MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

FINAL PROJECT REPORT

FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING

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COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

FINAL YEAR PROJECT REPORT

CIV4200

TITLE: DESIGN OF A MODEL IRRIGATION SCHEME THAT UTILISES GROUNDWATER IN THE CATTLE CORRIDOR AREA OF UGANDA

CASE STUDY: SEMBABULE DISTRICT.

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DECLARATION

We hereby do declare that to the best of our knowledge, this report, which is submitted in partial fulfillment of the requirements for the award of a degree of Bachelor of Science in Civil Engineering of Makerere University, is our own original work and has not been submitted to any other academic institution anywhere before for any award whatsoever.

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Date: 10TH JUNE 2013	**Date:** 12/06/2013

DEDICATION

To my parents and friends who have been by my side throughout this course.

Namukwaya Barbara Doreen

To my parents: I am because you are, all of you!

Ddiba Daniel Isaac Waya

ACKNOWLEDGEMENTS

We wish to extend special thanks to our supervisors, Dr.Albert Rugumayo and Dr. Michael Kizza who have made valuable amendments and additions, and also guided us throughout the entire course of this project. They kept pushing us to extents we never thought were possible before and this indeed brought out the best in us.

Our parents have supported us morally, physically, spiritually and financially throughout not only this project but the entire four-year study program and we are eternally indebted to them all.

We are very grateful to the Department of Water Resource Management in the Ministry of Water and Environment for giving us access to information from the National Water Ground Database and to the staff in the Agriculture Department of Sembabule District Local Government who provided us with valuable information about the state and practice of agriculture in Sembabule.

We would also like to acknowledge the following people for their generous assistance in carrying out this project: Dennis Nsubuga, Kenneth Cherimo, Johnson Nangalama, Tusubira Francis, Eddie Jjemba Sabaganzi, the Mulokole family, Mr Nyanzi John and Ssalongo Peter Ddungu who graciously allowed us to use his farm as a basis for our model design.

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Lastly but not least, we thank the Almighty God who is the author and finisher of our faith. Nothing would have been possible, let alone successful without him.

ABSTRACT

One of the national targets of Uganda is to ensure that through infrastructural development, 30% of the farmers should have access to irrigation by 2020. In contrast to the rest of the country, Sembabule district, which lies in the cattle corridor, receives very low annual rainfall amounts that cannot support farming activities amidst the prolonged dry spells, and as such could benefit from irrigation. The main objective of this project was to design a model irrigation scheme that provides water for crops and animals by abstracting groundwater and suggesting strategies for the adoption and implementation of similar schemes in the other cattle corridor districts.

The study included carrying out a literature review and desk study, identification of the case study area, preliminary and baseline survey and data collection, while the design of the scheme included the determination of the crop water requirements, determination of available groundwater and the design of the scheme components after putting all the aforementioned information into consideration.

The model scheme was done for a borehole of yield 9.5m^3/hr at DWD24184, to be installed with a solar powered submersible pump. The irrigation system, being of drip type with end-feed configuration was designed for bananas and the components include 49m manifold pipes (50mm HDPE PN6) and 17 laterals/dripper lines (Netafim 20mm Techline) totaling 3383m in length and fitted with a total of 1139 Netafim PCDj drippers. A 10,000-litre water tank supplying water to the cattle kraal at the lower end of the kraal is to be installed also. The two major components of the system (banana irrigation and water supply for the cattle) are to be operated non- simultaneously using shut-off valves near a node where the two branch out.

The total cost of the system was estimated at UGX33,761,806 with a pay-back period of 8 years.

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LIST OF ACRONYMS

AGLW	FAO Water Resources, Development and Management Service
BCM	Billion Cubic Metres
CWR	Crop Water Requirement
DWD	Directorate of Water Development
DWRM	Department of Water resource Management
ET	Evapo-transpiration
FAO	Food and Agricultural Organization
GDP	Gross Development Product
GWPA	Ground Water Protection Area
HGL	Hydraulic Grade Line
IR	Irrigation Requirement
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MWE	Ministry of Water and Environment
O&M	Operation and Maintenance
P	Precipitation
UCCE	University of California Cooperative Extension
UGX	Uganda Shillings
USA	United States of America
USDA NRCS	United States Development of Agriculture Natural Resources Conservation Service
USDA SCS	United States Development of Agriculture Soil Conservation Service
gph	Gallons per hour
$J_{\%}$	Frictional losses
l/s	Litres per second
m	metres
m/s	Metres per second
m^3	Cubic metres
m^3/hr	Cubic metres per hour
m^3/s	Cubic metres per second
m^2	Square metrres
psi	Pounds per square inch
Δz	Change in elevation

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1.0 INTRODUCTION

1.1 Introduction

Between 2007 and 2008, the world was hit by the worst food crisis since 1974 which shone the spotlight on the huge gap between the growing population and food production, rudely reminding people of Thomas Malthus' 18th century predictions (Hanlon, 2012). With the world population now standing at 7 billion (Population Reference Bureau, 2012), efforts are being made to increase global food production and some of these have included allocating more land to agricultural food production especially in Africa which still has vast tracts of arable land (Cotula *et al*, 2009; Harvey and Pilgrim, 2010). Africa and in particular Uganda which is located on the equator, is endowed with unique huge potential for agricultural production with its good climate (two planting seasons) and good fertile soils. This is one of the reasons for which Sir Winston Churchill named it the "Pearl of Africa". However, recent changes in the climate in the country have grossly affected the country's food production considering the over-reliance on rainfall for farming.

The cattle corridor is one of the areas in Uganda worst hit by this trend of climate change. This is a stretch of land covering an area of about one third of the country, extending from the districts of Isingiro, Mbarara and Kiruhura in the southwest through Sembabule, Rakai, Kyoga, Nakasongola and Moroto up to Kotido in the northeast. The major economic activities in this area are crop cultivation and livestock keeping. The area has the country's largest concentration of cattle kept for both beef and dairy products and it is from this that its name is derived. It is among the most degraded areas in the upper Nile basin, following years of overgrazing and charcoal production. This area has unreliable rainfall amounts with some semi-arid areas receiving averages of about 500mm per annum (Olupot, 2012). This leads to high frequency of water shortages which apart from severely decreasing the crop and animal yields often generate hostility among the herdsmen when they invade neighbouring farmers' lands with their cattle in search of pasture and water.

Although agriculture provides employment to about 80% of the population in Uganda and contributes 20% of gross development product (GDP) as well as 48% of exports (MAAIF, 2010), not much effort has been made to develop irrigation at a large scale to cover the entire sector like it is done in other countries like Sudan, Libya and Egypt (Mirghani *et al*, 2007). Until now, irrigation has been a preserve for a few large commercial farms like sugarcane plantations and flower farms which largely utilize surface water sources. However, surface water sources in the cattle corridor area are limited. Although up to 80% of households in Uganda rely largely on groundwater resources for domestic water supply (Mirghani *et al*, 2007) and the presence of boreholes in several parts of the cattle corridor indicate that there is potential for groundwater development (DWD, 2010), not much has been done to appropriate these resources for irrigation purposes (Van Steenbergen and Luutu, 2011).

1.2 Problem Statement

Crop cultivation and livestock farming are the major economic activities in the cattle corridor and yet the area has very low annual rainfall amounts which cannot support farming activities amidst the prolonged dry spells. Apart from Lake Kyoga which can only be accessed by the few districts around it, there are few other reliable perennial surface water sources and most of these water reserves dry up during dry seasons. This adversely affects yields from both crop and animal production.

1.3 Objectives

1.3.1 Main Objective

The main objective is to design a model irrigation scheme that provides water for crops and animals by abstracting groundwater and suggest strategies for the adoption and implementation of similar schemes in the other cattle corridor districts.

1.3.2 Specific Objectives

1. To determine the irrigation water requirements in the project area.
2. To assess how much groundwater can be extracted in the area.
3. To make a preliminary design of the scheme.
4. To provide a cost estimate and an economic analysis for the scheme.

1.4 Justification

The draft National Policy for Water for Agricultural Production (2009) indicates that one of the national targets is to ensure that through infrastructural development, 30% of the farmers should have access to irrigation by 2020. Utilization of groundwater can go a long way in enabling the achievement of this goal since groundwater resources are widely available in vast parts of the country and are much less drought prone than surface water due to large natural storage of aquifers (MacDonald *et al*, 2011). Moreover, unlike most surface irrigation systems, groundwater systems do not need a public service provider hence can be self-managed, both for domestic use and small scale irrigation.

With more farmers in the cattle corridor getting access to irrigation, farm yields for both crops and animals would drastically increase which would mean more food production for the mass markets hence contributing to easing world food shortages, availability of raw inputs to stimulate the development of the agro-processing industry, more income for the farmers and ultimately, increased socio-economic development in the area.

1.5 Project Scope

This project, while having a wide perspective of the entire cattle corridor, was limited to an assessment of the groundwater resources available in Sembabule District and in particular, Mateete Sub-county (shown in Figure 1-1), establishment of the irrigation water requirements in the area and the design of a pilot scheme which can then be replicated in other places in the district and throughout the cattle corridor.

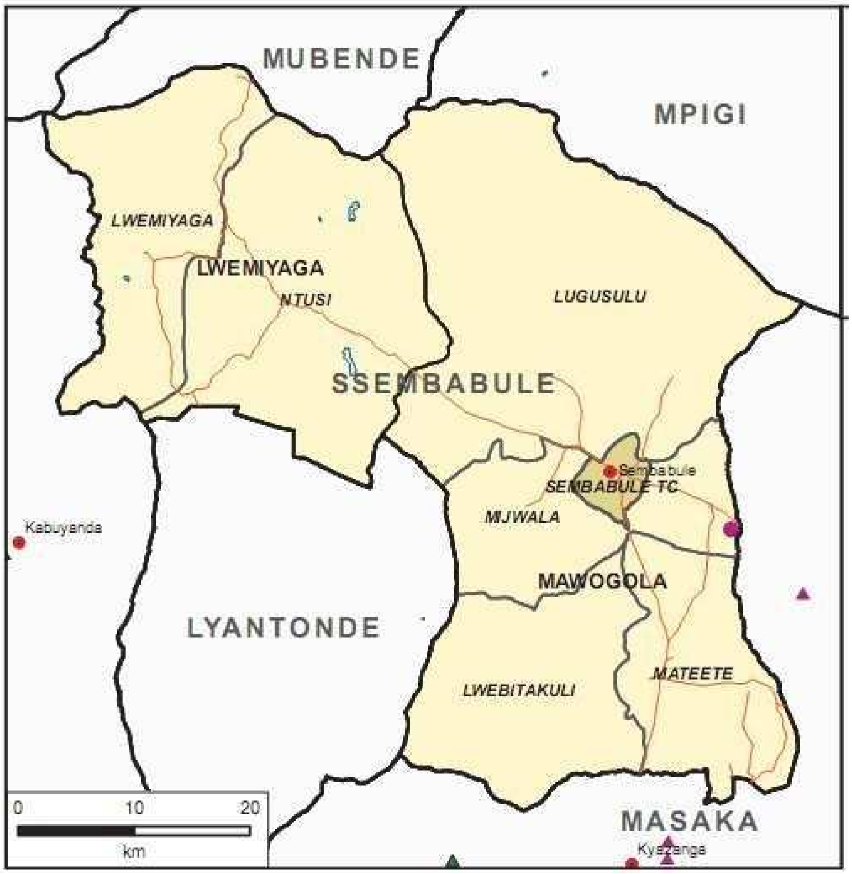

Figure 1-1: Location of Sembabule district and its constituent sub-counties
Source: Directorate of Water Development

1.6 Study Area

Sembabule District was created in July 1997, formerly being part of Masaka District. It lies between latitudes 00° 14’ 24”N and 00° 20’ 42”S and between longitudes 31° 00’ 36”E and 31° 36’ 36”E. The District is bordered by Mubende and Mpigi Districts in the North and North-east, Masaka District in the East and South East, Rakai District in the South-east and Mbarara District in the West.

Sembabule District has a total area of about 2,470.5 square kilometres with water coverage of zero-square kilometres (Sembabule District Local Government, 2002). The landscape and topography is rolling and undulating with vertically gully heads and valley bottoms, seasonal streams and swamps.

1.6.1 Climate

(a) Rainfall:

There are two rain seasons (bi-modal distribution).

1st Season – March to May.

2nd Season – September to December.

The mean annual rainfall varies from 1200 – 2000millimetres in Mateete Sub-county and decreases westwards to as low as 750 mm.

(b) Temperature:

The district records high temperature of up to 32°C in the dry hot months of January to February and July to August. The mean temperature is between 20°C and 27°C while the minimum recorded temperature is 17°C.

1.6.2 Economic Activities

The major economic activities in the district are crop cultivation, livestock farming and pastoral activities in some parts of the north. Most farmers practice subsistence agriculture depending on traditional tools with a few cash crops (coffee mainly, as shown in Figure 1-2) and other crops like maize, beans and bananas/plantains as shown in Figure 1-3. Livestock farming is still not well organized for efficient dairy and other related animal produces, although the District has an estimated population of 135,000 cattle, 50,000 goats, 10,000 sheep, and 5,000 Pigs. Most of the farmers also rear animals such as pigs and chicken. In the southern part of the district, brick-making is one of the rural industries engaged in (Sembabule District Local Government, 2002).

Figure 1-2: Coffee

Figure 1-3: Bananas

1.6.3 Water

The major sources of water are boreholes, springs and ponds, as shown in Figures 1-4 and 1-5. Sembabule district has very few clean surface water sources and most have dirty water.

Figure 1-4: A borehole in Mateete Central Parish

Figure 1-5: A water pond in Miteete Parish

A few of the boreholes have been found to have salty water and as a result have been abandoned by the community members, thus increasing the problem of water scarcity. In some places, the borehole water is sold at a price as high as UGX1,000 per 20-litre jerry can.

It was also discovered that there was a plan to construct five valley dams in each of the sub-counties in Sembabule district. However, at the time of the baseline survey, this plan had not yet been implemented, at least in Mateete sub-county.

2.0 LITERATURE REVIEW

2.1 Definitions

2.1.1 Groundwater

Groundwater: The American Science Heritage Dictionary (2010) defines groundwater as water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment, and rocks. Groundwater originates from rain and from melting snow and ice and is the source of water in aquifers, springs, and wells. Typically; 10–20% of precipitation eventually enters aquifers. Most groundwater is free of pathogenic organisms, and purification for domestic or industrial use is not necessary. Furthermore, groundwater supplies are not seriously affected by short droughts and are available in many areas that do not have dependable surface water supplies (MacDonald *et al*, 2011). Groundwater can be used for many different purposes including industrial processes, livestock watering, irrigation and domestic use especially for drinking. Its abstraction is done by using boreholes (hand-pumped), shallow dug wells, and deep wells, protected springs and using motorized pumps.

Groundwater table is the upper surface of an area filled with groundwater, separating the zone of aeration (the subsurface region of soil and rocks in which the pores are filled with air and usually some water) from the zone of saturation (the subsurface region in which the pores are filled only with water). Water tables rise and fall with seasonal moisture, water absorption by vegetation and the withdrawal of groundwater from wells, among other factors. The water table is not flat but has peaks and valleys that generally conform to the overlying land surface. (The American Science Heritage Dictionary, 2010)

Aquifer**:** this is an underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water. The pore spaces in aquifers are filled with water and are interconnected, so that water flows through them. Sandstones, unconsolidated gravels, and porous limestone make the best aquifers. They can range from a few square kilometers to thousands of square kilometers in size. (The American Science Heritage Dictionary, 2010)

2.1.1.1 Types of Aquifers

***Unconfined Aquifer*:** This is an aquifer which is not confined by an upper impermeable layer, but whose upper boundary is formed by the water table. The water level is the highest level to which water will rise and at this level, the pressure is atmospheric.

***Perched Aquifer*:** This is an unconfined aquifer above main water table

***Confined Aquifer*:** This is an aquifer in which the groundwater is confined by an overlying relatively impermeable layer. The pressure within a confined aquifer is greater than atmospheric pressure and if a well is drilled into it, the water in the well rises to some level (called the piezometric level), above the top of the aquifer.

***Aquitard*:** A geological formation that may contain groundwater but is not capable of transmitting significant quantities of it under normal hydraulic gradients.

2.1.2 Irrigation

Irrigation: Smajstrla and Zazueta (1995) define irrigation as the artificial application of water to the land or soil. Santosh (1998) adds that it must be in accordance with the 'crop requirements' throughout the 'crop period' for full-fledged nourishment of the crops. Irrigation is used to assist in the growing of agricultural crops, maintenance of landscapes, and re-vegetation of disturbed soils in dry areas and during periods of inadequate rainfall. The role of irrigation is to improve the production and the effectiveness of other inputs. The amount of irrigation water that needs to be applied will depend on numerous factors including the crop grown, field size and slope, soil type and variability, labour requirements and availability, and the method of applying the irrigation water to the crop (UCCE & GWPA, 2005).

Evapotranspiration (ET) includes water that is needed for both evaporation and transpiration.

Evaporation is the change of water from liquid to vapor form. Evaporation occurs from all moist or wet surfaces, including soil, water, plants among others.

Transpiration is evaporation from plant leaves through small openings in the leaves called stomata.
ET must occur to avoid plant water stress. Plant water stress will occur if ET is limited because water is not available to plants. Water stress will occur quickest on high climate demand days. Water stress

is avoided by rainfall or by irrigating to provide a crop with the water needed for evaporation and transpiration (Smajstrla & Zazueta, 1995).

The irrigation requirement: As far as crop production is concerned, this is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Estimates of irrigation requirements can be made from either long-term historical observations, or numerical models (Smajstrla & Zazueta, 1995).

2.2 Groundwater use for irrigation

Whereas various sources are used for the purpose of irrigation around the world, groundwater has emerged as one of the most commonly used water sources for irrigation purposes especially in areas with insufficient surface water sources. Several countries in the world have put a lot of emphasis on the development of groundwater for irrigation like Spain, United States of America (USA), India, Libya and even some countries in the Nile Basin like Sudan and Ethiopia (Mirghani *et al*, 2007).

In India, groundwater for irrigation has been developed since the 1950s to the extent where groundwater wells serve as much as 75-80 percent of India’s irrigated area today according to remote sensing data as well as national sample surveys. Of the 433.02 billion cubic metres (BCM) of groundwater available per year, 93% is used for irrigation and the rest covers domestic, industrial and other uses. However, the level of groundwater development currently lies at 58% (Gandhi and Bhamoriya, 2011). The contribution of India’s groundwater irrigation to the economy was approximated to be as much as 10% of the GDP by the early 1990s (Shar, 2008).

The development of groundwater irrigation in India hasn’t been government or policy driven but has happened through highly decentralized private activity. Previously, farming depended a lot on canal systems relying on surface water sources under the control of the government and/or its agencies. Though huge investments were made in surface water irrigation projects to provide water over vast areas to many farmers, canal systems of irrigation were poorly managed and left farmers dissatisfied hence the huge shift to decentralized groundwater development (Gandhi and Namboodiri, 2009). This was favoured by the wide availability of groundwater especially in the large alluvial basins (Kurup, 2012). Moreover, tube wells have the merits of reliability, timeliness and adequacy.

The abstraction of groundwater is done through dug wells, shallow tube wells and deep tube wells. The extraction technology mostly used is the submersible pump, unlike the 1970s to the 1980s when dug-cum-bore and centrifugal pumps were more common. Until 1960, Indian farmers owned just a few tens of thousands of mechanical pumps using mostly diesel to pump water but today India has over 20 million modern water extraction structures (Gandhi and Bhamoriya, 2011). Every fourth cultivator household has a tube well and two of the remaining three use purchased irrigation service supplied by tube well owners (Shah, 2008). The increase in electricity supply has also led to an increase in the availability of electric pumps (Kurup, 2012). 81% of dug wells are owned by individual farmers while 16% are owned by groups of farmers. Over 80% of tube wells and open wells are owned and controlled by large farmers with over 10 acres of land under cultivation (Shiferaw *et al*, 2008).

Farmers owning wells register higher yields and therefore, incomes compared to those without. Pump irrigated farms perform better than others in terms of yield, cropping intensity and input use.

2.3 Technical considerations for irrigation systems

2.3.1 Calculation of crop water requirements

To avoid water crop water stress, the sum of rainfall and irrigation must be sufficient to meet the crop's ET requirement. This means that for any period of time during the crop growing season, the net irrigation requirement (IR_{net}), which is calculated using Equation 2.1, is the amount of water which is not effectively provided by rainfall (Smajstrla & Zazueta, 1995):

$$\mathrm{IR_{net}} = \mathrm{ET_c} - \mathrm{P_{eff}} \tag{2.1}$$

Where; $\mathrm{IR_{net}}$ = net irrigation requirement

$\mathrm{ET_c}$ = crop evapotranspiration

$\mathrm{P_{eff}}$ = effective rainfall.

P_{eff} is that portion of rainfall which can be effectively used by a crop, that is, rain which is stored in the crop root zone. Therefore, P_{eff} is less than total rainfall due to interception, runoff and deep percolation (or drainage) losses.

