REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE, LIVESTOCK AND FISHERIES
STATE DEPARTMENT OF AGRICULTURE
DROUGHT RESILIENCE AND SUSTAINABLE LIVELIHOODS PROGRAMME (DRSLP)

HYDROGEOLOGICAL SURVEY REPORT

FOR

LAINI COMMUNITY

AUGUST 2020

CLIENT:
Principal Secretary,
Ministry of Agriculture, Livestock and Fisheries
P.O. BOX 30028-00100
NAIROBI.

INVESTIGATING HYDROGEOLOGISTS

GEOL. JOSEPH K. NZOMO **GEOL. DR. STEVEN OKOTH OWUOR**

……………………………………… ………………………………………

Ministry of Water and Sanitation&Irrigation,
State Department For Water Services
P. O. Box 49720-00100,
NAIROBI.

SUMMARY

Introduction

The proposed Kenya Small Scale Irrigation and Value Addition Project **(SIVAP)** is designed to focus on eleven counties within few arid and mostly semi-arid lands, namely Kitui, Makueni, Machakos, Tana River, Bomet, Meru, Tharaka Nithi, Nyandarua, Murang'a, Kajiado and Nyeri Counties. These counties have been chosen due to a number of factors, most importantly among them is that the areas receive low to moderate rainfall ranging from a low of 200 mm / year in the most arid areas to 1900 mm / year in the higher potential areas.The broad objective of SIVAP is to contribute to poverty reduction by enhancing agricultural productivity and income, and food security among beneficiaries of these 11 counties. The project has four main components which include: (i) Enhanced Irrigation Infrastructures and Water Resources Development; (ii) Improved Access to Markets and Strengthening Value Chains; (iii) Institutional Strengthening and Capacity Development; and (iv) Project Coordination and Management. The project will be implemented over a period of 6 years (2015-2021). The project will be executed by the Ministry of Agriculture, Livestock and Fisheries (MoALF). The MoALF is currently the executing agency for twoon-going the Bank-fundedprojects, which is the Small Scale Horticulture Development Project (SHDP) and Multinational: Drought Resilience and Sustainable Livelihoods Project (DRSLP)-Kenya.

The Small-scale Irrigation and Value Addition Project (SIVAP) focuses on improving high value crop production through construction/rehabilitation of twelve (12) irrigation schemes (3,205 ha)in the eleven counties. In addition to improved irrigation infrastructure, the project will also focus on improved access to markets, enhance agro-processing, storage and post-harvest handling technologies, nutrition and institutional and human capacity building. The project contributes to the achievement of the core Sustainable Development Goal (SDG) objectives of poverty alleviation and sustainable development, reduced undernourishments and promoting gender equality and empowerment of women through their involvement in project activities.The direct and indirect beneficiaries include 104,000 farming households, (54,000 are direct beneficiaries while over 50,000 are indirect beneficiaries) making a total of 520,000 persons – of which 58% are women and youths in eleven counties of the country. The project will result in increased

Tana River County has recently experienced unprecedented floods occasioned by higher than normal rains leading to disruption of people's livelihoods, loss of lives, infrastructure destruction and interruption of economic activities. The County's livelihood is largely drawn from farming on the River Tana flood plain. Frequent flooding has led to loss of crops. The SIVAP programme, plans establish borehole water supply for micro- irrigation purposes away from the flood zones and hence mitigate crop loss and improve the coping capacity of the river-line communities.

SIVAP through **MoALF**requested for technical support from the Ministry of Water and Sanitation and Irrigation**(MoW&S&I)** to carry out groundwater resources, geophysical and hydrogeological study of **12No** proposed boreholes to serve various targeted communities (Villages) in **Tana River County**.

This report describes the results of borehole geophysical/hydrogeological investigations carried out for the proposed borehole supply for **Laini Village Community.**The proposed borehole water source will be used for micro-irrigation purposes.

Objective of study

The objective of the present study was to assess the availability of groundwater, to recommend a borehole drilling site and comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality. For this purpose all available hydrogeological information of the area was analyzed, and a hydrogeological/geophysical survey done through:-

- Detailed desk study in which the available relevant geological and hydrogeological data was collected, analyzed, collated and evaluated within the context of the Client's requirements.
- Execution of hydrogeological, geophysical field investigations
- Making useful deductions and conclusions after synthesizing all the collected information.

Site Location

The investigated site is located ***in Laini Village, Laini Sub-Location, Milalulu Location, Galole Division, Chewani Ward Tana River Sub-County, Tana River County.*** It is defined by coordinates ***611817E, 9847495S*** at an elevation of ***67m*** *a.m.s.l* (taken with a GPS).The investigated site is covered by topographic sheet **No. SA-37-7(1:250,000).**

Climate

The climate is semi-arid with **400-600mm** of rainfall per annum. The rainfall follows a bimodal pattern with long rains occurring between March and April and short rains between October and December.

Water Demand

The community requires a borehole water source forirrigation of a **30 acre parcel of land** and domestic use. The irrigation needs and design will be reckoned on the basis of the factors and processes controlling movement and storage of water in the soil.

On the basis of the yield of existing wells, an average conservative supply of **20m^3/hr** is feasible with a large diameter well , constructed in compliance with the Ministry of Water and Irrigation standards. Assuming a **10 hour** pumping period**, 200,000 liters** is available per day, a sufficient for the intended irrigation demand.

