Commissioned by:	UN Environment, CTCN, Adaptation Fund
Project Title:	Solar based irrigation business mode 'pay as you irrigate' for women empowerment, water management and food security in Mozambique
Implemented by:	Practica Foundation & HUB
Country:	Mozambique
Deliverable:	2.3 Report data requested to define a fit-for-purpose PV pump system and irrigation infrastructure (supply side)

Nadege Trocellier

Solar-based irrigation business model 'pay as you irrigate' for women empowerment, water management and food security in Mozambique.

Report with the data requested to define a fit-for-purpose PV pump system and irrigation infrastructure (supply side) for a community in Moamba, Mozambique

PRACTICA HUB

December 2023

This project has been proposed by Universidade Pedagógica de Maputo.

With the support of the Ministry of Science and Technology and High Education

Implemented by PRACTICA & HUB

Commissioned by UN Environment, CTCN, Adaptation Fund

Disclaimer:

This document is an output of the Technical Assistance Response in Mozambique. The present report is the output of the project 'Solar based irrigation business model 'pay as you irrigate' for women empowerment, water management and food security in Mozambique. The views and information contained herein are a product of the international TA implementation team led by PRACTICA & HUB.

Table of Contents

List of Figures

List of Tables

1. Introduction

This report is part of the deliverables for the project *Solar-based irrigation business model' pay as you irrigate' for women empowerment, water management and food security in Mozambique* implemented by the consortium PRACTICA and HUB. The project's overall objective is to identify the best Solar Powered Irrigation System (SPIS) for the Pangalata association in Moamba that could be deployed using groundwater, surface water, and the possibility for rainwater harvesting. The system's design will be reinforced by the definition of a clear *pay-as-you-irrigate* business model that will be customized for the lowest-income farmers.

This deliverable aims to explore the existing options available in Mozambique to define a fit-for-purpose Powered Irrigation System and irrigation infrastructure. This includes the definition of the geometry of the irrigation system, selecting the application and conveyance system and determining the required pump yield. Estimate friction losses and total head. Finalizing with the selection of the pump and solar panels that fit the design needs and that are available in the Mozambican market.

2. Methodology

Irrigation systems design is not rocket science. However, to make a successful design, there are several steps to take to select the technology that better adapts to the farm situation. The steps are shown below:

1. Identify the water source and determine how much water is available during the driest season.
2. Determine how much water is needed to irrigate and the availability of sunshine hours.
3. Select the application and conveyance system and determine the required pump yield.
4. Calculate the friction losses and total head (Technical term that represents how much pressure the pump will need to provide).
5. Select the pump that fits the design needs and is available in the market.
6. Compare it with alternative pumps.
7. Buy the correct pump and irrigation equipment.

Deliverable 2.2 already covered the first and second steps. This deliverable uses the information from previous deliverables to finalize the technical design of the irrigation system.

3. Technical design of a solar-powered irrigation system

3.1 Basic information

As a result of deliverable 2.2, table 1 shows the summary information corresponding to the Pangalata association fields that will be used to finalize the design of the solar-powered irrigation system.

Table 1. Summary of information for the SPIS design.

Currently cultivated area (ha)	3
Expected area to be irrigated with SPIS (ha)	5
Water source	Surface water (Incomati River)
Water source flow rate (m^3/h)	30
Crop Evapotranspiration (ETc) (mm/day)	4.2
Daily water requirement per ha (m^3/ha)	42
Average daily Irradiation on a horizontal level (kWh/m^2) during the critical month	3.6
Daily average available sun hours for critical month (hours)	5.1 ≈5

3.2 Determine the irrigated area.

As the sustainable flow at the water source and the daily water requirements per hectare have been determined, we can estimate the maximum area that can be irrigated sustainably. This means without depleting the water source and ensuring that the pumping system will not operate without water. To calculate this, we perform the following calculations:

$$Maximum\ irrigable\ area = \frac{Water\ source\ flow\ \left(\frac{m^3}{h}\right) * Daily\ sun\ hours\ (h)}{Daily\ water\ requirement\ \left(\frac{m^3}{ha}\right)}$$

$$Maximum\ irrigable\ area = \frac{30\ \left(\frac{m^3}{h}\right) * 5\ (h)}{42\ \left(\frac{m^3}{ha}\right)} = 3.4\ ha$$

The maximum irrigable surface per pump is 3.4 ha. This means that to irrigate the expected 5 ha, the design needs to include at least two separate pumping systems.

3.3 Determine the water conveyance and application method and the pump yield.

When the pump extracts water from the source, it must be transported to the field. And from that point, it needs to be transported to the roots. The first part, from pump to field, is called the **conveyance method.** Often, this is done by using a pipe or hose. The second part, within the field, is called the **application method.** The most common water application practices are furrows, sprinklers, drip, buckets, hoses, or spray cans.

Determining the conveyance and application methods is important because different methods have different water efficiencies. As a matter of clarification, when a method is water efficient, it means very little water is lost. No matter the application system, there will be losses in the system, and these will be expressed in percentages. According to the University of Nebraska,[1] table 2 shows the indicative values of application efficiency methods.

Table 2. Irrigation methods and their efficiencies.

Irrigation method	Efficiency (%)
Surface irrigation (furrows, basins, etc.)	60-70
Overhead irrigation (sprinklers, spray tubes, misters, etc.)	70-85
Drip irrigation	85-95

Specifically, for the Pangalata association, the smallholder farmers are already familiar with the use of drip irrigation systems and expressed interest[2] in continuing with the same application method.

