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SCHOOL OF ENGINEERING
DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING

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PROJECT TITLE: DESIGN OF A SOLAR P0WERED SYSTEM FOR WATER ABSTRACTION IN EWASO NG'IRO, NAROK.

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

APRIL, 2016

Declaration

I declare that this project report is my work and has not been submitted for a degree award in any other university.

Signature: …………………………. Date…

Nabaala Harrison Leshao

This report has been submitted for examination with my approval as a university supervisor.

Signature: ……………………………………… Date…

Dr Christian Thine Omuto

Dedication

I dedicate this project to my family, for their never ending support and for trusting and believing in me in achieving greater heights in my academic life.; to my friends for their continued support, to my supervisor, Dr Christian Thine Omuto for his understanding and guidance. I finally dedicate it to the residents of Ewaso N'giro, Narok for their cooperation and inspiration to carry out this project.

Acknowledgement

I thank God for seeing me throughout my undergraduate studies and for keeping me in good health in the five years I have been in the university.

I give special thanks to my lecturer and supervisor, Dr Christian Thine Omuto, for his amazing support throughout my undergraduate studies and more so for his guidance during my project period.

My special thanks also goes to my parents, for their support, both monetary or in form of encouragement. To our Chairman, Prof Eng. Ayub Gitau and the entire university staff and all the students of Environmental and Biosystems engineering department who facilitated my success, I dearly appreciate working with them as a team throughout the period.

Thank you and May God bless you all.

To all those who contributed, my deepest gratitude

Abstract

In many arid countries rainfall is decreasing, making surface water scarce. This has increased the demand for groundwater, but the water table is also decreasing. Due to this, manual pumping has become more difficult. Diesel, petroleum, kerosene and windmills have traditionally been used to pump water from deeper levels, but solar photovoltaic pumps are becoming more common. Because of human need for energy, extra special attention is in the usage of renewable-energy sources in recent years. On the other hand, environmental pollution is created with fossil energy. Photovoltaic (PV) energy is also one of the renewable-energy sources that are available in almost all parts of the globe. For several years many different types of solar powered water abstraction systems have been field tested. In this paper, several steps are given to select a solar-PV water abstraction system. The steps for selection of stand-alone water abstraction system were: determining the type of PV module, type of controller unit, selecting pump type (diaphragm, piston, helical, or centrifugal), and analysing the daily water demand requirement. Also to demonstrate how to determine PV array size, motor/pump rated power, and type of pump.

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List of Acronyms and Abbreviations

ASALs Arid and semi-arid areas

PV Photovoltaic

ITCZ Intertropical convergence zone

QGIS Quantum geographic information system

UTM Universal Transverse Mercator coordinates

WHO World health organisation

SMP Submersible motor pump

FAO Food and Agriculture organization

PVC polyvinyl chloride

O$M operation and maintenance

NPC Net present cost

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1 INTRODUCTION

1.1 Background Information

There are about 40 million people living in Kenya, of which about 17 million (43 percent) do not have access to water ***(Marshall, 2011)***. For decades, water scarcity has been a major issue in Kenya, caused mainly by years of recurrent droughts, poor management of water supply, contamination of the available water, and a sharp increase in water demand resulting from relatively high population growth. In many areas, the shortage of water in Kenya has been amplified by the government's lack of investment in water, especially in rural areas which have potential sources of water. Water scarcity is a common problem that people in ASALs areas have been facing for a very long time. There has been frequent incidences of hunger and starvation in these areas. Parents will spend most of the time searching for water for domestic and farming purposes. A unique phenomenon to acquire water despite the harsh environmental conditions should be adopted in Semi-arid areas. This is possible because most semi-arid areas are endowed with resources that can help in achieving this. Water availability can be made possible due to availability of water bodies (rivers) and renewable forms of energy. The renewable forms of energy that can be utilized in these areas are solar and wind. Solar and wind can be harnessed and converted into mechanical energy to be used in pumping water to a reservoir which then distribute water to households/fields by means of gravity . Analysis of the current water crisis and the underlying abstraction constraints would form a basis of formulating appropriate management strategies for improved livelihoods in arid and semi-arid areas. This can be made a reality by designing a solar powered water abstraction system in such areas. Solar energy is considered to be the world's most valued innovation in energy production sector because of its effectiveness and it is a clean and renewable energy source. Solar powered water pumping has been recognized as suitable solution for grid-isolated rural locations in Kenya where there are high levels of solar radiation. Solar powered water pumping systems can provide drinking water without the need for any kind of fuel or the extensive maintenance required by diesel pumps. Land topography, water and solar energy potential of the site should be carefully studied before considering a solar powered water abstraction system implementation. In the region average solar energy experienced is 4.5 kWh per square meter per day ***(Gichungi, 2010).*** Feasibility studies are needed to ascertain appropriate sites and hence make use of the abundant resources available in the country for the wellbeing of the community.

1.2 Problem Statement

The main problem people are facing in the region is the lack of water because of low and inconsistent rainfall. People living along River Ewaso N'giro have adapted to the unfavourable climate change by purchasing diesel engine driven water pumps that are used to pump water to a reservoir and some even literally fetch water by use of Jeri cans and transport it by donkeys to raised tanks which then allow water to flow to various households by gravity. They continuously incur the daily cost of purchasing fuel and intervening human labour. Moreover, they have not been able to use canals to convey the water into a reservoir through a direct diversion because the river has a deep river bank and fluctuates more frequently. Alternatively, grid powered pump, could have been used by the locals but this is not so because there is low grid power coverage in the County.

1.3 Problem justification

To overcome the above problem and to improve water availability in the area, there is a need to design a solar powered system for water abstraction. Solar powered system for water abstraction will address their problem through the use of solar energy and submersible solar pump. The solar powered system for water abstraction uses the readily available renewable energy i.e. solar energy. Therefore, the stakeholders will not incur the daily cost for diesel engine pump. The cost incurred through human labour will also be minimised.

1.4 Site Analysis and inventory

1.4.1 Geographical Location

Narok county is situated in the southwest of Kenya and lies between latitudes 34°45'E and 36°00'E and longitudes 0°45'S and 2°00'S . My site, lies in 1° 9'13.09"S and 35°45'8.55"E at an altitude of 1821 at the lower end and 1832 m at the upper side above the sea level.

Figure 1 Site in relation to the map of the country (source topographical maps)

Figure 2 Site in relation to the map of the county (source google earth pro)

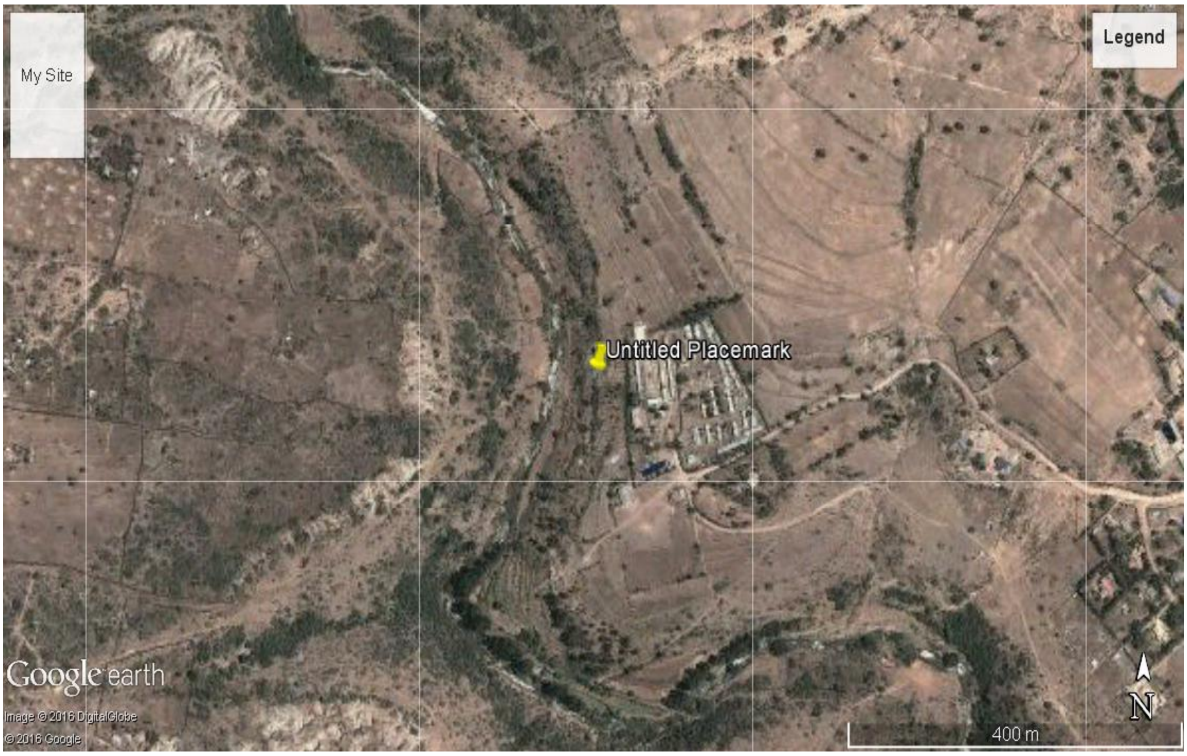
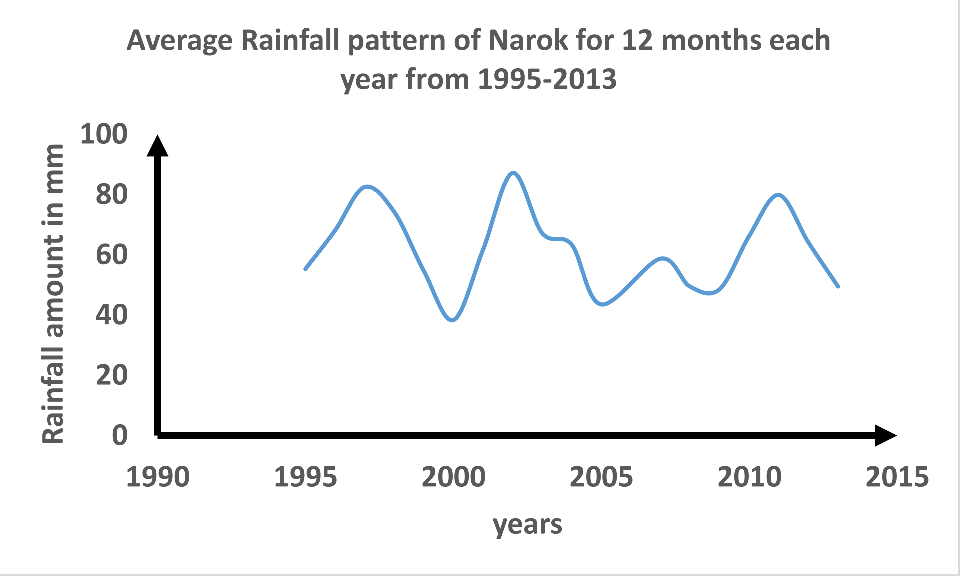


Figure 3 project site (source Google earth pro)

1.4.2 Climatic conditions

The rainfall of the region is partly related to the ITCZ, with local variations in topography playing a major role in the distribution patterns. In the experience of local people, it is much hotter during the dry seasons than during the wet. The rainfall pattern of Narok is unpredictable, it ranges from 497mm to 1132mm per year.



