HYDROGEOLOGICAL/ GEOPHYSICAL SURVEY REPORT

FOR

ONE PRODUCTION BOREHOLE

ON

L. R. NO…….

WITHIN

OLASITI VILLAGE, ENKONG'U-NAROK SUB-LOCATION, AMBOSELI LOCATION, CENTRAL DIVISION, LOITOKITOK SUB-COUNTY, KAJIADO COUNTY.

CLIENT: LEMPERUA PARPAKA LEPOSO

PROJECT: DOMESTIC WATER SUPPLY

NOVEMBER 2024

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EXECUTIVE SUMMARY

This report describes the results of borehole site investigations at Lemperua Parpaka's parcel of land located in Olasiti Village, Enkong'u-Narok Sub-Location, Amboseli Location, Central Division, Loitokitok Sub-County, Kajiado County.

The site predominantly lies on conglomerates, gravels, sands, silts and clays of fluviatile faces of Amboseli Lake Beds.

Geophysical fieldwork was executed on 7th November 2024. Electrical resistivity method was employed for the geophysical investigations. The method used is Frequency Domain survey. This is a law for finding the abnormality changes in the subsurface. It measures the source of natural electric field, the subsurface rock/groundwater's natural electric fields and variations at different frequency's and different depths.

From records of neighbouring boreholes, the expected yield is envisaged to range between 2.52 – 11.28m^3/hour and a mean value of 8.22m^3/hour.

Having considered all the possible options towards improving the water supply to meet the Client's demand, it is (in the opinion of the Consultant) advisable to sink a borehole at the proposed site to **a maximum depth of 100m bgl at point 8**. Should sufficient yield be obtained before attainment of this depth or encountering fresh basement rock, drilling may be stopped after adequate consultation with the supervising hydrogeologist, the client and the drilling contractor.

Regular monitoring should be instituted and maintained in the boreholes in order to keep track of groundwater levels. A monitoring tube should be installed in the borehole to be able to monitor the water level in the well.

Recommendations are given for borehole construction and completion methods. The importance of correct and comprehensive techniques in this particular aspect cannot be over-emphasized.

A drilling permit must be applied from the Water Resources Management Authority Sub-Regional office in Loitokitok under the Ministry of Water and Irrigation.

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ABBREVIATIONS (All S.I Units unless indicated otherwise)

agl	above ground level
amsl	above mean sea level
bgl	below ground level
E	East
EC	electrical conductivity (mS/cm)
h	head
hr	hour
K	hydraulic conductivity (m/day)
I	litre
m	metre
N	North
PWL	pumped water level
Q	discharge
sQ/s	specific capacity (discharge – drawdown ratio; in m. cu/hr/m)
Cu	cubic
Sq	square
S	drawdown (m)
S	South
Sec	second
SWL	static water level
T	transmissivity (m.sq/day)
VES	Vertical Electrical Sounding
W	West
WSL	water struck level
mS/cm	micro-Siemens per centimetre: Unit for electrical conductivity
°C	degrees Celsius: Unit for temperature
Ωm	Ohm-m:
ρ	apparent resistivity

GLOSSARY OF TERMS

Alluvium: General term for detrital material deposited by flowing water.

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

Colluvium: General term for detrital material deposited by hill slope gravitational process, with or without water as an agent. It's usually of mixed textures.

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 than pressure than atmospheric, and will therefore rise above the struck water level.

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 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 lowest > head.

Heterogeneous: Not uniform in structure or composition.

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

Hydrogeological: Those factors that deal with sub-surface 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.

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

Peneplain: A level surface, which has lost nearly all its relief by passing through a complete cycle of erosion (also used in a wider sense to describe a flat erosional surface in general)

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.

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 of sub-surface sources (e.g. rivers, rainfall and lateral groundwater flow) to the aquifer zones.

Saprolite: Weathered residual rock in place.

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. sq./day)

Unconfined: Referring to an aquifer situation whereby the water table is exposed to the atmosphere through openings in the overlying materials (as opposed to> confined conditions)

Yield: Volume of water discharged from a well.

1 INTRODUCTION

1.1 Background

Hydrogeological investigations were carried out on 7th November 2024 at Lemperua Parpaka Leposo's parcel of land located in Olasiti Village, Enkong'u-Narok Sub-Location, Amboseli Location, Central Division, Loitokitok Sub-County, Kajiado County. The borehole will be used to supply reliable water for use by the client.

Roof catchment, seasonal streams and waterholes are the main sources of water in the area. The aforementioned sources are unreliable hence the client requires detailed information on prospects of drilling a production borehole.

1.2 Objectives of this Study

The objective of the study was to assess the availability of potable groundwater and to advice on the viability of drilling a productive borehole to be equipped with a pump to supply water for use by the school. The investigations involved include:

- A desk study
- Reconnaissance survey of the project area
- Hydrogeological study and geophysical field investigations in which the available relevant geological and hydrogeological data was collected, analyzed, collated and evaluated within the context of the client's requirement. The data sources consulted were mainly in four categories:
  a) Published Master Plans.
  b) Geological and Hydrogeological Reports and Maps.
  c) Ministry of Water and Irrigation Borehole Completion records.
  d) Technical reports of the area by various organizations.
- Assessment of existing water supply with respect to demand, current land use around the project area, and the general compound set up.

1.3 Reporting Requirements

The format of writing the Hydrogeological Investigations Report, as described out in the Fourth Schedule of the Water Resources Management Rules, 2021. Such a report must consider the following (verbatim): —

1. Name and details of applicant
2. Location and description of proposed Activity
3. Details of climate
4. Details of geology and hydrogeology
5. Details of neighbouring boreholes, and neighbouring proposed valid authorizations, including location, distance from proposed borehole or boreholes, number and construction details, age, current status and use, current abstraction and use.
6. Description and details (including raw and processed data) of prospecting methods adopted, e.g. remote sensing, geophysics, geological and or hydrogeological cross sections. Hydrogeological characteristics and analysis, to include but not necessarily be limited to, the following:
    a. Aquifer transmissivity
    b. Borehole specific capacities
    c. Storage coefficient and or specific yield
    d. Hydraulic conductivity
    e. Groundwater flux
    f. Estimated mean annual recharge, and sensitivity to external factors
7. Assessment of water quality and potential infringement of National standards
8. Assessment of availability of groundwater
9. Analysis of the reserve
10. Impact of proposed activity on aquifer, water quality, other abstractors, including likelihood of coalescing cones of depression and implications for other groundwater users in any potentially impacted areas
11. Recommendations for borehole development, to include but not limited to, the following:
    a. Locations of recommended borehole(s) expressed as a coordinate(s) and indicated on a sketch map
    b. Recommendations regarding borehole or well density and minimum spacing in the project area
    c. Recommended depth and maximum diameter
    d. Recommended construction characteristics, e.g. wire-wound screen, grouting depth Anticipated yield
12. Any other relevant information (e.g. need to monitor neighbouring boreholes during tests).

