UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

FEB 540: ENGINEERING DESIGN PROJECT

PROJECT TITLE:

DESIGN OF A DRIP IRRIGATION SYSTEM (Case study of Namekhele village)

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A Report Submitted in Partial Fulfillment for the Requirements of the Degree of Bachelor of Science in Environmental and Biosystems Engineering, of the University Of Nairobi

MAY, 2015

DECLARATION

This design project is my original work and has not been submitted in any university or institution for award of honors or for any other purpose. I therefore submit it for evaluation and consequent award of Bsc Environmental and Biosystem Engineering.

Grace A .Amwata

Signature………………………………… Date………………………………..

This design project report has been submitted for examination with approval of my supervisor.

Signature………………………….Date…………………………..

Dr. Duncan Onyango Mbuge.

University of Nairobi.

ACKNOWLEDGEMENT

I thank God for the gift of life through the past years since I joined the department as a student and for enabling me undertake the project successfully.

The project is entirely based on the concepts of water and irrigation units and I therefore thank my lecturers for their effort towards imparting knowledge.

I would also like to thank my supervisor Dr Duncan Mbuge for taking his time to ensure the project comes to a conclusion as it has been quite hectic.

I also appreciate the effort of Mr Ndede of GEDO Associates in giving directions where necessary.

My appreciation also goes to my sisters and parents who have continually prayed with me and who made available all the resources needed for the project.

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMNS

UM- Upper Middle level

PERC- Percolation

SAT- Saturation

WL- Water layer

NIR- Net Irrigation Requirement

GIR- Gross Irrigation Requirement

SWR- Scheme Water Requirement.

FAO- Food and Agricultural Organisation, Rome

ISBN- International Standard Book Number

ETo- Evapotranspiration

ETc- Crop evapotranspiration

KARI- Kenya Agricultural Research Institute

AMREF- African Medical and Research Foundation.

Contents

ABSTRACT

Irrigation is a technology that ensures a good soil-moisture balance resulting into a good environment for crop growth. Irrigation has not been embraced in Kenya in large scale except for the well established canal irrigation systems like in Mwea, Ahero, Bura that came into existence way back. However organizations such as KARI and AMIRAN have tried to come up with affordable drip irrigation systems for which small scale farmers have been able to take up.

This project focuses on design of a drip irrigation system in Namekhele area in Tongaren location, Bungoma North sub-county. The area experiences a bimodal rainfall pattern however, for the second season the received rainfall cannot support crop production (as evidenced by rainfall data from Lugari farmers training centre) thus the farmers have to source for food stuffs from the neighboring counties. The specific objective will entail determination of pertinent parameters for the design, coming up with the system layout to ensure every farmer gets water and sizing of the pipelines.

The crop water requirement for the crops selected was estimated using the Penman Monteith method after incorporating CLIMWAT data into CROPWAT using climatic data for Kakamega station number 2318 and was found to be 4.8mm/day and 4.2 mm/day for sweet potatoes and kales respectively. Irrigation scheduling and frequency have been calculated based on the CWR. Irrigation frequency was found to be 2 days and time of operation of system was found to be 36 minutes for s/potatoe area and 31 minutes for kales.

The layout of the area was drawn from Global Earth guided by topography, land use and existing infrastructure. Blocking of the area was done (dividing the area into manageable portions) for supply of water through distribution lines. The conveyance was designed for a total length of 4065m with a diameter of 327mm, the mainline runs for 1270m with diameter ranging from 150-188mm.

Each distribution line serves as follows: D1-1-1 an area of 8.14 ha with a length of 442m, D1-1-2 an area of 6.56 ha with a length of 382m, D1-1-3 an area of 23.31 ha with a length of 661m, D1-2-1 an area of 9.93 ha with a length of 278m, D1-2-2 an area of 12.09 ha with a length of 528m.

In estimation of the various pipe line hydraulics excel spreadsheet was applied together with cad tools.

For the design of the infield system, hydro-calc software was used to come up with the various pipe sizes and classes which were, 59.2 mm Class B for the sub-mains and 20 mm diameter for the drip lines, the emitters chosen are pressure compensating to ensure same discharge whichever the pressure range at an operating flow rate of 1.6l/hr.

The application rate for the system was found to be 8.89mm/hr with an irrigation interval of 2 days.

1.0 INTRODUCTION

1.1 Background information.

Overtime there is need for a growing economy and need for self sustainability and this necessitates introduction of irrigation as a method to boost this. Irrigation is a mechanization tool that comes into play as one of the means of improving total volume or reliability of agricultural production by managing water for the crop (Barton, 1977). The world trend in irrigation is such that the total irrigated area was 311 million hectares from (FAO, 2009). As of 2010, the countries with the largest irrigated areas were India (39million hectares), China (19 million hectares) and United States.

Globally agriculture makes use of available water accounting for about 70% of all use. In countries where agriculture is the main activity as in India and Africa, 90% of water is used for agriculture entailing use of irrigation. It has been found that because of temporal and spatial variations potential in usable water supply is small (Megh, 2014).

In Kenya agricultural sector accounts for nearly 25% of the GDP, yet agricultural productivity is on the decline as the population increases. 74% of the Kenyan population depends on agriculture as a means of livelihood and therefore it is necessary that the agricultural sector be enhanced or promoted through introduction of certain technologies.

The government through vision 2030 under agricultural sector has proposed irrigation as a means to improve food supply with the available water and a way to bring more land under cultivation. The current state of the country is that 114,600 hectares of land out of a possible 10 million hectares is under irrigation which is about 9% (Oyuke 2008), with the major irrigation system adopted being surface irrigation. Olden surface irrigation methods are however still in use including use of bucket systems that result into water wastage resulting into decline in yield.

River Nzoia is the main surface water source for the area from which abstraction can be made to be utilized for irrigation to improve crop production. Currently it supports Bunyala Irrigation scheme which cuts across Siaya and Busia areas.

In Tongaren area no form of irrigation is ongoing even with the existing sources of water such as the small streams and the boreholes. The people in the area majorly rely on rain as a means of crop production. The rainfall in this area is however unreliable during certain times of the year (about 6 months) thus necessitating introduction of irrigation.

1.2 Problem Statement and problem analysis

Food security in Tongaren is not reliable and this is because of over reliance on rain fed agriculture. For nearly half of the year (from October to March) Tongaren area experiences drought as the amount of rainfall received cannot support crop growth.

During the long rains however, a lot of runoff is recorded that end up in the River Nzoia and this can be utilized in form of irrigation as the area sources for food stuffs from the neighboring counties during the six months dry spell. It is therefore anticipated that through irrigation there will be production even during the dry season and that the farmers will be able to market their produce during such times.

The area lies in the agro ecological zone UM-4(sun-flower and Maize) and with an average rainfall of between 1100-1300mm the area can be said to be agriculturally productive as it produces tones of maize for the country. However no form of irrigation is ongoing in the area even with the available water resources (streams and rivers). The most common water resources are boreholes that have been dug by individuals in the homesteads.

To guarantee food security, proper management of water resources is absolutely necessary. This encompasses taking all deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes (Mati, 2007).This includes practices such as drip irrigation and therefore this project is expected to make water available in the area thus boosting agricultural production, will also ensure a boost of land productivity as irrigation will mainly occur during the dry periods. It is also taken as a step towards empowering farmers to ensure they earn some income from marketed produce after harvest.

The project will make use of River Nzoia.

1.3 JUSTIFICATION

There is a problem of food supply in the area for nearly half of the year as the rainfall received cannot support crop production. This necessitates import of produce from other neighboring counties yet there exists a water resource that has not been exploited.

With the ever increasing population globally, there is a constraint in the available water resources and they are likely to be depleted overtime because of abstraction to cater for; irrigation which takes close to 69% of available water resource (Maff, 1976); hydro power production and many other activities. It is therefore necessary that most efficient methods be introduced especially when it comes to irrigation, that will effectively use the available water and at the same time result into increase in yield.

Food crops production throughout the year is a step towards hunger reduction as it ensures proper nutrition and efficient working of the body system. It is only then that the community will be able to carry out their tasks effectively. This is also a step towards achievement of sustainable development goals that focuses on seeing each individual living above the poverty line.

The area in particular, is in need of producing high valued crops that can be marketed easily especially during the 6 months dry spell period when there is not much competition in the market. Application of irrigation is also a means of income earning by the farmers and boost on revenue for the county.

This project is proposed to allow application of skills acquired during the attachment period as I found it relevant to what we have studied before.

1.4 SITE ANALYSIS AND INVENTORY.

1.4.1 Location

The site is located in Bungoma-north county, tongaren constituency, tongaren location and in tongaren sub-location. The area is about 65 km from Bungoma town and about 36km from Webuye town. The infrastructure in terms of accessibility is good with most roads being earth roads which are well maintained.

The area is particularly accessible through Luandeti-Naitiri corner.

1.4.2 Climate

a) Agro-ecological zone

Tongaren area falls within the agro ecological zone UM3-UM4 (transitional maize- sunflower zone) with the former being dominant as in the figure below.

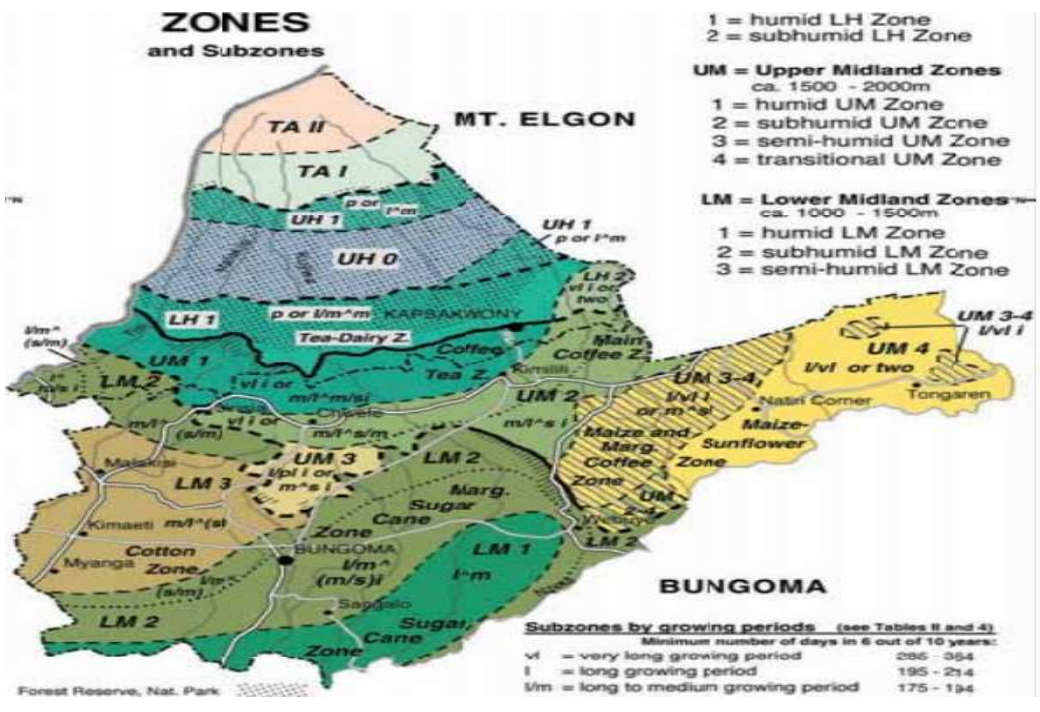


Figure 1-1: Agro-ecological zones

b) Rainfall

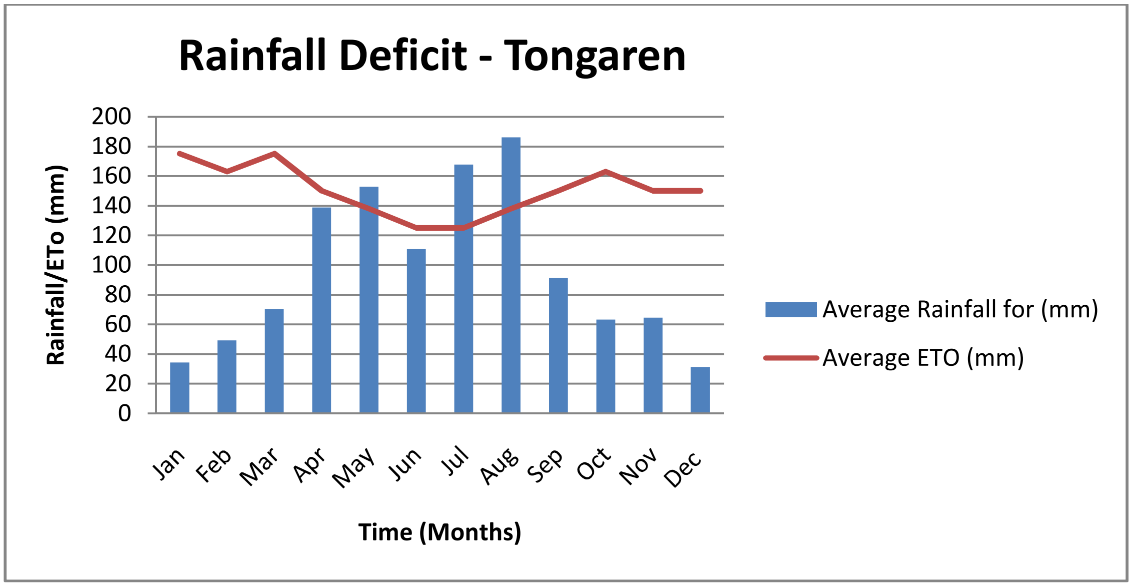
The annual rainfall amounts to between 1150-1400mm with the evapotranspiration rate amounting to 1800mm throughout the year.

Table 1.1: rainfall data of tongaren.

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	34	49	71	139	153	111	168	186	91	63	65	31
Aver ETo	175	163	175	150	138	125	125	138	150	163	150	150

Source: Farmers handbook by T Wood-head (1968)

Rainfall- deficit curve



c) **Temperature**

The temperature ranges for Tongaren is between 21^{0}C-18^{0}C throughout the year.

Table 1-2: Temperature classification

Temperature condition(^{o}C)	**Classification**
2-10	cold
10-15	cool
15-18	Moderately cool
18-21	Temperate(moderate, mild and warm)
21-24	warm
>24	Hot

Table 1-3:Tongaren average temperature variations

Month	Temperatures
Jan	20.7
Feb	21.4
March	21.7
April	21
May	20.6
June	19.8
July	20.2
August	19.6
September	20
October	20.6
November	20.6
December	20.5
	20.7

Source: Kenya Meteorological data centre (data for Kakamega station no 2318)

d) Maximum and minimum relative humidity

Crop water requirement is high in dry environment and low in humid environment. Too much humidity causes mould growth which causes plant diseases while too dry environment slows plant growth. The typical optimal relative humidity for various crops grown ranges from 50 – 70 %. Humidity within this area is moderate and ranges between (59% – 75%) monthly and an average of 68% in a year

The lowest and highest relative humidity occurs in the months of February and May respectively hence more crop water needs will be required in February and less crop water needs required in May. This information is presented in the table below.

Table 1-4: Relative Humidity

Month	Relative Humidity, %
January	60
February	59
March	62
April	73
May	75
June	74
July	73
August	73
September	70
October	68
November	68
December	65

Source: Cropwat: Kakamega Station (No. 2318)

1.4.3 Topography

The topography of tongaren region is such that it's undulating to hilly to rolling with slopes ranging from (2-10%).

1.4.4 Soils

The soils in the area range from deep to very deep dark yellowish brown to brown sandy loam with a bit of clay. Infertility level of the soils is high and thus a need for a good agronomical practice.

1.4.5 Land use

This is generally influenced by the physical environment including climate, relief, soils, hydrology and vegetation. The main activity in the area is crop and livestock agriculture, with maize grown as the main food crop.

1.4.6 Land ownership

Most of the land is individually owned by the residents of the area thus no complication arises as to where the pipelines should pass.

1.4.7 Vegetation

The area is covered by both natural and cultivated vegetation. Some of the crops cultivated in Tongaren include food crops (maize, beans, sunflower, cassava, millet, sorghum, potatoes, cassava, kunde, suja, kales, groundnuts, sweet potato etc); horticultural crops (Sukuma wiki, tomatoes, etc); cash crops (small scale sugarcane, etc) and fruit crops (avocado, guavas, bananas, mango, white sapote, etc), nappier grass as fodder and trees like blue gum, Cyprus, etc.

