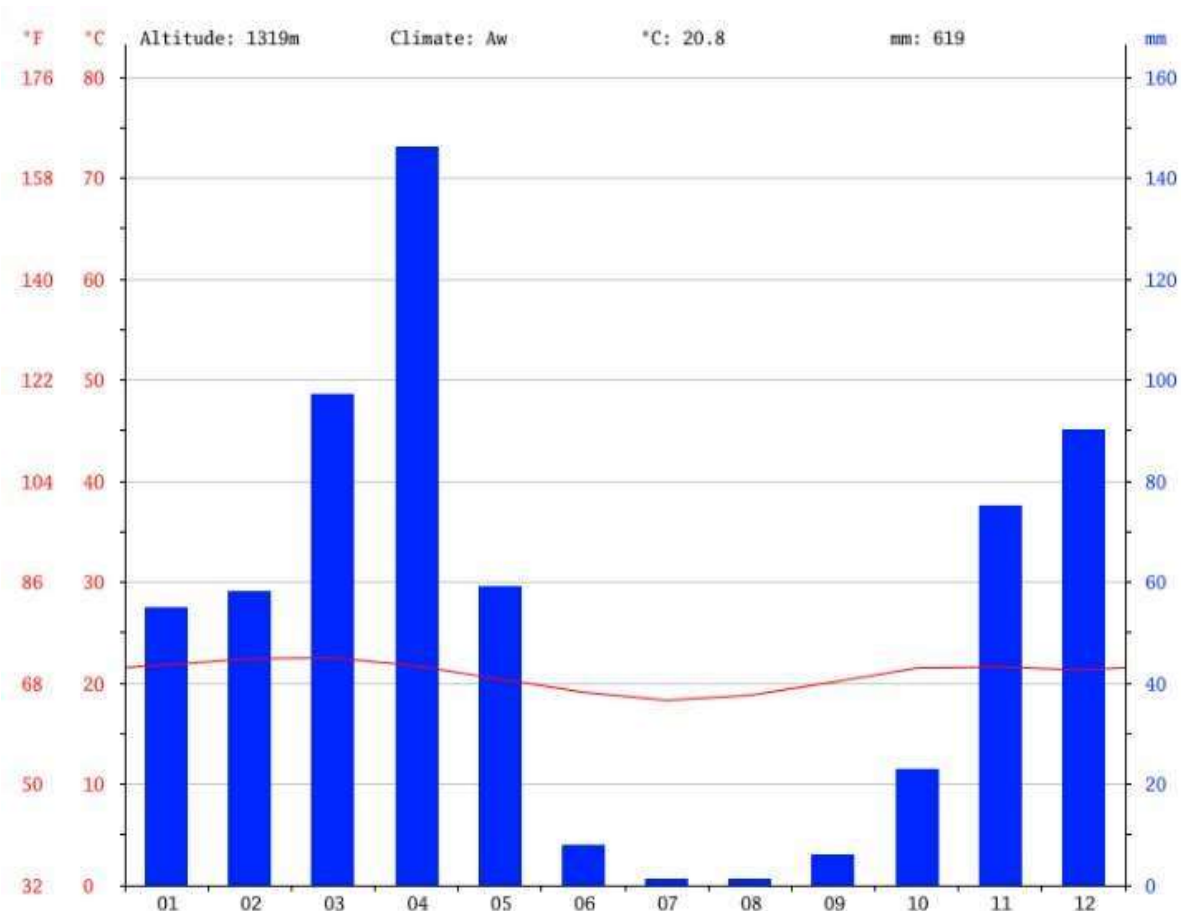
Figure1.2: Climate Graph of the Area

The least amount of rainfall occurs in July. The average in this month is 1 mm. Most precipitation falls in April, with an average of 146 mm. The temperatures are highest on average in March, at around 22.5 °C. In July, the average temperature is 18.3 °C. It is the lowest average temperature of the whole year.

1.6. Drainage

The area is drained by River Mara to the southwest and Regero River and its tributaries to the north. These rivers are seasonal and have water only during and immediately after the rain seasons otherwise they are dry most part of the year.

2.0 DETAILS OF GEOLOGY

2.1. Regional Geology

The oldest rocks exposed are quartzo—felspathie gneisses. quartzites and mica— quartxites of the Kenya Basement System. belieyed to be of late Precambrian age. The gneisses are exposed in windows within voleanies in the strum—eastern part of the area, and quartzites form the Loita Hills and the inselbeigs rising from the Lotta Plains. The rocks represent an original series oJ' arenaeeous shallow—water sediments which have been metamorphosed. recrystallized and folded.

Vulcanicity in the area is thought to have commenced in the Miocene with the eruption of a melanephelinite lava series in the southeast. on the downwarped sub— miocene peneplain. The lavas are between 600 and 900 ft thick along the ridge extending south from Legorinyo which is probably close to the fissure or line of wants from which they were erupted. and they are well developed further South in the Loita Hills area. They skirt the quartzite hill north of legorinyo. and become less widespread north of it. The lavas north~ west of Legorinyo may be the products of another eruptive centre in the south of the area the basic lavas are intruded by a highly porphyritic nephelinite.