This report is written so as to cover each of the above, in so far as data limitations allow. The report also includes maps, diagrams, tables and appendices as appropriate.

2 BACKGROUND INFORMATION

2.1 Location

The surveyed site is located approximately 2.09km SE of Amboseli Serena Safari Lodge, 2.92km ESE of Enkong'u Narok Dispensary, 2.99km ESE of Enkong'u Narok Primary School, 6.08km SSW of Ol Tukai Lodge Amboseli and 6.34km SSW of Amboseli Sopa Lodge. It lies within the 1:50,000 Survey of Kenya topographic sheets for Amboseli (No. 181/1). Its defining coordinates are S02°43'19.8" E37°16'26.3" or 37M 308122 UTM 9698979

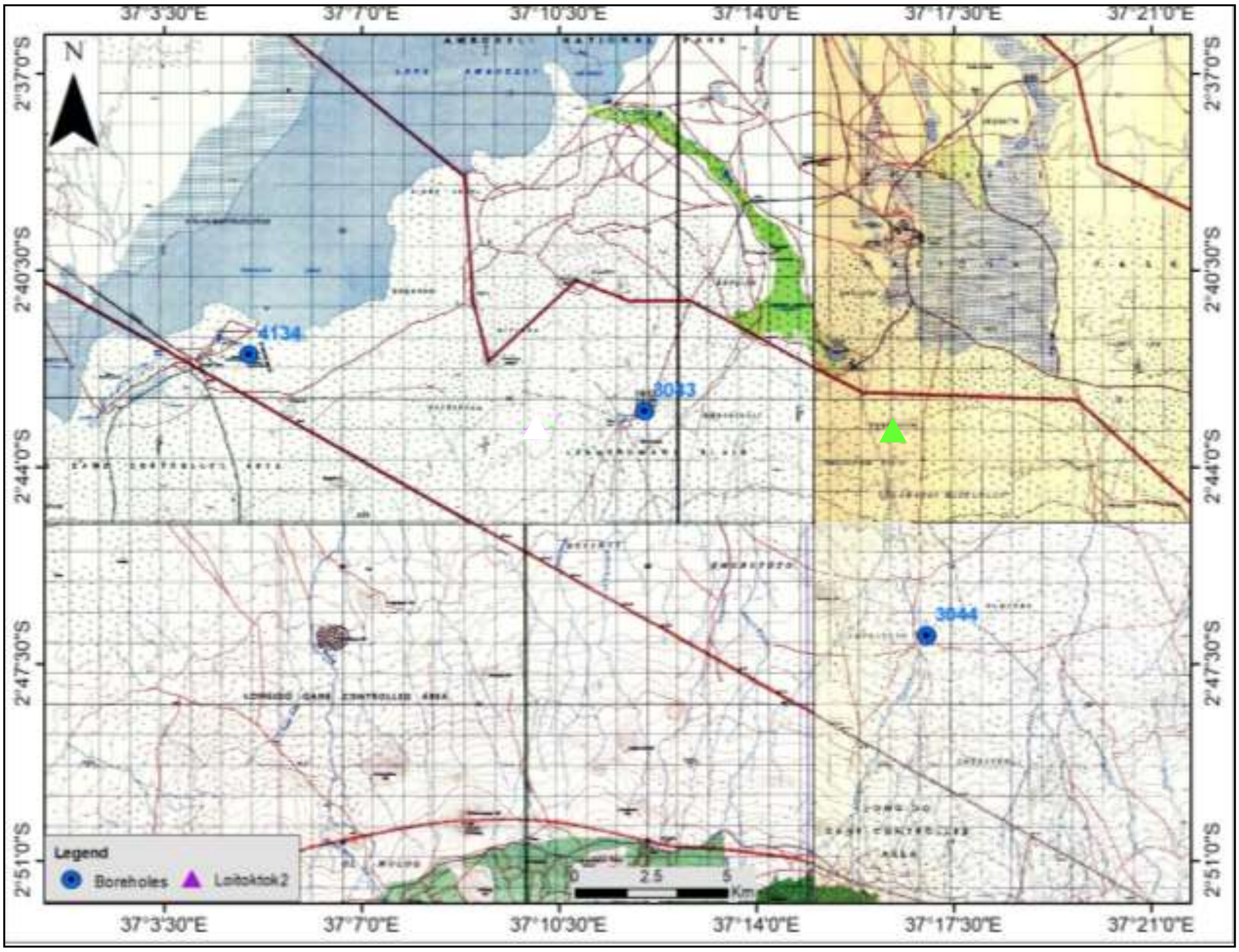

Figure 2.1: Location of the investigated site on a Topographical Map of the area

Figure 2.2: location of the investigated site on a Google Map of the area

2.2 Physiography

The project area lies at an altitude of about 1179m amsl and forms part of the volcanic plains and plateau which are on the eastern shoulders of the Rift Valley. The drainage system is dominated by perennial streams and very few springs emanating from the high altitudes.

2.3 Climate

Loitokitok's climate is classified as warm and temperate. In winter, there is much less rainfall than in summer. The average temperature in Loitokitok is 17.8°C. In a year, the average rainfall is 894 mm. The least amount of rainfall occurs in July. The average in this month is 5mm. Most precipitation falls in November, with an average of 199 mm. The temperatures are highest on average in February, at around 19.6°C. In July, the average temperature is 15.2°C. It is the lowest average temperature of the whole year. The variation in the precipitation between the driest and wettest months is 194 mm. The average temperatures vary during the year by 4.4°C.

