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Groundwater Pumping & Storage System

Summer Service Learning Program – Uganda 2015

Sandeep Arakali | Daniel Bejarano | Nathaniel Buescher
Nicholas Cheung | Selamile Dlamini | Alexander Lindqwister
Claus Omolo | Ashley Pete

Executive Summary

This report proposes design and construction considerations for a reproducible, groundwater pumping system that will increase both community access to clean water and crop productivity during the dry season. Currently, 44% of families in Uganda do not have access to safe water, creating a major public health concern. In addition, farms are susceptible to weather variations with high levels of crop failure caused by inadequate rainfall during the dry season. Not only does lack of access to water affect people and crops, but also animals commonly raised as livestock—including chickens, goats, and rabbits—which frequently fall ill and die from drinking adulterated water. Commercial farms in rural communities feature people, livestock, and crops sharing common water sources; this makes commercial farms a good focus for application of our system, although the system can be used in any setting.

We begin by providing background information on Southern Uganda. Then we provide a general methodology for designing and constructing the system. Lastly, we present a case study located in Ntungamo where the proposed project will first be implemented.

The general methodology is as follows: (1) perform initial surveys of the land being developed including elevation calculations and potential obstacles; (2) identify sources of groundwater and electricity; (3) design system layout and select parts such as pumps, pipes, fittings, tanks, foundations, and any accompanying structures; (4) determine construction considerations and produce a bill of quantities; and (5) consider maintenance of system.

For our case study, the system is driven by a submersible pump capable of transporting water from a water table depth of 90 meters to three 10,000-liter tanks located 44 meters above the borehole surface. HDPE and PPR pipes transport water from the borehole up to the storage tanks, and from the tanks down to a school and teachers' quarters. This system is designed to serve 2,000 people. The total estimated cost of this system, including labor, transportation, and materials is 238 million UGX. This total accounts for costs associated with safety measures to protect the system from vandalism, water theft, and accidents.

The projected social impact of this project is multifaceted. First, providing clean water to the community surrounding a commercial farm will improve public health. Reliable, pure water stems the spread of waterborne illnesses among both people and animals. Furthermore, increasing crop productivity of the targeted farm will require more labor to cultivate and harvest the increased yield. The labor will be sourced from the surrounding rural communities of the commercial farm. Increased demand for labor creates jobs for local rural communities. Increased employment enables families to gain income. Currently, 63% of total household expenditure in rural areas goes toward food costs. Therefore, higher incomes for these families will allow widespread rural development by providing the means to obtain an education, invest in other crops and livestock, and access health services.

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1 Introduction

This document outlines the context, methodology, and strategy for designing and constructing a groundwater-sourced pump system that transports water to storage tanks at a higher elevation. From the storage tanks, the water can be distributed to any destination at lower elevation using only pipes and gravity. The pump system is a proposed solution to address the lack of rainwater during the dry seasons and clean water throughout the year in Uganda. This solution is meant to be reproducible across the country for a variety of applications such as small-scale community water distribution, livestock water supply, and crop irrigation.

1.1 Scope of Report

This report focuses on the application of the pump system to a commercial farm to increase crop productivity and supply water to surrounding communities. We focus on commercial farms for their ability to finance such projects, their need for irrigation water during the dry season, and their potential to have a positive impact on the surrounding community where such a system may otherwise be cost prohibitive. This reflects in our case study of a commercial demonstration farm.

We begin by briefly introducing the topics of geography, climate, agriculture, and social context of Southern Uganda, where our case study is located. We then outline a methodology for implementing a pump system and apply it to the case study in order to illustrate the strategy of designing and constructing the pump system.

This document does not discuss how to determine the location of safe subterranean water sources or how to construct boreholes and wells. The proposed pump system targets commercial farms that have access to: (1) nearby potable groundwater sources and (2) reliable electricity. Additionally, we make no recommendations for specific materials to use in the system; however, a list of anticipated materials for the case study is available in Appendix G. All costs tabulated in the Appendix G are estimates.

1.2 Problem Statement

This project addresses the problem of limited rainfall during Uganda's two dry seasons and lack of access to clean water throughout the year. Currently, 44% of families in Uganda do not have access to safe water, creating a major public health concern.[1] In addition, farms are susceptible to weather variations with high levels of crop failure caused by inadequate rainfall during the dry season.[2][3] This project offers a more efficient method to supply water to commercial farms and to the surrounding community in locations that may be far from surface water sources, but near potable groundwater fed wells or boreholes.

1.3 Purpose of Project

The purpose of this project is to provide a reproducible, groundwater sourced pump system design for a commercial farm. This design will increase both community access to clean water and crop productivity during the dry season.

[1] http://ageconsearch.umn.edu/bitstream/135134/2/12-3Shively.Hao.pdf

[2] http:/www.fao.org/ag/agn/nutrition/docs/FSNL%20Fact%20sheet_Keyhole%20gardens.pdf

[3] http://www.ugandaexportsonline.com/strategies/zoning_plan.pdf

1.4 Projected Social Impact

The projected social impact of this project is multifaceted. First, providing clean water to the community surrounding a commercial farm will improve public health. Reliable, pure water stems the spread of waterborne illnesses among both people and animals. A convenient water distribution system will also decrease the effort and time people spend transporting water by hand. Furthermore, increasing crop productivity of the targeted farm will require more labor to cultivate and harvest the increased yield. The labor will be sourced from the surrounding rural communities of the commercial farm. Increased demand for labor creates jobs for local rural communities. Increased employment enables families to gain income. Currently, 63% of total household expenditure in rural areas goes toward food costs. Therefore, higher incomes for these families will allow widespread rural development by providing the means to obtain an education, invest in other crops and livestock, and access health services.

2. Background

2.1 Geography & Climate

The southern tip of Uganda consists of several highland districts including Kabale and Ntungamo. The geography creates a microclimate with considerably cooler temperatures and increased rainfall relative to the rest of Uganda and sub-Saharan Africa. These districts experience a two-season climate with wet seasons occurring from March to May and from September to November. The rest of the year experiences a dry season with low rainfall and slightly warmer temperatures. Periodic rains and heavy year-round fog make the hills and valleys fertile. For this reason, farmers heavily cultivate most of the hills in the region. A summary of the climate data is provided below:

- Elevation: 1,219 - 2,347 meters
- Temperature: 12ºC (night) - 25ºC (daytime)
- Humidity: 90-100% (morning); 42-75% (afternoon)
- Rainfall: 20 mm (dry season) - 150 mm (wet season)[4]

2.2 Agriculture

Uganda's economy relies heavily on agriculture. In recent years, food crops accounted for almost half of agricultural GDP[5] and as much as 85% of export earnings.[6] Uganda's main export is coffee; it also exports tea, cotton, tobacco, cassava, maize, millet and pulses. Agriculture employs over 80% of Uganda's workforce. Moreover, approximately 30% of Uganda's total land area is used for agricultural purposes. Despite the importance of agriculture, the overall share of agriculture in GDP declined from around 50% in the early 1990s to approximately 23% in 2008.[7] Although this figure increased slightly to 24% in 2012[8], the slowdown from the 1990's attributes to a decrease in agricultural production.[9]

[4] https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Kabale,Uganda
[5] http://www.ugandaexportsonline.com/strategies/zoning_plan.pdf.
[6] http://ageconsearch.umn.edu/bitstream/135134/2/12-3Shively.Hao.pdf
[7] *Ibid*
[8] http://www.africaneconomicoutlook.org/fileadmin/uploads/aeo/2014/PDF/CN_Long_EN/Ouganda_EN.pdf
[9] http:/www.fao.org/ag/agn/nutrition/docs/FSNL%20Fact%20sheet_Keyhole%20gardens.pdf

Over half of the country's agricultural production is consumed domestically. However, malnutrition still accounts for 40% of all child deaths.[10] In fact, Uganda is one of the most malnourished countries in the world, with 6% of households classified as "food insecure" and 21% "moderately food insecure" at the risk of becoming food insecure.[11] Uganda's agricultural sector is based on small-scale farms, both commercial and subsistence, that contribute approximately 70% of agricultural production.[12] However, small farms are highly dependent on weather and soil fertility. For these farms, inadequate rainfall, excessive rainfall, pests and diseases, and low crop yields are known to cause food insecurity.[13]

2.3 Social Context

Southern Uganda is primarily populated by the Bakiga people who practice agriculture using traditional methods and tools. Previous studies by the Kigezi Healthcare Foundation (KIHEFO)[14] show that some of these customs, such as use of the hand hoe to till the soil, hinder agricultural productivity. Another example of a traditional method is the land tenure system. Following the death of a landowner, the sons fragment the land into equal shares and divide it amongst themselves. Each son then cultivates his own parcel of land independently, rarely engaging in communal farming except for occasional assistance; this occurs even if all of the beneficiaries are residing in the same house. This land fragmentation occurs until plots of land become impractical to divide further. Land fragmentation impedes the use of more efficient mass cultivation techniques, reducing agricultural production.

Efforts to introduce reform have largely been met with indifference either due to a lack of viable and fair alternatives or unwillingness to change traditional ways. **Demonstration has proven to be the most effective way to introduce new ideas to rural communities.** Once people actively see new systems and technologies benefitting their neighbors, they become more open to changing their own practices. This underlines the importance of the demonstration farm in our case study and its implementation of novel ideas to improve farming productivity.

3 Project Methodology

3.1 Layout & Design

This section describes general methods and considerations for designing a groundwater sourced pump system that can store water in a reservoir tank(s) and deliver it to specified distribution point(s).

3.1.1 Site Mapping

The purpose of mapping the site is to:

1. Measure distances and directions between system infrastructure (both existing and proposed).
2. Use these dimensions to determine the necessary pump size and lengths of pipe.

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[10] Bridge, A., et al. "Nutritional status of food consumption patterns of young children living in Western Uganda." *East African medical journal* 83.11 (2007): 619-626.

[11] McKinney, P. (2009) Comprehensive Food Security & Vulnerability Analysis (CFSVA) Uganda. Rome, Italy: United Nations World Food Programme.

[12] http://www.eprc.or.ug/pdf_files/researchseries/series25.pdf.

[13] http://www.ugandaexportsonline.com/strategies/zoning_plan.pdf

[14] Kigezi Healthcare Foundation (KIHEFO) is a local not-for-profit; non-governmental organization (NGO) dedicated to community development in Kabale District.

To map the site:

1. Draw the system layout to illustrate the site and pump system design. Use clearly defined cardinal directions (North, East, South, West).
2. Add relevant site features such as:
    a. Property boundaries
    b. Existing roads, walls, structures, or other potential obstacles
    c. Sudden changes in elevation or terrain
    d. Electrical lines
3. Draw proposed locations for the water table access point, storage tank(s), pipes, pump, and water delivery points based on considerations presented in the following sections.
4. Add dimensions to the drawing as critical measurements are made (noted below by component).

There are many possible techniques for obtaining the necessary measurements, some utilizing modern technologies (usually more costly), and other well-established traditional techniques using very simple tools. Some suggested techniques are outlined in Appendix A, although the list is not comprehensive.

3.1.2 Water Source

Before undertaking a project of this nature, access to groundwater must be carefully considered. In many cases, an existing well or borehole may already provide direct access to the water source. If there is no existing infrastructure, then an investigation must be performed to locate the water table and determine a desirable placement to access it from the surface. This is accomplished by conducting a geological survey of the surrounding area. Surveying techniques are outside the scope of this document; however, reliable underground and water table information is critical, so we recommend any surveying to be undertaken by a professional.

It is highly recommended to obtain the well capacity (the rate at which water can be withdrawn without affecting the water table depth) from a geological survey as well. This is essential to ensure that the desired flow rate of the pump is less than the recharge rate so that the groundwater is not depleted due to over-pumping.

After determining the groundwater access point, one must consider what modifications must be made to existing infrastructure in order to directly access the water. This may require removing hardware such as a manual hand pump or enlarging the inner diameter of the borehole casing to fit a submersible pump or pipe.

The critical measurement at the access point is the depth of the water table – that is, how far below ground is the lowest point of the water. This number is necessary for selecting the right pump and can vary greatly. The water table depth can range from near surface to 100 meters with boreholes depths typically between 60 and 90 meters.