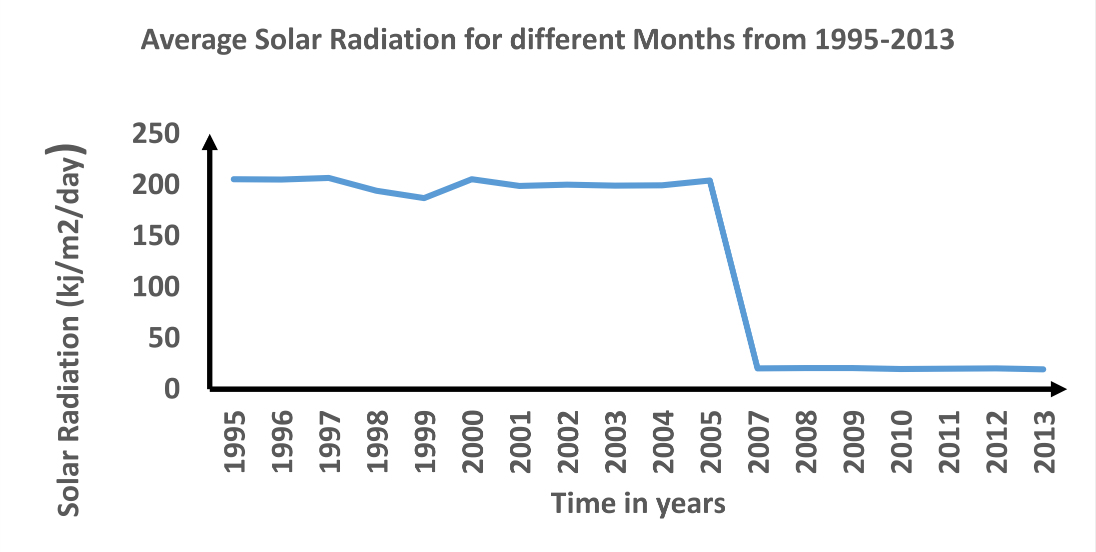
Graph 1 Rainfall pattern of Narok from 1995-2103

1.4.3 Topography

The topography of the county consists of highlands rising over 2300m and lowlands of 1000m -1,500m above sea level. This varied topography determines the county's climatic conditions.

1.4.4 Solar irradiation

Angles of declination were calculated and the extra-terrestrial solar radiation values were found to be 20.14 KJ/m2/day for parts of Narok, 20.13 KJ/m2/day for both areas along Ewaso N'giro and Narok. Average annual daily diffuse solar radiation for all the stations range between 16 – 18 KJ/m2/day. The average monthly daily diffuse solar radiation was found to be 16 – 18 KJ/m2/day and 16 – 18.5 KJ/m2/day respectively. The clearness index lay between 0.4 and 0.7. ***(Wasike, 2010).*** The distribution of solar irradiation in Kenya is clearly shown in (Appendix D).



Graph 2 solar radiation of Narok (1995-2013)

1.5 Overall objective

To design a solar powered system for water abstraction.

1.5.1 Specific objectives

i. To establish the pertinent parameters for the design.

ii. Using the pertinent parameters above to design a solar powered system for water abstraction.

iii. To access the relationship between pump sizing, flow rate and solar energy.

1.6 Statement of Scope

The design will cover determination of solar panel tilt angle, the sizing of a PV module, the population water demand, water flow rate and evaluation of the desirable water pump. It will also cover the system components and the specifications in order to design a suitable solar powered system for the abstraction of water.

2 LITERATURE REVIEW

2.1 Introduction

Recently the water demand has increased due to the increase in the population and the availability of water has become more crucial than ever before. A source of energy to pump water is also a big problem in developing countries like Kenya. Developing a grid system is often too expensive because rural villages are frequently located too far away from existing grid lines. Even if fuel is available within the country, transporting that fuel to remote, rural villages can be difficult. There are no roads or supporting infrastructure in many remote villages. The use of renewable energy is attractive for water pumping applications in remote areas for developing countries. Transportation of renewable energy systems, such as photovoltaic (PV) pumps, is much easier than the other types because they can be transported in pieces and reassembled on site ***(Khatib, 2010).*** Photovoltaic (PV) energy production is recognized as an important part of the future energy generation. Because it is non-polluting, free in its availability, and is of high reliability. Therefore, these facts make the PV energy resource attractive for many applications, especially in rural and remote areas of most of the developing countries like Kenya. Solar photovoltaic (PV) water pumping has been recognized as suitable for grid-isolated rural locations in poor countries where there are high levels of solar radiation. Solar photovoltaic water pumping systems can provide water for domestic and farming purposes without the need for any kind of fuel or the extensive maintenance required by diesel pumps. They are easy to install and operate, highly reliable, durable and modular, which enables future expansion. They can be installed at the site of use, rendering long pipelines unnecessary ***(Andrada and Castro, 2008).***

The output of solar power system varies throughout the day and with changes in weather conditions. Photovoltaic module, the power source for solar pumping, have no moving parts, requires no maintenance and last for decades. A properly designed solar pumping system will be efficient, simple and reliable. Solar powered pumping systems are used principally for three applications. Town, city water supply, livestock watering and irrigation.

The government is currently implementing a solar PV electrification of schools and other institutions in selected districts, which are remote from the national grid as part of a national strategy to enhance the contribution of renewable sources of energy to the overall energy supply mix. By the end of 2009, about 150 public institutions were expected to have installed a total capacity of 360 kW of PV electricity, and the total capacity of all solar PV installations in rural areas of Kenya would be in the order of 6 MW. Despite this success, the percentage contribution of solar energy to the total energy mix is insignificant (less than 1%). Studies sponsored by Ministry of Energy have shown that Kenya holds tremendous potential in solar energy but only a small potion has been tapped.

2.2 Status of Solar Energy in Kenya

A vibrant solar energy market has developed in Kenya over the years for providing electricity to homes and institutions remote from the national grid and for medium temperature water heaters for domestic and commercial usage. Solar electric systems are being imported and sold to end users in Kenya through a competitive and growing free market network that includes more than 10 import and manufacturing companies, as well as hundreds of vendors, installers, and after sale service providers. In 2003, the cumulative sales were estimated to be in excess of 220,000 units (more than 4 MW). On the other hand, about 7000 solar thermal (About 140,000 m2) are in use for drying of agricultural produce and water pumping ***(Mwangi, 2010).***

2.3 Water pumping

Water pumping is one of the simplest and most appropriate uses for photovoltaic. From crop irrigation to stock watering to domestic uses, photovoltaic-powered pumping systems meet a broad range of water needs. Most of these systems have the added advantage of storing water for use when the sun is not shining, eliminating the need for batteries, enhancing simplicity and reducing overall system costs. Many people considering installing a solar water pumping system are put off by the expense. Viewing the expense over a period of 10 years, however, gives a better idea of the actual cost. By comparing installation costs (including labour), fuel costs, and maintenance costs over 10 years, you may find that solar is an economical choice. A solar-powered pumping system is generally in the same price range as a new windmill but tends to be more reliable and require less maintenance. A solar-powered pumping system generally costs more initially than a gas, diesel, or propane-powered generator but again requires far less maintenance and labour ***(Eker, 2005)***

2.4 How Solar Systems Compare To Other Systems

The cost comparison between wind, solar, diesel engines and electricity, show that water pumping can be very cost competitive in certain circumstances. Every application is different and should be evaluated on its merit, giving consideration to the following:

- Initial cost of the system
- expected system life (15–20 years)
- running costs (e.g. fuel and oil for diesel engines)
- Maintenance costs
- Time and labor to supervise the system's operation
- Time value of money (discount rate of return).

Solar water pumping systems have many advantages over traditional windmill water pumps. They provide a more consistent supply of water and can be installed in wooded areas where wind exposure is poor. Solar pumps operate anywhere the sun shines while windmills work where there is a steady, constant wind supply. Both the initial and lifetime costs of solar powered systems are often far less than windmills due to lower shipping, installation, and maintenance costs. Finally windmills are stationary while solar systems can be more easily moved to meet seasonal or variable location needs. A PV array may be placed some distance away from the pump itself, even several hundred feet away.

Solar pumps are becoming a preferred choice in remote locations to replace the increasingly expensive diesel pumps. In such places, solar pumps are viable economically in comparison to extension of grid or running the pump on diesel.

2.5 Comparison of pumping techniques

Table 1 Comparison of pumping techniques

	Advantages	Disadvantages
Hand pumps	Easy to maintain No fuel cost	Loss of human productivity Only low flow rates are achievable
Wind pumps	Unattended operation Easy to maintain Long life No fuel requirements	Water storage is required in low wind periods High system design and project planning needs Not easy to install

Solar PV module	Unattended operation Low maintenance Easy installation Long life	High capital costs Water storage is required for cloudy periods Repair requires skilled labour
Diesel and gasoline pumps	Quick and easy to install Low capital costs Can be portable Widely used	Fuel supply is erratic and expensive High maintenance costs Short life expectancy Noise and fume pollution

2.6 Solar Radiation

Solar radiation is the energy from the sun that reaches the earth. It is commonly expressed in units of kilowatts per square meter (kW/m2). The earth receives a nearly constant 1.36 kW/m2 of solar radiation at its outer atmosphere. However, by the time this energy reaches the earth's surface, the total amount of solar radiation is reduced to approximately 1 kW/m2. ***(Weir, 2005)***

The intensity of sunshine (i.e. solar radiation) varies based on geographic location. A good analogy to describe this variation is the different conditions that can be found on the north slope of a mountain versus its south slope. The intensity of sunlight also varies based on the time of day. Through different amounts of the earth's atmosphere as the incident angle of the sun changes. Solar intensity is greatest when the sun is straight overhead (also known as solar noon) and light is passing through the least amount of atmosphere. Conversely, solar intensity is least during the early morning and late afternoon hours when the sunlight passes through the greatest amount of atmosphere. In most areas, the most productive hours of sunlight (when solar radiation levels approach 1 kW/m2) are from 9:00 a.m. to 3:00 p.m. Outside of this time range, solar power might still be produced, but at much lower levels.

2.7 Solar Irradiance

Solar irradiance on the other hand is the amount of solar energy received by or projected onto a specific surface. Solar irradiance is also expressed in units of kW/m2 and is measured at the surface of the material. In the case of a PV-powered system, this surface is the solar panel.

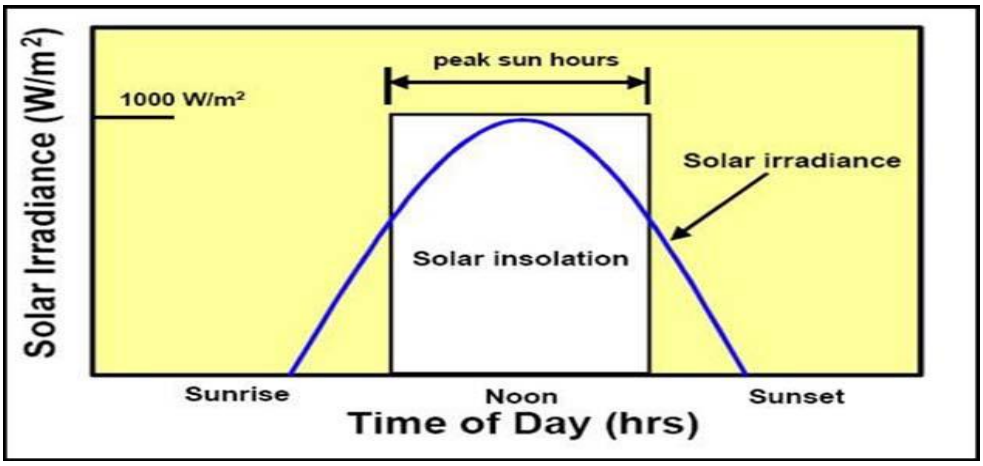


Figure 4 Solar irradiance and peak sun hours (Source: "Renewable Energy Primer-Solar.")

2.8 Solar insolation

Finally, solar insolation is the amount of solar irradiance measured over a given period of time. It is typically quantified in peak sun hours, which are the equivalent number of hours per day when solar irradiance averages 1 kW/m2. It is important to note that although the sun may be above the horizon for 14 hours in a given day, it may only generate energy equivalent to 6 peak sun hours. ***(agriculture, 2010)***

2.9 Solar energy system

A Solar Energy System is sometimes referred to as an Alternative Energy System. And while that's true, wind, geothermal, and hydro systems are also alternative energy sources. We focus primarily on Solar and will therefore simply use the phrase Solar Energy System or Solar Power System Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic generation is an efficient approach for using the solar energy. Solar panels (an array of photovoltaic cells) are nowadays extensively used for running street lights, for powering water heaters and to meet domestic loads. The cost of solar panels has been constantly decreasing which encourages its usage in various sectors. One of the application of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in Kenya. This a green way for energy production which provides free energy once an initial investment is made.