To determine the effective rainfall, daily rainfall data obtained over several years from a station in the area of interest is analysed to get total monthly values for each of the years as well as average monthly values over the entire period. The total annual rainfall amounts for each of the years are ranked and their probabilities of exceedance obtained using the Weibull formula which is shown in Equation 2.2.

$$P = \frac{100 \times m}{(N+1)} \tag{2.2}$$

Where; P is the probability of a rainfall event being equaled or exceeded in percentage

m is the order of rainfall event (rank within the data list)

N is the number of years for which rainfall data was obtained

The total annual rainfall amounts are plotted against the corresponding probabilities of exceedance on a logarithmic scale to obtain the total annual rainfall for the wet, normal and dry years which are defined as the rainfall with a 20%, 50% and 80% probability of exceedance respectively. The rainfall in normal years (50% probability) is in general well approached by the average rainfall. The rainfall in dry years (also called dependable rainfall) is used for the design of irrigation system capacity. The monthly rainfall values for the dry year are then calculated using Equation 2.3. To get the values for the wet and normal years, the parameters for the dry year in the equation are simply replaced with those for the wet and normal year accordingly.

$$P_{i_{dry}} = P_{i_{av}} \times \frac{P_{dry}}{P_{av}} \tag{2.3}$$

Where: $P_{i_{dry}}$ = monthly rainfall (dry year) for month *i*

$P_{i_{av}}$ = average monthly rainfall for month *i*

P_{dry} = annual rainfall at 80% probability of exceedance

P_{av} = average annual rainfall

After obtaining the monthly rainfall values, effective rainfall values (P_{eff}) are calculated using one of the many available methods which include; the empirical formula, fixed percentage method, dependable rain (FAO/AGLW formula) and the United States Department of Agriculture soil conservation service (USDA SCS) method. The USDA SCS method is often preferred over the other methods due to its high accuracy and small margin of error. It's most favoured for processing long term climatic and soil moisture data. Equation 2.4 and 2.5 are the formulae for this method.

$$P_{eff} = \frac{P_{tot}\,(125 - 0.2P_{tot})}{125} \quad \text{for } P < 250\text{mm} \tag{2.4}$$

$$P_{eff} = 125 + 0.1P_{tot} \quad \text{for } P > 250\text{mm} \tag{2.5}$$

Where; P_{eff} = effective rainfall

P_{tot} = total rainfall

The crop evapotranspiration is calculated as shown in Equation 2.6.

$$ET_c = K_c \times ET_o \quad (2.6)$$

Where; K_c = crop coefficient

ET_o = reference evapotranspiration.

The reference evapotranspiration is calculated according to the Penman-Monteith method using Equation 2.7.

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma\frac{900}{T+273}u_2\,(e_s - e_a)}{\Delta + \gamma\,(1+0.34\,u_2)} \quad (2.7)$$

Where ; ET_o = reference evapotranspiration [mm day^{-1}]

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]

G = soil heat flux density [MJ m^{-2} day^{-1}]

T = mean daily air temperature at 2m height [°C]

u_2 = wind speed at 2m height [m s^{-1}]

e_s = saturation vapour pressure [kPa]

e_a = actual vapour pressure [kPa]

e_s-e_a = saturation vapour pressure deficit [kPa]

Δ = slope vapour pressure curve [kPa °C^{-1}]

γ = psychrometric constant [kPa °C^{-1}]

IR_{net} is irrigation water which is delivered to the field and available for the crop to use. This is primarily water which is stored in soil in the crop root zone, although some of the water which is evaporated from water, soil, and plant surfaces during application also effectively reduces climate demand. From the definition for effective rainfall, a crop's irrigation requirement does not include water applied for leaching of salts, freeze protection, crop cooling, or other purposes, even though water for these purposes is required for crop production and is applied through an irrigation system. Some water is lost while transporting it from its source to the crop root zone. Losses occur due to such causes as leakage from pipelines, seepage and evaporation from open channels, and evaporation from droplets sprayed through the air. Because of these losses, more water must be pumped than that required to be stored in the crop root zone. The gross irrigation requirement (IR_{gross}) is the amount that must be pumped, taking into consideration all of the above factors. IR_{gross} is greater than IR_{net} by a factor which depends on the irrigation efficiency in percentage terms (EFF) and is calculated using Equation 2.8. The irrigation requirement may be calculated for any time period although it is normally calculated for monthly and seasonal or annual time periods.

$$IR_{gross} = \frac{IR_{net}}{EFF} \tag{2.8}$$

2.3.2 Irrigation methods and systems

There are several different methods of irrigation which are broadly categorised into two major groups; surface methods and micro methods, as shown in Figure 2-1.

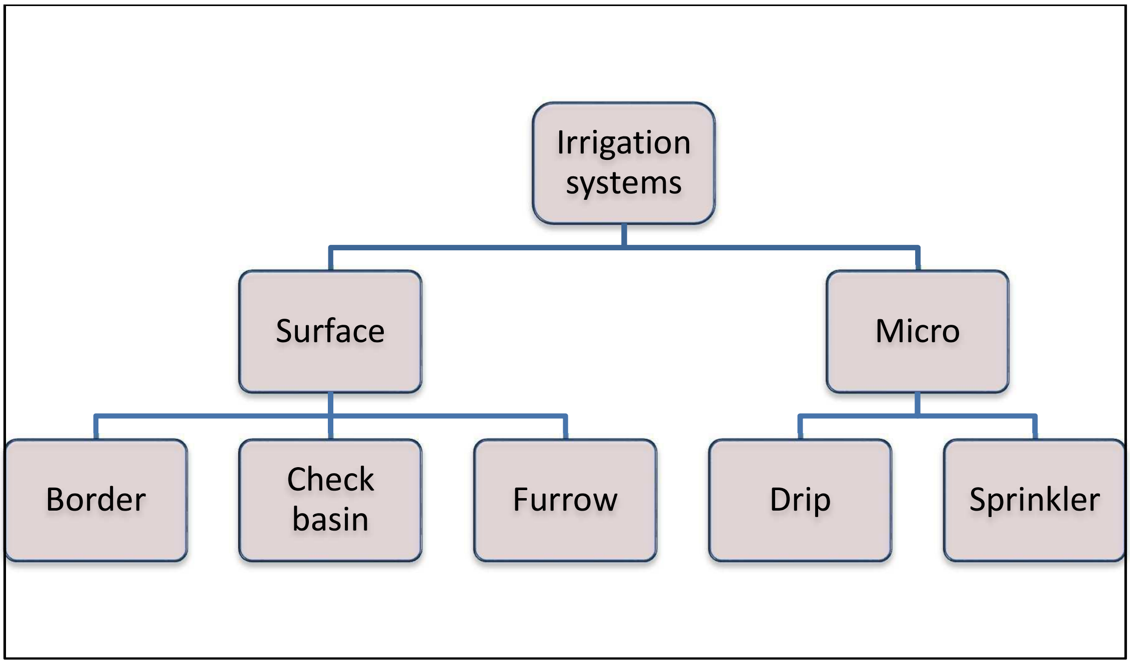

Figure 2-1: Irrigation systems and methods

2.3.2.1 Surface irrigation methods

These methods involve the introduction and distribution of water in a field by the gravity flow of water over the soil surface. The soil acts both as the growing medium in which water is stored and the conveyance medium over which water flows as it spreads and infiltrates (Ley, 2003).

Advantages of surface irrigation methods

a) Surface systems are often more acceptable to agriculturalists because it appears easier to apply the depths required to refill the root zone.
b) These systems can also be developed at the farm level with minimal capital investment.

c) The control and regulation structures are simple, durable and easily constructed with inexpensive and readily-available materials like wood, concrete, brick and mortar.
d) Energy requirements for surface irrigation systems come from gravity.
e) Surface systems are less affected by climatic and water quality characteristics.
f) Surface systems are better able to utilize water supplies that are available less frequently, more uncertain, and more variable in rate and duration. The gravity flow system is a highly flexible, relatively easily-managed method of irrigation.

Disadvantages of surface irrigation methods

a) Surface irrigation systems are much more difficult to design and implement since prior to the initiation of every surface irrigation event, two of the primary design variables, discharge and time of application must be estimated not only at the field layout stage but also judged by the irrigator.
b) Surface irrigation systems are typically less efficient in applying water.
c) These systems tend to be more affected by waterlogging if adequate drainage is not provided.
d) The need to use the field surface as a conveyance and distribution facility requires that fields be well graded if possible.
e) Land leveling costs can be high so the surface irrigation practice tends to be limited to land already having small, even slopes.
f) Surface systems tend to be labour-intensive. This labour need not be overly skilled but to achieve high efficiencies the irrigation practices imposed by the irrigator must be carefully implemented. The progress of the water over the field must be monitored in larger fields and good judgement is required to terminate the inflow at the appropriate time.
g) It is difficult to apply light, frequent irrigations early and late in the growing season of several crops.

2.3.2.2 Micro irrigation methods

Hla and Scherer (2003) described micro irrigation methods as precision irrigation methods of irrigation that constitute of low-pressure irrigation systems that spray, mist, sprinkle or drip with very high irrigation water efficiency. These methods save a substantial amount of water to levels of up to 58% for crops like bananas (National Horticulture Board, 2013) and they help to increase crop productivity.

Micro-irrigation components include pipes, tubes, water emitting devices, flow control equipment, installation tools, fittings and accessories. The two main micro irrigation systems are:

a. Sprinkler irrigation
b. Drip irrigation

Advantages of micro irrigation

i) Water saving.
ii) Efficient and economic use of fertilizers in case of fertigation.
iii) Easy installation and flexibility in operation.
iv) Suitable to all types of land terrain also suitable to waste lands.
v) Enhanced plant growth and yield.
vi) Uniform and better quality of produce.
vii) Less weed growth.
viii) Labour saving.
ix) No soil erosion.
x) Minimum diseases and pest infestation.

Disadvantages of micro irrigation

i) These systems are often very expensive.
ii) They have huge energy requirements for operation.
iii) Operation requires some good level of technical know-how.

2.3.3 Selection of an Irrigation System

Basak (1999) discussed some of the factors for the proper selection of an irrigation system. Careful consideration should be given to:

a. The environment in which the irrigation system will operate and;
b. The capabilities and limitations of all irrigation system alternatives which are economically feasible and have technically sound potential.

For any irrigation system chosen, its success will be affected by certain physical, social and economic factors.

Physical Factors

a. *Type of crop:* While selecting an irrigation system, it is important to know which crops and cultural practices exist in the area of interest.

b. *Agronomic practices:* Proper knowledge of agronomic practices and irrigation intervals is necessary for proper use of irrigation water and to increase water use efficiency.
c. *Soil conditions:* Care should be taken not to induce water stagnation since excess moisture may prove dangerous to crop growth.
d. *Soils Parameters:* Important soil parameters with respect to irrigation are texture and structure; depth of root zone and uniformity; infiltration rate and erosion potential; salinity and internal drainage, bearing strength. These parameters should be known.
e. *Field Topography:* Field slope and surface irregularity play important role in irrigation. Fields should be leveled.
f. *Climate and Weather Condition:* Climate and weather conditions of a region affect selection of irrigation system.
g. *Water Logging and Flood Hazard:* The productivity of land gets affected when the root zone of the plants gets flooded with water, and thus becomes ill aerated. Inadequate aeration reduces crop yield.

Water Supply

It is a key factor in selection of irrigation system. In fact, water supply alone may dictate the selection of appropriate irrigation method, if there is scarcity of quality water for irrigation. The following parameters are important:

a. Source and delivery schedule
b. Water quantity available and its reliability
c. Water quality
d. Water table in case of ground water source.
e. Availability and reliability of energy for pumping of water.

Economic considerations

a. Capital investment required and recurring cost.
b. Credit availability and interest rate
c. Life of irrigation system, efficiency and cost economics

Social considerations

a. The education and skills of common farmers available for handling the irrigation system.

b. Social understanding of the handling of co-operative activities and sharing of water resources by the farmers.
c. Local co-operation
d. Availability and skill of labour
e. Level of automatic control desired for the irrigation system.

2.3.4 Micro irrigation system components

According to Walker (1989), irrigation pipeline systems components are generally described as branching systems and are given names such as main, sub-main, manifold and lateral. Choosing the right size main, sub-main, manifold and lateral pipe to match the flow rates from the water source is important. Basic components can include a pump and power unit, a backflow prevention device if chemicals are used with water, a filter, a water distribution system, and some devices for controlling the volume of water and pressure in the system.

(a) Pumps and power unit

The type and size of pump selected depends on the amount of water required, the desired pressure and the location of the pump relative to the distribution network. Electric power units or internal combustion engine driven pumps are equally adaptable. However, the electric power unit is preferred because it is easier to automate.

(b) Filters

Filters remove sand and larger suspended particles before they enter the distribution network. However, the filters cannot remove dissolved minerals, bacteria and some algae. The three types generally used are screen, disk and sand filters.

(c) Distribution lines

The water distribution system is a network of pipes and tubes that can range in size from 1/2 inch to 6 inches in diameter. Water from the pump may be carried to the edge of the field by a single large main. Smaller sub-mains may then carry the water to manifolds and laterals and ultimately to the emitters.

(d) Control components

The control portion may include a combination of the following devices: pressure regulator, valve, vacuum relief valve and timing clock or controller. A flow meter should be used to measure the amount of water. Pressure gauges monitor the water pressure at the pump and other locations. Equipment to inject fertilizers into the water line is also frequently used, in which case the activity becomes known as ***fertigation***. Backflow prevention devices are used to prevent contamination of the water source.

2.4 Design of micro irrigation systems

The procedure for designing micro irrigation systems usually takes the following sequence (Azenkot, 2004):

a) Taking in considerations of the soil, topography, water supply and quality, type of crops.
b) Taking in considerations of the farm schedule.
c) Estimating the water application depth at each irrigation cycle.
d) Determining the peak period of daily water consumption.
e) Determining the frequency of water supply.
f) Determining the optimum water application rate.
g) Taking in considerations several alternatives of irrigation system types.
h) Determining the sprinklers or emitters spacing, discharge, nozzle sizes, water pressure.
i) Determining the minimum number of sprinklers or emitters (or a size of subplot) which must be operated simultaneously.
j) Dividing the field into sub-plots according to the crops, availability of water and number of shifts.
k) Determining the best layout of main and laterals.
l) Determining the required lateral size.
m) Determining the size of a main pipe.
n) Selecting a pump.
o) Preparing plans, schedules, and instructions for proper layout and operation.
p) Preparing a schematic diagram for each set of sub-mains or manifolds which can operate simultaneously.
q) Preparing a diagram to show the discharge, pressure requirement, elevation and pipe length.
r) Selecting appropriate pipes, starting at the downstream end and ending up by the water source.

2.4.1 Hydraulic design considerations

Common principles of hydraulics are used in the design of irrigation systems, just in the way they are applied to any other water supply systems. The following equations and formulae are commonly used, particularly in piped systems.

The continuity equation for flow within a pipe;

$$Q = V \times A \tag{2.9}$$

Where: Q = flow in the pipe in m^3/s

V = velocity of flow in the pipe in m/s

A = internal cross sectional area of the pipe in m^2

Bernoulli's equation for constant head along a pipe between two points (1 and 2) is also used:

$$Z_1 + P_1 + \frac{V_1}{2g} - \Delta h = Z_2 + P_2 + \frac{V_2}{2g} \tag{2.10}$$

Where: Z_1 and Z_2 are the elevations (static head) of the two points above the ground

P_1 and P_2 are the pressure head at the two points respectively in m

V_1 and V_2 are the velocities of flow at the two points respectively in m/s

g is the acceleration due to gravity in m/s^2

Δh is the total head loss along the pipe (due to friction and local energy losses)

The Darcy-Weisbach equation is used to determine head losses due to friction along a pipe;

$$J_{\%} = 8.38 \times 10^6 \times \frac{Q^{1.75}}{D^{4.75}} \tag{2.11}$$

Where: $J_{\%}$ = the head losses due to friction per 100-metre length of the pipe

Q = flow rate in the pipe in m^3/hr

D = internal diameter of the pipe in mm

In the hydraulic design of manifolds and laterals which discharge water along the length of the pipe through small openings, the head losses are calculated as if the pipe is plain and the outcome is multiplied by a coefficient, F, depending on the number of outlets, n, and the location of the first outlet. A table of the coefficients for plastic and aluminium pipes is given in Appendix 1.

The total head losses along the pipes are therefore calculated using Equation 2.12;

$$\Delta h = \Delta h_L \times F \times J\% \times L \qquad (2.12)$$

Where: Δh = total head losses along the pipe length

Δh_L = factor for local head losses

F = coefficient for perforated pipes

$J_{\%}$ = head losses due to friction

L = length of the pipe

2.4.2 Drippers/Emitters/Sprinklers

Drippers, emitters and sprinklers are selected depending on the application rate required. The suitable application rate depends on the irrigation schedule for the farm in consideration. Equation 2.13 is used to determine the application rate.

$$\text{Application rate (m/hr)} = \frac{Q_d}{S_d \times S_L} \qquad (2.13)$$

Where: Q_d = dripper discharge or flow rate (in m^3/hr)

S_d = spacing between drippers (in metres)

S_L = spacing between laterals (in metres)

The number of drippers or sprinklers on each dripper line or lateral depends on the spacing between each dripper line as seen in Equation 2.14.

$$\text{Number of drippers, } n_D = \frac{L(m)}{S_d(m)} \qquad (2.14)$$

L_L = estimated length of the lateral pipe

2.4.3 Lateral pipes/Dripper lines

The lateral pipes are those on which the drippers and/or sprinklers are placed.

The total flow in each lateral depends on the number of drippers along the lateral as shown in Equation 2.15.

$$Q_L = n_D \times Q_d \qquad (2.15)$$

Where; Q_L = total flow in the lateral (m^3/hr)

n_D = number of drippers along the lateral

Q_d = maximum flow in each dripper (m^3/hr)

The length of each lateral is calculated according to Equation 2.16;

$$\text{Actual lateral length, } L_L = S_1 + [S_d \times (n_D - 1)] \tag{2.16}$$

Where: n_D = total number of drippers along the line

S_1 = spacing between the lateral inlet and the first dripper

The pressure at the lateral inlet (h_u) is calculated according to Equation 2.17:

$$h_u = h_s + \frac{3}{4}\Delta h - \frac{\Delta z}{2} \tag{2.17}$$

Where: h_s = operating pressure in the pipe

Δh = total head losses in the pipe (including friction head losses and local head losses)

Δz = change in elevation between the two ends of the pipe

The pressure at the last dripper along the dripper line is calculated according to Equation 2.18 with the parameters having the same meaning as those in Equation 2.17;

$$h_{last} = h_u - \Delta h + \Delta z \tag{2.18}$$

2.4.4 Manifolds

Manifolds are designed in a way similar to lateral pipes since they discharge their water into the dripper lines along the way.

The number of laterals (n_L) along the manifolds is estimated according to Equation 2.19.

$$n_L = \frac{L_M}{S_L} \tag{2.19}$$

Where: L_M = estimated length of the manifold pipe

S_L = spacing between the laterals

The total flow in the manifold depends on the number of lateral dripper lines along the manifold as shown in Equation 2.20.

$$Q_M = n_L \times Q_L \tag{2.20}$$

The total length of a manifold is calculated as shown in Equation 2.21:

$$\text{Actual manifold length, } L_M = L_1 + [S_L \times (n_L - 1)] \tag{2.21}$$

Where: n_L = total number of laterals along the line

L_1 = spacing between the manifold inlet and the first lateral

The pressure at the manifold inlet (h_{u_m}) is calculated according to Equation 2.22:

$$h_{u_m} = h_u + \frac{3}{4}\Delta h - \frac{\Delta z}{2} \quad (2.22)$$

Where:

h_u = lateral inlet pressure

Δh = total head losses in the pipe (including friction head losses and local head losses)

Δz = change in elevation between the two ends of the pipe

The pressure at the last lateral inlet along the manifold is calculated according to the Equation below with the parameters having the same meaning as those in Equation 2.22.

$$h_{mlast} = h_{u_m} - \Delta h + \Delta z \quad (2.23)$$

All other pipes in the system including distribution pipes, transmission pipes, risers and suction pipes are designed according to the same principles of hydraulics.

2.4.5 Groundwater abstraction and selection of pumps

Abstraction of groundwater needs head gains and therefore, a pump is used to add energy or head gains to the flow to counteract head loss and hydraulic differentials within the system. A pump is defined by its characteristic curve which relates the pump head to the flow rate. The difference between well pumping and other pumping systems is that the pump suction head will vary due to the drawdown of the water table (piezometric surface) in the vicinity as water is pumped from it. The greater the flow rates through this pump, the larger the drop in water table elevation. In porous aquifers, there is no significant drop in the water table.

Pump selection is based on the total head consideration and safe yield of the borehole. The safe yield is established through pump testing while the pumping head is given by the Equation 2.24.

$$H = H_f + H_s + H_v \quad (2.24)$$

Where;

H_f is the total friction head losses between the pump and the point where water will be discharged (usually a reservoir)

H_s is the static head

H_v is the velocity lift

The total vertical lift (static head) is the difference between the level of the discharge point and the level of pump installation. It is usually estimated from a combination of topographic surveys (leveling) and the recommended borehole installation depth. The total friction head can be calculated from any one of several formulae available like the Hazen Williams formula or the Darcy-Weisbach formula (Equation 2.11).

The lift velocity for this purpose is small and is therefore considered negligible. For purposes of pump selection for preliminary designs, the total pumping head is first estimated at 100m. Performance curves from pump suppliers are used to select the pump that would deliver the required amount against a particular head.

The head provided by the pump must be sufficient to pump water to any point in the system and maintain the minimum pressure required. If there is any shortfall, it must be accounted for and hence added to the total design head so that the pump is sufficient for all purposes. The design head obtained along with the required discharge rate are used to select the pump basing on the pump curves available.

2.5 Irrigation water quality

The quality criteria for irrigation water largely depends on the type of crop in consideration. However, there are general guidelines for irrigation water which can be applied in all instances worldwide and these are shown in Table 2-1. The aim of these guidelines is to ensure that the chemical constituents in the water are not above certain limits which would be harmful to crop growth.