3.1.3 Storage Tanks

Capacity of the water storage tank(s) should be determined by the estimated quantity of water to be distributed to agricultural fields, houses, and/or the community. Any interruption between the water source and the reservoir tank(s), such as a routine power outage, electrical failure, or pipe rupture, means that only the stored water is available for distribution until the system can be repaired.

To ensure that water is able to flow from the tanks to the desired distribution points under the influence of gravity alone without reliance on electricity, the tank(s) must be placed at a higher elevation. This may be accomplished by placing the tanks at an uphill location, or by using a structure to elevate the tank(s); however this second approach is only feasible for relatively small tanks since the water weight of the full tank must be borne by the structure.

It is important to know the vertical height of the tank inlet (typically near the top of the tank) above the tank base, since the pump pressure must be sufficient to elevate the water this additional distance.

The layout of the system that we propose in the case study appears in Figure 3.1. The system is composed of a submersible pump that pumps water from the water table to the surface via a well. The water then travels uphill through pipes to be stored in tanks. The details of designing such a system are provided in Section 4.

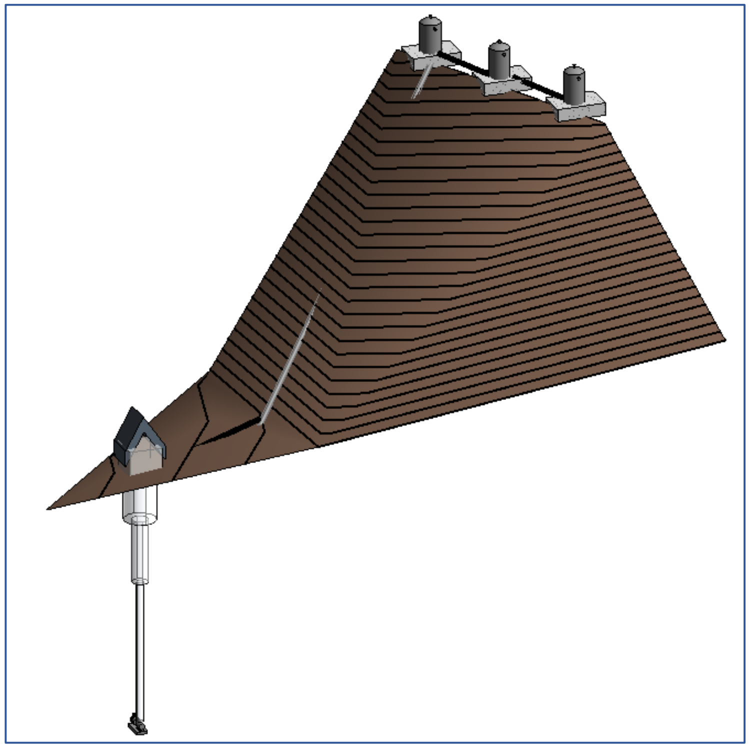

Figure 3.1: Sketch of underground water pumping system to storage tanks

3.1.4 Pipes, Valves & Fittings

A list of the system's pipes, valves, filters, and connections is provided below:

A. **Pipes** – Metal pipes (Copper, Galvanized Steel, Galvanized Iron, Stainless Steel, Cast Iron) and Plastic pipes (PB, Rigid PVC, HDPE, PEX, ABS, PPR)
B. **Pipe connector fittings** – Adaptors, couplings, elbows, bends, reducers, tees, plugs, nipples, saddle, etc.
C. **Flow control devices** – Directional devices (Stop valves, Check valves, Regulating valves), Measuring devices (Water meters, Flow meters, Pressure gauges), and Auxiliary devices (Air valves, Safety valves)
D. **Filters** – Fitting added at end/beginning of pumps to separate particles from water

3.1.4.1 Pipes

Pipes are chosen based on their ability to withstand mechanical stresses, extreme temperatures, solar radiation, and chemical exposure. For a detailed description of the considerations for each of these pipe properties, see Appendix B.2.

Common pipe materials are galvanized steel, copper, and plastic. Plastic pipes are the most widely used because of their versatility, flexibility, and rigidity. Although flexible pipes are often used domestically because of their ease of installation and low cost, the most widely used materials for main, sub-main, hydrants, and manifold pipelines are rigid PVC, HDPE, LDPE, and quick-coupling light steel or aluminum.

Regardless of the pipe type, to design a system, first obtain five key specifications:

1. Length of pipeline (add 5% as safety factor).
2. Quantity of pipe connector fittings (bends, tees, caps, plugs, reducers, etc.), including the number of pipe connectors that have the same type of connection and the number of pipe connectors that have two different types of connections (e.g. tee 90 mm x 90 mm x 2 in [internal threaded], bend 110mm x 3 in [flanged]).
3. Quantity of adaptors (starters). These fittings have one end threaded or flanged and the other end arranged in the same type of connection as the pipe. They are used at the starting point of the pipelines and at any other point where valves are fitted.
4. Quantity of shut-off and air valves (if any) on the distribution network. The air valves are fitted on riser pipes connected with clamp saddles on the mains.
5. Quantity of the riser pipes for the hydrants, the shut-off valves, or the special hydrant valves. Riser pipes are required if the mains are buried. If the mains are not buried, then the fittings for connecting clamp saddles with the shut-off valves must be determined. The number of these fittings is equal to the number of the hydrants.[15]

Even more important than choosing the pipe material is determining the proper pipe sizing. The right pipe size is a trade-off between a diameter that is small enough to minimize pipe cost but large enough to avoid in excessive friction losses (i.e. the reduction in pressure exerted by a liquid flowing through a pipe due to contact between the liquid and pipe walls, valves and fittings). Friction losses raise the required pumping energy and therefore pumping costs. Friction losses increase with decreasing pipe diameter and increasing flow rate. To aid in calculating the total pressure losses in the system due to friction, manufacturers provide friction loss tables for all pipe materials and pipe sizes. It is best to use data provided by the manufacturer for the specific product in use. To select a pipe size, determine:

1. Distance that the water will travel
2. Flow rate required (as well as the system allowance to enable pipes to stay full or drain)
3. Vertical distance between the water source and the outlet of the stock tank
4. Maximum pressure of the system[16]

[15] ftp://ftp.fao.org/agl/aglw/docs/pressirrig.pdf
[16] http://pubs.ext.vt.edu/442/442-755/442-755.html

3.1.4.2 Pipe Fittings

It is essential that fittings, valves, and pipes are of the same type and material. Several important properties, including expansion/contraction features and pressure ratings, are material-dependent, and use of mixed materials could cause failure. Similarly, the proper cement should be used with the proper pipe and fittings.

3.1.5 Pump Selection

To determine the pump requirements, it is necessary to have the following specifications:

1. **Depth** of the water table.
2. **Well capacity**, or the rate at which water is naturally refilled.
3. **Flow rate** that water needs to be pumped to the tanks. This can be estimated based on the number of people expected to use the water source, the area of farmland to be irrigated, and the water requirements for the crops on the land given the local climate.
4. **Head loss,** or energy losses, in the piping system between the pump and the tanks. Several factors contribute to energy losses in the system. Elevation is the dominant factor in determining head loss, and it can be measured using the borehole dimensions and the site surveying methods discussed in Sections 3.1.1-3. Pipe length, pipe diameter, valve restrictions, and bends in the pipe path increase friction, which also add to head loss. See Appendix C.1 for the governing equations of the water flow in the system that can calculate total head loss.

Figure 3.2 can be used as a guideline for selecting a pump. The depth of the well will determine the type of pump needed (green boxes). Pumps can be either surface or submersible. Three main types of pumps are commonly used:

- **Shallow Well Jet Pump** – located at the surface of the borehole, uses a vacuum jet and atmospheric pressure to suction water up, and then a motor and impeller to pressurize it. They are limited by the suction capacity and <u>cannot pull from a depth greater than 7 meters at sea level.</u>
- **Deep Well Jet Pump** – uses a similar concept, except the suction component, or jet, and the impeller are separated. The jet is submerged beneath the water level, while the motor and impeller are still located on at the surface of the borehole. It is <u>limited to a suction depth of about 30 meters.</u>
- **Submersible Borehole Pump** – is capable of pumping water from very deep wells, and the entire pump is submerged in the well. These pumps are generally more powerful but are less accessible than surface pumps for installation and maintenance.

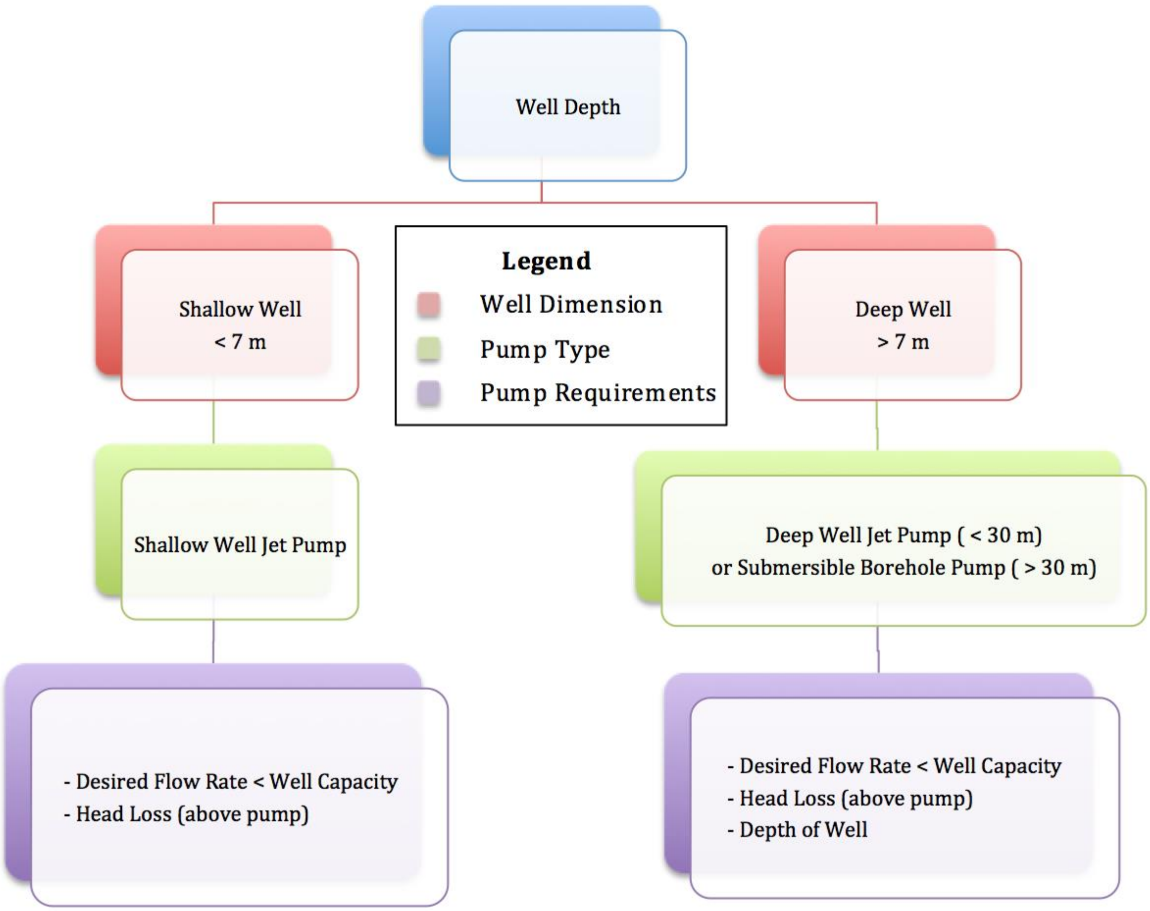

Figure 3.2: Pump Selection Flowchart

The pumping requirements (purple boxes) will determine the specific model of the pump needed to serve the given system. Additionally, power supply, whether via the electric grid or solar panels, must be specified prior to selecting a pump. Once this information is determined, it is recommended to consult a pump manufacturer to select a pump.

3.2 Construction

This section outlines the major components of construction for a generalized groundwater pump system, following the design and planning phase.

3.2.1 System Footprint

The system footprint is a physical representation of all the system components at the actual field site. The area of land occupied by each major component is laid out using stakes and string (or equivalent). This serves to verify the design geometry, as it allows engineers to confirm distances for pipe lengths and to ensure that all major site obstacles to construction have been identified and removed.