The consortium proposes to divide the 5 ha into two different irrigation sub-units covering 2.5 ha each with drip irrigation. Therefore, the next step is calculating the pump yield required to cover the water needs. The following formula is used:

$$Pump\ yield\ \left(\frac{m^3}{h}\right) = \frac{Water\ needs\left(\frac{m^3}{ha}\right) * \ irrigated\ area\ (ha}{Number\ of\ hours\ of\ sunshine\ in\ a\ day\ (h)}) * \ Efficiency\ (\%)$$

$$Pump\ yield\ \left(\frac{m^3}{h}\right) = \frac{42\left(\frac{m^3}{ha}\right) * 2.5\ (ha)}{5\ (h)} * \ 0.95 = 21.5 \cong 22\ m^3/h$$

3.4 Proposed geometry of the irrigation system

The proposed geometry of the solar-powered irrigation system divides the irrigated plot into two areas of 2.5 ha each. As shown in figure 1, each subplot of 2.5 ha will be irrigated by a separate

[1] https://passel2-stage.unl.edu/view/lesson/bda727eb8a5a/8

[2] Smallholder farmers expressed they do not want sprinklers as it is a lot of work and time required to operate them.

pump and different pipe system. The location of the pump(s), the solar panel(s), the main pipe, and the subplots to be irrigated are shown below (green[3] and yellow)[4].

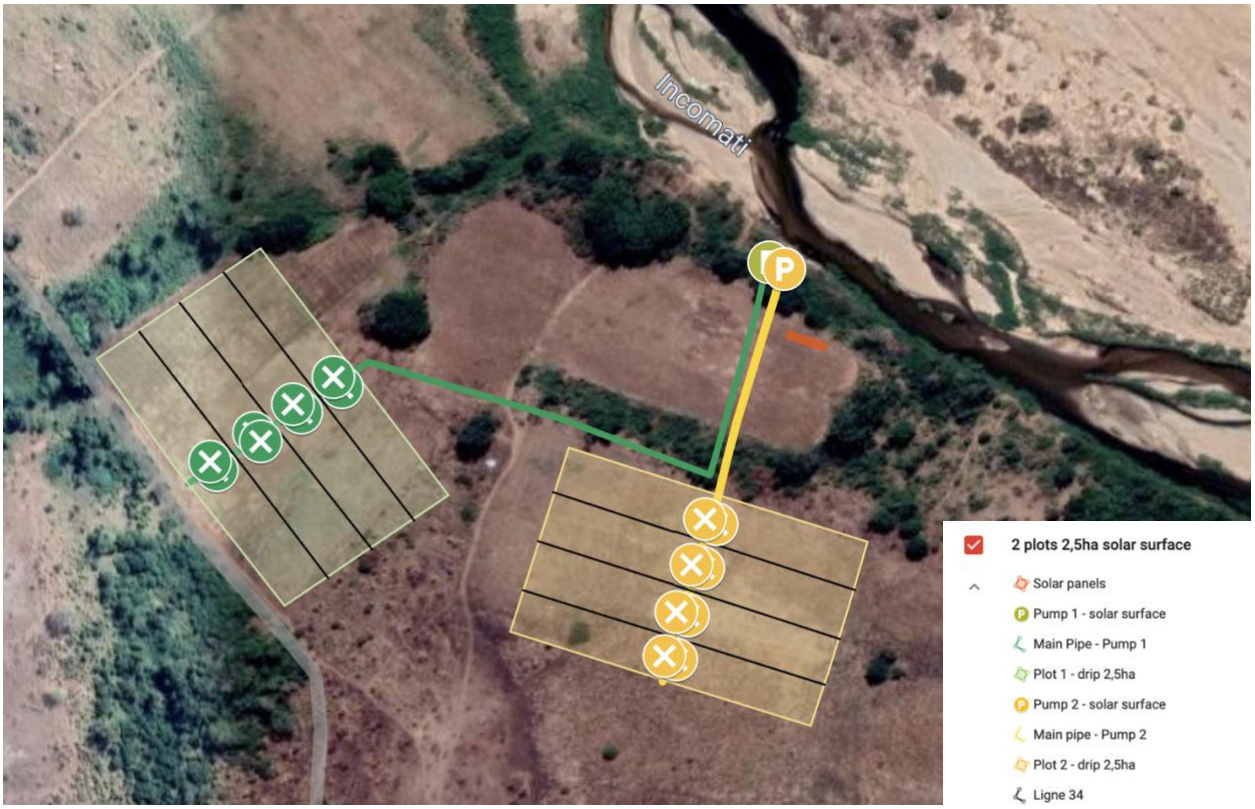


Figure 1. The geometry of the proposed irrigation system in the Pangalata association.

The specifications of the drip irrigation equipment are presented in table 3.

Table 3. Drip irrigation equipment specifications.

Spacing between emitter (m)	0.3
Dripper line length (m)	100
Total drip line length (m)	50,000
Total number of emitters	166
Total length of supply ramp (m)	125
Main pipe length (m)	510

Once the geometry of the irrigation system is clear. It is key to define irrigation management, considering aspects such as the crops, production practices and plot characteristics. For the

---

[3] The design shown in this document represents the configuration for the green system, as this represents the one with longer pipe and thus higher friction losses. This ensures that the critical conditions are also met in the yellow system.

[4] The design can be accessed in the following link: https://www.google.com/maps/d/u/0/viewer?mid=1ClP_cwe9Ngoj5uKyl6I1pVxQLU0_Br4&ll=-25.516013607801153%2C32.122568762189275&z=17

Pangalata drip irrigation system, the management includes cycles of 40 minutes, where 3,300 m^2 will be irrigated at once. See table 4 for more details.

