ENVIRONMENTAL IMPACT ASSESSMENT PROJECT REPORT

FOR THE PROPOSED BOREHOLE DRILLING FOR

HASS PETROLEUM

ON L.R NO:

IN

INDUSTRIAL AREA OF NAIROBI COUNTY

Submitted to the National Environmental Management Authority (NEMA) in conformity with the The Environmental Management and Coordination Act (EMCA ACT) Cap 387

Proponent/ owner:

HASS PETROLEUM

P.O. BOX,

.

JANUARY, 2021

EXPERT AND PROPONENT DETAILS

PROPONENT:

HASS PETROLEUM

P.O. BOX,

.

Signature…………………………………… Date: …………………………..

LEAD EXPERT

GREEN HEALTH AND SAFE ENVIRONS LTD

P.O BOX 12035- 00400,

NAIROBI.

Reg. No. 10732**.**

Name: ……………………………………………..

Signature: ………………………………………... Date: ……………………………….

(Lead Expert)

Disclaimer:

This environmental impact assessment project report is based on the information made available by the proponent to the consultant and findings from the field assessment. It is strictly confidential to the proponent and any materials thereof should strictly be in accordance with the agreement from the proponent. It is however, subject to conditions in the Environmental, (Impact Assessment and Audit) Regulations, 2003

ACCRONYMS

EMCA	Environmental management Coordination Act
EIA	Environmental impact assessment
EA	Environmental Audit
DTH	Down the hole Hammer
WRA	Water Resource Authority
NEMA	National Environmental Management Authority
EMP	Environmental management plan
PPE	Personal Protective Equipment
TDS	Total dissolved solutes
NCG	Nairobi County Government
m bgl	Metre below ground level
KM	Kilometers
mm	Millimeter
0_C	Degrees centigrade
N	North
S	South
E	East
W	West

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1 CHAPTER ONE: BASELINE INFORMATION ON THE AREA

1.1 Project Background

Industrial Area is in **Nairobi** County, Kenya. The area is located about 500 meters off Lunga Lunga Road. **The project site is located within Viwandani village of Nairobi**. Access to the site from Nairobi CBD is a left exit on Lunga Lunga Road towards Donholm on **L.R. No:.** The proponent land area generally has inadequate water supply thus prompting the proponent to sink the proposed replacement borehole in order to establish a reliable water supply source. **The project area is not connected to a public water supply system so the community relies on private boreholes and water vendors. Chronic water shortages have driven the client to think of drilling a borehole to act as the main water supply within this area for domestic and supply purposes**. If the client won't be authorized to sink a borehole at the site, they will rely on water vendors which are expensive and unreliable.

1.2 Project Site Location

The site is situated in Industrial area of **Nairobi** County. It lies within the Survey of Kenya topographic sheets for Nairobi (No. 148/4). The site can be accessed through Lang'ata Road on **L.R. No:**. Its defining coordinates are Zone 37M, 0264109 and UTM 9856050.

Figure 1.1: Satellite extract showing the general proposed borehole location

1.3 Project Activities

The proponent **HASS PETROLEUM** wishes to drill a **replacement borehole** to abstract water for domestic and supplies use on **L.R. No:**. **The borehole will be drilled with a truck mounted drill and a compressor. The borehole will later be equipped with a pump either powered by solar panels or an electricity source**. The estimated water requirement is **35.0m^3/day**. The most reliable water supply for the proponent is from ground water resources. This resource is renewable and gets replenished naturally. Sustainable management is however recommended for longevity.

1.4 Climate

The climate is warm and temperate in Nairobi. In winter, there is much less rainfall in Nairobi than in summer. The temperature here averages 19.0 °C. The average annual rainfall is 869 mm. The driest month is July, with 14 mm of rainfall. With an average of 191 mm, the most precipitation falls in April. The warmest month of the year is March, with an average temperature of 20.7 °C. July has the lowest average temperature of the year. It is 16.7 °C. The difference in precipitation between the driest month and the wettest month is 177 mm. During the year, the average temperatures vary by 4.0 °C.

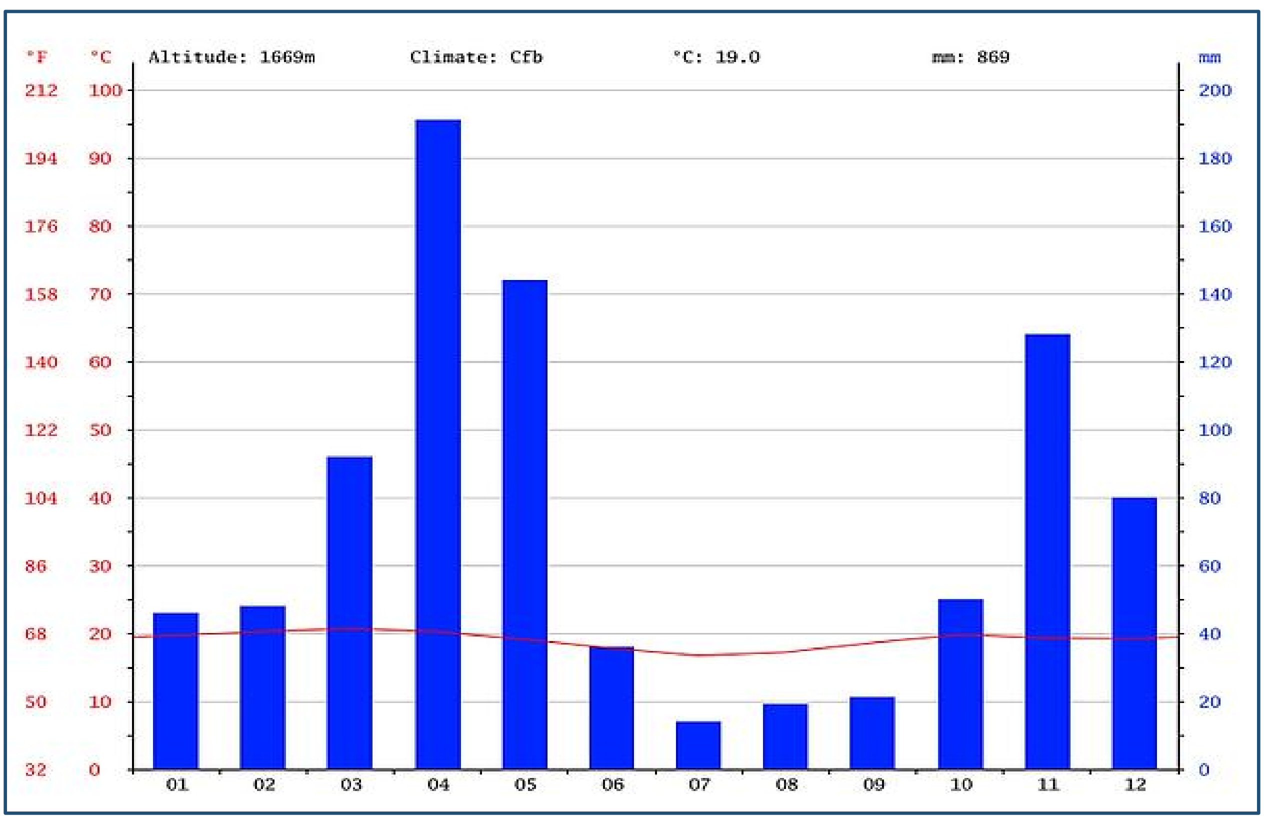

Figure 1.2: Annual climate graph of Nairobi Area

2 CHAPTER TWO: PROJECT ALTERNATIVES

Several alternatives to the project including water sources, site and drilling technology were considered during the EIA process. The alternatives given here below:

2.1 Alternative Water Sources

The supply is currently from roof catchments, private borehole and the water vendors in the area. However, the sources are insufficient and cannot sustain the proposed domestic water supply. This problem worsens during prolonged dry spells and water rationing. Thus the proposed borehole is expected to serve as an alternative to this source and ensure that the project has enough and reliable water supply. The other alternative water sources are from nearby private boreholes and water vendors whose price is high.

2.2 Alternative Site

The following project alternatives to the proposed water project were considered and their advantages and disadvantages outlined.

1. No Project option

This alternative would mean that the project does not proceed.

Advantages

- ✓ The proposed site will remain as it is without disturbance
- ✓ There wouldn’t be ground compaction as a result of heavy machinery use
- ✓ There would be no soil or water contamination from the alien materials that will be introduced in the earth’s system
- ✓ Air pollution from dust as a result of the drilling process will not occur

Disadvantages

- ✓ The proponent will not have reliable water supply for domestic use
- ✓ There will be no creation of employment across the project cycle
- ✓ The expected income to the developer and the economy will not be realized
- ✓ The value of land might improve but it will remain underdeveloped
- ✓ There will continue to be a water shortage especially when the rains fail

2. Underground water abstraction

Advantages

- ✓ It will provide reliable water supply to the proponent.

- ✓ Operational and maintenance costs are low
- ✓ Plans and designs have already been done for the proposed project
- ✓ Less time will be used for drilling
- ✓ It will utilize a small section of the total land area

Disadvantages

- ✓ It is expensive to drill the borehole
- ✓ This will translate to lower income for the project proponent or developers
- ✓ Underground water utilization will not be optimized sustainably

3. Rainwater harvesting

Advantages:

- It is cheaper than the proposed project
- Encourages water storage and conservation
- It will be easier to construct and manage
- It will serve individual users directly
- It is water of good quality if harnessed properly.

Disadvantages:

- Water harvesting is limited to the rainy season therefore they are an unreliable source of water supply to the proponent.
- Rainwater collected would not be sufficient
- There will be no saving of money and water will have to be bought from water vendors after much deliberation, alternative 2 was found to be the superior alternative and was therefore adopted**.**

The proposed drill sites have already been identified by the hydrogeologist.

3 CHAPTER THREE: PROJECT JUSTIFICATION

Water scarcity in Kenya has been an issue for decades, as only a small percentage of the country's land is optimal for agriculture, and the year-round climate is predominantly arid. Rapid urbanization has also pushed urban dwellers away from the city, where there is no sufficient water supply.

Therefore the major objectives of the project include:

- Provision of adequate water supply for the proponent for domestic and supply use.
- Curbing the problem of water shortage especially during the dry seasons.