3.2.2 Pipe Joints

In case of a poor fit (loose joint or interference) first attempt to remedy the problem by interchanging parts. If the problem persists, determine if the pipe diameter is larger or smaller than the diameter of the

corresponding fitting. If the pipe diameter is larger, sand components as necessary. Conversely, if the pipe diameter is smaller, apply two coats of solvent cement.[17]

3.2.3 Foundation & Bases

To design a foundation, a geotechnical/surveying engineer must perform and analyze soil tests to determine the soil's bearing capacity. Both the composition of the soil layers and the size/weight of the tank(s) should determine the appropriate foundation. Generally, a bearing capacity 3 to 4 times larger than the bearing stress exerted by the structure is desired. To select a foundation, consult a relevant engineering manual such as the American National Standards Institute (ANSI)/American Water Works Association (AWWA) standard: ANSI/AWWA D100-11: AWWA Standard for Welded Carbon Steel Tanks for Water Storage.[18]

Foundations for water storage tanks are usually shallow in the form of a spread footing or mat.[19] The goal is to distribute the load of the tank and its supporting structure over a large area for stability. However, a deep foundation may be required for heavy structures and/or when high bearing capacity soil is not present at shallow levels. The materials necessary for a shallow foundation for a water tank commonly include the following:

- A concrete bottom slab placed below ground
- Foundation walls made of brick or cement
- Backfill (gravel, sand, and rocks to fill the space between the base and the slab)
- A concrete top slab for the tank to sit on
- Drainage system to prevent flooding at the base of the foundation

Before starting construction, the cost of materials, transportation, and labor to build the foundation must be considered. For a sample explanation on how to build a tank foundation, please refer to Section 4.2.2.2.

A nonexistent or improperly constructed foundation poses serious hazards. Uniform settling of the soil will cause the tank to sink into the ground, damaging or breaking any connections leading into and out of the tank. Breakage of pipes or taps could lead to water leaks and expensive repairs. Another more dangerous outcome is uneven settling of the soil, especially when located on a sloped surface. In addition to breaking connections, the tank itself could tip over and start rolling at high speeds, causing injury and destruction of property. Therefore, a proper foundation and base are paramount for any system with high-capacity water tank(s).

3.2.4 Trenching

The trenches for the pipes must be wide enough to ensure proper soil compaction when a pipeline is buried. This is especially important for large diameter pipes. For pipe diameters above 4 inches, a trench at least 12 inches wider than the diameter of the pipe should be specified.[20] The depth of pipe placement should be at least 30 inches below the ground to protect against heavy machinery. Where possible, assemble the pipe above ground and then place it in the trench. If the trench curves, the pipe should be assembled on the outside of the curve to eliminate the possibility of it being too short.

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[17] https://edis.ifas.ufl.edu/pdffiles/CH/CH17100.pdf
[18] http://www.powderbulk.com/enews/story_pdf/pbe_20120321rihf.pdf
[19] http://theconstructor.org/geotechnical/foundations/soil-investigation-foundation-types/26/
[20] www.doa.go.th/aeri/files/pht2008/lecture%20slides/...1998/welcome.pdf

When backfilling, do it in layers with each layer compacted to allow uniform development of lateral passive soil forces, or the pressure that the soil exerts in the horizontal direction. Ensure the backfill material has particle sizes of half an inch or less. Soil may be packed by hand tamping or by using water. Hand tamping involves packing the backfill 2 inches at a time until it is at least 6 inches above the pipe. The bulk density of the compacted soil should be at least 85% of the trench sidewall's soil density.

For rapidly draining soils, compress by water packing. For the initial coverage of the pipe, use fine-grained materials that are free of rocks and clods. In the water packing method, the pipeline must be filled with water before beginning the backfilling operation to prevent the pipe from floating to the surface. Extend the backfill to approximately 8 inches over the pipe. Then add enough water to saturate the initial backfill without over-watering. Close all valves for the pipe to remain full and to allow the wetted fill to dry until firm before covering the rest of the trench.[21]

3.2.5 Maintenance

For general information on maintenance, refer to the following table. The left section of the table shows how frequently the parts of the system on each row must be checked. The right section of the table shows what parts of the system should be checked given a specific problem.

Table 3.1: Time Table for Maintenance Checks and Diagnostics

Time Table for Maintenance Checks					…	Diagnostic Table		
What to check / how often/problem	Weekly	Monthly	Per 2 Months	Per 6 Months	…	Decline in Water Quality	Drop in Pressure	Unusual Sounds
Above-ground Pipe	✓				…	✓	✓	
Water	✓				…	✓		
Valves		✓			…	✓	✓	
Fastenings		✓			…	✓	✓	
Foundation	✓**	✓			…		✓	
Filter			✓		…		✓	✓
Pump (s)				✓	…		✓	✓

** Foundation should be checked weekly during rainy season

4 Case Study

4.1 Background

4.1.1 Demonstration Farm

To illustrate how a commercial farm can improve the development of a rural community, we did a case study based at the Kigezi Healthcare Foundation's (KIHEFO) commercial farm located in Rwahi, Ntungamo. Currently, KIHEFO's commercial farm uses mixed farming techniques and grows onions, cabbage, carrots, pineapples, chili peppers, eggplant, cassava, bananas, kale, and coffee. Additionally, the farm rears goats, chickens, rabbits, and bees. KIHEFO's commercial farm is 10 hectares (25 acres), and is located approximately 180 meters from a school, 120 meters from teachers' quarters, and 200 meters from a river where much of the community grows its crops during the dry season.[22]

[21] https://edis.ifas.ufl.edu/pdffiles/CH/CH17100.pdf

[22] All distances are estimates based on measurements taken at the site (Section 4.2.1). The distance refers specifically to distance between storage tanks.

The location is optimal because it is on the border of the Ankole and Kigezi regions, providing visibility for the largest number of people. In addition, KIHEFO's partnership with both American and Ugandan universities allows students to conduct research and experiments to expand upon KIHEFO's projects. Therefore, the knowledge generated from this farm will be shared with the surrounding communities of Ankole and Kigezi.

4.1.2 Projected Impact

There are three main purposes of KIHEFO's commercial farm: (1) to water crops during the dry season; (2) to deliver clean water to the nearby school, teachers' quarters, and greater community; (3) and to act as a "demonstration farm" that offers vocational training to the surrounding community.

KIHEFO's water pump system will increase year-round access to clean water on the demonstration farm, and, in turn, increase crop productivity, increase food security, and improve the health of the surrounding community. Due to increased crop productivity, the demonstration farm will require more labor to grow and harvest the increased yield. The labor will be sourced from the surrounding rural communities of the Ankole and Kigezi regions. This increased demand for labor will create jobs for the rural communities of both regions and enable the employed rural families to increase their disposable income. In the long-term, higher incomes for the rural households will translate into rural development in Ankole and Kigezi.

In addition to providing jobs, the increased crop yield from the demonstration farm will serve as a marketing strategy to incentivize other commercial farms to adopt pump systems. The demonstration farm will serve as a learning facility for other commercial farms interested in implementing similar pump systems. Moreover, since the demonstration farm belongs to KIHEFO, groups from the surrounding communities as well as children from the nearby school will have the opportunity to learn about KIHEFO's other outreach programs,[23] and receive vocational training for reproducible programs such as the Rabbit Breeding Project and the Mushroom Project.[24]

4.2 Applied Methodology

This section applies the generalized project methodology laid out in Section 3 to the case study of the Ntungamo demonstration farm.

4.2.1 Layout & Design

4.2.1.1 Site Mapping

We performed site measurements using a combination of traditional and new technologies. Large distances and angles were measured using the Hypotenuse & Angle technique described in Appendix A.1. Elevation was calculated using trigonometry.

The site contains an existing borehole located on a banana plantation, which is only a few meters from aboveground electrical lines. The transport of water from the borehole to the proposed tank location requires crossing a dirt road and climbing a hill slope of approximately 18 to 25 degrees inclination above the horizontal. This local variability from average slope is important for pipe layout and trenching since the pipe must either follow the contour of the terrain or the trenches must be graded to allow for straight

[23] https://www.cfhi.org/community-health-projects

[24] https://kabalechronicle.wordpress.com/2014/02/14/mushrooms/

sections of pipe to be laid. Local slope variability was measured at intermittent locations along the hill using an electronic level. This measurement could also be achieved using a similar method as the Hypotenuse & Angle technique, where we are interested only in the local angle rather than the hypotenuse length.

A top view of the complete system layout is sketched below. The layout (drawn to-scale) includes all the main components, such as pump, pipes, tanks, and fittings, as well as the dimensions and elevations. Components can be identified with numbers that are referenced in Table 4.1.

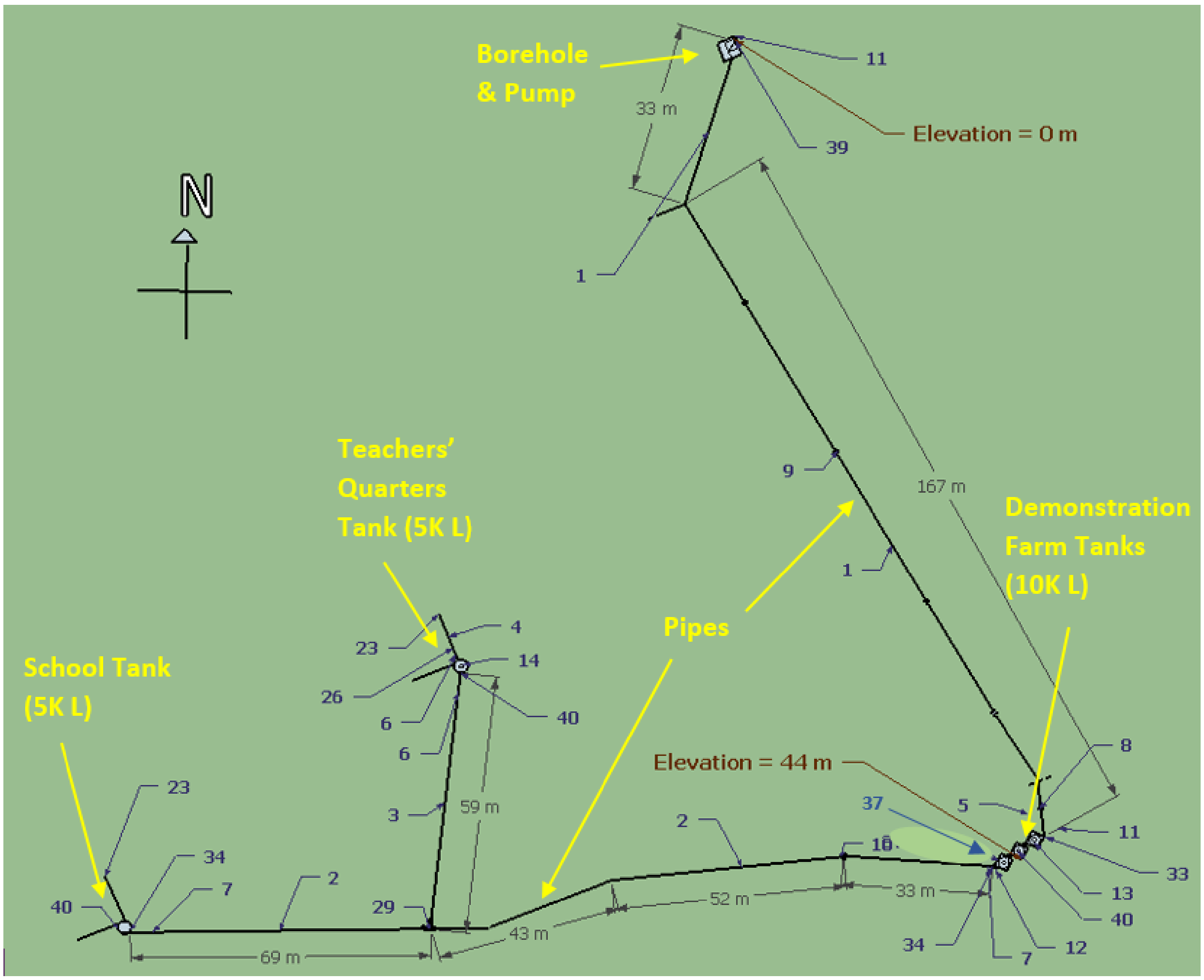


__Figure 4.1:__ Top view model of water pumping system (to scale). Numbers are referenced according to Table 4.1

Several low-level parts of the system (elbows, adapters, caps and unions) are not included in the sketch because this is a high-level preliminary design.