Table 4. Irrigation management.

Number of lines used per irrigation cycle	66
Duration of an irrigation cycle (min)	0h 40 min
Irrigated area of one irrigation cycle (m^2)	3,300

3.5 Calculating the head of the system and friction losses.

Total head is a technical term for calculating the pressure the pump needs to provide to let the system function as it was designed to do. It is expressed in meters. So, if the total head is calculated to be 10 meters, it means the pump needs to work as if it must pump the water 10 meters high. This step is of high relevance for selecting the right pump. Some pumps can provide a high flow and provide very little pressure (head). Some pumps provide a very low flow but very high pressure (head). Knowing the head and the required flow allows the technician to select the right pump. Not calculating the right head might result in a situation where no water will reach the field.

To calculate the head, the following data needs to be collected:

1. The dynamic water level at the water source
2. The height difference at the highest point in the path from the water source to the field (in meters)
3. The required pressure of the application method (in meters)
4. The friction losses of the pipes in the conveyance system (in meters).

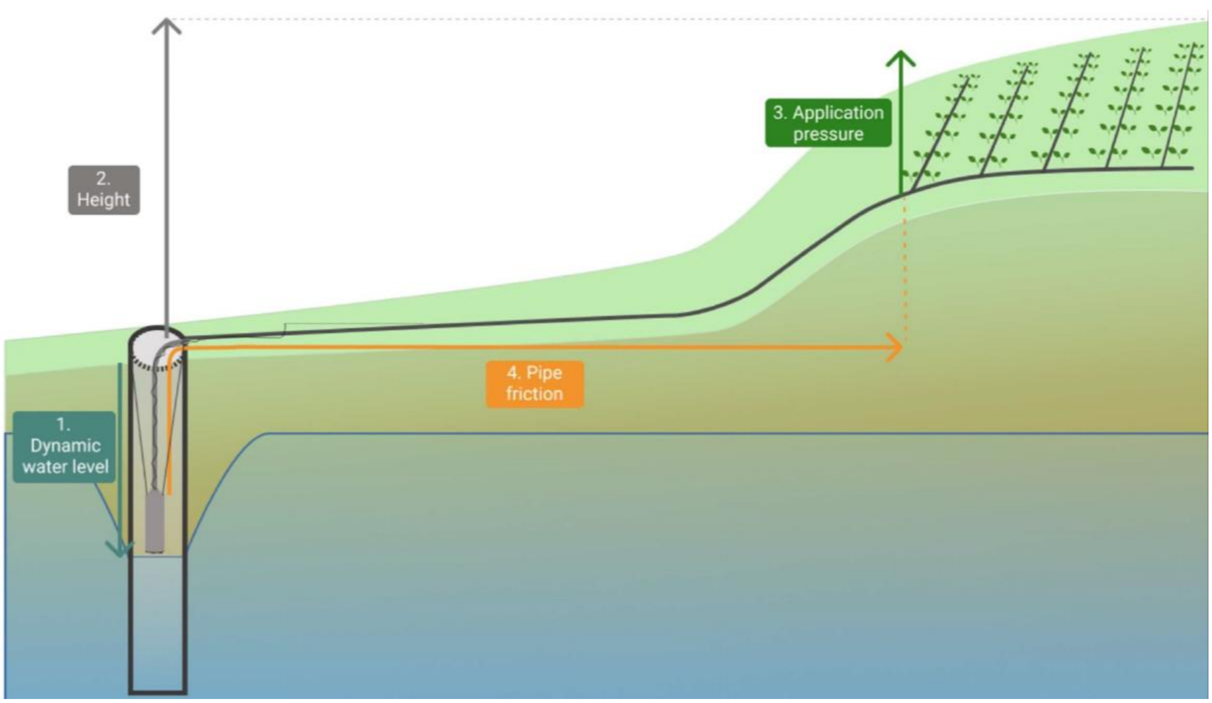


Figure 2. Schematic representation of total head, Practica 2022).

3.5.1 Dynamic water level at the water source & and height difference at the highest point in the field

As expressed in deliverable 2.2, the slope profile (figure 3) of the field does not represent a significant burden for the design of the solar irrigation system. The geometric height that the pump needs to provide to take water from the borehole to the plants will be considered as **1 meter**. As expressed by the smallholder farmers, the water levels directly in the river increase during the rainy season. Which possess a real threat to installing the pump directly in the river or even in the riverbed, as farmers refer the current becomes violent and they could lose the infrastructure. The construction of a borehole is thus recommended in the vicinities of the riverbed (max 30-50 m inland). Whereas in theory the aquifer connects directly with the flow coming from the Incomati river. The dynamic water level has thus been set at **15 meters**.

Figure 3. Slope profile for the Pangalata field.

3.5.2 Required pressure of the application method

Farmers are already working with the Irritec drip irrigation line (see figure 4) with the following characteristics: diameter 16mm 8 mil 1,5lh 30cm 0,9b. This means the flow is 1.5 lph and works under a pressure of 0.9 bar≈10 meters, a diameter of 16 mm, and a wall thickness of 8 mil, which assures its life expectancy of about 2 to 3 years (if used correctly).

The required pressure of the application method when designing a drip irrigation system can be set at **10 meters**.

3.5.3 Friction loss and residual pressure

Friction losses are energy losses in the pipeline due to the friction of the water when it moves through the pipe. One meter loss means that the pump must provide a pressure of one meter extra to pump the water through the pipes to overcome the friction losses. There will always be friction and, therefore, head losses, but it is important to limit them. High friction results in the need for bigger pumps and more solar panels, and therefore higher investments.