Geology, Soil Cover

The predominant geological deposits of the project area are the sands of the Quaternary era, ranging from Pleistocene to Recent. There are also some isolated pockets of fossil ferrous limestone of the Miocene age. The soil in cover in the project has been heavily influenced by the Tana River with the local geology of the investigated site comprising of alluvial sediments within the alluvial flat of the Tana, plio-pleistocene sandy sediments and calcareous crustal sediments away from the flood plain. The soil is mostly sandy silt with some areas containing clay and gravel.

Hydrogeology

Aquifers are expected within alluvial sediments of the Tana channel. Aquifer recharge if deduced to occur direct infiltration of from the river.

Water Quality

The water quality is expected to be good for irrigation purposes.

Conclusions and Recommendations

The conclusions and recommendations below are based on deductions made on the basis of all available geological, hydrogeological, hydrological and geophysical field data.

Conclusions

- The investigated site is located on alluvial sediments of the Tana channel
- In the sub-surface, aquifers are formed by combinations of sands, sandy silts with clay horizons.
- Recharge is deduced to occur through direct infiltration from the Tana waters
- There is sufficient groundwater to irrigate 30 acres
- It is also concluded that the alluvial aquifer has adequate and sustainable recharge and the abstraction will have an insignificant impact on the downstream users.
- Due to direct recharge of the alluvial aquifer, water quality is expected to be good for irrigation.

Recommendations

- Drilling is recommended to a maximum depth of depth of **80m.** A large diameter well of **say 317.5mm (12.5 Inches)** is recommended.
- Water quality analysis is mandatory before the water is put to irrigation use. Electrical conductivity must not exceed 250 micro-siemens per cm at 25^0C; Sodium absorption rate (SAR) should be in the range of 0-10. Quality values outside the above limits may require crop selection.
- Recommendations on drilling and construction are found in the appendix section of this report.
- Before drilling commences, an ***Authorization to Drill and the necessary permits*** must be obtained from ***WRA,TanaCatchment Area.***
- Quality guidelines for irrigation water are also included in this report

Contact Persons

The following community members were present during the survey and know the location of the proposed borehole site:

1. **Habiba Maro-** Chief **(0708885630)**
2. **Barakatu Dhadho Godhana**-Member **(070759974725)**

TABLE OF CONTENTS **Page**

List of Figures

List of Tables

List of Abbreviations (S.I. Units throughout, unless indicated otherwise)

agl	above ground level
amsl	above mean sea level
bgl	below ground level
d	day
E	East
EC	electrical conductivity (µS/cm)
GPS	Global Positioning System
Hr	hour
K	hydraulic conductivity (m/day)
l	litre
m	metre
N	North
PWL	pumped water level
Q	discharge (m3/hr)
S	South
sec	second
VES	Vertical Electrical Sounding
HEP	Horizontal Electrical Profiling
W	West
WSL	water struck level
µS/cm	Micro-Siemens Per Centimeter: Unit For Electrical conductivity
^0C	degrees Celsius: Unit for temperature
Ωm	Ohm-m: Unit for apparent resistivity
ρ_a	Apparent resistivity
"	Inch

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.
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.
Denudation	Surface erosion.
Evapo-transpiration	Loss of water from a land area through transpiration from plants and evaporation from the surface
Fault	A larger fracture surface along which appreciable displacement has taken place.
Fluvial	General term for detrital material deposited within a river environment and usually graded.
Granitization	The process by which solid rocks are converted into rocks of granitic character without melting into a magmatic stage.
Gneiss	Irregularly banded rock, with predominant quartz and feldspar over micaceous minerals. A product of regional metamorphism, especially of the higher grade.
Gradient	The rate of change in total head per unit of distance, which causes flow in the direction of the lowest head.
Heterogeneous	Not uniform in structure or composition throughout.
Hydraulic head	Energy contained in a water mass, produced by elevation, pressure of 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
Migmatite	Rocks in which the granitic component (granite, aplite, pegmatite etc) is intimately mixed with a metamorphic component (schist or gneiss).
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.
Permeability	The capacity of a porous medium for transmitting fluid.
Piezzometric 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 or subsurface sources (e.g. rivers, rainfall, lateral groundwater flow) to the aquifer zones.
Regolith	General term for the layer of weathered, fragmented and unconsolidated rock material that overlies the fresh bedrock.
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).

1. INTRODUCTION

1.1 Background

The objective of the present study is to assess the availability of groundwater, to recommend a borehole drilling site and comment on aspects of depth to potential aquifers, aquifer availability and type, possible yields and water quality. For this purpose all available hydrogeological information of the area has been analyzed, and a geophysical survey done.

The investigations involved hydrogeological, geophysical field investigations and a detailed desk study in which the available relevant geological and hydrogeological data were collected, analyzed, collated and evaluated within the context of the Client's requirements. 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 and consultants

.

1.2 Reporting Requirements

The format of writing the Hydrogeological Investigations Report, as described out in the Second Schedule of the Water Resources Management Rules, 2007. 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, 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
   e. 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, insofar as data limitations allow. The report also includes maps, diagrams, tables and appendices as appropriate.