Table 2-1: Irrigation Water Standards

Potential irrigation water quality problem	Units	Degree of restriction on use	
		None	Severe
Salinity (affects crop water availability) / **TDS** (Total Dissolved Solids)	mg/l	<450	>2000
EC (Electrical Conductivity)	µmhos	250	3000
Specific Ion Toxicity (affects sensitive crops) / Chlorine **(Cl)**	meq/l	<4	>10
Plugging potential from irrigation water used in micro-irrigation systems			
Problem / **Chemical**	**Units**	**Low**	**Severe**
pH		<7.0	>8.0
Guidelines for heavy metals and metalloids in Irrigation Water			
Metal	**Units**	**LTV (Long term Value)**	**STV (short term Value)**
Chromium **Cr (VI)**	mg/l	0.1	1
Fluoride (**F**)	mg/l	1	42
Iron (**Fe)**	mg/l	0.2	10
Manganese **(Mn)**	mg/l	0.2	10
Phosphorous **(P)**	mg/l	0.05	0.8-12
Nitrogen **(N)** / Nitrate **(NO_3^-)**	mg/l	5	25-125
Nitrite **(NO_2^-)**	mg/l		

Adapted from Western Fertilizer Handbook, 2002, Ninth Edition (USDA NCRS, 2013)

2.6 Operation and Maintenance

Operations refer to activities involved in the daily running of any system, this being the irrigation systems in this case. It involves the correct handling of facilities by users to ensure the longevity of the various individual components. Proper operation of an irrigation system results in its optimum use and contributes to a reduction in breakdowns and maintenance needs.

Maintenance refers to activities aimed at sustaining the system in a proper working condition. Maintenance generally falls into the following categories;

a) **Preventive maintenance** which is regular inspection and servicing to preserve assets and minimize breakdown.

b) **Corrective maintenance** which is minor repair and replacement of broken and worn out parts to sustain reliable facilities.

c) **Repair (crisis maintenance)** which involves responses to emergency breakdowns and user complaints restore a failed supply.

Potential benefits of O&M activities include the following;

- Ensuring that the system serves it's intended purposes effectively
- Ensuring a long service life of the system
- Ensuring that the system runs smoothly without abrupt breakdowns that can disrupt normal operations
- Minimizing costs incurred in repairs and breakdowns.

3.0 MATERIALS AND METHODS

3.1 Literature Review and Desk Study

This involved an in-depth study of literature related to groundwater, irrigation and agricultural productivity from various sources including existing reports of previous work done in these areas. The purpose of this study was to understand the subject matter at hand as well as to acquaint ourselves with the case study area. Several reports about the climate, demographics and economic conditions of the cattle corridor area were studied.

A topographical map of the case study area (see Appendix 2) was obtained to enable us identify surface level features that could have a bearing on the presence of groundwater. Geological maps were also obtained and studied to gain a better understanding of the lithological and hydrogeological characteristics of the area.

3.2 Preliminary survey

This involved first a general orientation visit to the study area as well as meetings with farmers, district officials and other local leaders to get further information and people's opinions and perceptions about groundwater, farming and irrigation. This was done to verify the findings made during the desk study as well as to get more information in addition to what had been obtained before so as to fill in any gaps identified.

3.3 Data collection

This stage involved aggregating information and data from various sources on the different aspects of the project.

3.3.1 Baseline survey

In the baseline survey, information was obtained on the available surface and ground water resources, agricultural practices and socio-economic status of the communities in the project area. This was done by way of discussions with district officials, community leaders and farmers in the area. Available records and documents from these officials were also reviewed to gain relevant information. At this stage, the crops most grown in the area were identified.

Monthly climate data was also obtained from a weather station in Sembabule as well as from the Food and Agricultural Organization (FAO) ClimWat 2.0 climate database for weather parameters like humidity, sunshine hours and wind speeds. This data was to be used in the calculation of crop water requirements prior to the design.

3.3.2 Borehole records

Records for previously drilled boreholes in the study area were obtained from the National Groundwater Database at the Department of Water Resource Management to enable us determine the well yields and amount of water that could be abstracted from pump test results. This enabled us to identify areas expected to have reasonable amounts of groundwater that could be considered as viable areas to implement this project.

Information about the quality of water in each borehole was also obtained to check its suitability for irrigation purposes in line with irrigation water quality guidelines.

3.3.3 Topographical survey

After a suitable location for the model irrigation system had been obtained, a survey was done using an automatic level to determine suitable system components siting, pipework vertical and horizontal alignment and routing. The results of this survey were used in the hydraulic design. Ground profiles produced showing the levels and chainages along the pipe routing are shown in Appendix 3.

3.4 Determination of crop water requirements

The software CropWat 8.0, a free copy of which was downloaded from the FAO website, was used to determine crop water requirements and to generate irrigation schedules for the model scheme. This software has eight modules which were used as described below;

- Climate/ET_o: This made use of monthly temperature, wind speed, humidity and sunshine hours to calculate monthly radiation and reference evapotranspiration (ET_o) by the Penman-Monteith formula (Equation 2.7).
- Rain: This made use of actual monthly rainfall values to calculate effective rainfall using the United States Department of Agriculture soil conservation service (USDA SCS) method. It can also use the empirical formula, fixed percentage method and dependable rain (FAO/AGLW formula).
- Crop: Data for the various crop parameters in consideration like stage days, rooting depth, critical depletion fraction and K_c values were put into this module to calculate ET_c.
- Soil: In this module, soil data like the maximum rooting depth and the total available soil moisture, depending on the soil type was input so as to generate irrigation schedules.

- CWR: This module generated crop water requirements for the entire growing season once data had been filled into the previous modules.
- Schedule: this module generated irrigation schedules according to different specifications about frequency and irrigation depth. It was also used to evaluate schedules in terms of yield reduction.
- Crop pattern: This module was used to set out a crop pattern for the scheme with the relevant planting dates so as to determine the necessary scheme supply for the entire growing season.
- Scheme supply: This module generated a table with values of the water amounts that would be needed in the scheme at every irrigation event.

3.5 Design

After the crop water requirements had been obtained using CropWat 8.0, a borehole with yields that could meet the crop water requirements was selected and an irrigation system for a model scheme was designed in the vicinity. The selected borehole is in Muguluka village in Miteete Parish. A farm belonging to Mr Peter Ddungu was selected as a suitable location for the model scheme. The farm has a banana garden of one-hectare size and a kraal with 50 heads of cattle.

An irrigation system design manual by Azenkot (2004) was used as a design aid along with catalogues from irrigation equipment manufacturers like Netafim, John Deere and Grundfos. Principles of hydraulics demonstrated in equations such as 2.9, 2.10 and 2.11 as well as the results of the topographic survey, were used to determine pipe sizing, pressure and flows.

3.6 Cost estimates and economic analysis

Once the preliminary design had been made, a cost estimates was done basing on price information obtained from equipment suppliers. Bills of Quantities were produced out of the cost estimates.

The economic analysis for the system was done using the cash flow analysis method and this indicated the pay-back period as well.

4.0 ANALYSIS AND DESIGN

4.1 Crop water requirements

Minimum and maximum daily temperature data obtained from a station in Sembabule for 25 years (1971 to 1995) was reduced to average monthly data for input into the CropWat 8.0 Climate/ET_o module. Data for the other parameters (humidity, wind speed and sunshine hours) was not available from that station so it was obtained from the FAO ClimWat 2.0 database for a nearby station in Mubende which lies in the same climatic region as Sembabule. Table 4-1 shows the climate data and the calculated radiation (in MJ/m^2/day) and ET_o (in mm/day).

Table 4-1: Printout of Sembabule Climate/ETo data

MONTHLY ETO PENMAN-MONTEITH DATA
(File: F:\Dropbox\FYP Work\Final Work\Sembabule 1 - ClimateETo.PEM)

Country: Uganda Station: SEMBABULE
Altitude: 1259 m. Latitude: 0.10 °S Longitude: 31.50 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	15.7	28.6	67	372	5.5	17.4	4.92
February	16.1	29.0	67	389	5.5	17.9	5.13
March	16.6	28.8	70	406	5.6	18.3	5.03
April	17.1	27.8	77	406	7.0	19.9	4.61
May	16.5	27.2	79	406	7.5	19.5	4.30
June	15.7	27.0	74	432	8.4	20.1	4.66
July	15.3	24.1	72	389	6.5	17.7	4.08
August	15.7	27.3	75	372	6.6	18.7	4.40
September	15.7	27.3	76	406	5.5	17.8	4.36
October	16.2	27.9	77	372	6.9	20.0	4.58
November	16.0	27.5	75	346	6.9	19.5	4.52
December	15.7	27.8	73	354	7.6	20.2	4.73
Average	16.0	27.5	74	388	6.6	18.9	4.61

Daily rainfall data for the same 25-year period was analyzed to get monthly values for each year (see Appendix 4). The total annual rainfall values were ranked and their probabilities of exceedance calculated using the Weibull formula (Equation 2.2). Figure 4-1 is a plot of the total annual rainfall amounts against the probabilities of exceedance on a logarithmic scale, which was used to obtain the total annual rainfall for the wet, normal and dry year.

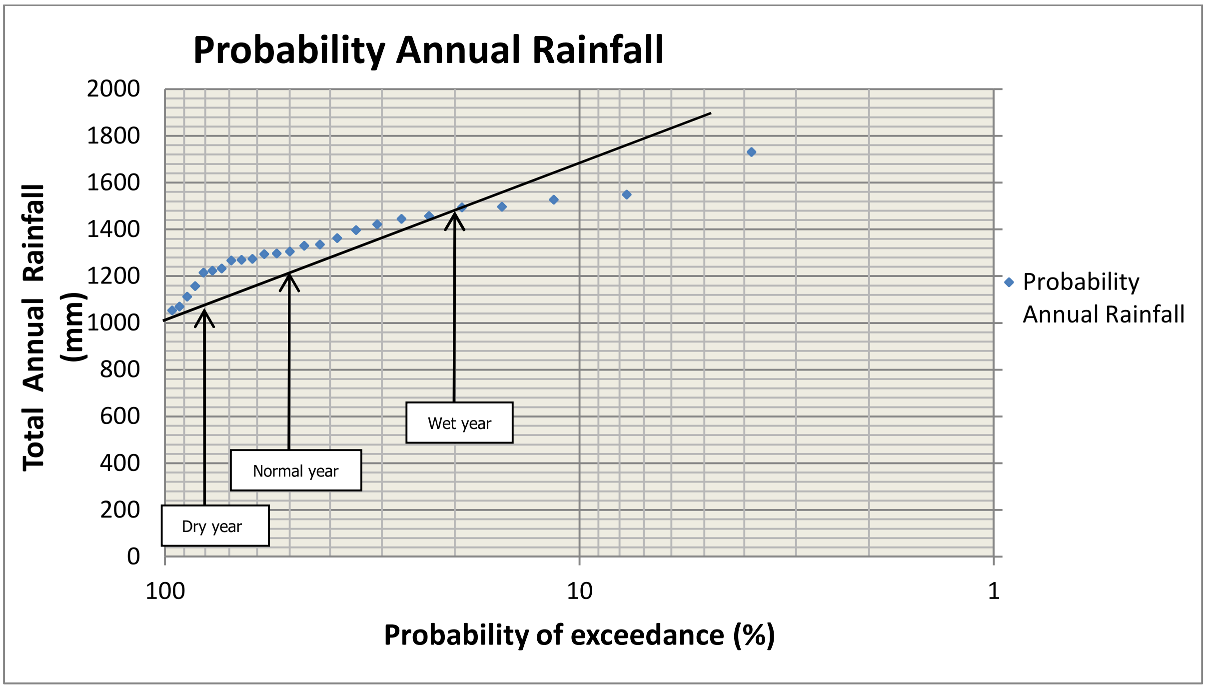

Figure 4-1: Plot showing the dry, normal and wet rainfall for Sembabule

Determining the total annual rainfall for the dry year (P80), normal year (P50) and wet year (P20) at 80%, 50% and 20% probability of exceedance respectively generated the following values;

P80 = 1120mm

P50 = 1250mm

P20 = 1480mm

The resulting values of monthly rainfall for the dry, normal and wet year which were calculated using Equation 2.3 are shown in Table 4-2. The values for the normal year are in general approached by the average rainfall values.

Table 4-2: Monthly rainfall values for the dry, normal, wet and average year

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dry	53	61	113	151	153	69	52	75	79	106	132	76	1120
Normal	59	68	126	169	171	77	58	84	88	118	147	85	1250
Average	63	72	135	180	182	82	62	89	94	126	157	91	1334
Wet	70	80	150	200	202	91	69	99	104	140	174	101	1480

Rainfall data for the dry year (dependable rainfall) was used for the design of the irrigation system capacity. When this data was put into the Rain module of CropWat 8.0, the effective rainfall was obtained using USDA SCS method (Equation 2.4 and 2.5).

Table 4-3 shows the values of effective rainfall as calculated for the dry year. Similar tables for the wet year, normal year and average year are given in Appendix 4.

Table 4-3: Monthly rainfall and effective rainfall for Sembabule (Dry year)

```
                    MONTHLY RAIN DATA
 (File: F:\Dropbox\FYP Work\Final Work\CropWat Files\Rainfall\Sembabule 1 - Dry.CRM)

 Station: Sembabule 1

 Eff. rain method: USDA Soil Conservation Service formula:
                   Peff = Pmon * (125 - 0.2 * Pmon) / 125  for Pmon <= 250 mm
                   Peff = 125 + 0.1 * Pmon                 for Pmon  > 250 mm


                Rain    Eff rain
                 mm        mm

 January        53.0      48.5
 February       60.8      54.9
 March         113.3      92.8
 April         151.2     114.6
 May           153.2     115.6
 June           68.6      61.1
 July           52.2      47.8
 August         74.9      65.9
 September      78.9      68.9
 October       106.1      88.1
 November      131.8     104.0
 December       76.1      66.8

 Total        1120.1     929.1
```

From the baseline survey, the major crops grown in the case study area were found to be: coffee, bananas, maize and beans. Data for the different crop parameters like the K_c values, growth stage lengths and rooting depths were put into the crop module for each of these crops and the printout for bananas is as shown in Table 4-4. The printouts for the other crops are given in Appendix 5.

Table 4-4: Crop data for bananas

```
                        DRY CROP DATA
(File: F:\Dropbox\FYP Work\Final Work\CropWat Files\Crop Data\BANANA1-0102.CRO)

  Crop Name:  BANANA 1st year        Planting date: 30/03    Harvest: 22/02

  Stage                 initial     develop      mid         late       total

  Length (days)           90         165          45          30         330
  Kc Values              0.50        -->         1.10        1.00
  Rooting depth (m)      0.30        -->         0.90        0.90
  Critical depletion     0.55        -->         0.45        0.45
  Yield response f.      1.00        1.00        1.00        1.00        1.00
  Cropheight (m)                                 3.00
```

The soils in the case study area were identified to be sandy loam as shown in Figure 4-2.

Figure 4-2: Soils in the study area

The soil parameters for sandy loam that were put into the soil module were obtained from the FAO CropWat database. Table 4-5 shows the printout of soil parameters for sandy loam.

Table 4-5: Soil data for sandy loam

```
                         SOIL DATA
      (File: F:\Dropbox\FYP Work\Working Documents\SANDY LOAM.SOI)

  Soil name: SANDY LOAM

  General soil data:

    Total available soil moisture (FC - WP)       140.0   mm/meter
    Maximum rain infiltration rate                  30    mm/day
    Maximum rooting depth                          900    centimeters
    Initial soil moisture depletion (as % TA         0    %
    Initial available soil moisture               140.0   mm/meter
```

The crop water requirements for each crop were finally determined using the crop water requirement (CWR) module. According to information obtained during the baseline survey, the planting seasons in Sembabule usually occur in March and September. To cater for variations in irrigation water requirements resulting from delays in planting dates, different planting dates at intervals of 15 days starting on February 1st and on August 1st were tried for each crop to note the irrigation requirements that would result. The planting date generating the highest total irrigation requirement was chosen so as to design the irrigation system capacity for the worst case scenario. Bananas were found to have the highest irrigation requirement among all the crops for a whole growing season with a planting date of 30th March. Table 4-6 shows the irrigation water requirements for bananas, a total of 533.6mm for a whole season. The highest crop water requirements for the other crops according to their varying planting dates are given in Appendix 6.

Table 4-6: Crop water requirements for bananas for a 30th-March planting date

CROP WATER REQUIREMENTS

ETo station: SEMBABULE — Crop: BANANA 1st year
Rain station: Sembabule 1 — Planting date: 30/03

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Mar	3	Init	0.50	2.44	4.9	6.1	4.9
Apr	1	Init	0.50	2.37	23.7	36.4	0.0
Apr	2	Init	0.50	2.30	23.0	39.2	0.0
Apr	3	Init	0.50	2.25	22.5	39.0	0.0
May	1	Init	0.50	2.20	22.0	40.2	0.0
May	2	Init	0.50	2.15	21.5	41.1	0.0
May	3	Init	0.50	2.21	24.3	34.2	0.0
Jun	1	Init	0.50	2.30	23.0	25.1	0.0
Jun	2	Init	0.50	2.38	23.8	18.4	5.4
Jun	3	Deve	0.50	2.28	22.8	17.6	5.2
Jul	1	Deve	0.54	2.29	22.9	16.5	6.4
Jul	2	Deve	0.58	2.35	23.5	14.5	9.0
Jul	3	Deve	0.62	2.59	28.5	17.0	11.5
Aug	1	Deve	0.66	2.85	28.5	20.4	8.0
Aug	2	Deve	0.70	3.10	31.0	22.7	8.3
Aug	3	Deve	0.75	3.28	36.1	22.8	13.3
Sep	1	Deve	0.79	3.46	34.6	22.1	12.5
Sep	2	Deve	0.83	3.63	36.3	22.2	14.1
Sep	3	Deve	0.87	3.87	38.7	24.6	14.1
Oct	1	Deve	0.92	4.12	41.2	27.3	13.9
Oct	2	Deve	0.96	4.38	43.8	29.5	14.3
Oct	3	Deve	1.00	4.56	50.1	31.2	18.9
Nov	1	Deve	1.04	4.73	47.3	34.6	12.8
Nov	2	Deve	1.08	4.90	49.0	37.2	11.8
Nov	3	Deve	1.13	5.16	51.6	32.2	19.4
Dec	1	Mid	1.17	5.43	54.3	25.8	28.5
Dec	2	Mid	1.18	5.58	55.8	21.4	34.4
Dec	3	Mid	1.18	5.66	62.3	19.7	42.6
Jan	1	Mid	1.18	5.74	57.4	17.4	39.9
Jan	2	Mid	1.18	5.81	58.1	15.0	43.1
Jan	3	Late	1.17	5.85	64.4	16.1	48.2
Feb	1	Late	1.14	5.78	57.8	16.6	41.2
Feb	2	Late	1.11	5.72	57.2	16.8	40.3
Feb	3	Late	1.10	5.59	11.2	5.4	11.2
					1253.4	826.4	533.6

The scheme supply module was used to determine the net irrigation requirement for a scheme having bananas only and the values in Table 4-7 were obtained (in mm/day, mm/month and l/s/h) with 100% of the scheme area being irrigated.

Table 4-7: Scheme water requirements for a scheme with only bananas

SCHEME SUPPLY

ETo station: SEMBABULE Cropping pattern:
Rain station: Sembabule 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. BANANA	131.7	93.0	4.9	0.0	0.0	10.8	27.4	30.2	41.3	47.8	44.7	106.0
Net scheme irr.req.												
in mm/day	4.2	3.3	0.2	0.0	0.0	0.4	0.9	1.0	1.4	1.5	1.5	3.4
in mm/month	131.7	93.0	4.9	0.0	0.0	10.8	27.4	30.2	41.3	47.8	44.7	106.0
in l/s/h	0.49	0.38	0.02	0.00	0.00	0.04	0.10	0.11	0.16	0.18	0.17	0.40
Irrigated area (% of total area)	100.0	100.0	100.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Irr.req. for actual area (l/s/h)	0.49	0.38	0.02	0.00	0.00	0.04	0.10	0.11	0.16	0.18	0.17	0.40

4.2 Determination of available groundwater

Table 4-8 is an extract showing information for some of the boreholes in the Mateete area with significant yields.

Table 4-8: Summary of data for some boreholes in Mateete sub-county

No.	Location	BH Number	BH Depth (m)	Water strikes (m)	Casing Depth (m)	Pump test yield (m^3/hr)
1	Mateete, Manyama Parish	CD1830	96.1	73.2 86.9	70.8	1.60
2	Manyama, Manyama Parish	CD1843	183.0	88.5	72.5	0.16
3	Katimba, Manyama Parish	CD3815	108.2	46.1 99.1		2.89
4	Mateete, Mateete Parish	DWD21811	85.9	62.0 68.0		0.76
5	Katimba B, Manyama Parish	DWD24177	122.0	60.0 122.0		4.50
6	Muguluka, Miteete Parish	DWD24184	78.0	54.0 78.0		9.50
7	Muguluka, Miteete Parish	DWD24185	120.3	35.0 90.0		53.00
8	Kyamuganga, Nakagongo Parish	DWD31631	77.1	56.9 76.0	77.3	0.50

From Table 4-8, the boreholes with the highest yields are those in Muguluka village, Miteete Parish with yields of 9.50m^3/hr and 53m^3/hr for numbers DWD24184 and DWD24185 respectively. These were considered for the design of the model scheme. Considering the fact that not so many boreholes had high yields, only one was finally selected so as to design the model scheme. Ideally, this model scheme was designed to follow the Indian approach, with the selected borehole serving only a small area given the limitations in yields. A comparison between the quality data for borehole DWD24184 and the guidelines for irrigation water quality revealed that this water is suitable for irrigation purposes. This comparison is in Table 4-9.