Currently, the population living in this area gets water from the private boreholes, water vendors and roof catchment, but the supply is insufficient for the client's needs. Water from the proposed borehole will be used for domestic and supply purposes within and around the plot. Water demand is estimated at **30.00m^3/day.**

4 CHAPTER FOUR: ENVIRONMENTAL AND SOCIAL IMPACTS OF THE PROPOSED PROJECT

4.1 Environmental Impacts

4.1.1 Underground water depletion

Ground-water depletion is primarily caused by un-sustained ground-water pumping. Some of the negative effects of ground-water depletion include increased pumping costs, deterioration of water quality, reduction of water in streams and lakes, or land subsidence. Such effects, while variable, happen to some degree with any ground-water use. Ground water can be recharged (deposited) by infiltration from precipitation, surface water, or applied irrigation water; it can be kept in storage (saved); and it can be discharged naturally to streams, springs, or seeps, or transpired by plants (withdrawn).

Mitigation measures:

1. Proper monitoring of number of boreholes being authorized by the Water Resources Management Authority within the proposed area.
2. The project proponent should not exceed the water usage limit per day.
3. Alternate water usage with rain water when available.
4. Encourage rain water harvesting and use that water for non-domestic uses like cleaning floors and watering flowers. Store the rain water in tanks for future use.
5. Monitor and meter the water system to determine the largest water consumption areas; monitoring also can help detect leaks in water systems (this step is more relevant to industrial water users).
6. Community service participation like tree planting.

4.1.2 Reduced surface-water flows

In most areas, the surface- and ground-water systems are intimately linked. Ground-water pumping can alter how water moves between an aquifer and a stream, lake, or wetland by either intercepting ground-water flow that discharges into the surface-water body under natural conditions, or by increasing the rate of water movement from the surface-water body into an aquifer. In either case, the net result is a reduction of flow to surface water, though the full effect may take many years to develop.

Mitigation measure:

Proper management and conservation of the catchment zones through tree planting.

4.1.3 Soil Compaction

Soil compaction will be minimal as the drilling will only take place within a 3 day period.

Mitigation:

1. The contractor will always use a predetermined route to the site.
2. Unnecessary heavy machines will be avoided.
3. Operations will be timed to take place during the dry season when the soils are dry to reduce the risk of soil compaction.

4.1.4 Soil pollution

Soil pollution may arise due to spillages of oil/grease and construction materials during construction, operation or decommissioning stage.

Mitigation:

1. Spillages will be minimized by using right machinery that is regularly serviced and operators who are qualified following the operations instructions strictly.
2. In case of accidental spillages, the leaking fluid should be tapped into a container and later dumped in a safe manner.
3. The contractor and the management will ensure effective wastewater management.
4. Foreign material will be removed from the site as soon drilling is complete.

4.1.5 Oil pollution

Oil pollution may occur during the drilling and in the operation phase.

Mitigation:

1. Proper storage, handling and disposal of oil and oil wastes.
2. Maintain machinery and equipment to avoid leaks.
3. Maintenance of drilling vehicles will be carried out in the contractor's yard.

4.1.6 Soil Erosion

Soil erosion may occur during the drilling phase. During drilling, the site will be dug out and top soil exposed. Erosion would probably be minor for this project due to the flat terrain, permeable soils and lack of proximity to surface water drainages.

Mitigation:

1. Control earthworks especially if works begin in the rainy season.
2. Loose soils will be compacted when necessary.
3. The contractor will ensure management of excavation activities.
4. Activities will be controlled especially if drilling will take place during rainy conditions.
5. Provide soil erosion control structures on the steep sides during drilling.

4.1.7 Loss of biodiversity

No vegetation will be cleared to pave way for the drilling.

Mitigation:

1. Access to the site should be via a designated route for the rigs and other vehicles.
2. No unnecessary cutting of vegetation should be done at the site.

4.1.8 Noise pollution

Mitigation:

1. Keep members of the public away from the drilling site during drilling.
2. Warn the sensitive neighboring establishment 5 days before drilling commences.
3. Maintain plant equipment to avoid annoying noises.
4. Construction activities to be restricted to daytime.
5. Workers in the vicinity of high-level noise to wear safety and protective gears.

4.1.9 Air quality/particulate matter (dust)

Vehicular/equipment engine exhaust emissions will be minor and temporary during construction. Air quality impacts will be temporary during construction. The project will not generate significant vehicle trips to the area. Vehicular and equipment exhaust emissions during project operations will, thus, have a minor incremental/cumulative impact locally and regionally.

Particulate matter (dust) would be generated by excavation and the movement of construction vehicles. It is not possible to accurately estimate the particulate concentration that might occur at the site because it is dependent on meteorological conditions and soil moisture.

Mitigation:

1. Discourage idling of vehicles i.e. vehicle and equipment engines will be turned off when not in direct use to reduce exhaust emissions.
2. Regular maintenance drilling plant and equipment

3. Engage sensitive drilling workers
4. Provide Personal protective Equipment such as nose masks to the workers on site
5. The contractor will water the site with exposed soil surfaces twice each day during dry weather.

4.2 SOCIAL IMPACTS

4.2.1 Water supply

Safe, reliable and cheap water supply for domestic use by the proponent

4.2.2 Hazard

Hazards due to falls are not possible as the borehole diameter is 8" in length. Hazards due to electric shocks are possible during pump installation.

Mitigation measures:

1. The management will ensure that electric wiring is checked and that shocks are prevented at all costs
2. Underage children and unauthorized person will not be allowed near the borehole vicinity as it will be cordoned off.

4.2.3 Contamination

Typically, groundwater is naturally clean and safe for consumption. Because the overlying soil acts as a filter, groundwater is usually free of disease-causing microorganisms. However, contamination may occur following improper installation of well casings or caps, after a break in the casing or as a result of contaminated surface water entering the well. Contamination can also occur if boreholes are drilled in fractured bedrock without an adequate layer of protective soil and with less than the recommended minimum casing length.

Mitigation measures:

1. Sealing off of upper aquifer to avoid contamination caused by seepage from pit latrines and septic tanks.
2. Construction of well head slab to avoid surface run-off in to the borehole.
3. Ensure proper installation of borehole casing avoiding breakages.

4.2.3.1 Testing Well Water for Microbiological Contamination

New boreholes should be disinfected by the borehole driller at the time of construction to eliminate any microbiological contamination that may have occurred during drilling. This should be done before collecting a sample for microbiological testing. Existing boreholes should be tested two or three times a year. The best time to sample the borehole water is when the probability of contamination is greatest. This is likely to be after an extended dry spell, following heavy rains or after lengthy periods of non-use.

4.2.3.2 Borehole Maintenance

Proper siting, location, construction and maintenance of the borehole will help to minimize the likelihood of contamination. The well cap should be checked regularly to ensure that it is securely in place and watertight. Joints, cracks and connections in the borehole casing should be sealed. Pumps and pipes should also be checked on a regular basis, and any changes in water quality should be investigated.

4.2.4 Safety (worker exposure, safety impacts)

Hazards generally comparable to conventional drilling methods, with special provisions anticipated for high noise levels and site-specific contamination issues.

Mitigation measures:

1. Worksite monitoring and personal protective equipment (PPE) required, as appropriate, for mechanical, noise, and potential contaminant exposure hazards. Typically 3-5 people operate drilling equipment.
2. Standard risks associated with the use of heavy equipment and hydraulics. Prevented by establishment of authorized/limited-access exclusion zones to be maintained during setup and drilling process.
3. Risk levels typical of those associated with any mobile, truck-mounted heavy equipment. Encourage employees to concentrate on their duties to avoid occupational accidents. Employees should also be encouraged to avoid negligence while on duty

4.2.5 Creation of employment especially during drilling

The government's policy is clear on the priority it gives enterprises keen on creating employment to the citizens. The drilling of the borehole will create employment during the drilling.

4.2.6 Promotion of secondary development

Secondary developments come as a result of the existence or creation of a development project in a given area. In this particular case, the project may lead the proponent getting more water both for domestic and commercial use. This will eventually contribute positively to the local communities.

5 CHAPTER FIVE: POTENTIAL NEGATIVE IMPACTS AND MITIGATION MEASURES

Table 5.1: Potential Negative Impacts and Mitigation Measures

Aspect Number	Possible Impacts	Details	Mitigation measures
1	Occupational health and safety	Construction phase: The residents and workers may be exposed to dust and noise	□ Provide the necessary PPEs □ Switch of the machines when not in operation □ Communicate and Display emergency signs □ Avoid working at night □ Create awareness on safety and health of the contract employees
2	Injuries/accidents to workers.	Workers or the residents may be injured by the materials or equipment working on the site.	□ Erect a perimeter wall to keep off unauthorized persons in the site. □ Provide PPEs and ensure that they are always worn while workers are on site □ Ensure that only trained workers run the machines □ Provide First Aid facilities.
3	Air pollution	Air may be polluted during construction phase due to the engines doing the work and dust	□ Ensure that the engines are well maintained □ Only operate them when needed. □ Water the ground before drilling
4	Noise	There will be noise from the machines used for construction.	□ Machines will be run only when necessary and within working hours (8-5pm)

6 CHAPTER SIX: COMPLIANCE TO THE RELEVANT REGULATIONS AND REQUIREMENTS

The proponent is committed to compliance with the relevant law and regulations. This is demonstrated by:

1. Carrying out Environmental Impact Assessment before commencement of the project as required by Environmental (Impact and Audit) regulations, 2003.
2. He has also put measures in place to control noise pollution by, for example, only operating between 0800hrs to 17hrs and using well maintained equipment during drilling. This is a requirement by the Noise and Vibration Control Act.
3. Obtaining of a Permit from WRA.
4. Committed to adhere to all the measures recommended under potential negative impacts and the EMP.

7 CHAPTER SEVEN: CONCLUSION

Long-term ground-water-level data from individual boreholes provide the information needed to monitor ground-water depletion locally. Periodic assessments of changes in ground-water storage could be made by measuring more boreholes over larger areas at 5- to 10-year intervals. Such changes could be documented for major aquifers and then compiled into regional and national assessments.

In order to preserve and optimize the use of our critical ground-water resources, science can provide the information necessary to make informed choices on issues that have long-term environmental and ecological effects. For many boreholes in Kenya, the basic data needed for such assessments are not available, and hence our knowledge of the water budget for them is limited.

Water Resource Authority (WRA) is given the task of monitoring the groundwater abstraction hence ensuring that boreholes are drilled sustainably for now and the future generations. The proponent has made all the necessary applications with WRA and this EIA report is one of the requirements by the WRA before drilling commences.

