UNIVERSITY OF NAIROBI

DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

FEB 540: DESIGN PROJECT DRAFT REPORT

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TITLE: DESIGN OF A SOLAR POWERED PISTON PUMPING SYSTEM IN NKANDO VILLAGE, LAIKIPIA COUNTY

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1. INTRODUCTION

1.1 BACKGROUND

Solar-powered water pumps have been implemented as an alternative water abstraction measure in many parts of the world such as Malawi, India and Brazil. Kenya is slowly embracing the concept of solar energy, in water abstraction projects especially, in an effort to curb the effects of climate change on drought and famine. In 2012, the Kenyan government had plans to install 2000 solar powered piston pumps in the arid regions of Kenya in an aim to reduce the water shortages caused by unpredictable rainfall, largely associated with climate change. One such beneficiary of this initiative was Tseikuru District located 230 kilometers east of Nairobi. The Ministry of Public Health and Sanitation had entered into a partnership with Bola Associates and a US-based, DACC global, to supply and install the systems which comprised of solar panels, submersible pumps, purification systems and holding tanks. The cost of each system was found to be approximately 11 million Kenyan shillings including the borehole drilling cost. (Kamadi, G. 2012). Solar powered pumping systems are a reliable and environmentally sustainable solution to water abstraction problems in the country.

1.2 STATEMENT OF THE PROBLEM AND PROBLEM ANALYSIS

The local farmers in Nkando village, Laikipia County do not have in place any form of machinery to abstract and convey water from the soon to be constructed water ponds to their farms which will force them to manually collect and transport the water they need for irrigation purposes. This will make it tedious and laborious to access the much needed daily quantities of water.

A manually operated pumping system would provide a credible solution to the problem of accessibility of water, because the system is simple to use and more affordable for the locals. However, this pumping system is disadvantaged in terms of the time and energy that would be required to operate it in order to provide the daily quantities of irrigation water for the farmers. Consequently, the overall efficiency of the manually operated system is lower compared to the efficiency of, for instance, an electric water pumping system.

Electric water pumping systems are run by the national grid or diesel generators. Fuel and electricity are quite expensive, for example, the cost of diesel in Nanyuki town, as quoted by the Energy Regulatory Board as from April 15th, 2015, to May 14, 2015 was Ksh 79.64 per liter. This makes electric pumps run by diesel generators costly to install, operate and maintain especially if they're to be run continuously for a given number of hours a day, to pump enough water for the locals to use and even store for future use.

1.3 SITE ANALYSIS AND INVENTORY

The proposed site for this design project is Nkando village near Nanyuki Town in Laikipia County, Kenya. The site is located 0° 0'4.92"N and 37° 6'22.63"E of the equator and has an elevation of approximately 6522 ft/ 1987m above sea level.

1.4 OVERALL OBJECTIVE

The overall objective is to design a solar-powered piston pumping system as a measure of reducing the time and effort required by a low-scale farmer to access adequate amounts of water for irrigation purposes.

1.4.1 SPECIFIC OBJECTIVES

i. To review existing data on the climate of the site area as well as the power requirements of existing piston pumps.
ii. To determine the power requirements of the piston pumping system in order to size and match the appropriate photovoltaic power system.
iii. To evaluate the cost and quantities of the materials required to construct the solar pumping system.

1.5 STATEMENT OF SCOPE

There are a number of solar-powered pumps available in the market. This project aims to review the existing data on solar-powered piston pumps that are available in the market as well as their water pumping requirements with the aim of selecting the suitable size of pump that will be able to abstract adequate amounts of water, for 7.2 hours a day, from a storm water harvesting pond with a minimum capacity of 1000 m^3, to an overhead storage tank which will be required to hold, at least a three-day water supply, determined from the peak irrigation requirement during peak sun hours. The solar panels that are to be used to power the piston pump will be sized and matched according to the power requirements of the pump.

2. LITERATURE REVIEW

Malawi Solar Powered Water Pump System

A solar water pumping project was done by Mercer's University Master's Program for Environmental Engineering in association with Mercer on a Mission, in an orphanage located in the Chuluchosema community of Malawi, Africa (H. King 2010).

This project aimed at pumping water from a nearby well up to a water tower in the orphanage center. The pump was designed to be powered using Solar Panels that capture the solar energy from the sun. The community had a water pump that had ceased to work causing them to manually pump the water that they required several times a day to a tank which was approximately 160 feet away. The total head was estimated to be between 40-50 vertical feet with the frictional losses assumed to be minimal. It was also estimated that the daily water use was between 400-500 liters per day. The solar radiation amount was also estimated to be about 5-6 kWh/m^2/day.

The students chose to use a solar panel design because of the limited energy resources surrounding the orphanage which made it difficult for the orphanage to access fuel supplies on a daily basis. The tree cover surrounding the area also made the possibility of using wind turbines to produce sustainable wind power to be eliminated. The System was broken down to four parts: the pump, the solar panel, the switches and controller and the water piping. The system in this case was, however, built and tested at Mercer University before being disassembled and shipped to Malawi where it would be reassembled by the team of students for permanent installation.

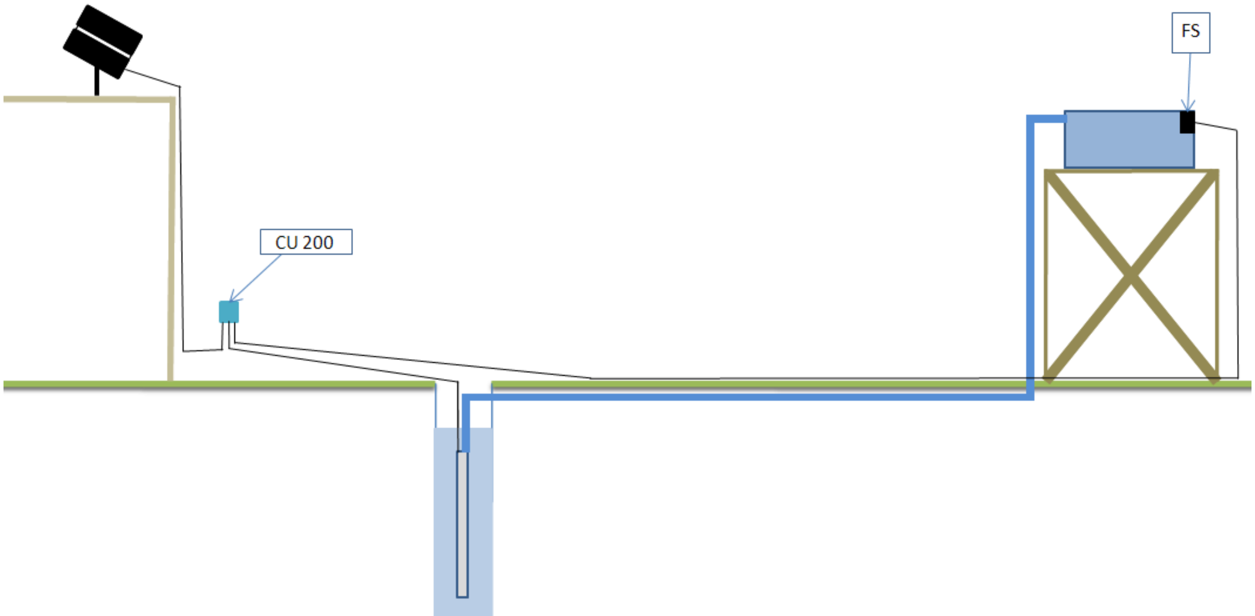
The pump that was selected was an 11ft^2 Grundfos Submersible Pump (positive displacement helical pump) capable of providing a maximum of 11 gallons of water per minute. It was to be powered by 2-180W Trina Solar Panels in order to obtain the maximum flowrate at the minimum voltage requirement of the pump. The panels were positioned on the roof of an adjacent building for full exposure to the sun. The panels, attached in series, were also to be tinted at an angle between 15^o and 45^o to the sun.

The controller used to monitor the power delivered to the pump as well as to switch the pump on and off was the CU 200 Grundfos controller. It was designed to automatically alarm the residents if an electrical overload occurred as well as monitor the water level in the storage tank (also notified the residents if/when the pump was not working). A float switch was also incorporated which communicated with the controller whenever the pump needed to be switched off or on depending on the tank capacity. The electrical wiring used in the system was also described.

The pipe, through which water was to be transported from the well to the storage tank, that was selected was a black Polyethylene Pipe with a diameter of 1.25 inches. The cost analysis was then done of the entire system and the results listed in the table below:

Part	Quantity	Price (each, $)	Total ($)
11 sqf^2 Grundfos pump	1	1699	1699
180W Trina solar panel	2	450	900
CU 200 controller	1	320	320
Float switch	1	28.50	28.50
Black polyethylene pipe (1.25 in)	2	100	200
AWG #12wire @ 25 in	1	20	20
AWG 10 wire @ 100 in	2	100	200
		Total:	$3367.5

Figure (i): Solar water pump Schematic (Hunter King, Dr. Andre Butler, 2010)



Challenges faced:

- Delivery of all the parts and materials to the remote project site.
- Difficulty in obtaining extra materials at the remote location in the event that a mistake/miscalculation was made.
- The site characteristics had to be as close to the measurements of the orphanage to accurately determine how the pump and the solar panels would perform at the permanent location.
- Training for the local people on how to operate the pump once the Mercer on Mission group left.

3. THEORETICAL FRAMEWORK

Classification of pumps

Pumps are classified based on:

- The method of transmitting power to the fluid
- The mechanical principle behind the energy transfer
- The mechanical device for moving the fluid

However, the two major classes of pumps are:

- **Kinetic** (dynamic or rotodynamic) and,
- **Positive displacement** (reciprocating).

Roto-dynamic/centrifugal pumps consist of an impeller rotated within a pressure casing by a shaft which produces energy that is then transferred to the fluid by the blades of the impeller. The casing surrounding the rotor (rotating blades) forms an internal passageway through which the fluid flows. They produce head and flow by increasing the velocity of the liquid through the machine with the help of the rotating vane impeller. They're of different types, including but not limited to:

- Regenerative pumps
- Axial flow pumps
- End suction pumps
- Double suction pumps
- Self-priming pumps

Positive displacement types of pumps operate by alternately filling a cavity and then displacing a given volume of liquid. It delivers a constant volume of liquid for each cycle against a varying discharge pressure/head. The various types of positive displacement pumps include:

- Reciprocating
- Power
- Steam
- Rotary pumps – gear, lobe, screw, vane, regenerative (peripheral) and progressive cavity

A simple piston pump is a type of reciprocating pump. It consists of a piston, two valves, a suction pipe and a delivery pipe. It has two valves; an upper valve called the piston valve found at the piston, and a lower one called the foot valve. The operating principle is that in the downward stroke, the piston valve is opened and the water passes through it while the piston moves downwards. During this stroke, the foot valve remains closed. In the upward stroke, the piston valve is closed and water is lifted above the piston. In the meantime, the volume under the piston is being depleted with water passing through the opened foot valve. This results in a pulsating water flow.

The some common pumps used in remote areas include hand pumps, electric pumps with diesel or gas generator and solar pumps. Their merits are demerits have been listed below:

TYPE OF PUMP	**ADVANTAGES**	**DISADVANTAGES**
Gravity	• Very low cost and maintenance (has no fuel costs or spills) • Easy to install • Simple and reliable	• It's practical in only a few places.
Hand pumps	• Can be manufactured locally • Easy to maintain • Low capital cost • No fuel cost	• Leads to loss of human productivity ie laborious and tedious • Has low delivery rates
Diesel and/or gasoline pumps	• Quick and easy to install • More widely used • Can be portable • Low capital costs	• Fuel supplies are erratic and expensive • High maintenance costs • Have short life expectancies • Generate noise and fume pollution

Solar pumps	• Can operate without needing attendance • Simple and reliable • Has no fuel cost • Requires low maintenance • Easy to install • Has a long life expectancy	• High capital (initial) costs • Water storage is required for cloudy periods • Repairs often require skilled technicians

The Photovoltaic System

A photovoltaic system or solar power system is a renewable energy system which uses photovoltaic modules to convert sunlight into electricity which can then be stored, used directly, fed back into the grid line or combined with one or more other electricity generators and/or more renewable energy sources.

The principle behind the operation of solar power systems is the photoelectric effect. The photoelectric effect occurs when incoming photons interact with a conductive surface such as a silicon cell or a metal film resulting in the dislodging and liberation of the electrons within the material. The electrons then move about the material producing a direct electric current.

Solar power systems are a very reliable and clean source of electricity that can suit a wide range of applications such as residences, industries, agriculture etc.

The major components of a solar power system are:

- Photovoltaic modules which convert sunlight into DC electricity.
- Solar charge controller which acts as a regulator for the voltage and current coming from the photovoltaic panels going to the battery thereby ensuring that the battery doesn't get overcharged and consequently, prolonging its life.
- Inverter that converts DC output from the Photovoltaic panels into a clean AC current for AC appliances or to be fed back into the grid line.

- The battery which stores energy for supplying power to electrical appliances when there is a demand.
- The load that comprises all the electrical appliances that are connected to the solar power system such as lights, radio, TVs, computers, refrigerators, electric pumps etc.

The solar powered pumping system

A solar-powered pump is a pump running on electricity generated by a solar powering system. The solar-powered pumping system consists of the following components:

A. Photovoltaic array

A photovoltaic cell is made up of a semi-conducting material that can convert sunlight directly into electricity. When sunlight strikes the cells electrons are dislodged and liberated and therefore they are free to move within the material resulting in the production of direct current (DC). PV cells are combined to make up a module encased in glass or clear plastic. The modules are in turn aggregated to make a PV array. The types of PV cells available are mono-crystalline, multi-crystalline and amorphous.

- Mono-crystalline cells are made with silicon wafers cut from a single cylindrical crystal of silicon. They’re the most efficient with approximately 15% efficiency (fraction of sunlight converted to electrical power). They’re also most expensive to produce.
- Multi-crystalline/polycrystalline cells are made by casting molten silicon into blocks which crystallize into a solid block of inter-grown crystals. They’re less expensive to produce than mono-crystalline ones because of the simpler manufacturing process and lower purity requirements for the starting material. They’re however, less efficient with average efficiency of about 12%.
- Amorphous cells are made from a thin layer of non-crystalline silicon placed on a rigid or flexible substrate. They’re relatively easy to manufacture making them less expensive than mono and poly-crystalline cells. However, they’re efficiencies are less (about 6%). Due to their low costs, they’re the best choice where high efficiency and space are not important.

B. Pump and charge controllers

A pump controller is an electronic linear current booster that acts as an interface between the PV array and the water pump. It provides optimum power to the pump despite wide variations in energy production from the sun. A charge controller is installed when batteries (charged by the solar array) are used in the system. Its purpose is to keep the batteries from overcharging or becoming completely discharged.

C. Passive trackers

These are trackers that don't require any energy input. Their source of energy is the heat from the sun which causes Freon or a substitute refrigerant to move between cylinders in the tracker assembly which in turn causes the panels to shift and maintain a constant 90^o angle ^{to} the sun throughout the day (Sinton C.2010) Their purpose is to ensure that the solar panels continuously face the incoming sunlight. They do this by rotating the PV panel about its axis and sometimes by controlling the panel tilt angle to keep the panels facing the sunlight throughout the year. The advantages of using theses trackers include:

- Increased energy production by up to 50% during some months
- Can reduce the number of PV panels required
- Can cause a reduction in pump stalling due to low light conditions during early mornings and late afternoons when the sun angles are low.

D. Electric-powered pump

Electric- powered pumps are driven by an electric motor which can either be AC or DC. Solar water pumps are designed to use direct current which is provided by the PV array.