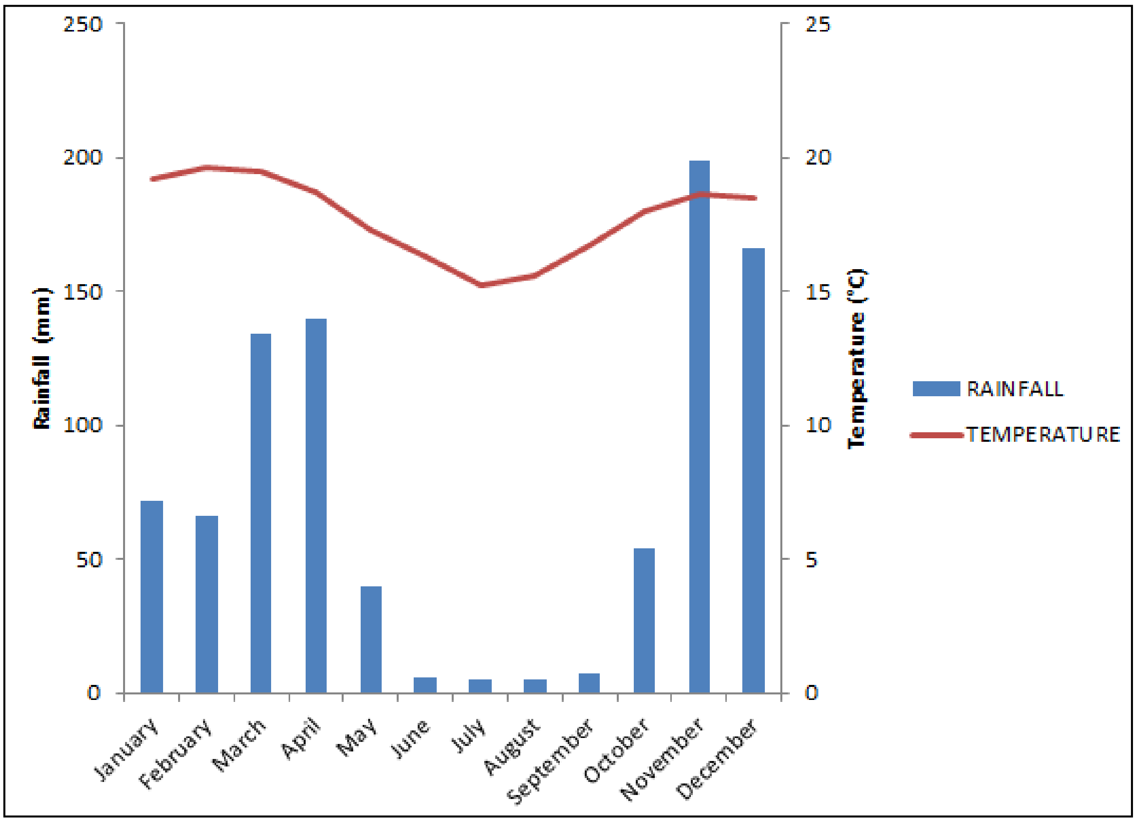

Figure 2.3: Climate graph of Loitokitok

2.4 Water Demand and existing water supplies.

Currently the client relies on waterholes and roof catchment which are unreliable hence the need for an alternative source: borehole. Water requirement is estimated at 20m³/day.

3 GEOLOGY

3.1 Regional Geology

The rocks of the Amboseli area fall readily into four groups

3.1.1 Precambrian metamorphic rocks.

Precambrian rocks, comprising a thick series of metamorphosed sediments, are sporadically exposed- across the northern half of the area, and granitoid gneisses of the same age outcrop near the Kenya-Tanzania border west of Sinya. Elsewhere the metamorphic rocks are overlain either by lava flows from Kilimanjaro or by sediments occupying the Amboseli basin.

The original Precambrian sedimentary succession included arenaceous, argillaceous and calcareous deposits that are now represented by a variety of gneisses, granulites and schists together with broad bands of marble. The latter form the only hill features in the northern half-of the; area, with less resistant rock types underlying a dissected plain. In' the "Ngorigaishi Hills crystalline limestones, are marked by numerous calc-silicate lenses and frequently by small flakes of brown or reddish brown mica. At Ol Doinyo Narigaa and Lerne Boti the marble locally bears a fine sprinkling of graphite. Metamorphosed . semi-calcareous. sediments are represented by diopside-garnet granulites and gneisses, which at one locality are 'hypersthene-bearing. Garnetiferous quartzo-felspathic -rocks and hornblende-garnet gneisses are believed to be metamorphosed shales, whilst biotite gneisses, biotite-garnet gneisses: and hornblende-biotite migmatites represent semi-pelitiç sediments, Quartzo-felspathic gneisses and granulites originated by the metamorphism of arenaceous deposits. Evidence of granitization is widespread, culminating in the local development of hornblende-biotite granitoid gneisses.

3.1.2 Tertiary to Recent volcanic rocks.

The geology of the Amboseli area is dominated by the influence of nearby Kilimanjaro, a spectacular central volcano which was probably active from late Pliocene to Recent times.

The earliest volcanic rocks mapped are olivine basalts with minor pyroclastic intercalations. The basaltic lavas are conveniently subdivided into a lower and an upper series-by flows of nephelinites.-melanephelinites, ankaratrites, tephrites and phonolites. Some basalts of the lower group and all those of the upper series are characterized by the development of large felspar phenocrysts. The basalts are overlain by a second group of nepheline-bearing lavas including nephelinites, melanephelinites and ankaratrites. These lavas are followed in turn by rhomb porphyries, fine olivine-bearing trachytes and phonolities, and finally by a single flow of nepheline-rich phonolite. Parasitic vents were active at various times during the history of the volcano.

3.1.3 Pleistocene lacustrine and fluviatile deposits.

Much of the flat-lying ground in the central parts of 'the Amboseli area is underlain by sediments which may attain a maximum thickness of several hundred feet. A great deal of the; material accumulated in a vast lake formed by damming of the drainage by volcanic eruptions during the Upper Pleistocene'. These deposits are known as the Amboseli Lake Beds and they include impure limestones, marls and sepiolitic clays; the latter were probably derived from showers of volcanic ash falling on the lake from the still-active Kilimanjaro, or from material of volcanic origin washed into the lake from the slopes of the mountain. Facies changes occur towards the' western and north-western parts of the basin, where sandy and pebbly deposits show that sediments were being supplied continuously to the lake basin from the Precambrian foundation. Towards the foothills of Kilimanjaro the lacustrine deposits grade into conglomerates containing only pebbles of volcanic rocks, indicating derivation by torrential outwash from the mountain at a time when the climate was wetter than at the present day.

The Amboseli Lake Beds are subdivided stratigraphically as follows:

3. Olfukai Beds (silts and clays, locally diatomaceous).
2. Amboseli Clays (clays, calcareous clays and silty clays).
1. Sinya Beds (marls, clays and silty clays).

3.1.4 Quaternary superficial deposits.

Much of the Amboseli area is mantled with Pleistocene and Recent superficial deposits. Soils: include reddish-brown sandy varieties derived principally from the metamorphic rocks, black cotton soils, alluvial soils, and dusty soils overlying the volcanic rocks. Windblown clayey, silts and sands in the western parts of the area locally attain a thickness of 30feet.

3.2 Geology of the Survey Area

The investigated site lies on conglomerates, gravels, sands, silts and clays.