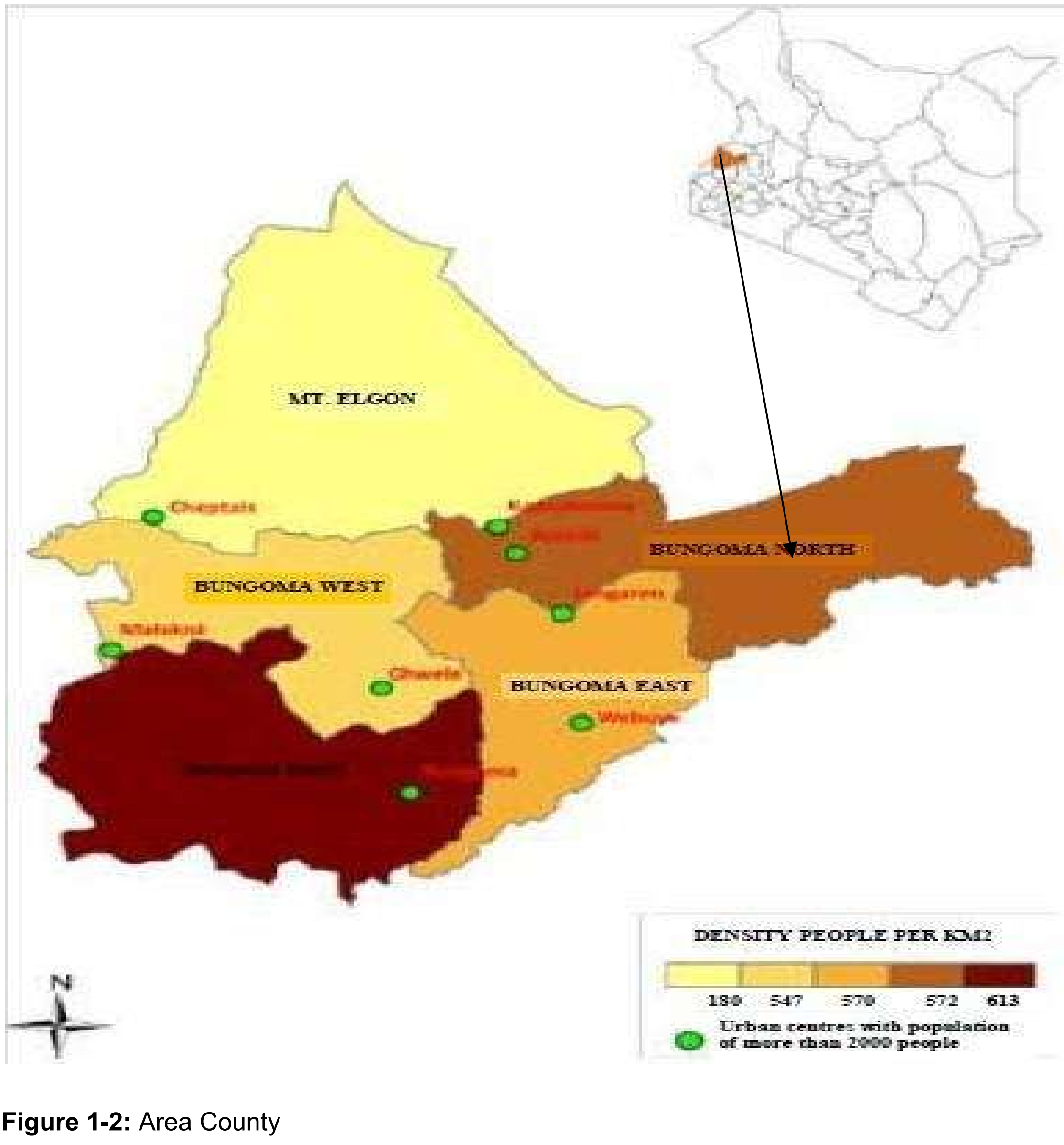


Figure 1-2: Area County

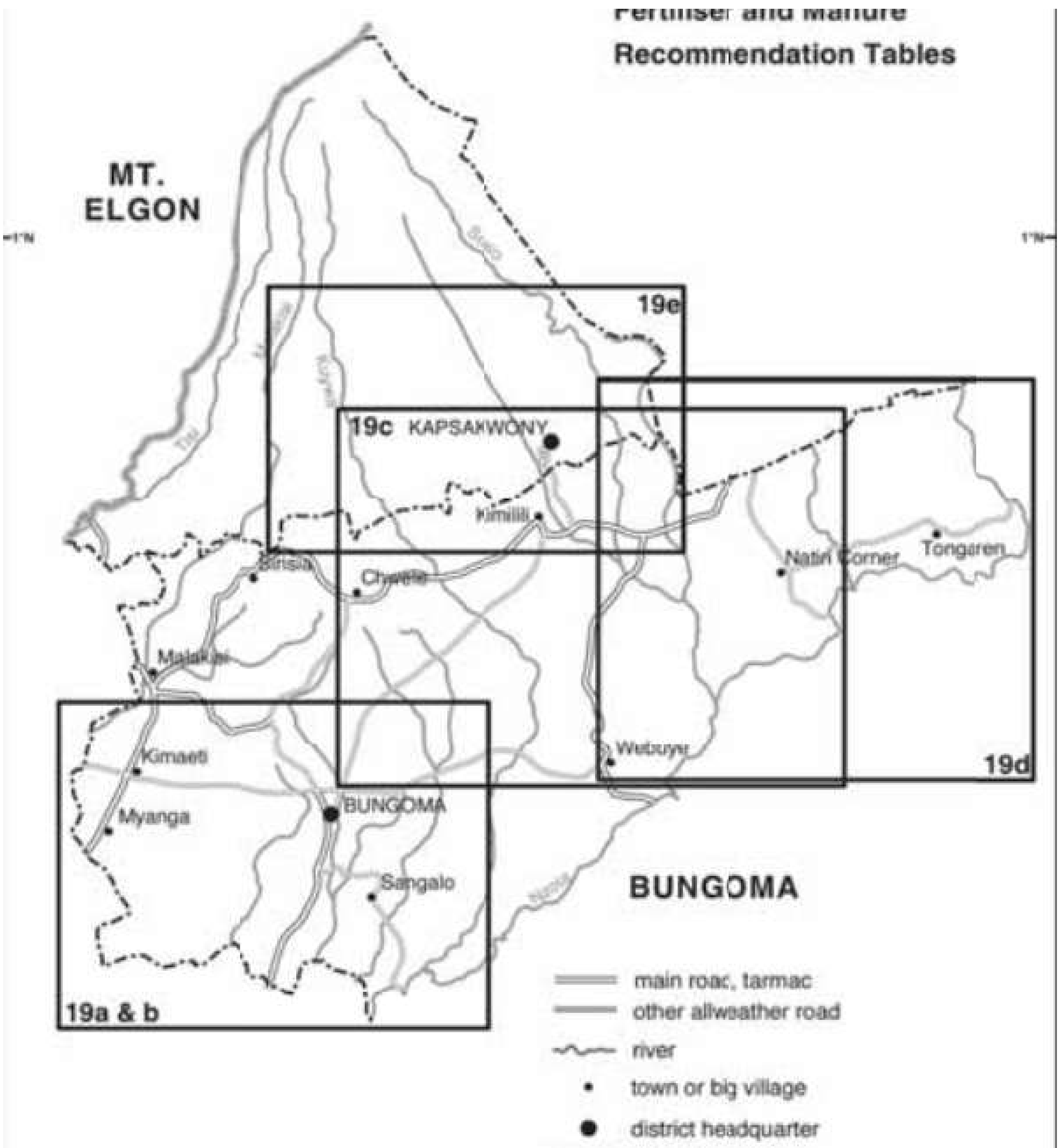


Figure 1-3: area accessibility

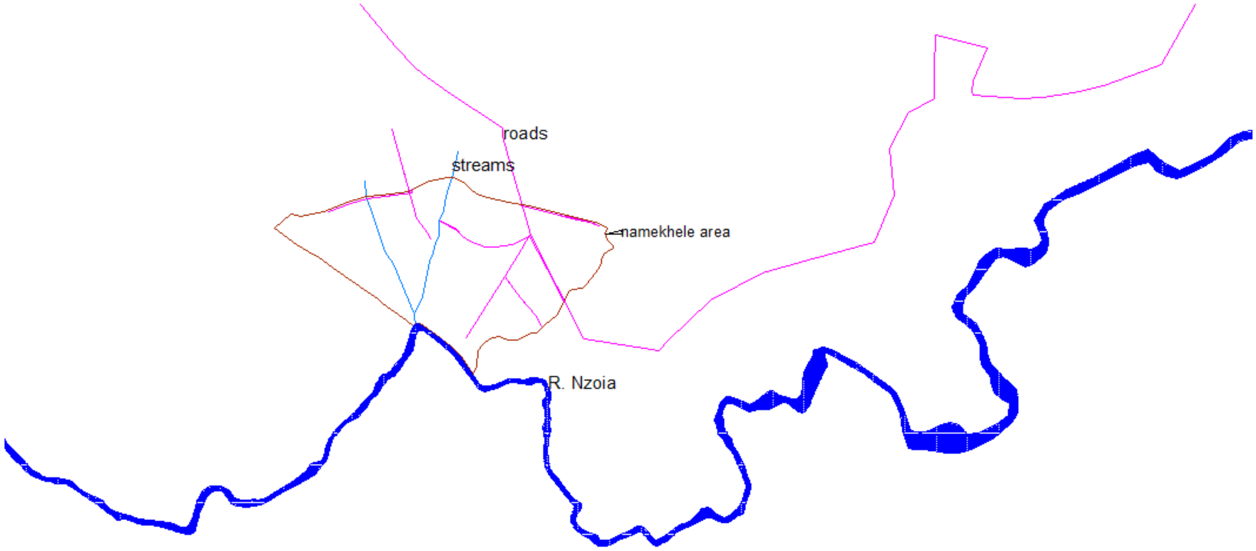


Figure 1-4: scheme area

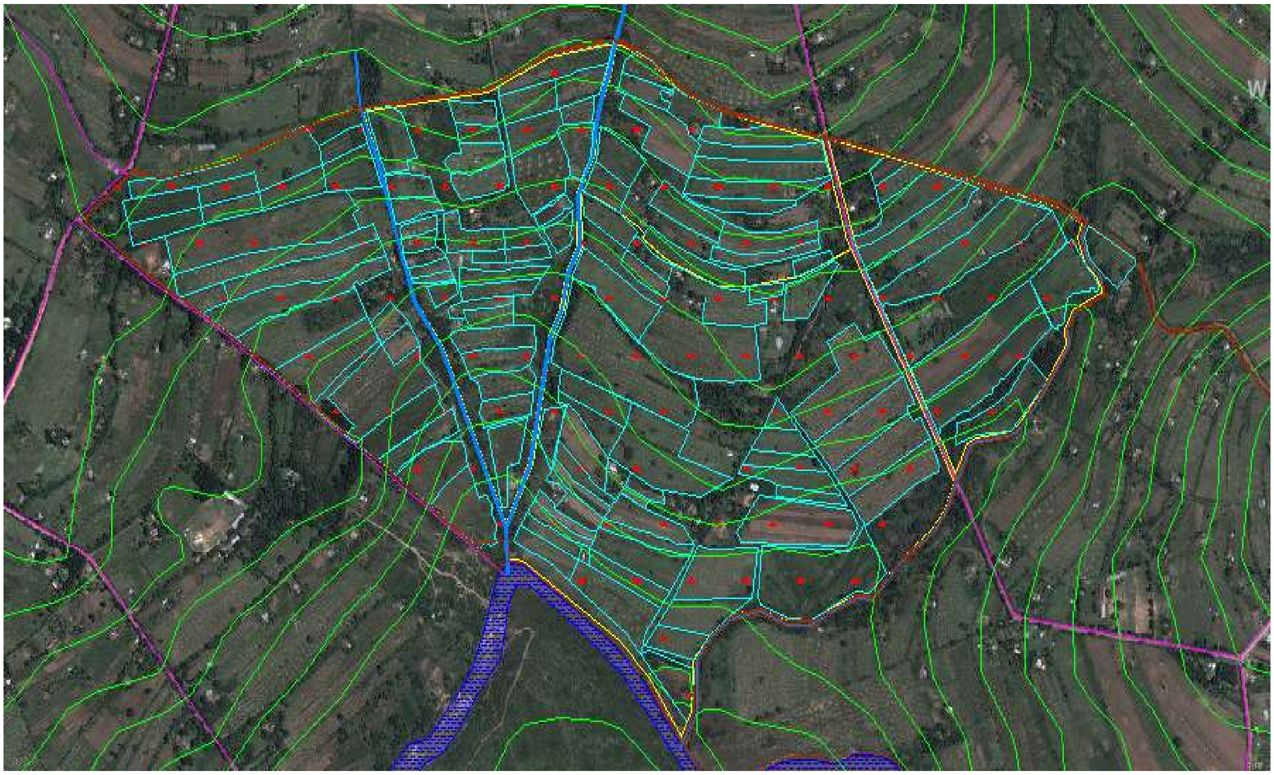


Figure 1-5: area contours**.**

1.5 Overall objective

The aim of the project is to design a drip irrigation system as a means of availing water for irrigation.

1.5.1 Specific objectives

The specific objectives for the project include**:**

1. To review the types of irrigation systems available to ascertain the design of a drip irrigation system**.**
2. To identify crop water requirement and other pertinent design parameters.
3. To use the pertinent parameters in (2) above to undertake preliminary designs (to include coming up with the system layout, specification for conveyance, main line, sub-mains, distribution lines and the infield system).

1.6 Statement of scope

The project intends to cover design of a drip irrigation system to include:

- ✓ Review on materials to ascertain the development of drip irrigation,
- ✓ Identification of pertinent design parameters like soil type, topography, climatic conditions of the area to allow estimation of crop water requirement.
- ✓ Determine parameters that would allow proper presentation of system layout.
- ✓ Design of a drip irrigation system including pipeline hydraulics for (main line, sub-mains, distribution lines, laterals and drip emitters).

The crops proposed for this project are kales and sweet potatoes.

The project intends to cover an area of about 60 hectares.

2.0 LITERATURE REVIEW

Irrigation can be defined as the process of slow application of water either on the surface of the soil or sub-surface (Punmia 1992). Many irrigation systems exist that have been exploited and that have been adopted for various places depending on certain conditions.

Water is naturally supplied to plants through rains, however the total rainfall in a particular area may be either insufficient or ill-timed. In order to get maximum yield it is essential to supply optimum quantity of water and maintain correct timing of water (Punmia 1992)

Necessity of irrigation can be summarized as follows: less rainfall, non- uniform rainfall, commercial crops with additional rainfall and controlled water supply (Punmia 1992). Much research has been done in the area of irrigation and many methods have been explored including, surface irrigation, sprinkler, localized irrigation systems and sub surface systems.

There are many factors to consider before selecting a particular irrigation system. These include water resources, topography, soils, climate, type of crops to be grown, availability and cost of capital and labor, type and appropriateness of a particular irrigation technology to farmers and its associated energy requirements, water use efficiencies, as well as socio-economic, health and environmental aspects (Andreas 2001).

It is not wise to use a single criterion for selection purposes. However, there are instances when one criterion can weigh heavily in favour of a particular irrigation system. The socio-economic impact of an irrigation system largely determines the success of the project. This embraces the socio-economic benefits, for and against, that can be derived not only by the government but also, more importantly, by the communities in which the project is located, and how these affect the sustainability of the project.

Health and environmental aspects are also important. The introduction of irrigation in a particular area can not only improve health, but also introduce health hazards, if mitigation measures are not adequately addressed during the scheme design, implementation, operation and management. Irrigation development may also introduce other environmental risks, such as salinization and the deterioration of biodiversity.

It is therefore necessary to obtain all available information and data and to carry out an analysis of all the factors before possibly ranking the criteria for purposes of selecting an irrigation system. In order for a project to be sustainable, all technical, socio-economic, health and environmental information should be analyzed in such a way that the system chosen is technically feasible, economically viable, socially acceptable and environmentally sound (Andreas 2001).

In Kenya irrigation can be dated back to the colonial times and some of the known existing irrigation systems include: Hola, Bura, Mwea and pekerra amongst others.

2.1 Irrigation process

Irrigation begins by determination of crop water requirement and how much of it can be met by other means such as rainfall. This process refers to determination of crop evapotranspiration (ETo) from which crop water requirement can be estimated. Many formulae have been developed from which crop evapotranspiration can be estimated and they are discussed below:

2.1.1 FAO Penman- Monteith method

This method was developed by defining reference surface as a hypothetical reference crop with an assumed crop height of 0.12m, fixed surface resistance of 70sec/m an albedo of 0.23(FAO,1998a). It derives its expression from measurement of standard climatological data entailing sunshine, temperature, humidity and wind speed.

The equation is as shown below.

$$ET_0 = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U_2(e_s-e_a)}{\Delta+\gamma(1+0.34U_2)} \quad [2\text{-}1]$$

Where Rn= net radiation at crop surface (MJ/m^2)

G- soil heat flux density (MJ/M^2)

T- Mean daily air temperature at 2m height (^oC)

$U_2 - Wind\ speed\ at\ 2m\ height\ (\frac{m}{\sec})$

$e_s - saturation\ vapour\ pressure(Kpa)$

$e_a - actual\ vapour\ pressure\ (kpa)$

$e_s - e_a$= saturation vapour pressure deficit (Kpa).

$\Delta - slope\ vapour\ pressure\ curve(kPa0C)$

$\gamma - Psychometric\ constant(kpa\ oC - 1)$

2.1.2 Pan Evaporation method

Despite FAO Penman- Monteith method being recommended as the best, pan evaporation method is still employed in so many places because of its simplicity and practicality.

Pan evaporation

The evaporation rate from pans filled with water can be easily determined. In the absence of rainfall, the amount of water evaporated during a given period corresponds to the decrease in water depth in the pan during the given period. Pans provide a measurement of the combined effect of radiation, wind, temperature and humidity on an open water surface.

The pan responds in a similar manner to the same climatic factors affecting crop transpiration. However several factors produce differences in the loss of water from a water surface and from a cropped surface.

Despite the difference between pan evaporation and reference crop evapotranspiration, the use of pans to predict ETo for periods of 10 days or longer is still practiced.

The measured evaporation from a pan (Epan) is related to the reference crop evapotranspiration (ETo) through an empirically derived pan coefficient (Kp) as given in the following equation from FAO (1998a):

$$ETo = Kp \times Epan \qquad [2\text{-}2]$$

Estimating reference crop evapotranspiration

Where:

ETo = Reference crop evapotranspiration (mm/day)

Kp = Pan Coefficient

Epan = Pan evaporation (mm/day)

The Class A pan

Various types of evaporation pans exist. The most common type is the Class A pan. According to FAO (1998a) The Class A evaporation pan is circular, 120.7 cm in diameter and 25 cm deep (Figure 3). It is made of galvanized iron (22 gauge) or Monel metal (0.8 mm). The pan is mounted on a wooden open frame platform, which is 15 cm above ground level. The soil is built up to within 5 cm of the bottom of the pan. The pan must be level. It is filled with water to 5 cm below the rim, and the water level should not be allowed to drop to more than 7.5 cm below the rim.

The water should be regularly renewed, at least weekly, to eliminate extreme turbidity. The pan, if galvanized, is painted annually with aluminium paint. Screens over the pan are not a standard requirement and should preferably not be used. Pans should be protected by fences to prevent animals from drinking the water in the pan.

2.1.3 Blaney criddle method

This takes into consideration temperature as the only parameter to be measured and therefore results either into overestimation or underestimation in certain conditions. It is an inaccurate method especially in windy, dry and sunny areas.

$$ET_o = p(0.46Tmean + 8) \quad [2\text{-}3]$$

Where:

ETo is the reference crop evapotranspiration in mm/day for the month considered

T is mean daily temperature in ^{0}C over the month considered

p is mean daily percentage of total annual daytime hours obtained for a given month and latitude

2.1.4 Effective rainfall

This is the amount of rainfall that can be utilized effectively

2.2 Methods of irrigation

Different types of irrigation methods exist namely:

2.2.1 Surface irrigation

This is the oldest method of irrigation that has been in existence since irrigation was discovered. It was first used in Mesopotamia and involves application of water by gravity across the soil surface by flooding or small channels such as basins, boarders, paddies, furrows, rills and corrugation.

The scheme layout up to field level, such as canals and drains, can be similar for each system According to FAO (1989), 95% of the irrigated area in the world is under surface irrigation.

Some of the major advantages of surface irrigation systems over other systems are that they are easy to operate and maintain with skilled labour, they are not affected by windy conditions and, with the exception of furrow irrigation, they are good for the leaching of the salts from the root zone. Generally, they are associated with low energy costs.

2.2.2 Sprinkler irrigation systems

A sprinkler irrigation system consists of a pipe network, through which water moves under pressure before being delivered to the crop via sprinkler nozzles. The system basically simulates rainfall in that water is applied through overhead spraying (therefore, these systems are also known as overhead irrigation systems (Andreas P 2002).

As such, the water distribution of certain sprinkler systems is affected to a large extent by the wind patterns and velocity in a particular area.

Sprinkler irrigation systems are suitable for most crops, except those whose leaves may be sensitive to prolonged contact with water or crops requiring ponding of water at some stage of their life. They are generally suitable for light, frequent irrigations, unlike most surface irrigation system.

There are several types of sprinkler irrigation systems, which can be broadly sub-divided into two groups: set systems (risers), which operate with sprinklers in a fixed position and can also be movable, and continuous move systems, which operate while moving including(centre pivot, linear move systems, travel gun systems).

2.2.3 Localized irrigation systems

Localized irrigation is a system for supplying filtered water (and fertilizer) directly onto or into the soil. The water is distributed under low pressure through a pipe network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. There are three main categories of localized irrigation:

a) drip irrigation- where drip emitters are used to apply water slowly to the soil surface
b) spray irrigation- where water is sprayed to the soil near individual trees
c) Bubbler irrigation- where a small stream is applied to flood small basins or the soil adjacent to individual tree.