The most efficient type of DC motor is the permanent magnet motor because DC motors that have carbon brushes may require frequent replacement of the brushes due to wearing out. However, brushless designs of DC motors exist which use electrical circuits instead of commentators and brushes and have a higher efficiency than the brushed motor (Sinton C, 2010) Conventional AC pumps use a centrifugal impeller. Where an AC pump is used, an inverter is required to convert the direct current from the PV panels to alternating current and then a battery to store the current. The disadvantages of the AC pumps are:

- When an inverter is used to convert the DC from the PV panels to AC electrical losses are experienced leading to less total energy being utilized.
- An AC pump would require a battery to also be included in the system which makes the system more costly to maintain.
- When operating at low power, the amount of water pumped by these centrifugal pumps drops dramatically thus making them a bit limited in solar applications.

Positive displacement pumps on the other hand, generally pump more slowly than other types of pumps but have good performance under low power conditions and can achieve a high lift.

E. Storage tank

Solar water pumping systems require some storage system to store water rather than store electricity in batteries. This reduces the cost and complexity of the system. As a general rule, the tank size is selected so as to hold at least three day amount of water (Sinton C.2010). A food-grade plastic placed at a high point for gravity feed to different fields may be used.

F. Supply pipes

The supply pipes include that piping from the water source to the pump and from the pump itself to the storage tank. The pipes most commonly used are of circular cross-section. The assumptions made when calculating the pipe parameters are that the fluid will completely fill the cross-section and that there is no free surface of fluid. The losses in the pipes will vary depending on the length, diameter and type of material used to make the pipe.

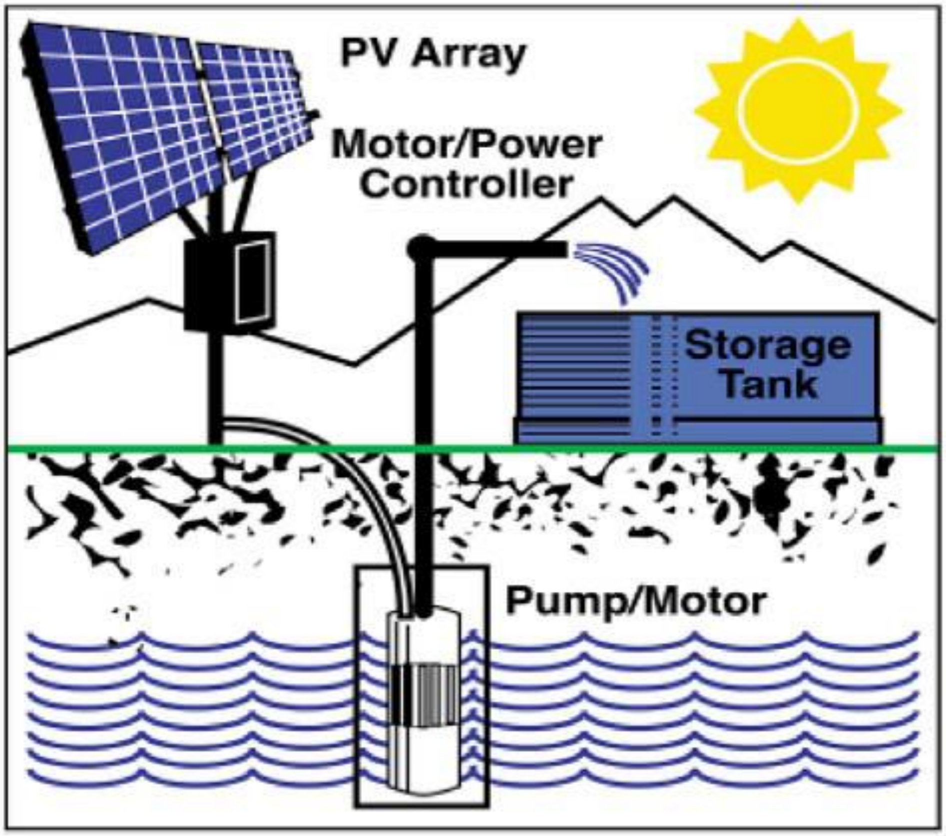


Fig 1: A typical solar-powered pumping system

Pump sizing and selection

Pump performance depends variedly on how much water the pump is moving and the pressure it is creating. Pump characteristics allow you to control the operation of the pump. The primary relationship worth noting is the fact that, as the flow increases, the fluid pressure decreases.

a) Flow rate of the liquid required to be pumped is determined by the amount of water needed ie the demand obtained by

$$Q = \frac{daily\ water\ needs\ of\ the\ operation}{number\ of\ peak\ sun\ hours\ per\ day} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn 1)}$$

where; Q is the daily water demand (liters/hour)

b) Total differential head (TDH) is determined by the flowrate required and the system itself. It has two components, the static head across the pump (H_{st}) and the total head loss (H_L). It's given by:

$$TDH = H_{st} + H_L \text{……………………………………(eqn 2)}$$

c) Static head difference which is the difference between the discharge static head and the suction static head ie

Static head difference = discharge static head – suction static head

where

- Discharge static head = Discharge vessel gas pressure head + elevation of discharge pipe outlet – elevation of pump center line

- Suction static head = Suction vessel gas pressure head + elevation of suction vessel liquid surface – elevation of pump center line

d) Total head loss

The total energy losses in the entire pipeline system includes friction losses, H_f, and minor losses, H_{m}, from bends, valves, meters, exit and entrance losses. The friction losses are determined by: pipe (inside) diameter, length of the pipe, the flow rate and the pipe's roughness.

The head lost due to friction within the pipes can be determined using the Hazen-Williams flow resistance formula for steady uniform flow;

<u>The Hazen-Williams equation:</u>

It was developed for water flow in larger pipes (diameters > 5cm) within a moderate range of water velocity ($V < 3m/s$)

Where Q is the flow rate, d_h is the hydraulic diameter, R is the hydraulic radius.

$$velocity\ of\ flow\ v = 0.85\ C\ R^{0.63} S^{0.54} \text{………………………………..(eqn 3)}$$

$$head\ loss, h_L = \left(\frac{\vartheta L^2}{C\left(\frac{D}{4}\right)^{0.63}}\right)^{1.85} \quad \text{………………………………………………(eqn 4)}$$

Hazen-williams coefficient, C, which depends on surface roughness, is determined using Reynold's number

For total loss to be determined, the following parameters need to be known:

- Length of the pipes
- Diameters of the pipes
- Number and types of fittings (valves, bends etc)

e) The actual head gained by the fluid (generated by the pump), H_P, Can be determined using Bernoulli's equation as follows:

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + H_{L\,(pump)} - H_p \quad \text{………………..(eqn 5)}$$

where $H_{L\,(pump)}$ is the head that is lost during the pumping operation.

$$H_p = \frac{P_2}{\rho g} - \frac{P_1}{\rho g} + \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + Z_2 - Z_1 + H_{L\,(pump)} \quad \text{………………………………(eqn 6)}$$

where $Z_2 - Z_1$ is the difference in water levels between the pump sump and the header tank

f) The Net Positive Suction Head

This is the energy available at the pump eye to push or force the fluid while it still remains in liquid from. It is the difference between the absolute pressure at the pump suction and the vapor pressure of the pumped liquid at the pumping temperature.

For the fluid to remain liquid while being pumped, the pressure at the suction should be greater than the fluid's vapor pressure. This helps prevent 'cavitation' (the existence of vapour bubbles within the fluid in the pump). 'Cavitation' could lead to loss of pump efficiency and significant pump damage.

The factors influencing it are:

- The absolute pressure on the fluid exerted by an outside source such as the atmosphere, H_a

- The static suction pressure which is the head of the fluid above or below the pump suction, H_s
- The vapor pressure of the fluid at that particular temperature, H_{vpa}; it defines the point which the liquid becomes vapor (the pressure at which a liquid and its vapor exist in equilibrium)
- The friction losses in the suction pipe, H_f
- The velocity head at the pump suction port, H_v,which is usually very small and thus can be ignored.

The $NPSH_A$ (available net positive suction head) should be greater than the $NPSH_R$ (required net positive suction head – the minimum pressure required at the suction port of the pump to keep the pump from cavitating) for the particular pump for correct pump operation. It is given by:

$$NPSH_A = absolute\ pressure\ head\ at\ pump\ suction - liquid\ vapor\ pressure\ head$$

$$= H_a - H_{vpa} \text{......(eqn 7)}$$

g) The theoretical power gained by the fluid, P_p, is given by:

$$P_p = \rho g Q H_p \text{......(eqn 8)}$$

This value differs from the actual power consumed by the motor driving the pump due to mechanical losses in the bearings and seals, leakages and/or fluid friction.

The static head, H_{st}, which is the difference in water levels in the pond/pump sump and header tank together with H_L, are system characteristics forming the equation:

$$H_S = H_L + H_{st} = KQ^2 + H_s \text{......(eqn 9)}$$

This is the equation that manufacturers use to generate the pump system curve as well as the pump curve from the equation:

$$H_p = K'Q^2 \text{......(eqn 10)}$$

The actual pump power, $P_{p(actual)}$, is given as:

$$= \frac{flow\ rate \times differential\ head \times liquid\ density \times gravitational\ acceleration}{pump\ efficiency}$$

$$= \frac{QH_p\rho g}{\eta_{pump}} \text{......(eqn 11)}$$

Pump efficiency is usually given by the manufacturer but can also be given by:

$$\frac{actual\ pump\ power}{input\ power\ at\ pump\ shaft} = \frac{QH_p\rho g}{power\ consumed\ by\ the\ motor} \text{..................... (eqn 12)}$$

Photovoltaic array sizing:

1) The total power and energy consumption of all the loads that need to be supplied by the solar power system is given as:

$$Minimum\ power\ required = peak\ pump\ power\ requirement\ \times\ factor\ catering\ for\ losses \text{..(eqn 13)}$$

2) The size of the PV modules is determined by (Morales, T., & Busch, J. 2010).

$$= \frac{minimum\ power\ required}{peak\ power\ output\ of\ the\ array} \text{...(eqn 14)}$$

The solar charge controller is rated against Ampereage and Voltage capacities. It is selected to match the voltage of the PV array and batteries. The size collection is based on the short circuit current of the PV array

$$Solar\ charge\ controller\ rating = Total\ short\ circuit\ current\ of\ PV\ array \times 1.3 \text{..(eqn 15)}$$

4) METHODOLOGY

1) Preliminary desk study which involved a review of existing information on piston water pumps.

2) Collection of primary and secondary data on:
   - Climate data especially the amount of solar insolation experienced at the site location through world weather websites and/or locally from the Kenya Meteorological Department. The evaluation done yielded data on the daily and seasonal variations of the solar insolation at the site.
   - The site coordinates and elevations using a GPS which aided in selecting the possible sites for the various components of the piston pumping system.

3) Calculation of the daily water requirements using CROPWAT 8.0
   CROPWAT 8.0 is a computer program used to calculate crop water requirements and irrigation requirements based on the soil, climate and crop data of choice. The program also enables one to develop an irrigation schedule for different management conditions as well as the calculation of scheme water supply for varying crop patterns. The calculations are done based on FAO (Food and Agriculture Organization) publications of irrigation and drainage series namely, No 56 "Crop Evapotranspiration- Guidelines for computing crop water requirements" and No 33 titled "Yield response to water". (FAO, 2013)

4) Design and selection of the storage tank

- The tank will be sized to store at least a three-day water supply during peak energy production to meet the water needs during cloudy weather or maintenance issues with the power system.
- The tank material will be selected on the basis of UV resistance to maximize its lifespan.

5) Pump sizing and selection

- The first step will be an examination of the existing solar pumps in the market.
- Thereafter, the design flow rate for the pump will be calculated by dividing the daily water needs of the operation and the peak sun hours experienced at the project location.

- The sum of the vertical lift, pressure head and friction losses (piping and fittings between the point of intake and the storage tank) will be calculated to yield the TDH using the appropriate formulas.
- Using the pump performance curves (such as the one in appendix 4), the peak power requirements for the pump can be obtained for the calculated flow rate and TDH.

6) PV panel sizing and matching

- From the peak power requirements, the solar panels or array of panels required to supply this power can be sized.
- The connection of the panels (series, parallel or a combination of both) can then be determined to meet the voltage and ampereage requirements of the pump.
- The total power produced by the array can then be obtained by summing up the individual power outputs of each panel.
- The support structure for the panels will also be designed although it is usually provided for by the supplier.

7) Material cost analysis

The entire system will be analyzed based on the quantities and cost of the materials required to design all the components.

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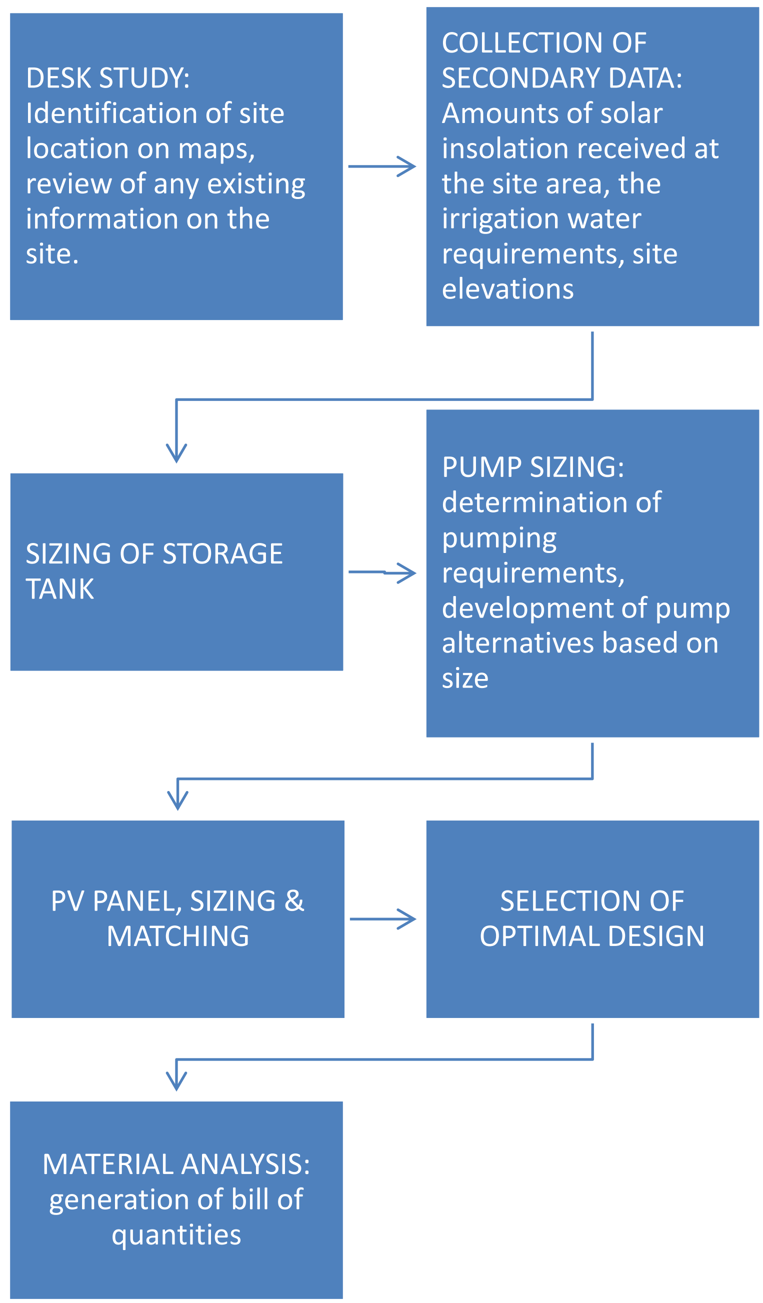
A flowchart demonstrating the concept design process.