The lead expert considers that the development will have an insignificant impact on the environment and is unlikely to have a substantial influence on underground water, since mitigation measures will be strictly adhered to by all the parties involved. Furthermore, the lead expert considers that the counteractive measures as outlined in this document presented by the developer can preclude noise and atmospheric pollution from the development from having any severe effect on the neighboring establishments. No major impact on the geological conservation value of the site is involved. Thus the lead expert concludes that the development will not have any considerable impact on landforms, landscape and built up environment.

REFERENCES

1. ***Republic of Kenya (1998)***. *Laws of Kenya: The Local Government Act, Cap 265. Government Printer, Nairobi.*

2. ***Republic of Kenya (1998).*** *Laws of Kenya: The Science and technology Act, Cap 250. Government Printer, Nairobi.*

3. ***Republic of Kenya (1999).*** *The Environmental Management and Co-ordination Act, No. 8 of 1999. Government Printer, Nairobi.*

4. ***Republic of Kenya (1999)***. *The Environmental Management and Co-ordination Act, No. 8 of 1999. The Environmental (Impact Assessment and Audit) (Amendment) Regulations, 2009. Government Printer, Nairobi.*

5. ***Republic of Kenya (2003)***. *Legislative Supplement No. 31, Legal Notice No. 101: The Environmental (Impact Assessment and Audit) Regulations, 2003. Government Printer, Nairobi.*

6. ***Republic of Kenya (2007)***. *Laws of Kenya: The Occupational, Safety and Health Act, 2007. Government Printer, Nairobi.*

7. ***Republic of Kenya. Physical Planning Act, CAP 286.*** *Government Printer, Nairobi*

APPENDICES

1. *Questionnaires of public participation.*
2. *Land Title:* ***L.R. NO:***
3. *Copy of the identification card of the proponent.*
4. *Copy of Authorization from Water Resources Authority (WRA).*
5. *Copy of the certificate of the lead expert.*

HYDROGEOLOGICAL ASSESSMENT REPORT

FOR

HASS PETROLEUM

P.O. BOX,

.

LOCATION:

INDUSTRIAL AREA –EMBAKASI WEST SUB COUNTY

L.R. NO:

Report Compiled by:

(Hydrogeologist)

Report Reviewed by:

(Registered Hydrogeologist)

JANUARY, 2021

SUMMARY

This Report discusses the results of a geophysical site survey for one borehole for HASS PETROLEUM **which is situated within** Industrial **area. The proposed borehole site is in** Makadara **Sub-County in** Nairobi **County.**

The Project area is situated in a zone with low to moderate groundwater potential. A borehole is recommended to be drilled at VES 1 position to maximum depth of 250m or until the hard confining layer is struck. **This will ensure that the existing indicated aquifer is fully penetrated.**

The surrounding older boreholes have varying yields that range between 11.18 – 24.0m^3/hr. **The yield of a borehole drilled at the recommended location is expected to be within the above range or more, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.**

It is thus recommended that:

i. The borehole should be drilled at the selected position to maximum depth of **250 metres**.
ii. The borehole be installed with mild steel casings and plasma-cut slotted casings.
iii. The borehole hydraulical properties and aquifer characteristics should be determined during a 24-hour constant discharge test.
iv. Samples taken during test pumping must be submitted to a recognized laboratory for full physical, chemical and bacteriological analyses.
v. A monitoring tube and master meter should be installed in the borehole to be able to monitor the water level and water consumption respectively.

With careful implementation of the project by adhering to the study's findings and recommendations and by following the Water Resources Authority's (WRA) Guidelines: Nairobi Sub-Region **(found in the Authorization letter to Drill the Borehole), the project will safely meet the clients' objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.**

The construction summary for the optimized drilling site is summarized in the immediate table below.-

Construction Summary

GPS Coordinates	Recommended Depth	Construction Requirements	Expected Yield (m^3/h)
37M **0264109.143, 9856050.165** **Elev:** 1646.34m	**250**	**203/153mm**	11.18 – 24 m^3/hr

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***
E	***East***
EC	***electrical conductivity (S/cm)***
Hr.	***hour***
L	***liter***
M	***meter***
N	***North***
NEMA	***National Environment Management Authority***
PWL	***pumped water level***
Q	***discharge (m^3/hr.)***
s	***drawdown (m)***
S	***South***
SWL	***static water level***
T	***transmissivity (m^2/day)***
VES	***Vertical Electrical Sounding***
W	***West***
WAB	***Water Apportionment Board***
WRA	***Water Resources Authority***
WSL	***water struck level***
S/cm	***micro-Siemens per centimetre: Unit for electrical conductivity***
°C	***degrees Celsius: Unit for temperature***
"	***Inch***

GLOSSARY OF TERMS

Aquifer	***A geological formation or structure, which stores and transmits water and which is able to supply water to wells, boreholes or springs.***
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.***
Development	***In borehole engineering, this is the general term for procedures applied to repair the damage done to the formation during drilling. Often the borehole walls are partially clogged by an impermeable "wall cake", consisting of fine debris crushed during drilling, and clays from the penetrated formations. Well development removes these clayey cakes, and increases the porosity and permeability of the materials around the intake portion of the well. As a result, a higher sustainable yield can be achieved.***
Fault	***A larger fracture surface along which appreciable displacement has taken place.***
Gradient	***The rate of change in total head per unit of distance, which causes flow in the direction of the lowest >head.***
Hydraulic head	***Energy contained in a water mass, produced by elevation, pressure or velocity.***
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.***
Percolation	***Process of water seeping through the unsaturated zone, generally from a surface source to the saturated zone.***
Old Land Surface	***Old Land Surface (OLS) is the term given to an ancient erosion surface 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. OLS's are a frequent occurrence in the Nairobi Volcanic Suite.***
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.***
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.***
Pyroclastic rocks	***Group of rocks consisting of volcanic dust, ashes, lapilli and coarse lumps of lava (volcanic bombs), explosively thrown up in molten condition, and deposited by gravity. Hardened masses of dust, ashes and lapilli are known as tuff, while coarse, consolidated pyroclastic debris is referred to as agglomerate.***
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.***
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 NAME AND DETAILS OF APPLICANT

The Client (HASS PETROLEUM) **as the proprietor of the land under investigation, commissioned the present consultant to carry out a hydrogeological and geophysical survey within a parcel of land belonging to them located in** Makadara **Sub County:** Nairobi County**.**

The hydrogeological survey was envisaged to determine the best location for drilling the proposed borehole to supply water for minor industrial purposes **within the piece of land.**

The Clients' contact details are as follows:

HASS PETROLEUM

P.O. BOX,

NAIROBI.

Figure 1.1: General view of the project area

The project area is not connected to any public water supply system. The clients depend on rain water. For economic utilisation of this farm, a reliable water source is needed. Currently, the clients have a moderate supply from the water vendors for minor industrial use. The water shortages have driven the clients to contemplate of drilling a borehole to augment the current untenable water source for better planning within the premise.

It is against this background that a detailed hydrogeological survey was envisaged to determine groundwater potential within the plot and the possibility of sinking the proposed borehole.

The hydrogeological assessment report gives the details of drilling depth, water quality and estimated yields with relation to the existing older boreholes within the area. It also

assists in registration of the borehole with the Water Resources Authority of the Ministry (WRA) of Water and Irrigation.

Based on the recommendations of the report, the contractor can project cost estimates for the drilling and construction works.

2 BACKGROUND INFORMATION

The investigated plot is located about 500m off Lunga Lunga Road. The proposed borehole site is within the 1:50,000 Topographic Sheet 148/4: Nairobi**, on** Zone 37M, 0264109.143 and UTM 9856050.165 **at an elevation of about** 1646.3 metres **above sea level.**

Figure 2.1: Satellite extract showing the proposed borehole location (Adapted from Google maps)

2.1 Climate

2.1.1 Precipitation

The climate of the project area is of the semi humid, cool temperate, tropical lower highland type. The average annual rainfall figure for the area is approximately 1100 mm. i.e. slightly wetter than the southern and south eastern parts of Nairobi (Sombroek, 1982). The rainfall pattern exhibits a bi modal distribution, with wet seasons in March May and October December, corresponding to the "long" and "short" rains, respectively and between 70 and 85% of precipitation falls during these rainy seasons.

2.1.2 Temperature

Average annual temperatures range from 16 to 18° C, with average minima and maxima of 10-12 and 22-24° C, respectively. The warmest period occurs from January to March. Average potential evaporation is between 1,450 and 2,200 mm per year.

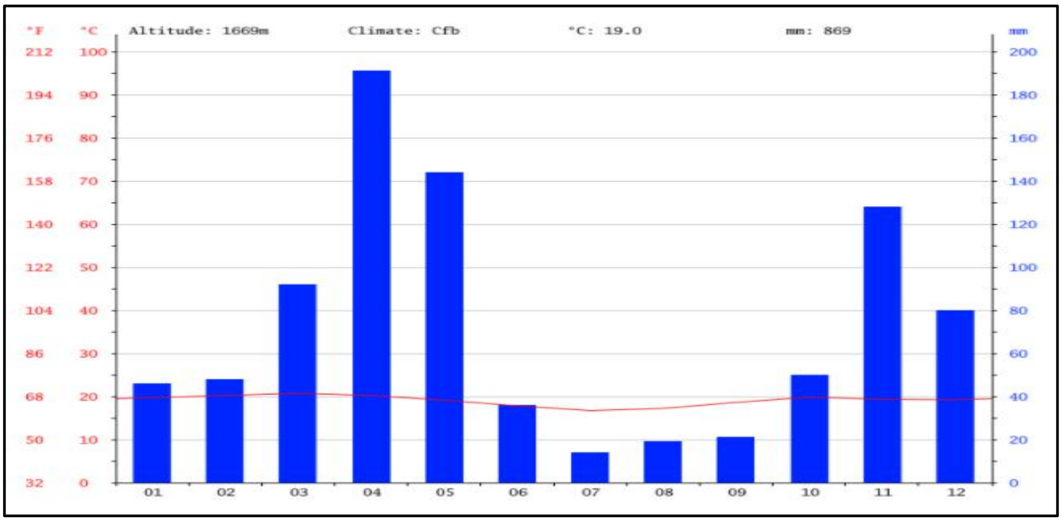

Figure 2.2: Nairobi annual climate data (Adapted from Climatedata.org)

2.2 Physiography

The site lies at an altitude of about 1646.34m **above** mean sea level**. The ground surface at the site is gently sloping. The project area has good drainage conditions. The drainage pattern in the locality is generally towards the North East characterized by River Nairobi.**

2.3 Water Demand

Water from the proposed borehole will be used for minor industrial purposes **through a properly laid pipping system within the area covered by the farm. Water requirement is estimated to be about** 35m³/day**. It lies within the 1:50,000 Survey of Kenya topographic sheet for** Nairobi (No. 148/4).