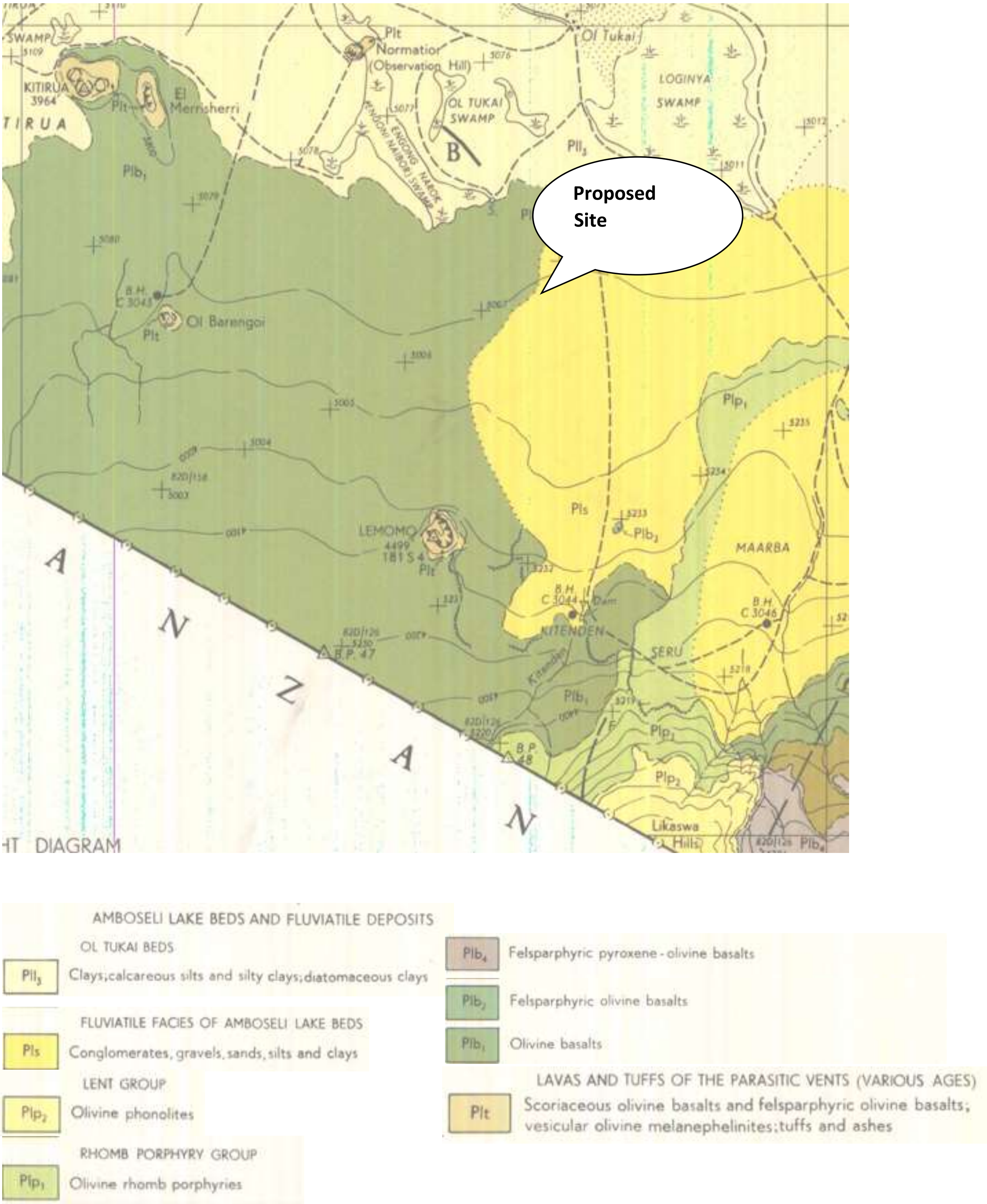

Figure 3.1: Geology of the investigated site and the surroundings

4 HYDROGEOLOGY AND HYDROLOGY

4.1 Hydrogeology

The hydrogeology of an area is normally intimately dependent upon the nature of the parent rock, structural features, weathering processes, recharge mechanism and the form and frequency of precipitation. It is evident that the borehole yields in the general area are very variable, depending on the coarseness, sorting, compaction and cementation of the aquifer material. The aquifers are basically confined as evidenced by the rise of the water level above the water struck levels.

4.2 Hydrogeology of the Investigated Area.

Based on the geology of the area, the hydrogeologic zone is the aquifers in the fluviatile faces of Amboseli Lake Beds. Due to the scanty nature of the information available however, it is difficult to precisely characterize this aquifer based on the geology. However, after analysis of borehole completion records, it can be concluded that groundwater in the area occurs:

a. Within the weathered top material on top of the hard rocks
b. Within major cracks (fractures and joints) in the hard rocks

Individual aquifers appear to be highly localized resulting in rapidly changing aquifer characteristics over considerable short distances.

4.3 Boreholes in the Immediate Vicinity of the Area

A number of boreholes have been drilled in the project area. Available records were studied for 3 boreholes within a radius of about 21.3km from the present site. Results of the data inventory are presented in Table 4.1 while the approximate location of the boreholes has been indicated in Figure 2.1.

Table 4.1: Boreholes in the Vicinity of the Site

A	B	C	D	E	F	G
BH No.	**Owner**	**Location (X km)**	**Depth (m bgl)**	**WSL (m bgl)**	**WRL (m bgl)**	**Q (m3/hr)**
3043	D.W.D	8.3	46	27	27	11.28
3044	D.W.D	6.8	100	75	62	10.86
4134	Olkejuado C Council	21.3	105	54	19	2.52
RANGE		**6.8 – 21.3**	**46 - 105**	**27 - 75**	**19 – 62**	**2.52 – 11.28**

Description of columns

A. Ministry of Water Resources Identification Number (lowest numbers represent oldest holes)
B. Owner
C. Distance in km from selected BH site

D. Total drilled depth in meters below ground level (m bgl)
E. Water Struck Level 1, 2 and 3, depth at which the aquifer was encountered, in meters below ground level (m bgl)
F. Water Rest Level, depth of piezometric surface, or water table, in meters below ground level (m bgl)
G. Tested yield in m^3/hr.

4.3.1 Borehole Data Analysis

From the data of the analyzed boreholes above, the boreholes exploit aquifers between 27 – 75m and beyond. When correlated with the geologic logs of the boreholes, the aquifers are located within the fluviatile faces of Amboseli Lake Beds.

The surrounding boreholes have been tested at yields ranging between 2.52 – 11.28m^3/hour and a mean value of 8.22m^3/hour. The proposed borehole is expected to give yields within the above range.

4.4 Aquifer Properties

Very little information is available concerning the aquifer characteristics in this area. It is not possible for example to determine if proper pump test were carried out on the existing borehole since some data of the analysed borehole are missing.

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. *To calculate the area Aquifer Properties, testing pumping data of borehole **C4134** was adopted.*

In summary, the borehole has a total drilled depth of 100m, yield of 10.86m^3/hr., Water Struck levels of 75m and Water Rest level of 62m. The borehole has fairly penetrated the productive upper aquifers and thus will be fair enough to deduce the aquifer properties of the project Area. It has a drawdown of 13.