2. BACKGROUND INFORMATION

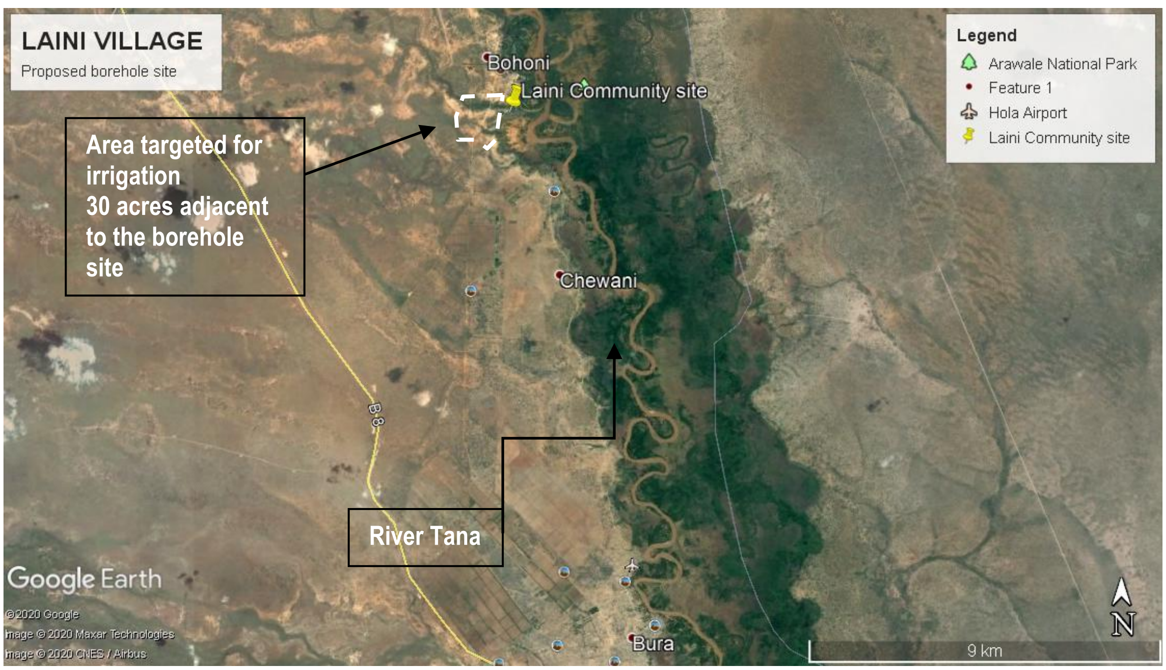
2.1 Details of Applicant

SIVAP through **MoALF– Tana River County** commissioned the hydrogeologists from the Ministry of Water and Sanitation & Irrigation to carry out a hydrogeological and geophysical survey for **Laini Village Community.** The contact details of the Client are:- ***Ministry of Agriculture, Livestock and Fisheries, (DRSLP), P.O. BOX 30028-00100, NAIROBI.***The Contact Person for **SIVAP** is the Project Coordinator, based at **Hill Plaza, P.O Box 30028-00100, Nairobi.**This hydrogeological survey report describes the results of the survey.The community largely practices commercial and subsistence farming along river Tana.

2.2 Site Location

Laini Village is located about **13km** north of Hola town. Administratively, investigated site is located in **Laini Village, Laini Sub-Location, Milalulu Location, Galole Division, Tana River Sub-County, Chewani Ward, Tana River County.** The co-ordinates for the site are ***611817E, 9847495S***at an elevation of **67m a.m.s.l**and its covered by topographic **sheet No. SA-37-7 (1:50,000).**A sketch map showing the approximate location of the proposed boreholeis shown on **Fig-1.**

Fig-1: Google map extract Showing the Location of Project Area



2.3 Proposed Activity

The activity to be undertaken is mainly to drill, construct and equip a borehole to abstract groundwater for irrigation purposes.

2.4 Water Supply, Demand

The general area is semi-arid and water scarce. Currently the residents of the project area get water mainly from shallow wells dug along the Tana flood plain. Laini village water demand aspects are summarized on the table below:

Table-1: Water Demand

Unit of Demand	Number	Remarks
Human population	1400	
Shoats	1200	
Cattle	100	
School	1	Laini Pr. School (400No pupils)
Mosques	1	Madrassa Sch (300No. Pupils)

The above community mainly rely on irrigated farming along the Tana flood plain. Due to flooding and loss of livelihood for the community, SIVAP Programme plans to relocate the irrigated area beyond the highest flood-line. Laini community has set aside initially about **30 acres** for irrigation. This land is located about 4km from the proposed borehole location. The following crops will be grown through irrigation:-

- Maize
- Green grams
- Cowpeas
- Water melons
- vegetables

The irrigation needs and design will be reckoned on the basis of the factors and processes controlling movement and storage of water in the soil. Generally the following considerations will apply:-

- Soil type. The type of soil in an area can affect not only the type irrigation method used but also the irrigation run times
- Land topography
- Local weather patterns
- Type of crops grown
- Waterquality.

On the basis of the yield of existing boreholes, an average conservative yield of **20m^3/hr** is feasible with a large diameter well constructed in compliance with the Ministry of Water and Irrigation standards. This will be sufficient for the intended irrigation demand assuming a 20 hour daily pumping period.

2.5 Physiography, Drainage

The investigated site is generally flat. The wider topography gentlyslopes towards the **south-east**and belongs to the Low Foreland Plateau Physiographic Unit interposed between the Duruma Wajir Low Belt and, Eastern Highlands and coastal lowlands. Tana River County is located within Coastal Lowlands

The drainage is dominated by Tana river and flows to the south-east into the Indian ocean.Few seasonal streams draining the area are sub-ordinate to Tana River. The immediate area is drained by Tana river.The area is located within Tana Drainage Basin.

2.6 Soils, Vegetation Cover

The soil in the project area has been heavily influenced by the Tana River. The soil is mostly sandy silt with some areas containing clay and gravel.