A complex equation usually used to calculate the friction loss in a pipeline is the formula of Hazen-Williams:

$$\Delta H_L = \frac{(10.69 * Q^{1,85} * L)}{c^{1,85} * D^{4,87}}$$

<u>In which:</u>
ΔH_L= the head loss in meters due to friction
Q=the water flow in m^3/s
L= the length of the pipeline in m
C= the Hazen-Williams coefficient for the roughness of the pipe (around 150 for PVC and PE pipes depending on type/age). It has no units.
D= diameter of the pipeline in m.

If one analyses the equation in more detail one can see:

- If you double the length of a pipe, the head loss doubles.
- If you pump more water through a pipe, the head loss will increase. It increases non-linear. Meaning, if you double the flow through a pipe, the head loss increases more than double.
- The rougher the surface of a pipe, the higher the head loss. This is influenced by the material of the pipe of the pipe but also the age. For example, a brand-new GI pipe will have a smoother surface than an old, rusted pipe. Therefore, the head loss of a new GI pipe will be less than an old GI pipe[5].
- The diameter of a pipe. It is the most important factor in the formula. Doubling the diameter of the pipeline results in a reduction factor.

A first pre calculation for selecting the commercial diameter needs to be done. This is done by following the formula below:

$$Estimation\ of\ pipe\ diameter = \sqrt{Q(\frac{m3}{S})}$$

$$Estimation\ of\ pipe\ diameter = \sqrt{0.00611(\frac{m3}{S})} = 0.078133m = 78.133\ mm$$

As there is no pipe in the market available for 78.133 mm, we round it to the next available commercial diameter in the sector, which is 90 mm diameter.

For the specific design of the irrigation system, the following data will be used.

Q= $22m^3/h$= 0.00611 m^3/s

[5] https://www.engineersedge.0.2com/flui0.4d_flow/hazenwilliams_coefficients_table_13220.htm

C=150
L=510m
D= 90mm=0.09m

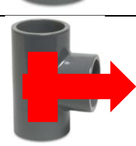
This results in the following calculation:

$$H_L = \frac{(10.69 * (0.00611)^{1,85} * (510)}{(150)^{1,85} * (0.09)^{4,87}} = 5.1026 \approx 5m$$

This value represents the friction losses in meters that the pump needs to cover for the friction losses only in the main pipe.

It is important to realize that elbows, valves, T-pieces, etc., will increase the friction of the piping. This can be calculated per piece of hardware. Or, as an alternative, use a faction of the total head loss of the pipe to cover the head loss of the elbows, valves, etc. Table 5 shows an overview of head losses per item. Note that the numbers are the equivalent length of straight pipe added to the total length of the distribution network. They are not the head losses expressed in meters.

Table 5. Equivalent length of straight pipe in meters.

Equivalent length of straight pipe in meters									
Pipe size (inch)		1/4	3/8	1/2	3/4	1	1 ¼	1 ½	2
Elbow 90 degree		0.7	0.9	1.1	1.3	1.6	2	2.3	2.6
Elbow 45 degree		0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8
T-piece (straight flow)		0.2	0.4	0.5	0.7	1	1.4	1.7	2.3
T piece (branched flow)		0.7	1.1	1.3	1.6	2	2.7	3	3.7
One way valve (swing type)		2.2	2.2	2.4	2.7	3.4	4	4.6	5.8

One can see that if one adds 10% to a total length of distribution pipe of 1000 meters of 1 inch (to account for head losses in fitting work), one will account for (100/1.6= nearly 60 elbows. Therefore, for the residual pressure, one can take a fixed percentage of the total length of the pipe, 10 % is a widely accepted value. For this case, the 10% of 5 meters is 0.5 meter. Therefore, the total friction losses for the main pipe (including accessories) are 5.5 m.

The following calculation to be performed is the estimation of the friction losses in the supply ramp.
For this case, the following data will be used:
Q= 22m^3/h= 0.00611 m^3/s
C=150
L=125m
D= 90mm=0.09m; commercial diameter

This results in:

$$H_L = \frac{(10.69 * (0.00611)^{1,85} * (125)}{(150)^{1,85} * (0.09)^{4,87}} = 1.2506 \approx 1.2\ m$$

Adding the 10% for accessories loss results in 1.5 meters of head pressure in the supply ramp.

Table 6 presents a clear overview of the total head the system will need to overcome to provide the required amount of water to the roots of the crops.

Table 6. Total Head to account for the pump selection.

Geometric height (m)	1
Dynamic level (m)	15
Friction Losses in the main pipe, including accessories (m)	5.5 ≈6
Friction losses in the supply ramp, including accessories (m)	1.3≈1.5
Friction losses due to filtration/water meter (m)	2
Operating pressure of the drip irrigation system (m)	10
Total Head (m)	**35.5**

Figure 5 shows graphically where are the friction losses distributed along the irrigation system designed for the Pangalata association.