4.4.1 Aquifer Transmissivity

Aquifer Transmissivity (T) is estimated as follows:

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

$T = 1.22 \times 10.86 \times 24/13 =$ **24.46m^2/day**

4.4.2 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 10m. Thus,

K = 24.46/10

K = **2.446m/day**

4.4.3 Specific Capacity

The aquifer Specific Capacity (S) = Q/∆s.

Where: **Q = Discharge (m^3/day) = 260.64m^3/day**
D = Drawdown (m) = 13m.
S= 20.05m^2/day

Table 4.2: Specific Capacity of other Surrounding boreholes

Borehole	Yield (m3/day)	Drawdown (m)	Specific Capacity (m^2/day)
4134	60.48	35	1.728

4.4.4 Groundwater Flux

The Groundwater Flux (F) is estimated based on borehole ***C-3044*** which more or less shares the same aquifers.

F = K.i.h.w Where K- Hydraulic Conductivity = 2.446m/day
i – Slope = 22 /1800
h- Aquifer Thickness =10m
w- Arbitrary distance, 6800m

Thus;
F = 2.446m (22/1800). 10. 6800

F = 2033**m^3/day**

4.5 Groundwater 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.

In the present study area, the principal recharge zones are the highlands within the eastern flanks of the rift valley. These areas probably receive higher rainfall than the investigated site. As a result, the aquifers identified are indirectly recharged by underground drainage of water falling some distance from their present locations.

4.5.1 Mean Annual Recharge

Rainfall within the study area is average (894 mm) and regional recharge is of great essence in this area. Much of regional recharge occurs within the western flanks of the rift valley followed by base flow within the thick volcanic sheets and faults which characterize the region.

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

894mm x 5%

Mean Annual Recharge = 44.7mm

However, this recharge amount is probably estimation due to the possibility of influent regional recharge through Lake Amboseli.

4.6 Groundwater Movement

Groundwater will always flow towards the area with the lowest piezometric head. For this area, this base level is ultimately found west of the investigated site.

With respect to the potential for faults to create aquifers and to recharge the aquifers, it is very important to establish whether the faults occurring in the rocks are groundwater barriers or preferential flow paths. The pervious faults have a larger secondary porosity. This macro porosity accounts for a greater mobility of the groundwater. The water stays in contact with the rock for a relatively short period; hence, mineralization stays low. Mobility in the (primary) micropores, on the contrary, is low. The groundwater in these pores will be highly mineralized by dissolved salts.

4.7 Impacts of the Proposed Borehole to Abstraction Trends of Existing Boreholes

From the records **none** of the 3 analyzed boreholes is located within 800m radius, however only deeper aquifers should be abstracted to maximize the yields.

4.8 Structural Influence

The potential for faults to create aquifers and to recharge the aquifers, remain a speculation and it is very important to establish whether the faults occurring in the rocks are groundwater barriers or preferential flow paths The water stays in contact with the rock for a relatively short period; hence, mineralization stays low hence groundwater in these pores will be likely mineralized by dissolved salts

4.9 Water Quality Consideration

When deposition occurs in a land-locked basin under conditions of semi-aridity, evaporation of the connate water occurs with the consequent precipitation of mineral salts, mainly carbonates, chlorides, and sulphates. These are disseminated throughout the succession with varying degrees

of concentration and, being partly soluble, are readily re-dissolved by meteoric groundwater; hence the water derived from these beds is liable to be saline.
Groundwater may be classified based on salinity as shown in Table 4.3 below.

Table 4.3: Groundwater Classification Based on Salinity

Category	**TDS (ppm)**	**EC (μS/cm)**
Fresh water	0-1,500	0-2,000
Brackish water	1,500-10,000	2,000-15,000
Saline water	10,000-100,000	15,000-150,000
Brine	>100,000	> 150,000

TDS : Total Dissolved Solids (in parts per million = mg per liter)

EC : Electrical Conductivity in micro Siemens per cm

Table 4.4: Salinity Limits for Groundwater Use

EC (μS/cm)	**TDS (ppm)**	**Use/Limitation**
< 2,000	< 1,500	Potable water
> 2,000	> 1,500	Unsuitable for domestic purposes
2,000-3,000	1,500-2,000	Generally too salty to drink but still fit for livestock
> 3,000	> 2,000	Generally unfit for dairy cattle and young cattle
> 7,000	> 4,500	Unfit for grazing cattle and sheep

5 GEOPHYSICAL INVESTIGATION METHODS

A great variety of geophysical methods are available to assist in the assessment of geological subsurface conditions e.g. Electrical resistivity, Magnetic, seismic, gravitational, electromagnetic etc. In the present survey, an instrument called as (Natural Electric Field Frequency Selection System) geophysical instrument, shortly known as frequency system was used.

Frequency Domain Method

The basic principle of the instrument is measuring the existing natural electric field of subsurface water / minerals /geological structures / ore bodies.

The natural electric field geophysical instrument is one of the geophysical instruments, working with the source of natural electric field, measuring the subsurface rock/groundwater's natural electric fields and variations at different frequency's and different depths, it is a law for finding the abnormality changes in the subsurface.

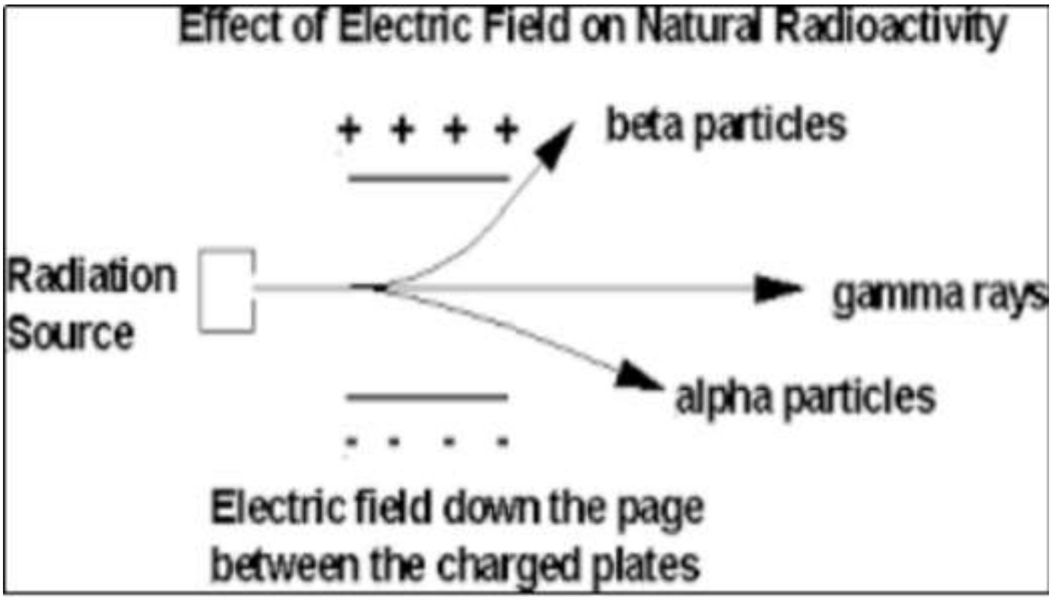

Figure 5.1: Schematic Diagram of Frequency Domain Method

Basic Principles

The instrument works on the principle of electrical difference of natural earth magnetic field (frequency 0 -30 kHz), the several different frequencies of electromagnetic field changes is the law to study the underground field / material changes to solve the Geological problems. It is a one of the method for an alternating current exploration method.