Figure 2.3: Scaled satellite Extract showing the specific location (Adapted from google earth)

3 TERMS OF REFERENCE

Under the specific Terms of reference, The Client (HASS PETROLEUM) **commissioned the project consultant to undertake Hydro-geological assessments/ Borehole site investigations aimed at developing one production borehole at a plot in** Industrial **area,** Makadara **Sub County:** Nairobi **County.**

The Consultants were thus commissioned by the clients to carry out the subject survey of the project site and subsequently present a hydro-geological report under the following Terms of Reference:

i) **Carry out a reconnaissance survey at the project site and generate a datum reference for the borehole site investigations; to conform to the WRA requirements.**

ii) **Integrate reconnaissance survey data with Geophysical borehole data obtained in the conduct of the surveys to define the recharge/discharge boundaries for the project site. I.e. calibrate the exploration data against known geological settings.**

iii) **Undertake comprehensive assessments of the existing borehole facilities located in the neighbouring areas with a view to quantify their inherent potential; and in addition use such data to define the operational aquifer parameters.**

iv) **Compile all the additional available hydro-geological, geological, geophysical, hydrological data for the project area.**

v) **Compute the hydraulic parameters of the aquifers in the general** Industrial **area, the general Aquifer Transmissivities and the specific capacity of the operational aquifer data.**

vi) **Analyse the above data in order to fully quantify the groundwater potential; and subsequently provide a comprehensive report on the groundwater exploration program.**

vii) **Optimize the drilling depth, and in addition re-evaluate the likely aquifer performance in the proposed water supply borehole.**

To achieve the specified Terms of Reference, the Consultant aimed at establishing and optimizing the base line conditions of the groundwater flow patterns, using the following conceptual approach.

3.1 Concept on the Anticipated Approach

The approach to this study is expected to apply the standard methods applied in the determination of aquifer parameters in order to establish the baseline conditions in aquifers underlying the project area.

Once these 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.

3.2 Concept: - Anticipated Methodology

A review on the existing data and collating it with the field data will be encompassed in this study.

The recommendations of the drilling procedure will lay emphasis on the construction methodologies that will allow for the development and design of a highly efficient system to meet the clients' requirements.

To achieve these objectives, the Consultant proposes to undertake a detailed desk study of the database inventory for boreholes located in the immediate vicinity of the project site, for the purposes of statistical evaluation of the down-hole borehole data, and also to define the general aquifer parameters and characteristics.

The results of the project findings need to be consolidated in this survey report in total conformity to the WRA requirements.

The current study lays emphasis on the clients' specific water requirements and is geared towards development of a high capacity borehole system with an estimated design flow of about 11.18 – 24.0m^3/hr.

4 GEOLOGICAL DETAILS

4.1 Regional Geology

The geology of Nairobi Area and its environs is comprehensively described in Saggerson (1991). In the study area, the surface rocks comprise Tertiary volcanic rocks and some Quaternary alluvium, clays and swamp soil. The intense tectonic activity associated with the formation of the Great Rift Valley led to a series of widespread eruptions and lava flows, which occurred from Mid-Miocene to Upper Pleistocene times. Subsequently volcanicity continued intermittently until Recent time, the area being covered by lavas and pyroclastics from fissure eruptions. The thick volcanic sheet is underlain at great depths (probably more than 700 m) by metamorphic Basement Rocks (gneisses and schists) of the Mozambican System. The crystalline rocks are rarely exposed but occasionally fragments are found in agglomerates derived from the former Ngong volcano.

A short description of the different geologic units is given below in order of geological age (oldest rocks first).

4.1.1 Deep Seated Geology

4.1.1.1 *Nairobi Phonolites*

A dark Grey, porphyritic lava containing both feldspar and biotite insets, the Nairobi Phonolites occurs as a number of distinct flows with phonolitic sands intercalated between the various lava units. Such sands make good potential aquifers, given adequate recharge conditions. Within the Karen area, the Nairobi Phonolites are encountered overlying the Mbagathi Trachytes. Due to over-abstraction, the potentially fair aquifers within the Nairobi Phonolites have gradually become less reliable.

4.1.1.2 *Nairobi Trachytes*

This trachytic lava is a greenish-grey, occasionally porphyritic rock, with feldspar phenocrysts in a fine-grained groundmass. Lamination and banding which are common in the Nairobi Trachytes are due to flow-patterns and pressures, as well as differences in viscosity.

In the Ongata Rongai area, shallow aquifers occur within the intercalated layers of sands and associated material separating the various flows of the Nairobi Trachytes and at the boundary between this formation and the underlying Mbagathi Phonolitic Trachytes. These sediments are absent from the formation further to the east.

4.1.1.3 *Kerichwa Valley Tuffs*

The Kerichwa Valley Tuffs are well exposed in the Kerichwa stream that flowsthrough Nairobi (Gregory, 1921p 164) and were designated by Shackleton (1945,table opp p 6) to include a group of trachytic tuffs and agglomerates in the Nairobi area younger than the Nairobi Trachyte. The pumice-rich formation is widespread and, from descriptions in other geological reports, it is probable that the rocks extend as far north as Nyeri and Nanyuki.

These ash and pumice flows termed froth flows by McCall (1964),occupy a considerable volume and appear to be the result of explosive eruption over a short interval of time. They cannot be traced to any volcanic vents however and it is probable that they are the result of rapid pressure release along fissures following, Rift faulting and graben-forming collapse. The tuffs are in turn affected by the later period of grid faulting. Throughout the Nairobi County, the formation can be subdivided into three main members that are recognised by their colour, texture, jointing, degree of welding and distribution: These are Lower, Middle and Upper Tuffs.

4.1.2 Surficial Geology

4.1.2.1 *Superficial Deposits*

Superficial deposits of recent age include alluvia and conglomerates exposed in the principal river courses. There are also black swamp soils and clays. The soils of the Nairobi area are products of weathering of mainly volcanic rocks under relatively high temperature, rainfall and good drainage.

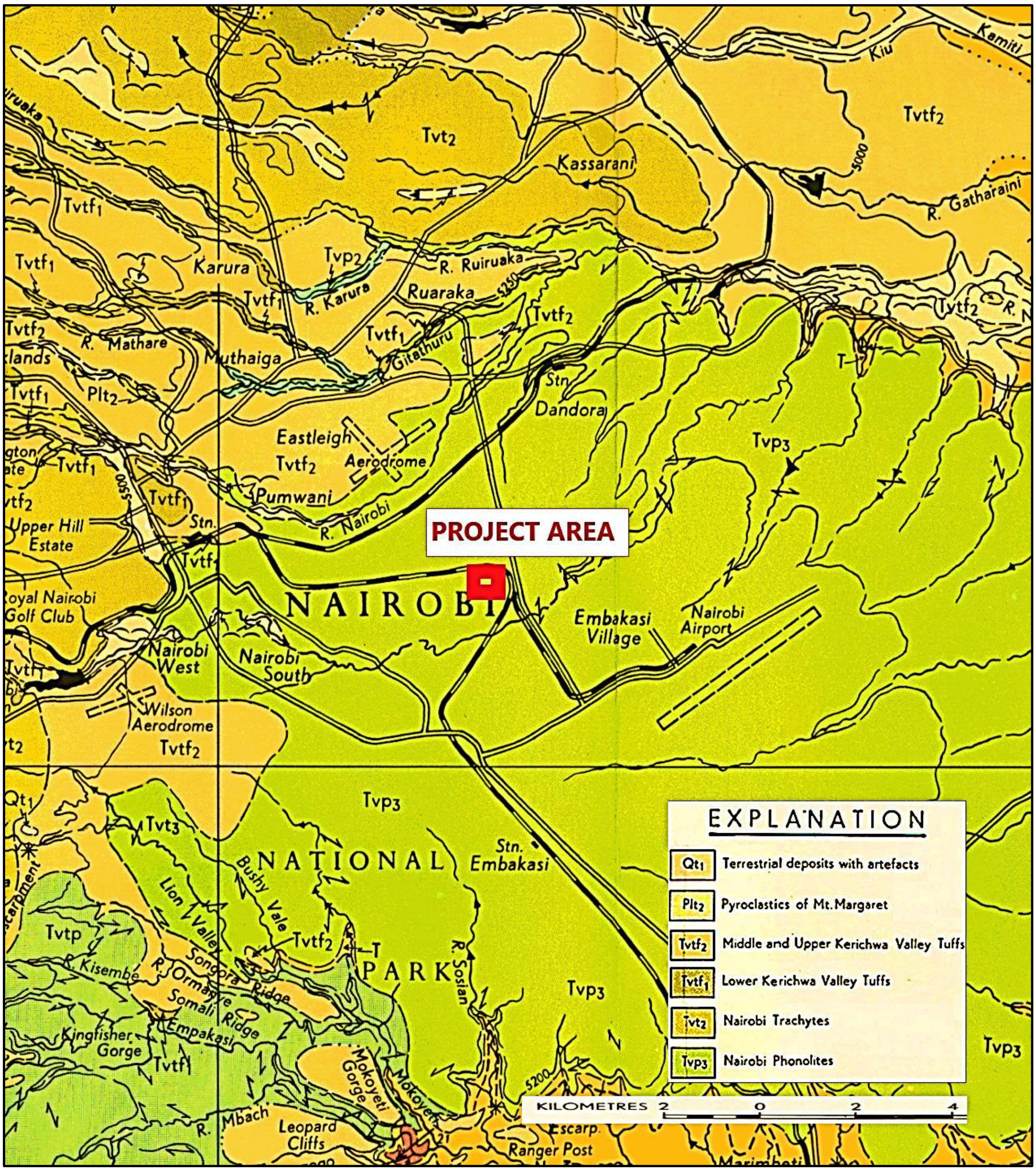

Figure 4.1: Geological map showing the proposed project area

5 HYDROGEOLOGICAL DETAILS

5.1 Background

The hydrogeology of an area is determined by the nature of the parent rock, structural features, weathering processes and precipitation patterns. Within volcanic rocks, groundwater primarily occurs within fissure zones, fractures, sedimentary beds, lithological contacts and Old Land Surfaces (OLS) which characterize periods of erosion between volcanic eruptions and subsequent lava flows are potential aquifers.