Table 4-9: Comparison of water quality of borehole DWD24184 with irrigation water quality guidelines

Potential Irrigation water Quality Problem	Units	Degree of restriction on use		BH DWD24184
		None	Severe	
Salinity (affects crop water availability)				
TDS (Total Dissolved Solids)	mg/l	<450	>2000	218.62
EC (Electrical Conductivity)	µmhos	250	3000	393.18
Specific Ion Toxicity (affects sensitive crops)				
Chlorine (Cl)	meq/l	<4	>10	5.5
Plugging potential from Irrigation water used in micro-irrigation systems				
Problem	**Units**	**Low**	**Severe**	**DWD24185**
Chemical				
pH	-	<7.0	>8.0	6.43
Guidelines for heavy metals and metalloids in Irrigation Water				
Metal	**Units**	**LTV (Long term Value)**	**STV (short term Value)**	**DWD24185**
Chromium Cr (VI)	mg/l	0.1	1	0.0011
Fluoride (F)	mg/l	1	42	0.63
Iron (Fe)	mg/l	0.2	10	0.43
Manganese (Mn)	mg/l	0.2	10	0.15
Phosphorous (P)	mg/l	0.05	0.8-12	0.036
Nitrogen (N)		5	25-125	
Nitrate (NO_3^-)	mg/l			0.42
Nitrite (NO_2^-)	mg/l			0.003

In the vicinity of borehole number DWD24184, the selected farm for the model design belonging to Mr Peter Ddungu, has a banana garden of 1 hectare in area and a kraal with 50 heads of cattle at the lower end. Since the farm had only bananas with sandy loam soils, it was decided that a drip system would be used and the layout is to be of an “end-feed” configuration as shown in Appendix 7. Each plant is to be served by a dripper along a lateral dripper line. The area was surveyed and levels taken along the edges of the farm at intervals of 25m, as well as up to the borehole location and the kraal at the lower end. The reduced levels, set to a temporary benchmark of 1200m above sea level are also indicated in the design drawings in Appendix 7.

4.3 Design calcultations

Reference	Calculations	Output
National Horticulture Board, 2013 Equation 2.13	**Drippers** The usual spacing of banana plants in Miteete is 3m by 3m. It is recommended that each plant gets at least 25litres of water per irrigation cycle in the dry months. This is in line with the peak gross irrigation requirement of 25mm on 1st January as per the irrigation schedule developed in the CropWat 8.0 Schedule module whose printout is shown in Appendix 8. For a critical root zone of at least 1m^2, water would be applied to a depth of 25mm following the schedule and this would total up to 25litres per plant.	S_d = 3m S_L = 3m
	Setting an application time of 6 hours per day for each irrigation cycle, each dripper would have a discharge of 25 litres within the 6 hours, hence a rate of 4.167*l*/hr.	Application time = 6 hours per irrigation cycle
	Drippers with model number PCDj20 from Netafim were selected. These have a maximum discharge of 2.0gph, an equivalent of 7.57litres per hour. Therefore, maximum discharge to each plant = 0.00757m^3/hr.	Use Netafim PCDj20 dripper. Flow = 2.0gph Q_d = 0.00757m^3/hr
	These drippers operate at a maximum pressure of 50psi which is an equivalent of 35m of pressure head. For design purposes, a pressure head of 30m was used for the entire system.	Maximum pressure head = 35m
Equation 2.14	For a spacing of 3m between each two plants along the length of the farm, a maximum of 67 drippers would fit per lateral dripper line.	n_D = 67 drippers per lateral/dripper line

	Laterals (Dripper lines)	
Equation 2.15	With each dripper line having 67 drippers, with Q_D = 0.00757m^3/hr the total maximum flow rate along the lateral = 0.507m^3/hr which is an equivalent of 0.14*l*/s.	Q_L = 0.507m^3/hr
Netafim USA, 2007	A 20mm TECHLINE dripper line, made of low-density polyethylene with blank tubing was selected for use as lateral.	Use TECHLINE 20mm dripper line
Equation 2.16	With the first dripper at 1m away from the lateral inlet, the length of the dripper line = 1 + (3 × 66) = 199m Internal diameter = 16mm = 0.016m Cross-sectional Area, A = $2.0106 \times 10^{-4}$$m^2$ Discharge, Q_L = $1.4083 \times 10^{-4}$$m^3$/s Velocity in the pipe = $\frac{Q}{A} = \frac{1.4083 \times 10^{-4}}{2.0106 \times 10^{-4}}$ = 0.70m/s	L_L = 199m
Equation 2.9	Checking for optimum velocity as per design criteria: (0.70m/s = 0.70m/s < 3.00m/s) **OK**	Velocity within the lateral pipes is adequate.
Equation 2.11	Determining head losses according to Darcy-Weisbach equation: $J_{\%} = 8.38 \times 10^6 \times \frac{Q^{1.75}}{D^{4.75}}$ Therefore $J_{\%}$ = 4.86m/100m	
Appendix 1	Since n_D = 67 drippers, F_{67} = 0.367	
Equation 2.12	An allowance of 10% was made for local head losses due to connections, bends and valves. $\Delta h = 1.1 \times 0.367 \times \frac{4.86}{100} \times 199 = 3.90$m	Total head losses = 3.90m
Equation 2.17	Pressure at the lateral inlet: $h_u = h_s + \frac{3}{4}\Delta h - \frac{\Delta z}{2}$ The change in elevation (Δz) for the first lateral is 7.007m. operating pressure, h_s = 30m $h_u = 30 + (\frac{3}{4} \times 3.90) - \frac{7.007}{2} = 29.42$m	h_u = 29.42m

Equation 2.18	Pressure at last dripper: $h_{67} = h_u - \Delta h + \Delta z$ $= 29.42 - 3.90 + 7.007 = 32.527$m Pressure loss between inlet and last dripper = 29.42 - 32.527= -3.107m (this implies that there's actually a head gain)	$h_{67} = 32.527$m There's a head gain along the dripper lines.
Equation 2.19	**Manifold:** The manifold is along the width of the farm (50m side). With a spacing of 3m between the laterals, this will allow a maximum of 17 laterals along the manifold.	$n_L = 17$ laterals
Equation 2.20	Since $Q_L = 0.507m^3/hr$, the total flow rate in the manifold will be $8.62m^3/hr$ which is an equivalent of 2.394*l*/s.	$Q_M = 8.62m^3/hr$
Equation 2.21	With the first lateral located 1m away from the manifold inlet, the total length of the manifold will be = 1 + (3 × 16) = 49m	$L_M = 49$m
Equation 2.9	Internal diameter = 42.2mm = 0.0422m Cross-sectional Area, A = $1.3987 \times 10^{-3}m^2$ Discharge, Q = $2.3942 \times 10^{-3}m^3/s$ Velocity in the pipe = $\frac{Q}{A} = \frac{2.3942 \times 10^{-3}}{1.3987 \times 10^{-3}}$ = 1.71m/s Checking for optimum velocity as per design criteria: (0.70m/s < 1.71m/s < 3.00m/s) **OK**	Use HDPE 50mm PN-6 Velocity within the manifold pipes is adequate.
Equation 2.11	Determining head losses according to the Darcy-Weisbach equation: $J_{\%} = 8.38 \times 10^6 \times \frac{Q^{1.75}}{D^{4.75}}$ Therefore $J_{\%} = 6.92$m/100m	
Appendix 1	Since the manifold has 17 laterals, $F_{17} = 0.375$ An allowance of 10% was made for local head losses due to connections, bends and valves.	
Equation 2.12	$\Delta h = 1.1 \times 0.375 \times \frac{6.92}{100} \times 49 = 1.40$m	

Equation 2.22	Pressure at the manifold inlet: The change in elevation (Δz) along the manifold is 1.55m. $= 29.42 + (\frac{3}{4} \times 1.40) - \frac{1.55}{2} = 29.695m$	$h_{u_m} = 29.695m$
Equation 2.23	Pressure at last lateral inlet: $= 29.695 - 1.40 + 1.55 = 29.845m$ Pressure loss between manifold inlet and last lateral inlet = 29.695 – 29.845 = - 0.15m (this is also a head gain) A Netafim Low volume control zone kit with a $1^1/_2$" disc filter and a pressure regulating valve for high flow will be placed at the inlet into the manifold pipe. A flush valve is to be placed at the lower end manifold pipe as well at mid-length.	$h_{17} = 29.845m$ Fix a Netafim Low Volume Control Zone LVCZ10075-LF includes 1" 24 VAC Valve, $1^1/_2$" disc filter and 3/4" PRV075LF45 Pressure Regulator
	Transmission pipe This is the pipe delivering water from the pump location to the manifold. Flow rate = 8.62m^3/hr Hence, a 50mm PN6 HDPE pipe was selected. Internal diameter = 42.2mm = 0.0422m Cross-sectional Area, $A = 1.3987 \times 10^{-3}m^2$	Use HDPE 50mm PN-6
Equation 2.9	Discharge, $Q = 2.3942 \times 10^{-3}m^3/s$ Velocity in the pipe $= \frac{Q}{A} = \frac{2.3942 \times 10^{-3}}{1.3987 \times 10^{-3}} = 1.71m/s$ Checking for optimum velocity as per design criteria: (0.70m/s < 1.71m/s < 3.00m/s) **OK**	Velocity within the manifold pipes is adequate.
Equation 2.11 Equation 2.12	Total length = 78.3m, $J_{\%} = 6.92m/100m$ Head losses $= 1.1 \times 78.3 \times \frac{6.92}{100} = 5.96m$	

	Distribution pipe and Tank The distribution pipe will convey water from the transmission pipe to the tank at the cattle kraal. Since water for the garden is to be applied for 6 hours per cycle, supply to the tank at the kraal is to be done non-simultaneously with supply to the banana garden. Number of cattle on the farm = 50 Daily water demand per animal = 40l per animal per day	
CAES, 2012	Total water demand = 2000l per day. Peak demand = 1.5 × 2000l = 3000l per day	
	Since the pump is not to be operated every day, a tank size allowing for at least 3 days' supply to be stored was selected Total tank capacity = 3 × 3000 = 9000l A tank capacity of 10,000 litres was therefore selected as it was the nearest available commercial size.	Supply a stainless steel tank of 10,000-litre capacity
	For a flow rate of 8.62m^3/hr, the tank would take 70 minutes to fill when pumping constantly. Therefore, a 50mm PN6 HDPE pipe was selected.	Use HDPE 50mm PN-6
Equation 2.11 Equation 2.12	Total length = 205m, $J_{\%}$ = 6.92m/100m Head losses = $1.1 \times 206 \times \frac{6.92}{100} = 15.60$m	
	Suction pipe and Pump Sizing The borehole located near the farm (DWD24184) has a yield of 9.5m^3/hr and a recommended installation depth of 82m below ground level. The maximum required discharge from the suction pipe = 8.62m^3/hr.	

	A GI pipe of 2" was selected for this pipe. Internal diameter = 50.8mm Internal diameter = 50.8mm = 0.0508m Cross-sectional Area, A = $2.0268 \times 10^{-3}m^2$ Discharge, Q = $2.3942 \times 10^{-3}m^3/s$	Use 2" GI pipe
Equation 2.9	Velocity in suction pipe = $\frac{Q}{A} = \frac{2.3942 \times 10^{-3}}{2.0268 \times 10^{-3}}$ = 1.18m/s Checking for optimum velocity as per design criteria: (0.70m/s < 1.18m/s < 3.00m/s) **OK**	The velocity in the pipe is adequate
Equation 2.11	Determining head losses according to Darcy-Weisbach equation: $J_{\%} = 8.38 \times 10^6 \times \frac{Q^{1.75}}{D^{4.75}}$ Therefore $J_{\%}$ = 2.87m/100m An allowance of 10% was made for local head losses due to connections.	
Equation 2.12	$\Delta h = 1.1 \times \frac{2.87}{100} \times 82 = 2.58m$	
Equation 2.24	**The pumping head requirements for the pump (H)** H = head losses in suction pipe + static head + residual pressure required at pump location Required installation depth = 82m Therefore, suction head = 82m To calculate the residual head required at the pump location, Bernoulli's equation was applied to determine the pressure at various points in the system	
Equation 2.10	**a) Between the pump (point 1) and tank (point 2):** $Z_1 + P_1 + \frac{V_1}{2g} - \Delta h = Z_2 + P_2 + \frac{V_2}{2g}$ Z_1 = 1203.921m P1 = pressure head required at the pump V_1 = velocity of water at the pump location The reduced level at the tank location = 1192.056m Height to the top of the tank above the ground = 2.5m	

	Therefore $Z_2 = 1194.556$m	
	P_2 = residual pressure required at the tank = 7m	
	V_2 = velocity of water at the tank location	
	Since the flow rate is the same throughout the pipe line,	
	$V_1 = V_2$	
	$\Delta h = 5.69 + 15.06 = 21.56$m	
	$1203.921 + P_1 - 21.56 = 1194.556 + 7$	
	Therefore, $P_1 = 19.195$m	
	b) Between the pump (1) and the last dripper at point D (2)	
	$Z_2 = 1192.993$m	
Equation 2.10	P_2 = pressure at the dripper (h_{67}) = 32.76,	
	V_2 = velocity of water in the lateral = 0.70m/s	
	$V_1 = 1.71$m/s	
	$\Delta h = 5.69 + 3.90 = 9.59$m	
	$1203.921 + P_1 + \frac{1.71}{2 \times 9.81} - 9.59 = 1192.993 + 32.76 + \frac{0.7}{2 \times 9.81}$	
	$P_1 = 31.37$m	
	c) Between the pump (point 1) and the last dripper at point C (point 2)	
Equation 2.10	$Z_2 = 1190.428$m	
	P_2 = pressure at the dripper	
	$= h_{17} - \Delta h + \Delta z = 29.845 - 3.90 + 8.023 = 33.968$m	
	V_2 = velocity of water in the lateral = 0.70m/s	
	$V_1 = 1.71$m/s	
	$\Delta h = 5.69 + 1.40 + 3.90 = 10.99$m	
	$1203.921 + P_1 + \frac{1.71}{2 \times 9.81} - 10.99 = 1190.428 + 33.968 + \frac{0.7}{2 \times 9.81}$	
	$P_1 = 31.73$m	

Equation 2.10	**d) Between the pump (point 1) and the end of the manifold pipe (point 2)** $Z_2 = 1198.450m$ P_2 = pressure at the last lateral inlet $= h_{17} = 29.845m$ V_2 = velocity of water in the manifold = 1.71m/s $V_1 = 1.71m/s$ $\Delta h = 5.69 + 1.40 = 7.09m$ $1203.921 + P_1 – 7.09 = 1198.450 + 29.845$ $P_1 = 31.464m$	
Equation 2.10	**e) Between the pump (point 1) and the inlet to the manifold pipe (point 2)** $Z_2 = 1200m$ P_2 = pressure at the dripper $= h_{u_m} = 29.695m$ V_2 = velocity of water in the manifold = 1.71m/s $V_1 = 1.71m/s$ $\Delta h = 5.69m$ $1203.921 + P_1 – 5.69 = 1200 + 29.695$ $P_1 = 31.464m$	
	Therefore, the maximum pressure head that the pump location must have to facilitate operating pressures at all points in the system = 31.73m Therefore H = 82 + 2.58 + 31.73 = 116.31m	Pump head = 116.31m
Appendix 9	Using performance curves obtained from pump suppliers, A GROUNDFOS submersible pump SP 8A-30 was selected having a maximum capacity of 120m head for a flow of 8.62m^3/hr.	Use Grundfos SP8A-30 submersible pump

4.4 Summary of system components

- Borehole of yield $9.5m^3/hr$ installed with an electric submersible pump: Grundfos SP 8A-30.
- An irrigation system comprising of two 49m manifold pipes (HDPE 50mm PN6) and 17 laterals/dripper lines (TechLine 20mm) totaling 3383m in length and fitted with a total of 1139 drippers (PCDj 2.0gph).
- A 10,000 litre water tank supplying water to the cattle kraal at the lower end of the kraal.
- Water to the two sections of the system (banana irrigation and water supply for the cattle) is to be supplied non-simultaneously by using shut-off valves.
- Complete design drawings for the entire system are provided in Appendix 7.

4.5 Cost estimate and Economic analysis

The cost of the entire system was estimated to be UGX33,761,806 as detailed in the bills of quantities in Appendix 10. This estimate was based on current market prices obtained from equipment manufacturers and suppliers.

In the schedule module of CropWat 8.0, a second schedule for the same bananas was created whereby they would grow on entirely rain-fed basis. This schedule, shown in Appendix 8 indicated that without irrigation, there would be a yield reduction of 27.3%! This therefore means that a farmer who would efficiently and effectively start practicing irrigation to a yield reduction of zero following a schedule like that in Appendix 8(a) would in effect have an increase in yield of 36.89% (approximately 37%) which is $\frac{27.3}{72.7}$!

On average, a farmer depending entirely on rain receives a yield of 33 tonnes per hectare per season, according to information from Makerere University Agricultural Research Institute, Kabanyoro (MUARIK). With each bunch of bananas going for about UGX8,000 and weighing about 30kg on average, a 37% increase in yield (12.21 tonnes) would result in extra income of UGX3,260,070 per hectare.

A cash flow analysis was done to determine the payback period for the system as follows;
Annual revenues from crops = UGX3,260,070
A similar estimate of revenues from the cattle was assumed as well
Therefore, total annual revenues = UGX6,520,140

Costs: Operation and maintenance

Since the electric pump is to run on solar power, this will limit costs in terms of energy. Annual operation and maintenance costs are assumed to be at least 5% of the cost of the pump system which is UGX788,300.

Therefore, usage of the irrigation system would result into income amounting to UGX5,731,840 after subtracting operation and maintenance costs.

A constant depreciation rate of 10% of the purchase price of the pump was assumed since it has a service life of between 10 and 20 years along with a tax rate of 30%. The analysis in Table 4-10 resulted. An interest rate of 15% was chosen as it approximates to the average rate of inflation over the past 3 years.

According to the pump manufacturer, the service life of the pump which is the most sensitive part of the whole system is estimated to be 10 to 20 years. Therefore, the cash flow analysis was done for a period of 10 years.

Table 4-10: Cash flow analysis for the irrigation system

Year	Rate	1	2	3	4	5	6	7	8	9	10
F/P, 15%, n		1.1500	1.3225	1.5209	1.7490	2.0114	2.3131	2.6600	3.0590	3.5179	4.0456
Revenues - Costs	5,731,840	6,591,616	7,580,358	8,717,412	10,025,024	11,528,778	13,258,094	15,246,808	17,533,830	20,163,904	23,188,490
Less depreciation	10%	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600
Earnings before taxes		5,015,016	6,003,758	7,140,812	8,448,424	9,952,178	11,681,494	13,670,208	15,957,230	18,587,304	21,611,890
Taxes	30%	1,504,505	1,801,128	2,142,244	2,534,527	2,985,653	3,504,448	4,101,063	4,787,169	5,576,191	6,483,567
Earnings after tax		3,510,511	4,202,631	4,998,569	5,913,897	6,966,524	8,177,046	9,569,146	11,170,061	13,011,113	15,128,323
Cashflows		5,087,111	5,779,231	6,575,169	7,490,497	8,543,124	9,753,646	11,145,746	12,746,661	14,587,713	16,704,923
P/F, 15%, n	15	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	0.2843	0.2472
Discounted Cash flow		4,423,575	4,369,929	4,323,280	4,282,716	4,247,443	4,216,770	4,190,099	4,166,906	4,146,738	4,129,201
NPV		4,423,575	8,793,504	13,116,784	17,399,500	21,646,942	25,863,713	30,053,811	**34,220,717**	38,367,456	42,496,657

The payback period from the above analysis was found to be 8 years.

5.0 RESULTS AND DISCUSSIONS

The design above consists of a system supplying water to a 1*ha* banana garden as well as to the adjacent cattle herd of 50 animals, from a borehole of 9.5m^3/hr yield.

Taking from the CropWat 8.0 Scheme supply module, it can be seen that the yield of the borehole is sufficient for the crop water needs when pumping for a duration of 7 hours a day as shown in Figure 5-1. This actually provides enough water for the animals also. The table with the actual figures of this comparison is in Appendix 11.