The method integrates natural electric, Magnetic field, high density resistivity and induced polarization for finding subsurface water resources and geological ore / mass bodies and its abnormalities. These variations useful to study and interpretations of characteristic of the materials to solving the geological, engineering, environmental and disaster problems.

The natural electric field geophysical instrument is one of the geophysical instrument, working with the source of natural electric field, measuring the subsurface rock /groundwater, natural electric fields and variations at different frequency's and different depths, it is a law for finding the abnormality changes in the subsurface

Why We Choose The Instrument?

- It is 3 methods integrated and developed, consisting of more & more data filters for analysing data and filtering errors etc.
- Natural Electrical field impacts the earths/material electrical field, the instrument recorded these variations of frequency's based and its at various depths.
- It is the easy operation, high-quality touch screen and highly standard
- The instrument profile map given results are very accurate: depth, quantity, quality, the shape of subsurface water either the source is continuing or perched or dry fractures and in the geological structure's / material's information getting exact changes depth / boundary / contact zones
- The instrument is small and easy to carry

6 FIELDWORK AND RESULTS

Field work comprising of one line of frequency domain investigation was carried out on 7th November 2024. The aim of the investigation was to determine the prevailing hydrostratigraphy at the site.

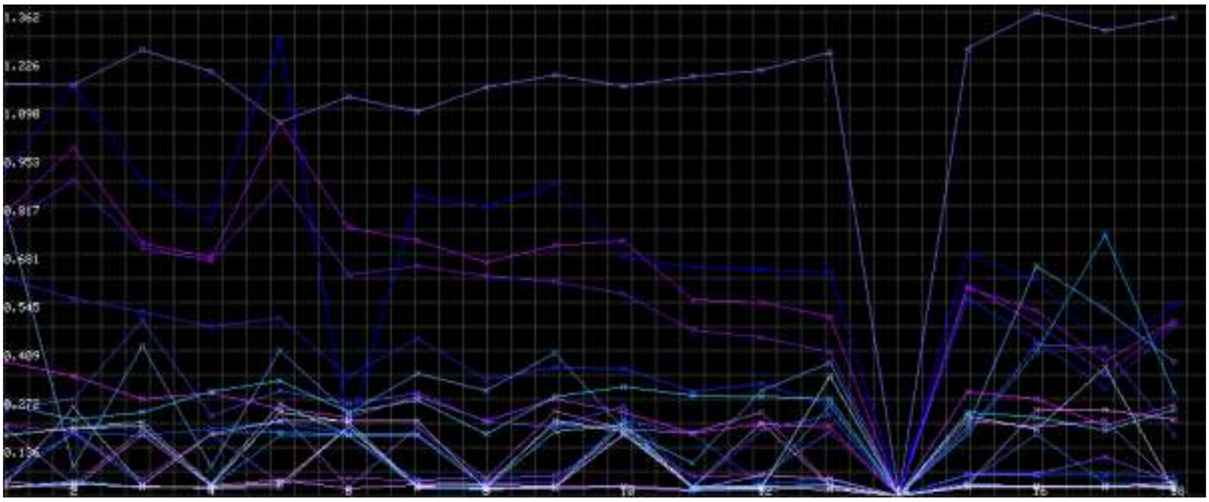

Figure 6.1: Horizontal Electrical Profile Line 1

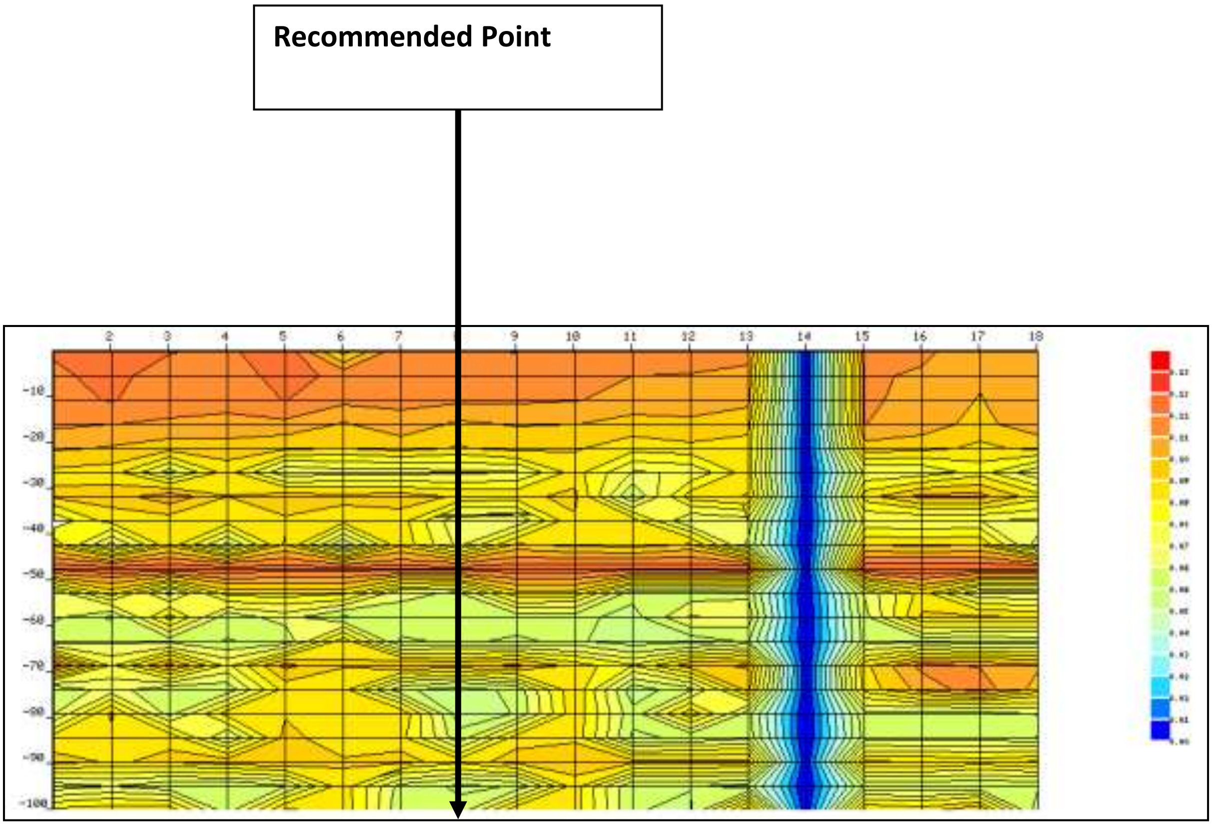

Figure 6.2: Horizontal Electrical Profile Map 1

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The study concludes that on the basis of geological and hydrogeological evidence, the prospects for sufficient groundwater are fair. The most productive aquifer has been identified to be the fluviatile faces of Amboseli Lake Beds which extends to greater depths.