The vegetation habitat type in the project areas is mainly bush grassland dominated by acacia tree species, prosopis juliflora (mathenge), indigenous grasses, shrubs, and layanas (creepers). Other tree species include Balanites and commiphora. Prosopis juliflora (mathenge) is a highly invasive species that is spreading very fast along the roads, towns, shopping centers, Manyattas and around homesteads. Endangered Plants Include Acacia Robusta, Ficus Sykomora and Acacia Nantalosis.

.2.7 Climate

Generally the climate is classified as semi-arid with an average annual rainfall of 300mm. The rains are bimodal in nature with long rains between March and May, and short rains between October and December. It is classified as dry to sub-humid climatic belt suitable for agriculture where soils and topography permit (National Water Master Plan, 1992).

The area is generally hot throughout the year. There is however a large diurnal range in temperatures with the maximum temperature during the day often being more than 10ºC higher than the minimum night temperatures. The mean annual temperatures range from 24 -30 ^{0}c with mean maximum temperatures of 30-36 ^{0}c and mean minimum temperatures of 18-24 ^{0}c.

3. GEOLOGY

Ground water presence and consequently the exploration techniques depend to a large extent on the geology of the area. Other factors, which influence the ground water occurrence like morphology, topography and pedology are strongly related with the geological setting of the region. Without a proper understanding of the geological framework of a ground water system, it is impossible to quantify the resources. The initial stage of ground water resources assessment must therefore be the study of the geology.

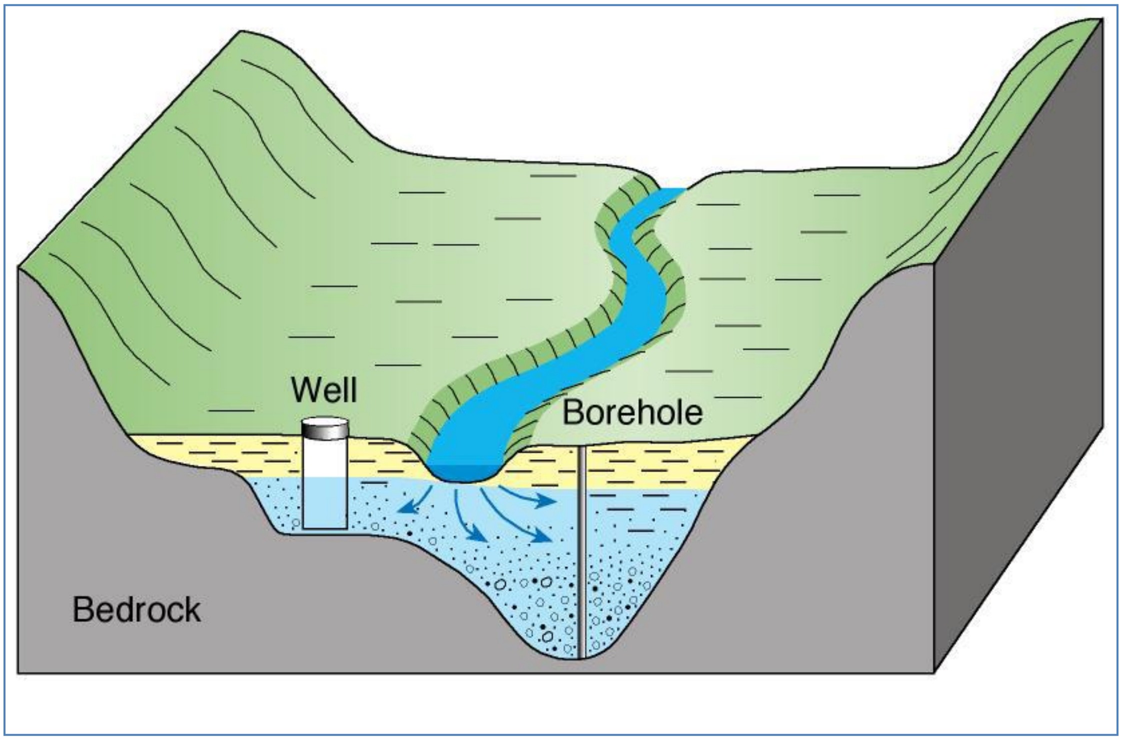
The regional geology is dominated by Precambrian Basement rocks overlain by Quaternary sediments. Prominent hills rising from the floor of the foreland plateau are typically Basement rocks. This is found to the north west of the area. At the project area up to Indian Ocean, sedimentary facies dominate. This site's formation varies from sand, limestone, mudstones to silts. The formation is generally made of loose sediments deposited during the flooding periods. The material is unconsolidated and may collapse during drilling or digging.The drilling contractor is highly advised to use mud pump with rock roller bit or percussion rig.

The predominant geological deposits of the project area are the sands of the Quaternary era, ranging from Pleistocene to Recent and river Tana alluvial deposits which from a rich source of ground water. There are also some isolated pockets of fossil ferrous limestone of the Miocene age.

4. HYDROGEOLOGY

The presence of wells and boreholes is a good indicator of availability groundwater. The yields of these well can give a good indicator of the transmissivity of the well. The investigated site is located on a zone of medium ground water potential. Potential aquifers are expected within alluvial deposits of river Tana channel and recharge comes directly from the river waters. The diagram below is a conceptual model of groundwater occurrence in alluvial aquifer areas such as the project area.

Fig 2:- *Groundwater Occurrence in alluvial flats eg* *Tana flood plain area.*



5. ANALYSIS OF BOREHOLE DATA

Borehole data is analyzed for the purpose of carrying out correlative studies and predicting the yields and depth(s) to aquiferous zone(s). This is based on the assumption that hydrogeological conditions are fairly uniform for the general area.