A basic localized irrigation system consists of the head of the system that filters and controls the supply of water and fertilizers to the network, the plastic buried pipes that supply the water to the laterals, the polyethylene laterals, usually 16-20 mm in diameter, that supply the water to the emitters, and the emitters that discharge the water to the pre-determined points and at pre-determined flows.

It is a capital-intensive system with built in management that requires very little but skilled labor.

2.3 Drip irrigation system

The total water present in the earth is about 1.41billion km^3 of which 97.5% is brackish and only about 2.5% is fresh (of which 87% is in ice caps or glaciers, in ground or deep inside the earth). In the last two centuries (1800-2000), irrigated area in the world has increased from 8 million to about 260 million hectares for producing required food for the ever growing population (Megh, 2014).

Water scarcity seems to be a threat to global food production thus necessitating use of water efficiently while at the same time aiming to improve productivity of land. This necessitates introduction of drip system.

In India for example drip has been used in irrigation of nearly 2million hectares out of the over 39 million hectares under irrigation.

In Kenya approximately 80% of land is classified under arid and semi arid, with low rainfall and frequent crop failures. A step towards drip irrigation promotion has been taken up by KARI through production of low-cost drip irrigation technologies. This has helped farmers across the country ie Maasai community in Namanga area through collaboration with Green Belt movement and AMREF. Drip irrigation is also being used in the green houses especially for high valued crops i.e tomatoes, spinach, cucumbers etc. Most areas across the country also make use of bucket systems and drum kits as reservoirs (FAO/IAEA, 2013).

Figure 2-1: Typical layout of a drip system for a small holder in Kenya.

Table 2-1 Comparison of the types of irrigation systems, source (Finger, L. 2005)

System	Application Efficiency	Topographical conditions	Water losses	labour	Energy requirements
Surface (furrow, border, basin)	Low to high depending on layout	Level land	Evaporation, surface runoff and seepage	Moderate to high	Low
Fixed/ portable solid set sprinkler	high	Generally fit for level to rolling slopes	Evaporation Wind dispersions	Substantial at set-up	Moderate
Travelling gun/ boom irrigators	Higher for boom systems	Level to rolling	Wind dispersions and excess runoff	Tractors may be required to move hard-hose machines	High to moderate
Micro irrigation	Very high	Suited for all slope	Low evaporative losses, depending on magement surface run off may occur.	Low since it only requires seasonal maintenance.	Low to moderate

2.3.1 Historical background

Drip irrigation was first used in glass houses in England in the late 1940s and in open fields in Israel in 1950s. In 1960s the importance of drip irrigation system grew with development of cheap plastic pipes and fittings (FAO 1984).

Then buried clay pots were the main form of localized systems and were used in Iran for irrigation of trees before development of modern localized irrigation systems.

Early field work on modern drip irrigation systems was carried out under desert conditions and on sandy soils where good performance was demonstrated in relation to surface and sprinkler irrigation under extreme conditions.

There are two basic methods of drip irrigation (surface and sub-surface methods).

2.3.2 Components of drip irrigation system

The various components involved in the design of a drip irrigation system include: source of water, the head unit including (the intake structure), pipe fittings, air release valves, filters, flow meters and the fertigation unit.

The field unit systems consists of distribution system (main lines, sub-mains, distribution lines and infield system), valves (flush and air release valves), end plugs and pressure gauges.

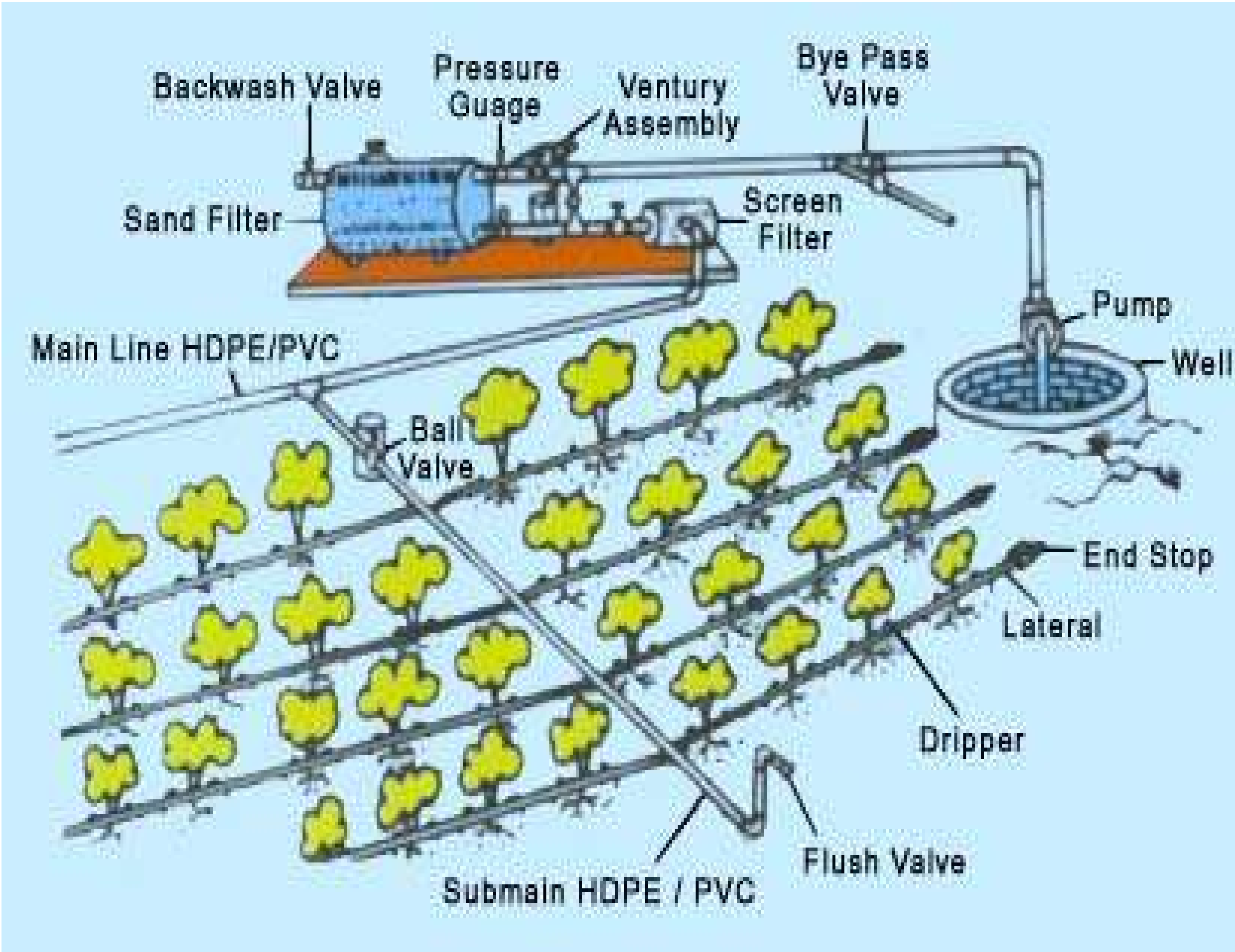


Figure 2-2: Drip irrigation components

2.3.2.1 Source of water

Sources of water for any irrigation system can be surface or ground water and this water can be abstracted from a river, lake, reservoir or spring (need to know elevation and pressure available at that point). For this project river Nzoia will be utilized as the source of water.

2.3.2.2 Intake facilities

This refers to structures built at the abstraction point from the water source to the conveyance system. It may involve a pumping or gravity system depending on the nature of the place.

2.3.2.3 Conveyance system

This involves the flow/ movement of water from the source to the field either through open channels as in the case with canals mostly suited for surface irrigation or closed conduits as in pipe system. For a proper conveyance system to occur a study of the area needs to be done checking into the topography and identifying highest points of the command area.

The conveyance system should be laid in such a way as to ensure water is delivered at the highest points of the command area.

2.3.2.4 Design of mainlines

Mainlines are pipelines that are connected to the conveyance lines and are mostly buried in the ground. They are made from either PVC or steel material depending on the nature of the place where they are to be laid.

Their sizes are determined by considering quantity of water flowing through the pipe, velocity required, ground elevation etc.

Design of mainlines looks into the following:

- Velocity (recommended range is between 0.5 to 1.5m/s)
- Class of pipe: If possible it is recommended that a low class pipe be used as it minimizes cost.
- Control measures- provide air release valves at suitable points, pressure reducing valves where necessary so that there's uniform distribution of water.
- Areas of minimal bends as bends result into head losses which should be minimized.

2.3.2.5 Design of sub-mains.

This is a conduit majorly that carries water from the main-line to serve a particular area. It's design is similar to that of the lateral main lines and it may include pressure regulators, flow control valves, manual or automatic control valves and filters. It is observed that discharge decreases across the length of the sub-main line.

There are ranges for drip system diameters for sub-main lines and these are chosen based on discharge required.

2.3.2.6 Distribution system

2.3.2.6.1 Design of distribution lines

These conduits carry water from sub-mains and distributes to the lateral lines. They have a smaller diameter compared to the sub-main lines. There size and length depends on topography, lateral flow rate, pressure loss in laterals and total pressure variation.

2.3.2.6.2 Design of lateral lines

These are conduits that carry water from the distribution lines to the emitters/drippers. Generally lateral sizes of between 10mm-20mm diameter PVC pipes with perforations at a distance equal to the spacing of crops.

Spacing of drippers to be fitted in these lines depends on planting distance along a row (which depends on type of crop chosen).

2.3.2.6.3 Emitters

Selection of a drip emitter is often based on expected pressure difference within the irrigation system. When pressure differences are expected to be significant a pressure compensating drip emitter is often used, otherwise regular emitters are used. Pressure differences always occur due to pipeline and lateral line friction losses. Such friction losses can be minimized by use of larger pipe or lateral lines.

Drip emitter selection is based on required emitter discharge rate (defined from manufacturers' charts). These are available in nominal discharge rates of 1-15l/h.

The choice of emitter discharge depends on the type of soil to which water is being applied.

Advantages of drip irrigation system

1. **More efficient use of water**: Compared to surface irrigation and sprinkler methods (with efficiencies of 50–75% in high-management systems), drip irrigation can achieve 90–95% efficiency. This is because percolation losses are minimal and direct evaporation from the soil surface and water uptake by weeds are reduced by not wetting the entire soil surface between plants.
2. **Reduced cost for fertilizers**: Precise application of nutrients is possible using drip irrigation. Fertilizer costs and nitrate losses can be reduced considerably when the fertilizers are applied through the irrigation water (termed fertigation). Nutrient applications can be better timed to coincide with plant needs since dressing can be carried out frequently in small amounts and fertilizers are brought to the immediate vicinity of the active roots.
3. **Reduced labor demand**: Water application is less labour demanding compared to surface irrigation. Cultural practices such as weeding can be performed when the plants are being irrigated.
4. **Low energy requirement**: A drip irrigation system requires less energy than a conventional pressurized system as it increases irrigation efficiency and therefore requires less water to be pumped. Compared to other pressurized systems, savings are also made because of the lower operational water pressure required for drip systems.
5. **Reduced salinity risk**: The drip lines are placed close to a row of plants and the root zone tends to be relatively free of salt accumulations as the salts always accumulate towards the edge of the wetted soil bulb.
6. With drip irrigation system there is a high degree of inbuilt management system so that losses resulting from deep percolation and runoff are kept at bay as it only allows slow movement of water through the soil.
7. Its adaptability to harsh topographical and soil conditions.
8. Its distribution is not affected by weather conditions thus the crops are disease free.

Disadvantages of drip irrigation systems

1. **Clogging of emitters**- this is a serious problem in drip systems and calls for good maintenance through flushing probably once a month.
2. **Water management**: When practicing drip irrigation, farmers do not see the water. This often results in over irrigation and the loss of the benefits of high irrigation efficiency. Over-irrigation will also make the soil excessively wet and therefore promote disease, weed growth and nutrient leaching.
3. **Cost**- generally the cost of installation of drip system is high and that is why it is used for high valued crops.
4. **Restricted root zone**: Plant root activity is limited to the soil bulbs wetted by the drip emitters; a much smaller soil volume than that wetted by full-coverage sprinkler or surface irrigation systems. Thus, if a drip irrigation installation fails (clogging), the crops will suffer more from drought than crops watered by sprinkler or surface irrigation. Under drip irrigation the confinement of roots to a small soil volume means less available soil water storage for the plants. As a result of this it is recommended to continue irrigation even after a rain

3.0 THEORETICAL FRAMEWORK

Irrigation starts with identification of crop water requirement which refers to amount of water required to compensate the evapotranspiration losses from the cropped field. It basically entails determination of evapotranspiration rate (ETo) and the different methods of determining the same have been mentioned above, however for this particular case CROPWAT model analysis together with crop coefficient were used in determination of crop water requirement and irrigation requirement.

3.1 Evapotranspiration rate.

Actual water consumption (evapotranspiration), is influenced by climatic factors, including air temperature, humidity, radiation, cloud cover, and wind, and by the nature of the plant itself including its stage of growth. It is also influenced by the amount of moisture in the soil at the time (soil moisture tension). In the face of this number of factors, values for many of which are frequently not known, simplified approximate methods of estimation are commonly used. One method that factors in all the climatic data is the Penman-Monteith method.

3.1.1 The FAO CROPWAT Model

CROPWAT is a computer model that was developed by FAO to help calculate crop water and Irrigation requirements from climatic and crop data. It equally allows development of irrigation schedules for different management conditions and allows for determination of scheme water requirements for the whole area.

The model is based on a water balance model where the soil moisture status is determined on a daily basis from calculated evapotranspiration and inputs of rainfall. The program makes use of climatic data ie maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, and rainfall data. It uses Penman Monteith method for calculation of evapotranspiration rate.

$$ET_0 = \frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U_2(e_s-e_a)}{\Delta+\gamma(1+0.34U_2)} \qquad [3.1]$$

Where Rn= net radiation at crop surface (MJ/m^2)

G- soil heat flux density (MJ/M^2)

T- Mean daily air temperature at 2m height (^{o}C)

$U_2 - Wind\ speed\ at\ 2m\ height\ (\frac{m}{\sec})$

$e_s - saturation\ vapour\ pressure (Kpa)$

$e_a - actual\ vapour\ pressure\ (kpa)$

$e_s - e_a$= saturation vapour pressure deficit (Kpa).

$\Delta - slope\ vapour\ pressure\ curve (kPa0C)$

$\gamma - Psychometric\ constant (kpa\ oC - 1)$

Data for use in the above equation was obtained from Kenya Metereological Department and Lugari Farmers Training centre. For an area whose climatic data cannot be found, CLIMWAT database can be accessed for these data. The CROPWAT models allows for calculation of crop water requirement.

3.1.2 Crop water requirement determination

This is defined as the daily crop water use assuming crop is kept at near optimum moisture condition. The resulting crop water requirement calculated from CROPWAT entails:

a) Giving details of the soil characteristics of the area including available soil moisture content, depth, depletion level etc.
b) Selecting the crop to be planted by specifying rooting depth, kc values depending on the stage of growth, yield factor and lastly specifying the time of planting.

With such input the model calculates the crop water requirement on a decade basis equivalent to 10 days.

3.1.3 Use of crop coefficient (Kc)

The crop coefficient is the coefficient for crops growing under conditions of optimum fertility and soil moisture and achieving full production potential. They are values dependent on growth stages of the crop and they influence crop water need of the plant.

$$ETc = Kc \times ETo \qquad [3.2]$$

Where:

$$Etc\ is\ crop\ evapotranspiration\ in\ \frac{mm}{day}$$

$$ETo\ is\ the\ reference\ crop\ evapotranspiration\ mm/day$$

$$Kc\ is\ the\ crop\ coefficient$$

This is an acceptable method of calculating crop evapotranspiration as during germination and initial crop development majority of water loss from plant and soil surface occur due to evaporation. At this point the value of ETc can almost be equated to ETo for a soil surface that is continually wetted.

3.2 Net Irrigation Requirement

The net irrigation requirement is the depth of irrigation water, exclusive of precipitation, carry-over soil moisture or groundwater contribution or other gains in soil moisture,that is required consumptively for crop production. It is the amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity. This is calculated using the formulae:

NIR= ETc- Pe + (SAT+PERC+WL) [3.3]

Where **ETc**- the crop water requirement (in mm/day)

Pe- effective rainfall.

SAT is water required for pudding (200mm/day).

PERC-is the percolation and seepage losses (0.1mm/day)

WL- is the water layer depth (100mm/day).

These values (SAT, PERC, and WL) are only applicable when paddy farming is carried out since paddy requires maintenance of a water layer thus the equation reduces to **NIR= ETc- Pe** for upland and horticulture crops.

3.2.1 Effective rainfall

This is the amount of rainfall utilizable i.e. that goes directly into use by the plants.

The most commonly used formulae for calculating is:

USDA S.C Method

$$P_{eff} = \frac{P_{mon} * (125 - 0.2 * P_{mon})}{125} \; for \; P_{mon} \leq 250mm \qquad [3.4]$$

$$P_{eff} = 125 + 0.1 * P_{mon} \; for \; P_{mon} > 250 \; mm \qquad [3.5]$$

3.2.1 Gross Irrigation Requirement

This takes into consideration losses encountered either during application, conveyance and distribution. The efficiency depends on the distribution system ie surface, sprinkler or drip system. It is given by:

$$GIR = \frac{NIR}{E_{ff}} \qquad [3.6]$$

$where: NIR \; is \; net \; irrigation \; requirement$ in mm

$Eff\ is\ overall\ efficiency$ as %

Overall efficiency is however given by $Eff = E_a \times E_d \times E_c$

Where:

Ea is application efficiency

Ed is distribution efficiency

Ec is conveyance efficiency

3.3 Leaching requirement

This refers to amount of water required to remove the salts from the root zones when it is felt that there's accumulation that may affect crop growth.

LR (mm) = $\frac{ET_c}{1-LR} - ET_c$ [3.7]

Where:

LR (mm) is the leaching requirement

ETc is the crop water requirement (mm/day)

LR (factor) is the leaching requirement factor (taken as 20% of irrigation water)

3.4 Management allowed depletion

This is the depth to which the plant is allowed to stress before application of irrigation water.

It is given by:

$MAD = P' * AW * D$ [3.8]

Where P' is allowed depletion

AW is available water that soil can hold between field capacity and permanent wilting point.

D is root zone depth.

3.5 Irrigation Interval

This refers to allowable interval between irrigations if crop is irrigated when management allowed depletion has been reached.

It is calculated by:

$$II(days) = \frac{MAD}{ET_c - P_e - G_w} \qquad [3.9]$$

Where:

MAD- is Management Allowed depletion (mm)

ETc- crop water requirement (mm/day)

Pe – effective rainfall (mm)

Gw- ground water contribution (mm)

3.6 Net application desired

Once the irrigation interval is known and assuming profile is filled to field capacity at previous irrigation and will be filled again with present irrigation:

Then net depth is given as:

d_{net}= II* ($ET_c - P_e$-Gw) [3.10]

Where:

II is maximum irrigation interval (days)

ETc is crop water requirement (mm/day)

Pe is effective rainfall

Gw is ground water contribution.

3.7 Gross application depth

It is the depth that is needed for application taking into consideration the losses incurred due to the type of system chosen for distribution.