2.9.1 Components of solar power system

Below are the basic components required to produce electricity from the sun, you will need one or more solar panels, a charger controller, a power inverter, and of course, batteries. A brief explanation on each follows.

2.9.1.1 PV Panel array

They supply electricity and charge batteries. A very small system could get away with a couple 80 watt panels.

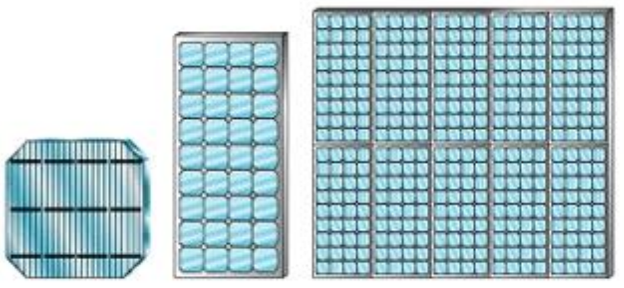


Figure 5 Solar cell, PV solar panel, and PV panel array. (Source: "Guide to Solar Powered Water Pumping Systems in New York State.")

2.9.1.2 Charger controller

Needed to prevent overcharging of the batteries. Proper charging will prevent damage and increase the life and performance of the batteries.

2.9.1.3 Power inverter

This is the heart of the system. It makes 120 volts AC from the 12 volts DC stored in the batteries. It can also charge the batteries if connected to a generator or the AC line.

2.9.1.4 Batteries

They store the electrical power in the form of a chemical reaction. Without storage you would only have power when the sun was shining or the generator was running.

2.9.1.5 Wires and cables

To connect the components of a Solar Energy System, you will need to use correct wire sizes to ensure low loss of energy and to prevent overheating and possible damage or even fire.

2.10 Solar-Powered Water Pumping System

2.10.1 Configurations

There are two basic types of solar-powered water pumping systems, battery-coupled and direct-coupled. A variety of factors must be considered in determining the optimum system for a particular application

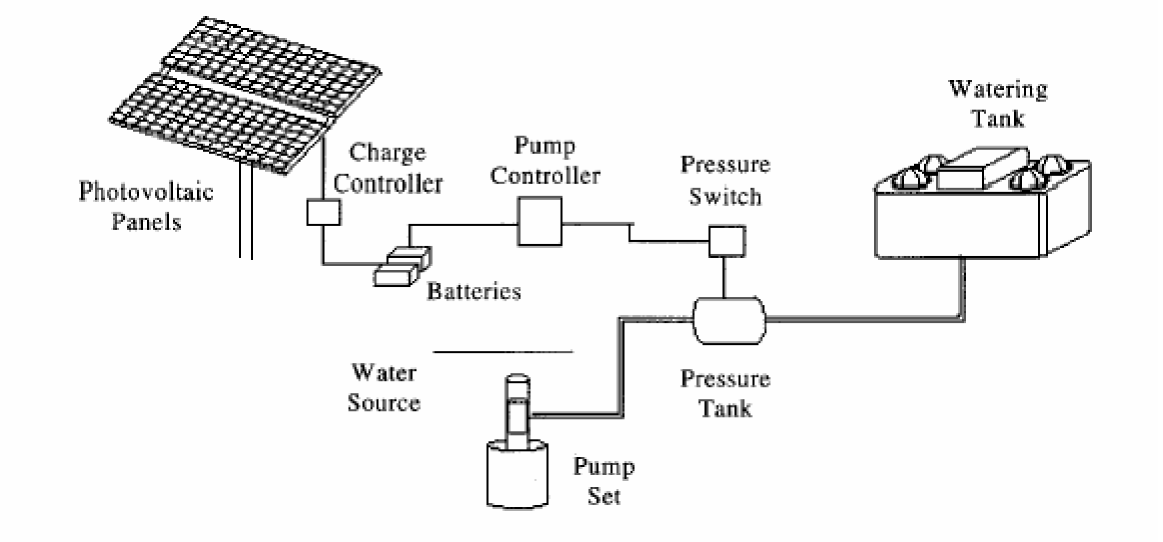


Figure 6 battery-coupled solar water pumping system (source Trakia journal of sciences)

2.10.2 Advantages of solar energy

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, solar energy can be produced free of charge.
- Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
- Solar energy causes no pollution.
- Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
- Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.

- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels.

2.10.3 Disadvantages of solar energy.

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investments.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

2.11 Solar powered water pumps

A solar powered pump is a pump running on the power of the sun. A solar powered pump can be more environmental friendly and economical in its operation compared to pumps powered by an internal combustion engine (ICE). A solar powered pump consists of two parts, namely (a) the actual pump, and (b) the energy source being powered by the sun. It can provide a reliable water supply and eliminate the installation of power lines in environmentally sensitive areas. Because power lines are not needed, there is no need to spray chemicals around the base of poles. Solar-powered pumps rely on photovoltaic (PV) panels or modules—composed of silicone cells connected in parallel or series— which generate electricity when sunshine strikes the surface of the cells.

2.11.1 Examples of solar water pumps

DC water pumps in general use one-third to one-half the energy of conventional AC (alternating current) pumps. DC pumps are classed as either displacement or centrifugal, and can be either submersible or surface types.

- **Displacement pumps**

Use diaphragms, vanes or pistons to seal water in a chamber and force it through a discharge outlet.

- **Centrifugal pumps**

Use a spinning impeller that adds energy to the water and pushes into the system, similar to a water wheel.

- **Submersible pumps**

Placed down a well or sump, are highly reliable because they are not exposed to freezing temperatures, do not need special protection from the elements, and do not require priming. Surface pumps, located at or near the water surface, are used primarily for moving water through a pipeline. Some surface pumps can develop high heads and are suitable for moving water long distances or to high elevations.

2.11.2 Working principles of solar-powered pumps

The process is simple, the pump is submersible and is lowered into the water source and it is powered by a direct drive renewable energy system i.e. Solar panels (PV). The solar panels produce electricity, which is passed through a control unit and can be connected to batteries as well, and this drives the pump. The pump can be powered by wind turbines, solar panels, generators and a combination of some or all three.

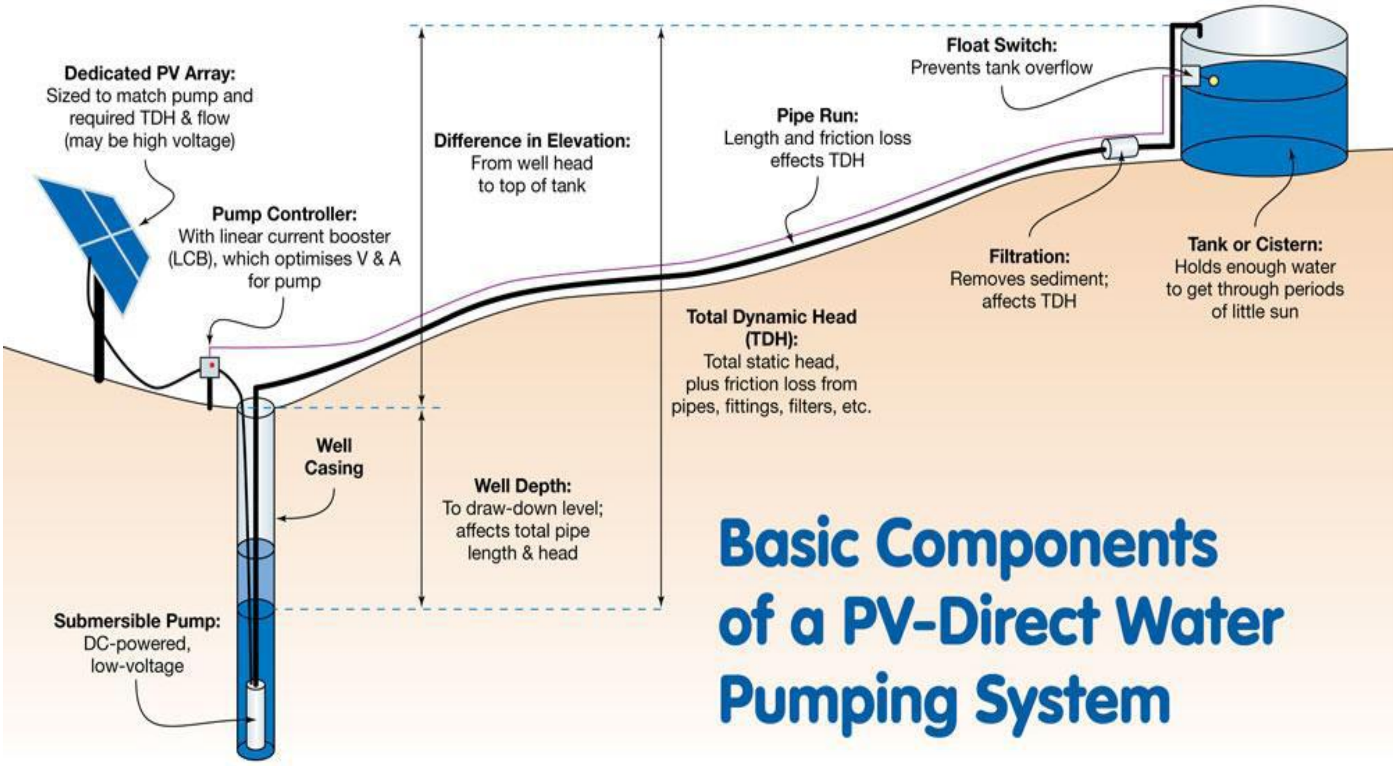


Figure 7 Schematic diagram of solar powered water pump system (source: SPWP systems)

2.11.3 Advantages of solar powered water pumps

- High flow rate of approximately $10m^3/h$ to $15m^3/h$
- They have excellent efficiency
- Lifts up to 240 m
- Simple installation and less Maintenance
- High reliability and life expectancy
- Cost-effective pumping

2.11.4 Disadvantages of solar powered water pumps

- High initial cost of installation
- Repair require skilled labour.

3 THEORITICAL FRAMEWORK

3.1 Orientation and Direction of the PV array

Orientation of the PV array is one of the most important aspects of the site assessment. The PV array is positioned in such a way that the sunlight is utilized to its maximum that is true south direction. The ideal orientation for panels is south as they will be exposed to the Sun for the maximum length of time during daylight hours.

3.2 Determination of Tilt Angle

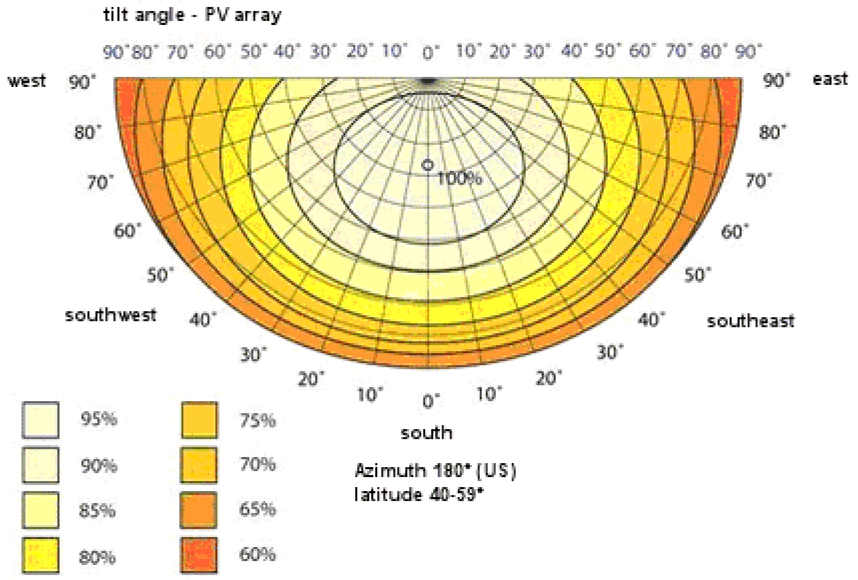


Figure 8 Solar energy yield - optimum tilt angle PV array (source http://www.renewable-energy-concepts.com)

The tilt angle will be selected in accordance with the latitude of the location. Latitude of Narok is 35° 23'E, therefore solar PV array was tilted at this angle with the help of Clinometer. (Refer Appendix A)

Figure 9 Image of Tilt PV module (Source: **IJESI)**

3.3 Sizing and Selection of PV Module

The size of solar system depends on the amount of power that is required (in watts) the amount of time it operates (in hours) and the amount of energy available from the sun in a particular area. The user has control of the first two parameters, while the third depend on the location.

