Siting of one Production Borehole in Mayuge District

Geophysical Survey Report for one Borehole in Bukabooli subcounty

February 2024

Project 2024-01

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Client: HFHU
Prepared by: Edward Ndagije
Quality Control: MT, VB, RS

WECONSULT

Lake Drive, Plot 57, Luzira, Kampala, Uganda
P.O. Box 22856, Kampala, Uganda

www.we-consult.info
contact@we-consult.ug

Phone: +256 200 912074
Fax: +256 (0) 414-505798

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EXECUTIVE SUMMARY

This report presents the results of the hydrogeological and geophysical survey for one production well in Bukabooli subcounty in Mayuge district. Detailed hydrogeologic, water quality, and geophysical information was collected around the project area.

The sole objective of the survey was to identify the best location with a high groundwater potential and good water quality suitable for a production well. To achieve this goal, an Inception and reconnaissance visit was carried out in six villages (Makoma, Kaliro, Matirinya A, Wandera, Mugumya and Kirongo A) within the project area. After assessment of the reconnaissance data, three (Makoma, Mugumya and Kirongo A) of the six villages were selected, for a geophysical survey.

A sum of five profiles and nine Vertical Electrical soundings (VESes) were carried out in the three villages. Subsequently, the geophysical measurements were modelled and analysed using Ipi2Win software.

One Vertical Electrical sounding (VES 1) located in Makoma village was recommended for drilling and two Vertical Electrical soundings (VES 7 and 6) in Kirongo A village were selected as alternative drilling points.

The borehole to be drilled will be motorized and developed into a piped water system serving the communities and institutions in the adjacent areas.

1 INTRODUCTION

1.1 Background

WE Consult was awarded a contract by Habitat for Humanity Uganda HFHU for Siting and drilling supervision of one production borehole in Bukabooli sub county, Mayuge district. The project had six target areas around Bukabooli subcounty in Mayuge district namely:

Makoma,

Bugumya,

Kirongo A, [1]

Kaliro,

Mayirinya A,

Lwandera

The site locations are given in Figure 1. Only 2 sites were to be selected for detailed investigation.

In order to achieve the project target, WE Consult deployed one team to carry out a reconnaissance survey. The results of the desk study and the reconnaissance survey were used to select the two villages where detailed geophysical surveys were carried out to identify potential borehole drill sites.

The collected data was analyzed together with the desk study information and formed the basis for the selection of the recommended drill sites.

[1] The village names Kirongo A and Mugumya have been used interchangeably

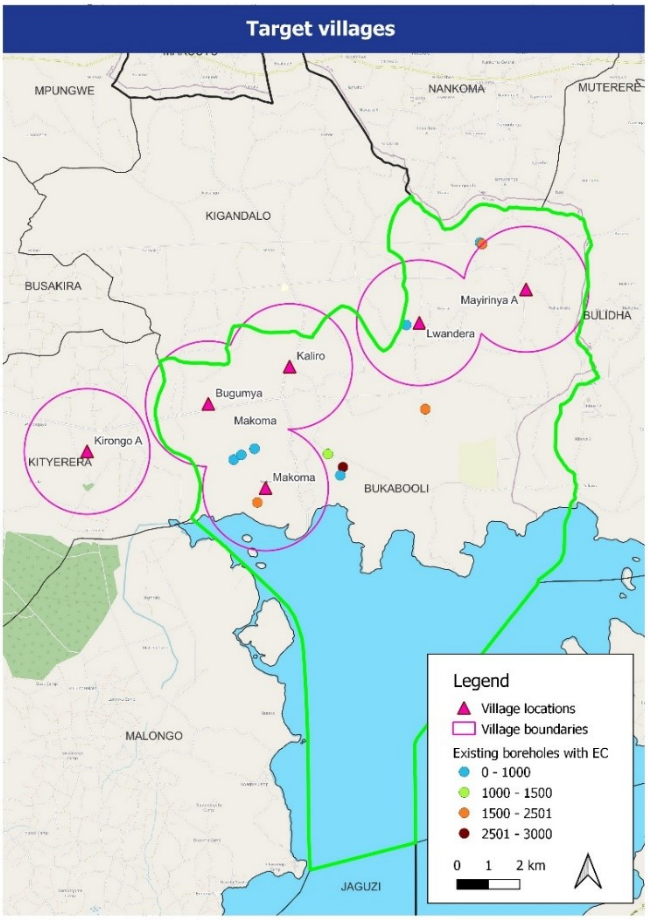

Figure 1 Location of the 6 villages

1.2 Scope of services

The project for siting of one production borehole around Bukabooli subcounty area consisted of three main phases:

1. A desk study was done on the potential sites provided by the client. Then a reconnaissance visit around the sites in the project area was undertaken. During this phase, data on elevation, geology and lineaments was gathered and existing siting information studied.
2. During the second phase, a geophysical survey (profiling and VESs) was carried out in the project area to get a better understanding of the hydrogeological build up and to identify possible drilling locations.
3. During the final phase, the results of the geophysical survey were analyzed and compiled in the current report.

1.3 Activity schedule

The geophysical survey was partly carried out with one team. The time and activity schedule are given in Table 1. The corresponding outputs have been combined in one report with sections for the desk study, the geophysical survey and the recommendations for water resources development.

Table 1 Project Activities

Activity	From	To	Days	Staff involved
Desk study	05/02/2024	06/02/2024	2	Edward Ndagije
Reconnaissance visit	07/02/2024	07/02/2024	1	Edward Ndagije
Geophysical fieldwork	08/02/2023	12/02/2024	5	Edward Ndagije
Analysis and Reporting	14/02/2024	20/02/2024	4	Edward Ndagije, Martin Twine, Vincent Byarugaba and Ron Sloots

2 DESK STUDY

2.1 Introduction

A description of the groundwater resources situation in Mayuge district and the surrounding area is described based on the results of a literature review and a review of other information. The aim of the information analysis is to get a better understanding of the hydrogeology of the area. This chapter contains the following information:

1. Rainfall and evapotranspiration
2. Digital elevation model, topographical cross sections and 10m contours
3. Geology
4. Surface water catchments
5. Hill shade map
6. Borehole yields per lithology and per subcounty
7. Lineament analysis
8. Water quality
9. Hydrogeology and aquifer recharge

Information is as much as possible supported by explanatory maps and graphs.

2.2 Rainfall and evaporation

2.2.1 Overview

Rainfall and evaporation data for the study area is shown in Figure 2 (*sourced from WorldClim v2 and Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2: https://www.sam-samwater.com/climate/*). It shows that the annual amount of rainfall is approximately 1,375 mm per year. The year has 2 wet seasons (March to May, and September to November) with precipitation more than 100 mm per month and two dry seasons (December to February and June to August with precipitation less than 80 mm per month.) The driest month is January with precipitation less than 63 mm per month. The precipitation contributes about 10% of the recharge.