It is calculated as:

$$d_g = \frac{dnet}{E_a} \qquad [3.11]$$

Where;

Dnet is net application depth

Ea is application efficiency

3.8 Emitter discharge

Emitter discharges come in various ranges depending on the type of emitter and a good emitter discharge is that which will not result into runoff or deep percolation depending on the type of soil one is dealing with. They are based upon manufacturers' standards.

They range from 15-0.6l/hr

3.9 Time period of irrigation

This is the time required for operation of system daily (always given in minutes for drip irrigation system).

$t = \frac{d_g * A}{Q}$ [3.12]

Where:

Dg is gross application depth in mm

A area over which water is applied

Q is flow rate in this case, emitter flow rate in l/hr.

3.10 Scheme water requirement (SWR)

This is the total amount of water in cubic that needs to be supplied for the area considered.

It is calculated as:

SWR= GIR$\times A$ [3.13]

Where:

GIR is gross irrigation requirement (in mm/day)

A is area (m^2)

3.11 Application rate

This is also known as precipitation rate, is a measure of the rate at which water is applied to an area by the irrigation system per unit of time. It is a critical factor in design because a system can easily apply water at rates greater than the soil's ability to absorb water (infiltration rate), which leads to runoff.

The application rate is used to determine how long the irrigation system should run to replace the moisture removed from the soil by the plant between irrigations.

It is calculated by:

AR = $\frac{Q}{S_1 * S2}$ [3.14]

Where:

AR = Application rate, mm/hr

Q = Emitter flow rate, litres per hour (lph)

S1 = Emitter spacing along line, m

S2 = Line spacing, m

3.12 Total run-time per day

This is the amount of time on each irrigation day that the irrigation system will operate during the 24 hr period. It is given by:

$$Td = \frac{OT}{IR} \qquad [3.15]$$

Where:

Td is total run time per day

IR is irrigation days.

3.13 Maximum run-time per cycle

This is calculated by dividing the soil infiltration rate by system application rate.

$$RC = \frac{Soil\ infiltration\ rate}{Application\ rate} \qquad [3.16]$$

3.5 PIPE CHARACTERISTICS

3.5.1 Pipe flow examples

The different lines that will be designed include: main lines, sub-mains and the distribution lines and the infield system. The different characteristics to be evaluated include velocity through the pipes which is limited to 0.5-2.5m/s for the various pipe materials. The discharge equation that will be used is:

(Q= A*V) [3.17]

Where:

Q is discharge (m^3/s)

A is cross sectional area (determined from inner diameter using the equation ($\frac{\pi d^2}{4}$).

Pressure within a pipe varies from one point to another especially where there is change in topography and also due to head losses resulting from friction as mentioned below.

3.5.2 Head loss in pipes

This refers to loss in energy of water cause due to viscous effects such as friction that depend on (conditions of flow and the physical properties of the system, movement of fluid molecules against each other, presence of bends or kinks in a piping system etc)(Munson B.R 2006).It is considered as a major loss.

This drop in energy is dependent on the wall shear stress between the fluid and pipe surface which is equally dependent on whether the flow is turbulent or laminar.

Methods of calculating friction loss may be use of:

3.5.2.1 Darcy Weisbach equation

Involves use of moody diagrams and examination of Reynolds number) for estimation of friction loss.

$$\text{Hf} = \frac{\text{4fLV2}}{2gD} \quad [3.18]$$

Where:

f is friction factor,

L is length of pipe (meters)

V is velocity (m/s)

g is gravitational constant.

D is diameter in(meters).

3.5.2.2 Hazen Williams equation

This is an empirical method in that it relates flow of water in a pipe with physical properties of the pipe and the pressure drop caused by friction. It is the most widely used formulae in determination of head loss.

$$H_l = \frac{L \times 10.67 \times Q^{1.85}}{C^{1.85} d^{4.87}} \qquad [3.19]$$

Where:

H_f is head loss

L is length of pipe (in meters)

Q is volumetric flow rate in m3/s

C is pipe roughness coefficient

D is inside pipe diameter (meters)

A table showing the roughness coefficients of various materials is as shown in appendix A-1

3.5.2.3 Pressure variation.

Pressure variations along the pipeline will be determined as follows:

- Static head (Hs) = Total head at a point in a pipeline.
- Energy Grade line(EGL) = Static head(Hs)- frictional losses(Hf)
- Hydraulic Grade Line (HGL) = EGL- Velocity head(Vf)
- Operating pressure head (Hp) = HGL- Pipe Invert Level.

3.5.2.4 Lateral and lateral spacing

These are pipelines that carry water from the sub-main line in an infield system to the emitters. Their spacing depends upon crop spacing and how large the plot is. The number of laterals for a typical field is calculated from:

$$No\ of\ laterals = \frac{Plot\ length}{Row\ spacing\ of\ crops} \qquad [3.20]$$

3.5.2.5 Emitter selection

This will be based on emitter characteristics that affect system efficiency including:

- Emitter discharge exponent
- Discharge pressure relationship
- Manufacturers coefficient of variation
- Range of operating pressure

The basic equation for the discharge-pressure relationship includes:

$$Q= KH^{x} \qquad [3.21]$$

Where:

Q is emitter discharge,

K is constant for each emitter,

H is pressure head at which the emitter operates x is the exponent characteristic by flow regime(measuring slope of log-log plot of head versus discharge)

3.5.2.6 Number of emitters.

This depends upon crop spacing and the lateral length and is calculated by:

$$number\ of\ emitters = \frac{lateral\ length}{crop\ spacing} \qquad [3.22]$$

4.0 METHODOLOGY

4.1 Review of literature

This was done by comparing various aspects of design involved in particular irrigation systems to enable the decision of drip irrigation system to be adopted.

A suitable method of distribution is based on:

i) Even distribution of water for the crops.
ii) Supply of an adequate amount of the water for the crops.
iii) Avoid water wastage and problems like soil erosion, water logging and salinity.

The major determinants of a suitable method include: natural conditions, type of crop, type of technology and previous experience with irrigation.

Decision criteria

This was based on:

a) Practical know how of the user
b) Adaptability to technology
c) Prevailing local conditions.

Three factors were considered during the assessment of the various methods available for irrigation:

a) Cost (in terms of operation and maintenance)
b) Technical considerations
c) Nature of the area(in terms of topographical variations)

4.2 Irrigation parameters

Some of the irrigation parameters to be determined included:

a) Application rate of the drip system, depending on the type of soil
b) Application efficiency which depends on system of distribution.
c) Irrigation water requirement.
d) Operating time of the system.
e) Management allowed depletion.
f) Total run-time of the system per day.
g) Maximum run-time per cycle.

4.3 Crop water requirement estimation

In determination of crop water requirement data was collected on climatic characteristics of the area (temperature, rainfall, humidity, sunshine hours and wind speed), soil characteristics of the area, existing crops with the cropping pattern and existing vegetation.

4.3.1 Determination of Irrigation water requirement

In determination of irrigation requirement several factors were looked into which include:

a) Evapotranspiration rate of the area based on reference crop.
b) Effective rainfall, calculated from CROPWAT as is displayed in the results sheet.
c) Irrigation efficiencies
d) Proposed crop and cropping patterns.
e) Assumption of no ground water contribution.

The crops selected for irrigation were determined based on:

4.3.2 Crop selection criteria

a) Land suitability in terms of (climate, soils, topography) for cultivation of various crops under irrigation.
b) Financial and economic returns to farmers.
c) Market potential and its requirement
d) Farmers' familiarity with various crops.

Two crops were chosen: sweet potatoes and kales.

It was however noted from the CROPWAT analysis that other crops can as well be considered as they have the similar water requirement as the crops above and these are: maize, cabbages, sun-flower, (tree crops- bananas, citrus etc)

JUSTIFICATION

Vegetables (kales)

- ✓ Vegetables usually have high gross margins hence high returns
- ✓ There exists a ready market since during the dry season the area sources for this from neighboring counties.
- ✓ It is generally labour intensive thus may result into creation of employment
- ✓ Results into nutritional security in the area.

In order to effectively come up with the crop water requirement a cropping calendar was developed for the two crops as displayed in the result in table 5-2

The crop area allocation was done on a 60% (food crops) and 40% vegetables (kales).

4.4 Design criteria for layout

In coming up with the layout various aspects were taken into consideration:

a) Topography in terms of ridges and valleys
b) Drainage system; natural water ways, existing streams.
c) Major existing roads and path ways.

4.4.1 Details of the layout

a) Intake

The area receives its irrigation water from R Nzoia with an intake along the river at an altitude of 1741m and at the following coordinate points

Northing: 0729774

Easting: 0085355

b) Conveyance line

A conveyance pipeline of 327mm diameter is used to supply water from the intake to the head of scheme. The total length of the conveyance line is 4065m because it has to follow the contour before reaching the head of scheme, based on the topography of the area. It is made of **uPVC** material.

c) Main pipeline

This receives water from the mainline at the head of scheme and supplies it across the block. The total length of the main pipeline is 1.7 km. It is designed to be of uPVC material.

d) Sub-main pipeline

This receives water from the mainline and supplies across the block. There are two sub-mains for the area with a total length of 175m for SB 1-1 and 480m for SB 1-2 with pipe diameter in the range of 97.2 mm- 141.2 mm. It’s designed to be made of Upvc material.

e) Distribution line

The distribution lines form points from which individual farms are connected, it abstracts water from the sub mains and distribute it within the various blocks to a group of farmers. The distribution lines have a total length of 2287m and pipe diameters range between 45.2 mm-97.2 mm .All distribution pipelines are of uPVC material.

f) Infield system

The infield system abstracts water from the distribution lines and supplies it to the individual plots for use by the farmers. The infield system considered is for drip.

The infield system was designed by use of the hydro-calc software. Having the flows required based on number of emitters and flow per emitter, the lateral size was selected and the sub-main and main-line sized accordingly. The results are displayed in section 5.

4.5 Overall design project criteria

a) Pipe materials/ characteristics

The proposed network for the system will consist of different pipe materials as shown below

- ✓ Steel/ GI pipe- this is suitable for rocky areas that require large pipe diameters >400 mm
- ✓ Upvc pipes- this is suitable for non rocky areas and diameters <400 mm (these are locally produced)
- ✓ PE- For infield irrigation systems

Table 4-1: General pipe characteristics

Feature	Steel/ GI pipes	Upvc/PE pipes
Pressure ranges in bars	47-18	1-16
Velocity range in m/s	0.35-5	0.35-2.5
Roughness coefficient (C)	125	140
Deflection	-	6.7
Availability	Locally available	Locally available
Available size range in mm	15-2200	20-400
Corrosion resistance	Non-resistant	resistant
Projected lifespan	30	50

Source: Technical specifications from manufacturers

Advantages and limitations of steel pipes

- ✓ Steel pipes have the advantage of accommodating higher velocities and pressures, as well as considerably increasing the head loss. These two factors enhance its suitability for use in situations calling for pressure reduction. However high cost per length as well as non-resistance to corrosion limits its use in some areas.
- ✓

Advantages and limitations of Upvc

- ✓ UPVC pipes have the advantage of lower cost per length, moderate head loss (3m for small systems and 12m for large systems - Water Supply Services Manual) and readily available in the local market. However they are limited in lower velocity, pressure and available size ranges.

b) Pipeline Hydraulic design

i) Design discharge

The overall discharge required for the project was determined based on the demand side of the crops and for the other pipelines is analyzed from excel and displayed in the design flows in the results sheet **figure 5-1.**

ii) Pipeline diameters

This was determined from the basic discharge equation of

$$Q = V * A$$

Where Q is discharge (m3/s)

A is cross-sectional area (m^2).

V is pipe flow velocity (m/s)

Selection of pipe diameters

The following design criteria were applied in determination of pipe sizes and in selection of pipe material.

i) A minimum flow velocity of 0.35m/s is set to avoid siltation in the pipe system.

ii) Maximum flow velocity of 2.5 m/s for Upvc and 5m/s for steel pipes.

iii) Hazen-Williams formula used in determination of friction losses within pipe system, roughness coefficient C=140 for Upvc and 125 for steel pipes.

iv) Inside pipe diameters have been used in the design.

v) Where ground is rising, larger pipe diameters are to be used to minimize friction losses and make more head available as long as flow velocity is within acceptable ranges.

vi) Lateral diameters are fixed between the ranges 25-20mm.

Using the above guidelines and employing the Hazen-Williams formula for friction losses determination, the pipe network for the project was designed using a MS-Excel spread-sheet and the results have been presented in appendices.

4.4 Tools employed.

Some of the tools that were incorporated during the design include:

- ✓ Global mapper together with Digital Elevation Model in generation of profiles,
- ✓ Google earth for preliminary estimation of aspects such as lengths and identification of a suitable area for intake.
- ✓ Excel spreadsheets for the design of pipeline hydraulics
- ✓ AUTOCAD for presentation of design drawings.

5.0 RESULTS AND DISCUSSION.

Net irrigable area- 60 ha.

Plot size considered- 1 acre (a plot of 48*84) m^2

Soil type: sandy loam soil.

5.1 Crop water requirement presentation.

The calculated crop water requirement as presented in section 5.1.3 is based on proposed cropping calendar although the area has its own cropping calendar.

5.1.1 Crops selected

The crops selected for the area are: sweet potatoes and kales as justified in section 4 above.

5.1.2 Reference crop evapotranspiration

Kakamega Meteorological station number 2318 has been used since its close and a representative of project area. Data for the area was acquired from the Kenya Meteorological Department in Nairobi and from Lugari Farmers Training Centre.

Table 5-1: Reference crop evapotranspiration rate, ETo.

Country: Location 8 | Station: KAKAMEGA

Altitude: 1530 m. | Latitude: 0.28 °N | Longitude: 34.78 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	10.3	31.1	60	86	8.0	21.1	4.40
February	10.7	32.0	59	86	8.0	21.8	4.64
March	10.8	32.6	62	104	7.6	21.4	4.79
April	10.5	31.4	73	78	6.5	19.1	4.06
May	10.3	30.9	75	69	6.8	18.6	3.81
June	9.9	29.7	74	69	7.3	18.6	3.66
July	10.1	30.3	73	69	6.9	18.3	3.68
August	9.8	29.4	73	78	7.3	19.8	3.95
September	10.0	30.0	70	78	7.1	20.3	4.12
October	10.3	30.8	68	86	7.2	20.5	4.28
November	10.3	30.8	68	95	6.5	18.9	4.09
December	10.2	30.7	65	112	7.9	20.6	4.41
Average	**10.3**	**30.8**	**68**	**84**	**7.3**	**19.9**	**4.16**

5.1.3 Effective rainfall

Effective rainfall for project has been calculated for each month using rainfall data from Lugari Farmers Training centre.

Effective rainfall amount has been calculated using equation **3.4** and **3.5** in section 3.

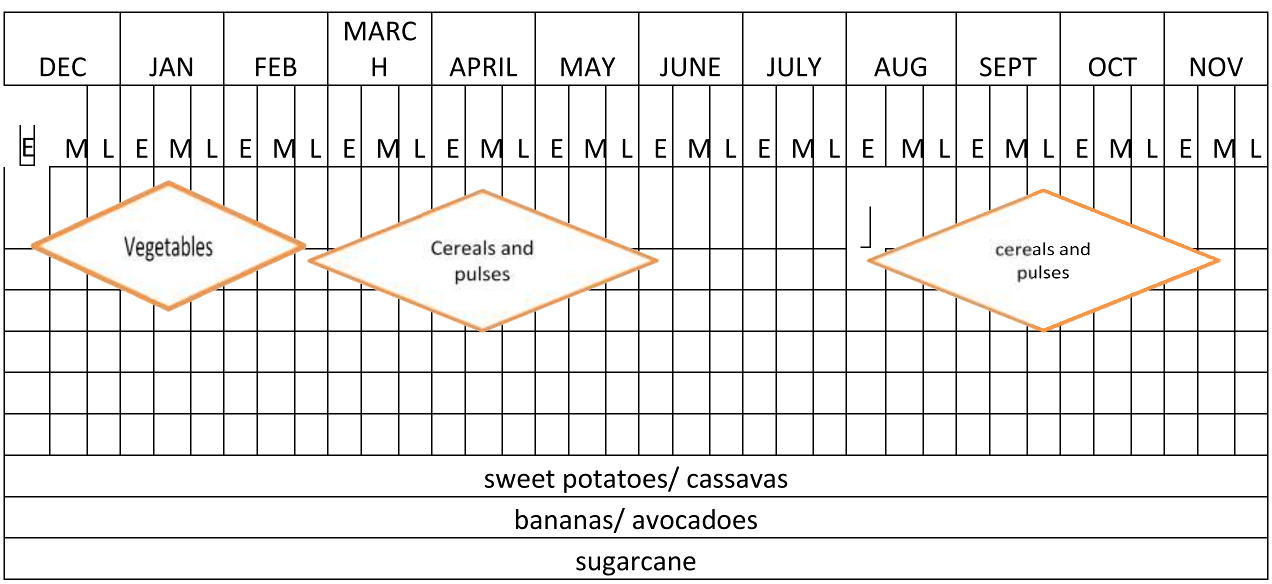
The result is displayed in the table below.

Table 5-2 1Effective Rainfall Calculation

Station: KAKAMEGA   Eff. rain method: USDA S.C. Method

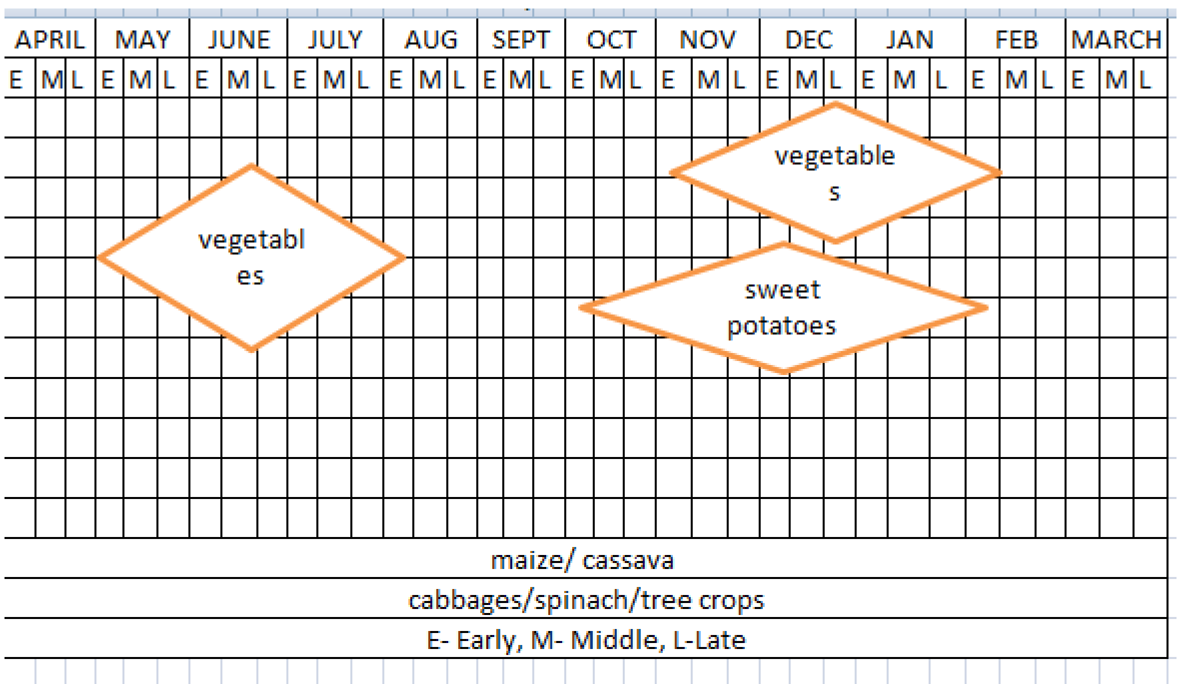
	Rain	Eff rain
	mm	mm
January	34.3	32.4
February	49.3	45.4
March	70.5	62.5
April	138.9	108.0
May	152.9	115.5
June	110.9	91.2
July	167.9	122.8
August	186.2	130.7
September	91.3	78.0
October	63.2	56.8
November	64.6	57.9
December	31.3	29.7
Total	1161.3	931.1

Table 5-3 1: present cropping calendar



Where E=Early, M= Middle, L= Late

Table 5-4 1: proposed cropping calendar



The cropping calendar was generated based on a number of considerations

a) Expected returns from produce sold (gross margins)

b) Demand for the various crops.