The size of a PV array was calculated by using following equation,

$$E= \frac{g\,H\,V}{3.6\times 10^{6}}$$

Where,

E = hydraulic energy required (kWh/day)

ρ = density of water (1000 kg/m^3)

g = gravitational acceleration (9.81 m/sec^2)

H = total hydraulic head (m)

V = volume of water required (m^3/day)

By putting above all values, equation reduces as shown below;

E=0.002725HV (kWh/day) **…Equation 3.3.1**

The solar array required (kWp) = Hydraulic energy required (kWh/day)/Average daily solar irradiation (kWh/m^2/day×F×E)

$E_s = \frac{E_h}{Av.I_{s \times F \times E}}$ **…Equation 3.3.2**

Where,

F- Array mismatch factor=0.85 on average

E- Daily subsystem efficiency=0.25 – 0.40 typically

3.4 Design population and daily water demand

Design population was arrived using the geometric growth model functions as shown below:

$p_n = p_o(1 + r)^n$ **…Equation 3.4.1**

Where p_n= population after n years

p_o= present population

r = percentage rate of growth per unit time

n = length of time for which the projection is made

In Kenya, expected increase in population is 3.0% per year, that is, r = 3.0% per year.

To determine the water demand, the average daily water requirement called per capita water consumption and the design population was used.

The daily water demand was calculated using the formula:

$Q = CP \times DP$ **…Equation 3.4.2**

Where:

Q =daily water demand (m^3/day)

CP= per capita consumption per day

DP=design population

3.5 Total differential head

The operating pressure of the system is a function of the flow through the system and the arrangement of the system in terms of the pipe length, fittings, pipe size, the change in liquid elevation, pressure on the liquid surface, etc. To achieve a required flow through a pumping system, we need to calculate what the operating pressure of the system will be to select a suitable pump.

The operating pressure or the total system head is defined as:

$H_{Total} = H_s + H_D + PR\ T - PR\ ES$ **…Equation 3.5.1**

Where,

$H\ s$ = Static head (m)

$H\ D$ = Dynamic head (m)

$PR\ T$ = Pressure on the surface of the water in the receiving tank (m)

$PR\ ES$ = Pressure on the surface of the water in the reservoir (m)

Although the atmospheric pressure changes with height, the change in pressure that occurs over the pumping height is often so small that it can be considered negligible. In this exemplar, the change in pressure over the elevation from the reservoir to the receiving tank is not that significant and hence is negligible, i.e.

$PR\ T - PR\ ES$ » 0

Therefore, equation (1) becomes:

$H_{Total} = H_s + H_D$ **…Equation 3.5.2**

The static head $H\ s$ is the physical change in elevation between the surface of the reservoir and the point of discharge into the receiving tank.

The dynamic head is generated as a result of friction within the system. The dynamic head is calculated using the basic Darcy Weisbach equation given by:

$H_D = \frac{K}{2g} \times v^2$ **…Equation 3.5.3**

Where

K = loss coefficient

v = velocity in the pipe (m/sec)

g = acceleration due to gravity (m/sec^2)

The loss coefficient *K* is made up of two elements:

K = *K* fittings + *K* pipe … (5)

K fittings is associated with the fittings used in the pipework's of the system to pump the water from reservoir to the receiving tank. Values can be obtained from standard tables and a total *K* fittings

K pipe is associated with the straight lengths of pipe used within the system and is defined as:

$K_{pipe} = \frac{fL}{D}$ **…Equation 3.5.4**

Where

f = friction coefficient

L = pipe length (m)

D = pipe diameter (m)

3.6 Selection of pump

The pump to be selected should obey the following principles.

First affinity law – Flow is proportional to the shaft speed, i.e.

$\frac{Q1}{Q2} = \frac{N1}{N2}$ **…Equation 3.6.1**

Where

Q = Flow through the pipe (m^3 /sec)

N = Shaft speed (rpm)

Second affinity law – Head is proportional to the square of the shaft speed, i.e.

$\frac{H1}{H2}=N1^2/N2^2$ **…Equation 3.6.2**

Where

H = Head (m)

The power requirement for the pump can be calculated by:

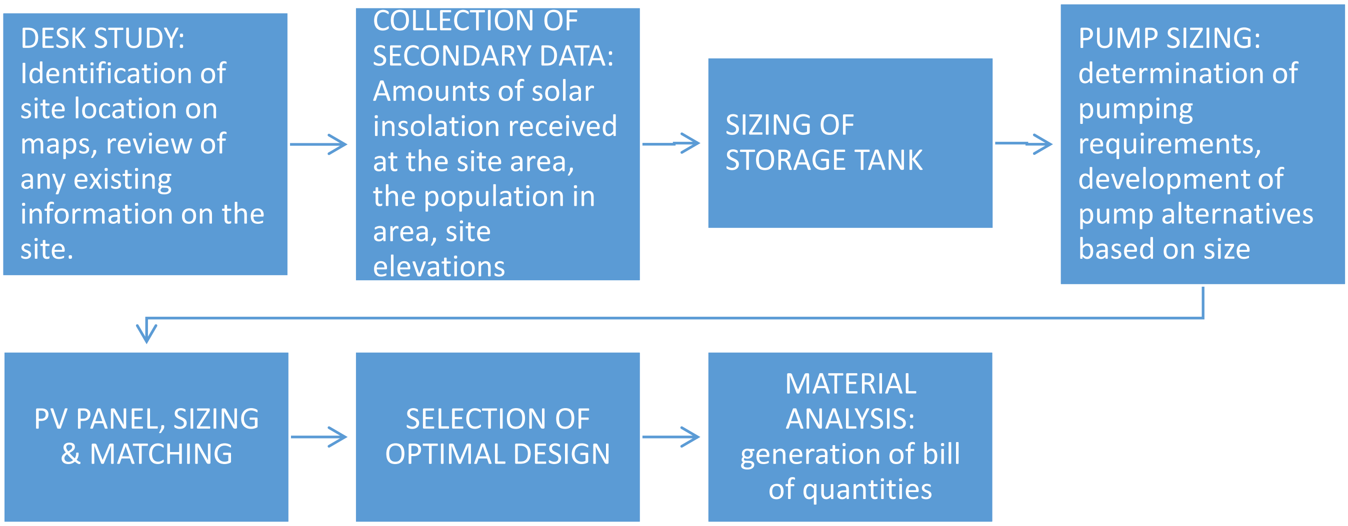
$P=\frac{Q \times g \times p}{pump\ efficiency}$ **….Equation 3.6.3**

Where

P = Power (W)

4 METHODLOGY

4.1 A flowchart demonstrating the concept design process.



4.2 Site evaluation for solar installation.

A site investigation visit was done to confirm whether the project site was suitable for solar installation. A suitability guideline was used in the evaluation process as shown in the (appendix B). Mean daily solar irradiation of the site was obtained from Kenya Meteorological department which was compared to those generated by use of FAO'S CLIMEWAT database for five year period.

4.3 Materials and methods

The set of data inputs used for this design project are:-

1. Climatic data of Narok County (Solar insolation, topography, Rainfall pattern, economic and social activities) from the Kenya meteorological Department

2. Spatial / geographical data for a comprehensive analysis of the site

4.3.1 Climatic Data

Materials used: Campbell stokes sunshine recorder.

- *Climatic data*

Describing the area's monthly levels of solar insolation, topography, Rainfall pattern, social and economic activities, atmospheric pressures and cloud cover will be sourced from The Kenya Meteorological Department (Narok Agromet) and from Kilgoris Agromet.

- *Spatial/ Geographic Data*

Materials used: Global Positioning System (GPS) Receiver, ArcGIS/ QGIS software, Topographical map of Narok.

During a visit to the site, a GPS receiver was used to obtain the spatial attributes of the area in relation to the area's elevation above sea level and its geographical and projected (UTM) coordinates. Waypoints was taken at an interval of 50metres along the border of the location for the purpose of mapping it on the GIS platform.

4.4 Storage tank elevation

The head associated with difference in elevations was determined by use of Google earth where a path was drawn across the site and the elevation profile was generated. The difference in the highest and the lowest point was the head. Total head requirement was obtained by summing all the friction losses and the difference in elevation. This lead to determination of the storage tank elevation.

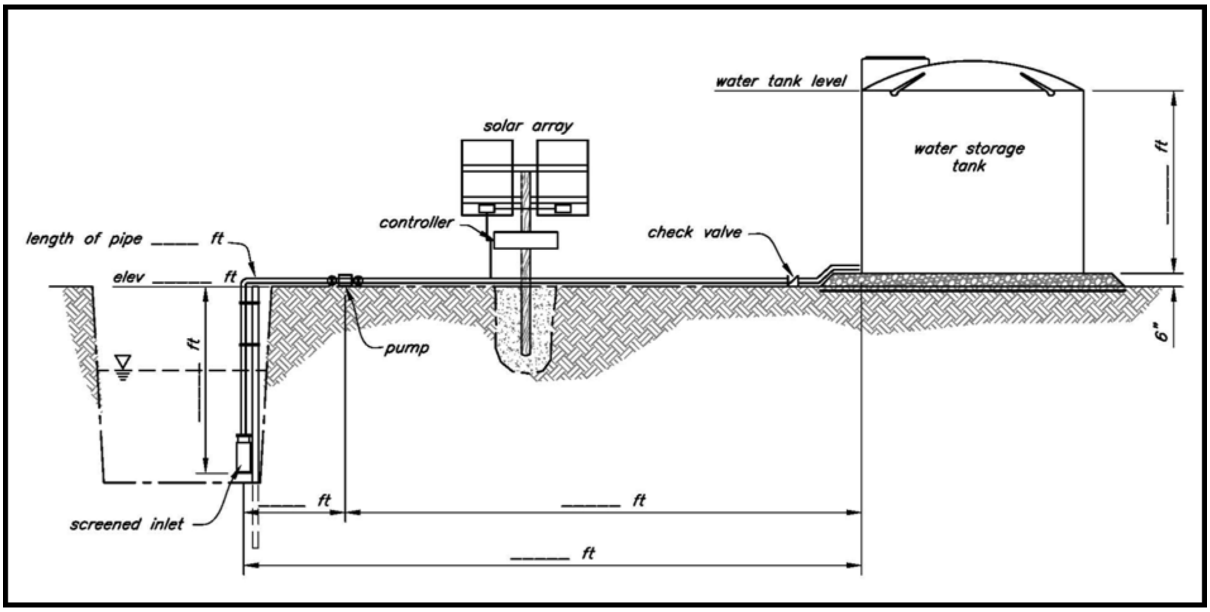


Figure 10 Typical surface installation with pertinent parameters. (Source: "Guide to Solar Powered Water Pumping Systems in New York State.'')