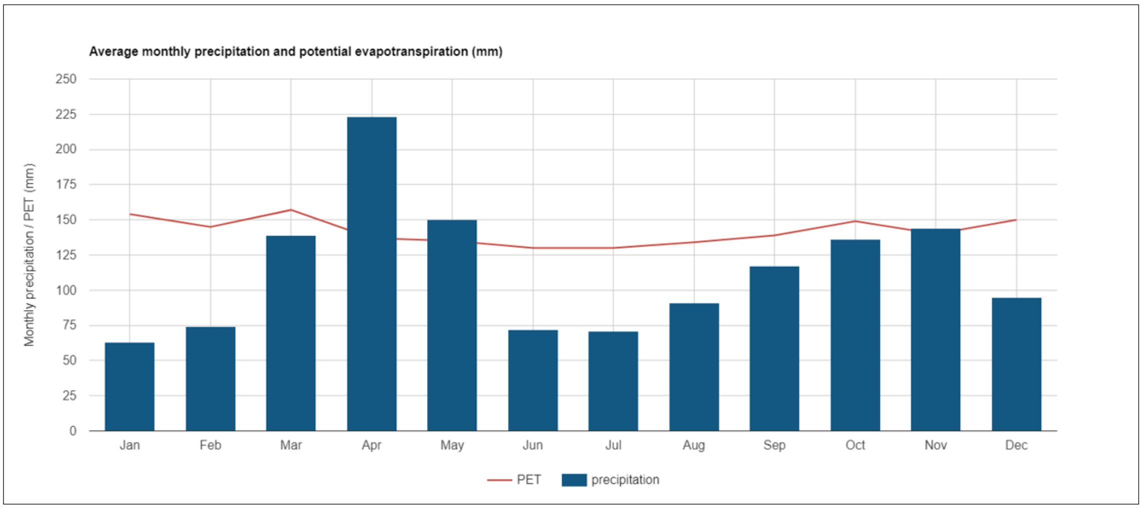

Figure 2 Precipitation and Potential ET data for Bukabooli sub county

2.2.2 Rainwater Harvesting

To estimate how much rainwater can be harvested in using roof catchments, we can use the following formula:

Harvested Rainwater (liters) = **Catchment Area** (sq meters) × **Rainfall** (mm) × **Runoff Coefficient**

Where:

- Catchment Area is the area of the roof that collects rainwater. It's typically measured in square meters (sq m).
- Rainfall is the depth of rain that falls, measured in millimeters (mm). In this case, it's 1,375 mm annually for Mayuge District.
- Runoff Coefficient is a factor that accounts for losses due to evaporation, leakage, and the first flush (which is often diverted to avoid contaminating the harvested water with the dirtiest initial runoff). This coefficient can vary but is often between 0.8 and 0.9 for efficient systems on impermeable surfaces like metal roofs.

Estimation example:

Taking an example of May from Figure 2, with a monthly rainfall intensity of 150 mm, and taking runoff coefficient as 0.8;

Harvested Rainwater (liters) = 100 (sq meters) × 150 (mm) × 0.8

Harvested Rainwater = 12,000 litres

2.3 Topography and satellite images

Since the topography is an important indicator for possible fractures and groundwater availability, this paragraph visualizes the topography in three different ways:

1. Digital Elevation Model (DEM) map with elevation on a colour scale;

2. 10m contour map;
3. Topographical cross sections

The DEM in Figure 3 shows that the project area is generally flat with small hills and valleys. The swamps and seasonal rivers form the valleys. The absolute elevation of the region varies between about 1,150 and 1,250 m amsl. The DEM was used to mark out lineaments during desk study.

The 10m contour maps are shown in Figure 3. These lines are helpful to identify changes in elevation that may be caused by changes in lithology and also lines of displacement. Usually, they are studied at two different scales, one to identify smaller structures / changes, one to identify regional changes. The maps can be used to identify faults in the field and as such provide valuable information for the lineament analysis. Regionally, it shows some clear topographical and/or geological structures. These structures appear as linear features, drainage channels and their patterns, riverbeds, river types, and valleys. While proposing profiles, they are designed in directions perpendicular the plotted linear structures.

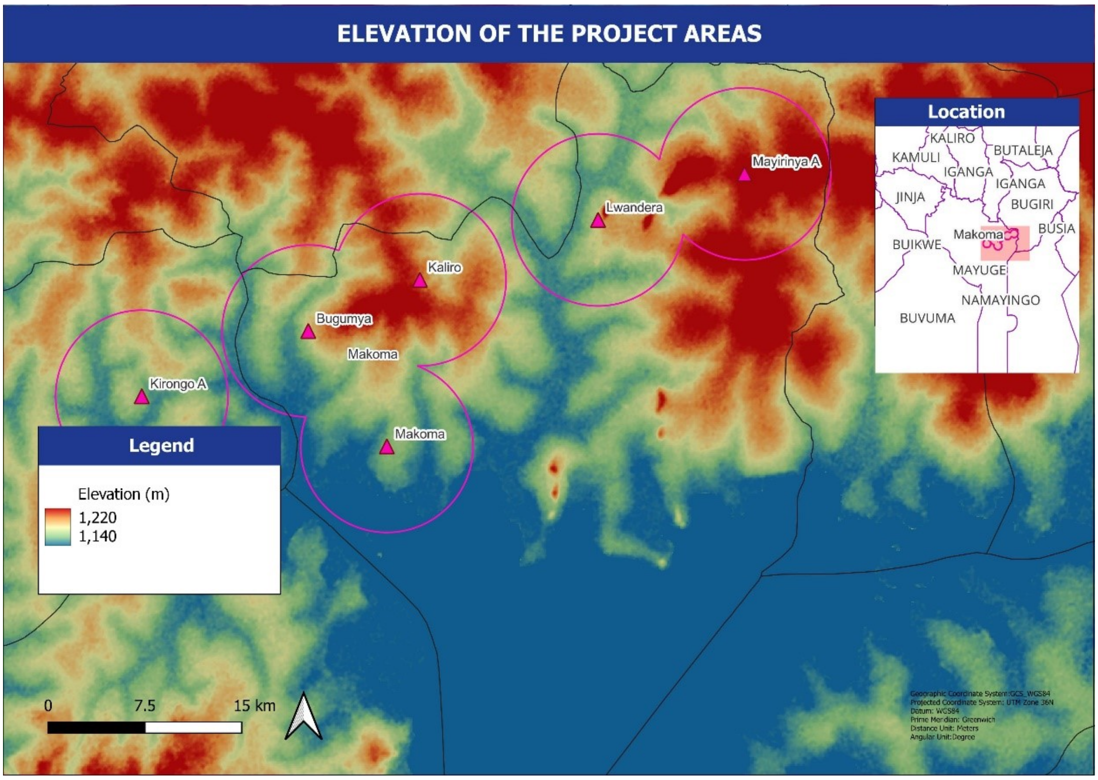

Figure 3 Digital elevation model of the project area

2.4 Geology

Like most of Uganda, the project area is dominated by different varieties of granite and gneiss. In the valleys layers of alluvium of various thicknesses occur. Granites are hard rocks which are hard to drill but make good aquifers when fractured.

2.4.1 Regional geology

The project area lies in the Iganga Suite which covers an area of over 2000 km^2 from north of Iganga town to Lake Victoria and is unconformably overlain by quartzites and shales of the Palaeoproterozoic Buganda Group in the west. The Iganga Suite has been divided into seven related calc-alkaline granitic to granodioritic members of which (1) the locally porphyritic Mayuge granite is the most extensive. Five less extensive members include (2) Gogero porphyritic granite, (3) Kibuye porphyritic granite, (4) Butte granite, (5) Porphyritic granodiorite and (6) Medium-grained granite

The specific lithologies in and around the project area, as described in the geological map, are displayed in Figure 4.