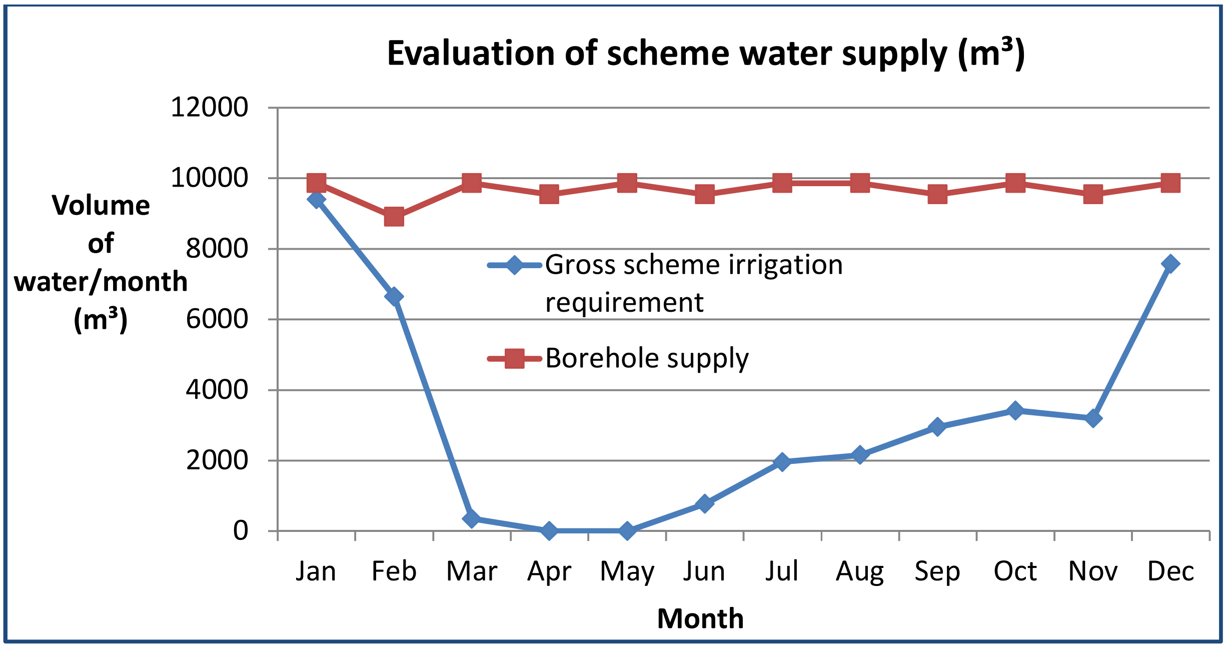

Figure 5-1: Comparison of the borehole water supply with irrigation requirements

Though this particular borehole had sufficient yield for the required crop water needs, not many other boreholes in the same area have similar yields as seen in Table 4-8. This was found to be in agreement with research that shows that aquifers in many African countries, though resilient to climate change, are not very high-yielding (MacDonald et al, 2012). This calls into question whether it is possible to adopt the use of groundwater for irrigation at a large scale in this particular area. However, it is possible, as shown by the results of this design, to adopt irrigation on small scale basis using groundwater resources. This nevertheless has to be subjected to further investigations of the borehole yields in any area that is a potential candidate for irrigation.

The two schedules developed in the CropWat 8.0 Schedule module, one with the bananas being irrigated (Appendix 8-a) and the other with the crops being entirely rain-fed throughout the season

(Appendix 8-b) showed a yield reduction of 27.3% in the latter schedule! This implies that it is very crucial to find ways of providing irrigation services to farmers so as to boost yields. This is in agreement with the results of research about rainfall reliability done by Rugumayo *et al* (2003).

The cash flow analysis done for the designed system indicated a pay-back period of 8 years for the system. Considering the service life of the submersible pump (10 – 20 years) which is the key component of the system, it is quite clear that the benefits of the system from the cash-flows are not sufficient to make quick returns. The high cost is understandable since all the equipment has to be imported from abroad which greatly hikes the costs considering taxes and freight charges. Moreover, drip irrigation systems are the most expensive of all due to the huge network of pipes used per plot. Possibly, using other types of irrigation systems like sprinkler systems and canal systems where appropriate would result into lower capital costs though drip irrigation is the most water efficient of all, sometimes saving water quantities used up to 53% (National Horticulture Board, 2011).

The high costs associated with irrigation systems are also due to the fact that irrigation (both from groundwater and other sources) is not yet wide-spread in Uganda as it is in other countries. This keeps the number of equipment suppliers and installers in the economy very low due to the low volume of business and therefore, monopolistic pricing tendencies result. A case in point is the difference in borehole drilling costs between Uganda and India, being US$10,000 and US$3,000 respectively.

Also affecting the cash flows of this particular system is the fact that the crop in consideration is not of very high value when grown on a small scale yet it can only have one season in a year. Therefore the revenues from the extra yields due to irrigation do not pay off quickly enough in comparison to the costs, both initial and operational. High value crops especially vegetables like cabbages, onions, tomatoes and carrots would fetch much higher revenues and hence result into quicker cost recovery for irrigation systems at a small scale. For example, cabbages would have a yield increase of 41.6% from irrigation which translates to 12 to 20 tonnes per hectare and extra revenues of at least UGX19,680,000 from the two seasons in the year. With this extra revenue streaming in and operational costs for the two seasons estimated at UGX3,153,200, a shorter pay-back period of 3 years would be possible as shown by the cash flow analysis in Appendix 12.

Tomatoes would in a similar way generate a yield increase of 35% (an extra 12 to 20 tonnes) and hence extra revenues of at least UGX12,780,000 and a pay-back period of 5 years.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

- The highest crop water requirements determined from the various crops in the study area were 533.6mm for an entire growing season for bananas.
- Only two boreholes in the study area had sufficient yields to meet the crop water requirements.
- A model irrigation system of an "end-feed" dripper configuration was designed for a farm of 1 hectare, also providing water for a herd of 50 cattle. Water is to be abstracted from borehole number DWD24184 with a yield of 8.62m^3/hr using an electric submersible pump (Grundfos SP8A-30).
- The cost of the system was estimated to be UGX33,761,806 with a payback period of 8 years.

6.2 Recommendations

- Farmers should adopt irrigation so as to improve their crop yields.
- A mix of water sources should be considered: rainwater, groundwater and surface water.
- Farmers should form groups so they can pool resources together to acquire and establish irrigation systems.
- It is also recommended that farmers who practice irrigation opt for high value crops especially vegetables like cabbages, carrots, tomatoes and onions to realise reasonable returns on their investment.
- Farmers should plant their crops earlier to avoid yield reductions due to moisture deficits.
- Wider investigations into the available groundwater resources to determine their suitability for irrigation and hence utilise them appropriately.

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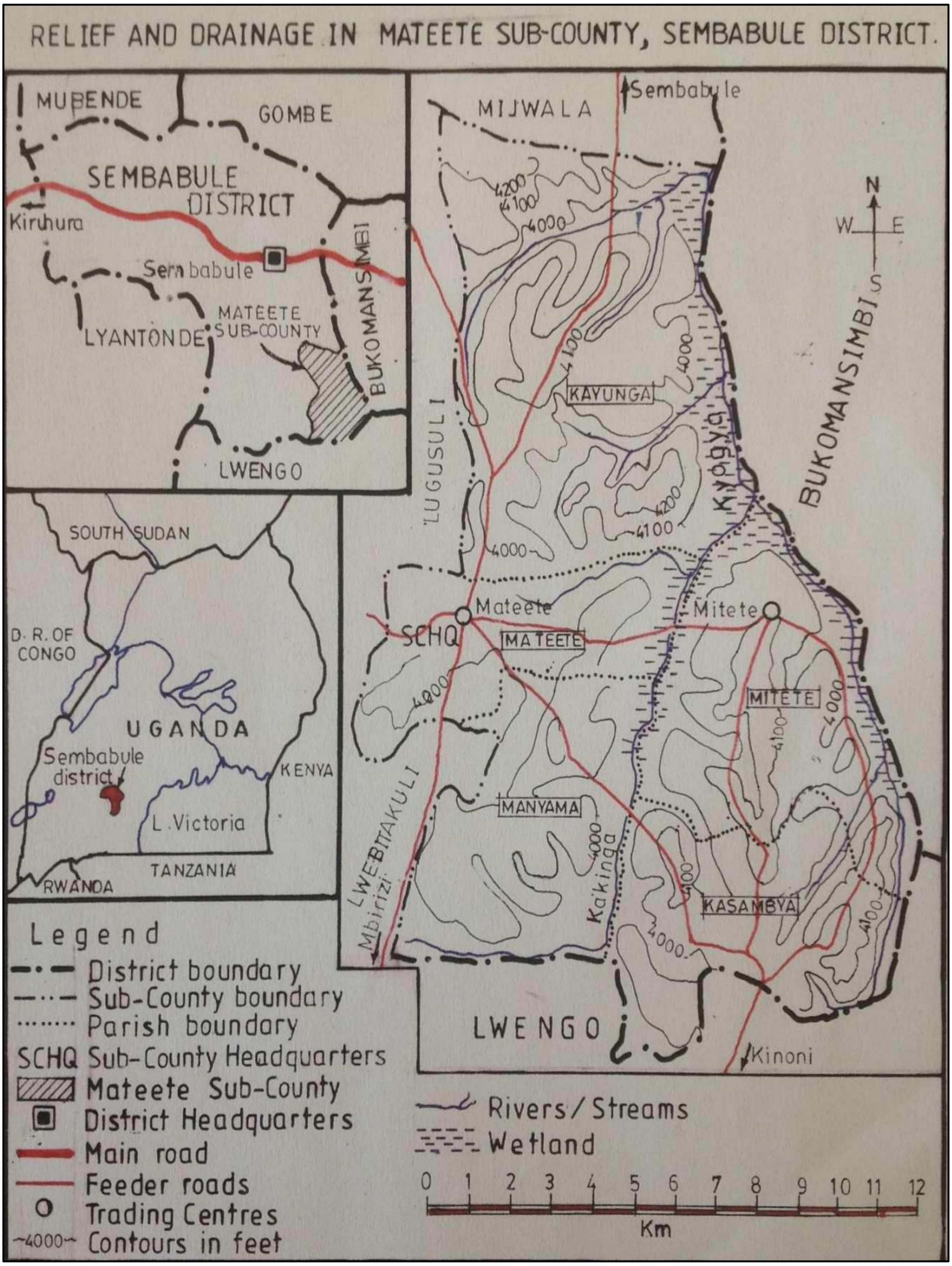
Appendices

Appendix 1: Coefficients for friction head losses in plastic and aluminum pipes with multiple outlets

n	Plastic lateral			Aluminum lateral		
	F_1	F_2	F_3	F_1	F_2	F_3
2				0.64		0.52
3				0.54		0.44
4				0.49		0.41
5	0.469	0.337	0.41	0.457	0.321	0.396
10	0.415	0.35	0.384	0.402	0.336	0.371
12	0.406	0.352	0.0.381	0.393	0.338	0.367
15	0.398	0.355	0.377	0.385	0.341	0.363
20	0.389	0.357	0.373	0.376	0.343	0.36
25	0.384	0.358	0.371	0.371	0.345	0.358
30	0.381	0.359	0.37	0.368	0.346	0.357
40	0.376	0.36	0.368	0.363	0.347	0.355
50	0.374	0.361	0.367	0.361	0.348	0.354
100	0.369	0.362	0.366	0.356	0.349	0.352

1. F1 to be used when the distance from the lateral inlet to the first outlet is s_1 meters.
2. F_2 to be used when the first outlet is just by the lateral inlet.
3. F_3 to be used when the distance from the lateral inlet to the first outlet is $S_{1/2}$ meters.

Appendix 2: Topographic map of Mateete sub-county, Sembabule district

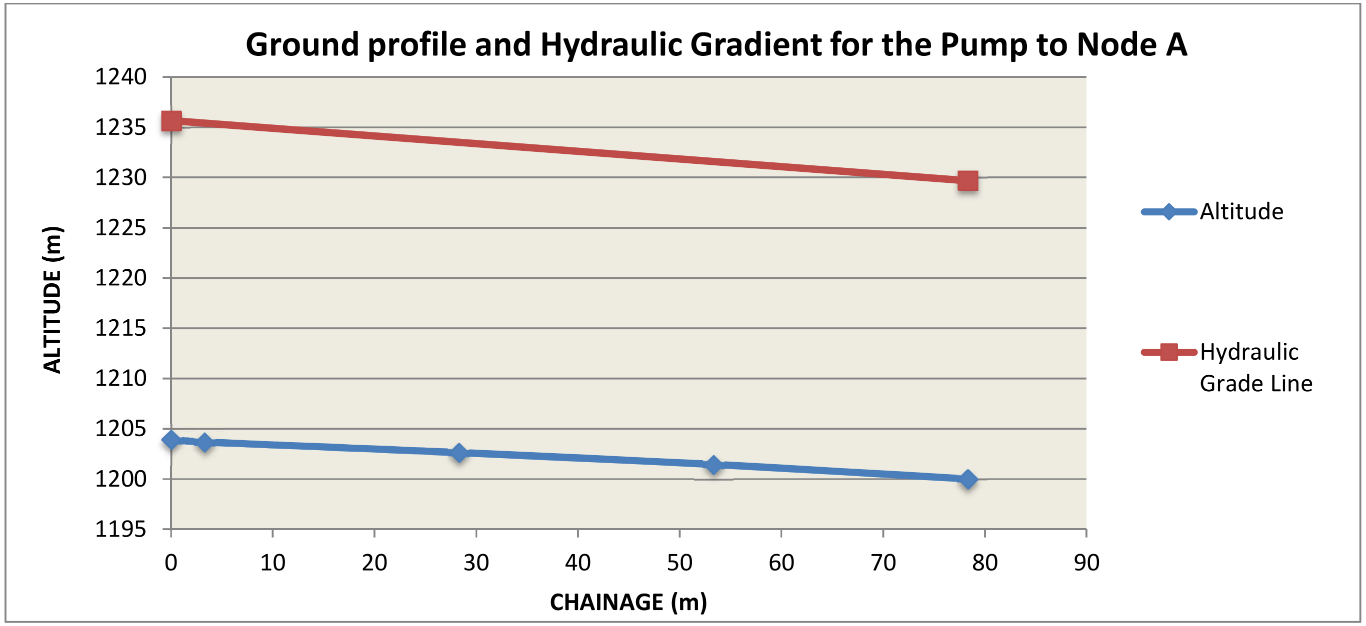


Appendix 3: Ground profiles of the design area

HYDRAULIC CALCULATIONS FOR THE TRANSMISSION LINE

PUMP LOCATION TO NODE A

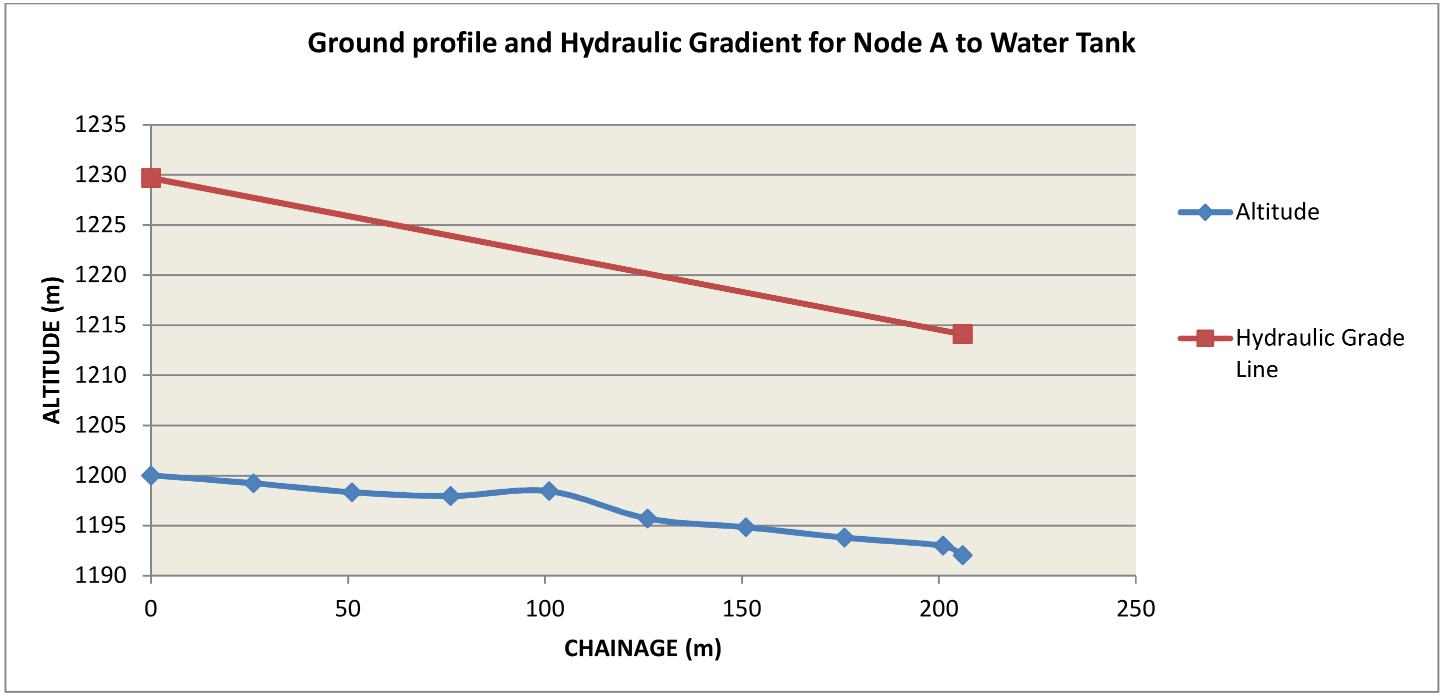
PIPE SECTION	CHAINAGE (m)	SECTION LENGTH (m)	SOIL/GROUND CONDITION	ALTITUDE (m)	POTENTIAL HEAD DIFFERENCE (m)	SECTION FLOWS (l/s)	SECTION PIPE		VELOCITY (m/s)	FRICTION LOSS (m)	CUMULATIVE FRICTION LOSS (m)	RESIDUAL HEAD (m)	HGL. ELEVATION (m)
							TYPE	SIZE					
PUMP	0			1203.921	0					0	0	31.730	1235.651
		78.3	Murram			2.39	HDPE PN6	50mm	1.71				
NODE A	78.3			1200.000	3.921					5.96	5.96	29.691	1229.691



HYDRAULIC CALCULATIONS FOR THE DISTRIBUTION LINE

NODE-A TO THE WATER TANK AT THE KRAAL

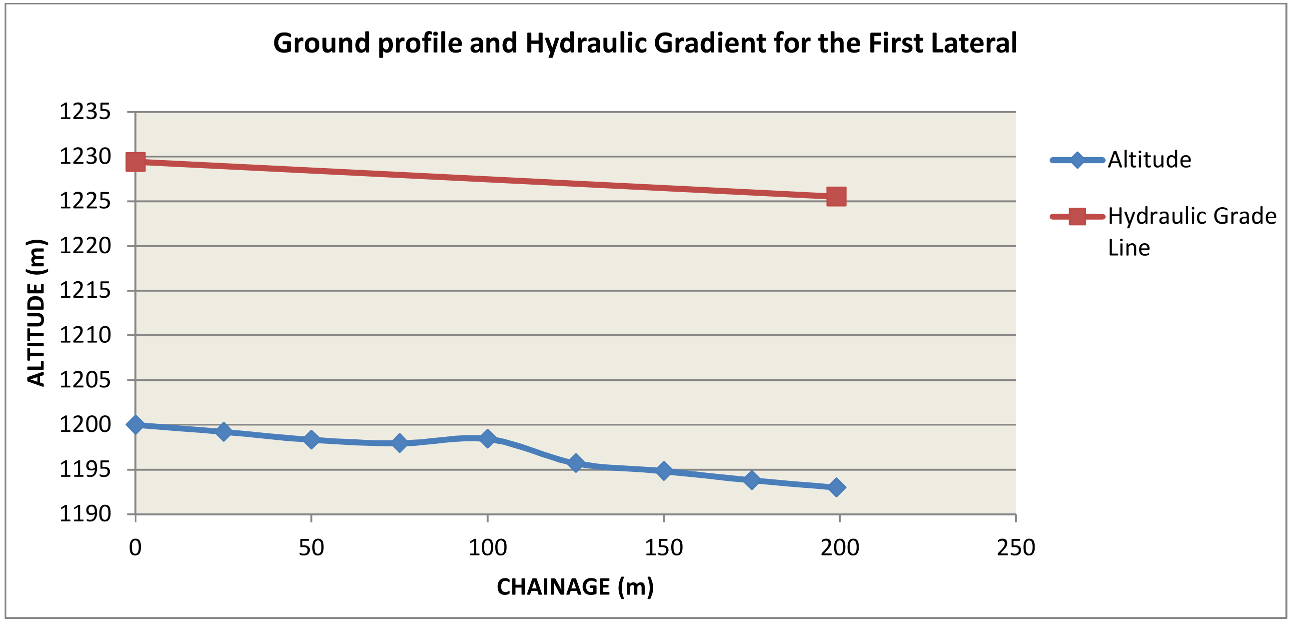
PIPE SECTION	CHAINAGE (m)	SECTION LENGTH (m)	SOIL/GROUND CONDITION	ALTITUDE (m)	POTENTIAL HEAD DIFFERENCE (m)	SECTION FLOWS (l/s)	SECTION PIPE		VELOCITY (m/s)	FRICTION LOSS (m)	CUMULATIVE FRICTION LOSS (m)	RESIDUAL HEAD (m)	HGL. ELEVATION (m)
							TYPE	SIZE					
NODE A	0			1200.000	0					0	0	29.691	1229.691
		206	Sandy loam			2.39	HDPE PN6	50mm	1.71				
WATER TANK	206			1192.056	7.944					15.600	15.600	22.035	1214.091