4.5 Selecting the most suitable solar water pump available in the market

The solar water pump type and size selected met the specifications to pump water to an elevated tank. It was selected based on the solar irradiation of the site, flow rate required and the pumping elevation. Specification sheet prepared by solar water pump manufacturer was adopted during the selection.

5 RESULTS AND ANALYSIS

This section reports all findings of the research undertakings that were analysed.

Solar radiation data were collected from Kenya Meteorological Department as shown in Appendix C.

5.1 The tilt angle

Various angles representing typical roof pitches were compared to that of the latitude angle (the optimum angle) to determine if using a typical roof slope would make any difference in the effectiveness of the solar water pumping system. ***(oloo, 2013)***

Narok town coordinates are 0.45°S and 35.23°E with an elevation of 1,850 m. Based on the Narok location the ideal array tilt would be 0.45 degrees and face north at zero degrees.

A PV-Watts analysis was conducted to determine approximate solar insolation. Data was collected was for fixed tilt panels using single tracking systems. Of the towns analysed, Narok town is the closest to my site and have similar climate. Therefore, Table 4 shows solar radiation data for the Narok town for an array at latitude as compared to one at various roof pitches.

Table 2 data for fixed panels at various roof-pitches in Narok

Elevation/slope(Degrees)	Array Type	Direction	Solar radiation kwh/m2/day
4/12	Fixed	North (0)	4.65
5/12	Fixed	North (0)	4.44
6/12	Fixed	North (0)	4.42
7/12	Fixed	North (0)	4.25
8/12	Fixed	North (0)	4.14

9/12	Fixed	North (0)	3.98
10/12	Fixed	North (0)	3.45
11/12	Fixed	North (0)	3.38
12/12	Fixed	North (0)	3.16

The data points ranged from 3.16 to 4.65kWh/m2/day, therefore the mean solar radiation the above different elevation is,

Mean solar radiation= $4.65 + 4.44 + 4.42 + 4.25 + 4.14 + 3.98 + 3.45 + 3.38 + 3.16/_{9}$

=3.986

The above value correspond to an elevation/slope of 0.75 which gives the recommended angle of tilt of the PV panel, when the north direction is fixed. (Refer to Appendix A)

5.2 Flowrate/Discharge

The population data was obtained from population census results. The population for Ewaso N'giro, was 2500 people. Kenya's population growth rate is 3% per annum.

Therefore:

present population p_o= 2500 persons.

Population growth rate (r) =3%

Design period = 20 years.

Therefore, design population, $p_n = p_o(1 + r)^n$

p_n=$2500(1 + 0.03)^{20}$

= 4516 persons

Therefore design population =4516 persons

the daily water demand was calculated using the formula:

$$Q = CP \times DP$$

Where:

Q =daily water demand (m^3/day)

CP= per capita consumption per day

DP=design population

Substituting a daily water requirement of 30 litres of per person per day (WHO guidelines aim for a per capita provision of 30 to 50 litres per day for domestic use only) in equation above we have

Q= 40 x 4516 =180640 litres per day.

= 180.64m^3/day

using the sunshine data from the area, the minimum hours of the sunshine are 5 hours, which is used in the design.

Discharge capacity = Q_d/T_s

Where;

T_s=hours of supply.

Q_d= Design discharge.

Substituting equation with the above values it results,

180.64 /5= 36.128 m^3/day/hour.

Therefore,

Q=36.128 m^3/day/hour.

$Q = \frac{36.128}{3600} = 0.0100356\ m^3$/day/sec

5.3 Sizing of the storage tank

Overhead storage tank will have a minimum capacity of,

The pump will operate during sunshine hours in a day. The minimum hours of the sunshine are 5 hours.

$volume\ of\ the\ tank = 36.128 \times 5 \times 1 = 180.64 m^3$

$180.64 \times 1000 = 180640 litres$

Tank selected = Masonry tank with a capacity of 19000L (470cm high and diameter of 360 cm)

5.4 Total differential head

5.4.1 Static head (H_s)

If the discharge point is at a level of 110.5 m above the mean sea level (also known as ***Above Ordnance Datum (AOD)*** in technical language) and the reservoir level varies between 95.5m AOD and 100.5 m AOD, then:

The maximum and minimum vertical linear distance between the delivery outlet and the water level (where the pump is to be fixed) is

H_{s-max} =110.5m – 95.5m = 15m

H_{s-min}=110.5m – 100.5m =10m

5.4.2 Dynamic head ($\boldsymbol{H_D}$)

The dynamic head is generated as a result of friction within the system.

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)

The dynamic head is calculated using the basic Darcy Weisbach equation given by:

$$H_D = \frac{K}{2g} \times v^2$$

Where

K = loss coefficient

v = velocity in the pipe (m/sec)

g = acceleration due to gravity (m/sec^2)

We can calculate the velocity in pipe using the following formula:

$$V = \frac{Q}{A}$$

Where,

Q = flow rate through the pipe (m^3//sec)

A = pipe cross sectional area (CSA) (m^2)

5.5 Pipe size selection

The pipe diameter that was selected was 10cm.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 ***(Shirtliff, 2014)***

(See Appendix F)

Using a pipe of diameter 10cm, the above equation reduces to

$V = \frac{0.0100356\ m^3/\text{day/sec}}{(\pi\times0.05^2)}$ =1.278 m/sec

Therefore, the dynamic head reduced to,

$H_D=\frac{K}{2g}\times v^2 = \frac{K\times1.278^2}{2\times9.81}$=0.08325k

The loss coefficient *K* is made up of two elements:

K = *K* fittings + *K* pipe

K fittings is associated with the fittings used in the pipework's of the system to pump the water from reservoir to the receiving tank. Values were obtained from standard tables and a total *K* fittings. Values were calculated by adding all the *K* fittings values for each individual fitting within the system. The following table shows the calculation of *K* fittings for the system under consideration.

Table 3 K fittings used in pipework's

Fitting Items	**No. of Items**	*K* fittings **Value**	**Item Total**
Pipe Entrance (bell mouth)	1	0.05	0.05
90 o Bend (short radius)	10	0.75	7.5
45 o Bend (short radius)	2	0.3	0.6
Butterfly Valve (Fully Open)	2	0.3	0.6
Non Return Valve	1	1.0	1.0

Bellmouth Outlet	1	0.2	0.2
Total *K* fittings **Value**			9.95

Hence, the total *K* fittings for the system under consideration is 9.95.

K pipe is associated with the straight lengths of pipe used within the system and is defined as:

$K_{pipe} = \frac{fL}{D}$

Where

f = friction coefficient

L = pipe length (m)

D = pipe diameter (m)

The friction coefficient *f* can be found using a modified version of the Colebrook White equation:

$f = \left(\frac{0.25}{\log\left[\frac{k}{3.7 \times D} + \frac{5.74}{Re^{0.9}}\right]}\right)^2$

Where,

k = Roughness factor (m)

Re = Reynolds number

Reynolds number is a dimensionless quantity associated with the smoothness of flow of a fluid and relating to the energy absorbed within the fluid as it moves. For any flow in pipe, Reynolds number can be calculated using the following formula:

$Re = \frac{ÞVD}{\mu}$

Where,

Þ = Fluid density (kg/m3)

V= velocity in the pipe (m/sec)

D= diameter of the pipe (m)

u = Kinematic viscosity (m 2 /s)

Kinematic viscosity of water at room temperature is 1.31×10^{-6} m2/ sec

$$Re = \frac{þVD}{\mu} = \frac{1 \times 1.278 \times 0.1}{1.31 \times 10^{-6}} = 9.756 \times 10^{4}$$

The pipe roughness factor *k* is a standard value obtained from standard tables and is based upon the material of the pipe, including any internal coatings, and the internal condition of the pipeline i.e. good, normal or poor.

Table 4 pipe materials and common pipe roughness values

Material	k (mm)	k (inches)
Concrete	0.3 - 3.0	0.012 - 0.12
Cast Iron	0.26	0.010
Galvanized Iron	0.15	0.006
Asphalted Cast Iron	0.12	0.0048
Commercial or Welded Steel	0.045	0.0018
PVC, Glass, Other Drawn Tubing	0.0015	0.00006

Using a modified version of the Colebrook White equation to obtain the friction coefficient,

$$f = \left(\frac{0.25}{\log[\frac{k}{3.7 \times D} + \frac{5.74}{Re^{0.9}}]}\right)^{2}$$

$$f = \left(\frac{0.25}{\log[\frac{1.5 \times 10^{-6}}{3.7 \times 0.1} + \frac{5.74}{9.756 \times 10^{4^{0.9}}}]}\right)^{2} = 0.004114$$

Given the length of the pipe as 100m and the diameter of the same as 0.05m then, *K* pipe is given

$K_{pipe}=\frac{fL}{D}=\frac{0.004114\times100}{0.1}=4.114$

Finally, the total *K* value for the system is:

K=4.114 +9.95=14.064

We can now calculate the dynamic head as follows:

$H_D=\frac{K}{2g}\times v^2=H_D=\frac{14.064\times1.278^2}{2\times9.81}$=1.1708m

Hence the maximum and minimum total differential head is.

$H_{total-max}$ =15m+1.1708=16.1708m

$H_{total-min}$ =10m+1.1708=11.1708m

5.6 Sizing and Selection of PV Module

The size of a PV array was calculated by using following equation,

$E=\frac{g\,H\,V}{3.6\times10^6}$

Where,

E = hydraulic energy required (kWh/day)

ρ = density of water (1000 kg/m^3)

g = gravitational acceleration (9.81 m/sec^2)

H = total hydraulic head (m)

V = volume of water required (m^3/day)

By putting above all values, equation reduces as shown below;

E_{max}=0.002725×16.1708×$0.0100356\times3600=1.59200$ (kWh/day)

E_{min}=0.002725×11.1708m×$0.0100356=1.09975$ (kWh/day)

The solar array required (kWp) = Hydraulic energy required (kWh/day)/Average daily solar irradiation (kWh/m²/day×F×E)

$E_{s\,max}=\frac{E_{h\,max}}{Av.I_{s\times F\times E}}=\frac{1.59200}{0.6803\times 0.85\times 0.325}$=8.471109 (kWh/day)

$E_{s\,min}=\frac{E_{h\,min}}{Av.I_{s\times F\times E}}=\frac{1.09975}{0.6803\times 0.85\times 0.325}=5.851823$ (kWh/day)

Where,

F- Array mismatch factor=0.85 on average

E- Daily subsystem efficiency=0.25 – 0.40 typically=mean=0.325

$Av.I_s$ –average daily solar irradiation of Narok from 2008 to 2013, which resulted from computing the data provided. This is shown in (Appendix C)

$Av.I_s=\frac{1020.5}{50\times 30}=0.6803$ (KWh/m²/day)

$E_{s\,mean}=\frac{E_{s\,max}+E_{s\,min}}{2}=\frac{8.4711+5.8518}{2}$=7.16145 (KWh/day)

Assuming, actual sunshine hours= 5 hrs in a day

Total wattage of PV panel= 7161.45/ 5 = 1432.29 W

Number of solar panels required= 280W panel each × 6 panels = 1680W power

The panel model that was selected was YL280 with a rated power of 280W, open circuit voltage of 45V and short circuit current of 8.35A (Refer to Appendix H).

The size of each battery needed is 2800 Watt hours divided by 45Volts = 62 Amp Hours of reserve battery power.

2800 / 45= 62.22A

Larger size batteries were selected, 70 Amp hours capacity each, giving a total of 420A hours.

The solar charge controller selection

Solar charger controller rating = Total short circuit current of PV array×1.3

$8.35 \times 1.3 = 10.855$ A

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.

(See Appendix H)

5.7 Pump power requirement

The power requirement for the pump can be calculated by:

$$P = \frac{Q \times g \times p \times H}{pump\ efficiency}$$

Assuming a pump efficiency of 70%

$$P = \frac{0.0100356 \times 13.6708 \times 9.81 \times 1000}{0.7} = 1922.685W$$

Where

P = Power (W)

5.8 Pump selection

Should meet the following specifications. Specification sheet prepared by solar water pump manufacturer was adopted during the selection.