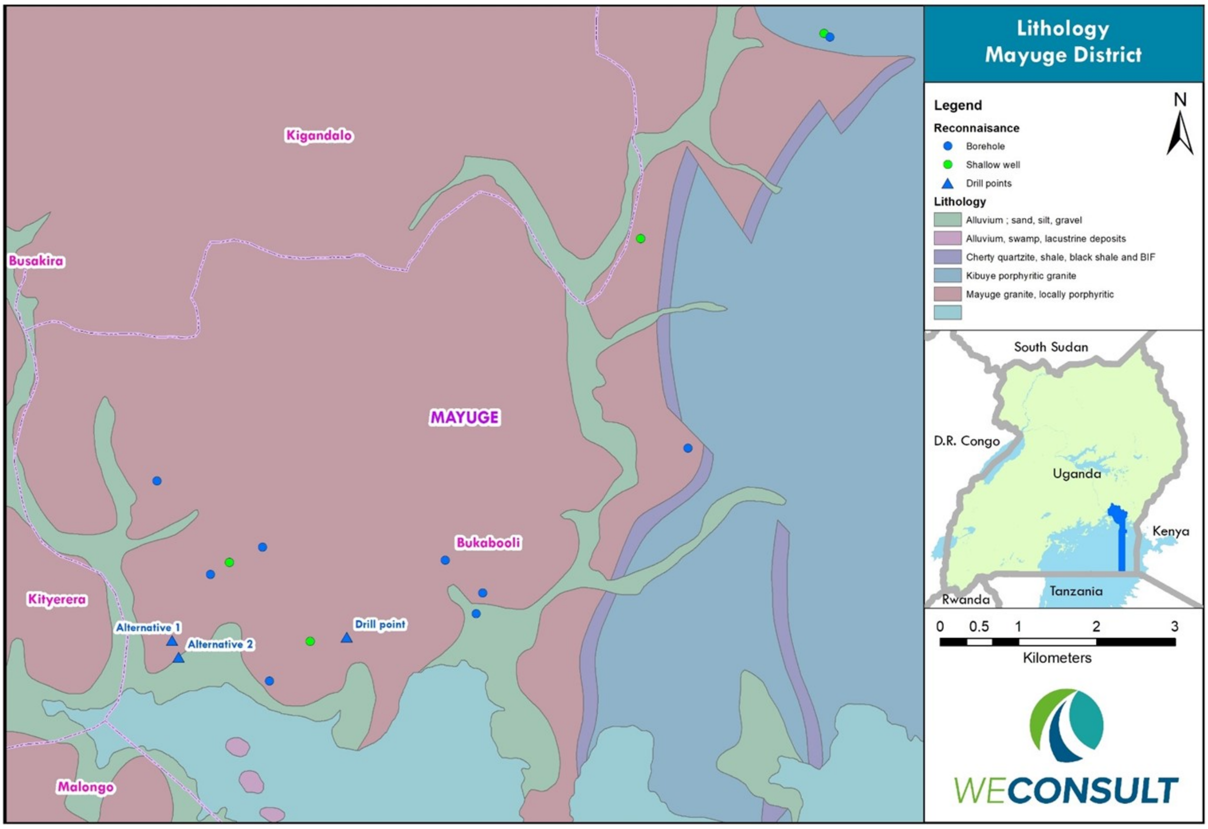

Figure 4 Geological map of Mayuge district

2.4.2 Geology of Bukabooli subcounty

Mayuge granite, locally porphyritic

The project area is underlain by the Mayuge granite and this granite covers the biggest area of the subcounty. The Mayuge granite is typically a red to pink, medium- to coarse-grained, generally equigranular but, locally, also porphyritic rock, exhibiting occasionally a weak E-W oriented planar fabric. It is a genuine alkali granite composed of quartz (30−50 vol%) and feldspar (40−60 vol%), whereby K-feldspar is dominant with white plagioclase only occurring in subordinate amount.

Mafic constituents include biotite (5−20 vol%) with or without hornblende. The existence of groundwater and the easiness of drilling in this geologic formation are described in Chapter 2.7

Alluvium, swamp, lacustrine deposits

This unit does not comprise any type of rock, it is questionable if the term 'lithology' is justified: it is relatively young and consists mainly of sand, clay and mud, deposited by the small streams that cut through the area. They are located in the valleys, which can reach widths of about 500m and are usually very wet. The alluvial deposits are expected to be relatively shallow and underneath them other lithologies can be found.

Maluba nepheline syenite

These are rare stocks of alkali syenite are known from the Lake Victoria Terrane. Nepheline syenite rocks are exposed on a peninsula at McDonald Bay and differ considerably from all other felsic and intermediate plutonic rocks of the Lake Victoria Terrane. The rocks form one single igneous intrusive, comprising of plutonic and sub-volcanic varieties of the same magmatic source. They appear as partly foliated, greyish, usually medium- to coarse-grained rocks with biotite (± amphibole), feldspars and foids and little if any quartz.

Kibuye porphyritic granite

Centred on the village of Kibuye, this granite member forms a near elliptical pluton, 7 x 10 km in size, on the northern shore of Lake Victoria. The Kibuye porphyritic granite stands out in the airborne magnetic map due to its low magnetic signature when compared to the Mayuge granite. Texturally, the Kibuye porphyritic granite is a strongly variable rock, locally having a distinctly porphyritic fabric with coarse euhedral (>2 cm) K-feldspar phenocrysts in a relatively fine-grained matrix. Elsewhere, concentrations of euhedral K-feldspar phenocrysts form localized patches in otherwise fine- to medium-grained, equigranular granite. The origin of these variable textures is uncertain, but it is possible that the concentration of K-feldspar phenocrysts may represent some form of disrupted flow cumulate. Mineral proportions are typically granitic with almost equal quantities of quartz, K-feldspar and plagioclase with biotite as the dominant ferromagnesian mineral

2.5 Existing borehole data

This paragraph provides an overview and analysis of the available borehole data. This data consists of borehole databases (from the ministry of Water and Environment and from WE Consult), national reports on the (hydro)geology of Uganda and data from the respective districts.

An extensive dataset of existing boreholes in the area is used to create an image of the favorability of the area in terms of groundwater. Figure 5 shows an overview of the boreholes that are used for this analysis. The overview is a result of combining the databases of WE Consult and the Ministry of Water and Environment for Mayuge district.

The quality of the data is relatively good but the user of the data should keep in mind the fact that some of the boreholes do not have the right coordinates because map datums (Arc60 versus

WGS84) were mixed up during the registration of the borehole. This results in a spatial deviation of approximately 300 m.

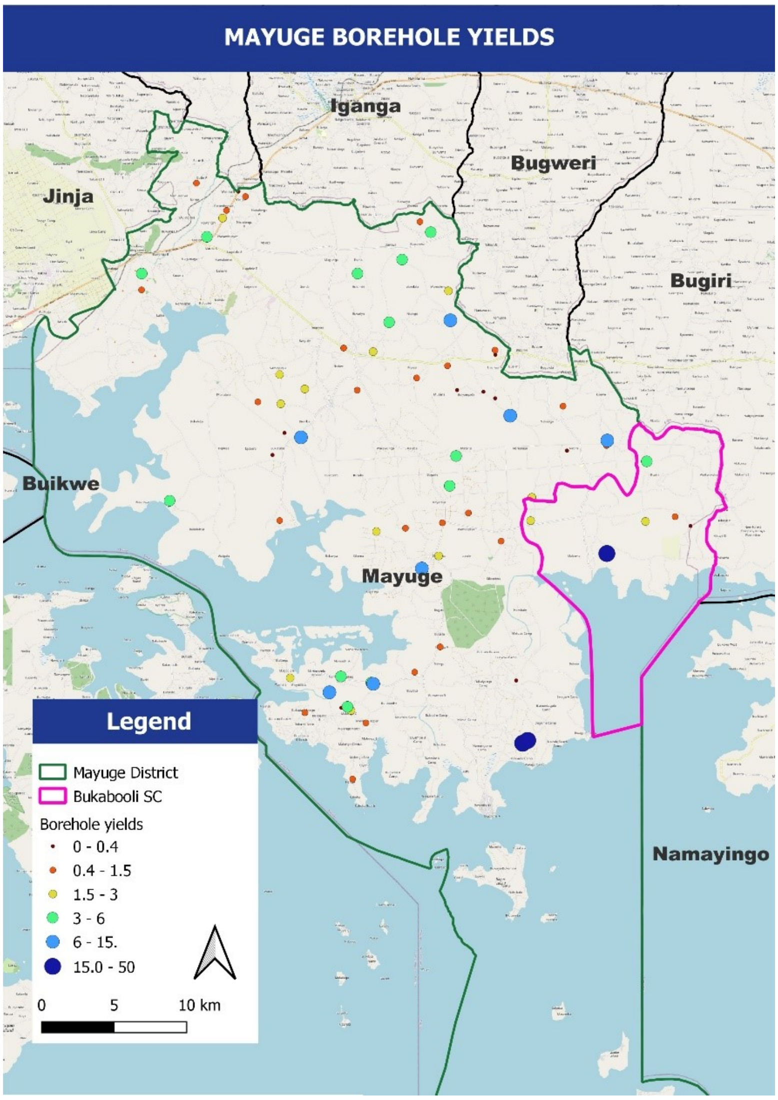

Figure 5 Borehole yield

The spatial distribution of the boreholes and their yields shows that boreholes between 6 and 15 m^3/hr are relatively common and occur in most areas of the district but rare in the project area (Bukabooli Subcounty). Boreholes higher than 15 m^3/hr mainly occur the south and east of the district. One borehole with a yield of 34.4 m^3/hr is found in the project area.

