REPORT OF CONSULTANCY SERVICES FOR BOREHOLE DRILLING HYDRO - GEOLOGICAL SURVEY

FOR

KENYA POWER & LIGHTNING COMPANY

LIMITED STAFF RETIREMENT SCHEME,

P.O.BOX 30177-00100, NAIROBI.

LOCATION;

BOGANI PARK, OFF BOGANI ROAD-KAREN AREA, NAIROBI COUNTY ON PLOT NO: LR.NO: 2259/708,

Submitted By:

NORKUN Intakes Ltd
P.O. BOX 605-00100, NAIROBI
EMAIL: info@norkun.com

9TH May 2022

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1. Introduction

The Kenya Power and Lighting Company Limited Retirement Benefits Scheme 2006 is a body established by a Trust Deed to receive, manage and provide benefits to employees of the Kenya Power and Lighting Company Limited upon their retirement or to their dependents in the event of their need as stipulated.

To achieve its mandate, the Board of Trusties developed a housing project in Karen commonly known as Bogani Park Estate. The project is located on Bogani Road, Karen, and Nairobi County. The project consists of forty-five (45) four and five-bedroom luxury town houses set on individual half-acre plots or thereabout and categorized in 3 house types to meet a diverse market. Other facilities developed within the complex include clubhouse, swimming pool, gatehouse and borehole. Current occupation is about 35 out of 45 houses, which is about 78%.

The client contracted **NORKUN** Intakes Ltd to *Provide Consultancy Services for Borehole Drilling Hydro-Geological Survey*.

2. Summary of the Scope of Works

The scope of works for NORKUN was as follows:

i. Collection of water usage data-using meter readings
ii. Water demand calculation
iii. Auditing existing equipment
iv. Site investigation and existing borehole
v. Test pumping
vi. Collect information on the hydrological condition of the area
vii. Review of existing data, records, studies, investigations etc.
viii. Conduct hydrological and geophysical survey
ix. Provide detailed report on hydrological and geophysical survey
x. Recommend the most suitable borehole drilling site and provide chances of success on each site
xi. Provide professional opinion on or against drilling the existing borehole deeper

xii. Provide detailed scope of the recommended remedial measures to be undertaken.

xiii. Prepare and provide the required design works, detail drawings, technical data, bill estimates and other documents including tender documents for the proposed remedial works.

xiv. To provide the Fund with specialist technical advice on all aspects of the project.

xv. To effectively monitor and inspect works being undertaken by the contractor.

xvi. Supervise the production of as built drawings and operation and maintenance manual.

xvii. Preparing any paperwork and or reports that may be required for submission and securing all the approvals and tests needed by relevant government entities before, during and upon completion of the remedial works. This shall include overseeing the payment of any requisite fees.

xviii. Upon completion of review and appointment of a contractor, provide supervision of and construction of all the remedial works.

xix. Undertake any other auxiliary or incidental consultancy duties and responsibilities related to the project.

3. SECTION A: AUDIT OF THE EXISTING WATER RESOURCES AND DEMAND

3.1 Water demand calculations and usage analysis

3.1a Analysis of Water Usage Based on Water Bills for Houses

Based on the data provided by the Property managers, we sampled five, houses of mixed types, randomly and analyzed their 5 months water bills as shown on the table below.

Table 1: Analysis of Water Usage Based on Water Bills for Houses

Month / Houses	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Average consumption per month	Average consumption per day per HSE(m^3)	Average consumption for 1No HSE per day (m^3) EXCL common services	Average consumption for 45No HSE per day (m^3) EXCL common services
HSE No 5	15	15	20	20	64	26.8	0.9	1.6	72
HSE No 10	27	32	31	32	28	30	1		
HSE No 18	78	85	85	106	108	92.4	3.1		
HSE No 38	18	79	50	43	53	48.6	1.6		
HSE No 45	35	45	52	40	37	41.8	1.4		

From the table above, it is clear that the average daily consumption for 1No house is 1.6 m3 (1600 Liters) excluding common services. Estimated average daily consumption for the 45No Houses is 72m3 (72,000 Liters) excluding common services.

3.1b Analysis of Water Usage Based on Water Bills for Bulk Meters/Sources

Table 2: Analysis of Water Usage Based on Water Bills for Bulk Meters/Sources

Month / Source	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	**Average Monthly Usage in m³ (35 No Hses) including common services**	**Average Daily Usage in m³(35 No Hses) including common services**	**Estimated Daily Water Usage in m³(45 No Hses) including common services**
NCC	46	53	103	119	123	89	3	4
Borehole	828	786	1,444	598	855	902	30	39
Bulk Bowser	1,000	1,200	700	800	400	820	27	35
Total Monthly Usage	**1,874**	**2,039**	**2,247**	**1,517**	**1,378**	**1,811**	**60**	**78**
Average Daily Usage	62	68	75	51	46			

From the table above main sources of water for the estate are;

i. Nairobi County Council (NCC) - Supplies average $3m^3$ daily.

ii. Borehole water- Supplies average $30m^3$ daily.

iii. Bulk Bowsers - Supplies average $27m^3$ daily.

From the table above, the average daily usage of water at the current occupation of 35No houses and all common areas is $60m^3$. When occupation is full capacity (45No houses), the estimated daily water usage will be $77m^3$ which includes common services.

Base on the amount supplied by bowsers daily, ($30m^3$), it is estimated that at full occupancy, the supply will need to be raised to $35m^3$.

The supply by NCC is assumed to remain as 3 m^3/day.

Calculations for the overall daily water deficit are as follows;

a. The estimated daily usage at full occupancy=$78m^3$
b. The amount supplied by NCC=$3m^3$
c. The amount supplied by the existing borehole=$30m^3$
d. Total daily deficit =

$$78 - 30 - 3 = 45\text{m}^3/\text{day}$$

3.2 Observations of existing borehole and equipment

3.2a Bore Hole Completion Report

Based on the borehole completion report for the existing borehole as received from the property manager, the following information was deduced;

i. The borehole was drilled on February 2014.
ii. Borehole was drilled to a depth of 327m.
iii. The entire borehole is steel cased
iv. Water Rest level was 117.9m.
v. Water was struck at 213m depth.
vi. Borehole tested yield was $3m^3$/hr with the pump set at 236m depth.

3.2b Borehole Pump Lifting and Endoscopic Camera Investigation

The investigation revealed the following information;

i. The existing borehole pump is Grundfos SP5A-6 complete with 5.5KW motor.
ii. The pump was set at 314m depth
iii. Borehole current depth is 319.2m
iv. Water Rest level is currently at 180.1m
v. Water clarity was ok.
vi. Detailed camera investigation report is attached in *Appendix i*.

3.2c Borehole Constant Discharge Test and Recovery Test

The test pumping exercise revealed the following:

i. The current borehole yield is $1m^3$/hr. (based on 24 hr. continuous pumping) with the pump set at 314m depth.
ii. The borehole recovered to 258.52m in 120 minutes period
iii. Detailed pump testing schedule attached in *Appendix ii*

3.2d Remarks

In view of the above findings, we note the following:

i. The borehole has since back filled from 327m to 319.2m.
ii. The pump is set at the lowest level possible.
iii. The water rest level has since dropped from 117.9m to 180.1m depth.
iv. The borehole yield has drastically reduced from $3m^3$/hr to $1m^3$/hr.
v. The current borehole yield is below the client water demand.