Flowrate, Q=36.128 m^3/day/hour.

$Total\ differential\ head, H_{total-mean}$ = 13.6708m

Pump power required, P=1922.685w

Table 5 photovoltaic pumping system specifications

Motor pump/ Configuration	Output (m³/day/hr)	Head (m)	Solar Array (W)	System Price US$ FOB
Submersible Motor pump-Lorentz centrifugal solar pump	40 25	20 20	2000 1200	2000-2500 6000-7000
Surface motor/ submerged pump	60	7	840	1500-2000
Reciprocating positive displacement pump	6	100	1200	2500-3000
Floating motor/pump set	100 10	3 3	530 85	2000 1000
Surface suction pump	40	4	350	1500

6 COST ESTIMATES

Table 6 the cost estimates of the design system

PVC pipe D100 @ Sh 106 per meter	100 m	Sh 10600
YL280W solar panel @Sh 28800 each (VAT excluded)	6	Sh 172800
SUNDAYA APPLE 15A charge controller @ Sh 5200 (VAT excluded)	6	Sh 31200
Converter 240V @ Sh 20000	1	20000
Submersible motor pump-Lorentz centrifugal solar pump	1	Sh 239400
	TOTAL	Sh 474000

6.1 Cost benefit analysis

Key outputs:

Initial capital cost: “first cost” for each option – assumes same pump costs

Operation cost/year: Average O&M costs per year. Does not include pump replacement costs which would be same for both.

Net Present Cost: The present value of the cost of installing and operating the system over the lifetime of the project (also referred to as lifecycle cost).

$ Per kilowatt: The cost per kilowatt of electricity per each option.

Table 7 the cost benefit analysis of solar and diesel pumping systems

systems	Initial capital cost(sh)	Fuel cost/litre(sh)	Consumption rate/ kilowatts/day	Operating cost/year(sh)	O$M cost in 20years	Total NPC(sh)
Solar pumps	474000			33500	670000	1144000
Diesel pumps	100000	87.04	3 litres=3×1.922w/day	190617.6	3812352	3912352

The net benefit over the design period of 20 years was found to be,

$Net\ benefit = 3912352 - 1144000$ =sh.2768352

=2.77millions Kenyan shillings

Therefore, solar pumping system is the most economical choice over design period of 20years.

7 DISCUSSION

The data analysis that was done yielded the following results:

The mean solar radiation of 3.986 which corresponds to an elevation/slope of 0.75 which gives the recommended angle of tilt of the PV panel, when the north direction is fixed.

The population data was obtained from population census results. The population for Ewaso N'giro, was 2500 people. Kenya's population growth rate is 3% per annum. Giving an approximate population of 4516 in 20years.The sunshine data from the area suggest that, the minimum hours of the sunshine are 5 hours, which gives a flow rate of

180.64 /5= 36.128 m^3/day/hour.

The daily water requirement is 30 litres per person per day (WHO guidelines aim for a per capita provision of 30 to 50 litres per day for domestic use only) this then resulted an average use of 40 litres per day.

The average total differential head was 13.671m and Total wattage of PV panel= 7161.45/ 5 = 1432.29 W

Number of solar panels required= 280W panel each × 6panels = 1680W power

The panel model that was selected was YL280 with a rated power of 280W, open circuit voltage of 45V and short circuit current of 8.35 A. The size of each battery needed is 2800Watt hours divided by 45 Volts = 62 Amp Hours of reserve battery power.

2800/ 45 = 62.22A

Larger size batteries were selected, 70 Amp hours capacity each, giving a total of 420A hours. The solar charge controller selection was found to be,

Solar charger controller rating = Total short circuit current of PV array×1.3

$8.35 \times 1.3 = 10.855$ A

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.

The power requirement for the pump was found to be 1922.685w

The Cost of the entire system was found to be Sh 454000. And the cost benefit analysis between diesel pump system and solar pump systems resulted the net benefit over the design period of 20 years of sh.2788352=2.77million shillings.

There were some assumptions that were made such as: the pump efficiency was 70% and the Kenya’s population growth rate is 3% per annum.

8 CONCLUSION

The objectives of the design project were met. The review of existing climatic data on the site as well as the pumping requirements of the available solar pumps in the market reveals solar power as an alternative source of energy, and a viable solution for the water abstraction problems experienced by the local people in Ewaso N'giro village.

The solution offered was that of a SMP 1950, 45V pump powered by 6YL280 solar panels each with a power rating of 280W operating for 5 hours a day and fitted with 15 Amp solar charge controller.(Refer Appendix M)

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.

9 RECOMMENDATION

In order to distribute water fairly to the rural community, it is recommended to first pump it to a storage facility and then distribute it by gravity. This way, enough pressures can be built up at the storage tank to facilitate water distribution by gravity. In addition, water will continuously flow in the tank, which helps to reduce growth of bacteria.

To fully implement the design, the following are recommended;

- In order to better design the system first hand data is needed and ground reconnaissance is encouraged.
- Water demand for the entire county should be done to observe how it will affect the existing water abstraction techniques therefore encouraging implementation of solar powered systems structures.
- Alternative techniques for water abstraction in area should be investigated.
- Feasibility studies should be carried out to identify suitable sites and therefore make use of solar powered system for water abstraction.
- Feasibility studies for the replacement of diesel pumps with solar pumps should be conducted. (Refer Appendix J)
- To ascertain the economic feasibility of the project, a cost benefit analysis should be done.

10 WORK PLAN

Schedule of Activities

Task Name	Start	Finish	Duration		1st Semester 2015			2nd Semester 2016			
				Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Identifying suitable project	9/25/15	10/2/15	7 Days								
Preparation of concept note	10/12/15	10/16/15	4 Days								
preparation of project proposal	10/23/15	11/10/15	18 Days								
preparation and presentation of project proposal	11/11/15	11/20/15	9 Days								
Data collection	11/23/15	1/8/16	46 Days								
Final report development	1/11/16	3/1/16	50 Days								
Preparation and defence of the project	3/2/16	3/25/16	23 Days								
preparation and handing in of the Final report	3/28/16	4/15/16	18 Days								
Logbook development	9/25/15	4/15/16	204 Days								

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12 APPENDICES

12.1 Appendix A

12.2 Appendix B

Evaluation	Yes	No
Is your site accessible?	✓	
Is your site highly populated?	✓	
Is there a reliable source of water?	✓	
Is the mean solar irradiation of your site 4.5kwh/m2	✓	
Is your site located in a conservation area or in an area of natural beauty (AONB)?		✓
Is the distance between your chosen solar system installation point and the nearest obstacle more than twice your proposed grid height?	✓	
Do you intend to mount your solar system to a roof of a dwelling?		✓

12.3 Appendix C

Radiation; total downward	1995	236.32	226.06	233.46	212.15	189.37	189.86	170.01	197.13	198.07	198.69	215.97	199.6	205.5575
Radiation; total downward	1996	224.75	223.47	220.63	220.22	182.87	154.98	170.49	206.39	214.89	227.94	177.06	238.3	205.1658
Radiation; total downward	1997	219.02	242.01	227.3	192.43	186.45	187.65	183.43	210.15	244.73	206.12	184.61	194.99	206.5742
Radiation; total downward	1998	192.3	212.67	242.54	193.53	155.41	162.76	137.19	164.42	212.92	219.53	204.29	233.92	194.29
Radiation; total downward	1999	224.63	245.22	198.29	20.73	193.88	184.14	179.4	162.06	211.88	211.95	192.86	218.71	186.9792
Radiation; total downward	2000	248.81	236.18	230.88	210.8	197.84	174.42	168.54	190.54	206.34	206.53	182.74	213.58	205.6
Radiation; total downward	2001	166.97	258.46	224.65	193.72	179.08	178.06	172.99	196.98	214.22	195.05	199.56	207	198.895
Radiation; total downward	2002	200.53	216.41	225.39	198.2	174	180.91	197.53	181.38	222.62	210.68	193.92	198.17	199.9783
Radiation; total downward	2003	244.82	235.4	239.25	202.29	169.42	174.19	183.34	164.8	192.68	208.47	185.73	188.27	199.055
Radiation; total downward	2004	202.37	189.02	209.25	192.45		183.77	203.27	197.4	208.01	193.83	210.34	206.48	199.6536
Radiation; total downward	2005	225.16	239.22	219.98	202.09	189.45	162.38	174.35	193.53	191.45		215.65	234.52	204.3436
Radiation; total downward	2007	22.42	22.03	24.16	22.02	18.86	16.19	15.7	17.75	20.7	22.16	20.92	21.82	20.39417
Radiation; total downward	2008	22.58	22.75	20.96	21.35	19.86	18.22	16.71	17.52	20.6	19.87	23.06	24.1	20.63167
Radiation; total downward	2009	21.73	23.12	24.52	19.9	18.83	20.15	20.36	19.08	21.34	18.68	19.7	20.59	20.66667
Radiation; total downward	2010	22.72	21.63	20.98	21.15	18.06	17.21	17.25	17.73	19.18	19.86	19.83	20.75	19.69583
Radiation; total downward	2011	24.01	22.28	21.45	22.15	19.05	16.31	19.02	16.63	19.31	19.64	19.13	20.39	19.9475
Radiation; total downward	2012	24.56	22.93	23.86	17.67	17.44	16.66	16.23	18.71	20.97	26.62	20.18	19.08	20.40917
Radiation; total downward	2013	22.26	23.53	21.39	18.83	18.87	17.89	18.99	17.87	17.54	17.7	18.98	19.07	19.41

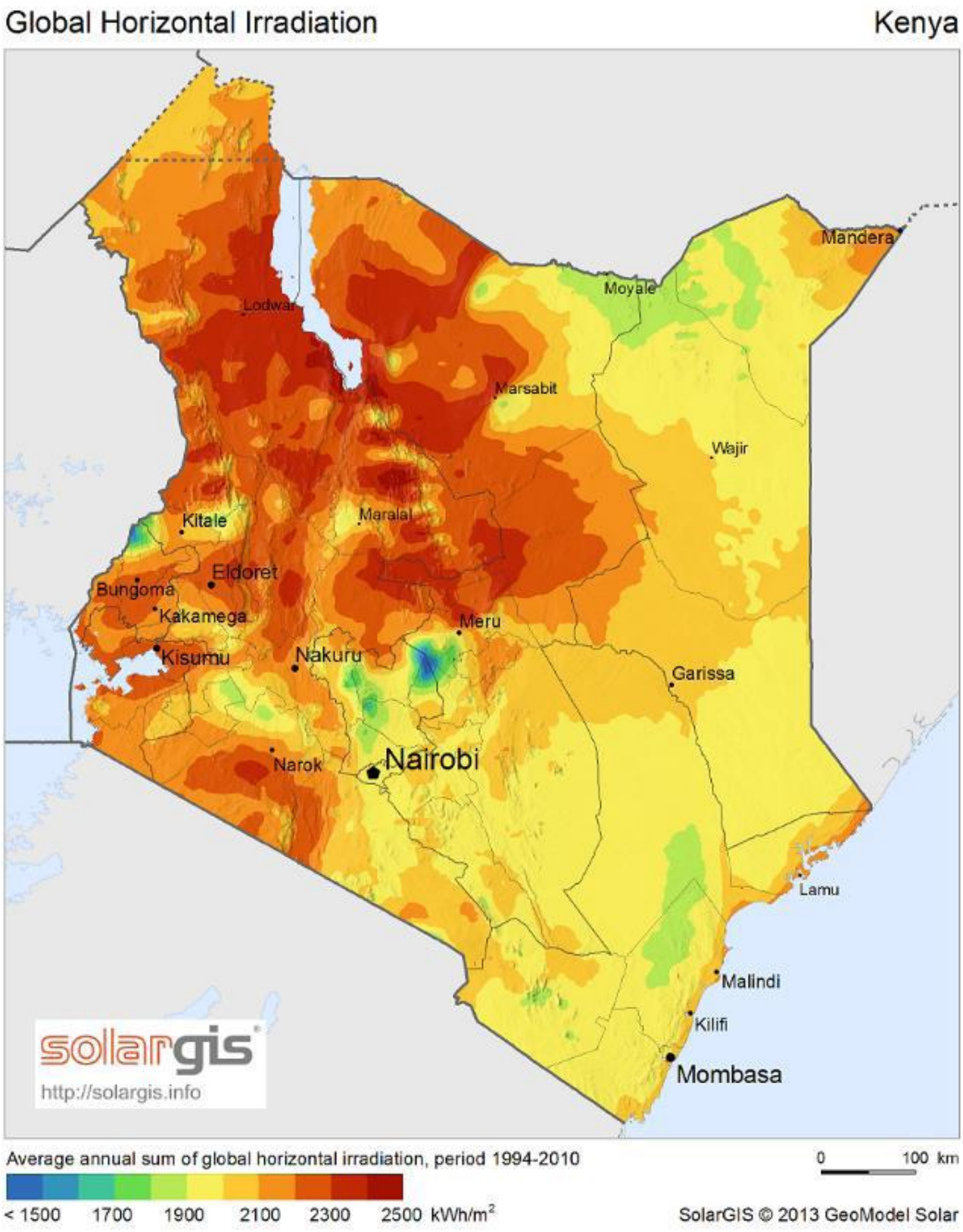
Solar radiation of Narok since 1995 to 2013 (Kenya meteorological department)