2.5.1 Borehole data per administrative unit

Table 2 shows an overview of the borehole data per subcounty in the Mayuge district. The data is used to indicate the favorability of the area in terms of groundwater. However, it is important to note that the data should be handled with care. Besides the possibilities of errors in the data, the dataset also mainly consists of handpumps, and most dry boreholes are not mentioned in the data.

The average yield in the Bukabooli subcounty where the villages of interest are located is 1.4 m^3/hr, with a maximum yield of 34.4 m^3/hr. The average drilling depth is 55 m and the maximum recorded drill depth is 73.5 m. The average depth to bedrock is 25.9 m and the maximum is 40 m. There is no much information about water strike levels in Bukabooli subcounty. The success rate (based on a hand pump yield) in Bukabooli subcounty is 93.3%

Table 2 Mayuge borehole data per subcounty

Sub county	Min of DTB(m)	Average of DTB (m)	Max of DTB(m)	Min of WSL(m)	Average of WSL(m)	Max of WSL(m)	Min of yield(m3/hr)	Average of yield(m3/hr)	Max of yield(m3/hr)	Min of Depth(m)	Average of Depth(m)	Max of Depth(m)	Success Rate(%)
BAITAMBOGWE	16	25.8	34.6	26.0	26.0	26.0	0.0	2.2	12.2	30.6	53.6	75.0	81.3
BUKABOOLI	15	25.9	40.0				0.2	1.4	34.4	27.0	55.4	73.5	93.3
BUKATUBE	12.43	25.4	39.8	35.0	47.3	65.0	0.0	1.8	10.2	30.7	53.3	84.3	74.5
BUSAKIRA	10.75	23.1	29.4	30.0	30.0	30.0	0.0	1.6	6.0	26.8	51.5	70.0	79.4
BUWAAYA							0.6	3.4	8.0	40.4	57.7	76.0	100.0
IMANYIRO	16.3	27.4	40.0	25.0	38.5	52.0	0.0	1.9	10.0	45.2	57.6	80.1	62.5
KIGANDALO	12.2	30.5	52.0	39.0	39.0	39.0	0.0	2.5	12.0	28.0	58.2	85.5	71.1
KITYERERA	15.2	34.4	58.0				0.0	2.4	10.0	27.4	57.7	82.2	80.0
MALONGO	18.94	27.6	36.6	14.0	31.3	80.0	0.1	2.0	7.0	22.0	46.9	87.2	62.5
MAYUGE TOWN COUN-CIL	27.6	27.6	27.6				0.6	0.7	1.0	46.1	52.0	61.0	100.0
MPUNGWE	40.5	45.7	48.6	40.0	46.7	55.0	0.0	1.8	9.0	39.9	61.2	84.6	61.9
WAIRASA	15.35	33.2	65.0				0.0	1.7	10.0	42.1	67.8	91.6	70.0

2.5.1 Borehole data per geological unit

Table 3 shows the data of all boreholes in Mayuge District per geological unit present in the districts. It should be noted that the geological map, on which the classification is based, is a simplification of reality. Therefore, the table contains a certain degree of uncertainty, however it provides useful insight in the situation. The project area is underlain by Mayuge granite (highlighted with green) that has a success rate of 73%, based on yield of a handpump borehole.

Table 3 Borehole data in Mayuge district per geological unit

Lithology	Min of DTB	Average of DTB	Max of DTB	Min of WSL	Average of WSL	Max of WSL	Min of yield	Average of yield	Max of yield	Min of Depth	Average of Depth	Max of Depth	Success Rate
Butte granite	18.3	21.1	23.9				0.2	3.0	11.4	42.7	52.6	75.0	92
Cherty quartzite, shale, black shale and BIF	38.0	38.0	38.0				0.6	0.6	0.6	73.5	73.5	73.5	100
Kayango granite				39.0	39.0	39.0	1.5	4.2	9.0	39.9	52.8	66.2	86
Kibuye porphyritic granite	12.2	21.5	30.9				0.4	2.0	9.0	45.7	53.8	64.4	100

Lithology	Min of DTB	Average of DTB	Max of DTB	Min of WSL	Average of WSL	Max of WSL	Min of yield	Average of yield	Max of yield	Min of Depth	Average of Depth	Max of Depth	Success Rate
Mayuge granite, locally porphyritic	10.8	29.5	58.0	14.0	37.9	80.0	0.0	1.9	12.2	22.0	55.9	87.2	73
Medium-grained granite							0.6	2.6	3.8	40.4	56.8	76.0	100
Porphyritic granodiorite	14.0	19.7	24.7	35.0	35.0	35.0	0.3	0.5	0.6	48.6	53.8	58.2	40
Shale, slate, phyllite	19.2	36.9	65.0				0.0	2.6	10.0	30.7	62.2	91.6	77

2.6 Water quality

2.6.1 Groundwater Quality Map

The water quality is determined by many different parameters together and therefore, it cannot be expressed as a single number. The parameters on which the water quality depends, can vary significantly over small distances and are not constant over time (dependent on rainfall amount, stream flow, land use etc.). Therefore, without detailed sampling and monitoring, it is not possible to draw conclusions about water quality on a detailed scale. However, the groundwater maps of the different water management zones in Uganda (MWE, 2015) provide information about the water quality on a larger, more regional scale. This results in some generic water quality conclusions for the region. According to the water quality map (Figure 6), the project area is in the marginal zone i.e., above guidance values and below maximum acceptable values.

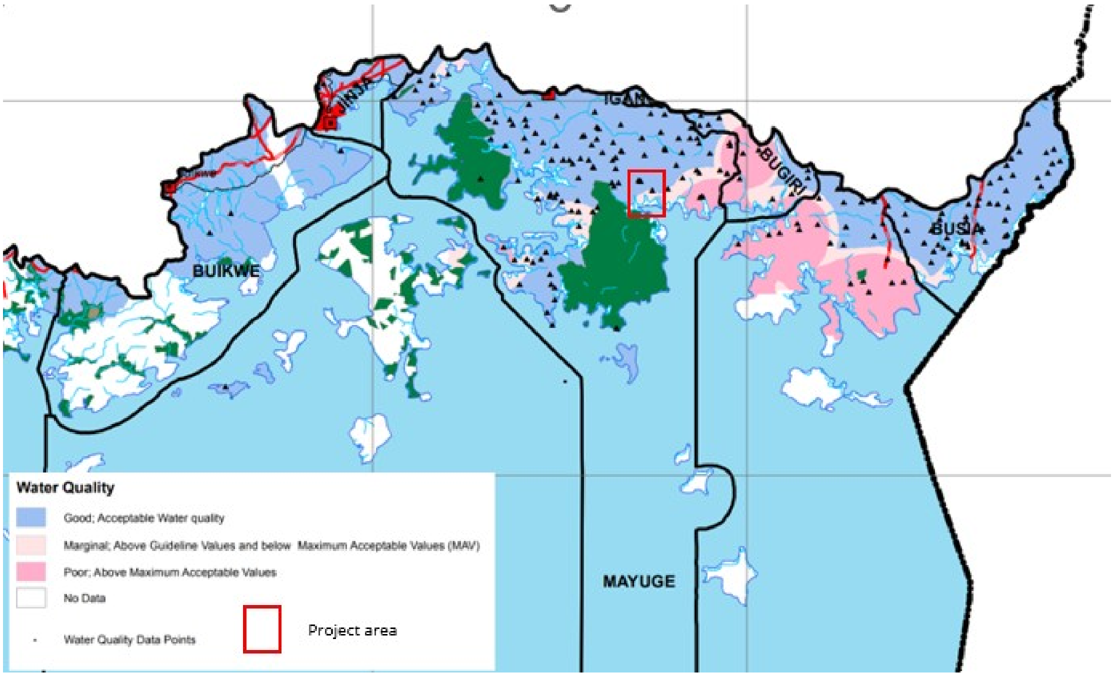

Figure 6 Water quality map (MWE, 2015)

Water quality problem areas are those areas where samples have been analyzed and found to contain concentrations above the maximum acceptable values. This does not necessarily mean that all water in such areas will be of poor quality. It does however give indications to areas where problems have occurred. The marginal and poor water quality areas are due to high levels of Total Iron, Total Hardness, Fluoride, Chloride, Sulphate and Total Dissolved Solids.