4. SECTION B: STUDY OF ADDITIONAL WATER RESOURCE TO MEET THE DEMAND

The team considered various available water resources and closed in on 2No options:

1. Sinking the existing borehole further
2. Sinking a new borehole to supplement the existing.

A preliminary hydrological study was conducted on the existing borehole and sites for an alternative borehole whereby the second option was zeroed in.

4.1 Hydrological study and report

With 34No 4-Bedroom and 11No 5 Bedroom units, the approximate number of persons is 300. The estimated daily water demand for 300No People and assuming 25% for recreation center, common areas cleaning and gardening is 75m3 [refer to table in 2.1 of annex iii-Hydrological Report].
Here below, please find an executive summary of the Hydrological survey report.

A borehole is recommended to be drilled at the selected position to min depth of 360m. This will ensure that the deeper aquifer will be fully penetrated. The surrounding boreholes have varying yields that range between 3 and 10.08m3 /hr. The yield of a borehole drilled at the recommended location is expected to be within the above range, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Water quality is expected to be good and suitable for domestic use.

It is thus recommended that:

- The borehole should be drilled at the selected position to minimum depth of 360m and maximum depth of 400m this will ensure the Mbagathi trachyte layer has been fully penetrated to tap water from the Athi series.
- The borehole should be installed 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 Management Authority's Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

  See appendix iii for full Hydrological report and recommendation.

5. SECTION C: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

- Based on the above information, it is evident that the existing borehole yield has dropped from the initial **3m^3** /hr to **1m^3**/hr. This could be due recent activities including multiple boreholes that have been sunk around the area.
- From the calculations, the estimated daily demand for the estate is **75m^3** against prorated daily usage of **78m^3**.
- The overall daily deficit of **44 m^3/hr**.
- The analysis of meter readings indicate that some houses have abnormally high amounts of water usage as high as **108m^3** per month e.g. House No 18. Their average daily usage is **3.6m^3** against a standard water demand of **1.6m^3** per day for a similar 4-Bedroom. This will need to be investigated further as well as other houses with such abnormally high usage of water.
- From the hydrological report, the proposed additional new borehole will be able to bridge the daily water demand deficit.

5.2Recommendations

Our recommendations are as follows;

a) Option 1:

Based on the completion report for the existing, the yield was 3m^3/hr. at a depth of 327m. In addition, a neighboring borehole (Thomas Letangule) at a depth of 325m has yield of 3m^3/hr. which compare well with the existing.

Sinking the existing borehole further down is not a guarantee that the yield will meet the daily water demand of 78m^3.

In view of the above, our recommendation is to sink an additional borehole to supplement the existing to be able to meet the daily demand.

b) Option 2

Enhancement of water supply from Nairobi water to supplement the existing borehole to meet the demand.

Please note that this is not a guarantee since the control of water supply is under the jurisdiction of others.

c) Option 3

Collaboration with neighbors with high yield boreholes to pipe water to the estate to meet the demand deficit.

Please note that this is not a guarantee since the control of water supply is under the jurisdiction of others.

6. SECTION D: FINANCIAL ESTIMATE OF THE ABOVE RECOMMENDATIONS

DESCRIPTIONS	COST
OPTION 1: DRILLING A NEW BOREHOLE	Ksh 6.5 million
OPTION 2: ENHANCEMENT OF NW&SC SUPPLY LINE	CANNOT BE DETERMINED AT THIS STAGE
OPTION 3: COLLABORATION WITH NEIGHBOURS	CANNOT BE DETERMINED AT THIS STAGE

7. SECTION E: APPENDIXES

i. Appendix i-Camera Inspection Report

ii. Appendix ii-Pumping Test-Discharge and Recovery Test Report

iii. Appendix iii- Hydrogeological Assessment Report

ANNEX I-CAMERA INSPECTION

DAVIS & SHIRTLIFF
know H2Ow through experience

Water Pumps
Borehole Service
Swimming Pools
Water Treatment
Generators
Solar Equipment
Irrigation

DAVIS & SHIRTLIFF LTD • PO Box 41762-00100, Nairobi, Kenya • Tel: (+254 20) 6968 000, 0711 079000 • Fax: (+254 20) 557617 • headoffice@dayliff.com

CUSTOMER	wet services Nairobi Kenya	SITE	BOGANI PARK
JOB#	79859	EQUIPMENT	CAMERA INSPECTION
JOB TYPE	UNDER WATER CAMERA INSPECTION	TECHNICIAN	PETER KIMANI
SCHEDULED	02/04/2022 - 09:00 AM	JOB COMPLETED	04/04/2022 - 08:56 PM

DESCRIPTION

BOREHOLE CAMERA INSPECTION

REPORT SUMMARY 1

Site Geolocation	Bogani Rd, Nairobi, Kenya,Nairobi (-1.3555355,36.7319856)
CUSTOMER CASE: (what customer reported)	SILTATION
SITE PHOTOS BEFORE- (For the overall equipment/site)	
FAULT: (Actual problem at site)	.
SITE PHOTOS BEFORE- (For the Fault)	
CAUSE OF FAULT:	.
PRODUCT / EQUIPMENT MAKE & MODEL	BH
ACTION TAKEN: (what was done)	CONDUCTED A BOREHOLE UNDER WATER CAMERA INSPECTION WHICH WATER REST LEVEL START AT 180M ,CASING LENGTH 319M ,WATER CLARITY OK AND TOTAL DEPTH IS 319M .
SITE PHOTOS AFTER- (For the overall equipment/site)	
Job complete	COMPLETED SUCCESSFULLY
Further Work Required	NONE
Main Items Used	UNDER WATER BOREHOLE CAMERA
Job Started at:	03:00 PM
Job Ended at:	05:00 PM
Site Contact Person (Names)	MR ERNEST

Site Contact Person (Tel. No.)	**0722864805**

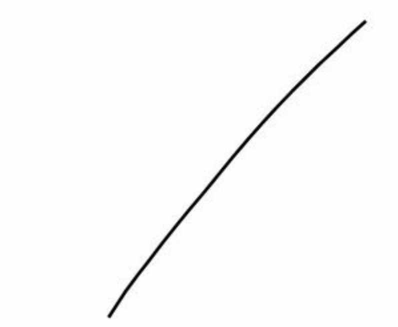
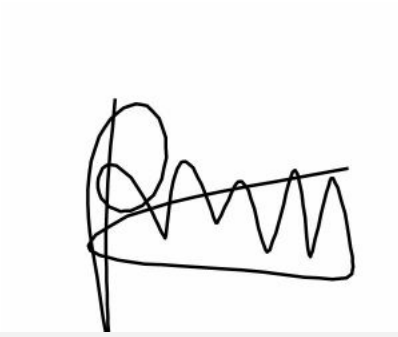
DELIVERED ITEMS 1

DELIVERED ITEMS	**NO**

IMPORTANT NOTICE

EQUIPMENT RECEIVED BY DAVIS & SHIRTLIFF LTD AND NOT COLLECTED BY THE CUSTOMER WITHIN THREE MONTHS OF RECEIPT WILL BE DISPOSED OF TO DEFRAY STORAGE AND CHECKING CHARGES AND NO RESPONSIBILITY WILL BE ACCEPTED FOR LOSS, DAMAGE, OR CONDITION AFTER THIS PERIOD.