Table 5-5 1: cropping dates

Crop	Date of planting	Date of harvest
Sweet potatoes	05/10	11/02
Kales	07/11 05/05	09/02 02/08

Table 5-6 1: Kales Crop Water Requirement

Crop Water Requirements

ETo station: KAKAMEGA | Crop: Small Vegetables

Rain station: KAKAMEGA | Planting date: 05/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.70	2.96	17.8	12.4	7.4
Oct	2	Init	0.70	3.00	30.0	17.9	12.0
Oct	3	Deve	0.73	3.08	33.9	18.4	15.5
Nov	1	Deve	0.85	3.54	35.4	20.1	15.4
Nov	2	Deve	0.98	3.99	39.9	20.7	19.3
Nov	3	Mid	1.07	4.47	44.7	17.1	27.6
Dec	1	Mid	1.07	4.60	46.0	12.1	33.9
Dec	2	Mid	1.07	4.72	47.2	8.5	38.7
Dec	3	Late	1.05	4.61	50.7	9.2	41.5
Jan	1	Late	0.99	4.35	30.4	7.1	20.2
					376.0	**143.4**	**231.6**

.

Table 5-7 1: Crop water requirement for sweet potatoes

Crop Water Requirements

ETo station: KAKAMEGA | Crop: Potato

Rain station: KAKAMEGA | Planting date: 05/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.50	2.11	12.7	12.4	2.4
Oct	2	Init	0.50	2.14	21.4	17.9	3.5
Oct	3	Deve	0.51	2.13	23.5	18.4	5.1
Nov	1	Deve	0.67	2.77	27.7	20.1	7.7
Nov	2	Deve	0.89	3.65	36.5	20.7	15.8
Nov	3	Mid	1.11	4.66	46.6	17.1	29.5
Dec	1	Mid	1.17	5.05	50.5	12.1	38.4
Dec	2	Mid	1.17	5.17	51.7	8.5	43.3
Dec	3	Mid	1.17	5.17	56.8	9.2	47.6
Jan	1	Mid	1.17	5.16	51.6	10.2	41.4
Jan	2	Late	1.12	4.94	49.4	10.4	39.0
Jan	3	Late	0.98	4.40	48.4	11.9	36.5
Feb	1	Late	0.84	3.84	38.4	13.6	24.8
Feb	2	Late	0.77	3.56	3.6	1.5	3.6
					518.8	**183.9**	**338.4**

Crop water requirement is water lost by crop through evapotranspiration when local conditions are taken into account. Tongaren lies in the agro ecological zone UM-4 and from table 5-1 (CROPWAT analysis), the CWR of sweet potatoes was found to be 4.8mm/day and that of vegetables as 4.2mm/day as displayed in the chart below.

Table 5-8 1: Chart for CWR (sweet potatoes)

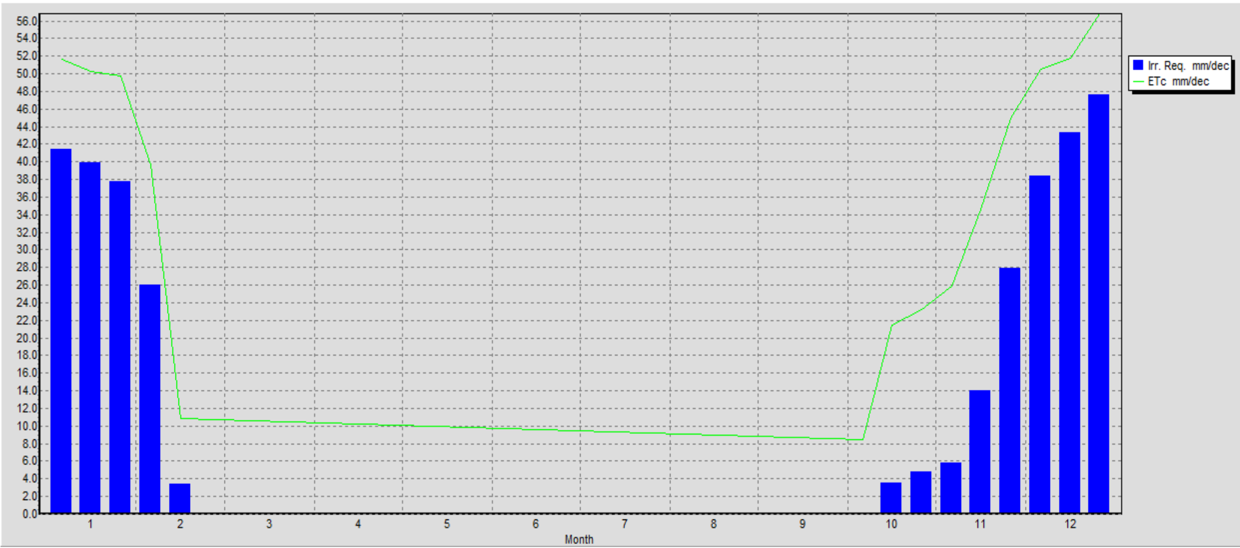
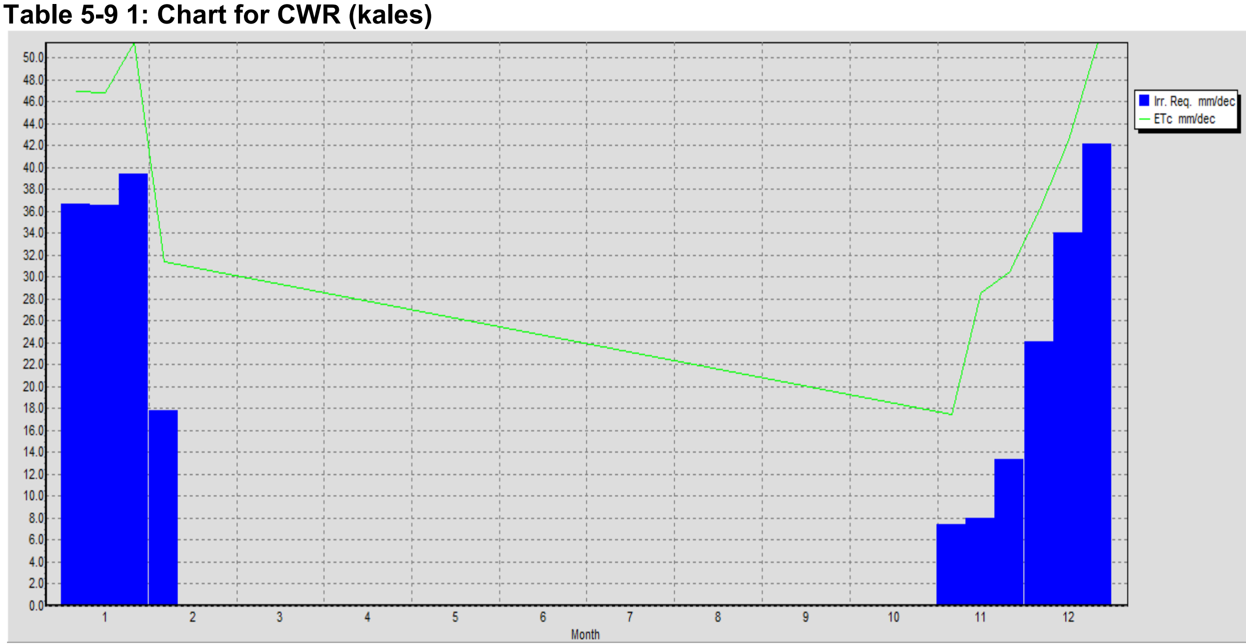


Table 5-9 1: Chart for CWR (kales)



5.2 Application rate/ drip precipitation

This was calculated based on equation 3.14 and was found to be 8.8 mm/hr which is an acceptable value as the maximum infiltration rate of sandy-loam is about 20 mm/hr (FAO, 2002).

This value then means that no runoff may occur once the application process is finished.

5.3 Net irrigation requirement

NIR has been determined using equation 3.3 in section 3 and was found to be 4.8mm/day for sweet potatoes and 4.2 mm/day for kales respectively. Designing for the worst case possible it was assumed that effective rainfall is nil.

5.4 Gross irrigation requirement:

Catering for losses being that a system can never be 100% efficient, an efficiency of 90% was chosen based on the fact that the distribution system is drip and it aims only to wet the soil at the point of application thus efficiency is high compared to other methods.

Based on this the gross irrigation requirement from equation 3.6 was found as 5.33mm/day and 4.67 mm/day for sweet potatoes and kales respectively.

5.4.1 Irrigation Interval

This is the period of irrigation before maximum depletion level is reached. This was calculated from equation 3.9 with the assumption of no ground water contribution and effective rainfall. The values found for both sweet potatoes and kales were 2 days. This is justifiable considering the system of distribution and the soil type for the area.

5.4.2 Time of operation

This is the time that the system will be in operation per day and it is calculated from equation 3.12, the values were found to be 36 minutes and 31.5 minutes for sweet potatoes and kales respectively**.**

5.5 Pipeline hydraulics

The length of the pipes for the various lines was based on the layout drawn in AUTOCAD and by help of google earth. The table is summarized as below.

Table 5-10 1: Pipeline lengths and areas served

TONGAREN IRRIGATION SCHEME			
BLOCK NAME	**PIPELINE NAME**	**PIPELINE LENGTH (m)**	**AREA SERVED(ha)**
Tongaren	**Conveyance**	**4065**	**60.00**
	Mainline	**1780**	**60.00**
B1	**Sub-main B1-1**	**176**	**38.01**
	D1-1-1	442	8.14
	D1-1-2	382	6.56
	D1-1-3	661	23.31
	Sub-main B1-2	**488**	**22.02**
	D1-2-1	278	9.93
	D1-2-2	528	12.09

5.5.1 Pipe diameters

From equations 3.14 and 3.16 and the discussion in section 3.5.2.3, using excel spreadsheet for iteration various pipe diameters were established for the pipelines mentioned above. Velocity ranges were set as is specified in section 4 and an example of a table generated from excel spreadsheet is as shown below:

Table 5-11 1: a sample of pipeline design from excel spreadsheet

SM1-1

Node	Ch	L	C	Q	D	A	V	Hl	Vf	G.E	Static Level	Pipe Invert	EL	HGL	Hp	Hs	D of E	Qofftake	
D1-1-1	0	0	140	0.0234	0.0972	0.007	3.153	0.000	0.507	1714.978	1745.000	1714.0	1723.5	1723.4	9.42	31.02	1.0	0.005	
D1-1-2	0	0	140	0.0184	0.0972	0.007	2.478	0.000	0.313	1714.989	1745.000	1714.0	1723.5	1731.0	17.01	31.01	1.0	0.004	
3	20	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1713.433	1745.000	1712.4	1723.5	1723.3	10.82	32.57	1.0		
4	40	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1712.275	1745.000	1711.3	1722.3	1722.0	10.77	33.72	1.0		
5	60	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1711.113	1745.000	1710.1	1721.1	1720.8	10.71	34.89	1.0		
6	80	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1709.952	1745.000	1709.0	1719.9	1719.6	10.66	36.05	1.0		
7	100	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1708.484	1745.000	1707.5	1718.7	1718.4	10.92	37.52	1.0		
8	120	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1706.678	1745.000	1705.7	1717.5	1717.2	11.51	39.32	1.0		1713
9	140	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1704.934	1745.000	1703.9	1713.0	1712.7	8.78	41.07	1.0		
10	160	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1703.254	1745.000	1702.3	1711.8	1711.5	9.25	42.75	1.0		
D1-1-3	175	15	140	0.0144	0.0880	0.006	2.359	0.914	0.284	1702.055	1745.000	1701.1	1710.9	1710.6	9.53	43.94	1.0	0.014	

5.6 Design flows

This was done in excel spread sheet using the formulae:

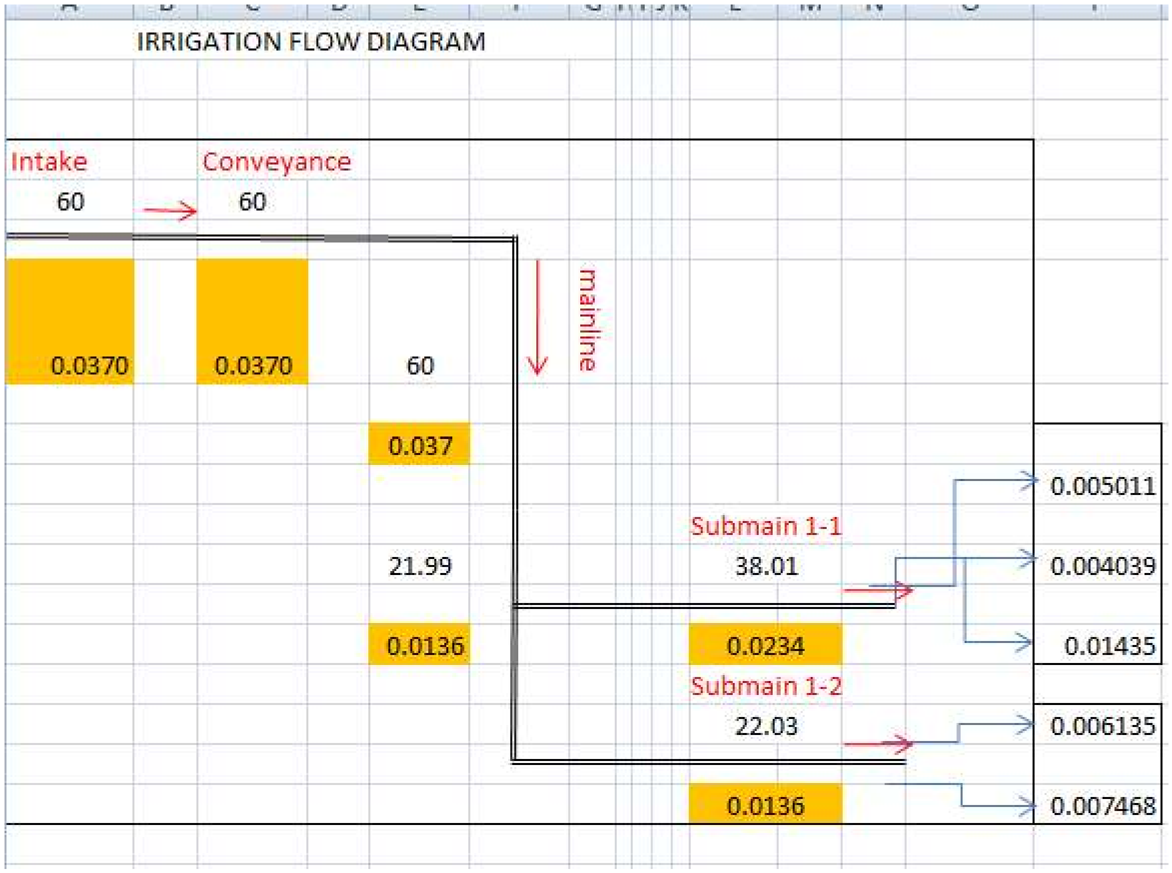
$$Q = \frac{Area\ served \times Overall\ flow}{Total\ area}$$

For all the pipelines as displayed below.

Flow per farm is thus:

$$Q_{farm} = \frac{0.4 \times 0.037}{60} = 2.47 * 10^{\wedge} - 4m3/s$$

Table 5-12 1: Design flows for the area



5.7 System Layout

The layout consists of: source of water, conveyance pipeline, main-line, sub-mains and distribution lines to the infield system. This is illustrated below:

5.7.1 Design criteria

In coming up with the layout various aspects were taken into consideration:

a) Topography in terms of ridges and valleys
b) Drainage system; natural water ways, existing streams.
c) Major existing roads and path ways.

- ✓ The conveyance line is ideally supposed to follow the shortest route possible and possibly existing roads (for this case it cuts through farm boundaries and therefore it is recommended that the area is opened up.
- ✓ The main-pipeline was drawn to follow a road
- ✓ The area was divided into blocks so that each distribution line supplies a specific block.