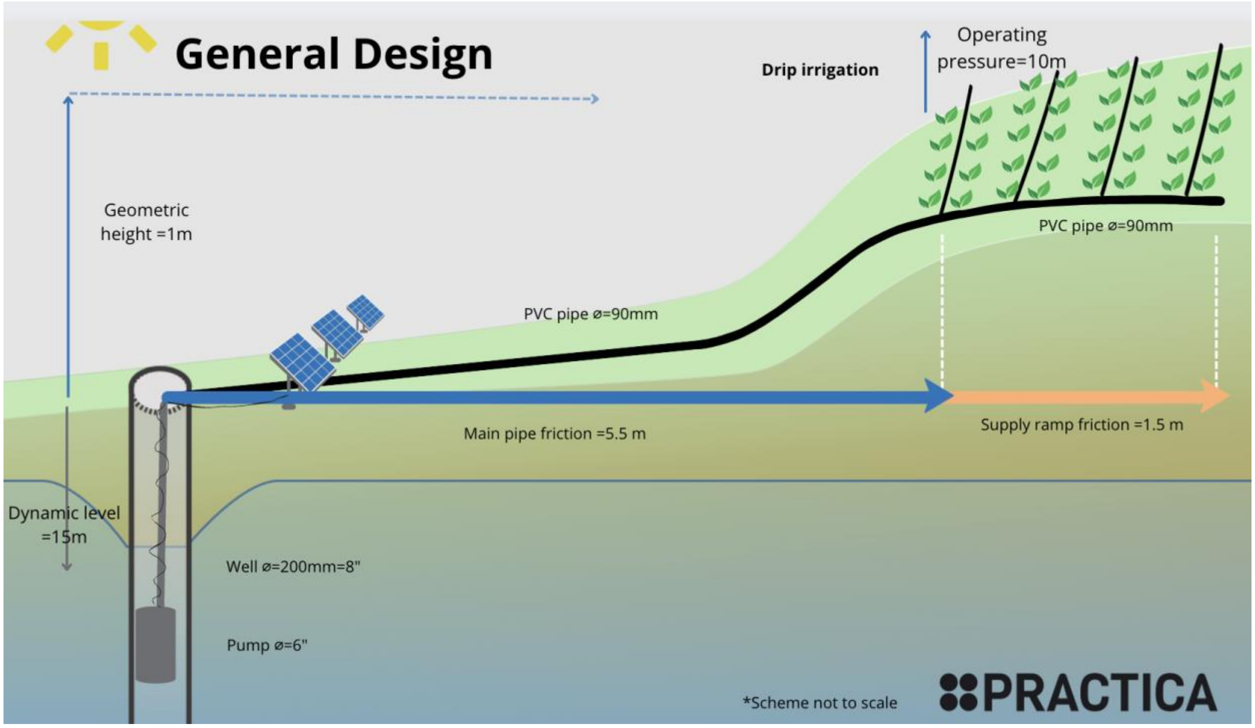


Figure 5. Total head in the design of the Pangalata irrigation system.

3.5.4 Water storage

Water storage is a reservoir or tank that stores water for its use. It serves as a 'water battery', storing water for use at a different moment. It is not always necessary to have water storage for irrigation. There are several possibilities when designing water storage options, see picture 4 for more detail:

a. **Small water storage/drum (picture 5 B):** the farmer can use drums on the ground to pump the water to it. From there, it can be fetched and applied with a bucket or spray can. It is labor-intensive and can only be applied to very small surfaces. However, in this water, water spillages are avoided compared to not using the drums.
b. **Low-intensity reservoir/drum (picture 5 C):** When the pump is connected directly to the application system, the sun's intensity might not be sufficient to supply the application system in the early morning and late evening. Instead of losing it, the water can be buffered in a small water reservoir on the ground. And the water from there can be fetched manually to irrigate other areas.
c. **Large tank (picture 5 D):** Water storage can be used if a well is low-yielding, and the farmer only needs to irrigate a plot every second day. On the day the farmer does not irrigate, the water can be buffered and used the day after this. It allows maximum use of the well and prevents the farmer from coming to the field daily.