SIGNATURE

	
wet services	**Davis and Shirtliff**
BOGANI PARK	**PETER KIMANI**
.	PETER KIMANI

DOCUMENTATIONS

Click the links below:

1. Operation Manual:

2. Electrical Wiring Diagram:

3. Dayliff Terms of Warranty: https://www.davisandshirtliff.com/davis-api/Warranty/DAYLIFF-TERMS-OF-WARRANTY.pdf

4. Website: https://www.davisandshirtliff.com/products-and-solutions

ANNEX II-PUMPING TEST-DISCARGE and RECOVERY TEST DATA

CONSTANT RATE DISCHARGE TEST PUMPING (24 HOURS):

Date	29/04/2022	Testing Contractor	WET SERVICES LIMITED
Client	KPLC STAFF RETIREMENT SCHEME		
Location	BOGANI [ARK, KAREN		
Bucket Size	....20...Litres	Static Water Level	180.1m
Water level Measured	Electric Dipper	Pump Intake Depth	314M
Power Source	GENERATOR	Final Pumping Water Level	296.86m
Pump Type Details	SP 5A-60	Discharge	1m³/hr

DRAW DOWN RECORD

Clock Time	Interval (Min)	Elapsed Time (Min)	Water Level (Mtrs)	Drawdown (m)	Discharge (m^3/hr)	Condition of Water/Gate Valve Position
10:00:00	0	0	180.10	3.12		Gate valve fully open
10:01:00	0:01:00	1	183.42	6.44	5.4m^3/hr	Clear water
10:02:00	0:01	2	186.66	9.68		
10:03:00	0:01	3	190.01	13.03		
10:04:00	0:01	4	193.10	16.12		
10:05:00	0:01	5	196.11	19.13		
10:06:00	0:01	6	199.32	22.34		
10:07:00	0:01	7	205.57	28.59		
10:08:00	0:01	8	208.47	31.49		
10:09:00	0:01	9	211.27	34.29	5.0m^3/hr	Clear Water
10:10:00	0:01	10	213.88	36.90		
10:12:00	0:02	12	219.29	42.31		
10:14:00	0:02	14	224.67	47.69		
10:16:00	0:02	16	230.05	53.07		
10:18:00	0:02	18	235.14	58.16	4.5m^3/hr	
10:20:00	0:02	20	240.86	63.88		Gate valve throttled
10:25:00	0:05	25	243.16	66.18	2.1m^3/hr	
10:30:00	0:05	30	245.47	68.49		Clear Water
10:35:00	0:05	35	247.87	70.89		
10:40:00	0:05	40	250.21	73.23		
10:45:00	0:05	45	252.51	75.53		
10:50:00	0:05	50	254.79	77.81		
10:55:00	0:05	55	257.08	80.10		
11:00:00	0:05	60	259.18	82.20	1,84m^3/hr	Clear Water
11:10:00	0:10	70	263.98	87.00		
11:20:00	0:10	80	268.24	91.26		
11:30:00	0:10	90	269.76	92.78		
11:40:00	0:10	100	270.84	93.86		
11:50:00	0:10	110	271.62	94.64		
12:00:00	0:10	120	272.56	95.58	1.33m^3/hr	Clear Water
12:30:00	0:30	150	275.48	98.50		
13:00:00	0:30	180	280.54	103.56		
13:30:00	0:30	210	284.76	107.78		
14:00:00	0:30	240	286.47	109.49		
15:00:00	1:00	300	290.72	113.74	1.2m^3/hr	
16:00:00	1:00	360	294.57	117.59		
17:00:00	1:00	420	296.74	119.76	1m^3/hr	
18:00:00	1:00	480	296.79	119.81	1m^3/hr	
						Night break
7:00:00	1:00	480	296.79	119.81		
8:00:00	1:00	540	296.81	119.83	1m^3/hr	Clear Water
9:00:00	1:00	600	296.86	119.88		
10:00:00	1:00	660	296.86	119.88		
11:00:00	1:00	720	296.86	119.88		
12:00:00	1:00	780	296.86	119.88		
13:00:00	1:00	840	296.86	119.88		
14:00:00	1:00	900	296.86	119.88		
15:00:00	1:00	960	296.86	119.88		
16:00:00	1:00	1020	296.86	119.88		
17:00:00	1:00	1080	296.86	119.88	1m^3/hr	
18:00:00	1:00	1140	296.86	119.88		
19:00:00	1:00	1200	296.86	119.88		

TEST CONDUCTED BY, (OPERATOR) : JAMES ISAIAH

CONSTANT RATE DISCHARGE RECOVERY TEST (2 HOURS)

Date	30/04/2022	Testing Contractor	WET SERVICES LIMITED
Client	KPLC STAFF RETIREMENT SCHEME		
Location	BOGANI [ARK, KAREN	Pump Setting Depth	314M
BOREHOLE DEPTH	319.2M	Recovery Level	258,52M
Measured by	Electric Dipper	Discharge	1.1m³/hr
Power Source	GENERATOR	Datum Level	Ground level
Pump Type Details	DS 5-60		

Time		Elapsed Time	Water Level	Time Since Test	T/T 1	Residual Drawdown
				(Min)T		
Hr	Min	(Min)T 1	(Mtr)	1000	0	S*(Mtr)
19:00:00	0:00:00	0	**296.86**	1001	1001	-116.76
19:01:00	0:01:00	1	295.72	1002	501	-84.83
19:02:00	0:02:00	2	294.58	1003	334	-83.69
19:03:00	0:03:00	3	293.48	1004	251	-82.59
19:04:00	0:04:00	4	292.47	1005	201	-81.58
19:05:00	0:05:00	5	291.56	1006	168	-80.67
19:06:00	0:06:00	6	290.69	1007	144	-79.80
19:07:00	0:07:00	7	289.70	1008	126	-78.81
19:08:00	0:08:00	8	287.92	1009	112	-77.03
19:09:00	0:09:00	9	286.54	1010	101	-75.65
19:10:00	0:10:00	10	285.46	1011	92	-74.57
19:11:00	0:11:00	11	284.72	1012	84	-73.83
19:12:00	0:12:00	12	283.41	1013	78	-72.52
19:13:00	0:13:00	13	282.54	1014	72	-71.65
19:14:00	0:14:00	14	280.45	1015	68	-69.56
19:15:00	0:15:00	15	279.60	1016	64	-68.71
19:16:00	0:16:00	16	278.52	1017	60	-67.63
19:17:00	0:17:00	17	277.48	1018	57	-66.59
19:18:00	0:18:00	18	276.76	1019	51	-65.87
19:20:00	0:20:00	20	274.57	1020	46	-63.68
19:22:00	0:22:00	22	270.47	1021	43	-59.58
19:24:00	0:24:00	24	269.48	1022	39	-58.59
19:26:00	0:26:00	26	267.92	1023	37	-57.03
19:28:00	0:28:00	28	266.92	1024	34	-56.03
19:30:00	0:30:00	30	266.27	1025	29	-55.38
19:35:00	0:35:00	35	264.72	1024	26	-53.83
19:40:00	0:40:00	40	262.82	1025	23	-51.93
19:45:00	0:45:00	45	261.42	1018	20	-50.53
19:50:00	0:50:00	50	260.54	1019	19	-49.65
19:55:00	0:55:00	55	260.32	1020	17	-49.43
20:00:00	1:00:00	60	260.12	1021	15	-49.23
20:10:00	1:10:00	70	260.00	1022	13	-49.11
20:20:00	1:20:00	80	259.92	1023	11	-49.03
20:30:00	1:30:00	90	259.78	1024	10	-48.89
20:40:00	1:40:00	100	258.84	1025	9	-47.95
21:00:00	2:00:00	120	258.52	1024	9	-47.63

TEST CONDUCTED BY, (OPERATOR) : JAMES ISAIAH

ANNEX III

HYDROGEOLOGICAL ASSESSMENT REPORT

FOR

CLIENT;

KENYA POWER & LIGHTNING COMPANY LIMITED STAFF RETIREMENT SCHEME,

P.O.BOX 30177-00100,

NAIROBI.