HYDRAULIC CALCULATIONS FOR LATERAL LINES

FIRST LATERAL

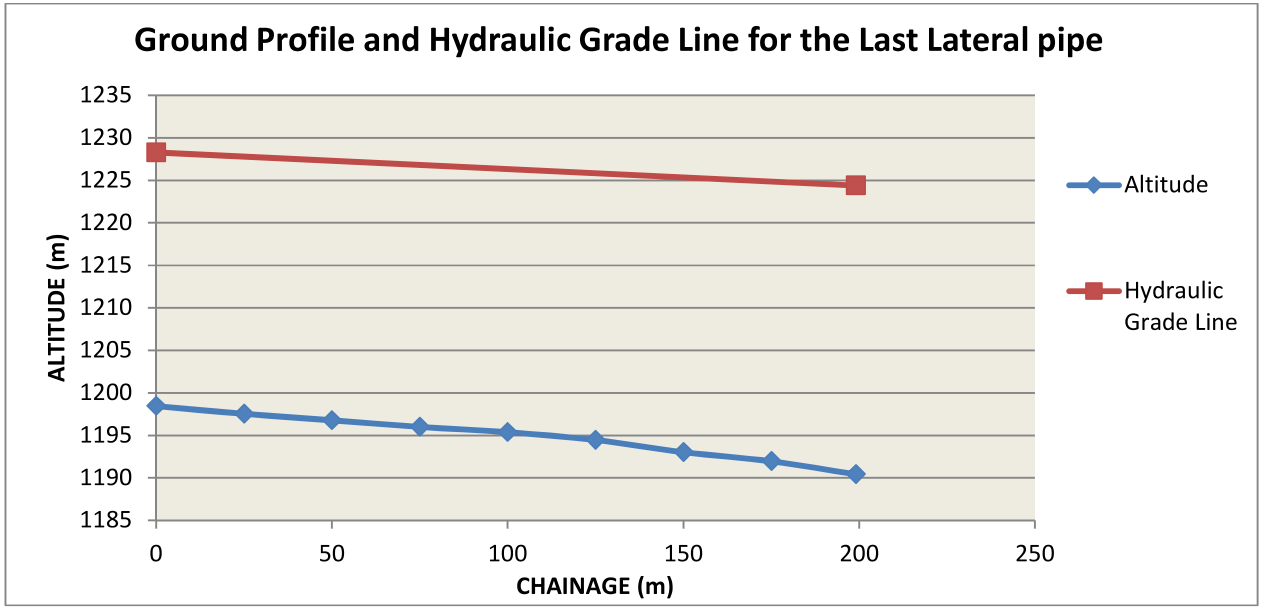
PIPE SECTION	CHAINAGE (m)	SECTION LENGTH (m)	SOIL/GROUND CONDITION	ALTITUDE (m)	POTENTIAL HEAD DIFFERENCE (m)	SECTION FLOWS (l/s)	SECTION PIPE		VELOCITY (m/s)	FRICTION LOSS (m)	CUMULATIVE FRICTION LOSS (m)	RESIDUAL HEAD (m)	HGL. ELEVATION (m)
							TYPE	SIZE					
Lateral Inlet	0			1200.000	0					0	0	29.420	1229.420
		199	Sandy loam			0.14	Techline Dripper-line	20mm	0.70				
Last Dripper (67)	199			1192.993	7.007					3.900	3.900	32.527	1225.520



HYDRAULIC CALCULATIONS FOR LATERAL LINES

LAST LATERAL

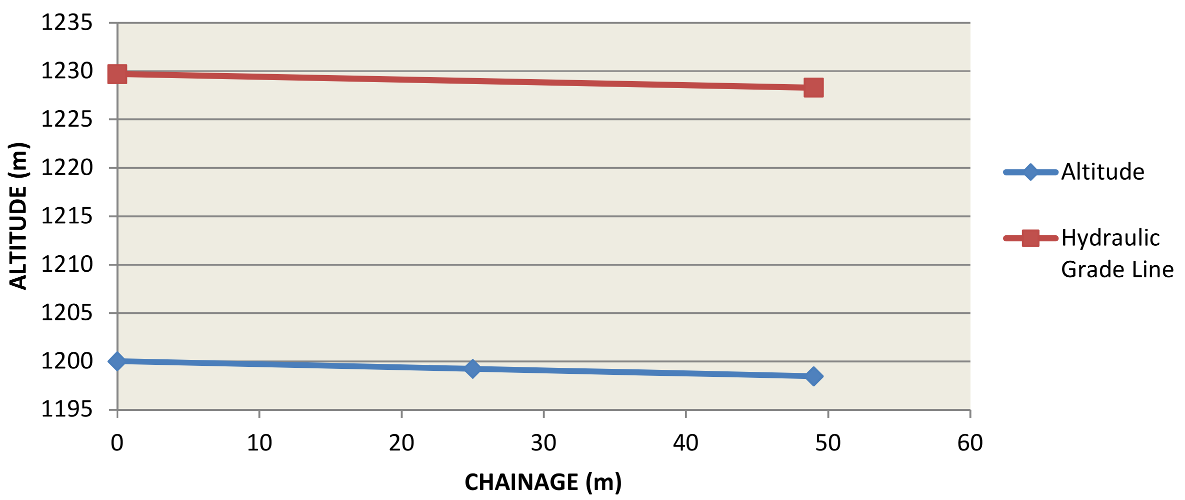
PIPE SECTION	CHAINAGE (m)	SECTION LENGTH (m)	SOIL/GROUND CONDITION	ALTITUDE (m)	POTENTIAL HEAD DIFFERENCE (m)	SECTION FLOWS (l/s)	SECTION PIPE		VELOCITY (m/s)	FRICTION LOSS (m)	CUMULATIVE FRICTION LOSS (m)	RESIDUAL HEAD (m)	HGL. ELEVATION (m)
							TYPE	SIZE					
Lateral Inlet	0			1198.450	0					0	0	29.845	1228.295
		199.000	Sandy loam			0.14	Techline Dripper-line	20 mm	0.70				
Last Dripper (67)	199.000			1190.428	8.022					3.900	3.900	33.967	1224.395



HYDRAULIC CALCULATIONS FOR THE MANIFOLD

PIPE SECTION	CHAINAGE (m)	SECTION LENGTH (m)	SOIL/GROUND CONDITION	ALTITUDE (m)	POTENTIAL HEAD DIFFERENCE (m)	SECTION FLOWS (l/s)	SECTION PIPE		VELOCITY (m/s)	FRICTION LOSS (m)	CUMULATIVE FRICTION LOSS (m)	RESIDUAL HEAD (m)	HGL. ELEVATION (m)
							TYPE	SIZE					
Manifold Inlet	0			1200.000	0					0	0	29.695	1229.695
		49	Sandy loam			2.39	HDPE PN6	50mm	1.71				
Manifold end - B	49			1198.450	1.550					1.400	1.400	29.845	1228.295

Ground profile and Hydraulic Gradient for the Manifold Pipe



Appendix 4: Rainfall data

a) Monthly rainfall data (1971 to 1995)

Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
January	95.7	61.4	81.2	78.1	35.0	69.2	55.2	13.4	108.7	68.8	85.2	69.1	18.1
February	21.7	40.2	104.9	89.3	78.9	88.7	86.0	155.7	196.4	124.3	37.5	12.8	6.4
March	52.3	73.5	43.5	97.8	154.6	165.9	116.9	174.8	123.8	212.4	192.2	140.9	84.8
April	167.5	126.4	189.2	163.8	178.9	45.8	286.8	295.5	241.2	268.5	129.5	203.7	211.6
May	201.3	119.7	171.8	119.3	246.1	173.7	112.8	237.1	157.6	237.1	172.3	173.6	166.2
June	56.6	113.4	75.7	96.6	128.7	70.5	72.7	78.1	112.9	102.9	71.9	56.3	69.9
July	123.4	43.8	33.0	152.6	56.7	83.8	76.8	117.6	60.0	53.3	66.8	68.9	43.9
August	102.6	103.3	119.8	48.8	105.1	56.4	155.1	94.1	59.2	63.3	140.6	26.8	121.5
September	82.6	72.0	83.8	154.7	140.0	107.4	73.5	119.2	44.8	38.3	152.5	58.8	64.9
October	165.7	129.1	138.2	112.1	129.1	127.9	143.1	170.2	55.6	114.0	126.7	197.0	142.3
November	145.9	34.8	205.2	63.6	59.1	220.1	225.3	185.6	163.3	183.8	46.3	147.9	87.5
December	79.3	152.7	24.6	39.1	86.0	88.3	90.7	90.0	99.1	60.8	115.2	78.0	37.7
Total	1294.6	1070.3	1270.9	1215.8	1398.2	1297.7	1494.9	1731.3	1422.6	1527.5	1336.7	1233.8	1054.8
Rank	15	24	17	21	9	14	5	1	8	3	11	19	25

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Average
January	16.4	41.7	18.7	29.4	123.3	28.8	77	74.3	58.7	150.6	37.1	81.7	63.072
February	20.9	15.2	40.4	61.3	89.7	49.3	92	87.2	37.2	105	69.1	99.1	72.368
March	58.3	201.6	129.8	158.6	108.7	144.1	195.5	124.2	88.8	197.2	129.5	202	134.868
April	204.7	154.4	181.5	138.6	143.5	111.4	199.2	153.1	129.4	190.9	173.7	212.9	180.068
May	186.2	168.4	151.5	227.1	149.6	204.5	342.6	246.1	162.9	94.2	225.6	111.7	182.36
June	100.5	21.7	66.1	89.3	70.5	65	14.6	67.7	81.6	134.4	85	138.5	81.644
July	87.9	65.2	29.6	21.2	108.4	4	49.1	24.7	86.7	30.9	31.6	34.2	62.164
August	87.8	25.9	15.7	83.4	92.7	130.8	103.1	98.5	85.2	60.9	216.4	32.7	89.188
September	45.3	50.4	181.2	173.5	116.8	120.8	63.3	82.6	60	79.7	19.3	161.7	93.884
October	106.9	78.9	74.9	148.8	48	128.4	117.9	138.5	144.6	130.1	114.4	176.5	126.356
November	216.8	249.5	138.3	160.5	171.5	240.8	133.2	160.9	145.8	159.5	310.1	68.6	156.956
December	92.7	40.0	130	38.8	83.2	230.1	110.4	10.5	193.2	30	34.1	230.2	90.588
Total	1224.4	1112.9	1157.7	1330.5	1305.9	1458	1497.9	1268.3	1274.1	1363.4	1445.9	1549.8	1333.516
Rank	20	23	22	12	13	6	4	18	16	10	7	2	

b) Total annual rainfall with rank and probability of exceedance

Year	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**
Annual Rainfall (mm/year)	1295	1070	1271	1216	1398	1298	1495	1731	1423	1528	1337	1234	1055
Rank Number, *m*	15	24	17	21	9	14	5	1	8	3	11	19	25
Probability of exceedance, P (%)	58	92	65	81	35	54	19	4	31	12	42	73	96

Year	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Annual Rainfall (mm/year)	1224	1113	1158	1331	1306	1458	1498	1268	1274	1363	1446	1550
Rank Number, *m*	20	23	22	12	13	6	4	18	16	10	7	2
Probability of exceedance, P (%)	77	88	85	46	50	23	15	69	62	38	27	8

c) Wet year rainfall

```
                              MONTHLY RAIN DATA
(File: F:\Dropbox\FYP Work\Final Work\CropWat Files\Rainfall\Sembabule 1 - Wet.CRM)

   Station: Sembabule 1

   Eff. rain method: USDA Soil Conservation Service formula:
                     Peff = Pmon * (125 - 0.2 * Pmon) / 125   for Pmon <= 250 mm
                     Peff = 125 + 0.1 * Pmon                  for Pmon  > 250 mm


                  Rain     Eff rain
                   mm         mm

   January        70.0       62.2
   February       80.3       70.0
   March         149.6      113.8
   April         199.8      135.9
   May           202.3      136.8
   June           90.6       77.5
   July           69.0       61.4
   August         98.9       83.3
   September     104.2       86.8
   October       140.2      108.8
   November      174.1      125.6
   December      100.5       84.3

   Total         1479.5     1146.3
```

d) Average year rainfall

```
                                MONTHLY RAIN DATA
      (File: F:\Dropbox\FYP Work\Final Work\Sembabule 1 - Average.CRM)

 Station: Sembabule 1- Average

 Eff. rain method: USDA Soil Conservation Service formula:
                   Peff = Pmon * (125 - 0.2 * Pmon) / 125  for Pmon <= 250 mm
                   Peff = 125 + 0.1 * Pmon                 for Pmon  > 250 mm


                Rain    Eff rain
                 mm        mm

 January        63.1      56.7
 February       72.4      64.0
 March         134.9     105.8
 April         180.1     128.2
 May           182.4     129.2
 June           81.6      70.9
 July           62.2      56.0
 August         89.2      76.5
 September      93.9      79.8
 October       126.4     100.8
 November      157.0     117.6
 December       90.6      77.5

 Total         1333.8    1063.0
```

e) Normal year rainfall

```
                                MONTHLY RAIN DATA
 (File: F:\Dropbox\FYP Work\Final Work\CropWat Files\Sembabule 1 - Normal.CRM)

 Station: Sembabule 1 - Normal

 Eff. rain method: USDA Soil Conservation Service formula:
                   Peff = Pmon * (125 - 0.2 * Pmon) / 125  for Pmon <= 250 mm
                   Peff = 125 + 0.1 * Pmon                 for Pmon  > 250 mm


                Rain    Eff rain
                 mm        mm

 January        59.1      53.5
 February       67.8      60.4
 March         126.4     100.8
 April         168.8     123.2
 May           170.9     124.2
 June           76.5      67.1
 July           58.3      52.9
 August         83.6      72.4
 September      88.0      75.6
 October       118.4      96.0
 November      147.1     112.5
 December       84.9      73.4

 Total         1249.8    1012.0
```

Appendix 5: Crop data files

a) Maize

DRY CROP DATA
(File: C:\ProgramData\CROPWAT\data\crops\FAO\MAIZE.CRO)

Crop Name: MAIZE (Grain) Planting date: 15/03 Harvest: 17/07

Stage	initial	develop	mid	late	total
Length (days)	20	35	40	30	125
Kc Values	0.30	-->	1.20	0.35	
Rooting depth (m)	0.30	-->	1.00	1.00	
Critical depletion	0.55	-->	0.55	0.80	
Yield response f.	0.40	0.40	1.30	0.50	1.25
Cropheight (m)			2.00		

b) Dry beans

DRY CROP DATA
(File: C:\ProgramData\CROPWAT\data\crops\FAO\BEANS-DR.CRO)

Crop Name: DRY BEANS Planting date: 15/03 Harvest: 02/07

Stage	initial	develop	mid	late	total
Length (days)	20	30	40	20	110
Kc Values	0.40	-->	1.15	0.35	
Rooting depth (m)	0.30	-->	0.90	0.90	
Critical depletion	0.45	-->	0.45	0.60	
Yield response f.	0.20	0.60	1.00	0.20	1.15
Cropheight (m)			0.40		

c) Banana – 2nd year

DRY CROP DATA
(File: C:\ProgramData\CROPWAT\data\crops\FAO\BANANA2.CRO)

Crop Name: BANANA 2nd Year Planting date: 07/02 Harvest: 04/10

Stage	initial	develop	mid	late	total
Length (days)	60	60	75	45	240
Kc Values	1.00	-->	1.20	1.10	
Rooting depth (m)	0.90	-->	0.90	0.90	
Critical depletion	0.55	-->	0.45	0.45	
Yield response f.	1.00	1.00	1.00	1.00	1.00
Cropheight (m)			4.00		

d) Coffee

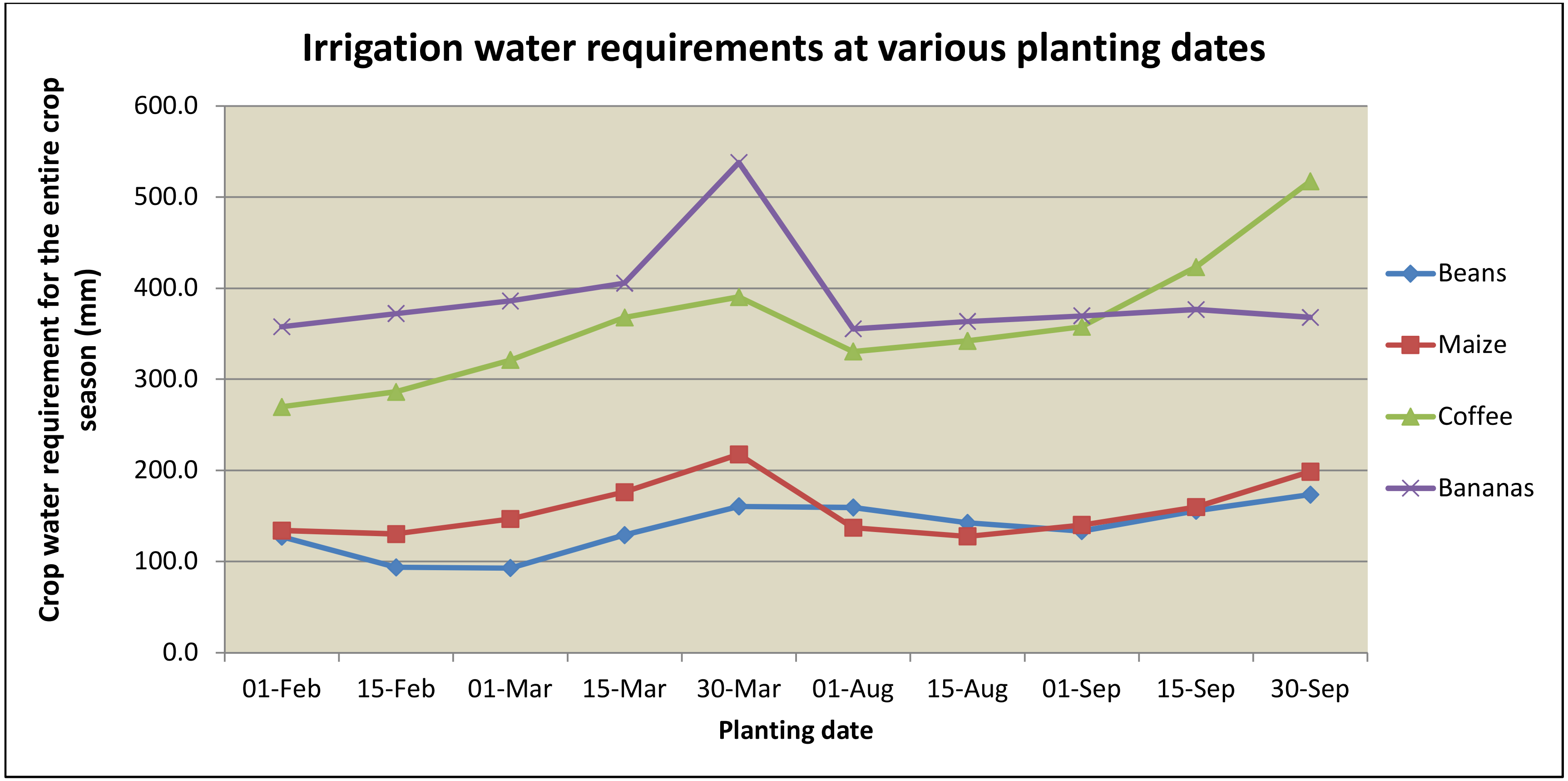
DRY CROP DATA
(File: F:\Dropbox\FYP Work\COFFEE.CRO)

Crop Name: Coffee Planting date: 15/03 Harvest: 08/03

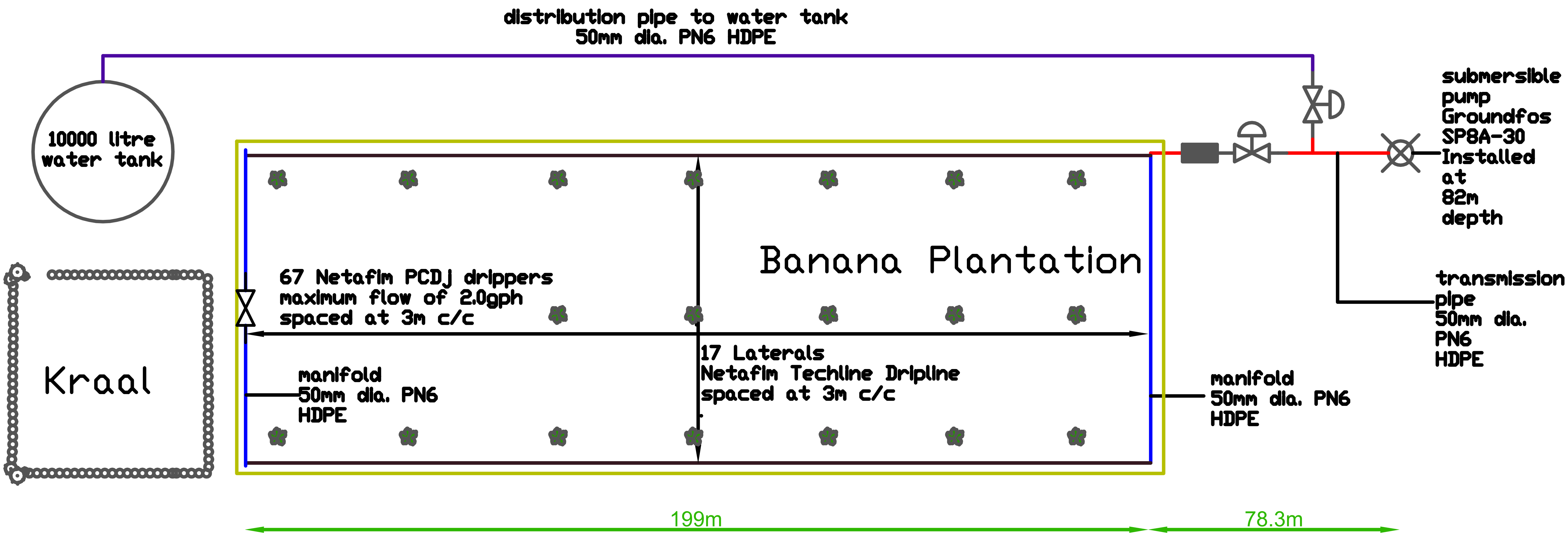
Stage	initial	develop	mid	late	total
Length (days)	115	180	340	90	725
Kc Values	1.05	-->	1.10	1.10	
Rooting depth (m)	0.90	-->	1.50	1.50	
Critical depletion	0.42	-->	0.43	0.41	
Yield response f.	0.50	0.70	1.20	0.10	1.20
Cropheight (m)			2.50		