Extrusion of phonolite followed later in The Miocene the main mass forming the high ground between Ntuka and inkintitini where two different phonolite types are distinguishable reaching a maximum combined thickness of about 900 ft. These were probably derived from local eruptive centres and differ from other phonolites originating from the Mau highlands exposed farther north in the Narok river.

The melanephelinite lavas were subsequently downfaulted eastwards along the Naitiami fault and the Pliocene Kirigiti basalts of the Magadi area were later erupted on to them wedging out near the fault scarp.

The Naitiami melanephelinite scarps had suffered considerable erosion and retreated about 1 1/2 miles by the early Pleistocene, when deposition of tuffs and ashes filled many irregularities in the older lava surfaces. Some of the pyroclastic rocks were laid down in temporary lakes occupying part of the present day Uaso Ngiro, Seyabei and Olongoirenito valleys. The tufts and ashes are thickest in the northeast and thin westwards across the Loita Plains: in the south of the area they are preserved only in valleys.

After deposition of the pyroclastic rocks had commenced the Enkorika fault was initiated and the Naitiami fault moved again. The Enkorika fault threw down about 350 ft, in the south—east and terminated near Enkorika. The renewed Naitiami fault terminated near Legorinyo, and its maximum throw was about 400 ft. in the south of the area.

The deposition of the pyroclastic rocks was punctuated by flows of basalt. alkali basalt. plateau trachyte and orthophyre-type trachyte lavas and by two movements along the Oletugathi fault. The tour olivine melanephelinite plugs distributed about the northern part of the area may also belong to this episode. The plateau trachytes are similar to those in the Magadi area described by Baker (1958. p. l8} and extend south and east outside the area. but are exposed northwards only as far as leinltorika. The orthophyre-type trachytes. which form the Angata Naado platform, are the equivalents of the orthophyre type trachytes in the Magadi area.

In the Karol area. Therefore, the bulk of volcanic activity took place at two widely separated periods, Miocene and Pleistocene. and erosion of the first Naitiami fault scarp must have

proceeded during a long interval in the Pliocene. The Tertiary to Pleistocene volcanic history of the area is summarized below: -

Pleistocene

- Final ash phase,
- Orthophyre type trachytes,
- Plateau trachytes,
- . . . Second Oletugathi fault, . .
- Alkali basalts of the Oletugathi plateau,
- Tuffs and ashes, in part waterlain
- . . . First Oletugathifault. . .
- Alkali basalts of the Enamankeon plateau
- . . . Second Naitiami fault.
- . . . Enkorika fault. . .
- Tuffs and ashes, in part waterlain

Pliocene

- . . . Erosion of first Naitiami fault scarp. . .
- Kirikiti basalts (in Magadi and Loita Hills areas)
- . . . First Naitiami fault. . .

Miocene

- Phonolites
- Kishalduga melanephelinite lavas
- . . . Arching of sub-Miocene peneplain.

2.2. Alluvial and Superficial deposits

Superficial deposits in the area comprise of brown and greyish-brown loams derived from volcanic ashes, though black clayey soils are well represented. Pale grey calcareous beds in the extreme south-west may have been derived from calcareous beds in the ash sequence.

2.3. Structural Geology

Structural features such as faults in the rocks often optimize storage, transmissivity and recharge, particularly when they occur adjacent to, or within, surface drainage systems. Several NNW-trending faults in the Mau Narok district clearly represent a continuation of the system of the Rift valley boundary faults.

Faulting will have the highest impact on hard and massive rock types; elastic formations such as tuffs and weakly consolidated deposits will bend (fold) rather than break (fault). As a result, they tend to suppress the radius of influence and the magnitude of the damage caused by tectonic events. In relatively plastic rocks, the porosity will not increase in the area affected by the fault. Fractures and joints, thus giving rise to increased (secondary) porosity, on the other hand, will break hard layers such as lavas.

3.0 HYDROGEOLOGY

This section briefly discusses some of the hydro geological characteristics of the aquifers and boreholes within project site and its surroundings. The hydrogeology of the area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within volcanic rocks, groundwater occurs within fissure zones, sediment beds, lithological contacts and old land surfaces (OLS).

3.1 Surface Water Resources

The project site is located in an area that is drained by surface water resources that are dry for the most parts of the year. There is a moderately elevated and some hills that lies to the north of the site, there few streams. The streams flow in a south-east direction.

These river systems are marked by dry river valleys as part of their seasonal flows. The floor of the river valleys is characterized by black cotton soils that have been transported from the volcanic terrains.

3.2. Groundwater Resources

In the absence of the nearby surface water sources and the unreliable rainfall patterns, groundwater thus suffices as the practical and feasible option for the sustainable & construction of a groundwater supply at the client's land.

The area is consider being within zones of medium to low groundwater potential whereupon supplies are obtained through a concentration of groundwater recharge from the North-western side of the flow.