LOCATION;

BOGANIPARK, OFF BOGANI ROAD-KAREN AREA, NAIROBI COUNTY

On

LR.NO: 2259/708,

Prepared By;

Wet Services Limited

Suite 213, 2nd Floor, Westlands Arcade,

Off Chiromo Road, Westlands,

P.O.Box 55461-00200 Nairobi

16TH APRIL, 2022

SUMMARY

The present report describes the results for hydrogeological/geophysical survey for ***Kenya Power & Lightning Company Limited' Staff Retirement Scheme*** parcel of land within Bogabi Park, Bogani Road, Karen sublocation, Karen Location,Langata Division in Nairobi County. The study is required for identifying a suitable site for drilling a replacement borehole for borehole whose yield has dropped over time. The borehole will be used as the sole water source for domestic purposes within the institution.

The Project area is situated in a zone with low to medium groundwater potential.

A borehole is recommended to be drilled at the selected **position to minimum depth of 360m.** This will ensure that the deeper aquifer will be fully penetrated.

The surrounding boreholes have varying yields that range between **3 and 10.08m^3/hr**. The yield of a borehole drilled at the recommended location is expected to be within the above range, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Water quality is expected to be good and suitable for domestic use.

It is thus recommended that:

- The borehole should be drilled at **the selected position to minimum depth of 360m and maximum depth of 400m this will ensure the mbagathi trachyte layer has been fully penetrated to tap water from the athi series.**
- The borehole should be installed with mild steel casings and gas-slotted screens
- The borehole hydraulical 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 Management Authority's Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

ABBREVIATIONS AND GLOSSARY OF TERMS

<u>ABBREVIATIONS (S.I. Units throughout, unless indicated otherwise)</u>

agl	above ground level
amsl	above mean sea level
bgl	below ground level
E	East
EC	electrical conductivity (S/cm)
hr	hour
l	litre
m	metre
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
WARMA	Water Resources Management 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.

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1.0 Introduction and background information

On 5th April 2022, ***Kenya Power & Lightning Company Limited Staff Retirement Scheme*** commissioned the carrying out of hydrogeological/geophysical site investigations at their parcel of land. The land is located within Bogani area in Nairobi County.

The address of the Client is:

Kenya Power & Lightning
Company Limited Staff
Retirement Scheme**,**
P.O. BOX 30177-
00100, Nairobi.

The **client** intends to drill the borehole within their parcel of land within Bogani area in order to have a reliable water supply.

2.0 Project location

The project plot is located in Bogani area as shown on the sketch. The client has developed the plot and thus a reliable water supply is required.

The approximate co-ordinates of the project plot is 37M0247709 and UTM 9850206 and it is located in Ngong Map sheet 148/3. The plot has elevation of 1,840 metres above sea level.

2.1 Water Supply and the proposed Activity

The client has been relying on the borehole whose yield has dropped thus need to sink a replacement borehole to supply water within the plot.

The amount of water used in a locality is directly proportional to the size of the population;

Population Density Estimations

Residential	***Number of Persons***
34 units 4 bedroom houses	*204*
11 units 5 bedroom house	*83*
Support staff	*13*

Residential water consumption

Homes use	***Daily water person in use per litres***	***Total consumption in litres per day***
300 people	***200***	***60,000***
Common services	***25% for club house cleaning and gardening***	***15,000***
Total water demand		***75,000***

The proposed borehole will serve approximately 300 people thus the domestic water demand is estimated to be **$75m^3$/day.**

3.0 Climate and land use

The climate is semi-arid, being dry for most of the year. Rainfall is bi-modal (March-May and October-December). Mean annual rainfall is approximately 530 mm. Temperatures are highest in the months January to March; Annual mean daily minimum and maximum temperatures are 13 to 26o C (TAMS, 1980).Potential evaporation is between 1,800 and 2,000 mm per year and these losses are exacerbated by frequent high winds in the area.

Potential evaporation is between 1,800 and 2,000 mm per year and these losses are exacerbated by frequent high winds in the area.

4.0 Geology and Hydrogeology

4.1 Regional Geology

The geology of Nairobi is comprehensively described in Saggerson (1991). In the project Area, the surface rocks exclusively comprise Pleistocene and Tertiary volcanic material. 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. The thick volcanic sheet is underlain at great depths (probably more than 700 m) by metamorphic rocks of the Basement complex (gneisses and schists) of the Mozambican System. The Tertiary volcanic period lasted approximately 13 million years, and was characterized by cyclic activity: eruptive episodes, marked by the ejection of lava flows, pyroclastic bombs, and ashes, were punctuated by periods of erosion and landmass denudation. During these times of relative quiescence, Old Land Surfaces were formed, which today important water are bearing layers within the volcanic succession.

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

4.1.1 Athi Tuffs

The Athi Series is a very important aquifer over much of the Nairobi area, and locally reaches impressive thicknesses (up to 260 m) of continuous sedimentary deposits (Saggerson, 1991). Its depth at the present site is expected to be greater than 200 m. Thin beds of Athi Tuffs may occur within the overlying phonolite and trachyte flows.

The Athi Tuffs and Lake Beds are a stratified group of tuffs, ashes and sediments laid down discordantly on top of the older Kapiti Phonolites. The relatively soft rocks are usually light grey in colour when fresh and yellowish grey when weathered.

The sequence was formed in an environment of explosive volcanic activity, combined with intensive erosion and re-deposition processes. Under the relatively humid climate that prevailed during Early Tertiary times, river systems would transport and rework the loose, recently formed volcanic material. The assumption that the Athi Tuffs were laid down under water (in lakes, river floodplains and mudflow deposits) is supported by the presence of clear stratification.

The lacustrine, deltaic and fluviatile sediments are intercalated with sub-aquatic pyroclastic material. They predominantly comprise re-worked tuffs and agglomerates, sands, clays and related sediments, which form a large proportion of the volcanic cover on the eastern shoulder of the Rift Valley.

4.1.2 Mbagathi Phonolitic Trachytes (MT)

The Mbagathi Trachytes overlie the Athi Tuffs, and have been exposed along Mbagathi Valley to the northeast. It is widely distributed to the northeast of the site in the Nairobi National Park area. This trachytic lava is suspected to have been ejected through vents now obscured by the younger Ngong volcanics towards the west. At least two distinct flows have been identified

(Saggerson, 1991) with a minimum total thickness of 61 m, while the maximum thickness encountered in boreholes is 122 m. The rock is characterized by insets of feldspar in a porphyritic groundmass. This formation is hard, massive and not water bearing where not faulted. It therefore forms a confining layer to the underlying water bearing Athi Series.

4.1.3 Nairobi Phonolites (NP)

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.

Phonolitic sands, probably derived from the parent phonolite flows during periods of quiescence between eruptive episodes, occur within the Nairobi Phonolites as intercalations. These comprise the primary aquifers in the Ongata Rongai Area, though are probably considerably supplemented by the “Old Land Surface” (OLS) aquifers located between this, and the younger Nairobi Trachytes. However, this formation is absent in the present area. In its stead, the Kandizi phonolites that is similar but of older age is found overlying the Mbagathi trachytes

4.1.4 Basalts

Basalts, basaltic sands and basaltic agglomerates, related to the Upper Ngong Basalts, (Gevaerts, 1970) are occasionally encountered in boreholes in Ongata Rongai area. They may either represent very localized *in situ* basaltic lava flows, or the erosional products derived from basaltic material further to the west. The basalts do not appear to exist east of the fault system, which forms the Mbagathi Ridge.