5. RESULTS

MONTH	RAINFALL (mm)	MIN TEMP (ºC)	MAX TEMP (ºC)	RELATIVE HUMIDITY (%)	SUNSHINE HOURS	WIND SPEED (m/sec)
JAN	29.4	9.5	25.9	55	8.5	3.9
FEB	14.2	9.6	27.3	48	9.7	4.1
MAR	47.9	10.8	27.2	55	6.4	3.9
APR	114.7	11.6	25.6	68	7.3	3.8
MAY	75.9	11.6	24.7	68	6.5	4.4
JUN	43.7	10.5	21.8	65	8.6	3.9
JUL	59.9	10.2	23.9	65	8.3	4.2
AUG	70.5	10.4	24.4	64	8.6	4.3
SEP	52.6	10.1	25.5	60	8.2	3.8
OCT	77.6	11.0	24.8	65	6.6	3.3
NOV	80.6	11.4	23.5	70	6.4	3.0
DEC	40.0	10.1	24.6	62	7.2	3.4

A review of the existing solar pumps available in the market was done (refer to the catalogue on appendix 4)

PUMP SIZING AND SELECTION:

A. Daily water requirements

Using CROPWAT 8.0 the net irrigation water requirements for the driest months of the year, selected on analysis of the climatic data, were designed as follows:

Table 1: cropping pattern 1 & irrigation water requirement

Crop	Gross irrigation requirement (mm)	Planting date	Length of crop season (days)	Harvest date	Area to be irrigated
Tomato	537.4	01/11	145	25/03	$\approx 0.0625acres$
Potato	488.8	01/11	130	10/03	$\approx 0.0625acres$
Maize	380.5	01/11	125	05/03	$\approx 0.125acres$

Table 2: net scheme irrigation requirement for the scheme

Irrigation months: scheme	Net scheme irrigation requirement (mm/day)
January	4.0
February	1.4
October	0.1
November	1.3
December	4.0

Table 3: projected pumping flowrates

Months	Flowrate (m^3/hr)	Flowrate (m^3/min)	Flowrate (L/min)
January	0.4761	0.007935	7.935
February	0.1460	0.002434	2.434
October	0.01536	0.000256	0.256
November	0.2055	0.003425	3.425
December	0.5621	0.009368	9.368
Worst case scenario	0.5621	0.009368	9.368

B. Total Differential Head

Overhead storage tank will have a minimum capacity of $\frac{4.0}{1000}m \times 1011.714m^2 \times 3days = 12.141m^3$= 12141L

Tank selected = plastic cylindrical roto tank with a capacity of 16000L (312 cm high and diameter of 240 cm)

- **Static head difference**

The vertical linear distance between the water level and delivery outlet = 10m - 6m = 4m

- **Head loss**

The pipe material that was selected was PVC pipes which have considerably low friction losses, making them a suitable choice for long pipes because lower friction losses leads to a reduced pump size and subsequent energy consumption. (Davis & Shirtliff, 2014 product manual, page 291)

Using Hazen-Williams equation, (equation 4) head loss, assuming the suction side of the pump will use a bigger pipe diameter (pipe length =6m), generated is tabulated below:

Table 4: head loss for different pipe diameters, length = 6m, Q = 0.5621m^3*/hr*

D (m)	$\boldsymbol{\vartheta}\ (\frac{\boldsymbol{m}}{\boldsymbol{sec}})$	$\boldsymbol{H_L}$**(m)**
0.025	0.048	3.72985241
0.032	0.030	1.12217745
0.04	0.019	0.37891855
0.05	0.012	0.12794703
0.063	0.008	0.04156017
0.075	0.005	0.01779337
0.09	0.004	0.00732828
0.11	0.002	0.00276040

0.16	0.001	0.00044589
0.2	0.001	0.00015056

Assuming also that the rest of the pipe, will have the same diameter (length =10m) the head loss generated is tabulated below:

*Table 5: Head loss for different pipe diameters, length = 10m, Q=*0.5621m^3*/hr*

D (m)	$\vartheta\ (\frac{m}{sec})$	H_L**(m)**
0.025	0.049	24.6906214
0.032	0.030	7.4285134
0.04	0.019	2.5083391
0.05	0.012	0.8469750
0.063	0.008	0.2751172
0.075	0.005	0.1177873
0.09	0.004	0.0485112
0.11	0.003	0.0182731
0.16	0.001	0.0029516
0.2	0.001	0.0009967

- **Pressure head**

  For this case, the pressure head was assumed to be negligible since the delivery point is a tank and pressure delivery is not necessary.

- **Pipe size selection**

  The pipe diameter that was selected was 50mm/0.050m for the suction pipe and 40mm/0.040m for the rest of the pipe. The smaller diameters were selected because for long pipes, the piping cost can be considerably more expensive than the pumping installation and a pipe size smaller matched to a larger sized pump can reduce the investment cost (Davis & Shirtliff 2014 product manual page 289) but increases the running cost.

$$TDH = H_S + H_L = 4m + 2.51m + 0.128m = 6.638m$$

- **NPSH**

  Using equation 7 the available net positive suction head was calculated as follows:

  H_{vpa} of water was taken as 0.03 atmospheres at 25°C (www.chem.purdue.edu/gchelp/liquids/vpress.html)

$$H_a - H_{vpa} = \frac{101326}{1000 \times 9.81} m - \frac{3039.75}{1000 \times 9.81}$$

  Available net positive suction head = 13.67m

- **Pump selection**

  Available net positive suction head = 13.67m

  Total differential head = 6.638m

  Pumping flowrate, $Q = 0.5621 m^3/hr$ = 9.368L/min =

  The piston pumps selected that closely met the above needs were:

	Grundfos BMP 1.0	Shurflo 2088 12V	SPB 2.5-23C	Apollo model 102	SFPP model 3020, 12PV
Max flow	10L/min	13.333L/min	11.356L/min	10.2 L/min (max)	17.8L/min
Voltage	3×380-415V, 50Hz	12V DC power input	45-90V DC	24V DC	12,24,48 OR 90V DC
Energy rating	4.0kW	7-120W	700W max		314W
Head (m)		10-35	15-30		6.7056
Power			0.75 HP	0.25HP	

The pump model that was selected was the (SFPP) Surface Force Piston Pump model 3020, 12V

- **Pump power**

Pump power = flow rate x total differential head x liquid density x acceleration due to gravity ÷ pump efficiency

Assuming a pump efficiency of 70%

$$Theoretical\ P_{pump} = \frac{0.000156 \times 6.638 \times 1000 \times 9.81}{0.7} = 14.5W$$

Actual pump power required = 314 W

- **PV module sizing and selection**

  - Minimum power needed to operate the pump = $314W \times 1.2 = 376.8W$
  - $No. PV\ panels = \frac{376.8}{125}$ = 4 panels (which is the most ideal choice)
  - The panel model that was selected was YL125 with a rated power of `125 W and open circuit voltage of 22V and total short circuit current of 7.89A
  - The solar charge controller selection

$$Solar\ charge\ controller\ rating$$
$$= Total\ short\ circuit\ current\ of\ PV\ array \times 1.3$$
$$= 7.89 \times 1.3 = 10.257A$$

The appropriate charge controllers would be the SUNDAYA Apple 15 and/or OPTI SC 15A

The charge controller that was selected was the SUNDAYA Apple 15 charge controller.

- **Cost estimates**

Item	Quantity	Cost
PVC pipe D40 @ Shs 48	10 meters	Shs 480
PVC pipe D50 @ Shs 58 per meter	6 meters	Shs 348
20,000 L tank	1	Shs 20000
YL-125 solar panel @ sh 14400 each (VAT excluded)	4	Sh 57600
SUNDAYA APPLE 15A charge controller @ sh 5200 (VAT excluded)	1	Sh 5200
Surface Force Piston Pump model 3020, 12V	1	Sh 239400
	TOTAL	= shs 323028

5) DISCUSSION

The data analysis done yielded the following results:

- An irrigation water requirement of 4.0 mm/day in the month of December which was the highest requirement calculated for an irrigation period between the months of October-February.
- This daily irrigation requirement was thereafter used to compute the pumping flowrate of 10.07L/min/ 0.60429m^3/*hr*
- Total Differential head of 6.638m
- $NPSH_A$ of 13.67m
- Cost of the entire system was found to be shs 308628

There were some assumptions that were made such as:

- That the farmer's cropping season would be from October to February which are typically the driest months of the year in the area.
- That the suction pipe will have a larger diameter than the delivery pipe because of the low head and pressure requirements on the suction side of the pipe compared to the delivery pipe.
- That the crops to be irrigated by the farmer are tomatoes (25% of the irrigation land), potatoes (25% of the irrigation land) and maize (50% irrigation land)

The selection of the solar powering system was based on the fact that a solar powering system is an environmentally friendly source of alternative energy. An electric wind pump, another type of alternative energy water abstraction method, would have been a credible solution but the presence of tall trees in the site farm, which generally act as wind barriers, as well as the fact that a long-lasting farm wind pump, manufactured from steel components and drive piston rods are quite expensive in relation to their power output (FAO,).Other than this, for the wind pump to become economically attractive technology requires that the site have a mean wind speed of 5m/s.

A manually operated hand pump, although a cheap and clean abstraction method, on the other hand, requires time and effort to operate. For example, a rope and washer pump can provide

1L/sec from a 5m depth when pumped by a child if pumped for 20 hours a week (enough to irrigate a quarter acre) while an adult can pump 20L/min from a depth of 20m. this time and effort can be reduced by installing the solar pump which doesn't need to be manned while it operates.

6) CONCLUSION AND RECOMMENDATIONS

The objectives of the design project were met. The review of existing climatic data on the site as well the pumping requirements of the available solar pumps in the market revealed that solar power as an alternative source of energy, is a viable solution for the water abstraction problems experienced by the local farmers in Nkando village.

The solution offered was that of a SFPP 3020, 12PV pump powered by 4 YL-125 solar panels each with a power rating of 125W operating for 7.2 hours a day and fitted with a 15A Sundaya charge controller. The overhead tank which will be fitted 5m above the ground level will have a storage capacity of 16000L.

My recommendations are that the water from the overhead tank can be supplied by gravity feed to the farms to reduce the entire cost of supplying irrigation water.

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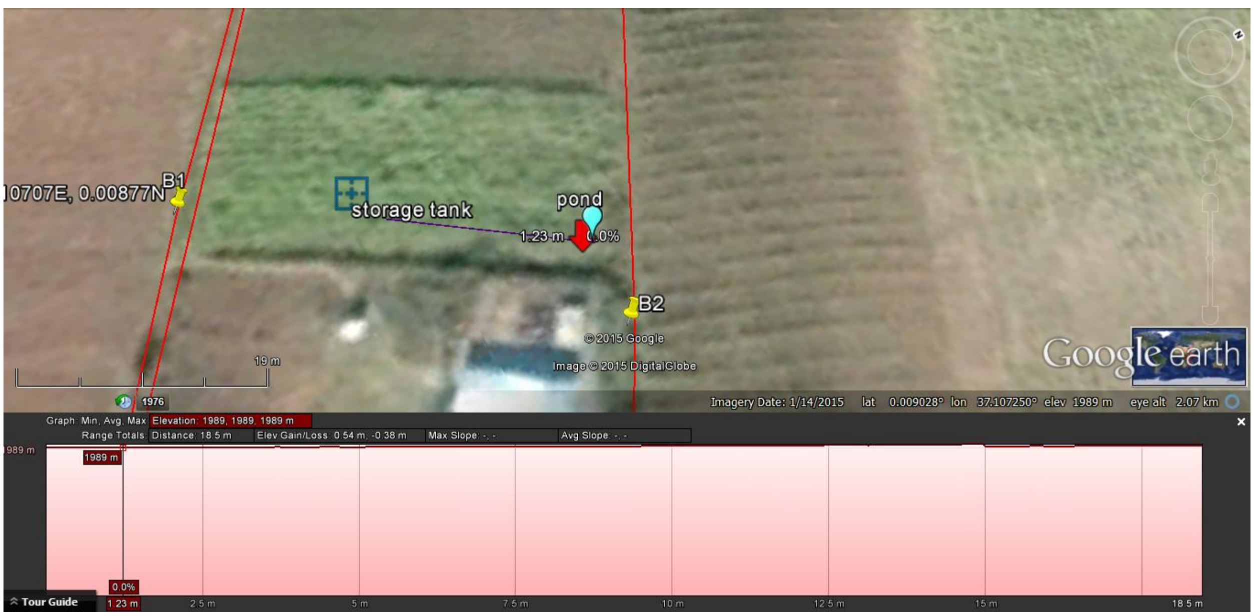
10. APPENDICES

APPENDIX 1: IMAGES OF THE SITE

Runoff water flowing beside the farm: the pond will be supplied with Rainwater and runoff water

APPENDIX 2: MAP OF THE FARM

Pond location and storage tank location



APPENDIX 3: CATALOGUE OF EXISTING SOLAR PUMPS

Some of the existing solar pumps in the market (courtesy of Davis & Shirtliff product catalogue)

Grundfos Novalobe 30/.33	9.0kW	14.4	4.5	-	-	viscous fluids		electric booster	65
SOLAR PUMPS									
Grundfos CRF 3-9	800W	5.0	1.0	4.5	70	clean cold water		solar power	202
Grundfos CRF 5-5	800W	10.0	3.0	4.5	40	clean cold water		solar power	202
Grundfos CRF 10-2	1000W	16.0	6.0	4.5	24	clean cold water		solar power	202
Grundfos SQF 0.6-2	80-350W	0.6	0.3	10	120	clean cold water		solar power	200
Grundfos SQF 1.2-2	100-650W	1.2	0.3	10	120	clean cold water		solar power	200
Grundfos SQF 1.2-3	200-1200W	1.2	0.4	90	250	clean cold water		solar power	200
Grundfos SQF 2.5-2	200-1300W	2.6	1.0	5	120	clean cold water		solar power	200
Grundfos SQF 3A-10	200-1300W	3.0	1.0	30	70	clean cold water		solar power	200
Grundfos SQF 5A-3	100-650W	7.5	2.0	2	15	clean cold water		solar power	200
Grundfos SQF 5A-7	200-1300W	7.5	2.5	10	50	clean cold water		solar power	200
Grundfos SQF 8A-3	150-1100W	13.0	5.0	2	15	clean cold water		solar power	200
Grundfos SQF 8A-5	200-1300W	14.0	5.0	2	30	clean cold water		solar power	200
Grundfos SQF 11A-3	150-1300W	17.0	7.0	2	15	clean cold water		solar power	200
Lorentz PS1800 HR-05L	200-900W	0.9	0.4	50	250	clean cold water		solar power	206
Lorentz PS600HR-07	100-450W	1.2	0.4	30	90	clean cold water		solar power	206
Lorentz PS1200 HR-14	140-700W	1.2	2.4	10	60	clean cold water		solar power	206
Lorentz PS1800 CSJ1-25	400-1400W	2.5	1.0	70	100	clean cold water		solar power	206
Lorentz PS150 CSJ5-8	50-250W	3.5	1.0	5	20	clean cold water		solar power	206
Lorentz PS4000 CSJ5-25	500-3000W	6.0	2.0	60	140	clean cold water		solar power	206
Lorentz PS1800CSJ5-12	250-1400W	7.0	1.0	20	70	clean cold water		solar power	206
Lorentx PS4000 CSJ8-15	400-2800W	13.0	3.0	30	80	clean cold water		solar power	206
Shurflo 8000 12V	40-90W	0.4	0.3	10	45	clean cold water		solar power	204
Shurflo 8030 12V	60-150W	0.4	0.3	10	100	clean cold water		solar power	204
Shurflo 9325 24V	60-160W	0.4	0.3	10	70	clean cold water		solar power	204
Shurflo 2088 12V	70-120W	0.8	0.4	10	35	clean cold water		solar power	204
CIRCULATOR PUMPS									
Grundfos UPA 15-90	0.12kW	1.5	0.5	2.5	8	clean cold water	clean hot water	electric circulator	61
Grundfos UPA 120	0.25kW	2.5	0.5	7.5	12.5	clean cold water	clean hot water	electric circulator	61
Grundfos UPS 25/60	0.1kW	3.0	0.5	1	4	clean hot water		electric circulator	62
Pedrollo DHL 25-65	0.1kW	3.0	0.5	1	5	clean hot water		electric circulator	90
Pedrollo DHL 32-70	0.14kW	5.5	1.0	1	6	clean hot water		electric circulator	90
Grundfos UPS 32/80	0.25kW	8.0	1.0	2	7	clean hot water		electric circulator	62
Grundfos UPS 40/120	0.5kW	16.0	4.0	3	9	clean hot water		electric circulator	63
Grundfos UPS 50/120	0.9kW	25.0	5.0	3	9	clean hot water		electric circulator	63