The basement system rocks are marked by a significant secondary permeability. The occurrence of the weathered formation renders the sequence highly susceptible to considerable recharge. Groundwater will thus occur in the weathered/fractured basement.

3.3. Existing Boreholes

Exploitation of groundwater within the area is on the rise. This is because of unreliable water supply systems within the vast Narok County. Data regarding a few boreholes drilled are tabulated while their locations are on Figure 3.1.

Table 3.1: Neighboring Borehole sites from the project site

BH NO. C-	NAME	Distance/ Bearing	TD(m)	WSL(m)	WRL(M)	Q(m3/hr)	PWL(m)
4442		10.5Km/N	125	26	13	9.1	24

3.4. Aquifer Properties

Aquifer characteristics: Transmissivities (T) and specific yield / storage coefficients

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

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

Logan's formula T=1.22 Q/s is the best for estimating transmissivity.

The area does not have aquifer tests and it is difficult to ascertain specific yields, storage coefficients of existing boreholes in the project area. From Driscoll 1986 the following summary of Specific Yield ranges for earth materials.

Hydraulic conductivity (K) and Groundwater Flux

Location's laboratory investigations and Isotope methods are very expensive methods and are the best for determining hydraulic conductivity and groundwater flux correctly. The results are confined to few locations, and they depend on the scale of the investigation method. Rock sample measurements in laboratory vary from well test results. Ministry of Water and Irrigation Services data is also not very reliable.

Hydraulic conductivity is calculated using the formula k=T/D where k is the hydraulic conductivity, T is the transmissivity and D is aquifer thickness. In the Ministry of Water and Irrigation Services data the start of the aquifer is the one recorded and most of the time the thickness is not given.

3.5. Recharge

Given that suitable storage media exist below ground, the mechanisms by which water must reach it also affect aquifer potential. Obviously, if no rainfall or river flow is able to percolate to a sandy weathered and fractured Basement aquifer due to the presence of an aquitard (impermeable layer) probably clay, the actual potential is very low.

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

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

Recharge is the term applied to the whole mechanism, and includes all the aspects of parent geology, effective rainfall and percolation. Some aquifer systems are recharged by water falling a substantial distance away. Percolation takes place at the high grounds to the northwest area of the project plot and this reaches the faults from where it is distributed into permeable aquifers.

3.6. Groundwater Quality

Generally, groundwater chemistry from the volcanic terrain varies from place to place due to mode of recharge and how long water has interacted with rocks. Water quality from the proposed borehole is expected to meet the WHO standards but with some slight modification due to the increased amounts of minerals.

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

Table 3.1: Maximum dissolved constituent limits as per WHO/EU standard

Parameter	WHO/EU Guideline
Cations (mg/l)	
Iron	0.2
Manganese	0.5
Calcium	No Guideline
Magnesium	No Guideline
Sodium	200
Potassium	No Guideline
Anions (mg/l)	
Chloride	250
Fluoride	1.5
Nitrate	50
Nitrite	0.50
Sulphate	250
Total Hardness CaCO3 (mg/l)	Desirable:150-500
Total Alkalinity CaCO3 (mg/l)	No Guideline
Physical Parameters	
PH	Desirable:6.5-8.5
Colour(Pt mg/l)	Desirable:15
Turbidity(NTU)	Desirable:<5
Conductivity(S/cm)	250microS/cm
Total Dissolved Solids(mg/l)	No Guideline

4.0 FIELD EXPLORATION PROGRAM

4.1. Prospecting Methods

4.1.1. Resistivity (Basic Principles)

The electrical properties of rocks in the upper part of the earth's crust are dependent upon the lithology, porosity, and the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivity than unsaturated and dry rocks.

The higher the porosity of the saturated rock, the lower is its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock. The resistivity of 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 cross-sectional area A, expressed as:

$$R = \rho * L.A \hspace{4cm} (1)$$

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

$$R = \Delta V/I \hspace{4cm} (2)$$

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

$$\rho = (A/L) \, \Delta \, V/I) \hspace{4cm} (3)$$

4.2. Survey Design

Two categories of field techniques exist for conventional resistivity analysis of the subsurface. These techniques are vertical electric sounding (VES), and Horizontal Electrical Profiling (HEP).

4.2.1. Vertical Electrical Sounding (VES).

The object of VES is to deduce the variation of resistivity with depth below a given point on the ground surface and to correlate it with the available geological information in order to infer the depths and resistivities of the layers present.

In VES, with wenner configuration, the array spacing "a" is increased by steps, keeping the midpoint fixed (a = 2 , 6, 18, 54…….) .

In VES, with schlumberger, the potential electrodes are moved only occasionally, and current electrode are systematically moved outwards in steps

AB > 5 MN

4.2.2. Horizontal Electrical profiling (HEP)

The object of HEP is to detect lateral variations in the resistivity of the ground, such as lithological changes, near- surface fault.

In the wenner procedure of HEP, the four electrodes with a definite array spacing "a" is moved as a whole in suitable steps, say 10-20 m. four electrodes are moving after each measurement.