From the existing borehole data, it can be concluded that these basaltic deposits are an important local aquifer, where they are encountered

4.1.5Nairobi Trachytes (NT)

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.

4.1.6 Kerichwa Valley Tuffs (KVT)

The Kerichwa Valley Series is an extensive and complex formation, which embraces the most recent volcanic material further to the south across the Mbagathi river. The unit surfacing around Ongata Rongai Shopping Centre is of the Middle or Upper Kerichwa Valley Tuffs. There are also some remnants of this formation overlying the Mbagathi Phonolitic Trachytes on either side along the Mbagathi Valley to the north of the site. These are the formations, which provide the characteristic Nairobi Building Stone, quarried widely within and adjacent to the Nairobi area

These rocks constitute a fair aquifer in the area around and to the north of the present site, which has unfortunately been strongly depleted by widespread over-pumping.

4.1.7 Recent deposits

Superficial deposits in the area comprise black cotton soils and light brown loamy soils. These form a thin cover at the study site.

4.2 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. In the general study area, a series of semi parallel faults runs in north-northwestern direction along the base of the Ngong Hills. This gives the terrain a "horst and graben" appearance, marked by several distinct steps.

Faults are directly responsible for the formation of springs in the upper Mbagathi catchment, where faulted Kerichwa Valley Tuffs and Nairobi Trachytes are overlain by vast series of much younger Limuru Trachyte. While there is no evidence of spring-flow in the Mbagathi, it is conceivable that recharge to aquifers within the river valley occurs during periods of flooding. There is, however, no direct evidence for this.

It is anticipated that buried faults in this region would be responsible for perched aquifers and hence localising the groundwater potential zones. This phenomenon would similarly cause heterogeneities in aquifer characteristics in the area.

Geology of the Area.

The study area is characterized by the following formations which are likely to be encountered during drilling:

- ✓ Recent soils, possibly underlain by a thin layer of Kerichwa Valley Tuffs
- ✓ Nairobi Trachytes
- ✓ Nairobi Phonolites
- ✓ Mbagathi Phonolitic Trachytes
- ✓ Upper Athi Series

5.0 Existing boreholes and recharge

Several boreholes have been drilled near the project area. Their data is given below.

Table of existing boreholes in the project area

A	B	C	D	E	F	G	H
BH No.	**Borehole Name**	**Distance /**	**Depth Metres**	**Water Strike**	**Static Water**	**Yield in M^3/hr**	**Pumpin g water Level,**
22782	Thomas Letangule	2.1NE	325	192,265,289	136.6	3	278..98
4882		1NE	150	140	89	10.08	-
1932		0.9NE	124	98	81	4.74	98
14726	Charetian Missionaries	1.3NE	290	154,196	116.8	9	174
13573	Marist brothers	0.9NW	174				
Range			**124-325**	**98-289**	**81 -136**	**3-10.8**	**98-278.98**

m bgl - metres below ground level.

The project area is located in an area that has medium to good groundwater potential. The wide variation of the tested yields is due to varying drilled depths, aquifer characteristics differences, and differences in casings and screens designs.The main aquifers are in the Athi Series that is composed of tuffs and sediments. There are other minor aquifers struck within the weathered and fractured zones and at the contact zones in the underlying lavas. The lavas are thick and Basement rocks are at very deep depths.

5.1 Borehole Specific Capacities

Borehole specific capacities are 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).

5.2 Transmissivity, Specific Yields and Storage Coefficients

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 gives the summary of pump test. It is ideal if the test pump data is in log scale.

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

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

Table of Specific Yield Ranges of Different Materials

Earth Material	Specific Yield %
Limestone & Shale	**0.5 - 5%**

Sandstone	**5 - 15%**
Clay	**1 - 10%**
Sand and Gravel	**15 - 25%**
Gravel	**15 - 30%**
Sand	**10 - 30%**

5.3 Hydraulic Conductivity and Groundwater Flux

Hydraulic conductivity and groundwater flux can only be determined accurately by use of locations laboratory investigations and Isotope methods that are very expensive methods. The results are confined to few locations, and they depend on the scale of the investigation method. Rock sample measurements in laboratory vary from well test results. Ministry of Water and Irrigation data is also not very reliable.

The Hydraulic Conductivity (K) is estimated as follows:

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

5.4 G*roundwater 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,

Table showing Hydraulic conductivities of typical geologic material

(Bear, 1972, Freeze and Cherry, 1979)

K(m/day)	**10^5**	**10^3**	**10^2**	**10**	**1**	**10^{-1}**	**10^{-2}**	**10^{-3}**	**10^{-4}**	**10^{-5}**	**10^{-6}**	**10^{-8}**	**10^{-10}**
K (ft/day)	**10^6**	**10^4**	**10^3**	**100**	**10**	**1**	**0.1**	**0.01**	**0.001**	**0.001**	**10^{-5}**	**10^{-7}**	**10^{-9}**
Relatively permeability aquifer	**Pervious**				**Semi- Pervious**				**Impervious**				
Unconsolidated Sand & Gravel	**Well sorted Gravel**		**Well sorted Sand or Sand & Gravel**			**Very fine Sand, Silt,Loess, Loam**							
Unconsolidated Clay & Organic				**Peat**		**Layered Clay**			**Unweathered Clay**				
Consolidated Rocks	**Highly Fractured Rocks**			**Oil Reservoir Rocks**			**Fresh Sandstone**		**Fresh Limestone, Dolomite**			**Fresh Granite**	

5.4 Recharge/ Discharge Considerations

With suitable storage media existing in the underlying rocks mechanisms by which water must reach it also affect aquifer potential.Both Basement Rocks and volcanic systems suffer the same limitations so far as recharge is concerned: if rainfall is low the volume of water which may eventually percolate to a suitable aquifer is likely to be relatively small, and possibly mineralised due to high evaporation rate.Percolation is dependent on soil structure, vegetable coverage and the erosion state of the parent rock. Rocks which weather to clayey soils will naturally inhibit percolation (such as black cotton soils); conversely, the sandy soils resulting from the erosion of some Basement rocks are eminently suited to deep, swift percolation.Recharge is the term applied to the whole mechanism, and includes all the aspects of parent geology, effective rainfall and percolation. Some aquifer systems are recharged by water falling a substantial distance away.

5.5 Assessment of Availability of Groundwater

Aquifers in this area are within the weathered, fractured and decomposed lavas. At the contacts of different lava flows and contact of lavas with basement rocks. Athi Series that is composed of sediments and tuffs form the main aquifers in the project area.The volcanic rocks show wide variation of porosity and permeability and have developed aquifer units separated by lower permeability strata. The aquifers mainly consist of Upper Athi Series.

5.6 Analysis of Reserve and Groundwater Evolution

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

6.0 Geophysics

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

Vertical Electrical Soundings (VES) are executed to probe the conditions at such anomalous zones within the sub-surface and to confirm the existence of deep groundwater. The VES probes the resistivity layering below.

6.1 Basic Principles of the Resistivity Methods

The electrical properties of the upper parts of the earth's crust are dependant upon the lithology, porosity, and the degree of pore space saturation and the salinity of the pore water. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of the saturated rocks, the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock.