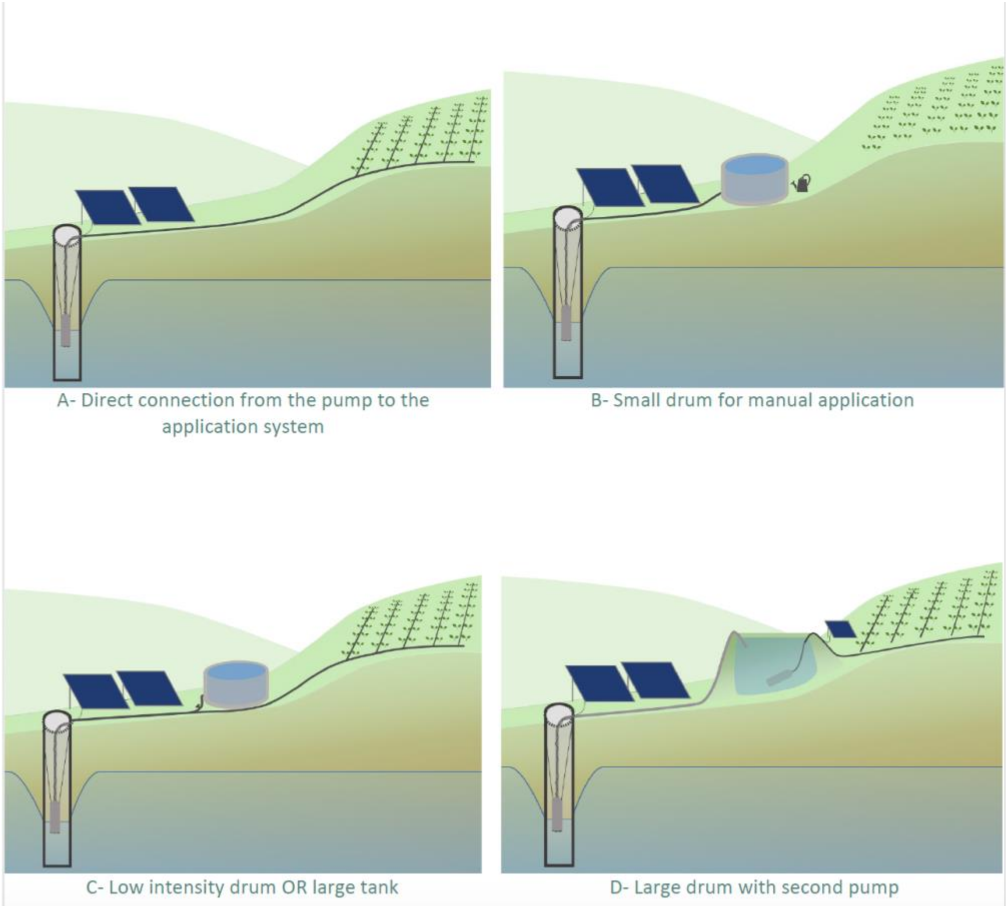


Figure 6. Different water storage possible configurations.

For the Pangalata design, water shortage is not an issue, so no water storage is required.

3.6 Pump selection

By knowing the total head and the maximum required daily water production of the pump, we can now select the pump. The first selection is to determine the type of pump that is needed. Pumps fall into two main categories:

1. Suction pump: this means the pump sucks the water up first and then pushes it up. To suck the water up, the vertical distance from the pump to the dynamic water level should not be more than 7 meters. If it is more than 7 meters, it does not work.
2. Submersible pump: as the name suggests, the pump is submerged in water. That means the pump is in the water. Therefore, it does not need to suck the water up first. It just needs to push the water up. This means it can pump water even from great depths.

Table 7. Comparison between suction and submersible pumps.

	Suction pump	**Submersible pump**
Placement	Next to the water source	Inside the source, below the water
Maximum water depth	7m maximum	Depending on pump- well below the water

Usually applied to	River, stream, pond, hand dug well, borehole (water at less than 7 m)	Hand dug well, borehole
Resistance to silt/salts in water	Usually more resistant	Usually more sensitive (But some suppliers offer warranty)
Type of installation	Generally portable	Generally fixed
Fuel	All fuel pumps are suction pumps	Submersibles run on electricity, including from solar panels.

Whether a submersible or suction pump is chosen, finding a pump with the right characteristics for the given situation is key. These characteristics depend on 2 main factors.

1. The required pump discharge.
2. The total head of the system.

Different pumps provide different amounts of water at different heads. This relation is shown in a pump curve. Each pump on the market has its own graph. Figure 6 shows 3 curves:

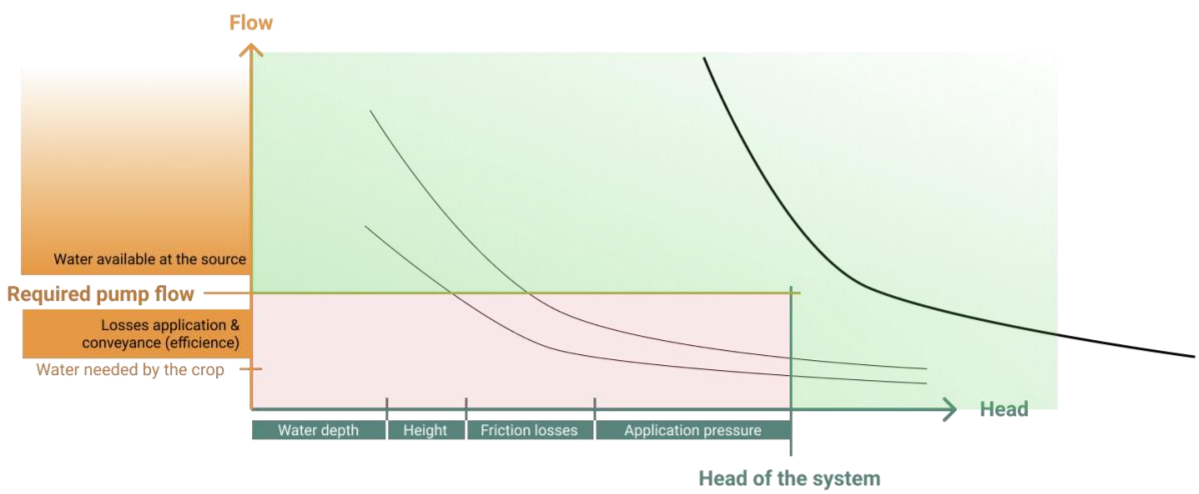


Figure 7. Flow vs Head of the system to select a pump.

The vertical axis shows the amount of water the pump will provide (the pump discharge), depending on the total head (horizontal axis).

- What can be seen is that **the higher the head, the less water the pump will provide** (each curve is going down as we go towards the right of the graph, so towards higher heads). **This is true for all pumps.**
- This graph also shows that **the pump is no longer available to provide any water at more than a specific head.**
- For the pump to work in the field, the curve must be in the green part of the graph. Here on the left, the pumps corresponding to each of the two curves are unsuitable because they do not provide enough water at the head of the system considered.

As explained above, the pump selection can be multifactorial (budget, brand representation, operation, and maintenance knowledge close to the installation site, etc.). Therefore, if the technical conditions (H&Q), the consortium recommends the Pangalata association select from one of the two most renowned submersible pump brands in the sector, a good represented in the Mozambican market. These are Lorentz and Grundfos. Each brand has its own design software. Therefore, it is the idea of the following paragraph to guide on how to supervise and ensure that the pump selection is done according to technical guidelines.