In the schlumberger method of HEP, the current electrodes remain fixed at a relatively large distance, for instance, a few hundred meters, and the potential electrode with a small constant separation (MN) are moved between A and B.

4.3. Field Work

A detailed exploration program was carried out on the 2nd April 2023, and it entailed both reconnaissance and hydro geological and geophysical surveys. Four soundings were carried out at the most anomalous zones to a maximum electrode spacing of AB/2 = 250 meters.

The results for the soundings are summarized on tables below;

VES 1

The interpretation of geophysics data is summarized on the table below and the model and curves have been annexed in the appendices.

Table 4.1 –VES 1

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION	REMARKS
0.0 – 1.6	11	Surfacial Deposits	Dry
1.6 – 6.3	4	Fractured sub-base	Dry
6.3 – 32.0	17	Weathered sub-base	Dry
32.0 – 50.0	24	Highly fractured volcanics	Moist
50.0 – 100.0	47	Deep fractured volcanics	Moist to Wet
100 -160	67	Slightly weathered vocanics	Wet
>160	85	Fractured volcanics	Wet

The results from the interpretation show variation in the different layers in terms of the rate of weathering and fracturing.

Water is expected to be struck within the fractured volcanics at depth. Groundwater prospect at this site VES 1 is not good hence not considered as a drill site for the proposed borehole.

VES 2

The interpretation of geophysics data is summarized on the table below and the model and curves have been annexed in the appendices.

Table 4.2 –VES 2

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION	REMARKS
0.0 – 1.6	52	Surfacial Deposits	Dry
1.6 – 6.3	137	Fractured sub-base	Dry
6.3 – 25.0	283	Weathered sub-base	Dry
25.0 – 40.0	386	Highly fractured volcanics	Moist
40.0 – 80.0	350	Deep fractured volcanics	Wet
80 -200	173	Highly Fractured volcanics	Wet
>200	147	Highly Weathered vocanics	Wet

The results from the interpretation show variation in the different layers in terms of the rate of weathering and fracturing.

Water is expected to be struck within the fractured and weathered volcanics at depth. Groundwater prospect at this site VES 2 is very good and has been considered and recommended as the best drill site for the proposed borehole.

VES 3

The interpretation of geophysics data is summarized on the table below and the model and curves have been annexed in the appendices.

Table 4.3 –VES 3

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION	REMARKS
0.0 – 1.6	44	Surfacial Deposits	Dry
1.6 – 6.3	104	Fractured sub-base	Dry
6.3 – 32.0	175	Weathered sub-base	Dry
32.0 – 50.0	177	Highly fractured volcanics	Moist
50.0 – 100.0	222	Deep fractured volcanics	Dry
100 – 160.0	132	Fractured volcanics	Moist to wet
160.0 – 200.0	111	Slightly weathered volcanics	Wet
>200	112	Highly fractured vocanics	Wet

The results from the interpretation show variation in the different layers in terms of the rate of weathering and fracturing.

Water is expected to be struck within the fractured and weathered volcanics at depth. Groundwater prospect at this site VES 3 is good and can be considered as an optional drill site for the proposed borehole.

VES 4

The interpretation of geophysics data is summarized on the table below and the model and curves have been annexed in the appendices.

Table 4.4 –VES 4

DEPTH (in meters)	RESISTIVITY (OHM)	FORMATION	REMARKS
0.0 – 1.6	23	Surfacial Deposits	Dry
1.6 – 6.3	59	Fractured sub-base	Dry
6.3 – 25.0	180	Weathered sub-base	Dry
25.0 – 80.0	269	Highly fractured volcanics	Moist
80.0 – 130.0	235	Deep fractured volcanics	Moist to Wet
130.0 – 200.0	258	Slightly weathered volcanics	Wet
>200	339	Slightly fractured vocanics	Wet to Dry

The results from the interpretation show variation in the different layers in terms of the rate of weathering and fracturing.

Water is expected to be struck within the fractured volcanics at depth. Groundwater prospect at this site VES 4 is good and has been considered as the last optional drill site for the proposed borehole.

5.0 IMPACTS OF PROPOSED DRILLING ACTIVITY

The area is characterized by a low density of boreholes as can be referenced from the table of neighboring boreholes in section 3. The boreholes are generally moderately yielding and the proposed borehole will not have any significant effect to the aquifer if drilled. Water abstraction from the borehole will have to be controlled.

The proposed borehole water will be used mainly for domestic applications. For this kind of abstraction, the effects to aquifer will be quite minimal as the aquifer is ample with an excellent recharge owing to its large recharge area and huge storage capacity.

Pumping this facility will unlikely cause any adverse effects to cone of depression hence there shall be no hydraulic interference to other boreholes in the neighborhood of the proposed site.

Groundwater contamination will be controlled by construction input where use of bentonite clay seal is proposed together with an 8" surface casing of at least 5m long. A 1x1x1 m slab must be constructed around the protruding 6" casing to limit surface water intrusion. Any water struck above 10 metres must be sealed off during construction for fear of pathogens from pit latrines.