4.2.1.2 Water Source

An existing borehole is located on the site within a banana plantation. Standard practice during borehole construction is to include a serial number that allows the installing company to retain all borehole information in a database. Although we did not have access to that information at the time this document was written, borehole depths in this region typically range from 80 to 100 meters with an average depth of 90

meters. In order to install the submersible pump and pipe in the borehole, the existing structure will need to be modified.

4.2.1.3 Storage Tanks

Three 10,000-liter storage tanks were selected to distribute water to the 10-hectare demonstration farm, local school, and surrounding community, serving approximately 2000 people.

The farm's largest agricultural plot is located on the side of a hill, which is at a higher elevation than both the borehole and the school. Placing the storage tanks at the most uphill location on the plot will ensure that a gravity-driven flow of water can reach both the crops and the school. We plan to position the tanks in a stair step-like arrangement so that the water cascades from the uppermost tank down to the lower tanks. As a result, the elevation of the highest tank from the borehole (measured as 46 meters) is a critical dimension for pump selection. To this value, we add the tank inlet height, which we estimate is about 1 meter above the base for a 10,000 liter tank.

4.2.1.4 Pipes, Valves, Filters & Connections

KIHEFO engineers specified the types of pipes, valves, and fittings to be used for this project. The materials chosen for the pipes were HDPE, PPR, and GI, in accordance with the general methodology for selecting and sizing pipes outlined in Section 3.1.5. Pipe properties and application suitability can be found in Appendix B.1. The Bill of Quantities can be found in Appendix G, and the item specifications can be found in Table 4.2.

4.2.1.5 Pump Selection

The depth of the borehole is roughly estimated at 90 meters. The elevation difference between the borehole and the top of the storage tank is 46 meters. Additionally, this analysis assumes infinite well capacity; the exact well capacity and depth will be measured by the government at a later point, and may significantly affect parts of this analysis and the ensuing pump sizing. We estimated the desired flow rate to be 3.5 cubic meters per hour based on the number of people in the community and the size of the farm.

Following the methodology outlined in Section 3.1.5, Figure 4.2 was created for the demonstration farm system. See Appendix C.2 for specific calculations and MATLAB source code. The total head loss (blue) is given as a function of specified flow rate. Power consumption of an ideal pump (green) is given as a function of flow rate. Note that actual power consumption will depend on the efficiency of a specific pump.

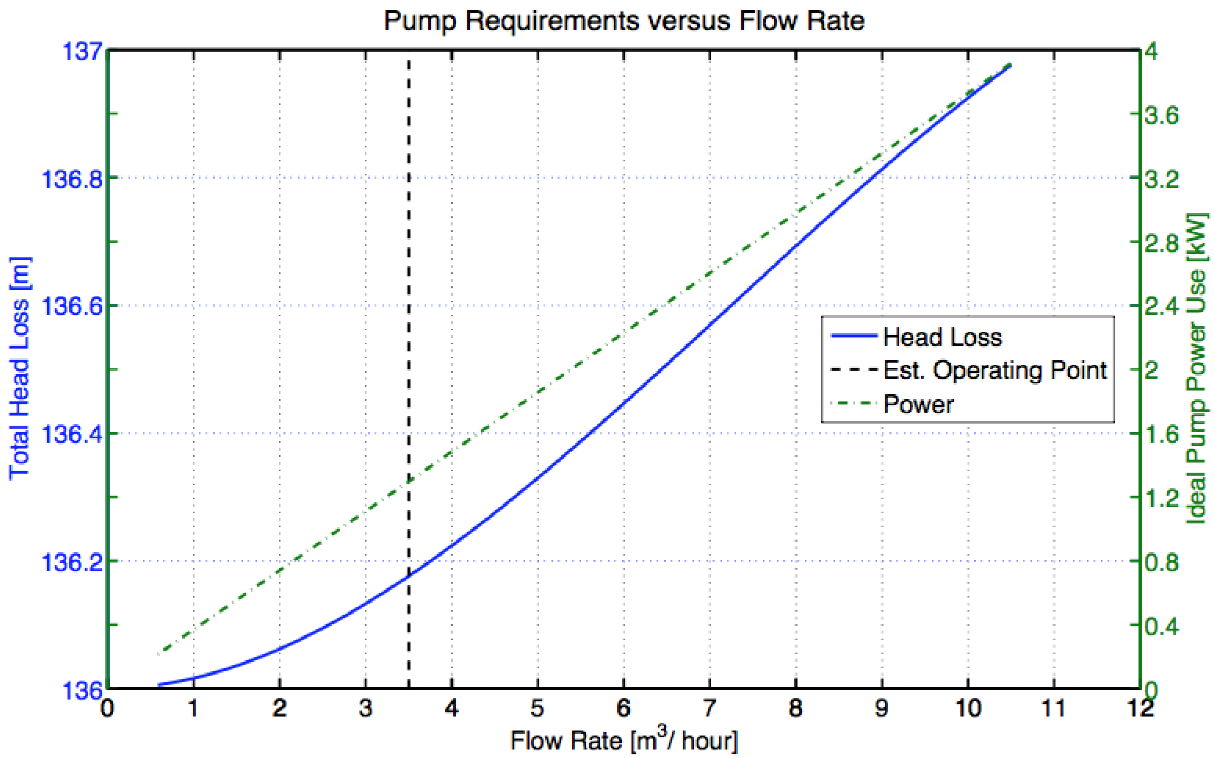


Figure 4.2: Pump Requirements versus Flow Rate

From the Pump Selection Flowchart and the figure above, we determined the following specifications for a pump suitable for the demonstration farm.

Pump Type: Submersible Borehole Pump
Flow Rate: 3.5 cubic meters / hour
Total Head Loss: 136.17 meters
- Gravity Head Loss: 136 meters
- Friction Head Loss: 0.16 meters
- Minor Head Losses: 0.00 meters

Ideal Pump Power Consumption: 1.27 kW

There are numerous pumps that can meet these specifications. Two examples are the Pedrollo 4SR2m/39, and the Grundfos SP 3A-39. Characteristic curves and performance data for these pumps can be found in Appendix D.

4.2.2 Construction

4.2.2.1 System Footprint

Using stakes and string, the major components of the system will be mapped directly on the terrain in the proposed locations. This effort comprises staking the area of the pump house, staking the proposed route

of the piping, and staking the areas of the water storage tanks. This may be an iterative process. For example, if there is an obstacle impeding the proposed pipe path, the entire pipe footprint can be shifted, negating the need to remove or circumvent the obstacle.

4.2.2.2 Tank Foundation

The heavy weight of each tank (10,000 kg) requires a strong foundation underneath, as discussed in Section 3.2.3. Our proposed design is based on the calculations and design provided by KIHEFO engineers. The dimensions and calculations necessary to determine the final design as well as the steps to build the foundation are detailed in Appendix F.

The following figure (not to scale) shows the main components of the tank foundation. While the top slab, beams, tank, and part of the wall are above ground, the foundation walls and bottom slab are buried. The planned dimensions are included in Appendix F.3. These dimensions might differ from the final ones depending on how the foundation is constructed, which in turn will depend on soil properties.

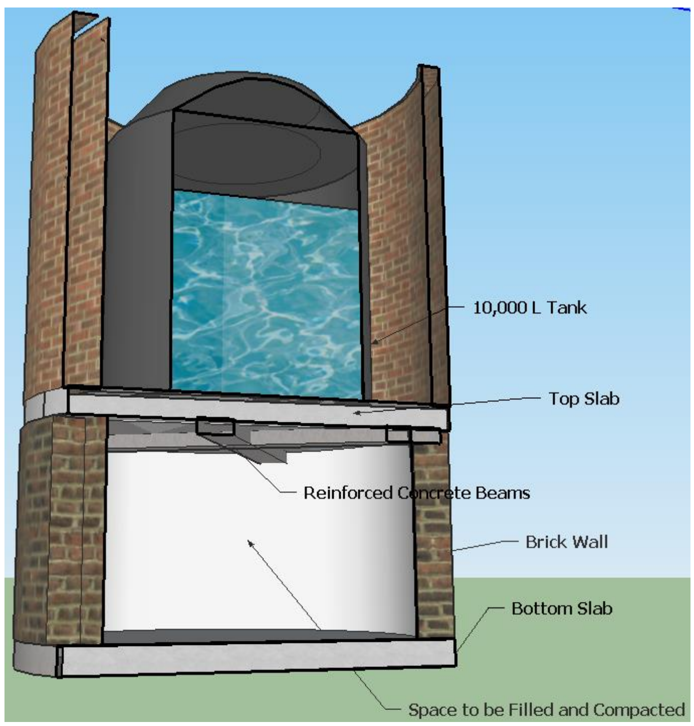


Figure 4.3: Cross-section of water tank on top of its foundation

4.2.2.3 Trenching

The entire network of pipes from the borehole to the tanks will be placed underground for protection from weather, corrosion damage, and road traffic. Trenching will be carried out to the specifications detailed in Section 3.2.3.

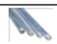
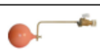
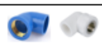
4.2.2.4 Maintenance

For maintenance details specific to the materials used in the case study, please refer to Appendix E and manufacturer recommendations.

4.3 Specifications

4.3.1 Components

Table 4.1: Equipment Specifications and Descriptions

Item No.	Item Image	uipment Specificatic	Description of Usage
1, 2, 3		HDPE pipes, PN 16.0 Bars, in compliance with ISO standards.	Sub-surface pipes serving as an inlet from the borehole to the water tanks, and outlets from tanks to the school and the teachers' quarters.
4,		Galvanized iron pipes	Outlet pipe from the school and teachers' quarters tanks to the taps.
5, 6, 7		PPR pipes	Above ground pipes used to join the tanks from the HDPE.
8		PPR unions	Connect two fixed pipes that are unable to be threaded into a regular coupling.
9, 10		HDPE unions, PN 16.0 Bars.	Connect two fixed pipes that are unable to be threaded into a regular coupling
11,		Non-return valves	Allows the fluid in the pipe to flow in one direction only, preventing backflow (works automatically)
12,		Gate valves	Valve situated between the point of connection and the rest of the plumbing system (usually remains wide open, but can shut down in case
13, 14		Ball valves	Quarter-turn valve which uses a hollow, perforated and pivoting ball (floating ball) to control flow through it.
15, 16, 17		Adapters, PN 16.0 Bars	Used to change the end of a non-threaded pipe to male or female threads as needed.
18, 19		Female elbow adapter	Change the direction of flow (produced primarily in 90, 60, 45, and 22.5 degree angles).
20, 21		Male elbow adapter	Change the direction of flow (produced primarily in 90, 60, 45, and 22.5 degree angles).
22, 23		Unthreaded elbow and GI elbow	Change the direction of flow (produced primarily in 90, 60, 45, and 22.5 degree angles).
24, 25		PPR sockets adapter one threaded internally, and the other non-threaded (Coupling).	Very short length of pipe or tube, with a socket at one or both ends that allows two pipes to be joined (has two female threads).

Item No.	Item Image	Equipment Specificatior	Description of Usage
26		PPR Reducer	Join pipe of different diameters (when the two ends of coupling use the same connection method but are of a different size).
27		PPR Nipple	Short stub of pipe, male-threaded at each end, used to connect straight pipe runs.
28		HDPE Tee	A long coupling with an outlet on the side at 90° from the inlet.
29		Saddle	Used to quickly add a tee to an existing length of pipe, without having to cut and re-solder what's there (glued to the pipe,
30		End caps	Close the end of a dead end pipe.
31		Plug	Used to cap a pipe end but usually fit inside the fitting, and are threaded to allow for future use of the pipe (close an opening on a pipe fitting).
32		Thread tape	Tape wrapped around threading to waterproof it.
33, 34		Long screws	Externally threaded pipe used to connect piping to tank transmitting flow internally.
35		Set of die	Used to create screw threads (threading) forming the male portion of the mating pair (e.g bolt).
36		Solvent cement	Substance used to bond thermoplastic sheets and piping together.
37		Silicon	Waterproofing for the tanks to prevent leakages.
38		PPR Machine	Machine that joins PPR pipes at unthreaded joints.
39, 40, 41, 42, 43, 44		Submersible pump, Control Panel, Submersible, Cable (4 * 2.5 MM2), Londex Sensor Cable, and Electrodes (Level Sensors).	Moves water uphill from the borehole to the tanks
45		Tanks	Large storage vessels for water

Note: Equipment should comply with ISO standards.