These OLS's comprise soils, weathered rocks and water-lain erosional material of volcanic origin. Lava flows rarely possess significant pores pace; instead, their porosity is largely determined by secondary features, such as cracks. However, pyroclastic deposits and especially sediments do have a primary porosity: the cavities between the mineral grains or clasts are usually open and interconnected. Consequently, they can contain and transmit water.

5.2 Hydrogeology of the Project Area

Within the phonolite lavas, weathered OLS, pyroclastic layers and bedding planes are often water bearing. However, in most cases such aquifers are only a few metres thick, and individual water bearing zones rarely produce yields in excess of 1-2 m3/hr. Consequently, it may require several water strikes to obtain a reasonable yield. Higher yields (say >5 m3/hr) can be achieved from boreholes located in "open" faults and fissure zones

Although faults are often associated with water bearing zones, it should be noted that they may also act as impermeable barrier zones ("closed faults"). In this case the structure acts as a "groundwater dam" and significant storage may build up on its upstream side. Drilling inside such a closed fault system, however, would in most cases be futile.

Combined with the high transmissivity of the old land services intercalated with various lava flows, a sustainable combined groundwater abstraction is plausible.

Groundwater of the project area thus occurs in:

a) **Fault zones and fractured zones: These form good aquifers in otherwise impermeable lava flows and other rock material.**
b) **Contact zones between lava flows. These aquifers are manly confined.**
c) **Old land surface (OLS) layers sometimes consisting of gravels and sands. These forms very good aquifer as the lateral extends of these OLS materials is vast.**

5.3 Existing boreholes

Some boreholes have been drilled in the project area. Available records were studied for 6 boreholes within a radius of about 1.5 km from the present site. Results of the data

inventory are presented in Table 5.1 while the approximate location of the boreholes has been indicated in Figure 5.1.

Table 5.1: Boreholes in the Vicinity of the Site

BH C NO.	*OWNER*	*Bearing*	*TD*	*WSL*	*WRL*	*Q*	*PWL*
Ref: HASS PETROLEUM'S Site							
14951	***MOMBASA MAIZE MILLERS***	***1km/NNE***	***240***	***150, 200***	***128***	*12*	***129.56***
21217	***IBER AFRICA***	***0.5km/NE***	***295***	***150, 14***	***137.67***	*22.153*	***139.99***
21260	***AFRICA MERCHANT ASSURANCE***	***1.7km/NW***	***220***	***175, 192***	***139.32***	*11.45*	***159.60***
21465	***ADIX PLASTICS LTD.***	***0.8km/SW***	***260***	***190,200,215***	***132.26***	*11.2*	***150.79***
20207	***PANKAS NATHANI AND OTHEERS***	***1.5km/SW***	***245***	***150,200,217***	***136.1***	*11.18*	***139.05***
19651	***GREENSPAN INVESTMENT LTD***	***1.7km/NE***	***220***	***105,159,205***	***95.25***	*24.0*	***103.26***
Range			*220 – 295*	*105 - 217*	*95.25 – 139.32*	*11.18 – 24.0*	*103.26 – 159.60*

Key to figure 5.1:

TD = Total Borehole Depth

WSL = Water Struck Level

WRL = Water Rest Level

Q = Total Yield

PWL = Pumping Water Level

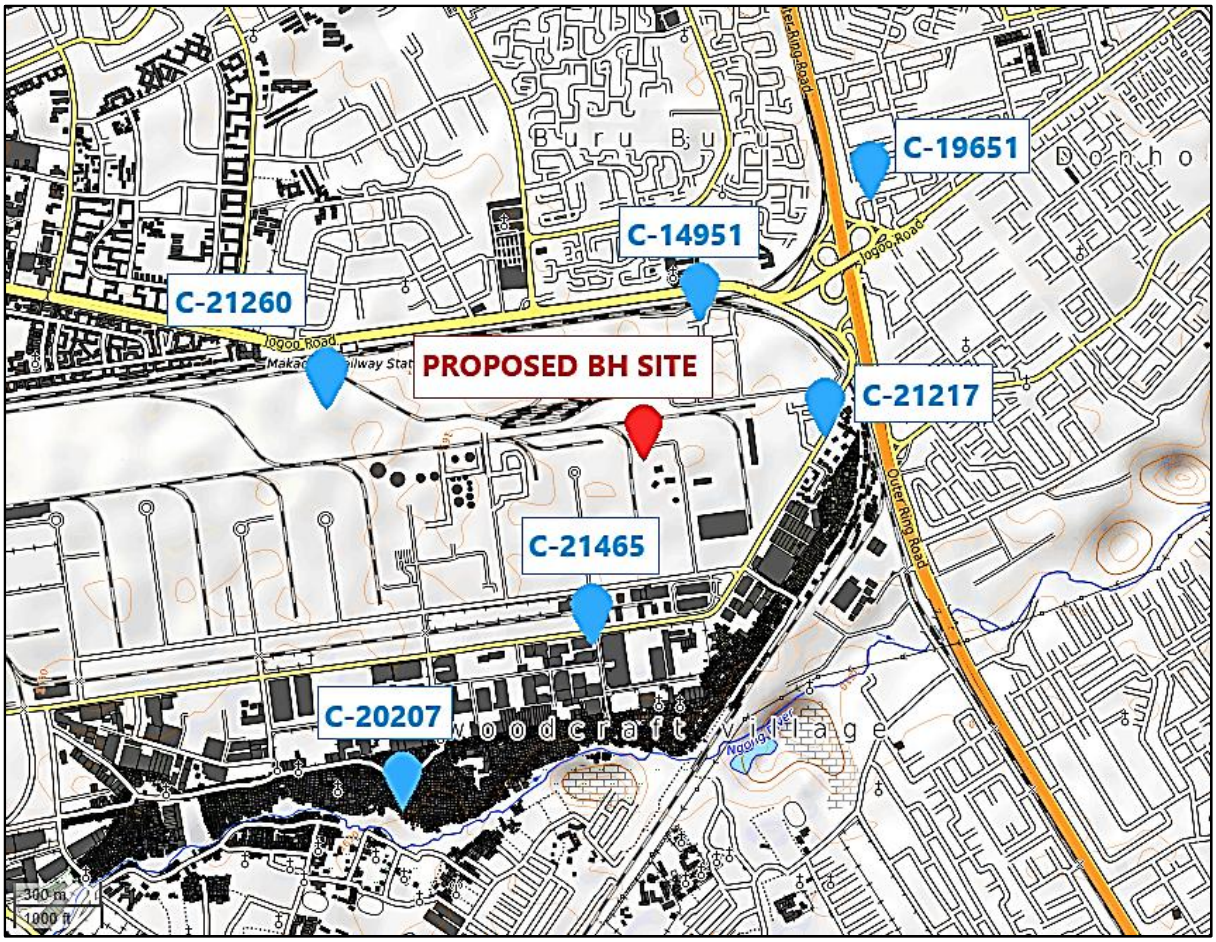

Figure 5.1: Topographic Map extract showing the proposed Borehole site and the surrounding boreholes (Topo sheet 148/4: Nairobi)

5.3.1 Borehole Data Analyses and Aquifer Outline of the Area

The available data indicates that various water struck levels occur within drilled depth ranging between 105 - 217m below ground level**.**

Groundwater of the project area thus occurs in:

a. **Contact zones between lava flows. These aquifers are manly confined.**
b. **Old land surface (OLS) layers sometimes consisting of gravels and sands. These forms very good aquifer as the lateral extend of these OLS materials is vast.**
c. **Fault zones and fractured zones: These form good aquifers in otherwise impermeable lava flows and other rock material**

The boreholes in this area have variable yields ranging between **11.18 – 24.0m^3/hour**. The proposed borehole is expected to give reasonably high yields as long as deeper drilling depth, sound drilling; borehole designing, construction and completion works are employed.

5.3.2 Impacts to Abstraction Trends and Analyses of Boreholes within 800-m from the Proposed Site

There are two boreholes within 800m radius. All aquifers encountered from ground level down to a penetration depth of about 90m should be sealed off with plain casings and bentonite cement to avoid any possible further depletion of these shallow groundwater resources and in turn avoid any impact to any surrounding boreholes abstracting water from this vulnerable level.

Thus there is no any foreseen interference with the existing boreholes or the groundwater abstraction trends. The boreholes have good yields which is an indication of underlying productive aquifers.

5.4 Recharge

The recharge mechanisms (and the rate of replenishment) of the local aquifers has not been fully established. The two major processes are probably direct recharge at surface (not necessarily local) and indirect recharge via faults and/or other aquifers.

Direct recharge is obtained through downward percolation of rainfall or river water into aquifer. If the infiltration rate is low due to the presence of an aquiclude (such as clay), the recharge to the aquifer is low. Percolation will depend on the soil structure, vegetation cover and the state of erosion of the parent rock. Rocks weathering to clayey soils naturally inhibit infiltration and downward percolation. Aquifers may also be recharged laterally if the rock is permeable over a wide area.

5.4.1 Mean Annual Recharge

Although rainfall within the study area is low, regional recharge is of great essence in this area. Much of regional recharge occurs within the eastern flanks of the rift valley followed by base flow within the thick volcanic sheets and faults which characterise the region. However, this recharge mechanism is mainly important for the replenishment of (regional) volcanic aquifers and is what has been used to estimate the Mean Annul Recharge.

At the present location, water also percolates directly into the faults, fractures, local rivers and streams (via fractures) thus deeper and adjacent units are recharged over time.

Mean Annual Recharge has therefore been estimated as follows:

The Recharge is estimated as 5% of the Mean Annual Rainfall of the recharge area

1100mm x 5%

Mean Annual Recharge = 55mm

However, this recharge amount is probably estimation due to the possibility of influent local recharge through local rivers and rainwater percolation through faults into the weathered/fractured volcanic rocks and overlaying OLS.

5.5 Discharge

Discharge from aquifers is either through natural processes as base-flow to streams and springs, or artificial discharge through human activities. However considering the few number of boreholes in the area this is form of discharge is not much pronounced.

The total effective discharge from the aquifers via either of the above means is not known, and should in fact be studied. The main form of discharge is through flow along formations and faults/ interconnected fractures.