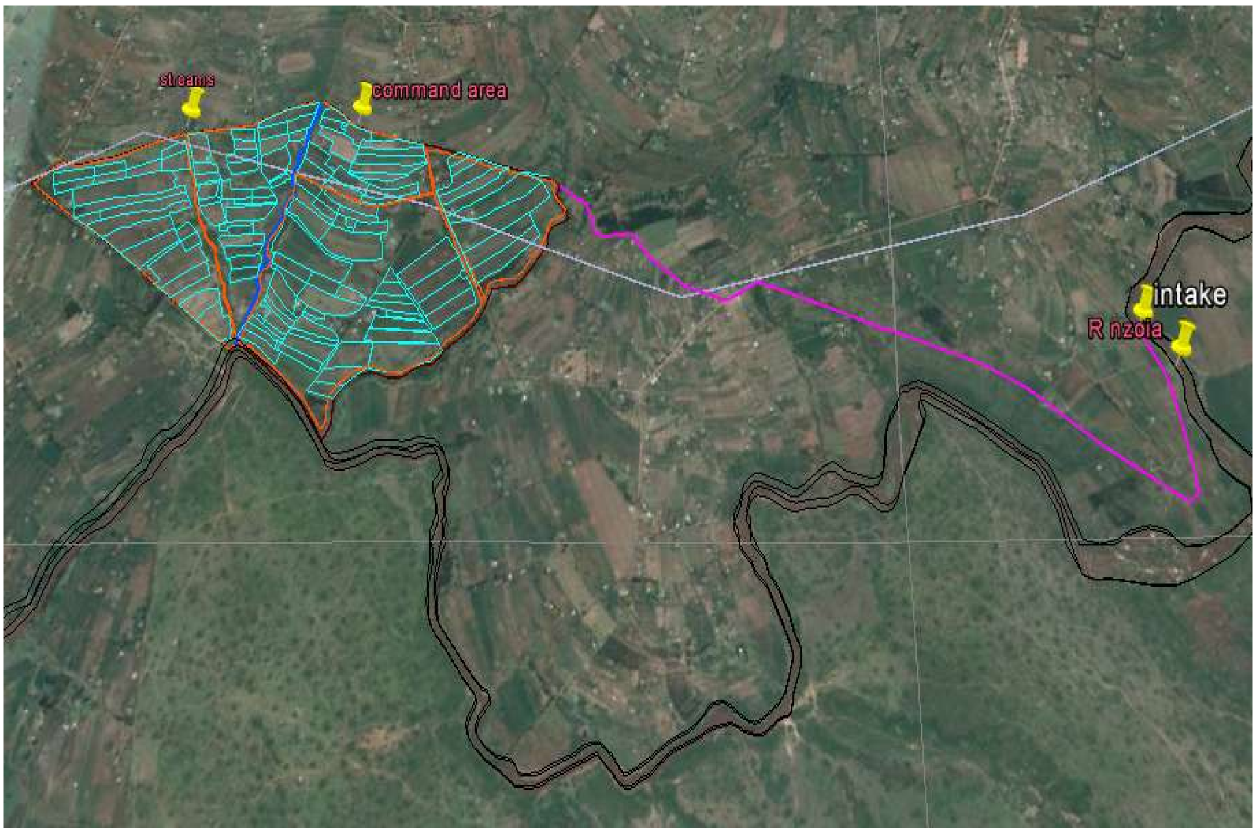


Figure 5-2: Google earth image of the area, showing intake point and blocking of the field

To ensure that water flows through the pipelines global mapper software was used to generate profiles for all the lines and a sample is as shown below:

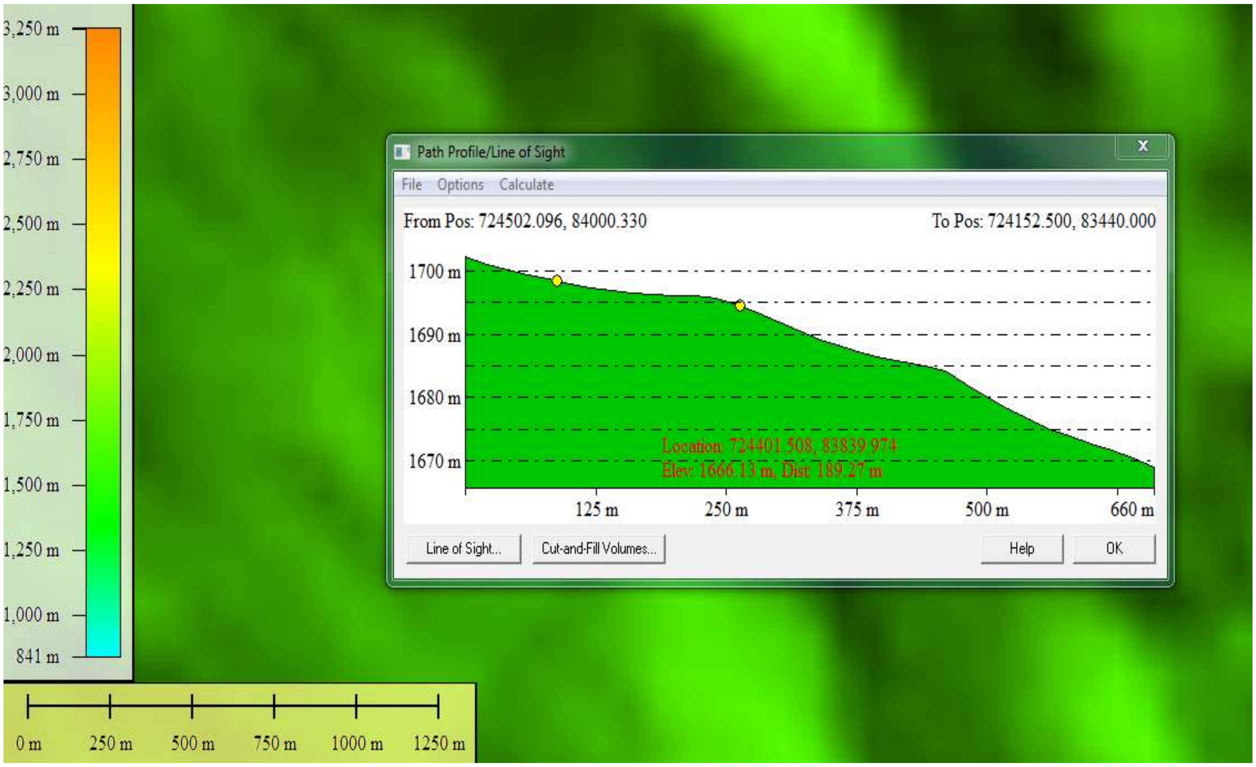


Figure 5-3: profiles generated from global mapper for D 1-1-3

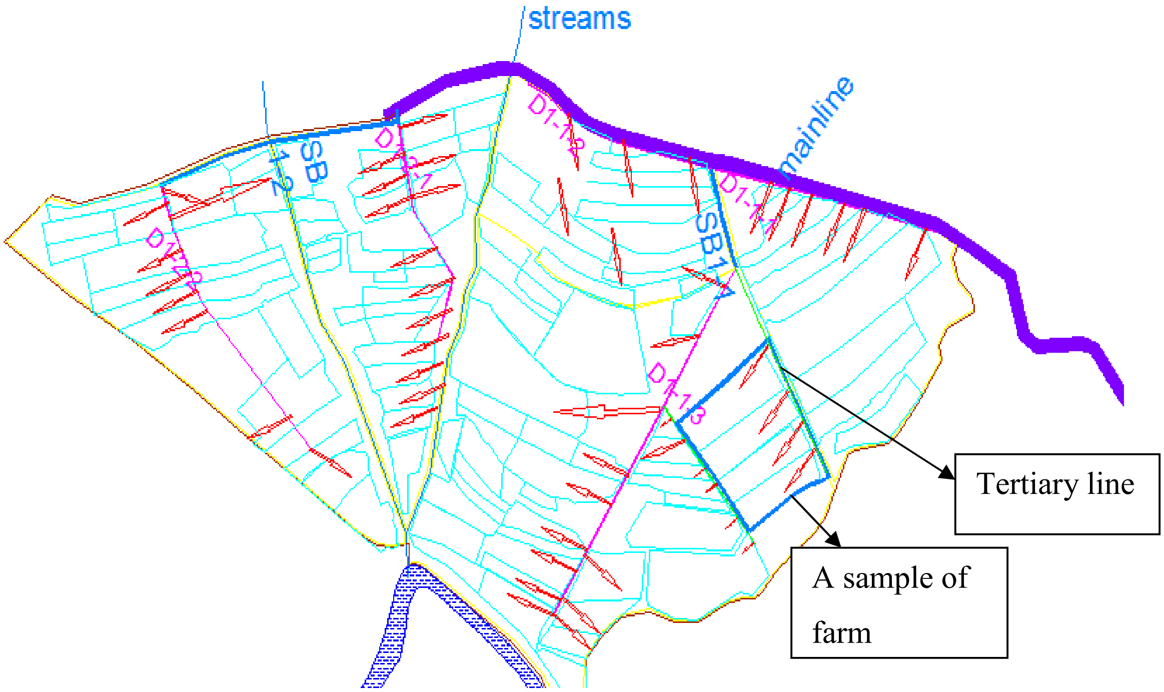


Figure 5-4: System layout

Where D- distribution lines

SB- sub-mains

5.8 Infield system

The infield system shows exactly how water will be able to reach individual plants in the field, this requires:

a) Lateral sizing and lateral spacing which is dependent on crop spacing.
b) Selection of suitable drippers depending on type of soil and the crop in question.
c) Determination of emitter discharges which is dependent on crop water needs and how much is to be supplemented.

5.8.1 Design criteria

a) Laterals come in the range of 12-32 mm according to manufacturers standards.

b) Emitter discharge is always in the range of 1-15l/hr form manufacturers standards based on the type of soil and the frequency with which the irrigation is to be carried out.

A row spacing of 0.6m has been selected for both crops according to good agronomic practices.

The number of laterals based on this spacing was found to be 80 laterals and the lateral length was found as 84 meters.

This is within acceptable range as very long emitters especially for a changing slope may result into great pressure differences.

5.8.2 Peak crop water requirement

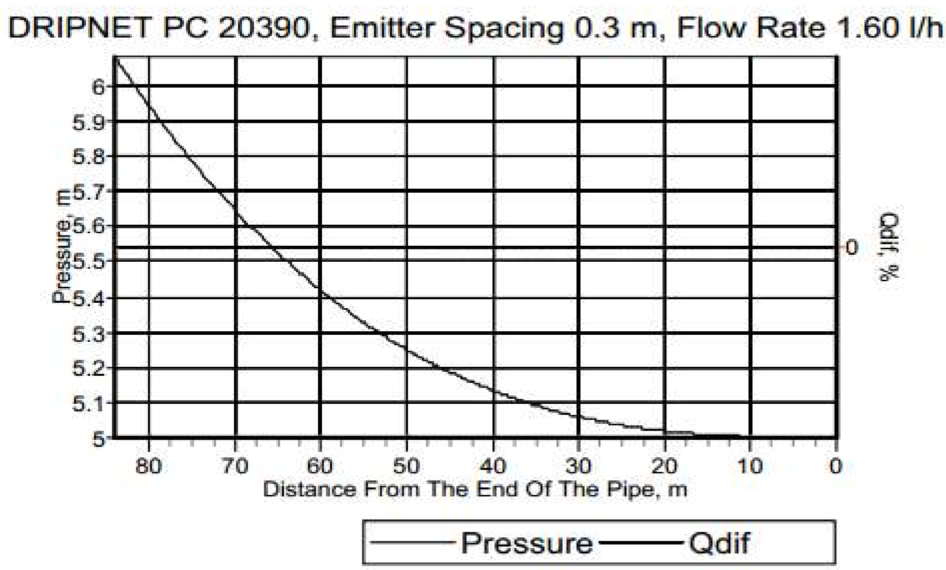
For drip design there is need to calculate peak crop water requirement per plant and using equation 3.13 this was determined as to 0.00146 m^3/ day for sweet potatoes and 0.00126 m^3/ day for kales. The highest value from the two is what is used for equipment design.

From manufacturers chart a design emitter discharge of 1.6l/hr was chosen as it is applicable in most cases.

5.8.3 Design of laterals

This was done using hydro calc software where the emitter spacing was taken as 0.3m and choosing a pressure compensating emitter with a diameter of 20mm a < 3% variation in head loss over the total length of the lateral was realized which is within acceptable limits. The pipe material for this case was taken as UPVC. The velocity was found to be 0.52m/s which is above the minimum recommended velocity of 0.3m/s in a uPVC pipeline.

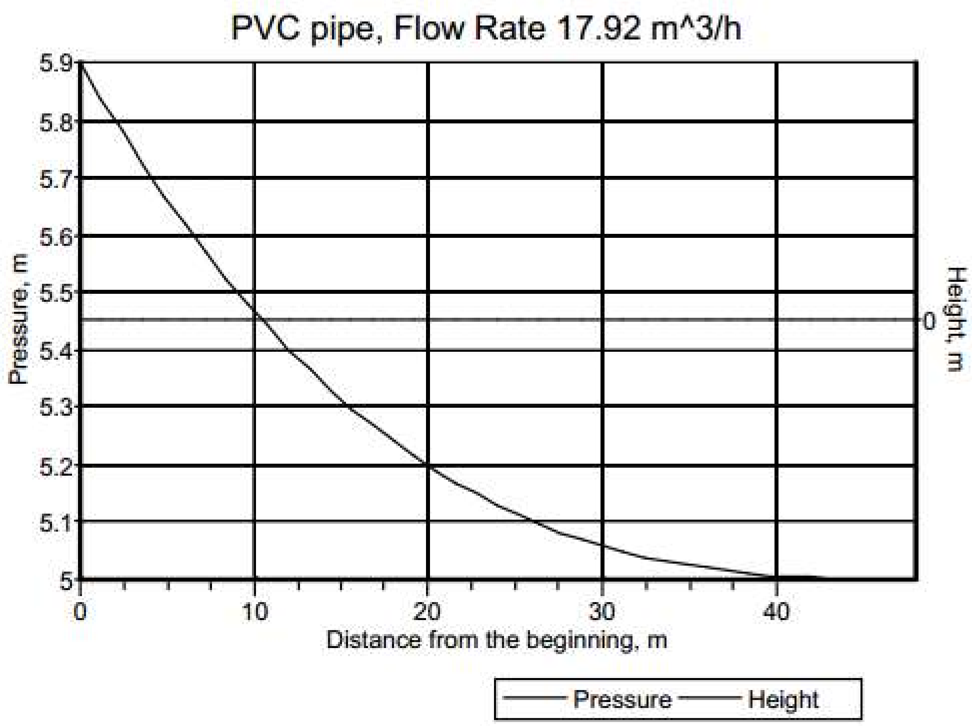
Table 5-11: chart on lateral design



5.8.4 Design of sub-main

This was also done in the hydro-calc and it supplies water to the laterals. The total volume of water carried by the sub-main is the total of the volume in all the laterals. The diameter of the pipeline was found to be 59.2 mm, class size 6(B) uPVC, with an operating pressure head of 11.1m. The flow through the sub-main was found to be 17.92 m^3/hr and the resulting flow velocity was determined as 1.81 m/s which is within the range as mentioned in section 4.

Table 5-12: Chart on sub-main design



NETAFIM

SUBMAIN WATER PIPE - RESULT REPORT

Formula for computation: H-W

Pipe Type	PVC pipe
Friction Factor	150
Flow Rate	17.92 m^3/h
Pipe Class	Class 6
Total Length	48.00 m
Head Pressure:	5.9 m
End Pressure:	5.00 m

Topography **Fixed**
Slope: 0

Nominal Diam mm	Inside Diam mm	Segment Length m	Pressure Loss m	Pressure m	Velocity m/s
63 mm	59.20	48.00	0.90	5.00	1.81

Cum	0.90 m

6.0 CONCLUSION

Data was loaded from CLIMWAT software (Kakamega station number 2318) for use in CROPWAT in estimation of crop water requirement. CROPWAT makes use of climatic data and thus it's the most recommended method of use in determination of CWR.

The output from the CROPWAT gave values of 4.8mm/day and 4.2 mm/day for s/potatoes and kales respectively. The total flow rate used for design of the conveyance line was 0.037m^3/s. The application rate of the drip system was established as 8.8 mm/hr based on an emitter discharge of 1.6l/hr with an operation time of 36 minutes. The irrigation interval for the system was found to be 2 days.

The system layout was drawn in AUTOCAD and by help of google earth, the various pipe lengths were generated using Cad tools and were found to range from between 175m- 4650m. The pipe diameters were equally sized and their values were found to range between 45.2 mm-327mm.

The infield system was designed based on hydro-cal software and the output gave various values for velocity, pressure loss, operating pressure head which were compared with the theoretical values and were found to be within range needed.

7.0 RECOMMENDATIONS

- ✓ A sample design of the area based on 0.4 hectares has been done to show how the irrigation design process is carried out, however this does not reflect for all the farms in the area because of the difference in orientation, if there will be need for implementation then there is a need for design of each plot taking into consideration its orientation.
- ✓ There is need for an environmental impact assessment to be carried out to help mitigate any negative impacts of the project towards the community.
- ✓ The intake structure has not been designed for and for implementation, there is need to design for it.

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9: APPENDICES

APPENDIX A1: CALCULATIONS

Application rate (mm/hr)

$$AR = \frac{Q}{Area}$$

The soil type being sandy-loam a flow rate of 1.6l/hr was chosen therefore the application rate would be:

AR$=\frac{\mathbf{1.6}}{\mathbf{(0.3*0.6)}} = \mathbf{8.8\ mm/hr}$

Net irrigation requirement calculation

NIR= ETc-Pe-Ge-Wb (mm/day)

Where ETc is crop water requirement.

Pe is effective rainfall

Ge is ground water contribution

Wb is the stored water contribution.

Assuming Pe is 0 then:

For sweet potatoes

NIR= 4.88 mm/day.

For kales

NIR= 4.2mm/day

Gross irrigation requirement:

For sweet potatoes

GIR $=\frac{NIR}{Ea} = \frac{4.8}{0.9} = 5.33\ mm/day$

For kales:

GIR$= \frac{NIR}{Ea} = \frac{4.2}{0.9} = 4.67 mm/day$

Maximum allowed depletion/ net depth of water application

Rooting depth considered for both cases is 50 cm, this is during the critical period when the plant is likely to be stressed if there's not enough water supply.

For sweet potatoes

$$dnet = p * TAW * RZD$$

$$= 0.2 * \frac{100mm}{m} * 0.5$$

=10mm/day

For kales

$$dnet = 0.2 * \frac{100mm}{m} * 0.5$$

=10mm/day

Irrigation interval

Thus to get Irrigation interval

Irrigation interval (sweet potatoes) = $\frac{dnet}{ETc} = \frac{10}{4.8} = 2\ days$

Thus irrigation interval (kales) = $\frac{dnet}{ETc} = \frac{10}{4.2} = 2.3 \approx 2days$

Depth of application

Depth of application caters for losses and thus the amount applied should be slightly more than what is actually needed.

$$d_g = \frac{dnet}{Efficiency}$$

For kales and sweet potatoes will be: $\frac{10}{0.9} = \frac{11.11mm}{day}$

Calculating water delivered to one block

1. Calculating number of laterals required.

Number of lateral= $\frac{length\ of\ field}{lateral\ spacing} = \frac{48}{0.6} = 80\ laterals$

Total number of laterals to be used is: $= 80\ laterals$

Total lateral length is 84 meters.

2. Number of emitters per lateral

$= \frac{length\ of\ lateral}{emitter\ spacing} = \frac{84}{0.3} =$ 280 emitters

Total number of emitters will thus be: $280 * 80 = 22{,}400\ emitters$

Assuming one emitter is used per plant then, number of plants= number of emitters.

The discharge through lateral is:

$$Q = \frac{Lateral\ length(l) * Emitter\ discharge(e_q)}{Emitter\ spacing(S_e)} = \frac{(84 * 1.6)}{0.3} = 448l/hr$$

Total discharge across the field is:

=448* 80

=35,840l/hr or 0.00996m3/s

Irrigation schedule

Time of operation

$$t = \frac{d_g * A}{Q}$$

Taking into consideration application efficiency: in this case for drip irrigation then:

For sweet potatoes

$t = \frac{5.33*0.3*0.6}{1.6}$= 36 minutes

For kales

$$t = \frac{d_g * A}{Q}$$

T= $\frac{4.67*0.3}{1.6} = 31.5\ minutes$

Peak crop water requirement

This was determined as shown below.

Sweet potatoes

Peak CWR from CROPWAT= 4.8mm/day.

Gross area according to spacing= 30*60= 1800 cm^2

Thus for the total area= gross area*ETc

=0.18* 4.8*10^-4= 0.000864 m^3/ day.

For vegetables (kales)

Gross area according to spacing is (30*60) = 1800 cm^2

Peak water requirement is thus= gross area*ETc (peak)

=$(\mathbf{1800 \times 10^{-4} * 4.2 * 10^{-3}})$

=0.000756 m^3/ day.

Considering the highest value out of the two, 0.000864 m^3/ day is considered for equipment design.