Water discharged during drilling process will however be discharged into a soak pit. Waste water has also one advantage as it can be reused during drilling in case need for water arises during drilling process.

The proposed borehole should be installed with the following devices to allow routine measurements of groundwater abstraction and water levels: -

    i.   Water master meter for monitoring groundwater abstraction.

    ii.   Airline for monitoring water table fluctuation.

However, all conditions given by Water Resources Authority should be adhered to and they include pumping 60% of the tested yield for a period of 10 hours a day.

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR BOREHOLE DEVELOPMENT

Conclusions

Based on the discussions in the previous chapters on hydrogeology, geophysics and existing boreholes, it has been concluded that a water supply borehole is to be developed on the proposed project site to a recommended maximum depth of 200 m below ground level. This depth is considered ideal considering the thickness of the aquifer that will be penetrated.

Based on the available information on geology and existing boreholes, combined with the hydro geological assessments, the following conclusions can be drawn:-

a) The maximum yield that can be obtained from a borehole which fully penetrates the formation is likely to be above 5 m³/hr.

b) The required depth of a fully penetrating hole would be at least 200 metres maximum.

The location is shown in the site sketch. Below is a tabulation of the construction summary to be adopted to realize the project objectives:-

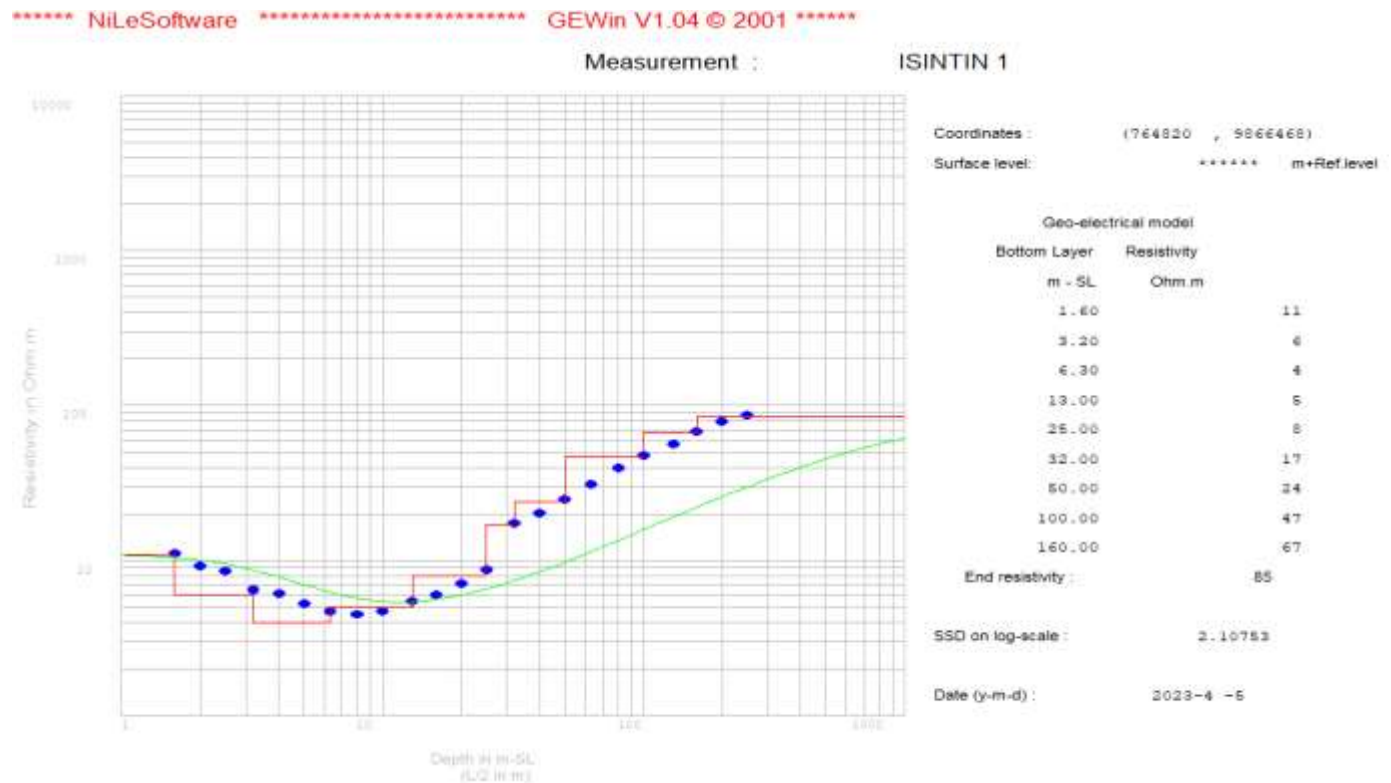**Table 6.1: Borehole Construction Recommendations**