2.7 Hydrogeology

2.7.1 General hydrogeological model

Groundwater in the gneissic and granitoid formations, which are found in Mayuge district, generally occurs in the weathered rock or overburden (regolith) and in fractured rock. The weathered rock may have a good transmissivity and storage abilities to provide some yield; however, generally, the better aquifers are found in the contact zone between the overburden and the fresh rock. This zone is mechanically disintegrated with less secondary clay minerals resulting in a higher transmissivity.

The highest yielding aquifers in these types of geological formations can be expected in the fractured bedrock. Boreholes are usually drilled into the fractured bedrock where the permeability is rather high and where the storage can be provided by the overburden. Large and deep, fractured aquifers may be recharged through a connected system of fractured zones. The recharge of shallow aquifers, found in the overburden or in a fractured upper part of the bedrock is generally dependent on the size of the catchment area and the lithological character of the overburden. A simple illustration of the different types of aquifers to be expected in basement formations is given in Figure 7.

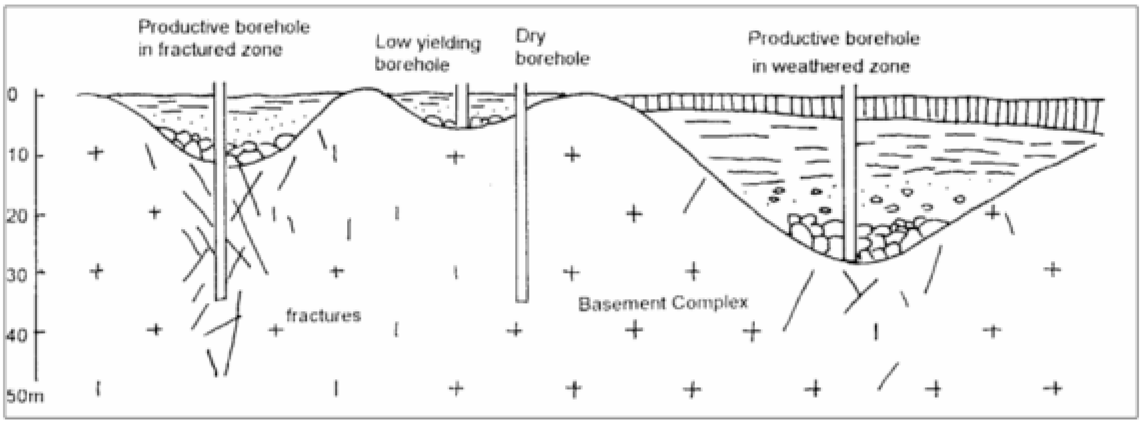

Figure 7 Conceptual model of aquifers in weathered and fractured zones in basement rocks

2.7.2 Factors determining hydrogeology

The hydrogeology of the area is dependent on a number of factors or parameters. The most important are listed below. Most of these have been described individually in the chapters before. Together, they determine the hydrogeology of the area and how suitable a region is for groundwater abstraction.

- Geology: lithology, fractures, faults, dykes, weathering etc. It was found that the area is dominated by different types of gneiss formations, which are not always easy to discriminate between. It is underlain by basement complex and at various places capped by laterite.
- Rainfall/recharge: rainfall amount and pattern, temperature, humidity etc. The Eastern part of Uganda is relatively warm all over the year. Furthermore, annual precipitation is on average above 1,300 m. The year is clearly divided in a dry and a wet season. During the wettest months (August – October), rainfall amount exceeds evapotranspiration. In general, this means that recharge possibilities are favorable.
- Drainage pattern: how intensely-drained is the area. Most of the streams and small rivers are surrounded by wood or wet vegetation like reed, which minimizes open water evaporation.

2.7.3 Conceptual hydrogeological model

The project area has a relatively homogeneous geology, mainly consisting of Mayuge granite. As mentioned before, for productive boreholes the fractured or thoroughly weathered zones have to be identified.

The hydrogeological model that can be applied to the project area, can be described as follows:

1. The higher areas serve as recharge zones, where surface water infiltrates.
2. Subsurface water flows through the soil or overburden, or in the valleys through sedimentary layers. This can yield some groundwater, but usually no substantial amounts.

3. Deeper groundwater will flow through fractures (secondary of the rock), which form preferential flow paths through which groundwater flows relatively fast and can be discharged quickly.

These fractures are expected to be found mainly at zones where a high density of lineaments is found or where they cross. These areas are targeted during the geophysical siting.

2.7.4 Recharge

Groundwater originates from rainwater. Part of the rain that falls, will collect in the channels, streams, swamps and rivers. Some of it, however, will infiltrate and part of that infiltrating water will recharge the aquifers from which boreholes pump the water. It is rather difficult to assess the runoff and recharge in an area because they are depending on many factors. Such factors include:

- soil type: laterite or outcrops will have a high runoff/low recharge rate, whereas organically rich soils have a high recharge rate;
- land cover/use: usually a high level of urbanization or vegetation with a high leaf cover has a relatively low recharge rate, whereas certain crops with relatively low leaf cover have a high recharge rate;
- intensity of the rainfall events: the more intense the rainfall events, the higher the runoff and lower the recharge;
- geological unit: alluvium will on average have a higher recharge rate than unfractured granite or gneiss rock;
- Slope/elevation: if slopes are relatively steep, this enhances quick runoff and will result in a low recharge rate.

Some quite advanced methods to estimate the recharge of an area exist, including modelling or GIS calculations. In this case, however, a simplified and straight forward method will be used, following the method as described in (NWRA, 2013). In this report, a rainfall-recharge relation has been obtained for southern and eastern Uganda, in which the project area falls as well. For the project area, the relation is as follows:

$$Re = 0.363P - 277.22$$

If an average annual rainfall amount of 1,350 mm is assumed, this results in an average recharge amount of about **135 - 203 mm** (which is about 10% - 15%). An average production borehole between 10 and 20 m^3/hr would in this case require a recharge area of about 0.35 or 0.7 km^2 respectively, assuming a daily pumping time of 20 hours and that there are no significant other groundwater abstractors. In places with relatively little industrial development, this is usually a valid assumption.

Given the fact that Mayuge district contains mainly agriculture (little urbanization), is relatively flat (no steep slopes) and has few outcrops, it can be concluded that recharge will not easily become a limiting factor for groundwater abstraction in the area.

3 RECONNAISSANCE VISIT

3.1 Activities

3.1.1 Borehole sampling

Electrical conductivity (EC) and pH were measured for some boreholes in the project area as shown in Table 4. Only one borehole had EC above 2500 µScm, which is above acceptable limits for untreated raw ground water as per the US EAS 12: 2014.