Shallow wells constructed in the area have sufficient quantities to meet domestic demand. It is deduced that sufficient quantities exist in the aquifer regime of the area for irrigation purposes.

6. GEOPHYSICS

Geophysical techniques in soil-water research form an important component of Water Resources Development and Management. It is the logical and compulsory approach not only to explore and assess the available resource in the light of its withdrawal, but also to ensure social acceptance of its different components e.g. Economic, environmental, legal, political etc. for a given area such as river basin, catchment, watershed, dry land and so on.

Geophysical techniques work on the basic concept of determining and understanding the physical contrasts in the soil-water systems. These contrasts are expressed as measurable physico-chemical parameters such as electrical resistivity or conductivity, dielectric constant, propagation velocity, attenuation coefficient, isotope content etc. of the subsurface configuration. Information on the general geology and hydrogeology conditions are essential to arrive at meaningful conclusions from the geophysical data at a given location.

Geophysical techniques are used to obtain more accurate information about sub-surface conditions such as type and depth of materials, depth of weathered or fractured zone, depth to groundwater, depth to bedrock, and salt component of groundwater.

In order to map out geological subsurface conditions, a variety of methods are used. In the present survey galvanic Resistivity method is used, and includes vertical electric sounding (VES) to establish vertical sub-surface resistivity layering and horizontal electric profiling (HEP) to detect lateral charges in electrical conductivity.

Vertical electric sounding (VES) and horizontal electric profiling (HEP) techniques were applied in the current project.

6.1 Basic Principles

The electrical properties of the upper parts of the earth's crust depend upon the rock type, porosity, pore-space saturation and interconnectivity, and the level of salinity of the pore water. Saturated rocks have lower resistivity than dry or unsaturated rocks. Both higher porosities and salinity of saturated rocks mean higher conductivities respectively.

Clays and conductive minerals in the sub-surface present low resistivities.

The resistivity of earth materials can be studied by measuring the electrical potential distribution produced at the earth's surface by injection of low frequency electric current. Two fundamental considerations are the basis of the theory behind galvanic resistivity methods viz:-

(1) Ohm's law :

$$\mathbf{E} = \rho \mathbf{i}$$

Where: **E** = Potential gradient (**Volts per meter**)
i = Current density (**Am^{-2}**)
ρ = Resistivity of the earth medium (**Ω-m**)

(2) The divergence condition for the current flux into the ground:

$$\mathbf{div\,i} = 0$$

It follows from above that the potential function **V** for a single point source at a distance of **r** meters on the earth's surface is given by:

(i) $$V_r = \rho I / 2\Pi r \text{ (Volts)}$$

In hydro-geological field surveys using galvanic Resistivity methods the quantities measured are current **I**, flowing between two electrodes **A&B** and potential difference **ΔV** between two measuring points **M & N.** The following generalized relationship applies to various electrodes configurations.

$$\text{(ii)} \quad \rho = K \times \Delta V / I_{AB} \quad (\Omega\text{-m})$$

Where **K** is defined as the geometrical factor derived from electrode configuration adopted. The most common field arrays are the Schlumberger and Wenner configurations.

6.2 Principle of Measurement

Resistivity meter Model No. **SSR-MP-AT** is used in this work. It contains mainly four units viz. the transmitter, receiver, microprocessor and power supply units. The transmitter is a constant current source which sends bipolar square wave current **(I)** signals into the ground at a fixed frequency of 0.8Hz. The receiver is a 4-1/2 digit dual-slope analog to digital converter capable of measuring ground potentials **(ΔV)** with a resolution of 10microvolts. The microprocessor controls the current signals, determines the attenuation level for potential measurements, computes the resistance values, stacks, averages the measured values, keeps the data in memory, displays and transfers the data to PC. The power unit supplies power to different units.

6.3 Data Interpretation

The interpretation of resistivity data is done in two stages:-

1. Processing of data to get physical parameters in terms of resistivity and depths.

2. Using these parameters to infer the nature of sub-surface formations on the basis of geological knowledge and correlative studies.

Data obtained is normally subjected to modeling analysis using a digital computer. Correlation with data from existing boreholes complements the modeling analysis to come up with the most realistic conclusion.

7. AQUIFER CHARACTERISTICS

7.1 Hydraulic Parameters

Data available from Ministry of Water and Irrigation is based on step-drawdown pumping tests and recovery measurements for the drilled boreholes. The constant discharge test necessary for determination of aquifer hydraulic characteristics has seldom been done.(Groundwater Master Plan-1992).Aquifer parameters presented here are estimated from the recovery test portion of the data and by use of Logan's method.

The table below summarizes the boreholes parameters for the area assuming uniform hydrogeological conditions in sedimentary rocks. The data is based on boreholes drilled in sedimentary of rocks.

Table-2: Aquifer Parameters

SAMPLE POPULATION OF BOREHOLES	*PARAMETER*	*AVERAGE MEASURED VALUE*	*STANDARD ERROR*
430	*Drawdown-M*	*17.4*	*±29.9*
239	*Recovery Time(Hrs)*	*5.8*	*±8.3*
127	*Storage Coefficient*	*0.02*	*±0.06*
709	*Yield-LPM*	*92.5*	*±106.5*
131	*Transmissivity(m^2/min)*	*0.01*	*±0.04*

7.2Borehole Specific Capacities, Transmissivities

Kenya is simplified to consist of three major rock types: Basement, Volcanics and Sedimentary rocks. Ground water occurs in those rock types alone or in various combinations as hereunder:-

(i) Volcanics (V)
(ii) Basements (B)
(iii) Sediments (S)
(iv) (V) over (B)
(v) (S) over (B)
(vi) (S) over (V)
(vii) (V) over (S)

The investigated site falls under category (iii) of sediments. The average specific capacity has been estimated to be **0.32 m^3/hr/m**(Groundwater Master Plan-1992, pp C-14). Nearby boreholes do not have sufficient data for estimation of borehole parameters.