4.3.2 Costs

To itemize the costs, we created a bill-of-quantities that divides the system in three main components: pumping system, powerhouse, and the foundation and enclosure of the tanks. Also, based on the estimate by the engineers, we added a contingency to reduce the risk of going over the estimated budget. The total costs are summarized below. For an itemized breakdown of the entire system (including materials, labor, transportation and studies) see Appendix G.

Table 4.2:: Cost Summary

Item	Costs
Pumping System	199,074,000
Pump Housing	13,555,350
Tank Foundations & Housings	23,793,750
Contingency	2,000,000
TOTAL (UGX)	**238,423,100**

Some portion of the total cost is allocated to the construction of a pump housing, fences and protecting structures for the tanks. Although these components to the system are not required for it to operate, they will be constructed to add security and prevent damage, vandalism, or water theft.

Although maintainability and operational costs are not part of the bill-of-quantities, they should be calculated if a project of this nature is to be undertaken.

5 Conclusion

5.1 Summary

This report outlines a methodology for designing and constructing a groundwater pumping and storage system, and provides a strategy for implementing such a system at a commercial demonstration farm in Ntungamo as a case study.

The proposed project addresses the challenges of water accessibility in Uganda, which are exacerbated during the dry seasons. Given an existing underground potable water source and a reliable power source, the system requires, at a minimum: a pump, a network of pipes, and storage tanks. Once water has been moved to higher elevations, it can be distributed to any number of points in the outlying areas including crop fields, community buildings (schools, government offices, etc.), and communal taps.

We chose to apply a pump system to a commercial farm because of its reproducibility and potential impact. The projected impact of this pump system is to increase crop productivity and distribute clean water. Greater yields allow farms to employ more laborers from the community and provide income to rural families. Access to clean water alleviates many public health problems related to contaminated water.

Following the general methodology, the report presents a case study proposal, which is intended as a model for other commercial farms seeking to increase water accessibility. Based on site-specific requirements, we discussed appropriate pumps and pipes along with a breakdown of construction techniques for foundations. Lastly, we tabulated a bill-of-quantities to show estimated material costs for the pump, pipes, surveying tools, and building materials; labor costs; and transportation of materials.

This report presents a framework to provide accessible water in rural areas. While it is applicable to many situations, it is not a completely comprehensive document for all possible scenarios. In these cases, it should be used as a starting point and modified as needed using good engineering judgement. For that reason, the following sections mention some of our recommendations and ideas for future work for the improvement of any system of a similar nature.

5.2 Recommendations

We strongly recommend that anyone considering the pump system described in this report investigate the following:

- A geological survey is highly recommended to determine soil content, topography, water table, etc. and to determine tank placement (based on cost and constructability). Geological data from previous mappings may already exist with the government or other organizations.
- Potential water sources should be tested for potability. Harmful microorganisms, heavy metals, or pollutants from runoff may still contaminate water that appears clean. This is especially important for water intended for drinking. Unpotable water should be treated and filtered, or the borehole must penetrate deeper to access non-contaminated levels of the water table.
- Routine maintenance is critical and is detailed in Section 3.2.5 and Appendix E. Failure to adequately maintain system hardware may damage components resulting in loss of pressure, interruption of water transmission, or water contamination.
- Security of the pump installation and the water tanks should be considered. Although this is a low-risk prospect in most communities, damage to the tanks due to water theft or vandalism would affect the entire community. Repairs to the pump or tank are costly, and the system may be inoperable until damages are fixed. Brick enclosures surrounded by fences built around the pump and the tanks can provide protection.

5.3 Possible Project Extensions

This preliminary design leaves room for increased efficiency and accessibility. Several extensions not previously discussed include:

- Solar powered pumps can be utilized in farms without readily available or reliable electric power. During the dry season, a network of solar panels would provide sufficient power to operate a pump. To implement solar power at the demonstration farm, a solar array would be required in addition to a battery for energy storage.
- Distribution of water from the tanks to the crop fields is not discussed in this paper and could include more efficient methods to distribute water among crops such as drip irrigation techniques, sprinklers, etc.
- Distribution of water from the tanks to the surrounding community is not thoroughly discussed in this paper. A convenient water distribution system and strategically chosen communal water tap locations will decrease the effort and time spent transporting water by hand. We believe there is immense potential for the social impact of such a system.
- The system in this report is limited to groundwater sources. However, a similar system could be extended to alternative water sources such as rivers or rainwater reservoirs.
- The system described can be expanded or reduced to fit any acreage and topography. However, the details of scaling are not thoroughly discussed.

While the case study takes place in Southern Uganda, the methods in this report can be applied to any location needing access to water and water storage for irrigation and distribution purposes. Irrigation will substantively improve the productivity and quality of crops in farms with access to water but no reliable method of water transportation; moreover, providing clean water has been proven to benefit the community at large directly and indirectly. We strongly advocate this project to any farm and community seeking to better their quality of life through increased access to clean water. This report is intended to be a public resource accessible to anyone who requires a solution to the water problem described. We further recommend that anyone constructing this system extends unrestricted water access to the surrounding community, and we publish this report in the sincere hope that it will serve societies over individuals.

Acknowledgments

We extend our sincere gratitude to Dr. Geoffrey Anguyo and Mr. Barnabas Nabaasa, who provided both resources and guidance for the completion of this proposal. Furthermore, we thank the staff of KIHEFO for their hospitality and the KIHEFO engineers--Dennis, Grant, and Geoffrey--for their expertise. Lastly, this program exists solely due to the initiative of Mrs. Victoria Wilhelmsen and the support of Stanford University.

Appendix A – Site Measurement Techniques

This section describes various methods for obtaining measurements used to map out a site. It is separated into Traditional Measurement Techniques (which rely on well-established methods with basic tools and materials) and New Measurement Techniques (which offer improved accuracy and efficiency at an expense that may be cost-prohibitive to many people, but are included here for completeness).

A.1 Traditional Measurement Techniques

Measuring Tape

Used to measure linear distance between two points. When measuring long distances, it is important to ensure that the measuring tape remains taut for an accurate measurement; slack in the tape will overestimate the actual linear distance.

Protractor

Used to measure angle between two lines. The protractor is leveled to horizontal using a bubble level, then the angle of the desired line, edge or surface can be read directly off of the protractor.

Hypotenuse & Angle Method

This technique is used to measure the distance between two points (hypotenuse) as well as the angle from horizontal of the line formed by the two points. A post is driven in at both points, and a string is run from one post to the other. (The vertical height of the string above ground should be consistent between the two posts.) For long distances, additional people may be needed to pull the string taut between the posts with the goal of removing sag from the string without artificially altering the slope. The string length is determined using a measuring tape, and a protractor is used to measure the angle between the hypotenuse and a horizontal reference.

If there is not enough clearance between the measuring tape and the ground or another obstacle (such as a rock or fence), the string can be raised by the same amount on both posts. For terrain with a lot of slope variation, it may not be possible to measure directly from one point to the other, and may require an intermediate point(s).

With the measured hypotenuse length and angle of inclination, the elevation can be computed using trigonometry.

A.2 New Measurement Techniques

Theodolite

A theodolite device relies upon angle measurement of two internal potentiometers to determine instrument orientation in 3D space. A measurement tape is used to obtain radial distance. From these values, spherical coordinates may be obtained. Projected lengths (such as horizontal distance or elevation) may be calculated using simple trigonometry.

Total station

Predominantly used for construction or geological surveying, a total station utilizes the capabilities of a theodolite in conjunction with built-in radial distance sensing (typically an infrared laser) to calculate point coordinates with a high degree of precision (typically < 5mm).

GPS measurements
For large-scale applications, GPS measurements can be used to obtain 3-D coordinates of points. Accuracy levels vary among different types of GPS devices, so it is important to account for measurement variation by adding an error term to measured values.

Barometer
A barometer can be used to measure elevation at various points. Because most traditional barometers sense deflection of a diaphragm under pressure, they can be influenced by local weather. For this reason, all measurements should be taken over a relatively small time window, and should be considered relative rather than absolute measurements. Many new smartphones contain an internal barometer.

A.3 Vector Component Calculations

For mapping purposes, all measurements should include compass heading (magnetic or electronic compass) so that both the magnitude *and* direction of the measurement can be accurately drawn on the map. Using basic trigonometry, the angle between North and the measured dimension can be used to break the horizontal component of a measurement into North/South and East/West components.

Appendix B – Pipe Properties

B.1 Pipe Materials

HDPE pipe

The High Density Polyethylene pipe is highly resistant to corrosion, flexible, very long lasting, and can be used to carry a wide variety of fluids. HDPE comes in long segments, and joints are formed through heat fusion. It has low resistance, making it a good choice for many plumbing applications. It is used mainly for drainage applications where it can withstand higher temperature discharges than PVC. To avoid warping and installation problems when laying pipe, HDPE is best used in straight lengths up to 6 meters long. Jointing is achieved by electrofusion welding, butt-fusion welding, or with compression-type joints for smaller diameter pipes and fittings.[25]

PPR pipe

This is a polypropylene random copolymer pipe. It has good impact resistance, long-term damage-resistance, and high reliability due to minimal leakages once installed and pressure tested. PPR Pipe is used in most home improvement projects and water supply pipelines. It requires less pressure, and the long-term working temperature should not exceed 70 degrees Celsius. Each piece has a maximum length, and cannot bend in construction. Constructing joints usually requires additional segments. The pipe diameters range from 16 mm diameter to 160mm, with the 20mm mainly used in home improvement.[26]

GI pipe

Galvanized iron pipe is constructed of rough iron dipped in molten zinc. It may be identified by its dull grayish color. GI pipe is widely used for transporting raw water and distributing treated water in a majority of rural water supply schemes where less water is required. Medium-quality screwed or socketed GI pipes are used most often. GI pipes are cheap, lightweight, easy to handle and transport, easy to join, and better suited for plumbing than steel pipes. Their sizes vary from 15mm to 150mm. They are manufactured conforming to IS-1239 (pt-I) 1990.[27]

B.2 Pipe Durability

Pipes are chosen based on their ability to withstand the following:

Mechanical stresses

Caused by:

(1) Internal conditions such as water pressure (the working pressure of the pipes to be installed should be at least two times higher than the system's operating pressure), water hammer (a sudden pressure surge experienced during the closing of a valve), and vacuum

(2) External forces such as earth load, thermal expansion and contraction, and mechanical blows to the component

[25] http://enlightenme.com/types-of-plumbing-pipes/
[26] http://www.hengxing-group.com/faq/products-knowledge/What-is-the-PPR-pipe.html
[27] http://megphed.gov.in/knowledge/standards/GIpipes.pdf

Extreme temperatures

In cases where components may be exposed to high temperatures (e.g. around pump stations), special high-temperature plastics or steel should be used instead of PVC. In areas subject to freezing conditions, choose materials that will not fracture easily (e.g. avoid cast iron).

Solar radiation

For surface pipes, additives such as carbon black may be used to prevent damage from UV light. Elastomers and metals are normally less influenced by UV radiation.

Chemical corrosion

The chemical properties of the fluid being transmitted may harm the components, as outlined below:

Acidic fluids will result in corrosion of most metals. Aluminum and zinc are the metals most sensitive to acid. Cast iron, carbon steel, and copper alloys are less sensitive, but for prolonged exposure to acidic conditions, a resistant material such as 316-stainless steel should be considered. Alkaline fluids may be harmful to aluminum, zinc, and titanium. Most other metals, as well as most plastics and elastomers, are not sensitive to alkaline conditions. Acidity/alkalinity applies only to the internally transmitted fluid, not the surrounding soil.

The effect of dissolved solids in water is to increase the electrical conductivity and acceleration of the corrosion processes. Common cations such as calcium, potassium, and sodium have almost no effect on most metals and plastics, while ammonium may attack some plastics and elastomers. Anions such as sulfides and sulfates are much more harmful to both metals and plastics.