Table 4 EC for visited boreholes during inception

No	Village name	Type	UTM X	UTM Y	EC (µS/cm)	PH
1	Mayirinya	Shallow well	575359	44467	530	6.3
2	Mayirinya	Borehole	575431	44422	1773	6.6
3	Rwandara	Shallow well	573013	41842	837	6.3
4	Kirongo B	Borehole	567512	37548	629	6.9
5	Kirongo B	Shallow well	567752	37700	86	7.1
6	Kirongo B	Borehole	568177	37897	613	6.3
7	Makoma	Borehole	568265	36184	1674	7.3
8	Bujoto	Borehole	570993	37312	2830	7.3
9	Bujoto	Borehole	570908	37047	414	7.3
10	Namulube	Borehole	570513	37730	1063	7.7
11	Namulwana B	Borehole	573617	39162	2470	7.3

3.2 Site selection criteria

After carrying out a reconnaissance visit around the six proposed villages, WE Consult decided to focus on two villages. The two villages were Makoma and Bugumya. While carrying out the geophysical measurements, the team decided to include Kirongo Village. Selection of the sites was based on the following:

- Distance from boreholes that had a saline taste and high EC
- Distance from a known high yielding borehole with a low EC value

3.3 Conclusions and recommendations

Based on all information obtained during the desk study and reconnaissance, initial target areas were identified. These are areas with a relatively high expected groundwater potential. This selection was mainly based on the presence of lineaments, where they cross, the topographical setting of the area and other relevant features. The focus area, however, is relatively small (roughly within 2 km around the villages of interest) and therefore options quite limited. An overview of the suggested profiles is given in Table 5 and their locations are shown in the map. Note that this is an indicative map to show the lines along which it was suggested to survey, rather than the real length of the profiles.

Table 5 Suggested profiles in the target areas, based on desk study

Profile	Start		End		Target
MAR-P1	566739	39520	566427	40032	Valley
MAR -P2	567465	40865	567522	40394	Valley
MAR -P3	567589	38920	568331	38686	Intersection of Lineaments
MAR -P4	567040	37420.	567032	38248	Valley
MAR -P5	568938	38654	569717	38216	Valley
MAR -P6	569090	36727	569738	36910	Valley
MAR -P7	575932	42647	576016	41821	Valley, Intersection of lineaments
MAR -P8	577431	44269	576865	43922	Valley, Intersection of lineaments
MAR -P9	576151	44338	575717	43807	Valley, Intersection of lineaments
MAR -P10	575352	44375	575169	43911	Valley, Intersection of lineaments

The target areas were visited during the reconnaissance survey and the coordinates for the start and end of the geophysical profiles were then recorded. Some of the targets within the target areas may not be suitable for geophysical measurements. Other locations not yet identified during the desk study may be selected based on field results. The final target sites are described in the next chapter.

4 GEOPHYSICAL SURVEY

4.1 Introduction and methodology

One siting team was deployed, headed by a hydrogeologist who was assisted by a geophysical field assistant. Four casual laborers were recruited from the project area to support the hydrogeologist with the physical work (hammering electrodes, carrying equipment, vegetation clearing etc.).

Detailed geophysical measurements were carried out using an SAS 1000 Terrameter. Measurements were carried out at the sites selected from reconnaissance. Resistivity profiles and Vertical Electrical Soundings (VES) were carried out at promising anomalies of the profiles. The profiles were carried out perpendicular to anticipated lineaments as identified during the desk study.

The measurements were processed and analyzed using IPI2Win software (for VES interpretation) and Excel spreadsheets. The best sites were selected basing on the analysis of the available information.

An overview of the sites that were surveyed can be found in the summary sheets in Annex 2

4.2 Discussion of survey results

4.2.1 Overview

A total of 3,160 m of profiling, 9 VESs, and 2 calibration VESs (VES at an existing water source) were carried out in 3 villages. Table 6 shows the summary of the profiles and VESs that were carried out.

Table 6 Summary of geophysical results

Profile	Start X	Start Y	End X	End Y	Length (m)	VESs
P1	568839	36699	568289	36644	540	1
P2	568883	36679	569322	36773	450	1
P3	567011	38214	566963	37860	350	2
P4	567435	37498	566965	37666	510	1
Calib P1	568294	36086	568211	36311	240	1
Calib P2	567809	37733	567468	37496	450	1
P5	567047	37050	567109	36431	620	4

4.2.2 Results of geophysical measurements

The siting results are described and discussed in detail per target area in the summary sheets in **Error! Reference source not found.**. This Annex also contains detailed maps where the locations of the surveys can be found. This chapter contains a more summarizing view of the results, as well as some general remarks and conclusions. The siting results are briefly described and interpreted in the next sections.

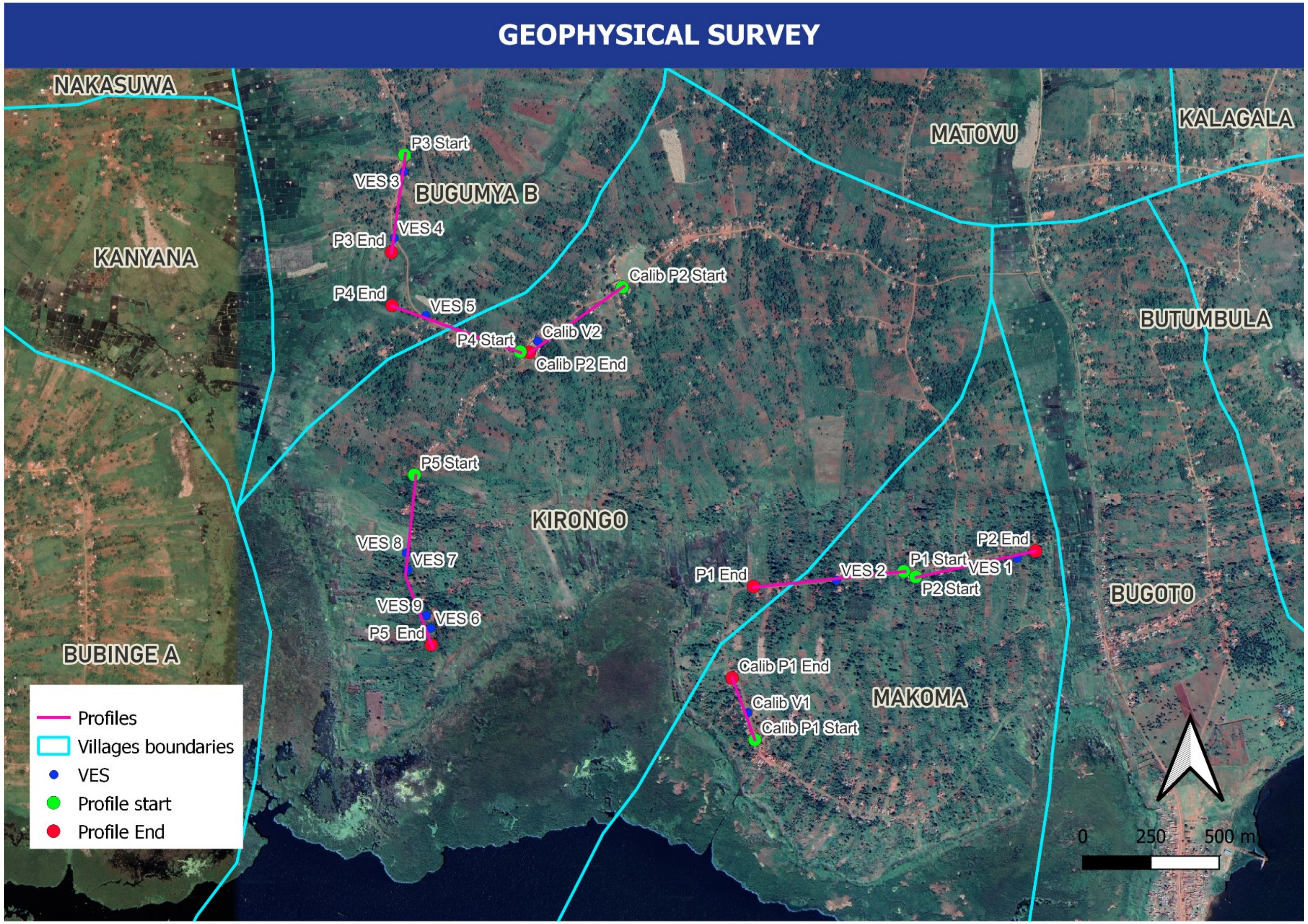

Figure 8 Geophysical survey profiles and VESes

4.2.2.1 Geophysical data

Profile 1

Profile 1 shows low resistivities and on it is a nonfunctional shallow well that is on a low value anomaly. One VES was carried out on this profile.