12.4 Appendix D

Precipitation; monthly total	1995	39.7	56.2	141.6	66.3	142.8	32.9	7	24.2	61	19	38.2	34.3	55.26667
Precipitation; monthly total	1996	81.7	124.2	140.6	85.9	18.2	113.8	89.2	35.8	25.3	8.8	52.5	40.1	68.00833
Precipitation; monthly total	1997	37.1	6.3	54.9	247.6	144.1	26.6	9.1	34.5	10	38.8	254.3	126	82.44167
Precipitation; monthly total	1998	205.6	172.9	13.9	131	191.8	61.2	3.3	31.5	40.7	10.5	27.6	0.9	74.24167
Precipitation; monthly total	1999	37.5	5.2	291.5	64.8	21.7	3.9	2.9	23.5	20.1	9.5	73	102.5	54.675
Precipitation; monthly total	2000	17.6	18	60.5	71.3	18.7	2.4	4.6	11.4	15.1	9.3	143.9	86.8	38.3
Precipitation; monthly total	2001	232.9	80	56.1	136	26.2	22.6	51.5	24.2	21.3	33.1	19.3	35.6	61.56667
Precipitation; monthly total	2002	166.1	59.2	95	120.6	140.4	2.9	9.6	10.1	12.2	47.6	186.7	194.8	87.1
Precipitation; monthly total	2003	103.6	73	54.9	156.4	261.4	8.6	2.5	79.3	8.9	19.9	22.1	15.4	67.16667
Precipitation; monthly total	2004	23.5	74.3	123.5	234.3	0	3.2	0	0	189.8	1.5	28.1	81.8	63.33333
Precipitation; monthly total	2005	22.8	45.4	116.2	81.7	126.3	7.8	21.2	12.5	7.6		23.3	13.6	43.49091
Precipitation; monthly total	2007	105.9	143.2	61.4	89.9	97.2	25.6	10.1	22.4	69.4	9	30.3	39.7	58.675
Precipitation; monthly total	2008	8.6	99	174.7	88.9	7.8	1.4	9.2	23.1	35.1	57.2	86.3	1.6	49.40833
Precipitation; monthly total	2009	52.9	24.4	22.9	106.2	107.7	36.7	0.5	3.1	17.2	33.7	53.5	123.8	48.55
Precipitation; monthly total	2010	141.3	103.4	93.3	69.4	113.9	12.1	5.1	38.2	61.6	49.2	69.3	38.1	66.24167
Precipitation; monthly total	2011	68.5	34.9	128.9	15.9	54.8	33.1	19.6	47.9	89.3	174	143.6	147.4	79.825
Precipitation; monthly total	2012	2.7	39.5	43.8	208	87.4	8.6	28.6	53.8	3.6	17.3	76.9	198.5	64.05833
Precipitation; monthly total	2013	63.4	73.6	103.4	240.7	53.4	2.7	16.4	14.9	13	12	0	0	49.45833

Rainfall pattern of Narok as from 1995 to 2013 (source Kenya meteorological department)

12.5 Appendix E



12.6 Appendix F

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
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

actual Inside Diameter (inches)

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"

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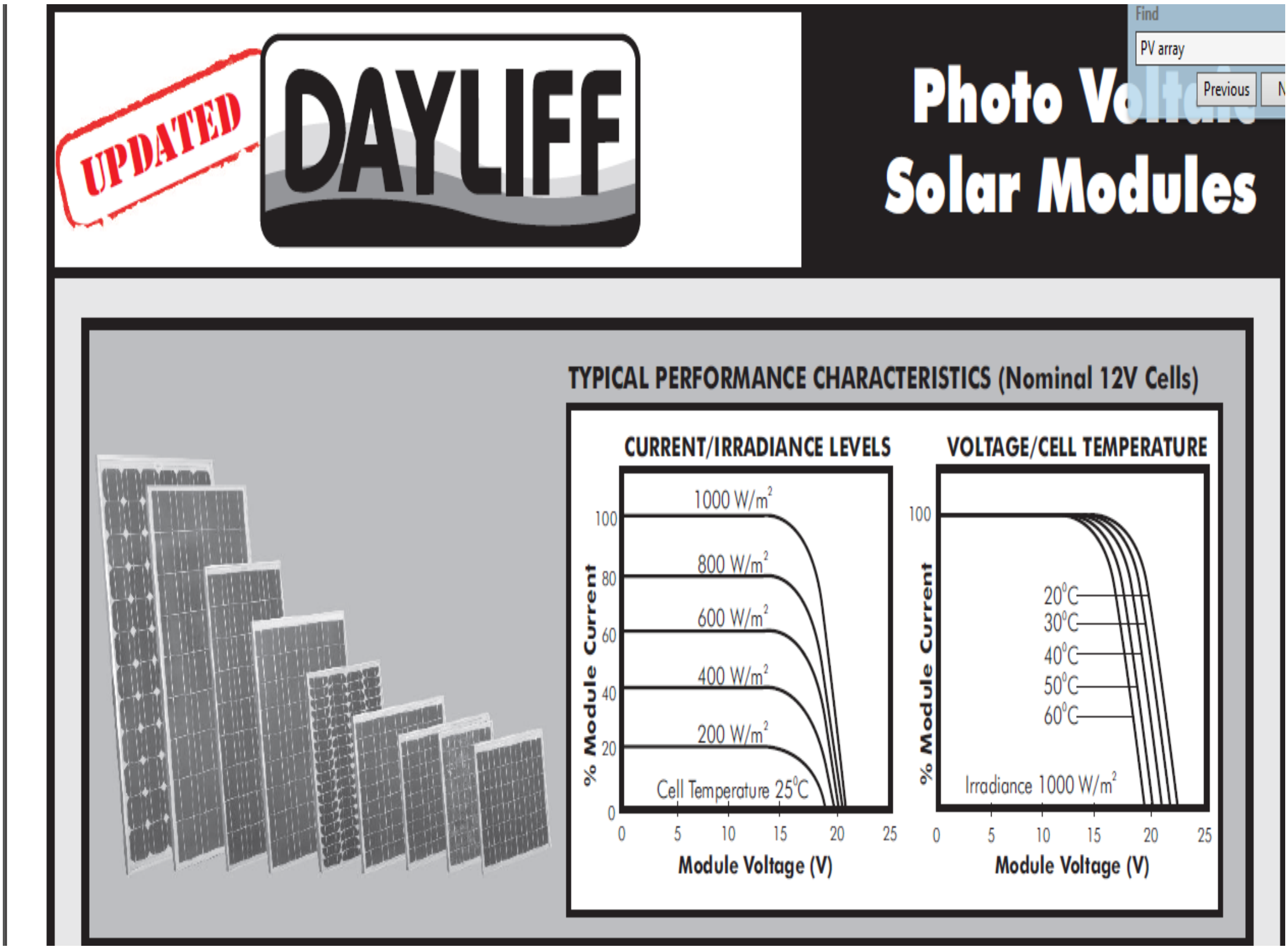
Since 1983

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)

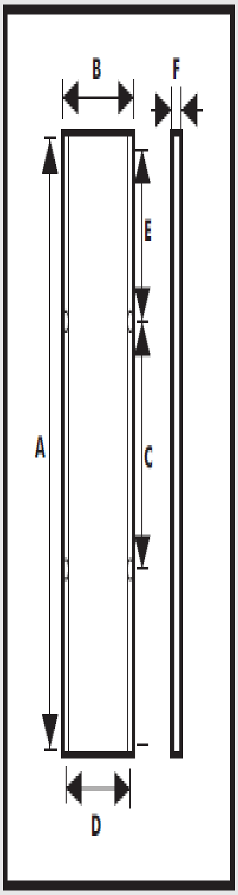
12.7 Appendix G



12.8 Appendix H

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)						Weight (kg)
								A	B	C	D	E	F	
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



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

12.9 Appendix I

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

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

12.10 Appendix J

Figure 11 Feasibility studies for the replacement of diesel pumps with solar pumps