Solid particles such as sand in the water stream can result in severe erosion of metal and plastic components. Erosion of surfaces can also result from cavitation. Hard metals or ceramics can coat cast iron, mild steel, and copper alloys to make them more resistant to cavitation. Plastics and elastomers are more resilient and resistant to cavitation erosion; however, they are more susceptible to abrasion damage from high-velocity solids. [28]

[28] https://edis.ifas.ufl.edu/pdffiles/CH/CH17100.pdf

Appendix C – Flow Analysis for Pump Selection

C.1 Governing Equations for Fluid Flow Analysis

Gravity Loss

$$h_{l\ gravity} = h$$

Where

$h_{l\ gravity}$ $[m]$ is the gravity head loss

h $[m]$ is the vertical height from the bottom of the water source to the top of the tanks

Friction Loss

$$h_{l\ friction} = \frac{f\left(\frac{L}{D}\right)\rho\frac{V_{avg}^2}{2}}{\rho g}$$

Where

$h_{l\ friction}$ $[m]$ is the friction head loss

f is the friction factor determined from the Moody Chart

L $[m]$ is the pipe length

D $[m]$ is the pipe diameter

ρ $[kg/m^3]$ is the density of water

V_{avg} $[m/s]$ is the average velocity of water in the pipe

g $[m/s^2]$ is the acceleration due to gravity

Minor Head Losses

$$h_{l\ bend} = \frac{k_L V_{avg}^2}{2g}$$

Where

$h_{l\ bend}$ $[m]$ is the head loss due to each pipe bend

k_L is the loss coefficient determined by the type of bend in the pipe

V_{avg} $[m/s]$ is the average velocity of water in the pipe

g $[m/s^2]$ is the acceleration due to gravity

$h_{l\ valve}$ $[m]$, the head loss due to each pipe valve, can be determined from manufacturer specifications

Total head loss is calculated by summing all head loss terms:

$$\boxed{h_{l\ total} = h_{l\ gravity} + h_{l\ friction} + h_{l\ minor}}$$

Ideal pump power consumption, ignoring inefficiencies, can be calculated as:

$$\boxed{P = Q * h_{l\ total} * \rho g}$$

Where

P $[W]$ is ideal power consumption of the pump

Q $[m^3/s]$ is the volumetric flow rate in the pipe

ρ $[kg/m^3]$ is the density of water

g $[m/s^2]$ is the acceleration due to gravity

C.2 MATLAB Source Code for Fluid Flow Calculations

```
%% ASSUMPTIONS
% 1) Well capacity is infinite
% 2) Steady state and incompressible flow
% 3) Entrance effects are negligible, and thus the flow is fully developed
% 4) Standard temperature and pressure

%% CONSTANTS AND SPECIFICATIONS
clear all, close all, clc

% Constants

rho = 1000; % [kg/m^3] density of water
g = 9.8;      % [m/s^2] acceleration due to gravity
mu = 1.002 * 10^-3; % [N*s/m^2] dynamic viscosity of water at 20 deg C
kin_visc = 1.004 * 10^-6; % [m/s^2] kinematic viscosity of water at 20 deg C

k_L_90_deg_bend = 0.3; % minor head loss coefficient for 90 degree flanged bend
k_L_45_deg_bend = 0.2; % minor head loss coefficient for 45 degree flanged bend

tank_size = 10; % [m^3] volume of each tank
num_tanks = 3; % number of storage tanks

% Specifications

bore_hole_depth = 90; % [m] A Submersible borehole jet pump will be used
tank_elevation = 46; % [m] from bore hole to top of tanks
L = 200 + bore_hole_depth; % [m] pipe length
D = 0.09; % [m] pipe diameter
pipe_roughness = 0.0025; % smooth pipe HDPE, estimated, from Moody chart
num_90_deg_bends = 12; % estimated from survey
num_45_deg_bends = 2; % estimated from survey

water_consumption = 14; % [L/person/day]
water_consumption = water_consumption / 1000 / 24 / 60 / 60; % [m^3/person/s];
people = 2000; % using water source, from Dr. Geoffrey Anguyo

flow_rate_estimate = water_consumption * people * 3; % [m^3/s], factor to factor in
water use for onion cartel farm, power outages...
time_to_fill_one_tank_hours = tank_size / flow_rate_estimate / 60 / 60  % reality check
on flow rate

%% ANALYSIS

min_flow_rate = flow_rate_estimate / 6;
max_flow_rate = 3 * flow_rate_estimate;
flow_rate = linspace(min_flow_rate, max_flow_rate, 50);
f_estimate = linspace(0.052, 0.027, 50); % estimate friction factors from Moody Chart,
Re, pipe roughness

%% GRAVITY LOSS

del_p_gravity = (tank_elevation + bore_hole_depth) * rho * g;
hl_gravity = tank_elevation + bore_hole_depth;
```

```
%% FRICTION LOSS

Vavg = flow_rate ./ (pi*D^2 / 4); % [m/s]
Re = rho .* Vavg .* D / mu;
if (Re < 2000)
    % Laminar Flow
    fprintf('\n Laminar Flow: Re < 2300 \n');
    f = 64 / Re;
else
    % Turbulent Flow
    fprintf('\n Turbulent Flow: Re > 2300 \n');
    % f = 0.035; % determined from Re, pipe roughness, and Moody Chart
    f = f_estimate;
end
del_P_friction = f .* L / D * rho .* Vavg.^2 / 2;
hl_friction = del_P_friction ./ rho / g;

%% LOCAL MINOR LOSSES

% Foot Valve
hl_foot_valve = 0; % foot valve not necessary for submersible bore hole pump

% Bends
k_L_total = num_90_deg_bends * k_L_90_deg_bend + num_45_deg_bends * k_L_45_deg_bend;
hl_bends = k_L_total * Vavg.^2 / (2*g);

hl_minor_losses = hl_bends + hl_foot_valve;

%% TOTAL PRESSURE LOSS

hl_total = hl_friction + hl_minor_losses + hl_gravity; % [m]
total_del_p = hl_total .* rho * g;
ideal_pump_power = flow_rate .* total_del_p;

%% RESULTS

flow_rate_plot = flow_rate * 60 * 60;
figure(1)
set(gcf,'color','w');
hold on
[AX,H1,H2] = plotyy(flow_rate_plot, hl_total, flow_rate_plot, ideal_pump_power/1000);
xlabel('Flow Rate [m^3/ hour]')
set(AX(1),'XTick',linspace(0, 12, 13))
set(get(AX(1),'Ylabel'),'String','Total Head Loss [m]')
set(get(AX(2),'Ylabel'),'FontSize',16);
set(get(AX(2),'Ylabel'),'String','Ideal Pump Power Use [kW]')
title('Pump Requirements versus Flow Rate')
grid on
set(H1,'LineStyle','-')
set(H2,'LineStyle','-.')
plotfixer()
set(gca,'FontSize',16)
set(AX(1),'YTick',linspace(46 + bore_hole_depth, 48 + bore_hole_depth, 11))
set(AX(2),'YTick',linspace(0, 4, 11))
x_operating_point = [flow_rate_estimate * 60 * 60, flow_rate_estimate * 60 * 60];
y_operating_point = [46 + bore_hole_depth, 48 + bore_hole_depth];
plot(x_operating_point, y_operating_point, 'k--')
plotfixer()
legend('Head Loss', 'Est. Operating Point', 'Power', 'Location','BEST')
```

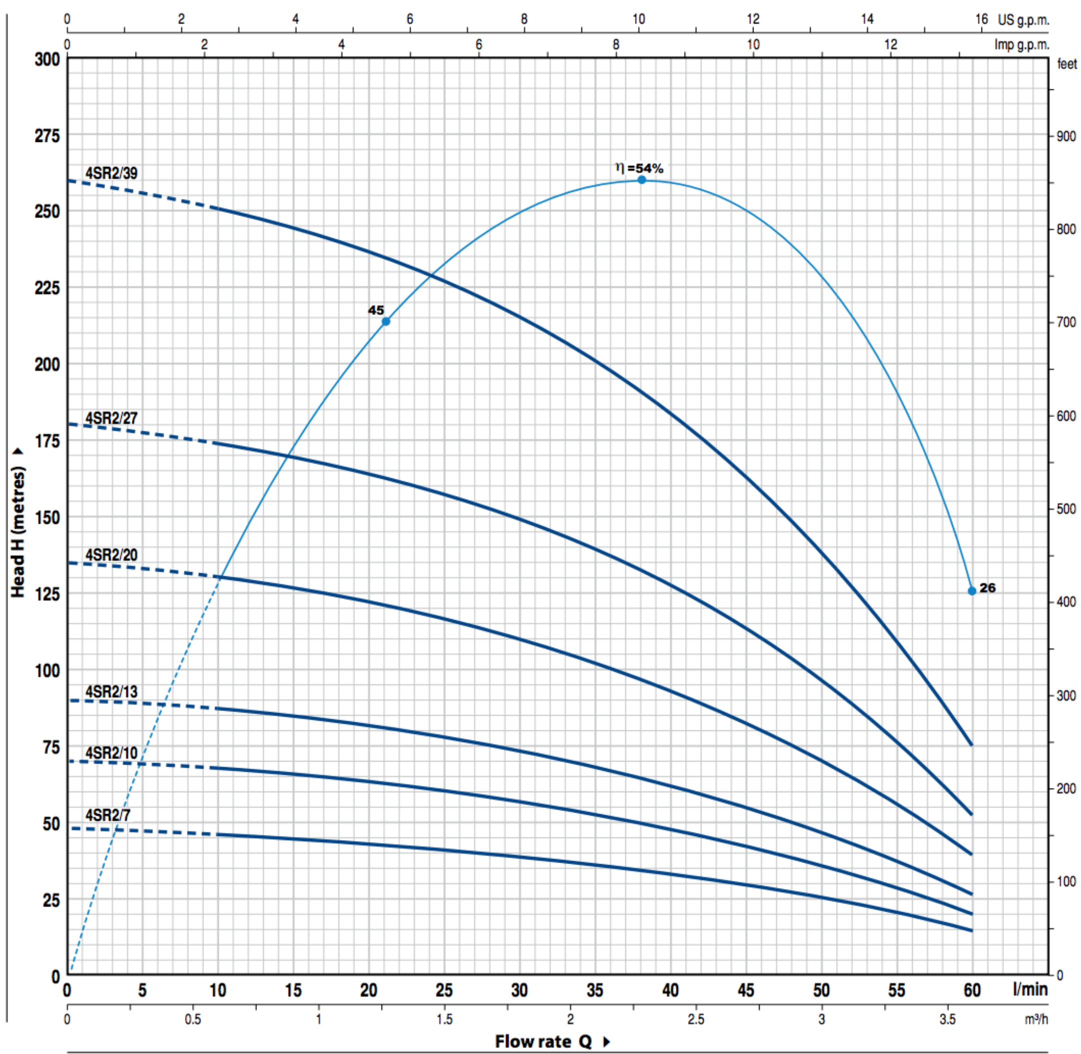
Web References:

Engineering toolbox:
http://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html
Water use per capita:
http://www.data360.org/dsg.aspx?Data_Set_Group_Id=757
Textbook chapter:
https://www.uio.no/studier/emner/matnat/math/MEK4450/h11/undervisningsmateriale/modul-5/Pipeflow_intro.pdf
Moody chart:
https://upload.wikimedia.org/wikipedia/commons/thumb/8/80/Moody_diagram.jpg/1024px-Moody_diagram.jpg
Foot Valve Head Loss:
http://www.hansenproducts.co.nz/downloads/pdf/brochures/Foot_Valve_Web.pdf
Minor Head Losses:
http://fluid.itcmp.pwr.wroc.pl/~znmp/dydaktyka/fundam_FM/Lecture11_12.pdf