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

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

R = Rs *L/A (in Ohm) (1)

Where Rs is known as the specific resistivity, characteristic of the material and independent of its shape or size.

With Ohm's Law

R = dV/I (Ohm) (2)

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

Rs = (A/L) *(dV/I) (in Ohm.m) (3)

6.2 Methods

6.2.1 Vertical Electrical Soundings (VES)

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

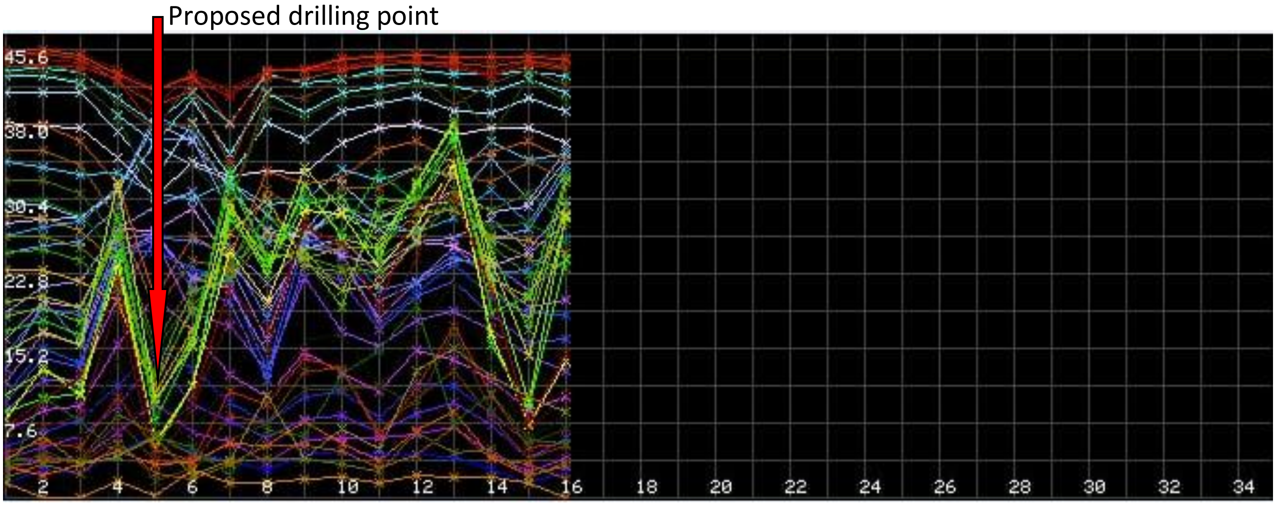
When carrying out a resistivity sounding, electric current is led into the ground by means of two electrodes and the potential field generated by the current is measured. The separation between the electrodes is step-wise increased (in what is known as a Schlumberger Array), thus causing the flow of current to penetrate greater depths. The observed resistivity values are plotted on log-log paper and the graph obtained depicts resistivity variation against depth. This graph can be interpreted with the aid of a computer, and the actual resistivity layering of the subsoil is obtained. The depths and resistivity values provide the hydrogeologist with information on the geological layering and thus the occurrence of groundwater

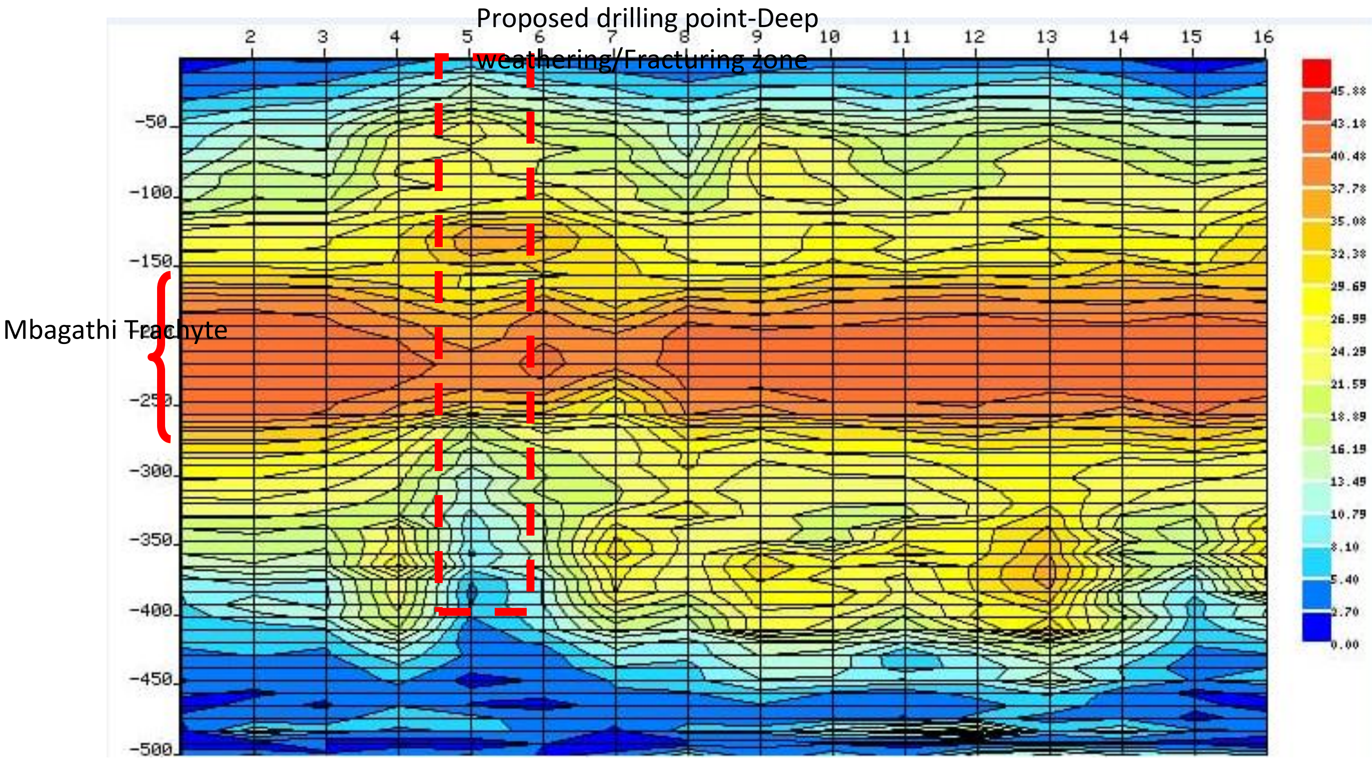
6.3 Fieldwork

Field work comprising of one profile survey was carried out on 5th of April 2022. This was meant to determine the prevailing hydrostratigraphy at the site.

6.3.1 Results

Profile Survey 1, Geoelectrical model and Data set.





Interpretation of the proposed drilling point

Depth (m)	Resistivity (Ohms)	Interpretation and description
0.0 – 1.6	8	Dry compact superficial soils
1.6-10.0	45	Trachytes
10-100	239	Phonolites
100-250	170	Mbagathi Phonolitic trachytes
>250	112	Sediments and tuffs

The results of measurements show that the site is covered at the surface by dry superficial soil to a depth of about 1.6m. These are underlain by weathered trachytes to 10m. A layer of Nairobi Phonolites occurs below the latter, to a depth of about 100m. These are further underlain by Mbagathi trachytes to about 280m. This layer is underlain by the Athi series which host the main aquifer

Drilling is thus recommended at this site to minimum depth of 360m and maximum 400m.