7.3 Groundwater Flux

Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface water to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a **flux** to the water table surface. Recharge occurs both naturally (through the water cycle) and anthropologically (i.e., "artificial groundwater recharge"), where rainwater and/ or reclaimed water is routed to the subsurface.

Accurate estimation of groundwater recharge is extremely important for proper management of groundwater systems. Many different approaches exist for estimating recharge. The water-table fluctuation method may be the most widely used technique for estimating recharge; it requires knowledge of specific yield and changes in water levels over time. Advantages of this approach include its simplicity and an insensitivity to the mechanism by which water moves through the unsaturated zone. Uncertainty in estimates generated by this method relate to the limited accuracy with which specific yield can be determined and to the extent to which assumptions inherent in the method are valid. Other methods use water levels mostly based on the Darcy equation (Hydrology Journal (2002) 10:91-109).

Water table changes over time have seldom been recorded for boreholes in Kenya making objective determination of groundwater flux rather intractable.

8. WATER QUALITY

8.1 GUIDELINES FOR IRRIGATION WATER QUALITY

Water quality is expected to be good for irrigation. The following guidelines on **Table -3** should however be applied after quality analysis.

Table 3: Irrigation water quality guidelines

No.	Irrigation Problem	Degree of Problem		
		No Problem	**Worsening Problem**	**Severe Problem**
1	Salinity (affects crop water availability) ECw (Mhos/cm)	<0.75	0.75-3.0	>3.0
2	Permeability (Affects rate of infiltration into soil) (i) ECw (mS/cm) (ii)Adj. SAR (Sodium adsorption ratio): -Mont. Clay -Illite Clay -Kaolinite Clay	>0.5 <6 <8 <16	0.5-0.2 6-9 8-16 16-24	<0.2 >9 >16 >24
3	Specific ion toxicity (affects sensitive crops) -Na (Adj. SAR) -Chloride (meq/l) -Boron (mg/l)	<3 <4 <0.75	3-9 4-10 0.75-2.0	>9 >10 >2
4.	Miscellaneous effects (affects susceptible crops): -NO_3 (mg/l) -HCO_3 (meq/l) overhead sprinkling -PH	<5 <1.5 6.5-8.4	5-30 1.5-8.5	>30 >8.5

8.2 GUIDELINES FOR WATER QUALITY FOR DOMESTIC USE

The water quality guideline values for water are those published by WHO. In the case of rural and community water supply, the WHO guideline values have to be often considered as long-term. Taking into account the local geographical, socio-economic , dietary and industrial conditions in the country , the following water quality parameters should be used to measure and assess the quality of water intended for water supply:

(1) Bacteriological aspects

(2) Chemical and physical aspects:-

- Turbidity
- Colour
- Taste & odour

- Electrical conductivity
- Fluoride
- Iron

The basic requirements of drinking water should be:-

(1) Free from pathogens
(2) Containing no compounds with an adverse acute or long term effect on human health.
(3) Fairly clear (low turbidity or little colour)
(4) Non-corrosive and non-staining.

8.2.1 Bacteriological Quality

The bacteriological quality of water is absolutely essential and should be tested before the selection of any source and during the operation of the supply. The table below details the bacteriological guideline values for drinking water:-

Table 4:- Bacteriological Guideline values for drinking water

Colliform Count (No. per 100ml)	Remarks
0-50	Disinfection only
50-5000	Full treatment
5000-50000	Heavily polluted, requires extensive treatment
>50000	Extreme pollution requiring special treatment; unacceptable source unless no alternative exists.

(Source:- Groundwater Mastr Plan-1992; Design Manual for Water Supply in Kenya-1986)

When more than 40% of the colliforms are found to be of faecal group, then the water source should be considered to fall under the next higher category with respect to the treatment required.

8.2.2 Chemical and Physical Quality.

The table below summarizes some pertinent chemical and physical guidelines values for drinking water:

Table 5: *chemical and physical guidelines for drinking water*

Inorganic Constituents		Organic Constituents		Desirable Aesthetic quality	
Parameter	ppm	Parameter	ppm	Parameter	ppm
Arsenic	0.05	Aldrin & diedrin	0.03	Al	0.2
Cd	0.005	Benzene	10	Cl	250
Cr	0.050	Benzo-a-pyrine	0.01	Color	15(TCU)
Cyanide	0.1	Carbon tetrachloride	3	Cu	1
F	1.5	Chlordane	0.3	Fe	0.3
F(Kenya)	3	Chlorobenzene	0.1-3	Mn	0.1
Pb	0.05	Chlorophenols	0.1	pH	6.5-8.5
Hg	0.001	Chloroforms	30	TDS	1000-1500
Se	0.01	2,4 D	100	Turbidity	5

$-NO_3$	10	DDT	1	Zn	15
		1,2,Dichloroethane	10	Hardness (As $CaCo_3$)	200
		1,2 Dichloroethylene	0.3	Taste & odour	500
		Heptachlor & heptachlor Epoxide	0.1	HS	Inoffensive
		Hexachlorobenzene	0.01		
		Lindane	3		
		Methoxychlor	30		
		Pentachlorophenol	10		
		Tetrachloroethylene	10		
		2,4,6 Tirchlorophenol	10		

(Source:- Design Manual for Water Supply in Kenya-1986)

Groundwater quality for the area is classified as generally good. After resource development, water quality analysis is also mandatory to ascertain the level of the above parameters and appropriate advice given.