Appendix D – Pump Characteristic Curves and Performance Data

D.1 Pedrollo 4SR2m/39

CHARACTERISTIC CURVES AND PERFORMANCE DATA **50 Hz n= 2900 1/min**



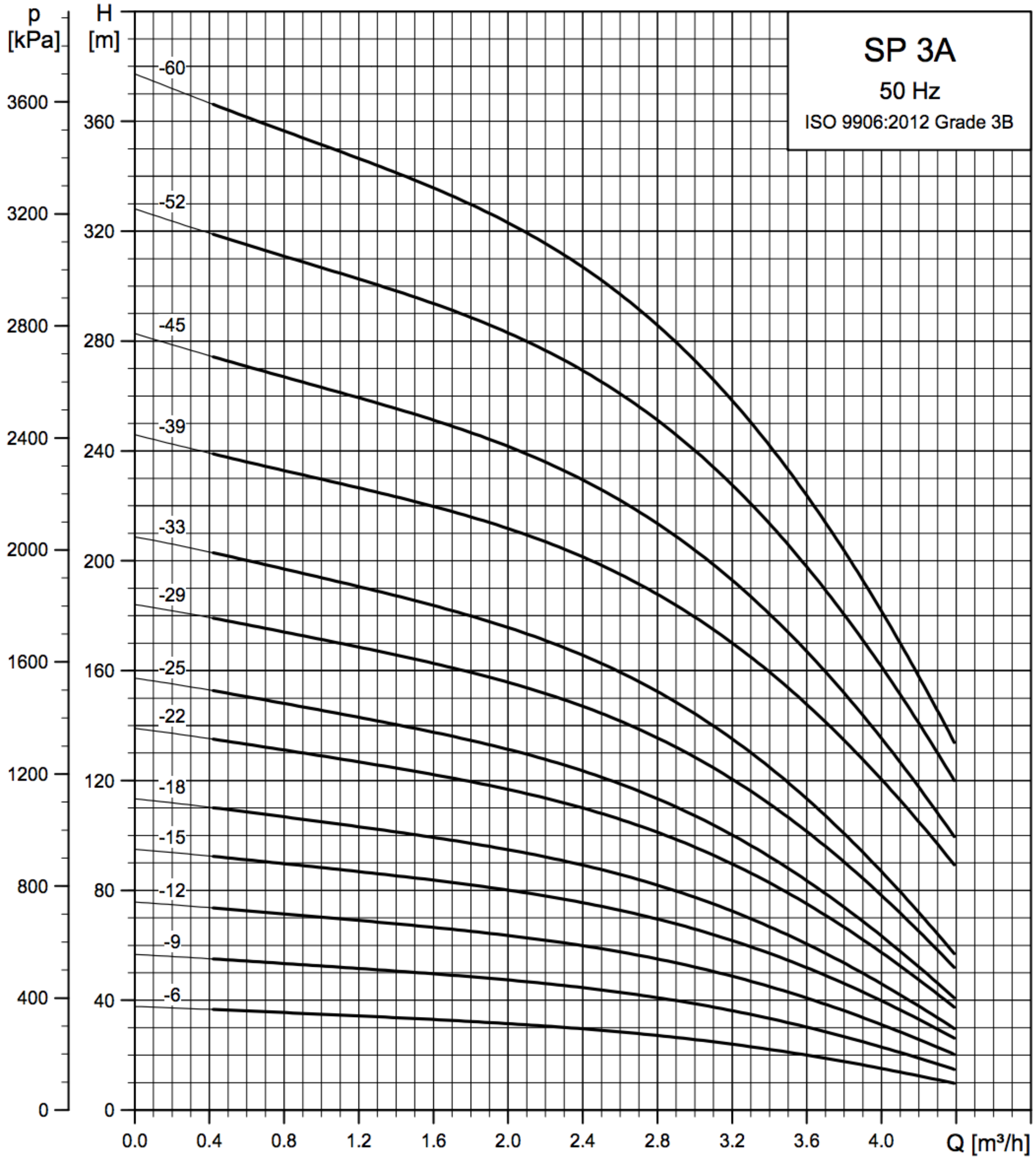
MODEL		POWER		Q m³/h	0	0.6	1.2	1.8	2.4	3.0	3.6
Single-phase	Three-phase	kW	HP	l/min	**0**	**10**	**20**	**30**	**40**	**50**	**60**
4SR2m/7	**4SR2/7**	0.37	0.50	H metres	48	46	44	39	33	25	14
4SR2m/10	**4SR2/10**	0.55	0.75		70	68	63	57	48	36	20
4SR2m/13	**4SR2/13**	0.75	1		90	88	82	74	62	46	26
4SR2m/20	**4SR2/20**	1.1	1.5		135	130	122	111	93	71	39
4SR2m/27	**4SR2/27**	1.5	2		180	173	164	150	126	96	52
4SR2m/39	**4SR2/39**	2.2	3		260	250	238	216	183	138	75

Q = Flow rate **H** = Total manometric head

Tolerance of characteristic curves in compliance with EN ISO 9906 Grade 3.

D.2 Grundfos SP 3A-39

Performance curves



Appendix E - Maintenance Protocols & Precautions

In this section, we address the various maintenance concerns associated with the pump system as well as our recommendations for general upkeep and repair.

E.1 High-Density Polyethylene (HDPE) Piping:

HDPE is a highly resilient material, making it an ideal choice for water-pump systems. Excavation machines (i.e. bulldozers, etc.) are the most common cause of pipe damage from cuts/lacerations. While HDPE pipes are resilient, scratches and other ablations can compromise their ability to maintain water pressure. Scarring to a maximum depth of 10% of pipe wall thickness is guaranteed tolerable; if deeper cuts are noticed but no leaks are present, our recommendation is to check the damaged area weekly and to apply sealant, if possible.

An important consideration is that most damage to these pipes comes in the form of kinking/bending. Bending certain segments of pipe puts significant pressure on joints and couplings, increasing the chance of leaks or breaks. This is of particular concern for irrigation systems, as there are significant portions of vulnerable piping above ground. The most apparent sources of bending come from changes in terrain caused by erosion/weather or damage from livestock/human traffic. To prevent this, we recommend securely fastening aboveground pipe to solid fixtures and constructing piping in low traffic areas.

In terms of general repair, we have several recommendations:

For small punctures, electrofusion patches may be utilized. In the event that electrofusion patches are unavailable, mechanical fittings can be used as an alternative. For larger problems, the damaged section needs to be removed and replaced with a transplant section of pipe secured mechanical fittings, flange adapters or electrofusion couplings. Depending on the extent of the damage full circle clamps may also be used as a temporary repair method. Experience has shown that most mechanical fittings work best when used in conjunction with a stainless steel stiffener and restrainers. For specific details consult with the pipe manufacturer.

E.2 Metal Fastenings, Valves & Adapters:

Any steel or iron component of the pipe system, especially those in contact with water, are at risk of rusting. This can lead to a loss of valve operability, decrease in water quality, and leaks at adapter sites. Readily visible metal components should be inspected monthly for possible rust damage. If valves become progressively more difficult to turn, they should be removed and checked for possible internal rusting. Other signs of rusting are a brown discoloration of the water supply and/or a metallic taste to the water. One possible long term solution to external rust problems is to purchase a rust resistant lacquer that can be applied to metal fittings.

E.3 Reservoirs and Foundations:

Each proposed tank reservoir can hold 10,000 liters of water apiece. The density of water is 1g/mL, meaning that when these tanks are full, each will weigh 10,000 kg. The reservoir's immense weight on a sloped surface puts significant strain on its supportive foundation. Should the foundations begin to slide down the incline, it would not only put large amounts of strain on any piping connected to the reservoir, but

also pose a significant safety risk for those lower on the hill. For this, each tank's concrete base will need to be inspected regularly for possible slippages from erosion, especially during the rainy season. A weekly or bimonthly check should be sufficient in addressing this problem. If cracks in the foundation or slippages are noticed, the reservoirs should be emptied as soon as possible and additional foundational support (retaining walls, etc.) should be constructed. Pipes feeding to and from the reservoir should also be checked for strain damages. Fortunately, base erosion and slippage can be largely avoided by digging a deep enough initial foundation.

E.4 Water Quality:

Groundwater and large bodies of stagnant water present a multitude of possible problems with regards to water purity. Before drinking water from a groundwater supply, the water should be tested for possible iron, manganese, and arsenic. If the water has proven to be pure enough for consumption, the storage containers must be sealed from outside contaminants. Insects, such as mosquitoes, can proliferate in stagnant water if left open. Microbes (viral, parasitic, or bacterial) can also survive in stagnant water. For this, we recommend that water from the reservoir should be boiled before human consumption should there be any question of contamination. Should the water pass a potability test, it should be safe for human consumption. Stagnant water should be checked weekly for possible contaminations. Notable particulate buildup or a sudden change in water taste/quality is an indication of impurity, meaning that the storage units must be checked immediately.

E.5 Filters:

The inlet pipe from the borehole may rely on a foot valve filter near the water source. If it is a self cleaning model, filter clogging is rare and will likely not be a problem. We recommend checking the filter once every two months for possible clogging. A sudden drop in water pressure is indicative of filter blockage and requires the pumps be shut off and the filters cleaned immediately. Access to the inside of the filter is simple: remove the outer circle of nuts from the bottom of the strainer, and then remove the bottom outer plastic disk. The screen should now be easily removable and cleanable. Refer to manufacturer if more complicated issues arise.

E.6 Water Pump:

The water pump should be inspected annually or semi-annually for possible repairs or upkeep fixes. Neglecting to check the pump for maintenance can result in premature pump failure. Indications of pump problems are decrease in water pressure, sudden decrease in water quality, loud or odd noises from the pump, or air being pushed into the tubes. The repair and pump maintenance is highly dependent on the type of pump purchased. Refer to the manufacturer for more specific instructions/maintenance needs.

Appendix F - Tank Foundation

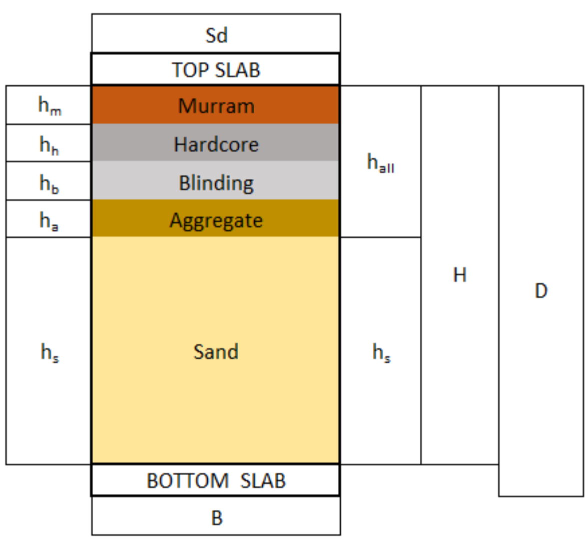
F.1 Construction

The steps that will be undertaken to build the foundations for the tanks are the following:

1. Excavate to the required depth (usually deep enough to reach bedrock or soil of similar bearing strength). In the case study site, it is estimated to be at 1.5 meters deep.
2. Flatten the bottom of the hole and pour the concrete for the bottom slab. Wait at least 24 hours for concrete curing.
3. Build brick wall at the perimeter of the base using a header layout.
4. Install a drainage system to avoid accumulation of water at the bottom or side of the structure.
5. Backfill and compact 81 cm of the sand removed during excavation, 8 cm of Murram, 15 cm of hardcore, 15 cm of blinding, and 15 cm of aggregates, in that order from bottom to top. Compact until the required level of soil compactness is reached.
6. Using plywood formwork, create the molds for the two reinforced concrete beams along with the rest of the top slab. Lay the reinforced concrete beams and pour additional concrete over them to create a single, fortified layer upon which the tank will sit. Note that Figure 4.2 shows the components of the top slab separately, while in fact they are a single layer. Let the top slab cure for 7 days.
7. Backfill the perimeter of the structure to fill out any remaining voids.
8. (Optional) To protect the stored water, construct the aboveground brick walls to protect the tank from being perforated and use concrete plaster as a cover for the bricks.

F.2 Cross-Section Sketch

The following figure shows a cross-sectional cut of the inside of the foundation, which will be backfilled with five materials. These materials are shown (not to scale). In addition, the symbols for the dimensions are shown below.



F.3 Design Calculations: Bearing Capacity and Safety Factor

The following series of tables contain sample calculations to determine the design of a foundation structure. From left to right, each column contains: substructure of the foundation, constant values and dimensions, values, units, and formulas.

Based on the estimates provided by the local engineers, and assuming specific soil property values, we calculated the bearing capacity of the soil and the expected structure pressure. These calculations are for each 10,000 L tank foundation, and based on our assumptions and preliminary analysis we calculated a safety factor of 3.38.