APPENDIX 4: H-W COEFFICIENTS

TABLE SHOWING PIPE ROUGHNESS FOR VARIOUS PIPE MATERIALS

(source: www.engineersedge.com/fluid_flow/hazenmilliams_coefficients_table_1322)

Material	Hazen-Williams C
Aluminium	130-150
Brass	130-140
Cast-iron (new unlined)	130
Ductile iron pipe	140
Fibre glass pipe	150
Plastic	130-150
polyethylene	140
Polyvinyl Chloride (PVC)	140
Metal pipes-very to extremely smooth	130-140

APPENDIX 6: CLIMATE DATA

Sourced from Kenya Meteorological Department

YEAR	JAN	FEB	MARCH	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1997							7.38	9.09	8.52	5.37	3.33	4.91
1998	5.94	8.97		7.55	6.71	7.96	7.95		8.27	7.25	6.53	8.95
1999	8.78	10.43	6.85	7.8					8.6	7.7	6.6	6.6
2000	10	10.4	0.9	7.7	8.5	9.1			8.1	7.1		
2001			0.76						7.5	6.6		
2002		9.7	7.3	5.9	0.73	7.9	9.2	8.9	8	6.5	7.1	6.3
2003	9.5	9.7	8.5	7.1	5.9	9	8.4	6.5	9.3	7.2		
2005	8.8	10.34	8.52	7.27	6.93	8.54	7.7	8.43	7.78	7.03	6.69	9.2
2007	8.85	8.99	8.41	7.46	7.33				8.51	6.68	6.77	8.15
2008	8.22	9.63	7.35	7.05	7.89	8.39	7.91	8.72	7.57	5.29		
2009	8.21	9.3	8.86	7.93	8.07	9.61	9.51	9.8	8.12	5.67	7.43	6.44
2010	8.28											
	76.58	87.46	57.45	65.76	52.06	60.5	58.05	51.44	90.27	72.39	44.45	50.55
AVERAGE MONTHLY SUNSHINE HOURS	8.5	9.7	6.4	7.3	6.5	8.6	8.3	8.6	8.2	6.6	6.4	7.2

YEAR	2008	2009	2010	2011	2012	AVERAGE WIND SPEED (Knots)	AVERAGE MONTHLY SPEED (km/day)	AVERAGE MONTHLY SPEED (m/sec)
JAN	7.4	7.4	7.0	8.7	7.0	7.5	334.1	3.9
FEB	8.0	9.7	7.0	7.9	7.6	8.0	357.0	4.1
MAR	6.9	8.2	6.5	8.6	7.9	7.6	338.5	3.9
APR	7.4	7.9	6.6	8.3	6.4	7.3	325.8	3.8
MAY	9.9	7.8	8.2	8.7	7.8	8.5	377.6	4.4
JUN	7.9	9.6	7.7	6.5	6.3	7.6	337.2	3.9
JUL	7.9	10.5	9.1	6.5	6.9	8.2	363.3	4.2
AUG	9.1	9.5	8.3	9.0	6.1	8.4	373.6	4.3
SEP	7.8	8.4	7.7	8.6	4.8	7.5	331.9	3.8
OCT	6.1	7.2	7.1	6.1	5.4	6.4	283.0	3.3
NOV	6.0	7.0	6.1	5.2	4.9	5.8	259.6	3.0
DEC	6.4	6.4	7.0	6.1	6.9	6.6	291.6	3.4
							Mean monthly speed =	3.8
							1 knot = 44.448001 km/day	1 knot = 0.514444 m/sec

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997				12.17	9.24	10.36	10.07	9.22	8.67	13	13.19	12.83
1998	12.88	10.06		11.88	12.02	9.61	9.65		9.21	9.37	10.38	7.1
1999	7.87	7.59	10.7	10.14	10.37	9.56	9.63	9.98	9.21	10.14	10.25	10.31
2000	7.81	8.33	9.87	11.06	11.45	10.78	10.49	10.76	10.16	11.14	11.95	10.71
2001	11.75	9.78	11.16	12.23	11.89	10.16	9.63	10.43	9.24	10.63	12.03	9.71
2002	9.67	9.54	10.93	11.93	11.67	9.7	9.62	10.25	10.07	10.75	11.34	12.16
2003	8.63	9.7	10.47	11.78	12.84	10.56	9.85	10.5	9.68	10.3	11.54	8.89
2005	9.91	9.49	11.07	11.79	12.36	10.92	10.42	10.44	10.96	10.55	10.26	9.12
2007	9.42	10.2	10.1	11.34	11.36	11.34	10.57	10.75	10.68	11.22	11.21	9.2
2008	9.21	9.8	11.03	11.04	10.94	9.73	10.99	10.53	10.35	12.11	11.45	9.14
2009	9.62	10.39	11.21	11.46	11.71	10.36	10.62	10.5	10.5	12.5	11.55	11.84
2010	10.72	12.16	12.58	12.56	12.47	11.4	10.59	11.05	10.07	11.18	10.49	8.62
2011	8.74	9.1		11.14	11.45	10.33	10.02	10.89	10.86	11.38	12.4	9.86
2012	7.2	8.96	9.79	12.23	11.99	10.45	10.16		9.67	10.98		10.87
2013	9.92	9.1	11.09			10.69	10.15	10.1	11.22	10.48	11.41	11.24
2014			11.03		12.11	11.56	10.79	10.83	10.36			
	133.35	134.2	141.03	162.75	173.87	167.51	163.25	146.23	160.91	165.73	159.45	151.6
AVERAGE MIN MONTHLY TEMP	9.5	9.6	10.8	11.6	11.6	10.5	10.2	10.4	10.1	11.0	11.4	10.1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997				82.2	77.6	76.4	77.0	75.5	68.2	78.6	85.2	84.4
1998	86.4	76.3		79.4	82.4	78.8	78.0		72.0	71.5	77.0	71.0
1999	67.6	56.2	75.6	76.0	71.8	68.1	72.1	69.9	61.2	66.5	76.3	76.4
2000	59.9	46.9	58.9	69.8	68.9	67.5	72.4	68.7	63.3	66.5	78.5	65.6
2001	73.7	62.8	69.9	79.0	70.4	72.5	76.5	72.8	66.9	69.1	82.7	72.0
2002	66.0	59.1	72.7	82.3	78.7	76.8	70.5	68.5	60.2	70.3	75.9	80.5
2003	64.7	52.5	62.9	74.8	81.1	75.5	75.1	77.3	65.6	71.7	78.9	74.4
2005	64.8	62.2	62.2	71.5	78.9	76.1	72.3	72.4	73.2	69.8	68.4	58.7
2007	70.9	62.8	58.2	76.0	74.6	78.8	78.7	74.8	71.5	74.0	72.1	63.7
2008	64.8	56.5	65.2	75.7	69.2	70.0	73.4	69.3	65.5	76.8	71.4	65.7
2009	60.7	57.1	57.9	67.3	72.4	65.1	65.1	67.3	62.3	71.4	71.4	75.3
2010	66.7	72.4	77.9	78.1	76.5	72.5	73.8	72.7	64.8	68.4	75.6	64.0
2011	58.0	49.1		68.4	73.4	75.8	76.3	76.6	72.8	71.8	80.9	76.0
2012	53.6	55.0	53.2	75.8	76.8	77.6	81.6		70.7	73.7		74.1
2013	66.4	55.4	66.4			77.8	76.6	74.5	69.4	65.0	76.6	75.2
2014			69.0		71.9	71.2	73.8	68.0	66.9			
AVERAGE MONTHLY R.H (%)	66.0	58.9	65.4	75.4	75.0	73.8	74.6	72.0	67.2	71.0	76.5	71.8

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1997				24.43	24.05	23.68	23.1	23.83	26.4	22.93	22.14	22.41
1998	23.48	25.85		26	25.02	24.18	23.63		25.13	25.65	22.99	25.17
1999	26.13	27.46	26.1	25.37	24.61	25.36	23.55	24.93	25.94	25.65	23.62	23.68
2000	26.2	27.57	27.97	26.57	25.8	24.86	24.57	24.55	26.16	25.14	23.6	24.83
2001						24.35	23.81	24.85	26.36	26.04	22.64	24.59
2002	26.01	28.19	27.02	24.74	24.87	24.96	25.38	25.23	26.75			
2003			28.09	26.05	24.47	24.17	24.27	24.01	25.33	25.3	23.4	23.96
2005	27.34	28.51	28.35	26.04	24.22	23.89	22.71	24.62	24.9	24.49	24.71	26.52
2007	25.39	27.02	27.21	25.2	24.3	23.85	22.87	23.34	24.46	24.1	24.19	25.23
2008	26.03	27.09	27.18	24.94	24.66	24.59	23.66	24.55	25.89	23.93	23.5	25.21
2009	25.95	26.94	28.24	26.68	25.48	25.98	24.62	25.25	26.5	24.38	24.32	24.17
2010	24.92	26.61	24.44	24.29	24.39	23.8	23.3	23.85	24.67	25.48	23.53	26.13
2011	26.66	27.96		26.19	24.58	24.8	24.26	23.27	23.88	24.16	23.63	23.81
2012	26.23	27.03	28.08	25.84	24.31	24.06	23.86		25.18	24.75		24.34
2013	26.54	27.83	27.72			24.28	24.21	23.81	25.92	25.58	23.3	24.13
2014			26.57		24.82	24.89	24.17	24.97	25.23			
	310.88	328.06	326.97	332.34	345.58	391.7	381.97	341.06	408.7	347.58	305.57	344.18
AVERAGE MAX MONTHLY TEMP	25.9	27.3	27.2	25.6	24.7	21.8	23.9	24.4	25.5	24.8	23.5	24.6

year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1998												11.6
2000		25.6	23.26	20.21	21.23	21.2	20.67	21.02	22	18.99	17.49	21.54
2001	20.34	24.87	19.47	19.05	20.92	19.46	20.97	21.23	19.51	18.52	15.34	20.43
2002	20.78	24.53	19.54	17.02	20.14	21.04	22.42	20.94	20.84	17.43	19.96	17.84
2003	23.58	23.92	21.83	18.92	19.03	20.22	20.08	18.61	22.67	17.27	16.27	21.1
2005	22.62	25.05	21.32	18.58	17.8	20.74	18.6	20.44	20.55	18.41	18.26	22.17
2007	21.32	21.8	21.07	17.54	17.81	18.1	18.75	19.51	20.08	17.18	17.46	19.69
2008	20.23	22.64	19.56	17.75	19.34	18.78	18.92	19.5	19.72	16.43	17.96	20.55
2009	21.05	21.59	22.24	18.33	18.61	20.89	20.57	21.94	20.14	16.53	19.27	17.13
2010	20.86	18.95	18.3	15.8	19.48	18.94	18.36	18.62	19.29	17.68	15.02	20.15
2011	22.01	23.29		18.19	19.04	19.01	20.26	19.33	19.72	18.16	16.14	20.68
2012	24.56	22.74	23.37	16.77	17.05	18.42	18.95		20.39	17.04		16.77
2013	20.45	22.95	18.82			18.26	19.14	19.29	19.94	18.48	15.25	18.33
2014			20.13		17.63	19.07	19.42	19.72	19.91			
	237.8	277.93	248.91	198.16	228.08	254.13	257.11	240.15	264.76	212.12	188.42	247.98
TOTAL MONTHLY RADIATION (Mj/m2/day)	21.62	23.16	20.74	18.01	19.01	19.55	19.78	20.01	20.37	17.68	17.13	19.08
Avg radiation (kwh/m2)	6.01	6.43	5.76	5.00	5.28	5.43	5.49	5.56	5.66	4.91	4.76	5.30

Month	Net scheme irrigation requirement (mm/day)	Area of land (acre)	Area (m^2)	Daily water needs (mm/day)	Daily water needs (L/day)	No sun hours (hrs/day)	Pump flow rate (l/min)	Pump flow rate (l/sec)	Pump flow rate (m^3/min)	Pump flow rate (m^3/hr)
Jan	4.0	0.25	1011.714	4.0	4046.9	8.5	7.935	0.1322	0.007935	0.4761
Feb	1.4	0.25	1011.714	1.4	1416.4	9.7	2.434	0.0406	0.002434	0.1460
Mar	0	0.25	1011.714	0	0	6.4	0.000	0.0000	0.000	0.0000
Apr	0	0.25	1011.714	0	0	7.3	0.000	0.0000	0.000	0.0000
May	0	0.25	1011.714	0	0	6.5	0.000	0.0000	0.000	0.0000
Jun	0	0.25	1011.714	0	0	8.6	0.000	0.0000	0.000	0.0000
Jul	0	0.25	1011.714	0	0	8.3	0.000	0.0000	0.000	0.0000
Aug	0	0.25	1011.714	0	0	8.6	0.000	0.0000	0.000	0.0000
Sep	0	0.25	1011.714	0	0	8.2	0.000	0.0000	0.000	0.0000
Oct	0.1	0.25	1011.714	0.1	101.2	6.6	0.256	0.0043	0.000256	0.01536
Nov	1.3	0.25	1011.714	1.3	1315.2	6.4	3.425	0.0571	0.003425	0.2055
Dec	4.0	0.25	1011.714	4.0	4046.9	7.2	9.368	0.1561	0.009368	0.5621

$$1\ hectare\ \equiv 2.4710\ acres \equiv 10000m^2$$

$$\frac{1}{4}\ of\ an\ acre\ \equiv 1011.714m^2$$

DIAMETER (m)	AREA, A (m^2)	FLOW RATE, Q (m^3/sec)	VELOCITY (m/sec)	PIPE LENGTH(m)	ϑL^2	CR^0.63	HEADLOSS (m)
0.025	0.000491	0.000156	0.324	6	11.656	5.722	3.72985241
0.032	0.000805	0.000156	0.198	6	7.114	6.685	1.12217745
0.04	0.001257	0.000156	0.126	6	4.553	7.694	0.37891855
0.05	0.001964	0.000156	0.081	6	2.914	8.855	0.12794703
0.063	0.003119	0.000156	0.051	6	1.835	10.243	0.04156017
0.075	0.004420	0.000156	0.036	6	1.295	11.432	0.01779337
0.09	0.006364	0.000156	0.025	6	0.899	12.823	0.00732828
0.11	0.009507	0.000156	0.017	6	0.602	14.551	0.00276040
0.16	0.020114	0.000156	0.008	6	0.285	18.426	0.00044589
0.2	0.031429	0.000156	0.005	6	0.182	21.207	0.00015056

Where $\vartheta = \frac{Q}{A}$

DIAMETER (m)	AREA (m^2)	FLOW RATE (m^3/sec)	VELOCITY (m/sec)	PIPE LENGTH(m)	ϑL^2	CR^0.63	HEADLOSS (m)
0.025	0.000491	0.000159	0.324	10	32.37818182	5.722	24.6906214
0.032	0.000805	0.000159	0.198	10	19.76207386	6.685	7.4285134
0.04	0.001257	0.000159	0.126	10	12.64772727	7.694	2.5083391
0.05	0.001964	0.000159	0.081	10	8.094545455	8.855	0.8469750
0.063	0.003119	0.000159	0.051	10	5.098605099	10.243	0.2751172
0.075	0.004420	0.000159	0.036	10	3.597575758	11.432	0.1177873
0.09	0.006364	0.000159	0.025	10	2.498316498	12.823	0.0485112
0.11	0.009507	0.000159	0.017	10	1.672426747	14.551	0.0182731
0.16	0.020114	0.000159	0.008	10	0.790482955	18.426	0.0029516
0.2	0.031429	0.000159	0.005	10	0.505909091	21.207	0.0009967