7.0 Groundwater Quality

The quality of groundwater throughout the project area is generally good, except for the fluoride content that might be higher but within the W.H.O. upper limit of1.5 ppm. Water sample from the proposed borehole should be analyzed before consumption. High fluoride intake, especially by growing infants, may cause ***dental or skeletal fluorosis***. Should the fluoride concentration of the proposed borehole exceed 1.5 ppm, it is advisable to provide an alternative source of drinking water for infants (bottled water would be the best option although mixing the borehole water with that of low fluoride content can also be adopted). Over a short time span, the consumption of water with excess fluoride is not harmful to adults.

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

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

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

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

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

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 (mg$CaCO_3$/l)	Desirable: 150-500
Total Alkalinity (mg$CaCO_3$/l)	No Guideline
Physical Parameters	
PH	Desirable: 6.5-8.5
Colour (mgPt/l)	Desirable: 15
Turbidity (NTU)	Desirable:< 5
Permanganate Value (mgO_2/l	No Guideline
Conductivity (S/cm)	250 microS/cm
Total Dissolved Solids (mg/l)	No Guideline
Free Carbon Dioxide (mg/l)	No Guideline

The main factors that determine the degree of mineralization of groundwater are as follows:-

Evaporation and Transpiration

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

Dissolution of Evaporites

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

Dissolution of Host Rock

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

Considering the above factors the quality of water in our project area is expected to vary from one borehole to the other but generally the water has a high fluoride content exceeding the WHO limit.

Water Bearing Zones

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

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

Contact zones
These are formed at the contacts of different lava flows. These are cooling joints and sometimes weathered layers resulting from quiet periods between lava flows. Water is also struck at the contact between the lavas and Basement rocks at great depths.

Fractured zones
These occur within different lava flows above the Basement Rocks. When properly developed it forms excellent aquifers.

Sands and sediments
These where trapped between impermeable rocks can form very good storage zones hence very good aquifers. These are well developed within the Athi Tuffs and Lake Beds and form the main aquifer in this area. They are confined and very high yielding.

8.0 Impacts of the Proposed Project on Aquifer

Over abstraction of groundwater from the proposed borehole may lead to depletion of groundwater levels. The project area has low density of boreholes and there are Two existing boreholes within the stipulated 800 metres from the proposed borehole site. In order to protect the existing close boreholes especially the shallow ones, it is important to monitor them during the test pumping of the proposed borehole.

The proposed borehole should be drilled to a minimum depth of **360 metres and maximum depth of 400m below ground level**. All conditions given by Water Resources Management Authority should be adhered to and they include pumping 60% of the tested yield and pump for a period of 10 hours a day.

9.0 Conclusion and Recommendations

On the basis of all the information gathered in the field, geological, geophysical and hydrogeological evidence,

A borehole is recommended to be drilled at **the selected position to maximum depth of 360m.** This will ensure that the deeper aquifer will be fully penetrated. The Selected position was marked with a peg and shown to the client representative, Mr. Charles Mireri.

The surrounding boreholes have varying yields that range between **3 and 10m^3/hr**. The yield of a borehole drilled at the recommended location is expected to be within the above range, but careful construction and development will lead to maximum borehole productivity, efficiency and long life.

Water quality is expected to be good and suitable for domestic use.

It is thus recommended that:

- ✓ The borehole should be drilled at **the selected position to a minimum depth of 360m and maximum depth of 400m.**
- ✓ The borehole should be installed with mild steel casings and gas-slotted screens
- ✓ The borehole hydraulical 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 Management Authority's Guidelines (found in the Authorization letter to Drill the Borehole), the project will safely meet the client's objectives successfully without any impact to groundwater abstraction trends in the area and surrounding boreholes.

10.0 References

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APPENDIX – Borehole Drilling

Drilling Technique

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

Well Design

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

Casing and Screens

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

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

Gravel Pack

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

Well Construction

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

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

Well Development

Once screen, pack, seals and backfill have been installed, the well should be developed. Development aims at repairing the damage done to the aquifer during the course of drilling by removing clays and other additives from the borehole walls. Secondly, it alters the physical characteristics of the aquifer around the screen and removes fine particles.

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

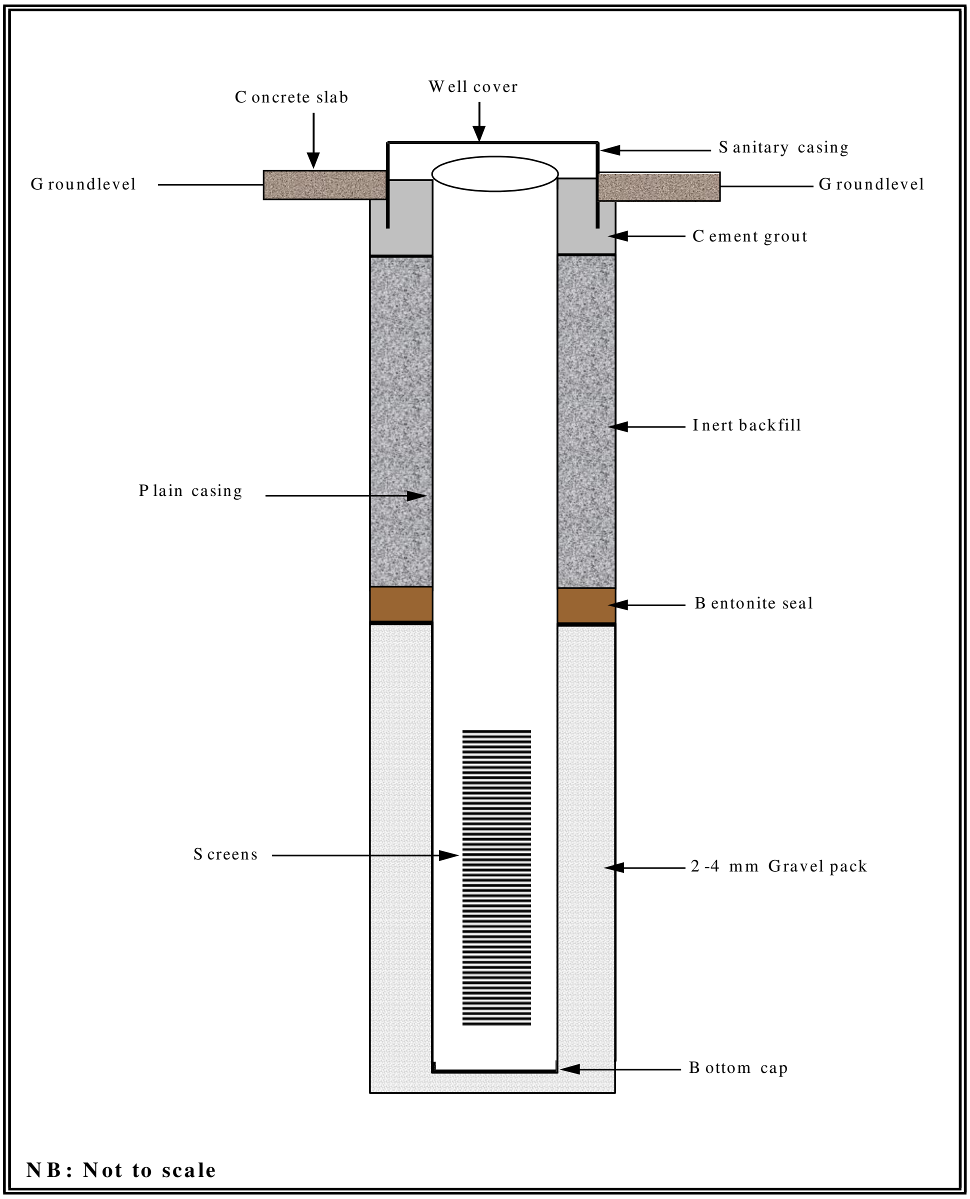
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2 m above the screen, certainly not at the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