Appendix 6: Irrigation water requirements (in mm) at various planting dates

Planting date	01-Feb	15-Feb	01-Mar	15-Mar	30-Mar	01-Aug	15-Aug	01-Sep	15-Sep	30-Sep
Beans	127.3	93.7	92.9	129.1	160.5	159.3	142.4	133.4	155.8	173.4
Maize	134	130.3	146.8	176.3	217.6	137.1	127.6	140.1	159.8	198.6
Coffee	269.8	286.25	321.2	367.9	390.3	330.5	342.2	357.7	423.2	517.4
Bananas	357.7	372.2	386	405.6	533.6	355.3	363.4	369.7	376.7	367.9



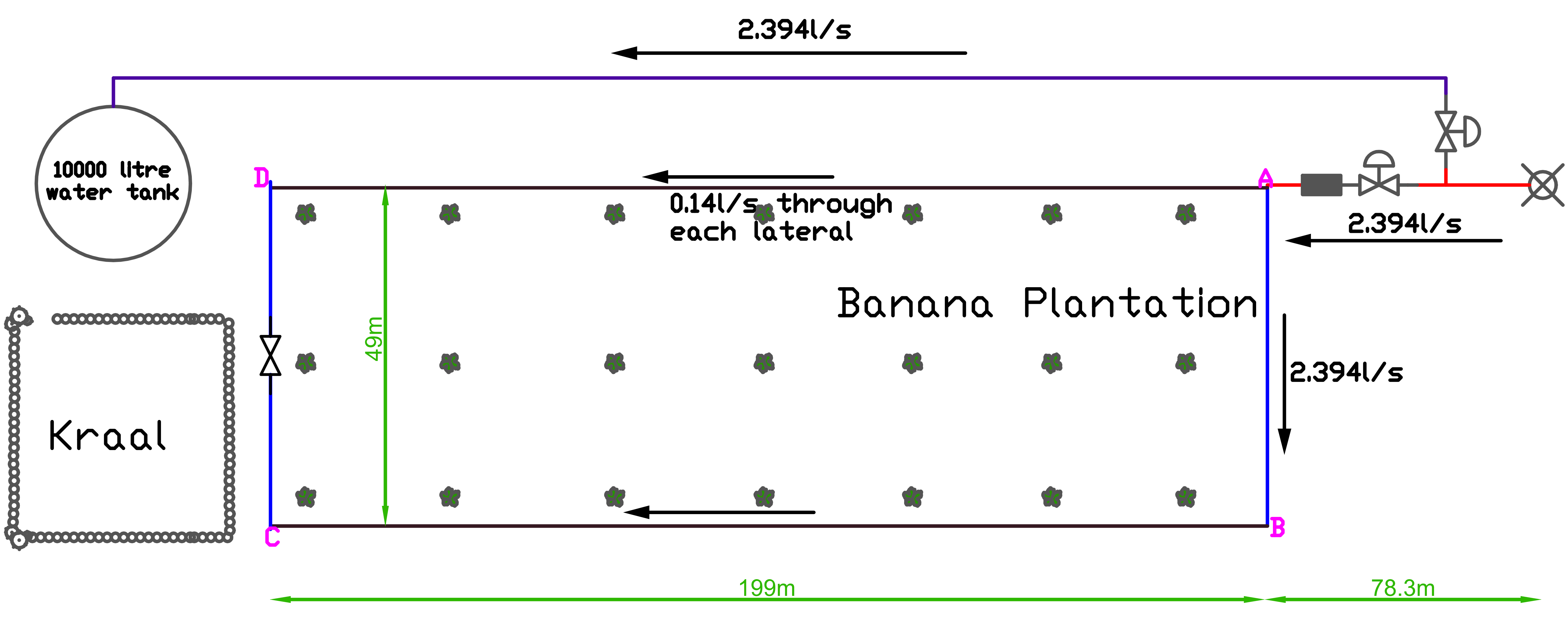
Appendix 7: Design drawing



LEGEND

Filter
Flush Valve
Valve
Crop farm boundaries
Pump
Direction of flow of water

Itemref	Quantity	1 Hectare banana plantation farm		Article No./Reference	
Designed by N. B. D		Checked by	Approved by - date	Date MAY 2013	Scale 1:2000
MR. DDUNGU PETER MUGULUKA PARISH SEMBABULE DISTRICT			SCHEME LAYOUT AND SPECIFICATIONS		
			DRAWING_NUMBER 01	Sheet 01	

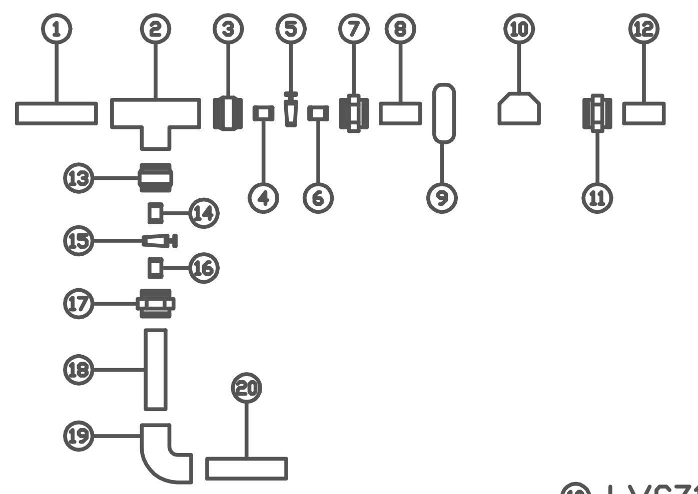


LEGEND

- Filter
- Valve
- Pump
- Flush Valve
- Crop farm boundaries
- Direction of flow of water
- Banana plants

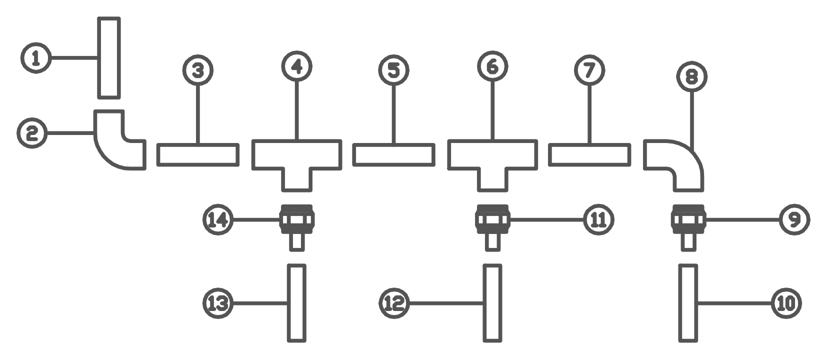
Itemref	Quantity	1 Hectare banana plantation farm		Article No./Reference	
Designed by N . B . D		Checked by	Approved by - date	Date MAY 2013	Scale 1:1250
MR. DDUNGU PETER MUGULUKA PARISH SEMBABULE DISTRICT			SCHEME LAYOUT AND WATER FLOWS		
			DRAWING_NUMBER 01	Sheet 02	

Connection details for the Transmission pipe and Distribution pipe



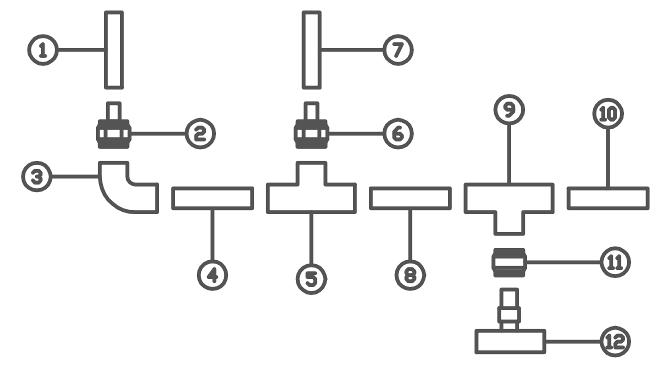
1. HDPE 50mm PN6
2. HDPE 50mm tee
3. HDPE adapter
4. Nipple
5. TLSOV Shut-off valve
6. Nipple
7. HDPE coupling
8. HDPE 50mm PN6
9. ¾" 140mesh filter
10. LVCZ10075-HF Netafim low volume control zone kit
11. HDPE coupling
12. HDPE 50mm PN6
13. HDPE adapter
14. Nipple
15. TLSOV Shut-off valve
16. Nipple
17. HDPE coupling
18. HDPE 50mm PN6
19. HDPE 50mm elbow
20. HDPE 50mm PN6

Manifold to intermediate and end lateral connection details



1. HDPE 50mm PN6
2. HDPE 50mm elbow
3. HDPE 50mm PN6, 1m long
4. HDPE 50mm tee
5. HDPE 50mm PN6, 3m long
6. HDPE 50mm tee
7. HDPE 50mm PN6, 3m long
8. HDPE 50mm elbow
9. Male Adapter
10. 20mm Techline Netafim 199m long Dripperline
11. Male Adapter
12. 20mm Techline Netafim 199m long Dripperline
13. 20mm Techline Netafim 199m long Dripperline
14. Male Adapter

Laterals to Manifold endpipe connection details

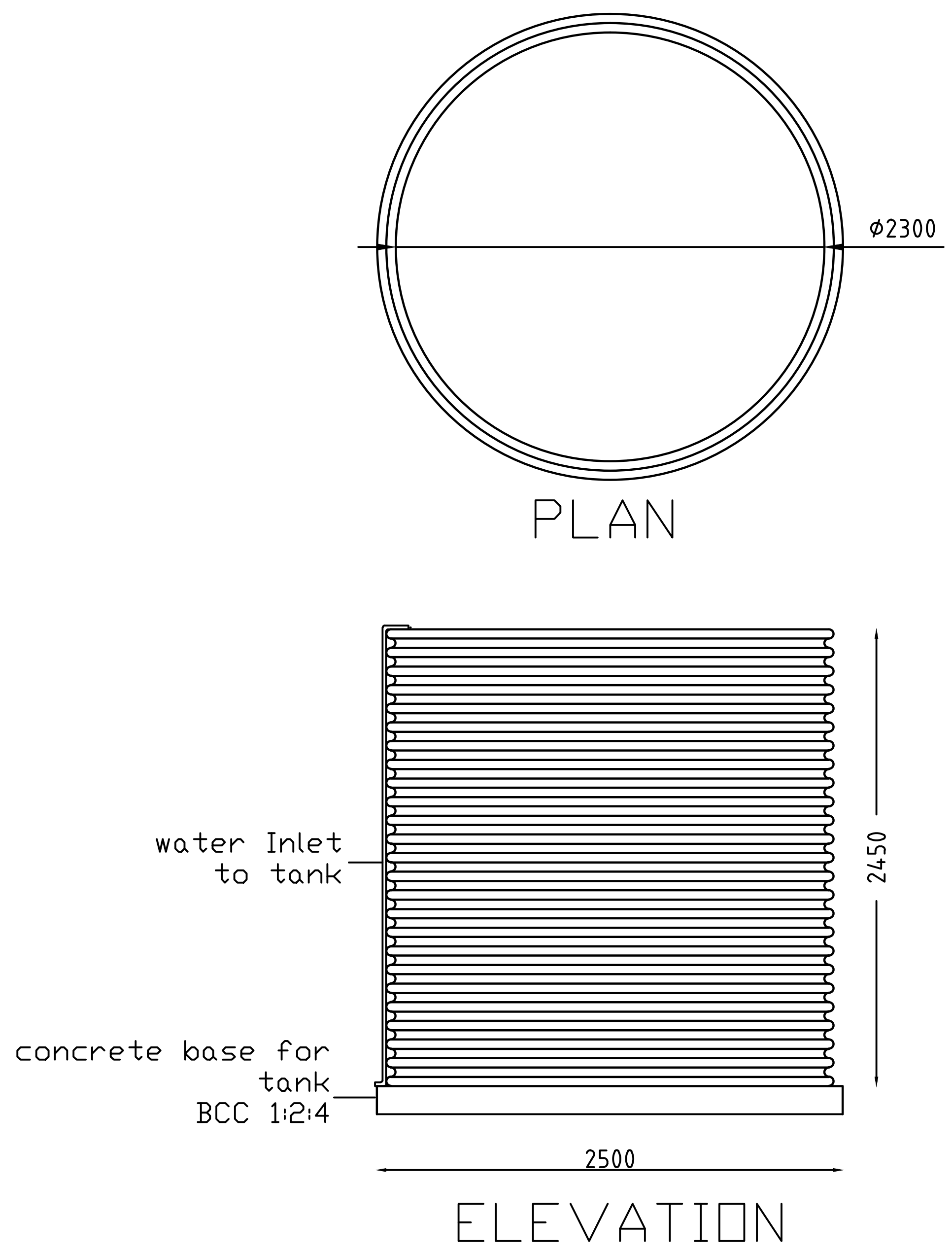


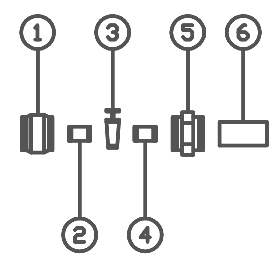
1. 20mm Techline Netafim 199m long Dripperline
2. Male Adapter
3. HDPE 50mm elbow
4. HDPE 50mm PN6, 1m long
5. HDPE 50mm tee
6. TL075MA 3/4" Male Adapter
7. 20mm Techline Netafim 199m long Dripperline
8. HDPE 50mm PN6, 3m long
9. HDPE 50mm tee
10. HDPE 50mm PN6, 3m long
11. HDPE adapter
12. TLFV-1 Flush valve

NOTES

1. Place TLS6 6" soil staples at approximately every 3 feet (0.9metres) of every tubing
2. Place two TLS6 6"soil staples on each tee, elbow or cross

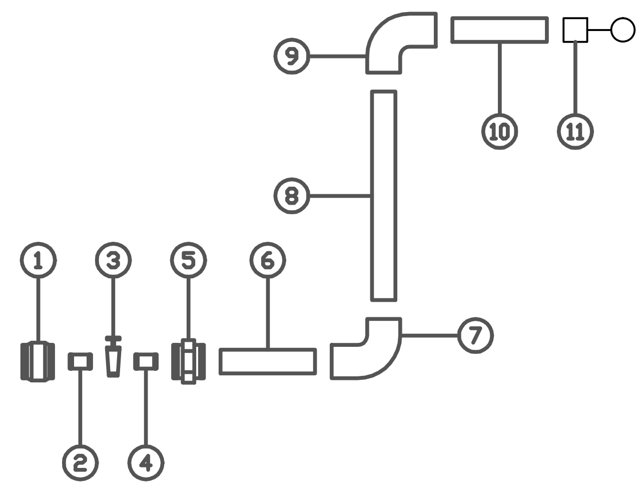
Itemref	Quantity	Details for the pipe fittings and pipe connections		Article No./Reference	
Designed by N. B. D		Checked by	Approved by - date	Date MAY 2013	Scale
MR. DDUNGU PETER MUGULUKA PARISH SEMBABULE DISTRICT		DETAILED DESIGN DRAWING			
		DRAWING_NUMBER	01	Sheet	03





Outlet fittings

1. Female adapter
2. GI Nipple
3. Brass gate valve
4. GI Nipple
5. GI Union
6. GI pipe



Inlet fittings

1. Female adapter
2. GI Nipple
3. Brass gate valve
4. GI Nipple
5. GI Union
6. GI pipe
7. GI Elbow
8. GI pipe
9. GI Elbow
10. GI pipe
11. Brass Float valve

NOTES

All dimensions in mm unless stated otherwise.

Itemref	Quantity	Details for the tank and fittings		Article No./Reference	
Designed by N. B. D		Checked by	Approved by - date	Date MAY 2013	Scale
MR. DDUNGU PETER MUGULUKA PARISH SEMBABULE DISTRICT			DETAILED DESIGN DRAWING		
			DRAWING_NUMBER 02	Sheet 04	

Appendix 8: Irrigation schedules for the banana garden

a) Irrigation at 100% depletion and refilling to 20% field capacity

CROP IRRIGATION SCHEDULE

ETo station: SEMBABULE | Crop: BANANA 1st year | Planting date: 30/03
Rain station: Sembabule 1 | Soil: SANDY LOAM | Harvest date: 22/02

Yield red.: 0.0 %

Crop scheduling options
Timing: Irrigate at 100 % depletion
Application: Refill to 20 % of field capacity
Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
2 Aug	126	Dev	0.0	1.00	100	54	10.2	35.3	0.0	14.5	0.01
22 Aug	146	Dev	0.0	1.00	100	52	9.6	37.2	0.0	13.7	0.08
6 Sep	161	Dev	0.0	1.00	100	51	10.4	38.5	0.0	14.8	0.11
20 Sep	175	Dev	0.0	1.00	100	51	11.1	39.7	0.0	15.9	0.13
1 Oct	186	Dev	0.0	1.00	100	52	13.4	40.6	0.0	19.1	0.20
12 Oct	197	Dev	0.0	1.00	100	51	12.7	41.5	0.0	18.1	0.19
1 Nov	217	Dev	0.0	1.00	100	51	14.8	42.9	0.0	21.1	0.12
1 Dec	247	Dev	0.0	1.00	100	49	15.0	44.9	0.0	21.4	0.08
6 Dec	252	Dev	0.0	1.00	100	45	11.6	45.2	0.0	16.6	0.38
11 Dec	257	Mid	0.0	1.00	100	45	11.9	45.4	0.0	17.0	0.39
16 Dec	262	Mid	0.0	1.00	100	49	16.0	45.4	0.0	22.8	0.53
21 Dec	267	Mid	0.0	1.00	100	49	16.1	45.4	0.0	23.0	0.53
25 Dec	271	Mid	0.0	1.00	100	45	11.7	45.4	0.0	16.8	0.49
29 Dec	275	Mid	0.0	1.00	100	45	11.7	45.4	0.0	16.8	0.49
1 Jan	278	Mid	0.0	1.00	100	50	17.1	45.4	0.0	24.4	0.94
5 Jan	282	Mid	0.0	1.00	100	47	13.3	45.4	0.0	19.0	0.55
9 Jan	286	Mid	0.0	1.00	100	47	13.3	45.4	0.0	19.0	0.55
11 Jan	288	Mid	0.0	1.00	100	45	11.6	45.4	0.0	16.5	0.96
15 Jan	292	Mid	0.0	1.00	100	48	15.1	45.4	0.0	21.6	0.63
19 Jan	296	Mid	0.0	1.00	100	48	15.1	45.4	0.0	21.6	0.63
21 Jan	298	Mid	0.0	1.00	100	45	11.7	45.4	0.0	16.7	0.96
25 Jan	302	End	0.0	1.00	100	48	14.6	45.4	0.0	20.9	0.60
29 Jan	306	End	0.0	1.00	100	48	14.6	45.4	0.0	20.9	0.60
31 Jan	308	End	0.0	1.00	100	45	11.7	45.4	0.0	16.7	0.97
2 Feb	310	End	0.0	1.00	100	45	11.6	45.4	0.0	16.5	0.96
6 Feb	314	End	0.0	1.00	100	47	14.1	45.4	0.0	20.2	0.58
10 Feb	318	End	0.0	1.00	100	47	14.1	45.4	0.0	20.2	0.58
12 Feb	320	End	0.0	1.00	100	45	11.4	45.4	0.0	16.3	0.95
16 Feb	324	End	0.0	1.00	100	47	13.8	45.4	0.0	19.7	0.57
20 Feb	328	End	0.0	1.00	100	47	13.8	45.4	0.0	19.7	0.57
22 Feb	End	End	0.0	1.00	0	40					

Totals:

Total gross irrigation	561.5	mm	Total rainfall	982.3	mm
Total net irrigation	393.1	mm	Effective rainfall	803.8	mm
Total irrigation losses	0.0	mm	Total rain loss	178.5	mm
Actual water use by crop	1247.8	mm	Moist deficit at harvest	51.0	mm
Potential water use by crop	1247.8	mm	Actual irrigation requirement	444.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	81.8	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	1.00	1.00	1.00	1.00	1.00	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

b) Schedule for rain-fed conditions

CROP IRRIGATION SCHEDULE

ETo station: SEMBABULE   Crop: BANANA   Planting date: 30/03
Rain station: Sembabule 1   Soil: SANDY LOAM   Harvest date: 22/02

Yield red.: 27.3 %

Crop scheduling options
Timing: No predefined irrigation
Application: Refill to 20 % of field capacity
Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
22 Feb	End	End	0.0	0.27	0	87					

Totals:

Total gross irrigation	0.0	mm	Total rainfall	973.4	mm
Total net irrigation	0.0	mm	Effective rainfall	797.9	mm
Total irrigation losses	0.0	mm	Total rain loss	175.5	mm
Actual water use by crop	907.0	mm	Moist deficit at harvest	109.1	mm
Potential water use by crop	1247.8	mm	Actual irrigation requirement	449.9	mm
Efficiency irrigation schedule	-	%	Efficiency rain	82.0	%
Deficiency irrigation schedule	27.3	%			