9. IMPACT OF PROPOSED ACTIVITY

The most important impact of the proposed activity once completed will be its effect on the groundwater regime of the locality. Tana alluvial aquifer has sufficient and sustainable recharge to sustain the micro-irrigation without affecting downstream users.

Borehole construction works should be guided by best practices in site management as laid down in the **FIDIC** to ensure environmental preservation. Drilling tailings, foam or any chemicals used should be properly disposed to avoid contamination of both ground and surface water sources. This can be achieved through supervision by a competent hydrogeologist.

10. GROUNDWATER AVAILABILITY ASSESSMENT

Data from neighbouringwells is used to give an assessment of groundwater availability in terms of quantity, quality and depth. Based on the yields nearby wells, there is sufficient groundwater reserve to satisfy the envisaged demand. A rigorous groundwater reserve analysis is beyond the scope of this assessment.

11. FIELD WORK AND RESULTS

Field work was carried out with the aim of:-

(i) Carrying out an on-site examination and constructing a conceptual model which would form a baseline for more elaborate investigations in the study.

(ii) Conducting geophysical investigations to determine geological layout and consequently the optimum depth of drilling to reach the potential water bearing formation where applicable.

Fieldwork was carried out in ***5th August, 2020*** using deep probe resistivity ***model No. SSR-MP-AT.*** During the survey one **VES** were executed with **AB/2** spread of **80m**. This way, vertical changes in resistivity were recorded and subjected to modeling analysis with a digital computer using **IPI2Win (Lite)** hydrogeology software.

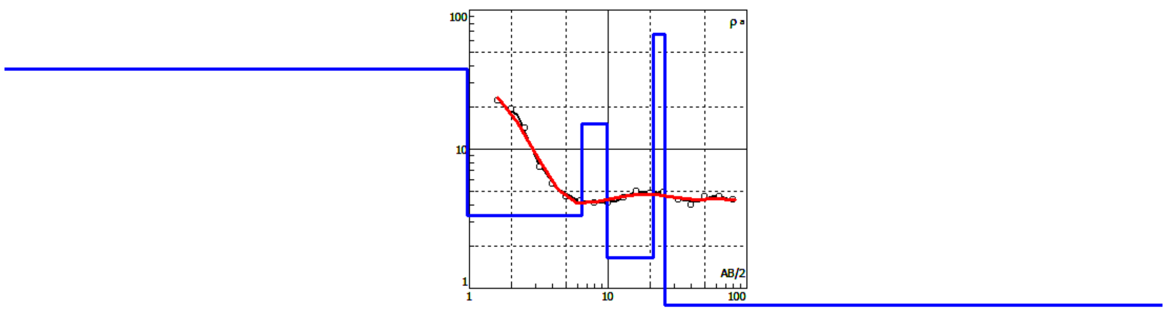
Data summary:

VES-1

AB/2	MN	Ro_a
1.6	0	40.1
2	0	28
2.5	0	11.2
3.2	0	13.3
4	0	12.3
5	0	12.6
6.3	0	14
8	0	14
10	0	14
13	0	13.9
16	0	13.4
20	0	13.4
20	0	20
25	0	17.3
32	0	15.7
40	0	11.9
40	0	13.1
50	0	10.2
63	0	8.5
80	0	0

DATA ANALYSIS AND INTERPRETATION

Fig-3: Geo-electric ModelVES-1



N	ρ	h	d	Alt
1	37.9	0.959	0.959	-0.9593
2	3.34	5.49	6.45	-6.45
3	15.2	3.38	9.83	-9.831
4	1.65	11.2	21	-21.02
5	67.5	4.67	25.7	-25.69
6	0.533			

Approx. Depth (m)	True Resistivity (ohm-m)	Geological inference	Prospects
1	38	Top soils	Dry
6.5	3	Clayey silt	Moist
10	15	Sands and gravels	Aquiferous
21	2	Sands and silts	Aquiferous
26	68	Gravelly sands	Aquiferous
>26	0.5	Silty sands with intercalated clay	Aquiferous

R.M.S. Error=5.13%

12. CONCLUSIONS AND RECOMMENDATIONS

12.1 Conclusions

- The study concludes that on the basis of geological and hydrogeological evidence, the prospects for sufficient groundwater for irrigation purposes are good. The most productive aquifer has been identified to be alluvial sands and gravels
- The aquifers in the study area are adequately replenished from Tana alluvial flat at several orders larger than the imposed abstraction, thereby ensuring a reliable long-term water supply.
- Groundwater quality in the area is good for both irrigation and human consumption.

12.2 Recommendations

In view of the above it is recommended that:

- An borehole be drilled as summarized on the table hereunder:-

Grid Reference of point to be drilled **VES-1**	**Diameter (mm)**	**Elevation (amsl)**	**Minimum Recommended Depth (m)**	**Maximum Recommended Depth (m)**	**Amount to be abstracted (m^3/day)**
611817E, 9847495S	317.5 (8")	67	60	80	200

- The borehole must be installed with a Water Meter and an Airline/piezometer to monitor groundwater abstraction and to facilitate regular measurements of the static water level in the borehole.
- Upon drilling completion, a 2-litre water sample from the borehole should be collected for reference to the WRMA Testing Laboratory, or any other competent Water Testing Authority for a full physical, chemical and bacteriological analysis before the water is put to any use.
- A copy of the water analysis report must be sent to the WRA – Regional Office for record.
- A drilling permit has to be acquired from WRMA Regional Office

In Appendix 1, additional recommendations on the construction and completion of a borehole are given.