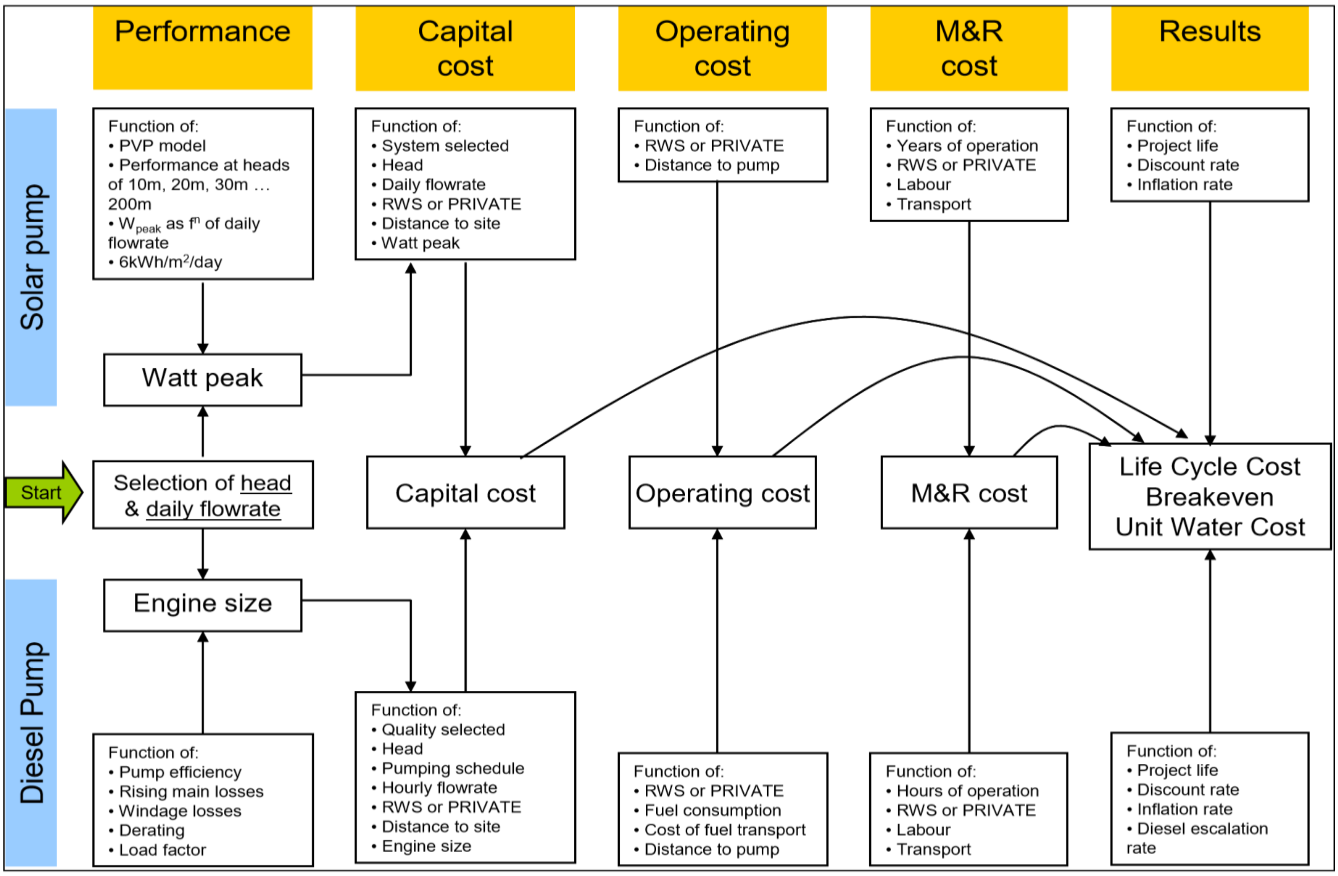
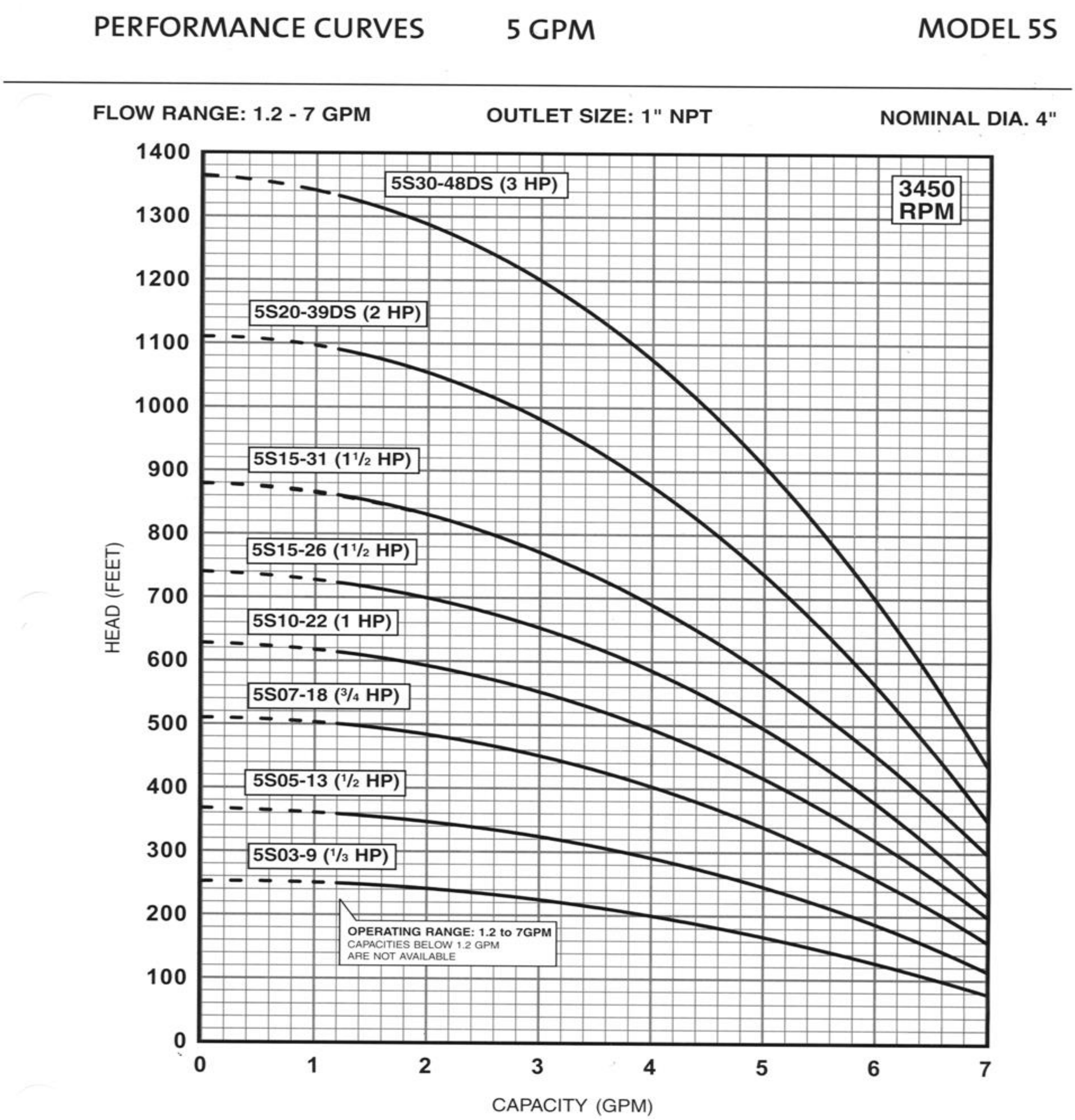


Figure 3.1: Overview of the life cycle costing structure in the spreadsheet

12.11 Appendix K

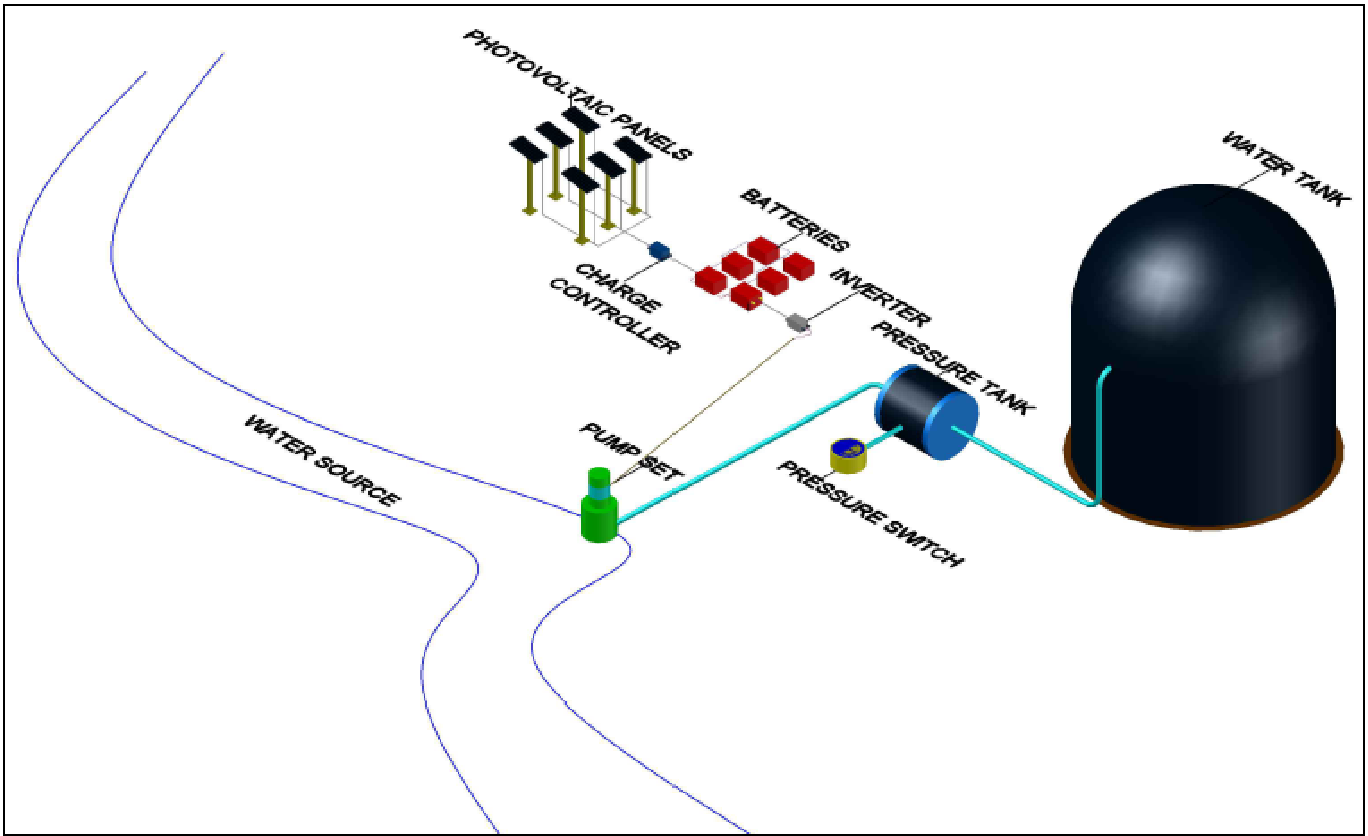
Lorentz Submersible solar pump (source 2013-pump sizing journal)

12.12 Appendix L



Pump performance curve (source 2013-pump sizing journal)

12.13 Appendix M



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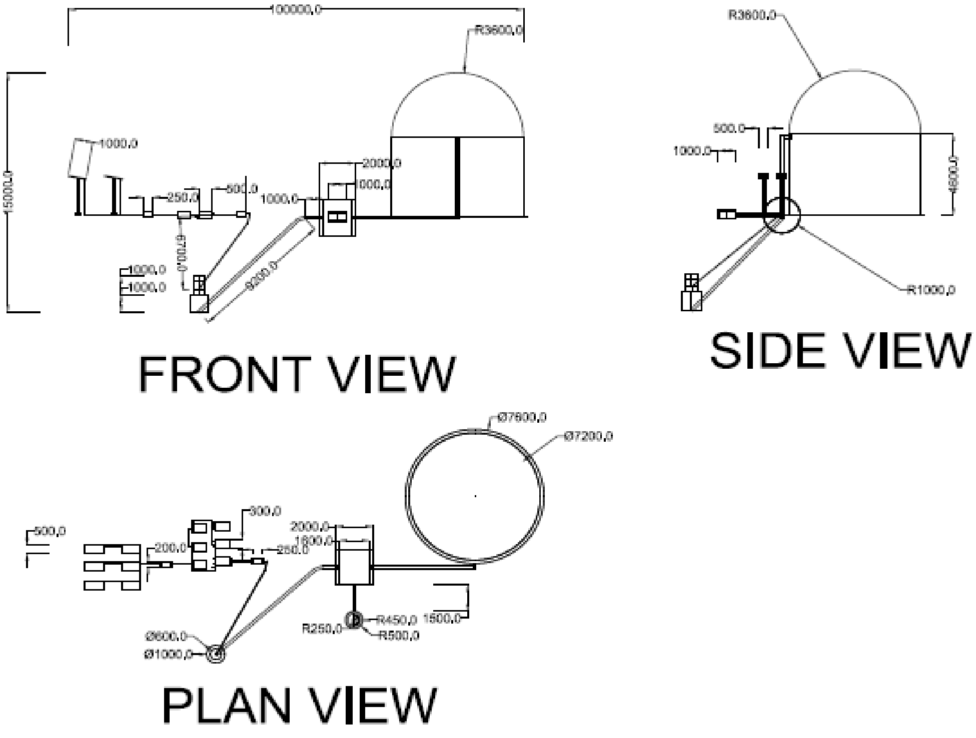
DIMENSIONS:ALL IN MILIMETERS	REG.NO: F21/1777/2011
DRAWN BY:NABAALA HARRISON LESHAO	SCALE:1:1
SUPERVISOR:DR.OMUTO	DATE:23 - 3 - 2016

12.14 Appendix N



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DIMENSIONS:ALL IN MILIMETERS	REG.NO: F21/1777/2011
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SUPERVISOR:DR.OMUTO	DATE:23 - 3 - 2016