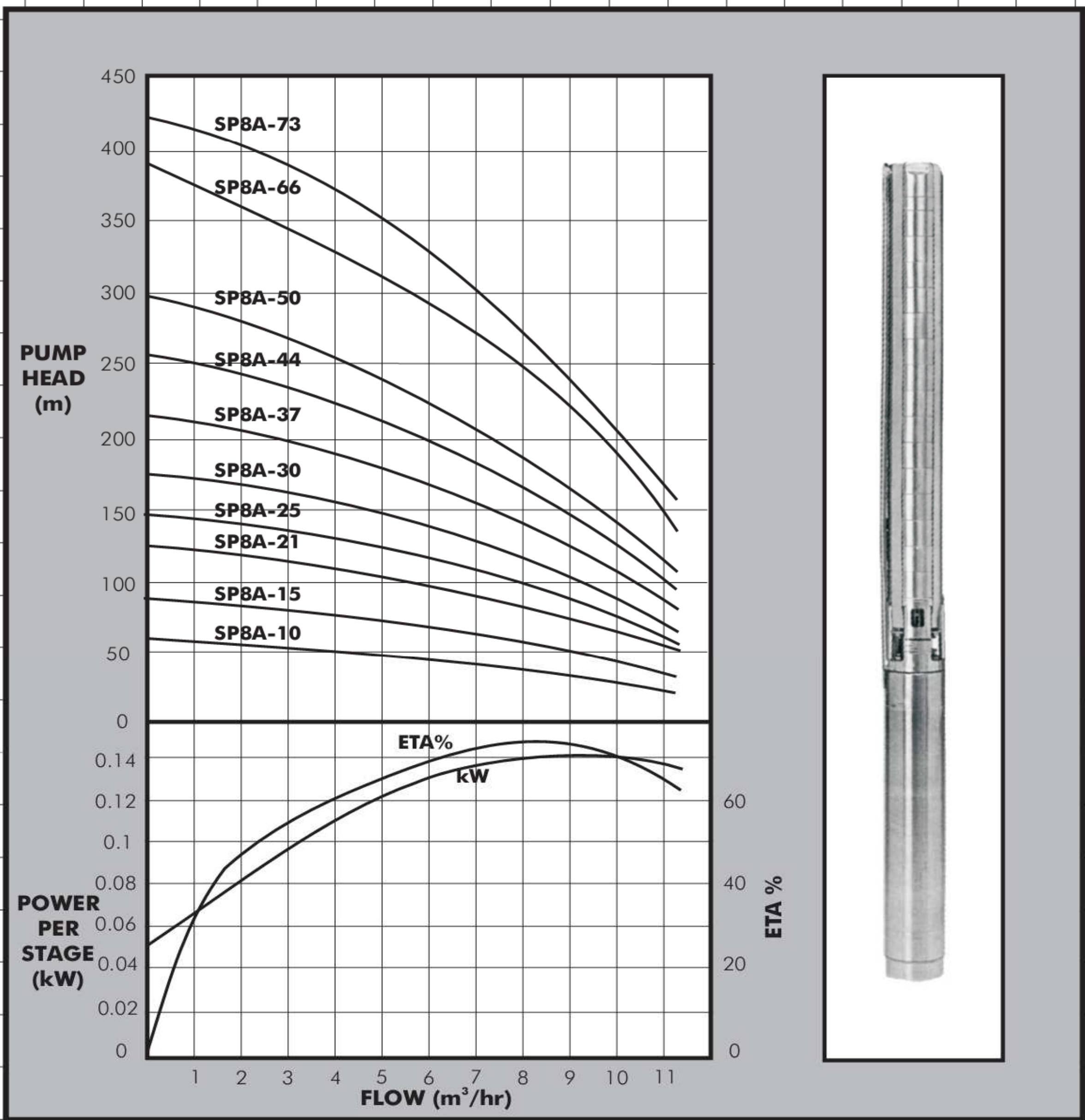
Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	13.0	55.9	70.1	27.3	%
Yield response factor	1.00	1.00	1.00	1.00	1.00	
Yield reduction	0.0	13.0	55.9	70.1	27.3	%
Cumulative yield reduction	0.0	13.0	61.6	88.5		%

Appendix 9: Pump curves and specifications

GRUNDFOS®

DATA SHEET Multistage Centrifugal Borehole Pumps **SP 8A**



PUMP

GRUNDFOS SP pumps are designed for a wide range of uses with a particular application to borehole supply. They are of multistage centrifugal impeller design and all parts are made from stainless steel with water lubricated rubber bearings. A submersible motor is fitted beneath the pump and suction is effected through a strainer between the pump and motor.

Standard pumps are designed for the pumping of non-aggressive water. An 'N' version is available for applications requiring a higher degree of corrosion resistance.

MOTOR

The pump is coupled to a sealed liquid cooled 2-pole asynchronous squirrel-cage GRUNDFOS motor constructed of stainless steel. Single phase motors are supplied complete with purpose designed control boxes, while three phase motors require a remote starter. For complete control including wireless low level and unstable main supply power a DAYLIFF electronic pump controller is recommended. Note that due to the low starting torques of submersible motors it is recommended that DOL starters are used for all motor sizes.

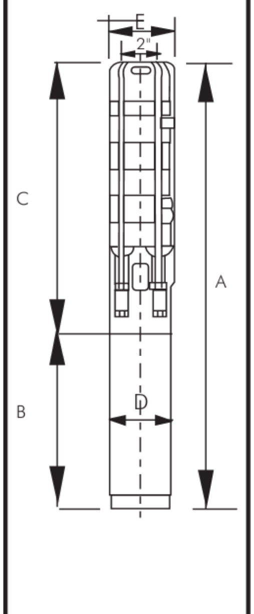
Enclosure Class : IP58 ***Insulation Class:*** B ***Speed:*** 2900 rpm

OPERATING CONDITION

Pumped Liquid: Thin, clean chemically non-aggressive liquids without solid particles or fibres.
Max. Liquid Temperature: +40°C
Max. Water Depth: Up to 1.5 kW 1ph & 2.2 kW 3 ph - 150m
All other models - 600m
Min. Borehole Diameter: 110mm (4" motor), 152mm (6" motor)

ELECTRICAL DATA

Pump Type	Motor Dia	Motor		Full Load Current (A)		Start Current (A)	
		kW	HP	1X240V	3X415V	1X240V	3X415V
SP 8A-10	4"	1.5	2.0	10.2	4.2	40	21
SP 8A-15	4"	2.2	3.0	14.0	5.5	62	26
SP 8A-21	4"	4.0	5.5		9.6		35
SP 8A-25	4"	4.0	5.5		9.6		35
SP 8A-30	4"	5.5	7.5		13.0		46
SP 8A-37	4"	5.5	7.5		13.0		46
SP 8A-44	6"	7.5	10.0		18.8		85
SP 8A-50	6"	7.5	10.0		18.8		85
SP 8A-66	6"	11.0	15.0		24.6		118
SP 8A-73	6"	11.0	15.0		24.6		118



DIMENSIONS AND WEIGHTS

Pump Type	Dimensions A		Dimensions B		C	D	E	Net Weight (kg)	
	1X240V	3X415V	1X240V	3X415V				1X240V	3X415V
SP 8A-10	965	965	346	346	619	95	101	19	19
SP 8A-15	1402	1175	573	346	829	95	101	32	23
SP 8A-21		1654		573	1081	95	101		35
SP 8A-25		1822		573	1249	95	101		37
SP 8A-30		2132		673	1459	95	101		45
SP 8A-37		2426		673	1753	95	101		49
SP 8A-44		2674		565	2109	143	138		66
SP 8A-50		2926		565	2361	143	138		70
SP 8A-66		4032		683	3349	143	140		114
SP 8A-73		4326		683	3643	143	140		120

E*=Maximum diameter of the pump inclusive of cable guard and motor

Appendix 10: Bills of Quantities for the irrigation system

MATEETE IRRIGATION SYSTEM			
MAIN SUMMARY			
BILL NO.	**ITEM DESCRIPTION** **MAIN SUMMARY**		**AMOUNT**
1	Transmission & Sub-main	S/1	6,940,000
2	Laterals and Manifolds	S/2	7,198,101
3	Pump and Pump house	S/3	18,016,000
	SUB-TOTAL 1		**32,154,101**
	ADD CONTINGENCIES Include a contigency of 5%to be expended in whole or in part as deemed necessary		**1,607,705**
GRAND TOTAL			**33,761,806**

MATEETE IRRIGATION SYSTEM					
BILL NO. 1 - DISTRIBUTION PIPES AND TANK					
ITEM NO.	**ITEM DESCRIPTION**	**UNIT**	**QTY**	**RATE UGX**	**AMOUNT UGX**
A	**SITE CLEARANCE.** General clearance along pipeline Excavate trench of width 300mm and depth 800mm in ordinary soil to accommodate one line of pipes for the transmission mains and distribution.	m	284	1,000	284,000
B	**GI PIPES** 2" GI Pipes to ISO 161, including unions and bends to BS 5114 and fittings	m	84	30,000	2,520,000
C	**DISTRIBUTION PIPES** HDPE 50mm PN6 with appropriate fittings including unions and bends laid in trench	m	284	4,000	1,136,000
D	**TANK** Supply and install a 10,000-litre corrugated stainless steel tank on a concrete and masonry base of diameter not exceeding 2.5m	no.	1	3,000,000	3,000,000
TOTAL BILL NO. 1 CARRIED TO SUMMARY					**6,940,000**

MATEETE IRRIGATION SYSTEM					
BILL NO. 2 MANIFOLDS AND LATERALS					
ITEM NO.	**ITEM DESCRIPTION**	**UNIT**	**QTY**	**RATE UGX**	**AMOUNT UGX**
A	**MANIFOLDS** HDPE 50mm PN6 with unions and fittings laid above ground	m	98	4,000	392,000
B	Supply and install Netafim Low volume control zone kit with 1.5" filters and PRV – HIGH FLOW LVCZ10075-HF	no.	1	92,750	92,750
C	**LATERALS** 20mm TechLine Netafim Dripperline with blank tubing laid above ground	m	3383	1,840	6,224,720
D	Netafim PCDj pressure compensating drippers with flow of 2.0gph and spacing 3m, each fitted with a staple	no.	1,139	429	488,631
TOTAL BILL NO. 2 CARRIED TO SUMMARY					**7,198,101**

MATEETE IRRIGATION SYSTEM					
BILL NO. 3 ELECTRO-MECHANICAL WORK					
ITEM NO.	**ITEM DESCRIPTION**	**UNIT**	**QTY**	**RATE UGX**	**AMOUNT UGX**
	ELECTRO-MECHANICAL WORK				
A	Supply and install stainless Electric submersible pump (Groundfos SP 8A-30) complete with starter and associated control devices including dry running protection, outlet pressure gauge and all cabling. To be fitted with an SQFlex AC/DC motor and a 900 Wp solar array at 5.5 kWh/m² /day	no.	1	15,766,000	15,766,000
B	Allow for construction of a pump house with appropriate dimensions and fittings	no.	1	2,000,000	2,000,000
C	Supply and install electrical services to pump house as follows: pump and control panel, internal lighting, 1no. bulkhead light and 1 no. 13 amp power socket	no.	1	250,000	250,000
TOTAL BILL NO. 3 CARRIED TO SUMMARY					**18,016,000**

Appendix 11: Comparison of the water supply from the borehole with crop water requirements

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Actual supply (m^3)	2062	1862	2062	1995	2062	1995	2062	2062	1995	2062	1995	2062
Net scheme irr. req. (mm/month)	131.7	93.0	4.9	0.0	0.0	10.8	27.4	30.2	41.3	47.8	44.7	106.0
Irrigation efficiency (%)	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
Gross scheme irr. req. (mm/month)	188.1	132.9	7.0	0.0	0.0	15.4	39.1	43.1	59.0	68.3	63.9	151.4
Irrigated area (ha)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Gross scheme irr. req. (m^3/month)	1881	1329	70	0	0	154	391	431	590	683	639	1514
Requirement/Supply (%)	91%	71%	3%	0%	0%	8%	19%	21%	30%	33%	32%	73%

Appendix 12: Irrigation schedules and cash flow analysis for cabbages and tomatoes

a) Irrigation schedules for cabbages

CROP IRRIGATION SCHEDULE

ETo station: SEMBABULE   Crop: CABBAGE Crucifers   Planting date: 30/03
Rain station: Sembabule 1   Soil: SANDY LOAM   Harvest date: 10/09

Yield red.: 0.0 %

Crop scheduling options
Timing: Irrigate at 100 % depletion
Application: Refill to 20 % of field capacity
Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
12 Apr	14	Init	0.0	1.00	100	49	5.4	14.4	0.0	7.7	0.06
2 Jun	65	Dev	0.0	1.00	100	45	5.4	20.8	0.0	7.7	0.02
11 Jun	74	Dev	0.0	1.00	100	45	5.8	21.9	0.0	8.2	0.11
15 Jun	78	Dev	0.0	1.00	100	48	7.7	22.4	0.0	11.0	0.32
19 Jun	82	Dev	0.0	1.00	100	48	7.7	22.9	0.0	11.0	0.32
21 Jun	84	Dev	0.0	1.00	100	50	8.8	23.2	0.0	12.6	0.73
25 Jun	88	Dev	0.0	1.00	100	49	8.4	23.7	0.0	11.9	0.35
29 Jun	92	Dev	0.0	1.00	100	48	8.4	24.2	0.0	11.9	0.35
1 Jul	94	Dev	0.0	1.00	100	49	8.9	24.4	0.0	12.7	0.74
5 Jul	98	Dev	0.0	1.00	100	49	8.8	24.9	0.0	12.5	0.36
9 Jul	102	Mid	0.0	1.00	100	49	9.0	25.2	0.0	12.9	0.37
11 Jul	104	Mid	0.0	1.00	100	49	9.0	25.2	0.0	12.9	0.74
15 Jul	108	Mid	0.0	1.00	100	50	9.9	25.2	0.0	14.1	0.41
19 Jul	112	Mid	0.0	1.00	100	50	9.9	25.2	0.0	14.1	0.41
21 Jul	114	Mid	0.0	1.00	100	49	9.0	25.2	0.0	12.8	0.74
25 Jul	118	Mid	0.0	1.00	100	49	8.8	25.2	0.0	12.6	0.36
29 Jul	122	Mid	0.0	1.00	100	49	8.8	25.2	0.0	12.6	0.36
31 Jul	124	Mid	0.0	1.00	100	49	9.1	25.2	0.0	13.0	0.75
2 Aug	126	Mid	0.0	1.00	100	49	9.3	25.2	0.0	13.3	0.77
6 Aug	130	Mid	0.0	1.00	100	46	7.1	25.2	0.0	10.2	0.29
10 Aug	134	Mid	0.0	1.00	100	46	7.1	25.2	0.0	10.2	0.29
12 Aug	136	Mid	0.0	1.00	100	50	9.5	25.2	0.0	13.6	0.79
19 Aug	143	Mid	0.0	1.00	100	47	7.6	25.2	0.0	10.8	0.18
21 Aug	145	Mid	0.0	1.00	100	50	9.5	25.2	0.0	13.6	0.78
26 Aug	150	Mid	0.0	1.00	100	51	10.6	25.2	0.0	15.2	0.35
31 Aug	155	End	0.0	1.00	100	51	10.6	25.2	0.0	15.2	0.35
2 Sep	157	End	0.0	1.00	100	49	8.9	25.2	0.0	12.8	0.74
10 Sep	End	End	0.0	1.00	0	45					

Totals:

Total gross irrigation	326.9	mm	Total rainfall	525.2	mm
Total net irrigation	228.8	mm	Effective rainfall	404.2	mm
Total irrigation losses	0.0	mm	Total rain loss	121.0	mm
Actual water use by crop	664.4	mm	Moist deficit at harvest	31.4	mm
Potential water use by crop	664.4	mm	Actual irrigation requirement	260.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	77.0	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.20	0.40	0.45	0.60	0.95	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

b) Irrigation schedule for tomatoes

CROP IRRIGATION SCHEDULE

ETo station: SEMBABULE   Crop: Tomato   Planting date: 30/03
Rain station: Sembabule 1   Soil: SANDY LOAM   Harvest date: 21/08

Yield red.: 0.0 %

Crop scheduling options
Timing: Irrigate at 100 % depletion
Application: Refill to 20 % of field capacity
Field eff. 70 %

Table format: Irrigation schedule

Date	Day	Stage	Rain mm	Ks fract.	Eta %	Depl %	Net Irr mm	Deficit mm	Loss mm	Gr. Irr mm	Flow l/s/ha
12 Apr	14	Init	0.0	1.00	100	30	3.5	13.4	0.0	5.0	0.04
12 Jun	75	Mid	0.0	1.00	100	41	12.6	44.8	0.0	18.0	0.03
16 Jun	79	Mid	0.0	1.00	100	41	12.9	44.8	0.0	18.5	0.53
20 Jun	83	Mid	0.0	1.00	100	41	12.9	44.8	0.0	18.5	0.53
24 Jun	87	Mid	0.0	1.00	100	41	12.2	44.8	0.0	17.5	0.51
28 Jun	91	Mid	0.0	1.00	100	41	12.2	44.8	0.0	17.5	0.51
1 Jul	94	Mid	0.0	1.00	100	43	16.0	44.8	0.0	22.8	0.88
5 Jul	98	Mid	0.0	1.00	100	40	11.4	44.8	0.0	16.3	0.47
9 Jul	102	Mid	0.0	1.00	100	40	11.4	44.8	0.0	16.3	0.47
12 Jul	105	Mid	0.0	1.00	100	43	14.9	44.8	0.0	21.2	0.82
16 Jul	109	Mid	0.0	1.00	100	40	11.7	44.8	0.0	16.7	0.48
20 Jul	113	Mid	0.0	1.00	100	40	11.7	44.8	0.0	16.7	0.48
25 Jul	118	End	0.0	1.00	100	42	13.5	45.9	0.0	19.3	0.45
30 Jul	123	End	0.0	1.00	100	43	12.8	47.8	0.0	18.3	0.42
2 Aug	126	End	0.0	1.00	100	44	12.5	48.9	0.0	17.8	0.69
12 Aug	136	End	0.0	1.00	100	49	16.4	52.6	0.0	23.5	0.27
21 Aug	End	End	0.0	1.00	100	42					

Totals:

Total gross irrigation	283.9	mm	Total rainfall	474.1	mm
Total net irrigation	198.8	mm	Effective rainfall	351.0	mm
Total irrigation losses	0.0	mm	Total rain loss	123.1	mm
Actual water use by crop	608.5	mm	Moist deficit at harvest	58.7	mm
Potential water use by crop	608.5	mm	Actual irrigation requirement	257.5	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	74.0	%
Deficiency irrigation schedule	0.0	%			

Yield reductions:

Stagelabel	A	B	C	D	Season	
Reductions in ETc	0.0	0.0	0.0	0.0	0.0	%
Yield response factor	0.50	0.60	1.10	0.80	1.05	
Yield reduction	0.0	0.0	0.0	0.0	0.0	%
Cumulative yield reduction	0.0	0.0	0.0	0.0		%

c) Cash flow analysis – Irrigation for cabbages

Year	**Rate**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
F/P, 15%, n		1.1500	1.3225	1.5209	1.7490	2.0114	2.3131	2.6600	3.0590
Revenues - Costs	16,526,800	19,005,820	21,856,693	25,135,197	28,905,476	33,241,298	38,227,493	43,961,617	50,555,859
Less depreciation	10%	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600
Earnings before taxes		17,429,220	20,280,093	23,558,597	27,328,876	31,664,698	36,650,893	42,385,017	48,979,259
Taxes	30%	5,228,766	6,084,028	7,067,579	8,198,663	9,499,409	10,995,268	12,715,505	14,693,778
Earnings after tax		12,200,454	14,196,065	16,491,018	19,130,214	22,165,289	25,655,625	29,669,512	34,285,481
Cashflows		13,777,054	15,772,665	18,067,618	20,706,814	23,741,889	27,232,225	31,246,112	35,862,081
P/F, 15%, n	15	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269
Discounted Cash flow		11,980,047	11,926,401	11,879,752	11,839,188	11,803,915	11,773,242	11,746,571	11,723,378
NPV		11,980,047	23,906,448	**35,786,200**	47,625,388	59,429,302	71,202,545	82,949,115	94,672,493

d) Cash flow analysis – Irrigation for tomatoes

Year	**Rate**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
F/P, 15%, n		1.1500	1.3225	1.5209	1.7490	2.0114	2.3131	2.6600	3.0590
Revenues - Costs	9,626,800	11,070,820	12,731,443	14,641,159	16,837,333	19,362,933	22,267,373	25,607,479	29,448,601
Less depreciation	10%	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600	1,576,600
Earnings before taxes		9,494,220	11,154,843	13,064,559	15,260,733	17,786,333	20,690,773	24,030,879	27,872,001
Taxes	30%	2,848,266	3,346,453	3,919,368	4,578,220	5,335,900	6,207,232	7,209,264	8,361,600
Earnings after tax		6,645,954	7,808,390	9,145,192	10,682,513	12,450,433	14,483,541	16,821,616	19,510,401
Cashflows		8,222,554	9,384,990	10,721,792	12,259,113	14,027,033	16,060,141	18,398,216	21,087,001
P/F, 15%, n	15	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269
Discounted Cash flow		7,150,047	7,096,401	7,049,752	7,009,188	6,973,915	6,943,242	6,916,571	6,893,378
NPV		7,150,047	14,246,448	21,296,200	28,305,388	35,279,302	42,222,545	49,139,115	56,032,493