The water quality is expected to be within the recommended WHO limits. Groundwater quality in the area is good for human consumption.

7.2 Recommendations

- Drilling to **a maximum depth of 100m bgl at point 8.** Although shallow aquifers may be encountered at shallow depths, drilling should continue to the final depth of with an 8” diameter hammer.
- Good quality casings and screens should be installed to the final depth in order to penetrate sufficiently the deep aquifers. The borehole should be installed with 6” diameter steel casings and screens with slots of 1.5 mm and high % open surface area.
- Geological rock samples should be collected at 2 meter intervals. Struck and Rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be recorded.
- A piezometer should be installed in the borehole to enable monitoring of the water level.
- If fluoride concentrations are above 1.5 ppm, it is not recommended to use the borehole as a permanent source for drinking water. Children especially are susceptible to fluorosis if they depend on drinking water with high fluoride concentrations (see Appendix 2).
- A master meter should be installed to record the amount of water abstracted from the borehole.
- A water sample should be collected at the end of the test pumping to be taken to a competent lab for a complete water quality test

Additional recommendations on the construction and completion of a borehole are given in Appendix 1.

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APPENDIX 1: DRILLING AND CONSTRUCTION OF A 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. 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.

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 gravel pack is recommended within the aquifer zone, because the aquifer could contain sands or silts which are finer than the screen slot size. An 8" 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 wellhead 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.

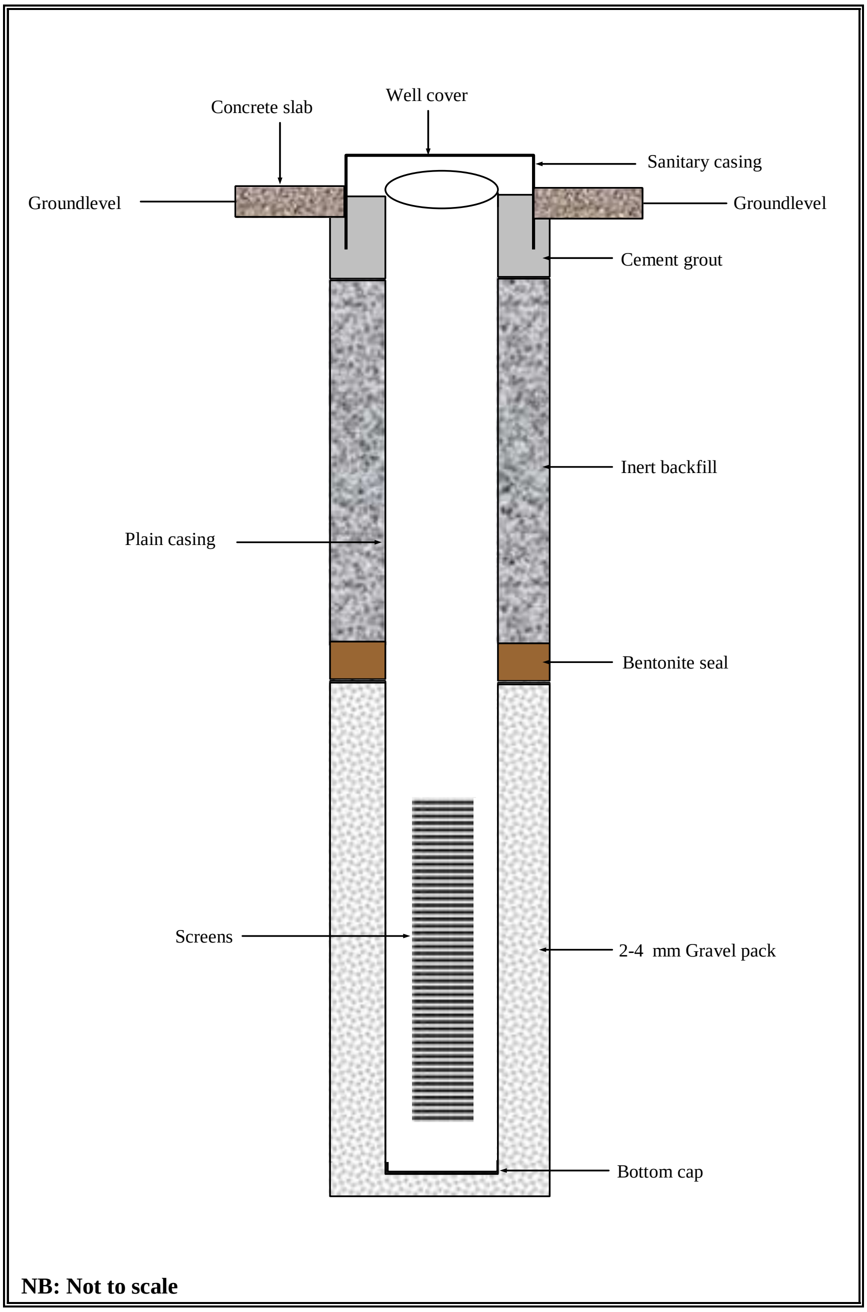
Well development is an expensive element in the completion of a well, but is usually justified in longer well-life, greater efficiencies, lower operational and maintenance costs and a more constant yield. Within this frame the pump should be installed at least 2 m above the screen, certainly not at the 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 drawdown as a function of time. Once a dynamic water level (DWL) is reached, the rate of inflow to the well equals the rate of pumping. Usually the rate of pumping is increased stepwise during the test each time equilibrium has been reached (Step 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

APPENDIX 2: FLUORIDE IN GROUNDWATER

Fluoride in Groundwater

(Source: Endemic Fluorosis in Developing Countries, 1991, J.E. Frenken, editor, TNO Institute for Preventive Health Care, The Netherlands)

Introduction

Fluoride is an essential constituent of the human body where it concentrates mainly in bones and teeth. A deficiency as well as an excess of fluorine may have negative effects on someone's health. Excessive intake of fluorine may lead to Fluorosis, a disease associated with dental and skeletal deterioration.

Especially for drinking water purposes these high concentrations form a limitation. In this appendix the aspects of fluoride in groundwater e.g., the source of fluoride, the health hazard of high fluoride concentrations and fluoride removal methods, will be discussed briefly.