The example will be followed using the Grundfos product selection tool (https://product-selection.grundfos.com/). By introducing the Q (22 m^3/h) and the H (35.5 m), previously calculated. The software displays the pump SP 30-5, which is within the required operational ranges, see figure 8.

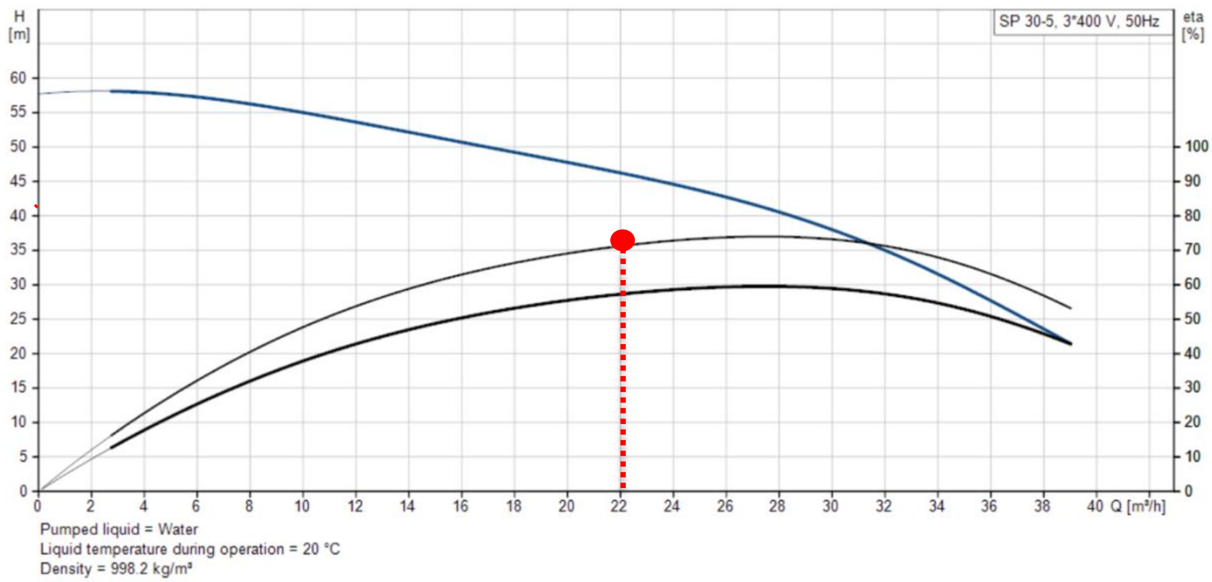


Figure 8. Pump curve of SP[6] 30-5 submersible groundwater pump from Grundfos.

Note: It is the idea of the consortium to discuss and refine the pump selection during the revision process. A more detailed pump selection will be provided in the following deliverables.

3.7 Calculating the power requirements of the solar array.

Calculating the power requirement of the solar array can be done using the following steps.

1) Calculate the hydraulic output power demand of the system.
2) Factor in the pumping efficiency.
3) Factor in the electric efficiency of the system.

[6] Grundfos SP are submersible borehole pumps, designed for pumping groundwater. Grundfos SP are all stainless-steel pumps, and they are available in 3 material grades. The pumps are suitable for boreholes in sizes ranging from 4” over 6” and 8” to 10”. The motor sizes for the pumps are available in 0.37-250 kW.

3.7.1 Calculating the hydraulic energy demand of the system.

This calculation can be done in several ways. For a good understanding of the equations used, we first give the general formula of potential energy. Every day, the daily water production requirement (in m^3) needs to be lifted over a certain height level H, from the water source to the application point. The general equation for potential energy is the following:

$$E_{pot} = m * g * H$$

In which:

M= the mass lifted (kg). Every m^3 of water has a mass of 1000kg.
g= the gravity force constant=9.81 (m/s^2)
H=the difference in height level = the hydraulic head (m)

This formula needs to be adjusted slightly to the situation. We calculate the energy per day. If Q is the daily water demand (m^3/day), then the mass of L is Q*1000 (kg/day). So, instead of m for mass, we write 1000*Q. We also fill in the value of the gravity force constant. The formula for the energy required per day becomes:

$$E_{day} = 1000Q * 9.81 * H = 9810\ Q * H$$

3.7.2 Calculating the hydraulic power output of the array.

This amount of energy per day needs to be produced in the number of peak sunshine hours (Psh) available per day during the critical month. So, we would need a power output per hour of:

$$P = \frac{9810 * Q * H}{Psh\left(\frac{J}{hr}\right) or\ (W * \frac{s}{hr})}$$

To calculate the required power per second, we divide this through 3600. As there are 3600 seconds in one hour. This equals to:

$$P = \frac{2.73 * Q * H}{Psh}$$

In which:

Q= water need in m^3/day
H= hydraulic height in m
Psh= number of peak sunshine hours per day in kW/m^2/day
Pout= the hydraulic output power. It does not yet consider the system's hydraulic efficiency nor the electric efficiency of the system.

3.7.3 Factoring the electric and hydraulic efficiencies of the system.

The total power demand P_{tot} of the system can be calculated with the following formula:

$$P_{tot} = \frac{Pout}{\eta * \varepsilon}$$

In which:

Pout= the hydraulic output power
η= the hydraulic efficiency of the pumping system. This is the proportion of the energy that the pump receives from the pump motor that is effectively used for the water to flow. The rest of the energy is converted into heat. Note that other hydraulic losses (friction losses) have been considered whilst calculating the hydraulic head.
ε= the electric efficiency (considering losses in motor, converter, losses through dust, losses through the aging of panels, etc.)