5.6 Aquifer Properties

5.6.1 Estimation Aquifer Transmissivity

Thus, in absence of proper pump test data, the Logan method of approximation has been employed (Logan, 1965). This method however has errors of 50% or more and is thus used for estimation purpose only. The derivation of the aquifer properties is as follows:

Aquifer Transmissivity (T) is thus estimated as follows:

$$T=1.22Q/\Delta S$$ **Where: Q = Yield per day**

ΔS = Draw down

T = = m²/day

5.6.2 Hydraulic Conductivity

The Hydraulic Conductivity (K) is estimated as follows:

$$K = T/\text{Aquifer Thickness}$$

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

K = m/X

K = m/day

5.6.3 Specific Capacity

The aquifer Specific Capacity (S) = Q/Δs.

Where: Q = Discharge (m^3/day) = m^3/day

D = Drawdown (m).

S= m^2/day

5.6.4 Groundwater Flux

The Groundwater Flux (F) is estimated based on boreholes which more or less share the same aquifers. F = K.i.h.w Where K- Hydraulic Conductivity

i - Slope

h- Aquifer Thickness

w- Arbitrary distance

5.7 Water Quality

The water quality of the aquifers around the area is expected to be drawn from deeper fracture systems. These aquifers are adequately recharged from the surface thus the chemical characteristics of groundwater that is relatively young and potable is expected. The water is likely to be a little mineralized and hard, but not brackish. Seasonal changes may however occur, whereby an increase in salinity is experienced during the dry season. Due to the nature of the surrounding Basement rocks, high levels of calcium are envisaged, which may lead to encrustation of pipeworks. It is therefore recommended to use uPVC casings and screens inside the borehole, and galvanized steel mains (high quality – Class C) and collector pipes.W.H.O. and EC guideline concentrations are included for reference in the **appendix** section.

5.8 Impacts of the Proposed Activity to Water Quality, Wetlands

The Proposed drill site and related works are expected to pose no impact on water quality, either Surface or groundwater resources. There is no any surface water body near the drill site that can be contaminated by waste waters generated during drilling. The entire drilling, borehole construction, pump tests, and completion works will be done under supervision to professional standards. Entry of any foreign material until completion will be avoided to avoid any entry of foreign material into the borehole and only inert materials will be used in construction. The borehole will be properly developed to open up the aquifers and clean the borehole water. Monitoring of ec during drilling will be done to detect and seal any aquifer with elevated mineralization.

The site is not located within a wetland and has no negative impacts on biodiversity.

6 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 (also known as the geo-electrical method) has been used.

1.1 Resistivity Method

Vertical electrical soundings (VES) were carried out to probe the condition of the sub-surface and to confirm the existence of deep groundwater. The VES investigates the resistivity layering below the site of measurement. This technique is described below.

1.2 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 its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by an electric current that is passed through the earth.

The resistance R of a certain material is directly proportional to its length L and cross-sectional area A, expressed as:

$$R = Rs * L/A \qquad \text{(Ohm)} \qquad (1)$$

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

$$R = dV/I \qquad \text{(Ohm)} \qquad (2)$$

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

$$Rs = (A/L) * (dV/I) \qquad \text{(Ohm-m)} \qquad (3)$$

1.3 Vertical Electrical Soundings (VES)

When carrying out a resistivity sounding, current is led into the ground by means of two electrodes. With two other electrodes, situated near the Centre of the array, the potential field generated by the current is measured. From the observations of the current strength

and the potential difference, and taking into account the electrode separations, the ground resistivity can be determined.

While carrying out the resistivity sounding the separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. When plotting the observed resistivity values against depth on double logarithmic paper, a resistivity graph is formed, which depicts the variation of resistivity with depth.

This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater.

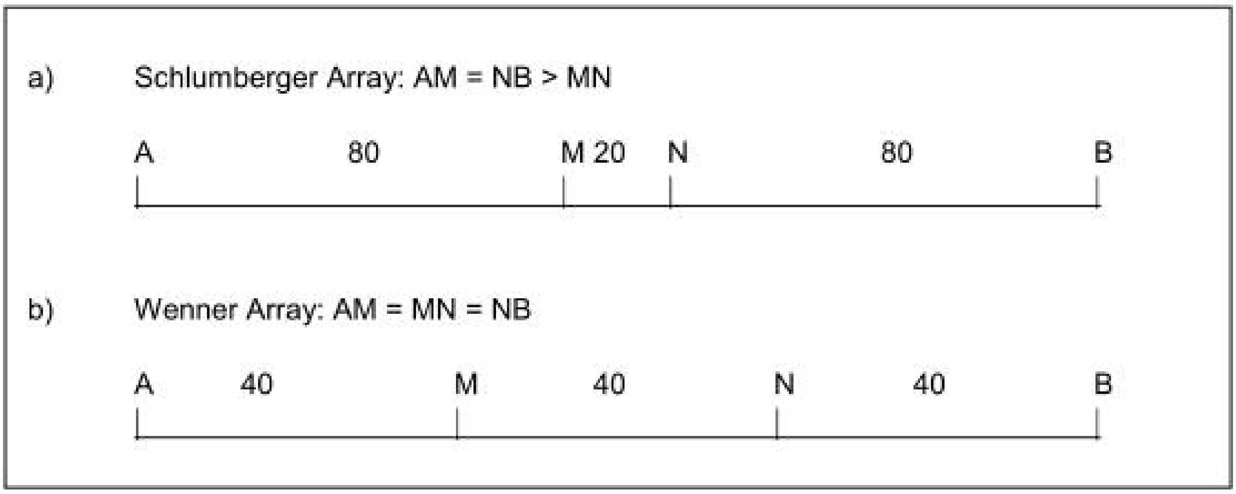

Figure 6.1: Examples of Schlumberger and Wenner Configurations for Resistivity Measurements, where: AB = current electrodes; MN = potential electrodes

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 a 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 resistivity's 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 analyzed. In general, resistivity soundings should never be interpreted in isolation as this may lead to erroneous results.

1.4 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):

$\rho = F \times \rho\, w = F \times 10{,}000 / EC$ (μ S/cm), where: ρ w = 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 μ S/cm will give a formation resistivity of 100 μ m. The same material, when containing water with an EC of 1,500 μ S/cm, will have a resistivity of only 20 ρ m. Brackish water is marked by an EC of 2,000 to 10,000 μ S/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 μ m). Saline water with an EC of about 30,000 μ S/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 µ m. 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 favorable 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.

7 FIELDWORK AND RESULTS

Field work was carried out on the 15th of January, 2021. A proper VES was carried out then analysis done. The aim of the VES was to determine the prevailing hydro-stratigraphy, weathered zones, Fracture zones and any fault line at the selected area.

7.1 Results

7.1.1 VES 1 Results

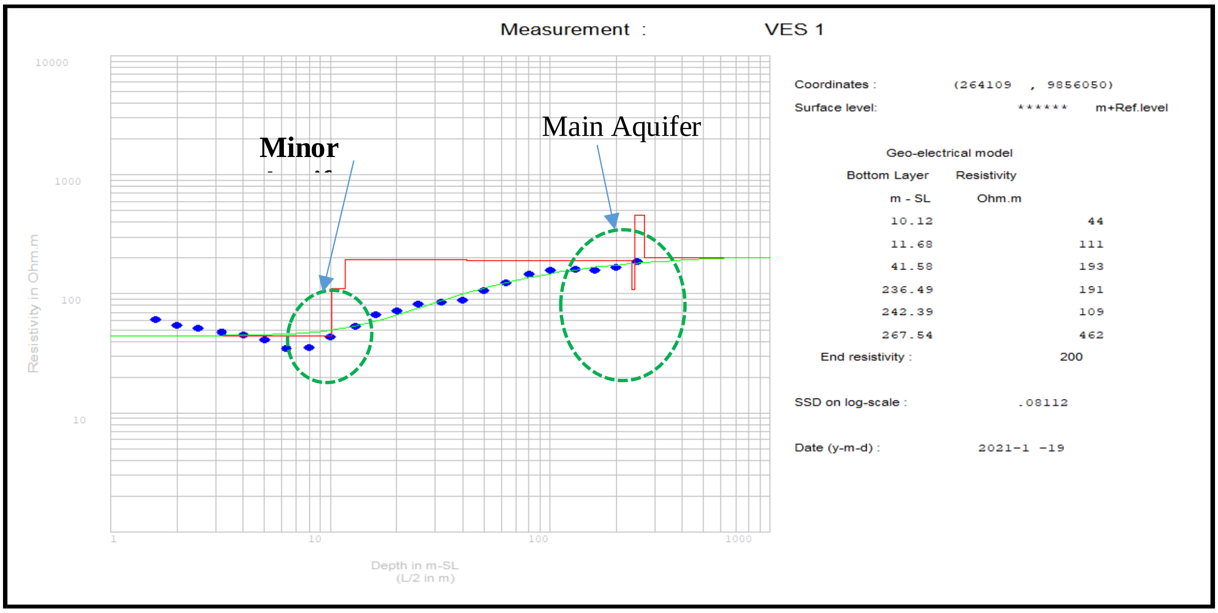

Figure 7.1: VES I Sounding Curve, Geoelectrical model (Modelled in Gewin)

Table 7.1: VES I Sounding Curve, Geoelectrical model data (Obtained from Gewin)

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	1.60	61.20		21	160.00	158.82	
2	2.00	54.70		22	200.00	166.93	
3	2.50	51.90		23	250.00	185.54	
4	3.20	47.90			.00	.00	
5	4.00	45.10			.00	.00	
6	5.00	40.90			.00	.00	
7	6.30	34.60			.00	.00	
8	8.00	35.30			.00	.00	
9	10.00	43.60			.00	.00	
10	13.00	53.30			.00	.00	
11	16.00	66.40			.00	.00	
12	20.00	71.50			.00	.00	
13	25.00	82.80			.00	.00	
14	32.00	85.90			.00	.00	
15	40.00	87.96			.00	.00	
16	50.00	105.91			.00	.00	
17	63.00	123.66			.00	.00	
18	80.00	147.67			.00	.00	
19	100.00	157.30			.00	.00	
20	130.00	161.96			.00	.00	

Table 7.2: Data Interpretation

Resistivity Curve No.	GPS & Elevation (M)	Formation Thickness (M)	Apparent Resistivity	Expected geological Formation
VES1	37M 264109 and 9856050 Elev. 1646m	0-10.12 10.12-11.68 11.6 -41.58 41.58-236.49 236.49-242.39 242.39-267.54 Beyond 267.54	44 111 193 191 109 462 200	-Top Black Soils - Kerichwa Valley Tuffs - Slightly Fractured Trachytes -Slightly Fractured Trachytes -Highly Fractured Phonolites - Slightly Fractured/Weathered Phonolites

The VES I sounding indicates deep weathering/fracturing considered optimal for groundwater development. The VES indicates the occurrence of the highly weathered /fractured volcanic rocks between depths of about 236.49-242.39 meters thus isolating the location as the most reliable prospect for the proposed development of a borehole facility.