Sources of Fluoride

Fluoride (F^-) is an ion of the chemical element fluorine (F). The elemental form does not occur in nature due to the electro-negativity and high chemical reactivity.
The geochemical behavior of fluoride is similar to that of the hydroxyl ion (OH^{-}).

Fluorine bearing minerals are found in igneous, sedimentary and metamorphic rock. Especially in contact metamorphic rocks high concentrations are found. The main fluorine bearing minerals are listed in the Table below.

Table 7: Fluorine bearing minerals

Group	Examples
Silicates	Amphiboles, Micas
Halides	Fluorite, Villiaumite
Phosphates	Apatite
Others	Aragonite

The most important mineral containing fluorine is fluorite (CaF_2). Furthermore volcanic gases may contain fluorine; examples are HF, SiF_4 and H_2SiF_6.

Other sources of fluorine are related to pollution caused by agricultural and industrial activity (use of phosphatic fertilizers, processing of phosphatic raw materials).

Furthermore fluoride concentrations in water are determined by weathering processes (CO_2 pressure, hydrothermal activity), evaporation and calcium concentration. At low calcium concentrations (in environments with high alkalinity and when calcite limits calcium concentrations) fluoride cannot be equilibrated by fluorite solubility and can reach very high concentrations.

In volcanic areas without hydrothermal activity the fluoride concentrations are mainly determined by the weathering of amphiboles or volcanic glass. Both are important constituents of phonolites. Volcanic tuffs on an average have a higher content of soluble volcanic glass than phonolites.

Health hazard of fluoride

The prevalence and severity of dental and skeletal fluorosis is depending on many factors but the most important risk indicator will be fluoridated drinking water. Results of several investigations show that especially children are susceptible to fluorosis if they depend on (drinking) water with high fluoride concentrations. The results indicate that mild dental fluorosis can occur when concentrations of 0.4 ppm are considered. More serious problems occur at fluoride concentrations of 2.1 ppm (100 % prevalence of dental fluorosis in age group 10 - 15 years) and 3.6 ppm (skeletal changes in 11 - 15 years old). Above 10 ppm skeletal deformities may occur in children.

The World Health Organization uses the guideline limit of 1.5-ppm fluoride. This limit is based on the assumption that people consume only 2 liters of water per day. This assumption seems to be rather low since people, especially in countries with hot climates, consume more than 2 liters per day. The recommended WHO concentration limits together with the possible effects are listed in the Table below.

Table 8: Fluoride contents in drinking water and possible effects (WHO)

Concentration Fluoride ppm	Possible effects
0.5 - 1.5	Fluoride in water has no adverse effects, incidence of caries decreases
> 1.5	Mottling of teeth may occur to an objectionable degree e.g. dental fluorosis
3.0 - 6.0	Association with skeletal fluorosis incidence of caries decreases
> 10.0	crippling skeletal fluorosis

Results of investigations in tropical areas suggest a maximum recommended level of 0.6 ppm more appropriate for tropical regions. Above this value mottling of teeth may occur.

Some countries however use higher permissible or maximum recommended levels, simply because of the absence of water with lower concentrations. The maximum permissible level in Tanzania is 8 ppm, while the Kenyan maximum permissible level is set at 1.5 ppm.

Removal of fluoride from groundwater

Especially during the last decade several methods have been developed to remove or reduce the fluoride concentration in drinking water. However most of the methods are rather complicated and expensive and are still in the laboratory or experimental stage. The methods are mainly based on:

- -- Precipitation (use of lime, alum, sulphate, gypsum, etc.)
- -- Adsorption / ion exchange (use of bones, charcoal, clays, etc.)
- -- Osmosis
- -- Electrochemically stimulated coagulation
- -- Electro dialysis

Although the methods are still in the laboratory phase, the application potential for the bone char, gypsum / fluorite and clay method are rather good. These methods are simple and the raw materials are often available at the site. The methods can be applied at household and community level.

The *gypsum / fluorite* method can reduce the fluoride concentrations to 4 ppm only. More advanced steps are necessary to reduce the concentrations below 1.5 ppm. The basic principle of the method is the dissolution of gypsum in drinking water with high fluoride concentrations. Fluoride concentrations will be reduced due to the precipitation of fluorite according the following reaction:

$CaSO_42H_2O + 2F^- \text{--->} CaF2 + SO42^- + 2H2O$

Fluorite will precipitate as soon as the water is saturated with fluorite. The equilibrium constant for fluorite:

$CaF_2 \text{<---->} Ca2^+ + 2F^- \quad K = 10^{-10.7}$

The water is saturated as soon as:

$SI = \log ([Ca] * [F]^2 / K)^3 1$

Bone media have been used successfully to remove fluoride. Reductions of the fluoride concentration to less than 1.0 mg/lit are reported.

The principle of the method is based on the fact that the bone media is reacting with fluoride in a similar way as bones and teeth of the human body. The fluoride is immobilized in the filter medium through the process of ion exchange.

The equipment used in laboratory and field tests is rather simple. The defluoridator unit consists of a container and a filter. The filter has a bottom layer of 300 gr crushed charcoal for adsorption of color and odor. The middle layer consists of 1000 gr bone media. At the top 200 gr of pebbles are used to prevent the middle layer of floating. The bone media can be either granulated bone media or bone char. In both cases the material has to be pretreated carefully to optimize the results. For the granulated bone media, the bones selected have to be clean, non-porous and crushed into chippings of 1 to 2 mm. For the bone char the bones have to be activated by heating to a temperature of 600°C. For both methods it is advised to treat the bone media with sodium hydroxide before it is used.

The time over which the filtering material remains active depends on the amount of water, which has been treated, and the initial fluoride content. In experiments in Argentine (contact time necessary to allow fluoride to chemically combine with granulated bone media amounted to 0.5 hours) the filter had to be replaced every 3 months at a production of 20 l/day and an initial concentration of 10 ppm.

Different *types of clay* have been used in laboratories to reduce the fluoride contents. Kaolinite, serpentinite, china clay and clay pot are used as natural adsorbents. Reductions from 10 ppm to 1.5 ppm and lower are reported.

For this methods pH, temperature and/or salt content should be maintained at a level predetermined through laboratory experiments.

Conclusions and recommendations

High fluoride concentrations in drinking water may cause dental and / or skeletal fluorosis. The maximum recommended levels differ per country; the recommended WHO limit is 1.5 ppm. In fact the maximum advisable level depends on factors such as diet, climate and age.

Nevertheless it can be concluded that especially children are susceptible to fluorosis. Therefore it is recommended not to use borehole water with fluoride concentrations exceeding 0.5 ppm as drinking water for children. The recommended maximum level for adults is 1.0 ppm. These levels only have to be considered when the borehole water is used as a permanent source for drinking water.

The equipment for the removal of fluoride from drinking water is not yet available for domestic purposes but future prospect are good.