Infield system

Discharge across one lateral

$$Q = \frac{Lateral\ length(l) * Emitter\ discharge(e_q)}{Emitter\ spacing(S_e)} = \frac{(84 * 1.6)}{0.3} = 448l/hr$$

APPENDIX A2: Roughness coefficient of materials

Material	**C value**
Cast iron(new, 10yr,20yr,30yr,40yr)	130, 113,100.90,83 respectively.
Asbestos cement	140
Brass	130-140
Concrete/concrete lined	120-140
Copper	130-140
Galvanized iron	120
Glass	140
lead	130-140
plastic	140-150
steel	110-150
tin	130
Wood stave	120

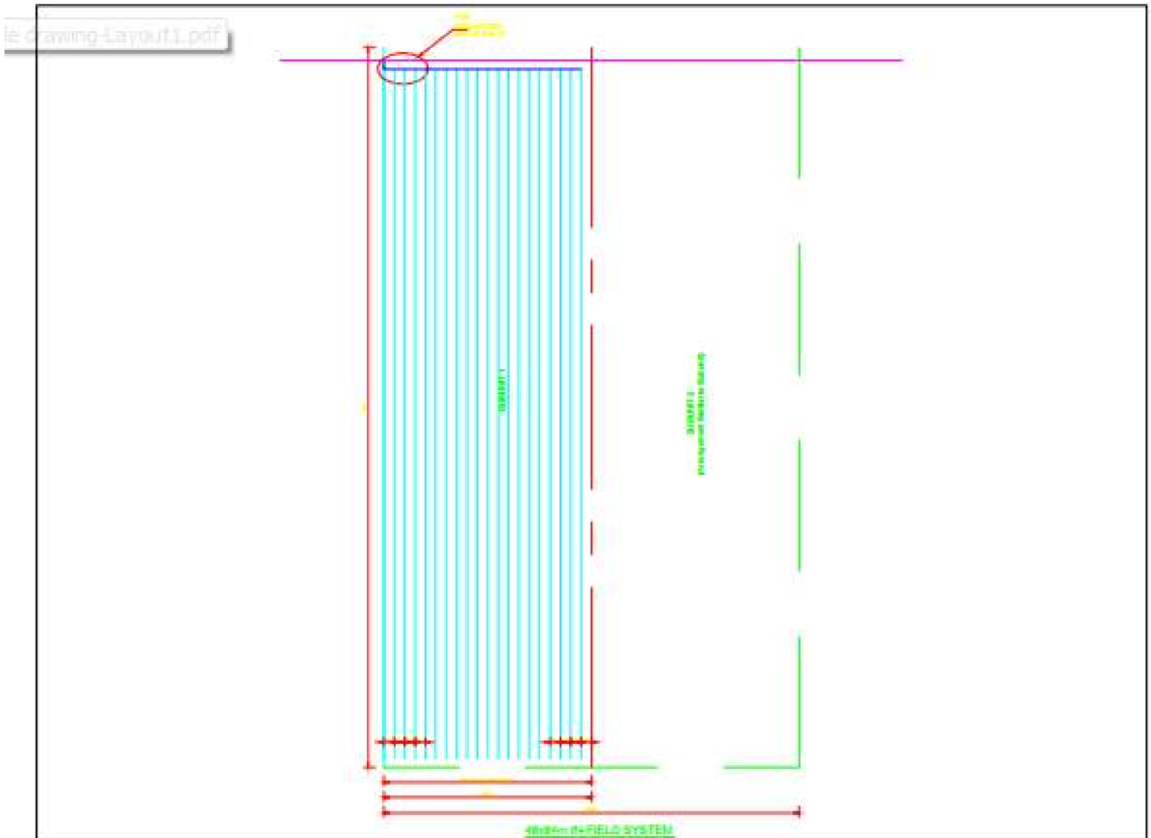
APPENDIX A3: Pipe diameter ranges in the market.

PIPE DIAMETERS

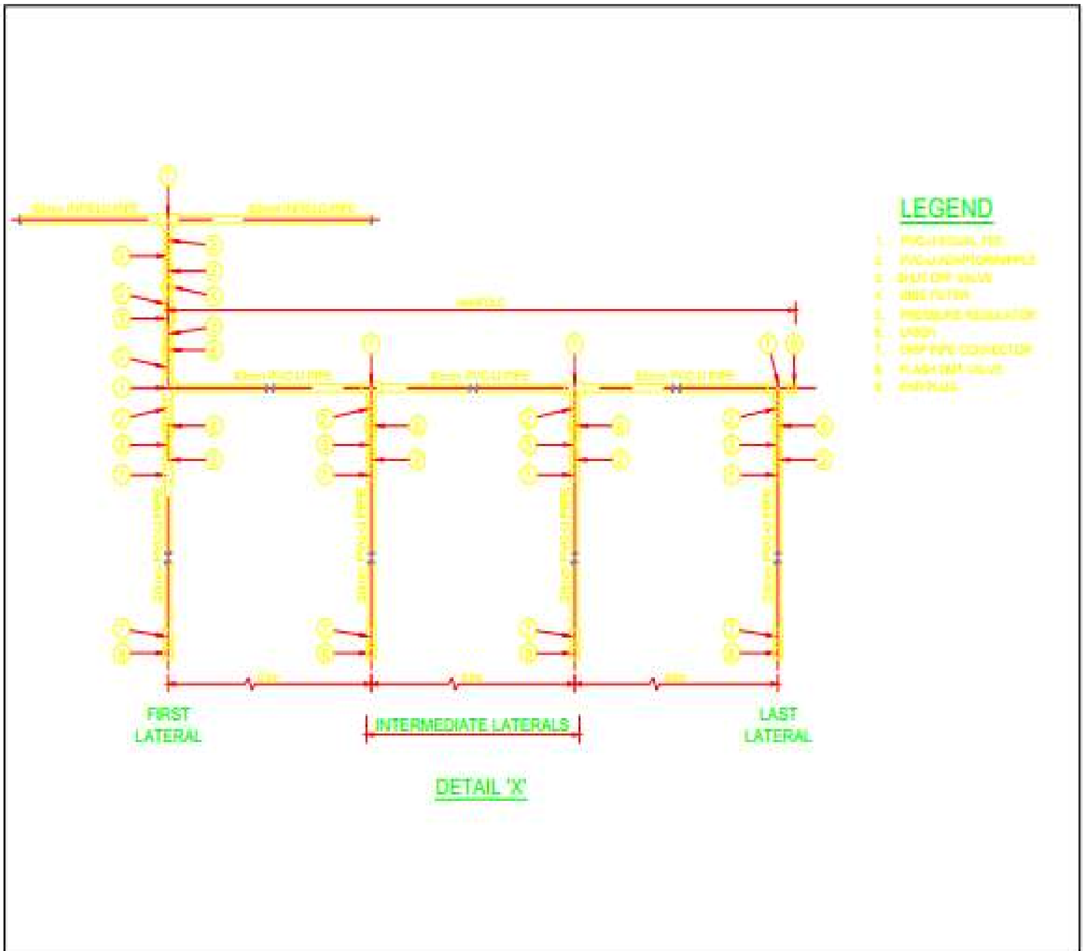
	CLASS B				
Outside dia/ mm	*Wall thickness (t), min.*	*Wall thickness (t), max.*	*Max inside dia, mm*	*Min inside dia, mm*	*Average dia, mm*
20.0	0.00	0.00	20.0	20.0	20.00
25.0	0.00	0.00	25.0	25.0	25.00
32.0	1.40	1.80	29.2	28.4	28.80
40.0	1.60	2.00	36.8	36.0	36.40
50.0	2.00	2.40	46.0	45.2	45.60
63.0	2.50	3.00	58.0	57.0	57.50
75.0	3.00	3.50	69.0	68.0	68.50
90.0	3.60	4.20	82.8	81.6	82.20
110.0	4.40	5.10	101.2	99.8	100.50
125.0	5.00	5.70	115.0	113.6	114.30
140.0	5.50	6.30	129.0	127.4	128.20
160.0	6.30	7.20	147.4	145.6	146.50
200.0	7.10	8.00	185.8	184.0	184.90
225.0	8.00	9.00	209.0	207.0	208.00
250.0	8.90	10.00	232.2	230.0	231.10
280.0	9.90	11.10	260.2	257.8	259.00
315.0	11.20	12.60	292.6	289.8	291.20
355.0	12.60	14.10	329.8	326.8	328.30
400.0	14.20	15.90	371.6	368.8	369.90
450.0	16.00	17.80	418.0	414.4	416.20
500.0	17.70	19.70	464.6	460.6	462.60
560.0	19.90	22.10	520.2	515.8	518.00
630.0	22.30	24.80	585.4	580.4	582.90

	CLASS C				
Outside dia/ mm	*Wall thickness (t), min.*	*Wall thickness (t), max.*	*Max inside dia, mm*	*Min inside dia, mm*	*Average dia, mm*
20.0	1.40	1.80	17.2	16.4	16.80
25.0	1.40	1.80	22.2	21.4	21.80
32.0	1.70	2.10	28.6	27.8	28.20
40.0	2.10	2.60	35.8	34.8	35.30
50.0	2.60	3.10	44.8	43.8	44.30
63.0	3.30	3.90	56.4	55.2	55.80
75.0	3.90	4.50	67.2	66.0	66.60
90.0	4.70	5.40	80.6	79.2	79.90
110.0	5.80	6.40	98.4	97.2	97.80
125.0	6.50	7.40	112.0	110.2	111.10
140.0	7.30	8.30	125.4	123.4	124.40
160.0	8.30	9.40	143.4	141.2	142.30
200.0	9.40	10.60	181.2	178.8	180.00
225.0	10.50	11.80	204.0	201.4	202.70
250.0	11.70	13.10	226.6	223.8	225.20
280.0	13.10	14.70	253.8	250.6	252.20
315.0	14.70	16.40	285.6	282.2	283.90
355.0	16.60	18.50	321.8	318.0	319.90
400.0	18.70	20.80	362.6	358.4	360.50
450.0	21.00	23.30	408.0	403.4	405.70
500.0	23.40	26.00	453.2	448.0	450.60
560.0	26.20	29.00	507.6	502.0	504.80
630.00	29.40	32.60	571.2	564.8	568.00

APPENDIX A4: Design Drawing



FACULTY OF ENGINEERING	FEB 540: DESIGN PROJECT	SCALE 1:1	REG NO: F21/1723/2010	
	DRIP IRRIGATION LAYOUT	DRAWN BY: GRACE A AMWATA	CHECKED BY: DR ONYANGO D	



FACULTY OF ENGINEERING	FEB 540: DESIGN PROJECT	SCALE 1:1	REG NO: F21/1723/2010
	INFIELD SYSTEM OF DRIP IRRIGATION	DRAWN BY: GRACE A AMWATA	CHECKED BY: DR ONYANGO DUNCAN

APPENDIX A5: Pipeline design spreadsheets

Mainline Pipeline design

Node	Ch	L	C	Q	D	A	V	Hl	Vf	G.E	Static Level	Pipe Invert	Energy Line Level, EL	HGL	Hp	Hs	D of E	PRV	Qofftake
J1	0	0	140	0.037	0.188	0.028	1.333	0.000	0.091	1734.903	1745.000	1733.903	1741.096	1741.006	7.10	11.10	1.0		
2	20	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1729.240	1745.00	1728.240	1740.923	1740.832	12.59	16.76	1.0		
3	40	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1728.943	1745.00	1727.943	1740.749	1740.659	12.72	17.06	1.0		
4	60	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1728.762	1745.00	1727.762	1740.575	1740.485	12.72	17.24	1.0		
5	80	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1728.494	1745.00	1727.494	1740.402	1740.311	12.82	17.51	1.0		
6	100	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1728.089	1745.00	1727.089	1740.228	1740.138	13.05	17.91	1.0		
7	120	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1727.837	1745.00	1726.837	1740.054	1739.964	13.13	18.16	1.0		
8	140	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1727.768	1745.00	1726.768	1739.881	1739.790	13.02	18.23	1.0		
9	160	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1727.680	1745.00	1726.680	1739.707	1739.617	12.94	18.32	1.0		
10	180	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1727.292	1745.00	1726.292	1739.533	1739.443	13.15	18.71	1.0		
11	200	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1726.610	1745.00	1725.610	1739.360	1739.269	13.66	19.39	1.0		
12	220	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1725.928	1745.00	1724.928	1739.186	1739.096	14.17	20.07	1.0		
13	240	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1725.245	1745.00	1724.245	1739.012	1738.922	14.68	20.76	1.0		
14	260	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1724.563	1745.00	1723.563	1738.839	1738.748	15.19	21.44	1.0		
15	280	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1723.576	1745.00	1722.576	1738.665	1738.575	16.00	22.42	1.0		
16	300	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1722.469	1745.00	1721.469	1738.491	1738.401	16.93	23.53	1.0		
17	320	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1720.913	1745.00	1719.913	1738.318	1738.227	18.31	25.09	1.0		
18	340	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1719.188	1745.00	1718.188	1738.144	1738.054	19.87	26.81	1.0		
19	360	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1717.649	1745.00	1716.649	1737.970	1737.880	21.23	28.35	1.0		
20	380	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1716.295	1745.00	1715.295	1737.797	1737.706	22.41	29.70	1.0		
21	400	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1714.873	1745.00	1713.873	1737.623	1737.533	23.66	31.13	1.0		
22	420	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1713.303	1745.00	1712.303	1737.449	1737.359	25.06	32.70	1.0		
23	440	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1711.796	1745.00	1710.796	1737.276	1737.185	26.39	34.20	1.0		
24	460	20	140	0.037	0.188	0.028	1.333	0.174	0.091	1709.685	1745.00	1708.685	1737.102	1737.012	28.33	36.32	1.0		
25	480	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1707.171	1745.00	1706.171	1736.818	1736.683	30.51	38.83	1.0		
26	500	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1704.656	1745.00	1703.656	1736.535	1736.400	32.74	41.34	1.0		
27	520	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1702.141	1745.00	1701.141	1736.251	1736.116	34.97	43.86	1.0		
28	540	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1699.783	1745.00	1698.783	1735.968	1735.832	37.05	46.22	1.0		
29	560	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1697.973	1745.00	1696.973	1735.684	1735.549	38.58	48.03	1.0		
30	580	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1696.744	1745.00	1695.744	1735.401	1735.265	39.52	49.26	1.0		
31	600	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1695.413	1745.00	1694.413	1735.117	1734.982	40.57	50.59	1.0		
32	620	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1694.074	1745.00	1693.074	1734.834	1734.698	41.62	51.93	1.0		
33	640	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1692.646	1745.00	1691.646	1734.550	1734.415	42.77	53.35	1.0		
34	660	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1690.691	1745.00	1689.691	1734.267	1734.131	44.44	55.31	1.0		
35	680	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1689.110	1745.00	1688.110	1733.983	1733.848	45.74	56.89	1.0		
36	700	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1688.437	1745.00	1687.437	1733.699	1733.564	46.13	57.56	1.0		
37	720	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1687.779	1745.00	1686.779	1733.416	1733.280	46.50	58.22	1.0		
38	740	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1687.227	1745.00	1686.227	1733.132	1732.997	46.77	58.77	1.0		
39	760	20	140	0.037	0.170	0.023	1.630	0.284	0.135	1686.771	1745.00	1685.771	1732.849	1732.713	46.94	59.23	1.0		
40	780	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1686.667	1745.00	1685.667	1732.548	1732.406	46.74	59.33	1.0		
41	800	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1686.526	1745.00	1685.526	1732.248	1732.106	46.58	59.47	1.0		
42	820	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1687.172	1745.00	1686.172	1731.948	1731.806	45.63	58.83	1.0		
43	840	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1687.782	1745.00	1686.782	1731.647	1731.505	44.72	58.22	1.0		
44	860	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1688.350	1745.00	1687.350	1731.347	1731.205	43.85	57.65	1.0		
45	880	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1688.872	1745.00	1687.872	1731.047	1730.905	43.03	57.13	1.0		
46	900	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1689.355	1745.00	1688.355	1730.746	1730.604	42.25	56.65	1.0		
47	920	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1690.205	1745.00	1689.205	1730.446	1730.304	41.10	55.80	1.0		
48	940	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1691.361	1745.00	1690.361	1730.145	1730.003	39.64	54.64	1.0		
49	960	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1692.513	1745.00	1691.513	1729.845	1729.703	38.19	53.49	1.0		
50	980	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1693.725	1745.00	1692.725	1729.545	1729.403	36.68	52.28	1.0		
51	1000	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1694.984	1745.00	1693.984	1729.244	1729.102	35.12	51.02	1.0		
52	1020	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1696.104	1745.00	1695.104	1728.944	1728.802	33.70	49.90	1.0		
53	1040	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1697.154	1745.00	1696.154	1728.644	1728.502	32.35	48.85	1.0		

54	1060	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1698.204	1745.00	1697.204	1728.343	1728.201	31.00	47.80	1.0		
55	1080	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1699.254	1745.00	1698.254	1728.043	1727.901	29.65	46.75	1.0		
56	1100	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1700.303	1745.00	1699.303	1727.742	1727.600	28.30	45.70	1.0		
57	1120	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1701.504	1745.00	1700.504	1727.442	1727.300	26.80	44.50	1.0		
58	1140	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1702.764	1745.00	1701.764	1727.142	1727.000	25.24	43.24	1.0		
59	1160	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1704.067	1745.00	1703.067	1726.841	1726.699	23.63	41.93	1.0		
60	1180	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1705.416	1745.00	1704.416	1726.541	1726.399	21.98	40.58	1.0		
61	1200	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1706.787	1745.00	1705.787	1726.241	1726.099	20.31	39.21	1.0		
62	1220	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1707.998	1745.00	1706.998	1725.940	1725.798	18.80	38.00	1.0		
63	1240	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1709.191	1745.00	1708.191	1725.640	1725.498	17.31	36.81	1.0		
64	1260	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1710.361	1745.00	1709.361	1725.339	1725.197	15.84	35.64	1.0		
65	1280	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1711.511	1745.00	1710.511	1725.039	1724.897	14.39	34.49	1.0		
66	1300	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1712.483	1745.00	1711.483	1724.739	1724.597	13.11	33.52	1.0		
67	1320	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1713.157	1745.00	1712.157	1724.438	1724.296	12.14	32.84	1.0		
68	1340	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1713.831	1745.00	1712.831	1724.138	1723.996	11.16	32.17	1.0		
69	1360	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1714.417	1745.00	1713.417	1723.838	1723.696	10.28	31.58	1.0		
70	1380	20	140	0.037	0.168	0.022	1.669	0.300	0.142	1714.978	1745.00	1713.978	1723.537	1723.395	9.42	31.02	1.0		0.023
71	1400	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1715.403	1745.00	1714.403	1723.490	1723.471	9.07	30.60	1.0		
72	1420	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1715.752	1745.00	1714.752	1723.443	1723.424	8.67	30.25	1.0		
73	1440	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1716.157	1745.00	1715.157	1723.396	1723.377	8.22	29.84	1.0		
74	1460	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1716.626	1745.00	1715.626	1723.349	1723.330	7.70	29.37	1.0		
75	1480	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1717.156	1745.00	1716.156	1723.302	1723.283	7.13	28.84	1.0		
76	1500	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1717.286	1745.00	1716.286	1723.255	1723.236	6.95	28.71	1.0		
77	1520	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1717.246	1745.00	1716.246	1723.208	1723.189	6.94	28.75	1.0		
78	1540	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1717.103	1745.00	1716.103	1723.161	1723.141	7.04	28.90	1.0		
79	1560	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1716.856	1745.00	1715.856	1723.114	1723.094	7.24	29.14	1.0		
80	1580	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1716.538	1745.00	1715.538	1723.067	1723.047	7.51	29.46	1.0		
81	1600	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1716.049	1745.00	1715.049	1723.019	1723.000	7.95	29.95	1.0		
82	1620	20	140	0.014	0.168	0.022	0.613	0.047	0.019	1715.667	1745.00	1714.667	1722.972	1722.953	8.29	30.33	1.0		
83	1640	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1715.738	1745.00	1714.738	1722.891	1722.860	8.12	30.26	1.0		
84	1660	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1715.921	1745.00	1714.921	1722.809	1722.779	7.86	30.08	1.0		
85	1680	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1716.550	1745.00	1715.550	1722.727	1722.697	7.15	29.45	1.0		
86	1700	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1717.073	1745.00	1716.073	1722.645	1722.615	6.54	28.93	1.0		
87	1720	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1717.266	1745.00	1716.266	1722.564	1722.534	6.27	28.73	1.0		
88	1740	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1717.002	1745.00	1716.002	1722.482	1722.452	6.45	29.00	1.0		
89	1760	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1716.842	1745.00	1715.842	1722.400	1722.370	6.53	29.16	1.0		
J2	1780	20	140	0.014	0.150	0.018	0.770	0.082	0.030	1716.659	1745.00	1715.659	1722.319	1722.288	6.63	29.34	1.0		0.014