Profile 2

Profile 2 starts with low resistivity values and towards the end the values raise from below 50 to 300 Ohmm within laterite outcrops. There were well pronounced anomalies on this section of the profile. One VES was carried out on this profile.

Profile 3

It shows remarkably low resistivity values from the start to the end just like profile 1. Two VESes were carried out on this profile.

Profile 4

Profile 4 targets a small valley. It has low resistivities similar to those on profiles 1 and 3. Two VESes were carried out on these anomalies.

Profile 5

Shows low resistivity values at the start and high values towards the valley. VESes were carried out in both low resistivity values and high resistivity value anomalies.

4.2.2.2 Calibration

Two calibration profiles were carried out, the first profile (Calib 1) was carried out on a borehole with EC of 1560 μS/cm and the VES was carried out on a borehole of EC of 650 μS/cm.

Profile Calib 1

Shows low resistivity values and the borehole is not on a clearly pronounced anomaly.

Profile Calib 2

This profile has 2 boreholes on it and it has low resistivity values below 50. The first borehole is on a high anomaly with a value of 80 Ohmm, higher than the other values and the second borehole too.

4.2.3 Recommended drilling sites

The project needs one production borehole to be drilled. Based on the analysis of the geophysical survey results and the desk study, the most promising site has been selected and two alternative sites, in case the first site is not successful for any reason.

Drilling should only be done on the recommended sites or alternative site. The outcome and progress of drilling should be followed carefully during the project execution. These results should be analysed in relation to the geophysical results and decisions on drill sites should be adapted if necessary.

The geophysical results and hydrogeological motivation are given below.

An overview of the sites is given in Table 7.

Table 7 Details recommended drilling sites

Drilling priority	VES	Profile	Sta-tion	X	Y	Latitude	Longitude	Remarks
Drill point	1	2	38	569255	36747	0.332442	33.622375	VES looks like VES J a (VES for 30 m^3/hr) and they were both carried out in sections with re-sistivities greater than 100 Ohmm
Alternative 1	7	5	35	567023	36705	0.332063	33.602318	Carried out on a low value anomaly
Alternative 2	6	5	58	567107	36492	0.330136	33.603072	Wide anomaly

For a complete overview of all siting results, reference is made to **Error! Reference source not found.**., An overview per site of the VES and anomaly is given in the figures 13 to 15.

VES 1

Profile of VES 1

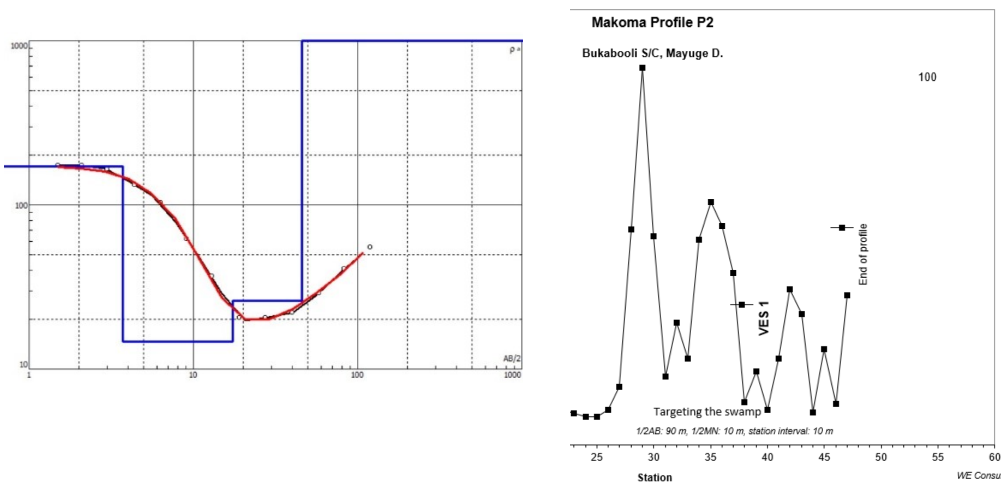

Figure 9 Siting results drilling recommendation (VES 1)

VES 7 **Profile of VES 7**

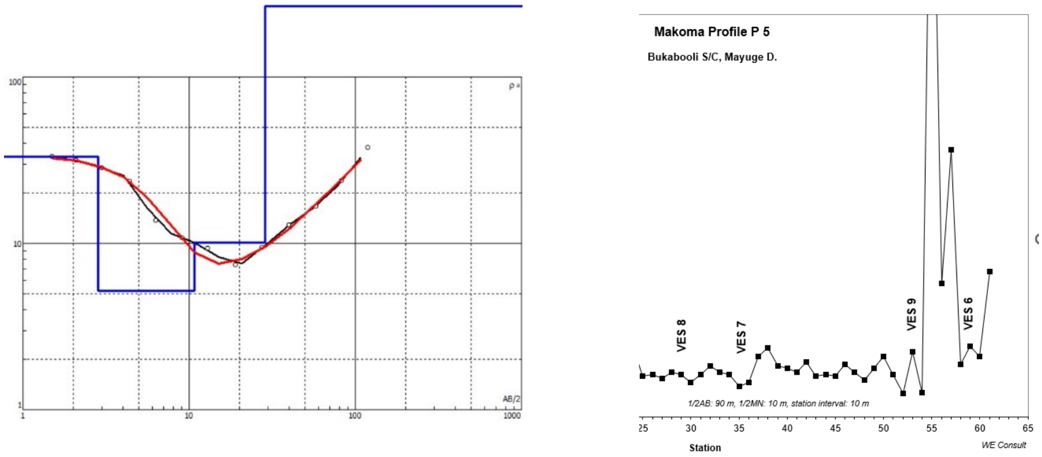

Figure 10 Siting results drilling recommendation (VES 7)

VES 6 **Profile of VES 6**

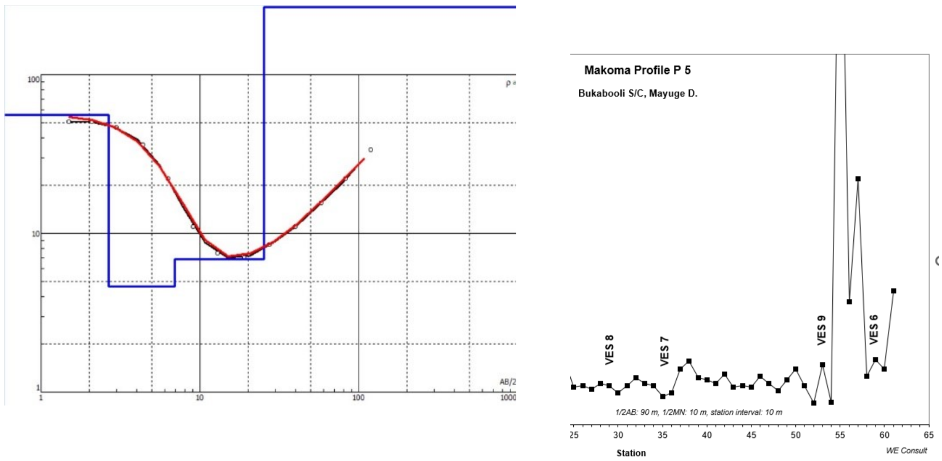

Figure 11 Siting results alternative (VES 6)

5 BOREHOLE DESIGN AND TESTPUMPING

5.1 Borehole Design

The production borehole should be drilled and cased to the bottom. In this kind of design, the well diameters may differ, but the final well diameter must allow for installation of 6”-6.5” for production boreholes (large diameter, high yield boreholes) down to the bottom of the well. Because the borehole is cased to the bottom, this borehole design is most often referred to as “Shallow well design”.