Site coordinates	VES No. & ranking in Yield Potential	Recommended depth in meters	Construction Requirements.	Anticipated Yield m³/hr
36M 763898 E UTM 9866571 S Elev. 1905m	**VES 2**	**200m**	**216mm/153mm**	**5-10**

Recommendations

i. The drilling should ideally be carried out with a Rotary drilling plant rotary in order to attain the maximum recommended drill depth of 200 m below ground level unless enough water has been struck or the formation is complicated to continue drilling.

ii. A monitoring tube is to 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.

iii. 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 cone of depression coalescence and contamination by surface water.

iv. The recommendations on well construction cannot be considered complete without the mention of the requirement to test pump the water supply bore to British standards BS 6316 (1992), which is an industry standard. At least 10hours 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. In order to maximize yields in this part of the aquifer systems, the proposed borehole will have to be drilled to the recommended depth, very carefully constructed and developed. A larger diameter of about 12' can also be used to maximize the yield.

Appendices
Appendix I; VES Geo-Electric Curves and Data
VES 1

****** NiLeSoftware *************************** GEWin V1.04 © 2001 ******

Measurement :   ISINTIN 1

Coordinates :   (764820 , 9866468)

Surface level: ****** m+Ref.level

Geo-electrical model

Bottom Layer	Resistivity
m - SL	Ohm.m
1.60	11
3.20	6
6.30	4
13.00	5
25.00	8
32.00	17
50.00	24
100.00	47
160.00	67

End resistivity :   85

SSD on log-scale :   2.10753

Date (y-m-d) :   2023-4 -6

Resistivity in Ohm.m

Depth in m-SL
(L/2 in m)

Input measured curve   ✕

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m	don't use
1	1.6	11.1	☐	21	130	56.2	☐
2	2	9.3	☐	22	160	67.7	☐
3	2.5	8.5	☐	23	200	77.7	☐
4	3.2	6.49	☐	24	250	85.7	☐
5	4	6.1	☐		.00	.00	☐
6	5	5.3	☐		.00	.00	☐
7	6.3	4.7	☐		.00	.00	☐
8	8	4.5	☐		.00	.00	☐
9	10	4.7	☐		.00	.00	☐
10	13	5.5	☐		.00	.00	☐
11	16	6.0	☐		.00	.00	☐
12	20	7.1	☐		.00	.00	☐
13	25	8.7	☐		.00	.00	☐
14	32	17.3	☐		.00	.00	☐
15	32	17.1	☐		.00	.00	☐
16	40	20.1	☐		.00	.00	☐
17	50	24.6	☐		.00	.00	☐
18	63	31.0	☐		.00	.00	☐
19	80	39.3	☐		.00	.00	☐
20	100	47.5	☐		.00	.00	☐

OK
Cancel

i : insert measurement
e : erase measurement
c : clear down

VES 2 Geo-Electric Curves and Data

****** NiLeSoftware ***************************** GEWin V1.04 © 2001 ******

Measurement :   ISINTIN 2
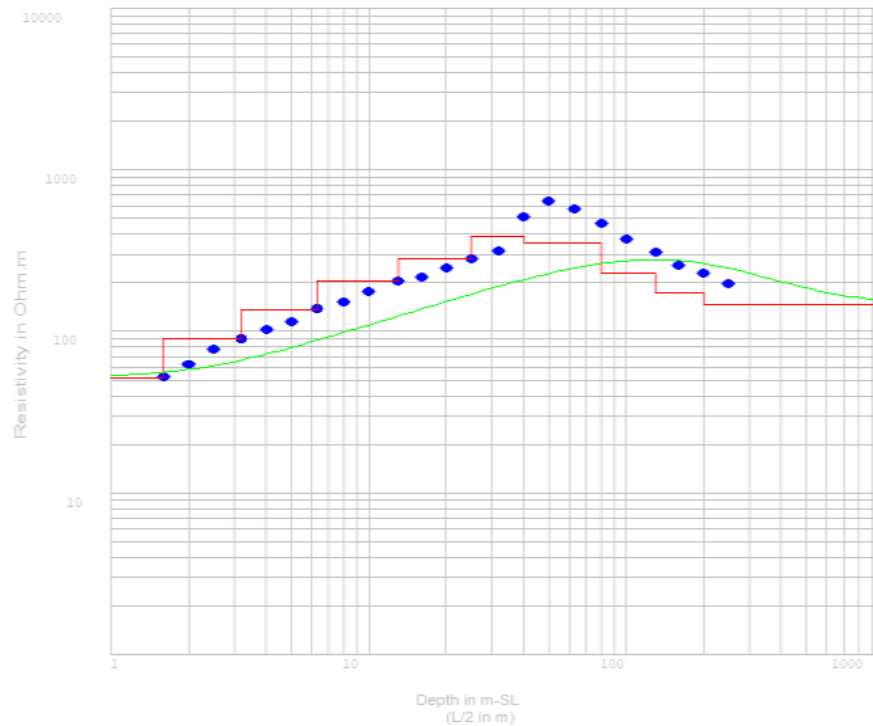
Coordinates :   (763898 , 9866571)