APPENDIX 7: DATA ANALYSIS

Determination of crop water requirements and irrigation requirements using CROPWAT 8.0

Climate/ETo | Rain | Crop | Soil | CWR

Country: KENYA | Station: LAIKIPIA AIRBASE

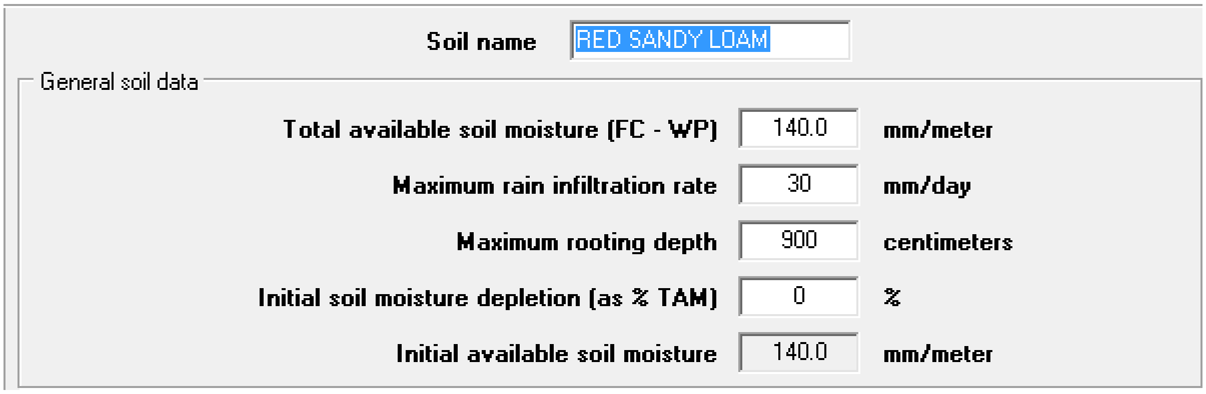
Altitude: 1846 m. | Latitude: 0.06 °S | Longitude: 36.86 °E

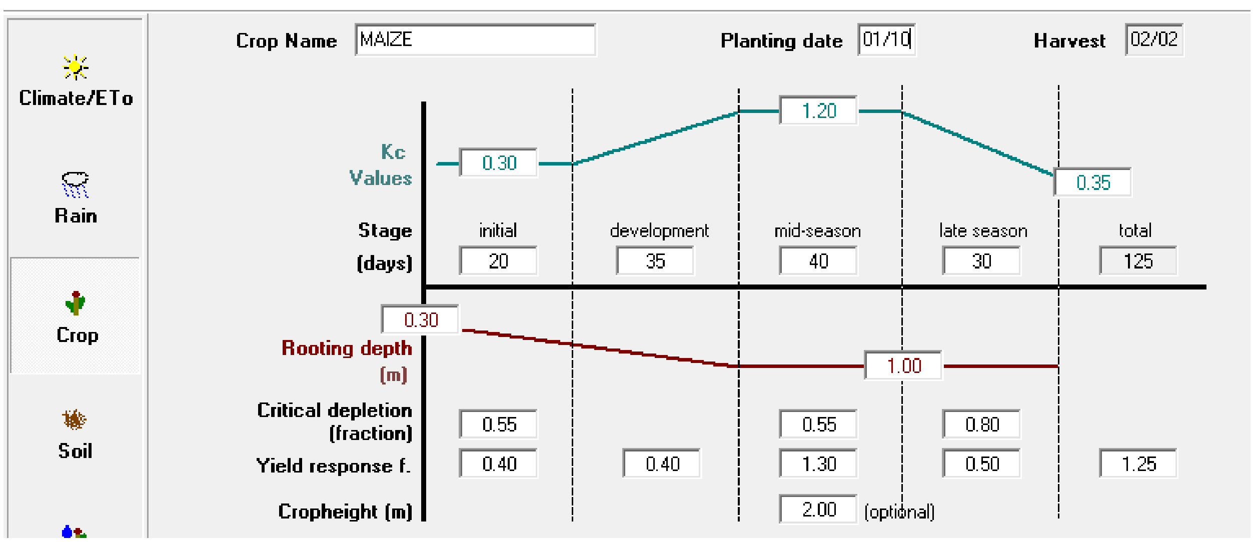
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.5	25.9	55	48	8.5	21.9	3.91
February	9.6	27.3	48	357	9.7	24.5	6.35
March	10.8	27.2	55	339	6.4	19.5	5.48
April	11.6	25.6	68	326	7.3	20.3	4.69
May	11.6	24.7	68	378	6.5	18.1	4.43
June	10.5	21.8	65	337	8.6	20.4	4.25
July	10.2	23.9	65	363	8.3	20.2	4.54
August	10.4	24.4	64	374	8.6	21.7	4.90
September	10.1	25.5	60	332	8.2	22.0	5.20
October	11.0	24.8	65	283	6.6	19.6	4.52
November	11.4	23.5	70	260	6.4	18.8	4.02
December	10.1	24.6	62	292	7.2	19.6	4.58
Average	**10.6**	**24.9**	**62**	**307**	**7.7**	**20.5**	**4.74**

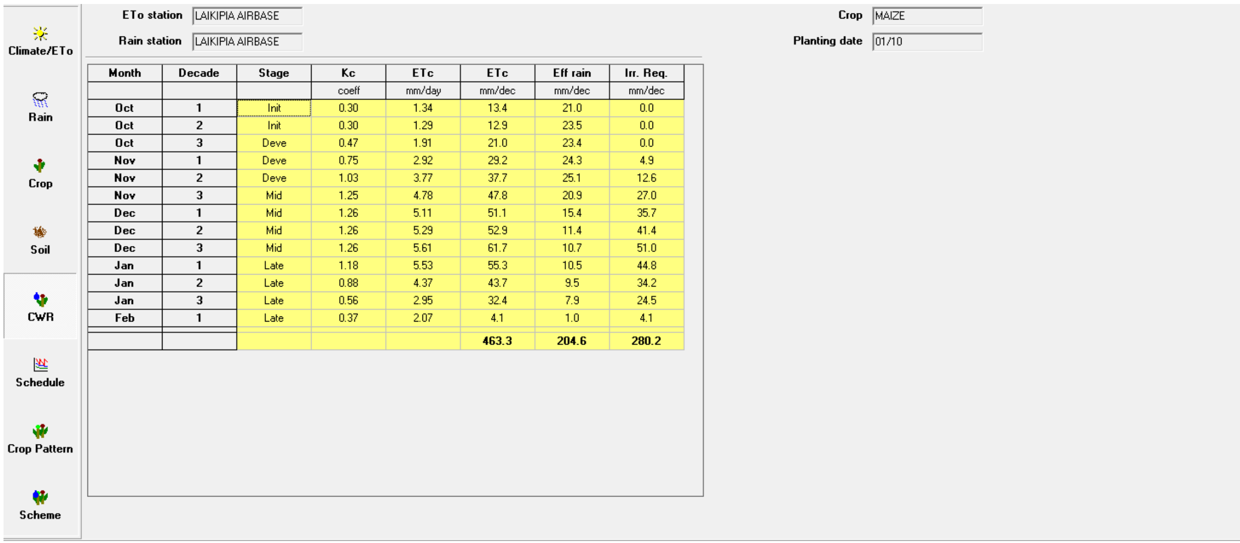
Climate/ETo | Rain | Crop | Soil | CWR

Station: LAIKIPIA AIRBASE | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	29.4	28.0
February	14.2	13.9
March	47.9	44.2
April	114.7	93.7
May	75.9	66.7
June	43.7	40.6
July	59.9	54.2
August	70.5	62.5
September	52.6	48.2
October	77.6	68.0
November	80.6	70.2
December	40.0	37.4
Total	**707.0**	**627.6**

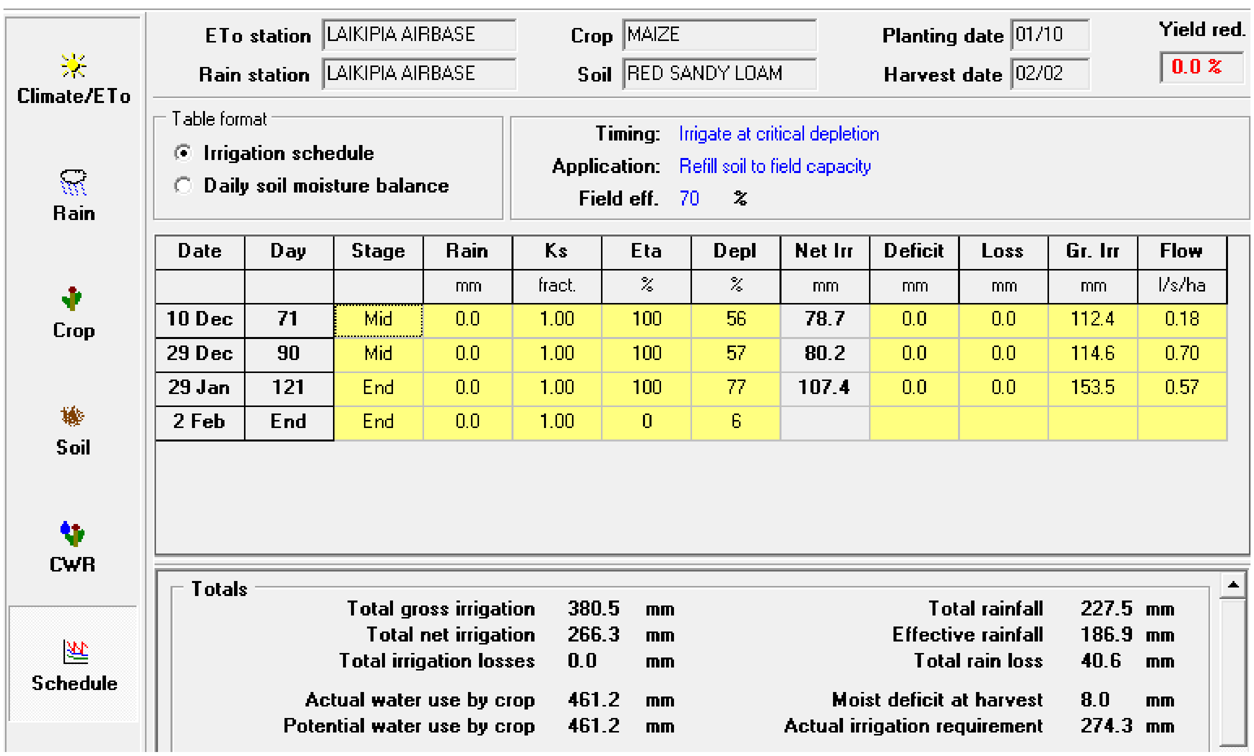

Soil name
RED SANDY LOAM
General soil data
Total available soil moisture (FC - WP)
140.0
mm/meter
Maximum rain infiltration rate
30
mm/day
Maximum rooting depth
900
centimeters
Initial soil moisture depletion (as % TAM)
0
%
Initial available soil moisture
140.0
mm/meter


Climate/ETo
Rain
Crop
Soil
Crop Name
MAIZE
Planting date
01/10
Harvest
02/02
Kc Values
0.30
1.20
0.35
Stage (days)
initial
development
mid-season
late season
total
20
35
40
30
125
0.30
Rooting depth (m)
1.00
Critical depletion (fraction)
0.55
0.55
0.80
Yield response f.
0.40
0.40
1.30
0.50
1.25
Cropheight (m)
2.00
(optional)



ETo station: LAIKIPIA AIRBASE
Rain station: LAIKIPIA AIRBASE
Crop: MAIZE
Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.30	1.34	13.4	21.0	0.0
Oct	2	Init	0.30	1.29	12.9	23.5	0.0
Oct	3	Deve	0.47	1.91	21.0	23.4	0.0
Nov	1	Deve	0.75	2.92	29.2	24.3	4.9
Nov	2	Deve	1.03	3.77	37.7	25.1	12.6
Nov	3	Mid	1.25	4.78	47.8	20.9	27.0
Dec	1	Mid	1.26	5.11	51.1	15.4	35.7
Dec	2	Mid	1.26	5.29	52.9	11.4	41.4
Dec	3	Mid	1.26	5.61	61.7	10.7	51.0
Jan	1	Late	1.18	5.53	55.3	10.5	44.8
Jan	2	Late	0.88	4.37	43.7	9.5	34.2
Jan	3	Late	0.56	2.95	32.4	7.9	24.5
Feb	1	Late	0.37	2.07	4.1	1.0	4.1
					463.3	**204.6**	**280.2**



ETo station: LAIKIPIA AIRBASE
Rain station: LAIKIPIA AIRBASE
Crop: MAIZE
Soil: RED SANDY LOAM
Planting date: 01/10
Harvest date: 02/02
Yield red. 0.0 %

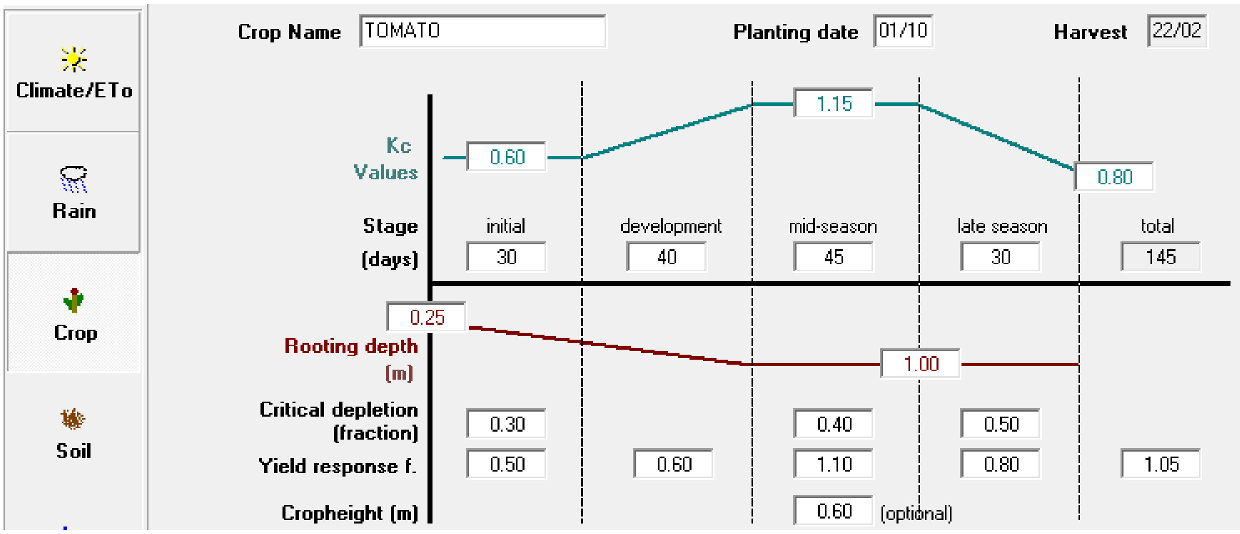
Table format
- Irrigation schedule (selected)
- Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Dec	71	Mid	0.0	1.00	100	56	78.7	0.0	0.0	112.4	0.18
29 Dec	90	Mid	0.0	1.00	100	57	80.2	0.0	0.0	114.6	0.70
29 Jan	121	End	0.0	1.00	100	77	107.4	0.0	0.0	153.5	0.57
2 Feb	End	End	0.0	1.00	0	6					

Totals

Total gross irrigation	380.5	mm	Total rainfall	227.5	mm
Total net irrigation	266.3	mm	Effective rainfall	186.9	mm
Total irrigation losses	0.0	mm	Total rain loss	40.6	mm
Actual water use by crop	461.2	mm	Moist deficit at harvest	8.0	mm
Potential water use by crop	461.2	mm	Actual irrigation requirement	274.3	mm