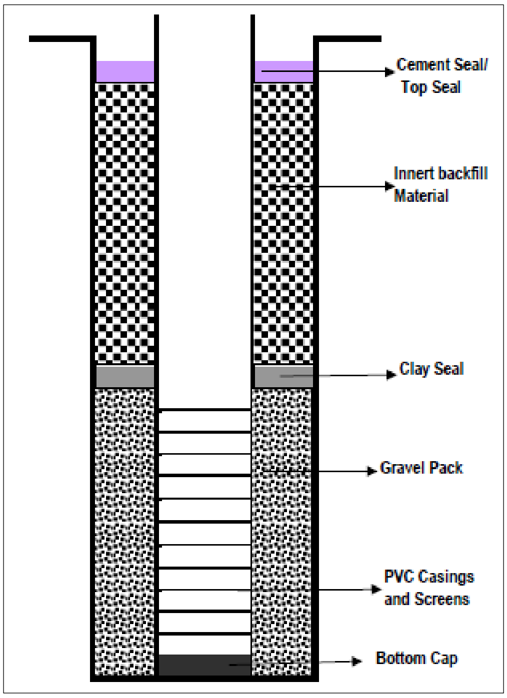

Figure 12: Shallow well design

The production borehole should be drilled at 300mm (12”) through soft collapsible overburden until firm rock is encountered. Drilled further with 250mm (10”) bit for 3m or more through non-collapsing formation; and finished with either 10” or 8” to final recommended depth. Cased with 6"/6.5” (152/165mm) ND uPVC Class D casing, 6mm wall thickness. Screened sections adjacent to aquifer zones at depths as instructed by the Supervisor. The screened sections are to be gravel packed. The size of the casings and their length should depend on the amount of water anticipated or obtained. Bottom annular space between uPVC casing and borehole to be grouted with cement slurry of 1.67-2.08 Kg cement/litre (24-30 litres of water per 50 Kg bag of cement). Grout is to be injected into the annulus using tremie pipes, or a method approved by the Supervisor, in a continuous operation so that a complete and continuous seal is achieved. In general, since these boreholes are installed with motor driven pumps, it is preferred that they are fully cased.

The following table can be used for guidance;

Yield [m³/hr]	Pump Duty lift [m]	Motor/Pump dia. [mm]	Rising Pipe dia.	Min Casing dia.
<8	<170	95 / 101	2"	5"
<14	<110	95 / 101	2"	5"
<17	<75	95 / 131	2½	6"
<17	<220	138 / 142	2½	6"
<30	<190	138 / 142	3"	6"
<46	<170	138 / 147	4"	8"
<60	<180	138 / 147	5"	8"
<77	<130	143 / 200	5"	8"
<95	<95	143 / 200	5"	8"
<95	<150	192 / 209	5"	10"

(Source: Technical Specifications for Drilling, Test pumping, Pump Installation and Associated Works, MWE 2019)

5.2 Test pumping

The Contractor shall perform test pumping to establish the performance and yield of the borehole, and shall provide a suitable, self-contained, mobile test pumping unit, approved by the Client, for this purpose. The type of test will depend on the yield and the use of the borehole. The depth of installation of the pump for the test shall be above the lowest water strike.

Boreholes to be installed with motor driven pumps will initially be tested in the manner of step tests with the initial step being at approximately1/3 of driller's estimated yield; the 2nd, 3rd and 4th steps will be approx. 2/3, 3/3 and 4/3 of driller's estimated yield; additional steps may be recommended by the supervisor and the last step should stress the borehole (steep drop in water level). The duration of each step shall be 90 minutes and a minimum of three steps of increasing discharge will be undertaken. The final step should lower the dynamic water level to approximately three metres above the level of the pump. Discharge for each step should be kept constant. On completion of the final step, the recovery of water level should be monitored by the contractor until 95% recovery has been achieved, or until advised by the Supervisor. The well should then be tested for 72hours at a constant discharge rate based on the step test results and as mutually agreed upon by the Supervisor and the drilling contractor. After which the well should be allowed to recover to 95% or as advised by the Supervisor.

Water levels shall be measured during test pumping by the Contractor by means of an electric contact gauge (dipper). The frequency of measurement shall be as specified on an agreed test pumping data form or as otherwise determined by the Supervisor.

5.3 Cost Estimates

Below is an estimate of drilling a production borehole installed with 5 inch or 6 inch ID UPVC casings and screens following the above drilling method;

Item	5 inch	6 inch
Preliminaries and General	5,000,000	6,000,000
Borehole construction and well development	16,800,000	26,800,000
Test pumping (72 hours)	8,200,000	8,200,000
Casting of (1x1) m platform including pedestal	850,000	850,000
Total excl VAT	**30,850,000**	**41,850,000**
VAT 18%	**5,553,000**	**7,533,000**
Total Incl VAT	**36,403,000**	**49,383,000**

Experience shows that, it is normal to drill two-three attempts to achieve one production (high-yield) well. This does not imply that, the cost of drilling doubles or triples since the client only incurs direct costs as per utilized items in the drilling contract BoQ. Therefore, it is advisable to prepare a proper drilling BoQ, that balances the interests of the client and contractor.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The current study was carried out to investigate the hydrogeology of Bukabooli subcounty and to come up with one recommended drilling site.

The following conclusions have been drawn, based on the desk study and the siting results:

1. The desk study has shown that the area has groundwater potential.
2. Based on the results of the desk study and the geophysical results, 1 drilling site plus 2 alternative sites have been recommended.
3. The low resistivity values show that there is a chance of getting saline water though the calibrated borehole with fresh water had low resistivity values too; the reason drilling has been recommended.
4. The existing borehole of 30m3/hr that is installed with a hand pump currently has fresh water based on the EC and the PH. This borehole could be a candidate for motorization provided;
    i. The demand will not exceed 15m3/hr or roughly 120m3/day (solar powered) or 300m3/day if it will be powered by grid+solar or grid alone. This less output per hour and per day is generally assumed to be low with the assumption that the well is installed with a 5" ID casings, common for hand pumps. The casing diameter still has to be investigated.
    ii. The host community where it is located, would have to consent to the well motorization, through the community, political and technical leaders from community level to District level.
    iii. Fresh tests would be carried out on the well. These would include, video analysis of the well lining to the bottom (with borehole camera), test pumping (step tests & long duration constant test), and water quality analysis (physiochemical and bacterialogical).

6.2 Recommendations

Drilling should only be done on the recommended sites or alternative site. The outcome and progress of drilling should be followed carefully during the project execution. These results should be analysed in relation to the geophysical results and decisions on drill sites should be adapted if necessary. The recommended drill depth is based on the data of existing boreholes and the geophysical measurements carried out. It should be noted that the interpretations are a simplification of the collected data. The actual depth to bedrock and final decision on when to stop drilling has to be made on site by the supervisor in consultation with the driller.

The next step of preparation of technical specifications, drilling and test pumping BoQs, and site supervision require an experienced hydrogeologist to be involved. Drilling and Test pumping supervision is a must if the results of this stage must be relied upon for the next steps.

6.3 Next Steps

In order to achieve the overall objectives of the project, if a piped water has to be built to supply safe water to the intended beneficiaries, the following steps are envisaged.

1. Borehole drilling, Test Pumping and Water Quality analysis. This should be done by a competent driller and supervised fulltime by an experienced hydrogeologist.
2. Preliminary studies, feasibility, and detailed design for the water supply system; development of drawings and Tender documents (drawings, specifications, scope of works, etc). The source of water can be the drilled well or the existing borehole. This phase will have a complementary task of ESIA (likely a project brief, not a full ESIA). The design should be approved before the next phase.
3. Procurement of a competent contractor for the construction
4. The construction of the water supply system and construction supervision.

WE Consult would be delighted to support HFHU in the next stages above up to completion of the project.

Annex 1 Maps

Annex 2 Siting Summary Sheets Per Target Area