Surface level: ****** m+Ref.level

Geo-electrical model

Bottom Layer	Resistivity
m - SL	Ohm.m
1.60	52
3.20	90
6.30	137
13.00	206
25.00	283
40.00	386
80.00	350
130.00	231
200.00	173

End resistivity :   147

SSD on log-scale :   1.00710

Date (y-m-d) :   2023-4 -5

Input measured curve   ×

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m	don't use
1	1.6	52.6	☐	21	130	231.6	☐
2	2	62.7	☐	22	160	194.2	☐
3	2.5	78.3	☐	23	200	173.7	☐
4	3.2	90.3	☐	24	250	147.9	☐
5	4	102.1	☐		.00	.00	☐
6	5	115.3	☐		.00	.00	☐
7	6.3	137.7	☐		.00	.00	☐
8	8	152.5	☐		.00	.00	☐
9	10	178.3	☐		.00	.00	☐
10	13	206.3	☐		.00	.00	☐
11	16	217.7	☐		.00	.00	☐
12	20	246.2	☐		.00	.00	☐
13	25	283.7	☐		.00	.00	☐
14	32	313.1	☐		.00	.00	☐
15	32	235.6	☐		.00	.00	☐
16	40	386.9	☐		.00	.00	☐
17	50	481.5	☐		.00	.00	☐
18	63	429.5	☐		.00	.00	☐
19	80	350.7	☐		.00	.00	☐
20	100	282.1	☐		.00	.00	☐

OK

Cancel
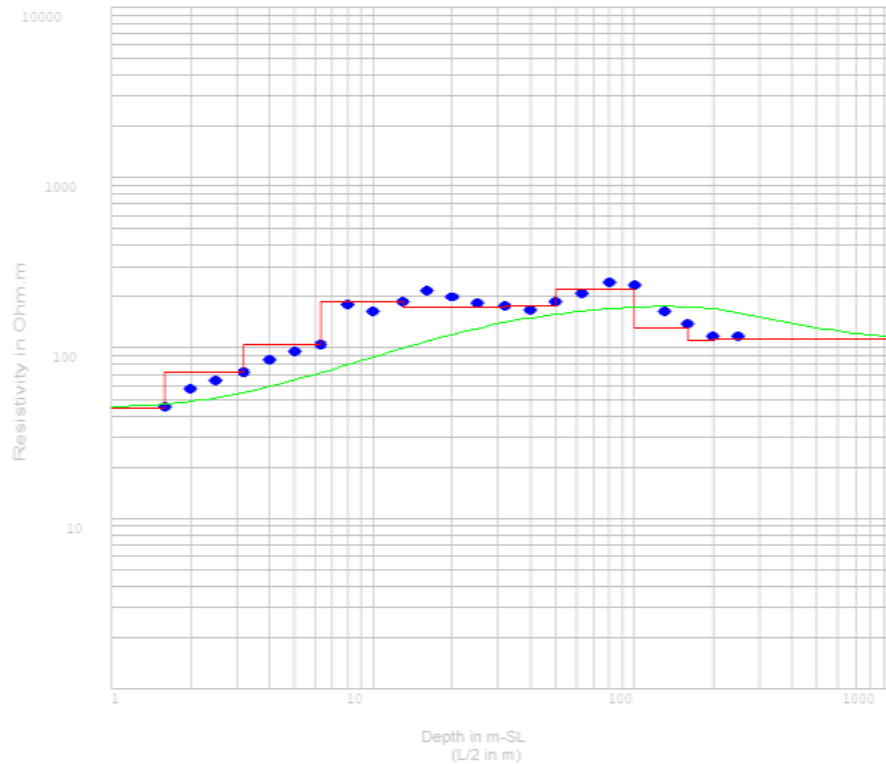
i : insert measurement
e : erase measurement
c : clear down

VES 3 Geo-Electric Curves and Data

****** NiLeSoftware ************************* GEWin V1.04 © 2001 ******

Measurement :   ISINTIN 3

Coordinates :   (763853 , 9866793)

Surface level: ****** m+Ref.level

Geo-electrical model

Bottom Layer	Resistivity
m - SL	Ohm.m
1.60	44
3.20	72
6.30	104
13.00	186
32.00	175
50.00	177
100.00	222
160.00	132
200.00	111
End resistivity :	112

SSD on log-scale :   .66382

Date (y-m-d) :   2023-4 -5

Input measured curve   ✕

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m	don't use
1	1.6	44.9	☐	21	130	157	☐
2	2	58	☐	22	160	132.7	☐
3	2.5	64	☐	23	200	111.9	☐
4	3.2	72	☐	24	250	112.3	☐
5	4	86	☐		.00	.00	☐
6	5	95.2	☐		.00	.00	☐
7	6.3	104.3	☐		.00	.00	☐
8	8	180.1	☐		.00	.00	☐
9	10	164.3	☐		.00	.00	☐
10	13	186.1	☐		.00	.00	☐
11	16	215.6	☐		.00	.00	☐
12	20	199.6	☐		.00	.00	☐
13	25	184.4	☐		.00	.00	☐
14	32	175.9	☐		.00	.00	☐
15	32	167.8	☐		.00	.00	☐
16	40	160.1	☐		.00	.00	☐
17	50	177.6	☐		.00	.00	☐
18	63	200.8	☐		.00	.00	☐
19	80	231.3	☐		.00	.00	☐
20	100	222.9	☐		.00	.00	☐