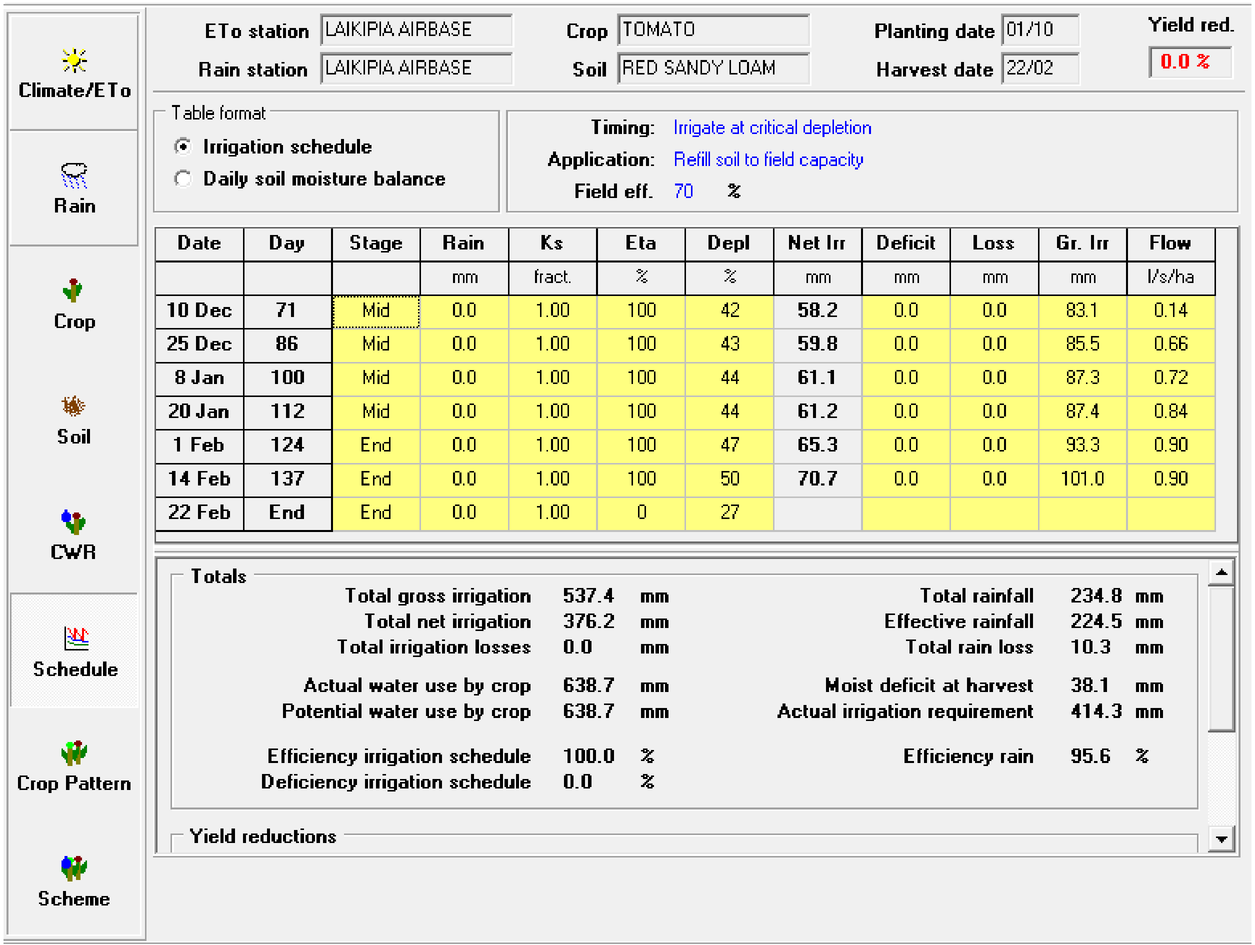


Climate/ETo | Rain | Crop | Soil | CWR | Schedule

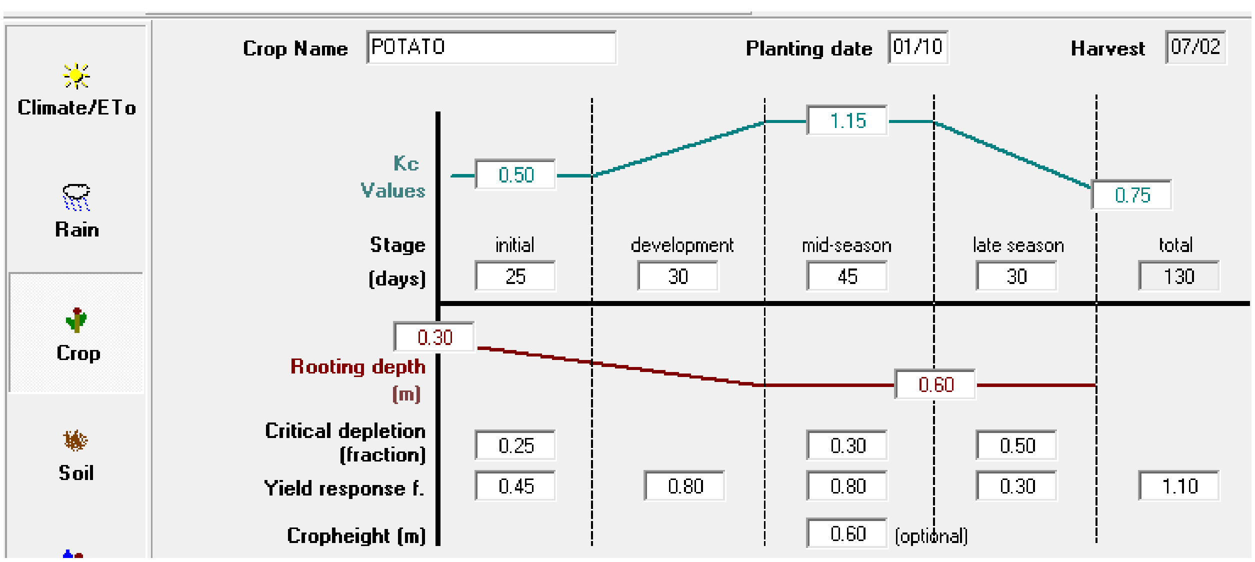
ETo station: LAIKIPIA AIRBASE

Rain station: LAIKIPIA AIRBASE

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.60	2.69	26.9	21.0	5.9
Oct	2	Init	0.60	2.57	25.7	23.5	2.3
Oct	3	Deve	0.60	2.47	27.2	23.4	3.8
Nov	1	Deve	0.70	2.70	27.0	24.3	2.8
Nov	2	Deve	0.85	3.11	31.1	25.1	6.1
Nov	3	Deve	1.00	3.85	38.5	20.9	17.6
Dec	1	Mid	1.15	4.66	46.6	15.4	31.2
Dec	2	Mid	1.21	5.05	50.5	11.4	39.1
Dec	3	Mid	1.21	5.36	59.0	10.7	48.3
Jan	1	Mid	1.21	5.67	56.7	10.5	46.2
Jan	2	Mid	1.21	5.98	59.8	9.5	50.3
Jan	3	Late	1.17	6.14	67.5	7.9	59.6
Feb	1	Late	1.06	6.00	60.0	4.8	55.2
Feb	2	Late	0.95	5.71	57.1	2.5	54.6
Feb	3	Late	0.88	5.02	10.0	1.6	10.0
					643.7	**212.6**	**432.8**



Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Dec	71	Mid	0.0	1.00	100	42	58.2	0.0	0.0	83.1	0.14
25 Dec	86	Mid	0.0	1.00	100	43	59.8	0.0	0.0	85.5	0.66
8 Jan	100	Mid	0.0	1.00	100	44	61.1	0.0	0.0	87.3	0.72
20 Jan	112	Mid	0.0	1.00	100	44	61.2	0.0	0.0	87.4	0.84
1 Feb	124	End	0.0	1.00	100	47	65.3	0.0	0.0	93.3	0.90
14 Feb	137	End	0.0	1.00	100	50	70.7	0.0	0.0	101.0	0.90
22 Feb	End	End	0.0	1.00	0	27					



Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme

ETo station: LAIKIPIA AIRBASE
Rain station: LAIKIPIA AIRBASE
Crop: POTATO
Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.50	2.24	22.4	21.0	1.4
Oct	2	Init	0.50	2.14	21.4	23.5	0.0
Oct	3	Deve	0.54	2.24	24.6	23.4	1.2
Nov	1	Deve	0.77	2.97	29.7	24.3	5.4
Nov	2	Deve	1.00	3.66	36.6	25.1	11.5
Nov	3	Mid	1.18	4.54	45.4	20.9	24.5
Dec	1	Mid	1.20	4.84	48.4	15.4	33.0
Dec	2	Mid	1.20	5.01	50.1	11.4	38.7
Dec	3	Mid	1.20	5.31	58.5	10.7	47.7
Jan	1	Late	1.19	5.60	56.0	10.5	45.5
Jan	2	Late	1.10	5.46	54.6	9.5	45.1
Jan	3	Late	0.97	5.09	56.0	7.9	48.1
Feb	1	Late	0.86	4.86	34.0	3.4	29.3
					537.7	**206.9**	**331.4**

Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme

ETo station: LAIKIPIA AIRBASE
Rain station: LAIKIPIA AIRBASE
Crop: POTATO
Soil: RED SANDY LOAM
Planting date: 01/10
Harvest date: 07/02
Yield red.: 0.0 %

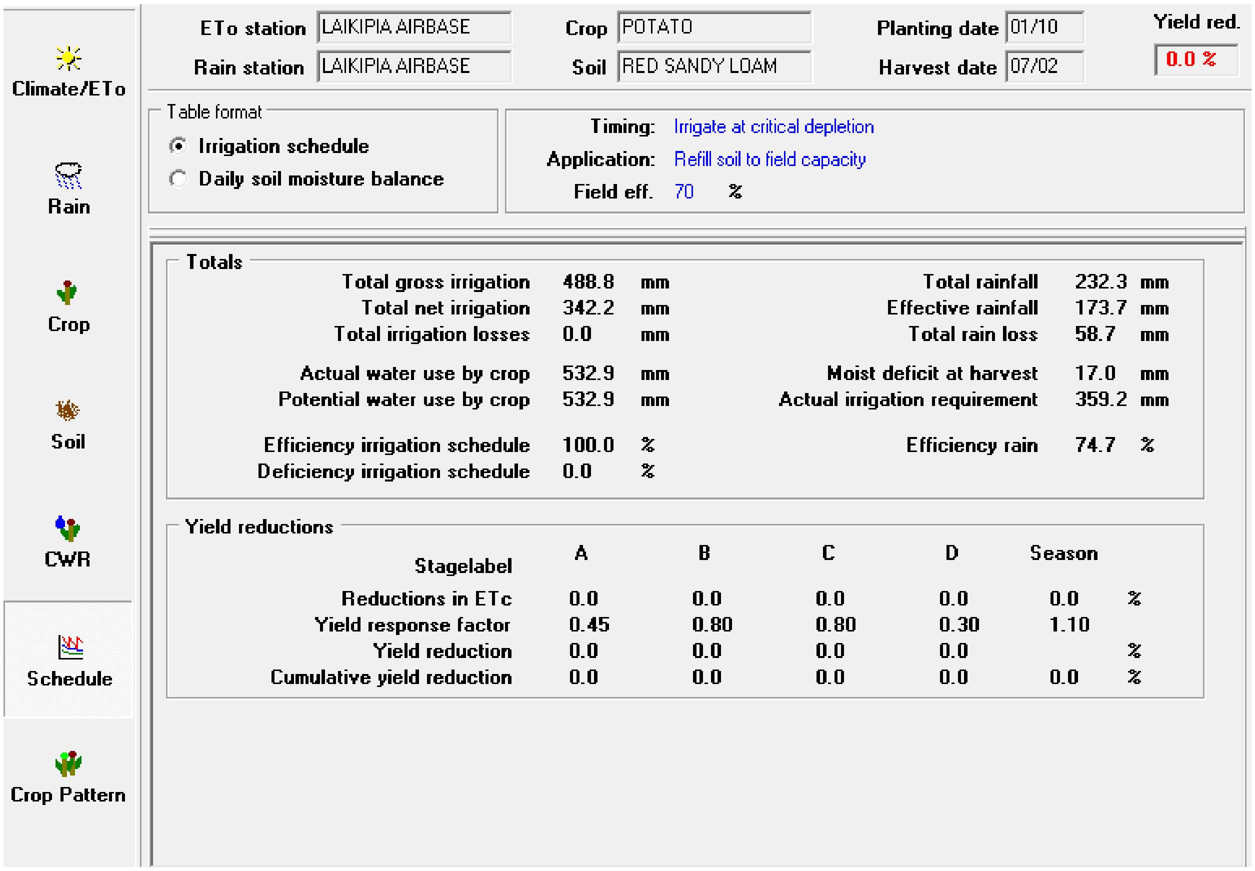
Table format
- (•) Irrigation schedule
- ( ) Daily soil moisture balance

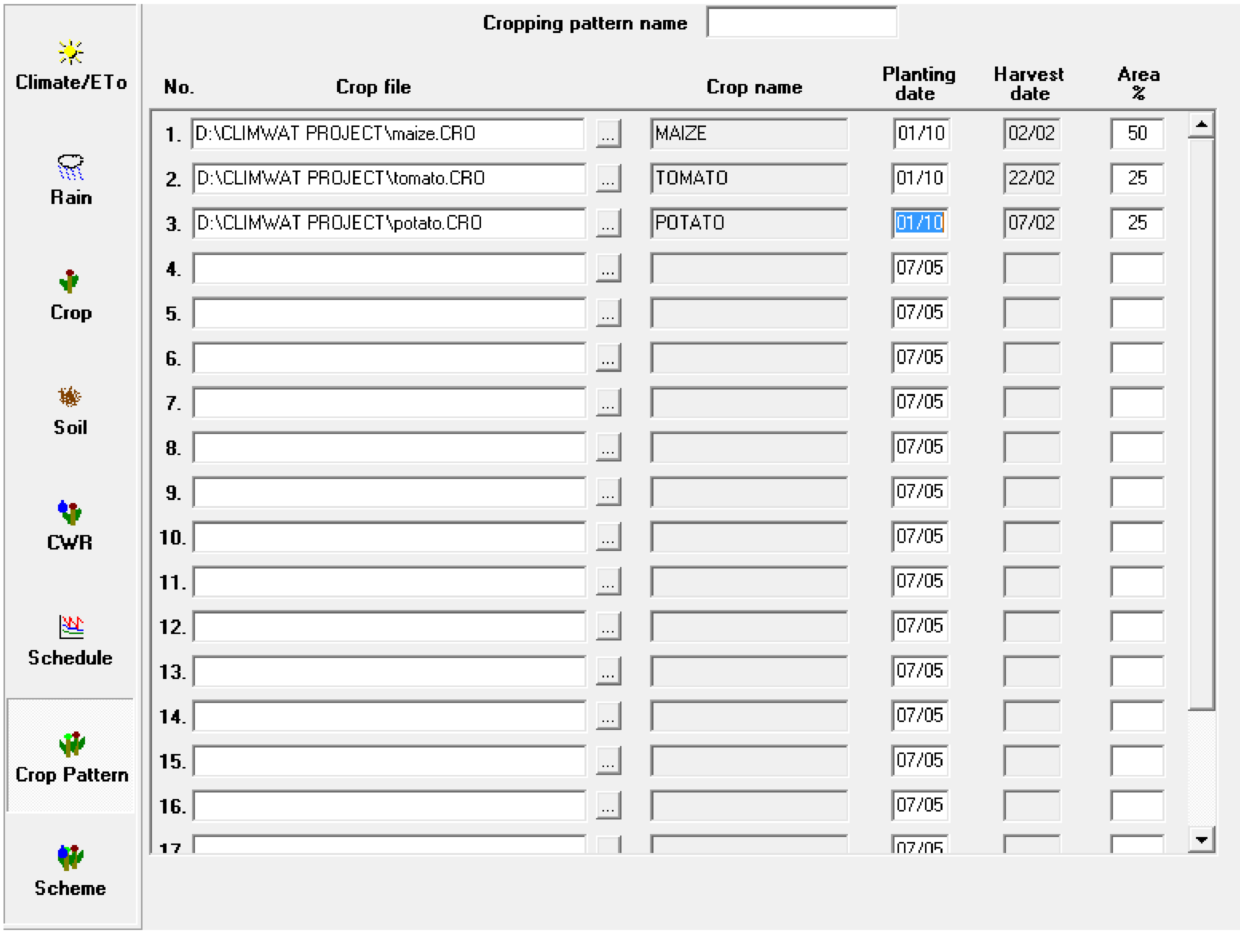
Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