REFERENCES

GREENBAUM, D. 1985.

Review of remote sensing applications to groundwater exploration in basement and rigolith. British Geological Survey, Nottingham, UK, pp. 36.

MAC FARLANE , M.J. 1985.

The weathering profile above crystalline basement rocks under tropical weathering conditions and in the context of hydrogeology. Department of Microbiology , Reading University, UK, pp. 152.

SNOW, D.T. 1968.

Hydraulic character of Fractured Metamorphic Rocks of Front Range (Colorado) and Implications to the Rocky Mountain Arsenal Well. Quart. Color. Sch. Of Mines. Vol. 63 (1) , pp 167-199

Appendix:

- Borehole Drilling and Construction
- Copy of Topo-map showing location of proposed borehole

Borehole Drilling and Construction

Drilling Technique

Drilling should be carried out with an appropriate tool preferably a rotary drilling machine. Mud drilling is recommended. Geological rock samples should be collected at 2 meter intervals. Struck and rest water levels and if possible, estimates of the yield of individual aquifers encountered, should also be noted.

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 meter 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 meters 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.

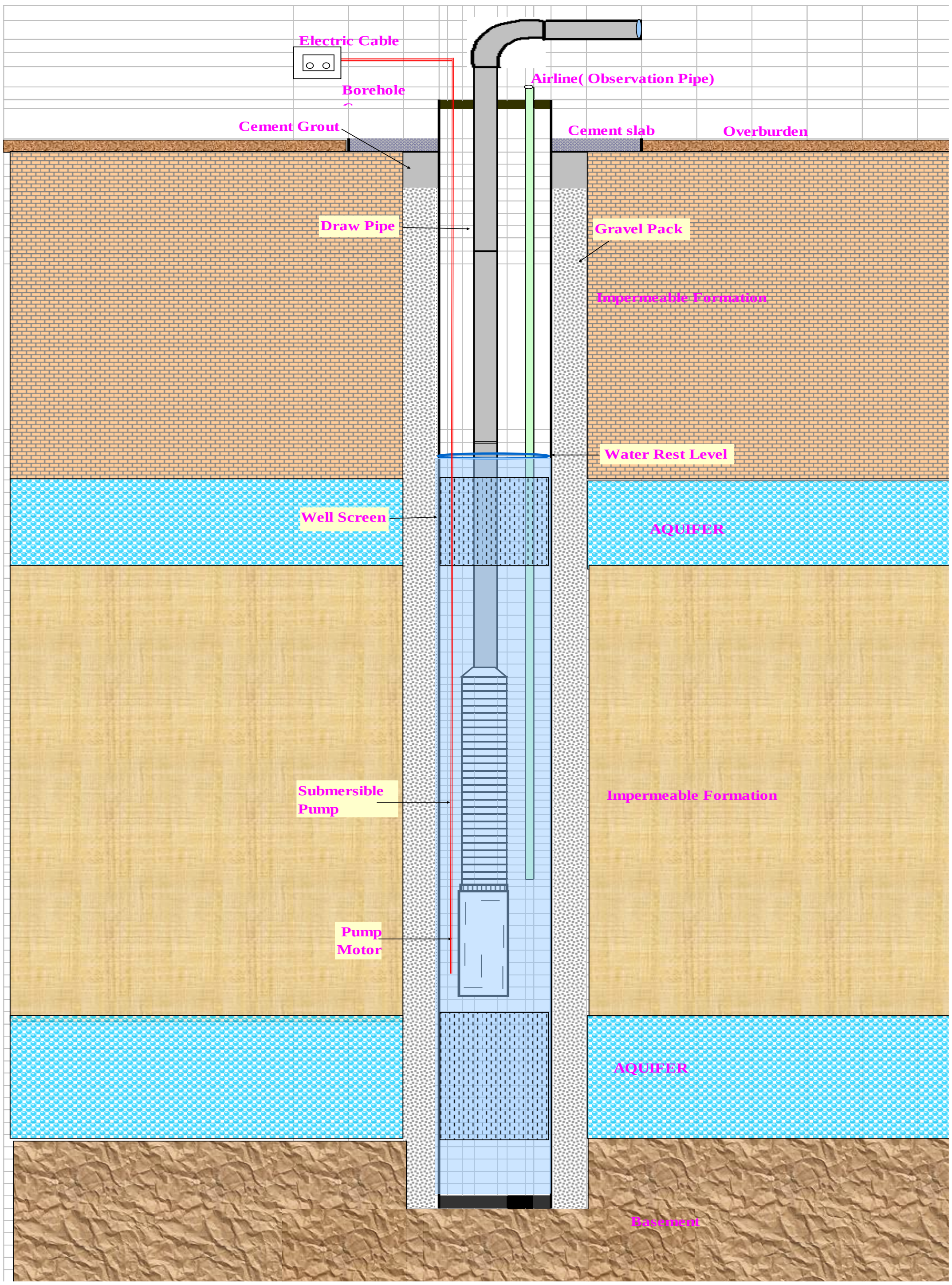
Well Testing

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.

STANDARD BOREHOLE DESIGN



APPENDIX-2

Topographic map extract (SA-37-7; 1:250,000) showing the approximate location of the proposed borehole and nearby boreholes.