TANKS STRUCTURE & SHALLOW FOUNDATION

Concrete	Density, φ	2403	kg/m3	
	Depth of Foundation, D	1.50	m	**
	Bottom Slab Diameter, B	3.46	m	$B = Wt + 2*(dt + 0.3)$
	Bottom Slab Thickness, Bt	0.16	m	**
	Outside Radius, R	1.73	m	$R = B/2$
	Inside Radius, r	1.50	m	$r = B/2 - W_t$
	Height of Space in Foundation to Fill, H	1.34	m	$H = D - B_t$
	Top Slab Diameter, Sd	3.00	m	**
	Top Slab Thickness, St	0.23	m	**
	Reinforced Beams Length, bl	3.00	m	**
	Reinforced Beam Width, bw	0.23	m	**
	ReinforcedBeam Height, bh	0.23	m	**
	Wall Thickness, Wt	0.23	m	**
	Total Volume of Concrete, Vc	6.57	m3	$V_c = \pi*(R^2 * B_t + (S_d/2)^2*S_t + H*R^2 - r^2) + (b_l*b_w*b_h*2)$
	Total Structure Weight, Ws	**15800**	**kg**	$Ws = \varphi * Vc$

Fill	Total Volume to Fill, Vf	9.47	m3	$V_f = \pi * H * r^2$
	Height of Murram + Hardcore + Blinding + Agg, hall	0.53	m	**
	Height of Sand (backfill) Column, hs	0.81	m	$h_s = H - d_{all}$
	Volume of Sand (backfill), vs	5.73	m3	$v_s = \pi * r^2 * h_s$
	Density of Sand (backfill), γ	1665.00	kg/m3	
	Weight of Sand (backfill), ws	9533.05	kg	$w_s = \gamma * v_s$
	Height of Murram Column, hm	0.08	m	**
	Volume of Murram, vm	0.57	m3	$v_m = \pi * r^2 * h_m$
	Density of Murram, γm	1600	kg/m3	
	Weight of Murram, wm	905	kg	$w_m = \gamma * v_m$
	Height of Hardcore Column, hh	0.15	m	**
	Volume of Hardcore, vh	1.06	m3	$v_h = \pi * r^2 * h_h$
	Density of Hardcore, γh	1620	kg/m3	
	Weight of Hardcore, wh	1718	kg	$w_h = \gamma * v_h$
	Height of Blinding Column, hb	0.15	m	**
	Volume of Blinding, vb	1.06	m3	$v_b = \pi * r^2 * h_b$
	Density of Blinding, γb	1200	kg/m3	* Approximate density
	Weight of Blinding, wb	1272	kg	$w_b = \gamma * v_b$
	Height of Aggregate Column, ha	0.15	m	**
	Volume of Aggregate, va	1.06	m3	$v_h = \pi * r^2 * h_h$
	Density of Aggregate, γa	1650	kg/m3	
	Weight of Aggregate, wa	1749	kg	$w_m = \gamma * v_m$
	Total Weight of Fill, Wf	**15177**	**kg**	$W_f = w_s + w_m\ w_h + w_b + w_m$

Tank	Diameter, dt	2.40	m	**
	Height, ht	2.53	m	**
	Weight, wt	700	kg	**
	Capacity, ct	10,000	L	
	Water Weight, ww	10,000	kg	
	Total Weight, Wt	**10700**	**kg**	$W_t = W_s + W_f$

Soil Properties	Total Weight on Soil, W	41677	kg	$W = W_s + W_f + W_t$
	Soil Pressure, P	4433	kg/m2	$P = W / R$
	Soil Bearing Capacity (shallow foundation), qf	15,000	kg/m2	***$q_f = c.N_c + q_o.N_q + ½\gamma.B .N_g$
	Safety Factor, F	**3.38**	-	$F = q_f / W$

**: Dimensions were provided by local engineers and are for the most part preliminary estimates

***: 15,000 was taken as the average bearing capacity of moist clay and sand

c = apparent cohesion intercept

$q_o = \gamma$.□D (i.e. density x depth)

D = founding depth

B = breadth of foundation

γ = unit weight of the soil removed

For **drained loading**, calculations are in terms of effective stresses; ϕ' is > 0 and N_c, N_q and $N\gamma$ are all > 0.

For **undrained loading**, calculations are in terms of total stresses; the undrained shear strength (s_u); $N_q = 1.0$ and $N\gamma = 0$

Source: http://environment.uwe.ac.uk/geocal/foundations/founbear.htm

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Appendix G - Bill of Quantities (BOQ)

System	Subsystem	#	Description/Item	Unit	Quantity	Cost per 1 Unit	Total cost (UG Shilling)
PUMPING SYSTEM							
	Pipes						
		1	HDPE pipes 90mm PN16	Rolls (100m)	6	4,000,000	24,000,000
		2	HDPE pipes 110mm PN16	Rolls (100m)	4	4,500,000	18,000,000
		3	HDPE pipe 32mm PN16	No (number)	2	750,000	1,500,000
		4	GI pipe: 25mm	No	2	70,000	140,000
		5	PPR pipes (90mm)	No	15	750,000	11,250,000
		6	PPR pipe (25mm)	No	1	45,000	45,000
		7	PPR pipes (110mm)	No	2	950,000	1,900,000
		Total Pipes Cost					56,835,000
	Fittings						
		8	PPR unions (90mm)	No	4	150,000	600,000
		9	HDPE unions 90mm PN16	No	5	150,000	750,000
		10	Unions HDPE (110mm)	No	4	350,000	1,400,000
		11	Non-return valves (90mm)	No	3	450,000	1,350,000
		12	Gate valves (40mm)	No	12	350,000	4,200,000
		13	Ball valves (90mm)	No	3	55,000	165,000
		14	Ball valves (32mm)	No	2	120,000	240,000
		15	Adapters (90mm)	No	6	180,000	1,080,000
		16	Adapters (110mm)	No	5	250,000	1,250,000
		17	Adapter 32mm PN16	No	2	85,000	170,000
		18	Elbow adapter (F) 90mm	No	20	180,000	3,600,000
		19	Elbow adapter (F) 110mm	No	6	250,000	1,500,000
		20	Elbow adapter (plane) 90mm	No	20	170,000	3,400,000
		21	Elbow Adapter plane (110mm)	No	6	250,000	1,500,000
		22	Elbow plane (110mm)	No	4	220,000	880,000
		23	Elbows (GI 25mm)	No	10	10,000	100,000
		24	PPR socket adapter (F) 90mm	No	20	220,000	4,400,000
		25	PPR sockets adapter (plane) (90mm)	No	6	280,000	1,680,000
		26	PPR Reduced Sockets (32*25mm) (F)	No	4	150,000	600,000
		27	PPR Nipple Adapter	No	4	160,000	640,000
		28	HDPE Tee (32mm)	No	2	50,000	100,000
		29	Saddle (110x32mm)	No	4	180,000	720,000
		30	End caps	No	4	200,000	800,000
		31	Plugs (90mm)	No	5	200,000	1,000,000
		32	Thread tapes	No	30	6,000	180,000
		33	Long screws (90mm)	No	12	170,000	2,040,000
		34	Long screws (110mm)	No	3	250,000	750,000
		35	Set of Die	No	1	1,500,000	1,500,000
		36	Solvent cement	No	10	40,000	400,000
		37	Silicon	No	5	15,000	75,000
		38	PPR machine	No	1	450,000	450,000
		39	Pump	No	1	3,970,000	3,970,000
		40	Control Panel	No	1	2,509,000	2,509,000
		41	Submersible Cable (4x2.5 MM2)	No	100	17,000	1,700,000
		42	Londex Sensor Cable	No	200	1,600	320,000
		43	Electrodes (level sensors)	No	2	110,000	220,000
		44	Other pipe fittings	-	1	3,000,000	3,000,000
		45	Tanks (10,000l)	No	4	7,000,000	28,000,000
		Total Fittings Cost					77,239,000
	Transport						
		46	Transport	Trips	-	20,000,000	20,000,000
		Total Excavation & Transport Cost					20,000,000
	Labor Cost						
		47	Labor	-	35%	46,925,900	46,925,900
		48	Flow Rate Testing		-	15,000,000	15,000,000
		49	Borehole Repair	-	-	30,000,000	30,000,000
		50	Food	-	-	15,000,000	15,000,000
		Total Labor Cost					45,000,000
Materials TOTAL							**134,074,000**
Materials + Transport + Labor TOTAL							**199,074,000**

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System	Subsystem	#	Description/Item	Unit	Quantity	Cost per 1 Unit	Total cost (UG Shilling)
POWER HOUSE (PUMP HOUSE)							
	Site Preparation						
		1	Site preparation	-	-	-	200,000
	PowerHouse Foundation						
		2	Excavation of foundation	-	-	-	250,000
		3	Bricks (4x4)	No	1200	400	480,000
		4	Transport (for bricks)	trips	1	100,000	100,000
		5	Sand	trips	1	200,000	200,000
		6	Cement (for foundation)	bags	15	40,000	600,000
		7	Extra excavation depth >1.5m	-	-	-	150,000
		8	Timber for Formwork	pcs	5	8,000	40,000
		Total Foundation Cost					1,820,000
	Backfilling						
		9	Murram + Transport	trips	1	150,000	150,000
		10	Hardcore (incl. transport)	trips	1	200,000	200,000
		11	Aggregate (incl. transport)	trips	1	400,000	400,000
		12	Cement for slab	bags	8	40,000	320,000
		13	Sand (for blinding)	trips	1	200,000	200,000
		Total Backfilling Cost					1,270,000
	Walling						
		14	Bricks (transport)	trips	2	100,000	200,000
		15	Bricks	No	2400	400	960,000
		16	Cement (for building)	bags	25	40,000	1,000,000
		17	Sand (for building)	trips	2	200,000	400,000
		18	Iron bar	No	6	35,000	210,000
		19	Aggregate (incl. transport)	trips	1	400,000	400,000
		20	Cement (for ringbeam)	bags	5	40,000	200,000
		21	Sand (for plastering)	trips	1	200,000	200,000
		22	Sand (for rendering)	trips	1	200,000	200,000
		Total Walling Cost					3,770,000
	Tools						
		23	Wheelbarrow	No	3	105,000	315,000
		24	Spade	No	4	15,000	60,000
		25	Hoe	No	4	15,000	60,000
		26	Pick-axe	No	3	20,000	60,000
		26	Door	No	1	500,000	500,000
		Total Cost of Tools					995,000
	Roofing						
		27	Hard iron sheets	piece	16	55,000	880,000
		28	Timbers (4*2inches) + transport	trips	1	700,000	700,000
		29	Roofing nail	kg	4	7,000	28,000
		30	Hoop iron	roll	1	50,000	50,000
		31	Nails (2 inches)	25kg	1	65,000	65,000
		32	Nails (3 inches)	25kg	1	65,000	65,000
		33	Nails (4 inches)	25kg	1	65,000	65,000
		34	Nails (5 inches)	25kg	1	65,000	65,000
		35	Binding wire	kg	4	5,000	20,000
		36	Stirrups	pairs	6	8,000	48,000
		Total Roofing Cost					1,986,000
	Labor Cost						
		37	Labor		35%		3,514,350
Power House Total Cost							13,555,350

System	Subsystem	#	Description/Item	Unit	Quantity	Cost per 1 Unit	Total cost (UG Shilling)
PUMP & TANKS HOUSES							
	Tanks Base and Walls Construction						
			BRC wire		1	430,000	430,000
			Bricks (each foundation has 3600 bricks)	No	14,400	400	5,760,000
			Bricks (transport)	trips	12	100,000	1,200,000
			Murram + Transport	trips	4	150,000	600,000
			Hardcore (incl. transport)	trips	8	200,000	1,600,000
			Aggregate (incl. transport)	trips	5	400,000	2,000,000
			Iron bar	No	15	35,000	525,000
			Binding wire	kg	6	5,000	30,000
			Stirrups	pairs	10	8,000	80,000
			Cement	bags	100	40,000	4,000,000
			Plywood for Formwork	pieces	20	30,000	600,000
			Sand for Plastering	trips	4	200,000	800,000
		Total Tanks Cost					17,625,000
	Labor Cost						
			Labor	-	35%	-	6,168,750
Tanks Foundation and House Total Cost							**23,793,750**

TOTAL COSTS OF PUMPING SYSTEM + POWERHOUSE + TANK HOUSES	
Pumping System	199,074,000
PowerHouse	13,555,350
Tank Houses	23,793,750
Contingency	2,000,000
TOTAL COST (UGX)	**238,423,100**