Drilling is recommended at VES 1 Position to an ideal depth of about 250m or until enough water has been struck.

7.2 Site Identification

The study thus recommends that the borehole be drilled at VES 1, to a depth of about 250 m. This site is well marked and well pegged on the ground at GPS 37M, 0264109 and UTM 9856050 and known to the clients and their representative.

Figure 7.2: Image showing the selected site location

8 CONCLUSIONS AND RECOMMENDATIONS

On the basis of all the information gathered in the field, geological and hydrogeological evidence, it is concluded that the hydrogeological conditions and prospects for groundwater are high and deeper aquifer levels. A borehole is recommended to be drilled at the site of VES 1 **to a depth of about** 250 m below ground level. **This will ensure that the envisaged entire aquifer zone will be fully penetrated.**

Boreholes drilled within the neighbourhood of the investigated area are quite productive and have recorded yields ranging from **11.18 – 24.0**$\mathbf{m^3/hr}$ and the main aquifer is stable during prolonged pumping. The yield of a borehole drilled at the plot is expected to be within the above range, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

The aquifer zones occur at:

- **Fault zones and fractured zones: These form good aquifers in otherwise impermeable lava flows and other rock material**

- **Old land surface (OLS) layers sometimes consisting of gravels and sands. These forms very good aquifer as the lateral extent of these OLS materials is vast.**

- **Contact zones between lava flows. These aquifers are manly confined.**

It is thus recommended that:

- ✓ **The borehole should be drilled at** VES I **position at a minimum of 8 inch diameter and to** a depth of about 250m. **This will ensure that the deeper aquifers will be fully penetrated.**
- ✓ **To install the borehole with mild steel casings and gas-slotted screens**
- ✓ **The borehole hydraulic properties and aquifer characteristics should be determined during a 24-hour constant discharge test.**
- ✓ **Samples taken during test pumping must be submitted to a recognized laboratory for full physical, chemical and bacteriological analyses.**
- ✓ **A monitoring tube and master meter should be installed in the borehole to be able to monitor the water level and water consumption respectively.**

With careful implementation of the project by adhering to the study's findings and recommendations and by following the Water Resources Authority's Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the clients' objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

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APPENDICES

APPENDIX I: Acceptable Ionic Concentration - 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		Guideline Value (GV)	Upper limit (HL), (tentative)	Guide Level (GL)	Max. Admissible Concentration (MAC)
Inorganic Constituents of health significance;					
Antimony	Sb				0.01
Arsenic	As	0.05	0.05		0.05
Cadmium	Cd	0.005	0.01		0.005
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 N03)	25 (as NO3)	50 (as NO3)
Selenium	Se		0.01		0.01

Other Substances	GV: Desirable Level:	Highest Maximum Permissible Level:	GV:	MAC:

Aluminium	Al	0.20					0.05		0.20
Ammonium	NH4						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 SulphideH2S	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	NO2								0.10
Potassium	K						10		12
Silver	Ag								0.01
Sodium	Na	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 CaCO3		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	(JTU)	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	°C						12		25
EC	uS/cm						400		
Notes	ND - Not Detectable			IO - Inoffensive					
	GL - Guide Level			UO - Unobjectionable					

(Based on Table 6.1, in Twort, Law & Crowley, 1985 - Water Supply, Edward Anorld, London).

APPENDIX II: DRILLING CONSIDERATIONS

Introduction

Boreholes may be drilled with either percussion (cable-tool) or rotary plant: the former have the advantage of lower cost, but the disadvantages of longer site time and less flexibility in borehole development. In addition, there is a greater possibility that temporary casing will be needed to hold back heaving or unstable formations.

Rotary plant is more expensive to use, but it is considerably faster. Rigs having a compressor and mudpump allow a wider and more effective range of development (i.e. jetting and air lifting) that percussion rigs cannot emulate. In addition, approximate yields may be estimated during drilling, from the air-blown volume of water and cuttings (when air rotary techniques are used).

Borehole Drilling, Completion and Maintenance

1. ***Drilling Technique and Diameter***

Volcanic formations are most efficiently drilled using the air-hammer technique. In the Nairobi area, the unconsolidated top layers are usually clayey and not collapsing: it is not expected that more than 6 m of temporary casing may be required.

Drilling additives to be used (e.g. foam or polymer) must be non-toxic and bio-degradable. The use of bentonite, or other clay-based additives, should not be acceptable: these may plug the aquifer zones and are extremely difficult to remove during development.

The minimum casing diameter for a submersible pump with a capacity of 10 m^3/hr at a head of 150 m is 152 mm. The diameter should therefore be chosen so that it can easily accommodate the 6" casings and screens used in installation. To allow for an annular of 1" for the insertion of gravelpack, drilling should be carried out at not less than 8". The final borehole width will depend on the drilling contractor selected to undertake the works, the nature of the penetrated formations and aquifers, the available bit diameters, and the type of casings to be installed.

The drilling rig engaged in the works should be able to drill to a depth of at least 250 m, at the specified diameter. The rig and the drilling method adopted must be suitable for drilling through both unconsolidated material, and very hard, compact rocks.

Geological rock samples should be collected at 2 metre intervals. Water struck and rest 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 (rotary) or bailed (percussion) yield. On-site analysis using an EC meter, and preferably a portable laboratory, is recommended.

2. Borehole Design

If reasonable quantities of water are encountered in the borehole, and if the aquifer is confined, a permanent design of the following type may be installed:

Base of hole to base + 6m	*6 m plain casing with end cap (sediment trap)*
Base + 6 to base + 48 m	*42 m of screen*
Base + 48 to base + 54 m	*6 m of plain casing ("pump blank")*
Base + 54 to base + 60 m	*6 m of screen*
1 m above first significant aquifer strike to surface	*plain cased throughout*

Installation should preferably be undertaken with 6" Galvanised Steel casings and 6" machine slotted screens. Alternatively, less expensive gas-or plasma-slotted Mild Steel screens may be used. However, important disadvantages of the gas-slotted type include a shorter lifespan (less corrosion resistive and therfore less durable) lower open area (about

50% of the machine-slotted type), and a non-uniform slot-size. The finishing of plasma-cut screens is much better, and approaches the machine-cut version.

It should be noted that the here mentioned design is strictly tentative. The final installation should always depend on the formations encountered, water quality aspects, aquifer type, and the good judgement of the driller or drilling engineer on site. In an unconfined aquifer, for instance, screens should be placed towards the base of the water bearing zone, and hydraulic continuity provided by the gravelpack.

3. *Gravel Pack*

Volcanic formations often incorporate unstable layers of pyroclastic rocks, ashes, Old Land Surfaces, boulder beds, semi-consolidated sediments, etc. To avoid collapsing and sediment intake into the completed well, the installation of a gravel pack is strongly recommended. The filter material should consist of 4 to 6 mm diameter, washed, preferably rounded, quartzose fragments. The gravel is installed either by tremie pipe or run in by hand and washed down with copious amounts of water to prevent bridging.

The volume of pack to be inserted should be calculated on the basis of known annular space, and the actual amount of pack installed should be measured. A physical check should be made to ensure that the top of the gravel pack is at least 6 m above the top of the upper-most screen, to allow for settlement during development.

4. *Well and Aquifer Development*

Development is the term used to describe the procedures designed to maximise well yield. It has two broad objectives:

To repair the damage done to the aquifer material during drilling and restore the natural hydraulic properties.

During drilling, the bit action chips and crushes the rock, and mixes it with water and other fine material into a viscous mud. The pounding of the bit forces this slurry into the openings in the wall of the borehole, thus blocking the pores and impeding the flow of water from the aquifer. A thick "wallcake" may form, especially when clay additives (such as bentonite) have been used during the drilling, or where natural clays occur in the penetrated formations. This cake, if not removed, may virtually plug the borehole, and significantly reduce the discharge. It should be noted that the maximum yield of a formation can only be realised if all the fractures and crevices are unblocked and able to supply water to the well.

<u>Borehole development</u> techniques are applied to break down and remove the impermeable layer of clayey material from the borehole wall. Swabbing, wall-scratching, airlift rawhiding and polyphosphate dosing are all borehole development techniques.

To alter the characteristics of the aquifer volume in the vicinity of the borehole, by improving hydraulic contact between the aquifer and the hole. This is essentially <u>aquifer development</u>, and is also known as aquifer stimulation.

Polyphosphate dosing, hydrofracturing and acidizing are examples of aquifer stimulation techniques.

Development with rotary plant: If a rotary rig equipped with a strong air compressor is used, the following, highly effective development techniques should be applied:

Airlift rawhiding, into and through the screened sections. This should continue until the water lifted is clean and clear, with electrical conductivity stable. Rawhiding comprises cyclic airlifting: once the airlift has been established, air supply is cut off and water allowed to cascade down the hole. This creates overpressures across the borehole wall, which agitates the formation and enhances cleaning. The airlift is then started again and the cycle repeated.

Water jetting with an on-wall velocity of 30 m/s: at least 0.3 m^3 of fluid should be jetted per linear metre of screen. Jetting should start from the top of the screen rotating downwards. The water used must be absolutely free of particles; to increase the effectiveness of the procedure, it is mixed with sodium hexametaphosphate and calcium hypochlorite. Recommended concentrations are 3.8 kg/m^3 of sodium hexametaphosphate (a locally available, common food additive and clay disaggregant known under the trade names "Calgon" or "SHMP"), and 1.5 kg/m^3 of calcium hypochlorite. The jetting tool should be so constructed that the jet openings are not more than 0.5" (13 mm) from the screen. After the entire screen has been jetted, the hole should be left for at least 12 hours or overnight, to allow the hexametaphosphate to work on the "wallcake" and any clays present in the gravelpack and the aquifer astride the screens.

Airlift rawhiding again, from the bottom of the hole, until airlifted water is absolutely clean and electrical conductivity stable.

During development, an estimate of the bailed or air-blown yield should be made. This usually gives a fair indication of the final abstraction that can be expected from the borehole.

5. Recommended Test Pumping

After development and confirmation of the approximate borehole yield, a step-drawdown test should be carried out, followed by a 24-hour long-duration test at constant discharge rate. The tests should be performed with a submersible pump, set within the blank casing between the screened sections. The capacity of the test pump should be sufficient to provide a minimum discharge of 15 m^3/hr at a head of 150 metres.