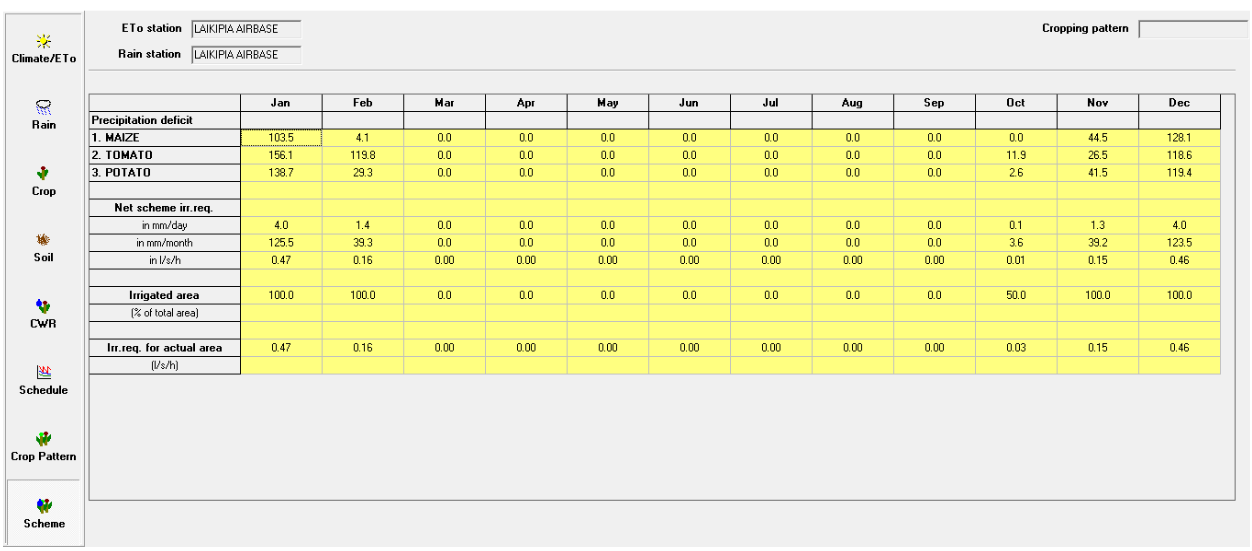
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
12 Oct	12	Init	0.0	1.00	100	26	13.2	0.0	0.0	18.9	0.18
21 Nov	52	Dev	0.0	1.00	100	31	25.2	0.0	0.0	36.0	0.10
1 Dec	62	Mid	0.0	1.00	100	35	29.3	0.0	0.0	41.8	0.48
9 Dec	70	Mid	0.0	1.00	100	30	25.4	0.0	0.0	36.3	0.53
16 Dec	77	Mid	0.0	1.00	100	34	28.9	0.0	0.0	41.3	0.68
21 Dec	82	Mid	0.0	1.00	100	30	25.3	0.0	0.0	36.2	0.84
28 Dec	89	Mid	0.0	1.00	100	31	26.3	0.0	0.0	37.5	0.62
2 Jan	94	Mid	0.0	1.00	100	32	27.1	0.0	0.0	38.8	0.90
8 Jan	100	Mid	0.0	1.00	100	33	28.1	0.0	0.0	40.1	0.77
15 Jan	107	End	0.0	1.00	100	40	33.5	0.0	0.0	47.9	0.79
24 Jan	116	End	0.0	1.00	100	46	38.6	0.0	0.0	55.1	0.71
2 Feb	125	End	0.0	1.00	100	49	41.2	0.0	0.0	58.9	0.76
7 Feb	End	End	2.4	1.00	100	20					

Totals

Total gross irrigation	488.8	mm	Total rainfall	232.3	mm
Total net irrigation	342.2	mm	Effective rainfall	173.7	mm
Total irrigation losses	0.0	mm	Total rain loss	58.7	mm


Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
ETo station LAIKIPIA AIRBASE
Rain station LAIKIPIA AIRBASE
Crop POTATO
Soil RED SANDY LOAM
Planting date 01/10
Harvest date 07/02
Yield red.
0.0 %
Table format
Irrigation schedule
Daily soil moisture balance
Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %
Totals
Total gross irrigation 488.8 mm
Total net irrigation 342.2 mm
Total irrigation losses 0.0 mm
Actual water use by crop 532.9 mm
Potential water use by crop 532.9 mm
Efficiency irrigation schedule 100.0 %
Deficiency irrigation schedule 0.0 %
Total rainfall 232.3 mm
Effective rainfall 173.7 mm
Total rain loss 58.7 mm
Moist deficit at harvest 17.0 mm
Actual irrigation requirement 359.2 mm
Efficiency rain 74.7 %
Yield reductions
Stagelabel A B C D Season
Reductions in ETc 0.0 0.0 0.0 0.0 0.0 %
Yield response factor 0.45 0.80 0.80 0.30 1.10
Yield reduction 0.0 0.0 0.0 0.0 %
Cumulative yield reduction 0.0 0.0 0.0 0.0 0.0 %


Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme
Cropping pattern name
No.
Crop file
Crop name
Planting date
Harvest date
Area %
1. D:\CLIMWAT PROJECT\maize.CRO MAIZE 01/10 02/02 50
2. D:\CLIMWAT PROJECT\tomato.CRO TOMATO 01/10 22/02 25
3. D:\CLIMWAT PROJECT\potato.CRO POTATO 01/10 07/02 25
4. 07/05
5. 07/05
6. 07/05
7. 07/05
8. 07/05
9. 07/05
10. 07/05
11. 07/05
12. 07/05
13. 07/05
14. 07/05
15. 07/05
16. 07/05


Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme
ETo station LAIKIPIA AIRBASE
Rain station LAIKIPIA AIRBASE
Cropping pattern
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Precipitation deficit
1. MAIZE 103.5 4.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 44.5 128.1
2. TOMATO 156.1 119.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 11.9 26.5 118.6
3. POTATO 138.7 29.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.6 41.5 119.4
Net scheme irr.req.
in mm/day 4.0 1.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 1.3 4.0
in mm/month 125.5 39.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 3.6 39.2 123.5
in l/s/h 0.47 0.16 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01 0.15 0.46
Irrigated area 100.0 100.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 50.0 100.0 100.0
(% of total area)
Irr.req. for actual area 0.47 0.16 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.03 0.15 0.46
(l/s/h)

APPENDIX 8: SELECTION CHARTS

A WATER PIPE SIZING CHART FOR PLASTIC (PVC) PIPES

(Source: Dankoff Solar, Pipe Sizing Chart (Water) http://www.affordable-solar.com/Learning-Center/Water-Pumping/pipe-sizing-chart)

Water Pipe Sizing Chart

Friction Loss in Plastic Pipe with Standard Inside Diameter (SIDR)

THIS CHART APPLIES ONLY TO: PVC pipe, Schedule 40 (160 PSI) and to PE (polyethylene) pipe with SIDR designation (most common 100 PSI black pipe)

HEAD LOSS in VERTICAL FEET per HUNDRED FEET of pipe or VERTICAL METERS per HUNDRED METERS of pipe

Nominal Pipe Diameter (Inches)

FLOW RATE		1/2*	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6
GPM	LPM	.662	.82	1.05	1.38	1.61	2.07	2.47	3.07	4.03	5.05	6.06
									actual Inside Diameter (inches)			
1	3.8	1.13	0.14	0.05	0.02	.	.	.	.	.	.	.
2	7.6	4.16	0.35	0.14	0.05	0.02	.	.	.	.	.	.
3	11	8.55	2.19	0.32	0.09	0.05	.	.	.			
4	15	14.8	3.70	0.53	0.16	0.09	0.02	.	.			
5	19	22.2	5.78	0.81	0.25	0.12	0.04	.	.			
6	23	31.0	7.85	1.00	0.35	0.18	0.07	0.02	.			
7	27	.	10.6	1.52	0.46	0.23	0.08	0.03	.			
8	30	.	13.4	1.94	0.58	0.30	0.09	0.05	.	.	.	.
9	34	.	16.9	2.43	0.72	0.37	0.12	0.06	.	.	.	.
10	38	.	20.3	2.93	0.88	0.46	0.16	0.07	0.02	.	.	.
11	42	.	24.3	3.51	1.04	0.53	0.18	0.08	0.03	.	.	.
12	46	.	28.6	4.11	1.22	0.65	0.21	0.09	0.04	.	.	.
14	53	.	.	5.47	1.64	0.85	0.28	0.12	0.05	.	.	.
16	61	.	.	7.02	2.10	1.09	0.37	0.14	0.06	.	.	.
18	68	.	.	8.73	2.61	1.34	0.46	0.18	0.07	.	.	.
20	76	.	.	10.6	3.16	1.64	0.55	0.21	0.08	0.02	.	.
22	83	.	.	13.3	3.79	1.96	0.67	0.25	0.09	0.03	.	.
24	91	.	.	14.9	4.44	2.31	0.79	0.30	0.11	0.04	.	.
26	99	.	.	.	5.15	2.66	0.90	0.35	0.14	0.05	.	.
28	106	.	.	.	5.91	3.05	1.04	0.42	0.16	0.05	.	.
30	114	.	.	.	6.72	3.46	1.18	0.46	0.18	0.06	.	.
35	133		.	.	8.94	4.62	1.57	0.62	0.23	0.07	.	.
40	152		.	.	11.0	5.91	1.99	0.79	0.30	0.09	0.02	.
45	171		.	.	14.2	7.37	2.49	0.97	0.37	0.12	0.04	.
50	190		.	.	17.3	8.96	3.03	1.20	0.46	0.14	0.05	.
55	208		.	.	.	10.7	3.60	1.43	0.55	0.16	0.06	.
60	227		.	.	.	12.5	4.23	1.66	0.65	0.18	0.07	0.02
65	246			.	.	14.5	4.90	1.94	0.74	0.22	0.08	0.03
70	265			.	.	16.7	5.64	2.22	0.85	0.25	0.09	0.04
75	284				.	19.0	6.40	2.52	0.97	0.28	0.10	0.05
80	303				.	.	7.21	2.84	1.09	0.32	0.12	0.06
85	322				.	.	8.06	3.19	1.22	0.37	0.13	0.07
90	341				.	.	8.96	3.53	1.36	0.39	0.14	0.08
95	360			.	.	.	9.91	3.90	1.50	0.44	0.16	0.09
100	379	.	.	.	.	.	10.9	4.30	1.66	0.49	0.18	0.12
150	569	.	.	.	.	.	23.1	9.10	3.51	1.04	0.37	0.16
200	758	.	.	.	.	.	.	15.5	5.98	1.76	0.62	0.28

NOTE: Shaded values are at velocities over 5 feet per second and should be selected with caution.

* NOTE: 1/2" data applies to PE pipe only. PVC has smaller ID of .612"

Dankoff Solar Products, Inc.
2810 Industrial Rd. • Santa Fe, NM 87505 USA
(505) 473-3800 • Fax (505) 473-3830 • www.dankoffsolar.com

Since 1983

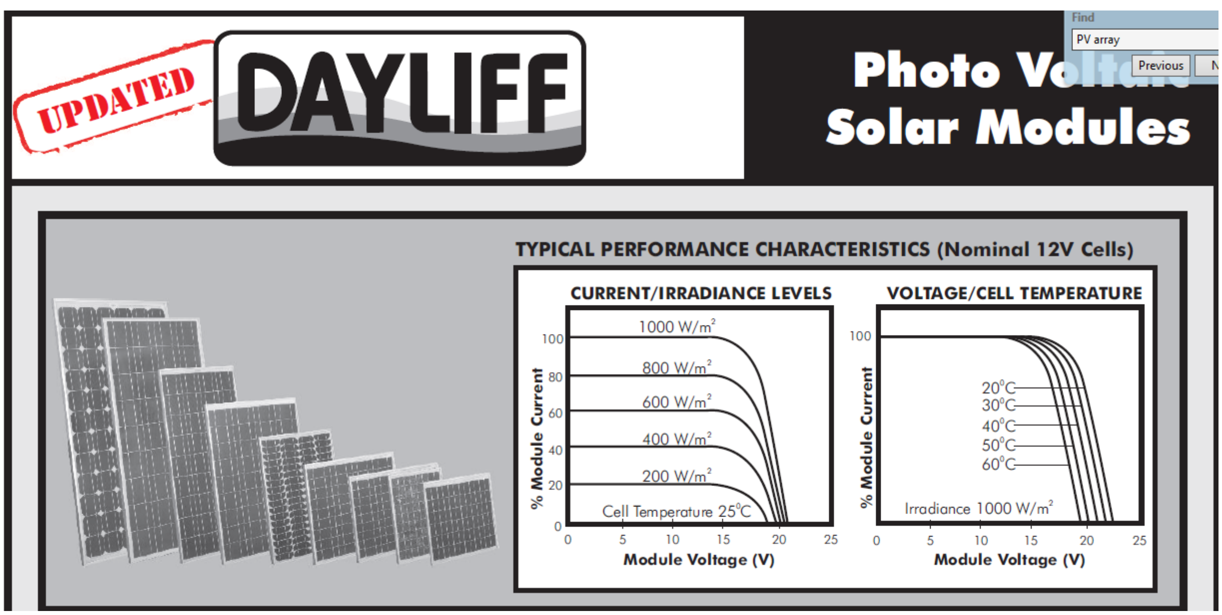
PVC pipe technical specifications (Davis & Shirtliff product catalogue)

TABLE 3: PVC PIPE SPECIFICATIONS

NOMINAL DIAMETRE (mm)	OUTSIDE DIAMETRE (mm)	WALL THICKNESS (mm)				PER 6 METRE EFFECTIVE LENGTH				IMPERIAL SIZE (inch)
		CLASS B	CLASS C	CLASS D	CLASS E	CLASS B	CLASS C	CLASS D	CLASS E	
D25	25.2			1.6	1.8				1.2	3/4
D32	32.0		1.6	1.9	2.35			1.6	1.9	1
D40	40.2		1.8	2.4	2.85		1.9	2.5	3.0	1 1/4
D50	50.2	1.6	2.2	2.9	3.5	2.1	3.0	3.8	4.6	1 1/2
D63	63.2	1.9	2.8	3.6	4.45	3.3	4.7	6.1	7.4	2
D75	75.2	2.2	3.3	4.2	5.15	4.6	6.7	8.5	10.2	2 1/2
D90	90.2	2.7	3.9	5.1	6.2	6.7	9.6	12.2	14.8	3
D110	110.2	3.3	4.8	6.1	7.55	10.0	14.3	18.4	22.2	4
D160	160.3	4.7	6.8	8.9	10.95	29.5	42.2	54.9	66.4	6
D200	200.3	5.2	7.6	10.0	12.3	37.6	53.7	69.1	83.9	7

NOTE: Maximum Pressure Ratings

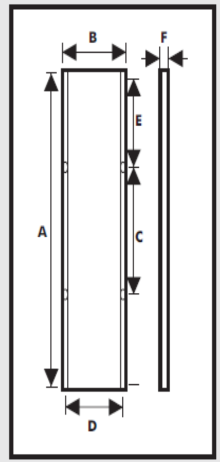
Class B = 6 Bar
Class C = 9 Bar
Class D = 12 Bar
Class E = 15 Bar