Sub-main pipeline 1-1

SM1-1

Node	Ch	L	C	Q	D	A	V	Hl	Vf	G.E	Static Level	Pipe Invert	EL	HGL	Hp	Hs	D of E	Qofftake	
D1-1-1	0	0	140	0.0234	0.0972	0.007	3.153	0.000	0.507	1714.978	1745.000	1714.0	1723.5	1723.4	9.42	31.02	1.0	0.005	
D1-1-2	0	0	140	0.0184	0.0972	0.007	2.478	0.000	0.313	1714.989	1745.000	1714.0	1723.5	1731.0	17.01	31.01	1.0	0.004	
3	20	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1713.433	1745.000	1712.4	1723.5	1723.3	10.82	32.57	1.0		
4	40	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1712.275	1745.000	1711.3	1722.3	1722.0	10.77	33.72	1.0		
5	60	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1711.113	1745.000	1710.1	1721.1	1720.8	10.71	34.89	1.0		
6	80	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1709.952	1745.000	1709.0	1719.9	1719.6	10.66	36.05	1.0		
7	100	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1708.484	1745.000	1707.5	1718.7	1718.4	10.92	37.52	1.0		
8	120	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1706.678	1745.000	1705.7	1717.5	1717.2	11.51	39.32	1.0		1713
9	140	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1704.934	1745.000	1703.9	1713.0	1712.7	8.78	41.07	1.0		
10	160	20	140	0.0144	0.0880	0.006	2.359	1.213	0.284	1703.254	1745.000	1702.3	1711.8	1711.5	9.25	42.75	1.0		
D1-1-3	175	15	140	0.0144	0.0880	0.006	2.359	0.914	0.284	1702.055	1745.000	1701.1	1710.9	1710.6	9.53	43.94	1.0	0.014	

Sub-main pipeline 1-2

Node	Ch	L	C	Q	D	A	V	Hl	Vf	G.E	SL	PI	EL	HGL	Hp	Hs	D.O. E	Q(off)
1	0	0	140	0.014	0.0972	0.007	1.833	0.000	0.171	1716.659	1745.00	1715.659	1722.3	1722.29	6.63	29.34	1.0	
D1-2-1	20	20	140	0.014	0.0972	0.007	1.833	0.676	0.171	1713.621	1745.00	1712.621	1721.6	1721.47	8.85	32.38	1.0	0.006
3	40	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1714.022	1745.00	1713.022	1721.4	1721.37	8.35	31.98	1.0	
4	60	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1714.407	1745.00	1713.407	1721.2	1721.15	7.74	31.59	1.0	
5	80	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1714.678	1745.00	1713.678	1721.0	1720.92	7.24	31.32	1.0	
6	100	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1714.207	1745.00	1713.207	1720.8	1720.70	7.49	31.79	1.0	
7	120	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1713.723	1745.00	1712.723	1720.5	1720.48	7.75	32.28	1.0	
8	140	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1713.226	1745.00	1712.226	1720.3	1720.25	8.03	32.77	1.0	
9	160	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1712.718	1745.00	1711.718	1720.1	1720.03	8.31	33.28	1.0	
10	180	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1712.100	1745.00	1711.100	1719.9	1719.81	8.71	33.90	1.0	
11	200	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1711.381	1745.00	1710.381	1719.6	1719.59	9.20	34.62	1.0	
12	220	20	140	0.007	0.0972	0.007	1.006	0.223	0.052	1710.674	1745.00	1709.674	1719.4	1719.36	9.69	35.33	1.0	
13	240	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.979	1745.00	1708.979	1718.9	1718.79	9.81	36.02	1.0	
14	260	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.296	1745.00	1708.296	1718.4	1718.27	9.97	36.70	1.0	
15	280	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.125	1745.00	1708.125	1717.8	1717.74	9.62	36.88	1.0	
16	300	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.120	1745.00	1708.120	1717.3	1717.22	9.10	36.88	1.0	
17	320	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.161	1745.00	1708.161	1716.8	1716.70	8.54	36.84	1.0	
18	340	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.249	1745.00	1708.249	1716.3	1716.18	7.93	36.75	1.0	
19	360	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.366	1745.00	1708.366	1715.8	1715.66	7.29	36.63	1.0	
20	380	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.468	1745.00	1708.468	1715.2	1715.13	6.67	36.53	1.0	
21	400	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.503	1745.00	1708.503	1714.7	1714.61	6.11	36.50	1.0	
22	420	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.526	1745.00	1708.526	1714.2	1714.09	5.56	36.47	1.0	
23	440	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.550	1745.00	1708.550	1713.7	1713.57	5.02	36.45	1.0	
24	460	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1709.567	1745.00	1708.567	1713.1	1713.04	4.48	36.43	1.0	
D1-2-2	480	20	140	0.007	0.0816	0.005	1.427	0.522	0.104	1706.488	1745.00	1705.488	1712.6	1712.52	7.03	39.51	1.0	0.007

Distribution lines

Node	CH	L	C	Q	D	A	V	HL	Vf	Gelev	EL static	P Invert	EL	HGL	Hp	Hs	Dexc av	Qofftake
1	0	0	140	0.005	0.0660	0.003	1.465	0.000	0.109	1714.978	1745.000	1713.978	1723.537	1723.395	9.42	31.02	1.0	
2	20	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1713.594	1745.000	1712.594	1722.836	1722.726	10.13	32.41	1.0	
3	40	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1712.930	1745.000	1711.930	1722.134	1722.025	10.09	33.07	1.0	
4	60	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1712.266	1745.000	1711.266	1721.432	1721.323	10.06	33.73	1.0	
5	80	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1711.602	1745.000	1710.602	1720.731	1720.621	10.02	34.40	1.0	
6	100	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1710.525	1745.000	1709.525	1720.029	1719.920	10.39	35.47	1.0	
7	120	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1709.351	1745.000	1708.351	1719.327	1719.218	10.87	36.65	1.0	
J1-1-1-1	140	20	140	0.005	0.0660	0.003	1.465	0.702	0.109	1708.155	1745.000	1707.155	1718.626	1718.517	11.36	37.85	1.0	0.0017
9	160	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1706.940	1745.000	1705.940	1716.533	1716.312	10.37	39.06	1.0	
10	180	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1705.697	1745.000	1704.697	1714.440	1714.219	9.52	40.30	1.0	
11	200	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1704.392	1745.000	1703.392	1712.346	1712.126	8.73	41.61	1.0	
12	220	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1703.121	1745.000	1702.121	1710.253	1710.032	7.91	42.88	1.0	
13	240	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1701.886	1745.000	1700.886	1708.160	1707.939	7.05	44.11	1.0	
14	260	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1700.694	1745.000	1699.694	1706.067	1705.846	6.15	45.31	1.0	
15	280	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1699.573	1745.000	1698.573	1703.974	1703.753	5.18	46.43	1.0	
J1-1-1-2	300	20	140	0.003	0.0452	0.002	2.082	2.093	0.221	1698.525	1745.000	1697.525	1701.881	1701.660	4.13	47.47	1.0	0.0017
17	320	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1697.476	1745.000	1696.476	1701.288	1701.232	4.76	48.52	1.0	
18	340	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1696.428	1745.000	1695.428	1700.696	1700.640	5.21	49.57	1.0	
19	360	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1695.383	1745.000	1694.383	1700.103	1700.047	5.66	50.62	1.0	
20	380	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1694.284	1745.000	1693.284	1699.511	1699.455	6.17	51.72	1.0	
21	400	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1693.105	1745.000	1692.105	1698.918	1698.862	6.76	52.90	1.0	
22	420	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1691.948	1745.000	1690.948	1698.326	1698.270	7.32	54.05	1.0	
23	440	20	140	0.002	0.0450	0.002	1.050	0.592	0.056	1690.815	1745.000	1689.815	1697.733	1697.677	7.86	55.18	1.0	
J1-1-1-3	443	2.6	140	0.002	0.0450	0.002	1.050	0.078	0.056	1690.668	1745.000	1689.668	1697.656	1697.599	7.93	55.33	1.0	0.0017

D1-1-2 PIPELINE DESIGN

Node	CH	L	C	Q	D	A	V	HL	Vf	Gelev	EL static	P Invert	EL	HGL	Hp	Hs	Dexc av	Qofftake
1	0	0	140	0.004	0.0792	0.005	0.820	0.000	0.034	1714.989	1745.000	1713.989	1723.537	1731.002	17.01	31.01	1.0	
2	20	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1714.742	1745.000	1713.742	1723.344	1723.309	9.57	31.26	1.0	
3	40	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1714.993	1745.000	1713.993	1723.150	1723.116	9.12	31.01	1.0	
4	60	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1715.311	1745.000	1714.311	1722.956	1722.922	8.61	30.69	1.0	
5	80	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1715.689	1745.000	1714.689	1722.763	1722.729	8.04	30.31	1.0	
6	100	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1716.128	1745.000	1715.128	1722.569	1722.535	7.41	29.87	1.0	
1-1-2-1	120	20	140	0.004	0.0792	0.005	0.820	0.194	0.034	1716.373	1745.000	1715.373	1722.376	1722.341	6.97	29.63	1.0	0.001
8	140	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1716.467	1745.000	1715.467	1722.184	1722.156	6.69	29.53	1.0	
9	160	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1716.459	1745.000	1715.459	1721.992	1721.964	6.50	29.54	1.0	
10	180	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1716.349	1745.000	1715.349	1721.800	1721.772	6.42	29.65	1.0	
11	200	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1716.174	1745.000	1715.174	1721.608	1721.580	6.41	29.83	1.0	
12	220	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1715.571	1745.000	1714.571	1721.416	1721.388	6.82	30.43	1.0	
1-1-2-2	240	20	140	0.003	0.0680	0.004	0.741	0.192	0.028	1715.090	1745.000	1714.090	1721.224	1721.196	7.11	30.91	1.0	0.001
14	260	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1714.930	1745.000	1713.930	1721.147	1721.137	7.21	31.07	1.0	
15	280	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1714.995	1745.000	1713.995	1721.069	1721.060	7.06	31.01	1.0	
16	300	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1715.323	1745.000	1714.323	1720.992	1720.983	6.66	30.68	1.0	
17	320	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1715.635	1745.000	1714.635	1720.915	1720.906	6.27	30.37	1.0	
18	340	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1715.950	1745.000	1714.950	1720.838	1720.828	5.88	30.05	1.0	
19	360	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1715.760	1745.000	1714.760	1720.761	1720.751	5.99	30.24	1.0	
20	380	20	140	0.001	0.0630	0.003	0.432	0.077	0.010	1715.544	1745.000	1714.544	1720.684	1720.674	6.13	30.46	1.0	
1-1-2-3	381	0.8	140	0.001	0.0630	0.003	0.432	0.003	0.010	1715.535	1745.000	1714.535	1720.680	1720.671	6.14	30.46	1.0	0.001

D1-2-1 PIPELINE DESIGN

Node	CH	L	C	Q	D	A	V	HL	Vf	Gelev	EL static	P Invert	EL	HGL	Hp	Hs	Dexc av	Qofftake
1	0	0	140	0.006	0.0550	0.002	2.582	0.000	0.340	1713.621	1745.000	1712.621	1721.642	1721.471	8.85	32.38	1.0	
2	20	20	140	0.006	0.0550	0.002	2.582	2.481	0.340	1711.809	1745.000	1710.809	1719.162	1718.822	8.01	34.19	1.0	
3	40	20	140	0.006	0.0550	0.002	2.582	2.481	0.340	1710.094	1745.000	1709.094	1716.681	1716.341	7.25	35.91	1.0	
4	60	20	140	0.006	0.0550	0.002	2.582	2.481	0.340	1708.342	1745.000	1707.342	1714.200	1713.861	6.52	37.66	1.0	
5	80	20	140	0.006	0.0550	0.002	2.582	2.481	0.340	1706.464	1745.000	1705.464	1711.720	1711.380	5.92	39.54	1.0	
J1-2-1-1	100	20	140	0.006	0.0550	0.002	2.582	2.481	0.340	1704.566	1745.000	1703.566	1709.239	1708.900	5.33	41.43	1.0	0.002
7	120	20	140	0.004	0.0550	0.002	1.721	1.171	0.151	1702.687	1745.000	1701.687	1708.069	1707.918	6.23	43.31	1.0	
8	140	20	140	0.004	0.0550	0.002	1.721	1.171	0.151	1700.825	1745.000	1699.825	1706.898	1706.747	6.92	45.18	1.0	
9	160	20	140	0.004	0.0550	0.002	1.721	1.171	0.151	1699.064	1745.000	1698.064	1705.727	1705.576	7.51	46.94	1.0	
J1-2-1-2	180	20	140	0.004	0.0550	0.002	1.721	1.171	0.151	1697.827	1745.000	1696.827	1704.557	1704.406	7.58	48.17	1.0	0.002
11	200	20	140	0.002	0.0452	0.002	1.274	0.843	0.083	1696.570	1725.000	1695.570	1703.713	1703.630	8.06	29.43	1.0	
12	220	20	140	0.002	0.0452	0.002	1.274	0.843	0.083	1695.268	1725.000	1694.268	1702.870	1702.787	8.52	30.73	1.0	
13	240	20	140	0.002	0.0452	0.002	1.274	0.843	0.083	1693.920	1725.000	1692.920	1702.026	1701.944	9.02	32.08	1.0	
14	260	20	140	0.002	0.0452	0.002	1.274	0.843	0.083	1692.527	1725.000	1691.527	1701.183	1701.100	9.57	33.47	1.0	
J1-2-1-3	277	17	140	0.002	0.0452	0.002	1.274	0.728	0.083	1691.328	1725.000	1690.328	1700.455	1700.372	10.04	34.67	1.0	0.002

D1-2-2 PIPELINE DESIGN

Node	CH	L	C	Q	D	A	V	HL	Vf	Gelev	EL static	P Invert	EL	HGL	Hp	Hs	Dexc av	Qofftake
1	0	0	140	0.007	0.0792	0.005	1.515	0.000	0.117	1706.488	1745.000	1705.488	1712.626	1712.522	7.03	39.51	1.0	
2	20	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1708.182	1745.000	1707.182	1712.022	1711.905	4.72	37.82	1.0	
3	40	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1707.037	1745.000	1706.037	1711.418	1711.301	5.26	38.96	1.0	
4	60	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1705.951	1745.000	1704.951	1710.814	1710.697	5.75	40.05	1.0	
5	80	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1704.932	1745.000	1703.932	1710.210	1710.093	6.16	41.07	1.0	
6	100	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1703.738	1745.000	1702.738	1709.606	1709.489	6.75	42.26	1.0	
7	120	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1702.501	1745.000	1701.501	1709.002	1708.885	7.38	43.50	1.0	
8	140	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1701.229	1745.000	1700.229	1708.398	1708.281	8.05	44.77	1.0	
9	160	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1699.923	1745.000	1698.923	1707.794	1707.677	8.75	46.08	1.0	
J1-2-2-1	180	20	140	0.007	0.0792	0.005	1.515	0.604	0.117	1698.644	1745.000	1697.644	1707.190	1707.073	9.43	47.36	1.0	0.002
11	200	20	140	0.005	0.0570	0.003	1.950	1.415	0.194	1697.434	1745.000	1696.434	1705.775	1705.582	9.15	48.57	1.0	
12	220	20	140	0.005	0.0570	0.003	1.950	1.415	0.194	1696.335	1745.000	1695.335	1704.361	1704.167	8.83	49.67	1.0	
13	240	20	140	0.005	0.0570	0.003	1.950	1.415	0.194	1695.355	1745.000	1694.355	1702.946	1702.752	8.40	50.65	1.0	
14	260	20	140	0.005	0.0570	0.003	1.950	1.415	0.194	1694.467	1745.000	1693.467	1701.531	1701.337	7.87	51.53	1.0	
15	280	20	140	0.005	0.0570	0.003	1.950	1.415	0.194	1693.512	1745.000	1692.512	1700.116	1699.922	7.41	52.49	1.0	
16	300	20	140	0.005	0.0580	0.003	1.883	1.300	0.181	1692.368	1745.000	1691.368	1698.816	1698.635	7.27	53.63	1.0	
17	320	20	140	0.005	0.0580	0.003	1.883	1.300	0.181	1691.177	1745.000	1690.177	1697.516	1697.335	7.16	54.82	1.0	
18	340	20	140	0.005	0.0580	0.003	1.883	1.300	0.181	1689.941	1745.000	1688.941	1696.216	1696.035	7.09	56.06	1.0	
J1-2-2-2	360	20	140	0.005	0.0580	0.003	1.883	1.300	0.181	1688.657	1745.000	1687.657	1694.916	1694.736	7.08	57.34	1.0	0.002
20	380	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1687.327	1745.000	1686.327	1694.556	1694.511	8.18	58.67	1.0	
21	400	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1686.340	1745.000	1685.340	1694.196	1694.151	8.81	59.66	1.0	
22	420	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1686.581	1745.000	1685.581	1693.836	1693.791	8.21	59.42	1.0	
23	440	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1686.501	1745.000	1685.501	1693.476	1693.431	7.93	59.50	1.0	
24	460	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1686.003	1745.000	1685.003	1693.116	1693.071	8.07	60.00	1.0	
25	480	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1685.087	1745.000	1684.087	1692.756	1692.711	8.62	60.91	1.0	
26	500	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1683.752	1745.000	1682.752	1692.396	1692.350	9.60	62.25	1.0	
27	520	20	140	0.002	0.0580	0.003	0.942	0.360	0.045	1682.023	1745.000	1681.023	1692.036	1691.990	10.97	63.98	1.0	
J1-2-2-3	527	6.9	140	0.002	0.0580	0.003	0.942	0.124	0.045	1681.434	1745.000	1680.434	1691.911	1691.866	11.43	64.57	1.0	0.002