Combining all equations, we come to the final equation:

$$P_{tot} = \frac{2.73 * Q * H}{P_{sh} * \eta * \varepsilon}$$

In which:

Q= water need in m^3/day
H= hydraulic height in m
Psh= number of peak sunshine hours per day in kW/m^2/day
η= the hydraulic efficiency of the pumping system.
ε= the electric efficiency

Therefore, the theoretical output can be calculated.

$$P_{theo} = \frac{2.73 * 35.5 * 22}{1000} = 2.13\ kW$$

To calculate the minimum pump required for the pump, we will assume a pump hydraulic efficiency (η)of 60%. Therefore, the minimum power required in the pump in kW is calculated as follows:

$$Min\ Pump\ power = \frac{P_{theo}}{\eta}$$

Using the Pangalata data, the calculation is as follows:

$$Min\ Pump\ power = \frac{2.13kW}{0.6} = 3.5\ kW$$

Once the minimum power in the pump is calculated, we need to factor the capacity of the panels to convert the sun power into electricity. The efficiency of the solar panels (ε) considered as 50%. Therefore, the formula is as follows:

$$Min\ solar\ panels\ power = \frac{Min\ Pump\ power}{\varepsilon}$$

The calculation is as follows:

$$Min\ solar\ panels\ power = \frac{3.5\ kW}{0.5} = 7.1\ kW$$

3.7.4 Configuration of the PV Array

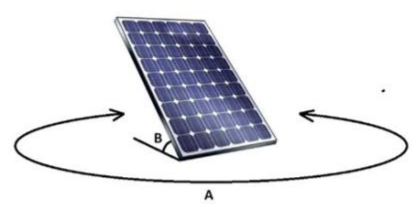
For the configuration of the PV array, we must first know the voltage used in the system, that is the voltage needed to operate the pump. This voltage must be produced by matching the voltage requirement with the number of solar panels in series, depending on the voltage output of one panel. The sizing of the cables and the configuration of the solar panels can be calculated manually. However, this is not easy. This is usually done by suppliers who have software packages to calculate it: they should be able to provide the right configuration and cable sizes[7]. Table 8 presents a summary of the power array calculations that should be matched and carefully reviewed against the supplier's proposal.

Table 8. Summary of the power requirements of the power array.

Pump group efficiency (%)	60
Power required in the pump theoretical (kW)	2.13
Minimum power required in the pump (kW)	3.5
Solar panel efficiency (%)	50
Minimal solar panel power (kW)	7.1

The sizing of the solar array is only correct if the panels are placed correctly. There are two main factors to be considered for this:

1. The orientation of the solar panels.
2. Shadow.



Orientation of the solar panels: The panels can be oriented in two different ways:

a. The direction it faces (A): north, west, east, or south.
b. The angle it is placed in with the ground.

To get as much sun as possible on the panels, the following rules should be applied:

Panels should always face the equator. If panels are placed in the northern hemisphere, panels should face south. If panels are in the southern hemisphere, they should face north. For the Mozambique case, they should always face North.

---

[7] A good resource to calculate it manually is the book: 'Solar Pumping for water supply. Harnessing solar power in humanitarian and developmental contexts.' Kiprono and Ilario,2020. It can be downloaded for free at Practical Action Publishing.

Secondly, the latitude expresses how close or far the location is from the equator. They are expressed in degrees. The panels should be at an angle on the degree of the location. The angle should never be less than 15 degrees to ensure the panels stay as clean as possible.
For the Pangalata association, the latitude is 25°30'55'' South. Therefore, **the panels should be inclined towards the North with an inclination decree of 25°.**

Shadow: Shadow on the solar panels must be avoided at all costs. The effects of it are often underestimated and not well understood. Shadow, even the slightest bit, can disrupt the functionality of the entire panel and array. Just 10% shading of a solar array can lead to a considerable decline in efficiency and even, on occasion, total loss of water flow. Apart from the panels' placement, dust will influence the efficiency. Dust losses can be around 0-15%. Thus, panels should be cleaned regularly with clean water and only during the early morning/late afternoon when the panels are no longer hot.

Solar trackers: are devices that monitor the position of the sun and automatically or semi-automatically adjust the direction of the solar panels towards the sun so that productivity is increased. This can be done on two axes: the azimuth angle axe, which means following the sun from east to west during the day, and the zenith angle axe, which means following the sun's position from north to south. The ideal tracker adjusts both axes continuously to face the sun during the day and during the seasons. The main disadvantage of such trackers is the price, they require operation and maintenance and have the risk of breaking down. When installing trackers, it is more difficult and costly to take the correct precautions against theft of the panels. And with the current price levels, generally, it is cheaper, more convenient, and reliable to install some more solar panels for the extra power than to install a solar tracking system of whatever kind. Therefore, **the design of the Pangalata association excludes the installation of solar tracking devices.**

4. Sources

FAO, 2014. Economic valuation of water resources in agriculture. From the sectoral to a functional perspective of a natural resource management. Available at: https://www.fao.org/3/y5582e/y5582e00.htm#Contents

Mindú, A.J.; Capece, J.A.; Araújo, R.E.; Oliveira, A.C. Feasibility of Utilizing Photovoltaics for Irrigation Purposes in Moamba, Mozambique. Sustainability 2021, 13, 10998. https://doi.org/10.3390/ su131910998