PV module technical data (source: Davis & Shirtliff 2014 product catalogue)

PV MODULE DATA

Model	Type	Rated Power (W)	Nominal Voltage (V)	Peak Voltage (V)	Open Circuit Voltage (V)	Short Circuit Current (A)	Number of Cells	Dimensions (mm) A	B	C	D	E	F	Weight (kg)
YL20	Multicrystalline	20	12	17.5	21	1.3	36	610	291	309	256	149	25	2.5
YL40	Multicrystalline	40	12	17.9	21.5	2.41	36	660	540	279	625	130	25	6
YL50	Multicrystalline	50	12	17.5	22	3.1	36	800	541	400	506	200	35	6
YL65	Multicrystalline	65	12	17.5	22	4.1	36	770	660	389	626	190	35	8
YL85	Multicrystalline	85	12	17.5	22	5.1	36	1171	540	592	507	290	35	8
SW80	Polycrystalline	80	12	17.9	21.9	4.8	36	958	680	640	640	159	34	8
YL125	Multicrystalline	125	12	17.5	22	7.89	36	1470	680	870	646	300	35	12
SW130	Polycrystalline	130	12	17.4	21.5	7.9	36	1508	680	880	640	314	34	12
YL160	Multicrystalline	160	24	34.5	43	5.17	72	1182	990	682	956	250	35	14
SW175	Polycrystalline	175	24	35.8	44.4	5.3	72	1610	810	1100	761	255	31	15
YL195	Multicrystalline	195	24	36.7	45.4	5.65	72	1310	990	770	955	270	35	14
YL280	Multicrystalline	280	24	35.5	45	8.35	72	1970	990	1154	946	408	50	27

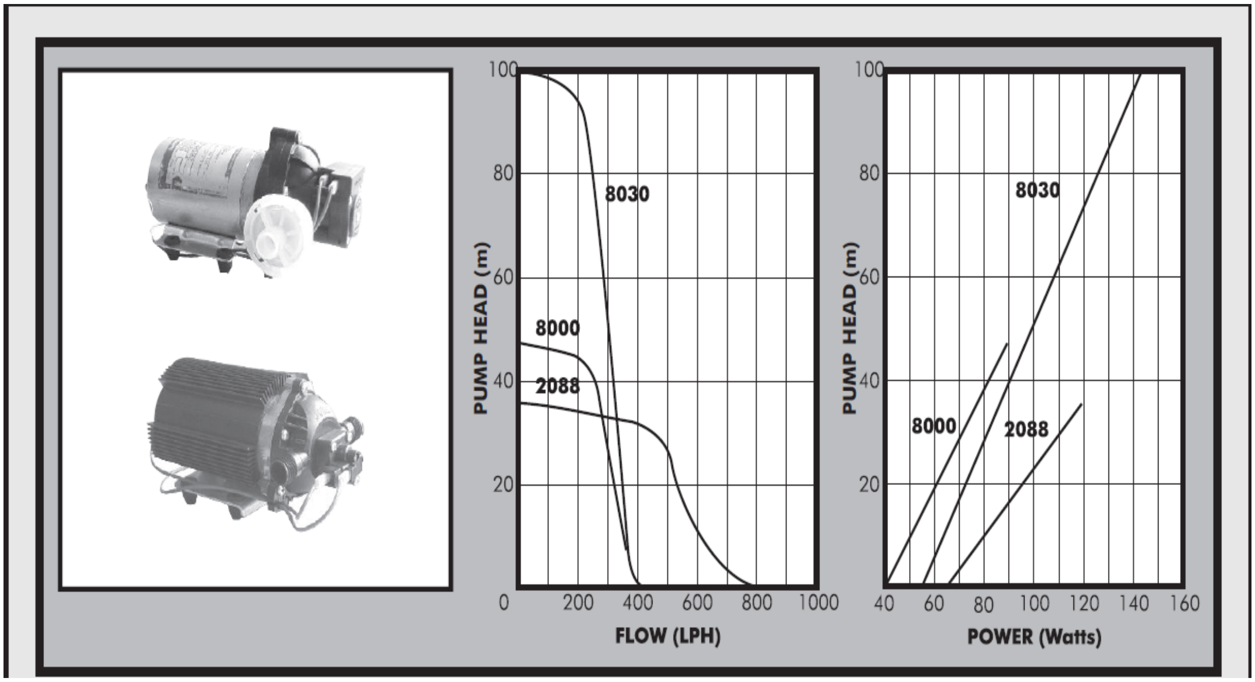


Charge controller technical specification (Davis &Shirtliff 2014 Product catalogue)

TECHNICAL SPECIFICATIONS

	SUNDAYA		STECA				OPTI				
	Apple 10	Apple 15	Solarix PRS 2020	Solarix PRS 3030	PR 3030	Tarom 4545-48	SC 10SM	SC 15SM	SC 20SM	SC 50 MPPT	SC 80 MPPT
Max. Module Current	10A	15A	20A	30A	30A	45A	10A	15A	20A	50A	80A
Nominal Battery Voltage	12VDC		12/24VDC			12/24 48VDC	12/24VDC			12-48VDC	
Input Voltage	12VDC		12/24VDC			12/24 48VDC	12/24VDC			140VDC	
Self Consumption	4mA		4mA		13mA	30mA	13mA			14mA	
Max PV Array Power (Watts)	240		900			2400	120/240	180/360	240/480	3250	5200
Low Voltage Disconnect (LVD)	11.5V		11.2-11.6V(22.4-23.2V)			46.8V	10.8-11.9V(21.6-23.8V)			(11.5/22.4/44.4)V	
Reconnection Voltage (LVR)	12.7V		12.4V-12.7(24.8V-25.4V)			50V	12-13.2V(24-26.4)V			(12.4/24.6/50.4)V	
Display	LED				LCD		LED			LCD	
IP Rating	IP 30		IP 32			IP 31	IP 67			IP 20	
Dimensions (mm)	120Øx40		187x96x45			218x134 x65	85x70 x20	85x85x20		268x196 x147	415x225 x147
Weight (kg)	0.24		0.35			0.8	0.2	0.21		4.3	7.1

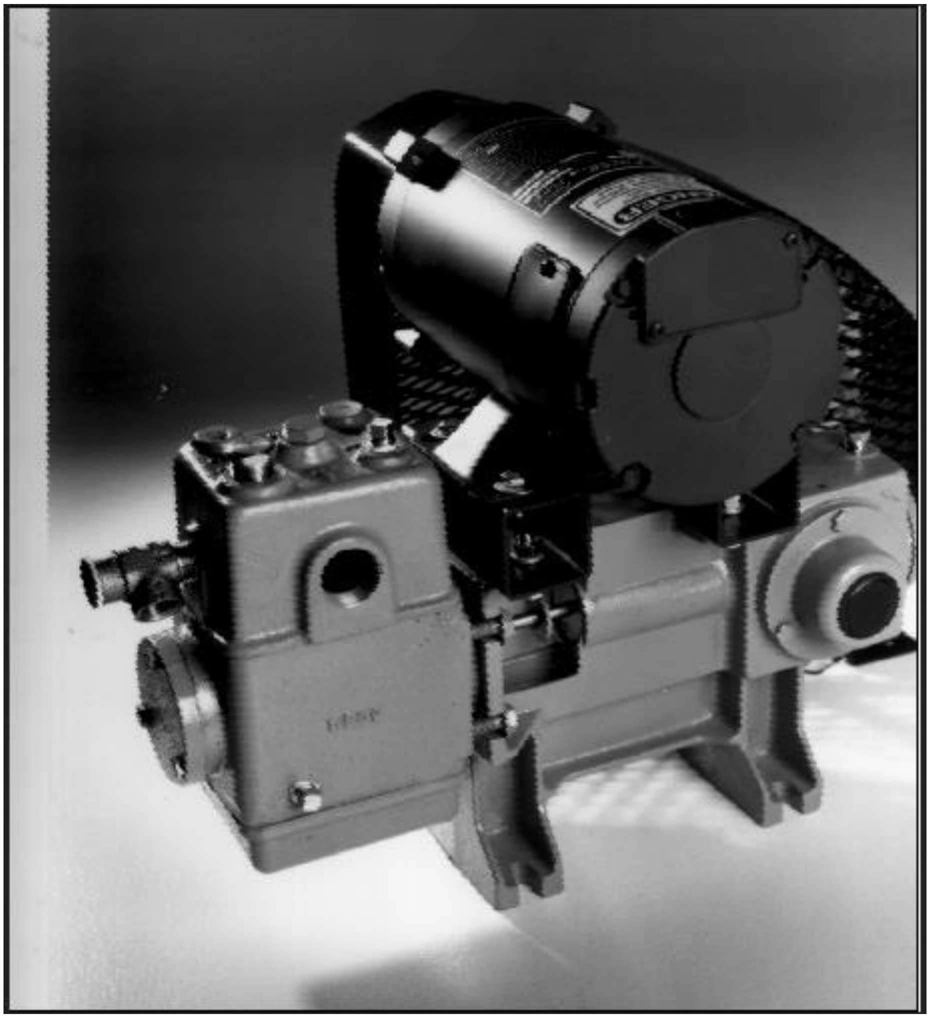
Shurflo Pumps (courtesy of Davis and Shirtliff 2014 product manual)



Price list for the SFPP model 3020 pump (source:

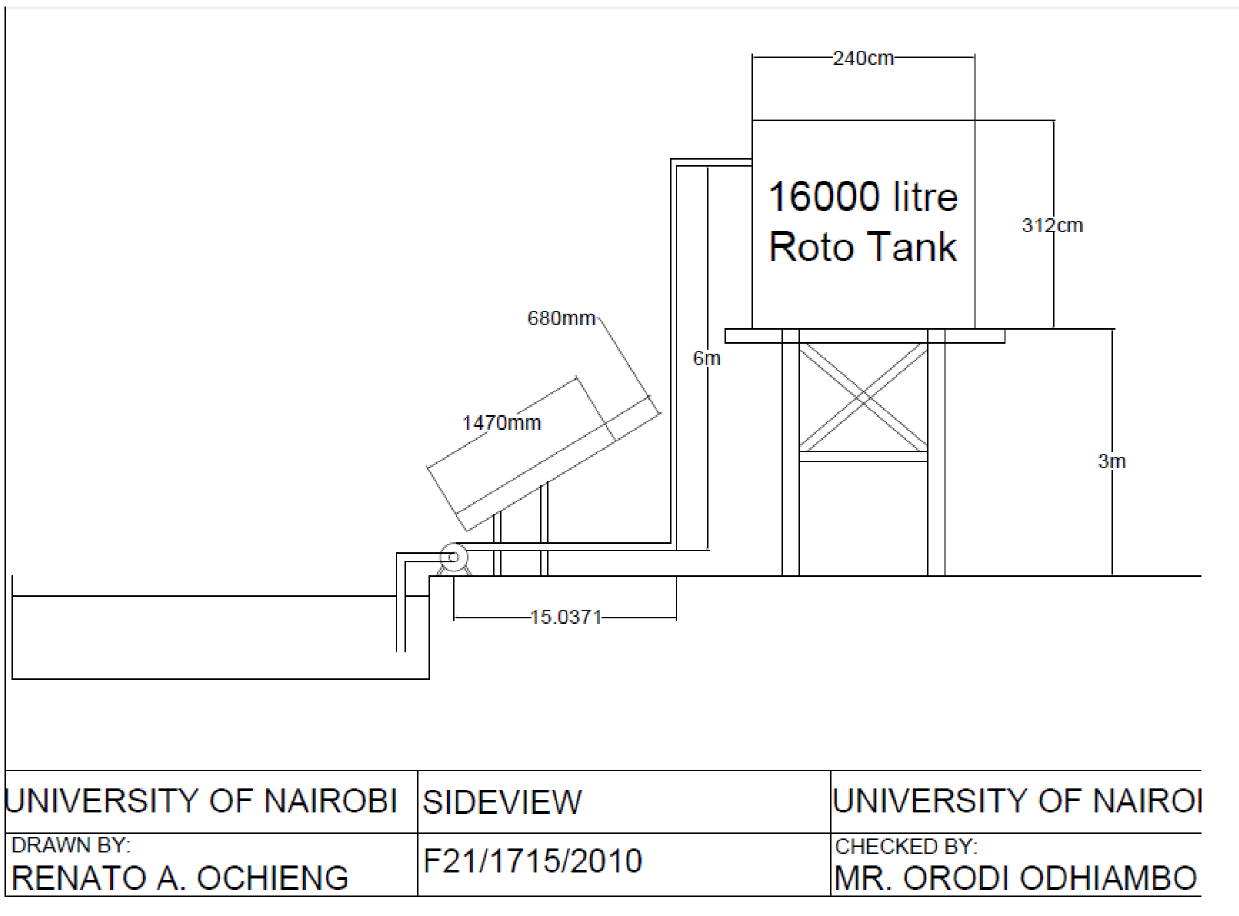
DC PV DIRECT						
Solar Force Piston Pump 3020-12PV	12	PV	70	075-04273	$2660	Buy Now
Solar Force Piston Pump 3040-12PV	12	PV	70	075-04287	$2793	Buy Now
Solar Force Piston Pump 3020-24PV	24	PV	70	075-04277	$2649	Buy Now
Solar Force Piston Pump 3040-24PV	24	PV	70	075-04291	$2619	Buy Now
Solar Force Piston Pump 3020-48PV	48	PV	70	075-04281	$2637	Buy Now
Solar Force Piston Pump 3040-48PV	48	PV	70	075-04295	$2608	Buy Now

Image of the solar force piston pump (source:



APPENDIX 8: SYSTEM LAYOUT

AutoCAD drawing of the layout of the Solar powered Piston Pumping System



Technical specifications of the Solar Force Piston Pumps (source: 2015 solar products catalogue by Linda and Terry Wolff retrieved from http://solar-catalog.com/pumps_surface.html#Shurflo_Pump_Accessories)

Vertical Lift (feet)	Pressure (PSI)	Model 3010			Model 3020			Model 3040		
		Battery Only			PV or Battery			PV or Battery		
		GPM	LPM	Watts	GPM	LPM	Watts*	GPM	LPM	Watts*
20	8.7	5.9	22.3	77	5.2	19.7	110	9.3	35.2	168
40	17.4	5.6	21.3	104	5.2	19.7	132	9.3	35.2	207
60	26.0	5.3	20.2	123	5.1	19.2	154	9.2	34.9	252
80	35.0	5.2	19.7	152	5.1	19.2	182	9.2	34.9	286
100	43.0	5.1	19.2	171	5	18.9	202	9.1	34.5	322
120	52.0	4.9	18.7	200	5	18.9	224	9.1	34.5	364
140	61.0	4.9	18.7	226	5	18.9	252	9.1	34.5	403
160	70.0				4.9	18.6	269			
180	78.0				4.9	18.6	280			
200	86.0				4.8	18.2	308			
220	95.0				4.7	17.8	314			

' Watts listed is pump power used. For array direct operation array must be at least 20% larger

APPENDIX 9: BUDGET

ACTIVITY NO.	ACTIVITY	ESTIMATED COSTS (ksh)
1.	Travel costs	850
2.	Communication	1000
3.	Stationery	1000
4.	Documentation	1500
	TOTAL	= 6200

APPENDIX 10: WORK SCHEDULE

	ACTIVITY	**WEEK NUMBER (16/02/2015 – 29/05/2015)**														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation of project proposal															
2	Submit project proposal															
3	Project proposal presentation															
4	Site visit															
5	Acquisition of secondary data															
6	Data analysis and documentation															
7	Development of alternative designs															
8	Selection of optimal design based on performance															
9	Testing and re-designing															
10	Cost analysis															
11	Submit draft project report															
12	Submit final project report															