Well Testing

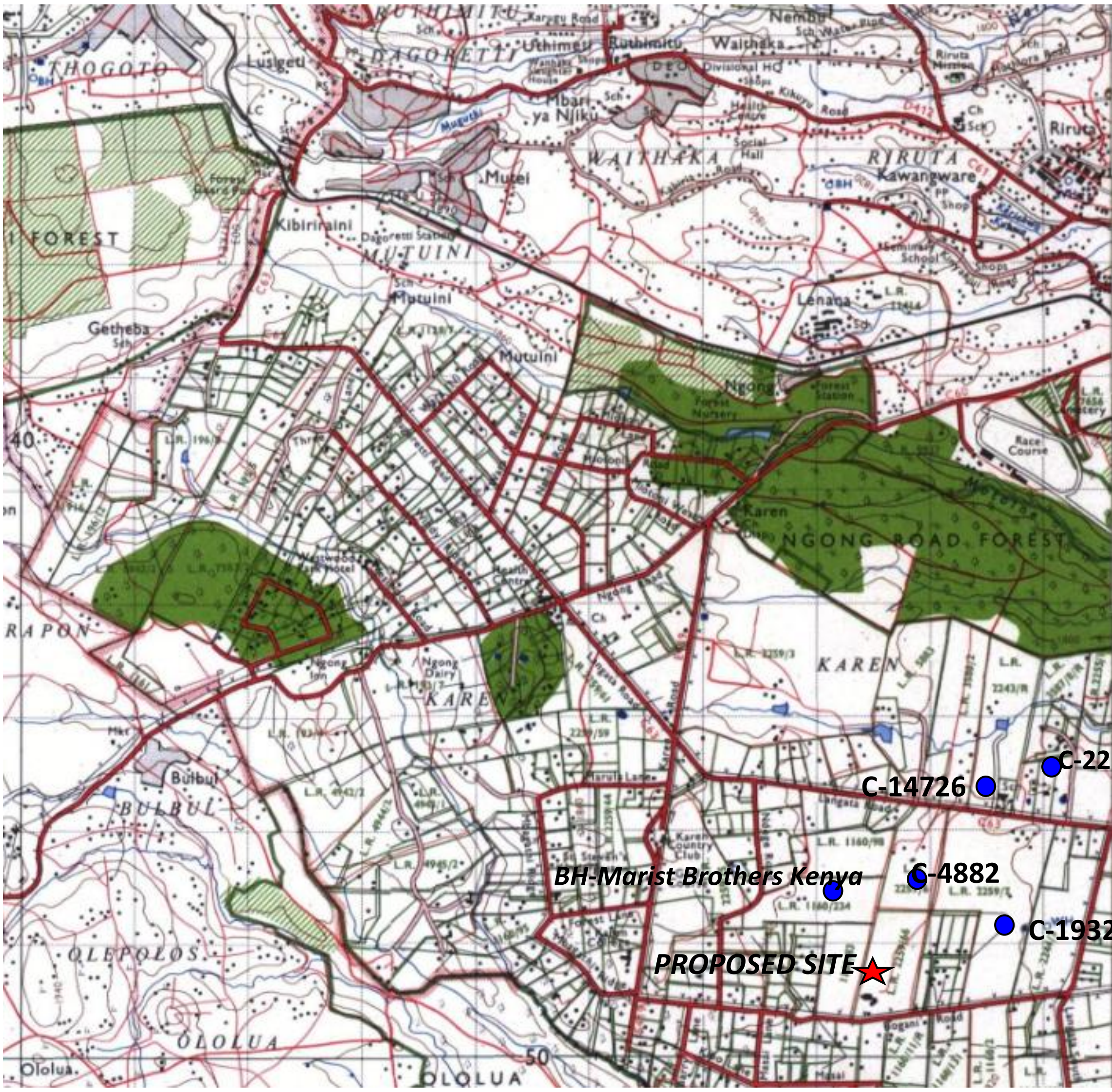
After development and preliminary tests, a long-duration well test should be carried out. Well tests have to be carried out on all newly completed wells, because apart from giving an indication of the quality of drilling, design and development, it also yields information on aquifer parameters, which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

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

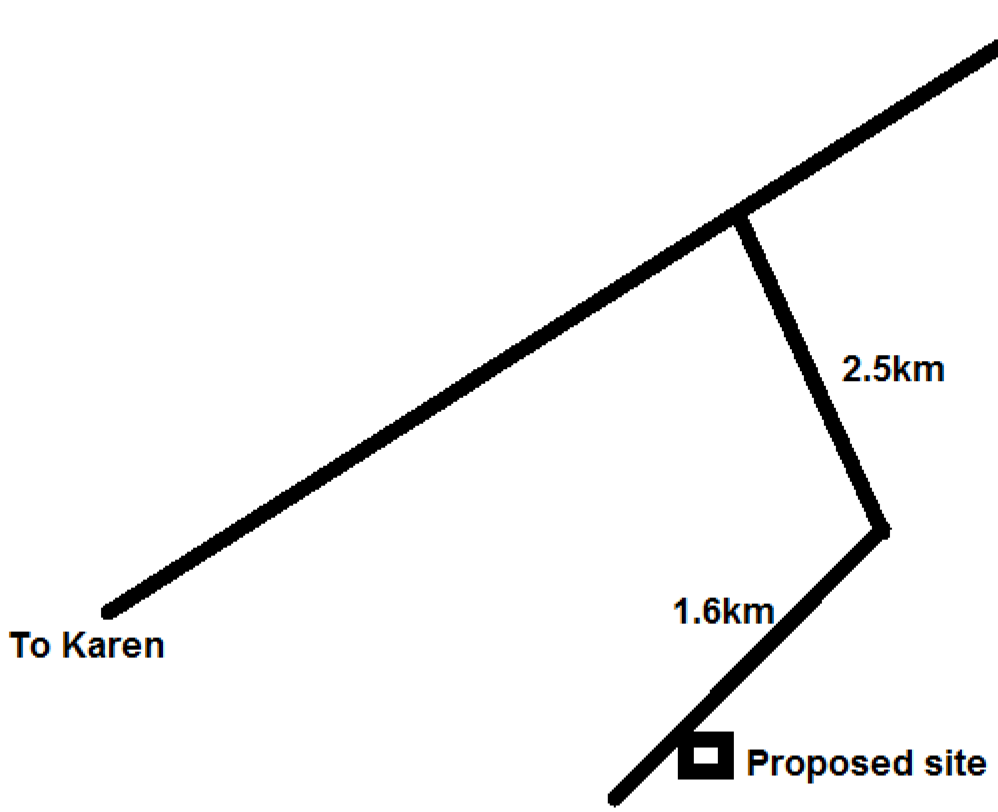
The duration of the test should be 24 hours, followed by a recovery test for a further 24 hours, or alternatively until the initial WRL has been reached (during which the rate of recovery to WRL is recorded). The results of the test will enable a hydrogeologist to calculate the optimum pumping rate,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



Schematic Design for Borehole completion



TOPO MAP EXTRACT



SKETCH TO THE SITE NOT TO SCALE