OK

Cancel
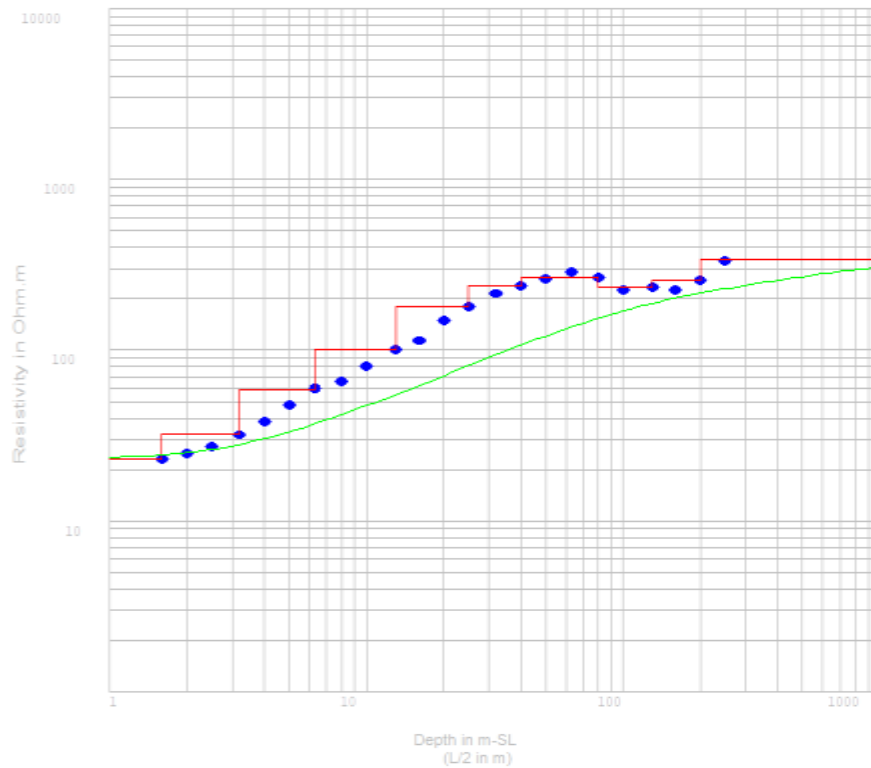
i : insert measurement
e : erase measurement
c : clear down

VES 4 Geo-Electric Curves and Data

****** NiLeSoftware   ***************************   GEWin V1.04 © 2001 ******

Measurement :   ISINTIN 4

Coordinates :   (764344 , 9867282)

Surface level: ****** m+Ref.level

Geo-electrical model

Bottom Layer	Resistivity
m - SL	Ohm.m
1.60	23
3.20	32
6.30	59
13.00	100
25.00	180
40.00	240
80.00	269
130.00	235
200.00	258
End resistivity :	339

SSD on log-scale :   1.12013

Date (y-m-d) :   2023-4 -5

Input measured curve   ×

Meas. #	L/2 in m	R in Ohm.m	don't use	Meas. #	L/2 in m	R in Ohm.m	don't use
1	1.6	23.1	☐	21	130	235.8	☐
2	2	24.7	☐	22	160	228.5	☐
3	2.5	27.1	☐	23	200	258.4	☐
4	3.2	32	☐	24	250	339.6	☐
5	4	38.1	☐		.00	.00	☐
6	5	48.1	☐		.00	.00	☐
7	6.3	59.7	☐		.00	.00	☐
8	8	65.2	☐		.00	.00	☐
9	10	80.1	☐		.00	.00	☐
10	13	100.7	☐		.00	.00	☐
11	16	114	☐		.00	.00	☐
12	20	150.7	☐		.00	.00	☐
13	25	180.1	☐		.00	.00	☐
14	32	215.1	☐		.00	.00	☐
15	32	217.1	☐		.00	.00	☐
16	40	240.9	☐		.00	.00	☐
17	50	263.6	☐		.00	.00	☐
18	63	288.7	☐		.00	.00	☐
19	80	269.8	☐		.00	.00	☐
20	100	229.2	☐		.00	.00	☐

OK

Cancel

i : insert measurement
e : erase measurement
c : clear down

Appendix II; Drilling Design 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 metre intervals. Struck and rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

Well Design

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

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.

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 8" (203mm) 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.

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 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.

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.

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 hydrogeologist. 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 drawdowns as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually the rate of pumping is increased 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 litres 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 III; Topographical map of the location of the proposed site

Appendix IV; Sketch map of the location of the proposed site