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 at least 4 stages of not less than 60 minutes each. The pumping rates are increased in a step-by-step manner.

Recovery may be measured after the last step, but this is not really necessary if a constant discharge test is also conducted. However, before starting the constant discharge test, 95%

of the pumped drawdown must be recovered, or no increase in level must be observed for a period of more than 4 hours. Alternatively, the constant discharge test may be conducted as a direct extension of the step-drawdown test, without stopping the pump.

The constant discharge test allows calculation of specific aquifer parameters, such as transmissivity, hydraulic conductivity and storage coefficient. The shape of the test pumping curve will reveal the aquifer type: confined/unconfined, fracture, heterogeneous/homogeneous, etc. 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 12 hours, followed by 6 hours of recovery observations, or alternatively until 95% of the total drawdown has been regained.

6. ***Drilling Records and Logs***

Good drilling records are essential in evaluating the results of a borehole drilling exercise (such as the reasons for success or failure). It is highly recommended to record, as a rule, all the relevant borehole parameters: location sketch, depth, rate of penetration, water struck level, static water level, air-blown yield during drilling, tested yield, test pumping records, pumped water level, drawdown, sustainable yield, pump setting, water quality (TDS or EC), and adequate and detailed geological logs. In addition, breakdowns, reasons for stoppage, difficulties encountered during drilling, etc. should be documented.

7. ***Drilling Supervision***

It is strongly recommended to engage the services of an experienced hydrogeologist during the drilling, design, installation, and testing of the borehole. Apart from inspecting the quality of materials and verifying the quantities of items billed by the Contractor, the main tasks of the supervisor are:

- *To ensure that the borehole is completed according to the technical specifications, and*
- *To provide sound professional judgement on design aspects, required drilling depth, sustainable yield and selection of the permanent pumping plant.*

8. ***Borehole Maintenance***

Boreholes, like any other structure, age with time. Ageing may take the form of corrosion of installed ferrous metals (such as casing and screen, rising main, and pump), and in the case of almost all boreholes there will be an inevitable decline in efficiency over time.

If boreholes are installed with mild steel casing and screens, chemical corrosion may occur over the years. However, the lifespan of a borehole installed with GS machine-slotted screens is expected to be more than 40 years.

If cyclic drawdown into the screens occurs frequently, deposition of insoluble bicarbonates may take place. This, ultimately, will reduce the borehole efficiency by creating greater well-entry losses (because of higher inflow velocities).

There are various ways of monitoring efficiency, but the most effective and certainly the least equivocal is the repetition of step-drawdown tests at intervals in a borehole's life. As the screens become progressively less efficient, the discharge-drawdown equation will change, indicating greater drawdowns than hitherto for the same discharge.

Once this has declined to approximately 60 to 70% of original tested discharge for a given drawdown, the borehole should be rehabilitated. This exercise should take the form of airlift surging from the bottom of the hole, after treatment by jetting with a polyphosphate solution. Jetting breaks down the bicarbonates, and strips out any decomposed feldspars, or clays and other fines trapped in or near the screen and gravel pack. If the exercise is undertaken correctly the borehole should be almost as efficient as it was when first completed.

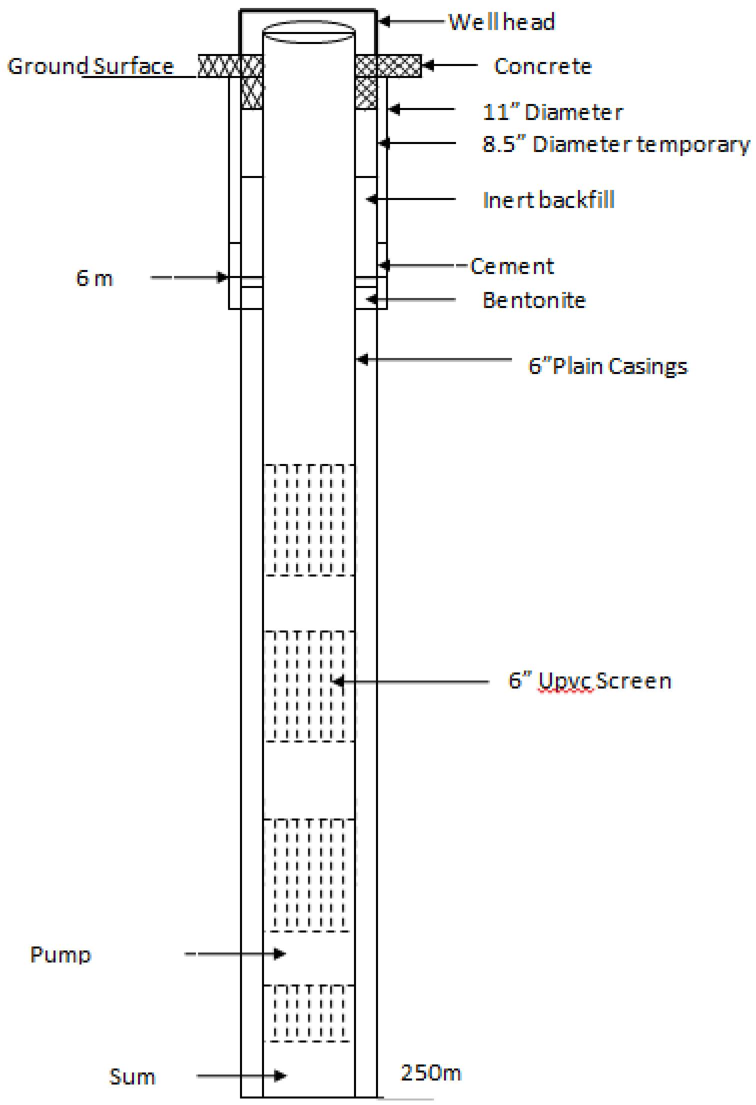
In extreme cases (as when an aquifer is contaminated with iron or sulphate bacteria, or where groundwater chemistry deposits a persistent bicarbonate coating on screens), the borehole may require acid treatment.

A crude measure of ageing, which can be calculated whenever both static and dynamic water levels for a borehole have been collected, is specific capacity for a fixed discharge value (specific capacity, Q/s, is the discharge divided by drawdown). If this ever changes dramatically, it indicates that a significant change has occurred in the borehole. If this kind of monitoring data exists it is a comparatively straightforward task for a hydrogeologist to diagnose downhole problems.

9. *Legal Requirements*

It is a legislated condition imposed by the Water Resource Management Authority (WRA) (through the Water Resource Management Rules,2007), 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.

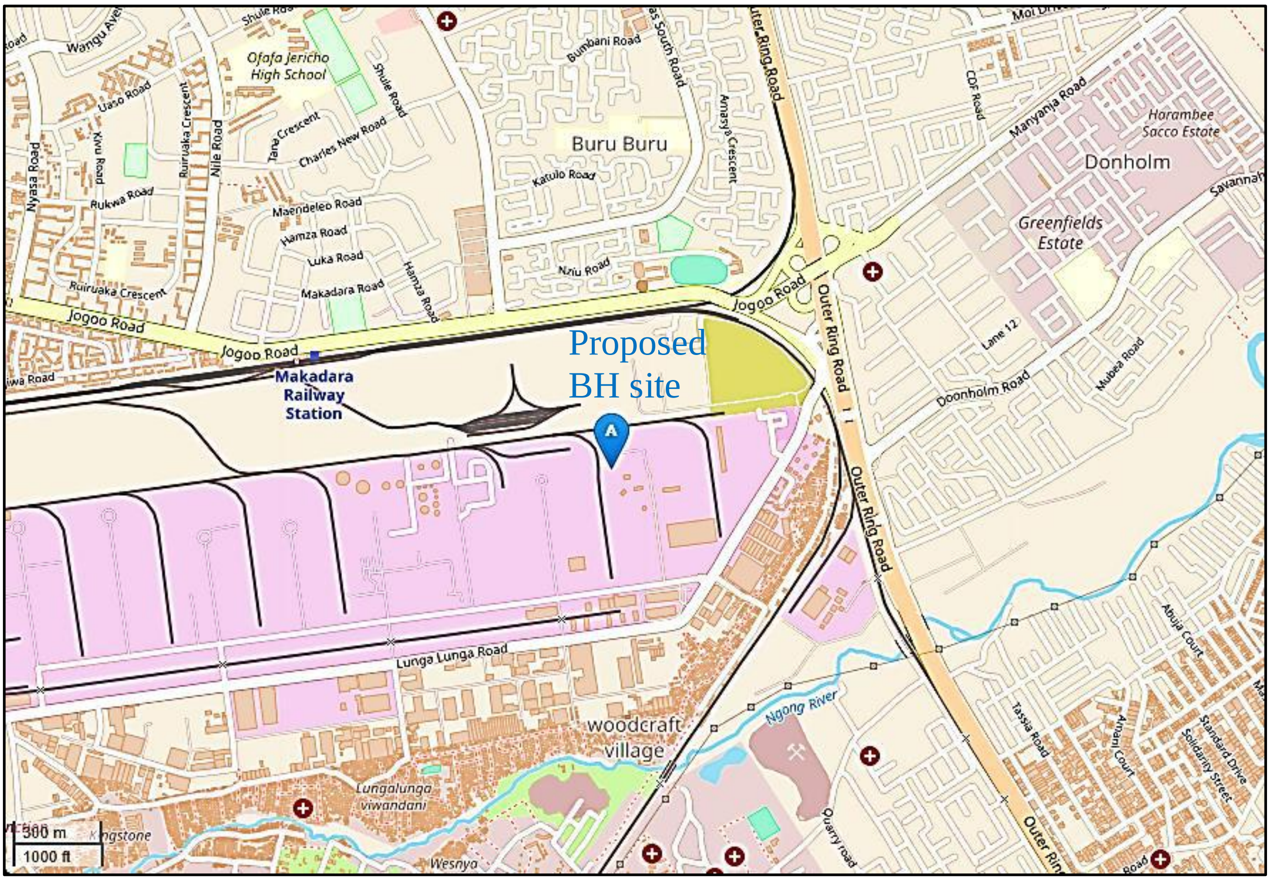
BOREHOLE SCHEMATIC DESIGN



Total Depth 250 m

NTS

APPENDIX III: SKETCH MAP



Scaled satellite Extract showing the specific site location (Adapted from google earth)